Laser-driven Ion Acceleration and Societal Applications at the Extreme Light Infrastructure (ELI)

Daniele Margarone

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- **ELI-Beamlines**: *F. Schillaci, L. Giuffrida, F. Grepl, A. Velyhan, M. Tryus, T. Chagovets, M. Zakova, J. Psikal, V. Scuderi, G. Korn*
- **INFN-LNS:** *G.A.P. Cirrone, G. Petringa, F. Romano, G. Cuttone*
- **Queen's Un.**: *M. Borghesi, S. Kar, H. Ahmed, G. Milluzzo, A. McIlvenny, P. Martin, D. Doria*

EAAC, Elba, September 16-20, 2019

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Contents

- **ELIMAIA user beamline**
  - *“a laser-driven ion accelerator for multidisciplinary applications”*
  - *why radiobiology with laser-accelerated ion bunches?*

- **R&D on high rep. rate targetry and detectors**
  - *debris-free cryogenic targets*
  - *real-time ion diagnostics*

- **First particles (ions and electrons) accelerated at the TERESA testbed by the HAPLS (L3) laser @ 10s TW**

ELI-Beamlines experimental areas

www.eli-beams.eu

Laser Building

First Floor

Ground Floor

Basement

Support Room
Cryogenic systems, power supply cooling, aux

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

Experimental Hall 1
Material & biomolecular applications

Experimental Hall 2
X-ray sources

Experimental Hall 3
Plasma Physics

Laser 4c
10 PW pulse compressors

Experimental Hall 4
Proton acceleration

Experimental Hall 5
Electron acceleration

Experimental Hall 6

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ELI-Beamlines: lasers

Invited talk by G. Korn (Thursday, 11:00)

Beamline	L1	L2 (development)	L3	L4
Peak power	7 TW	100 TW	≥1 PW	10 PW
Energy in pulse	100 mJ	1.5	≥30 J	≥1.5 kJ
Pulse duration	<15 fs	<15 fs	≤30 fs	≤150 fs
Rep rate	kHz	20 Hz	10 Hz	1 per min
Supplier	Pump lasers from industry (Trumpf)	Subsystems from STFC	LLNL	National Energetics
ELI-Beamlines	**OPCPA pulse chain, pulse compressors, controls & timing systems**	**Pump laser subsystems, ps OPCPA, controls & timing systems**	**Compressor, short pulse diagnostics, controls & timing systems**	**Compressor design, OPCPA design, short pulse diagnostics, timing system**

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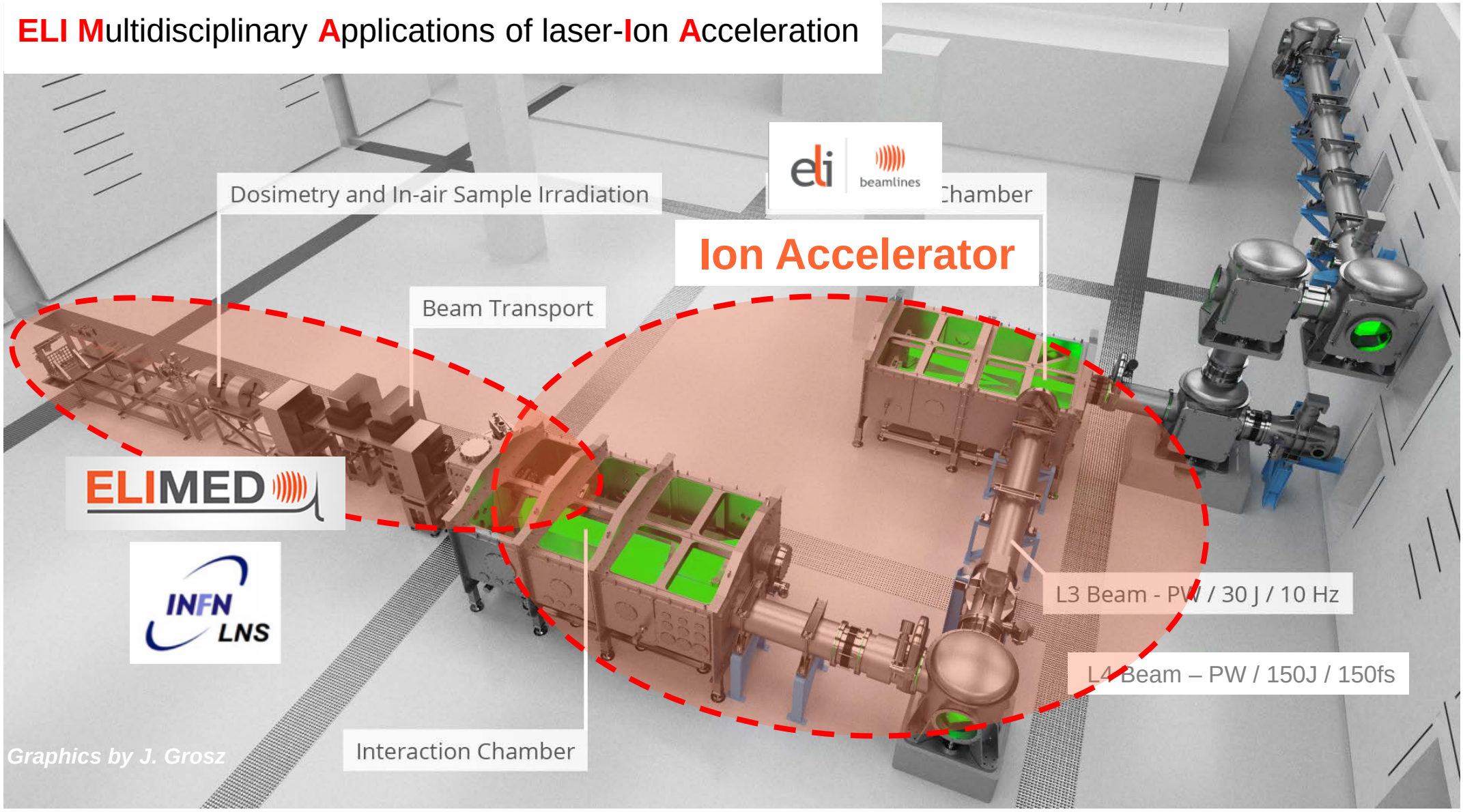
ELIMAIA: a User Beamline

