Laser Acceleration of Protons and Ions at Salamanca

Michael Seimetz and Pablo Bellido
for the PLA collaboration

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Table of contents

Production of radioisotopes

Proton **L**aser **A**pplications: Development of medical applications of laser-accelerated proton and ion beams.
Example: Production of radiopharmaceuticals.

Current situation: 35M patient examinations per year, thereof

- 90% SPECT/planar scintigraphy: γ emitters, mostly ^{99m}Tc. Derived from nuclear reactors (only 5 worldwide). Risk of shortage.
- 10% PET: e^+ emitters, mostly ^{18}F ($T_{1/2} = 2$ h), also ^{11}C (20 min), ^{13}N (10 min), ^{15}O (2 min). Produced in cyclotrons.

Disadvantages of distribution system (production site $\rightarrow$ hospitals):

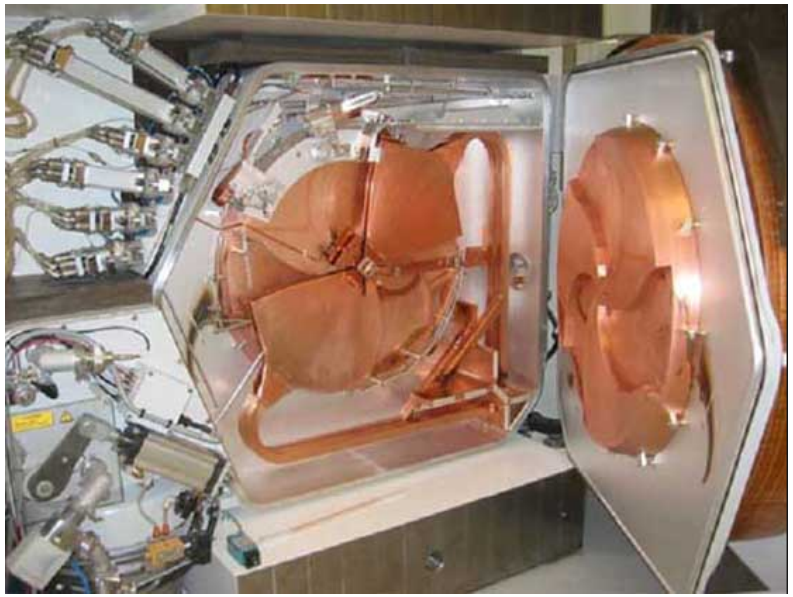
- Decay of short-lived isotopes during transport.
- Limited to ^{99m}Tc and ^{18}F.
- Lack of flexibility in daily schedule.
- Dependency on external supplier.

Production of radioisotopes

Significant improvements with on-site production. Commercial cyclotrons:

GE PETtrace (only PET isotopes):

- 16.5 MeV H^- (80 μA),
  8.4 MeV D^- (60 μA)
- $1.2 \times 1.3 \times 1.9$ m^3
  + external beamlines
- 20 tons
- 2.5 M\$.

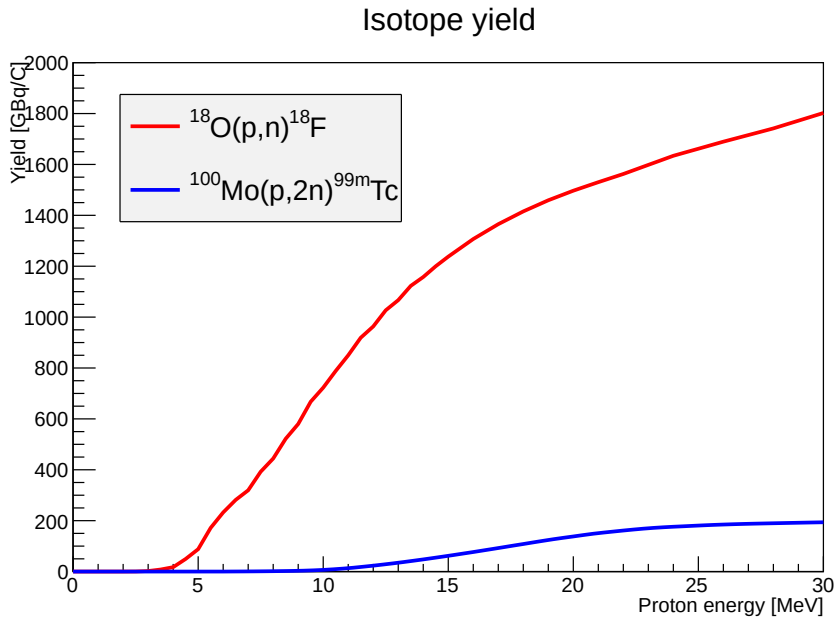


Laser-based technology may be cheaper and more compact.

Production of radioisotopes

Physical requirements:

- Sufficient p energy (> 10 MeV)



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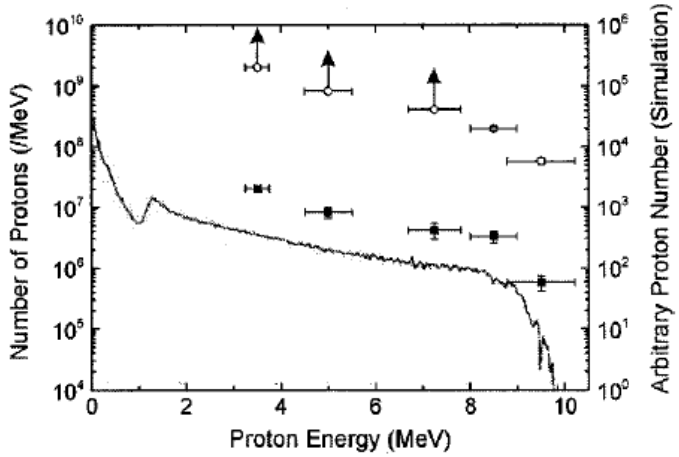
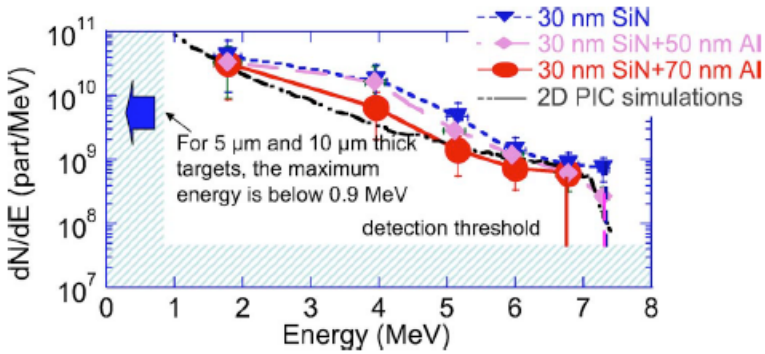


