CNR-INO
ISTITUTO NAZIONALE DI OTTICA
CONSIGLIO NAZIONALE DELLE RICERCHE

Ion acceleration at the Intense Laser Irradiation Laboratory: from exploration to exploitation

Fernando Brandi

SPIE
Applying Laser-driven Particle Acceleration Workshop,
Prague 02/04/2019

Presentation Lay-out

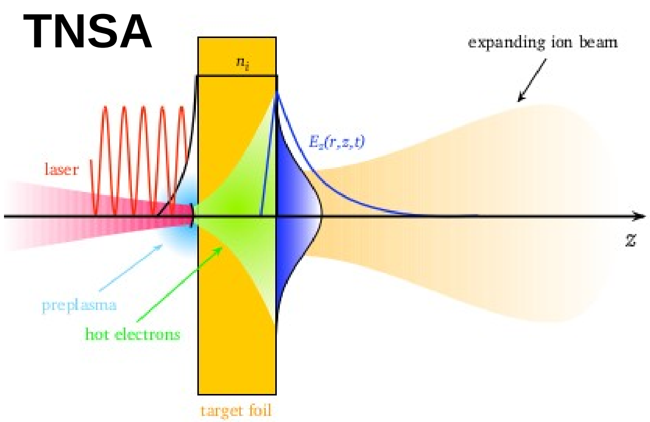
- ***Introduction***:
  Laser Proton acceleration from exploration to exploitation

- ***The Intense Lsaer Irradiation Laboratory laser system***:
  1) the 10 TW beam line
  2) towards 200 TW beam line

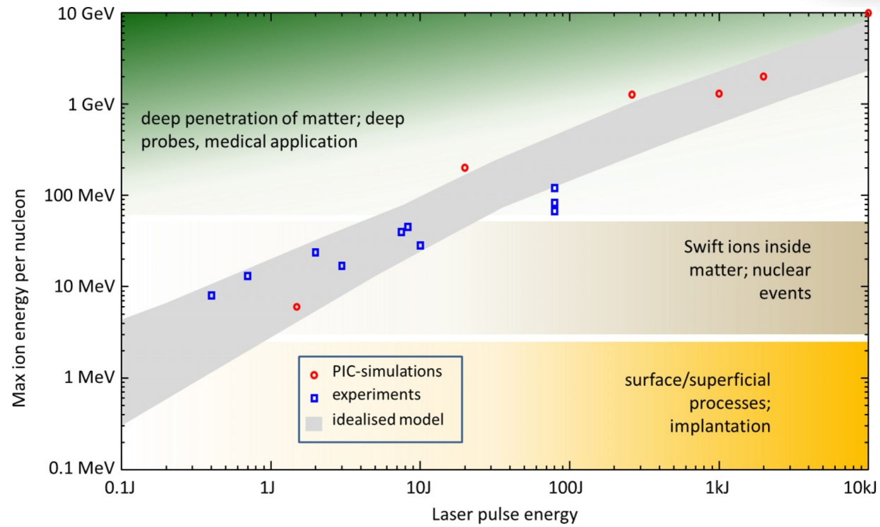
- ***On-going and foreseen exploitation activities***:
  1) PIXE with laser driven source
  2) small batch radioisotopes production

- ***Conclusions and Out-look***

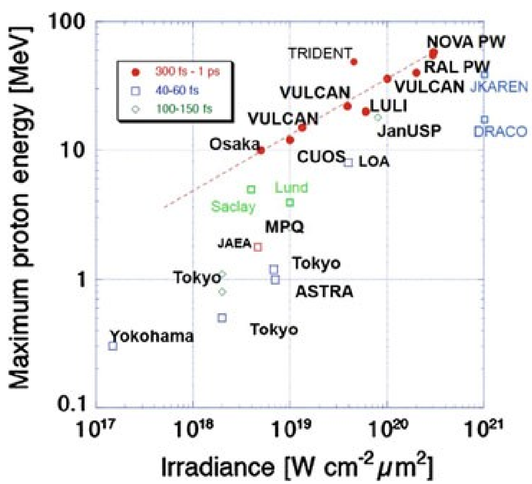
Proton laser-plasma acceleration Exploration

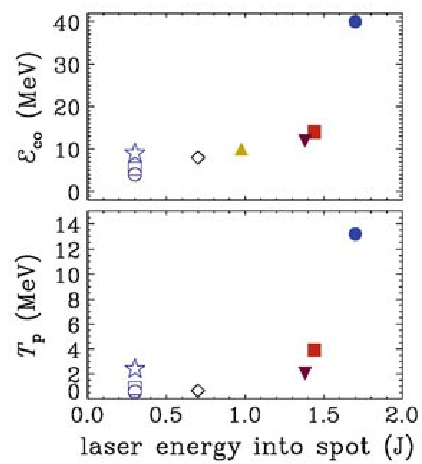


M. Roth and M. Schollmeier,Proceedings of the CAS-CERN Accelerator School: Plasma Wake Acc., 2014



J. Schreiber, P. R. Bolton, and K. Parodi. Review of Scientific Instruments 87, 071101 (2016)



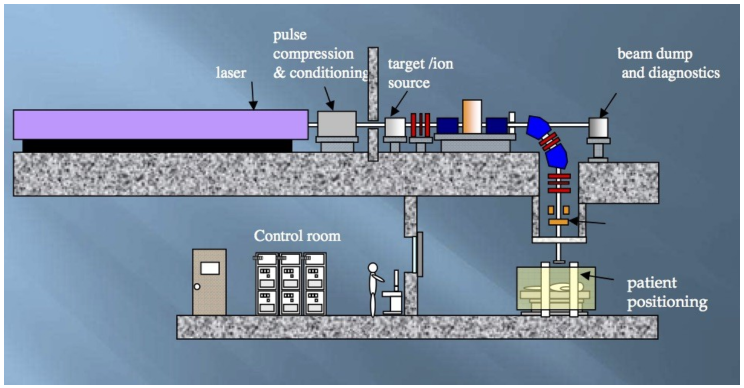


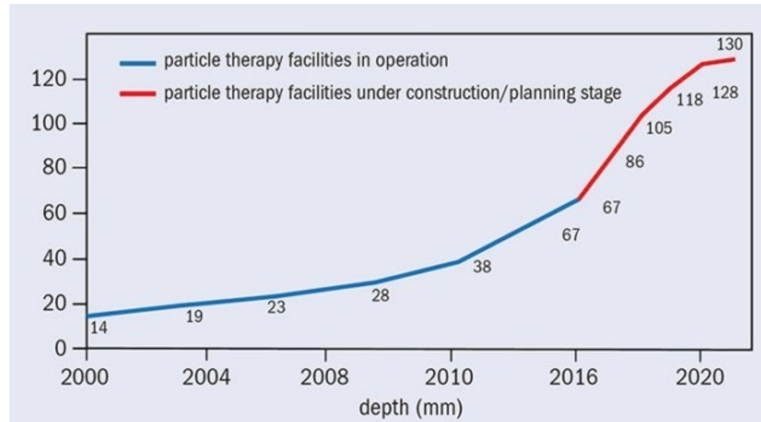
Macchi, Borghesi, Passoni
Rev. Mod. Phys 85 (2013)

Daido, Nishiuchi, Pirozhkov,
Rep. Prog. Phys. 75 (2012)

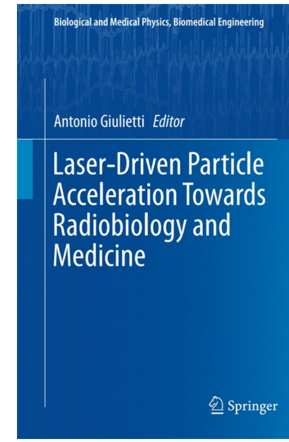
Proton laser-plasma acceleration Exploitation

Radiobiology and Radiotherapy





Hadron therapy facilities in operation worldwide,
under construction and in the planning stage,
at the end of 2016.
From: January/February 2018 issue of CERN Courier.



