2nd International Workshop on
Proton-Boron Fusion

Pulsed laser deposition of boron-based targets for p-^{11}B studies

Davide Orecchia

Catania, 7/9/2022

Overview

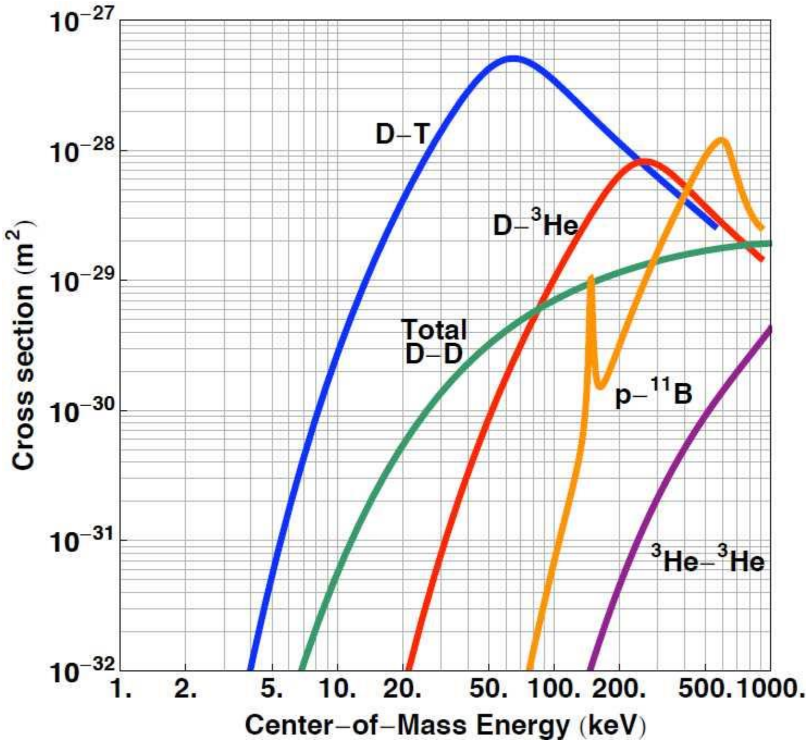
- Introduction
- Targets for p-^{11}B studies
- Pulsed Laser Deposition (PLD) as a flexible technique
- Compact boron films
  - Application to p-^{11}B cross section studies
- Low density boron nanofoams
- Conclusion and perspectives