S. Fritzler *et al.*, Appl. Phys. Lett. 83 (2003)



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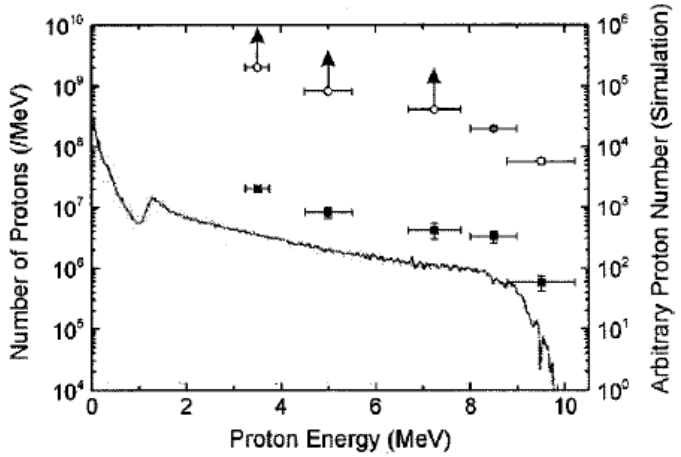

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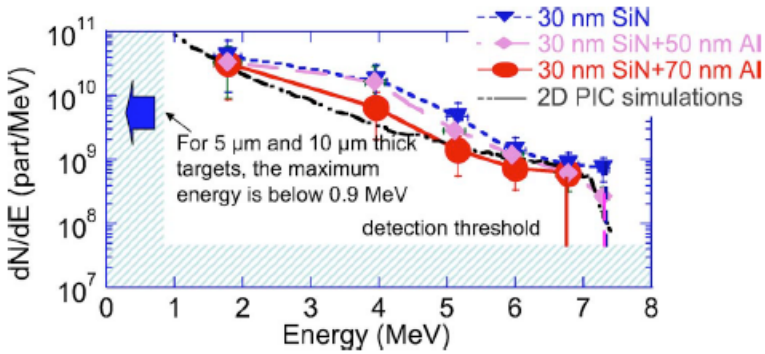

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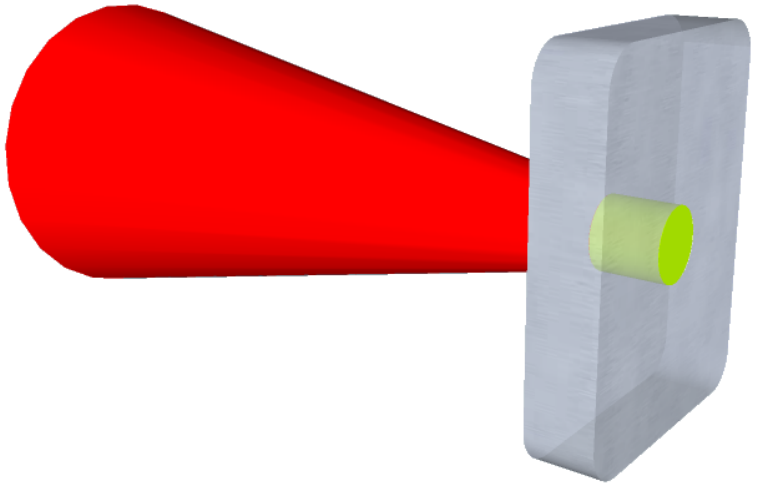

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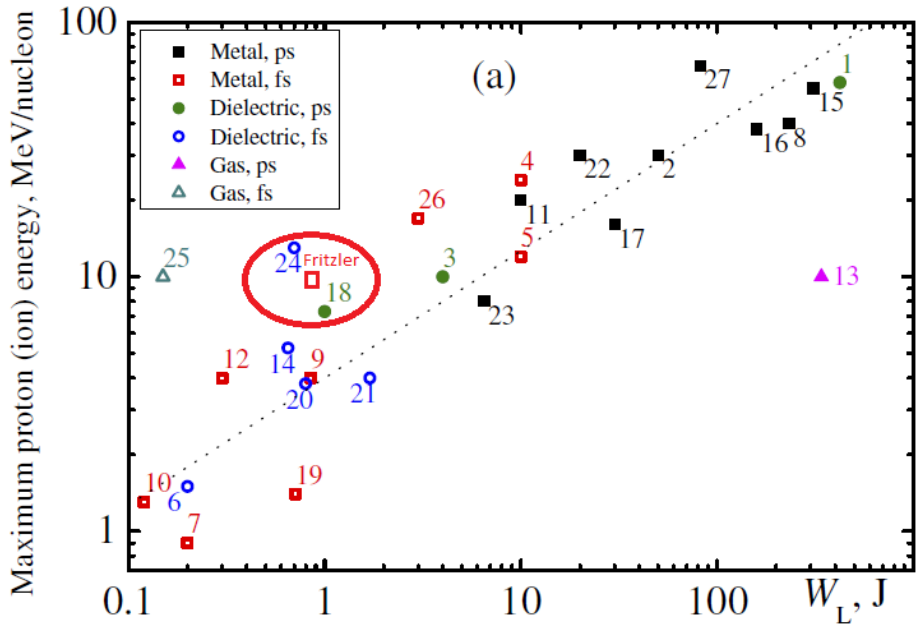

H. Daido *et al.*, Rep. Prog. Phys. 75 (2012)

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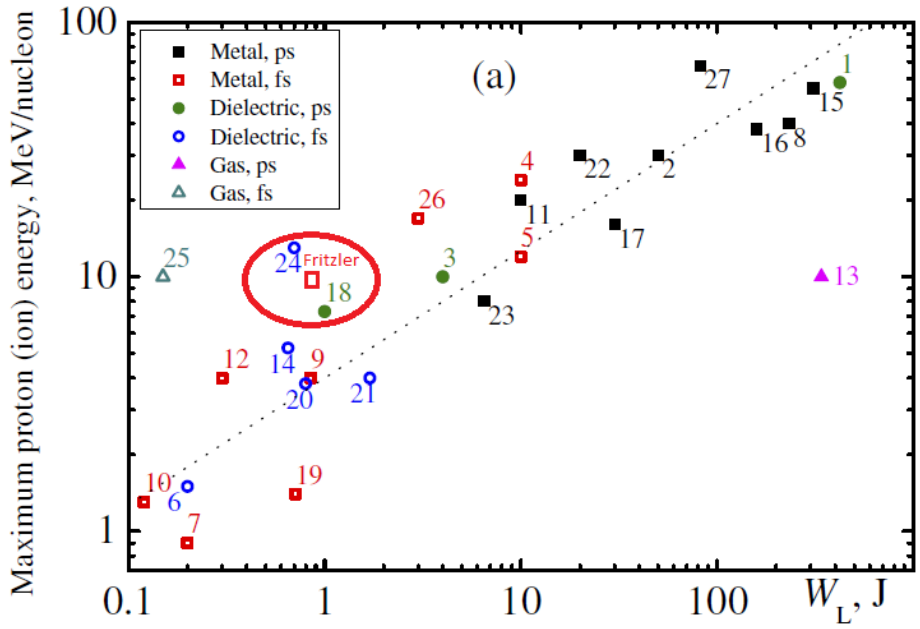

