Status of I-LUCE

Jan, 2024

Pablo Cirrone, INFN-LNS

lasers and particle acceleration?

The main ingredients for radiation productions

A laser

- High power (TW - PW)
- Short pulse duration (ps - fs)
- Intensity > 10^{16} W/cm^2

A Target:

- Thin/thick solid/liquid/gassous

…

Other useful things

- High contrast laser
- High quality target fabrication
- High quality wave front-end
- …..

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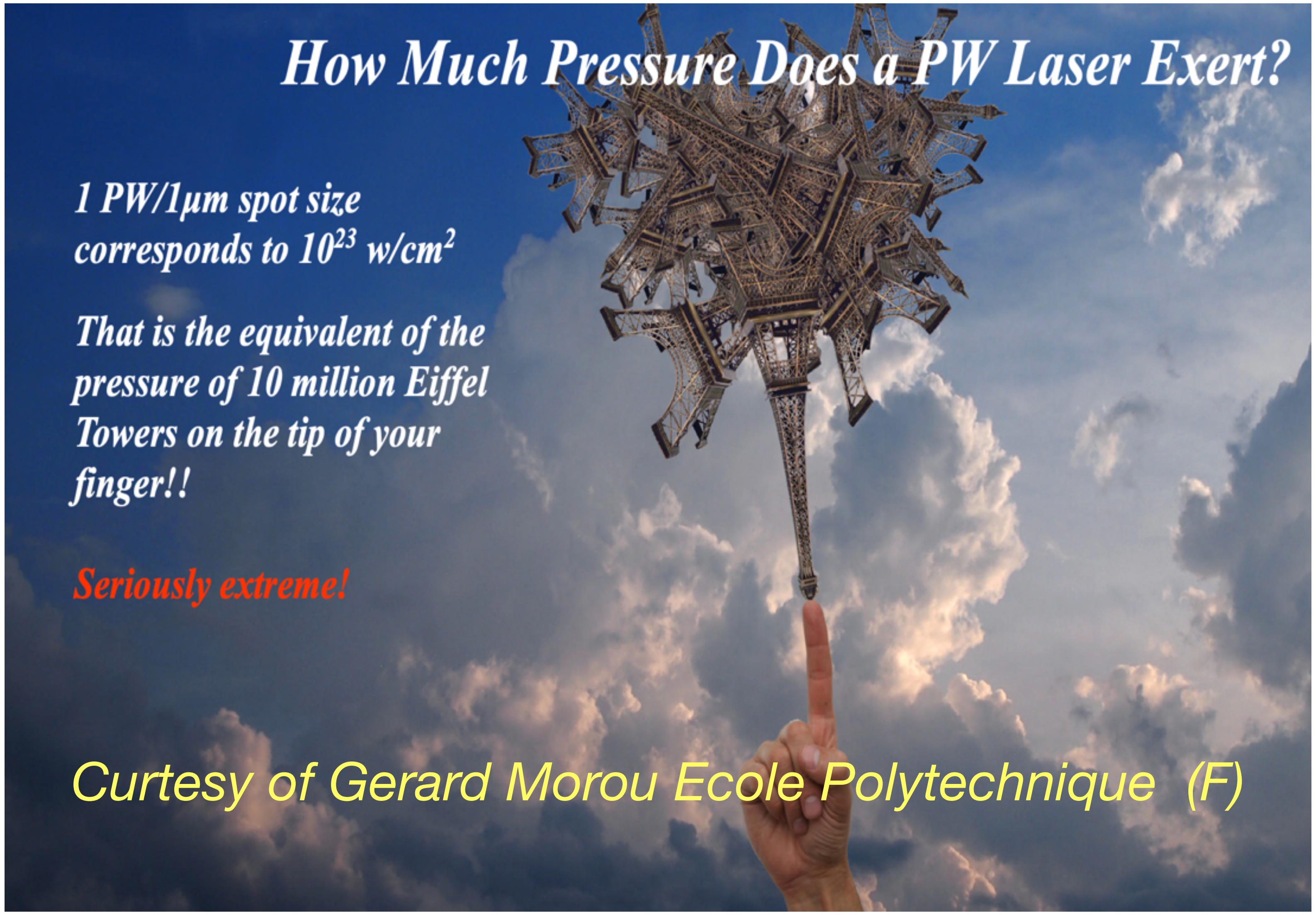

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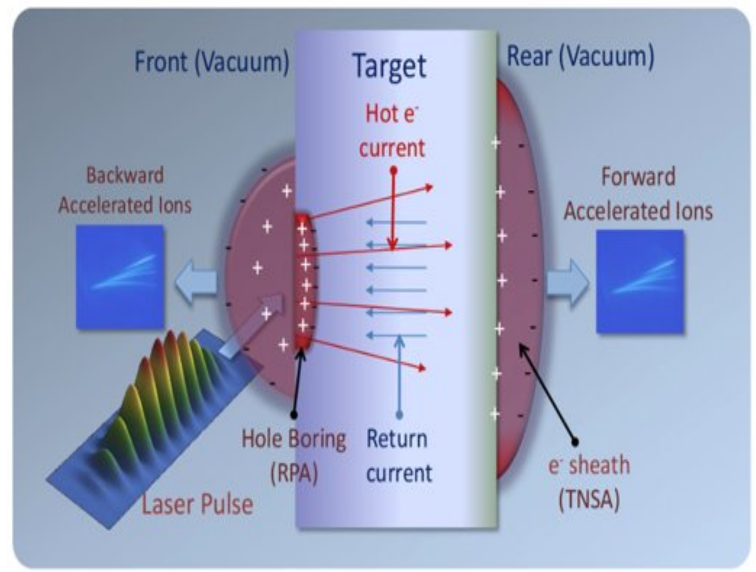
…. [many other laser and target parameters]

Laser-solid target interaction for protons, ions acceleration



- •Multi species production: g, e-, p, ions
- • Emax ~ 10 TV/m
- •Short distance (~μm)

Proton characteristics

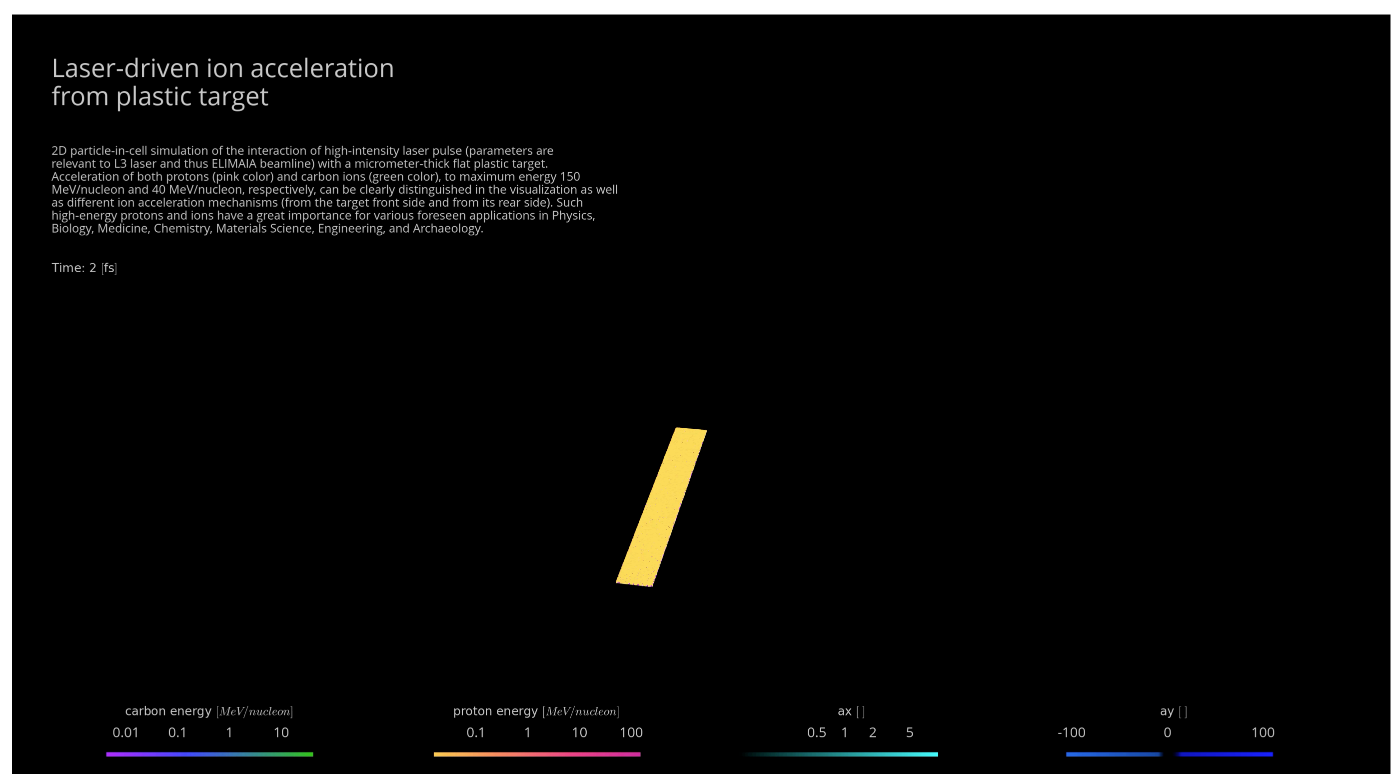
High energy: up to ~ 100 MeV

Pulse duration ≈ 10s fs - 100s ps

ppb ≈ 108-1011

Broad energy spectra (100%)

Wide angular divergence (≈ 10°-20°)



Pablo Cirrone, PhD - pablo.cirrone@lns.infn.it

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4

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- …. [many other laser and target parameters]

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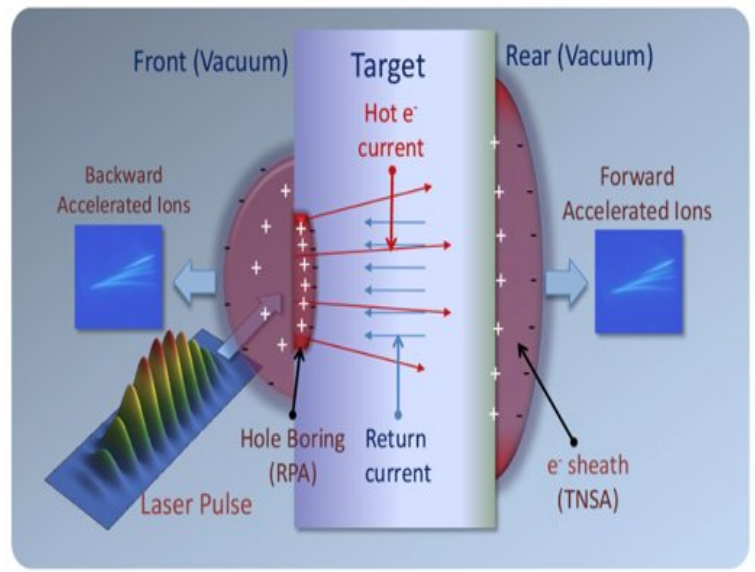

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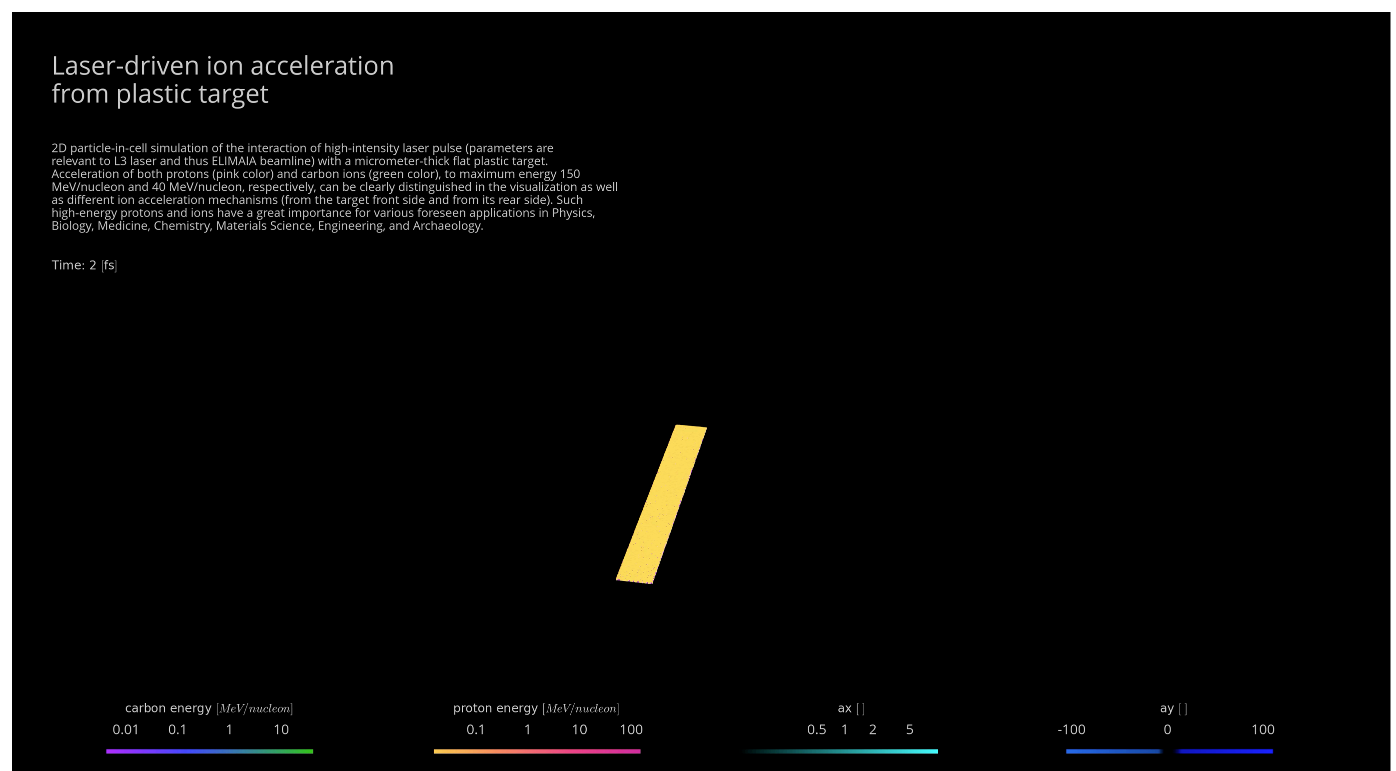

The main ingredients for radiation productions

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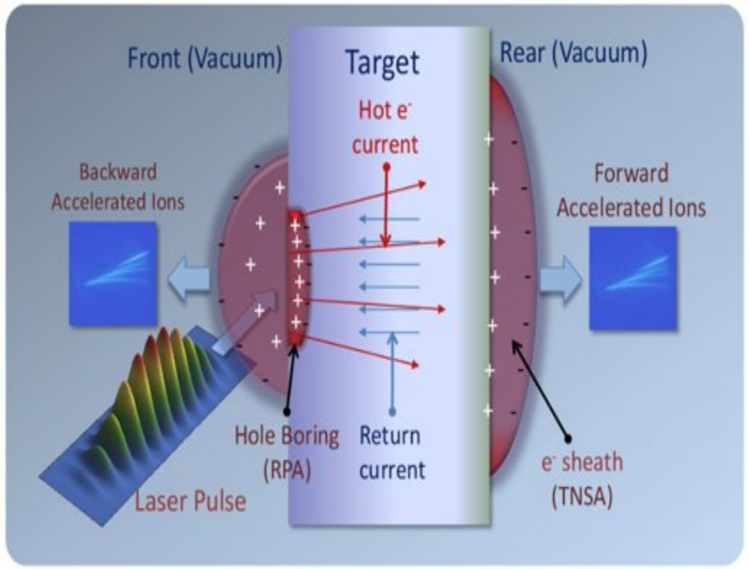

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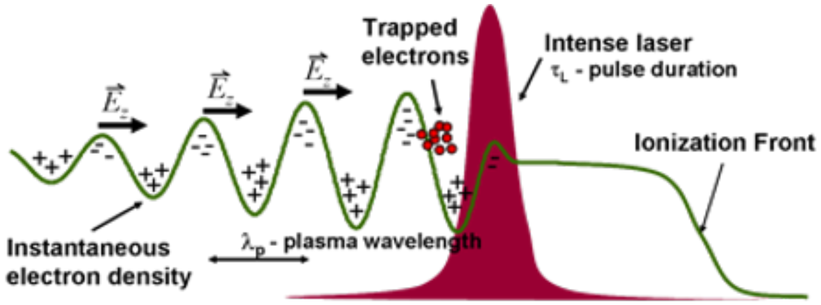
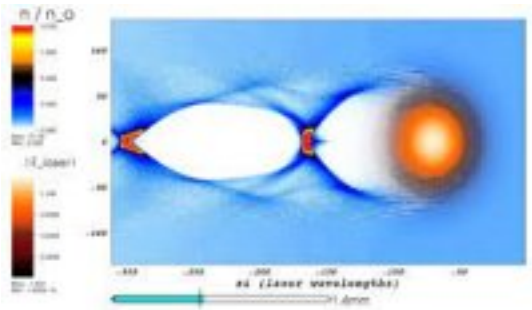
Laser Wake Field Acceleration (LWFA) for electrons

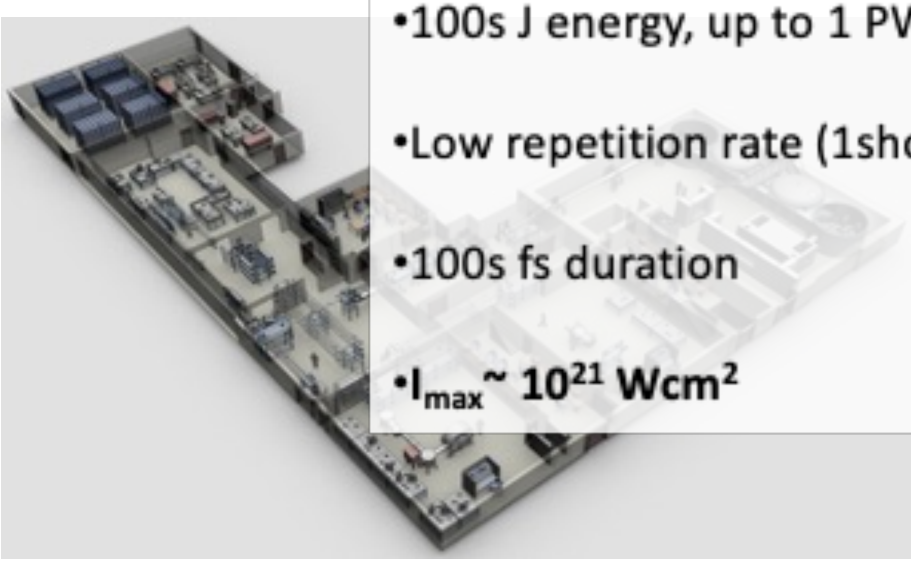




7.8 GeV have been reached at the BELLA (Berkeley Lab) in 2019 using two lasers

Laser plasma ion-acceleration

current facilities



High energy CPA systems

•Nd: Glass technology

•100s J energy, up to 1 PW power

•Low repetition rate (1shot/30min)

•100s fs duration

•I_{max}~ 10^{21} Wcm^2

I_{max}~ 10^{21} W/cm^2

VULCAN, RAL (UK)
Phelix, GSI (De)
Texas PW (US)
...
ATON-L4 (ELI Beamlines)
***10 PW** (1.5kJ/150fs)*

E_{max}~ 100 MeV

Laser plasma ion-acceleration

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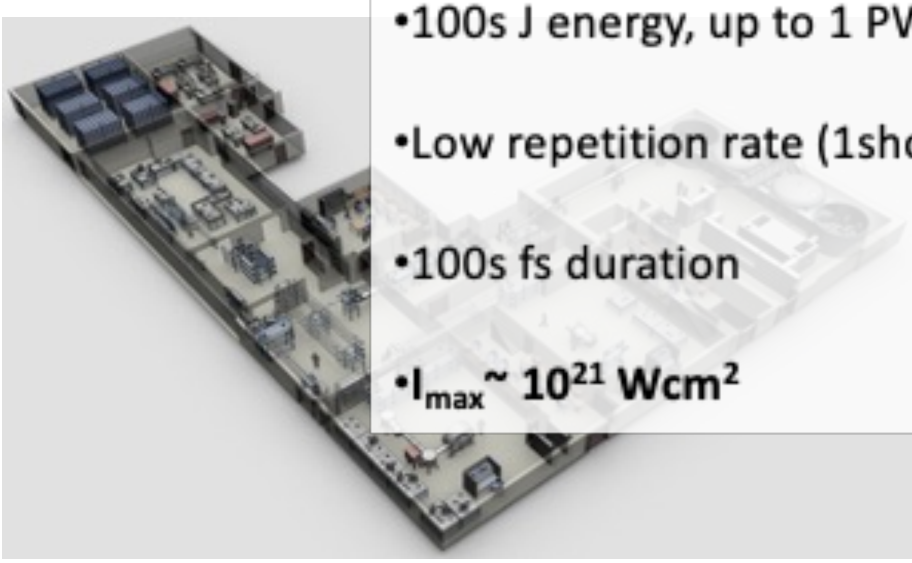