Laser-Driven Particle Acceleration Towards Radiobiology and Medicine, Ed. Antonio Giulietti, Springer 2016

<u>Need a Break-through for laser-plasma based accelerator.</u>

-) **electron** laser-plasma acceleration in **user oriented facility** (e.g., EuPRAXIA project), and generation of X and gamma rays for **NDT**.
-) **proton** acceleration application in Particle Induced X-ray Emission (**PIXE**) and **radioisotope** production.

The ILIL group

The ILIL group is part of the Istituto Nazionale di Ottica and has been involved in laser-plasma acceleration in Italy since the beginning. With ELI-Italy contribution a new 200TW beam line is being constructed at ILIL in Pisa.

ELI-ITALY
INO-CNR (Pisa)

Laser plasma proton acceleration
The LILIA (laser induced light ions acceleration) experiment at LNF
NIM B 331 (**2014**) 15–19, S. Agosteo et. al.

Laser wake-fied electron acceletartion
First Experimental Results from the Plasmon-X Project,
Proceedings of the 51st Workshop of the CHANNELING 2008, p. 495,
L. A. Gizzi,et.al.

Istituto Nazionale di Ottica - CNR

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- Luca **LABATE** (CNR)*
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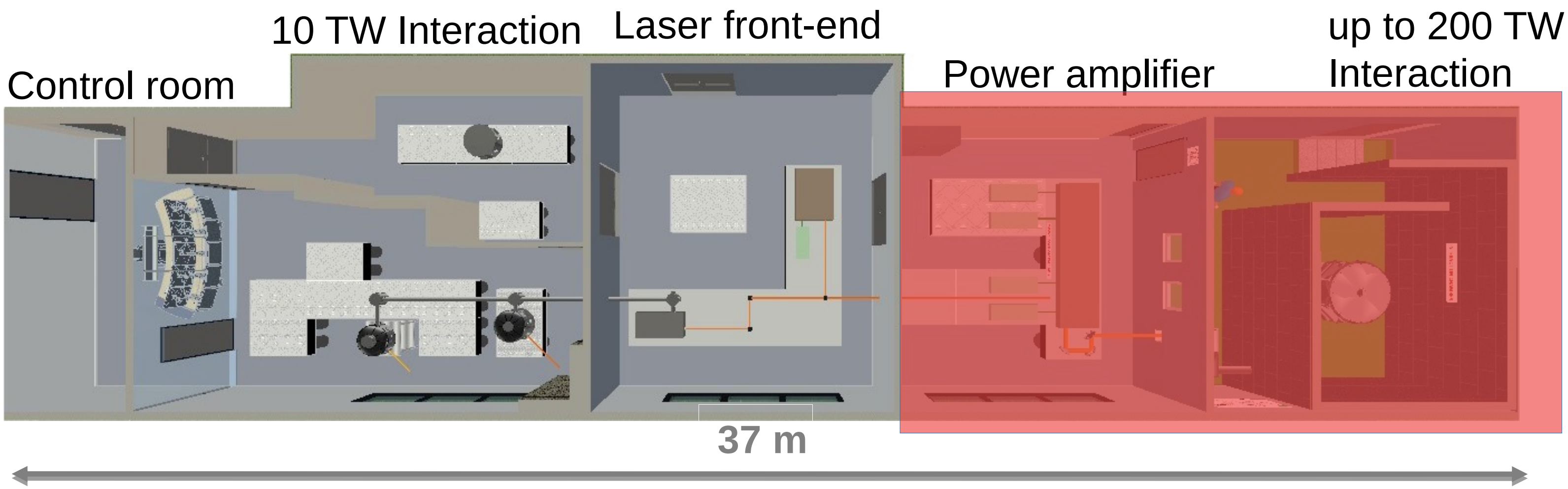
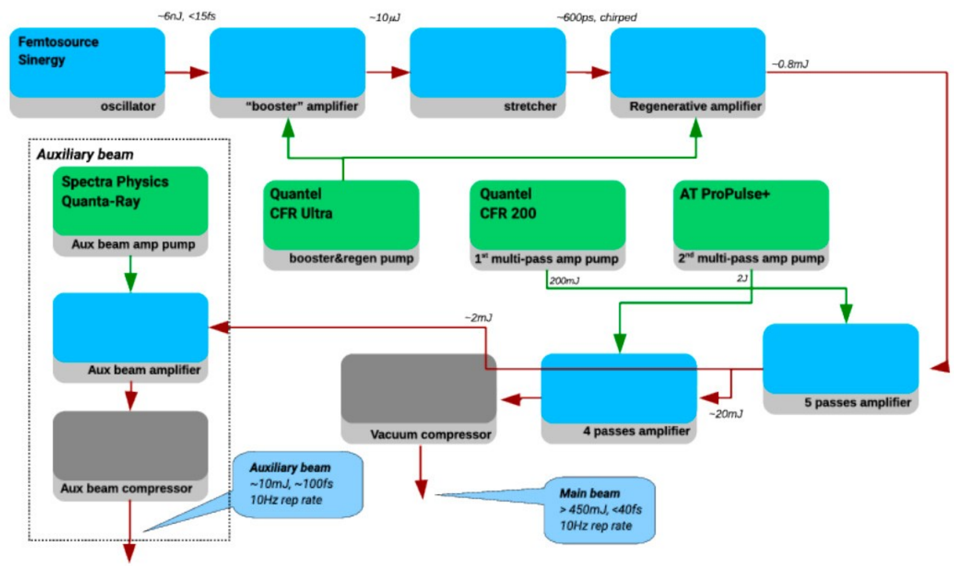
- Davide **TERZANI**, PostDoc Student*(Pi)

