Stopping Power in plasma within the infn FUSION project

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C. ALTANA

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Physical case:
Stopping power in laser-generated plasmas

Stopping power of ions in plasma is a process of fundamental importance in many applications:

- Inertial Confinement Fusion
- Astrophysics and Nuclear Astrophysics
- High-energy Density Physics
- Plasma strippers
- Solid State Physics

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❑ High-energy

$$v_p \gg v_{th}$$

- The stopping power (energy deposited per unit length) of the ions in the plasma can be described by perturbative approaches based on a first Born approximation
- Most stopping experiments can be interpreted within the SSM frame

❑ Low-energy

$$v_p \approx v_{th}$$

- The ion-plasma interaction involves both strong collisions and collective plasma excitations, and the coupling between the projectile and the plasma is maximal
- Large discrepancies appear between the various theories, reaching up to 30-50 % between perturbative predictions and data from nonperturbative approaches

SSD:
Standard Stopping Model

$$-\frac{dE}{dx} = \frac{4\pi e^4 Z_{eff}^2}{m_e v_p^2}\left[n_{be}\ln\left(\frac{2m_e v_p^2}{\bar{I}}\right) + n_{fe} G\left(\frac{v_p}{v_{th}}\right)\ln\left(\frac{2m_e v_p^2}{\hbar\omega_{pe}}\right)\right]$$

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- $\bar{I}$ is the excitation energy of the bound target electrons
- $\hbar\omega_{pe}$ is the plasmon energy

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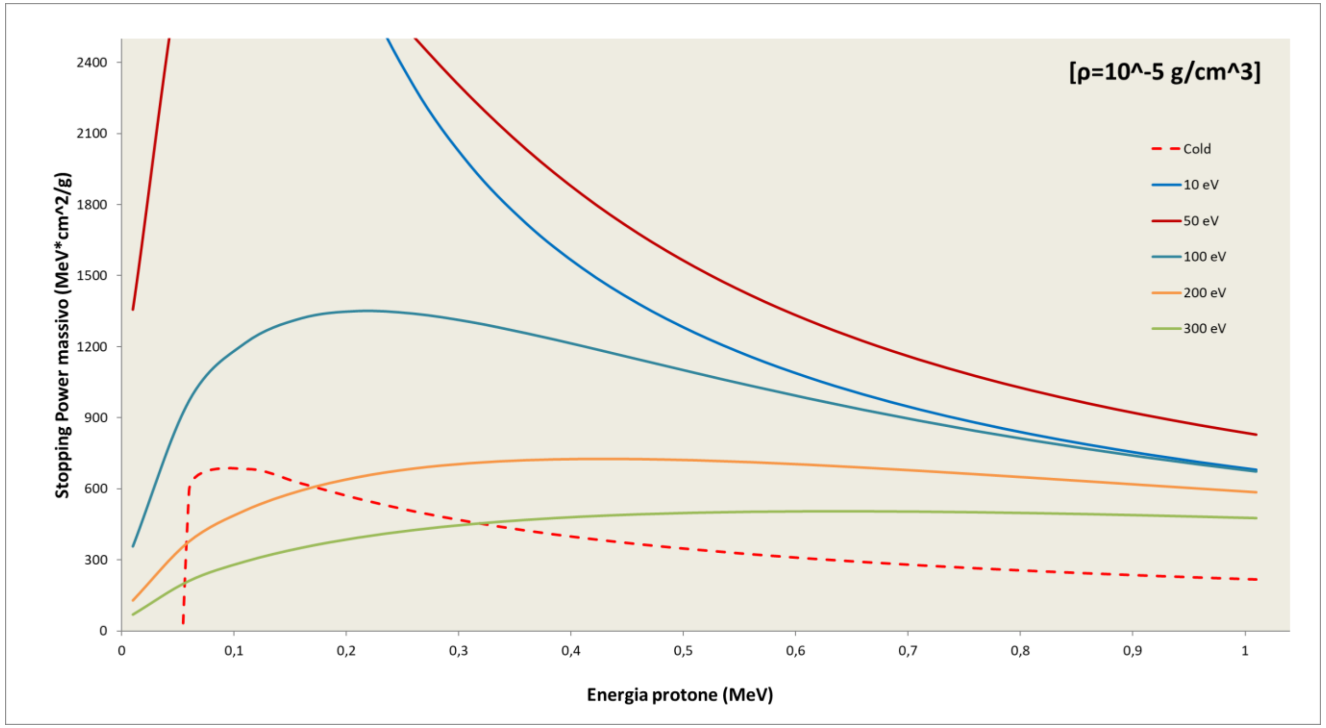
- ❑ For increasing plasma ionisation degree, the stopping power increases substantially with respect to the cold matter value
- ❑ At higher temperatures, the average velocity of the plasma electrons becomes comparable to or exceeds that of projectile protons and the stopping power decreases
- ❑ The free electron density also affects plasma stopping power that decreases with increasing density