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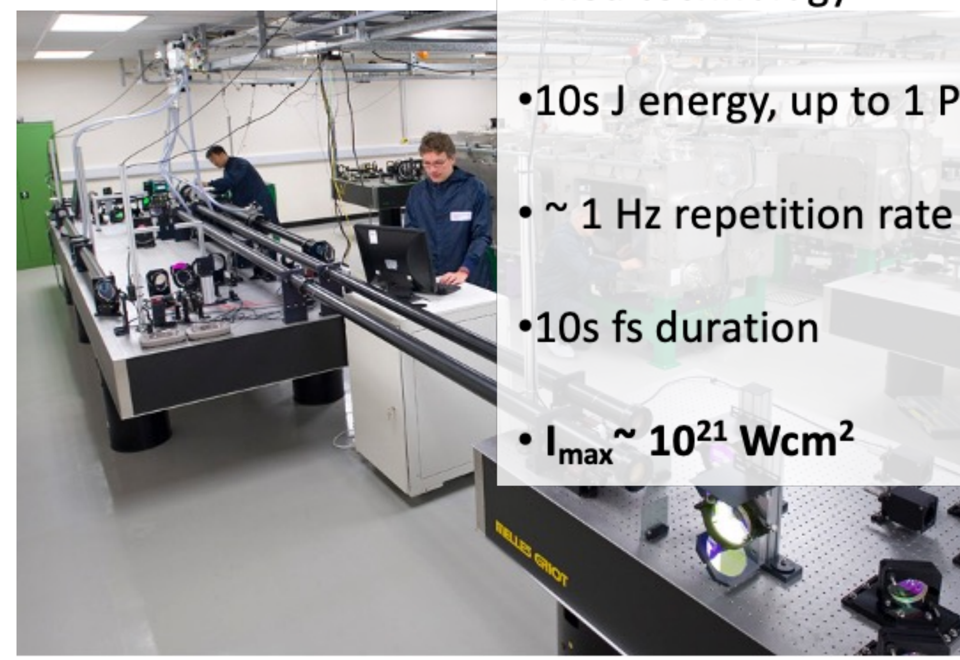
***10 PW** (1.5kJ/150fs)*

E_{max}~ 100 MeV

Ultrashort CPA systems

- Ti:Sa technology
- 10s J energy, up to 1 PW power
- ~ 1 Hz repetition rate
- 10s fs duration
- I_{max}~ 10^{21} Wcm^2



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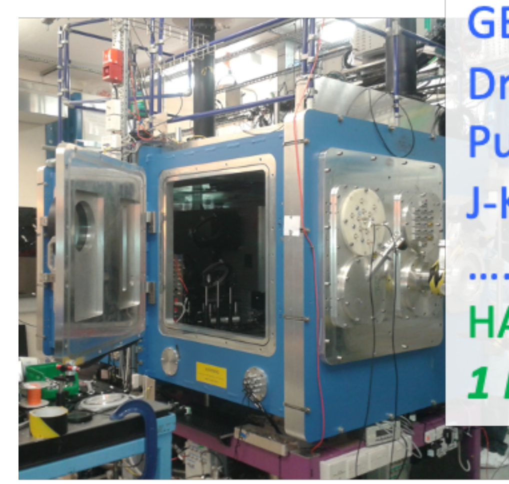
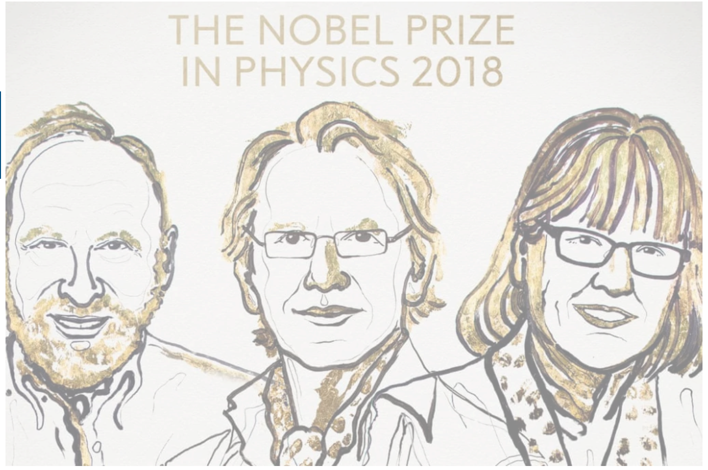
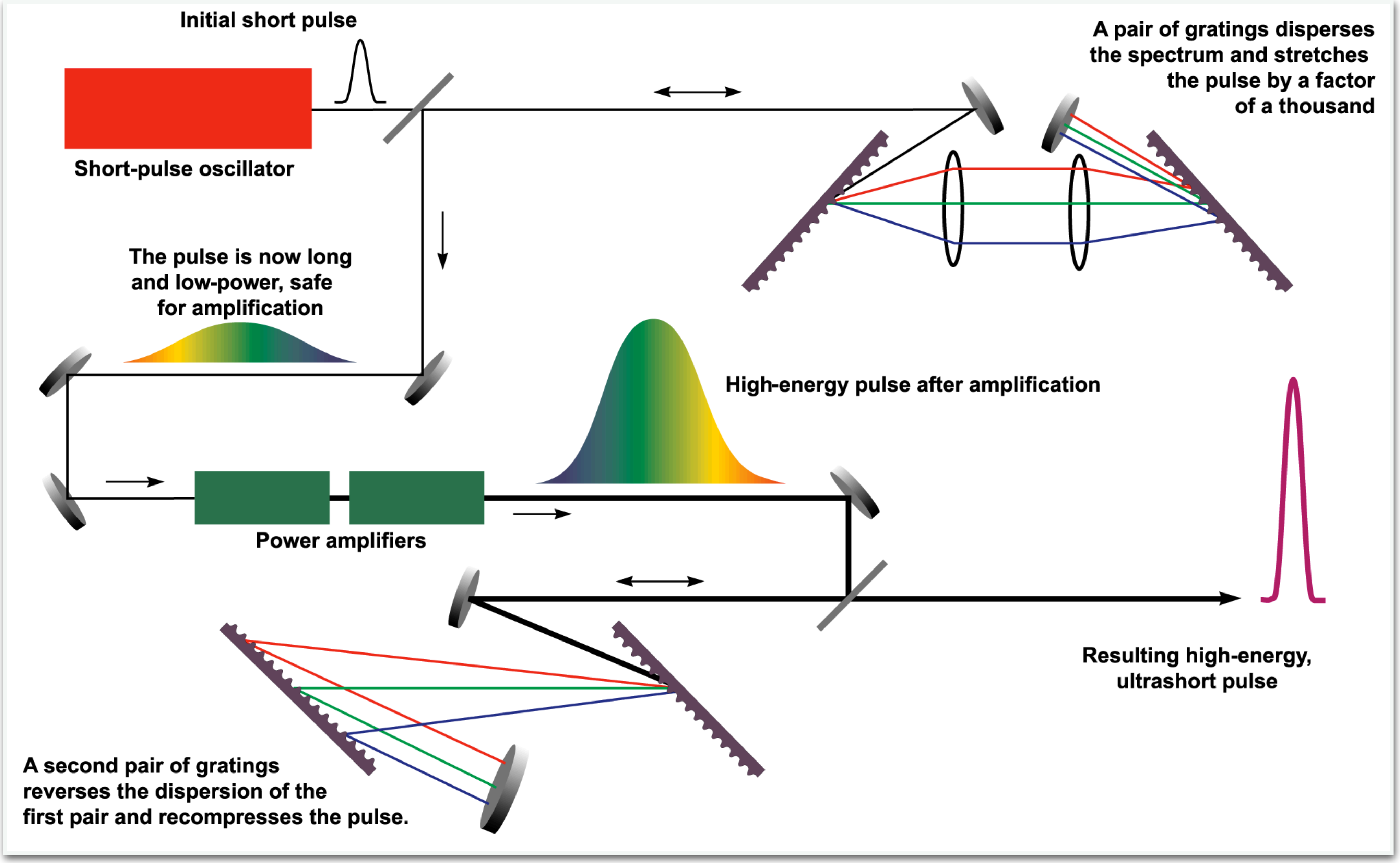


GEMINI, RAL (UK)
Draco, HZDR (De)
Pulser I, APRI (Kr)
J-Karen, JAEA (J)
....
HAPLS-L3, (ELI Beamlines)
***1 PW** (30J/30fs/**10Hz**)*

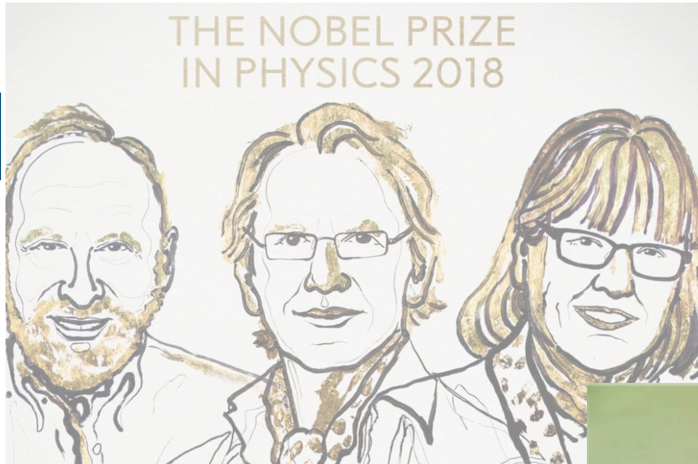
E_{max}~ 70-110 MeV

The basic ingredients: an high-power, short-pulse laser





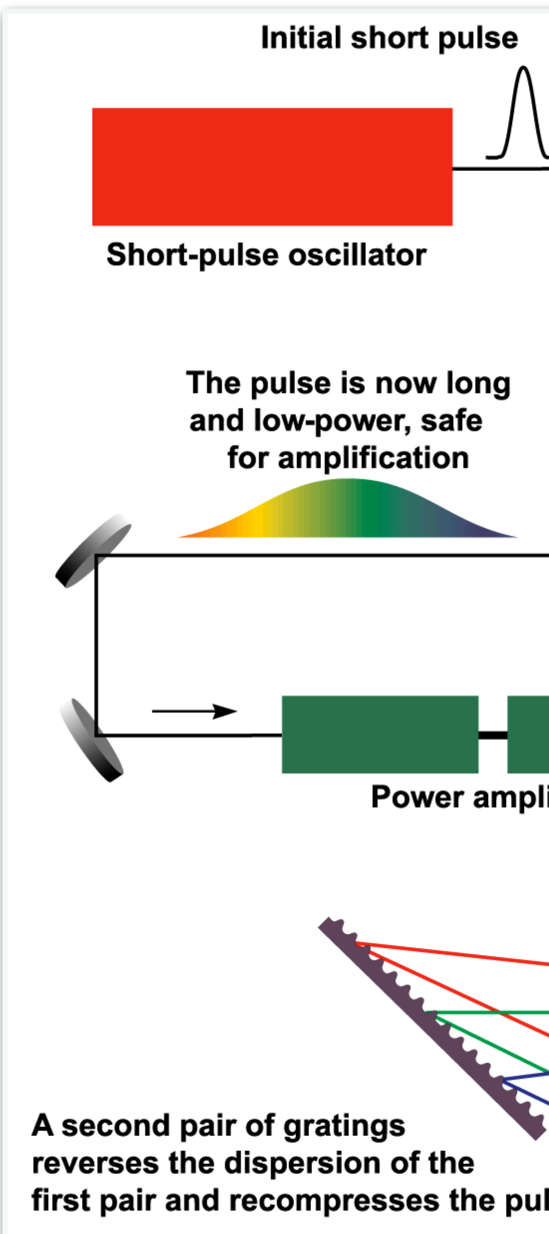
The basic ingredients: an high-power, short-pulse laser

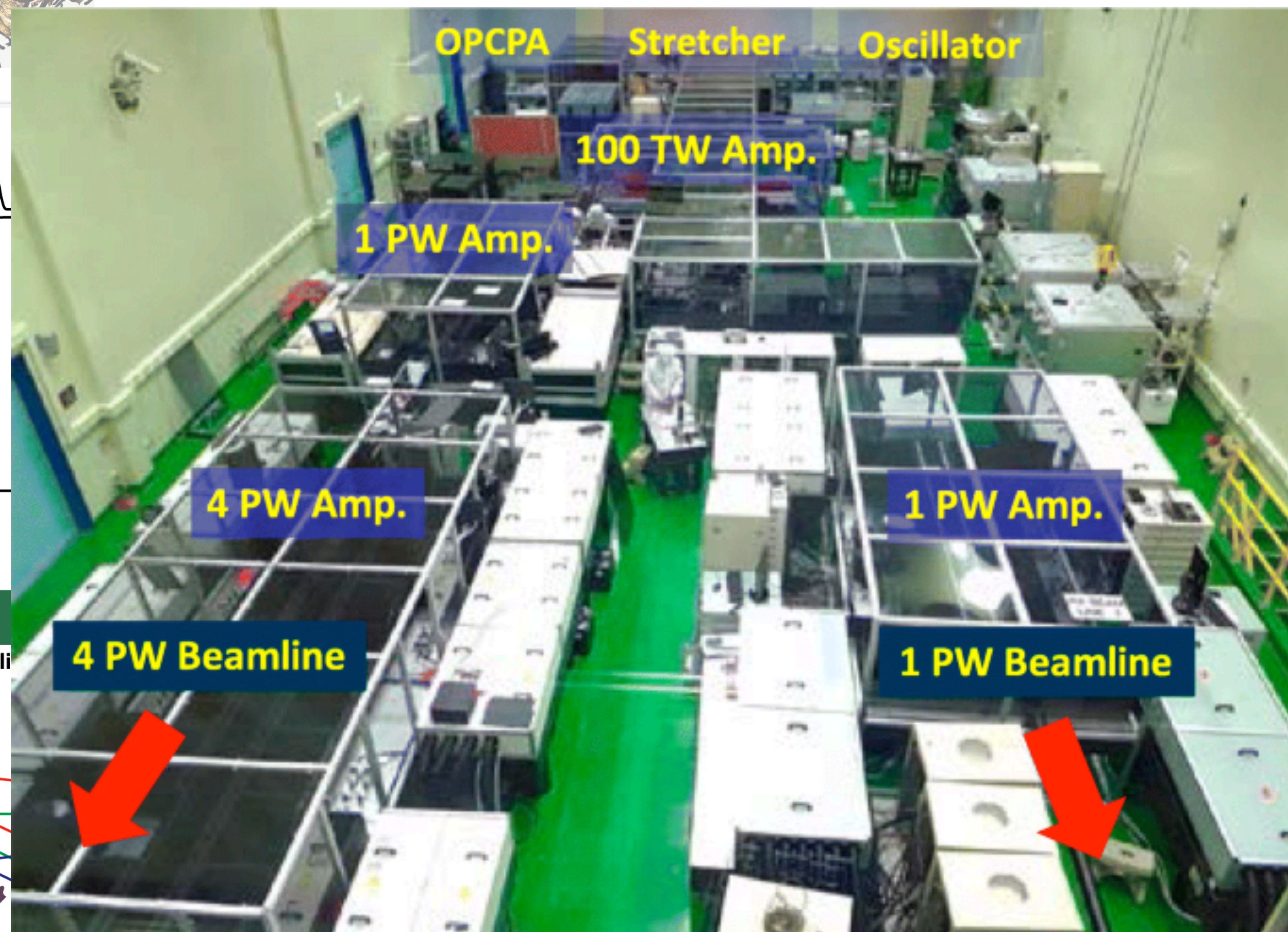


Center for Relativistic Laser Science

Explore the interaction between ultra-intense light and matter

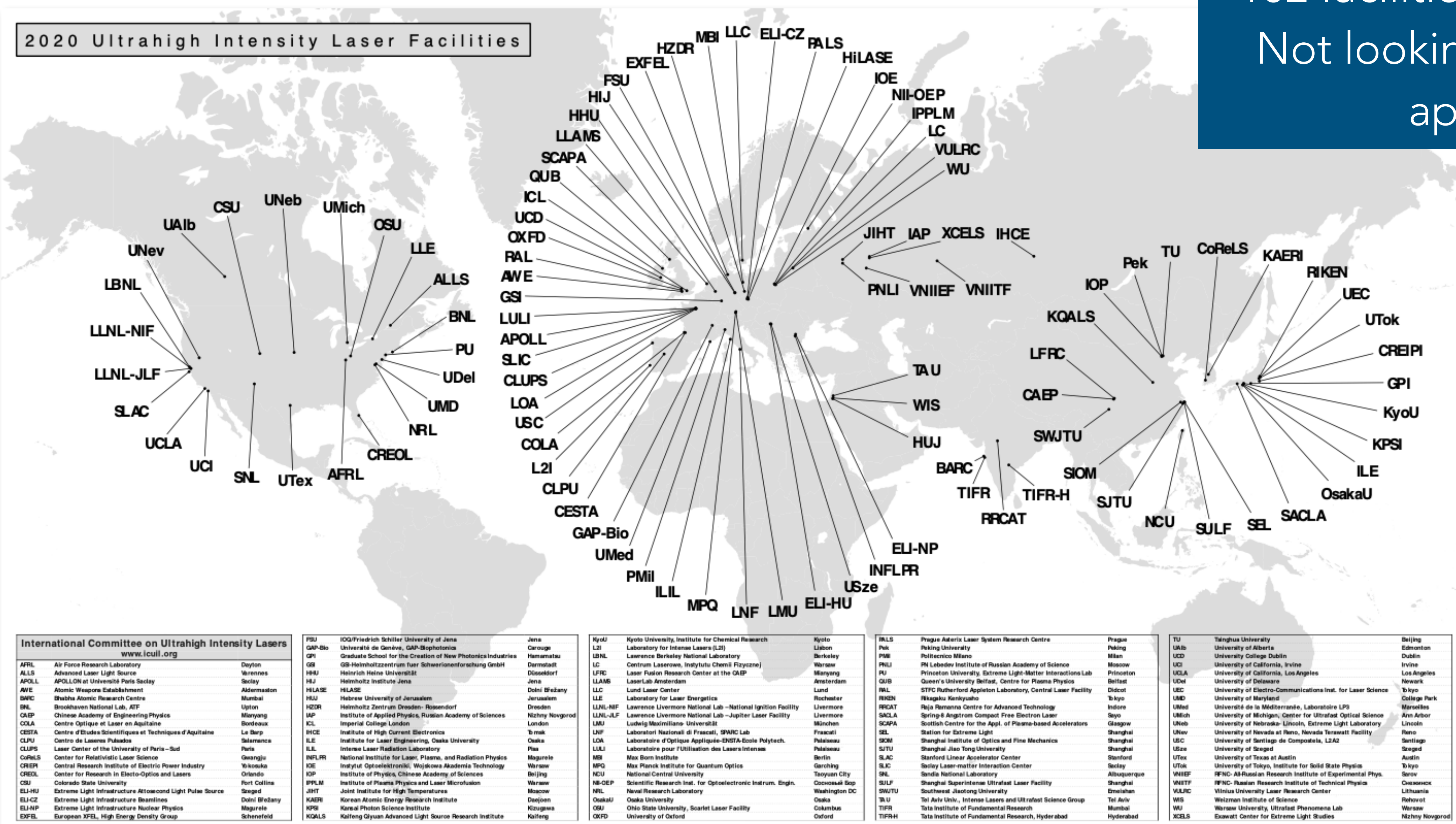
South Korea





2020 world lasers facilities

102 facilities (approx > 1TW)
Not looking to the specific application



From ICUIL (International Committee on Ultra-High Intensity Lasers)
https://www.icuil.org/

