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)
Laser Plasma Accelerator (laser + thin foil)

LHC @ CERN: circular tunnel (27 km long); supercond. electromagnets; E-field_{MAX} \sim 10s MV/m (breakdown)

- Acc. Length ➔ \lambda_D = 2.4\,\mu m \cdot \frac{T_{hot}}{1\,MeV} \cdot \sqrt{10^{19}\,cm^{-3}} \rightarrow \text{few } \mu m!
- Acc. time ➔ \tau = \sqrt{\frac{\lambda_D^2 m_{ion}}{T_{hot}}} = 0.24\,ps \cdot \sqrt{\frac{\lambda_D^2 n_{hot}}{10^{19}}} \rightarrow \text{few ps!}
- Acc. Field ➔ \tau = \frac{T_{hot}}{e\lambda_D} \approx \frac{MV}{\mu m} \rightarrow \text{tens of TV/m!}

10s MeV in a few \mu m! (no breakdown limit in plasma)
Laser-driven ion «beams»

TNSA (Target Normal Sheath Acceleration)

- Large proton number: $10^{10} \div 10^{13}$
- Short bunch duration: few ps
- Very high Beam Currents: few kA
- Low emittance: $\varepsilon \sim 5 \cdot 10^{-3} \pi \text{ mm mrad}$
  (RF LINAC: $\varepsilon \sim 0.5 \pi \text{ mm mrad}$)
- High Beam Divergence: 10-20°
- High energy spread: $\Delta E/E >> 10\%$
- Low shot-to-shot reproducibility

Snavely et al., PRL 85 (2000) 2945 $\rightarrow$ 60 MeV
Wagner et al., PRL 116 (2016) 205002 $\rightarrow$ 85 MeV
«Societal» motivation: hadrontherapy

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

Biological advantage
Density of secondary electrons is higher for charged radiation and it enhances DNA double strand break
Conventional hadrontherapy facilities:
- High complexity for the beam, acceleration, transport and delivery
- High cost

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???

Cell irradiation experiments with laser-driven protons
- Doria et al., AIP Advances (2012)
## Applications of Laser-driven Protons

<table>
<thead>
<tr>
<th>Application field</th>
<th>Energy range</th>
<th>Bibliography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time-resolved Proton Radiography of dense materials</td>
<td>&gt;3 MeV</td>
<td>Borghesi et al., PPCF (2001)</td>
</tr>
<tr>
<td>ICF fast ignition with proton beam</td>
<td>10-30 MeV</td>
<td>Roth et al., PRL (2001)</td>
</tr>
<tr>
<td>Pitcher-catcher nuclear reactions <em>(neutrons, alphas,...)</em></td>
<td>≥1 MeV</td>
<td>McKenna PRL (2005)</td>
</tr>
<tr>
<td>Innovative approaches to hadrontherapy</td>
<td>60-300 MeV</td>
<td>Bulanov, Khoroshkov, PPR (2002); Bulanov et al, UFN (2014)</td>
</tr>
<tr>
<td>Radiation chemistry – pulsed radiolysis of water <em>(radiobiology, nuclear power plant industry)</em></td>
<td>10-20 MeV</td>
<td>Baldacchino, RPC (2008)</td>
</tr>
<tr>
<td>Radio-isotopes for positron emission tomography <em>(PET)</em></td>
<td>~30 MeV</td>
<td>Spencer et al., NIMB (2001)</td>
</tr>
<tr>
<td>Space Radiation for testing space-grade electronics <em>(protons, electrons, X-rays)</em></td>
<td>&gt;1 MeV</td>
<td>Hidding et al., NIMA (2011)</td>
</tr>
<tr>
<td>PIXE analysis for cultural heritage</td>
<td>&gt;3 MeV</td>
<td>Pappalardo et al., NIMB (2008)</td>
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</table>
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

<table>
<thead>
<tr>
<th>Ion Beam Features (PW)</th>
<th>Enabling Experiments</th>
<th>Flagship Experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range</td>
<td>3-60 MeV/u</td>
<td>3-300 MeV/u</td>
</tr>
<tr>
<td>Ion No./laser shot</td>
<td>&gt;10^9 (0.1 nC) in 10% BW</td>
<td>&gt;10^10 (1 nC) in 10% BW</td>
</tr>
<tr>
<td>Bunch duration</td>
<td>1-10 ns</td>
<td>0.1-10 ns</td>
</tr>
<tr>
<td>Energy spread</td>
<td>±5%</td>
<td>±2.5%</td>
</tr>
<tr>
<td>Divergence</td>
<td>±0.5°</td>
<td>±0.2°</td>
</tr>
<tr>
<td>Ion Spot Size</td>
<td>0.1-10 mm</td>
<td>0.1-10 mm</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>0.01-1 Hz</td>
<td>0.01-10 Hz</td>
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ELI-Beamlines aerial view
Ion Acceleration Beamline

Laser Building

First Floor

Laser 1
100 mJ, 1kHz beamlines

Laser 2
PW / 20 J / 10 Hz beamline

Laser 3
PW / 30 J / 10 Hz beamline

Laser 4
10 PW / 1.5 kJ beamline

Support Room
Cryogenic systems, power supply cooling, auxiliary systems

Ground Floor

Experimental Hall 1
Material & biomolecular applications

Experimental Hall 2
X-ray sources

Experimental Hall 3
Plasma Physics

Experimental Hall 4c
10 PW pulse compressors

Proton acceleration

Basement

Experimental Hall 5
Electron acceleration

Experimental Hall 6

Fyzikální ústav
Akademie věd ČR, v.v.i.
ELIMAIA: a user beamline

ELI Multidisciplinary Applications of laser-Ion Acceleration

Graphics by J. Grosz
Advanced Targetry

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

0.4 μm spheres

Energy range (MeV):
- 2-5
- 5-8
- 8-11
- 11-14

PT
NST

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)

Fyzikální ústav
Akademie věd ČR, v. v. i.
THANK YOU AND HAVE FUN!
(...AND BE ACTIVE!)

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