Introduction I: ELIMAIA

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3rd ELIMED Workshop, Catania, 7-9 September 2016

3rd ELIMED Workshop: MEDical and multidisciplinary applications of laser-driven ion beams at ELI-Beamlines

- **Non-conventional Ion Acceleration Techniques** (Wednesday, 10:05-12:55)
- **New generation Ion Acceleration Beamlines** (Wednesday, 14:15-19:00)
- **Radiation Biology and Medical Applications** (Thursday, 09:00-12:30)
- **Multidisciplinary Applications** (Thursday, 13:30-17:55)
- **Targetry, Diagnostics and Dosimetry** (Friday, 09:00-15:50)
- Round Table discussion (Friday, 15.50-16.50)

Fyzikální ústav Akademie věd ČR, v. v. i.
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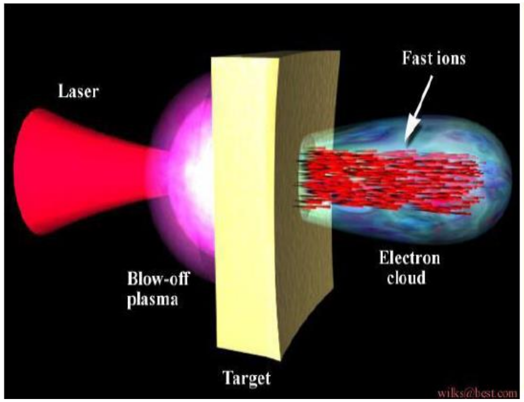
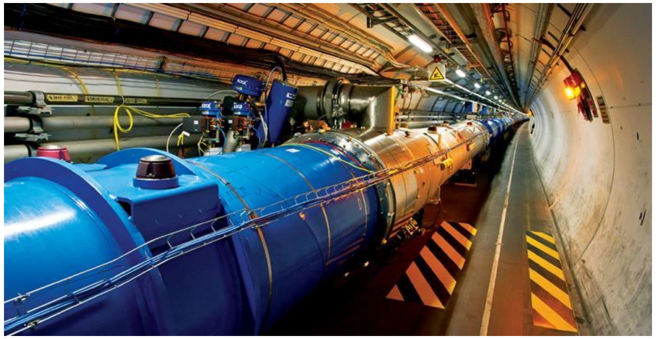
EVROPSKÁ UNIE
MINISTERSTVO ŠKOLSTVÍ MLÁDEŽE A TĚLOVÝCHOVY
OP Vzdělávání pro konkurenceschopnost
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ
OP Výzkum a vývoj pro inovace

«Macroscopic» motivation

Laser Plasma Accelerator (laser + thin foil)



LHC @ CERN: circular tunnel (<u>27 km long</u>); supercond. electromagnets; E-field$_{MAX}$ ~10s MV/m (breakdown)