Istituto Nazionale di Fisica Nucleare

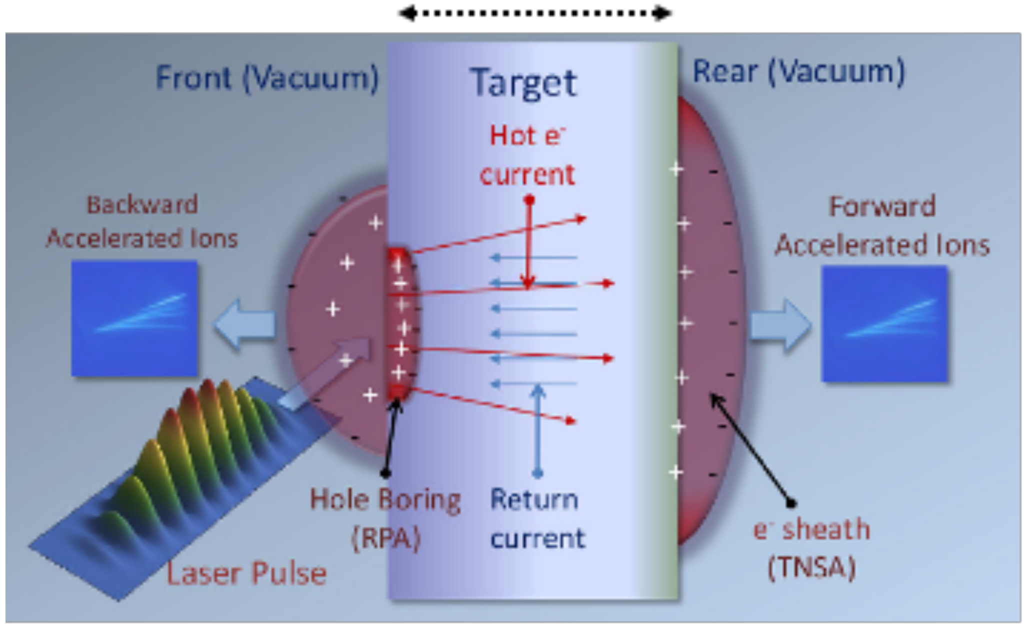
Let's concentrate on ion acceleration

Laser plasma ion-acceleration

physical picture

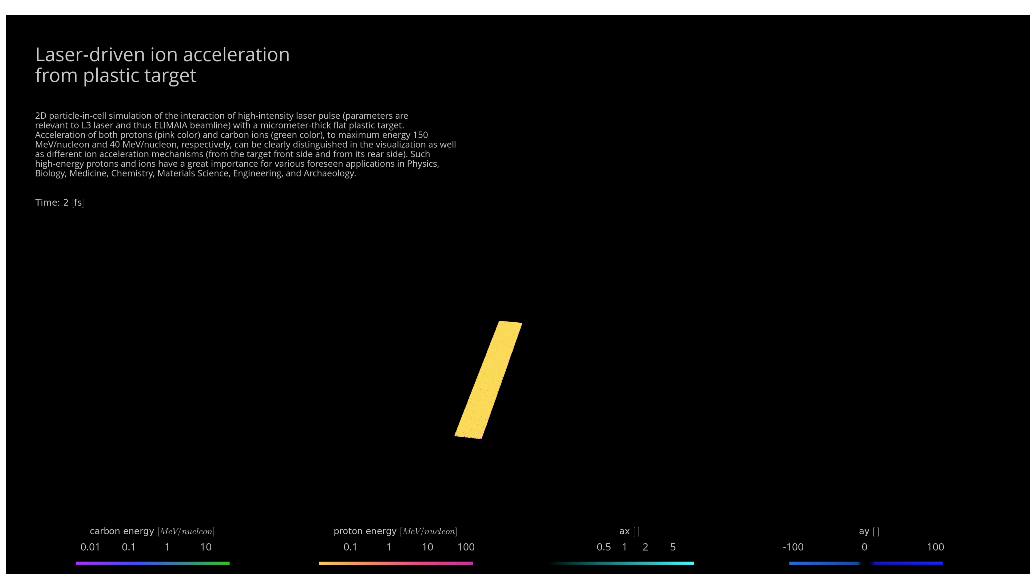
Target Normal Sheath Acceleration

0.1-10 µm long



REVIEW PAPERS:

- *Macchi, Borghesi, Passoni, Rev. Mod. Phys. 85 (2013) 751*
- *Borghesi et al, Springer Proc. Phys. 231 (2019) 143*



Role of the ponderomotive force on electrons energy gain

In an oscillating, quasi-monochromatic electromagnetic field described by a vector potential **a**(**r**,t), the relativistic ponderomotive force is given by:

$$f_p = -m_e c^2 \nabla \sqrt{(1 + <a>^2)}$$

$$f_p = \frac{dp^s}{dt} = -mc^2 \nabla \gamma$$

Energy Gain: 100 MeV/um (in a plasma medium)!!!

Laser plasma ion-acceleration

physical picture

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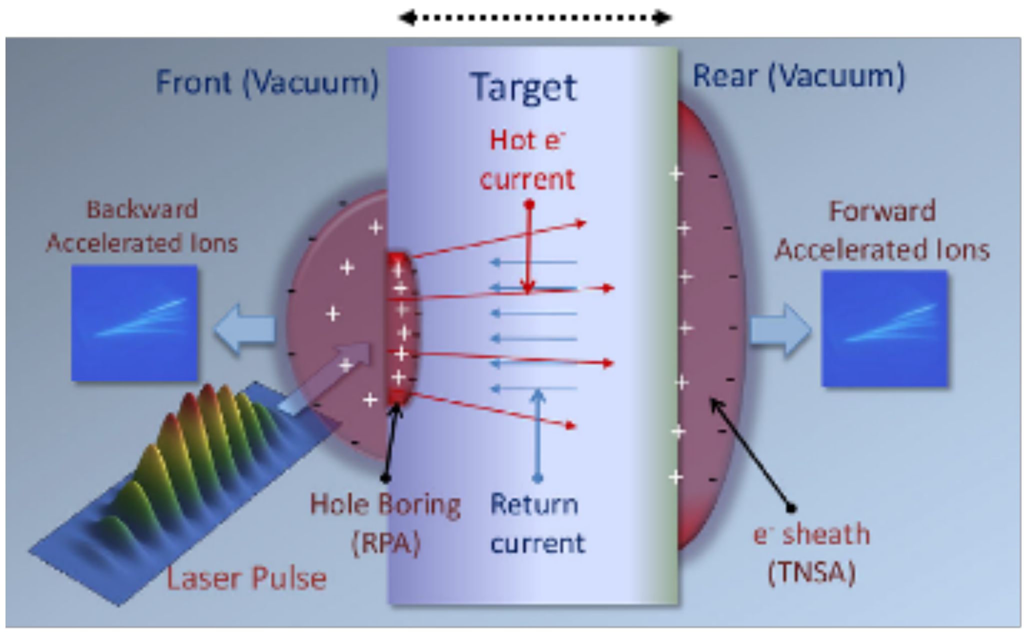

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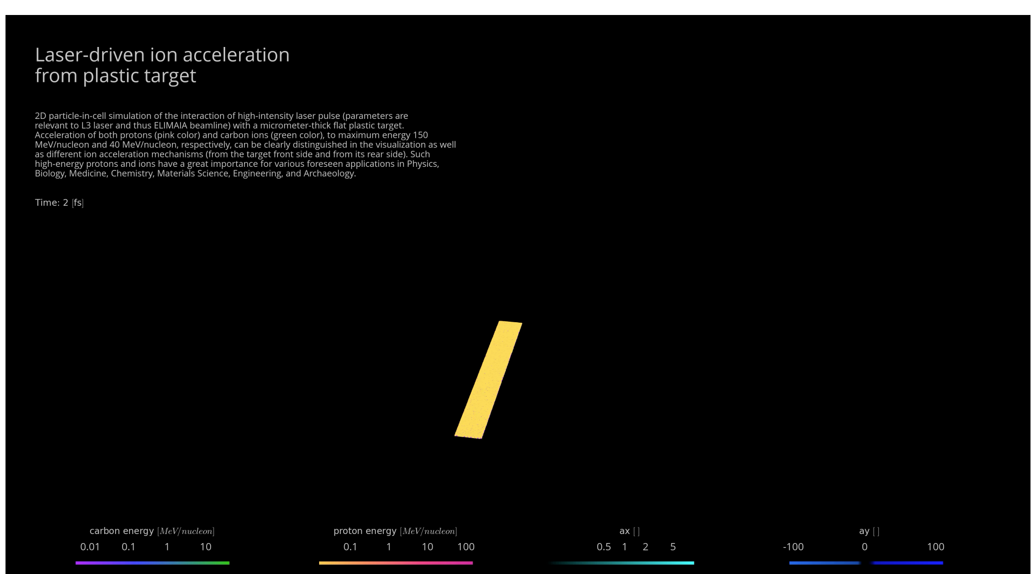

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Energy Gain: 100 MeV/um (in a plasma medium)!!!

Maximum proton energy

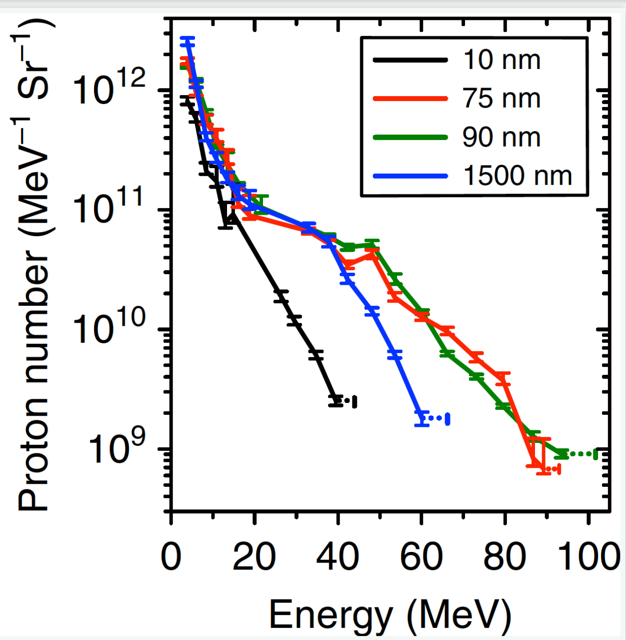
experimental scaling laws (TNSA)

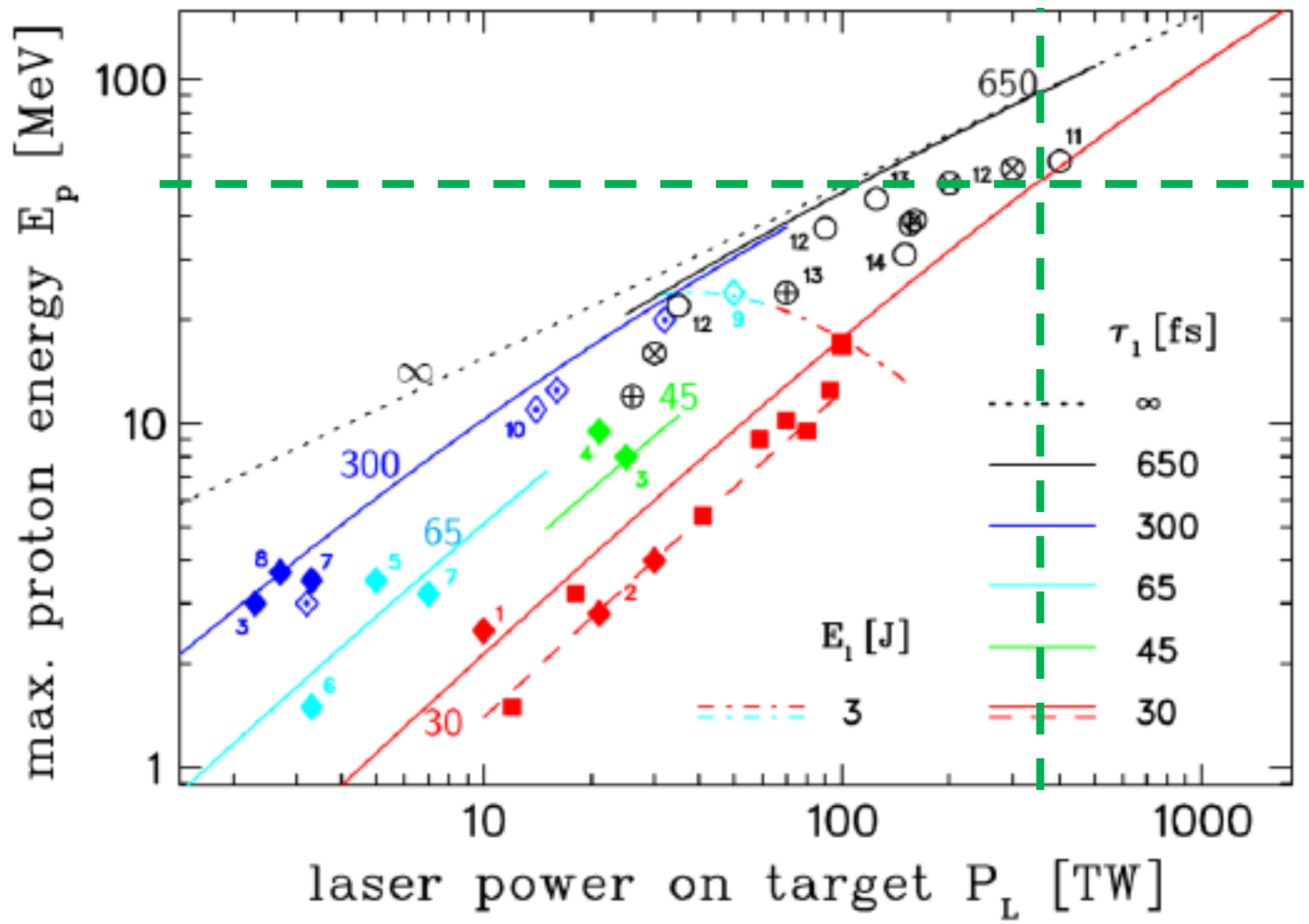
ARTICLE

DOI: 10.1038/s41467-018-03063-9 OPEN

Near-100 MeV protons via a laser-driven transparency-enhanced hybrid acceleration scheme

A. Higginson[1], R.J. Gray[1], M. King[1], R.J. Dance[1], S.D.R. Williamson[1], N.M.H. Butler[1], R. Wilson[1], R. Capdessus[1], C. Armstrong[1,2], J.S. Green[2], S.J. Hawkes[1,2], P. Martin[3], W.Q. Wei[4], S.R. Mirfayzi[3], X.H. Yuan[4], S. Kar[2,3], M. Borghesi[3], R.J. Clarke[2], D. Neely[1,2] & P. McKenna[1]





The scaling of proton energies in ultrashort pulse laser plasma acceleration
K Zeil et al 2010 New J. Phys. 12 045015

proton energy

$$I \propto \frac{E_p}{\tau A}$$

Intensity W/cm^2

pulse lenght

spot surface on target

I-LUCE at INFN-LNS

INFN Laser indUCEd radiation production

Goal: realisation of a new European laser facility for new beams, new physics and new Users

EuAPS

Roma TV, LNF, Pisa CNR, LNS
15 M€

7.9 M€ WP3 High-Power lasers

Infrastructure

Laser system and interaction chaml

Electrons and ion acceleration

EuPRAXIA

Anthem

Advanced technologies for Human Centred Medicine

23 Istituti; Spoke 4: Caserta, Pavia, INFN

1.3 M€

Electron acceleration for conventional and ultra high dose rate beams nell'accelerazione di elettroni e UHDR

LUC

INFN Laser indUCEd radiation production

0.8 M€

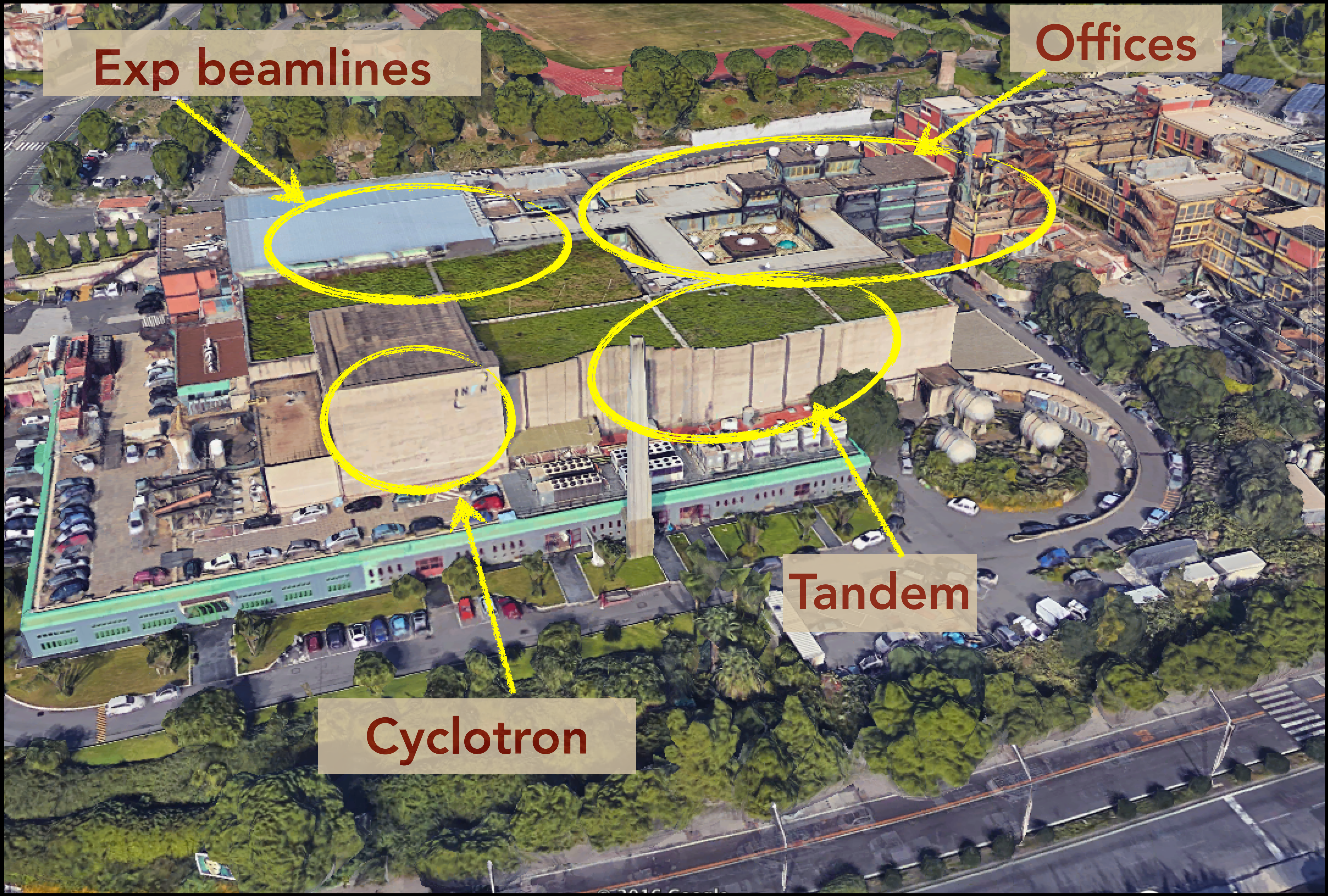
Demonstration of a micro-acceleration system for laser-driven proton beams