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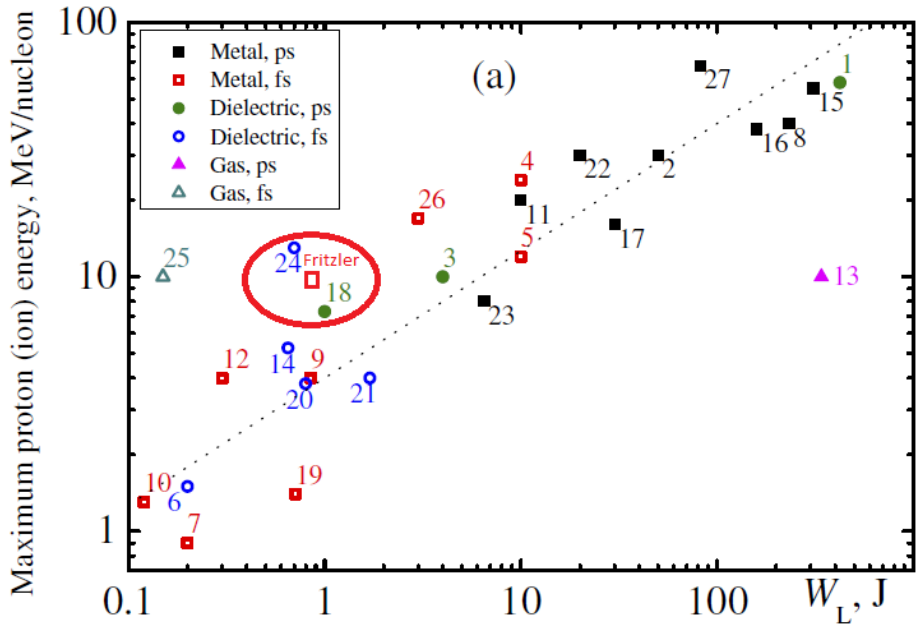

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Our strategy: Demonstrate proton acceleration at large-scale installations (CLPU), then optimise components to reduce size, energy, etc.

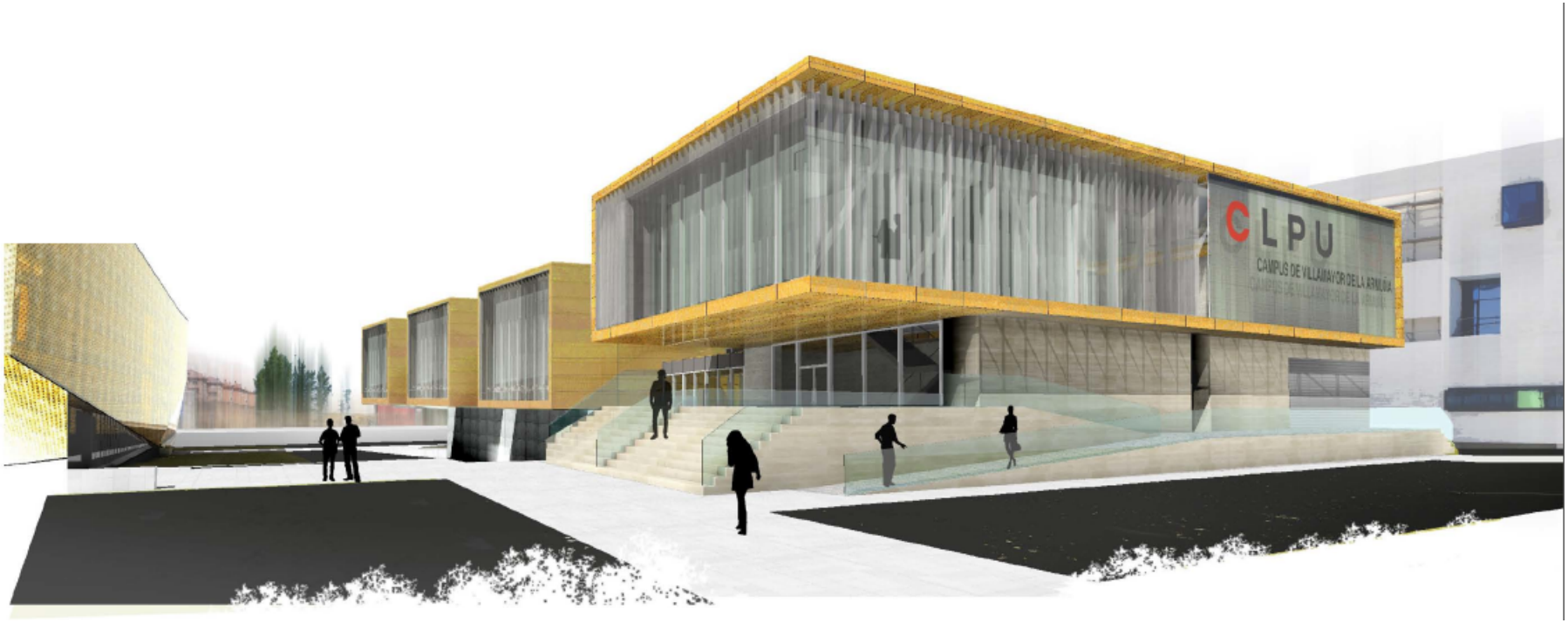
Collaboration members

Collaboration INNPACTO-PLA (since 2011):

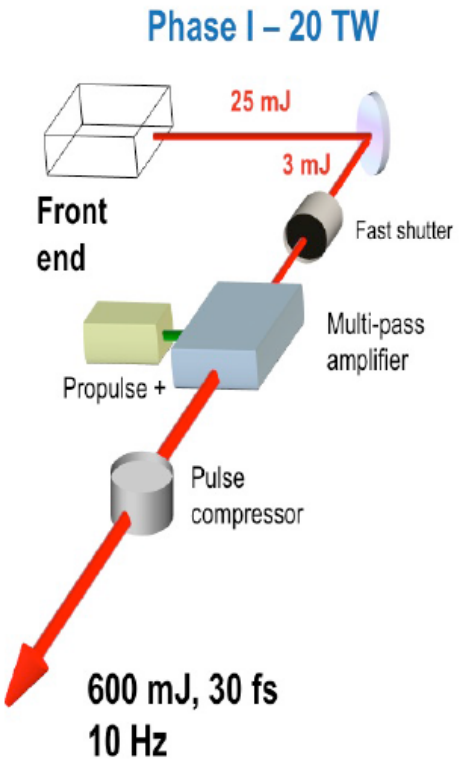
- I3M (Institute for Instrumentation in Molecular Imaging, Valencia):
  - Senior scientists: J.M. Benlloch, F. Sánchez, M.J. Rodríguez-Álvarez
  - Postdocs: M. Seimetz, A.J. González, A. Soriano, J.P. Rigla
  - Ph.D. students: P. Bellido, L. Moliner, P. Conde, A. Iborra
  - Technicians: L. Hernández, L.F. Vidal, F. Martos, E. Crespo.
- CLPU (Spanish Pulsed Laser Centre, Salamanca):
  - Senior scientists: L. Roso
  - Postdocs: J.I. Apiñaniz, A. Peralta Conde, M. Sánchez Albaneda, M. Rico
  - Ph.D. students: F. Valle Brozas.
- Proton Laser Applications S.L. (Salamanca):
  - Senior scientists: M. Galán
  - Postdocs: A. Ruiz, S. Torres
  - Ph.D. students: R. Lera.