Proton-boron fusion

$$p + {}^{11}B \rightarrow 3\alpha + 8.7\ MeV$$

Aneutronic reaction

Different **applications**



thermonuclear fusion

laser technology advances + **Target development**

laser driven fusion schemes

Yield advances in recent years

Margarone D. et al., Applied Sciences 12.3, 2022

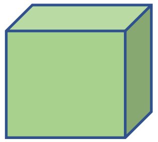
Targets for p-^{11}B studies

I. Prencipe et al., New Journal of Physics 23.9 (2021)

Different targets for **different aims**

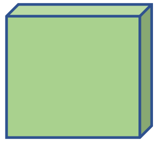
1 **p-B reaction studies**

α yield



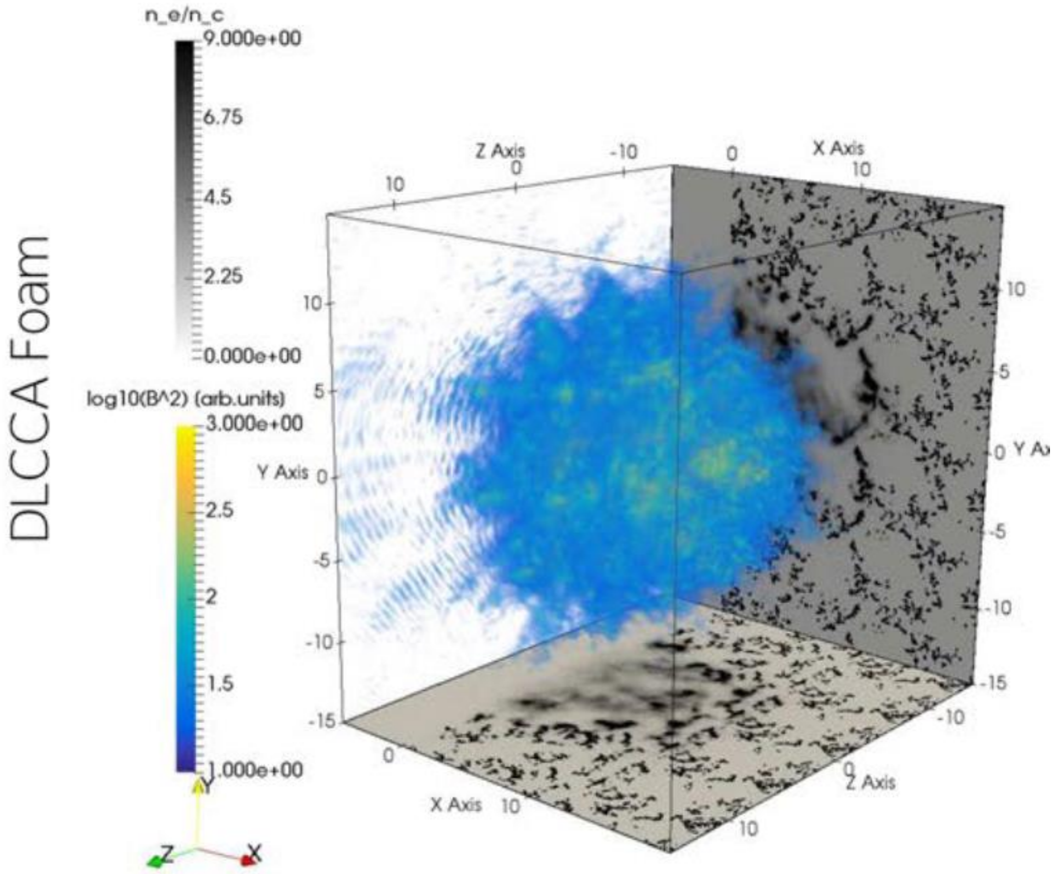
Thicker targets

cross section



Thinner targets

Laser-driven p-B fusion ⟺ **Laser-driven** particle acceleration



adapted from Fedeli L. et al., Scientific reports 8.1, 2018

Near-critical nanostructured materials

⇩

Enhanced laser-matter interaction

- Self-focusing
- Coulomb explosion
- **Volumetric** laser-matter interaction

Targets for p-^{11}B studies

Different targets for **different aims**

1 **p-B reaction studies**

α yield → Thicker targets

cross section → Thinner targets

2 **Direct irradiation p-B fusion**

In-foam

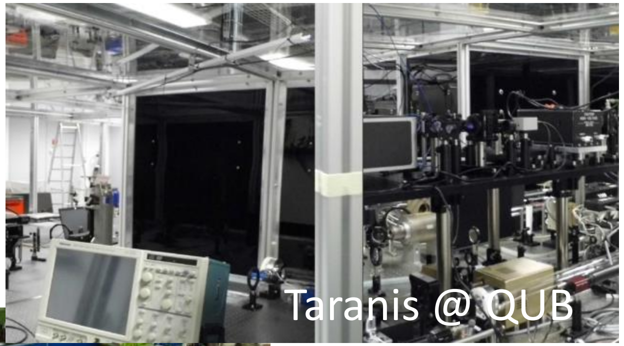
In-target

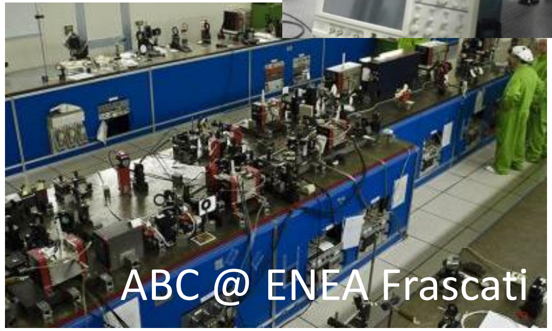
How to produce them?

