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MILANO 1863

ENSURE & INTER ERC projects

Matteo Passoni

Milano, March 15° 2017

The ENSURE project in a nutshell

Exploring the **N**ew **S**cience and engineering unveiled by **U**ltraintense and ultrashort **R**adiation interaction with matt**E**r

Five year project: September 2015 – September 2020

Fields of interest: Physics of laser-plasma interaction, material science, nuclear science & engineering, computational physics

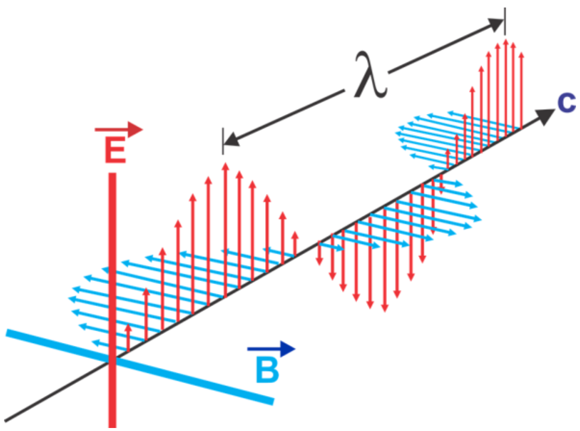
Main goals:

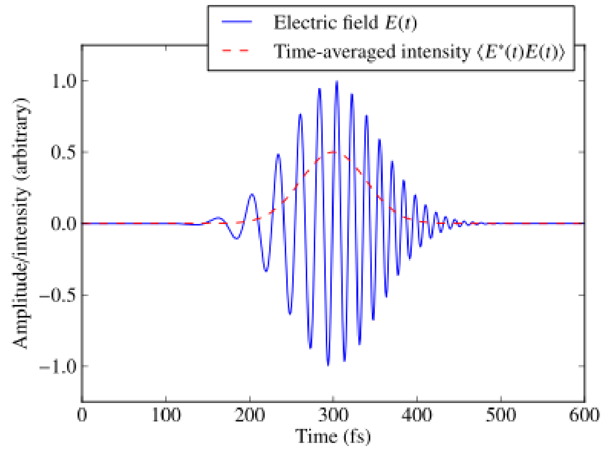
Investigation and development of **novel ion acceleration** schemes using **superintense laser** pulses

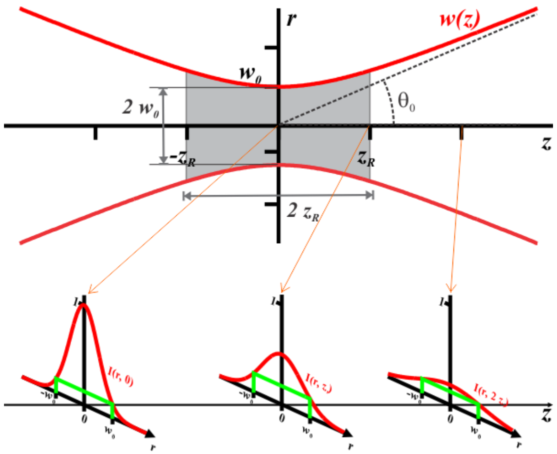
Investigation of **applications** of **laser-driven ion beams** of scientific, technological and societal interest

The Laser:

A revolution in the generation of electromagnetic radiation







Spatial and temporal coherence | Short pulse duration | Spatial focusing

Extremely high Intensity possible!

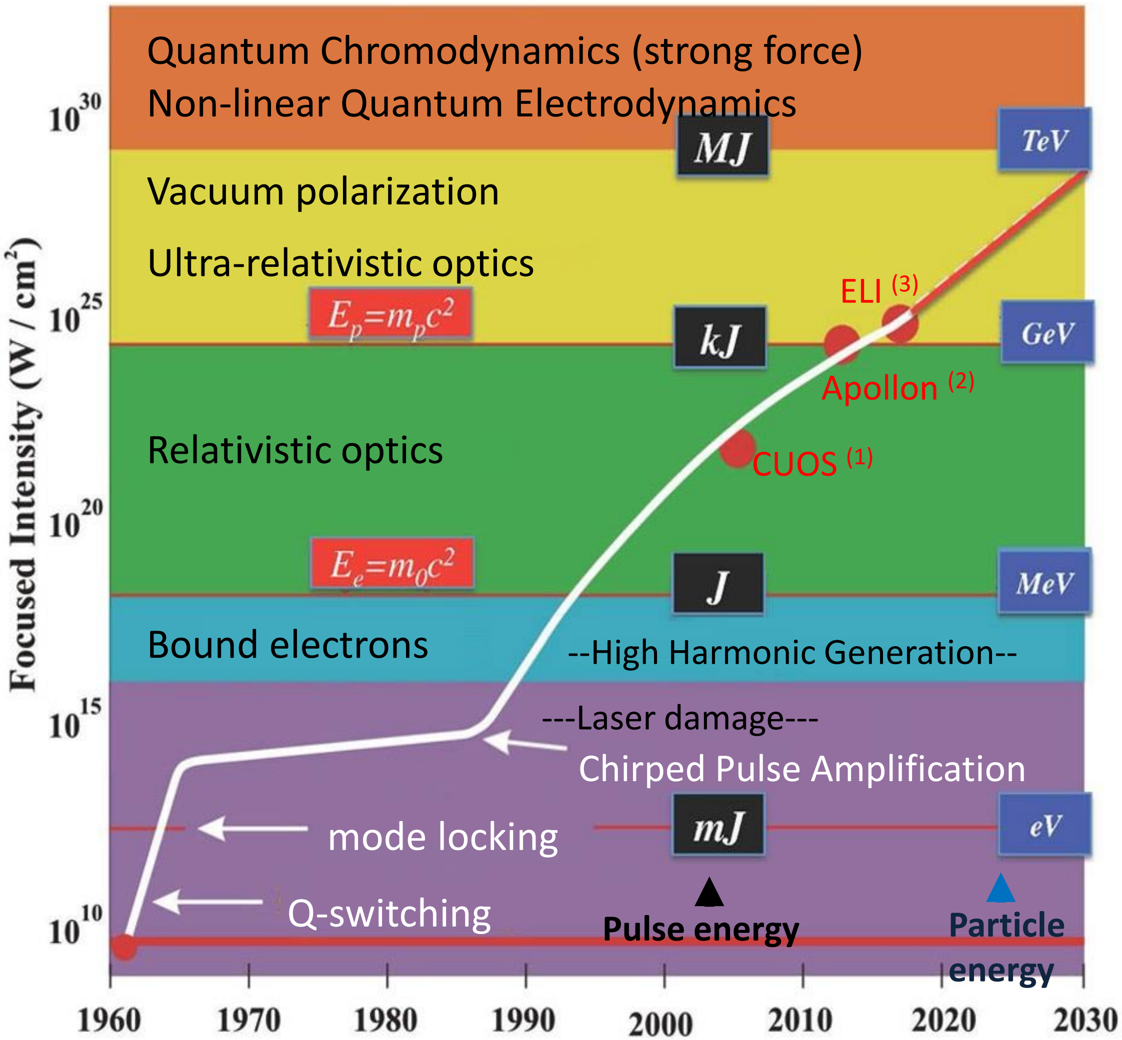
Electric field associated to the laser pulse:

$$I = cE_{\max}^2 / 8\pi$$

$$I\left(\frac{\mathrm{W}}{\mathrm{cm}^2}\right) \approx 1.4\times10^{15} E^2\left(10^9\,\frac{\mathrm{V}}{\mathrm{cm}}\right)$$