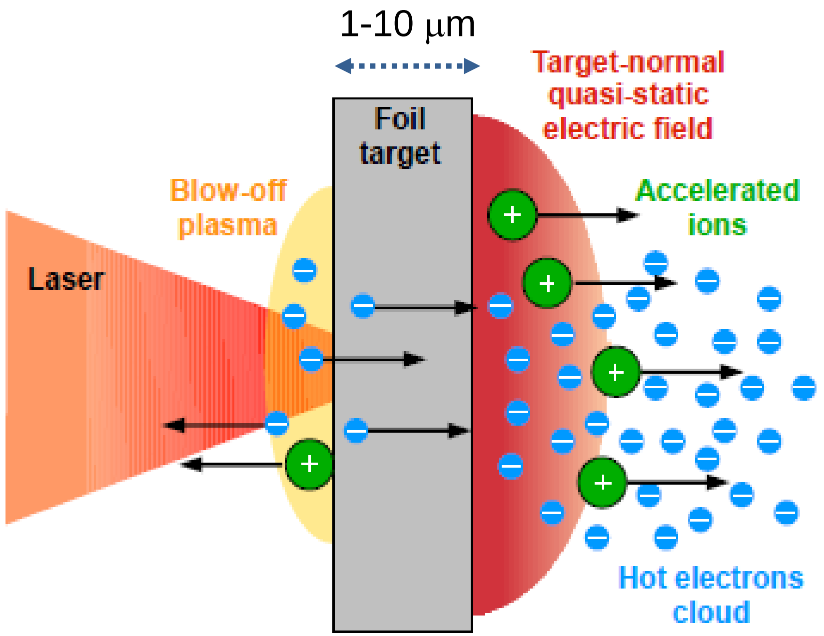


- **Acc. Length** ⟶ $\lambda_D = 2.4\mu m \cdot \sqrt{\frac{T_{hot}}{1MeV}} \cdot \sqrt{\frac{10^{19}\,cm^{-3}}{N_{hot}}}$ ⟶ **few μm!**
- **Acc. time** ⟹ $\tau = \sqrt{\frac{\lambda_D^2 m_{ion}}{T_{hot}}} = 0.24ps\sqrt{\frac{\lambda_D^2 n_{hot}}{10^{19}}}$ ⟹ **few ps!**
- **Acc. Field** ⟹ $\tau = \frac{T_{hot}}{e\lambda_D} \approx \frac{MV}{\mu m}$ ⟹ **<u>tens of TV/m!</u>**

<u>10s MeV in a few μm!</u> (no breakdown limit in plasma)

Laser-driven ion «beams»

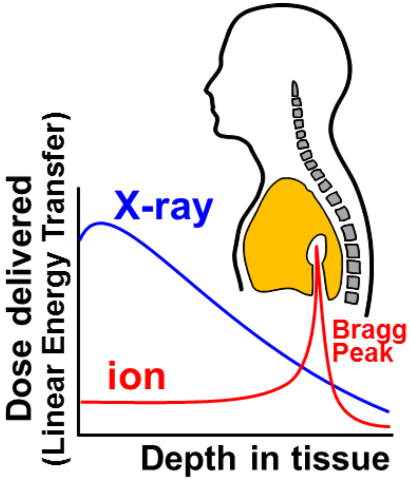
TNSA (Target Normal Sheath Acceleration)



- Large proton number: $\mathbf{10^{10} \div 10^{13}}$
- Short bunch duration: few **ps**
- Very high Beam Currents: few **kA**
- Low emittance: ε ~ **5 ·10^{-3} π mm mrad** (RF LINAC: ε ~ 0.5 π mm mrad)
- High Beam Divergence: **10-20°**
- High energy spread: **ΔE/E >>10%**
- Low shot-to-shot reproducibility

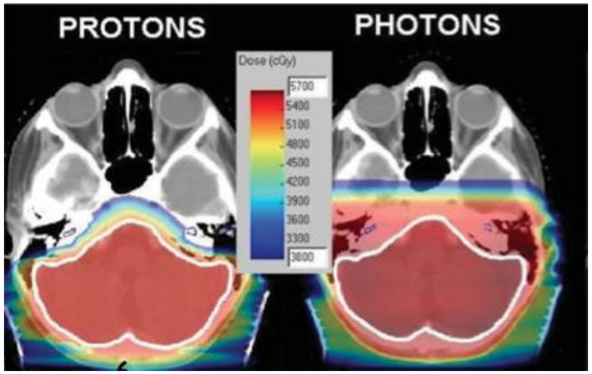
Snavely et al., PRL 85 (2000) 2945 → 60 MeV
*Wagner et al., PRL 116 (2016) 205002 → **85 MeV***

