

October 5-8, 2026

Istanbul, Türkiye

# IWPROBONO

International Workshop on  
**PROton - BOron Nuclear fusion:**  
*from energy to medical applicatiOns*

**BOOK OF ABSTRACTS**



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Türkiye

# BOOK OF ABSTRACTS

## PROGRAMME & CONTRIBUTIONS

IWPROBONO 2026

International Workshop on **PRO**ton **BO**ron Nuclear fusion: from energy  
production to medical applicati**Ons**  
5-8 October 2026, İstanbul, Türkiye

|                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Title</b>                  | <b>BOOK OF ABSTRACTS</b><br>IWPROBONO 2026<br>International Workshop on <b>PRO</b> ton <b>BO</b> ron Nuclear fusion: from energy production to medical applicati <b>On</b> s                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
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| <b>Editors</b>                | Mirac Kamislioglu, Ioannis Ftilis, Katarzyna Batani, Dimitri Batani                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Technical design</b>       | Mirac Kamislioglu                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
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| <b>Authors</b>                | Various Authors<br><br>The book of abstracts contains abstracts reviewed and accepted by the members of the Scientific Committee as the contributions at the PROton BORon Nuclear fusion: from energy production to medical applicati <b>On</b> s, Türkiye, October 5 <sup>th</sup> -8 <sup>th</sup> 2026.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>ISBN</b>                   | 978-975-307-171-0 (Online edition)<br><br>This work has been carried out within the framework of the COST Action CA21128- PROBONO “PROton BORon Nuclear fusion: from energy production to medical applicati <b>On</b> s” ( <a href="http://www.ca-probono.eu">www.ca-probono.eu</a> ), supported by COST (European Cooperation in Science and Technology- <a href="http://www.cost.eu">www.cost.eu</a> ).<br>COST (European Cooperation in Science and Technology) is a funding agency for research and innovation networks. Our Actions help connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers. This boosts their research, career and innovation.<br><br>Department of Engineering Sciences, Bandirma Onyedi Eylul University, Balikesir, Türkiye & Department of Physics, Yeditepe University, Istanbul, Türkiye.<br><br>©Copyright by Yeditepe University<br><br>The information and the opinions given in this publication are provisional. Yeditepe University and Bandirma Onyedi Eylul University, Editors or Scientific Committee are not responsible for any interpretations, their consequences or typographical errors. |

International Workshop on **PRO**ton **BO**ron Nuclear fusion:  
from energy production to medical applicati**On**s  
October 5<sup>th</sup>-8<sup>th</sup> 2026, İstanbul, Türkiye

**Organizers:**

**Department of Engineering Sciences,  
Bandirma Onyedi Eylul University,  
Balıkesir, Türkiye**



**BANDIRMA  
ONYEDİ EYLÜL  
UNIVERSITY**

**Department of Physics, Yeditepe  
University,  
İstanbul, Türkiye**



**YEDİTEPE  
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<https://www.cost.eu/actions/CA21128>



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from energy production to medical applicati**On**s  
October 5<sup>th</sup>-8<sup>th</sup> 2026, İstanbul, Türkiye

## **WORKSHOP TOPICS**

New experimental results and applications  
Advanced fusion approaches  
Diagnostics  
Materials for targetry and nuclear reactors  
Theory and simulations

## **SCIENTIFIC COMMITTEE**

K. Batani (Chair), IPPLM, Poland  
D. Margarone, ELI Beamlines, Czech Republic  
I. Fitis, HCU, Greece  
L. Giuffrida, ELI Beamlines, Czech Republic  
A. Bonasera, INFN, Italy  
F. Consoli, ENEA, Italy  
M. Londeborough, CAS, Czech Republic  
M. Tatarakis, HCU, Greece  
D. Batani, Univ. Bordeaux, CELIA, France  
F. Belloni, UNSW Sydney, Australia  
G.A.P. Cirrone, INFN-LNS, Italy  
I.C.E. Turcu, UKRI/STFC CLF, RAL, UK  
D.H.H. Hoffmann, Xi'an Jiaotong University, China

## **LOCAL ORGANIZING COMMITTEE**

Şerife İpek Karaaslan (Chair), Yeditepe University, Türkiye  
Mirac Kamislioglu (Co-Chair), Bandirma Onyedi Eylül University, Türkiye  
Vildan Üstoğlu Ünal, Yeditepe University, Türkiye  
Bulent Buyuk, BANU, Türkiye  
Ilyas Ozer, BANU, Türkiye  
Ismail Kocak, BANU, Türkiye  
Canan Can, BANU, Türkiye  
Yılmaz Tuna, Yeditepe University, Türkiye  
Dilara Sipahi\*  
Zehra Sinmez\*  
Aysenur Aydin\*

\* Undergraduate students help local organization committee.

This book contains abstracts of nine invited lectures, twenty-one oral contributions, twelve poster contributions, which are accepted for presentation at the International Workshop on  
**PRO**ton **BO**ron Nuclear fusion: from energy production to medical applications

International Workshop on **PRO**ton **BO**ron Nuclear fusion:  
from energy production to medical applicati**On**s  
October 5<sup>th</sup>-8<sup>th</sup> 2026, İstanbul, Türkiye

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Eti Maden is developing commercially viable boron technologies based on advanced materials and highly efficient production processes - to provide most abundant and permanent supply of clean industrial and energy solutions. Our R&D program is guided by the need for practical energy transition technology, so we focus on sustainable boron derivatives and green applications.

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## WORKSHOP INFORMATION

### Workshop Scope

The International Workshop on PROton BORon Nuclear fusion: from energy production to medical applicatiOns (IWPROBONO) take place in Istanbul from October 5th to 8th, 2026. The workshop is organized in the final year of the COST Action PROBONO (CA21128) and represents a major scientific meeting of the Action.

Proton–boron ( $p-^{11}\text{B}$ ) fusion is an attractive aneutronic alternative to conventional deuterium–tritium fusion, avoiding neutron-related challenges and relying on stable, abundant fuels. Recent advances in research and high-power laser technologies have enabled laser-driven  $p-^{11}\text{B}$  fusion with increasing alpha-particle yields and have also stimulated interest in biomedical applications such as Proton Boron Capture Therapy (PBCT).

Over the past four years, PROBONO has established an international research network addressing the physics, technology, and applications of proton–boron fusion, with particular focus on laser-driven approaches, advanced diagnostics, targetry, theory, and numerical simulations. This workshop provides an opportunity to present and discuss the main scientific and technological results achieved within the Action, to assess their significance, and to place them in a broader international context.

The meeting bring together members of the Action, external experts, early-career researchers, and stakeholders active in proton–boron fusion research and applications, with the aim of reviewing the progress achieved and discussing perspectives beyond PROBONO, including future research directions, new collaborations, and larger-scale initiatives.

### Workshop Topics

#### New experimental results and applications

Recent experimental advances and emerging applications of proton–boron fusion, including energy-related and biomedical aspects.

#### Advanced fusion approaches

Investigation of non-conventional, laser-driven fusion schemes, including novel ignition concepts and alternative pathways toward high-yield fusion regimes.

#### Diagnostics

Development and application of advanced diagnostic techniques for the detection and characterization of fusion products, plasma conditions, and particle emission in laser–plasma experiments.

#### Materials for targetry and nuclear reactors

Design, fabrication, and characterization of materials and targets optimized for proton–boron fusion experiments, including radiation-resistant materials and concepts relevant to future nuclear environments.

#### Theory and simulations

Theoretical modeling and numerical simulations of laser–plasma interactions, proton–boron fusion processes, and particle transport, supporting experimental interpretation and guiding future experimental designs.

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**Type of contributions**

Invited contributions : duration 30 min (25+5).

Oral contributions : duration 20 min (15+5).

Poster presentations: maximum dimensions 70x100 cm.

The official language of the workshop is English.

**Workshop location**

Istanbul, Türkiye. It is the cultural and economic center of the country, is located at the crossroads of Europe and Asia. The official language is Turkish, and the currency is Turkish Lira.

**Workshop venue**

Yeditepe University, 26 Ağustos Campus, Inonu Mah. Kayisdagi Cad. No: 326/A, 34755 Atasehir, Istanbul, Türkiye.

# IWPROBONO

International Workshop on PROton BORon Nuclear fusion:  
from energy production to medical applications

**TIMETABLE** Monday 5 - Thursday 8 October 2026 - Yeditepe University, Istanbul, Türkiye

| Monday      |                                                                                                                             | Tuesday                                  |                                                                                                                                        | Wednesday   |                                                                                                                                                                                 | Thursday    |                                                                                                                                                        |
|-------------|-----------------------------------------------------------------------------------------------------------------------------|------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| 5 October   |                                                                                                                             | 6 October                                |                                                                                                                                        | 7 October   |                                                                                                                                                                                 | 8 October   |                                                                                                                                                        |
| 08:15-09:00 | Registration on site                                                                                                        | 09:00-09:30                              | Chair: D. Milovanović<br>B. Liu<br>Overview of ENN proton-boron fusion research                                                        | 09:00-09:30 | Chair: G. Lastovicka-Medin<br>C. Verona<br>Advanced Time-of-Flight Diamond Diagnostics for Ion Discrimination                                                                   | 09:00-09:30 | Chair: A. Maffini<br>I.C.E. Turcu<br>Ammonia Borane P-B Fusion Fuel: from 2022 Proposal at Catania Workshop to Experimental Results                    |
| 09:00-09:20 | Chair: D. Margaronne<br>Welcome and Opening Ceremony                                                                        | 09:30-09:50                              | D. Hoffmann<br>The Fusion Portfolio: Why p- <sup>11</sup> B Deserves a Place at the Table                                              | 09:30-09:50 | F. Consoli<br>Advances on alpha particle identification in low-rate laser-triggered nuclear fusion reactions                                                                    | 09:30-09:50 | M. G. S. Londresborough<br>From Borax mines to Sophisticated Nano-Structured Borane-based Targets for p- <sup>11</sup> B Fusion: The complete chain    |
| 09:20-09:50 | M. Scisciò<br>Laser-driven low-rate nuclear fusion reactions: single-pulse and high-repetition-rate approaches              | 09:50-10:10                              | R. Huo<br>Net Energy Gain Attempt via Nonthermal Equilibrium at ENN                                                                    | 09:50-10:10 | D. Pacella<br>Efficient Detection of alpha particles in proton-boron experiments with pixelated 2-D ASIC detectors like Timepix3                                                | 09:50-10:10 | D. Orecchia<br>Pulsed Laser Deposition as a versatile technique for tailored boron-based targets in proton-boron fusion                                |
| 09:50-10:00 | Welcome Ceremony - Prof. Dr. Oguz Bayat, Vice Rector                                                                        | 10:10-10:30                              | G. Lastovicka-Medin<br>Challenges of utilizing SI & SC detectors towards X-ray/alpha particle discrimination in pB related experiments | 10:10-10:30 | F. Abubaker<br>Unlocking Proton-Boron Fusion with Laser-Driven Ion Beams: High-Energy Proton Acceleration, Advanced Diagnostics, and Fusion Yield Characterization              | 10:10-10:30 | P. J. Kervallishvili<br>Using Pulsed Laser Deposition for Target Preparation in Proton-Boron Fusion Experiments                                        |
| 10:00-10:20 | T.-X. Huang<br>Recent progress in laser-driven proton acceleration and proton-boron fusion at the NCU 100-TW laser facility | 10:30-10:50                              | Coffee Break                                                                                                                           | 10:30-10:50 | M. S. Dimitrijević<br>Broadening of nitrogen lines for diagnostics of proton-boron fusion plasma obtained with BN target                                                        | 10:30-10:50 | Coffee Break                                                                                                                                           |
| 10:20-10:50 | Coffee Break                                                                                                                | 10:50-11:20                              | Chair: I. Fitilis<br>A. Kulířka<br>The pB reaction in Plasma-Focus device, status of the experiments                                   | 10:50-11:10 | Coffee Break                                                                                                                                                                    | 10:50-11:10 | Chair: M.G.S. Londresborough<br>D. Mancelli<br>Study of proton stopping power in warm dense matter using low-density foams at the XGIII laser facility |
| 11:20-11:40 | L. Reichwein<br>Updates on the plasma-based acceleration of polarized protons and helium-3                                  | 11:20-11:40                              | V. Munzar<br>Charged-Particle Diagnostics for Proton-Boron and Deuterium-Deuterium Fusion Experiments on Plasma Focus                  | 11:10-11:40 | Chair: J. Pasley<br>GAP. Cirrone<br>PLASMA: a Roadmap for Integrating Plasma-Aware Charged-Particle Transport Models into the Geant4 toolkit                                    | 11:10-11:30 | A. Maffini<br>CA25144: Inertial fusion energy: supply Chain of laser-targets from Exploration to Delivery (ICED)                                       |
| 11:40-12:00 | H. Zhang<br>Enhanced laser-proton acceleration and nuclear reaction via nano structure                                      | 11:40-12:00                              | C. Karvounis<br>2D MHD simulations of a miniature Plasma Focus device                                                                  | 11:40-12:00 | Z. Li<br>Spin-Polarized p- <sup>11</sup> B: From Generation to Maintenance                                                                                                      | 11:30-11:50 | Discussion: CA25144: ICED - A. Maffini / F. Consoli                                                                                                    |
| 12:00-13:30 | Lunch Break                                                                                                                 | 12:00-12:30                              | Discussion: HIPER+ / COST / Perspectives - D. Batani / G.A.P. Cirrone                                                                  | 12:00-12:20 | T. Apostolova<br>Orientation-Dependent High-Harmonic Generation in Semiconductors and Potential for High Energy Attosecond Driving of Proton-Boron Fusion                       | 11:50-12:00 | Closing Ceremony                                                                                                                                       |
| 13:30-14:00 | Chair: D. Hoffmann<br>D. Batani<br>Proton boron fusion for laser driven production of medical radioisotopes                 | 12:30-13:00                              | Break (laptop drop-off to the hotel)                                                                                                   | 12:20-12:40 | P. Thörz<br>Demonstration of bidirectional alpha particle emission from proton-boron reaction using low-density boron catchers and cavity-type pitcher with ns, kJ laser system | 12:00-14:00 | Lunch                                                                                                                                                  |
| 14:00-14:20 | S. Arjmand<br>A Roadmap to Potential Fusion Applications Using Novel Approaches                                             | Historical Peninsula Tour<br>Boxed lunch |                                                                                                                                        |             |                                                                                                                                                                                 | 12:40-14:00 | Lunch Break                                                                                                                                            |
| 14:20-14:50 | Chair: D. Batani<br>K. Batani<br>Equation of State of Shock Compressed BN in the Megabar Pressure Range                     |                                          |                                                                                                                                        |             |                                                                                                                                                                                 | 14:00-14:30 | CG Meeting CA21128 / PROBONO - Chair: K. Batani - closed, in person                                                                                    |
| 14:50-15:10 | J. Pasley<br>Shock waves launched by short-pulse laser-solid interaction                                                    | 13:00-18:00                              |                                                                                                                                        | 14:30-16:30 | MC Meeting CA21128 / PROBONO - Chair: K. Batani - closed & hybrid                                                                                                               |             |                                                                                                                                                        |
| 15:10-15:40 | Discussion: PROBONO - K. Batani / D. Margaronne                                                                             |                                          |                                                                                                                                        | 18:00-21:00 | Gala Dinner                                                                                                                                                                     |             |                                                                                                                                                        |
| 15:40-17:00 | Poster Session + Coffee Break                                                                                               |                                          |                                                                                                                                        |             |                                                                                                                                                                                 |             |                                                                                                                                                        |
| 17:00-18:00 | Welcome Cocktail                                                                                                            |                                          |                                                                                                                                        |             |                                                                                                                                                                                 |             |                                                                                                                                                        |



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 Invited talk (I)

 Lunch / break

 Coffee break

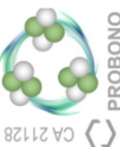
 Discussion / meeting

 Oral talk (O)