Superintense laser-matter interaction

New physics available by progress in laser technology



(1) CUOS: Center for Ultrafast Optical Science (University Michigan)
(2) Apollon Laser, Centre Interdisciplinaire Lumière Extrême (France)
(3) Extreme Light Infastructure (EU) https://eli-laser.eu/

Important laser quantities

Typical laser parameters with Chirped Pulse Amplification (since '80s)

Laser wavelength (μm): ≈ 1 (Nd-Yag), 0.8 (Ti-Sa), ≈ 10 (CO_2)

Energy (per pulse): 10^{-1} - 10^{3} J

Power: ≈ 100 TW - few PW (PW lines now available)

Pulse duration: ≈ 10 - 10^{3} fs (at $\lambda = 1\ \mu$m, $\tau = c/\lambda = 3.3$ fs)

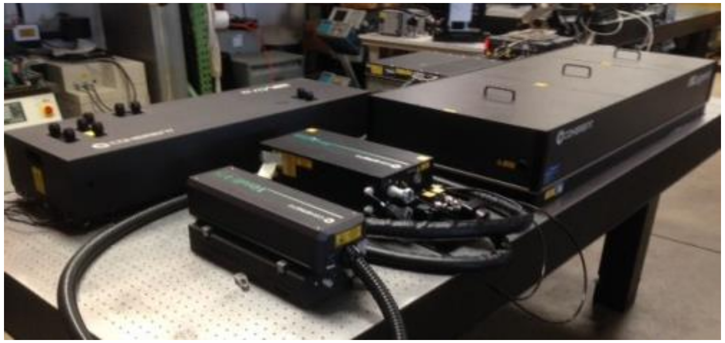
Spot size at focus: down to diffraction limit → typically ø < 10 μm

Intensity (power per unit area): 10^{18} W/cm^2 up to 10^{22} W/cm^2

From huge facilities……

Nova laser, LLNL, 1984

… to table-top systems!

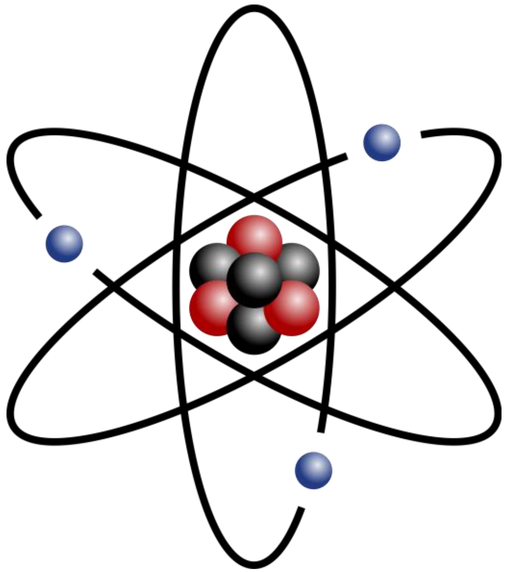


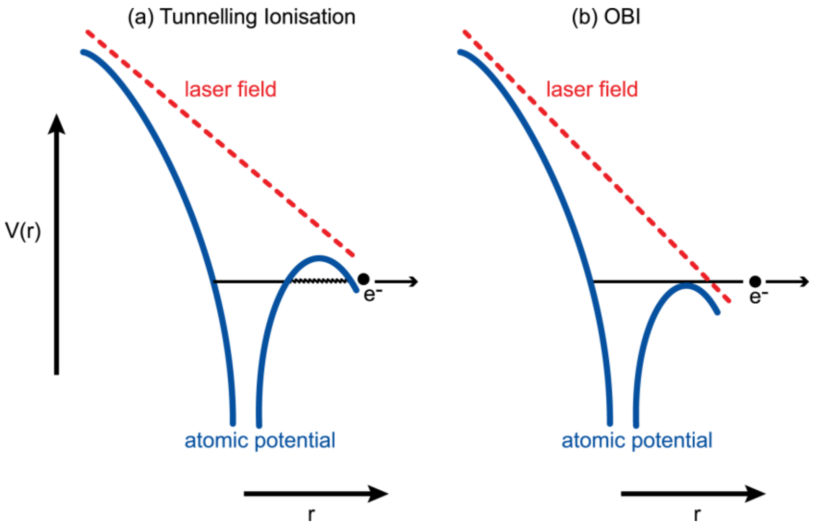
Commercial TW class laser, 2010s

The strength of laser fields:

Laser field vs. atomic fields

Atomic field → $$\frac{e}{a_0^2} \cong 5.15\times10^9\,\frac{\text{V}}{\text{cm}} \Rightarrow I \cong 3.6\times10^{16}\,\frac{\text{W}}{\text{cm}^2}$$





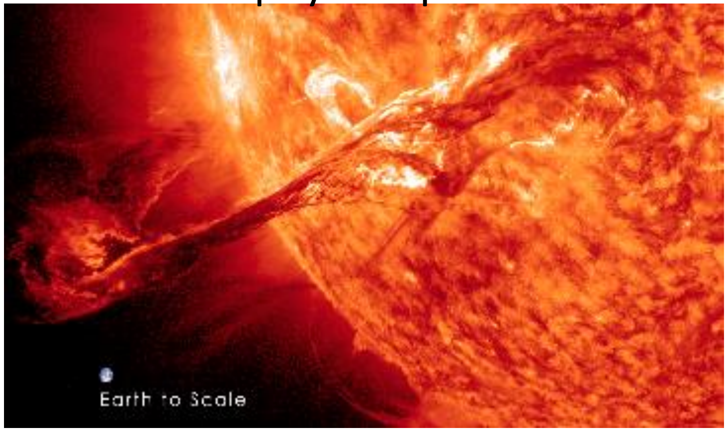
Calvert, J., Palmer, A., Litvinyuk, I., & Sang, R. (2016). Metastable noble gas atoms in strong-field ionization experiments. High Power Laser Science and Engineering

