60th International Winter Meeting
on Nuclear Physics

22 - 26 January 2024
Bormio, Italy

INFN
Istituto Nazionale di Fisica Nucleare

I-LUCE

High power lasers for basic science and applications: the perspectives of the I-LUCE Italian facility

Pablo Cirrone - INFN

Bormio (I), January 22-26, 2024

Outline

High power lasers and particle acceleration

I will better **focus on proton** beams

The upcoming INFN I-LUCE **high-power laser facility** with some example of future perspectives

lasers and particle acceleration?

Istituto Nazionale di Fisica Nucleare

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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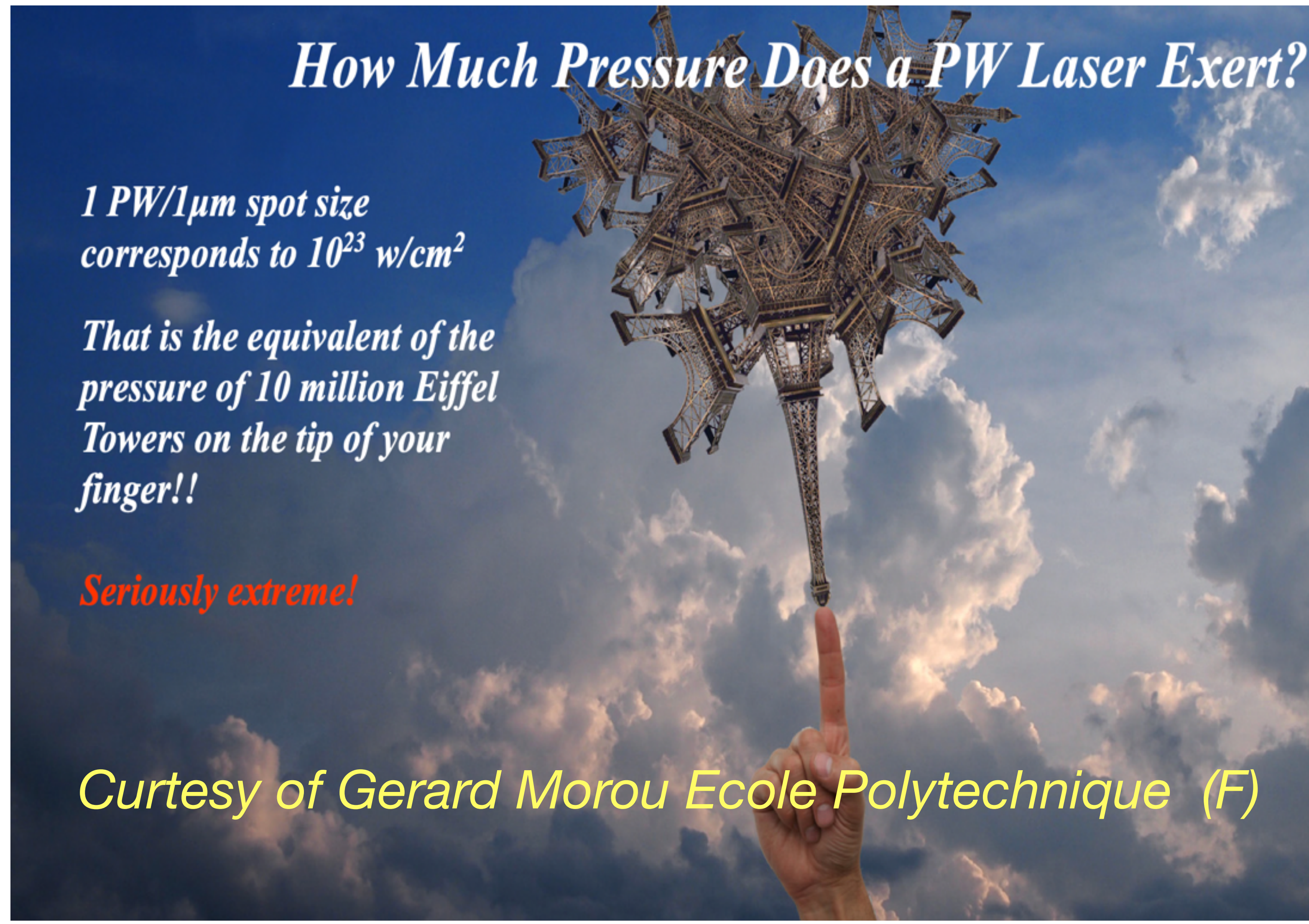

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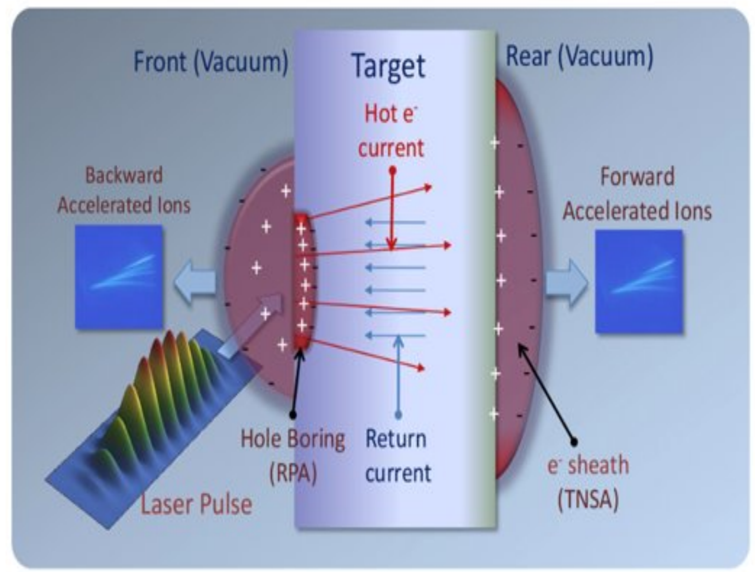
…. [many other laser and target parameters]

Laser-solid target interaction for protons, ions acceleration



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

Proton characteristics

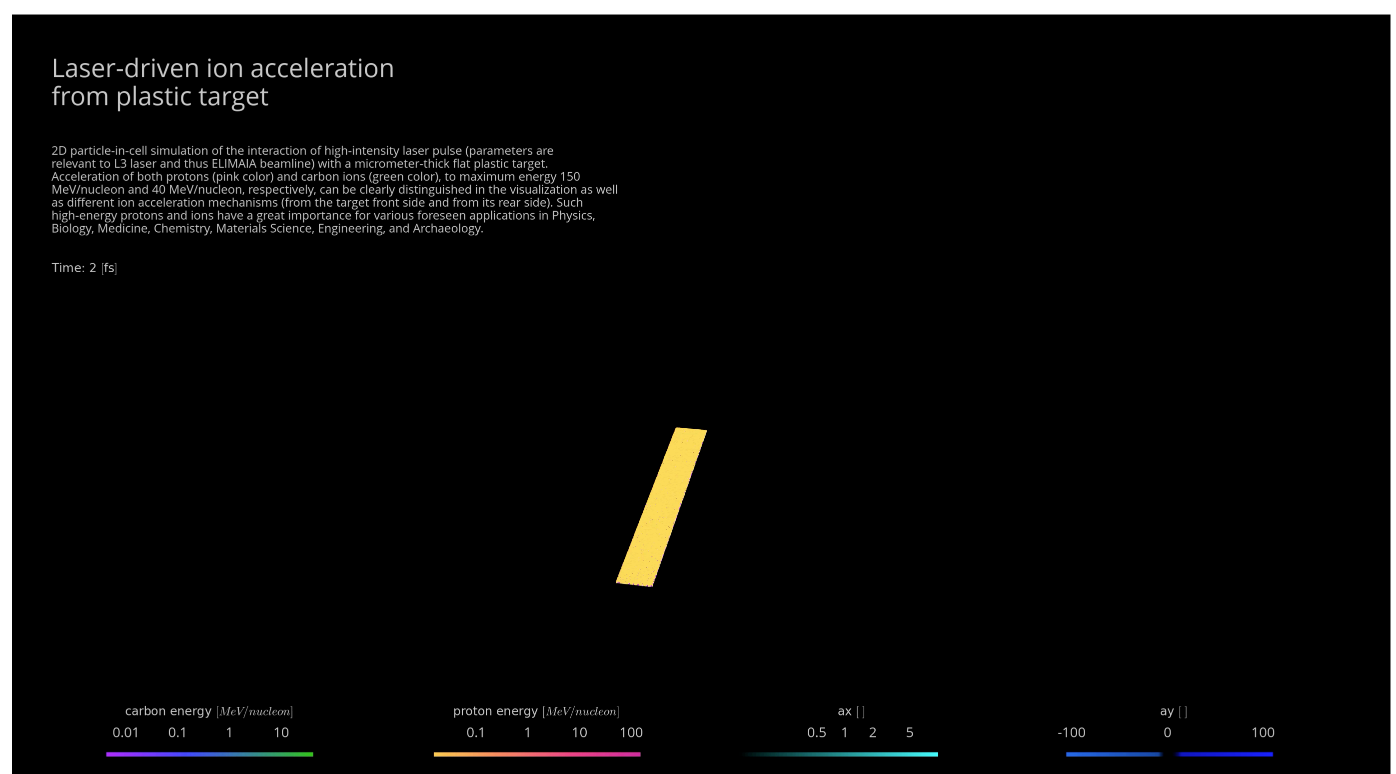
High energy: up to ~ 100 MeV

Pulse duration ≈ 10s fs - 100s ps

ppb ≈ 108-1011

Broad energy spectra (100%)

Wide angular divergence (≈ 10°-20°)



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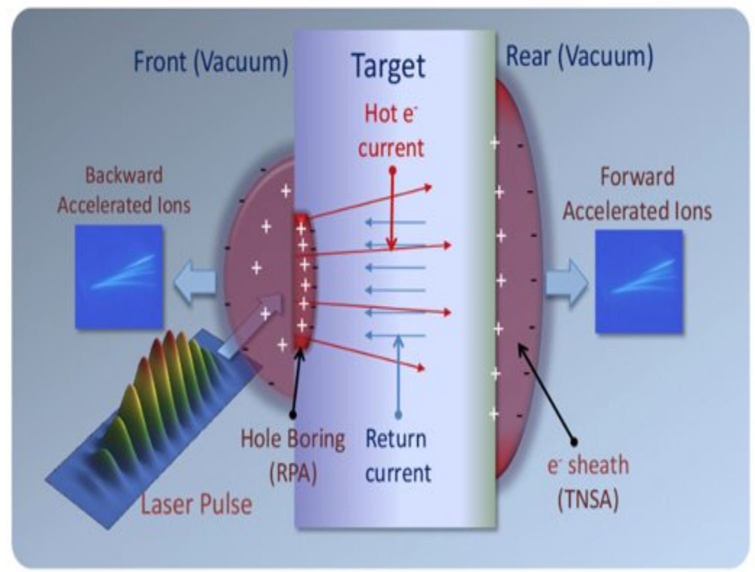

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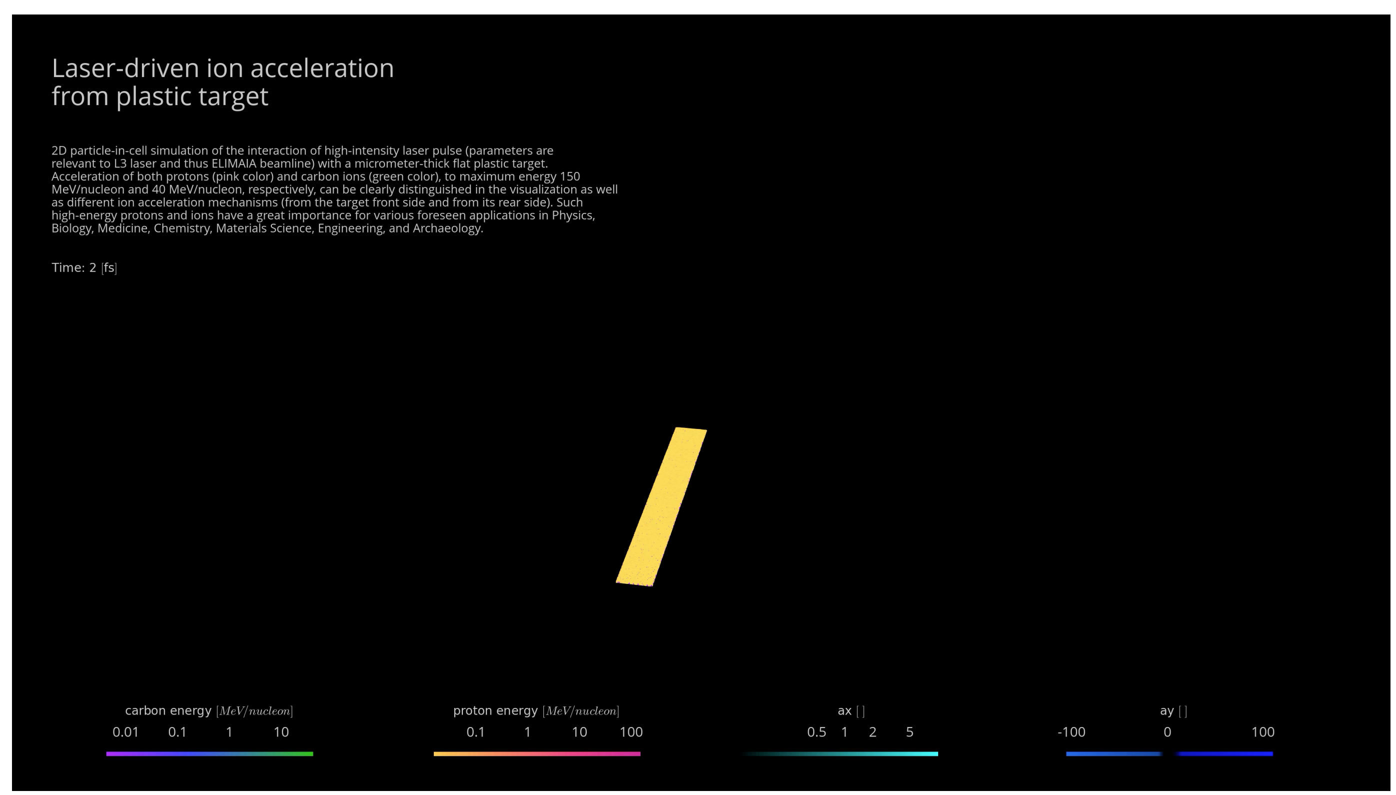

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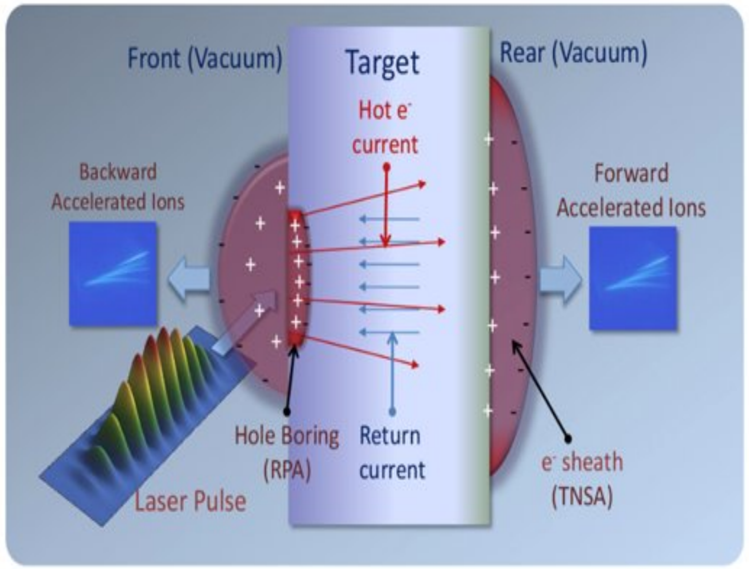

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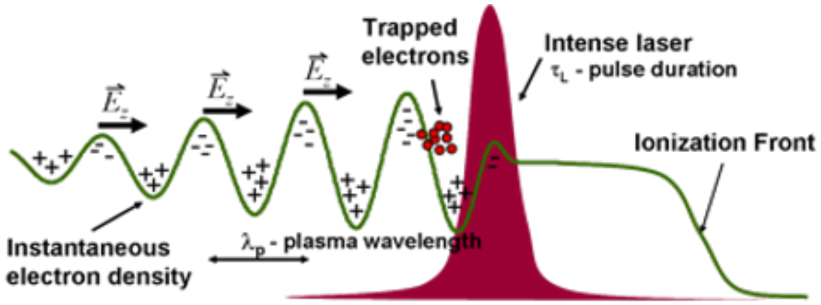
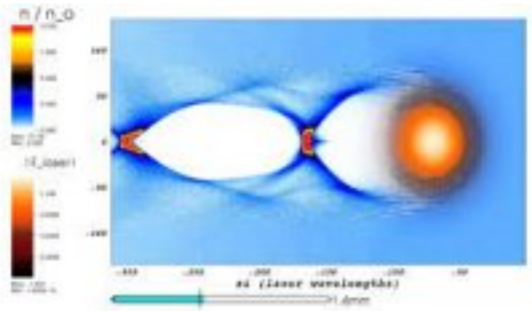
Laser Wake Field Acceleration (LWFA) for electrons





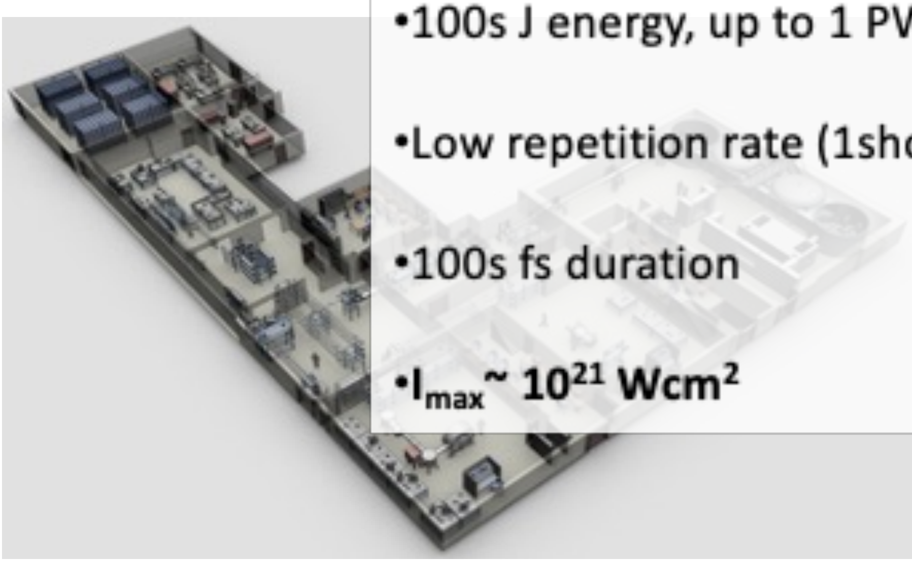
7.8 GeV have been reached at the BELLA (Berkeley Lab) in 2019 using two lasers

