Proton Acceleration with a Table-Top TW Laser

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2 - Proton Laser Applications S.L. (PLA), Olèrdola (Barcelona)
3 - Centro de Láseres Pulsados (CLPU), Villamayor (Salamanca)

3rd ELIMED Workshop
Catania

September 7-9, 2016

The PLA collaboration

Collaborators (since 2012):

- Proton Laser Applications S.L. (PLA, private company located close to Barcelona): Development of high-power laser systems.
- Institute for Instrumentation in Molecular Imaging (I3M, Valencia): Targets, particle detectors.
- Spanish Pulsed Laser Centre (CLPU, Salamanca).

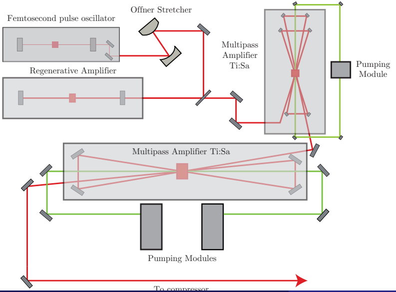
Entire system built from scratch:

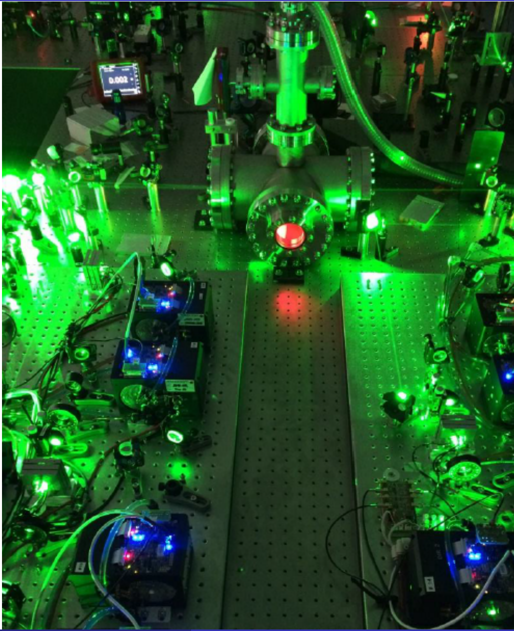
- Table-top laser developed by PLA. Strong private contribution.
- Detectors built and calibrated by I3M.
- Experiments performed at PLA installations.

PLA laser system

Table-top Ti:Sapphire laser:

- Diode pumping (Nd:YAG) for high rate (10-100 Hz)
- Multi-pass amp. stages (1.5 → 30 → 265 mJ)
- 2 saturable absorbers for enhanced contrast.





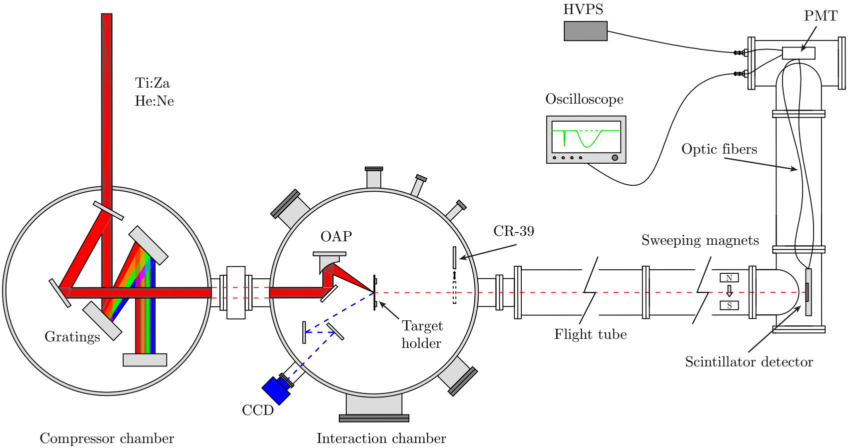
Laser parameters

	Series 1 Nov 2015
Pulse energy before comp.	150 mJ
Pulse energy on target	93 mJ
Pulse duration (FWHM)	43 fs
Peak power	2 TW
Focal spot (FWHM, μm^2)	5.0×9.0
Peak intensity (10^{18} W/cm^2)	3.7
Contrast over ASE	10^5
Pump rate	100 Hz