 Social event

KEY

- Invited talk (I)
- Invited talk (O)
- Coffee break
- Lunch / break
- Discussion / meeting
- Social event



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International Workshop on  
**PRO**ton-**BO**ron Nuclear fusion: from energy production to medical applicati**Ons**

**DETAILED PROGRAMME**

International Workshop on **PRO**ton **BO**ron Nuclear fusion:  
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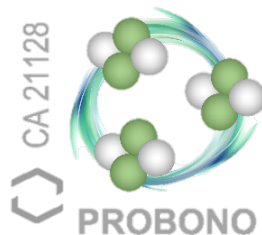
| Monday (5 <sup>th</sup> October) |                            |                                                                                                                                 |
|----------------------------------|----------------------------|---------------------------------------------------------------------------------------------------------------------------------|
|                                  | 08.15-09.00                | Registration on site                                                                                                            |
| S1                               | <b>Chair: D. Margarone</b> |                                                                                                                                 |
|                                  | 09:00-09:20                | Welcome and Opening Ceremony                                                                                                    |
|                                  | 09:20-09:50                | M. Scisciò, Laser-driven low-rate nuclear fusion reactions: single-pulse and high-repetition- rate approaches (I-1)             |
|                                  | 09:50-10:00                | Welcome Ceremony (Prof. Dr. Oguz BAYAT, Vice Rector)                                                                            |
|                                  | 10:00-10:20                | T.-Y. Huang, Recent progress in laser-driven proton acceleration and proton-boron fusion at the NCU 100-TW laser facility (O-1) |
|                                  | 10.20-10.50                | Coffee Break                                                                                                                    |
| S2                               | <b>Chair: F. Consoli</b>   |                                                                                                                                 |
|                                  | 10:50-11:20                | O. Rosmeyer Boost of electron and proton acceleration using low density foams (I-2)                                             |
|                                  | 11:20-11:40                | L. Reichwein, Updates on the plasma-based acceleration of polarized protons and helium-3 (O-2)                                  |
|                                  | 11:40-12:00                | H. Zhang, Enhanced laser-proton acceleration and nuclear reaction via nano structure (O-3)                                      |
|                                  | 12:00-13:30                | Lunch Break                                                                                                                     |
| S3                               | <b>Chair: D. Hoffmann</b>  |                                                                                                                                 |
|                                  | 13:30-14:00                | D. Batani Proton boron fusion for laser driven production of medical radioisotopes (I-3)                                        |
|                                  | 14:00-14:20                | S. Arjmand, A Roadmap to Potential Fusion Applications Using Novel Approaches (O-4)                                             |
| S4                               | <b>Chair: D. Batani</b>    |                                                                                                                                 |
|                                  | 14:20-14:50                | K. Batani, Equation of State of Shock Compressed BN in the Megabar Pressure Range (I-4)                                         |
|                                  | 14:50-15:10                | J. Pasley Shock waves launched by short-pulse laser-solid interaction (O-5)                                                     |
|                                  | 15:10-15:40                | Discussion: PROBONO, K. Batani                                                                                                  |
|                                  | 15:40-17:00                | POSTER SESSION + COFFEE BREAK                                                                                                   |
|                                  | 17:00-18:00                | Welcome Cocktail                                                                                                                |

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| Tuesday (6 <sup>th</sup> October)   |                                   |                                                                                                                                                                         |
|-------------------------------------|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| S5                                  | <b>Chair: D. Milovanović</b>      |                                                                                                                                                                         |
|                                     | 09:00-09:30                       | B. Liu, Overview of ENN proton-boron fusion research (I-5)                                                                                                              |
|                                     | 09:30-09:50                       | D. Hoffmann, The Fusion Portfolio: Why p-11B Deserves a Place at the Table (O-6)                                                                                        |
|                                     | 09:50-10:10                       | R. Huo, Net Energy Gain Attempt via Nonthermal Equilibrium at ENN (O-7)                                                                                                 |
|                                     | 10:10-10:30                       | G. Gordana Lastovicka-Medin, Challenges of utilizing Si & SiC detectors towards X-ray/alpha particle discrimination in pB related experiments (O-8)                     |
|                                     | 10:30-10:50                       | Coffee Break                                                                                                                                                            |
| <b>Chair: I. Fitis</b>              |                                   |                                                                                                                                                                         |
| S6                                  | 10:50-11:20                       | A. Kulińska, The pB reaction in Plasma-Focus device, status of the experiments (I-6)                                                                                    |
|                                     | 11:20-11:40                       | V. Munzar, Charged-Particle Diagnostics for Proton–Boron and Deuterium–Deuterium Fusion Experiments on Plasma Focus (O-9)                                               |
|                                     | 11:40-12:00                       | C. Karvounis, 2D MHD simulations of a miniature Plasma Focus device (O-10)                                                                                              |
|                                     | 12:00-12:30                       | Discussion: HiPER+ / COST / Perspectives, D. Batani / G.A.P. Cirrone                                                                                                    |
|                                     | 12:30- 13:00                      | Break (laptop drop-off to the hotel)                                                                                                                                    |
|                                     | 13:00- 18:00                      | Historical Peninsula Tour (Boxed Lunch)                                                                                                                                 |
| Wednesday (7 <sup>th</sup> October) |                                   |                                                                                                                                                                         |
| S7                                  | <b>Chair: G. Lastovicka-Medin</b> |                                                                                                                                                                         |
|                                     | 09:00-09:30                       | C. Verona Advanced Time-of-Flight Diamond Diagnostics for Ion Discrimination (I-7)                                                                                      |
|                                     | 09:30-09:50                       | F. Consoli, Advances on alpha particle identification in low-rate laser-triggered nuclear fusion reactions (O-11)                                                       |
|                                     | 09:50-10:10                       | D. Pacella Efficient Detection of alpha particles in proton-boron experiments with pixellated 2-D ASIC detectors like Timepix3 (O-12)                                   |
|                                     | 10:10-10:30                       | F. Abubaker, Unlocking Proton–Boron Fusion with Laser-Driven Ion Beams: High-Energy Proton Acceleration, Advanced Diagnostics, and Fusion Yield Characterization (O-13) |
|                                     | 10:30-10:50                       | M. S. Dimitrijević, Broadening of nitrogen lines for diagnostics of proton- boron fusion plasma obtained with BN target (O-14)                                          |
|                                     | 10:50-11:10                       | Coffee Break                                                                                                                                                            |
| S8                                  | <b>Chair: F. Consoli</b>          |                                                                                                                                                                         |
|                                     | 11:10-11:40                       | G.A.P. Cirrone, G4PLASMA: a Roadmap for Integrating Plasma Aware Charged-Particle Transport Models into the Geant4 Toolkit (I-8)                                        |

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|                               |                                    |                                                                                                                                                                                       |
|-------------------------------|------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                               | 11:40-12:00                        | Z. Li, Spin-Polarized p-11B: From Generation to Maintenance (O-15)                                                                                                                    |
|                               | 12:00-12:20                        | T. Apostolova, Orientation-Dependent High-Harmonic Generation in Semiconductors and Potential for High Energy Attosecond Driving of Proton-Boron Fusion (O-16)                        |
|                               | 12:20-12:40                        | P. Tchorz, Demonstration of bidirectional alpha particle emission from proton-boron reaction using low-density boron catchers and cavity-type pitcher with ns, kJ laser system (O-17) |
|                               | 12:40-14:00                        | Lunch Break                                                                                                                                                                           |
|                               | 14:00-14:30                        | CG Meeting CA21128 / PROBONO chaired / Chair: K. Batani (closed in person)                                                                                                            |
|                               | 14:30-16:30                        | MC Meeting CA21128 / PROBONO / Chair: K. Batani (closed & hybrid)                                                                                                                     |
|                               |                                    |                                                                                                                                                                                       |
|                               | 18:00- 21:00                       | Gala Dinner                                                                                                                                                                           |
| <b>Thursday (8th October)</b> |                                    |                                                                                                                                                                                       |
| <b>S9</b>                     | <b>Chair: A. Maffini</b>           |                                                                                                                                                                                       |
|                               | 09:00-09:30                        | I.C.E. Turcu, Ammonia Borane P-B Fusion Fuel: from 2022 Proposal at Catania Workshop to Experimental Results (I-9)                                                                    |
|                               | 09:30-09:50                        | M. G. S. Londesborough, From Borax mines to Sophisticated Nano-Structured Borane-based Targets for p-11B Fusion: The complete chain (O-18)                                            |
|                               | 09:50-10:10                        | D. Orecchia, Pulsed Laser Deposition as a versatile technique for tailored boron-based targets in proton-boron fusion (O-19)                                                          |
|                               | 10:10-10:30                        | P. J. Kervalishvili Using Pulsed Laser Deposition for Target Preparation in Proton-Boron Fusion Experiments (O-20)                                                                    |
|                               | 10:30-10:50                        | Coffee Break                                                                                                                                                                          |
| <b>S10</b>                    | <b>Chair: M.G.S. Londesborough</b> |                                                                                                                                                                                       |
|                               | 10:50-11:10                        | D. Mancelli, Study of proton stopping power in warm dense matter using low-density Foams at the XGIII laser facility (O-21)                                                           |
|                               | 11:10-11:30                        | A. Maffini, CA25144: Inertial fusion energy: supply Chain of laser targets from Exploration to Delivery (ICED) (O-22)                                                                 |
|                               | 11:30-11:50                        | Discussion: CA25144: ICED, A. Maffini / F. Consoli                                                                                                                                    |
|                               | 11:50-12:00                        | Closing Ceremony                                                                                                                                                                      |
|                               | 12:00-14:00                        | Lunch                                                                                                                                                                                 |



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**International Workshop on  
PROton-BOron Nuclear fusion: from energy production to medical applicati**Ons****

**INVITED LECTURES**

We are honored to present  
**IWPROBONO 2026 INVITED SPEAKER**

**Dr. Massimiliano Scisciò**

ENEA Nuclear Department, Italy

**INVITED TALK:**

Laser-driven low-rate nuclear fusion reactions: single-pulse and high-repetition- rate approaches.



Massimiliano Scisciò is a researcher at the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), working within the Nuclear Fusion Department at the Frascati Research Centre. His research activities focus on laser-plasma interaction physics, with particular emphasis on inertial confinement fusion, high-energy-density plasmas, laser-driven particle acceleration, laser-driven low-rate fusion reactions and advanced diagnostics for experiments of high-intensity laser-matter interaction. He received a joint Ph.D. in Accelerator Physics and Energy and Materials Science from Sapienza University of Rome and the Institut National de la Recherche Scientifique (INRS) in Canada, graduating with distinction. His doctoral and early post-doctoral research focused on the acceleration, transport, and manipulation of laser-generated particle beams. Throughout his career, he has contributed to research programs in laser-driven particle acceleration, accelerator physics for CERN, and fusion energy science. M. Scisciò is the author of numerous scientific publications and conference contributions and is actively involved in several national and international collaborations, including EuroFusion ENR project “HIPER+RF” (where he currently serves as Work Package Coordinator for Laser-Plasma and Nuclear Fusion Diagnostics), the INFN-ENEA project “Fusion”, the COST Action PROBONO and Laserlab-Europe expert group on laser-driven electromagnetic pulses.

## Laser-driven low-rate nuclear fusion reactions: single-pulse and high-repetition-rate approaches

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### Abstract

Laser-driven low-rate nuclear fusion reactions can be triggered by the interaction of high-power laser pulses with matter. Recently, the  $p+^{11}\text{B} \rightarrow 3\alpha + 8.7 \text{ MeV}$  fusion reaction driven by lasers, has been extensively studied, as it represents to only a potential alternative to tritium-based fuels for fusion energy production [1], but it is also attracting interest for many applications such as astrophysics [2] and alpha-particle generation for medical treatments [3]. Possible schemes for laser-driven  $p-^{11}\text{B}$  reactions are to directly irradiate a borated target with energetic laser pulses at high intensity or, alternatively, direct a beam of laser-accelerated protons onto a boron sample (the so-called “pitcher-catcher” scheme). The several experiments that have been performed in the last years, implementing both these methodologies, can be divided into two main approaches: maximizing the laser energy in one single pulse with the attempt of inducing a high number of fusion reactions and generating a high alpha particle flux in burst mode, typically using a kJ-class laser system [4,5]; alternatively, using laser systems with moderate pulse energy (in the range of few tens of J) at high repetition rate (potentially multi-Hz), with the goal of improving the average flux of alpha particles generated by the fusion reactions, by accumulating long shot series [6,7]. The first approach has delivered the highest number of alpha particles in a single shot, but it is possible only on a few large installations and for a limited number of shots. Using a high-repetition rate system allowed various experiments with hundreds (up to thousands) of laser shots, leading to an improved optimization of the diagnostic techniques and an enhanced statistic of the obtained results.

The activities of this community over the last years, have approached laser-driven low-rate fusion using both these methodologies, focusing not only on studying  $p-^{11}\text{B}$  fusion for energy, but also addressing applications, e.g. a laser-driven source of radioisotope production [8,9], and developing novel diagnostics. We will show here the main challenges of these two approaches, highlighting not only the different obtained results (in terms of induced fusion reactions and measured alpha particle yield from  $p-^{11}\text{B}$ ) in the last years experiments, but also illustrating the different types of experimental complications and different methodologies of diagnosing (and analyzing) the products of the laser driven fusion reactions.

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### Acknowledgements

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We are honored to present  
**IWPROBONO 2026 INVITED SPEAKER**

**Prof. Olga N. Rosmej**  
Goethe University Frankfurt, Germany

**INVITED TALK:**

Boost of electron and proton acceleration using low density foams



Olga N. Rosmej is a Professor at Goethe University Frankfurt and a Staff Scientist at the GSI Helmholtzzentrum für Schwerionenforschung (GSI), Darmstadt, Germany, where she has held a permanent research position since 2000. She received her Ph.D. in Experimental Plasma Physics from the Kurchatov Research Centre (Moscow, Russia) for her research on radiation from dense pinch plasmas and completed her Habilitation at Goethe University Frankfurt in 2012. She has been Professor at Goethe University Frankfurt since 2019. Her research focuses on high-energy-density physics using intense laser and heavy-ion beams, including X-ray spectroscopy of hot plasmas, heavy-ion stopping in matter, laser-plasma interaction, particle acceleration, secondary laser-driven photon and particle sources, and nanostructured materials for advanced applications. Since 2017, her work has particularly emphasized relativistic laser interactions with low-density foam targets for the generation of ultra-intense sources of MeV electrons, protons, neutrons, isotopes, and high-energy radiation. Prof. Rosmej has extensive experience in plasma X-ray spectroscopy and has been actively involved in teaching graduate courses and international summer schools in plasma physics and high-energy-density science, including programs at Goethe University, Erice (Italy), and Salamanca (Spain).

## Boost of electron and proton acceleration using low density foams

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<sup>1</sup>GSI Helholtzzentrum, Planck Str.1, 64291 Darmstadt, Germany

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### Abstract

A low-density foam of sub-mm thickness, pre-ionized by a well-controlled nanosecond pulse serves as an excellent plasma target to boost the direct laser acceleration (DLA) of electrons and subsequent proton acceleration driven by sub-picosecond relativistic laser pulses.

The application of the foam-converted plasma at the front of the foil results in a greater than 10-fold increase in both the effective electron temperature and the local charge of the forward-directed electron beam compared to a bare foil target [1], as well as a 1.5-fold enhancement of the proton cutoff energy.

The robustness of this approach was analyzed in [2] and has been confirmed across numerous experimental campaigns at the PHELIX laser facility (GSI Darmstadt) over the last eight years.

The application of foam targets has also demonstrated excellent results on electron acceleration at near-relativistic laser intensities, which are characteristic of large-scale laser facilities such as the Advanced Radiographic Capability (ARC) at the National Ignition Facility (NIF). Furthermore, the foam facilitates the smoothing of the laser energy deposition, which is clearly reflected in the improved homogeneity of the proton beam profile when using a large, imperfect focal spot.