BCT

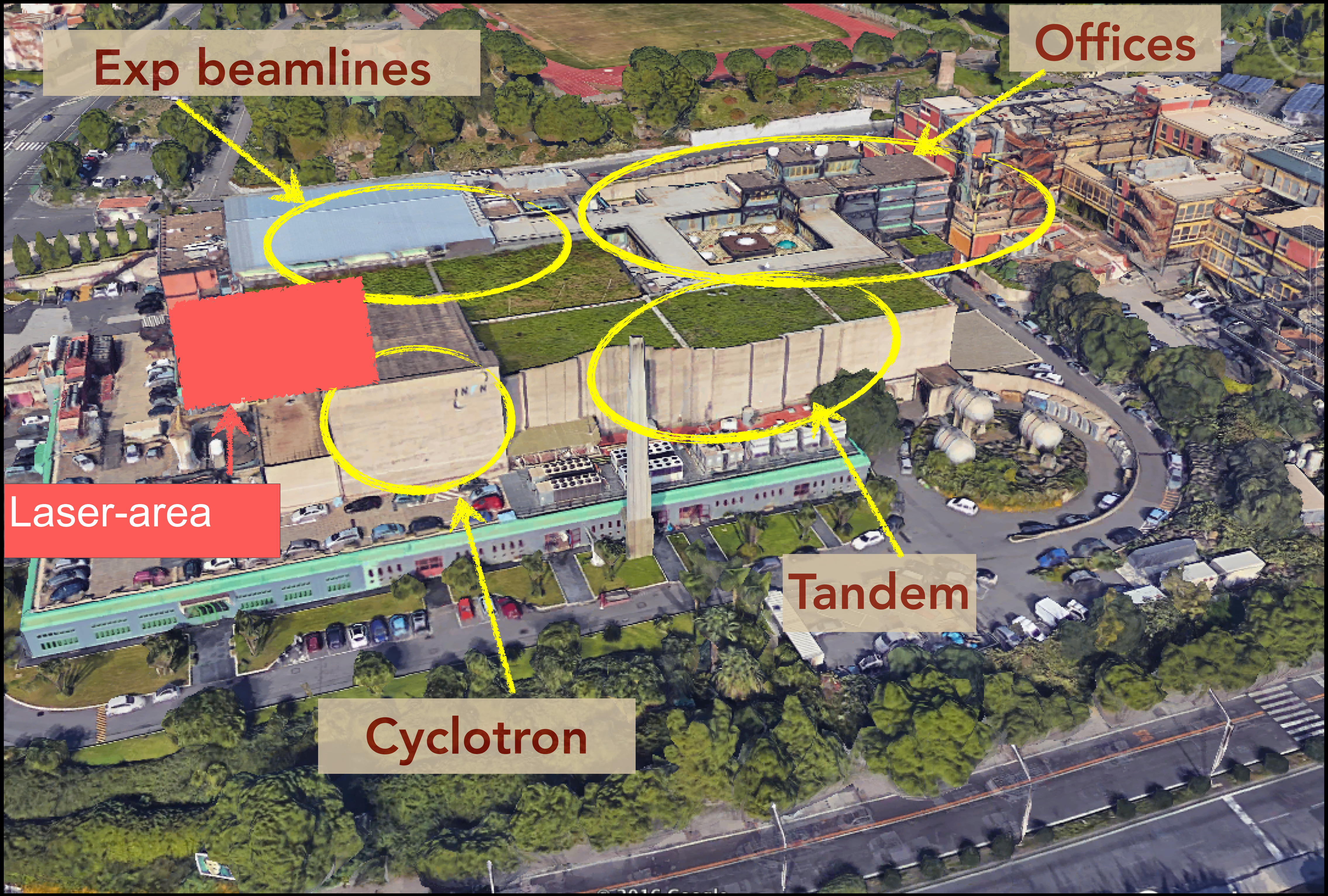
Breast Cancer Therapy

2.0 M€

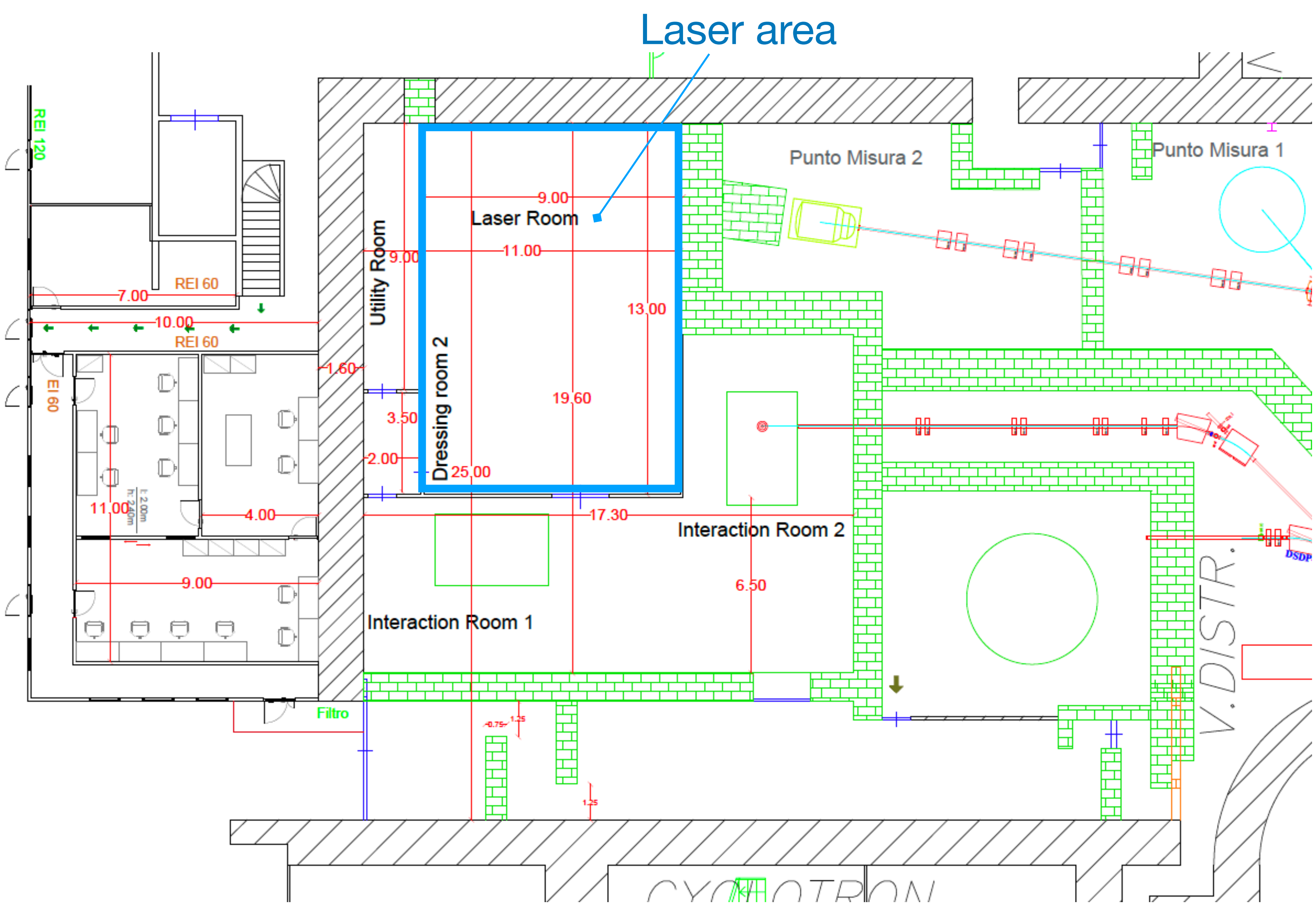
Ottimizzazione nella selezione di fasci di protoni per applicazioni mediche