Stopping power in plasma:
Effect of temperature and density



$\frac{dE}{dx}$ decreases with increasing temperature

S.N. Chen *et al.*, Nat. Sci. Rep. 8, 14586 (2018)
INFN-LNS Master's Thesis

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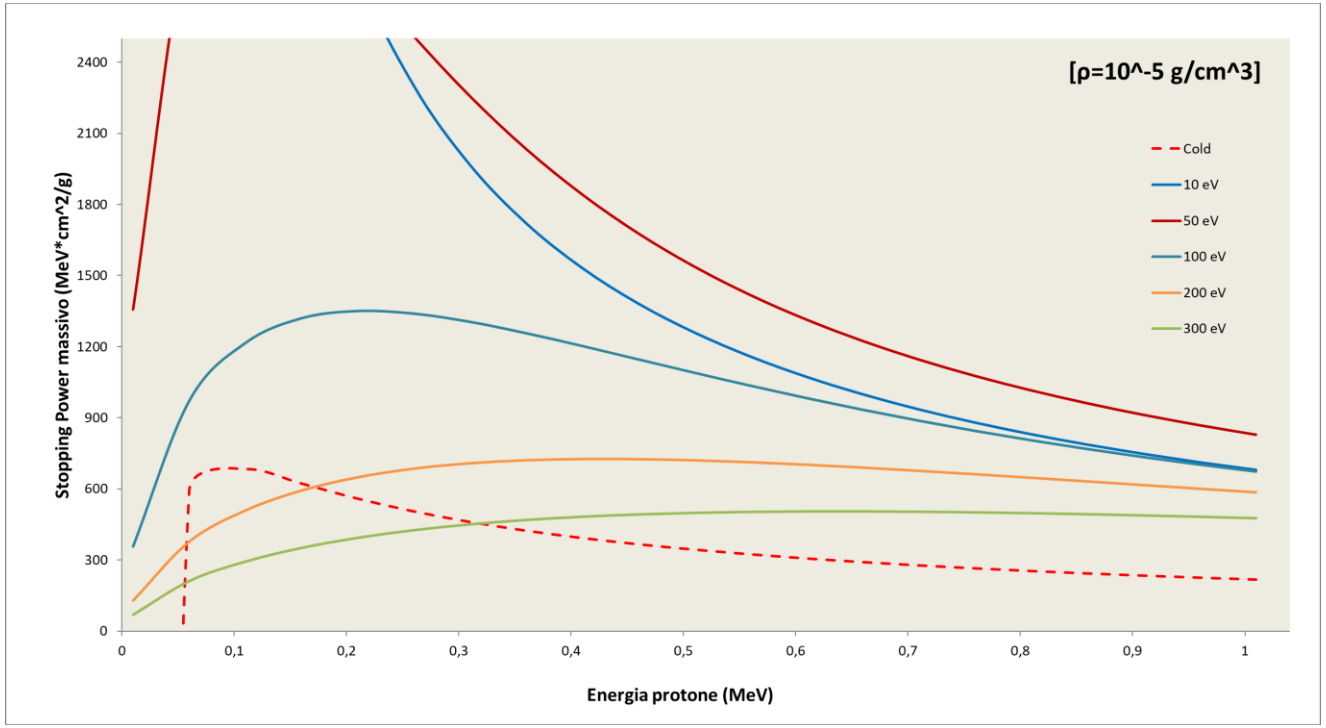