ELI Multidisciplinary **A**pplications of laser-**I**on **A**cceleration



ELIMAIA-ELIMED mission profile

- The **ELIMAIA** beamline *(ion accelerator + transport + user stations)*
  ELI Multidisciplinary Applications of laser-Ion Acceleration
  Dual bid:
  - provide an experimental platform to users who
    accelerators with multi-PW, high rep. rate lasers
  - provide laser driven ion beams with unique feat
    for applications in biomedicine, chemistry, mate

Tallk by R. Catalano

- The **ELIMED** line *(transport and dosimetry)*
  ELI MEDical applications
  Dual bid:
  - carry out transport and absolute dosimetry of laser-accelerated ion beams with ultrahigh dose rate
  - gather a user community with future goal of clinical applications using a compact approach to cancer therapy (radiobiologists, medical doctors)

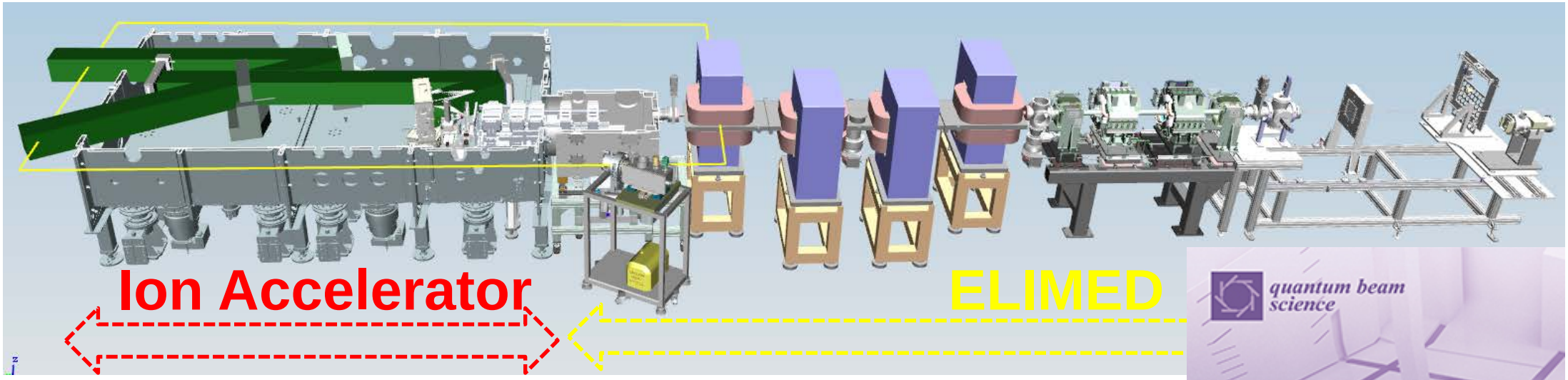
ELIMAIA technical development: completed