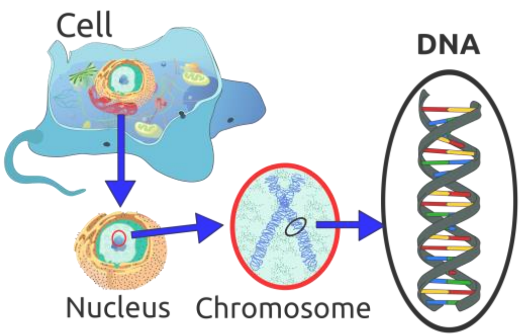
«Societal» motivation: hadrontherapy



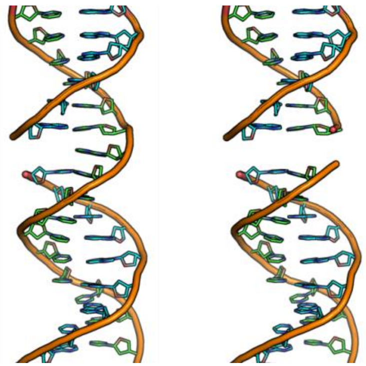
Physical advantage

Protons/ions allow precise tumor irradiation minimizing doses to healthy tissues





photons protons



Biological advantage

Density of secondary electrons is higher for charged radiation and it enhances DNA <u>double strand break</u>

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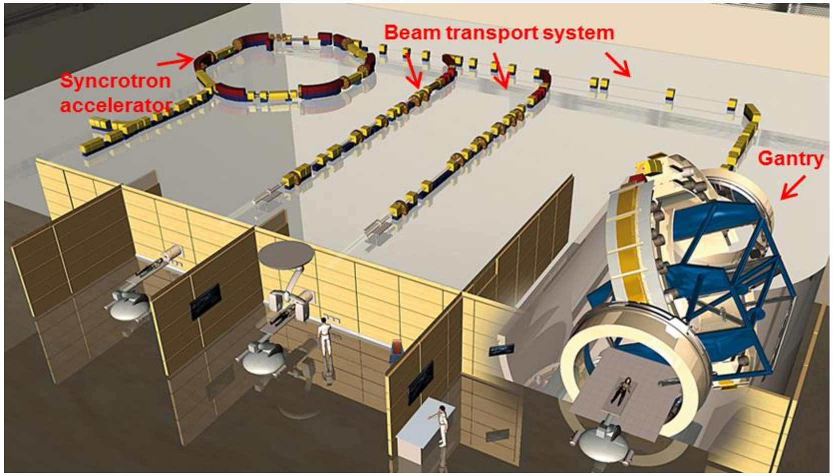
Laser-driven hadrontherapy

Conventional hadrontherapy facilities:

- ***High complexity for the beam, acceleration, transport and delivery***
- ***High cost***

http://newscenter.lbl.gov/2010/10/18/ion-beam-therapy/

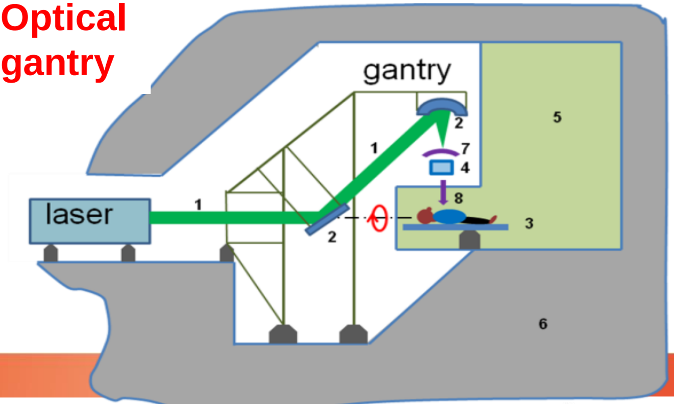


Laser-based hadrontherapy facilities:

- ***Compactness*** (hospital-room size)
- ***Cost-reduction*** (optical gantry)
- ***Innovative treatment modalities:***
  - Variable energies in the accelerator (no degraders needed)
  - Hybrid treatment (protons, ions, electrons, gamma-rays, neutrons)
  - In-situ diagnostics (PET, X-rays)
  - Low emittance: normal-tissue sparing?
  - High fluence rate (ultrashort pulses): higher RBE???