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

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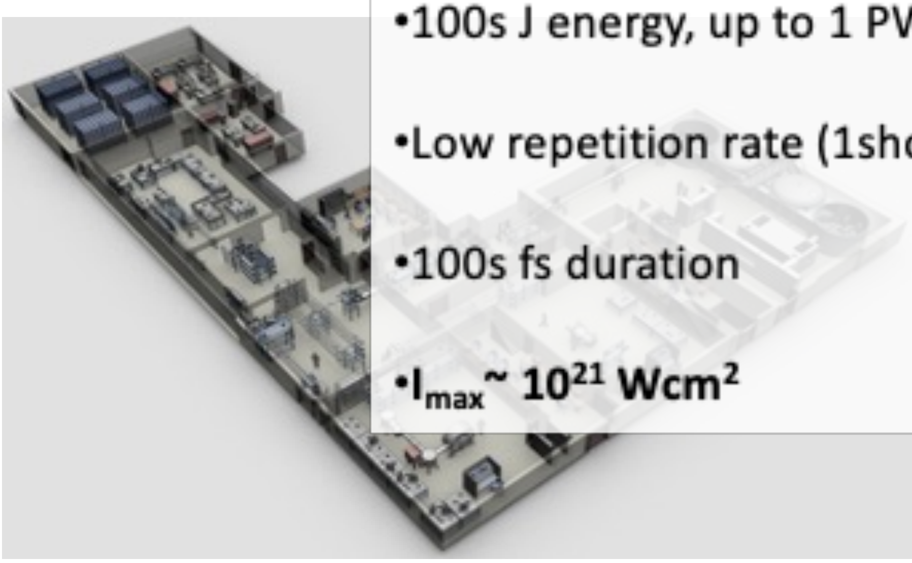

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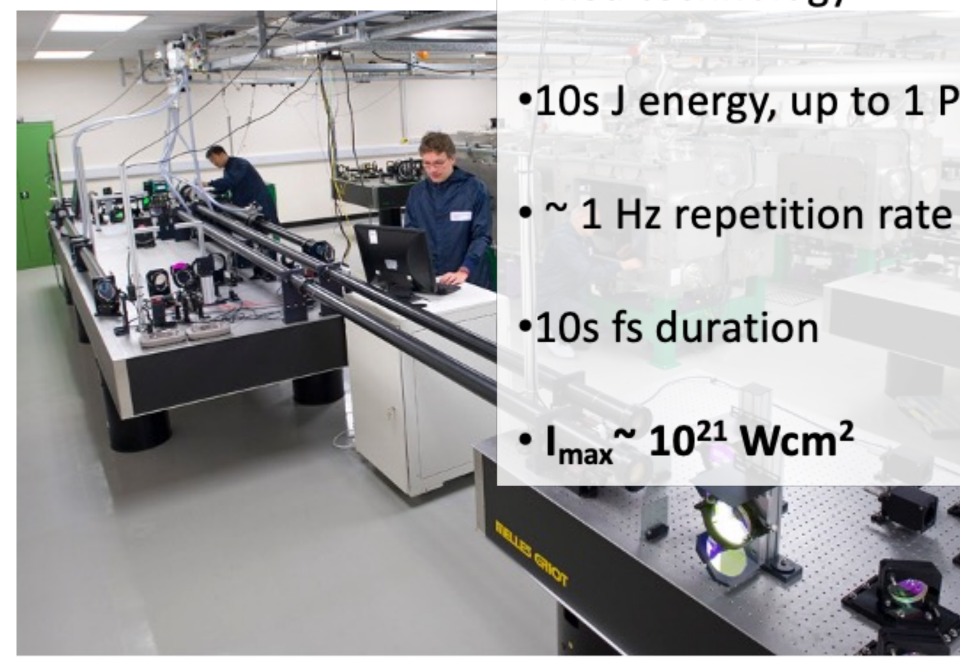
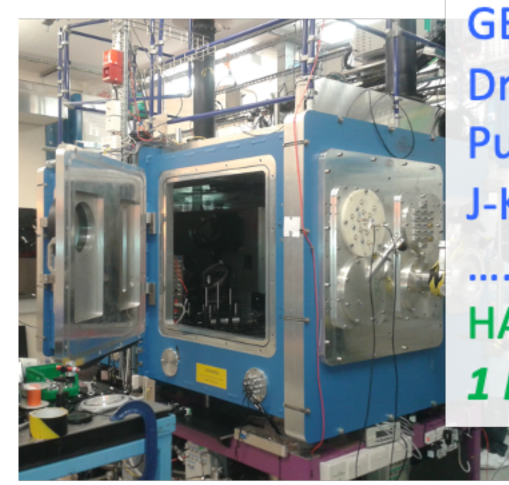


Ultrashort CPA systems

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

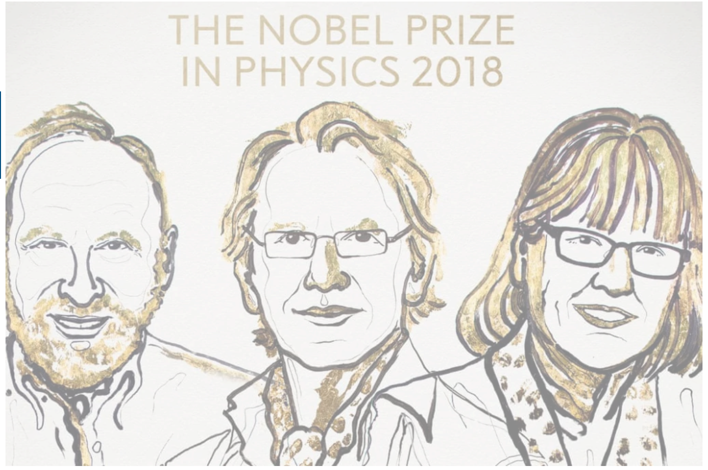
I_{max}~ 10^{21} W/cm^2

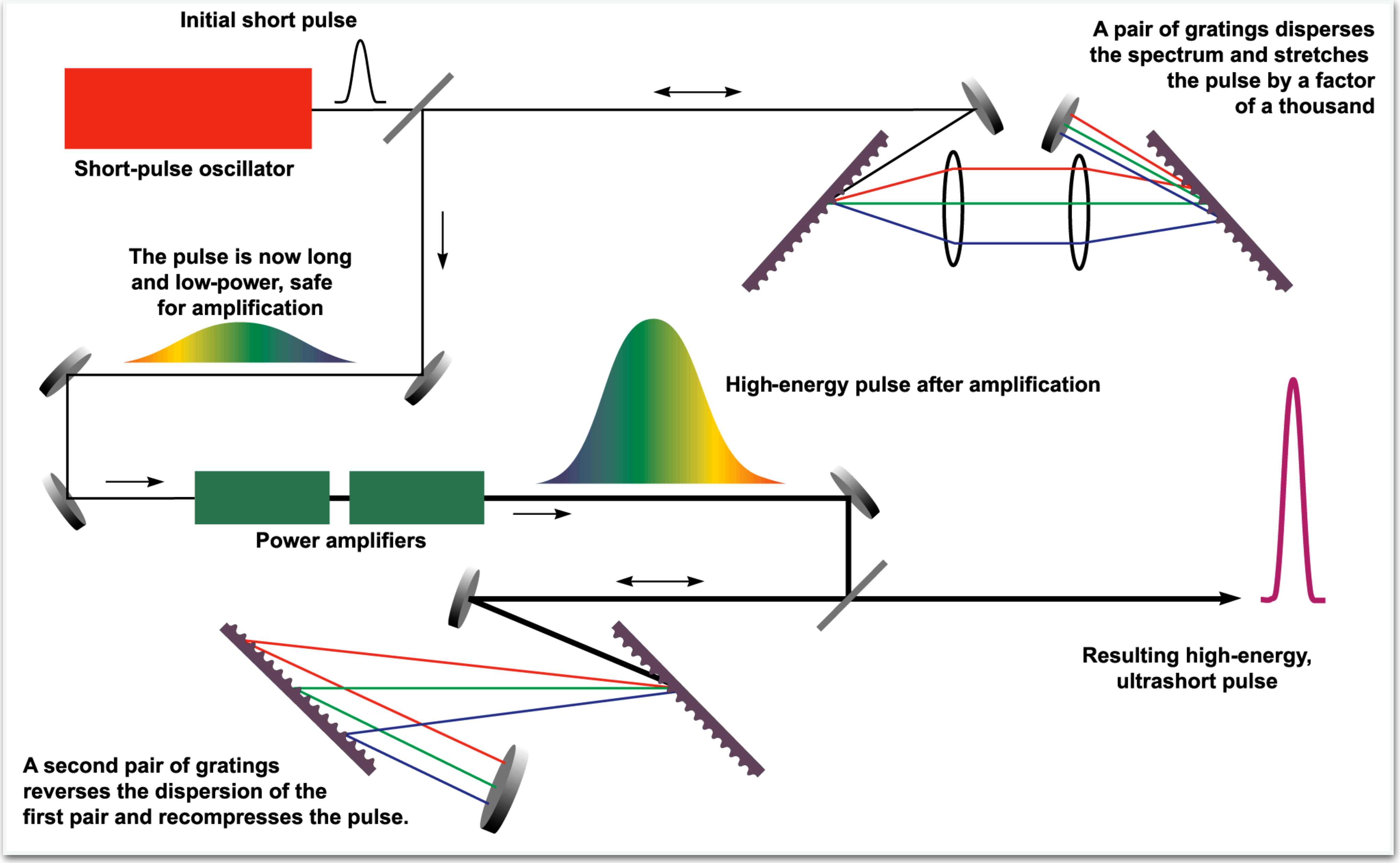


GEMINI, RAL (UK)
Draco, HZDR (De)
Pulser I, APRI (Kr)
J-Karen, JAEA (J)
….
HAPLS-L3, (ELI Beamlines)
***1 PW** (30J/30fs/**10Hz**)*

E_{max}~ 70-110 MeV

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





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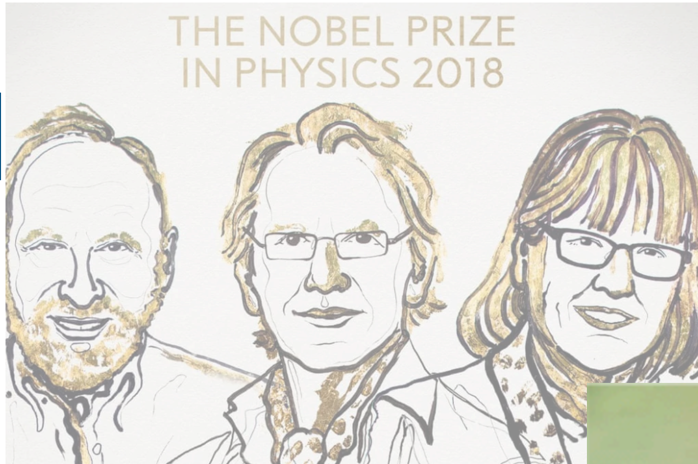
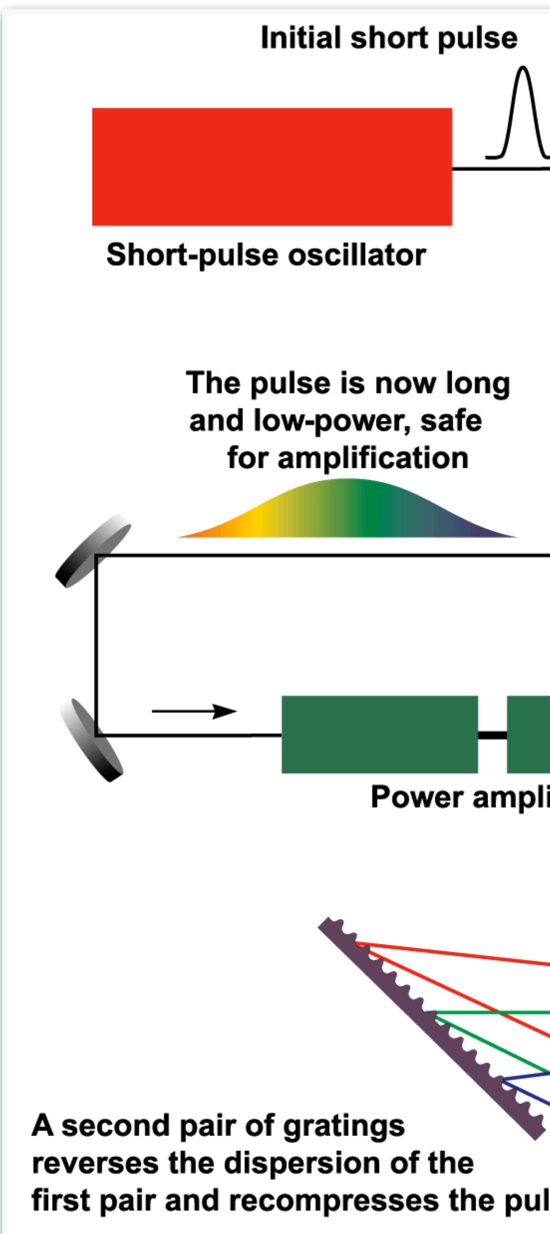
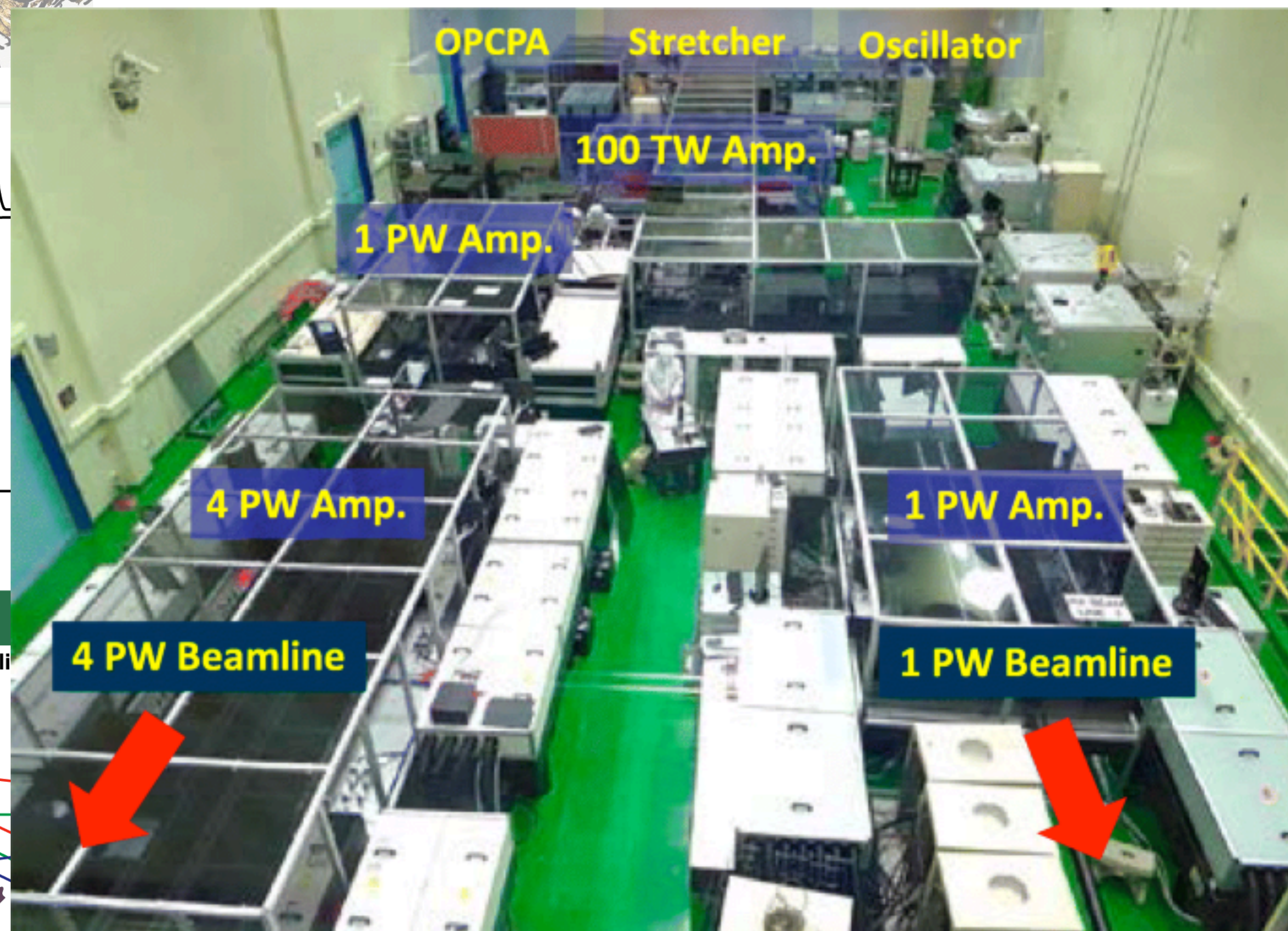


Center for Relativistic Laser Science

Explore the interaction between ultra-intense light and matter

South Korea





2020 world lasers facilities

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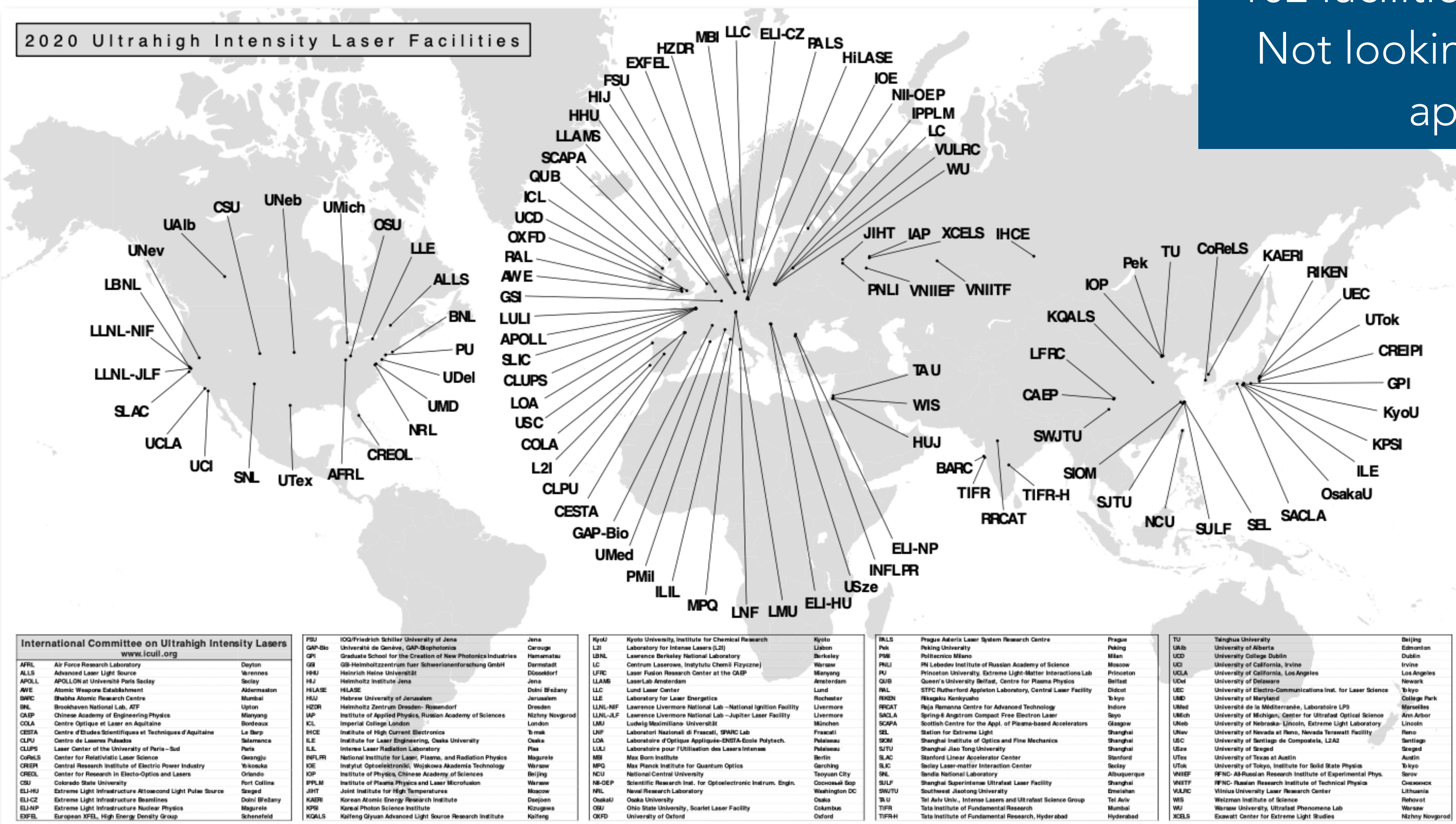
102 facilities (approx > 1TW)
Not looking to the specific application