beamlines

Acceleration, Collimation & Diagnostics

Selection, Transport & Diagnostics

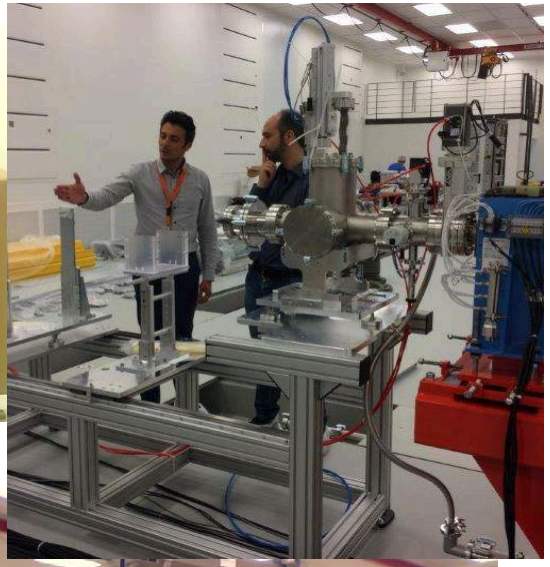
Dosimetry & Sample Irradiation

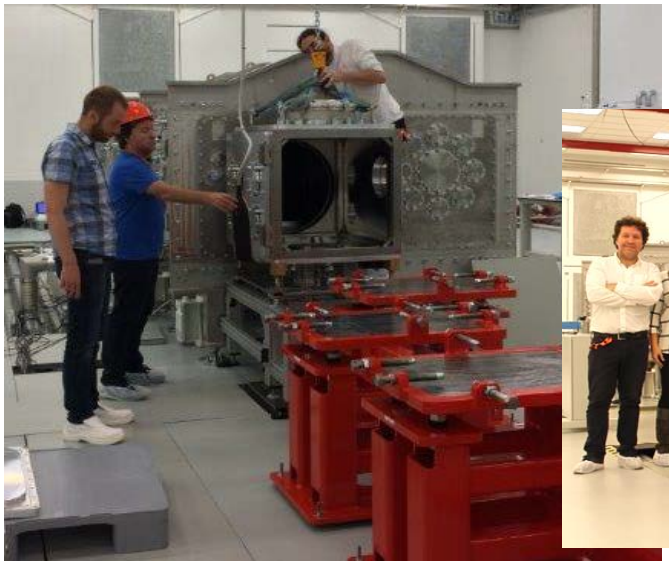


*D. Margarone et al., "**ELIMAIA: A Laser-Driven Ion Accelerator for Multidisciplinary Applications**", Quantum Beam Sci. 2 (2018) 8*

ELIMAIA installations

June-July 2018





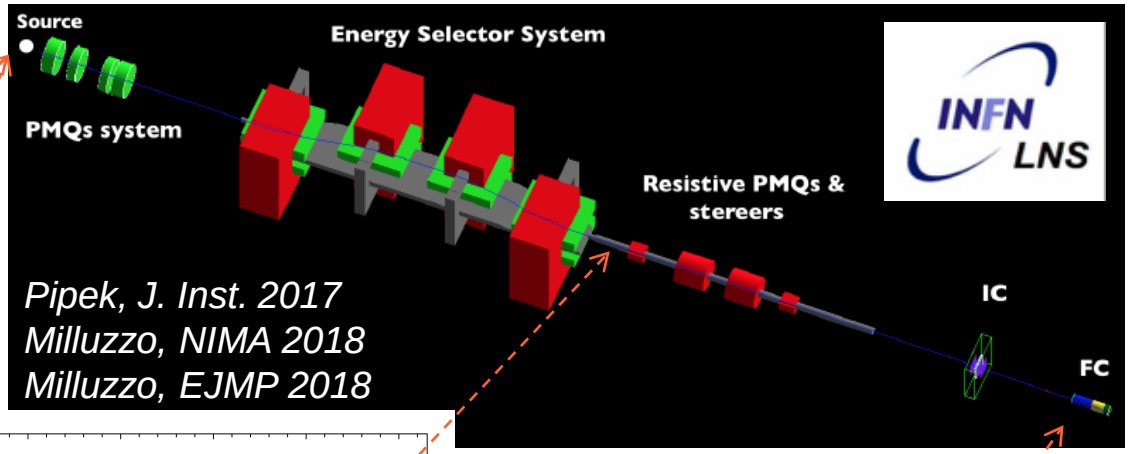
ELIMAIA-ELIMED @ ELI-Beamlines

August 2018

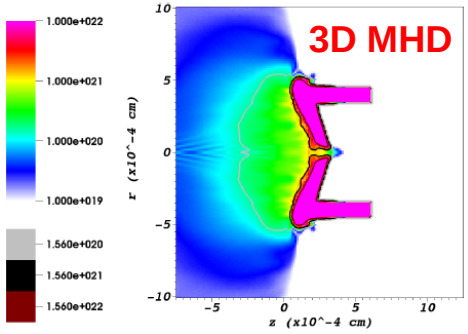
ELI Multidisciplinary Applications of laser-Ion Acceleration