* Also at INFN

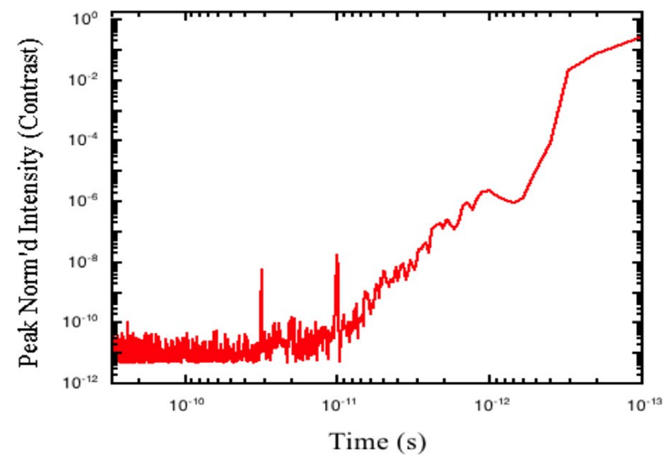
The laser system: 10 TW beam line





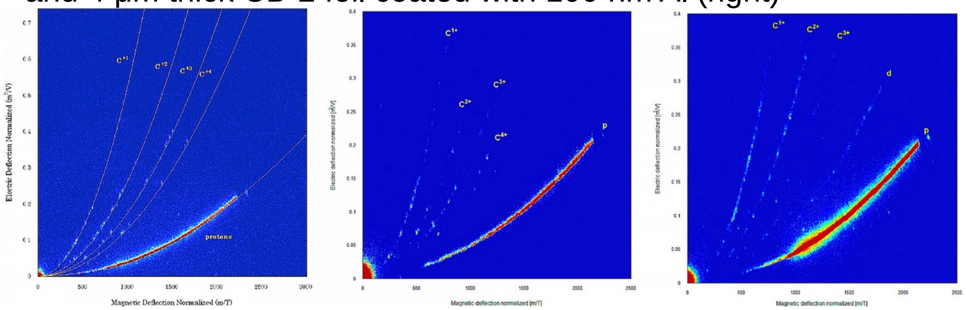
Proton acceleration with the 10 TW beam-line

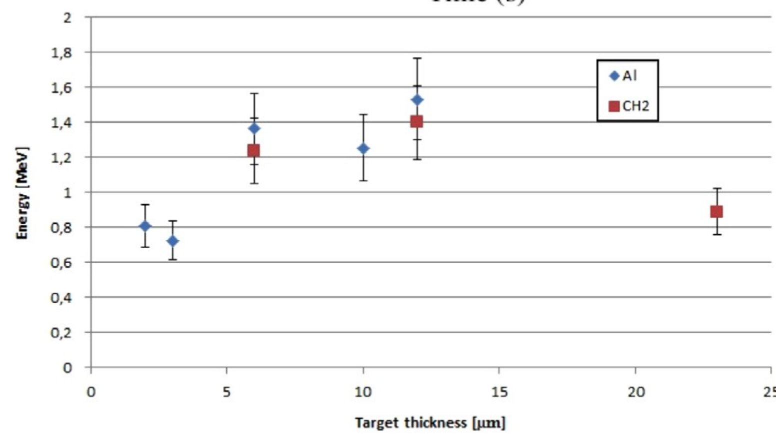
10 TW Ti:Sa laser system, up to 450 mJ on target, M^2 ~1.5.
angle of incidence of 15°, f/4.5 Off-Axis Parabolic mirror (OAP),
spot size of 6.2 μ m FWHM, giving a nominal intensity on target of about 2×10^{19} W/cm^2.
Nanosecond temporal contrast better than10^{10}

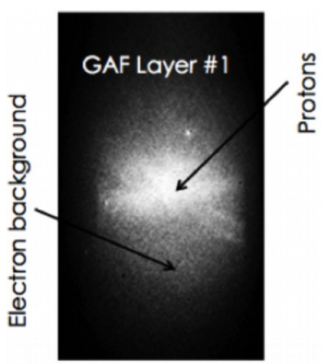


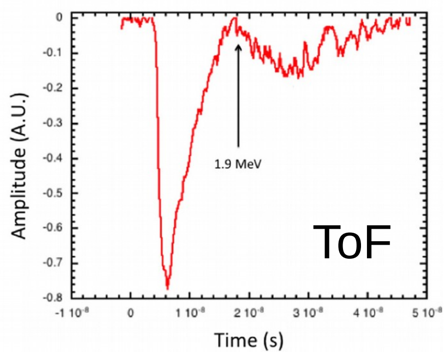
Thomson Parabola

10 μm thick Al (left), 4 μm thick CH_2 foil coated with 100 nm Al (centre), and 4 μm thick CD 2 foil coated with 100 nm Al (right)



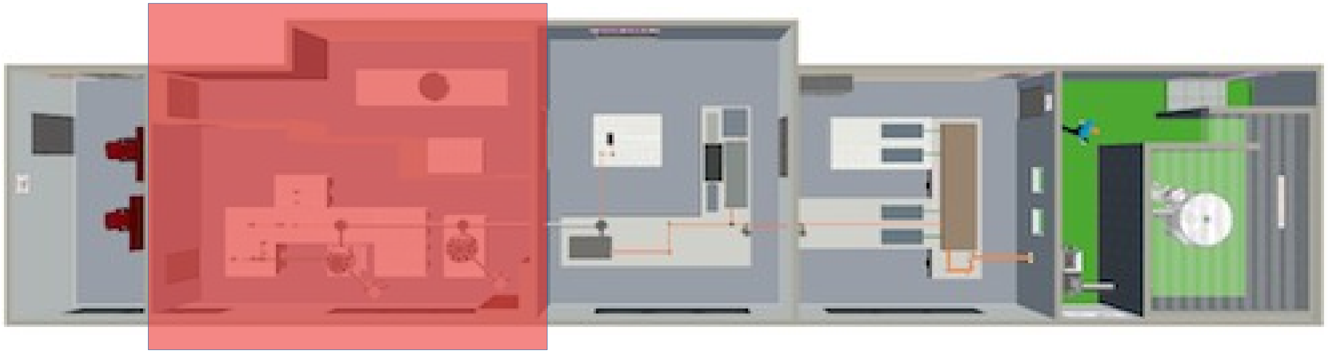


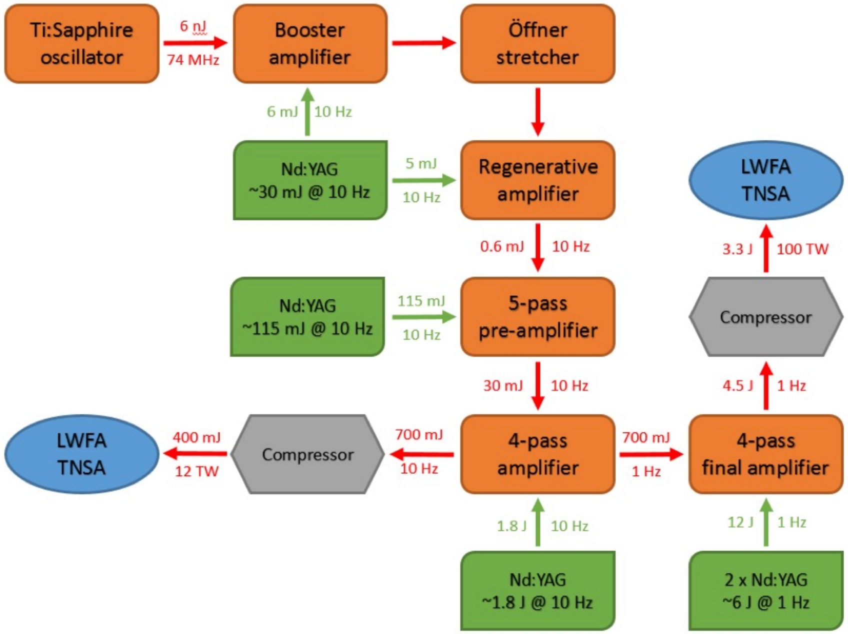


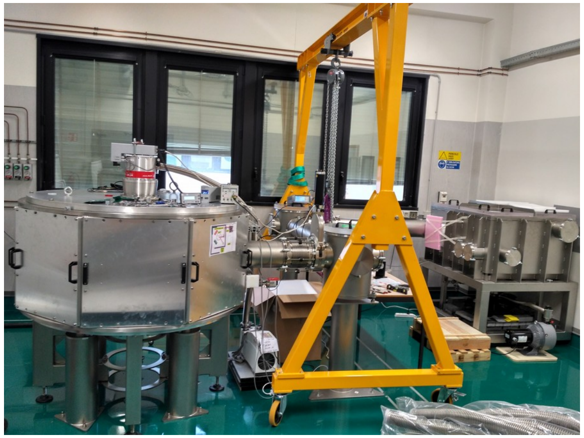


NIMA 829 (2016) 144–148, Role of laser contrast and foil thickness in target normal sheath acceleration,L.A. Gizzi et.al.