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We are honored to present  
**IWPROBONO 2026 INVITED SPEAKER**

**Prof. Dimitri Batani**

University of Bordeaux, France

**INVITED TALK:**

Proton boron fusion for laser driven production of medical radioisotopes.



Dimitri Batani received his PhD in Physics from the University of Pisa (Italy), with a thesis on the generation and characterization of soft X-rays from laser-produced plasmas. He subsequently joined the Plasma Physics group at the University of Milan and later moved to the University of Milano-Bicocca (Italy) as Senior Researcher and Associate Professor. In 2011, he was appointed Full Professor at the University of Bordeaux (CELIA laboratory), where he has held the rank of Professor of Exceptional Class since 2014. He is a Fellow of the European Physical Society (EPS), a Senior Member of the Institut Universitaire de France (IUF), and a member of the European Academy of Sciences (EURASC). His research interests span laser-driven particle and radiation sources, inertial confinement fusion, the study of matter under extreme pressure conditions, and the development of plasma diagnostics. Since 2017, he has coordinated several EUROfusion Enabling Research projects on the physics of direct-drive inertial fusion and shock ignition. He currently serves as spokesperson of the HiPER+ initiative and as coordinator of the Enabling Research project devoted to the "Conceptual Design for a European High Power Laser Fusion Research Facility" (HiPER+RF).

## Proton boron fusion for laser driven production of medical radioisotopes

Dimitri Batani

University of Boredeaux, France

### Abstract

The record production of alpha particles obtained by irradiating boron-hydrogen targets with high-intensity lasers [<sup>1</sup>], [<sup>2</sup>] opened the way to studies on proton-boron fusion related to nuclear fusion [<sup>3</sup>], generation of novel laser-driven a-particle sources [<sup>4</sup>], enhancing the effectiveness of Proton Boron Capture Therapy (PBCT) [<sup>5</sup>], and, finally, the production of radioisotopes of medical interest [<sup>6</sup>].

The present work discusses the possibility of producing radioisotopes of medical interest and specifically radioisotopes for use in PET (Positron Emission Tomography) such as <sup>11</sup>C, <sup>18</sup>F, <sup>43</sup>Sc, and <sup>44</sup>Sc.

I discuss the results from experiments performed using the PW-class, short duration and high repetition laser VEGA-III at CLPU, Spain. In the experiment, we used the pitcher-catcher scheme, using thin Al foils to produce accelerated protons, which were directed on various targets including boron catchers (BN, BNH<sub>6</sub>) to produce a particle through proton boron fusion reactions. We used a HPGe (High-purity Germanium) detector to detect gamma ray emission lines from the activated catcher showing emission lines from <sup>7</sup>Be, <sup>11</sup>C, and <sup>18</sup>F, measuring their lifetime and estimating their activity [<sup>7,8</sup>].

We also used high density calcium silicate (Ca<sub>2</sub>SiO<sub>4</sub>) catchers to produce scandium radioisotopes either by the interaction with a-particles produced by pB fusion or directly by the accelerated proton beam [<sup>8</sup>]. The results indicate the presence of the scandium radioisotopes: <sup>43</sup>Sc, <sup>44</sup>Sc, and <sup>48</sup>Sc. We are reporting on two experiments. The first one demonstrated possibility of radioisotope production, the second one put light on developments, which might allow developing laser-driven sources of radioisotopes for medical applications.

Finally in the talk I will discuss the scalability of present results towards the possibility of practical production of medical radioisotopes at the industrial level.

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### Acknowledgements

This work has been carried out within the framework of the COST Action CA21128- PROBONO “PROton BORon Nuclear fusion: from energy production to medical applications”, supported by COST (European Cooperation in Science and Technology- [www.cost.eu](http://www.cost.eu)).

We are honored to present  
**IWPROBONO 2026 INVITED SPEAKER**

**Prof. Katarzyna Batani**

Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland

**INVITED TALK:**

Equation of State of Shock Compressed BN in the Megabar Pressure Range



Katarzyna Batani is Associate Professor at the Institute of Plasma Physics and Laser Microfusion (IPPLM), Warsaw, Poland. She is an experimental physicist with many years of experience in plasma physics, fusion research, laser–plasma interactions and high-energy-density physics. Her work combines experimental research, diagnostics development and data analysis, with extensive experience gained through collaborations at major international laser and fusion facilities. Her research interests include laser-driven fusion, proton–boron fusion, plasma diagnostics, spectroscopy, and warm dense matter. She has substantial experience in scientific leadership and international coordination. She currently chairs COST Action CA21128 PROBONO, a European network dedicated to advancing research in laser-driven proton–boron fusion and strengthening collaboration among researchers across Europe and beyond. Through involvement in Hiper+ and co-leadership of WP7, contributing to the advancement of European inertial fusion. From 2021 to 2025, she served as Editor-in-Chief of the international open-access journal Laser and Particle Beams, during which the journal's Impact Factor increased. Katarzyna Batani is strongly committed to international scientific collaboration, the development of young researchers, and communication between science and society. Throughout her career she has been closely involved in organising scientific conferences, educational activities and public-engagement initiatives, and has served as a lecturer, scientific committee member and event organiser for numerous international and national scientific meetings.

## Equation of State of Shock Compressed BN in the Megabar Pressure Range

K. Batani

*Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland*

### Abstract

The equation of state (EoS) of boron nitride (BN) under extreme conditions is of significant interest for applications related to inertial confinement fusion (ICF), high-energy-density physics, and hydrogen-boron fusion studies. However, the database for EoS of BN available when we started research in this area was extremely limited, consisting of only three points for cubic BN (c-BN) [1].

In this work, we present a comprehensive experimental investigation of the BN EoS performed at the ELI Beamlines, PALS [2], GEKKO, and SGIII-p [3] laser facilities. Experiments were carried out using both direct-drive and indirect-drive shock-compression schemes in order to explore the Hugoniot curve of BN over a broad pressure range. Lasers were operating either at 2w or 3w with pulse length  $\tau_L$  from  $\sim 350$  ps up to 4 ns, and energies up to 470 J in the direct drive approach and up to 6400 J in the indirect drive approach. A flat-top intensity profile within the focal spot of  $\sim 350$ -600  $\mu\text{m}$  diameter was assured by using a phase plate. The shock parameters were determined using standard high-energy-density plasma diagnostics, including the Velocity Interferometer System for Any Reflector (VISAR) and Streaked Optical Pyrometry (SOP). Shock velocities were simultaneously measured in BN samples and reference materials, and the impedance mismatch technique was applied to derive new EoS points. We used multilayer stepped targets, with either aluminum or quartz as reference, produced by Scitech Precision, UK, or by LFRC and HPSTAR in China.

The experiments provided several new Hugoniot data points for both hexagonal BN (h-BN) and cubic BN (c-BN) along the principal Hugoniot curve at multi-megabar pressures, significantly extending the currently available experimental database. The obtained results are compared with existing theoretical models and simulations, showing generally good agreement while also providing important constraints for future EoS calculations of boron-based materials under extreme conditions.

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### Acknowledgements

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This scientific work has been carried out as part of the international 'PMW' project, co-financed by the Polish Ministry of Science and Higher Education.

We are honored to present  
**IWPROBONO 2026 INVITED SPEAKER**

**Prof. Bing Liu**

Beijing ENN Fusion Energy Science and Technology Co. China

**INVITED TALK:**

Overview of ENN proton-boron fusion research



Prof. Bing Liu has conducted research in experimental plasma turbulence for tokamak, stellarator, and reversed-field pinch devices, including research at the University of Padua and Universidad Carlos III de Madrid. Previously, he worked at the Southwestern Institute of Physics and Southwest Jiaotong University, focusing on liquid-metal magnetohydrodynamics (MHD) and stellarator development, respectively. In 2018, he joined ENN, where he led research on plasma energy confinement for the EXL-50. He subsequently established the proton–boron (p–B) Reaction Group, focusing on proton–boron nuclear physics, non-thermal plasma properties, and key nuclear technologies for proton–boron fusion.

## Overview of ENN proton-boron fusion research

B Liu, Z. Li, X. Xiao, H.R. Huang, D. Luo, G.C. Zhao, Y.J Shi, H.Y. Zhao, Y. Bai, Z.Y. Gao, Y.C. Li, W. Yang, R. Huo, Y.M. Wang, T.T. Sun, Y.Y. Li, J.Q. Dong, Y.-K.M. Peng, Y.F. Liang

*Beijing ENN Fusion Energy Science and Technology Co., Ltd., Beijing 101111, China*

### Abstract

Fusion energy research is moving toward commercialization. Proton-boron (p-<sup>11</sup>B) fusion is attracting interest as an aneutronic, clean energy pathway, trading formidable scientific challenges for reduced engineering complexity. ENN Fusion is developing a magnetic-confinement path to demonstrate tritium-free p-<sup>11</sup>B power based on compact spherical torus (ST) plasmas by 2035.

Accelerator-based reactions under multi-Tesla fields revealed enhanced reactivity, while evaluated spin-polarization techniques predict a ~60% cross-section boost. Strategies to maintain essential non-thermal equilibrium were analyzed, including hot-ion modes ( $T_i/T_e > 1$ ), non-Maxwellian plasmas, Rider's constraints, and beam-driven selective ion acceleration.

The EXL-50 device demonstrated solenoid-free RF/ECRH current startup and long-pulse operation. Extending this, EXL-50U achieved high-performance hydrogen-boron operation with a 1 MA plasma current, multi-keV temperatures, and the first reported high-confinement-mode in p-<sup>11</sup>B plasmas. Concurrently, ENN-NIFS joint experiments on the LHD highlighted simultaneous alpha and gamma emission measurements.

Supported by megawatt-class heating and AI-assisted control, the next-step EHL-2 device targets 3 MA, 3 T, 30 keV ion temperature,  $1.3 \times 10^{20} \text{ m}^{-3}$  density, and 0.5 s confinement to validate p-<sup>11</sup>B reaction physics, energy gain, and DEMO-relevant direct electricity generation.

We are honored to present  
**IWPROBONO 2026 INVITED SPEAKER**

**Prof. Agnieszka Kulińska**

Henryk Niewodniczański Institute of Nuclear Physics, Poland

**INVITED TALK:**

The pB reaction in Plasma-Focus device, status of the experiments



Agnieszka Kulińska is Associate Professor at the Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN) in Kraków, Poland, where she has been conducting research since 1995. She holds a PhD in Physics and a habilitation degree in the field of materials science. Her current research focuses on proton-boron fusion in Plasma-Focus devices, plasma diagnostics, and the detection of fusion reaction products. She has led and participated in national and international research projects, in plasma physics, fusion energy and material; science, and has extensive experience in experimental, nuclear methods, materials science, and diagnostics related to discharges in Plasma-Focus. Her research career includes research stays and joint experimental work at the University of Göttingen, Czech Technical University in Prague, and Tallinn University, as well as collaborations with research groups in Poland, Europe and beyond. Agnieszka Kulińska is also actively involved in supervision of PhD students, tutoring students, organization of scientific events, and science communication. She regularly participates in outreach activities for children and the general public.

## The pB reaction in Plasma-Focus device, status of the experiments

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### Abstract

The  $^{11}\text{B}$  (p,  $\alpha$ ) $2\alpha$  nuclear fusion reaction occurring in boron-hydrogen fuel is attracting increasing interest due to its potential applications. It is currently the subject of extensive research in various systems, such as inertial confinement fusion, high-power lasers, and Z-pinches [1, 2, 3].

A dense, hot, magnetized plasma column is generated during high-voltage and high-current discharge in a Plasma-Focus (PF) device, a type of Z-pinch device. The physical principles of the PF operation will be described based on experiments and models describing plasma behavior. The role of phenomena occurring in the plasma generated in the PF system, leading to the fusion of light hydrogen nuclei, will be presented, with particular emphasis on the proton-boron reaction. The concept of doping plasma by means of laser ablation of a solid boron target during discharge in PF 24 will be described, along with the possibility of ignition the pB reaction [4]. To detect reaction products, in addition to the commonly used CR-39 detectors, a new method of alpha-particle spectroscopy based on LiF fluorescent track detectors has been applied. The status of experiments performed on various PF devices will be reported, and the results obtained to date will be summarized.

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### Acknowledgements

This work was co-financed by the National Science Centre (NCN), Poland, Grant No. 2023/49/B/ST2/02325.

This work has been carried out within the framework of the COST Action CA21128- PROBONO “PROton Boron Nuclear fusion: from energy production to medical applications”, supported by COST (European Cooperation in Science and Technology- [www.cost.eu](http://www.cost.eu))

We are honored to present  
**IWPROBONO 2026 INVITED SPEAKER**

**Prof. Claudio Verona**

University of Rome "Tor Vergata", Italy

**INVITED TALK:**

Advanced Time-of-Flight Diamond Diagnostics for Ion Discrimination



Prof. Claudio Verona graduated in Physics from Sapienza University of Rome in 2005 and received his Ph.D. in Microsystem Engineering from the University of Rome Tor Vergata in 2010. Since 2022, he has been Associate Professor of Applied Physics in the Department of Industrial Engineering at the University of Rome Tor Vergata. His research focuses on the development and characterization of synthetic diamond materials and on the design, fabrication, modelling, and experimental validation of diamond-based radiation detectors. His main research interests include medical physics, radiotherapy dosimetry and microdosimetry, laser-plasma particle diagnostics, fusion-plasma monitoring, neutron detection, and UV and soft X-ray diagnostics. He has extensive expertise in diamond detectors for fusion-plasma diagnostics and time-of-flight measurements of particles generated in high-intensity laser-matter interactions. Several detector systems developed by his research group have been installed at the Joint European Torus (JET) in Culham, UK. He has also participated in numerous experimental campaigns at major international laser facilities, including PALS, ELI-ALPS, CLPU, CELIA, ENEA-ABC, and INFN-LNF. His current research focuses on laser-driven ion acceleration and aneutronic proton-boron fusion, with particular emphasis on advanced time-of-flight diagnostics, diamond detector arrays, and multi-detector configurations for energy-resolved measurements and ion-species discrimination in complex multi-species beams. In medical physics, his group developed a synthetic single-crystal diamond Schottky-diode dosimeter subsequently commercialized by PTW Freiburg GmbH. He has served as principal investigator and scientific coordinator of several national research projects. He is the author of more than 200 peer-reviewed scientific publications. According to Scopus, his work received approximately 5,000 citations, with an h-index of 40.

## Advanced Time-of-Flight Diamond Diagnostics for Ion Discrimination

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### Abstract

Time-of-Flight (TOF) diagnostics are widely employed in laser–plasma experiments for the characterization of accelerated ion beams. Diamond detectors are particularly suitable for this application because of their fast temporal response, radiation hardness and capability to operate under the demanding conditions typical of high-power laser experiments. However, conventional single-detector TOF measurements provide limited information on the ion species since particles with different mass and charge can produce overlapping temporal signatures.

To overcome these limitations, advanced diamond-based TOF configurations are being developed. These include arrays of diamond detectors coupled with different absorber filters [1], as well as stacked architectures composed of successive active diamond detector layers. In filtered detector arrays, the different energy losses produced by the absorbers provide complementary information on the incident particles. In stacked configurations, ion populations evolve differently while propagating through the detector layers according to their mass, energy and stopping behaviour. These detection systems can improve ion-species discrimination compared with conventional single-layer TOF measurements. Alongside the development of these detector architectures, a self-consistent methodology is proposed for reconstructing and discriminating the ion populations [2]. Starting from candidate ion spectra obtained under different species hypotheses, particle transport calculations, stopping-power data and detector-response models are used to generate the signals expected in the different detectors, filters or active diamond layers. The synthetic responses are then compared with the measured signals to assess the compatibility of each hypothesis and reconstruct possible single-species or mixed-species contributions. These advanced diamond TOF systems, combined with physics-based signal reconstruction, represent a promising approach for improving the reliability of ion identification in high-power laser plasma experiments.