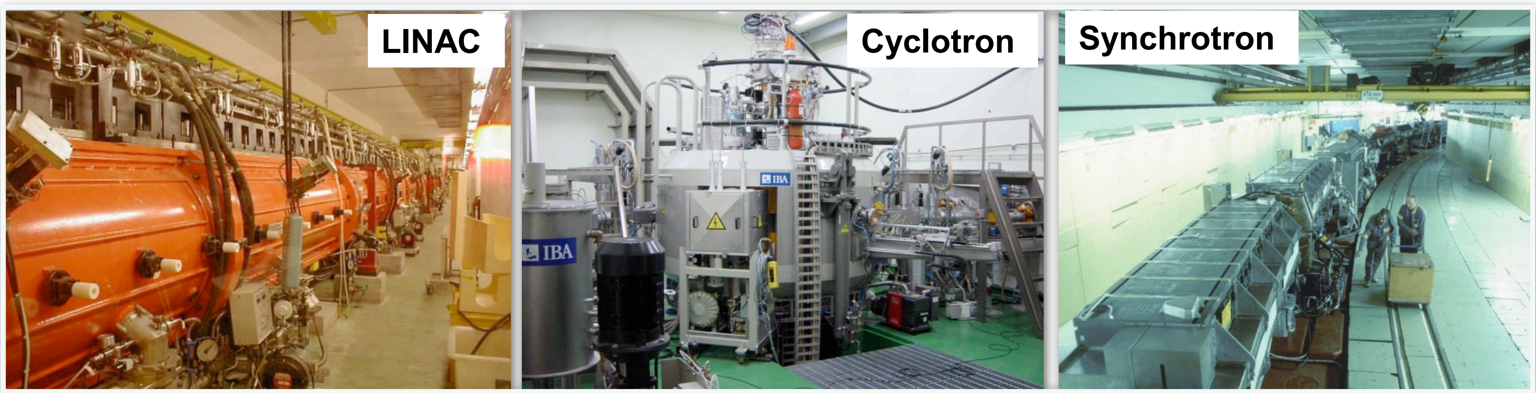
From ICUIL (International Committee on Ultra-High Intensity Lasers)
https://www.icuil.org/

Let's concentrate on ion acceleration

Istituto Nazionale di Fisica Nucleare

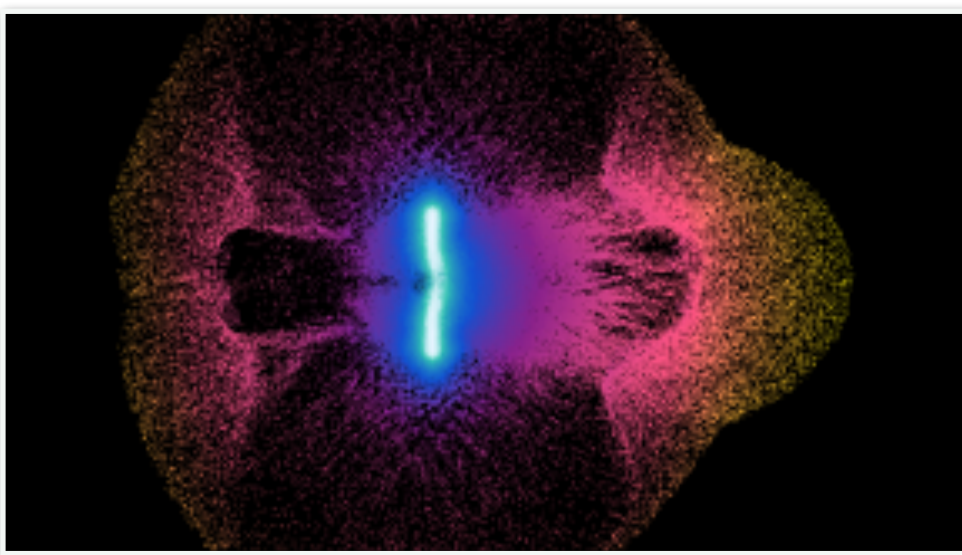
Laser plasma ion-acceleration

principal motivation



E_{max} ~ 50 MV/m

L_{acc} ~ 1-10 m



E_{max} ~ 1 TV/m → 10,000 smaller!!!

L_{acc} ~ 1 μm

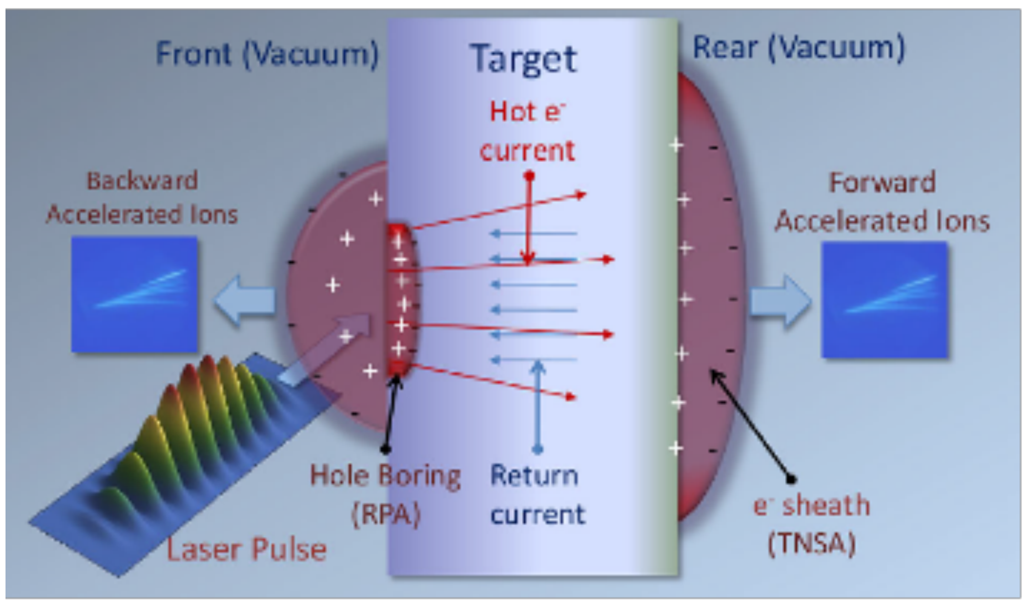
BUT…

Laser plasma ion-acceleration

physical picture

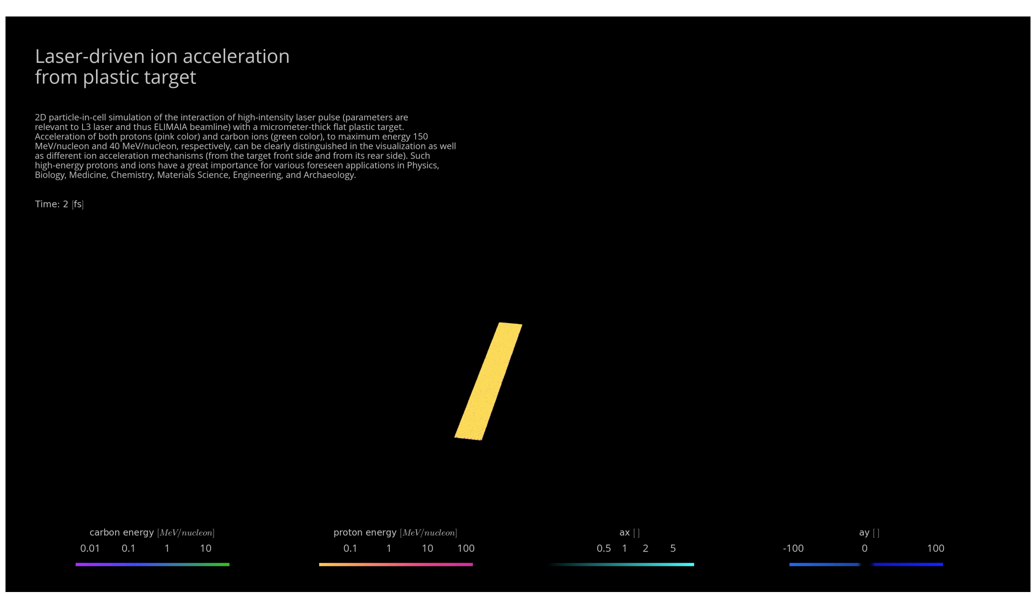
Target Normal Sheath Acceleration

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)!!!

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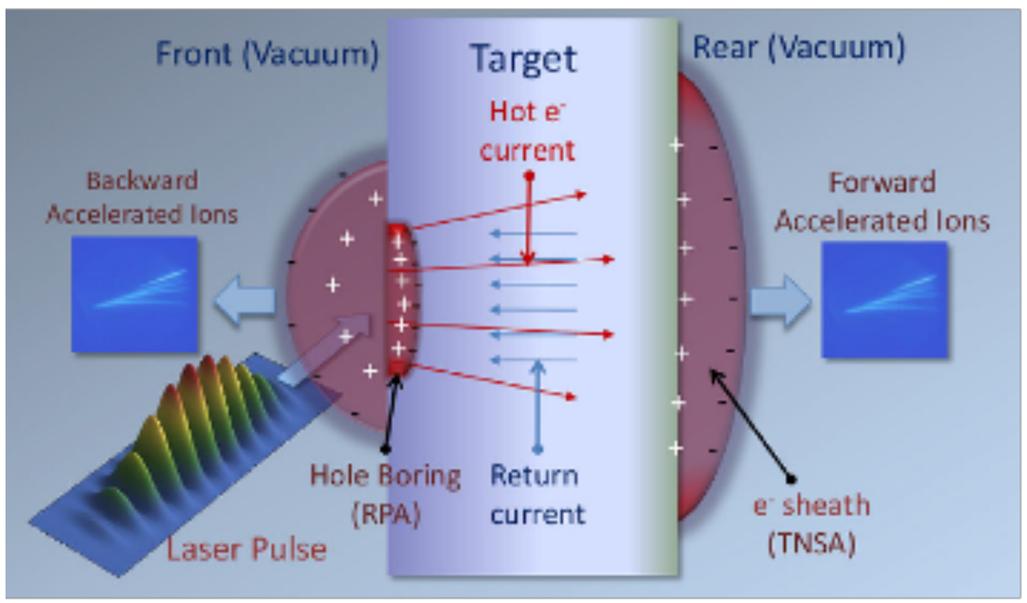

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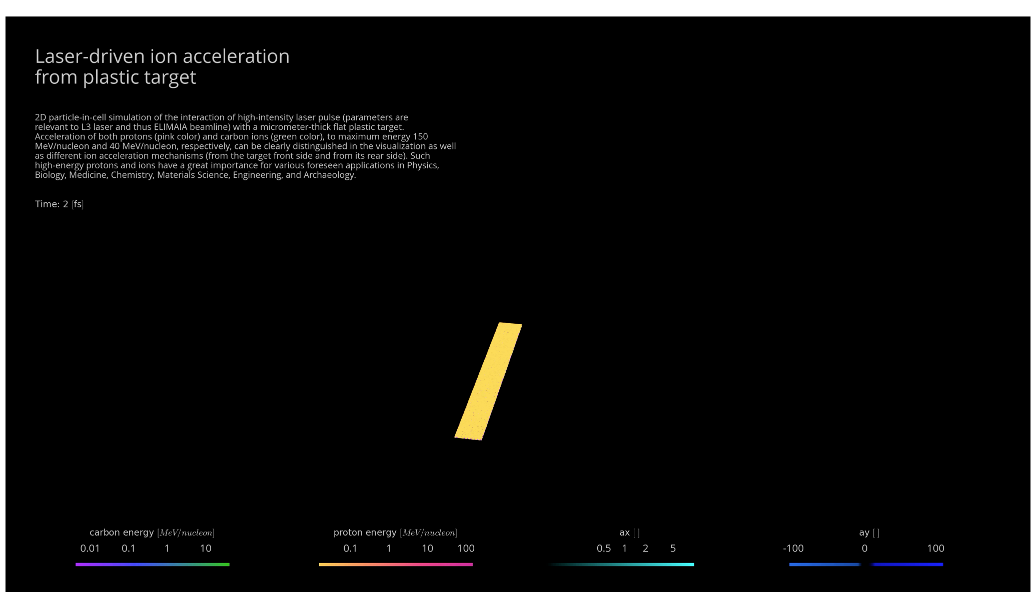

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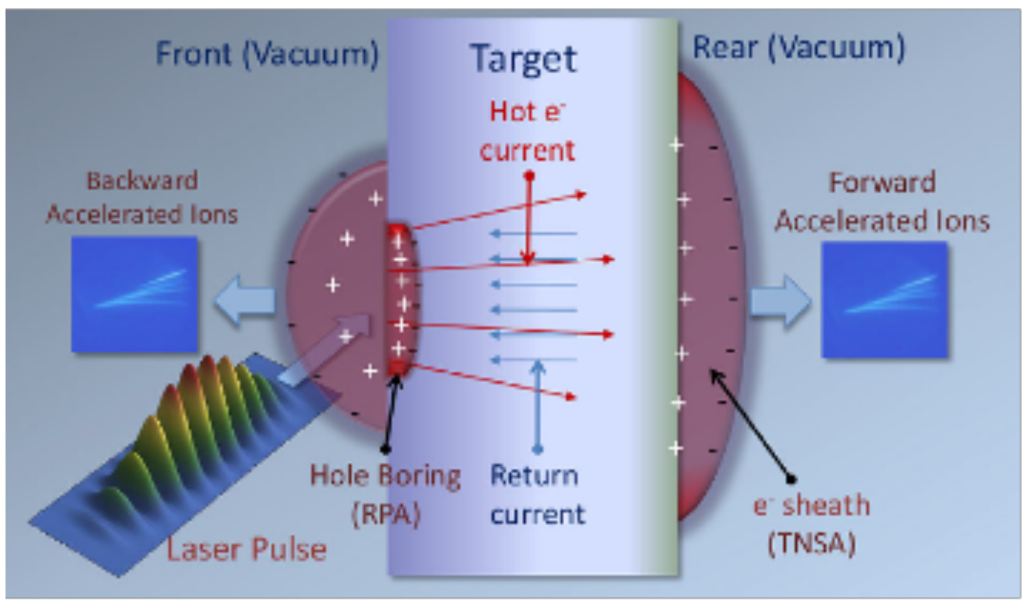

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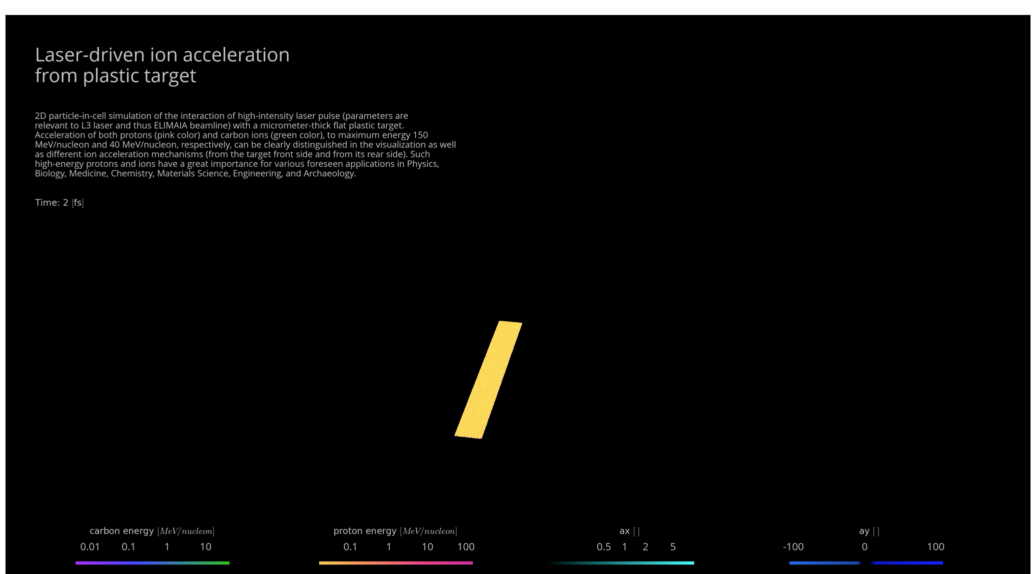

I_L (laser intensity) = $E/\tau/S$ = **10^{21} W/cm²**

Direct Laser interaction:

- $E \sim I_L^{1/2}\lambda = 10^{14}$ V/m
- $B = E/c = 3\times10^5$ T
- $P_{rad} = I_L/c = 3\times10^{10}$ J/cm³ = 300 Gbar

Laser-Plasma interaction:

- Debye Length

$$\lambda_D = 2.4\,\mu m \cdot \sqrt{\frac{T_{hot}}{1MeV}} \cdot \sqrt{\frac{10^{19}\,cm^{-3}}{N_{hot}}}$$ ⟹ **~ μm!**

- Acceleration time

$$\tau = \sqrt{\frac{\lambda_D^2 m_{ion}}{T_{hot}}} = 0.24\,ps\sqrt{\frac{\lambda_D^2 n_{hot}}{10^{19}}}$$ ⟹ **~ ps!**