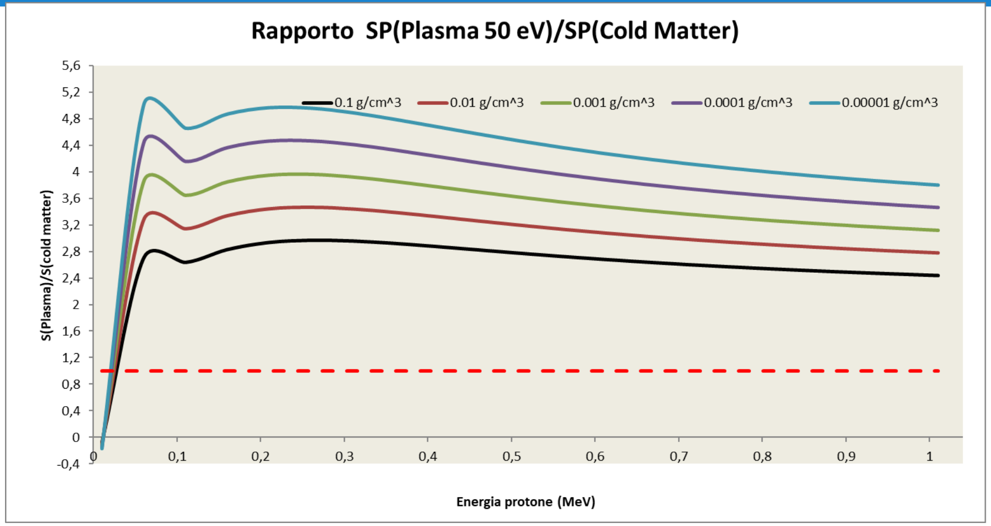

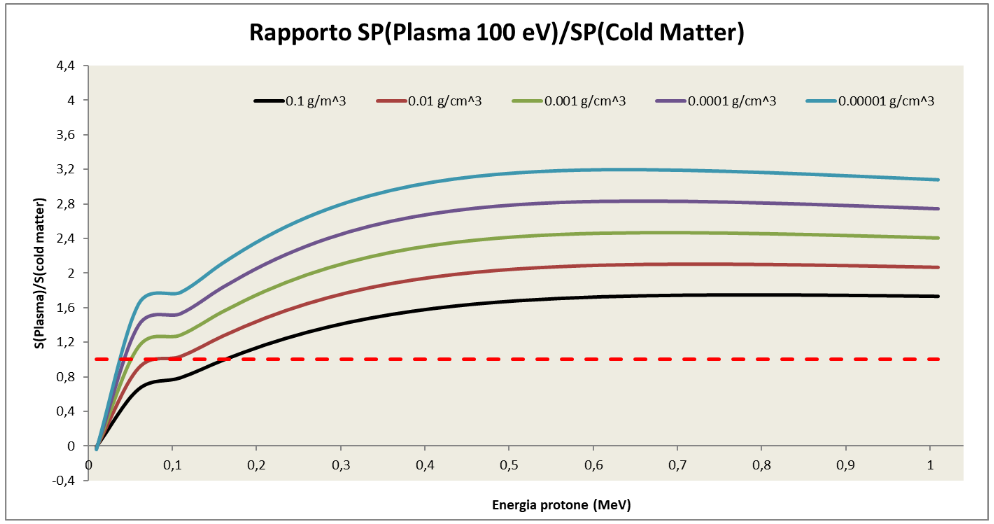

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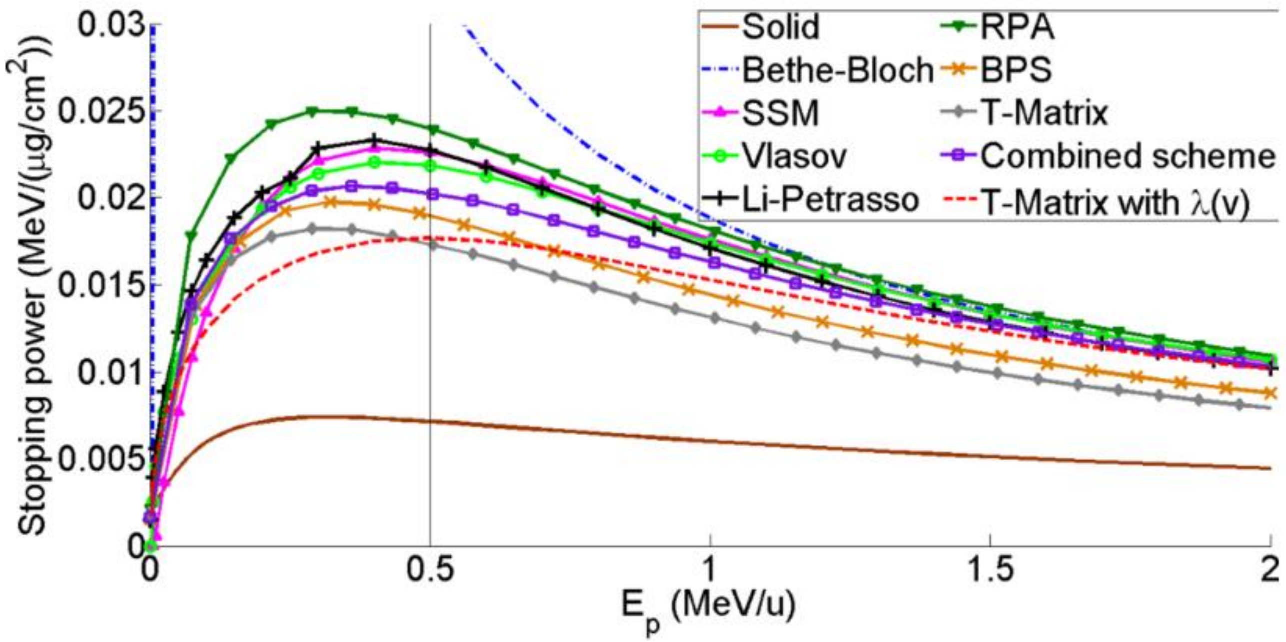
Stopping power in plasma:
Models



W. Cayzac *et al.*, Phys. Rev. E 92, 053109 (2015)

Assuming different models can drastically change the stopping power, particularly in the Bragg peak region.

- Few data reported in literature
- Scarce accordance with simulation

Systematic and careful measurements of stopping power for several ions in plasmas, especially in the low energy region, where the ion speed approaches the thermal velocity of plasma electrons

Fusion Project:
StudIes of prOton boron Neutronless reaction in laser-generated plasma

Responsabili nazionali
G A Pablo Cirrone INFN;
Fabrizio Consoli, ENEA,

Sezioni INFN partecipanti
Catania, Lecce, LNS, LNGS, Milano, Roma2, Torino, TIFPA, Bologna,, Firenze

Istituti esteri in collaborazione
ELI-Beamlines (CZ), HILASE (CZ), Physic Institute of Czech Academy of Science (CZ)

”FUSION main aim is the study of the p^{11}B reaction in laser generated plasmas in order to investigate its possible applications for energetic and multidisciplinary applications.“