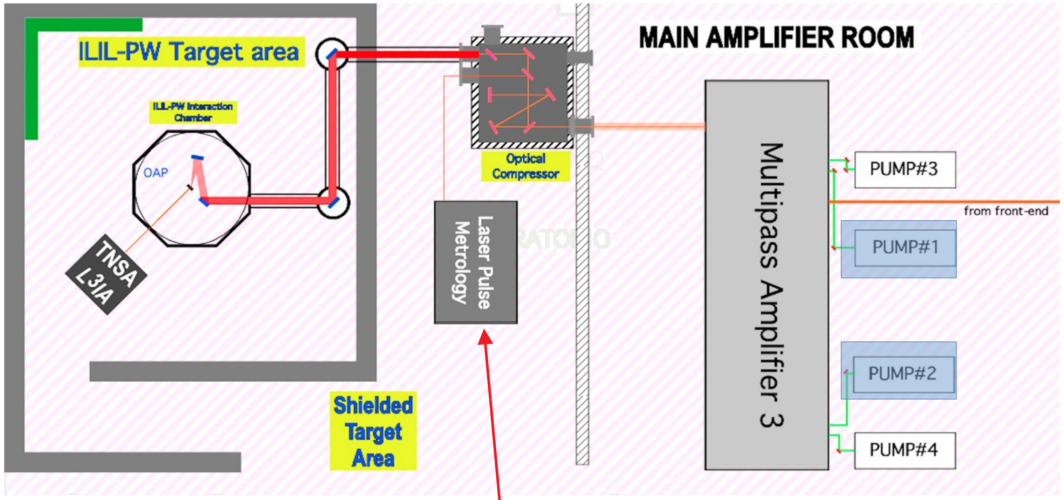
200 TW beam-line





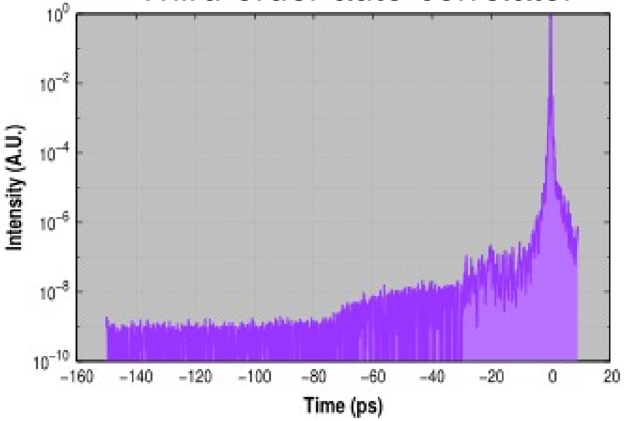


100 TW beam-line: characterization

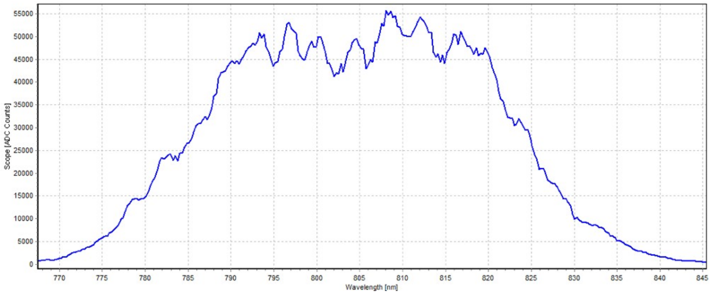


Laser diagnostic table

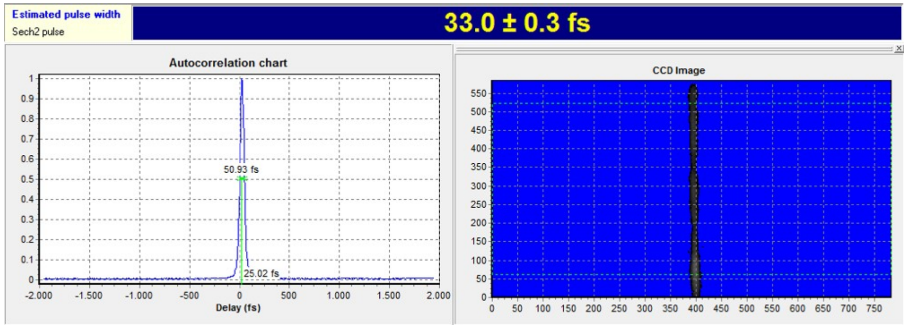
Third-order auto-correlator



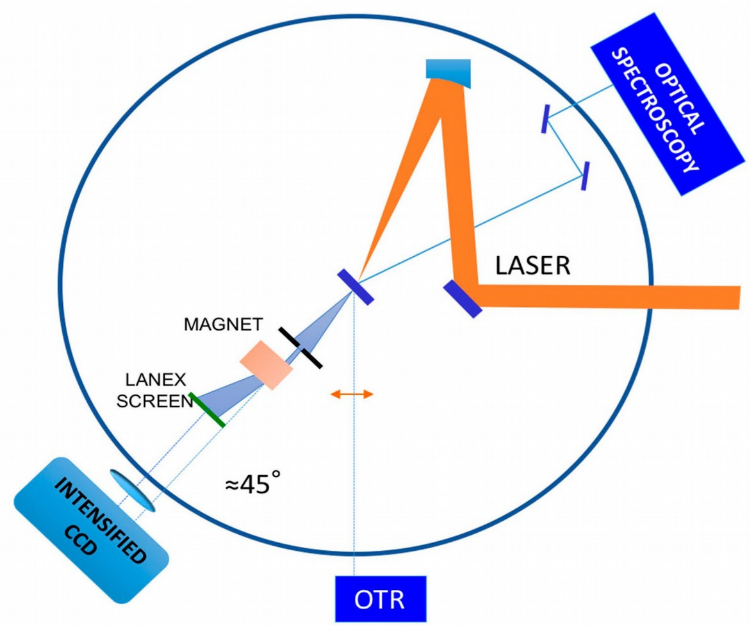
Spectrum

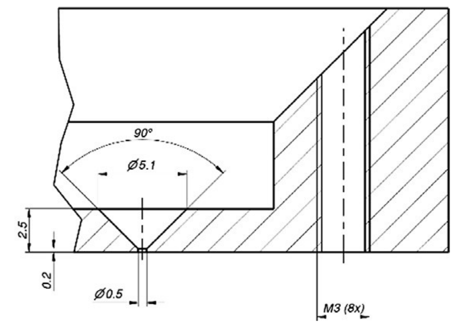


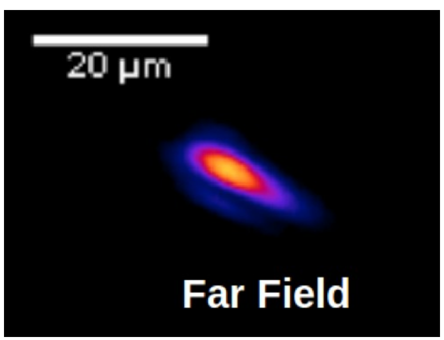
Pulse duration

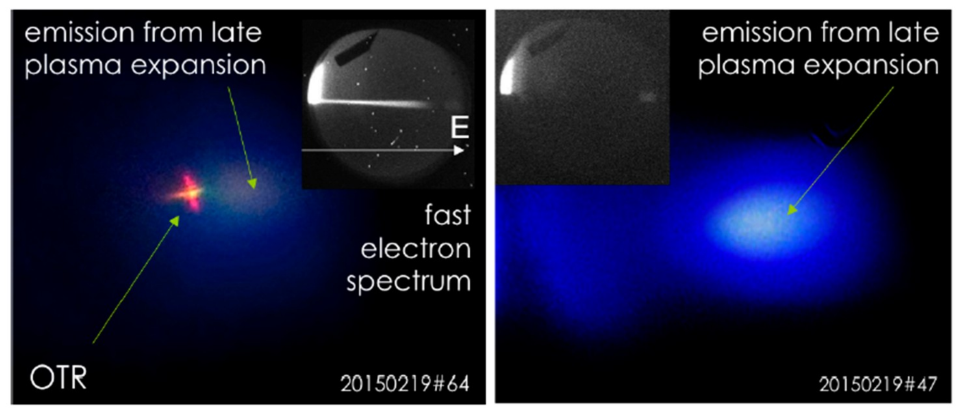


100 TW beam-line: Pilot experiments



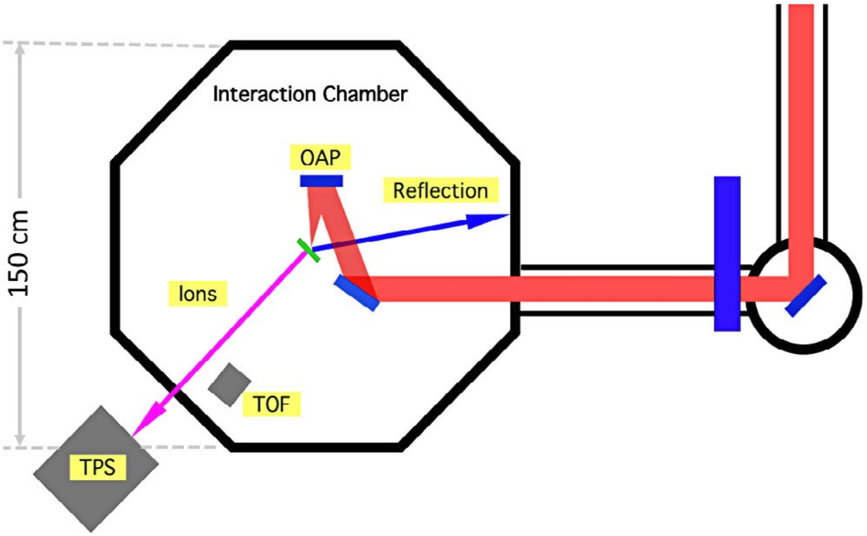


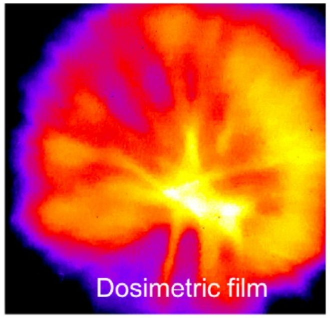