- Electric Field

$$E = \frac{T_{hot}}{e\lambda_D} \approx \frac{MV}{\mu m}$$ ⟹ **~ TV/m!**

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Laser plasma ion-acceleration

physical picture

Target Normal Sheath Acceleration

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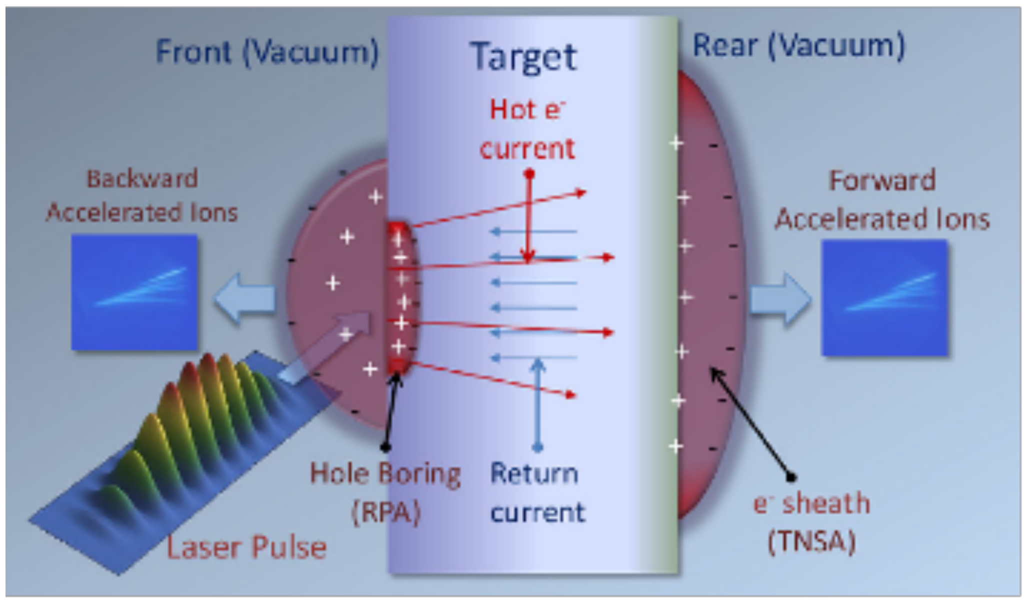

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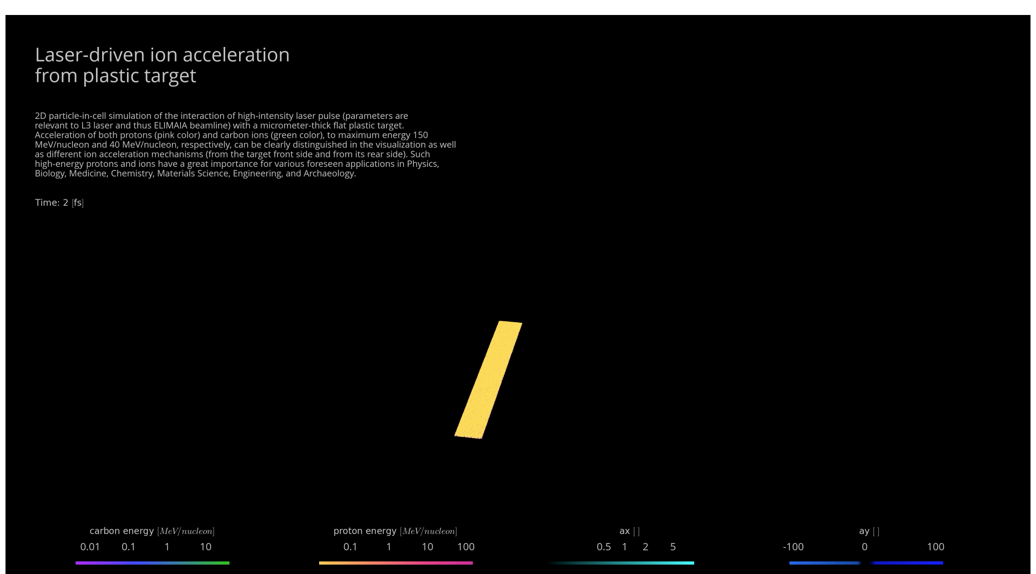

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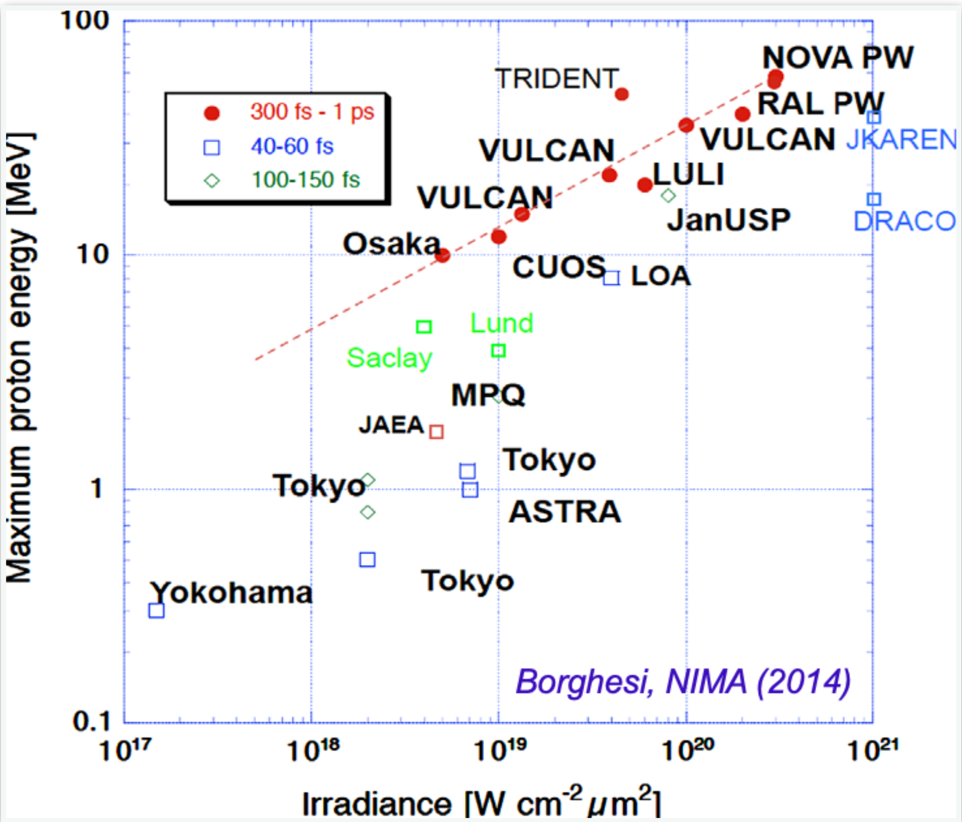
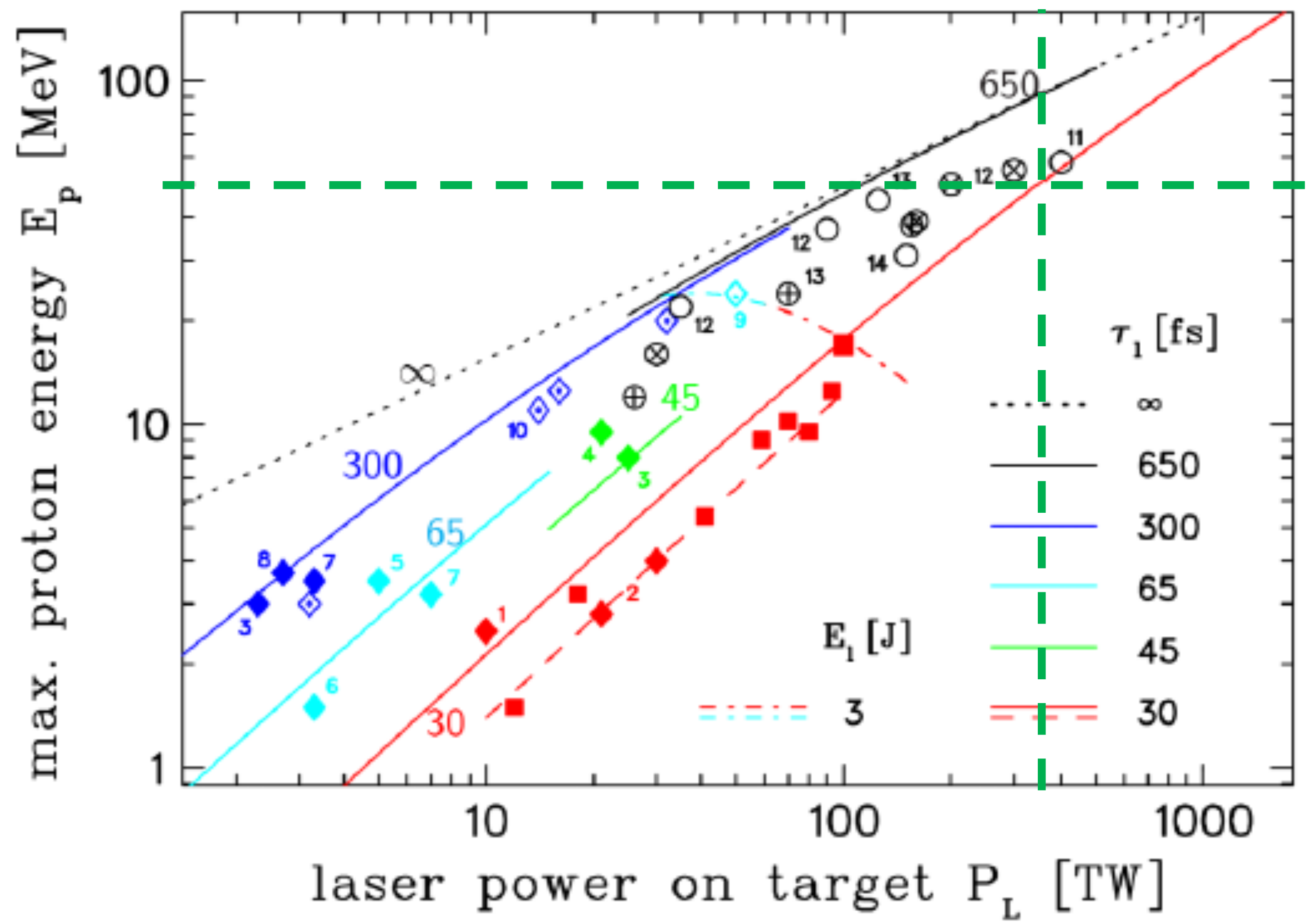
Maximum proton energy

experimental scaling laws (TNSA)



$E \sim I_L^{1/2}$



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

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

Intensity W/cm^2 → I

proton energy → E_p

pulse lenght → τ

spot surface on target → A

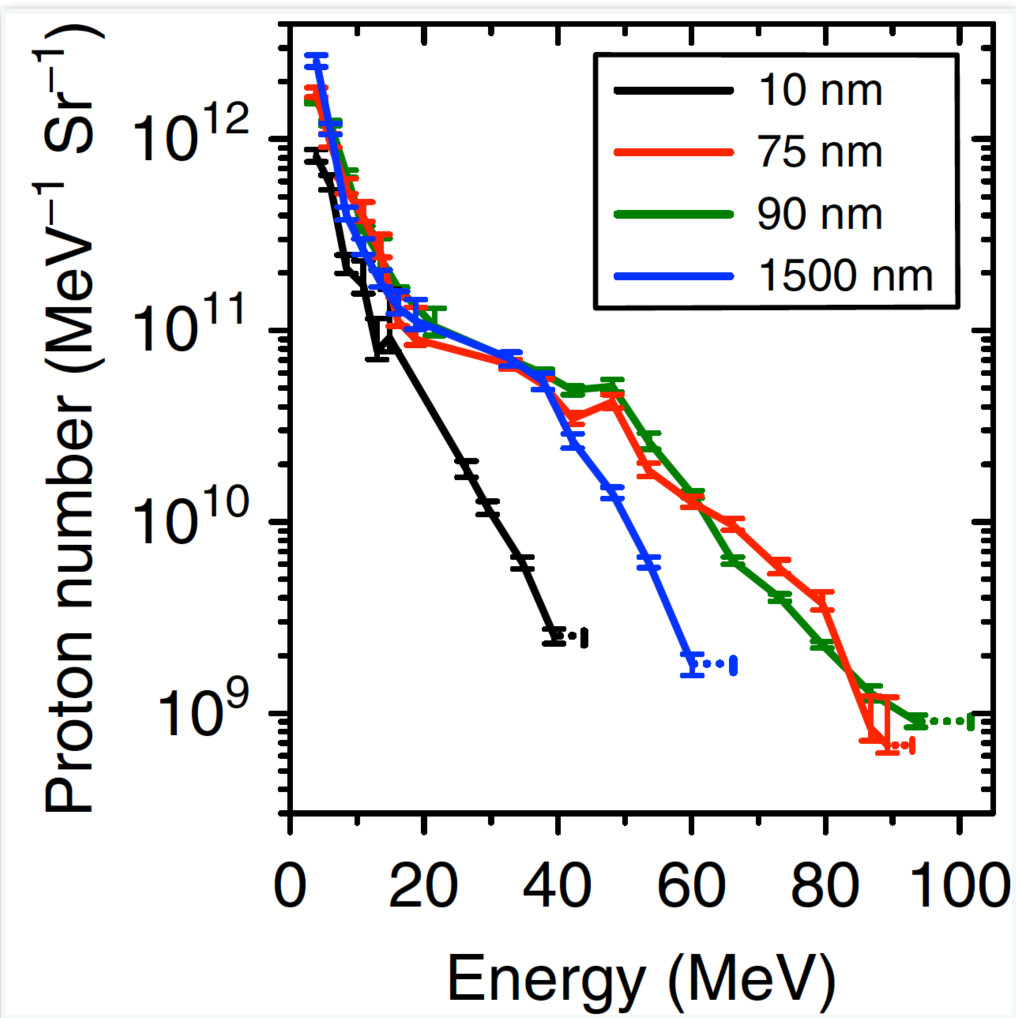
ARTICLE

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]

2018



Vulcan laser at the Rutherford Appleton Laboratory (UK)

Intensity = ~ 10^{20} Wcm^{-2}

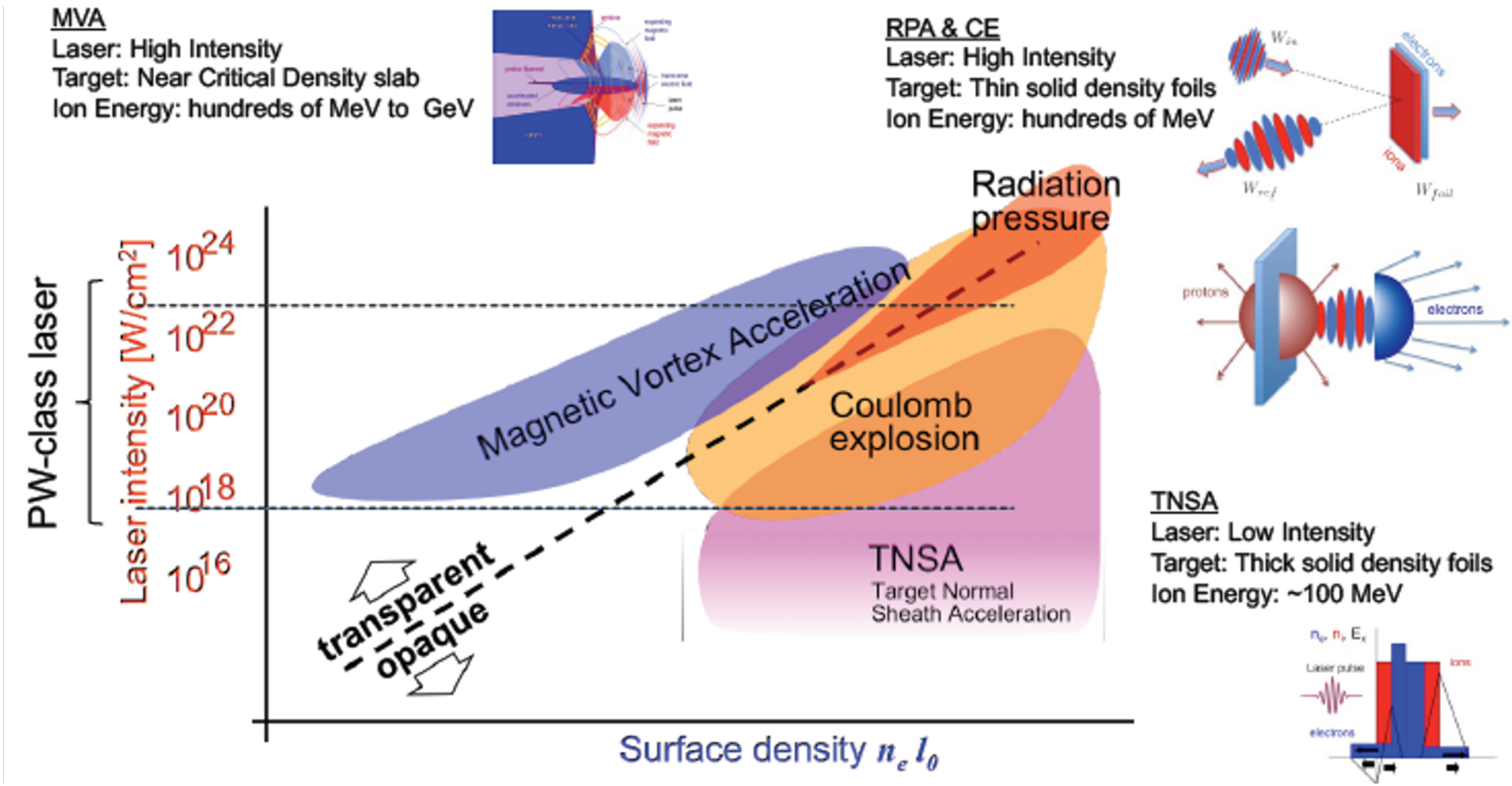
Pulses of p-polarised, **1.053 µm-wavelength**

Pulse duration τ = (0.9 ± 0.1) ps (FWHM)