Ionization process → unbound mixture of electrons and ions → **Plasma**

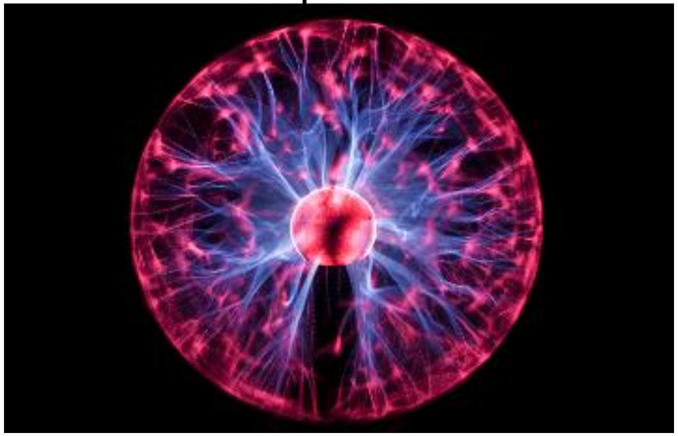
Plasma physics

99% of matter in the visible universe is in the state of plasma

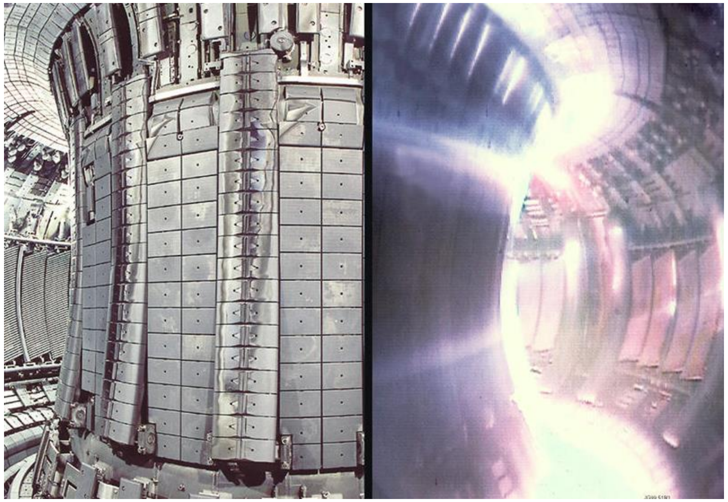
Astrophysical plasmas



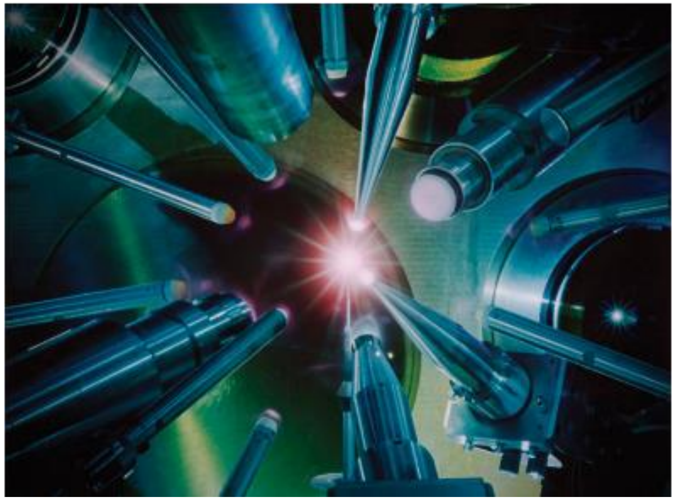
"Cold plasmas"



Magnetic fusion research



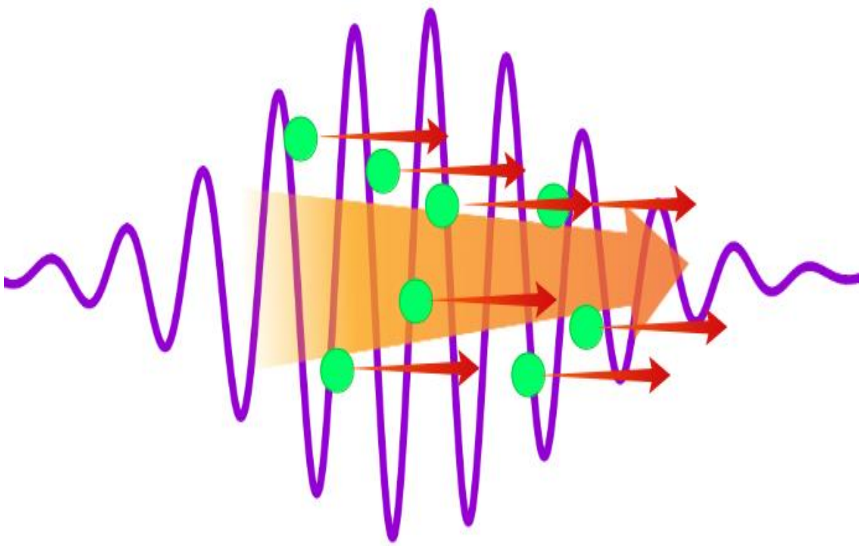
Laser-Plasma interction



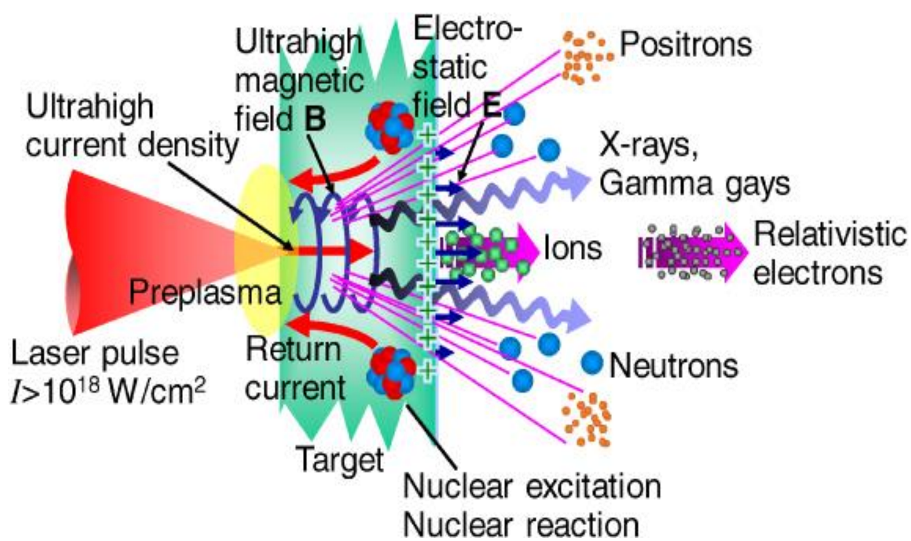
The strength of laser fields:

Laser field vs. "relativistic" field

Relativistic field → $$\frac{m_e \omega c}{e} \cong \frac{3.2\times10^{10}}{\lambda(\mu\mathrm{m})}\,\frac{\mathrm{V}}{\mathrm{cm}} \Rightarrow I \cong \frac{1.4\times10^{18}}{\lambda^2(\mu\mathrm{m})}\,\frac{\mathrm{W}}{\mathrm{cm}^2}$$