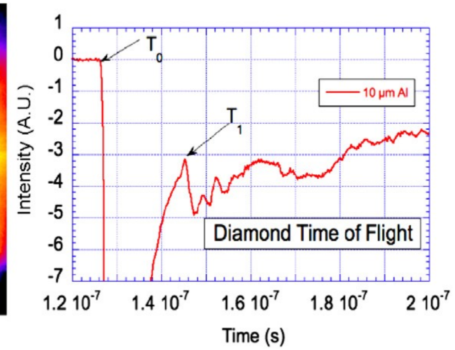


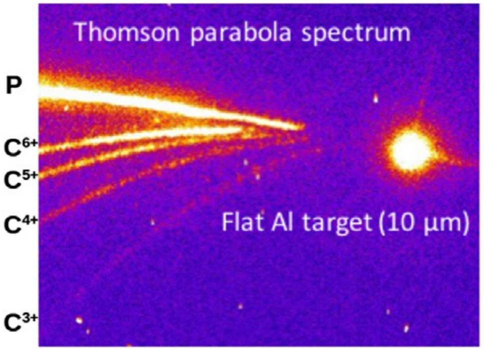
A New Line for Laser-Driven Light Ions Acceleration and Related TNSA Studies, L.A. Gizzi et.al., Appl. Sci. 2017, 7, 984;

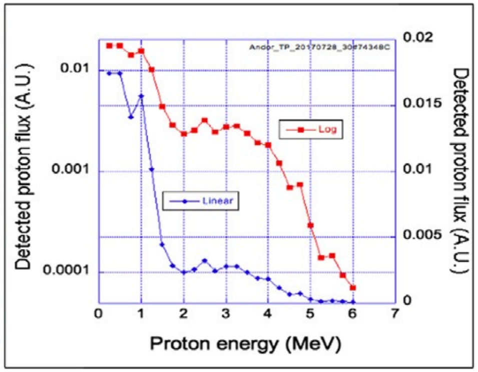
Towards a Light-Ion Laser Acceleration Beamline (L3IA)









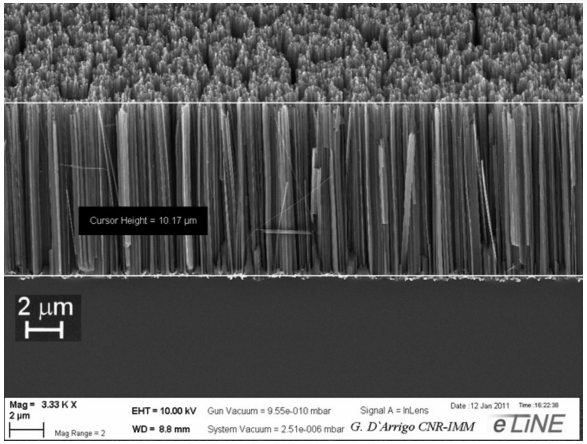


L3IA is a INFN funded project (CN5) to design and build a 14 MeV laser-driven proton beamline.
The ion beam will be used as a test site for experiments in multidisciplinary applications
L3IA will be based on the ILIL laser installation currently undergoing a 250 TW upgrade.