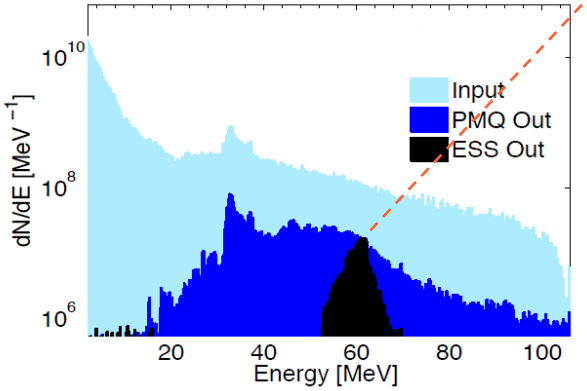
Start-to-end simulations

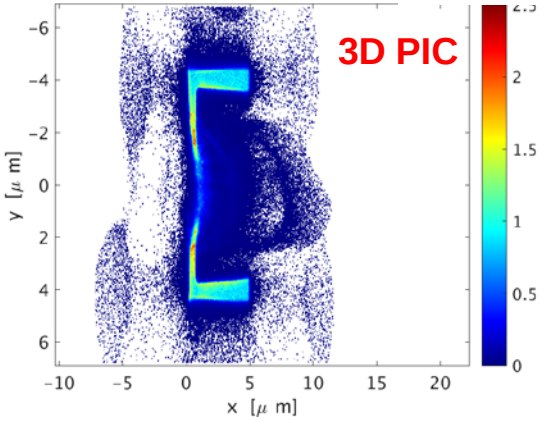
- *3D MHD (pre-plasma)*
- *3D PIC (acceleration)*
- *3D GEANT4 (transport & dosimetry)*



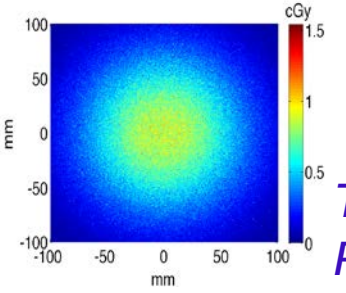
Cooperation with KIAM & LBNL





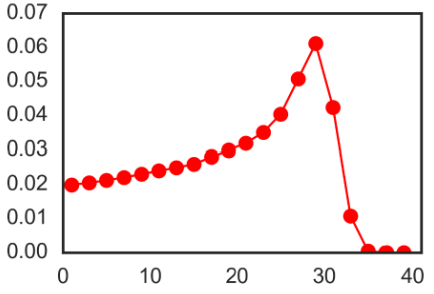


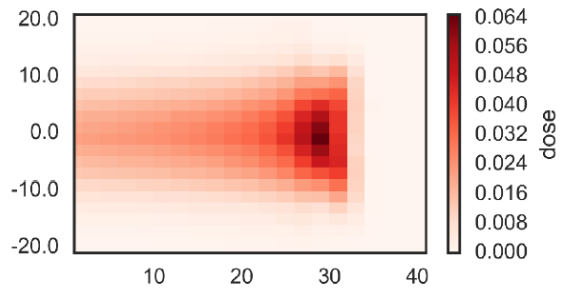
Cooperation with INFN-LNS



Tallk by R. Catalano

Bragg peak, dose in Gy per shot





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The ELIMAIA beamline User Offer

Summary of key equipment

Equipment	2019	2020+
Vacumm chambers	Target chamb., plasma mirr. chamb., user station	Dedicated chamber for 10 PW
Focusing Optics (OAP)	f/1.5 (L3)	f/3 or f/4 (L4)
Targets (0.01-10 Hz)	thin foils @1Hz (0.01-10 μm)	Cryog. H @10Hz (5-100 μm)
Diagnostics (0.01-10 Hz)	TP ion spectr., TOF detectors, optical probes, Espec, X-ray cameras	Streak cameras
Ion beam transport	PMQs, energy selector, conventional elements	Ion buncher (sub-ns beams)
Ion beam dosimeters	Faraday cup, ionization chamber, SEM	
Sample irradiation	In-air and in-vacuum system	