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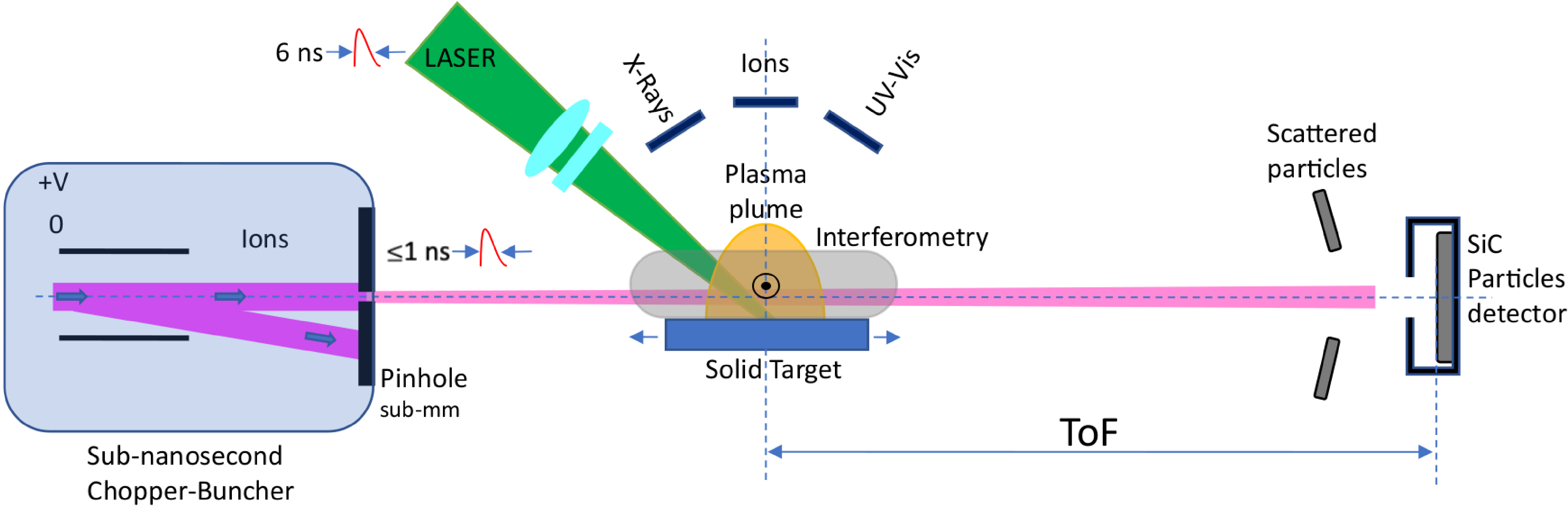
"FUSION main aim is the study of the $p^{11}B$ reaction in laser generated plasmas in order to investigate its possible applications for energetic and multidisciplinary applications."

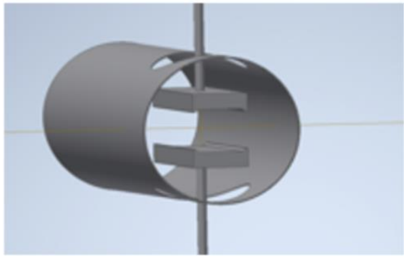
- **Characterization of protons and alpha stopping power in plasma**
- Optimisation of the setup to maximise the $p^{11}B$ reaction rate in plasma
- developing new-generation solid targets, exploiting different laser systems
- development of innovative diagnostic systems for plasma and radiation
- simulation and modelling of the phenomena at the basis of the reaction