Bulanov & Khoroshkov, Plasma Phys. Rep. (2002)

Optical gantry



Cell irradiation experiments with laser-driven protons

- *Yogo et al, Appl. Phys. Lett., (2009)*
- *Kraft, et al. NJP (2010)*
- *Doria et al., AIP Advances (2012)*
- *Bin, App. Phys. Lett (2012)*

Applications of Laser-driven Protons

Application field	Energy range	Bibliography
Time-resolved Proton Radiography of dense materials	>3 MeV	*Borghesi et al., PPCF (2001)*
Pump-probe investigations (WDM,…)	>1 MeV	*Patel et al., PRL (2003)*
ICF fast ignition with proton beam	10-30 MeV	*Roth et al., PRL (2001)*
Pitcher-catcher nuclear reactions (neutrons, alphas,…)	≥1 MeV	*McKenna PRL (2005)*
Innovative approaches to hadrontherapy	60-300 MeV	*Bulanov, Khoroshkov, PPR (2002); Bulanov et al, UFN (2014)*
Radiobiology with short ion bunches (0.1-10 ns)	3-300 MeV	*Yogo et al, APL (2009) Kraft, et al. NJP (2010)*
Radiation chemistry – pulsed radiolysis of water (radiobiology, nuclear power plant industry)	10-20 MeV	*Baldacchino, RPC (2008)*
Radio-isotopes for positron emission tomography (PET)	~30 MeV	*Spencer et al., NIMB (2001)*
Space Radiation for testing space-grade electronics (protons, electrons, X-rays)	>1 MeV	*Hidding et al., NIMA (2011)*
PIXE analysis for cultural heritage	>3 MeV	*Pappalardo et al., NIMB (2008)*
…………………………………………………………………		

«Ion Accelerator» User requirements

Typical user requirements

- Wide **energy** and **fluence** range
- Small energy spread (**quasi-monoenergetic** beams)
- **Homogeneous** transverse beam distribution
- Shot-to-shot **stability** (energy and fluence)
- Variable beam spot size
- Full beam **control** (fluence and dose) with < 5% error
- Possibility of **in-air irradiation** (e.g. bio-samples)
- Use of **different ion species** (H, He, Li, C)

What the users get

Ion Beam Features (PW)	Enabling Experiments	Flagship Experiments
Energy range	3-60 MeV/u	3-300 MeV/u
Ion No./laser shot	$>10^9$ (0.1 nC) in 10% BW	$>10^{10}$ (1 nC) in 10% BW
Bunch duration	1-10 ns	0.1-10 ns
Energy spread	±5%	±2.5%
Divergence	±0.5°	± 0.2°
Ion Spot Size	0.1-10 mm	0.1-10 mm
Repetition rate	0.01-1 Hz	0.01-10 Hz