3 **Pitcher-catcher p-B fusion**

4 **p-B implosion**

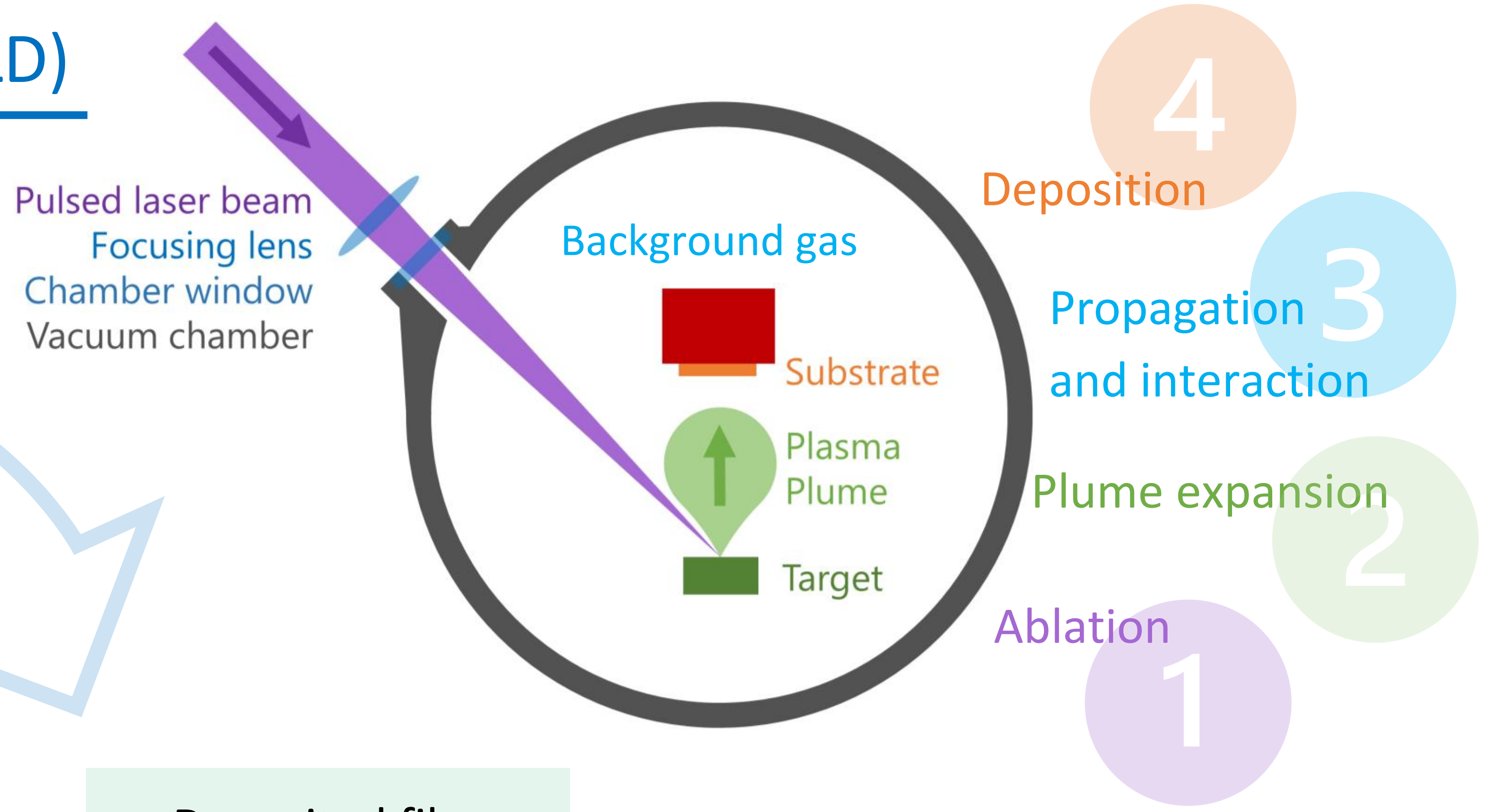
Ultrashort **sub-ps** lasers





long **ns** lasers

Pulsed Laser Deposition (PLD)



Process parameters

- Pulse energy
- Target-substrate distance
- Background gas pressure
- Substrate

Deposited film
properties control

(density, thickness, elemental composition)

Laser **pulse duration**

ns-PLD

Well established

fs-PLD

Nonstandard

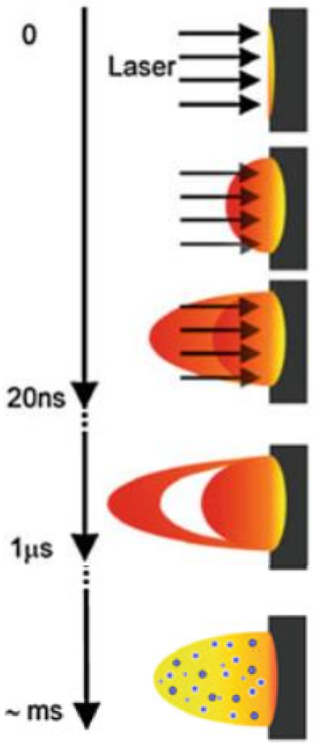
Flexible technique

Maffini A. et al., in Nanoporous Carbons for Soft and Flexible Energy Devices, Springer, 2022

ns-PLD vs fs-PLD

Different ablation regimes

Nanosecond

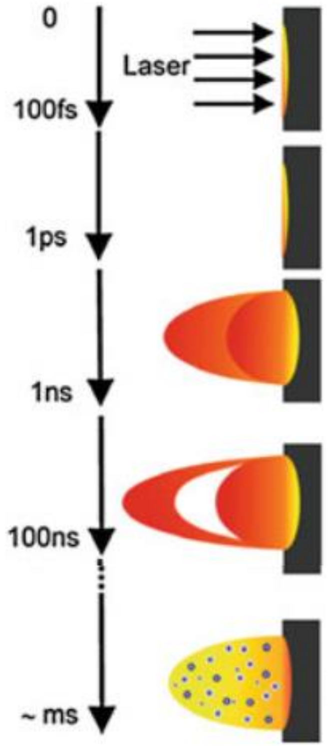


Thermal vaporization of **atoms** and **ions**

Plasma expansion

Plume condensation

Femtosecond



Electronic ablation of **nanoparticles**

Plasma expansion

Plume condensation

adapted from Harilal S.S. et al., in "Laser-induced breakdown spectroscopy", ch. 6, 2014