The Spanish Pulsed Laser Centre

- Started at University of Salamanca (0.5 TW in March 2003)
- Now: CLPU at Villamayor, VEGA TW lasers operative
- New building nearly finished, PW laser operative by end of 2014.



VEGA system


Phase I – 20 TW
25 mJ
3 mJ
Front
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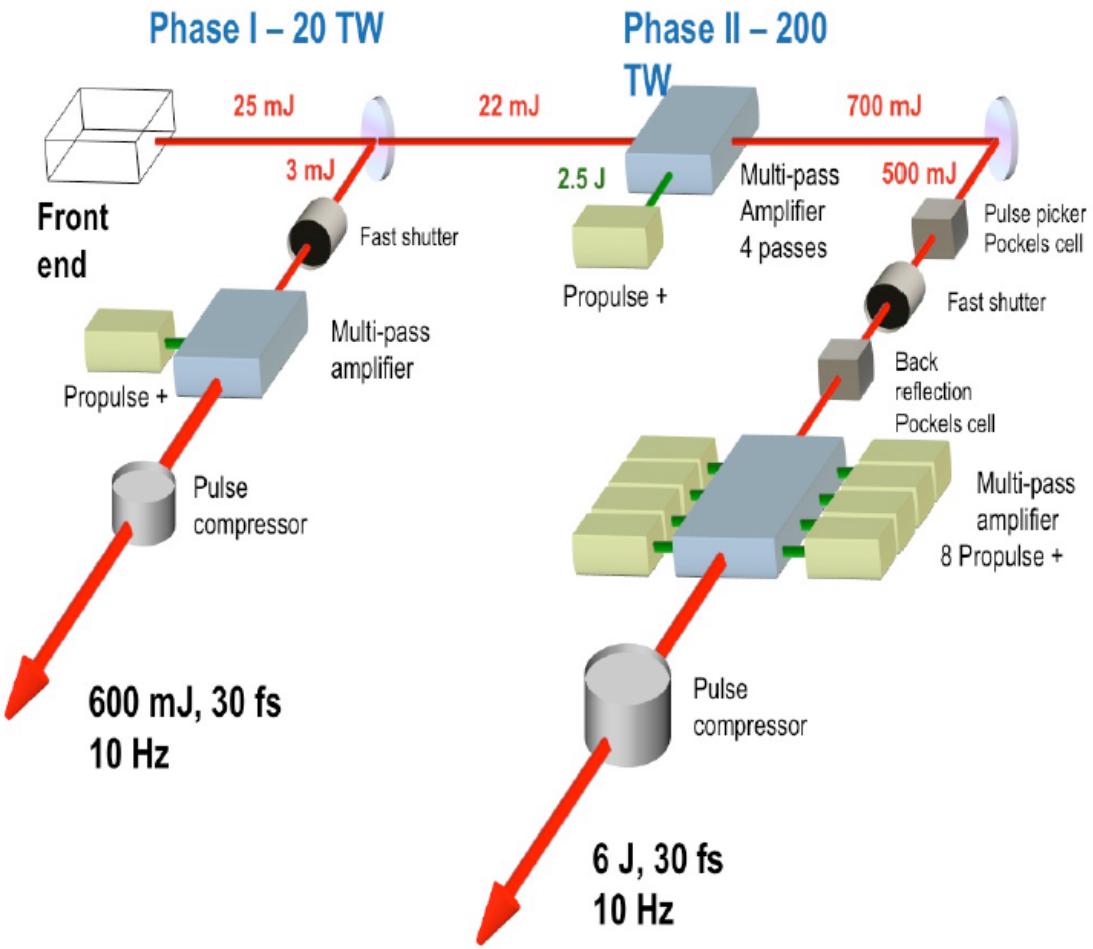
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22 mJ
700 mJ
3 mJ
2.5 J
500 mJ
Front end
Fast shutter
Multi-pass Amplifier 4 passes
Pulse picker Pockels cell
Propulse +
Fast shutter
Back reflection Pockels cell
Multi-pass amplifier
Propulse +
Multi-pass amplifier
8 Propulse +
Pulse compressor
Pulse compressor
600 mJ, 30 fs
10 Hz
6 J, 30 fs
10 Hz