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### Acknowledgements

This work has been partially carried out within the framework of the INFN-FUSION project, supported by CNSV. Participation in the IWPROBONO has been supported by the framework of the COST Action CA21128- PROBONO “PROton Boron Nuclear fusion: from energy production to medical applications”, supported by COST (European Cooperation in Science and Technology- [www.cost.eu](http://www.cost.eu))

We are honored to present  
**IWPROBONO 2026 INVITED SPEAKER**

**Prof. G.A.P. Cirrone**

INFN-LNS, Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud, Italy

**INVITED TALK:**

G4PLASMA: a Roadmap for Integrating Plasma Aware Charged-Particle Transport Models into the Geant4 Toolkit



Giuseppe Antonio Pablo Cirrone is a Senior Researcher at INFN-LNS, with a PhD in Physics and specialist training in Medical and Environmental Physics. His career connects radiation physics and clinical applications with Monte Carlo modelling and laser-plasma research. Early contributions to CATANA helped establish proton therapy in Italy in 2002; his clinical experience as a medical physicist includes involvement in the treatment of over 300 patients. This clinical background shaped a research programme spanning radiobiology, advanced dosimetry and innovative treatment approaches, including Proton Boron Capture Therapy. Detector development, particularly with silicon carbide, extends this work to FLASH and laser-driven beams. In parallel, contributions to Geant4 include the Hadrontherapy and Radiobiology applications, alongside responsibilities in its scientific governance. The transition towards high-power lasers led to the conception and coordination of ELIMED at ELI-Beamlines and to the development of I-LUCE at INFN-LNS, where Cirrone is Scientific Lead. These infrastructures connect particle acceleration with biomedical and energy research. National leadership of FUSION and participation in PROBONO extend this work to proton-boron fusion, while involvement in Hiper+ and leadership of WP7 support European inertial fusion. Scientific leadership across national and European programmes has involved managing approximately €20.12 million, including €18.32 million from competitive funding. With 449 indexed publications and a Scopus h-index of 39, his scientific record is complemented by patents, international collaborations and the 2018 Michael Goitein Award. Supervision of 53 theses, advanced teaching and editorial work underpin a sustained commitment to training.

## G4PLASMA: a Roadmap for Integrating Plasma Aware Charged-Particle Transport Models into the Geant4 Toolkit

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### Abstract

Geant4 is a widely used Monte Carlo toolkit for simulating particle transport and interactions in matter. It provides a comprehensive and continuously evolving set of physics processes and models, covering electromagnetic and hadronic interactions in condensed materials over a broad range of particle types and energies. Geant4 also enables the detailed description of complex geometries, including geometries imported from CAD models through dedicated conversion tools and interfaces. Moreover, it supports simulations at different spatial scales, down to the nanometre scale through the Geant4-DNA track-structure models. However, many applications in nuclear fusion and high energy-density physics, including inertial-confinement and magnetic confinement fusion, fast-ignition schemes, heavy-ion fusion, ion-beam heating of warm dense matter, laser-driven ion acceleration and transport, plasma diagnostics, and laboratory astrophysics, involve the propagation of charged particles through plasma media. Under these conditions, ion energy loss depends explicitly on plasma temperature and density, ionization state, charge-state evolution, and collective effects. These plasma-specific dependencies are not accounted for by the standard stopping-power models currently available in Geant4.

This work presents a roadmap for extending Geant4 toward plasma-aware charged-particle transport while preserving its modular software Architecture. The proposed development follows a staged implementation strategy. As the first stage, the modified Li-Petrasso (MLP) stopping-power model is integrated as a continuous energy-loss model within the Geant4 electromagnetic framework. Initial software verification is performed against an independent MATLAB implementation for alpha particles in homogeneous deuterium-tritium plasma at  $T_e=T_i=0.1, 1, \text{ and } 20 \text{ keV}$  and  $\rho=10 \text{ g/cm}^3$ , and for protons at  $T_e=T_i=5 \text{ KeV}$  and  $\rho=418 \text{ g/cm}^3$ . As a prospective second stage, dielectric response models based on the random-phase approximation and local-density approximation (RPA-LDA) are considered for warm-dense, partially degenerate, and partially ionised matter. Extension toward strongly coupled conditions will require additional physics beyond the baseline RPA treatment, including appropriate local-field and strong-collision corrections.

The proposed framework preserves the flexibility and extensibility of Geant4 while enabling self-consistent Monte Carlo simulations in which plasma stopping physics, particle transport, realistic target geometries, and detector response are treated within a unified simulation environment. Such capabilities provide a foundation for future applications in nuclear fusion diagnostics, inertial confinement fusion, and high-energy-density physics experiments.

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## Acknowledgements

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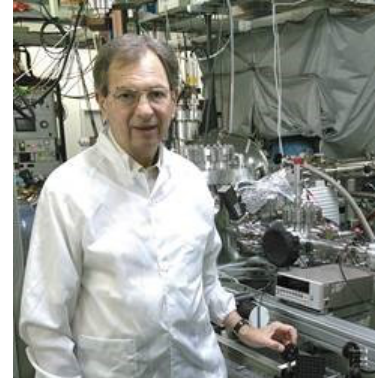
"This work has been carried out within the framework of the COST Action CA21128- PROBONO "PROton BORon Nuclear fusion: from energy production to medical applications", supported by COST (European Cooperation in Science and Technology - [www.cost.eu](http://www.cost.eu)

We are honored to present  
**IWPROBONO 2026 INVITED SPEAKER**

**Prof. I.C. Edmond Turcu**

Rutherford Appleton Laboratory, United Kingdom

**INVITED TALK:** Ammonia Borane P-B Fusion Fuel: from 2022  
Proposal at Catania Workshop to Experimental Results



Obtained BSc Honours (1974) and PhD from Imperial College, University of London. 40 years Senior Scientist (after retirement as consultant) at Central Laser Facility, UKRI/STFC Rutherford Appleton Laboratory, Harwell Campus, Oxfordshire, UK. Book on original research (CLF): “X-rays from Laser Plasmas: Generation and Applications”. Invented Soft X-ray Source for proximity Nanolithography of Semiconductor Chips (CLF) and achieved record 30Watt average power soft X-ray Source (~1keV photons, ~1nm wavelength) driven by 300W diode pumped solid state laser (while on leave at JAMAR Research in California). Invented (JAMAR) the Laser-Driven Tin Droplet EUV (13.4nm) Source for EUV imaging nanolithography. Invented and built (Principal Investigator) the ARTEMIS Facility (at CLF) for Femtosecond Time Resolved Photoelectron Spectroscopy (TR-ARPES) of Solid Materials using a Mid-IR femtosecond laser excitation pulse and an XUV (10-100eV) femtosecond probe pulse. Built similar system at Nanjing University, as Professor in School of Electronic Science and Engineering – also taught PhD, MSc and Undergraduate students. At the Extreme Light Infrastructure – Nuclear Physics (Bucharest Romania) I designed (Principal Investigator) and written with collaborators the Technical Design Review for the colliding 2x10PW Lasers Interaction Chamber for “High Field Physics and QED Experiments At ELI-NP”, Technical Design Review published in Romanian Reports in Physics. As a visiting scientist to SIOM (Shanghai) I advised on the 10PW and 100PW laser interaction chambers for HF QED experiments. Recently I worked and published in the Field of Laser-Driven Nuclear Fusion: targets materials like Ammonia Borane Proton-Boron Fusion and Heavy Ammonia Borane of DD and DT fusion; contribution to “Nuclear Fusion Power Reactor First Wall Lifetime Problem: Proposed Solutions” paper in print in HPLSE- Vol 14 (2026), regarding mainly DT Fusion Reactors with a brief section on Proton-Boron Fusion Reactors. Proposed this year, DDFIW-2026 a system of “Nuclear Fusion by Xray Direct Drive Capsule Compression in Double Shell Targets Driven by High Power Lasers”.

**Author and co-author** of two books, seven patents, and more than 200 journal publications including in: Nature Materials, Nature Comms., Phys Rev Lett., Applied Phys. Lett.

Member of Professional Societies: IOP(London) and Member Inst of Chartered Physicists (London), EPS, OSA, IEEE, SPIE.

## Ammonia Borane P-B Fusion Fuel: from 2022 Proposal at Catania Workshop to Experimental Results

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### Abstract

Boranes and specifically Ammonia Borane (AB), BNH<sub>6</sub>, have been proposed by ICET at the 2nd IWPBF2022 in Catania [1, 2] as nuclear-fusion fuel target material for laser-driven Proton Boron (P-B or HB11) fusion reactions because molecules contain Boron and are very rich in Hydrogen: AB has higher Hydrogen density than liquid Hydrogen.

Record number of fusion Alpha particles normalized to the energy of the laser pulse: 6x10<sup>7</sup> Alphas/sr/J was obtained by irradiating AB with the TARANIS Laser at QUB [3], slightly higher than the record of Giuffrida (2020): 5x10<sup>7</sup> Alphas/sr/J.

Medically important radioactive isotopes C11 and F18 were produced [4] when AB pellets were irradiated with VEGA-3 (at CLPS, Salamanca).

High proton energies and PB Fusion yields were measured when AB was irradiated with PALS (Prague) laser in 2024 and 2025 experiments Cirrone-PA, analysis in progress.

D-D Fusion Neutrons were measured from BND6 targets (proposed by ICET at 4th IWPBF2024 in Frascati [5]) irradiated with L4n laser at ELI-BL (Dolny Brezany) during PROBONO (Tchórz – PI) experiment in 2025.

ICET proposed high repetition rate AB target irradiation at 3rd IWPBF2023 in Prague [6]. An independent experiment with 1kHz laser irradiated B-H disc targets to generate high fluxes of Fusion

Alpha particles (Istokskaia, 2023). ICET proposes to repeat the experiment but irradiating AB disc targets instead, and in Helium atmosphere.

In the future ICET proposes to use AB foam, low density – sub-critical density- targets to increase the P-B fusion yield by >10x due to the increased penetration of the focused laser in the foam volume: hence larger volume P-B fusion. We propose to deposit such AB foams by Pulsed Laser Deposition: same method reported at the 4th IWOBF2024 in Frascati by the Passoni Group from Milano Poly for PLD deposition of B-H materials [7].

In the next 3 years we will also study the effect of increased laser intensities by irradiating AB targets with the 10PW ELI-NP as part of the experimental campaign PFI-PROBONO – D. Batani PI, scheduled as part of the “ELI Inertial Fusion Energy (IFE) Mission Based Program”

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## Acknowledgements

"This work has been carried out within the framework of the COST Action CA21128- PROBONO “PROton BORon Nuclear fusion: from energy production to medical applications”, supported by COST (European Cooperation in Science and Technology - [www.cost.eu](http://www.cost.eu)). LG was supported by the Czech Science Foundation through Grant No. GACR24-11398S.

**International Workshop on  
PROton-BOron Nuclear fusion: from energy production to  
medical applicati**Ons****

**ORAL PRESENTATION**

## Recent progress in laser-driven proton acceleration and proton-boron fusion at the NCU 100-TW laser facility

T.-Y. Huang<sup>1</sup>, W. Lin<sup>1</sup>, C.-H. Chen<sup>1</sup>, Y.-P. Yang<sup>1</sup>, C.-K. Huang<sup>1,2</sup>, H.-h. Chu<sup>1,2</sup>, S.-H. Chen<sup>1</sup>, and C.-H. Pai<sup>1,2</sup>

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### Abstract

The NCU 100-TW laser facility in Taiwan is dedicated to the development of laser-plasma particle accelerators and laser-assisted proton-boron (p-B) fusion using high-intensity femtosecond laser pulses [1]. Since the p-B fusion reaction has a smaller cross section than the conventional deuterium-tritium (D-T) reaction, it requires high-temperature and high-density plasma conditions that can be produced by ultra-intense lasers.

To quantitatively characterize laser-driven ion acceleration and fusion products, two complementary diagnostic systems have been developed: a high-sensitivity diagnostic based on CR 39 solid-state nuclear track detectors and an in-situ, shot-to-shot diagnostic based on CsI:Tl scintillators or P-43 phosphor screens coupled to an intensified CCD camera. A homemade Thomson parabola spectrometer has been calibrated against CR-39 using target normal sheath acceleration (TNSA) experiments, providing reliable ion energy measurements over a wide energy range.

To improve laser energy coupling and proton acceleration efficiency, we investigate near critical-density (NCD) gas targets, which enable enhanced laser deposition into the plasmas [2]. By tailoring the plasma density profile with a transverse pre-ionizing laser pulse, we demonstrate laser driven proton acceleration from NCD gas targets. Maximum proton energies up to 5 MeV are achieved with a laser normalized vector potential of  $a_0 = 4$ .

We also report preliminary studies of laser-assisted p-B fusion using CH-coated boron nitride targets. Alpha particles produced by fusion reactions are identified with CR-39 detectors positioned behind the Thomson parabola spectrometer. These results demonstrate the feasibility of laser-driven p-B fusion experiments at a laser normalized potential of  $a_0 = 1$  and establish a foundation for future optimization of laser-driven aneutronic fusion.

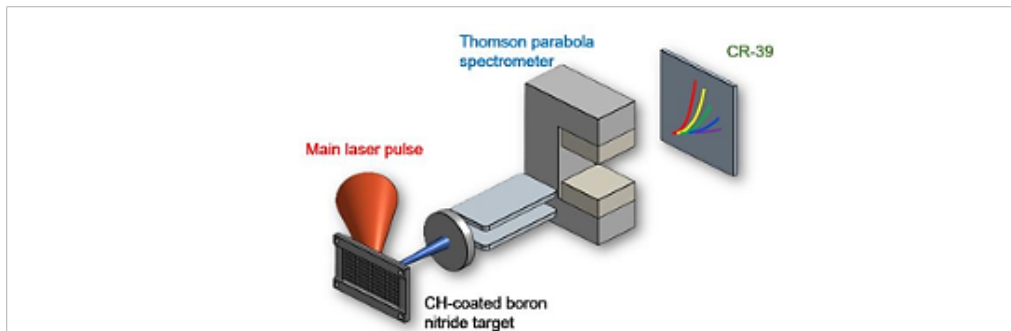


**Figure 1.** Schematic of the experimental setup and Thomson parabola spectrometer

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## Updates on the plasma-based acceleration of polarized protons and helium-3

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### Abstract

In recent years, plasma-based sources of spin-polarized particle beams have gained significant interest due to their applications in various areas of physics, including surface physics, deep-inelastic scattering to probe the proton's nuclear structure or even physics beyond the Standard Model in the search for axions [1]. Kulsrud et al. already realized in 1982 that polarization also has consequences for nuclear fusion [2]: if polarized reactants are utilized, the fusion cross-section for  $d + t \rightarrow \alpha + n$  is increased by 50%. A similar improvement was predicted for the case of proton-boron fusion [3]. In this talk, we give an update on the recent experimental and theoretical progress on spin-polarized proton and helium-3 beams. This includes the first proof-of-principle experiment on the acceleration of polarized helium-3 using PW-class laser pulses [4] as well as theoretical studies on hydrogen.