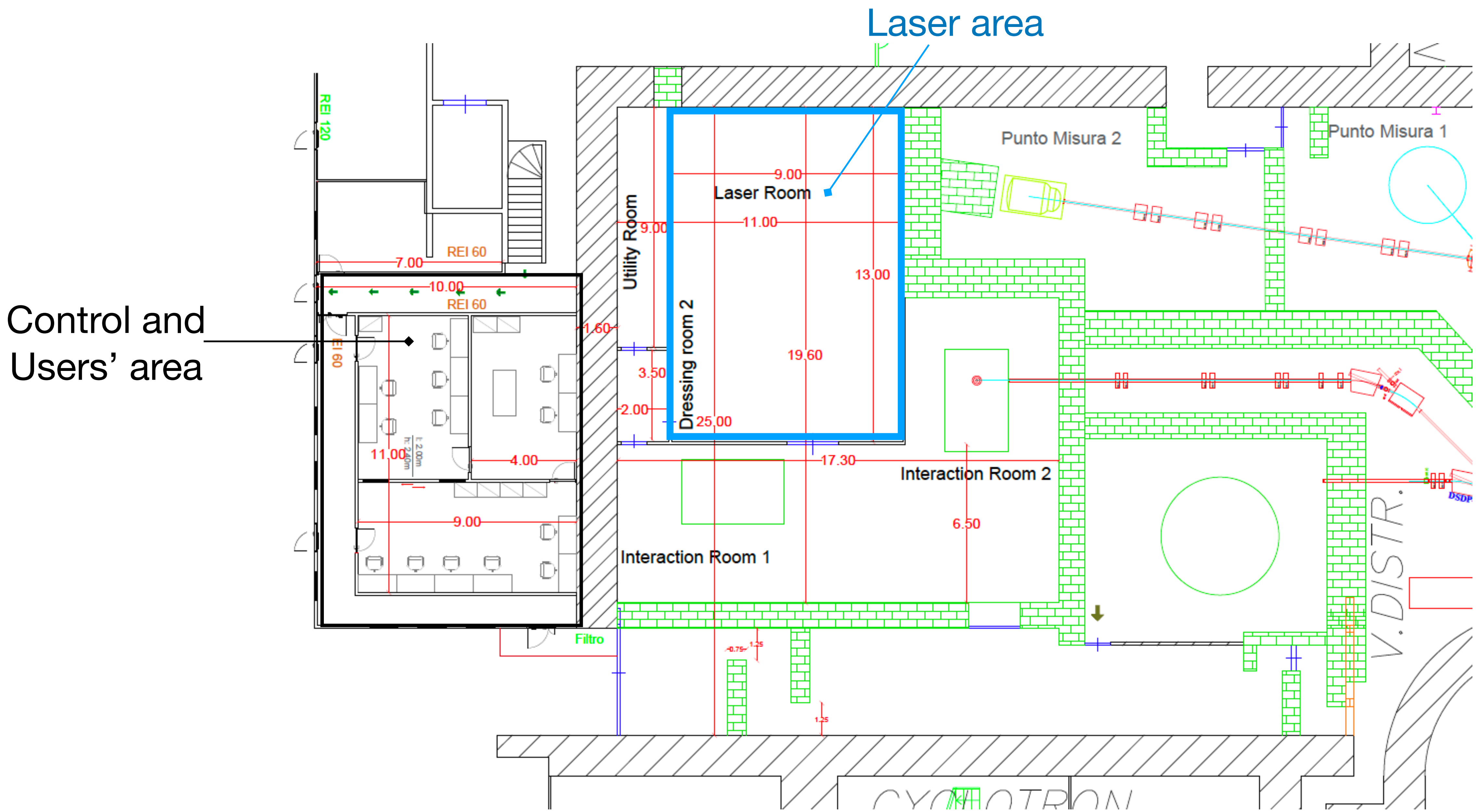
Exp beamlines
Offices
Tandem
Cyclotron


Exp beamlines
Offices
Laser-area
Tandem
Cyclotron

I-LUCE layout



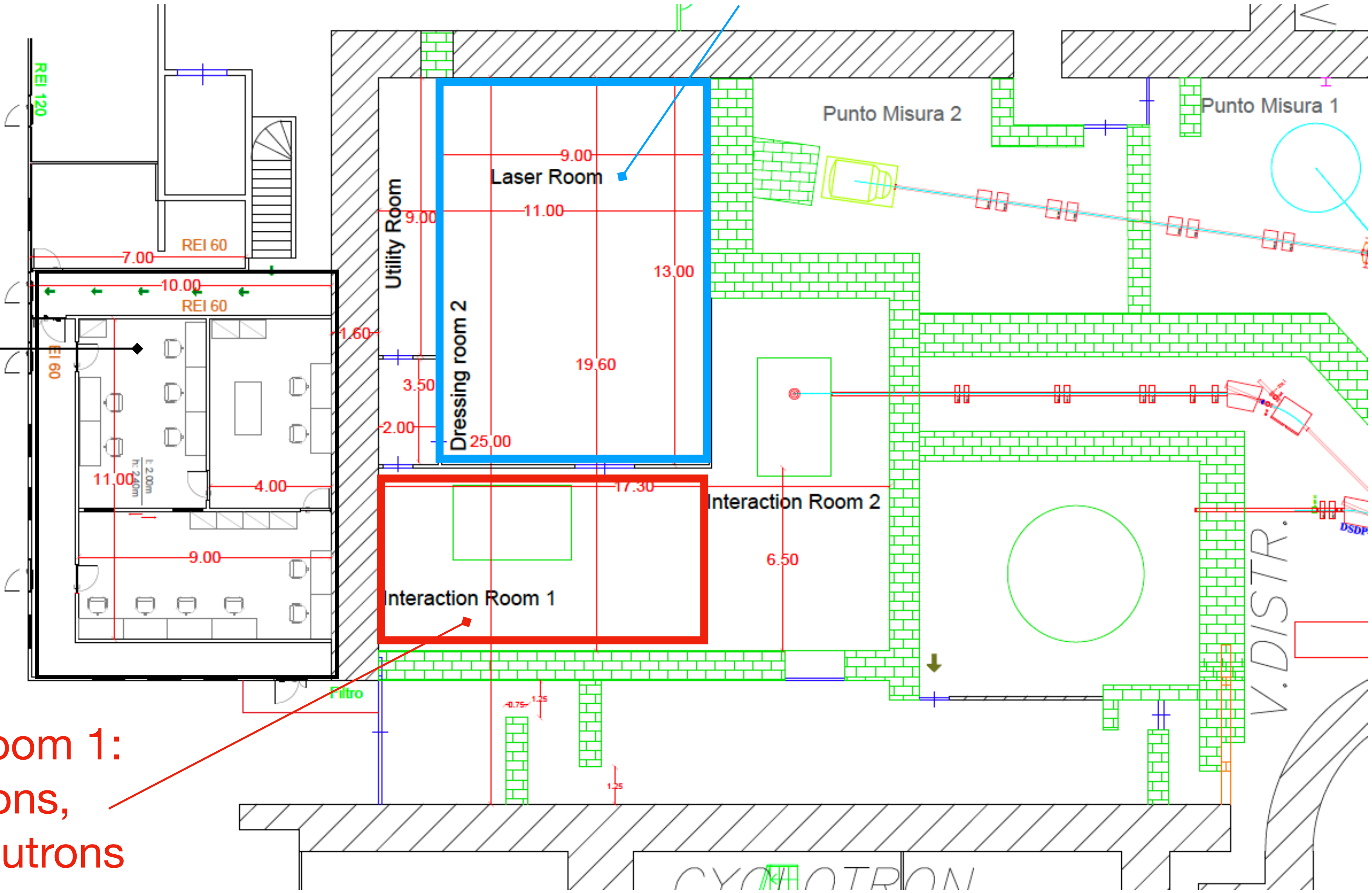
I-LUCE layout



I-LUCE layout

Laser area

Control and Users' area

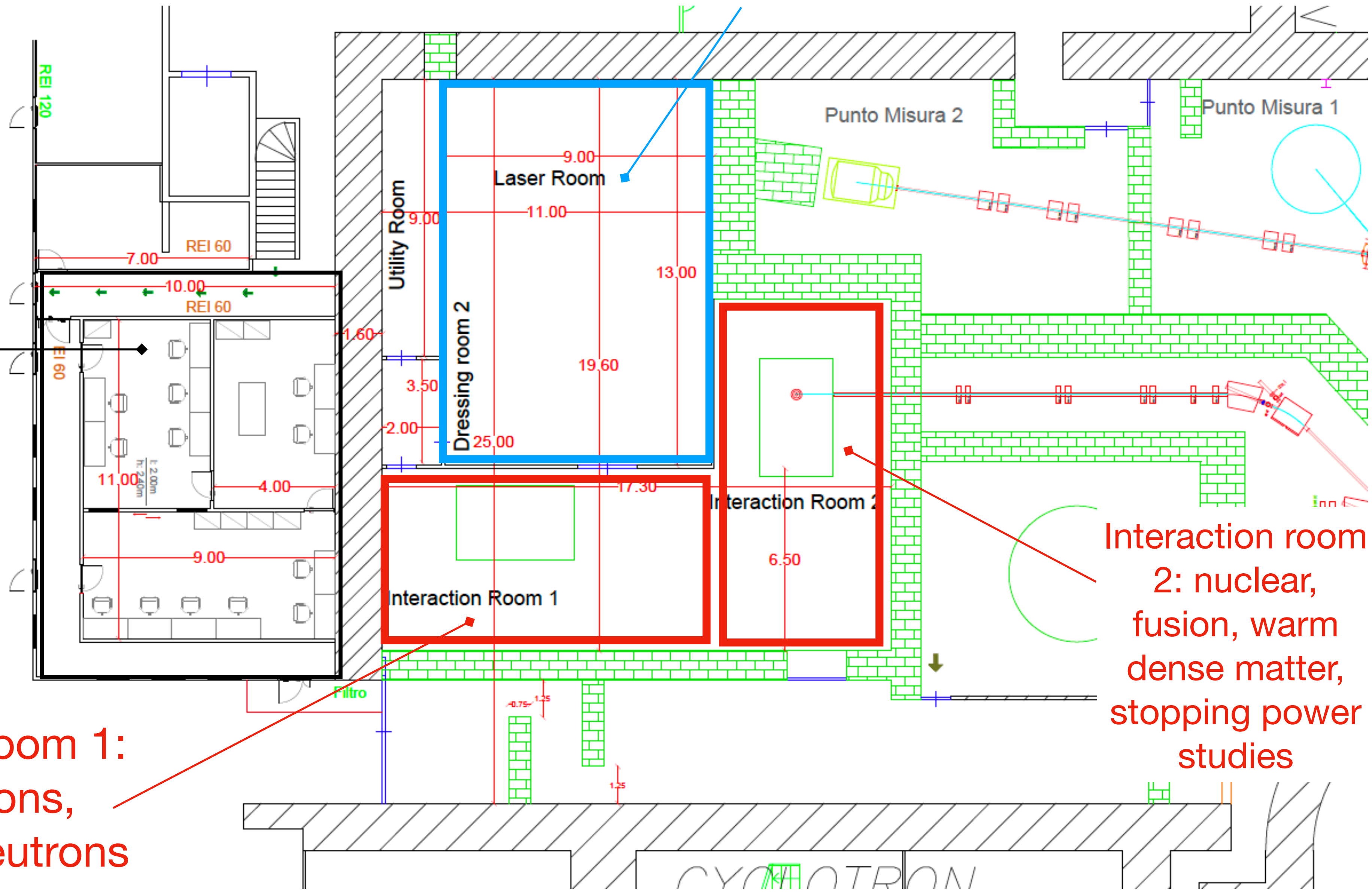


Interaction room 1: protons, ions, electrons, neutrons accelerations

I-LUCE layout

Laser area

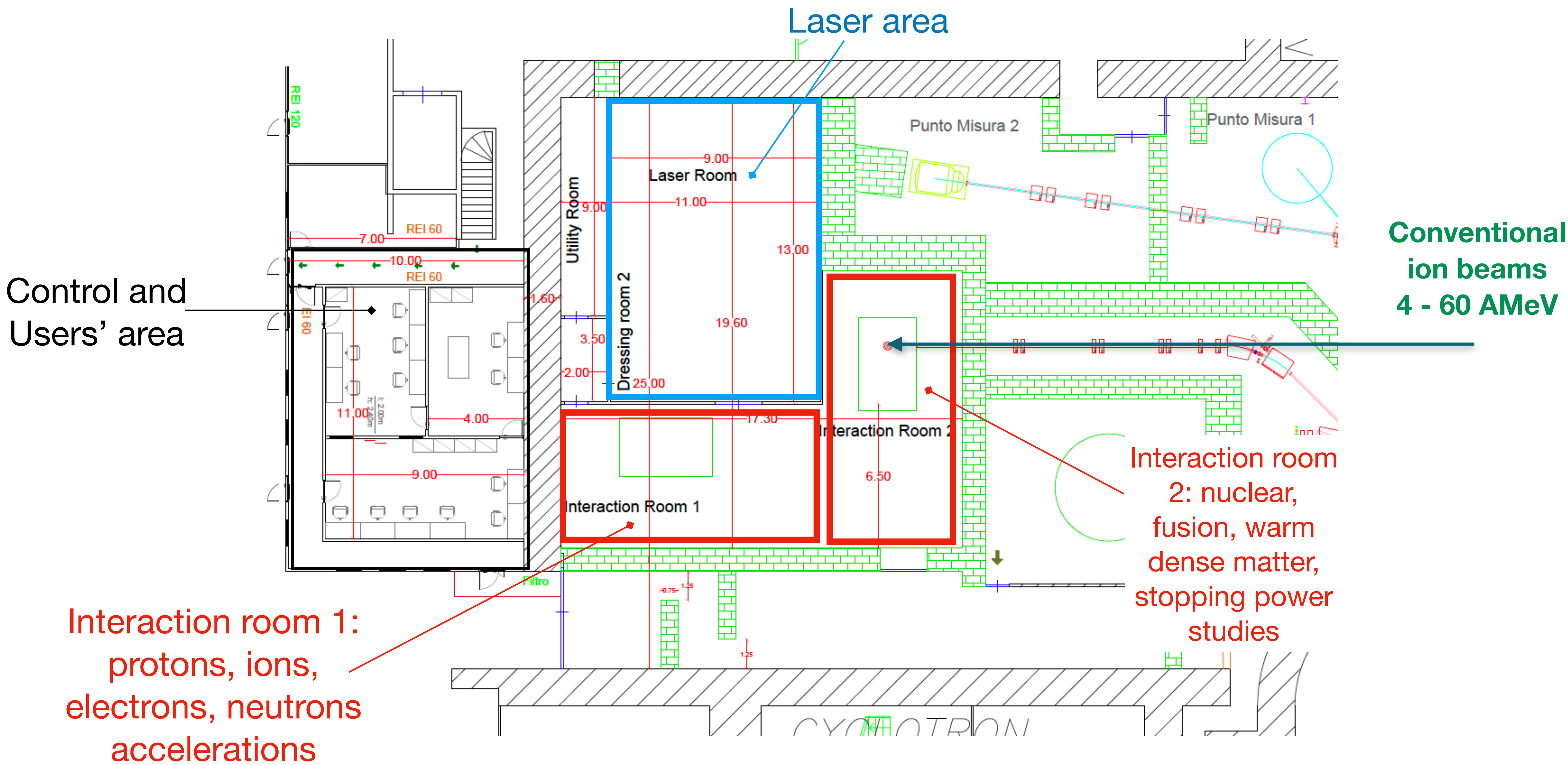
Control and Users' area

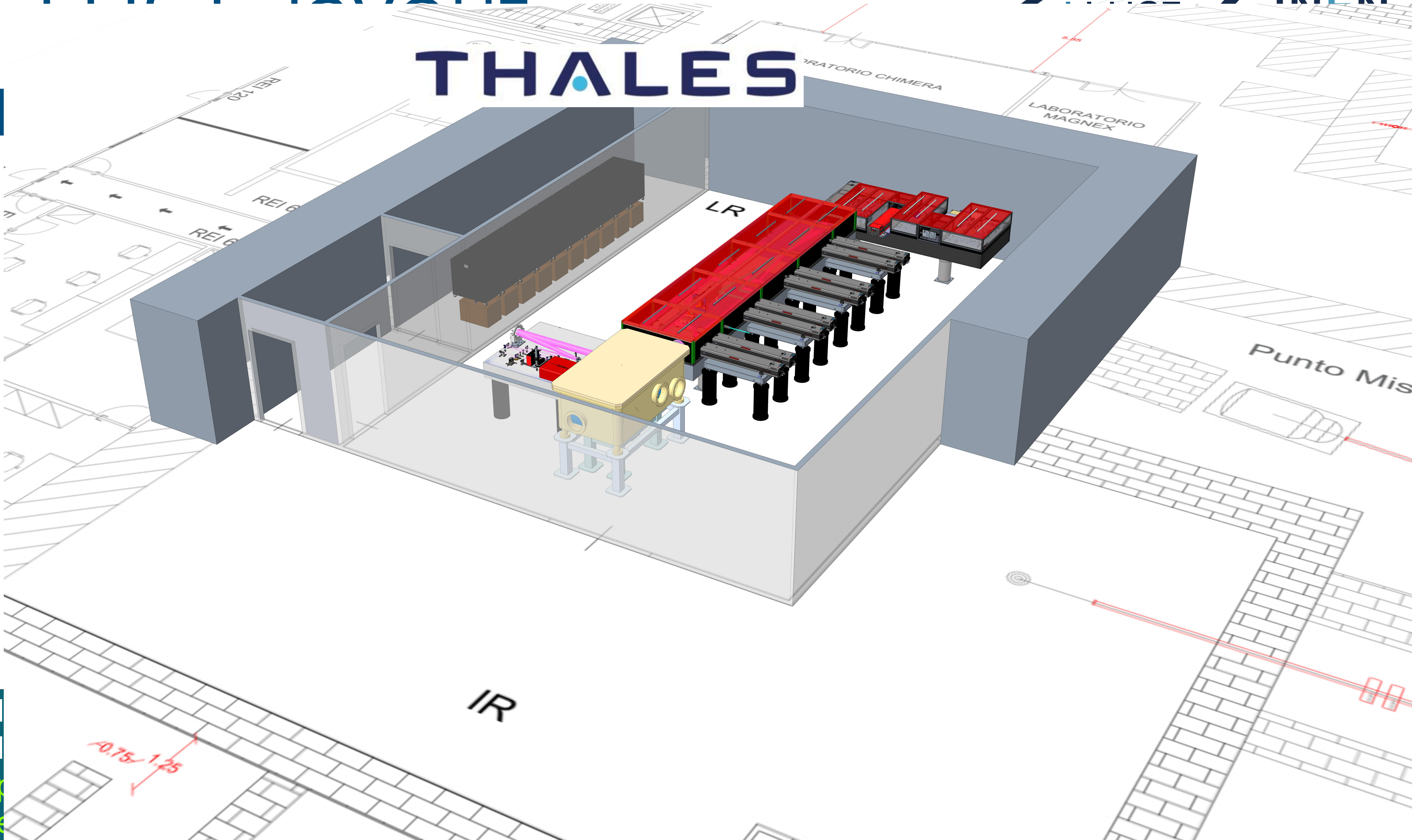


Interaction room 2: nuclear, fusion, warm dense matter, stopping power studies

Interaction room 1: protons, ions, electrons, neutrons accelerations

I-LUCE layout



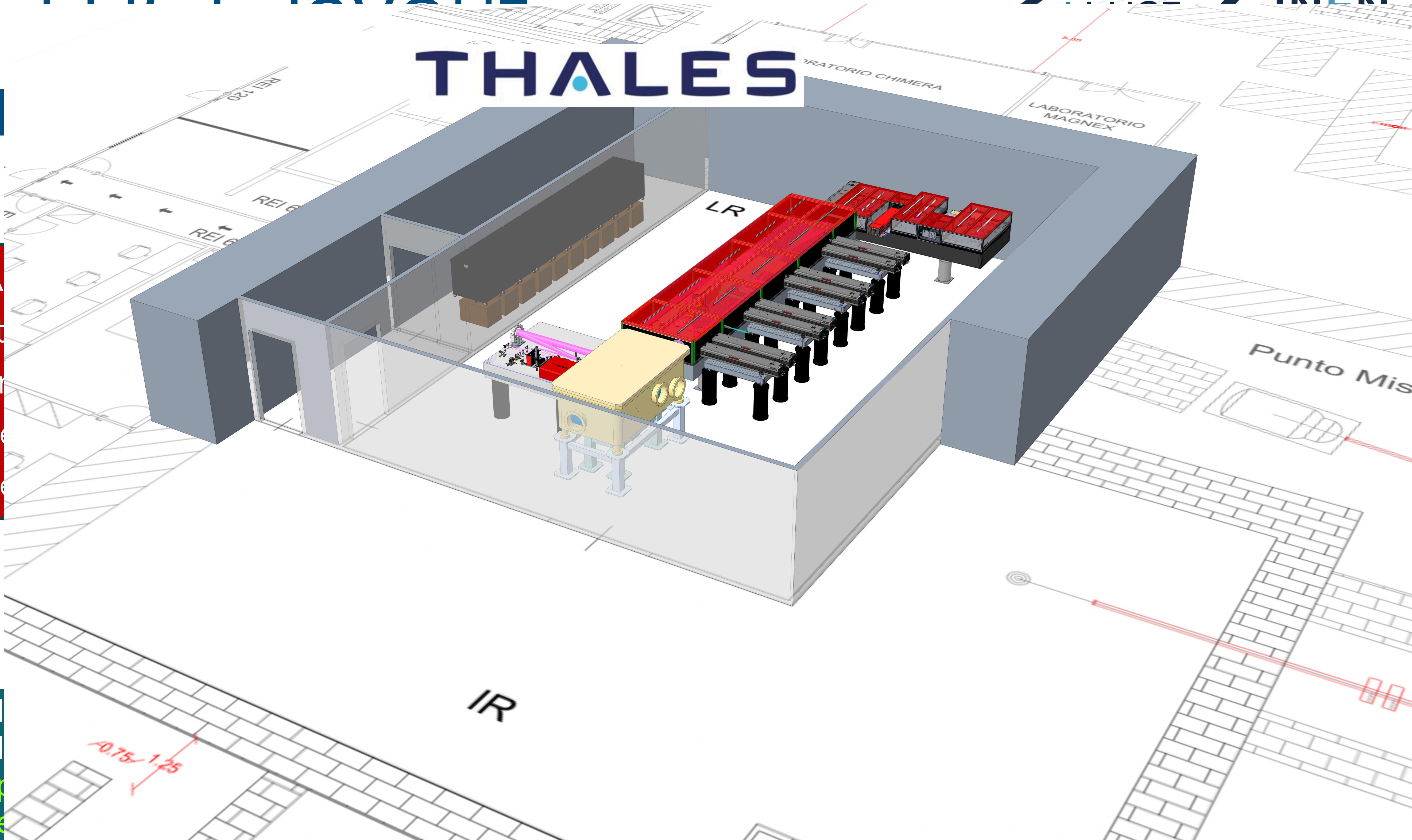


production

In-air irradiation station

Conventional ions: from TANDEM and Cyclotron

LUCE layout



production

In-air irradiation station

Conventional ions:
from TANDEM and Cyclotron

I-LUCE first phase

Two interaction chambers

1) **Interaction Chamber n.1:** Radiation production (protons/ions, electrons, neutrons, gamma, etc.)
    - One in-air irradiation station for multidisciplinary studies

2) **Interaction Chamber n.2:** Warm Dense Matter studies (WDM)
    - Nuclear physics in plasma
    - Interaction of conventional ion beams with laser-generated plasma
    - Nuclear physics fusion studies in plasma
    - ……

Two working modalities

1) Low power: 50 TW/23fs/10Hz
2) High power: 350 TW/23fs/1Hz

Upgrade from 350 TW to 500 TW (0.5 M€)

I-LUCE first phase

Two interaction chambers

1) **Interaction Ch**

neutrons, gam

- One in-air

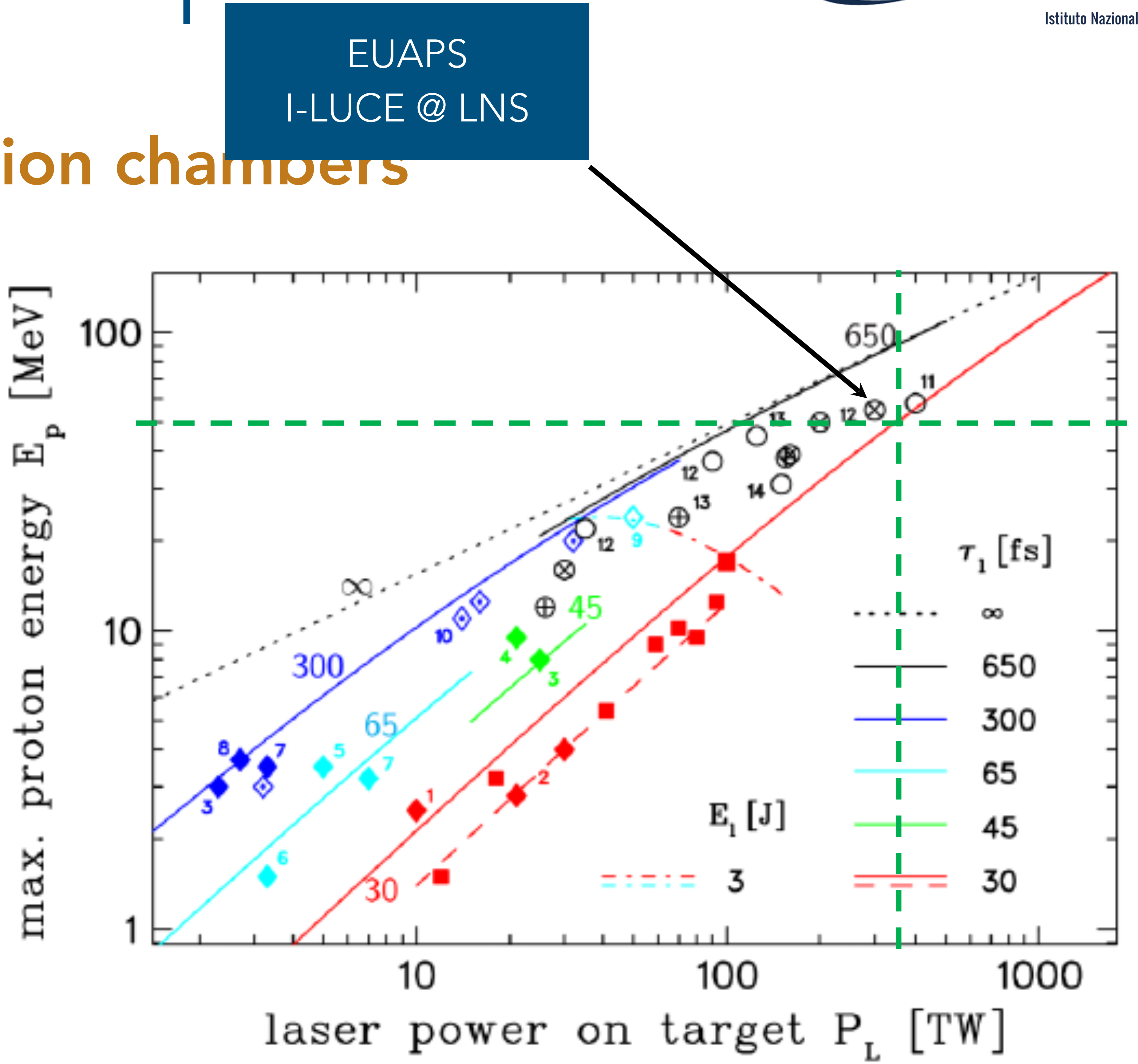
2) **Interaction Ch**

- Nuclear ph
- Interactior
- Nuclear ph
- ……

Two workin

1) Low power: 50

2) High power: 35



Low power modality: 50 TW

Laser Power		≥ 50 TW
Energy per pulse		≥ 1 J
Pulse duration		≤ 23 fs
Focusing surface		36 μm^2
Max power density (at the target)		$1.21 \cdot 10^{20}$
$I^*\lambda^2$		$7.72 \cdot 10^{19}$
Contrast ratio @100 ps (ASE)		> 10^{10}
Repetition rate		≥ 10 Hz
Protons Ions	Max energy	4 MeV
	Particle per pulse (at 2 MeV)	10^{11} MeV^{-1} Sr^{-1}
	Energy spread	100%
	Beam divergency (max)	±20°
Eletrons	Max energy	0.1 GeV
	Particles per pulse	10^{9}
	Beam divergency (max)	± 20 mad
Neutrons	Max energy	TBD
	Particles per pulse	
	Energy spread	
	Beam divergency	
Gamma X-beams	Synchrotron radiation of the electrons inside the plasma or breemsstrahlung	
	Energy	up to 20 MeV
	Beam divergency	Directionality in the beam propabgation direction

Fusion studies,
nuclear studies,
radioisotopes production,
…..

Acting on the compression procedure, the pulse duration can be increased up to 1/10 ps:

==> $2.78 \cdot 10^{18}$ W/cm^2

$2.78 \cdot 10^{17}$ W/cm^2

==> $i\lambda^2 = 1.77 \cdot 10^{18}$

$i\lambda^2 = 1.77 \cdot 10^{17}$

Longer plasma expansion times:

— *Decay studies*
— *Stopping powers studies*
— *WDM characterisation*

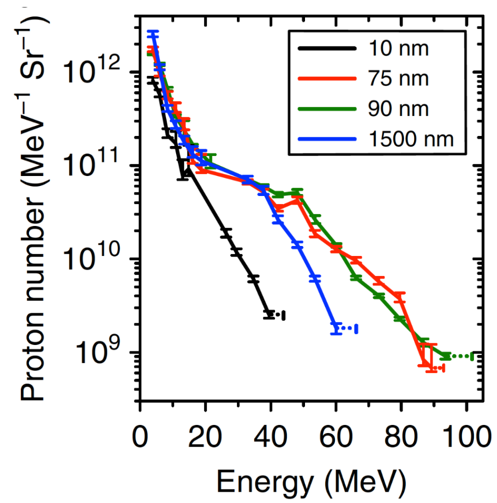
Power densities can be improved reducing the focusing spot:
— shorter focusing parabola
— but issues related to the: target degree, back reflection, …

High-power modality: 350 TW

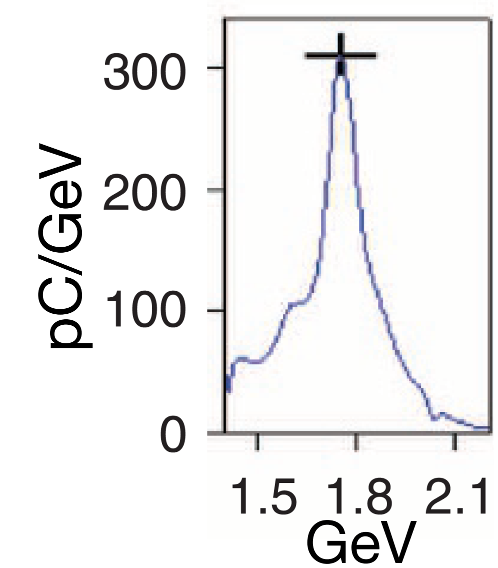
I-LUCE INFN Istituto Nazionale di Fisica Nucleare

Laser Power		350 TW
Energy per pulse		>7 J
Pulse duration		≤ 25 fs
Focusing surface		36 μm² or better
Max power density (at the target)		$8.82\cdot10^{20}$
$I^*\lambda^2$		$5.64\cdot10^{20}$
Contrast ratio @100 ps (ASE)		$> 10^{10}$
Repetition rate		1 Hz
Protons Ions	Max energy	50 MeV
	Particle per pulse (at 30 MeV)	10^{11} MeV^{-1} Sr^{-1}
	Energy spread	100%
	Beam divergency (max)	±20°
Eletrons	Max energy	3 GeV
	Particles per pulse	10^9
	Beam divergency (max)	± 20 mad
Neutrons	Max energy	20 MeV
	Particles per pulse	10^{10}
	Energy spread	100
	Beam divergency	Isotropic
Gamma X-beams	Synchrotron radiation of the electrons inside the plasma or	
	Energy	up to 80 MeV
	Beam divergency	Directionality in the beam

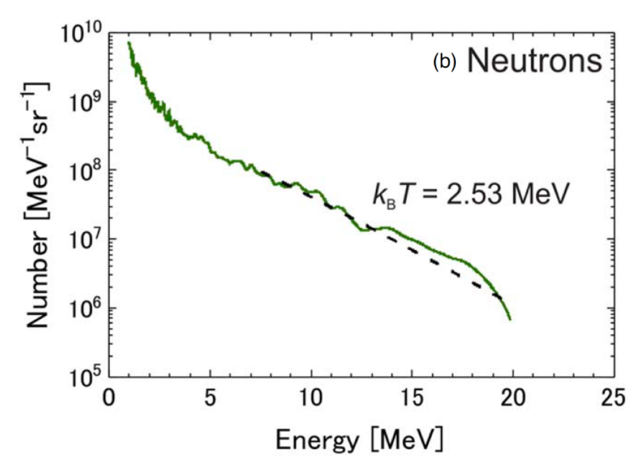
Protons spectra from A. Higginson et al. "Near-100 MeV protons via a laser-driven transparency-enhanced hybrid acceleration scheme", NATURE COMMUNICATIONS | (2018) 9:724



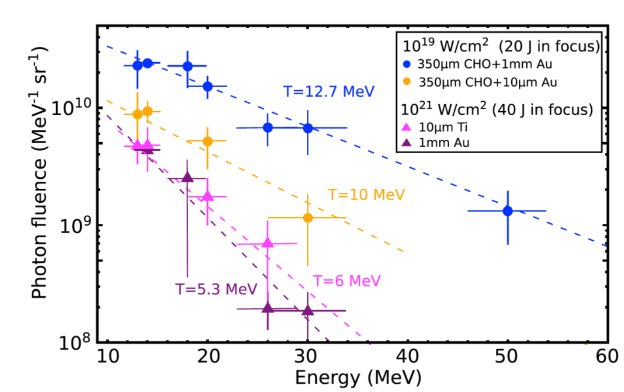
Electrons spectra from X. Wang et al. "Quasi-monoenergetic laser-plasma acceleration of electrons to 2 GeV", NATURE COMMUNICATIONS, 4:1988 2018 DOI: 10.1038/ncomms2988



Neutrons spectra from A.Yogo et al. "Single shot radiography by a bright source of laser-driven thermal neutrons and x-rays", Applied Physics Express 14, 106001 (2021)