Energy after the plasma mirror: (210 ± 40) J

Target: thin planar plastic foil with thickness in the range 10 nm-1.5 um

Laser-driven ion acceleration mechanisms: laser intensity vs target density



Curtesy of S Bulanov

Istituto Nazionale di Fisica Nucleare

I-LUCE at INFN-LNS

I-LUCE

INFN Laser indUCEd radiation production

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

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

Advanced technologies for Human Centred Medicine

Anthem

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

INFN Laser indUCEd radiation production

0.8 M€

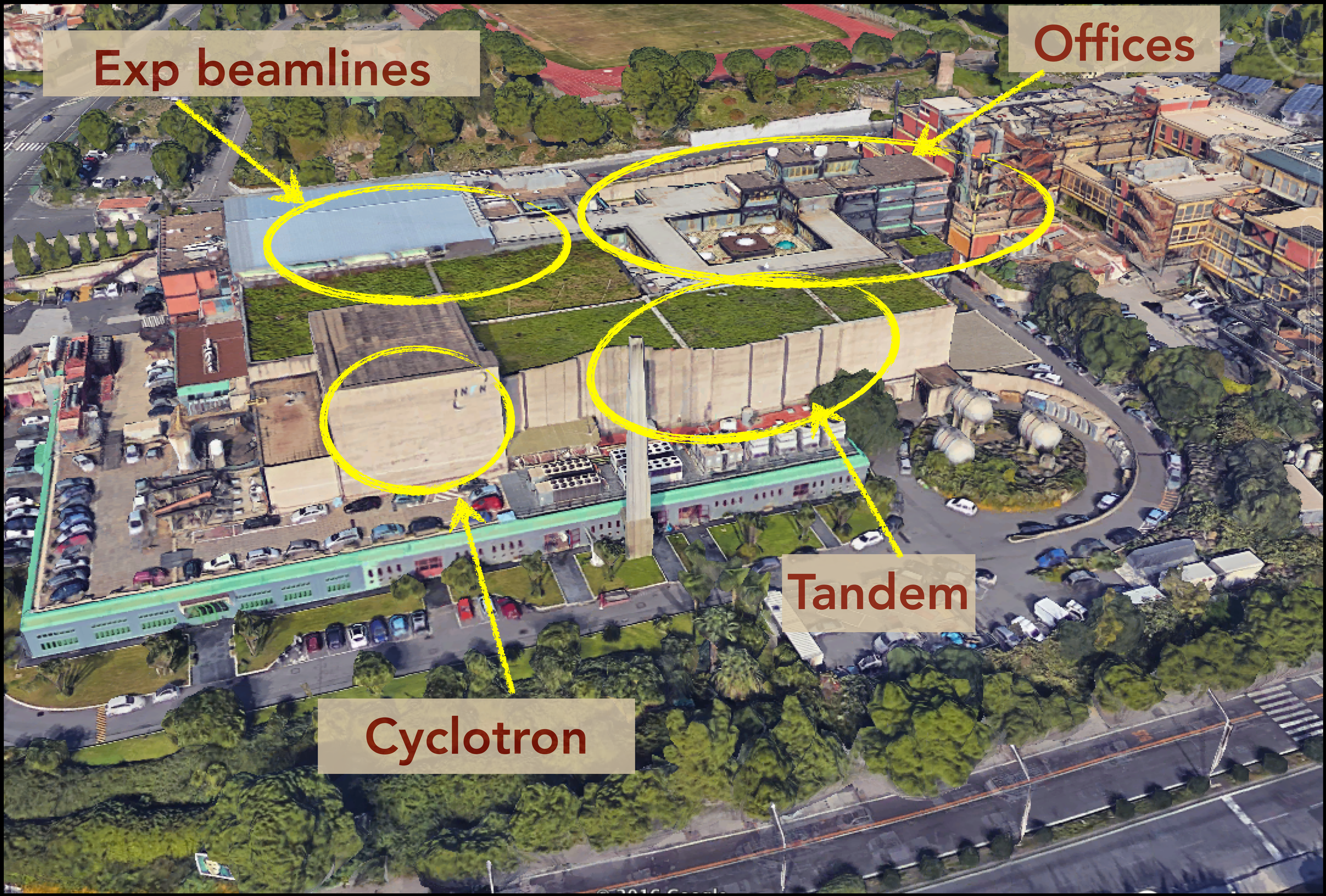
Demonstration of a micro-acceleration system for laser-driven proton beams

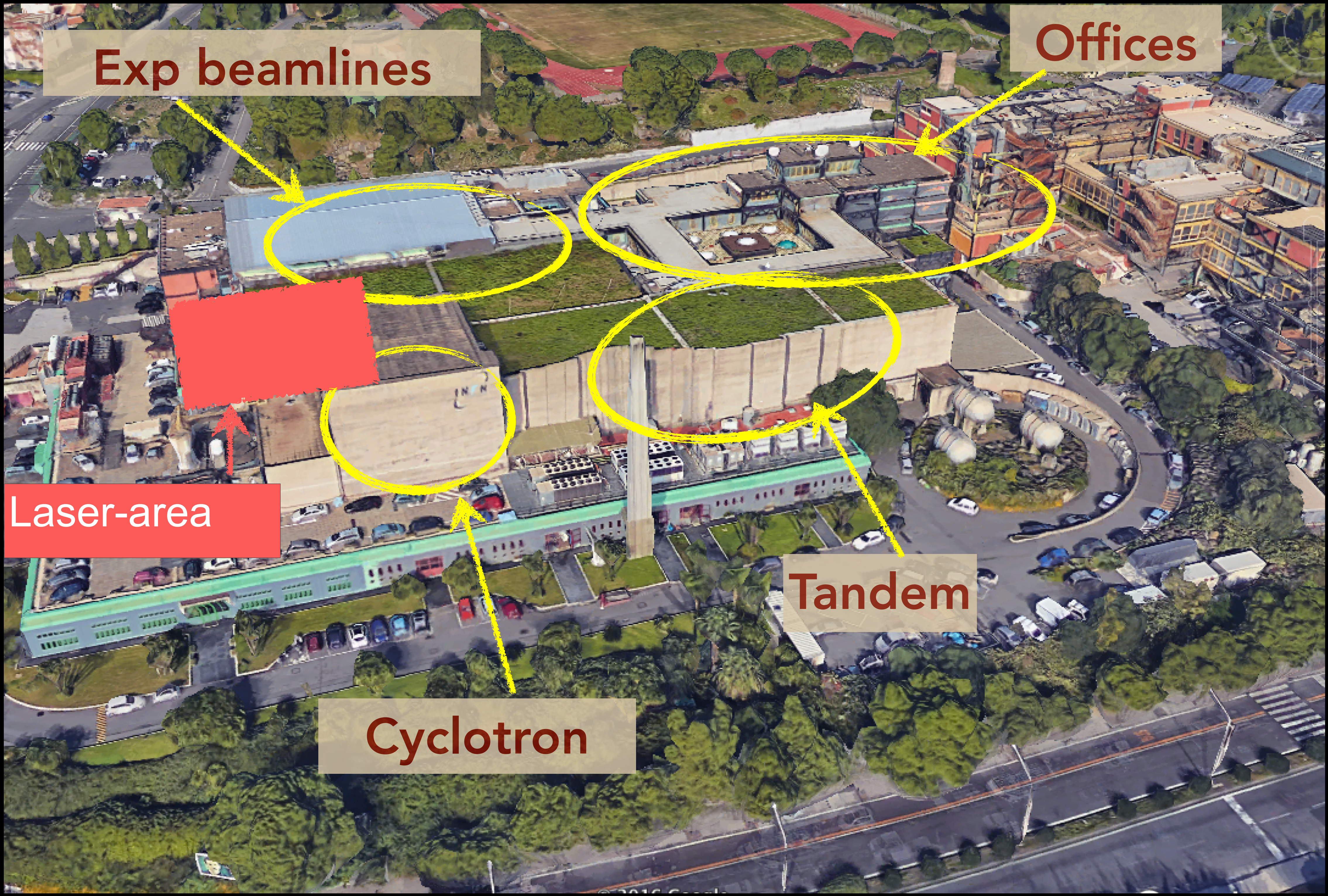
BCT

Breast Cancer Therapy

2.0 M€

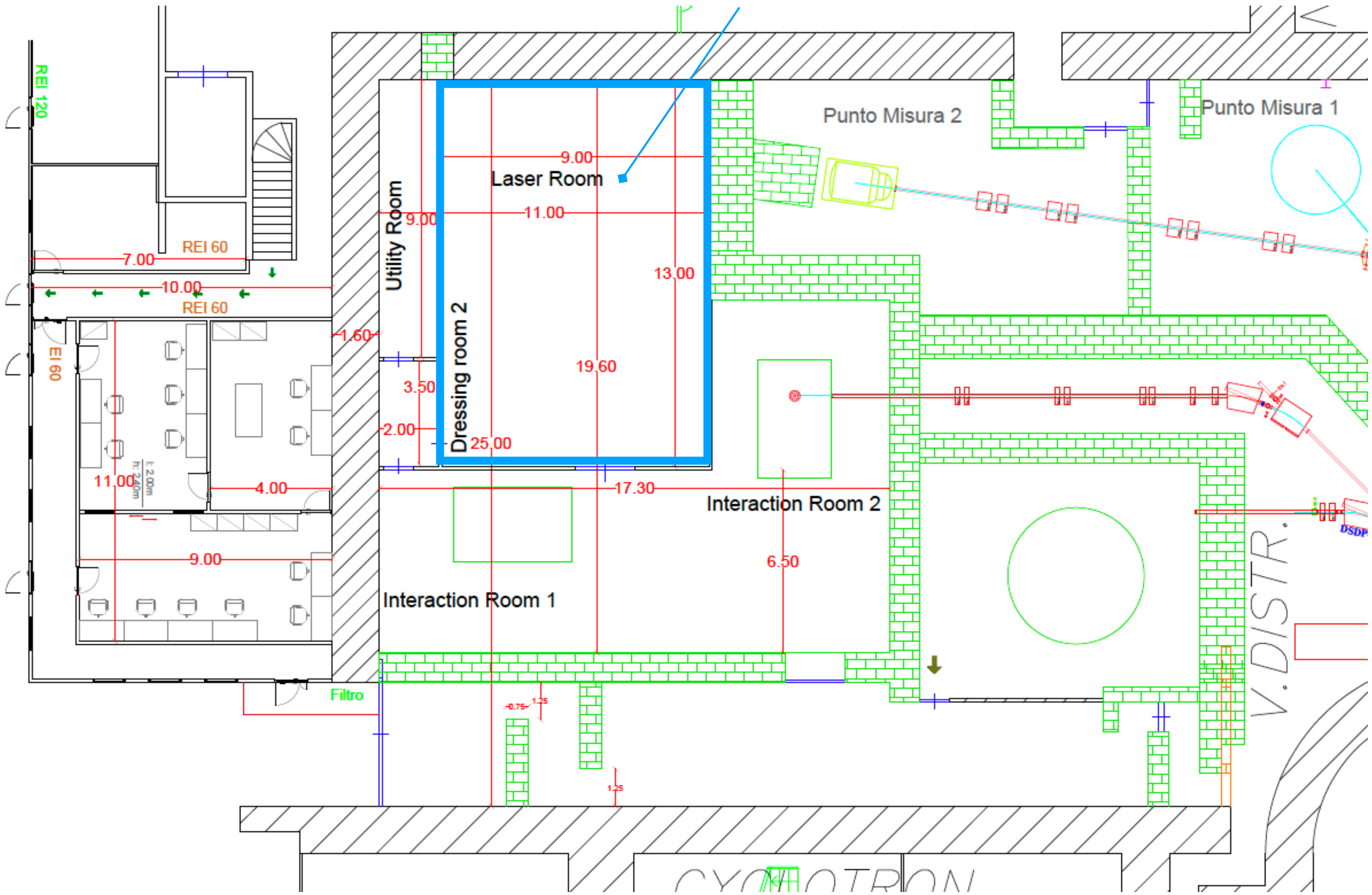
Ottimizzazione nella selezione di fasci di protoni per applicazioni mediche


