Nuova Proposta
L3IA

Line for Laser Light Ion Acceleration

Milano, Pisa, LNS, Bologna, LNF, Napoli
Target Normal Sheath Acceleration

*Laser-foil interactions creates huge currents of relativistic electrons propagating in the solid and giving rise to intense X-ray emission and, ultimately, ion emission from the rear surface of the foil.*

Acceleration of the target ions driven by the field created by fast electrons

Laser driven ion acceleration

- High gradient acceleration: $\text{MeV}\mu\text{m}^{-1}$, compared with $\sim\text{MeV m}^{-1}$ provided by radio frequency (RF) based accelerators;

- Ultra-short duration at the source of the ion bunch of the order of picoseconds;

- Very small effective source size: $\approx 10$ $\mu\text{m}$;

- Highly laminarity and very low emittance;

- Broad energy spectrum

- High charge: $10^8$-$10^9$ particles

Macchi, Passoni, Borghesi, RMP, 85,751 (2013)
Current effort

• **New acceleration mechanisms** at ultrahigh intensity
  – Radiation pressure acceleration
  – Collisionless shock acceleration

• **Target engineering**: surface, geometry, conductivity

• **Post acceleration**: selection, collimation, injection

• **Dosimetry and radiobiology**: fast (ps) ion source
Previous activity (CSN5)

- **LILIA** – Laser Induced Light Ion acceleration R&D and first preliminary experiments at Flame; Completed 2013

- **PlasmaMeD** - Proton LAser-drive beam transport, diagnostic and Multidisciplinary Applications Ends 2015
Recent progress (2013-14)

• Dedicated experimental chamber for ion acceleration commissioned 2014 (Pisa, ILIL laser);
• Ion acceleration runs started Oct. 2014 with existing laser parameters (10 TW);
• Successful collaboration Pisa, Milano, LNF, Bologna;
Since October 2014 a new experimental chamber “Pavone” is operational for laser-solid interaction, dedicated to:
1. TNSA acceleration of light ions;
2. Fast electron transport;
3. Shock generation in nanoengineered target;
4. X-ray generation and applications

A separate target chamber is dedicated to laser-gas interaction for:
1. electron acceleration with self injection,
2. radiobiology applications
3. γ-ray generation (Thomson scattering and bremsstrahlung) and
Proton Acceleration - TNSA

Macchi, Passoni, Borghesi, RMP, 85, 751 (2013)
Proton Acceleration
Our proposal indeed aims at establishing outstanding beam-line operation of a laser-plasma source in Italy taking advantage of the results achieved so far in this field by our collaboration through joint experimental campaigns and numerical modeling.

The proposal is based upon four main pillars, including:

- a primary “home” laser facility
- a deep knowledge and expertise on beam drive components to allow compact scheme for future accelerators
- a range of tools for numerical predictive modeling
- access to external leading facilities within collaborative/competitive schemes.
The Pisa-ILIL facility, as previously discussed, currently features a high power, Ti:Sa laser system capable of 10+TW main pulse (0.5 J on target) in a pulse duration of <40 fs. Also available at the lab are two fully equipped experimental chambers for laser-plasma acceleration.

The Lab is undergoing a major upgrade (already funded by Italian National Council of Research – CNR in the framework of a 4 years project) which includes an additional power amplifier and a new, fully shielded target area for high energy protons and electrons beams applications. The new amplifier, which relies on 4 additional main laser pumps, with full pumping up to 24 J, is capable of up to 250 TW peak power (7 J per pulse) in a 25 fs pulse duration.

The time scale of the upgrade is as follows:

- Summer 2016: 100 TW laser power (estimated proton energy 8 MeV)
- December 2016: 150 TW laser power (estimated proton energy 10 MeV)
- Spring 2018: 250 TW laser power (estimated proton energy 14 MeV).

The first version of the shielded area has been already designed (see figure below) and the project has been submitted along with the CNR appointed Radiation Protection Officer for the final approval expected by mid 2016. In the last meeting held on May 29 2015 at the Ministry in Rome, the status of the approval procedure is well in schedule.