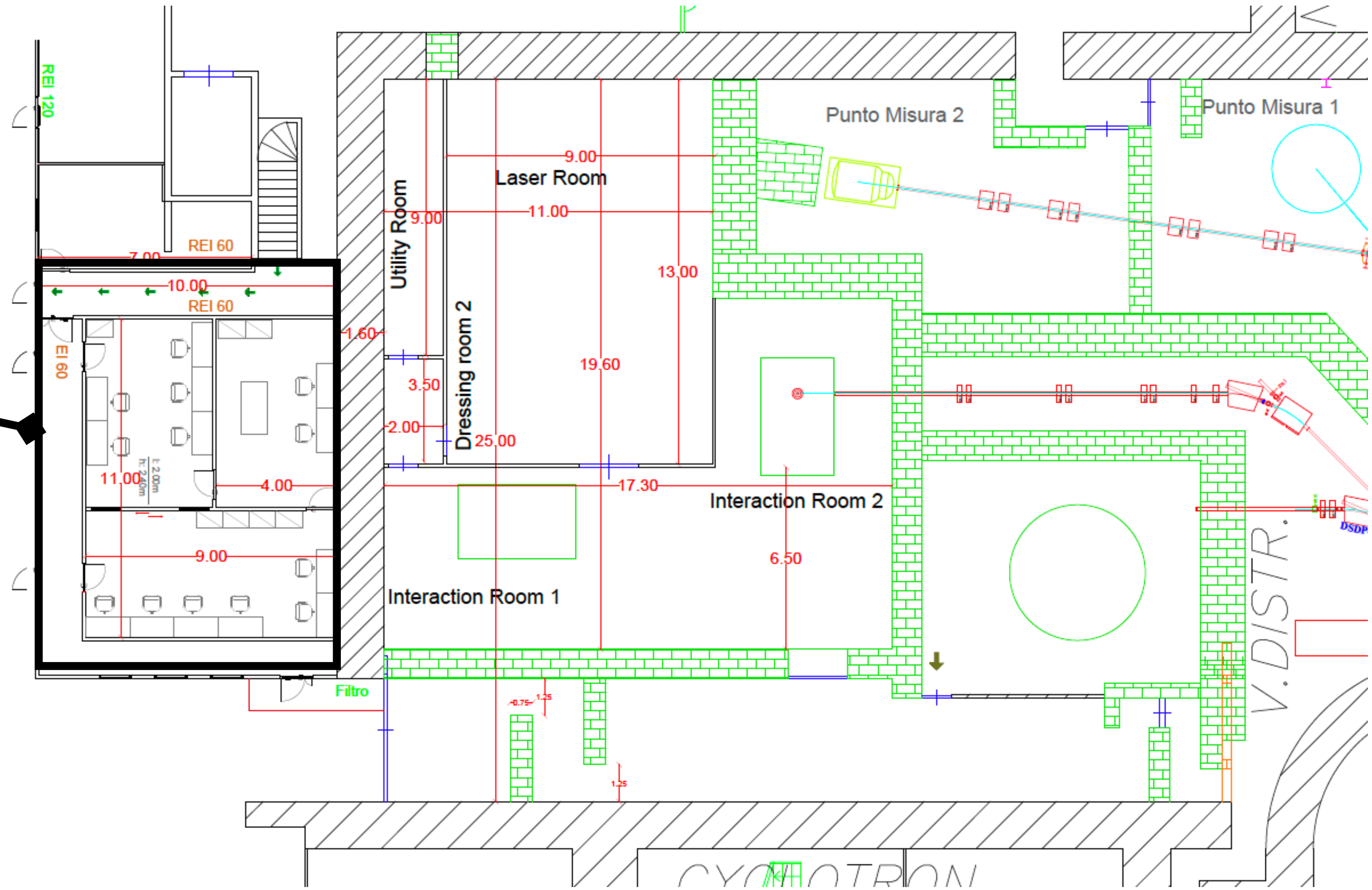


Gamma spectra from M. M. Günther et al "Forward-looking insights in laser-generated ultraintense γ-ray and neutron sources for nuclear application and science" NATURE COMMUNICATIONS | (2022) 13:170



I-LUCE current status

Control area under construction



I-LUCE current status

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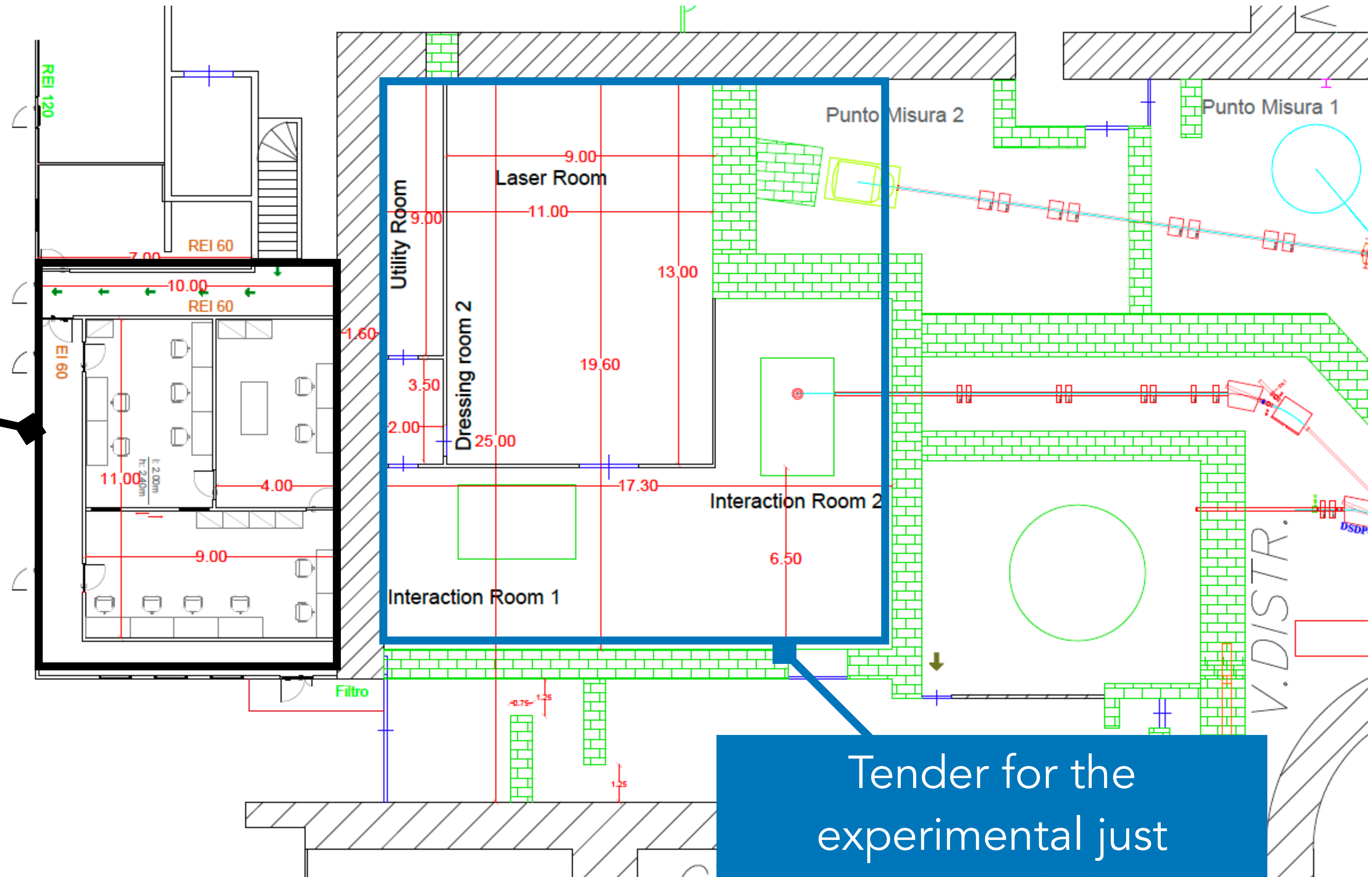
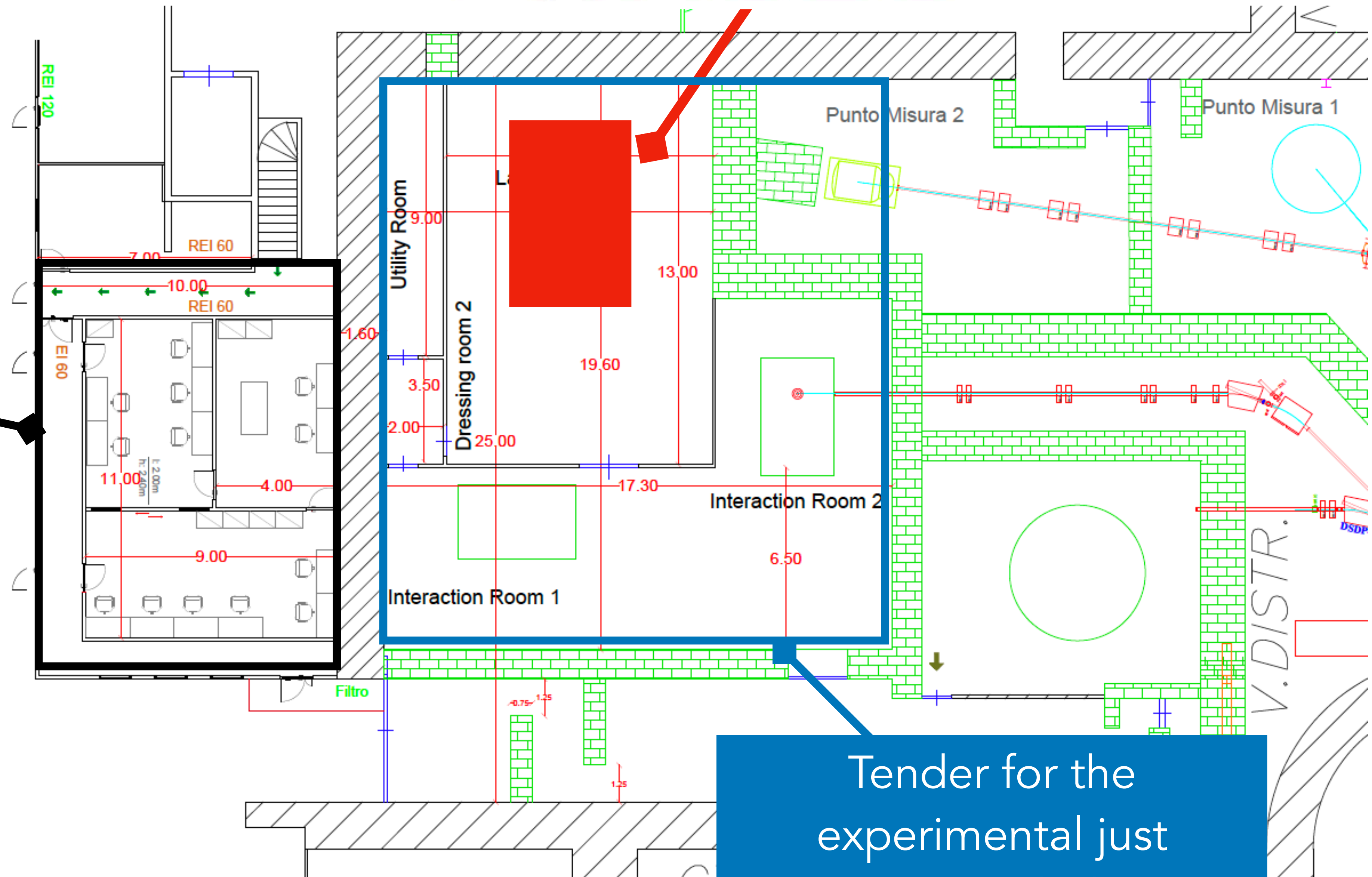


Tender for the experimental just concluded

I-LUCE current status

Laser tender concluded
Contract to be signed

THALES

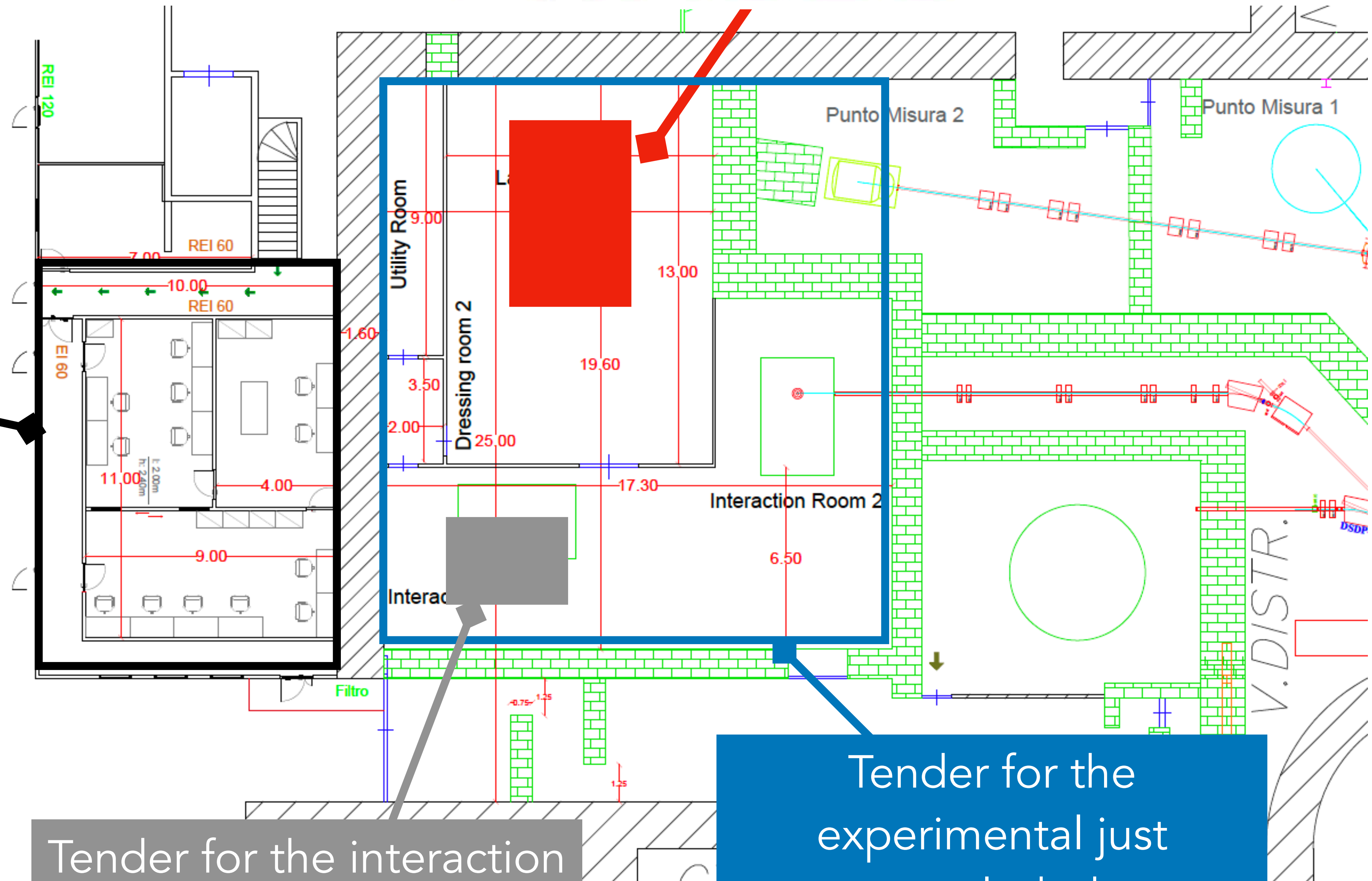


Control area under construction

Tender for the experimental just concluded

I-LUCE current status

Control area under construction



Laser tender concluded
Contract to be signed

THALES

Tender for the interaction chamber just concluded

Tender for the experimental just concluded

One physics cases at I-LUCE: proton acceleration an transportation

Medical and interdisciplinary applications

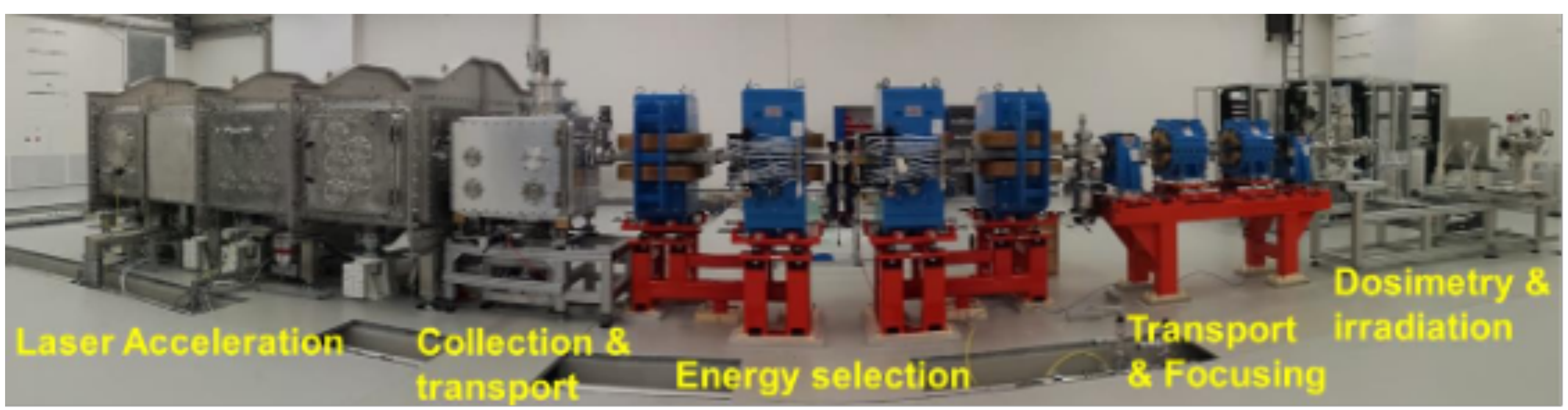
....for radiobiology studies

....for radioisotope production

... for hydrogen production

....for cultural heritage applications

... for inertial confinement studies



ELIMED/LIMAIA beamline th ELI-Beamlies facility (CZ)


quantum beam science
MDPI

Review

ELIMAIA: A Laser-Driven Ion Accelerator for Multidisciplinary Applications

Daniele Margarone [1,*], G. A. Pablo Cirrone [1,2], Giacomo Cuttone [2], Antonio Amico [2], Lucio Andò [2], Marco Borghesi [3], Stepan S. Bulanov [4], Sergei V. Bulanov [1], Denis Chatain [5], Antonín Fajstavr [1], Lorenzo Giuffrida [1], Filip Grepl [1], Satyabrata Kar [3], Josef Krasa [1], Daniel Kramer [1], Giuseppina Larosa [2], Renata Leanza [2], Tadzio Levato [1], Mario Maggiore [6], Lorenzo Manti [7], Guliana Milluzzo [2,3], Boris Odlozilik [1], Veronika Olsovcova [1], Jean-Paul Perin [5], Jan Pipek [2], Jan Psikal [1], Giada Petringa [2], Jan Ridky [1], Francesco Romano [2,8], Bedřich Rus [1], Antonio Russo [2], Francesco Schillaci [1,2], Valentina Scuderi [1,2], Andriy Velyhan [1], Roberto Versaci [1], Tuomas Wiste [1], Martina Zakova [1] and Georg Korn [1]

1. Enhancing the maximum proton energy and flux

2. Reducing the beam angular divergence or improving the beam homogeneity

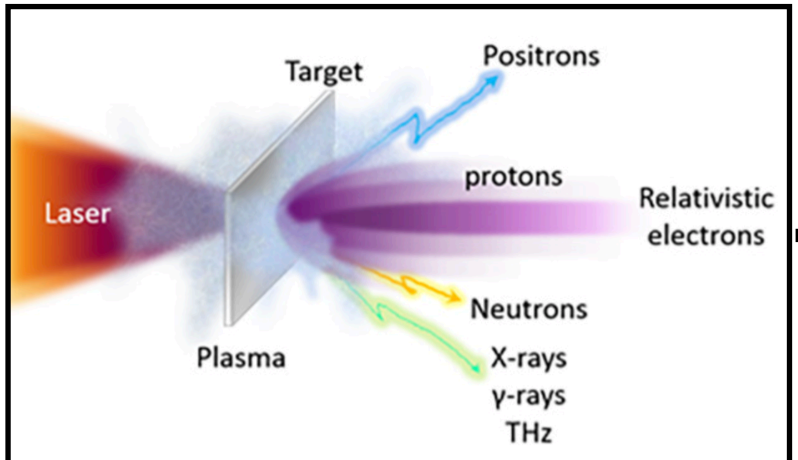
} Transport and selection system

} Target optimization

3. Reducing the ion contamination of the beam

4. Developing new technologies and strategies for diagnostics and dosimetry

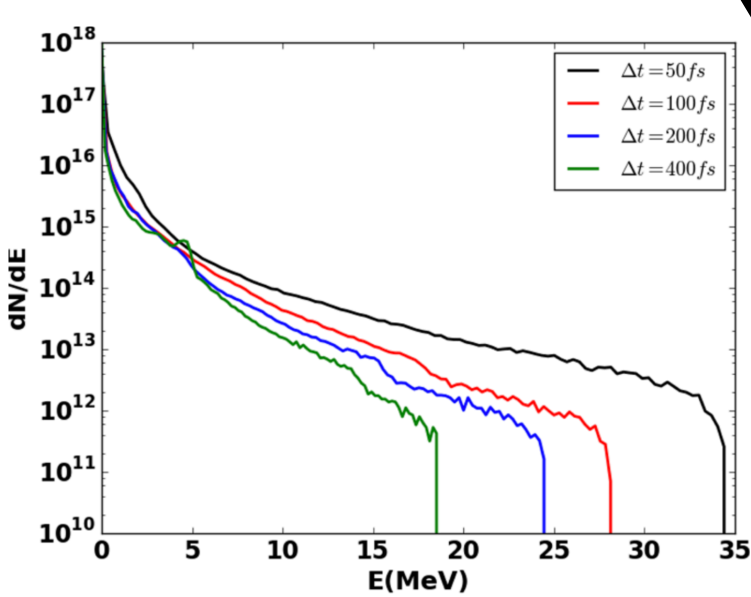
A typical irradiation set-up

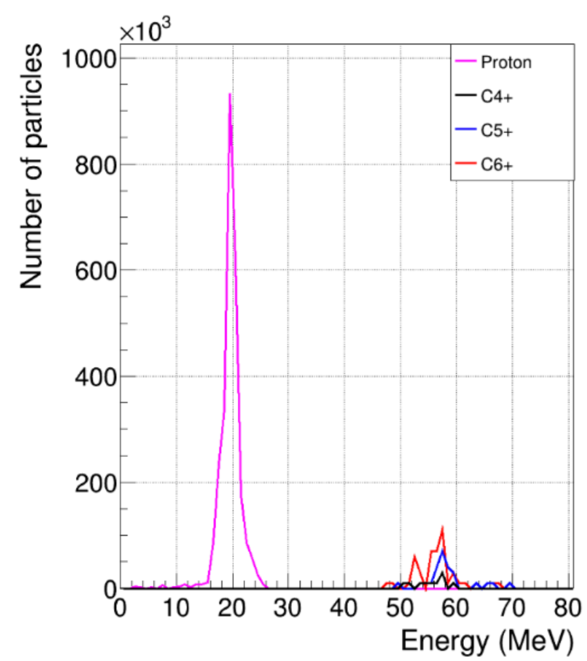


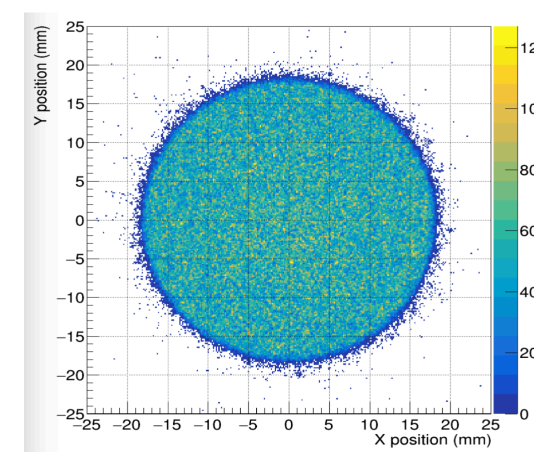
Focusing and Selection System

Diagnostic and Dosimetry

Sample Irradiation







S. M. Barba, et al. Appl.Sci. 11(21), 9623 (2021)

ELIMAIA, ELIBEAMLINES (CZ)

ELIMAIA experimental area
30J / 30fs
Protons are emitted from metallic/plastic foils um thickness
cut-off energy of up to ~40 MeV.