Milano, INFN and UNI (Coord)
Pisa, INO-CNR and INFN (Coord)
Bologna, INFN and UNIBO
Firenze, INFN
Catania, INFN
Napoli, INFN and UNI

Light Ion Accelerating Line (L3IA): Test experiment at ILIL-PW, L.A. Gizzi et.al.,**909**, 2018, 160

Laser-plasma with nanostructured targets



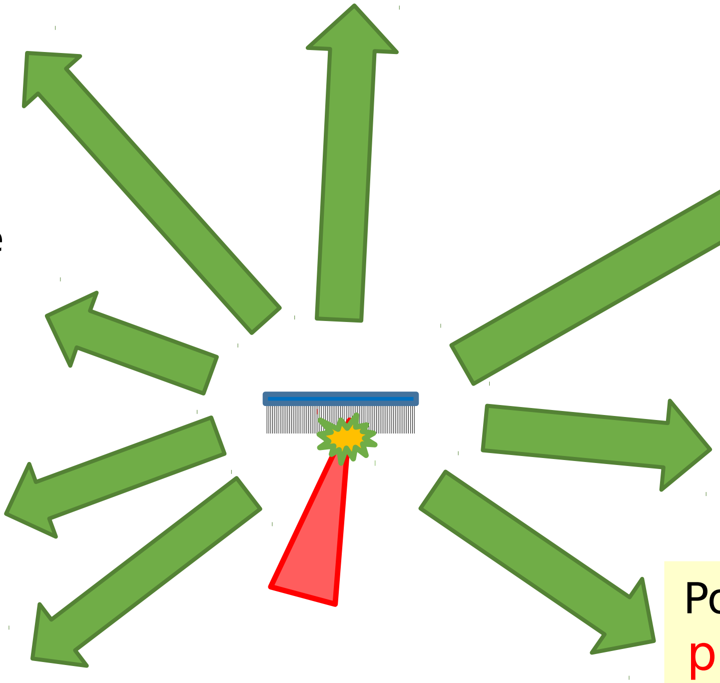
Up too hundreds MG magnetic field behind thin substrate; collimated relativistic electron transport in MA currents

Near complete absorption

Warm Dense Matter Plasmas with temperature of several keV at near solid density

Gbar pressure expected

Larger yield of hot electrons
Much hotter fast electrons



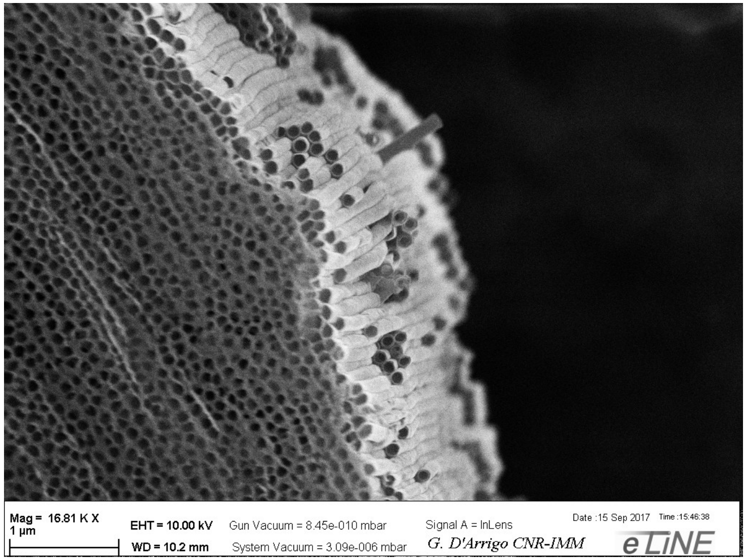
Enhancement of Kα emission from the substrate

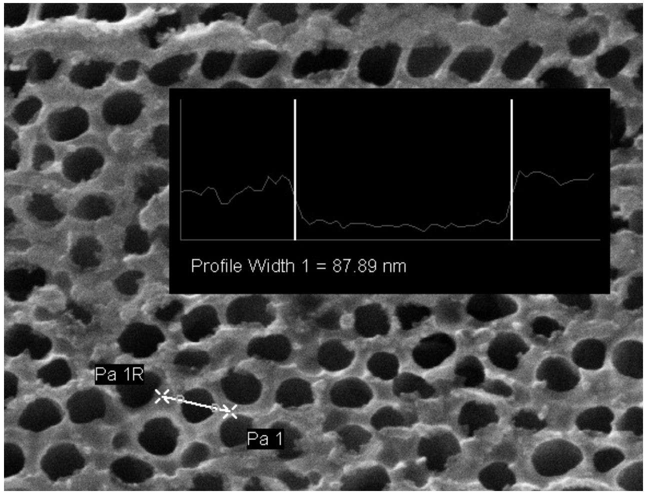
enhancement of hard X-rays Bremsstrahlung emission

Possible application for **proton acceleration**

Cristoforetti et al., Scientific Reports, 7,1479, 2017
Sarkar et al., APL Photonics, 2, 066105, 2017

TiO_2 nanochannels for proton acceleration



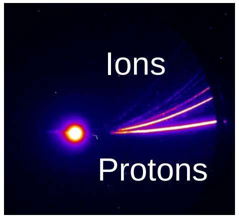


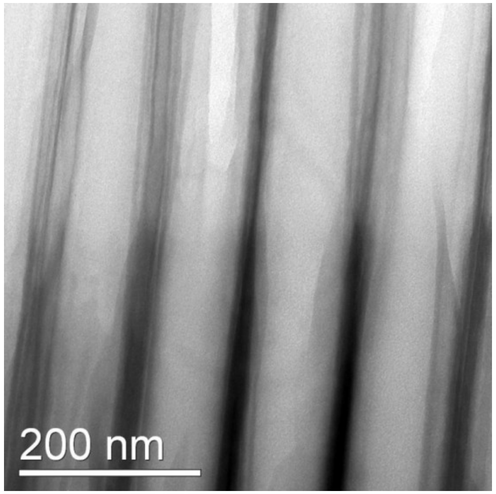
Produced by G. D'Arrigo

Institute for Microelectronics and Microsystems (IMM-CNR)
Catania, Italy

Target Thickness 14 microns, no bulk on the rear side
Pore Diameter ~100 nm, Porosity ~43%