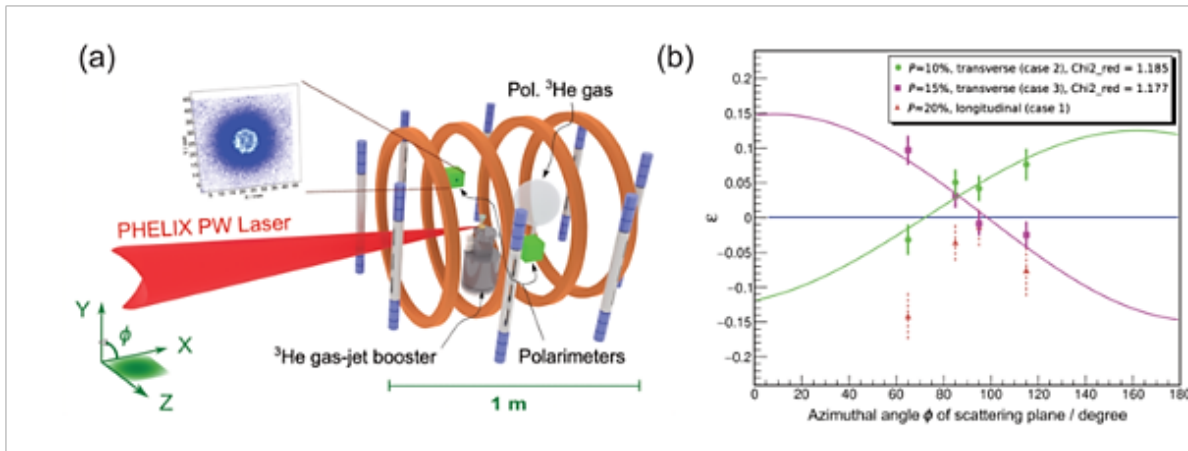


**Figure 1.** (a) Experimental setup at PHELIX for accelerating nuclear-polarized helium-3. (b) Count-rate difference for  $\alpha$ -particles measured in the polarimeters, confirming the preservation of polarization after acceleration. Adapted from [4], licensed under CC-BY-4.0.

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## Enhanced laser-proton acceleration and nuclear reaction via nano structure

Hui Zhang<sup>1</sup>, Liangliang Ji<sup>1</sup>, Baifei Shen<sup>2</sup> and Ruxin Li<sup>2</sup>

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### Abstract

Based on the chirped pulse amplification technology, the output peak power of ultra-intense lasers has reached up to the 10-PW class, providing new experimental means for many frontier research in strong field laser physics. Among these, laser-driven ion acceleration is attracting widespread interest because of prospects of realizing compact and ultrafast ion sources, which has potential applications in many fields, such as proton-boron fusion and fast ignition. To improve the ion quality, nano/micro structured targets, such as nano sphere, micro cylinder/tub, foam layer, near-critical-density material, and wire array, have been explored to enhance laser energy absorption, electron generation and finally ion acceleration.

Here, we present the recent progress on laser-driven proton acceleration and nuclear reaction carried out on the Shanghai Superintense Ultrafast Laser Facility (SULF), where two types of nano structures are used. In experiment, using the 3D-printed nano-wire array structure, the conversion efficiency from laser to protons reaches up to 9%, 3.5 times higher than that of the planar target [1]. Meanwhile, by employing the carbon nano-tube foam, the proton energy is increased by 130%, with the cutoff energy up to 90 MeV [2]. Based on the improved proton source, we also experimentally observe the enhanced neutron production and proton-boron fusion reaction.

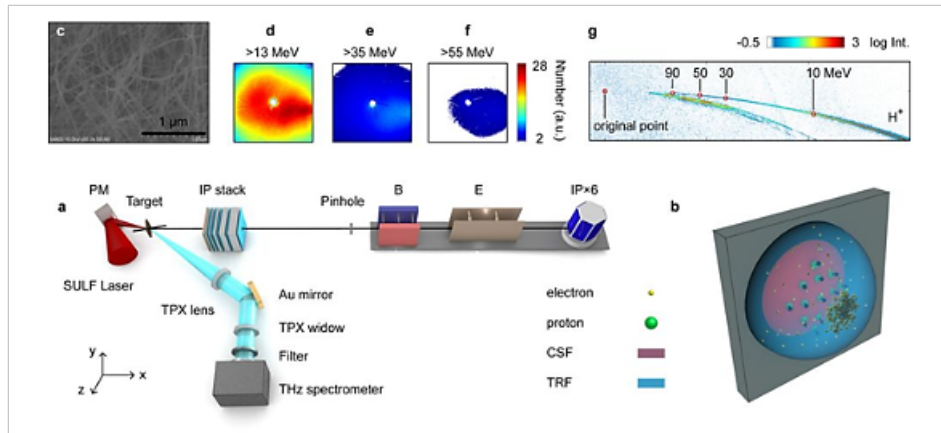


**Figure 1.** Experimental results using the carbon-nano-tube foam.

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## A Roadmap to Potential Fusion Applications Using Novel Approaches

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### Abstract

The proton-Boron ( $p\text{-}^{11}\text{B}$ ) neutron-free fusion reaction offers a clean path to fusion energy, producing three alpha particles (8.7 MeV) suitable for direct energy conversion. However, its cross-section is  $\sim 300$  times smaller than D-T, requiring temperatures near 3 billion K and in laser-driven schemes, interaction probabilities remain extremely low. Recent work by Tosca et al [1] demonstrated that confined geometries (cylindrical and spherical targets) can enhance yield by up to two orders of magnitude through geometric trapping, self-generated fields, and extended interaction times. Other experiments using gas jets [2] have generated proton beams via Collisional Shock Acceleration (CSA). Building on these findings, we propose two novel approaches extending confinement beyond static solid walls toward actively controlled plasma environments: capillary channels and gas jets. The capillary approach uses a pre-ionized, gas-filled capillary [3] to guide the laser over mm–cm scales, enabling extended interaction and precise density control. The gas jet approach employs a supersonic jet to deliver a fresh, debris-free target per shot, allowing high-repetition-rate operation. These novel techniques are considered in future I-LUCE (INFN-Laser induCED Radiation Production) facility [4] at INFN-LNS in Catania Italy which currently is under construction and expected to be fully operational by 2028, which will consider applications as radiation generation (primary/secondary sources, high-brightness X/gamma rays), particle acceleration (e.g., laser-driven electron/proton beams), nuclear physics (nuclear reactions in plasma, cross sections in warm dense matter), fusion Studies [5] (inertial confinement fusion, laser-induced fusion reactions) and medical physics (e.g., compact hadron therapy, radiobiology studies). Diagnostics include interferometry, contrast monitoring, Thomson spectrometry, and alpha detectors (CR-39, SiC, scintillators) areas where INFN-LNS has strong expertise [6,7].

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## Shock waves launched by short-pulse laser-solid interaction

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### Abstract

Hydrodynamic motion is inevitably initiated by the interaction of a short-pulse laser with a solid target [1-13]. While such interactions do not provide such a readily controllable platform for hydrodynamic experimentation as their long-pulse counterparts, it is nevertheless interesting to investigate such interactions as they can facilitate the exploration of regimes that are beyond the reach of long pulse lasers of comparable size [1,9]. In addition, such work can have relevance to some of the 'advanced' approaches to Laser-Fusion, including those based on proton-boron fusion. In this presentation we will consider some experimental results from both picosecond [1,2,9] and 10s femtosecond laser systems [4,6,8,10-13] alongside modelling using PIC, hydrodynamic and radiation hydrodynamics simulation codes, run in combination, in both 1- and 2-D. In addition, we will consider some purely simulation-based studies both to investigate the regimes in which hydrodynamics is important [3] and to consider how this physics may be usefully employed in future investigations [5,7].

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## The Fusion Portfolio: Why p-11B Deserves a Place at the Table

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### Abstract

The recent ignition achieved at the National Ignition Facility has conclusively demonstrated that laboratory fusion burn is possible. Yet the road to a commercially viable fusion power plant remains long, with formidable challenges in materials science, tritium breeding, and reactor economics. This reality invites us to reconsider not only how we confine plasmas, but also which fuel we choose to burn.

For decades, the deuterium-tritium reaction has been the undisputed focus of fusion research. Its large cross-section at relatively low temperatures makes it the logical first choice. However, DT fusion comes with intrinsic costs: dependence on tritium a radioactive isotope with no natural supply and a 12.3-year half-life and on a flux of 14-MeV neutrons that will activate reactor structures and demand exotic materials. These challenges may be solvable, but they raise a strategic question: Should we rely on a single fuel or diversify our portfolio?

Here we report on a systematic investigation of the p-<sup>11</sup>B reaction, a quasi-neutron-free pathway whose primary products are three alpha particles. Using complementary platforms, the 320 kV accelerator at IMP Lanzhou and intense laser-driven proton beams at the Laser Fusion Research Center in Mianyang we have obtained results that challenge textbook assumptions.

**1. Hydrogen doping enhances yield.** At IMP Lanzhou, boron targets doped with hydrogen showed an approximately 30% increase in alpha yield compared to pure boron. This effect, not predicted by standard cross-section data, suggests the microscopic environment of the boron nucleus matters in ways not yet understood.

**2. Nonlinear scaling with beam current.** At Mianyang, alpha yield scaled nonlinearly with proton beam current. In optimized conditions, we measured up to 10<sup>10</sup> alphas/cm<sup>2</sup> per laser shot at the time, the highest normalized yield reported for this reaction.

**3. Reaction channel complexity.** Spectroscopy reveals that the three alphas are not emitted simultaneously with equal energy. The reaction proceeds through intermediate channels, notably <sup>8</sup>Be, with implications for energy deposition in the plasma.

These results do not yet constitute a path to a reactor. The challenge of creating non-equilibrium conditions maintaining ion temperatures significantly above electron temperatures remains formidable. However, our findings demonstrate that nuclear physics is richer and potentially more favorable than previously assumed.

The strategic case for including p-<sup>11</sup>B in the fusion portfolio grows stronger as DT challenges become clearer. A successful p-<sup>11</sup>B reactor would offer:

- Fuel abundance: Protons are universal; boron is plentiful, eliminating fuel supply concerns.
- Reduced neutron flux: Secondary neutrons are at least two orders of magnitude below DT, simplifying materials and waste.
- No tritium breeding: Closed fuel cycle without lithium blankets or complex tritium handling.

These experiments began with a single question from a scientist at ENN in 2018: "What about proton-boron?" That question led us to re-examine old data, design new experiments, and discover effects not in the textbooks. Some of our latest findings will be discussed.

## Net Energy Gain Attempt via Nonthermal Equilibrium at ENN

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### Abstract

The realization of net-energy proton–boron fusion is fundamentally constrained by the combined challenges of bremsstrahlung losses and Rider's recirculation power requirement<sup>1</sup> the latter being crucial for sustaining a hot-ion/cold-electron regime (which enhances reactivity while suppressing bremsstrahlung) against Coulomb collisional relaxation. In this work, we present our theoretical and experimental efforts at ENN Fusion to overcome these obstacles.

We begin by revisiting the highQ parameter space identified by Putvinski<sup>2</sup>, which, using updated cross-sections and kinetic treatments of energetic protons, predicted a self-consistent hot-ion mode. However, under more explicit and rigorous plasma conditions, our re-evaluation demonstrates that ignition is not achievable in this benchmark scenario. Within this framework, Rider's recirculation effectively manifests as collisional heating of the bulk ion species. To validate this, we plan to conduct direct experimental measurements at the EXL-50U facility, inferring the collisional energy transfer from the post-heating temperature decay slope immediately after auxiliary heating is switched off.

To circumvent Rider's Coulomb-scattering relaxation altogether, we have developed two novel proton-heating techniques. The first employs an alpha-channeling mechanism<sup>3</sup>: Ion Bernstein Waves with phase velocities far exceeding the background thermal speed are resonantly excited by fusion-born alpha particles possessing a positive velocity gradient ( $\partial f / \partial v > 0$ ). These waves subsequently generate suprathermal ions via a wakefield-like process, in which phase-matched ions are captured and efficiently accelerated. The second approach utilizes laser-driven ion acceleration. An ablation cloud, produced by the injection of a hydrogen or hydrogen-boron pellet, is irradiated by an external ultra-intense, pulsed laser, driving the ablated species to high energies. Notably, 2D PIC simulations demonstrate that protons can be accelerated to 500–1500 keV, thereby directly targeting the main resonant peak of the p-<sup>11</sup>B fusion cross-section and offering a viable path to bypass traditional thermalization losses.

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## Challenges of utilizing Si & SiC detectors towards X-ray/alpha particle discrimination in pB related experiments

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### Abstract

In Laser-driven p11B fusion generates an initial, hyper-intense burst of X-rays and prompt electrons (the "laser flash"), followed immediately by a dense bunch of fusion-born alpha-particles. Silicon Carbide (principally the 4H-SiC polytype) as a wide-bandgap semiconductor ( $E_g \sim 3.26$  eV) exhibits a displacement threshold energy double that of silicon, meaning it can survive orders-of-magnitude higher radiation doses before experiencing severe lattice damage. Moreover, (SiC detector is inherently drastically more sensitive to the alpha (alpha) particles than to the prompt X-rays. This difference in sensitivity comes down to fundamental radiation interactions with wide-bandgap semiconductors, moving past the common misconception that "more signal equals higher sensitivity". X-rays interact primarily via the photoelectric effect and Compton scattering. Because SiC has a relatively low effective atomic number ( $Z_{eff} \sim 10-11$ ), it is exceptionally transparent to mid-to-high-energy X-rays compared to heavier materials like Silicon ( $Z=14$ ) or GaAs. Most X-rays pass straight through a thin (25–50  $\mu$ m) SiC active volume without interacting at all. As a result, only a small fraction of the X-ray energy is deposited per unit volume. However, in actual laser fusion environments, a paradox occurs because the absolute quantity of X-rays generated at the target during the laser-matter interaction is orders of magnitude larger than the number of fusion alphas. The "Laser Flash" (X-rays/Electrons) arrives at the detector first (at the speed of light). Even though the detector is individually insensitive to X-ray photons, the sheer volume of the flash creates a massive, narrow photo-peak. The Fusion Alphas arrive later due to their slower velocities; they create a broader, well-defined delayed peak. If a traditional silicon detector were used, the X-ray flash would completely flood the sensor, causing long-charge-collection tails that blind the detector during the crucial window when the alpha particles finally arrive. SiC's low baseline sensitivity to X-rays allows it to rapidly recover from the initial laser flash, cleanly registering the dense, highly ionizing energy deposited by the subsequent alpha-particles.

DRD3 Collaboration driven LGADs with their ultra-fast timing capabilities (10-30 ps jitter) allow researchers to temporally decouple the electromagnetic plasma noise from the incoming alpha-particles. This enables real-time mapping of the alpha-particle energy spectrum rather than relying on slow, post experiment chemical etching of passive plastics like CR-39. From other side, not only Si, but also SiC devices are now integrating gain creating highly doped layer inside device. However, gain in SiC would enhance not only alpha- detection but also X-ray. The success in X-ray/alpha discrimination and alpha detection depends on the reduction of X-ray and relative enhancement of alpha contribution. In this contribution we will be examining and discussing several examples of conducted experiments.

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## Charged-Particle Diagnostics for Proton–Boron and Deuterium–Deuterium Fusion Experiments on Plasma Focus

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### Abstract

The Plasma-Focus (PF) device provides a promising platform for studying fusion reactions under non-thermal plasma conditions, including proton–boron (p–11B) and deuterium–deuterium (D–D) fusion. Reliable diagnostics of energetic particles and fusion products are essential for these experiments.

We present the development of a charged-particle diagnostic system based on CR-39 and LiF crystal detectors for Plasma-Focus experiments, with a particular focus on its application to p–11B fusion studies on the PF-24 device. The complementary response of the two detector technologies enables particle identification, energy-dependent measurements, and angular distribution studies. The diagnostic system can also be used for proton deflectometry measurements, enabling the reconstruction of self-generated magnetic fields and estimation of the current flowing through the pinch plasma. Initial CR-39 measurements were performed in D–D Plasma-Focus experiments on the PF-1000 device. The combined CR-39 and LiF diagnostic system is being developed for p <sup>11</sup>B fusion experiments on PF-24. In addition, preliminary tests of LiF detectors for the detection of neutrons produced in D–D fusion reactions were performed.