Beamline	L3 HAPLS	L4 ATON
Peak power	≥1 PW	10 PW
Energy in pulse	≥30 J	≥1.5 kJ
Pulse duration	≤30 fs	≤150 fs
Rep rate	10 Hz	1 per min
Supplier	LLNL	National Energetics
ELI-Beamlines	**Compressor, short pulse diagnostics, controls & timing systems**	**Compressor design, OPCPA design, short pulse diagnostics, timing system**

ELIMAIA, ELIBEAMLINES (CZ)

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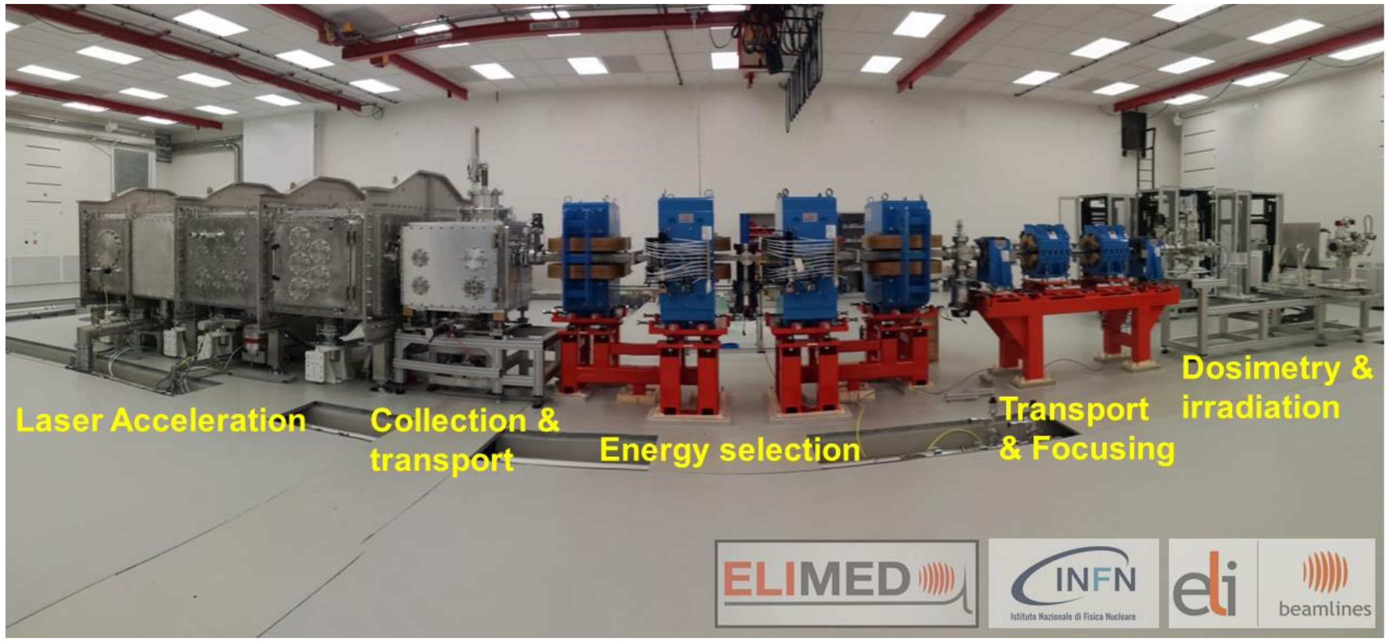
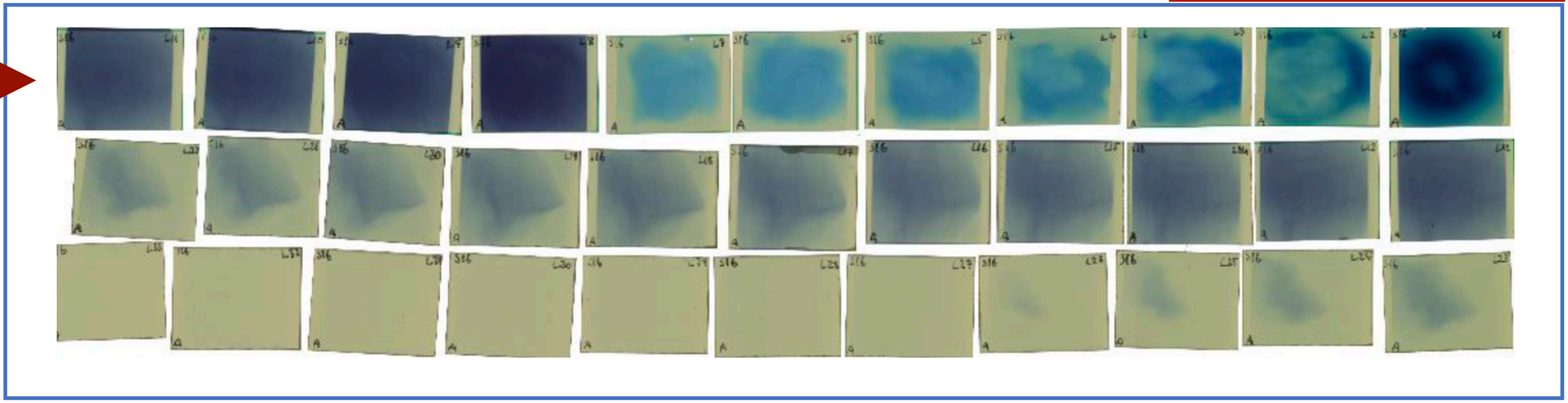


Queen's University Belfast
eli beamlines
INFN LNS Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Sud

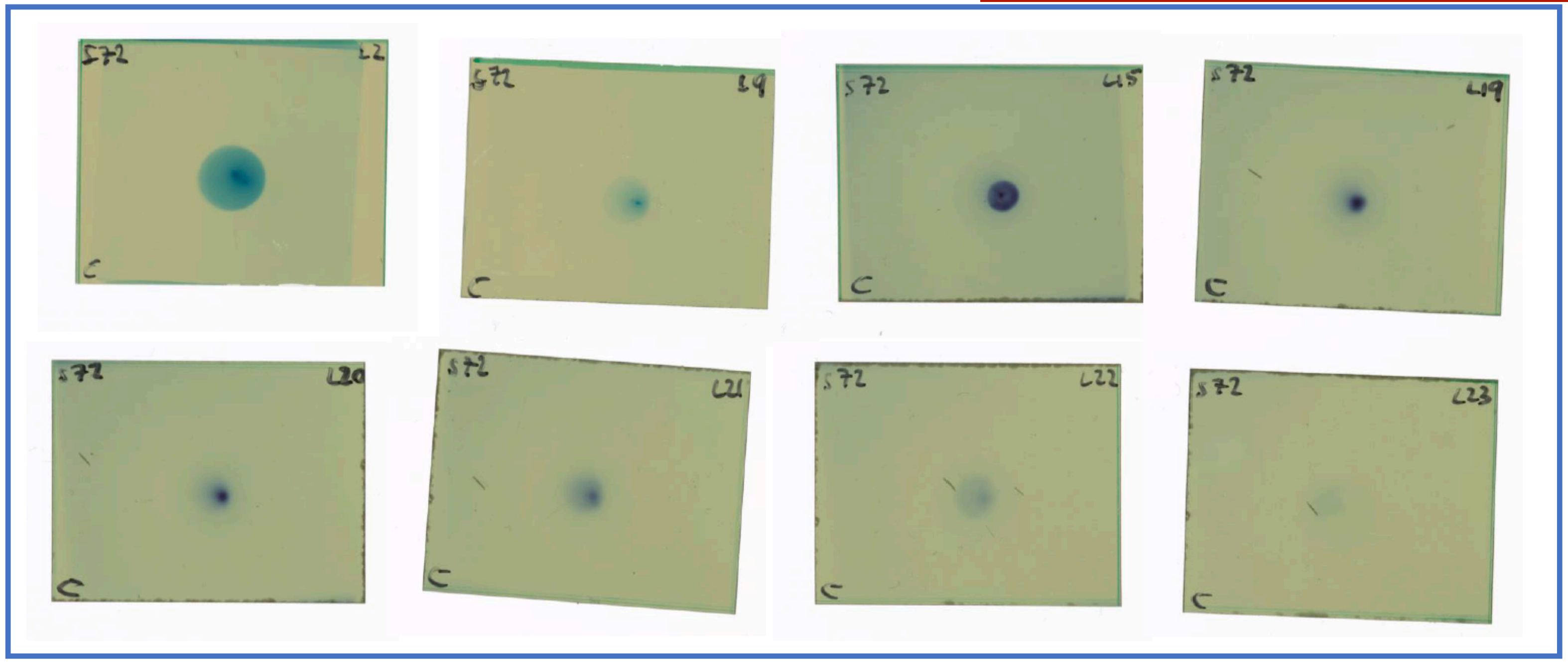
Laser-driven flash?

Preliminary results

proton beam



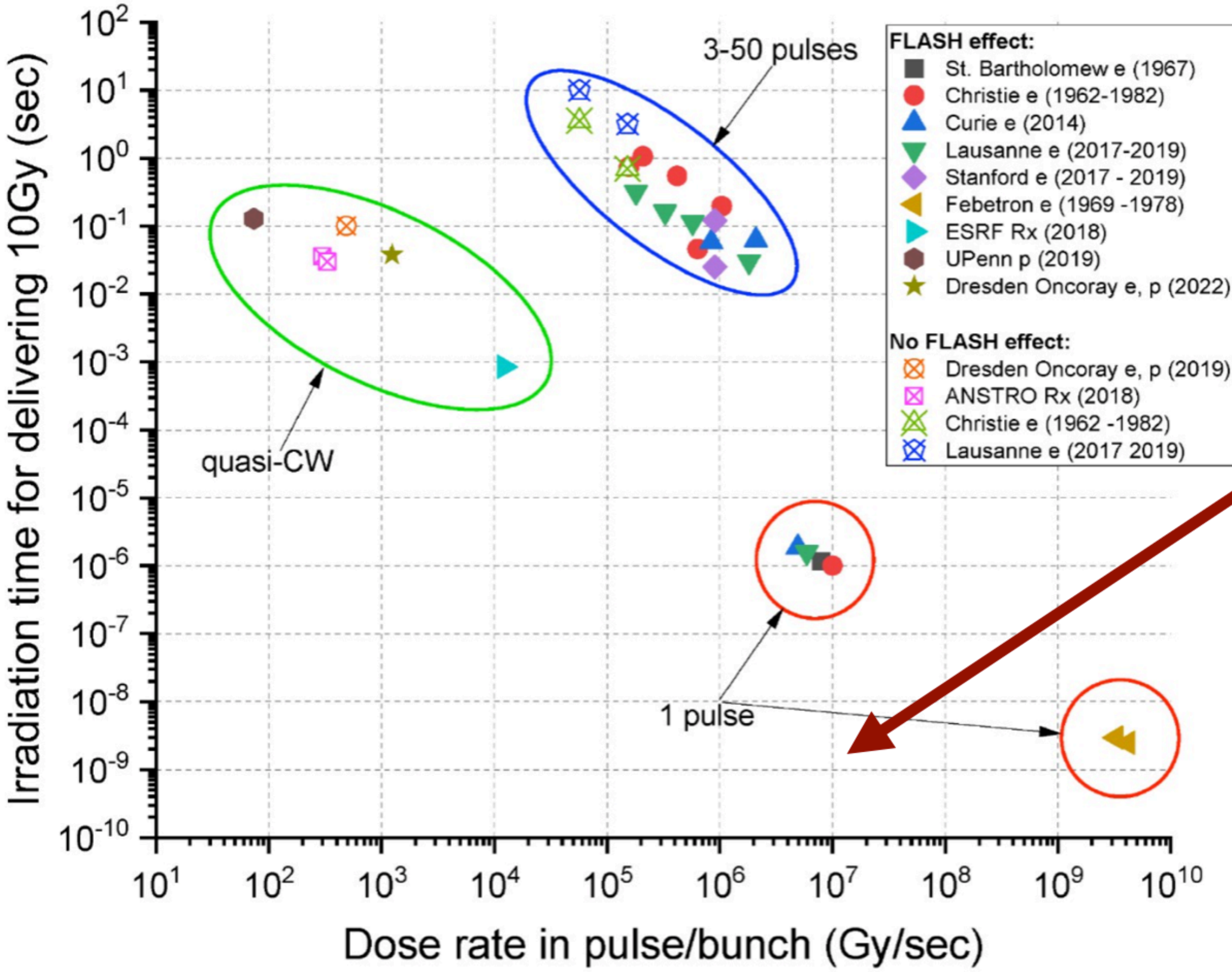
Not published data



Pablo Cirrone, PhD - pablo.cirrone@lns.infn.it

Coil target

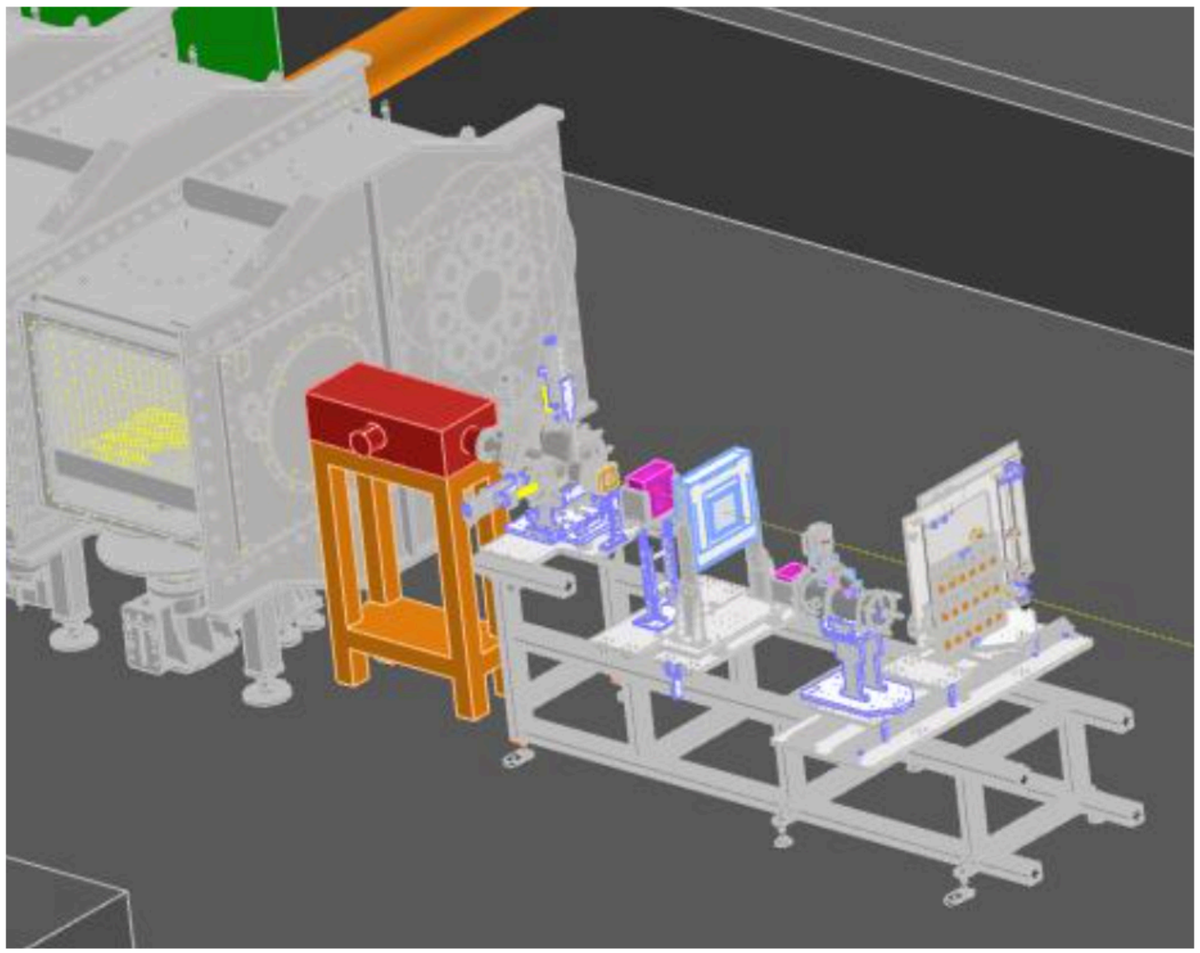
Energy: 10 J - Target: 2um Cu



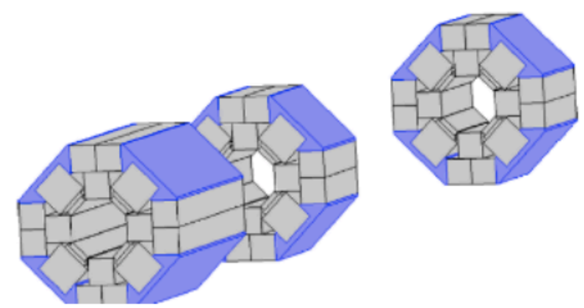
Dose [Gy]	Energy [MeV]
69,47	16,9
28	17,8
12	19,3
10,53	21,4
9,35	23,3
11,85	25,1
10,8	27
13,5	28,8
11,08	30,7
10,69	32,6
8,74	34,5

Preliminary results

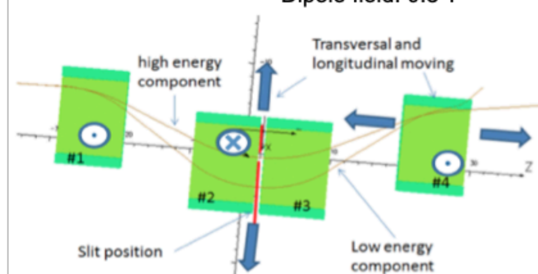
Samples irradiation and radiobiology

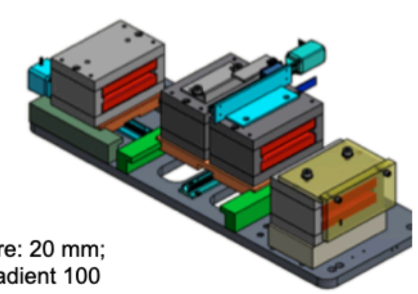


Protons / Ions	Max energy	50 MeV
	Particle per pulse (at 30 MeV)	10^{11} MeV^{-1} Sr^{-1}
Eletrons	Max energy	3 GeV
	Particles per pulse	10^{9}



Dipole field: 0.8 T



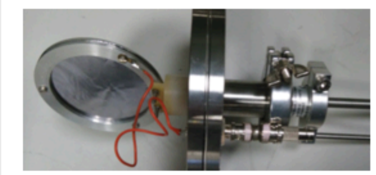


Bore: 20 mm; Gradient 100 T/m

Quadrupoles + energy selector

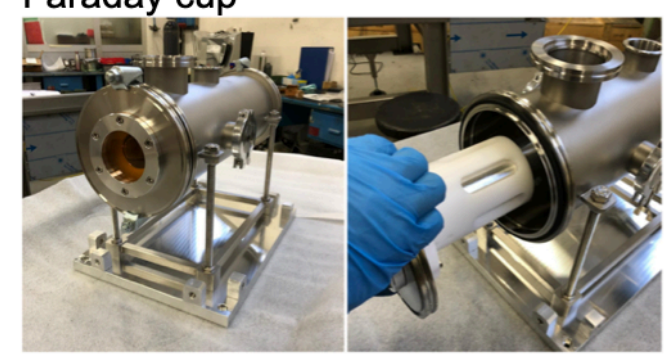
Transport up to 30 MeV with an energy revolution of 5 %

SEM



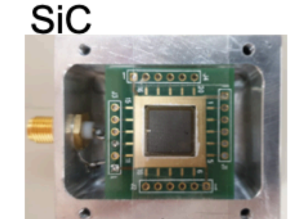
ICT

Faraday cup



Scintillator

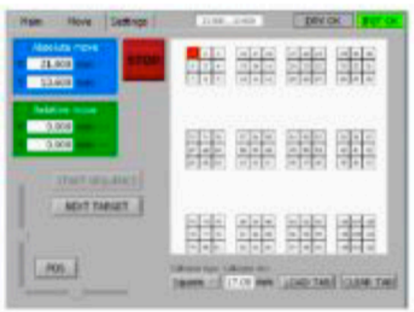
SiC



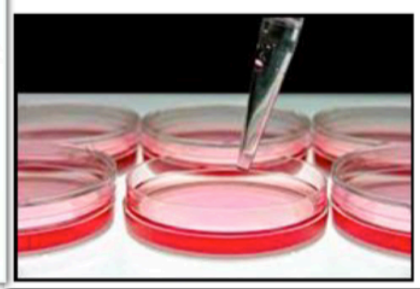
Diamond

Samples irradiation and radiobiology

In-vitro positioning system



Analysis pre and post irradiation



In-vivo positioning system

Types of equipment into the Bio-Lab:

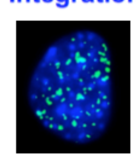
- ✓Laboratory Hood
- ✓Inverted microscopy
- ✓Centrifuge
- ✓Incubator
- ✓-80°C for storage of biological samples
- ✓Dewar for long term storage of different cellular batch

Fluorescence Microscopy

16.25 megapixel CMOS image sensors for microscopy

High sensitivity
Excellent linearity
High – frame rate
Low Noise

Integration with imaging SF



Small animals storage

What we will have at disposal at I-LUCE?