What users will get *(after commissioning)*

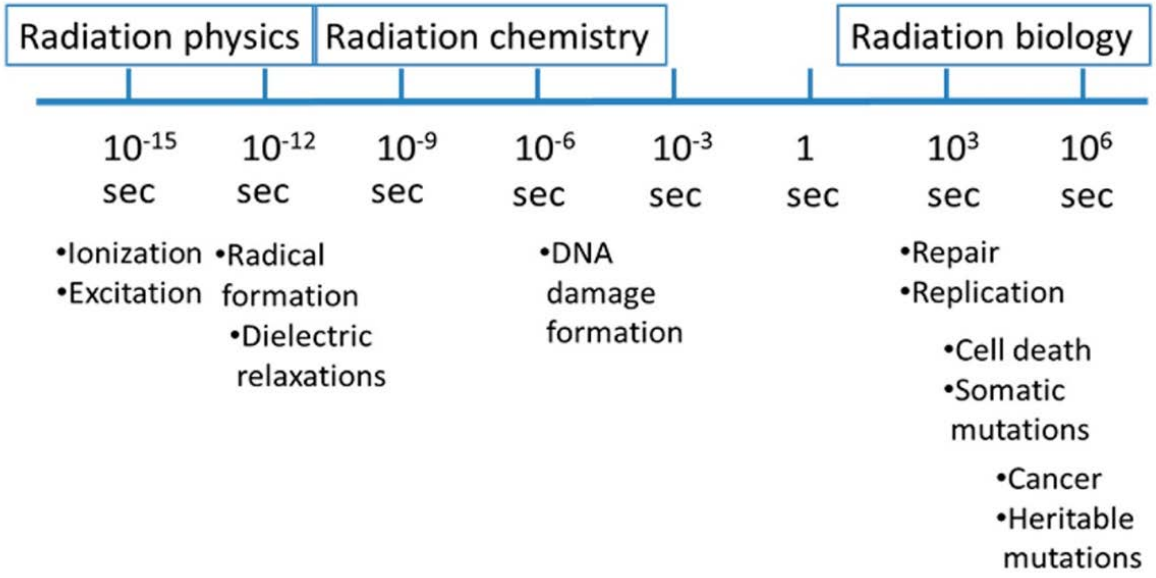
Ion Beam Features	Enabling/pilot exp. (2020)	Flagship exp. (2020+)
Energy range	**3-60 MeV/u**	**3-300 MeV/u**
Ion No. / laser shot	$>10^8$ in 10% BW	$>10^9$ in 10% BW
Bunch duration	1-10 ns	0.1-10 ns
Energy spread	**±5%**	**±2.5%**
Divergence	±0.5°	± 0.2°
Ion Spot Size	0.1-10 mm	0.1-10 mm
Repetition rate	0.01-**1 Hz**	0.01-**10 Hz**

Multidisciplinary Applications of laser driven ion beams

- ✓ Diagnosis of intense interaction phenomena by **Proton Radiography**
- ✓ Isochoric heating for WDM (warm dense matter) by **Proton Heating**
- ✓ **Nuclear Reactions** initiated by Laser-Driven Ions (fast and brilliant **neutron source** for radiography, ICF fast ignition with protons, proton-boron fusion, …)
- ✓ Studies of **ion stopping power in plasmas**

- ✓ Innovative approaches to **Radiobiology**, **Hadrontherapy**, **nuclear medicine** (PET)
- ✓ **Radiation chemistry** (pulsed radiolysis of water, management of nuclear wastes, medical therapy)
- ✓ Mimicking **space radiation** (electronics/detectors, radiobiology)
- ✓ Archeology/**cultural heritage** (PIXE, PAA, DPAA)

Radiobiology
laser-accelerated ions



Remarks:

- ✓ Laser-driven ions are emitted at the source within a time $\Delta T <$ ps resulting in dose deposition in **100s ps - ns pulses** at the sample
- ✓ **Prompt dose rates > 10^9 Gy/s** can be achieved *(compared with Gy/min used in radiotherapy)*

Possible effects proposed in literature:

- **Spatio-temporal overlap of independent tracks** causing collective effects and enhancing LET, hence RBE (tumor)
- **Local depletion of oxygen** causing a reduction in cell radiosensitivity (healthy tissues)

Motivations:

- ➢ Development of a methodology and demonstration of viability at **ultra-high dose rate** hadron beams
- ➢ Validation of laser-driven sources in view of future **therapeutic use**
- ➢ Provision of an alternative, flexible source for **radiobiological studies**

L. Manti et al., J. Inst. 12 (2017)
M. Durante et al., Br. J. Radiol. 91 (2018)

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  - *debris-free cryogenic targets*
  - *real-time ion diagnostics*