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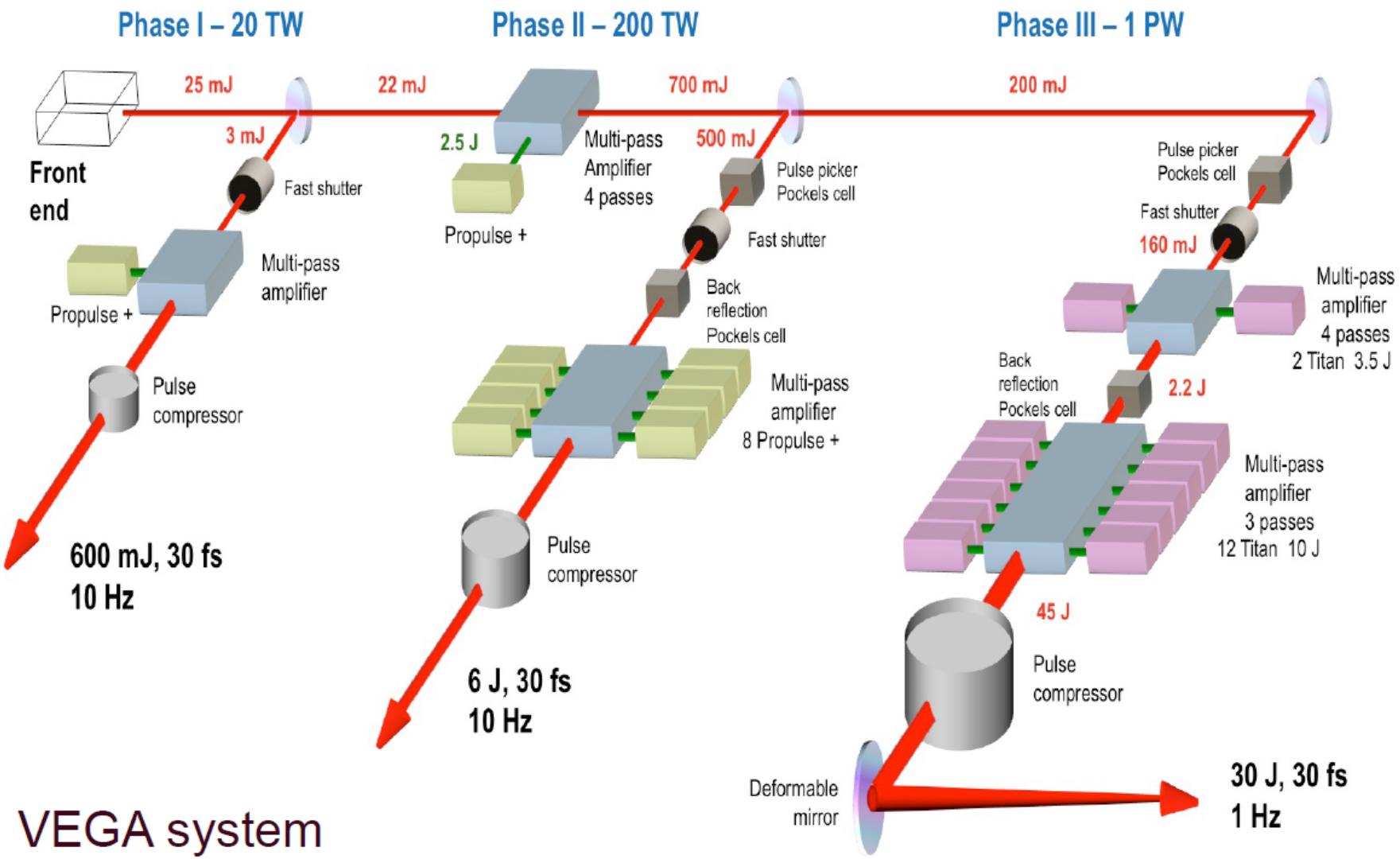
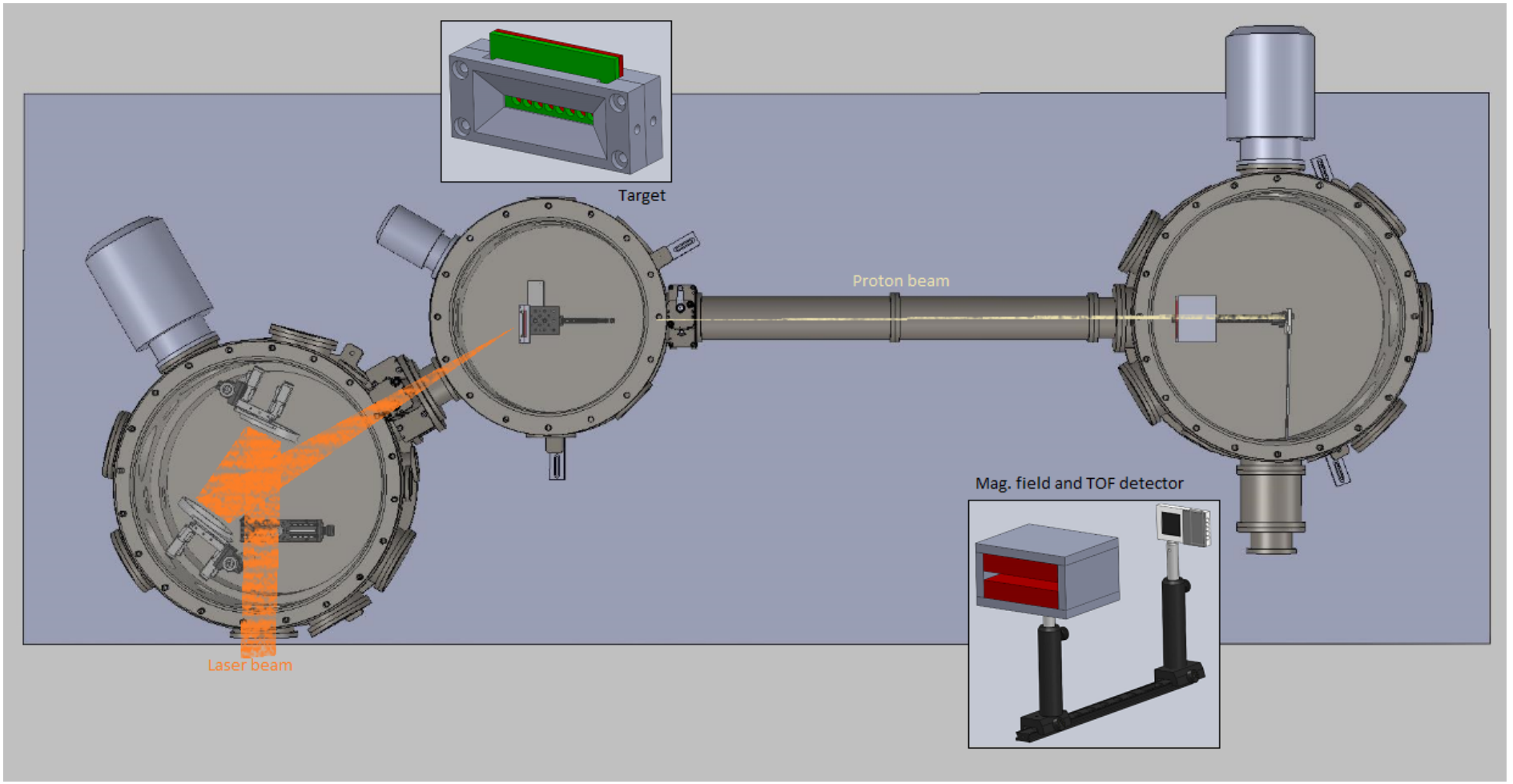


VEGA system

PLA setup

Vacuum systems for first experiments at VEGA I and II (20-200 TW):



The I3M institute at Valencia

Institute for Instrumentation in Molecular Imaging (I3M):

- Founded in 2011
- Located at Polytechnical University (UPV)
- Detector group: formerly at IFIC (Particle Physics Institute)
- Research activities: medical and preclinical imaging devices; PLA.

Particle detectors for PLA

Starting point for detector development: What are we looking for?