Compact solid density films ⇩ **ns-PLD**

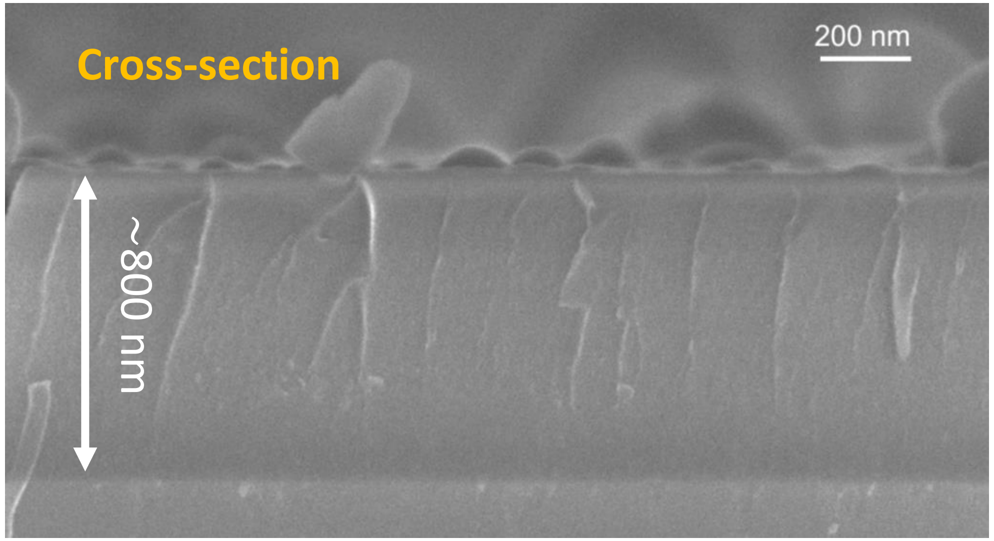
Foam-like low density materials ⇩ **fs-PLD**

ns-PLD		fs-PLD
✓	Elemental flexibility	✓
✗	Heating issues	⚙

ns-PLD		fs-PLD	
⚙	Droplets	Nanopartices	✓
⚙	Stresses	Film stability	✗
✓	Reliable	Challenging	⚙

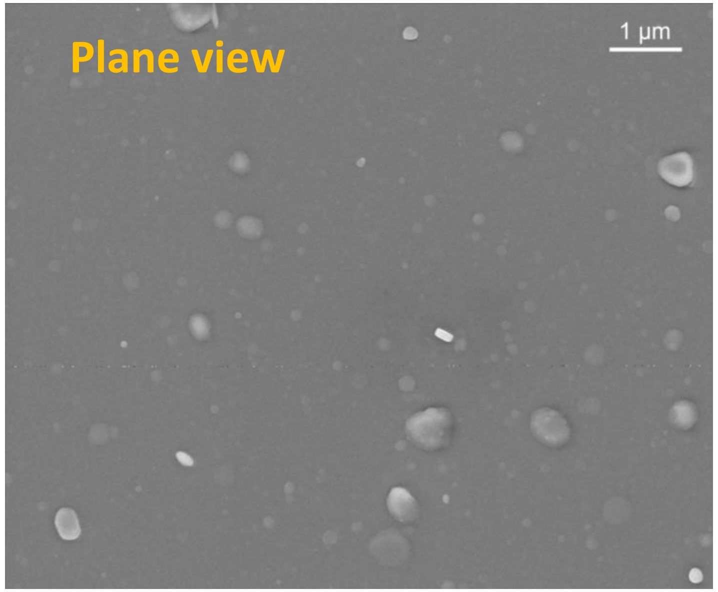
Complementary techniques

Compact boron films with ns-PLD



Higher target-substrate distance

- **Less** droplets ✓
- **Lower** deposition rate ✗



Deposition parameters:

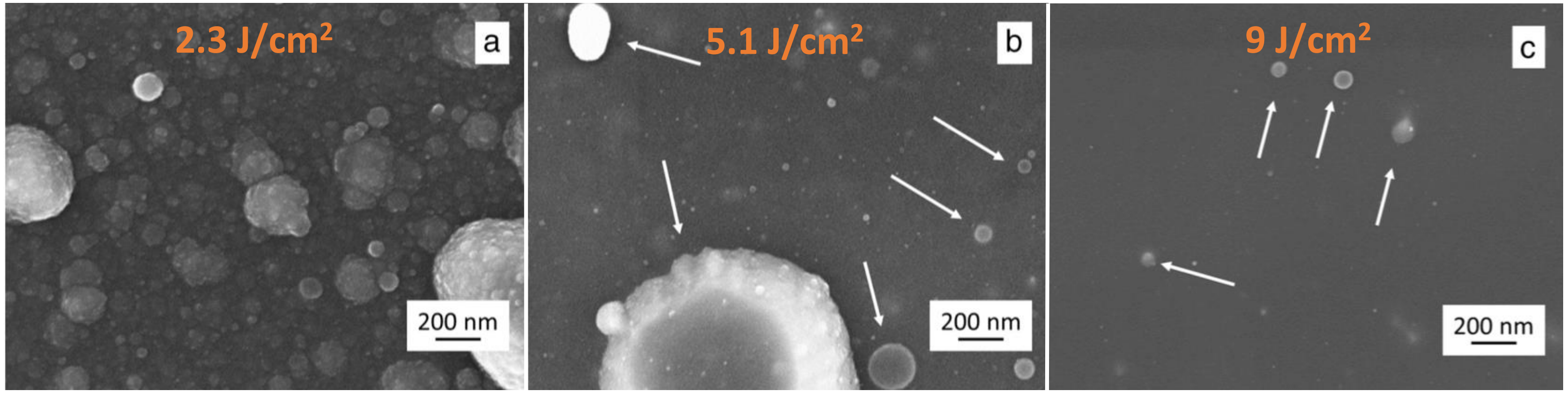
- **ns-PLD** (532 nm, 7 ns)
- High vacuum ($10^{-3} - 10^{-4}$ Pa)
- High fluence ($8 - 9\ \mathrm{J/cm^2}$)
- Tradeoff target-substrate distance ($6 - 9$ cm)

Film properties:

- ✓ Solid density ($\sim 2.35\ \mathrm{g/cm^3}$)
- ✓ Compact film with few defects
- ✓ $100s$ nm $- 10$ μm thickness

Match the experimental needs

Compact boron films with ns-PLD



Pulse **energy** & **fluence** →

High fluence

Few defects
Lower oxygen intake

Limitations:

- Substrate **heating**
- Natural boron target with Mg impurities (~ 2%)
- **Oxygen** content (10-20%) higher for thinner films
- **Amorphous** films

Residual stresses

Dellasega D. et al., Materials & Design 134, 2017

Application: p-^{11}B cross section investigation

Radiation metrology group @ PoliMi

Open points in the physics of the reaction, especially at **low energies**

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- Cross section
- α particle energy and angle distribution

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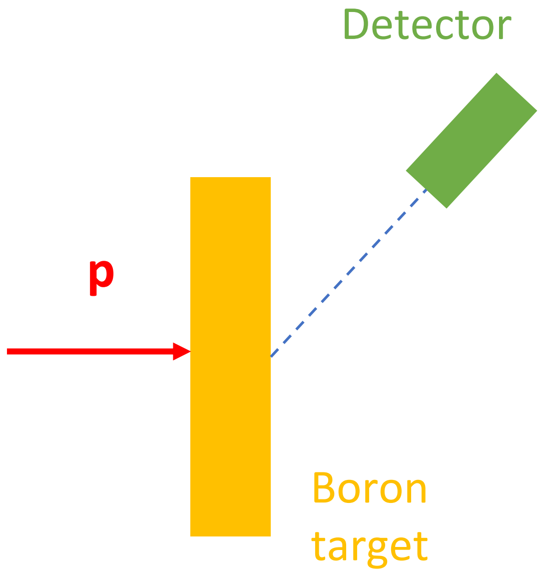
Fundamental for **applications**

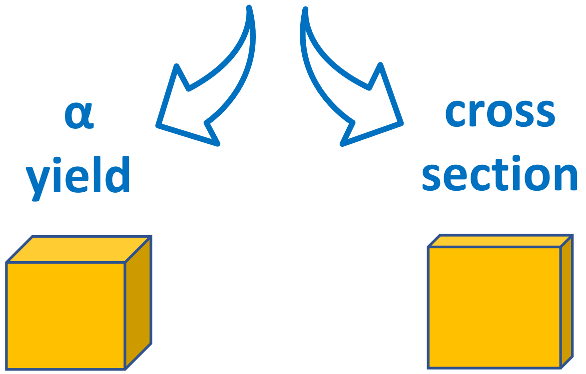


Proton accelerator

@ INFN – Laboratori Nazionali di Legnaro

Boron targets:

- Well characterized in density and composition
- Variable thickness



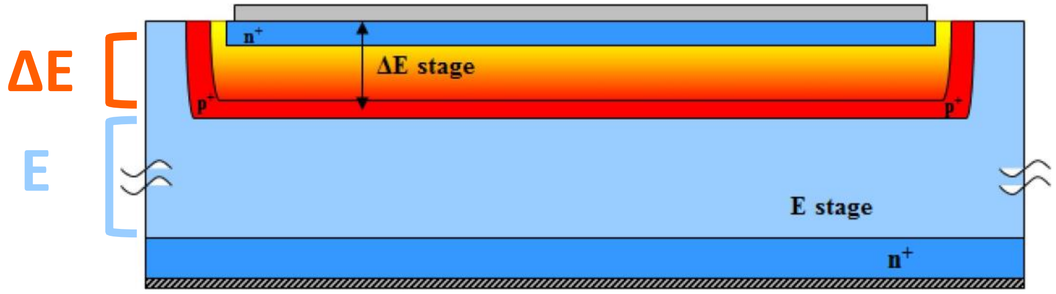
Detector + Target

Mazzucconi D. et al., submitted to Radiation Physics and Chemistry

Application: p-^{11}B cross section investigation

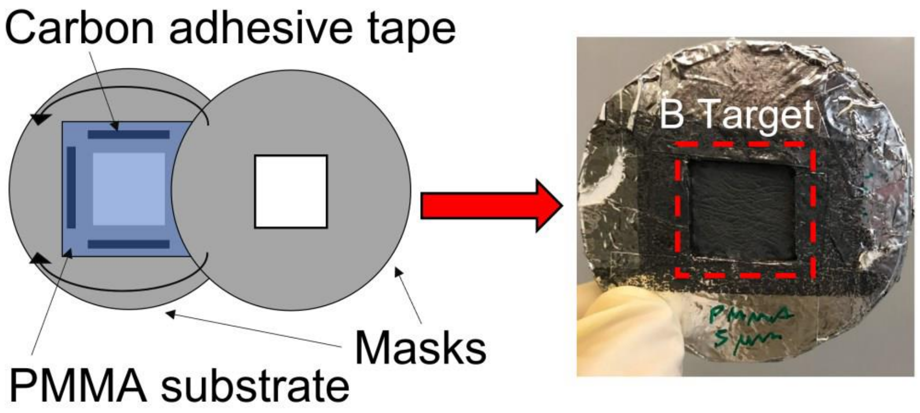
Radiation metrology group @ PoliMi

Silicon **telescope detector**



p and **α discrimination**

avoid film deformation



Feasible approach

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Further experiments planned

Slow protons to < 2 MeV ⇨ (**50 µm PMMA** substrate + **5 µm boron** film)

Pola A. et al., Radiation Measurements 133, 2020

Mazzucconi D. et al., Physica Medica 89, 2021

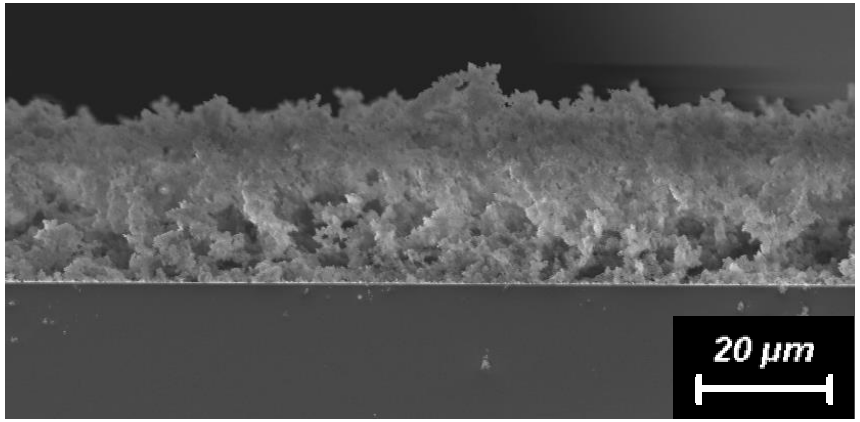
Mazzucconi D. et al., submitted to Radiation Physics and Chemistry