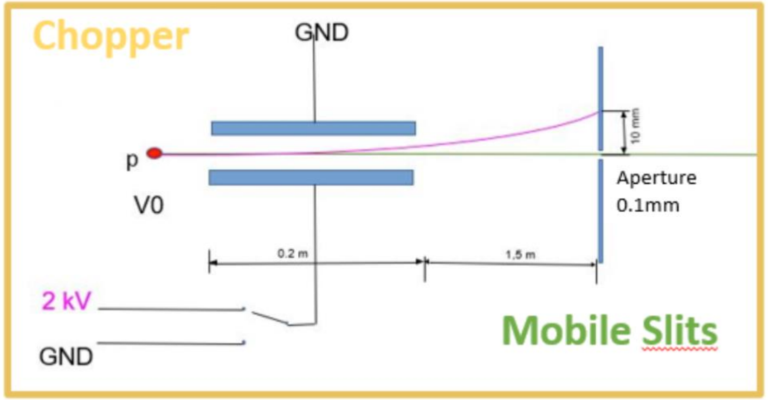
Fusion project WP2:
Proposed Setup

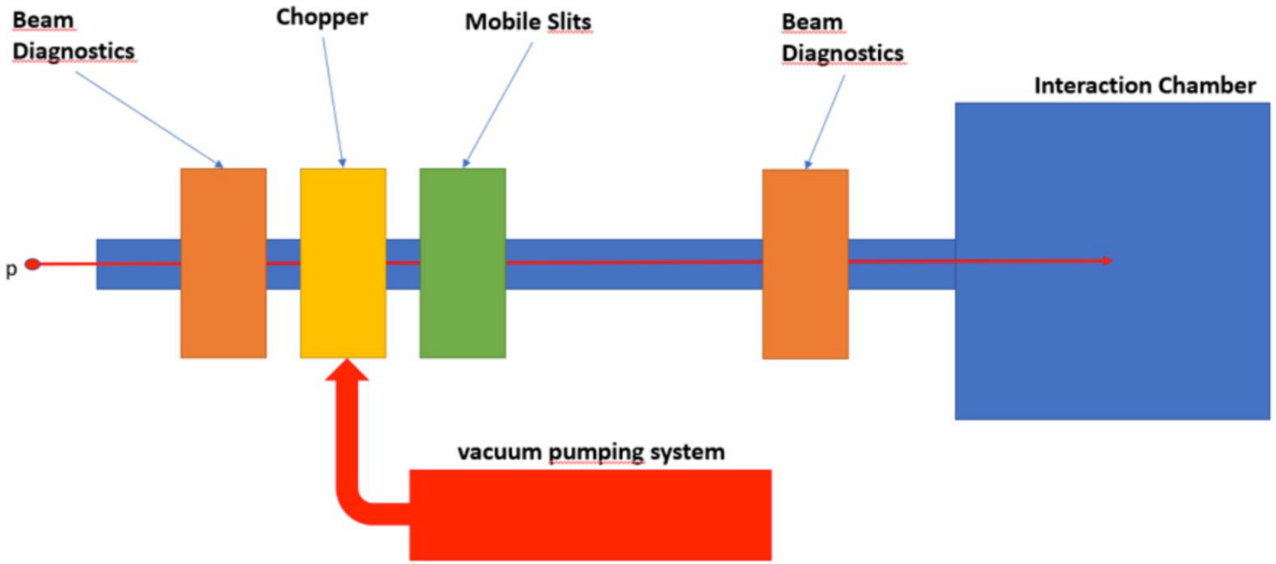


The proposed setup exploits 0.5-3 MeV proton and bunched microbeams delivered by Singletron electrostatic accelerator (Physics Dept., Catania University), crossing a plasma plume generated under vacuum by a laser beam interacting with a solid target

Chopper plates







Chopper → electrostatic deflector of the beam.

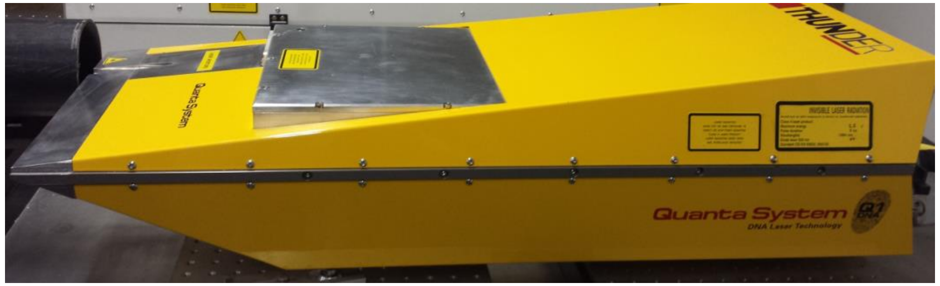
- Two metallic plates with switching voltage
- Adjustable slit (down to ~100 um)

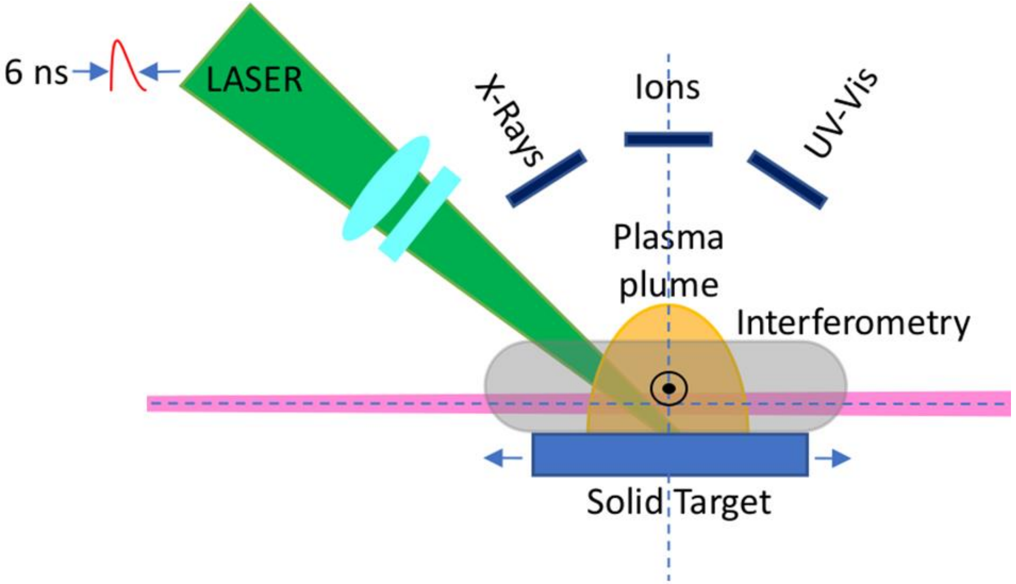
The beam goes through the adjustable slit for a very short time → a pulsed beam (bunch FWHM<1ns) is obtained.