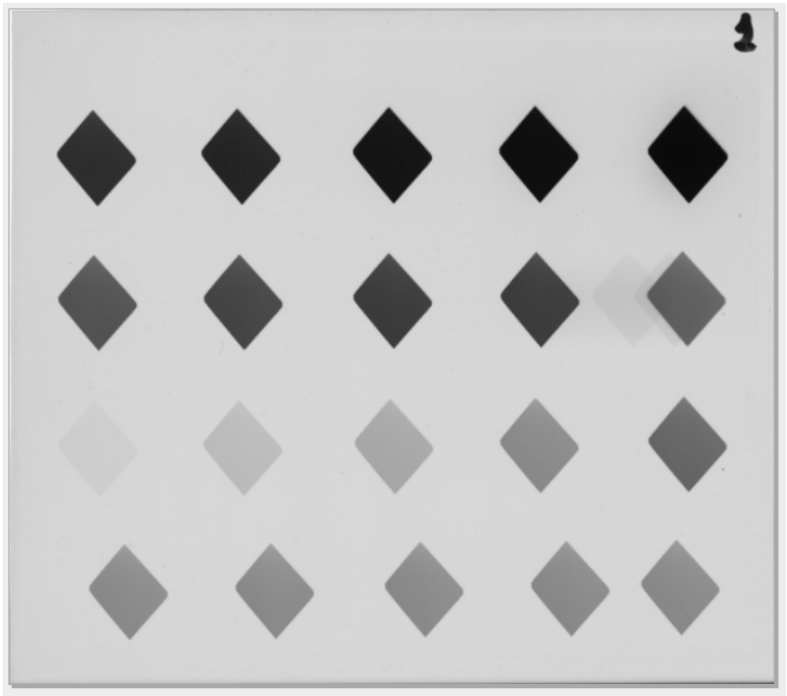
- Laser accelerated protons:
  - Energies: 0.5-12 MeV (hopefully)
  - Particle numbers: 10^3-10^{11} per shot and energy interval
  - Spatial distribution: suppose small opening angle

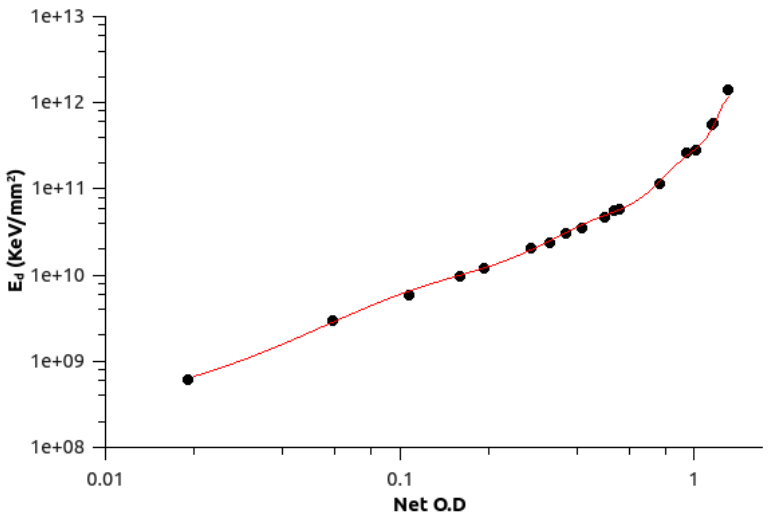
  $\Rightarrow$ Need versatile detector, at least for first trials.
- Ion acceleration (esp. carbon): Maybe similar spectra (in MeV/u), but more difficult to detect due to limited range in matter.

Particle detectors for PLA

Radiochromic films:

- Radiation sensitive film (Gafchromic HD-V2, 10-1000 Gy)
- Grey scale (OD) $\sim$ dose, calibrated at 6 MeV tandem accelerator (CNA Sevilla)
- High spatial resolution for particle distribution
- Stack $\Rightarrow$ proton energy spectra.

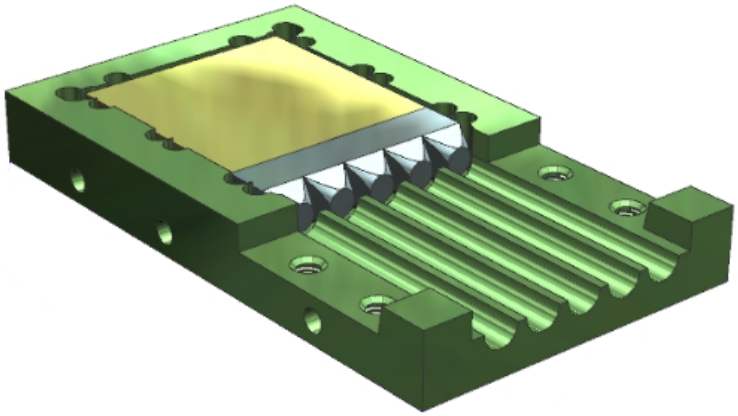


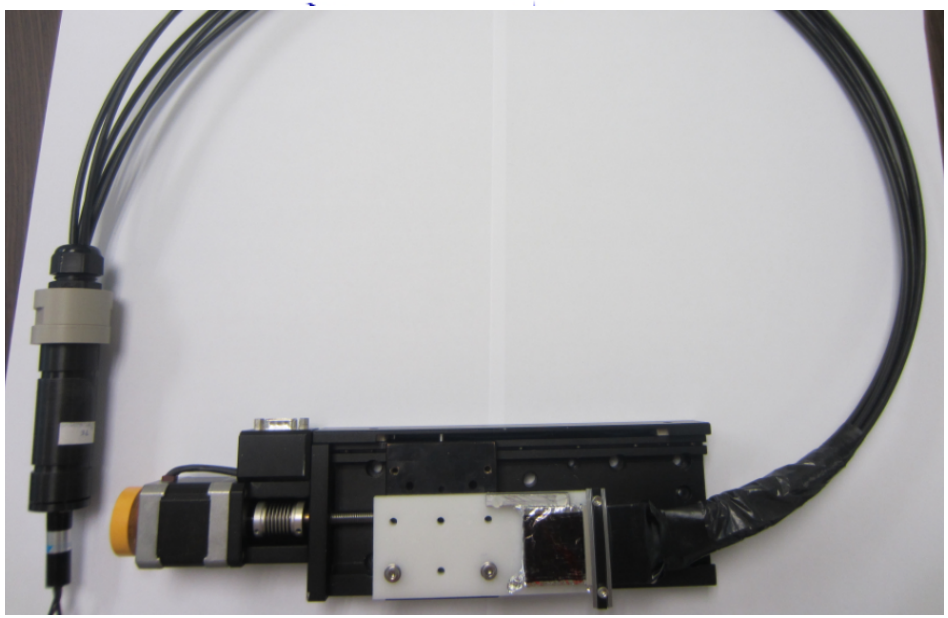


Particle detectors for PLA

TOF detector:

- Plastic scintillator, $25 \times 25 \times 5$ mm^3
- Coupling to PMT via optical fibres





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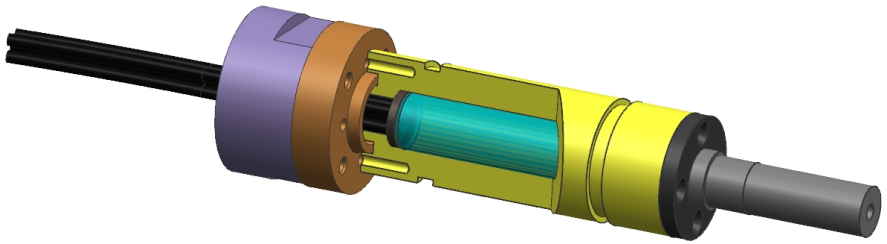