These results demonstrate the potential of CR-39 and LiF detectors for particle diagnostics in Plasma-Focus plasmas and support their further development for p–11B fusion experiments and proton deflectometry studies.

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## 2D MHD simulations of a miniature Plasma Focus device

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### Abstract

The Dense Plasma Focus (DPF) device is a Z-pinch configuration capable of producing dense, high temperature plasma [1,2] for a wide range of applications, including fundamental plasma physics studies, neutron activation analysis using deuterium [3], X-ray lithography [4], and proton–boron fusion research [5]. During the discharge in the coaxial electrode geometry, a current sheath forms near the insulator, then accelerates axially and is compressed at the anode tip, where the plasma pinch occurs. The resulting secondary emissions (deuterons, electrons, neutrons, and X-rays) are strongly influenced by the underlying plasma dynamics. Understanding the physical processes that occur throughout the discharge requires detailed numerical simulations, which are essential for interpreting experimental observations and guiding the design of future devices. In this work, we present a comprehensive two-dimensional resistive magnetohydrodynamic (MHD) study of a miniature deuterium-filled plasma focus device using the FLASH code. The simulations model the plasma evolution from the initial breakdown (“cold start”) through sheath propagation, pinch formation, and final disruption. A dynamic tracking algorithm is developed to identify the evolving plasma sheath and implement a self-consistent magnetic field update across the entire geometry, including corrections for skin effects. These simulations, together with future studies incorporating boron, will support the design of proton–boron fusion experiments using DPF devices by providing a well characterized understanding of DPF dynamics.

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## Advances on alpha particle identification in low-rate laser-triggered nuclear fusion reactions

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### Abstract

The identification of laser-accelerated ions is a delicate issue, especially in case of alpha particles in experiments of low-rate laser-triggered nuclear fusion reactions, such as p-11B. Several methodologies of particle detection exist and are commonly used but, in many situations, they lack in the capability of identifying alpha particles, especially for high repetition-rate laser regimes [1]. In many cases, the problem cannot be resolved using a single detection methodology. The simultaneous combination of multiple diagnostic methodologies is therefore necessary and, in many cases, it proves effective [1-6]. In this presentation the limitations of common diagnostic methodologies of ion characterization and identification will be discussed, and advanced solutions combining different methodologies, leading to ion identification, will be described. The presentation will illustrate solutions for laser-triggered nuclear fusion experiments, with a focus on low-rate nuclear fusion reactions, such as p-11B, and will discuss the application to high-repetition-rate regimes.

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## Efficient Detection of alpha particles in proton-boron experiments with pixellated 2-D ASIC detectors like Timepix3

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### Abstract

Proton-Boron experiments are becoming more and more of interest not only for future nuclear fusion but also for proton-boron capture therapy and production of radiopharmaceuticals. Crucial point in all these kinds of experiments and applications is the detection of the alpha particles. The difficulties in detecting alphas arise mainly because of the limited numbers of particles produced and the presence of a significant background due to other radiations like fast ions and gammas. So, the requirement for a high sensitivity detection system for alpha particles, also able to measure its energy and discriminate against all the other source of particles and radiation, is highly desirable.

To address these requirements, we proposed the use of Timepix3 detector, a pixellated ASIC 2-D detector. Its active layer is a semiconductor (Silicon or Cadmium Telluride) and is coupled with bump-bonding on an underneath ASIC. It results in a 2-D matrix detector with  $256 \times 256$  pixels,  $55 \text{ mm} \times 55 \text{ mm}$  size, each one with its own independent electronic chain (pulse shaping, amplification, discrimination and digitalization). With an accurate analysis of the bidimensional tracks produced by the particles, a classification based on their morphology and the released energies, we can distinguish alphas, tritons, fast ions, neutrons and gammas and estimate their energy. We measured the capability of alpha detection in three different reactions:

- 1)  $n + \text{Li6} \Rightarrow \alpha (2.05 \text{ MeV}) + \text{triton} (2.73 \text{ MeV})$  measured with CdTe Timepix3
- 2)  $n + \text{B10} \Rightarrow \text{Li7} + \alpha (1.47 \text{ MeV}) + \text{gamma}$  measured with Si Timepix3
- 3)  $\alpha$ -emission of Po214  $\Rightarrow$  Pb210 in the Rn226 decays measured with CdTe Timepix3

The detector can distinguish traces of  $\alpha$ , protons, tritons, beta, gamma and measure the energy of  $\alpha$  as well. All these particles and their traces are also temporally resolved with a time resolution of about 1.6 ns, providing the possibility to measure fast lifetime decay products like observed for  $^{214}\text{Po}$ . For instance, recently it has also been used in experiments of laser fusion of deuterated targets at the ELI beamline for the measurement of neutrons coming from the DD reactions. In this case, it has been equipped with  $100 \mu\text{m}$  HDPE converter to detect the recoil protons and we observed the 2.45 MeV neutrons at 80 ns later than the gamma flash, corresponding exactly to the time of flight expected at that distance and energy. Timepix3 detector can be also located under vacuum, offering the possibility of detecting all these particles directly. Due to these advantages, we believe that it could play an important role in all the proton-boron experiments.

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## Unlocking Proton–Boron Fusion with Laser-Driven Ion Beams: High-Energy Proton Acceleration, Advanced Diagnostics, and Fusion Yield Characterization

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### Abstract

Experiments were performed at the Prague Asterix Laser System (PALS) using a high-energy long-pulse laser delivering up to 600 J in 300 ps to investigate laser-driven proton acceleration and proton–boron (p–<sup>11</sup>B) fusion. Two complementary configurations, in-target and pitcher–catcher, were employed to study proton generation, transport, and fusion yield. Different target materials and geometries were explored to optimize proton acceleration and fusion performance. Ion emission was characterized using a comprehensive diagnostic system, including CR-39 detectors, Time-of-Flight (TOF) detectors for angularly resolved proton measurements, and Thomson parabola spectrometers for charge-to-mass and energy-resolved ion spectra. Compressed solid ammonia borane (AB) pellets showed outstanding performance, producing maximum proton energies up to 5 MeV, the highest values obtained during the campaign. This result demonstrates the strong influence of target

composition on laser-driven proton acceleration and highlights the potential of AB targets for improving p-11B fusion schemes.

In parallel, FLUKA and Geant4 simulations were performed to model charged-particle transport, evaluate catcher backscattering effects, and support the interpretation of experimental results. Fusion yields were estimated using the activation method, furthermore, a complementary calcium activation technique, with a calcium converter positioned in front of the catcher, was used to estimate the number of  $\alpha$ -particles produced from the catcher. The  $\alpha$ -particles interacting with the calcium material induced activation reactions, enabling an independent estimation of the  $\alpha$ -particle yield and the total p-11B fusion reaction rate

The combined experimental, simulation, and activation results provide important benchmarks for validating models of laser-driven ion acceleration, particle transport, and fusion yield in laser-generated plasmas. These findings contribute to the optimization of target design, energy coupling, and predictive modelling for future direct drive aneutronic fusion concepts.

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It is also supported by the EUROfusion Enabling Research Project: CfP-FSD-AWP26-ENR-01 “Conceptual design for a European High Power Laser Fusion Research Facility” (HiPER+RF), funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 EUROfusion). Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

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## **Broadening of nitrogen lines for diagnostics of proton-boron fusion plasma obtained with BN target**

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### **Abstract**

In investigations of p-B fusion, the target is often boron nitride - BN, so that the lines of N ions are of interest for investigation, modelling and diagnostics of proton-boron fusion plasma. In order to enable better diagnostic of such plasma, during the PROBONO CA we have calculated data for nitrogen line profiles broadened by collisions with charged particles (Stark broadening) for the most important spectral lines of N II, NIII, NIV, N V and N VI, needed for calculation of absorption coefficient and optical and transport characteristics of proton-boron fusion plasma, in the case of BN target. So, for the first time will be provided data needed for modelling, investigation, characterization and diagnostics of BN plasma evolution from low to high temperatures and from the center to the edges.

Such data on profiles of N II – N VI nitrogen lines are of interest for design and optimization of experiments, and analysis of results, since the profiles enter in the calculation of absorption coefficient which is important for the investigation of laser produced plasma. Also, obtained line profiles are useful for the spectral analysis and diagnostics of plasma in proton-boron fusion experiments, and of particular interest for boron-nitride target and its use.

In this contribution we will present the obtained results and will discuss their interest for plasma research with particular accent on their use for proton – boron fusion. We will also review shortly the databases where such reliable data can be found and discuss how to estimate their accuracy and reliability.

## Spin-Polarized p-<sup>11</sup>B: From Generation to Maintenance

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### Abstract

Spin polarization offers a promising route to overcome the stringent ignition requirements and inherently low cross-section of p-<sup>11</sup>B fusion. Theoretical calculations predict that aligning proton and <sup>11</sup>B spins to the quantum numbers (+1/2, +3/2) can enhance the 675 keV resonant cross-sections by 60% [1,2], a result that awaits experimental validation. However, realizing this potential requires addressing a complete chain of physics and engineering challenges: polarizing hydrogen and boron-11 fuel, injecting polarized species into magnetically confined plasmas, and critically sustaining the polarization under reactor-relevant plasma conditions.

Our research addresses these challenges through three interconnected directions: polarization generation, reaction studies, and polarization maintenance. Among these, polarization maintenance in magnetically confined plasmas is particularly challenging and under-explored, with p-<sup>11</sup>B fusion facing a unique issue absent in D-T, D-<sup>3</sup>He or D-D [3-7]: boron ions are injected only partially ionized and undergo successive stripping collisions in the plasma, during which electron exchange and spin-dependent interactions can cause significant depolarization. Additional mechanisms such as fluctuating electromagnetic fields, non-adiabatic transport, and background collisions further contribute to spin relaxation. We are conducting systematic simulations of these processes and performing <sup>3</sup>He-based experiments to validate the underlying models. Together with our ongoing work on optical pumping [8-10] and DNP-based [11-13] polarization generation, these efforts form a comprehensive framework toward spin-polarized p-<sup>11</sup>B fusion as a clean, low-neutron energy source.

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## Orientation-Dependent High-Harmonic Generation in Semiconductors and Potential for High Energy Attosecond Driving of Proton - Boron Fusion

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### Abstract

This study experimentally and theoretically investigates orientation-dependent high-harmonic generation (HHG) in zinc oxide (ZnO) and silicon (Si) subjected to intense femtosecond mid infrared (MIR) laser pulses. The experiments were carried out at the ELI-ALPS facility using a high-power laser system operating at a 100 kHz repetition rate, delivering pulses with a wavelength of 3.2  $\mu\text{m}$  and a duration of 45 fs. By irradiating (0001)-cut and (1120)-cut ZnO samples of varying thicknesses, as well as silicon substrates, at optimized laser intensities, non-perturbative harmonic spectra extending well into the extreme ultraviolet (XUV) region - beyond the materials' band gaps - were generated without causing sample damage [1]. A primary observation is that the harmonic yields depend sensitively on the orientation of the crystal with respect to the laser polarization direction. For the ZnO samples, a four-fold rotational periodicity was experimentally observed in both the (0001) and (1120) crystal planes. To benchmark these measurements, detailed theoretical simulations were performed [2]. Within the explored ranges of laser intensity and wavelength, the theoretical model yields the expected six-fold and two-fold symmetries in the (0001) and (1120) planes, respectively, rather than the measured four-fold symmetry. Despite this difference in symmetry order for ZnO, the theoretical model achieves good qualitative agreement with the experiment regarding the strong angular modulation of the harmonic intensity. This modulation is governed by the intrinsic anisotropy of the complex ZnO band structure, which features multiple coupled valence bands affecting the dynamics of electron - hole pair excitation and solid-state high harmonic generation. Furthermore, parallel experiments conducted on silicon revealed a three-fold modulation of the harmonic intensity with respect to the angle between the orientation of the crystal and the laser polarization direction, which is entirely consistent with the corresponding theoretical results, validating the predictive capabilities of the model in symmetric covalent structures.

Beyond advancing fundamental solid-state physics, the efficient generation of XUV harmonics demonstrated in this work highlights the potential of semiconductor based HHG for the production of coherent soft X-ray attosecond pulses of light [3,4]. These ultra-short, high-energy pulses hold immense promise as a driver for kinetic, athermal fusion within solid proton-Boron (p-11B) targets. A critical advantage of utilizing the soft X-ray wavelength range is its superior capacity to deeply penetrate dense, solid-state targets compared to longer wavelength optical drivers, minimizing early surface ionization and thermal dissipation. This allows the attosecond pulse to directly couple its energy into the bulk material, efficiently driving the non-thermal, kinetic ion dynamics necessary to trigger clean, neutron-free p-11B fusion reactions before hydrodynamic expansion disrupts the target [5].

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## Demonstration of bidirectional alpha particle emission from proton-boron reaction using low-density boron catchers and cavity-type pitcher with ns, kJ laser system

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### Abstract

In this work, we report the successful demonstration of bidirectional alpha-particle emission from the proton–boron reaction in a pitcher–catcher configuration driven by a 1 ns, 430 J laser pulse. The proton beam used to irradiate the catcher was accelerated from cavity targets, which exhibited enhanced performance compared with flat targets in terms of maximum proton energy and proton yield, while maintaining a lower beam divergence, as characterized using a diamond time-of-flight detector and a Thomson parabola spectrometer. The experimental design enabled the identification and measurement of alpha-particle emission in both the forward and backward directions with respect to the catcher using CR-39 detectors, yielding a total alpha-particle emission of  $10^8$  sr<sup>-1</sup>. In addition, in-plasma alpha-particle production using the cavity-target geometry was investigated. The approach

developed for the fabrication of the boron catchers used in this experiment paves the way for the development of potential high-repetition-rate, laser-driven alpha-particle sources, enabling further applications of the resulting alpha-particle beams, for example in medicine.

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## From Borax mines to Sophisticated Nano-Structured Borane-based Targets for $p\text{--}^{11}\text{B}$ Fusion: The complete chain

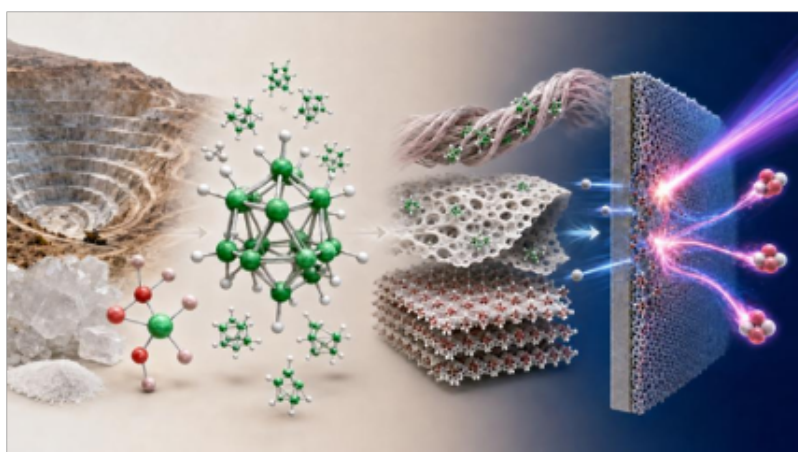
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### Abstract

The rapid growth of proton–boron-11 ( $p\text{--}^{11}\text{B}$ ) fusion research is creating a demand for targets whose chemical composition, isotopic content, hydrogen loading, dimensions and morphology can be controlled with far greater precision than is possible with conventional elemental boron or boron nitride. This contribution maps the complete materials chain from the most elementary mineral feedstocks to sophisticated, nano-structured targets and asks how a boron chemist can help to close the gap between an abundant raw material and a reproducible fusion experiment.