Relativistic electron momenta (p ~ mc) in one laser cycle



Hiroyuki Daido and Mamiko Nishiuchi and Alexander S Pirozhkov. Review of laser-driven ion sources and their applications , Reports on Progress in Physics 75(5), 056401 (2012)

The strength of laser fields:

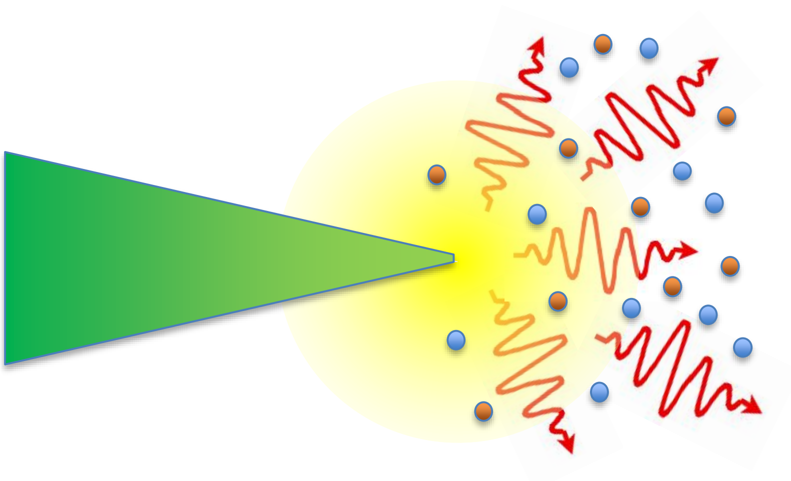
Laser field vs. "Schwinger" field

Schwinger limit

[Vacuum break-down: J. Schwinger, *Phys. Rev.* **82**, 664 (1951)]

$$e E \lambda\!\!\!^{-}_C = 2 m_e c^2 \Rightarrow$$

$$E \approx 2.7 \times 10^{16} \frac{\mathrm{V}}{\mathrm{cm}} \Rightarrow I \approx 10^{30} \frac{\mathrm{W}}{\mathrm{cm}^2}$$

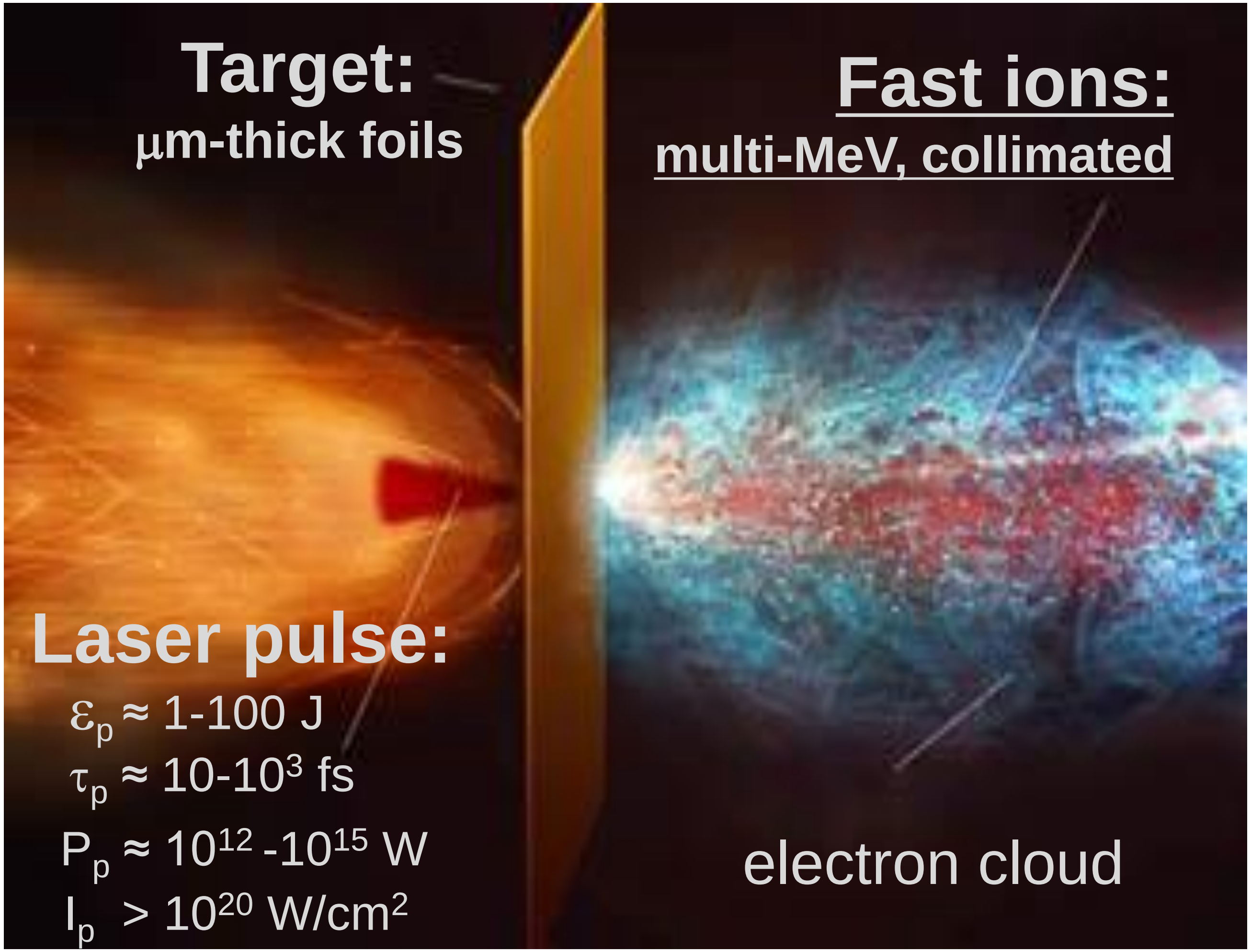


$e^+ e^-$ couples and ϒ photons extracted from the vacuum!