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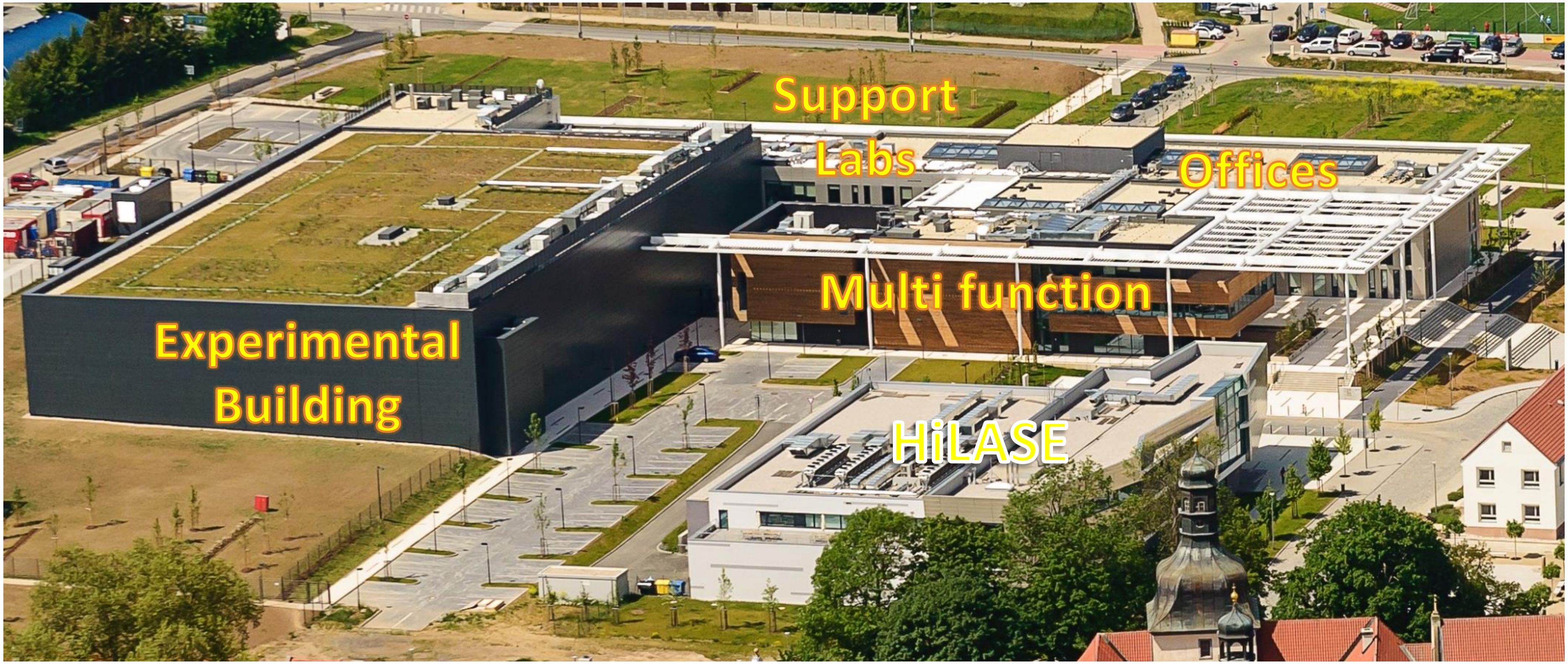