Laser parameters

	Series 1 Nov 2015	Series 2 Jul 2016
Pulse energy before comp.	150 mJ	265 mJ
Pulse energy on target	93 mJ	165 mJ
Pulse duration (FWHM)	43 fs	55 fs
Peak power	2 TW	3 TW
Focal spot (FWHM, μm^2)	5.0×9.0	5.0×11.5
Peak intensity (10^{18} W/cm^2)	3.7	4.2
Contrast over ASE	10^5	10^8
Pump rate	100 Hz	10 Hz

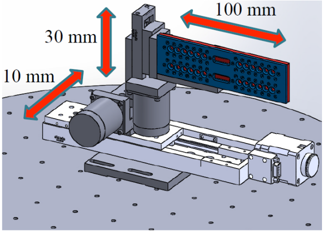
Experimental setup downstream to PLA laser:



Target and focus diagnostics

Interaction chamber (10^{-2} mbar):

- Support for 24 foil targets



Target and focus diagnostics

Interaction chamber (10^{-2} mbar):

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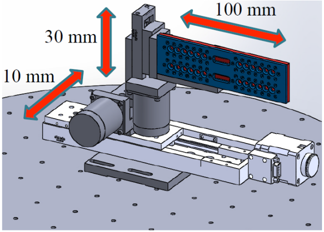
- Al target foils (0.65-25 µm)
- Mylar foils (2-13 µm)
- Au foils (0.1-2 µm)



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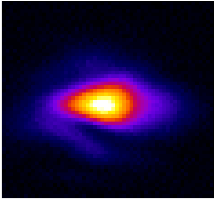

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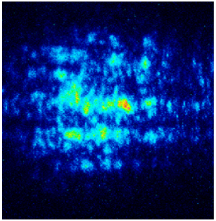
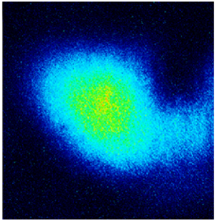
- Position control with He:Ne laser

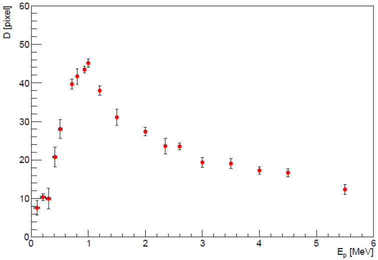


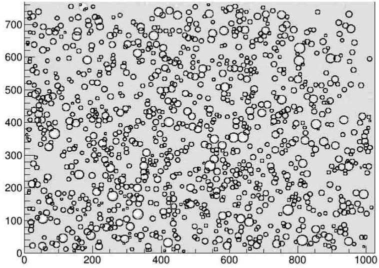


Particle detectors

CR-39 plates, 1 cm^2 (Radosys, Budapest):

- Relation E_p - track diameter calibrated on 3 MV tandem accelerator (Centro Nacional de Aceleradores, CNA, Seville)
- Up to 1 MeV, unique relation
- For higher energies, thin Al absorbers
- Etching in 6.25N NaOH, 90°C, 4 hours
- Automatic readout (Radosys PT10 microscope)
- Self-developed track recognition software for image analysis
- Placed 100 cm behind the target.

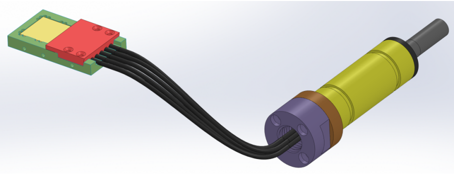


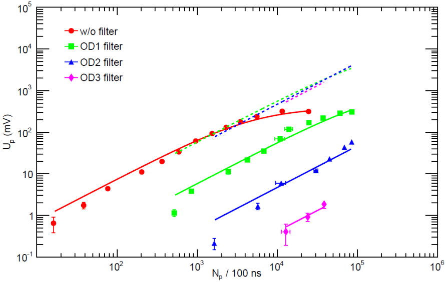


Particle detectors

Time-of-flight detector:

- Based on fast plastic scintillator
- Dynamic range adjustable with optical filters
- Calibrated with pulsed proton beam as function of beam current (CNA)
- 227 cm behind target.