The bunch width in time increases for larger beam energy, since the deflection at the slit decreases, while the switching time does not change

Fusion project WP2:
Laser system and diagnostics

- Nd:YAG laser system
- Pulse duration: 6 ns
- Fundamental wavelength: 1064 nm
- Maximum energy: 2 J
- Angle of incidence on target: 30°
- Maximum intensity on target was up to 10^{12} W/cm^2





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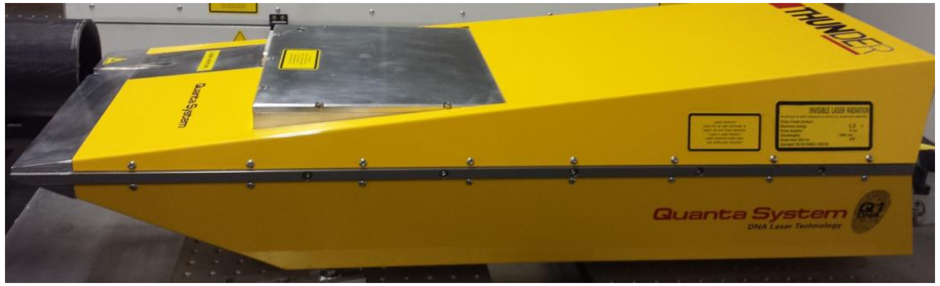
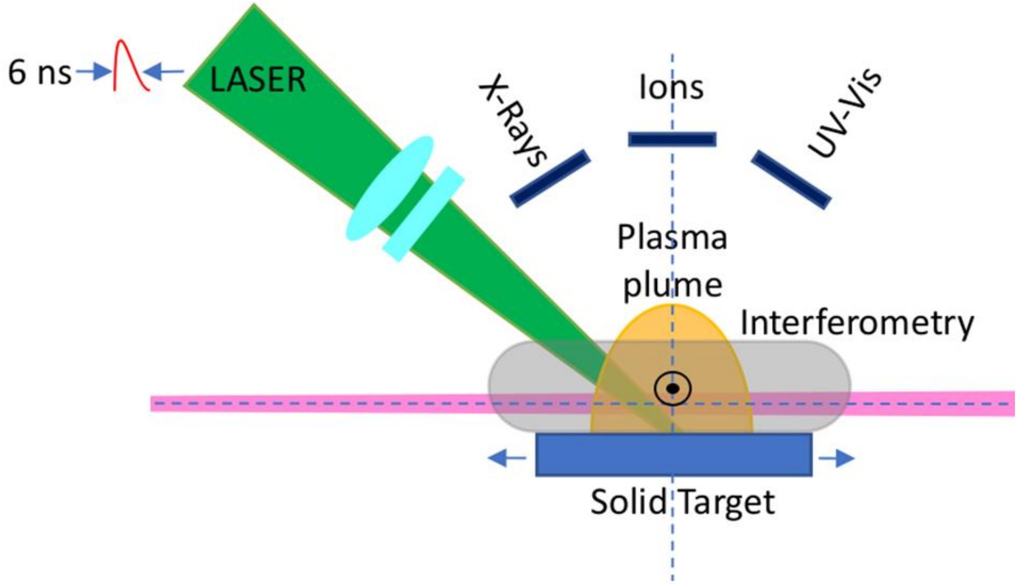




Intensified CCD device allows to acquire images in a small-time widows (at list about 2 ns). Useful to study the spatio-temporal evolution and velocities of laser generated plasmas.