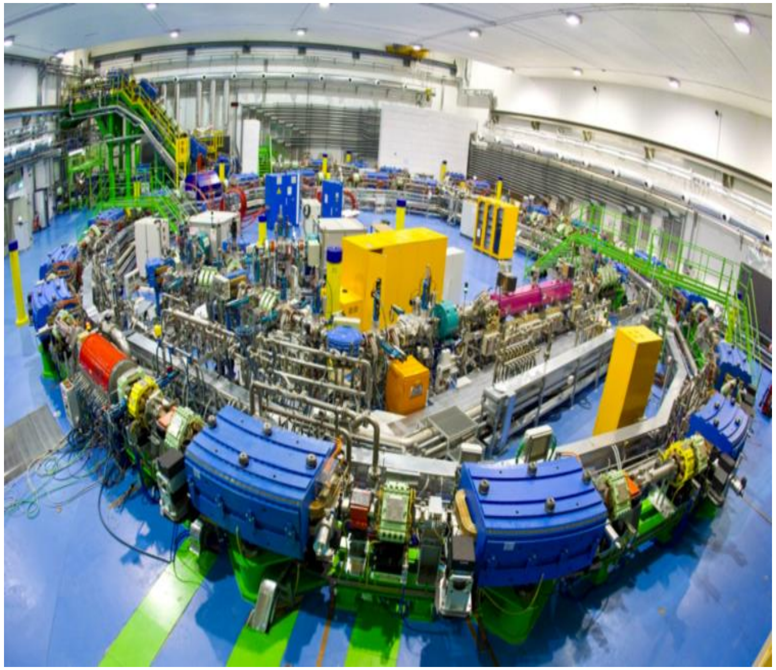
Ultimate intensity limit

Superintense laser-matter interaction

Laser-driven proton acceleration



Conventional ion accelerators:



CNAO Synchrotron (Pavia)

High-energy particle beams crucial for:

- Medicine: radiotherapy, nuclear diagnostics,…
- Material engineering: ion beam analysis, implantation
- Nuclear engineering: Inertial Confinement Fusion,…
- Basic science: particle & high energy physics,…

Laser-driven ion accelerator:

Appealing potential:

- Compactness
- Cost effectiveness
- Flexibility

Critical issues:

- Gain control of the process
- Increase efficiency/performance
- Limitation and cost of lasers

?

Novel targets can be the key!

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ERC-2014-CoG No. 647554

Main goals of ENSURE:

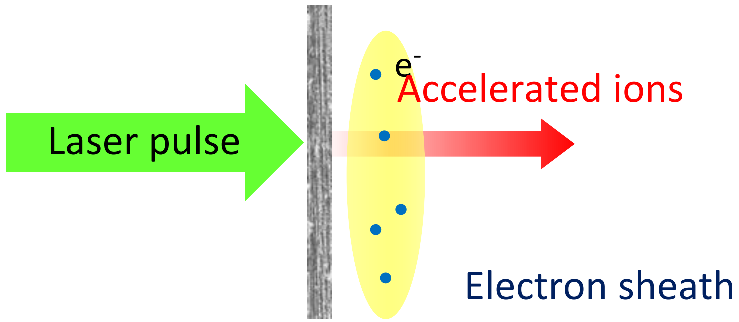
Design and **production of innovative targets** for laser-driven ion acceleration

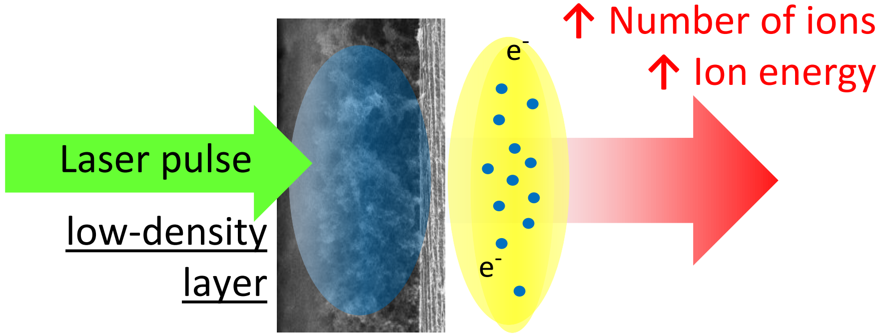
Theoretical investigations of novel laser-driven ion acceleration mechanisms and interaction of laser-generated ions with matter

New **experimental** campaigns of laser-driven **ion acceleration**

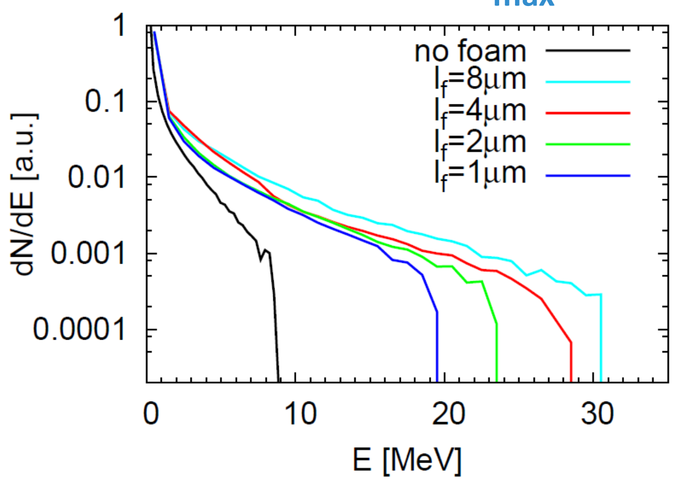
Applications of laser-driven ions for **nuclear** and **materials engineering**

Novel target is key

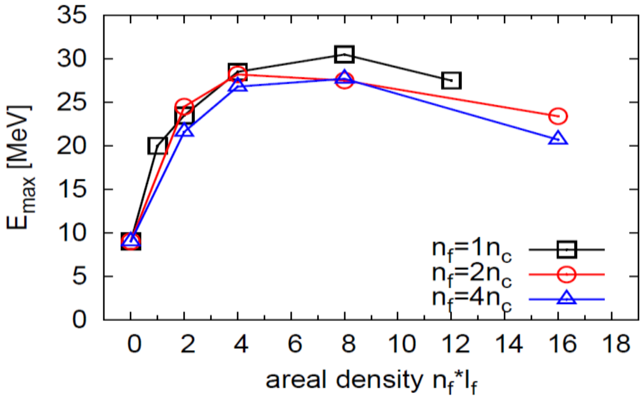




Enhanced E_{max} !



… but foam optimization required

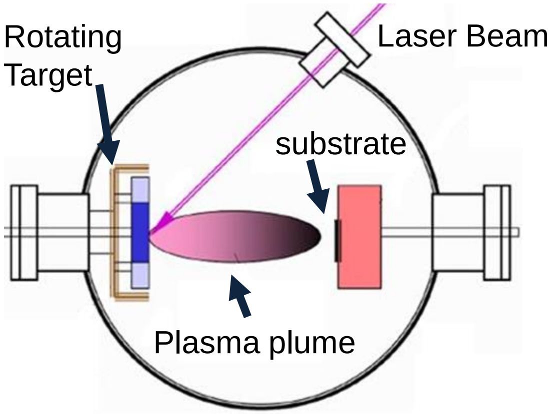


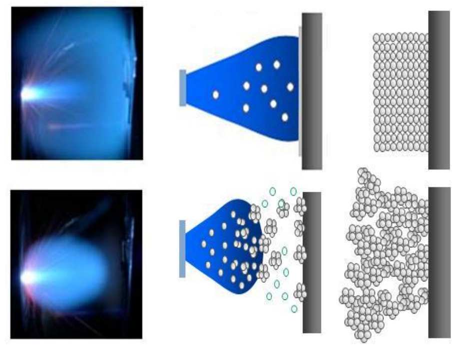
Quite challenging!