Exp beamlines
Offices
Tandem
Cyclotron


Exp beamlines
Offices
Laser-area
Tandem
Cyclotron

I-LUCE layout

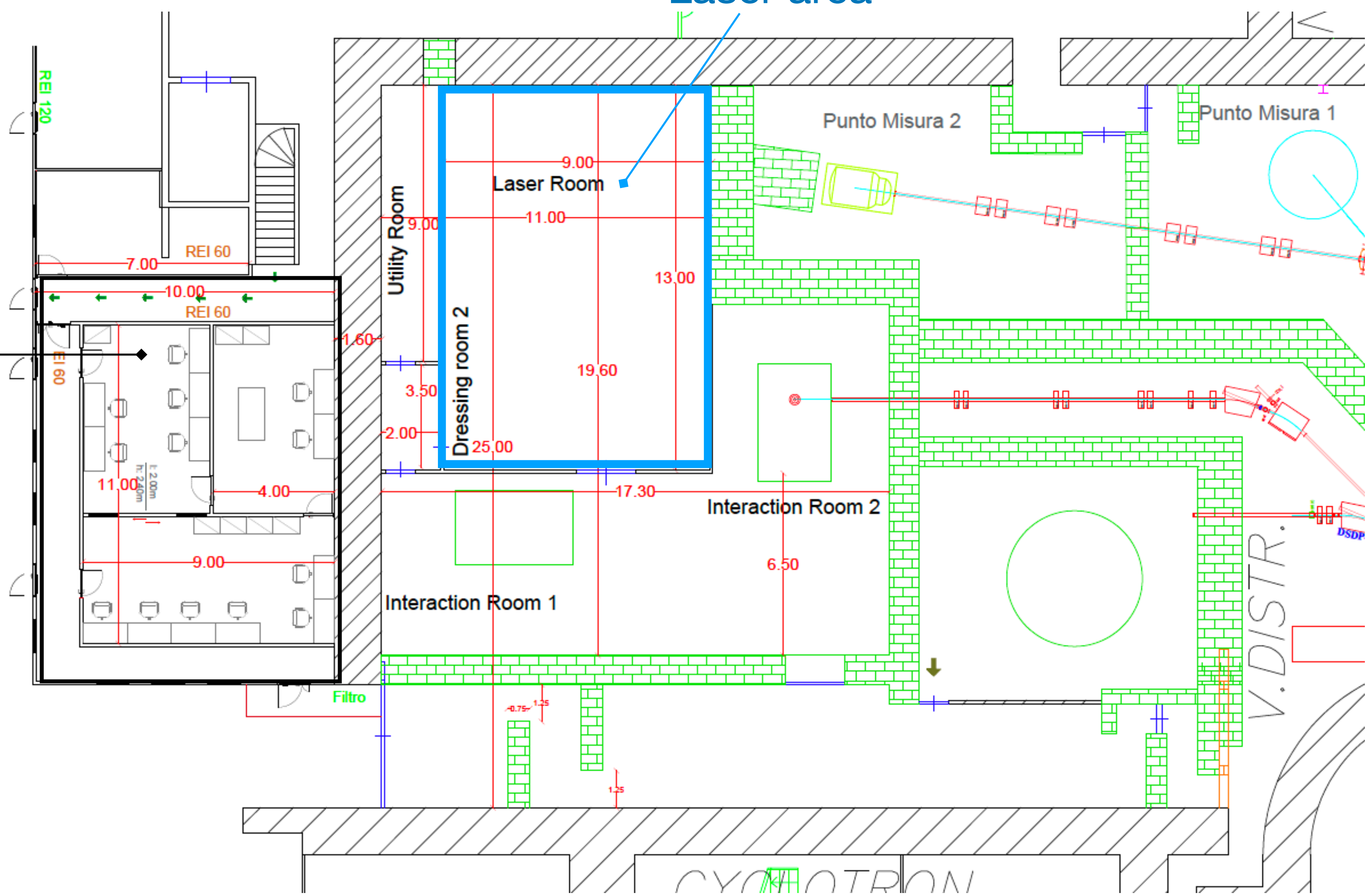
Laser area



I-LUCE layout

Laser area

Control and Users' area



I-LUCE layout

Laser area

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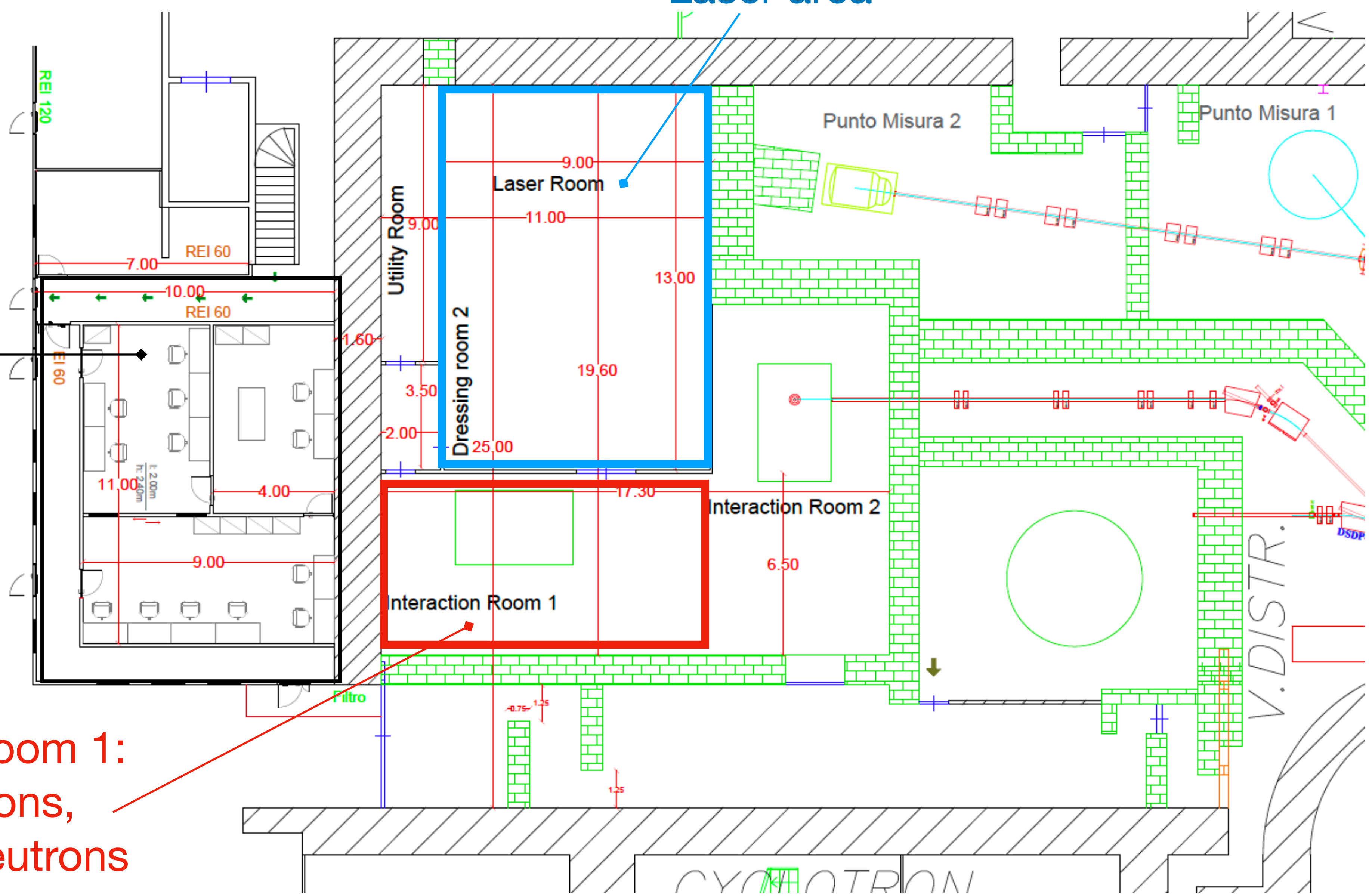
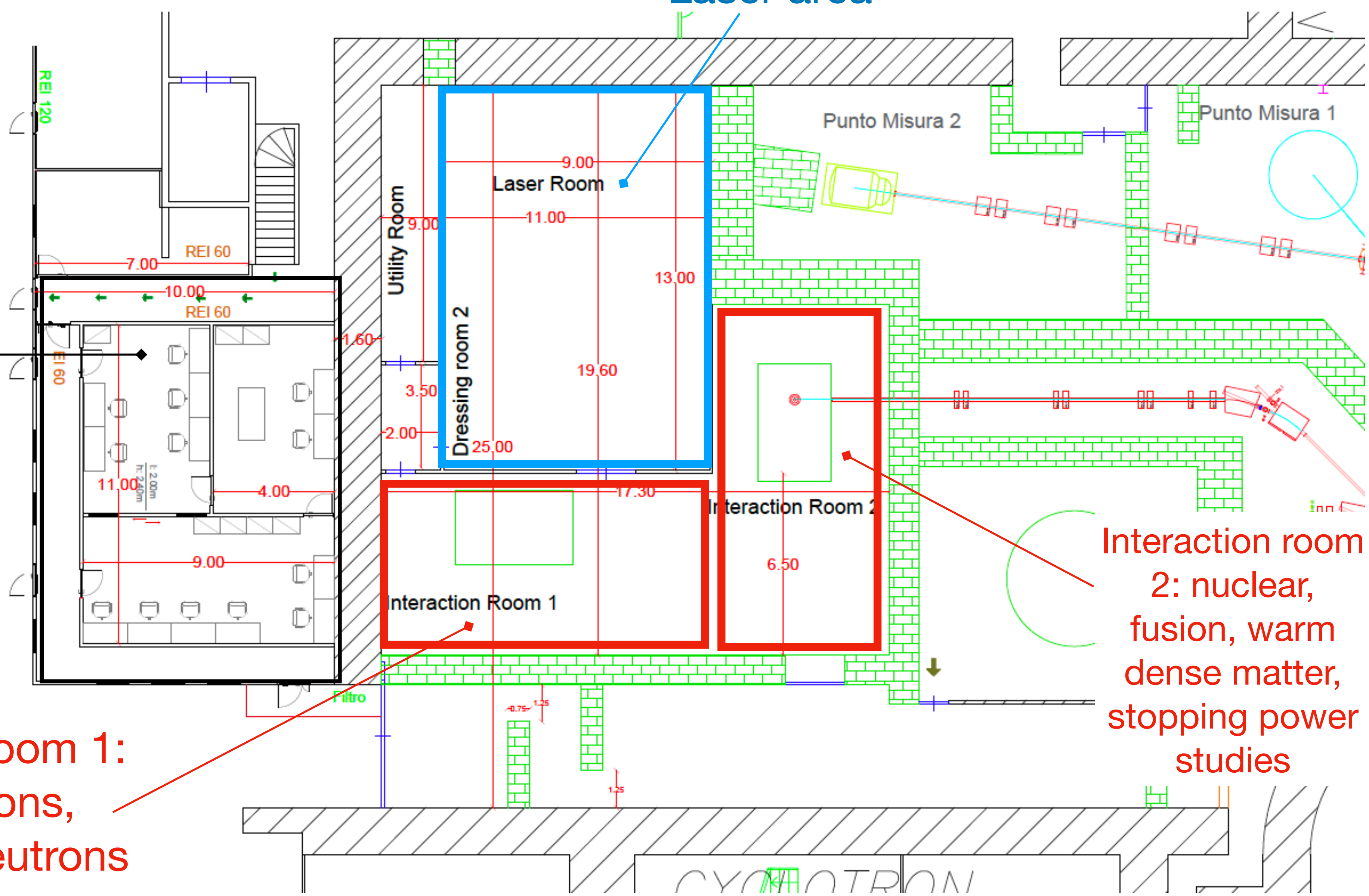


Interaction room 1:
protons, ions,
electrons, neutrons
accelerations

I-LUCE layout

Laser area

Control and Users' area



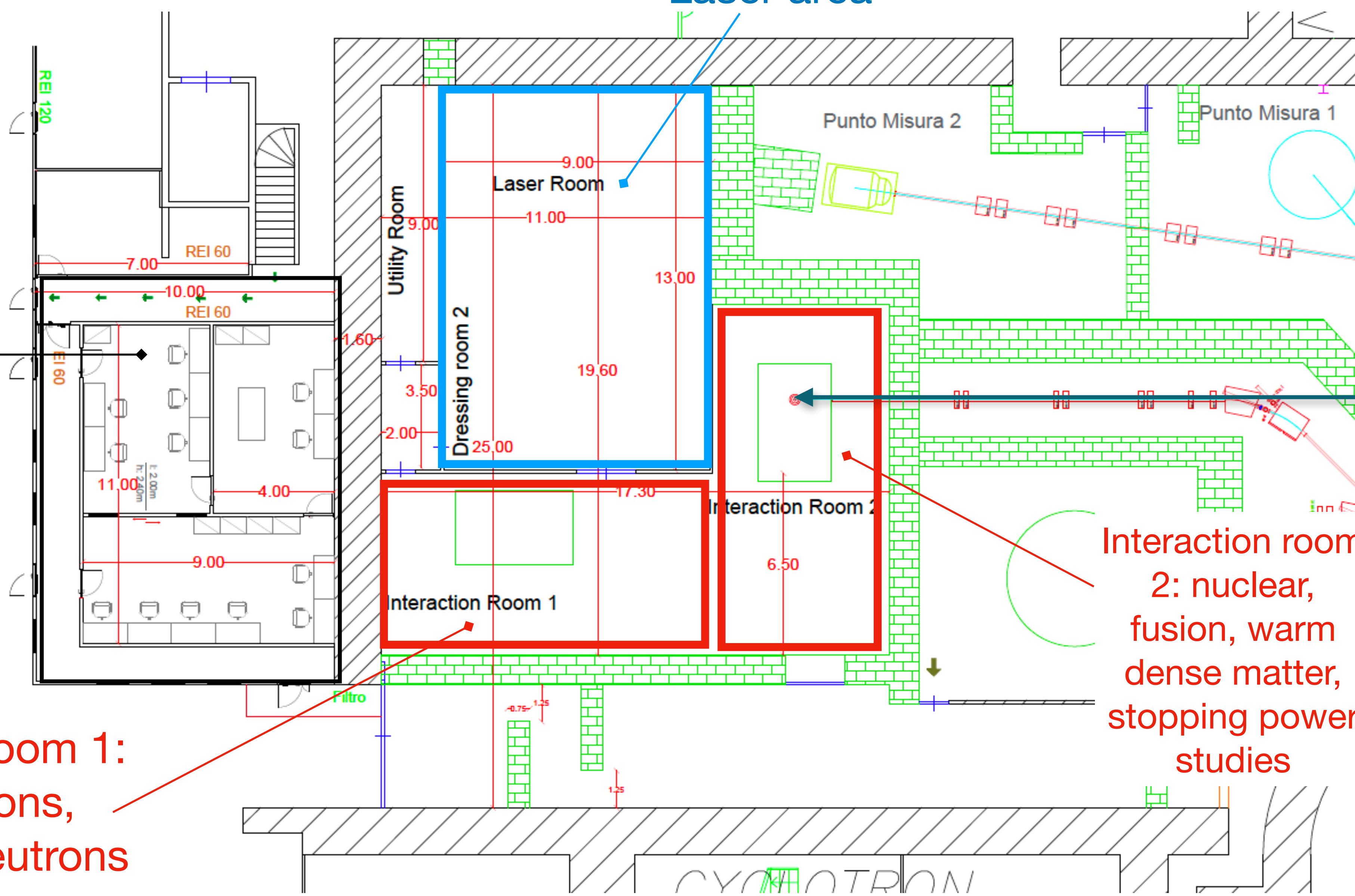
Interaction room 1: protons, ions, electrons, neutrons accelerations

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

I-LUCE layout

Laser area

Control and Users' area

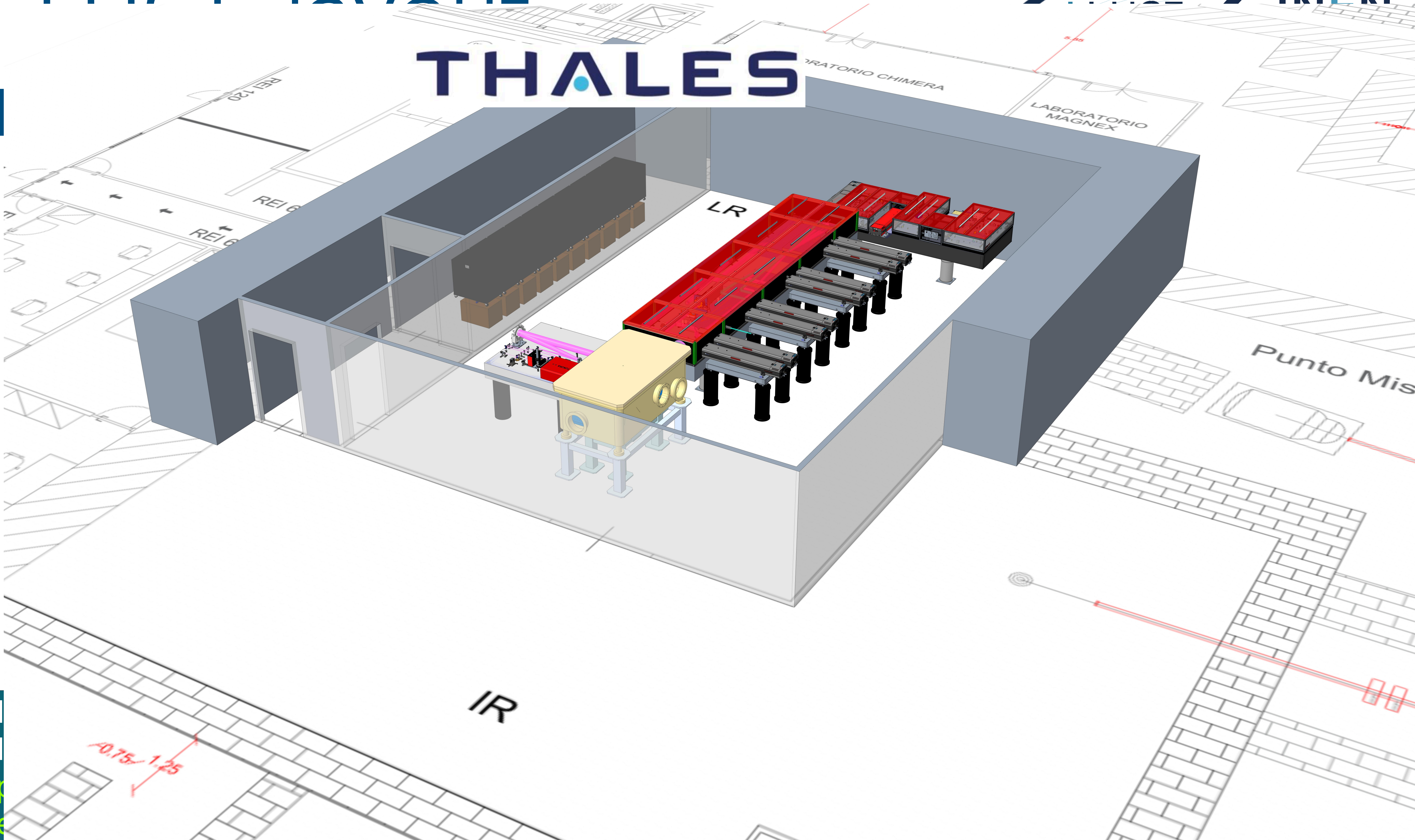


Conventional ion beams 4 - 60 AMeV

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

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

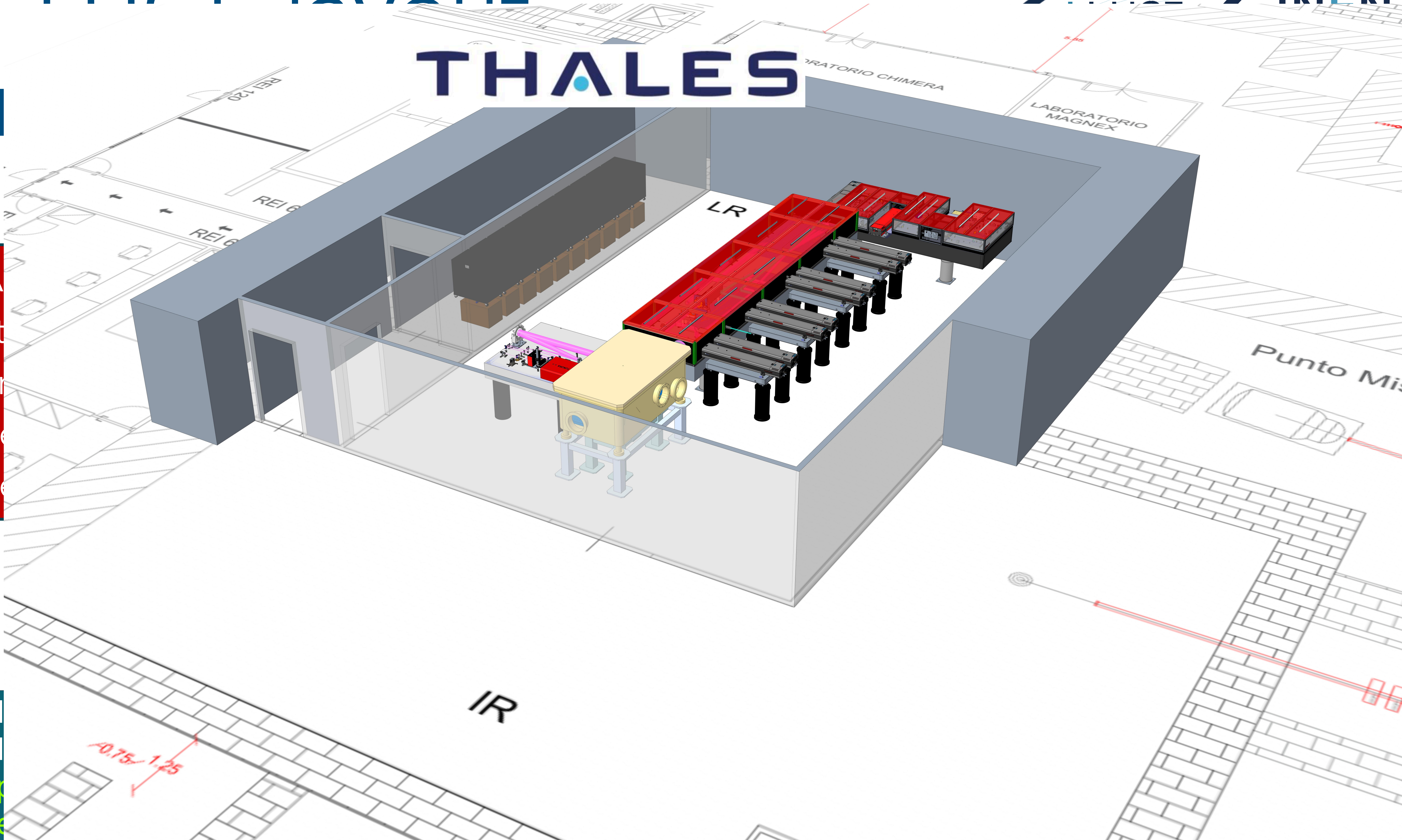
LUCE layout



production

In-air irradiation station

Conventional Ions:
from TANDEM and Cyclotron



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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

EUAPS
I-LUCE @ LNS

Two interaction chambers

1) **Interaction Ch**

neutrons, gam

- One in-air

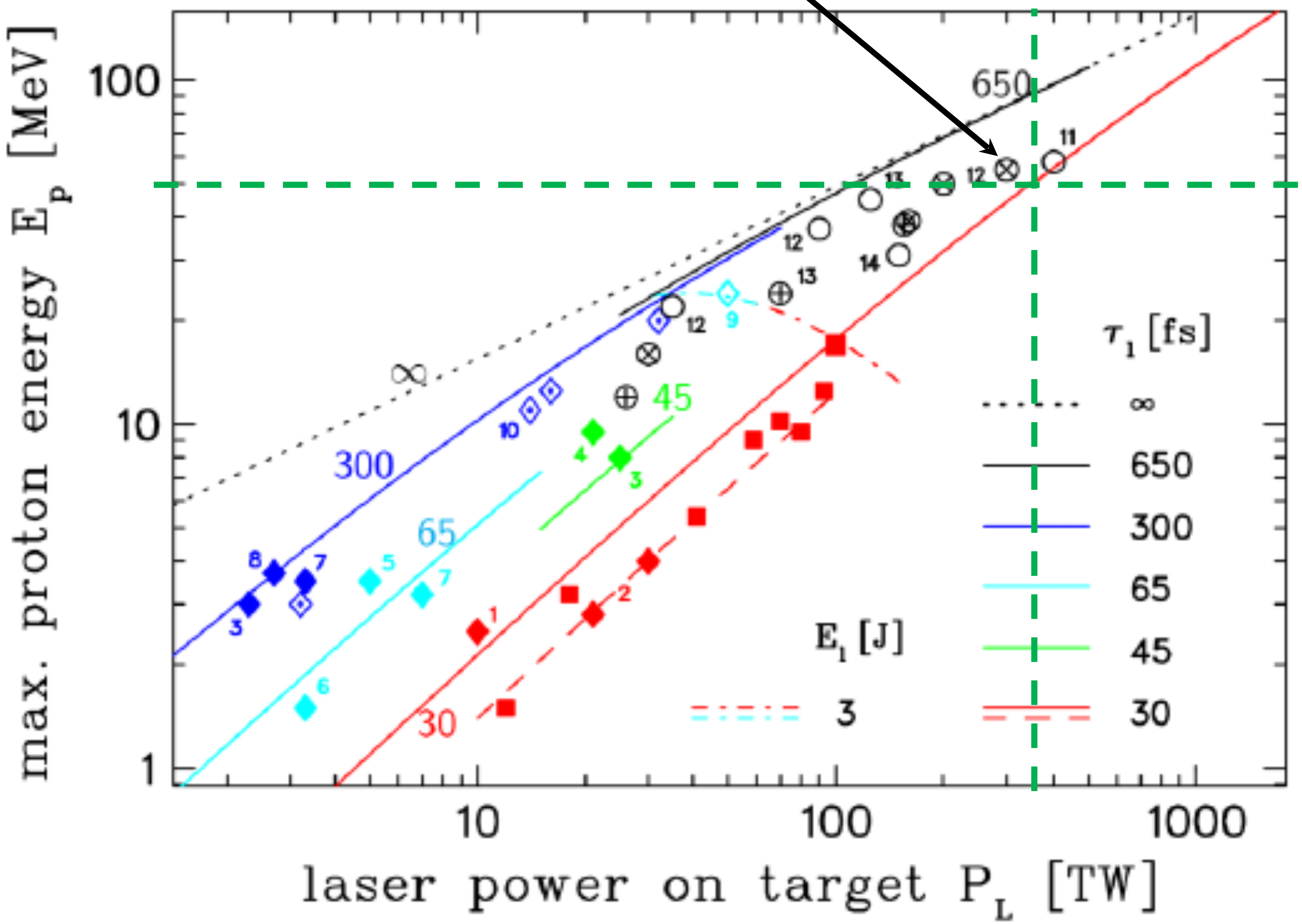
2) **Interaction Ch**

- Nuclear pl
- Interactior
- Nuclear pl
- ……

Two workin

1) Low power: 50

2) High power: 35



N

Low power modality: 50 TW

I LUCE

INFN Istituto Nazionale di Fisica Nucleare

Laser Power		≥ 50 TW
Energy per pulse		≥ 1 J
Pulse duration		≤ 23 fs
Focusing surface		36 μm²
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/cm²
$2.78 \cdot 10^{17}$ W/cm²