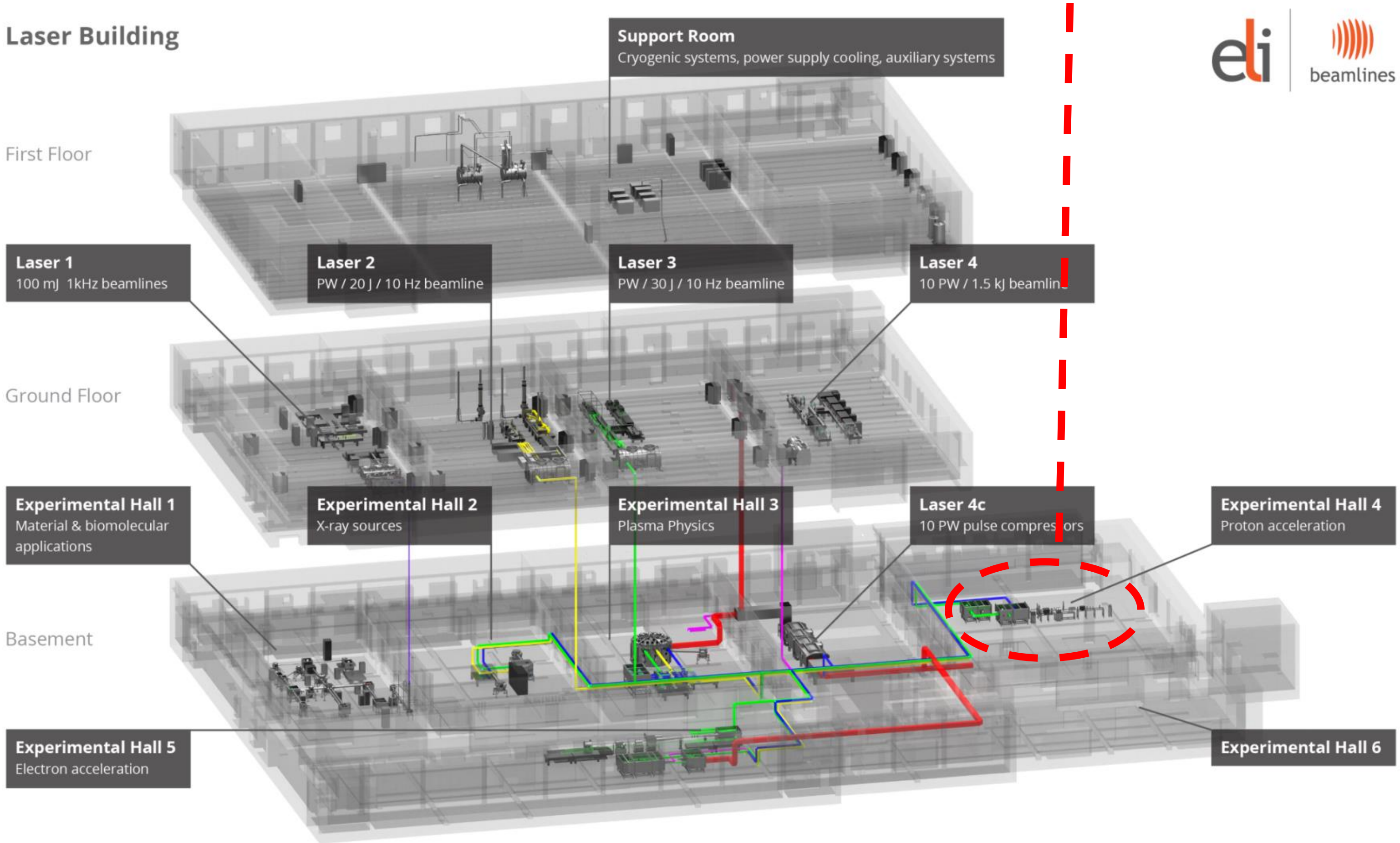
ELI-Beamlines aerial view