Low density boron nanofoams with fs-PLD

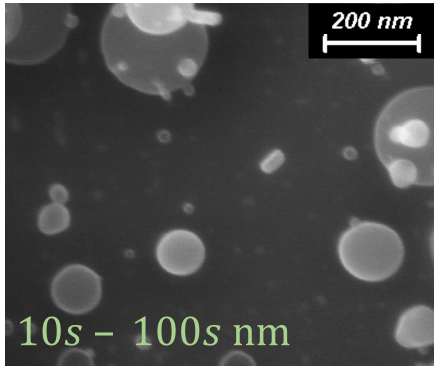
Dimensions, **energetics** and **concentration** of the nanoparticles ⇔ Relative **slowing efficiency** of the background gas

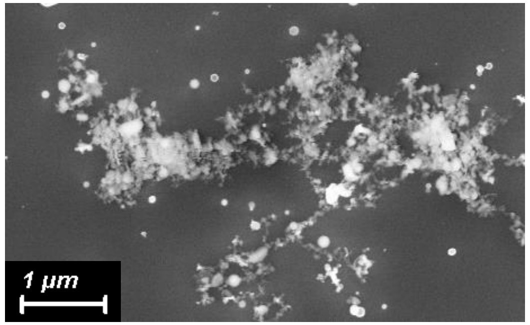
Material properties

- Density
- Thickness
- Uniformity



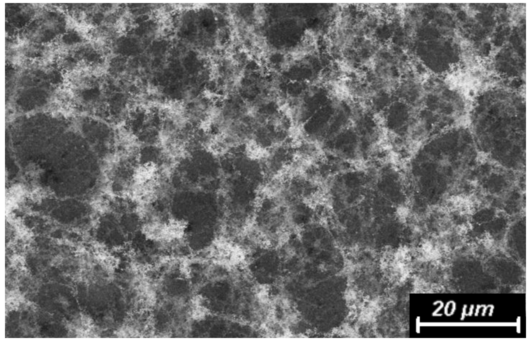
1 Direct **nanoparticle** production





In flight **fractal aggregate** formation 2

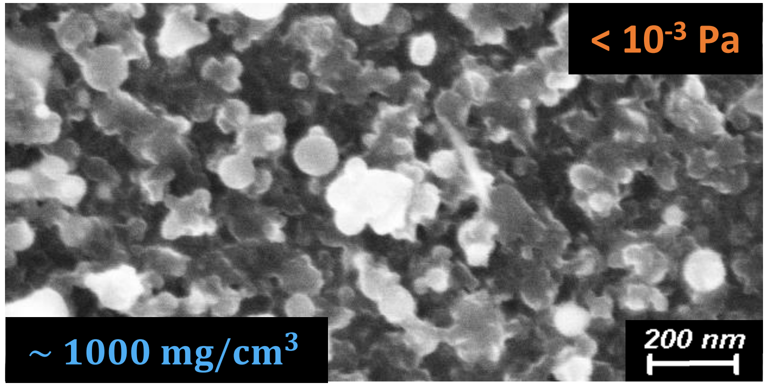
3 **Deposition** on the substrate and foam growth

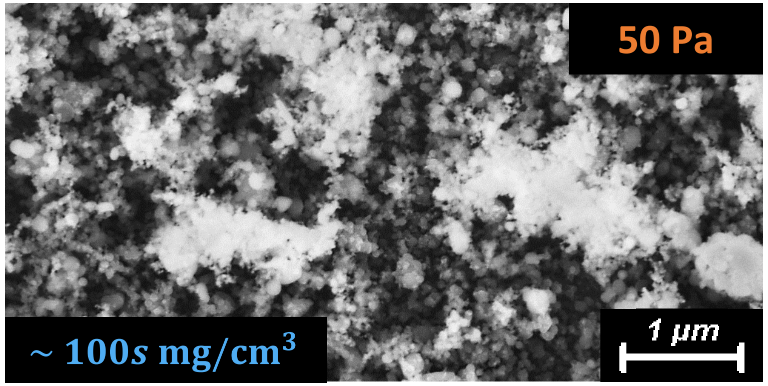


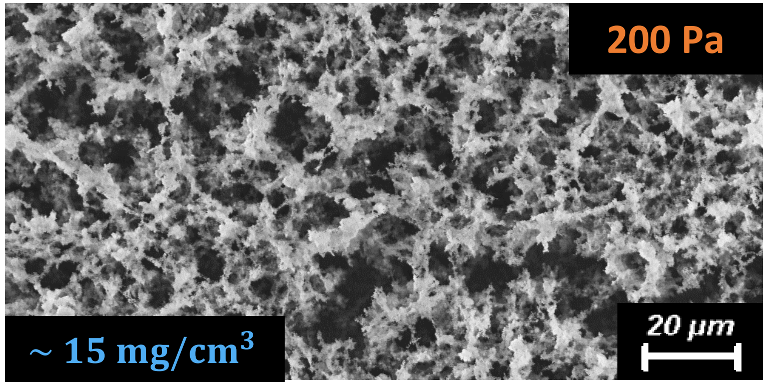
Low density boron nanofoams with fs-PLD

All are nanostructured films

Argon gas **pressure** →







← **Density**

Deposition parameters:

- **fs-PLD** (800 nm, 80 fs)
- Background argon gas pressure ($\sim 100s$ Pa)
- "High" fluence (~ 0.1 J/cm^2)
- Low target-substrate distance (~ 3 cm)

⇒

Film properties:

- Low average density, down to ~ 15 mg/cm^3 ✓
- 10 μm – ~100 μm thickness ✓
- $\sim 2\%$ Mg impurities and $\sim 20\%$ oxygen content
- Uniformity scale of ~ 10 μm

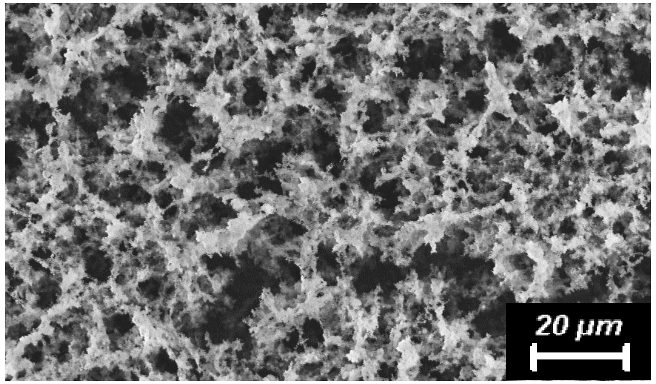
Freedom in **material choice**

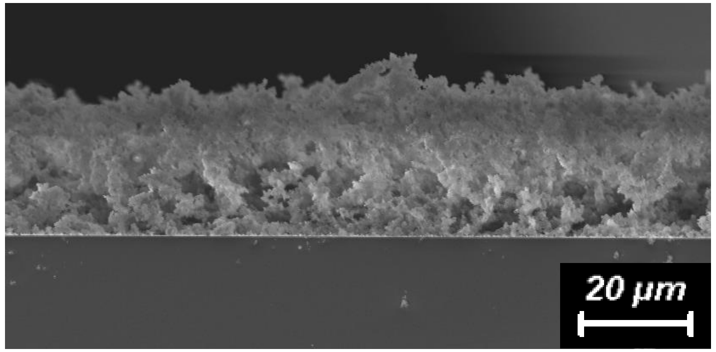
⇓

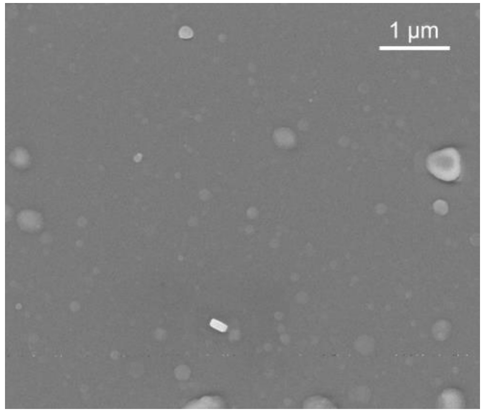
Hydrogen enrichment

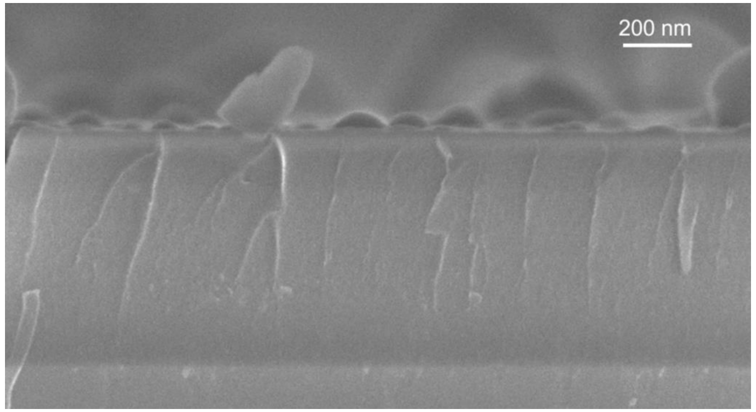
Conclusions and perspectives

Boron **nanofoams**









Compact boron films

ns-PLD + **fs-PLD** ⇨ **Versatile** and **flexible** for **boron target** production

Isotopic ^{11}B, BN, plastic targets for PLD

Improve the **material properties control**

Employ the targets in **p-^{11}B fusion experiments**

Thank you for your attention!