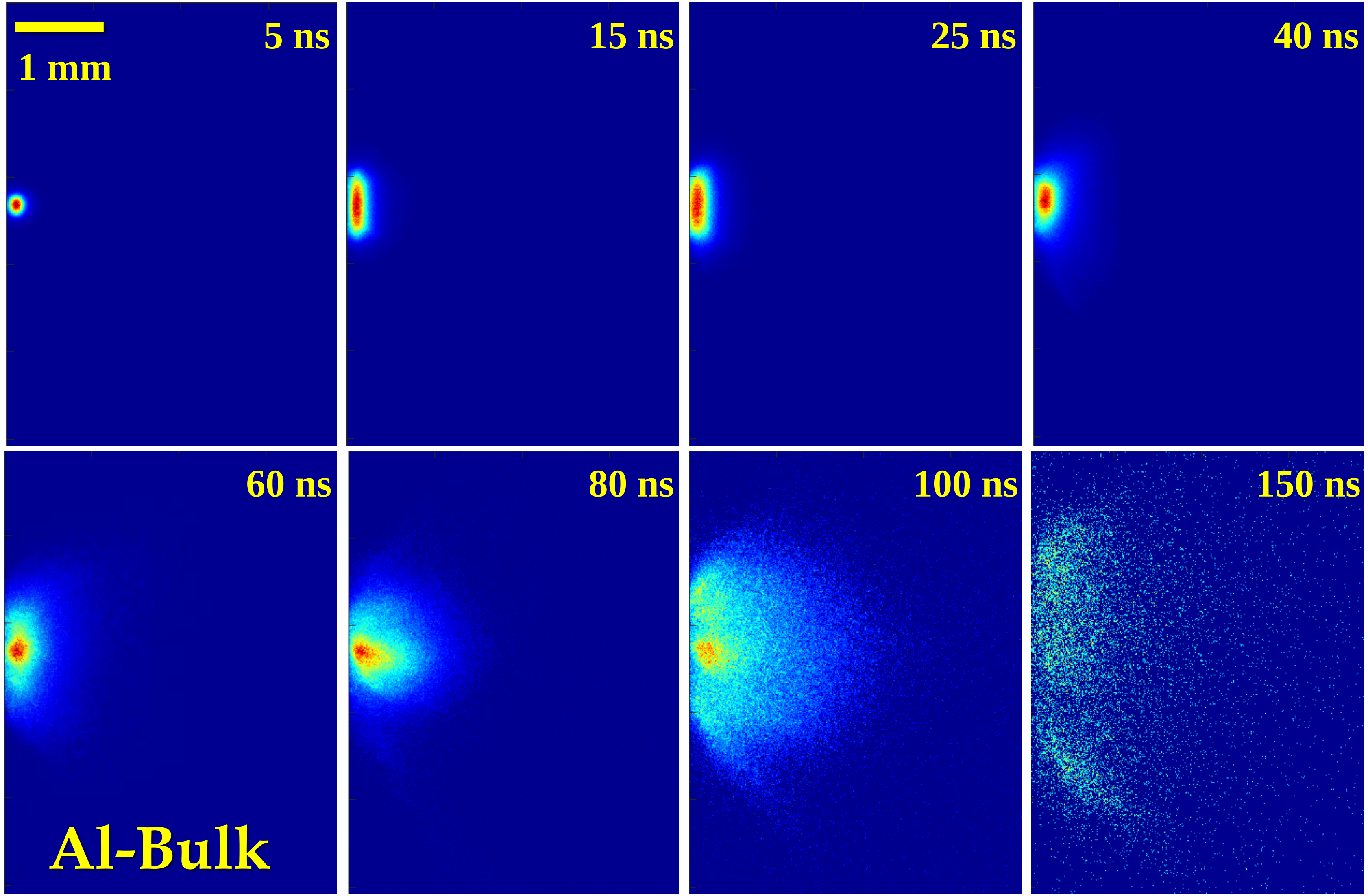
X-ray Bragg's diffraction spectrograph allows to acquire X-ray spectra. Useful to describe the X-ray plasma emission and to estimate the plasma temperature.

Customisation of a device developed in the PLANETA experiment (CSN5)

Time-resolved laser Normaski interferometry allows to measure the plasma density spatial profile.

SiC detectors in Time of Flight configuration and single particle mode allow to detect ions.

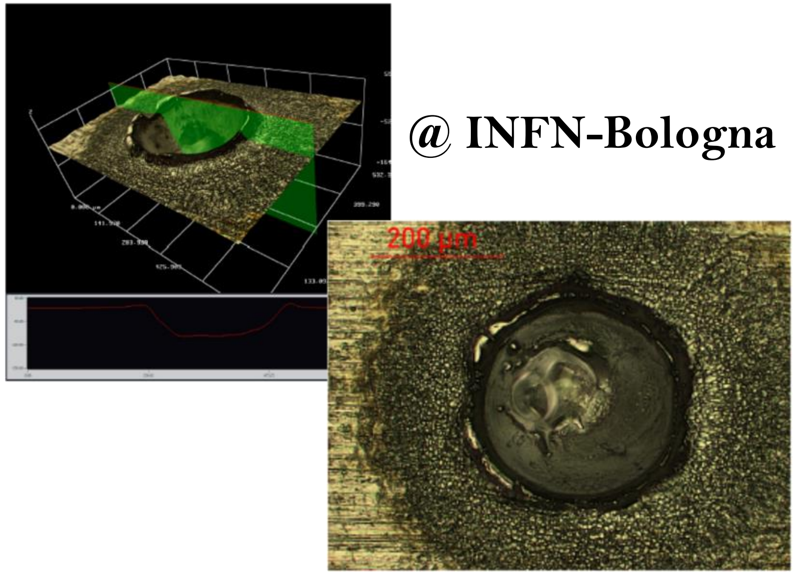
Fusion project WP2:
Previous Measurements



Spatio-temporal evolution in visible domain

Target	*Fast velocity* $[m/s]\times10^4$	*Slow velocity* $[m/s]\times10^4$
Al-Bulk	4.18±0.95	1.07±0.24