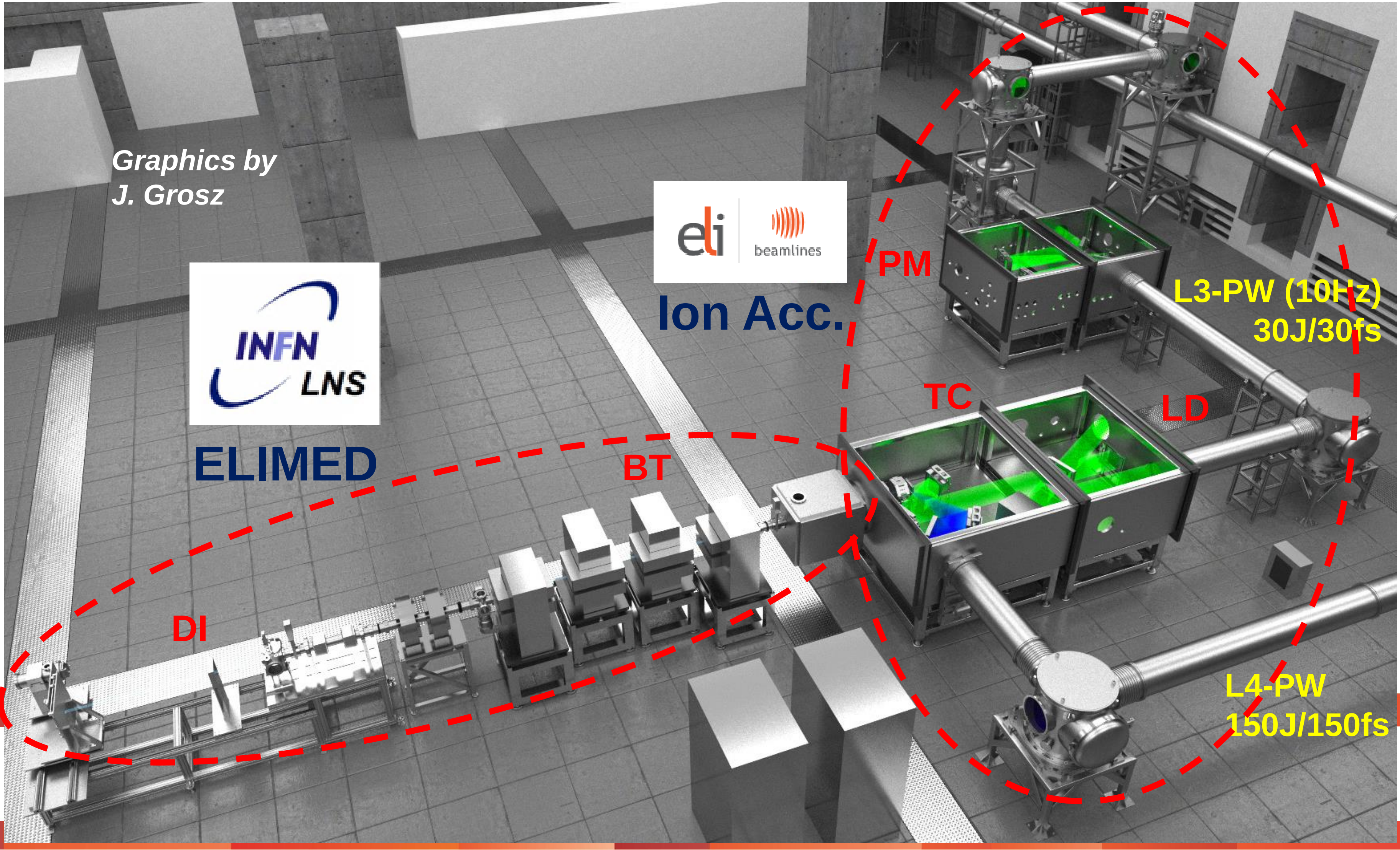


Ion Acceleration Beamline

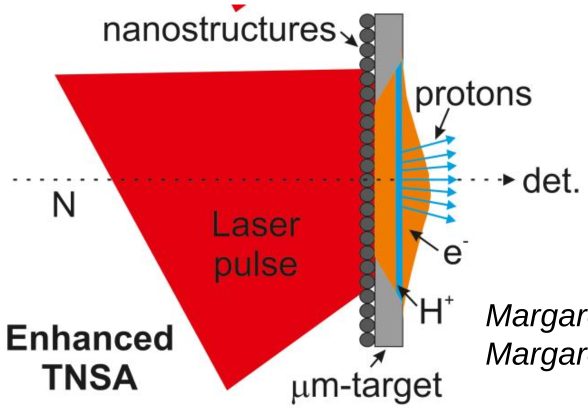


ELIMAIA: a user beamline

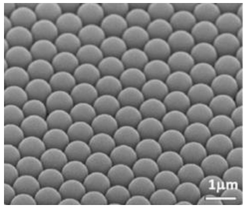
ELI Multidisciplinary Applications of laser-Ion Acceleration