==> $i\lambda^2 = 1.77 \cdot 10^{18}$
$i\lambda^2 = 1.77 \cdot 10^{17}$

Longer plasma expansion times:

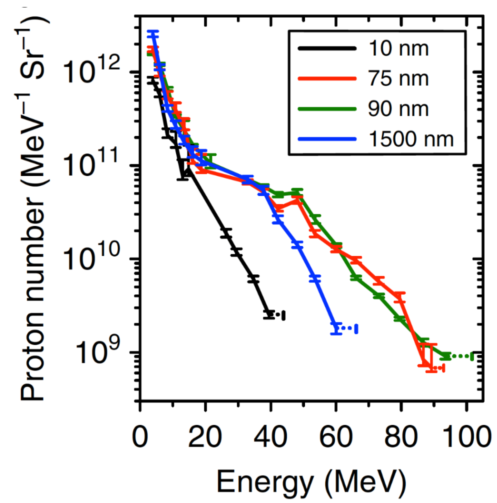
— *Decay studies*
— *Stopping powers studies*
— *WDM characterisation*

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

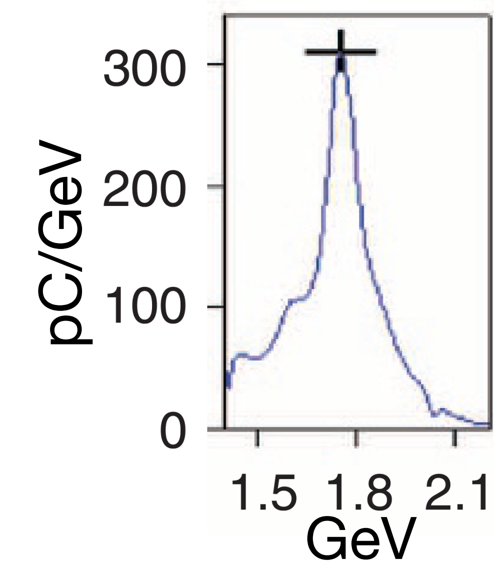
High-power modality: 350 TW

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)		$8.82 \cdot 10^{20}$
$I^*\lambda^2$		$5.64 \cdot 10^{20}$
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

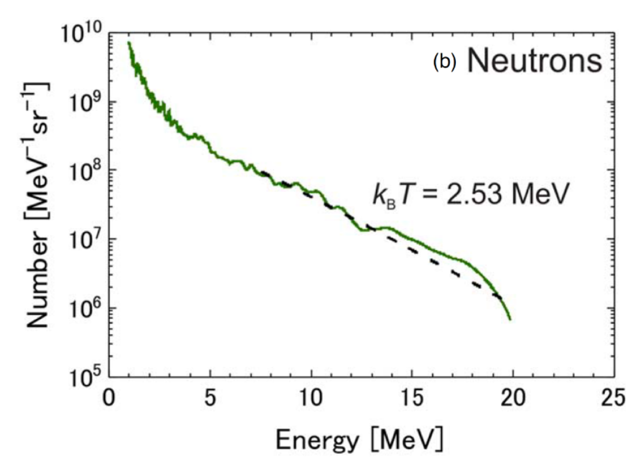
Protons spectra from A. Higginson et al. "Near-100 MeV protons via a laser-driven transparency-enhanced hybrid acceleration scheme", NATURE COMMUNICATIONS | (2018) 9:724



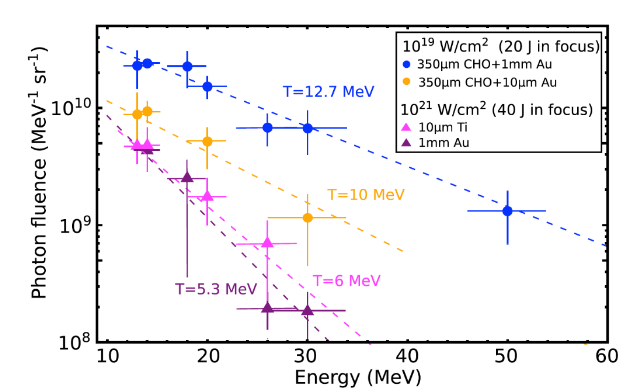
Electrons spectra from X. Wang et al. "Quasi-monoenergetic laser-plasma acceleration of electrons to 2 GeV", NATURE COMMUNICATIONS, 4:1988 2018 DOI: 10.1038/ncomms2988



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)

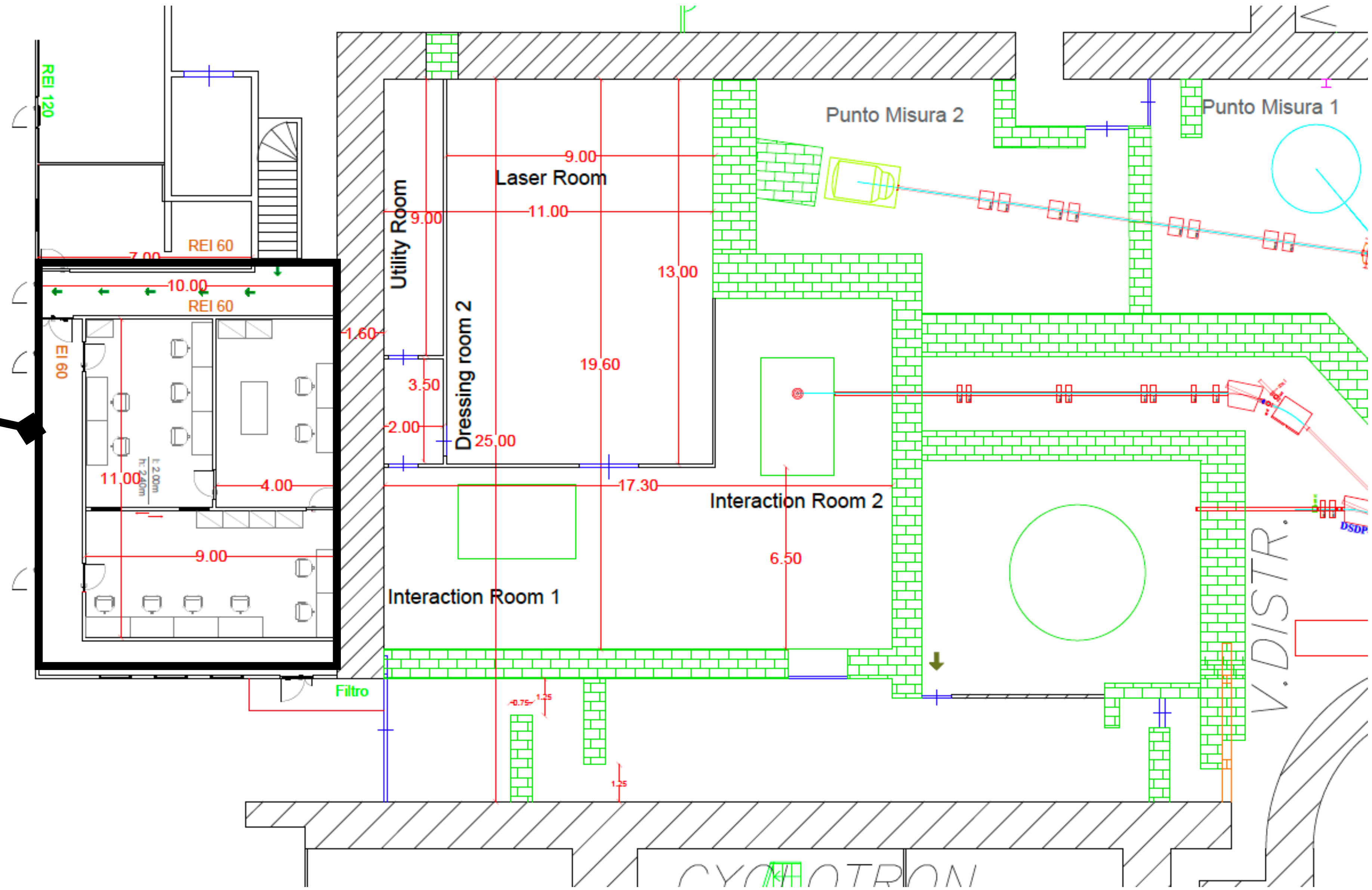


Gamma spectra from M. M. Günther et al "Forward-looking insights in laser-generated ultraintense γ-ray and neutron sources for nuclear application and science" NATURE COMMUNICATIONS | (2022) 13:170



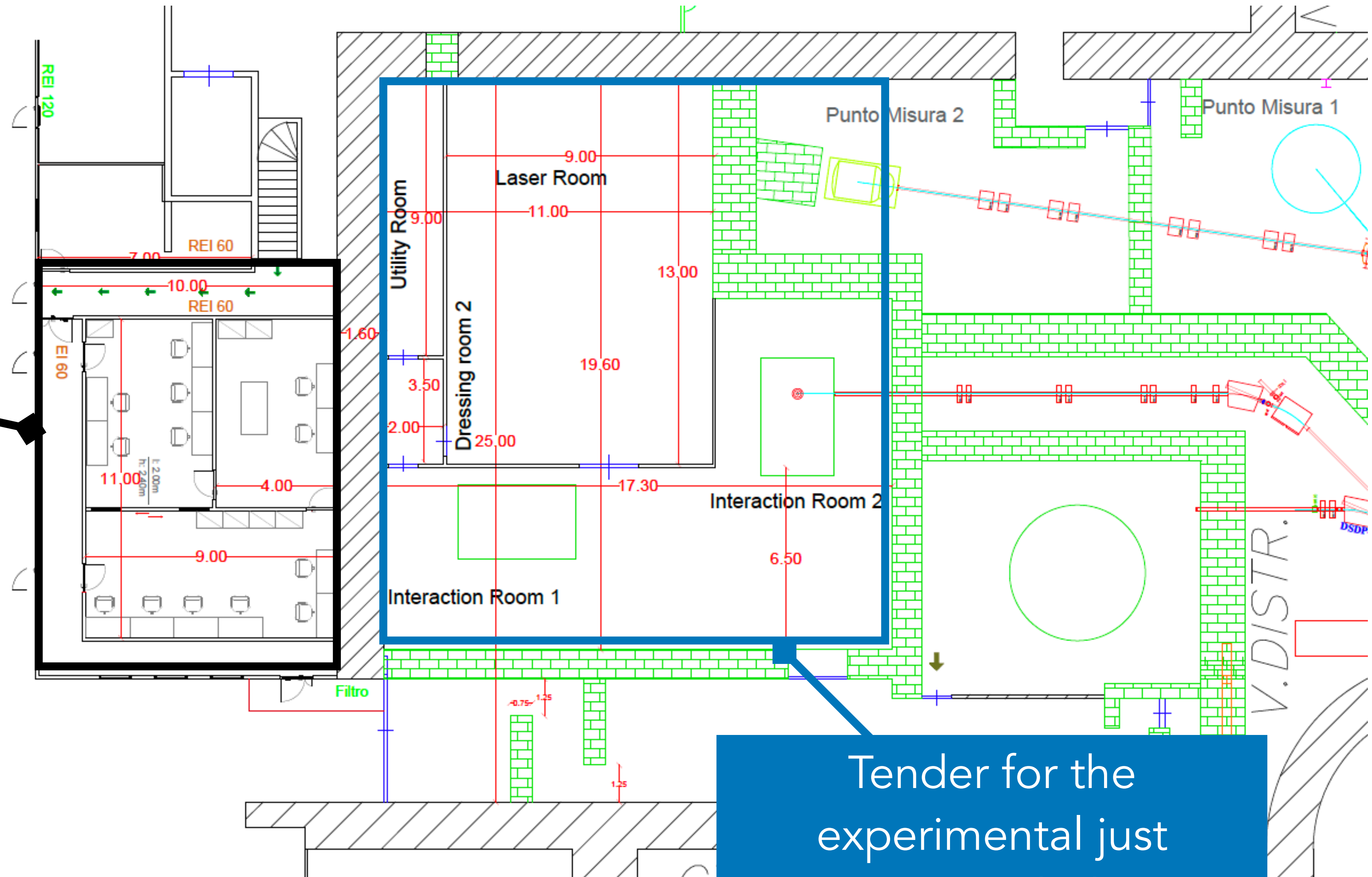
I-LUCE current status

Control area under construction



I-LUCE current status

Control area under construction

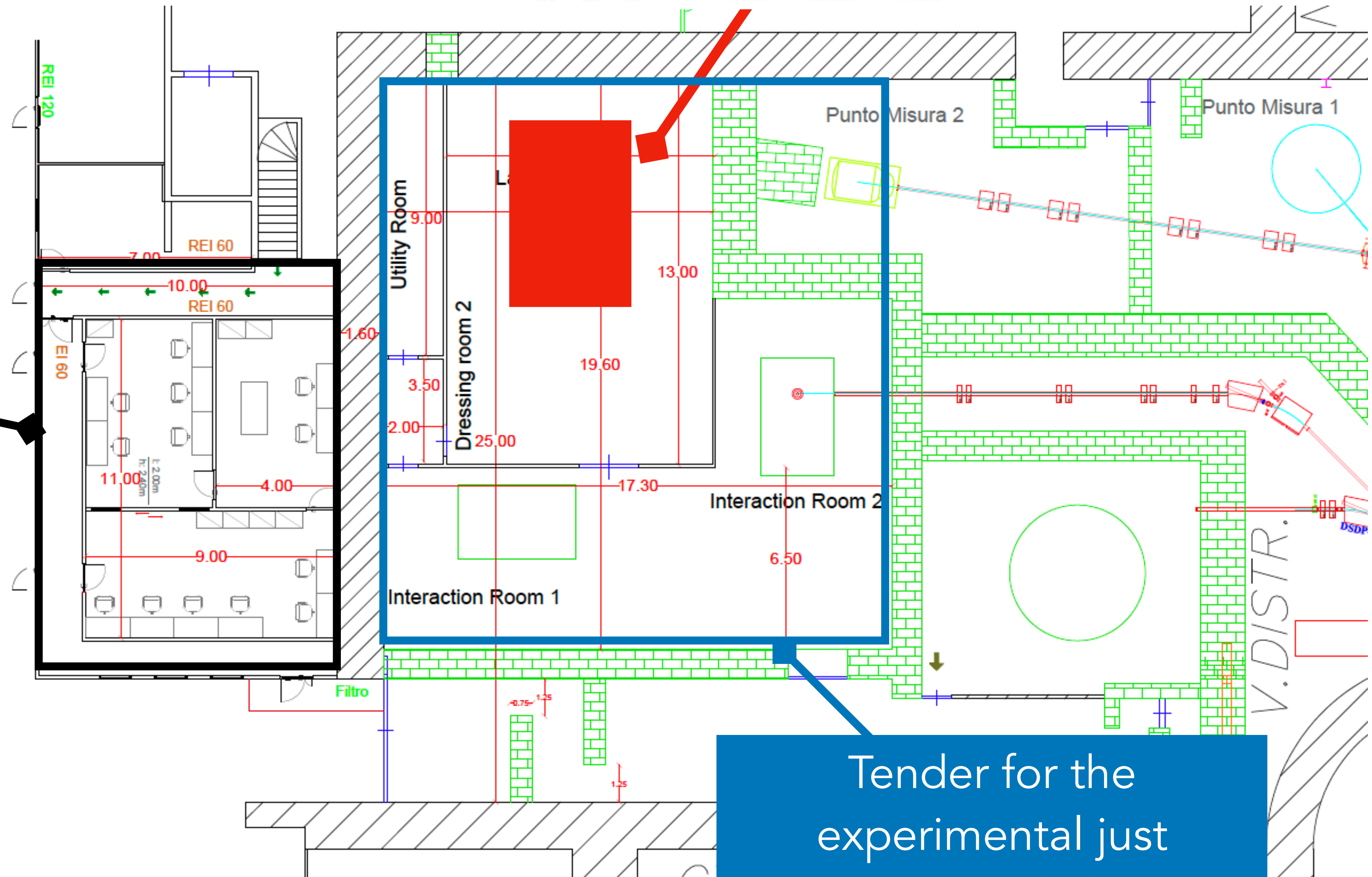


Tender for the experimental just concluded

I-LUCE current status

Laser tender concluded
Contract to be signed

THALES



Control area under construction

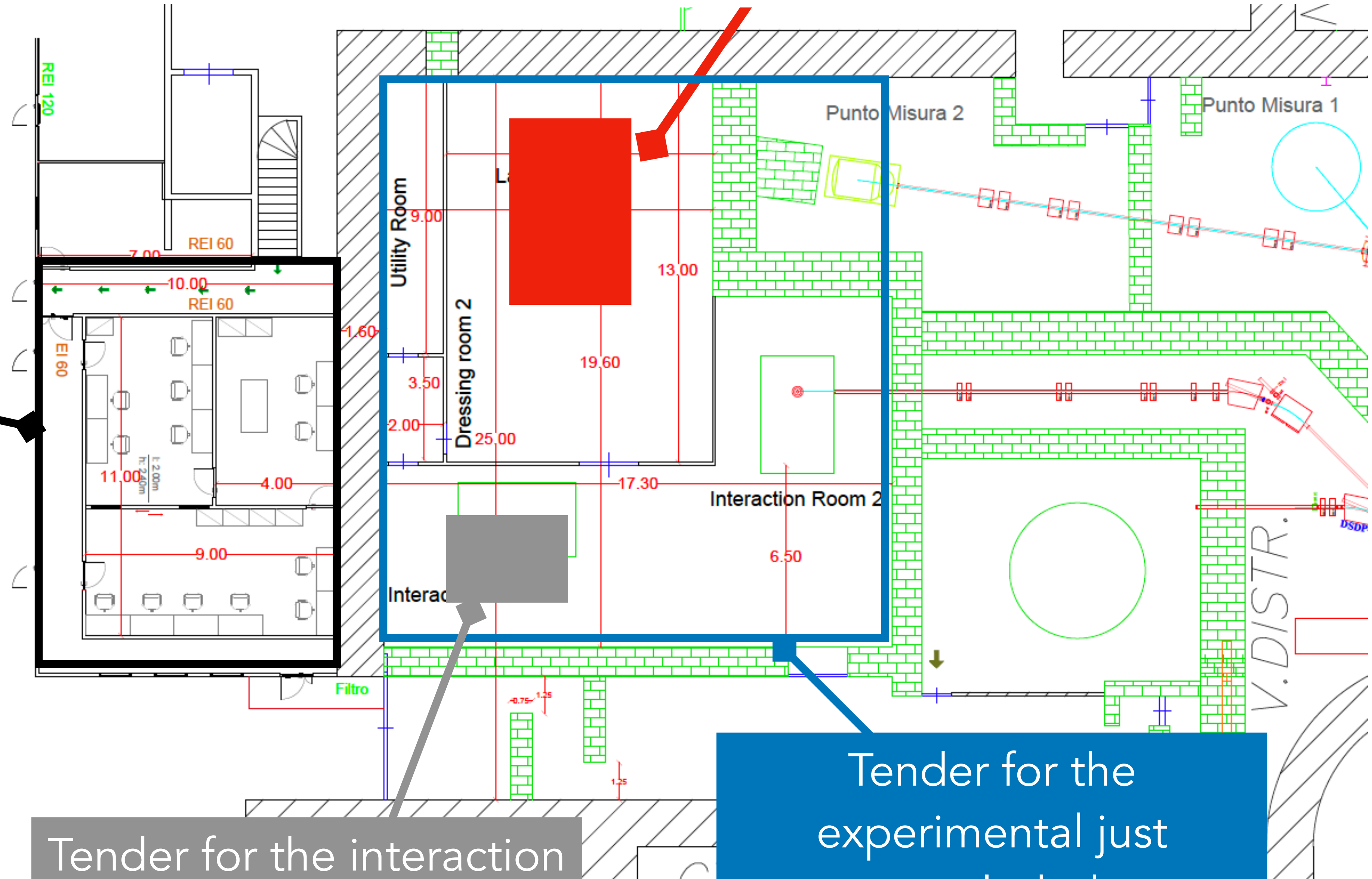
Tender for the experimental just concluded

I-LUCE current status

Laser tender concluded
Contract to be signed

THALES

Control area under construction



Tender for the interaction chamber just concluded

Tender for the experimental just concluded

Istituto Nazionale di Fisica Nucleare

Physics cases at I-LUCE

What we will have at disposal?