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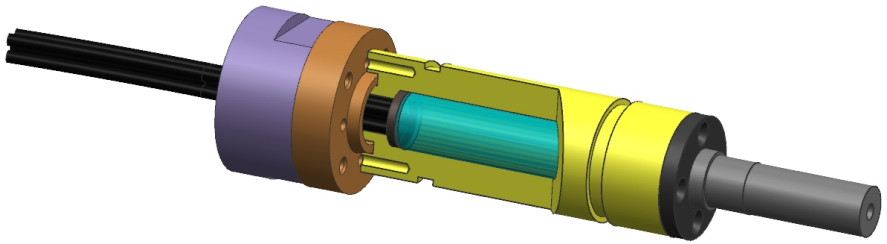

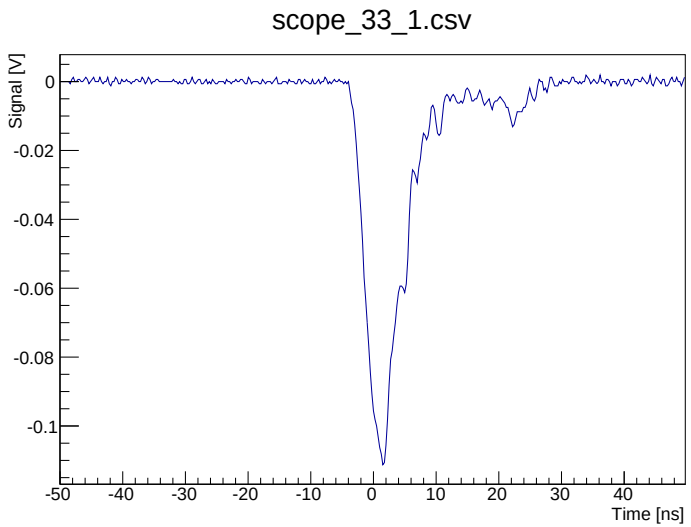

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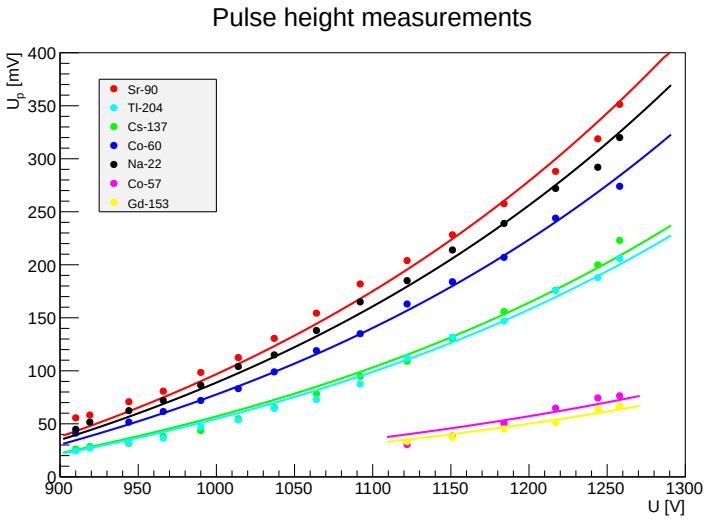

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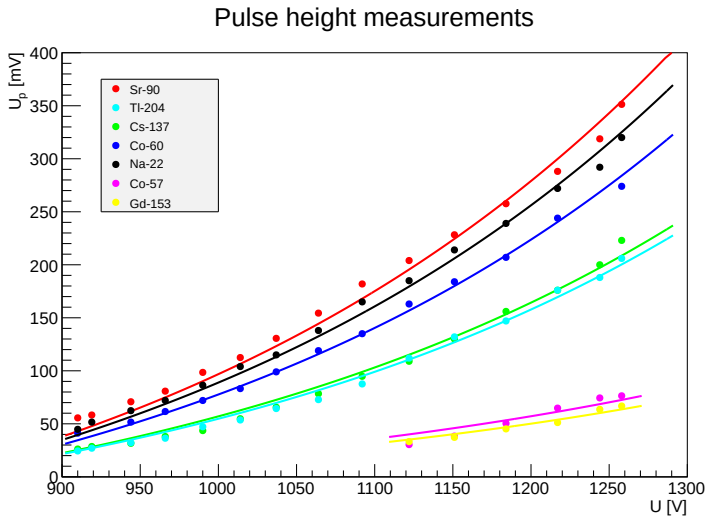

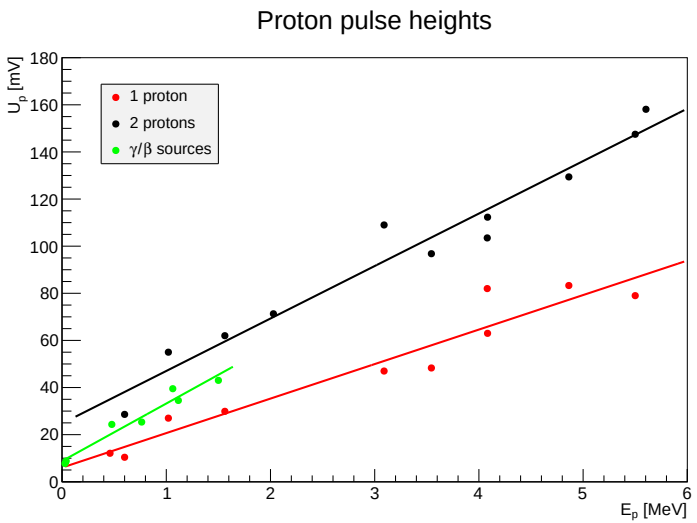

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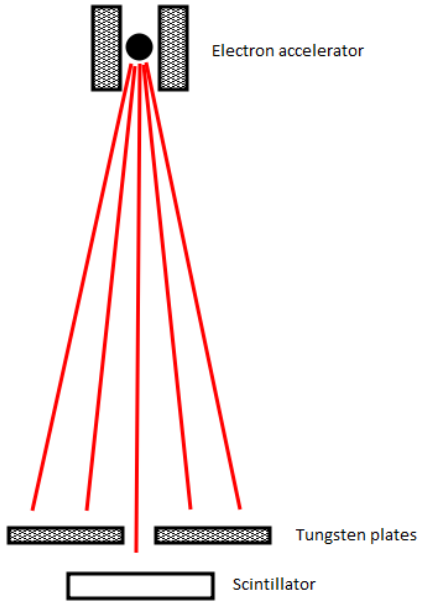
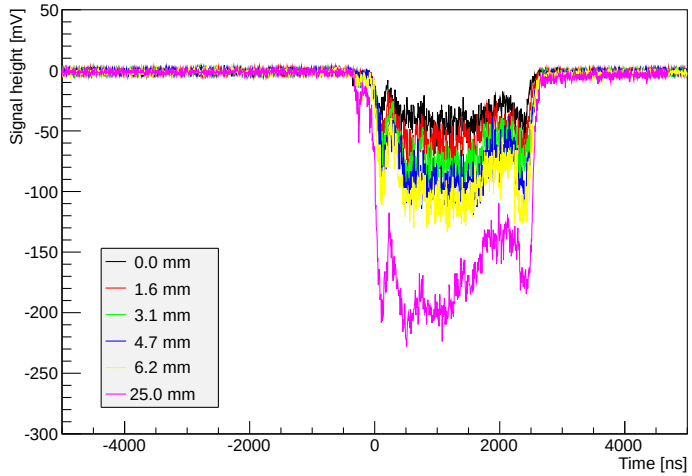