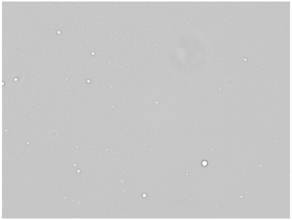




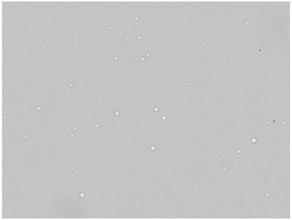
Results from Series 1 (93 mJ, LC)

Al target foils, 2-25 µm; CR-39 at 100 cm target distance:

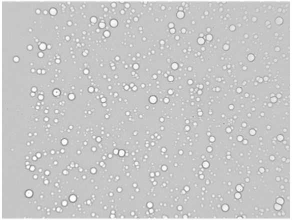
4 µm



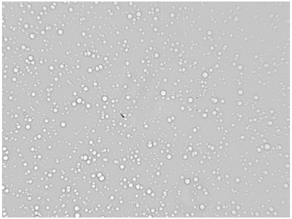
7 µm



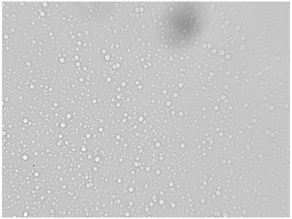
10 µm



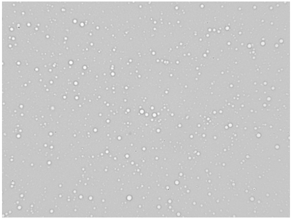
12.5 µm



18 µm



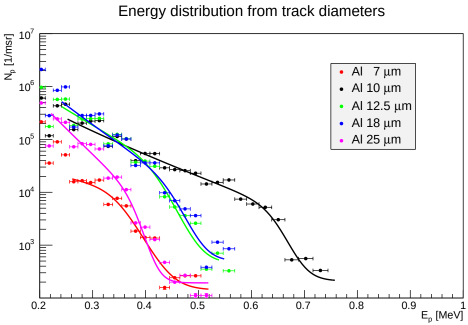
25 µm



Results from Series 1 (93 mJ, LC)

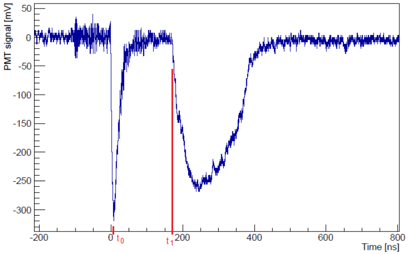
- Max. proton energy at 2 TW: ~ 650 keV
- Max. proton number: $\sim 10^6$/msr
- No eff. acceleration with 2-4 µm Al
- Much lower energies and particle numbers with Mylar foils

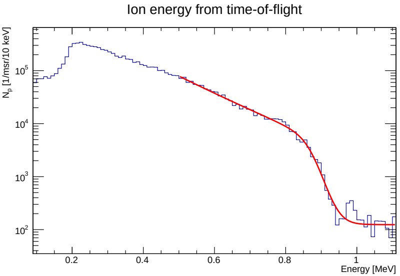
Spectra approximated by $N_p = \frac{N_0}{E_p} \cdot e^{-E_p/E_0} / (1 + e^{(E_p - E_{\max})/\Delta E}) + N_{bg}$.



Results from Series 2 (165 mJ, HC)

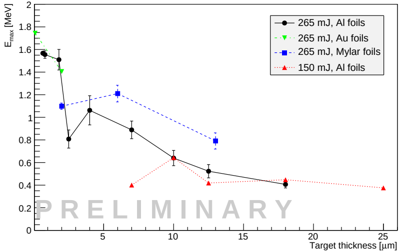
- Proton energies calculated from TOF
- Spectral distributions approximated by same analytic function as CR-39
- Similar results from CR-39 covered with Al absorbers ($\Delta E_{\max} = 100$ keV).

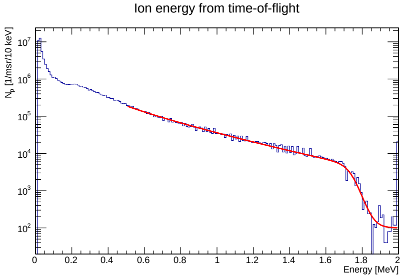


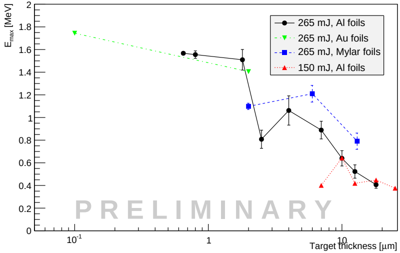


As compared to Series 1:

- Best results from thin Al/Au foils (< 2 µm)
- Protons from Mylar foils
- Effect of increased contrast seems more important than beam energy.