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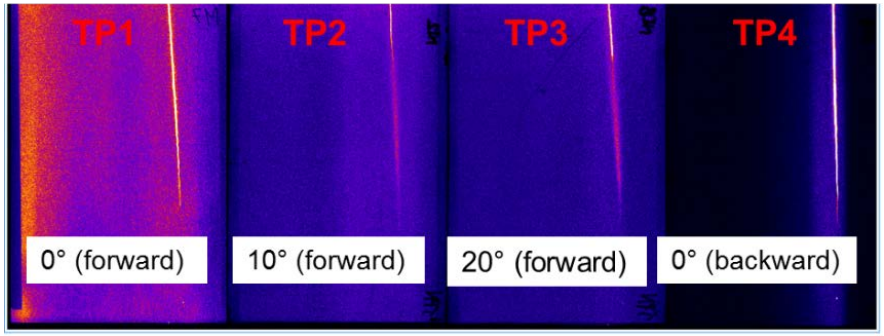
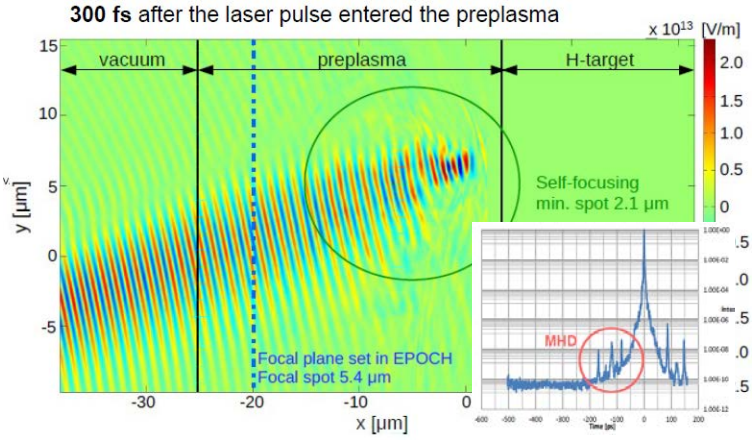
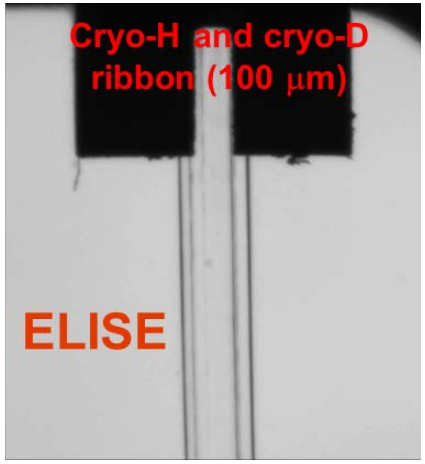
High rep. rate targetry

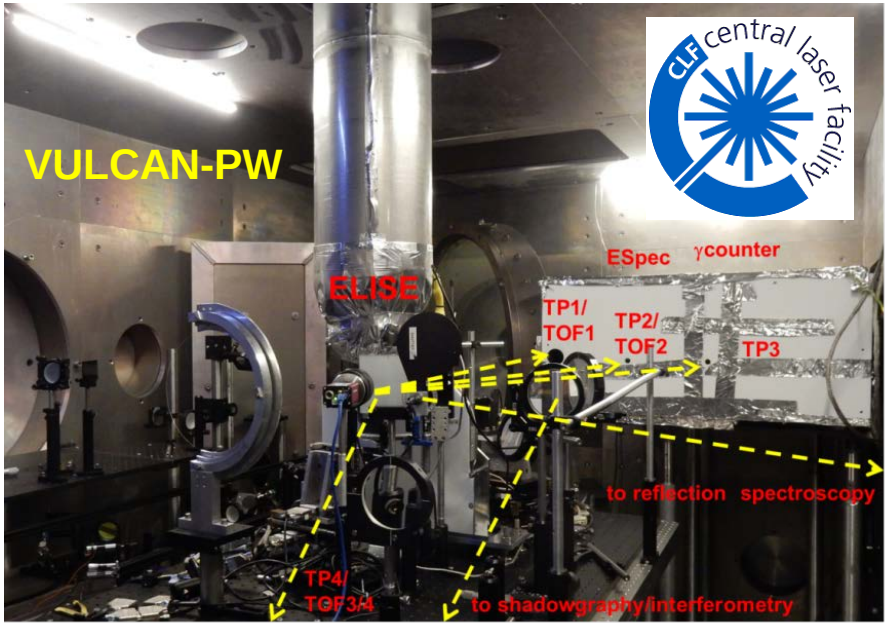
debris-free cryogenic targets

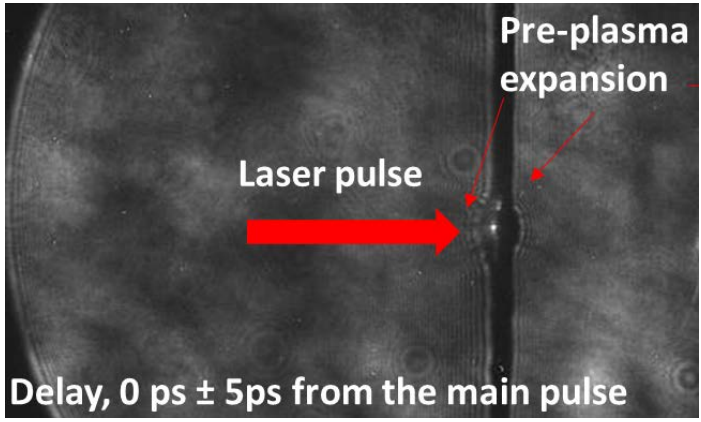
Garcia LPB (2014)
Margarone PRX (2016)