- ρ < 10 mg/cm^3 (for $\lambda \approx 1$ μm)
- thickness from 5 to 10s μm

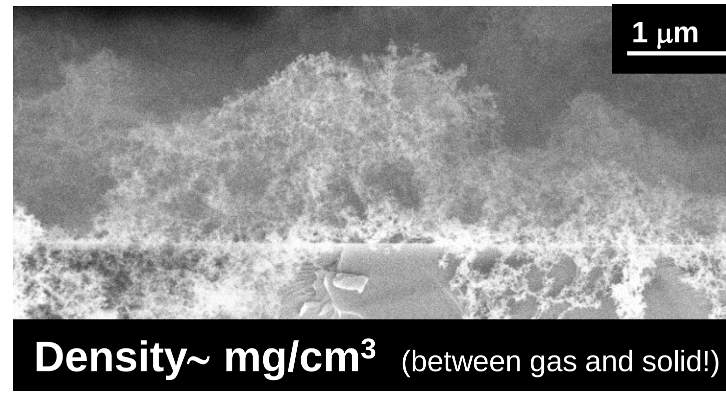
Development of advanced targets

Pulsed Laser Deposition (PLD) of nanostructured targets





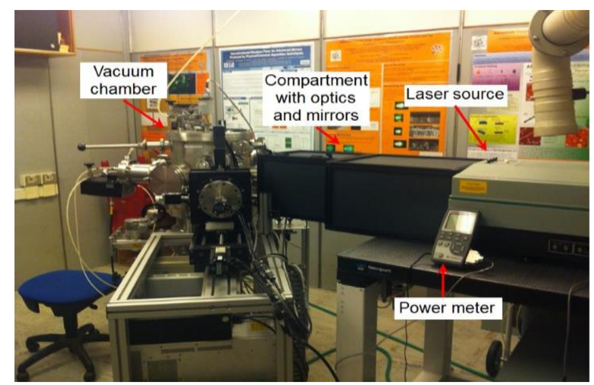
Carbon "foams"



Support from NanoLab facilities and infrastructures:

Two ns-Pulsed laser deposition (PLD) systems
Thermal treatment systems

SEM, STM, AFM microscopy
Raman & Brillouin spectroscopy



New laboratories under development

Today

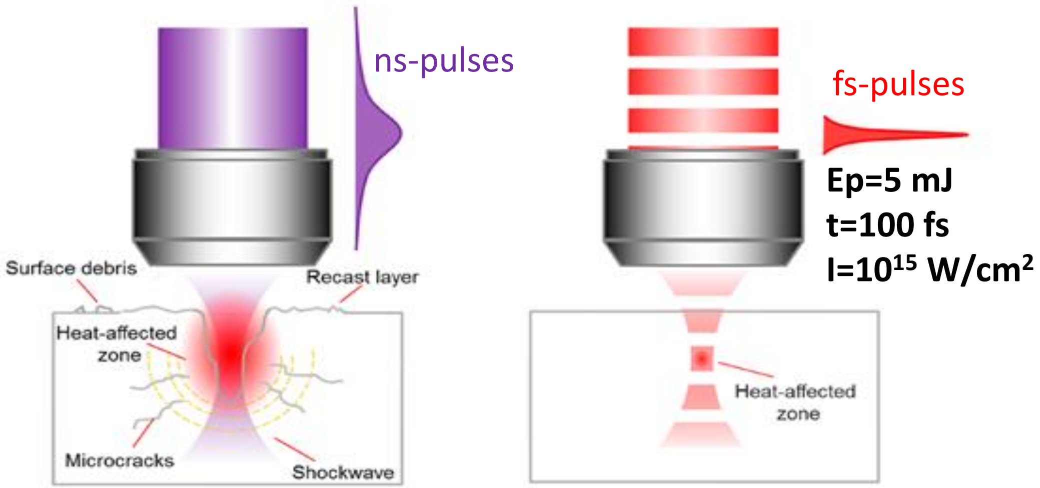
Tomorrow (within 2017)

New techniques to improve capability in **advanced target production**:

- femtosecond PLD
- HiPIMS

HiPIMS

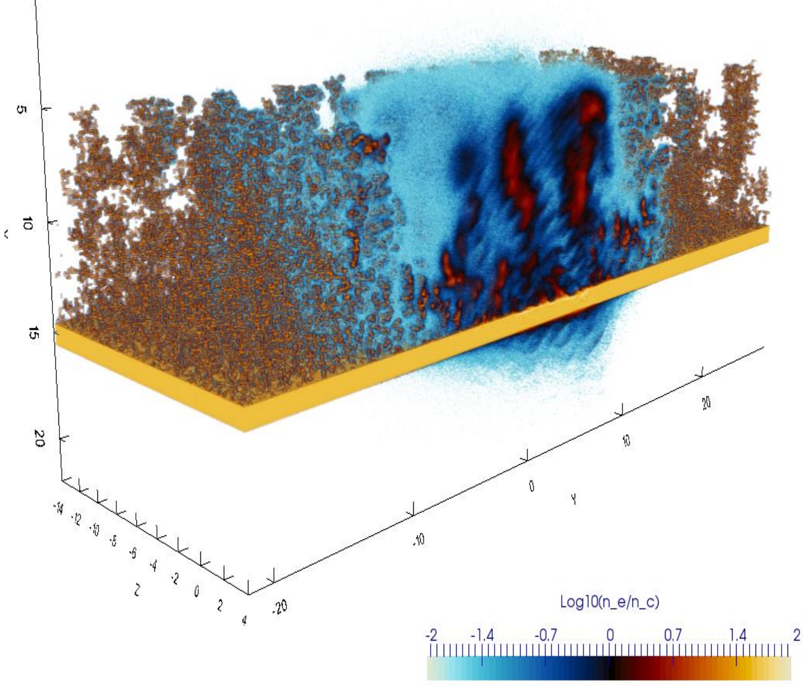
femtosecond PLD



Theoretical/numerical investigation

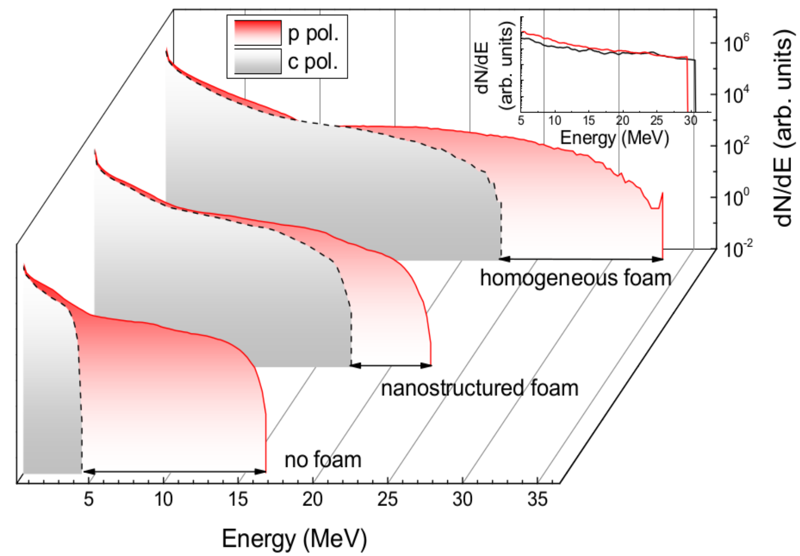
Particle-In-Cell simulations

- Simulation of relativistic laser interaction with nanostructured materials



High Performance computing

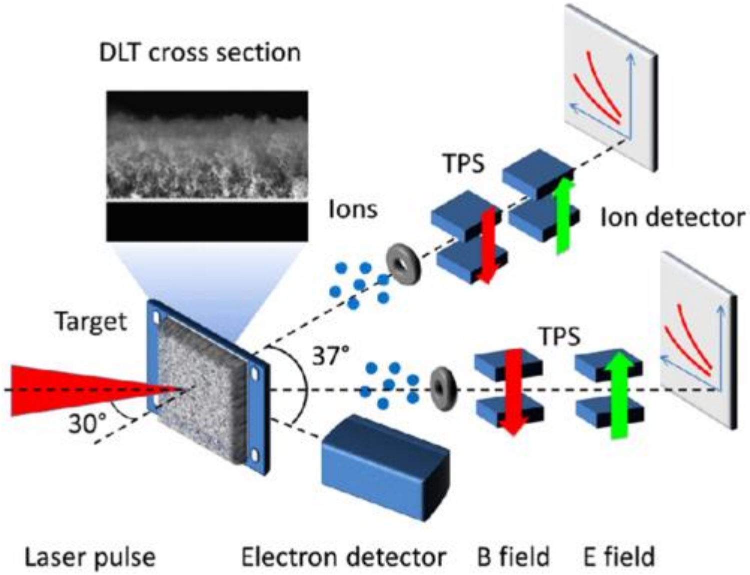
- 2D and 3D simulations are performed on Marconi supercomputer (CINECA, Bologna)



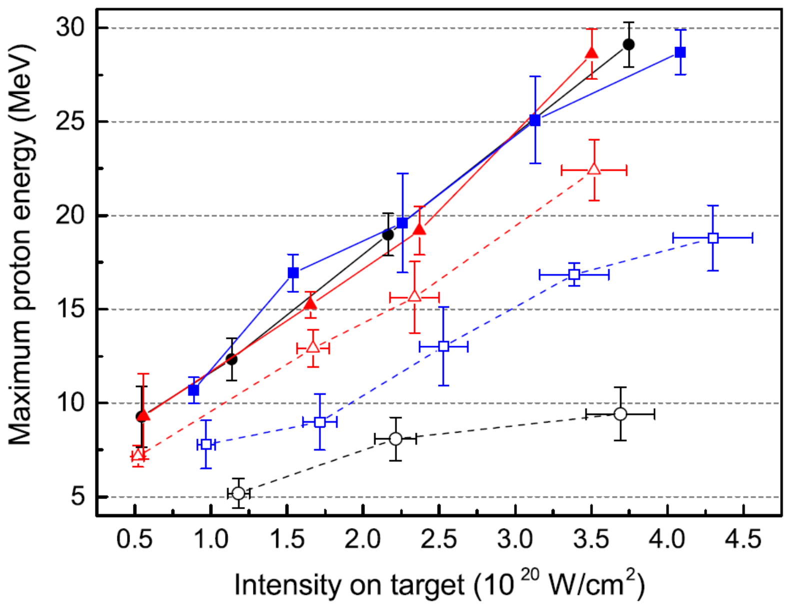
Energy spectra of laser-accelerated protons for linear (P) and circular (C) polarization

Experiments on laser facilities

Setup of an ion acceleration experiment:



Effects of advanced targets:



Ion acceleration experiments:

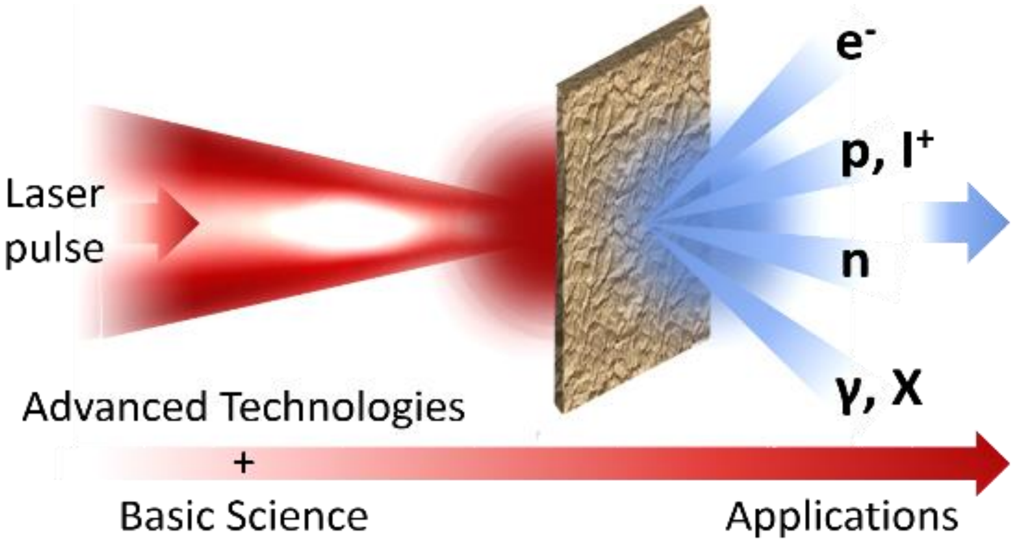
- Performed at **GIST** (Rep. of Korea) in 2015-2016
- to be performed at **HZDR** (Germany) in 2017
- to be performed at **ILE** (Osaka) in 2017

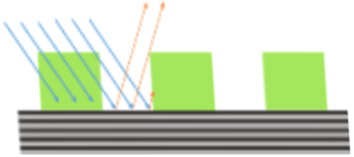
An example of application:

Material characterization & processing

- Ion beam analysis: RBS, NRA, PIXE,…
- Neutron imaging and radiography….

- Ion implantation
- Radiation damaging…





Laser-driven ion beam may *ensure* major advantages!