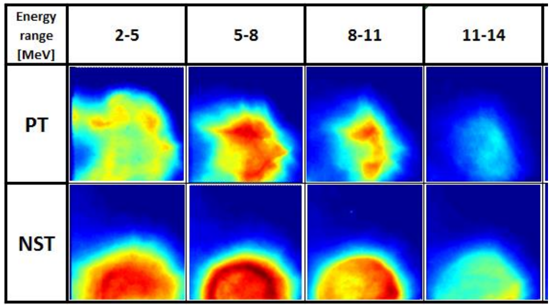


Advanced Targetry



0.4 µm spheres

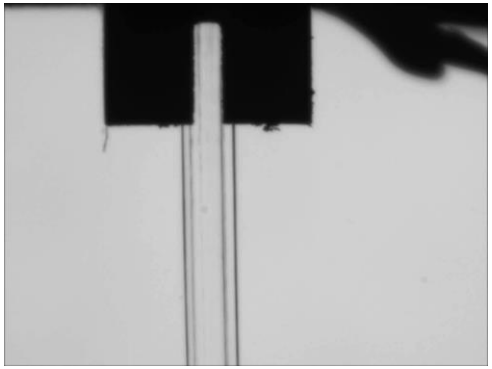




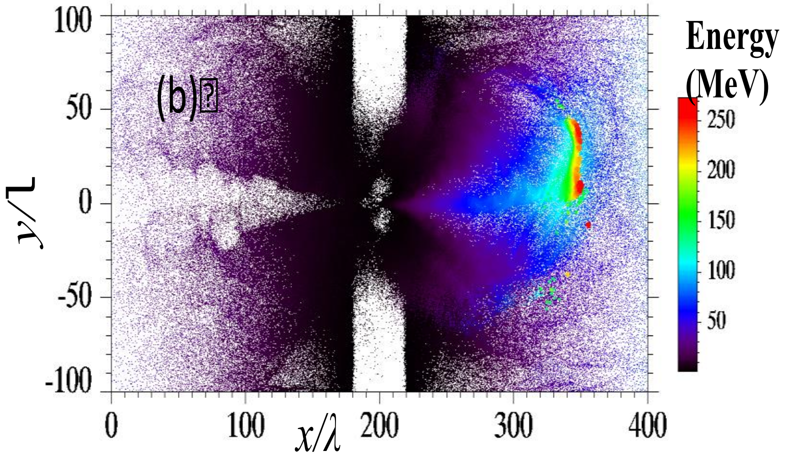
Margarone et al PRL (2012)
Margarone et al PRSTAB (2015)

- ***L. Giuffrida's talk***
- ***J.P. Perin's talk***
- ***A. Velyhan's talk***

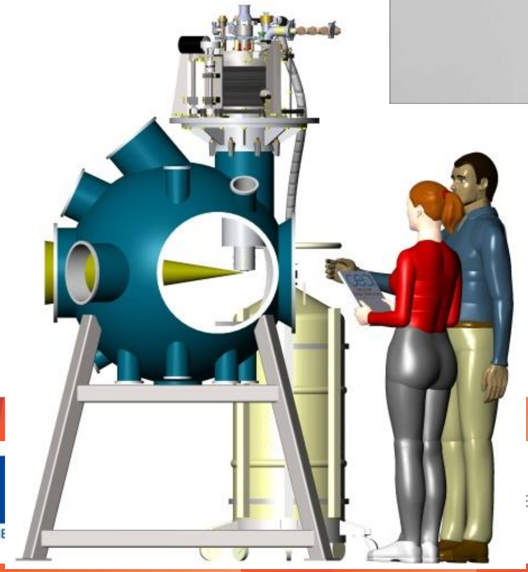
Solid H-ribbon



Courtesy of T. Esirkepov



Margarone et al PRX (submitted)



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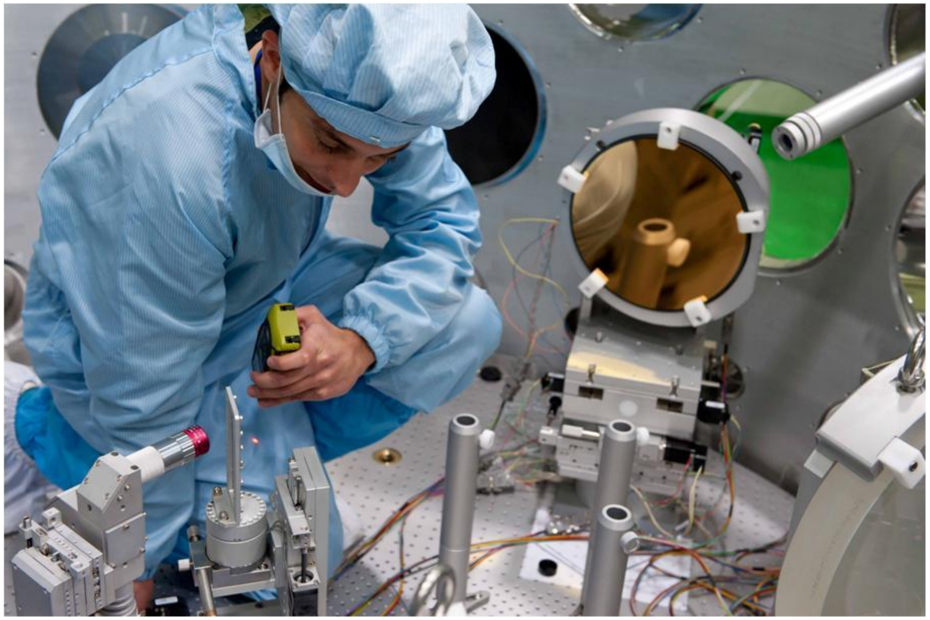
THANK YOU AND HAVE FUN!

(...AND BE ACTIVE!)



http://www.eli-beams.eu/

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