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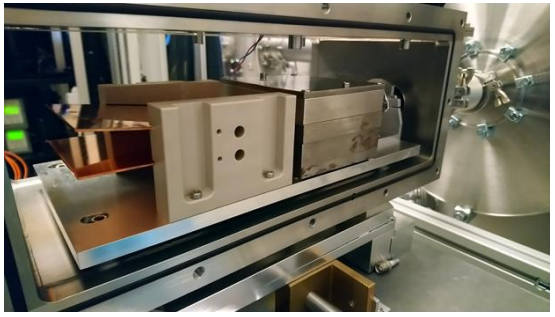
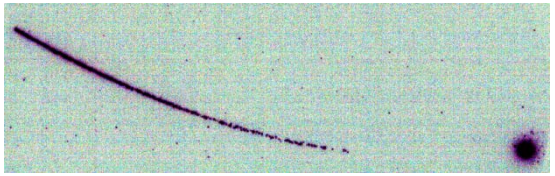
High rep. rate detectors
ion diagnostics & dosimetry

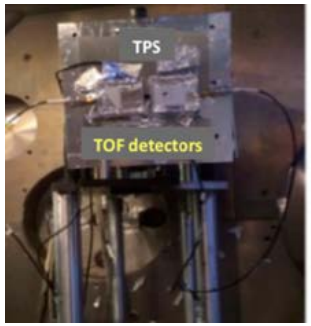
beamlines

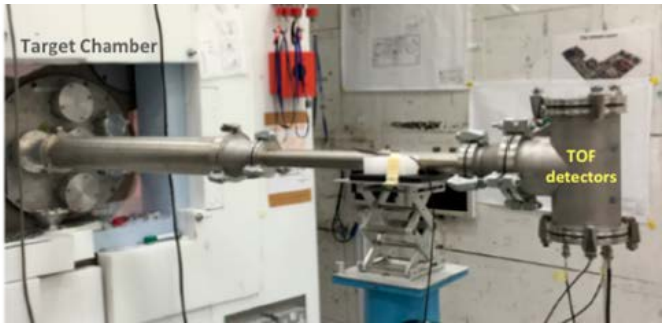
TP spectrometer

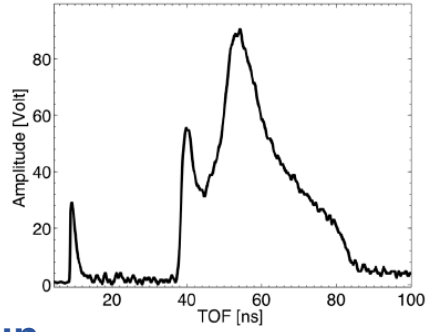


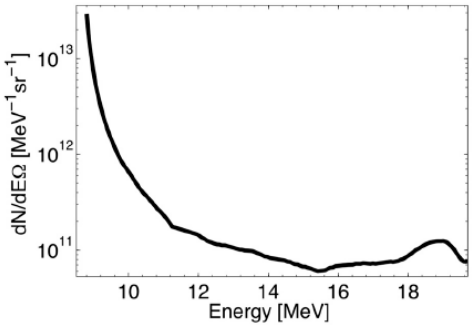


TOF (diamond)

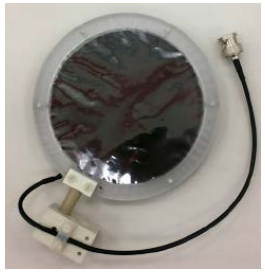




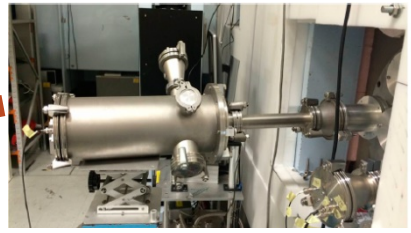


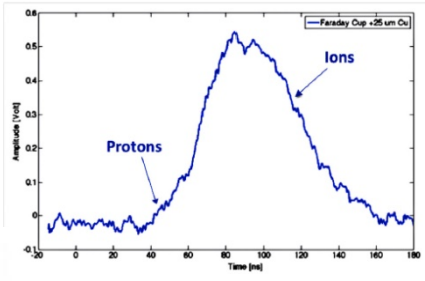


SEM

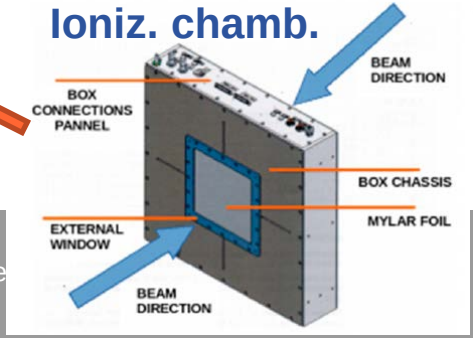


Faraday cup





Ioniz. chamb.