An high power laser: 8J/23fs/1Hz

A plasma generated by the laser:

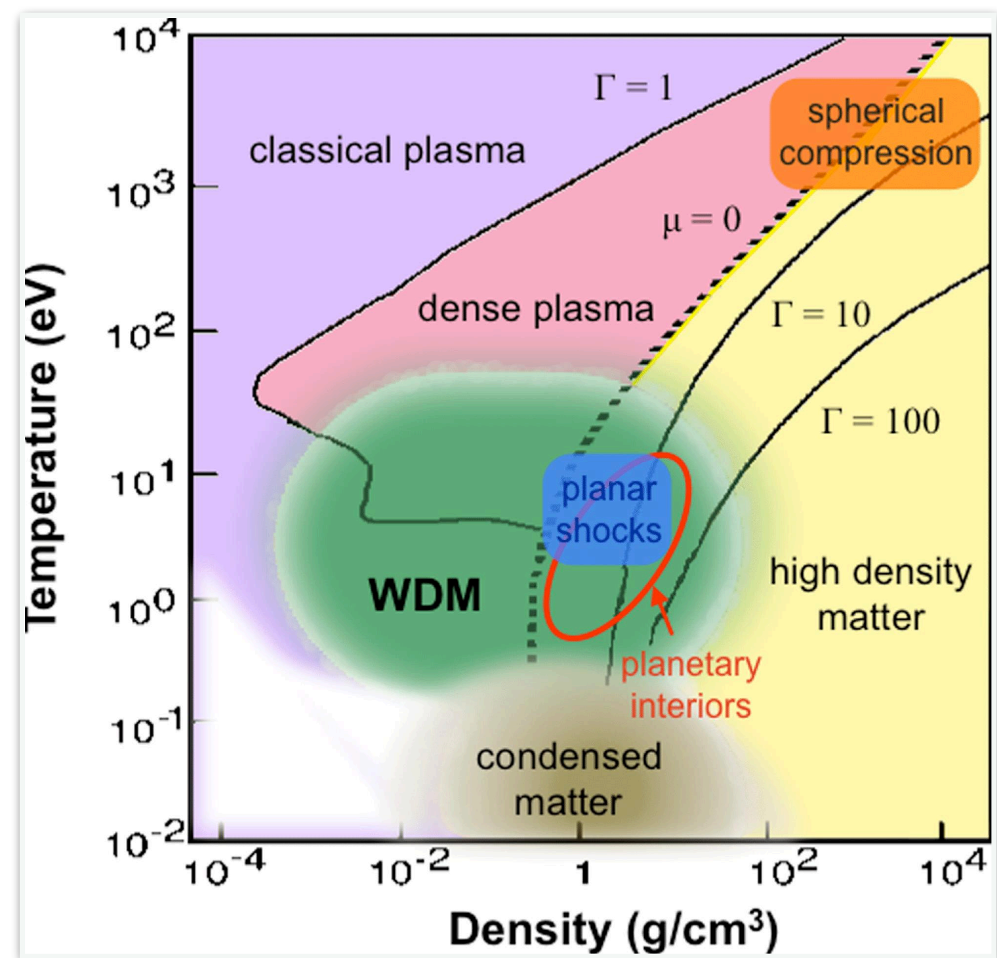
Temperature: 2 eV - 200 eV

$$T \approx \left(\frac{I}{1.37 \times 10^{16}\ \mathrm{W/cm^2}} \right)^{1/2}$$

$$n \approx \frac{I}{e^2 T}$$

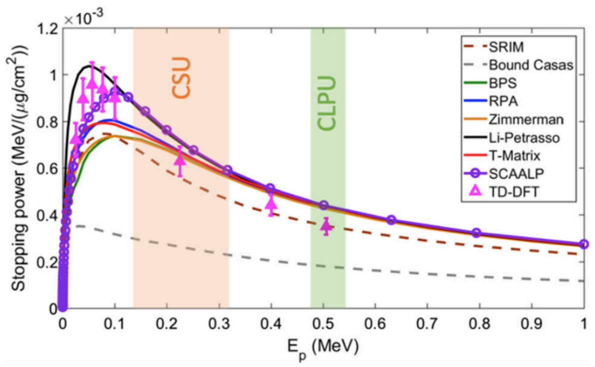
Density: 10^{25} m^{-3}

$$n \approx \frac{\varepsilon_0 m_e \omega_p^2}{e^2}$$

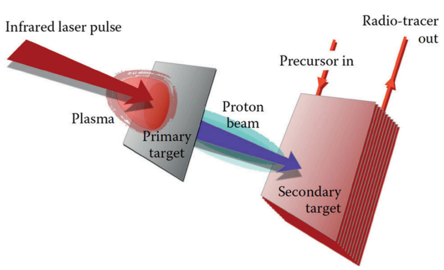


Ion beams in a wide Z range and energy up to 70 AMeV

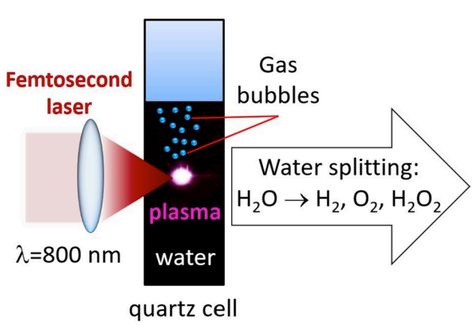
Nuclear physics mid-term plan



Stopping power in plasma



Radioisotopes



Hydrogen generation

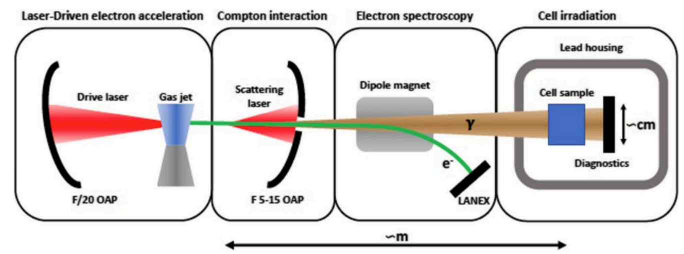
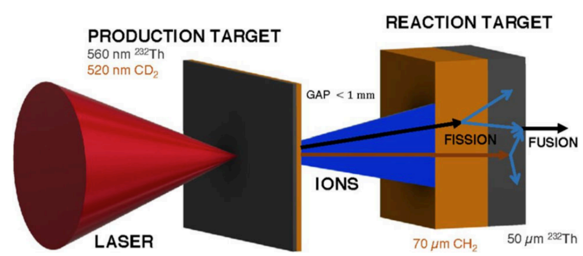
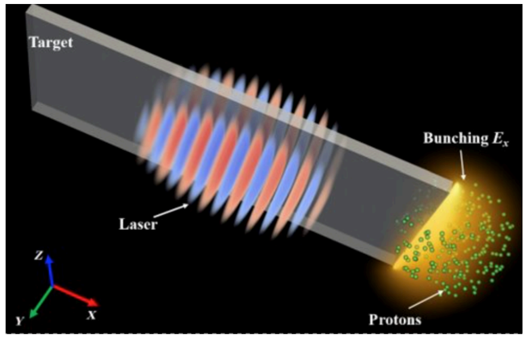


Fig. 48 Setup for the high-brilliance γ production via inverse Compton-scattering (from Sarri et al. [371])

Positrons generation

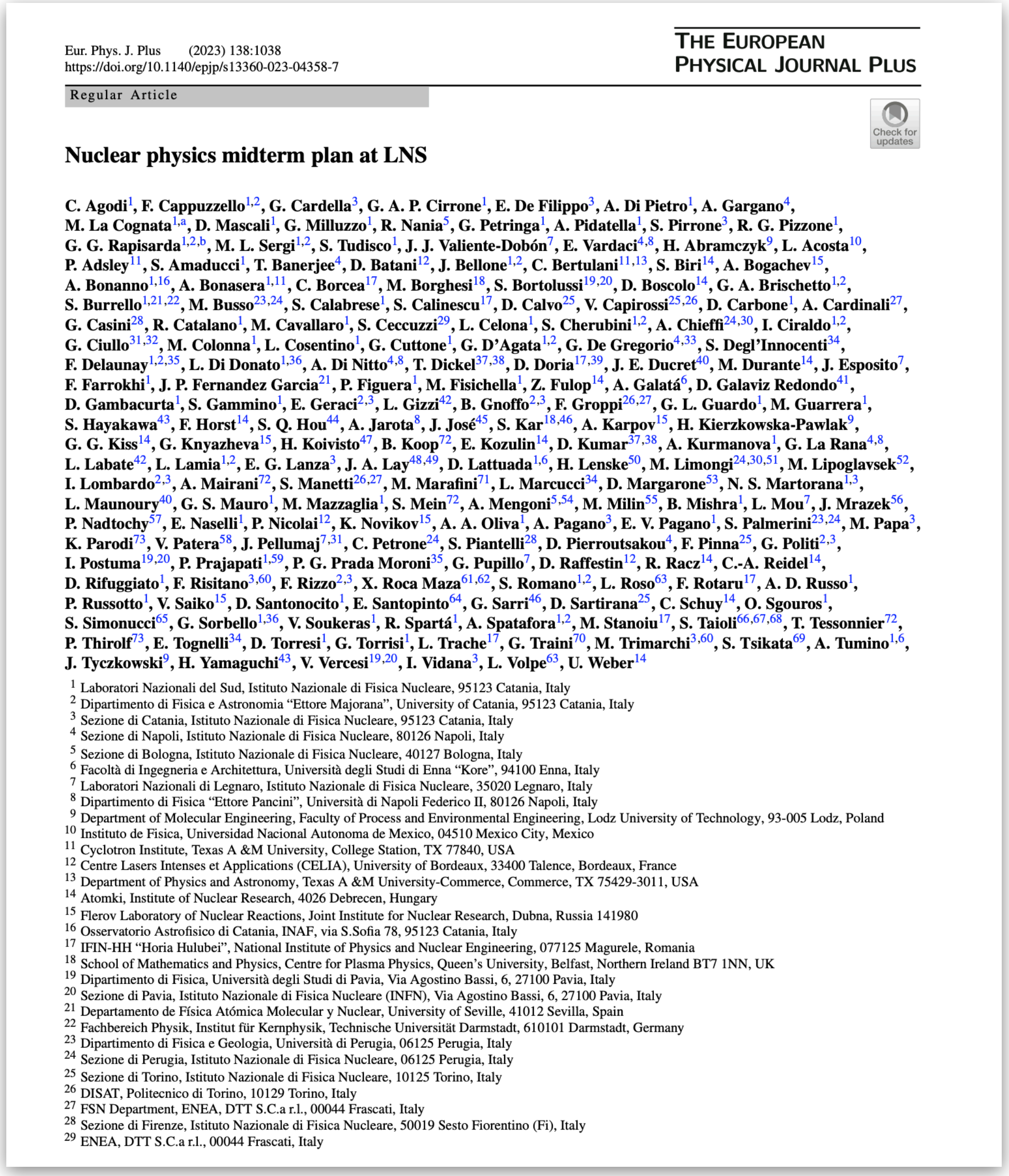


Nuclear reaction schemes



Protons and electrons generation

Chapter 6.2 Laser applications



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THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

Check for updates

Nuclear physics midterm plan at LNS

C. Agodi[1], F. Cappuzzello[1,2], G. Cardella[3], G. A. P. Cirrone[1], E. De Filippo[3], A. Di Pietro[1], A. Gargano[4], M. La Cognata[1,a], D. Mascali[1], G. Milluzzo[1], R. Nania[5], G. Petringa[1], A. Pidatella[1], S. Pirrone[3], R. G. Pizzone[1], G. G. Rapisarda[1,2,b], M. L. Sergi[1,2], S. Tudisco[1], J. J. Valiente-Dobón[7], E. Vardaci[4,8], H. Abramczyk[9], L. Acosta[10], P. Adsley[11], S. Amaducci[1], T. Banerjee[4], D. Batani[12], J. Bellone[1,2], C. Bertulani[11,13], S. Biri[14], A. Bogachev[15], A. Bonanno[1,16], A. Bonasera[1,11], C. Borcea[17], M. Borghesi[18], S. Bortolussi[19,20], D. Boscolo[14], G. A. Brischetto[1,2], S. Burrello[1,21,22], M. Busso[23,24], S. Calabrese[1], S. Calinescu[17], D. Calvo[25], V. Capirossi[25,26], D. Carbone[1], A. Cardinali[27], G. Casini[28], R. Catalano[1], M. Cavallaro[1], S. Ceccuzzi[29], L. Celona[1], S. Cherubini[1,2], A. Chieffi[24,30], I. Ciraldo[1,2], G. Ciullo[31,32], M. Colonna[1], L. Cosentino[1], G. Cuttone[1], G. D'Agata[1,2], G. De Gregorio[4,33], S. Degl'Innocenti[34], F. Delaunay[1,2,35], L. Di Donato[1,36], A. Di Nitto[4,8], T. Dickel[37,38], D. Doria[17,39], J. E. Ducret[40], M. Durante[14], J. Esposito[7], F. Farrokhi[1], J. P. Fernandez Garcia[21], P. Figuera[1], M. Fisichella[1], Z. Fulop[14], A. Galatá[6], D. Galaviz Redondo[41], D. Gambacurta[1], S. Gammino[1], E. Geraci[2,3], L. Gizzi[42], B. Gnoffo[2,3], F. Groppi[26,27], G. L. Guardo[1], M. Guarrera[1], S. Hayakawa[43], F. Horst[14], S. Q. Hou[44], A. Jarota[8], J. José[45], S. Kar[18,46], A. Karpov[15], H. Kierzkowska-Pawlak[9], G. G. Kiss[14], G. Knyazheva[15], H. Koivisto[47], B. Koop[72], E. Kozulin[14], D. Kumar[37,38], A. Kurmanova[1], G. La Rana[4,8], L. Labate[42], L. Lamia[1,2], E. G. Lanza[3], J. A. Lay[48,49], D. Lattuada[1,6], H. Lenske[50], M. Limongi[24,30,51], M. Lipoglavsek[52], I. Lombardo[2,3], A. Mairani[72], S. Manetti[26,27], M. Marafini[71], L. Marcucci[34], D. Margarone[53], N. S. Martorana[1,3], L. Maunoury[40], G. S. Mauro[1], M. Mazzaglia[1], S. Mein[72], A. Mengoni[5,54], M. Milin[55], B. Mishra[1], L. Mou[7], J. Mrazek[56], P. Nadtochy[57], E. Naselli[1], P. Nicolai[12], K. Novikov[15], A. A. Oliva[1], A. Pagano[3], E. V. Pagano[1], S. Palmerini[23,24], M. Papa[3], K. Parodi[73], V. Patera[58], J. Pellumaj[7,31], C. Petrone[24], S. Piantelli[28], D. Pierroutsakou[4], F. Pinna[25], G. Politi[2,3], I. Postuma[19,20], P. Prajapati[1,59], P. G. Prada Moroni[35], G. Pupillo[7], D. Raffestin[12], R. Racz[14], C.-A. Reidel[14], D. Rifuggiato[1], F. Risitano[3,60], F. Rizzo[2,3], X. Roca Maza[61,62], S. Romano[1,2], L. Roso[63], F. Rotaru[17], A. D. Russo[1], P. Russotto[1], V. Saiko[15], D. Santonocito[1], E. Santopinto[64], G. Sarri[46], D. Sartirana[25], C. Schuy[14], O. Sgouros[1], S. Simonucci[65], G. Sorbello[1,36], V. Soukeras[1], R. Spartá[1], A. Spatafora[1,2], M. Stanoiu[17], S. Taioli[66,67,68], T. Tessonnier[72], P. Thirolf[73], E. Tognelli[34], D. Torresi[1], G. Torrisi[1], L. Trache[17], G. Traini[70], M. Trimarchi[3,60], S. Tsikata[69], A. Tumino[1,6], J. Tyczkowski[9], H. Yamaguchi[43], V. Vercesi[19,20], I. Vidana[3], L. Volpe[63], U. Weber[14]

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29 ENEA, DTT S.C.a r.l., 00044 Frascati, Italy

Future

ELI-Beamlines MoU

ELI-NP MoU

First official experiments at ELI-beamlines (ongoing)

Next ELI-Beamlines call: proof of principle for a neutron source with laser-driven electron and proton beams

Paper ongoing

Future

ELI-Beamlines MoU

ELI-NP MoU

First official experimen

Next ELI-Beamlines cal
source with laser-drive

Paper ongoing

PARTICIPANT NUMBER & NAME	EU	TYPE	ROLE
1. (Coo) – CNRS (Centre National de la Recherche Scientifique)	FR	RTO	Coordinator
2. CELIA (Université de Bordeaux CELIA)	FR	UNI	Affiliated entity to CNRS - Participation to WP3, WP5, WP7
3. LULI (Ecole Polytechnique)	FR	UNI	Affiliated entity to CNRS -
4. UPM (Universidad Politécnica de Madrid)	ES	UNI	
5. ETSI-ETSIAE (Higher Technical School of Aeronautical and Space Engineering)	ES	UNI	Affiliated entity to UPM -
6. IFN (Instituto Fusion Nucleare)	ES	RTO	Affiliated entity to UPM -
7. CLPU (Centro de Láseres Pulsados Ultracortos Ultraintensos)	ES	RTO	
8. ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development)	IT	RTO	
9. INFN-LNS (Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud)	IT	RTO	Affiliated entity to ENEA -
10. CNR (Consiglio Nazionale Delle Ricerche)	IT	RTO	
11. GSI-JENA (Helmholtz Institute Jena)	DE	RTO	
12. HZDR (Helmholtz Zentrum)	DE	RTO	Participation WP 4 and WP5
13. STFC (UK Research and Innovation: Science and Technology Facilities Council)	UK	RTO	
14. HMU (Hellenic Mediterranean University)	GR	UNI	
15. FZU-PALS (Academy of Science of CZ)	CZ	ORG	
16. ELI-ERIC (Extreme Light Infrastructure - European Research Infrastructure Consortium)	CZ	RTO	Participation in WP2, WP5, and WP7
17. ULisboa (Instituto Superior Técnico)	PT	RTO	
18. IPPiLM (Institute of Plasma Physics and Laser Microfusion)	PL	RTO	Participation in WP3, WP5, and WP7

HIPER+ Initiative on Inertial Confinement Fusion as “affiliated” of ENEA

Future

ELI-Beamlines Mo

ELI-NP MoU

First official experi

Next ELI-Beamline
source with laser-

Paper ongoing

High Power Lasers and Applications Workshop (next edition in November 2024 with an international Geant4 school)

Thanks to everyone