The journey begins with borax salts and boric acid: inexpensive, widely available and chemically unassuming sources of boron. Through established sequences of acidification, dehydration, reduction and hydride chemistry, these oxygen-rich starting materials can be converted into boron–hydrogen compounds. Molecular boranes offer an unusually attractive design space because boron and hydrogen are incorporated within the same discrete cluster. Their nuclearity, B:H ratio, isotopic constitution, charge, solubility, thermal behaviour and peripheral functionality can therefore be selected and adjusted before a target is fabricated. Compounds ranging from readily handled molecular hydrides to larger borane clusters, most notably solid octadecaborane, anti-B18H22 illustrate the progression from synthetic chemistry to candidate fusion fuel. Recent laser experiments with anti-B18H22 provide an important proof of principle for this materials-led approach. The next step is to move beyond the molecule. Functionalised borane clusters can serve as high-boron building blocks for other macromolecular architectures. By controlling intermolecular interactions, cross-linking and deposition conditions, these systems may self-organise into hierarchical nano structures.



I shall present our attempts to assemble a portfolio of borane-based target materials spanning molecular crystals, composite and porous-foam forms, and emerging nano structured constructs. The purpose is not to nominate a single universal target, but to establish a modular supply chain in which feedstock, synthesis, molecular design, self-assembly and target engineering remain traceable and unable. In this way, a commodity

refined from borax ore can become a precision experimental material, and chemistry can provide the growing  $p\text{--}^{11}\text{B}$  fusion community with targets matched to different laser regimes, geometries and scientific questions.

**Acknowledgements:** This work has been carried out within the framework of the COST Action CA21128- PROBONO “PROton BORon Nuclear fusion: from energy production to medical applications, supported by COST (European Cooperation in Science and Technology - [www.cost.eu](http://www.cost.eu))

## Pulsed Laser Deposition as a versatile technique for tailored boron-based targets in proton-boron fusion

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### Abstract

As the COST Action PROBONO attests, the  $11\text{B}(\text{p}, \alpha)2\alpha$  fusion reaction has gathered significant interest in the scientific community, not just as a potential alternative fuel in fusion energy production but also for bright alpha particle sources [1] and in medical applications [2]. The laser-driven approach emerged as the most promising, either in the pitcher-catcher or in-target configurations, depending on whether the laser-driven proton acceleration and p11B fusion steps are separated or not. In both scenarios, the targets design plays a crucial role in efficiently promoting laser-matter interaction. Indeed, low density nanostructured materials show great promise [3], enhancing proton acceleration in the ultrashort high-intensity regime [4] (relevant for pitcher-catcher schemes) and improving laser matter coupling in the long-pulse high-energy regime [5] (key for in target approaches).

We report on our approach based on Pulsed Laser Deposition (PLD) as a flexible technique to produce targets for proton-boron fusion studies, from compact boron films for cross section investigation [6] and radioisotope production [7] to nanostructured materials with controlled morphology and composition [8] for laser-driven p11B fusion experiments. The bottom-up PLD synthesis allows control over the material density, thickness, composition and morphology down to the nanoscale, thanks to the many process parameters available and the complementarity between conventional ns-PLD (exploiting nanosecond lasers) and the innovative fs-PLD approach (which involves ultrafast ablation with femtosecond lasers).

In the framework of the PROBONO project, the potential of this class of materials in enhancing alpha particle production has been confirmed experimentally [9], exploiting hydrogen-enriched boron nanofoams in the in-target configuration on an 8 J, 800 fs laser (Taranis). Further experiments are planned to take advantage of nanostructured foam targets under different laser conditions 10 J, 25 fs, high contrast particularly interesting to better explore the nanostructure beneficial influence on proton-boron fusion and have a clearer picture of the underlying physics.

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### Acknowledgements

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## Using Pulsed Laser Deposition for Target Preparation in Proton–Boron Fusion Experiments

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### Abstract

Proton–boron ( $p\text{--}^{11}\text{B}$ ) fusion has emerged as a promising aneutronic pathway for advanced nuclear energy generation due to its potential for producing predominantly charged particles with minimal neutron yield. However, the realization of efficient  $p\text{--}^{11}\text{B}$  fusion critically depends on the development of high-quality boron-based targets with controlled composition, morphology, and structural properties. In this context, Pulsed Laser Deposition (PLD) represents a versatile and highly controllable thin-film fabrication technique capable of meeting the stringent requirements of fusion-grade target preparation.

This work explores the application of PLD technology for the synthesis of boron-rich and boron-containing composite targets tailored for proton–boron fusion experiments. The PLD process enables precise stoichiometric transfer from target to substrate, high purity film growth, and tunable microstructure through adjustment of laser fluence, pulse duration, ambient pressure, and substrate temperature. [1,2]. These parameters are systematically analyzed to optimize film density, adhesion, crystallinity, and surface uniformity key factors influencing proton stopping power and reaction cross-section efficiency. (Figure). Special attention is given to the fabrication of nanostructured and multilayered targets, including boron doped matrices and boron-carbon composites, which can enhance ion interaction probability and thermal stability under high energy proton irradiation. The resulting films are characterized using complementary techniques: scanning electron microscopy (SEM), X-ray diffraction (XRD), and Rutherford backscattering spectrometry (RBS), providing insights into their structural and compositional fidelity.

Furthermore, the role of PLD-grown targets in laser-driven and accelerator-based fusion setups is discussed, highlighting their advantages in terms of reproducibility, scalability, and compatibility with high-intensity experimental conditions. The study demonstrates that PLD is a highly promising route for engineering advanced boron targets, contributing to the ongoing development of aneutronic fusion technologies.

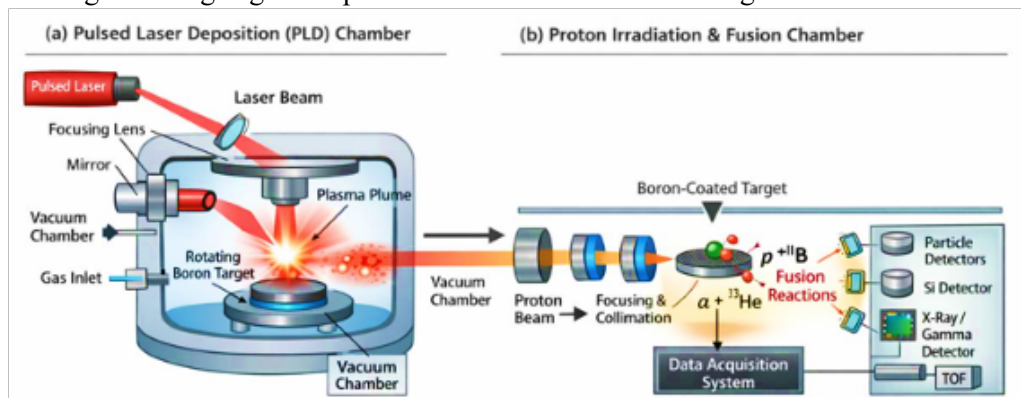


**Figure.** Schematic representation of an integrated system combining pulsed laser deposition (PLD) for boron-based thin film fabrication and a proton irradiation chamber for proton–boron fusion experiments. The PLD module enables controlled synthesis of high-purity boron coatings, while the irradiation module facilitates interaction with a focused proton beam and detection of resulting fusion products.

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## Study of proton stopping power in warm dense matter using low-density Foams at the XGIII laser facility

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### Abstract

Stopping power is defined as the differential energy loss per unit path length of a charged particle traversing matter. The study of proton stopping power produced using lasers<sup>1</sup> is a central topic in warm dense matter (WDM), inertial confinement fusion (ICF), and laboratory astrophysics. In the WDM regime, there are not much experimental data validating the theoretical models, which sensibly differ from each other in the region of the Bragg peak of protons. We performed an experiment at the XG-III2 Laser Facility in Mianyang (China) using MeV proton beams generated by the interaction of short-pulse, high-intensity lasers with solid targets via Target Normal Sheath Acceleration (TNSA). This produced a population of protons with energies extending to 12 MeV and an approximately exponential energy distribution. An energy selector placed after the TNSA target allowed selecting a narrow energy spectrum (2-5 MeV). These protons were then crossing a foam target before reaching a Thomson Parabola spectrometer, where their residual energy was measured. At the same time, a synchronized nanosecond beam was used to create controlled plasma conditions in the foam target, a 3D-printed low-density plastic foam (CHNO 89 mg/cc) consisting in a cube of size 1 mm covered on one side by an Al foil. The longer pulse duration focused on the Al ablator/pusher allowed to create a strong shock in the foam, ensuring volumetric heating and the formation of an extended plasma with relatively smooth density gradients as compared to what could be achievable with solid-density targets. The foam density was chosen so that, upon heating, the plasma reached conditions characteristic of the warm dense matter regime, with electron densities approaching  $10^{21}$ – $10^{22}$  cm<sup>-3</sup> and temperatures in the range of several eV, i.e. a strongly coupled and partially degenerate plasma. The shock breakout time at the rear of the foam target was measured using an SOP diagnostic, allowing to fix the delay between the nanosecond heating pulse and the ps proton-generating pulse, which can be precisely controlled, allowing the proton beam to probe the plasma at selected stages of its hydrodynamic evolution. In this preliminary experiment, however, we just limited ourselves to measure the stopping power in the cold plastic foam. In conclusion, the combination of ps TNSA proton generation and nanosecond-driven foam plasma production can enable a controlled study of proton stopping power in warm dense matter conditions. These results contribute to the broader understanding of ion transport in matter in extreme conditions and provide experimental constraints for advanced stopping power theories relevant to fusion and astrophysical plasmas.

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**International Workshop on  
PROton-BORon Nuclear fusion: from energy production to medical applicati**Ons****

**POSTER CONTRIBUTIONS**

## Analysis of the BNCT Tumor System with Caputo Fractional Derivative

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### Abstract

Boron Neutron Capture Therapy (BNCT) is a highly precise targeting method that utilizes boron molecules to capture tumor cells. In BNCT, the reaction of boron-10 isotope with neutrons produces alpha and lithium particles that kill tumor cells while preventing damage to healthy cells. Therefore, BNCT is an ideal treatment method for cases where conventional radiation therapy might cause unhealthy damage to surrounding tissues.

Caputo fractional derivative, unlike the classical integer derivative, incorporates information about the past states of systems encountered in daily life into the model. While the classical derivative considers the rate of change in the current state, the fractional derivative, due to its integral structure that reveals the memory effect, shows the influence of the system's previous state on its current state. For example, in a tumor system with the classical derivative, the tumor growth rate depends on the current tumor size, while in the fractional Caputo derivative; growth is also influenced by the past. In other words, the Caputo derivative incorporates the fact that the tumor and its surroundings are affected by past biological events into the system.

This study focuses on a mathematical model including BNCT with Caputo fractional derivative. We give the solution properties of the fractional system and then examine the long-term behavior of the system. Through these analyses, the effect of the fractional-order Caputo derivative on the system dynamics and the future behavior of tumor development, taking into account its past state, will be understood. Furthermore, it is considered that the results obtained can serve as an example and guide for Proton Boron Capture Therapy (PBCT) studies.

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## A Modelling Based Assessment of the Radiation Environment and Secondary Particle Production in Laser-Driven p-11B Fusion Devices

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### Abstract

Proton-Boron (p-11B) fusion is increasingly regarded as an attractive pathway toward clean energy production, as the primary reaction channel  $p+^{11}\text{B} \rightarrow 3\alpha$  is aneutronic. However, secondary neutron-producing channels, most notably  $^{11}\text{B}(p,n)^{11}\text{C}$ , yield non-negligible neutron fluxes that affect structural and functional materials of the target chamber and surrounding components. Characterizing this radiation environment is essential for radiation protection, component lifetime estimation, and waste classification, yet the extreme conditions of laser-driven pB fusion make direct experimental measurements challenging. Validated computational modelling therefore serves as the primary tool for assessing neutron irradiation effects in these devices.

This work employs the Monte Carlo transport code MCNP6 coupled with the activation inventory code FISPACT-II and validated nuclear data libraries (TENDL-2019, 2021; EAF-2010) to perform an integrated neutronics and activation analysis of a representative laser-driven pB fusion device. A representative 3D geometric model of the target chamber, shielding assemblies, and beam transport line is developed to evaluate neutron and photon flux distributions, energy spectra, and spatial dose rate maps. The activation calculations provide time dependent activity, decay heat, dose rates, and dominant radionuclide inventories for candidate structural materials, for a comprehensive assessment of activation evolution from initial irradiation through long term post operational cooling.

Advanced variance reduction techniques, including weight window generators (ADVANTG), are applied to resolve deep penetration neutron streaming through shielding penetrations and beam ports with acceptable statistical uncertainty. The results inform material selection for critical components, quantify radiological hazard levels for personnel access and maintenance planning, and provide preliminary waste classification data under relevant regulatory frameworks. By establishing a systematic computational methodology for neutronics assessment of pB fusion devices, this study contributes to the growing body of knowledge on radiation safety for next generation aneutronic fusion concepts and supports ongoing efforts within the COST Action CA21128 PROBONO.

**Keywords:** Proton-Boron Fusion, Neutron Transport, MCNP6, FISPACT-II, Radiation Shielding, Activation Analysis, Waste

### Acknowledgements

This work has been carried out within the framework of the COST Action CA21128- PROBONO “PROton BORon Nuclear fusion: from energy production to medical applications, supported by COST (European Cooperation in Science and Technology - [www.cost.eu](http://www.cost.eu))

## Energetic-Ion Generation Study in a Miniature Plasma Focus

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<sup>2</sup>*Department of Electronic Engineering, Hellenic Mediterranean University, Chania, Greece*

### Abstract

In this work, energetic-ion emission and fusion-neutron production were investigated in a miniature plasma-focus device operating with deuterium at a stored energy of 600 J and a peak discharge current of approximately 80 kA. An axially positioned Faraday cup, coupled to a differential-pumping system, was used to measure the time-resolved deuteron-beam current while minimizing ion-energy losses caused by collisions with the background gas. A photomultiplier–scintillator detector simultaneously recorded prompt hard X-ray emission and delayed neutron signals. The hard X-ray peak served as the temporal reference for the ion and neutron time-of-flight analyses.

A sequence of consecutive discharges was classified into successful and unsuccessful pinch events according to the amplitude and temporal characteristics of the hard X-ray signal. Successful pinches produced higher deuteron densities, narrower temporal profiles, and a substantially enhanced high energy ion population. The reconstructed deuteron energy spectra extended from a few keV to 500 keV. Below approximately 20 keV, the distributions were described by a quasi-thermal component with characteristic energies of approximately 2.6–3.0 keV. Above approximately 30 keV, however, the spectra exhibited a pronounced non-Maxwellian power-law tail, indicating the presence of a strong non-thermal ion-acceleration mechanism. In successful pinch events, the deuteron population above 20–30 keV was approximately one order of magnitude higher than that observed in unsuccessful discharges.

Although the present experiments were performed using deuterium, the demonstrated acceleration of non-thermal ions into the several-hundred-keV range indicates that the miniature plasma-focus device can access ion-energy regimes of interest for beam-driven proton–boron fusion studies [2]. The results establish a diagnostic methodology for correlating pinch quality with energetic-ion production and fusion-reaction signatures. These provide an experimental basis for future studies employing hydrogen–boron gas mixtures or boron-containing targets in compact plasma-focus devices.

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## Experimental investigation on LGAD-based time-of-flight diagnostics in a laser driven proton-boron fusion environment -Post-campaign insight & Lessons Learnt -

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### Abstract

For the first time, LGADs was employed in a laser fusion environment (PROBONO laser induced DD  $\rightarrow$  pB experiment at ELI Beamlines in Prague) to measure time-of-flight signals. The detectors successfully resolved prompt X-ray signals and subsequent arrivals, which may originate from charged particles, enabling reconstruction of an energy spectrum compatible with that of alpha particles; this claim was further supported by additional diagnostics (CR39) and simulations (FLUKA). We also present the preliminary results from the most recent studies conducted at the Institute of Plasma Physics and Laser Microfusion (IPLLM) in Warsaw (studies were conducted with aim to clarify LGAD behavior under mixed irradiation).