The value of the existing facility may be estimate in nearly 1.5 MEuro, while the laser plant up to the final power of 250 TW may be estimated in nearly 2.5 MEuro.
Light ion acceleration

Macchi, Passoni, Borghesi, RMP, 85,751 (2013)
L3IA PROPOSAL

In addition to that, the proposed programme includes a number of technological developments that will bring added value to the wider community. They may be summarized as below:

- the development of a first prototype version of a plasma mirror that may be installed on the ILIL laser line to improve the pulse contrast of a factor of 100-1000, thus allowing to use very thin targets with the possibility to have more energy in the emitted proton beam and more stable operations;
- the implementation of a short focal length off-axis parabolic mirror in conjunction with an adaptive optics loop for wavefront correction and Strehl ratio maximization;
- the development of a dedicated test chamber for beam formation and transport tests up to 15 MeV proton beams, with a fixed scheme to allow the switch-off of unwanted generated and co-propagating electron beams (high and low energy) and for the deflection of the proton beam from the straight line of emission;
- the development of focusing schemes for the emitted beams based upon static and pulsed magnetic fields;
- the development and test of dedicated detectors for these kind of short pulse beams;
- the development of more stable target schemes with sophisticated designs as a result of numerical predictive analysis.
L3IA PROPOSAL

• L3IA is a proposal to allow the INFN community to gain a role in the European scenario of laser-plasma sources
• L3IA **NOW** will take advantage of the collaborations and synergies with other European Labs
• L3IA will produce valuable results in a very short time (2016 !) taking advantage of the opportunity offered by a unique collaboration between all the subjects that worked in the area in the past 5 years
• L3IA will play a unique rule as a test bench for the components that INFN will provide to ELI (contract signed in 2014)
• L3IA will use an existing, advanced (and in the process of development) laser facility at ILIL-PISA (we will provide a support of nearly 30 Keuro/year for disposal materials)
• L3IA elements (plasma mirrors, focusing parabola, experimental chamber, pulsed solenoid, diagnostic elements, laser characterization instruments) will be elements suitable for future re-use in other INFN plasma-sources in Italy
L3IA PROPOSAL

L3IA is organized in the following Work Packages (WP), identifying six strategic branches of the project.

<table>
<thead>
<tr>
<th>Work Package</th>
<th>Leader</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP1: Laser Facility</td>
<td>Gizzi Leonida</td>
<td>Pisa - Milan</td>
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<tr>
<td>WP2: Beam Line Scheme - Targets, Focusing Elements and Diagnostic Devices</td>
<td>Giove Dario</td>
<td>Milan – LNS - LNF</td>
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<tr>
<td>WP3: Semi-analytical Methods and Numerical Modeling Computer Simulations</td>
<td>Fedele Renato</td>
<td>Naples – Bologna</td>
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<tr>
<td>WP4: ELIMED Testing Facility</td>
<td>Cirrone Pablo</td>
<td>LNS</td>
</tr>
<tr>
<td>WP5: Radiobiological Testing Facility</td>
<td>Labate Luca</td>
<td>Pisa - Naples</td>
</tr>
<tr>
<td>WP6: Compact Laser based Accelerators for Ion Beam Analysis Applications</td>
<td>Manti Lorenzo</td>
<td>Florence</td>
</tr>
<tr>
<td>WP7: Project Management</td>
<td>Gizzi Leonida</td>
<td>Pisa - Milan</td>
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<td></td>
<td>Giove Dario</td>
<td></td>
</tr>
<tr>
<td>Unit</td>
<td>Unit Responsible</td>
<td>FTE Unit</td>
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<tr>
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<td>------------------</td>
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<tr>
<td>Milan</td>
<td>Giove Dario</td>
<td>4.0</td>
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<tr>
<td>Pisa</td>
<td>Gizzi Leonida</td>
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<tr>
<td>Bologna</td>
<td>Bazzani Armando</td>
<td>1.4</td>
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<tr>
<td>LNS-Catania</td>
<td>Cirrone Pablo</td>
<td>10.4</td>
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<tr>
<td>Naples</td>
<td>Fedele Renato</td>
<td>2.7</td>
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<tr>
<td>LNF-Frascati</td>
<td>Maria Pia Anania</td>
<td>1.0</td>
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<tr>
<td>Florence</td>
<td>Chiari Massimo</td>
<td>0.5</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>22.3</strong></td>
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<table>
<thead>
<tr>
<th>TYPE OF COST</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missioni</td>
<td>76.50</td>
<td>52.0</td>
<td>45.0</td>
<td>173.50</td>
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<tr>
<td>Consumi</td>
<td>106.00</td>
<td>89.00</td>
<td>35.0</td>
<td>230.00</td>
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<tr>
<td>Trasporti</td>
<td>7.00</td>
<td>5.0</td>
<td>5.0</td>
<td>17.00</td>
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<tr>
<td>Inventario</td>
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<td>136.00</td>
<td>98.00</td>
<td>416.00</td>
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<tr>
<td>Licenze SW</td>
<td>12.00</td>
<td>3.00</td>
<td>3.00</td>
<td>18.00</td>
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<tr>
<td>Apparati</td>
<td>135.00</td>
<td>81.00</td>
<td>35.00</td>
<td>251.00</td>
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<tr>
<td><strong>OVERALL TOTAL</strong></td>
<td><strong>518.5</strong></td>
<td><strong>366.00</strong></td>
<td><strong>221.00</strong></td>
<td><strong>1,105.00</strong></td>
</tr>
</tbody>
</table>
ILIL Laser upgrade

- Upgrade will be developed in phases:
- 1° phase (mid 2016) will deliver a minimum of 1.5 J on target, >4x current energy.
- Ion energy scaling sets max ion energy around 5 MeV
- Final goal is 12 MeV, to be achieved with 5 J of energy on target.