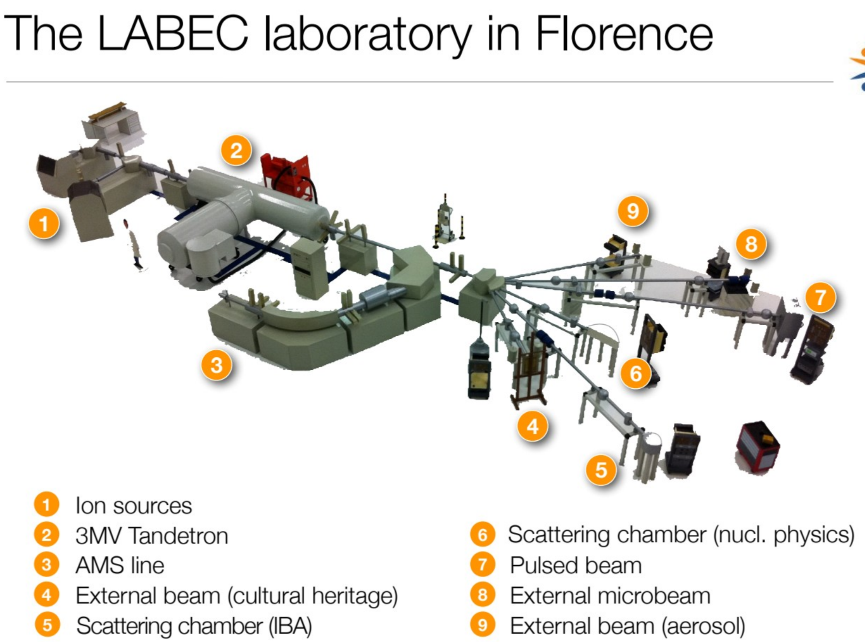
Experiments and simulations in progress



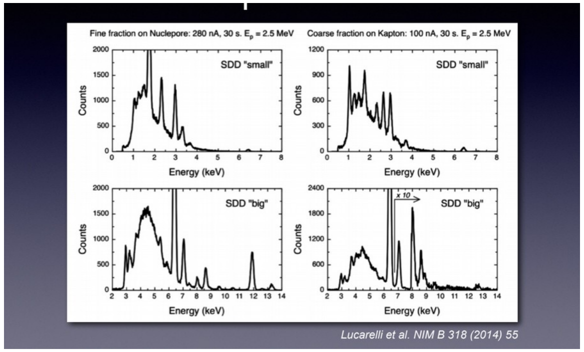


PIXE with laser-plasma based accelerators: the LaserPIXE project

LaserPIXE is a technology Transfer project, co-funded by UE, through Regione Toscana, and VCS S.r.l (Parma-Italy), a company expert in custom vacuum chambers and components.
Research Partners: LABEC Laboratory (INFN-Florence), Institute of Clinical Physiology (CNR, Pisa).
Goal: design a prototype proton laser-plasma accelerator (up to ~3 MeV) to perform PIXE measurements.



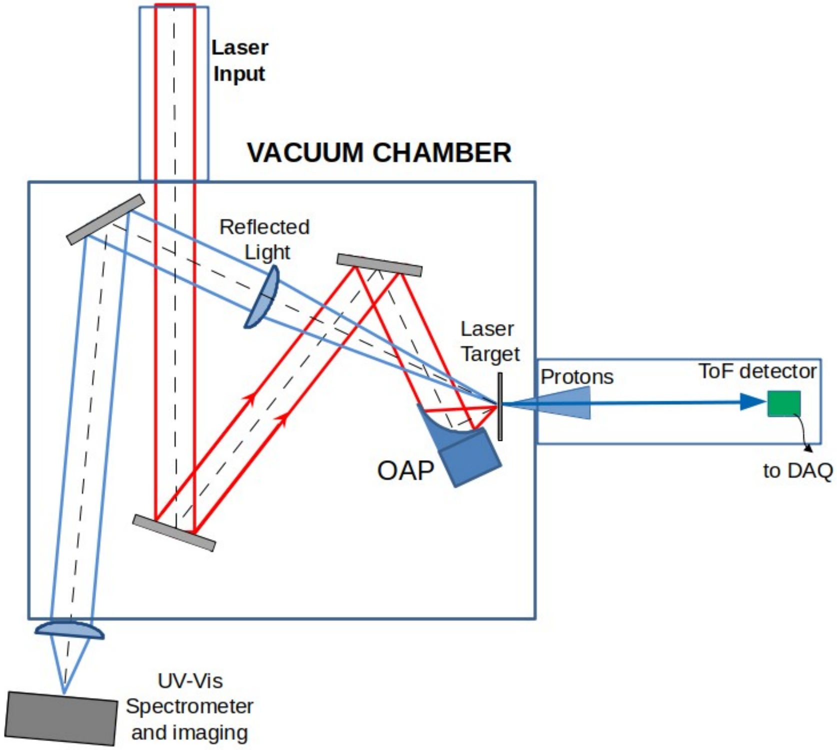
PIXE measurements at LABEC of aerosol from air quality monitoring stations.



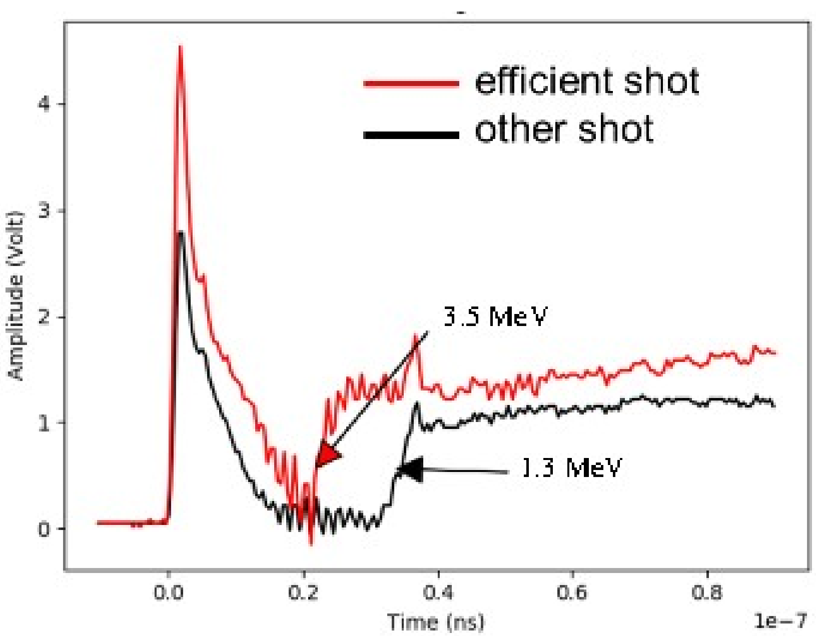
Courtesy of Massimo Chiari, INFN LABEC laboratory Florence

PIXE with laser-plasma based accelerators: production of > 3 MeV cut-off protons

-) 10TW beam line;
-) Off-the-shelf OAP: f/1, 90 degrees
-) Laser-plasma acceleration targets: Al 10 micron, **Ti 5 micron.**