The INTER project in a nutshell

Innovative **N**eutron source for non destructive **TE**sting and t**R**eatments

18 months project: Foreseen starting date May 2017

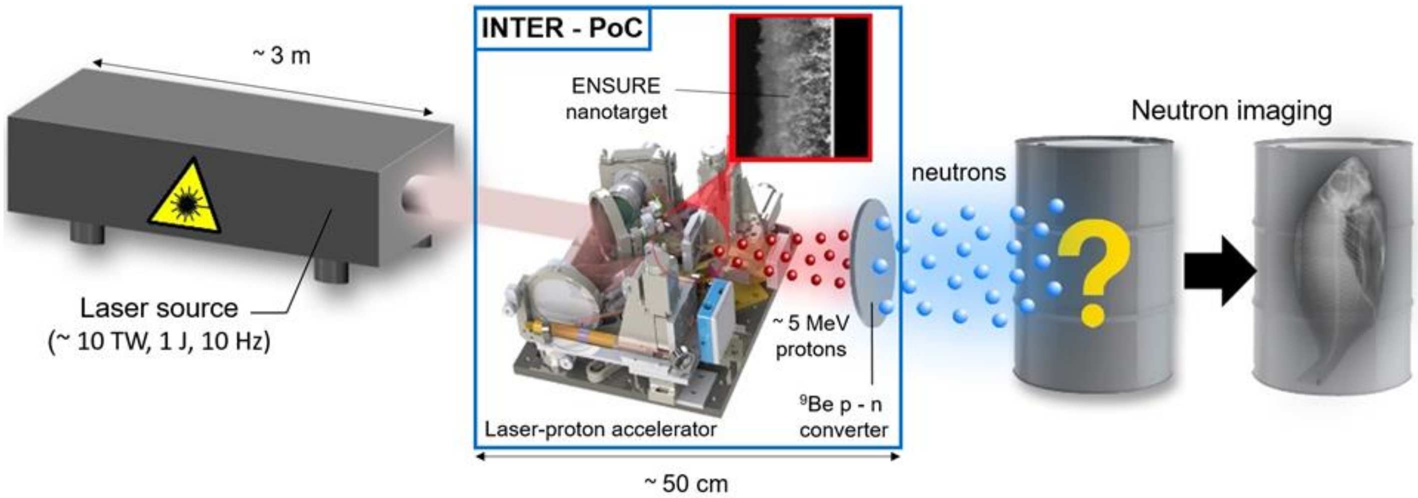
Fields of interest: Laser-matter interaction, material science, neutron imaging and diagnostics, physics for cultural heritage

Main goal: Development of a **compact accelerator module** for the generation of an innovative **portable laser-driven neutron source**

Partners: Industrial partners strongly involved SourceLAB

The INTER concept:

Towards a portable neutron source



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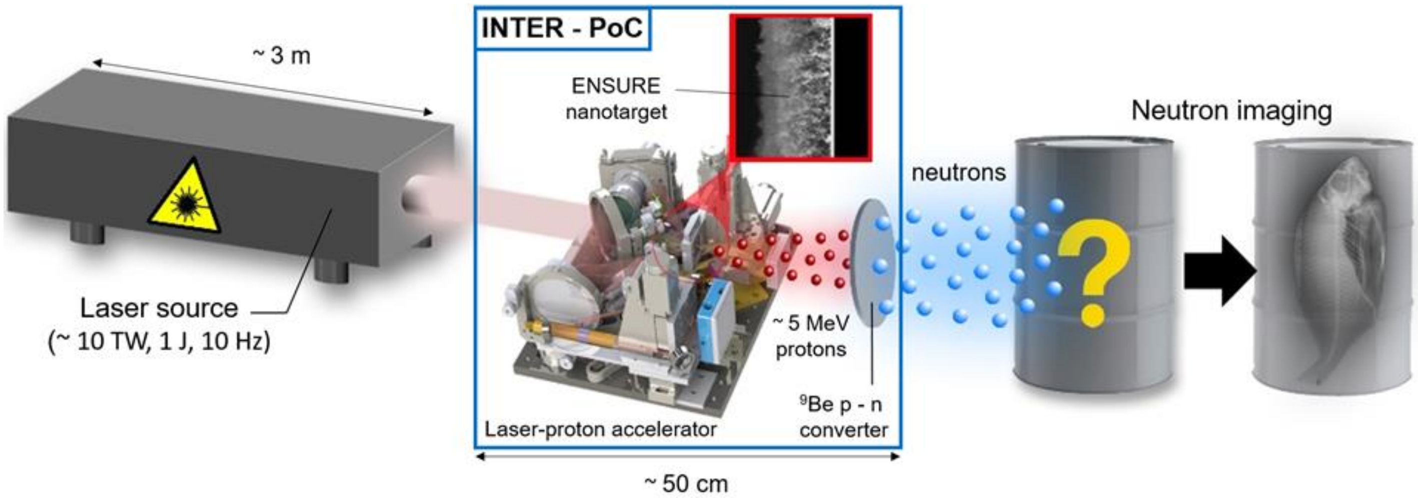
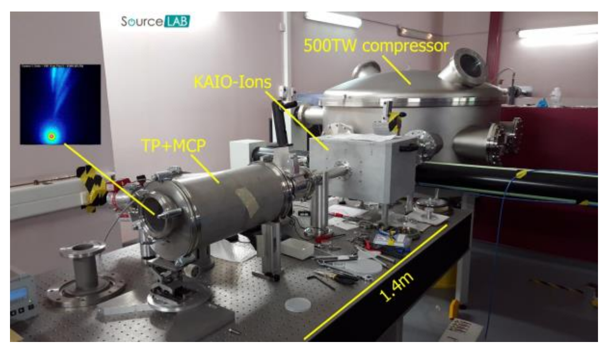
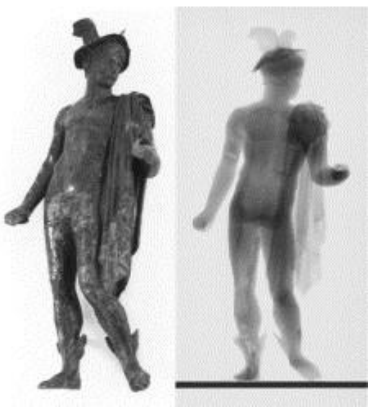


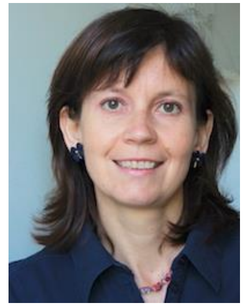




E. H. Lehmann et al. NIMA A 542(1-3), 68-75(2005)

The ENSURE team:

Matteo Passoni
Associate professor,
Principal investigator



Margherita Zavelani Rossi
Associate professor

Valeria Russo
Researcher

David Dellasega
Post-doc

Alessandro Maffini
Post-doc

Luca Fedeli
Post-doc

3 PhD students

Lorenzo

Arianna

Andrea

1 Master's student

Francesco

Thanks for your attention!

ENSURE

Exploring the **N**ew **S**cience and engineering unveiled by **U**ltraintense ultrashort **R**adiation interaction with matt**E**r

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