<table>
<thead>
<tr>
<th>ILIL(Pisa) - MAIN LASER BEAM PARAM.</th>
<th>Current (dec.2015)</th>
<th>1° phase (6-2016)</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength (nm)</td>
<td>800</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Pump Energy (J)</td>
<td>1.8</td>
<td>6(12)</td>
<td>24</td>
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<tr>
<td>Pulse duration(fs)</td>
<td>40</td>
<td>30</td>
<td>25</td>
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<tr>
<td>Energy before compression (J)</td>
<td>0.6</td>
<td>2(4)</td>
<td>7</td>
</tr>
<tr>
<td>Energy after compression (J)</td>
<td>0.4</td>
<td>1.5(3)</td>
<td>5</td>
</tr>
<tr>
<td>Rep rate (Hz)</td>
<td>10</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Max Intensity on target</td>
<td>2E19</td>
<td>7.5E19(1.2E20)</td>
<td>4E20</td>
</tr>
<tr>
<td>Contrast (ns)</td>
<td>&gt;1E9</td>
<td>&gt;1E9</td>
<td>&gt;1E10</td>
</tr>
<tr>
<td>Expected proton beam energy (MeV)</td>
<td>2</td>
<td>6(8)</td>
<td>12</td>
</tr>
</tbody>
</table>
ILIL-PW – Layout
Valore apparato laser PISA al 2018: 3 Meuro

Laser: da 10 TW a 200 TW

Double Plasma Mirror

Nuova parabola off-axis
Qualifica temporale sistema laser
Progettazione double plasma mirror

145 Keuro

Camere di Interazione

Solenoide

Test di fascio e diagnostiche

190 Keuro

Progetto e costruzione camera
Solenoide pulsato ad alta intensità
Completamento diagnostiche Target

Test radiobiologia

Test componenti ELIMED

60 Keuro
2nd European Advanced Accelerator Concepts workshop
Supported by EU via EuCARD-2, GA 312453
13-19 September 2015, La Biodola - Isola d'Elba – Italy
http://agenda.infn.it/event/EAAC2015

Electron Beams from Plasmas
Ion Beams from Plasmas
Electron beams from Electromagnetic Structures, including Dielectric and Laser-driven Structures
Applications of compact and high-gradient accelerators / Advanced beam manipulation and control
High-gradient plasma structures / Advanced beam diagnostics
Theory and simulations
Laser technology for advanced accelerators

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International scenario

State of the art – and some considerations

Maximum proton energies (published):

- 60-70 MeV on ~ ps systems
  (NOVA PW, Trident)
- 30-40 MeV on fs systems
  (GEMINI, PULSAR, J-KAREN)

+ Several unconfirmed/unpublished results

M. Borghesi, Ion acceleration working group Summary, EAAC, 2015
Laser Ion acceleration: Items in agenda

Increase particle energy,
Enable spectral control,
Increase reliability
Enable repetition rate

- LASER SIDE:
  - advance power,
  - pulse shape control,
  - wavelength (?)

- INTERACTION SIDE:
  - target shape and density
  - engineer plasma gradient
  - micro/nano-manipulation

M. Borghesi, Ion acceleration working group Summary, EAAC, 2015
WG summary: Highlight of main groups

- LIGHT collaboration: Laser Ion Generation, Handling and Transport (GSI, Germany)
  - 10 MeV laser based proton beamline, low rep rate, Applications to WDM;

- A-SAIL: Advanced Strategies for Accelerating ions with lasers (RAL, QUB, Ustrath, UK)
  - Target embedded post acceleration;

- L3IA: National initiative involving groups from MI, PI, NA, LNS, LNF, FI, BO;
  - 15 MeV laser based proton beamline; reprated (1-5Hz); Very promising;

- OncoOPTICS: Laser-ion acceleration using truly mass-limited targets (UJena, Germany)

- CALA: Center for Advanced Laser Applications (MPQ, Germany)
  - Levitating targets

- ... 

Main lasers involved: GEMINI (UK), PULSER, (Korea). POLARIS (Germany), VULCAN (UK).
Taranis (UK), CALA (MPQ), Saphir (France) ...

U. Schramm, Ion acceleration working group Summary, EAAC, 2015