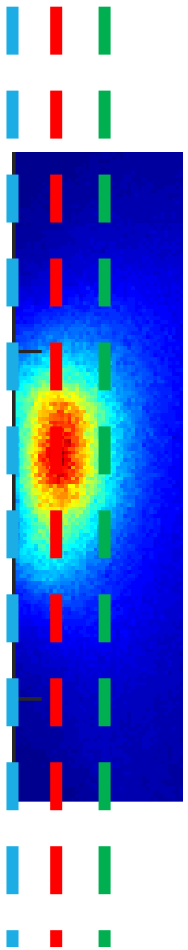
Crater morphology analysis

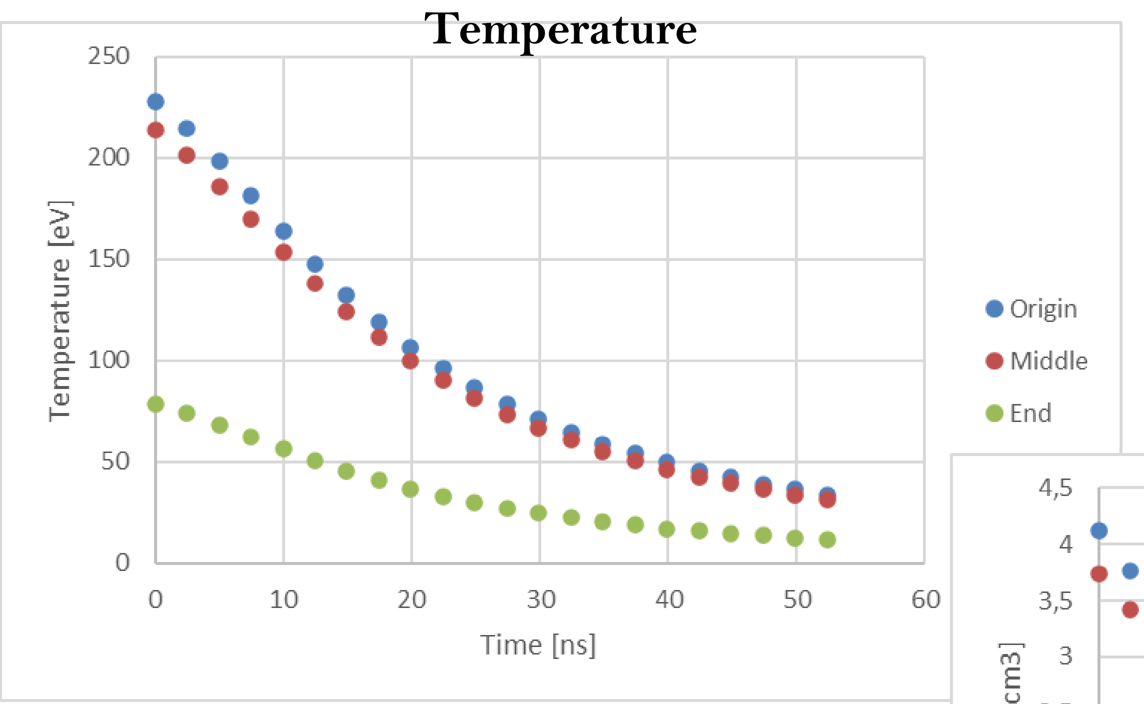


@ INFN-Bologna

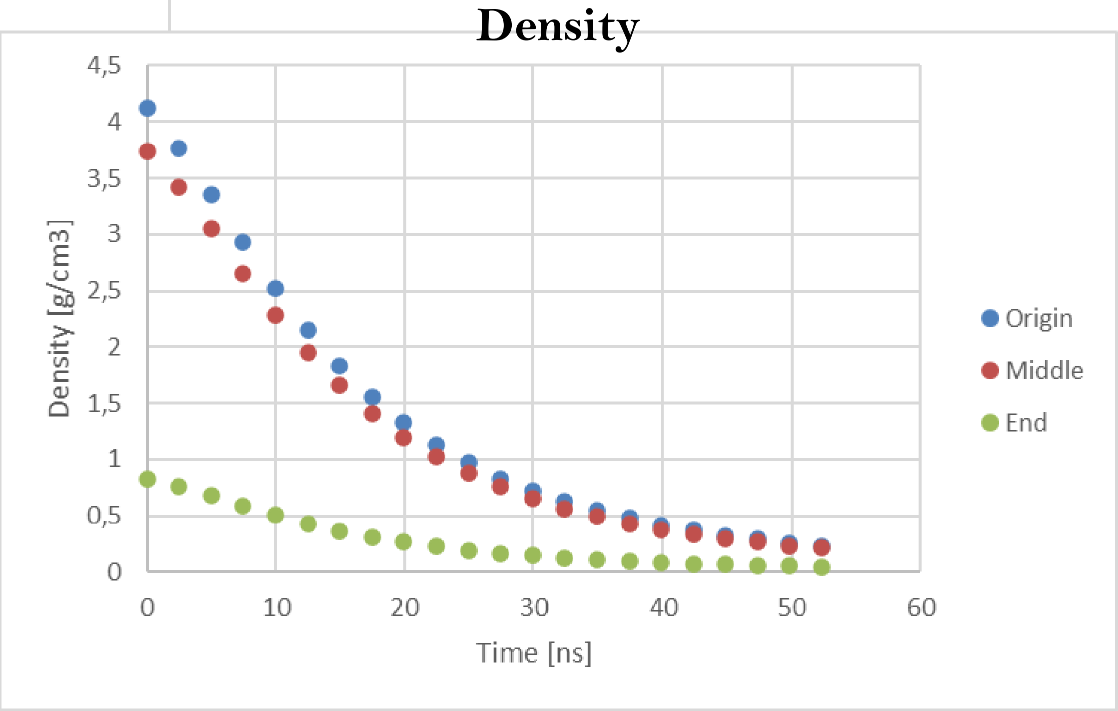
Target	*Depth* $[\mu m]$	*Volume* $[\mu m^3/10^6]$
Al-bulk	139±3	3.67±0.13

Fusion project WP2:
Simulation





@ Master's thesis
R. De Angelis



Thanks for the attention