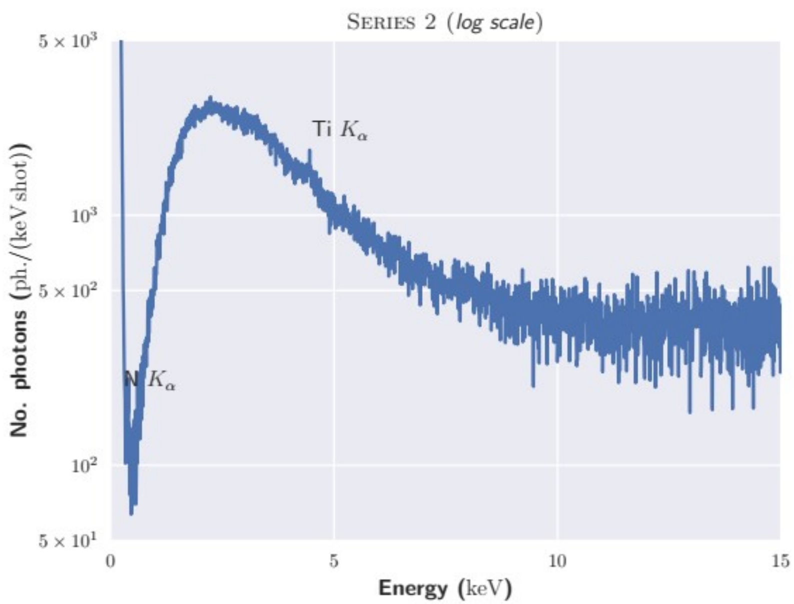


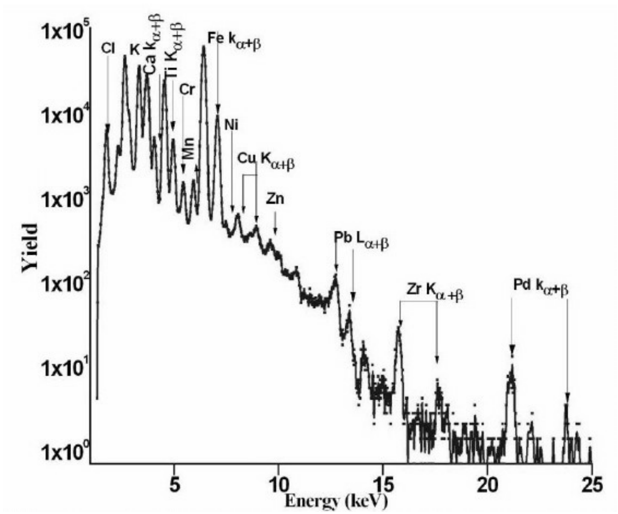
ToF measurements



PIXE with laser-plasma based accelerators: pilot PIXE measurement

PIXE Target: **Titanium**





Start-to-end simulations from the proton source through the magnets up to the X-Ray detector are in progress using GEANT4 tool kit

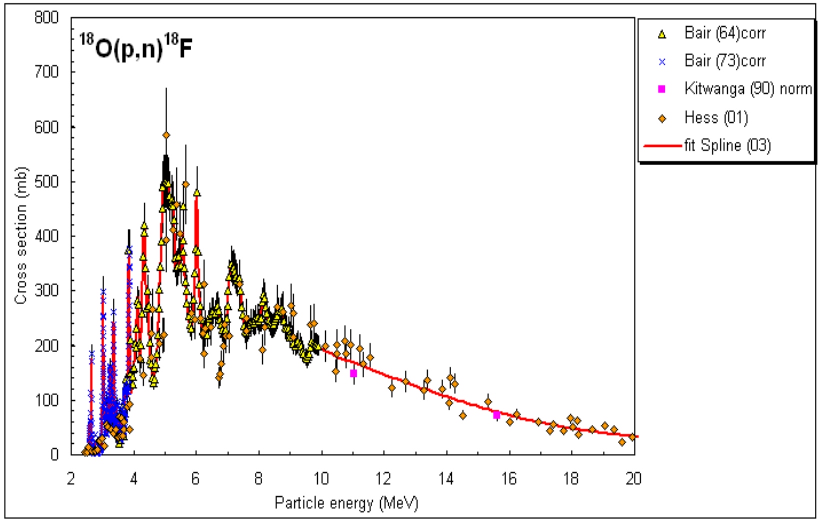
A typical NIST reference esturine sediments sample PIXE spectra, Standard Reference Material 1646a. (International Journal of PIXE 21, 75, 2011)

Radioisotope production

<u>Reaction</u>: $^{18}O\ (p, n)^{18}F$

$T_{1/2}(^{18}F) = 109{,}7\ min = 6582\ s$

Energy (MeV)	Cross section (mb)		
	[IAEA 2001]	IAEA 2003	[Hess et al, 2001]
2,5	8,3	2,7	4,6
3,0	33,4	88,0	30,1
3,5	44,4	46,9	31,7
4,0	199,0	156,8	175,0
4,5	182,0	220,2	221,7
5,0	501,0	502,4	585,9



e.g. radioisotopes with shorter life time: ^{11}C (20 min); ^{13}N (10 min).

<u>Laser driven radioisotope production</u>

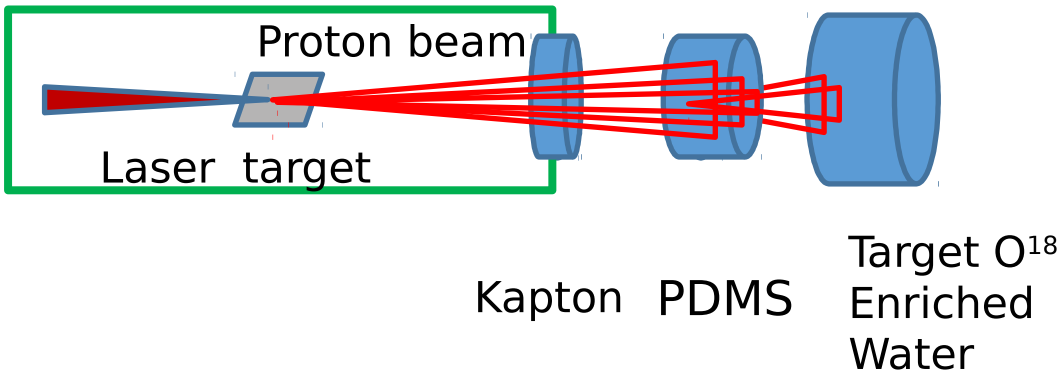
Activation target	LOA laser at 10 Hz MBq (mCi)	LOA laser at 1 kHz MBq (mCi)
^{11}B	13.4 (0.36)	1340 (36.2)
^{18}O	2.9 (0.08)	290 (7.9)

Proton beams generated with high-intensity lasers: Applications to medical isotope production,
S. Fritzler et. al., Appl. Phys. Lett.83:3039, 2003

Radioisotope production

The goal of this activity is to investigate the feasibility of the production of small batch of radioisotopes in combination with a micro-fluidic device

SET-UP OUTLINE



Initial Energy (MeV)	Final Energy (MeV)	Cross section (mb)	Stoppin Power In target (MeV g/cm2)
3,0	2,5	4,6	124,5
3,5	3,0	47,3	108,2
4,0	3,6	60,2	95,9
4,5	4,6	221,7	78,8
5,5	5,2	404,6	67,2
6,0	5,7	248,5	63,0

Collaborators:
-) Australian Nuclear Science and Technology Organisatio (ANSTO) – Radiochemistry team;
-) Institute of Clinical Physiology, CNR;
-) Institute of Nanotechnology, CNR.

CNRNANOTEC INSTITUTE OF NANOTECHNOLOGY

Conclusions

-) The new laser system and beam-lines at ILIL has been presented

-) the use of nanostructured solid targets at ILIL has been discussed

-) on-going research activity towards applications of laser driven ion accelerators has been presented

Out-look:

-) After decades of intense exploration of laser driven acceleration the technology is mature enough to foreseen in the short term a break-through in non-biological applications

-) the break-through will trigger interest and further advanced research needed for biological applications

Acknowledgments

L. A. Gizzi[1,2], F. Baffigi[1], G. Bussolino[1], G. Cristoforetti[1], A. Fazzi[3,4], L. Fulgentini[1], D. Giove[4], A. Giulietti[1], P. Koester[1], L. Labate[1,2], G. Maero[4,5], G. Messina[1], D. Palla[1], M. Romé[5], P. Tomassini[1]

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Thank You

for the attention