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## Optimization of Porous Boron Foam Targets for Proton-Boron Fusion: A FLUKA Monte Carlo Study

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### Abstract

Proton-boron ( $p\text{-}^{11}\text{B}$ ) fusion has emerged as a promising aneutronic fusion concept for future compact fusion systems and charged-particle sources due to its predominantly alpha-particle products and minimal neutron generation. The development of advanced boron-containing targets is essential for improving fusion performance, and porous boron foam structures offer unique advantages by modifying proton transport, increasing the effective interaction volume, and facilitating alpha-particle escape [1]. In this study, the performance of boron foam targets with different porosity and thickness values is systematically investigated using the FLUKA Monte Carlo simulation code. Three-dimensional foam geometries were modeled to evaluate proton transport, energy deposition, fusion reaction distributions, alpha-particle production, and alpha-particle escape probability under incident proton beams. The influence of structural parameters on reaction yield and particle transport was analyzed to identify optimized target configurations [2,3]. The simulation results provide insight into the relationship between foam architecture and fusion performance, demonstrating the applicability of FLUKA for the design and optimization of advanced boron-based targets and providing guidance for future laser-driven  $p\text{-}^{11}\text{B}$  fusion experiments.

**Keywords:** Proton-boron fusion; Boron foam targets; FLUKA Monte Carlo simulation; Porosity optimization; Alpha-particle transport.

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## Preliminary experimental results of laser-accelerated ions from optically shaped gaseous targets

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### Abstract

Near-critical density (NCD) targets are considered a promising candidate for high-repetition-rate (HRR), debris-free laser-driven ion sources. Simulations predict ion beams with cutoff energies of hundreds of MeV through advanced acceleration mechanisms that dominate in the NCD regime. However, the experimental implementation of gaseous NCD targets remains challenging, particularly for intense femtosecond laser systems, owing to the stringent control required over the target peak density and density gradients. As a result, only a limited number of experimental demonstrations have been reported.

Here, we present results on an optical shaping approach that compresses underdense gaseous targets into near-critical-density profiles suitable for high-repetition-rate laser-driven ion acceleration. Building upon the experimental and numerical results previously reported in [1], ion acceleration experiments were performed using the 45 TW femtosecond Zeus laser system at the Institute of Plasma Physics and Lasers (IPPL) of the Hellenic Mediterranean University [2]. Following the first experimental validation of the concept, a collaborative experimental campaign was carried out with the Institute of Plasma Physics and Laser Microfusion (IPPLM), during which the experimental setup was upgraded with a suite of online diagnostics.

Experimental results on the temporal evolution of the optically shaped targets are presented together with passive measurements of multi-MeV ion beam spectra and high-flux electron beams, as well as preliminary results obtained using the newly implemented online diagnostics. The generated ion beams are of potential interest for medical applications, while the achieved energy range is also relevant for the pitcher–catcher pB Fusion scheme [3-4].

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## MCNP-Based Characterization of a Handheld Scintillation Probe for Real-Time Monitoring of Laser-Driven Alpha Particles in Clinical Environments

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### Abstract

The clinical translation of Proton Boron Capture Therapy (PBCT) and the optimization of laser driven  $p\text{-}^{11}\text{B}$  fusion sources are currently constrained by a critical lack of deployable, real-time diagnostic instrumentation capable of operating within complex, mixed-radiation environments. While solid-state nuclear track detectors (such as CR-39) and Thomson parabola spectrometers provide high-fidelity retrospective data regarding alpha yield, they cannot offer the immediate, in vivo dosimetric verification required during surgical or clinical radiotherapy procedures. In this study, I propose the computational design and characterization of an original, highly adaptable intraoperative handheld scintillation probe specifically engineered for the real-time detection of the 3.5 MeV alpha particles generated in  $p\text{-}^{11}\text{B}$  fusion reactions.

The conceptual architecture of the probe leverages the enhanced timing and energy resolution properties of Cerium-doped Lanthanum Bromide co-doped with Strontium ( $\text{LaBr}_3\text{:Ce,Sr}$ ), building upon my previous iterations of  $\text{SrI}_2/\text{LaBr}_3$  gamma-probe designs. To overcome the inherent penetration limitations of heavy charged particles while maintaining complete optical integrity, I incorporated an ultra-thin, aluminized Mylar entrance window into the probe design.

I executed a rigorous computational methodology utilizing the Monte Carlo N-Particle (MCNP6.2) transport code. I explicitly modeled the specific detector geometry and invoked heavy charged particle transport parameters to precisely quantify the energy straggling induced by the Mylar window. To simulate the detector's specific spectral response function, I utilized the F8 pulse height tally, augmented with Gaussian Energy Broadening (GEB) derived from empirical scintillator calibration data. Furthermore, my simulation evaluated the theoretical efficacy of digital Pulse Shape Discrimination (PSD) metrics by modeling the discrete energy deposition profiles of alpha particles versus background bremsstrahlung and secondary gamma radiation.

My computational results indicate that the adapted  $\text{LaBr}_3\text{:Ce,Sr}$  probe configuration achieves a theoretical intrinsic detection efficiency capable of resolving the 3.5 MeV alpha peak distinctly from background noise, despite the kinetic energy degradation inherent to the window material. The modeled spectral output confirms that applying specific GEB parameters yields a Full Width at Half Maximum (FWHM) resolution sufficient to accurately verify localized alpha production rates in real time.

In conclusion, this MCNP-based model substantiates the physical feasibility of engineering intraoperative scintillation probes for the immediate verification of PBCT fusion events. Beyond clinical oncology, I believe this adaptable framework provides a robust diagnostic mechanism for monitoring high-brightness radioisotope production directly at the source, thereby supporting the diagnostic innovation mandates of the wider scientific community.

# Reconnection-driven non-thermal proton acceleration to p-<sup>11</sup>B fusion energies at joule-class laser energy: a ring-geometry hybrid-PIC study

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## Abstract

Aneutronic proton-boron-11 (p-<sup>11</sup>B) fusion is attractive for clean, neutron-poor energy and for medical radioisotope production, but its high (~500 keV) reaction threshold has confined laser-driven demonstrations to facilities coupling hundreds of joules or more [2]. We report 2D guide-field hybrid-PIC simulations (WarpX) showing that an engineered eight-spot ring magnetic-reconnection geometry drives protons to fusion-relevant energies non-thermally at only 5 J of coupled laser energy. At this energy a thermodynamic bound limits bulk-thermal heating to 12–46 eV per ion roughly four orders of magnitude below the ~327 keV the reacting population reaches so a purely thermal plasma of this fuel produces zero p-<sup>11</sup>B fusion, and every reaction observed is reconnection-driven by construction. The ring topology forces magnetic reconnection at eight predictable X-lines whose outflows converge on the geometric center. Over a common 0–1153 ps window the configuration yields a total fusion gain of 4.08 at 512<sup>2</sup> resolution, grid-converged across a 256<sup>2</sup>–1024<sup>2</sup> ladder, with

a conservative, event-terminated first-transit lower bound of  $G_{FT} = 3.63$ [1]. Across a realistic perturbation envelope pointing jitter, inter-spot energy imbalance, and single-spot dropout the  $\sigma$ -weighted gain varies by under 2%, indicating the mechanism does not require fine-tuned beam placement. A seed-field scan reveals a sharp reconnection threshold: seeds  $\geq 85$  T sustain the mechanism while weaker seeds (45–51 T) fail to reconnect. Because the outcome is set by field topology rather than by coupled energy, the 5 J budget is compatible with commodity joule-class diode-pumped solid-state lasers, placing experimental validation within reach of present-day systems and of the laser-driven p-<sup>11</sup>B platforms being developed within the PROBONO community.

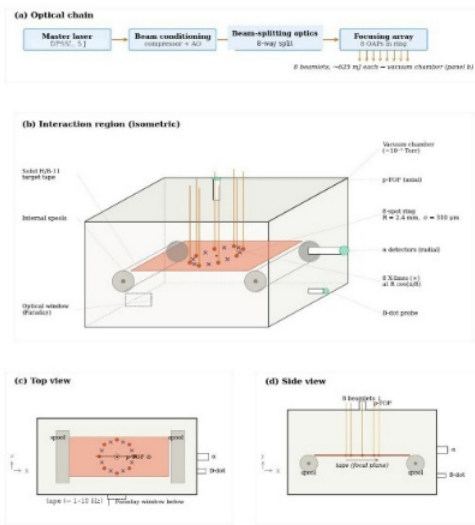


**Figure 1.** Engineering schematic of the proposed realization: a master laser is split into eight beamlets focused onto a hydrogenated boron-rich target tape in an eight-spot ring ( $R = 2.4$  mm); the topology forces reconnection at eight X-lines ( $R \cos(\pi/8) = 2.217$  mm) whose outflows converge on the geometric center.

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## Boron Targets and Pellets for Fusion Applications

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### Abstract

Boron targets and boron pellets both play a crucial role in inertial confinement fusion and magnetic confinement fusion research. Boron targets are utilized in studies of plasma-wall interactions, and hydrogen-boron reactions. Boron pellets are employed for fueling and particle transport studies, plasma disruption mitigation, Edge Localized Mode (ELM) control, plasma diagnostics, and real-time wall conditioning.

In this study, technologies have been developed for the preparation of pure boron targets (via magnetron sputtering), hydrogen-containing boron targets (via PECVD), and boron pellets (via sintering and isostatic pressing). This has enabled the preparation of boron targets with thicknesses ranging from 0.1 to 10  $\mu\text{m}$  and hydrogen contents ranging from 0 to 40 at%. Additionally, boron pellets with a sphericity of over 95%, a diameter of approximately 1 mm, have been successfully fabricated.

Samples prepared by these technologies have been used in research for both magnetic confinement fusion and inertial confinement fusion.

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## Raman Spectroscopy Analysis of CVD-on-HPHT Diamond Before and After Neutron Irradiation

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### Abstract

Chemical vapor deposited (CVD) diamond layers grown on high-pressure high-temperature (HPHT) diamond substrates were investigated before and after neutron irradiation using optical microscopy, SEM/EDX, and Raman spectroscopy. Two samples were received from the University of Rome Tor Vergata. SEM imaging using a Phenom Pro system showed both samples to be morphologically similar. Using the Helios 5 Series SEM–EDS system, the detector side of both samples was shown to contain carbon (C), silicon (Si), and chromium (Cr). Elemental mapping showed that chromium was concentrated in the central region as a circle and toward the corners as triangles, consistent with the square Cr electrode geometry reported in the literature [1], where the metallic layer forms the Schottky contact and defines the active charge-collection area. In contrast, the opposite side, consisting of the thick HPHT diamond substrate acting as the structural base, showed only the carbon signal, with no detectable Cr or Si contributions.

Neutron irradiation was performed at the FTMC (Center for Physical Sciences and Technology) in Vilnius. We used four Pu-Be (Plutonium-Beryllium) sources (<sup>239</sup>Pu-Be and <sup>238</sup>Pu-Be (plutonium-239 and Plutonium-238 mixed with Beryllium)) with a total yield of about  $4.5 \times 10^7$  neutrons. The diamonds were exposed in the C-channel (experimental core channel) for 13 days, 17 hours, and 28 minutes. MCNP (Monte Carlo N-Particle) simulations showed a total deposited neutron dose of  $\sim 11$  Sv and a fast neutron fluence of  $\sim 1 \times 10^{10} \text{ cm}^{-2}$  (20% of the energy spectrum).

Raman spectroscopy was carried out using a TriVista CRS Confocal Raman System (TriVista 777 triple spectrometer, Princeton Instruments) with a 532 nm excitation laser. The Raman signal was strongest in regions without metal contacts, although a distinct Raman response was also successfully detected through the thin chromium contact area. Before irradiation, the CVD layers exhibited asymmetric diamond Raman peaks. These asymmetric Raman spectra were well fitted using two Gaussian functions, indicating residual compressive stress characteristic of heteroepitaxial CVD diamond growth. After neutron irradiation, the Raman line shifted toward lower wavenumbers (redshift), consistent with lattice expansion caused by vacancy formation and radiation-induced defects. The effective redshift was  $4.12 \text{ cm}^{-1}$  for Sample A and  $4.84 \text{ cm}^{-1}$  for Sample B, indicating a higher defect concentration in Sample B. After irradiation, Raman spectra were measured from both the detector and substrate sides. Although the spectral trends were similar, the measurements obtained from the substrate and detector sides could not be directly compared because of the rough sample surface.

While this substantial redshift was accompanied by a measurable broadening of the full width at half maximum (FWHM) due to lattice strain, the diamond Raman peak remained prominent and well defined, demonstrating that the underlying crystalline structure of the diamond matrix was macroscopically preserved rather than amorphized.

In summary, neutron irradiation of the CVD/HPHT diamond structures under a Pu–Be neutron spectrum produced measurable lattice expansion and defect formation, evidenced by the pronounced Raman redshift. These results demonstrate that even moderate neutron fluences induce highly detectable local structural changes in diamond-based detector architectures.

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## Integration and Advanced Modelling of Collisional Datasets for Proton–Boron Fusion Plasma

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### Abstract

Accurate atomic and molecular collision data are essential for modelling partially ionized fusion plasmas and interpreting spectroscopic diagnostics in proton–boron fusion experiments. This work presents the integration, validation, and advanced modelling of collisional datasets for electron interactions with molecular ions relevant to boron–hydrogen plasma chemistry, including  $\text{HD}^+$ ,  $\text{H}_2^+$ ,  $\text{HB}^+$ , and the newly investigated  $\text{BF}^+$  system. The study combines Multichannel Quantum Defect Theory (MQDT) with machine learning techniques to improve the determination of cross sections and reaction rate coefficients over a broad energy range. Numerical procedures for fitting potential energy curves are refined to obtain robust analytical representations suitable for interpolation and extrapolation. In parallel, data-driven models, including Random Forest, XGBoost, K-Nearest Neighbours, Ridge Regression, and neural networks, are evaluated as complementary tools for predicting reaction rates in regions where theoretical calculations or experimental measurements are unavailable. The validated datasets are formatted according to VAMDC standards and integrated into interoperable database structures, enabling long-term accessibility and efficient use in plasma simulations. The resulting data support plasma transport modelling, plasma–surface interaction studies, and spectroscopic diagnostics in proton–boron fusion devices, while also providing valuable input for large-scale fusion facilities such as ITER. Beyond fusion research, the developed datasets are expected to benefit laboratory, laser-produced, and astrophysical plasma modelling, where reliable atomic and molecular collision data remain a key requirement.

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## Laser Surface Processing of Metallic Materials for Extreme Conditions Application

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### Abstract

Studying the materials responses / behaviour in extreme conditions, such as ultra-high temperatures (>2000 K), extreme pressures, intense irradiation, and corrosive environments, as well as overcoming the limitations of conventional materials by increasing their structural integrity and resilience have been in the continuous research focus [1-3].

In the presented study, the titanium-based alloy, nickel-based superalloy, and metallic coatings and thin films on silicon substrate were exposed to pulsed Nd:YAG laser radiation at different wavelengths, ranging from infrared to visible spectral range. The effects on surface morphology, chemical composition under different ambient conditions (based on N<sub>2</sub>, Ar, He, H<sub>2</sub>) were investigated by combining the physicochemical characterization techniques (SEM/EDS, profilometry) and mechanical properties evaluation (microhardness). Dependence on the gaseous mixture compositions and comparison to the results from the processing at standard ambient conditions was also investigated.

Materials surface micro- and nano-structuring by highly controllable direct laser irradiation has proved to be significant technique for improvement of materials and enhancement of their properties. Therefore, the conditions for the formation of the laser-induced periodic surface structures [4] in the different ambient conditions were also investigated as part of the presented study. Laser Induced Breakdown Spectroscopy (LIBS) was employed to acquire emission spectra and evaluate the elemental composition of laser treated surfaces, as well as to determine the plasma temperature and electron density.

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