Pulse height with OD1 filter



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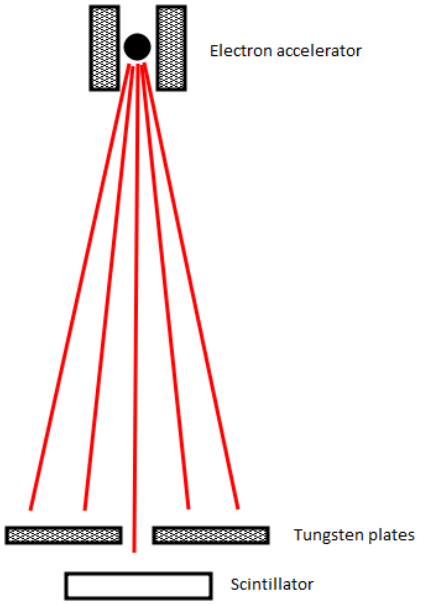
- Many-particle detection (μs long pulses) with electron accelerator
- Aim: Measurement of proton flight time $\Rightarrow$ 1.5 m path length.



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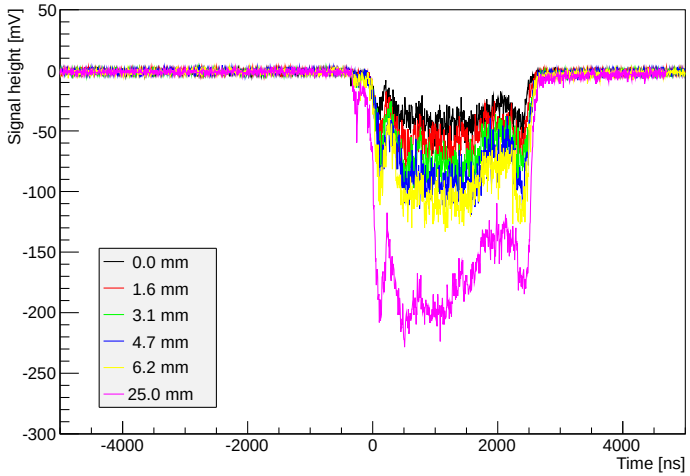
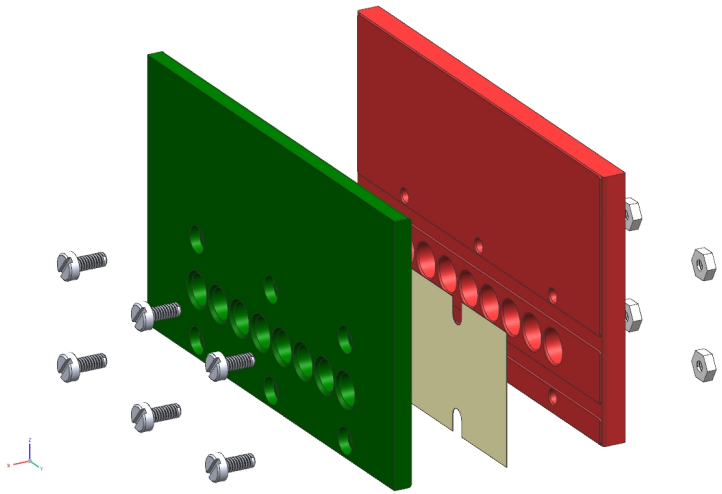
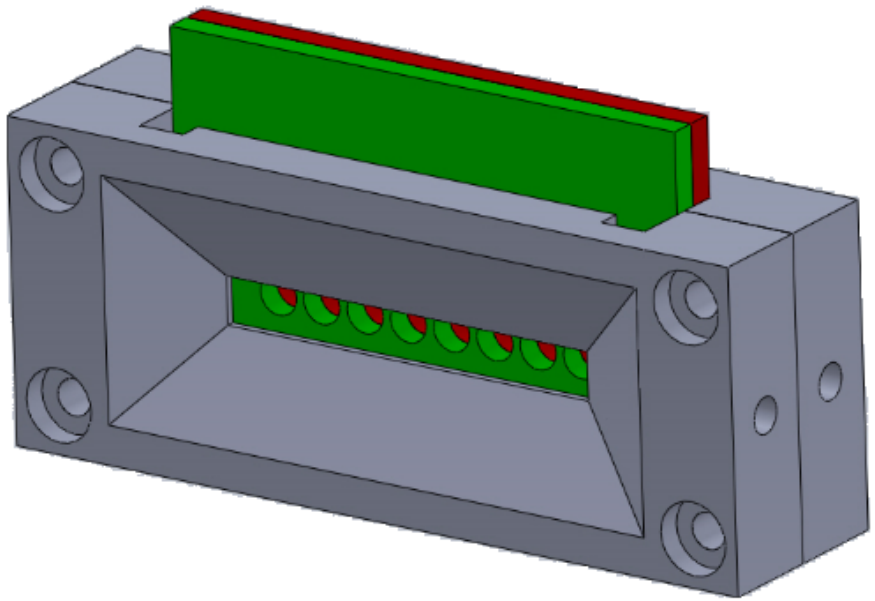


Laser targets for PLA

Start with thin foil targets (Al, metal-hydrocarbon). Basic needs:

- Hold and tighten foil $\Rightarrow$ small knobs
- Allow for various laser shots $\Rightarrow$ array of targets
- Adjust target position in (x, z) $\Rightarrow$ motor controlled cart.





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Possible improvements:

- Foil in constant motion (rotating disk, spool).
- Droplet target (B. Ramakrishna *et al.*, Phys. Plasmas 17, 083113 (2010)).
- Gas targets: proton numbers too low.

Summary and outlook

- New laser-plasma collaboration in Spain.
- Experiments at CLPU facilities (20/200 TW) to start in 2013.
- Short-term objective: Demonstrate p acceleration. Simple target design, versatile detectors.
- Mid-term objectives: High proton flux up to 12 MeV; "heavy" ions.
  - Optimise target design.
  - Laser with high repetition rate.
  - Particle detectors with good energy/mass resolution (*e.g.*, Thomson parabola) and DAQ.