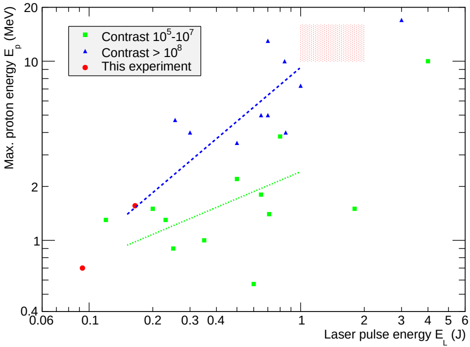


Status and perspectives

First experimental steps accomplished:

- Stable operation of PLA laser at 10-100 Hz
- Focussing and target diagnostics
- Clear proton signals demonstrated
- Proton spectra measured from several foil targets.

Results consistent with other experiments at low pulse energies.



Status and perspectives

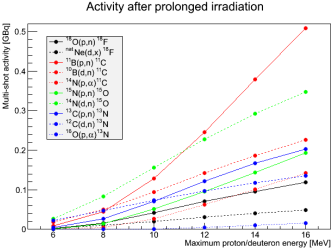
Next steps:

- Modified target design based on Si wafers for
  - Mass production
  - High rate capability
  - Limited target area
  - Controlled CH layer

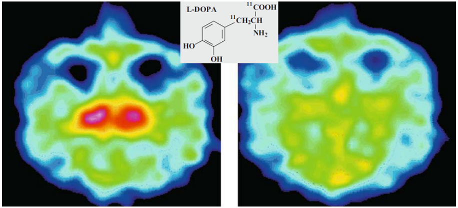
  (R. Zaffino, Centro Nacional de Microelectrónica, Barcelona).
- Laser upgrade for increased pulse energy:
  - 500 mJ before comp., 10 Hz with larger crystals
  - 100 Hz require additional cooling
  - 1 J with 3rd multi-pass amp.?
- Detector upgrade: TPS with fast readout.
- Accelerate C ions.

Possible applications: Versatile tools for research

- Radioisotope production (esp. ^{11}C): requires 10-16 MeV *p* at 100 Hz for preclinical studies (small animal models):
  - Use ^{11}C to label *any* organic molecule without structural change.
  - Labels at different sites to study details of metabolization.
  - Mol. biology, pharmaceutical research, models of pathologies, etc.



MS *et al.*, IEEE NSS-MIC Conf. Record (2015)



G. Antoni, B. Långström (2005)

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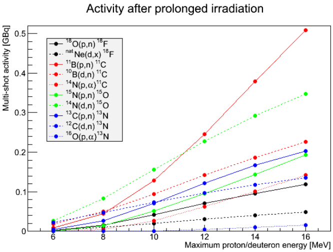

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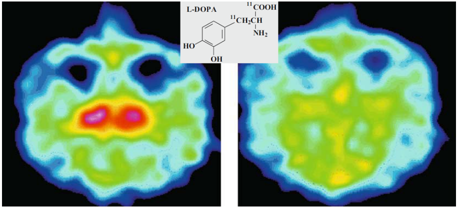

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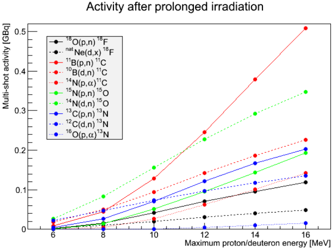
- Ion therapy of superficial lesions (⇒ Poster by P. Mur).



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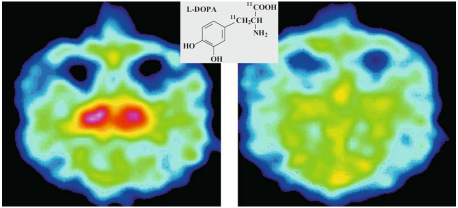

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Acknowledgements

Project funded by:

- Centro para el Desarrollo Tecnológico Industrial (CDTI), grant no. IPT-20111027
- EUROSTARS project E9113
- Spanish Ministry for Economy and Competitiveness, ref. RTC-2015-3278-1
- CSIC, Garantía Juvenil en I+D+i (P. Mur).

Very special thanks to Radosys (Budapest) for CR-39 detector material, etching bath, and readout equipment.