Tallk by R. Catalano

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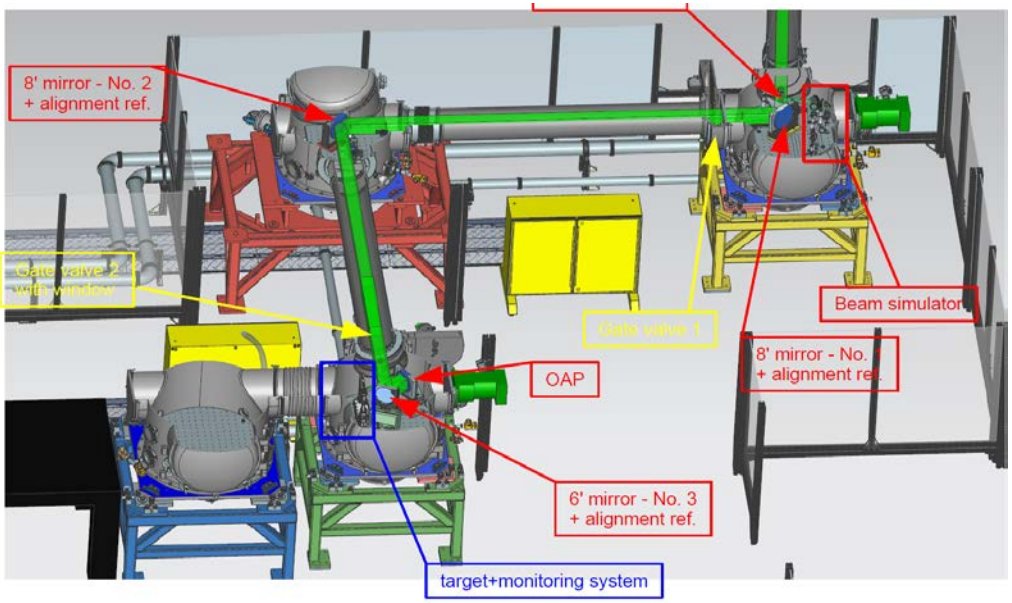
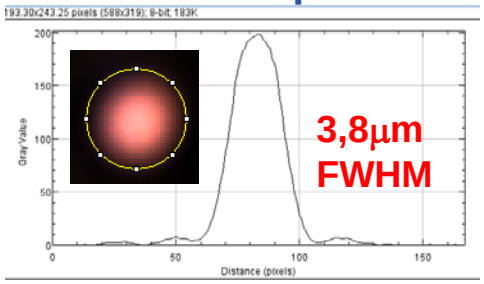
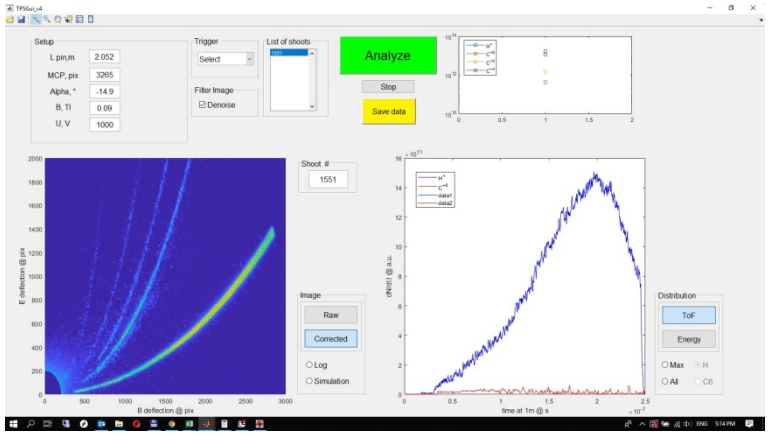
TERESA testbed for “commissioning zero”

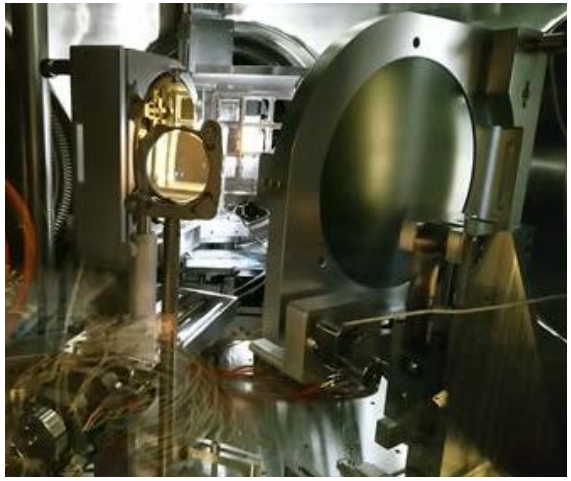
first acceleration experiments with L3-HAPLS



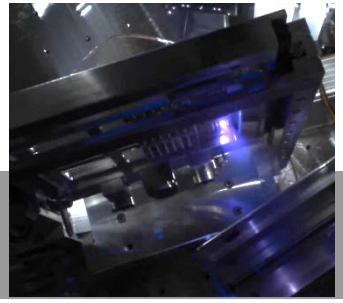
Focal spot







First shot on target!



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