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

A plasma generated by the laser:

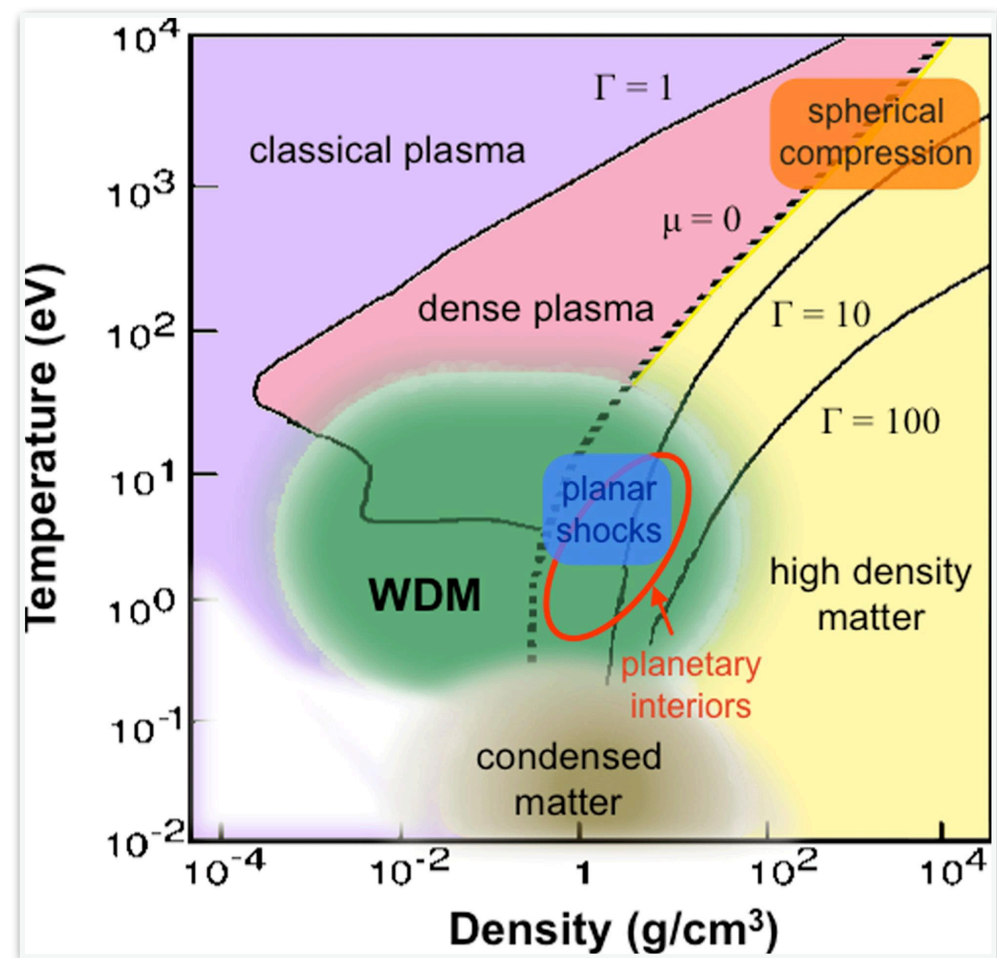
Temperature: 2 eV - 200 eV

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

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

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

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

Medical and interdisciplinary applications

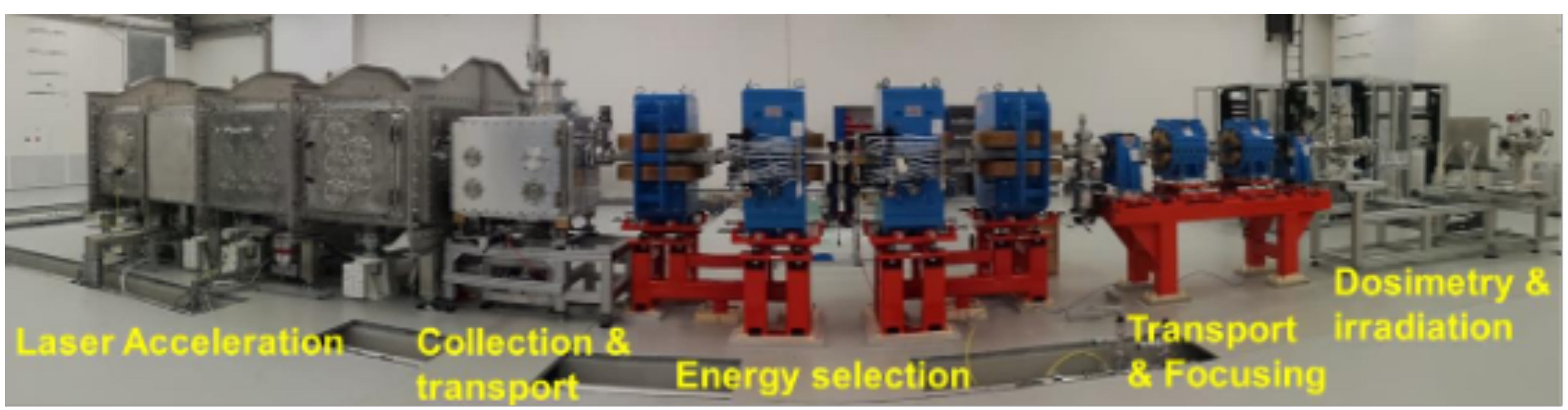
Use of ions/electrons beams for radiobiology studies

....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]

Nuclear astrophysics

THE COULOMB EXPLOSION PARADIGMA

The interaction of ultra-short laser pulses with an expanding gas mixture at controlled temperature and pressure inside a vacuum chamber causes the formation of **plasmas with multi-keV temperature**. These energies overlap with the typical temperatures of stellar environments **where thermonuclear reactions occur**, thus making this paradigm a <u>perfect scenario for nuclear astrophysics research</u>.

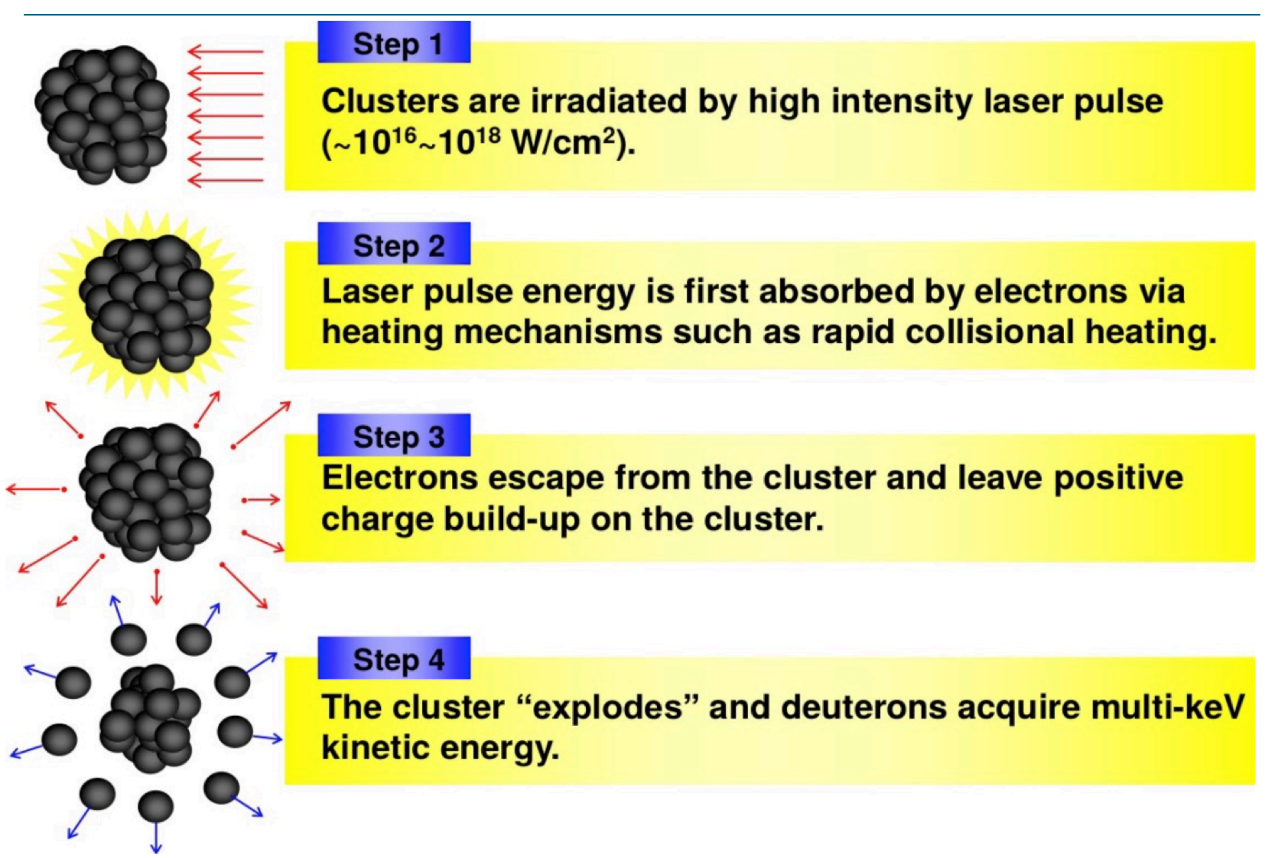
The AsFiN laser collaboration:
A.Bonasera, G.L. Guardo, M. La Cognata, L. Lamia, D. Lattuada, A.A. Oliva, R.G. Pizzone, G.G. Rapisarda, S. Romano, D. Santonocito, A. Tumino

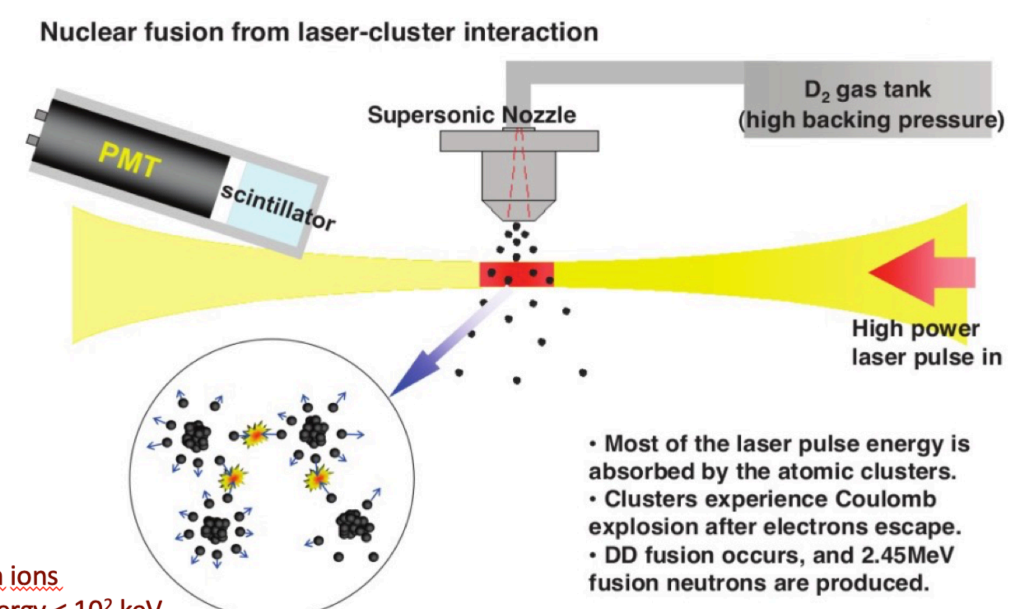
Example: deuterium-deuterium fusion

$$d + d \rightarrow {}^3\mathrm{He}(0.82MeV) + n(2.45MeV)$$

$$d + d \rightarrow p(3.02MeV) + t(1.01MeV)$$

$$d + {}^3\mathrm{He} \rightarrow p(14.7MeV) + {}^4\mathrm{He}(3.6MeV)$$





deuterium ions
Kinetic Energy < 10^2 keV
Density ~ 10^{18} atoms/cm^3
10^5-10^7 neutrons per shot

Nuclear astrophysics: dd fusion

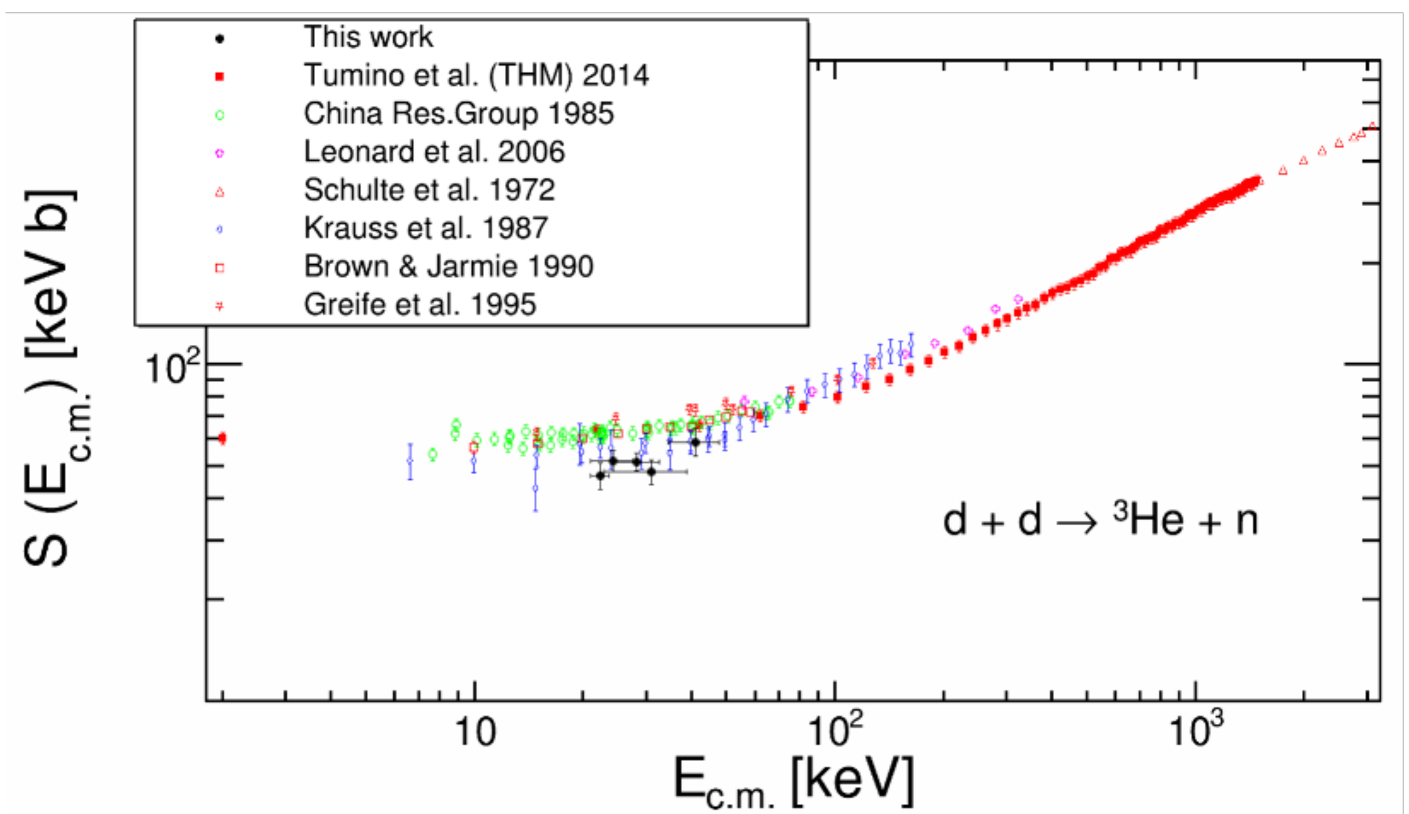
PHYSICAL REVIEW C
covering nuclear physics

Highlights Recent Accepted Authors Referees Search Press About

Model-independent determination of the astrophysical *S* factor in laser-induced fusion plasmas

D. Lattuada, M. Barbarino, A. Bonasera, W. Bang, H. J. Quevedo, M. Warren, F. Consoli, R. De Angelis, P. Andreoli, S. Kimura, G. Dyer, A. C. Bernstein, K. Hagel, M. Barbui, K. Schmidt, E. Gaul, M. E. Donovan, J. B. Natowitz, and T. Ditmire

Phys. Rev. C **93**, 045808 – Published 19 April 2016



This method will open the way for a new approach to study nuclear astrophysics reactions such as:

-deuterium- deuterium

-deuterium-^{3}He

-proton-lithium

-proton-boron

-^{12}C-^{12}C

-^{16}O-^{16}O

-and much more….

Stopping powers in plasma

Stopping power of ions in plasma is a process of fundamental importance in many applications:

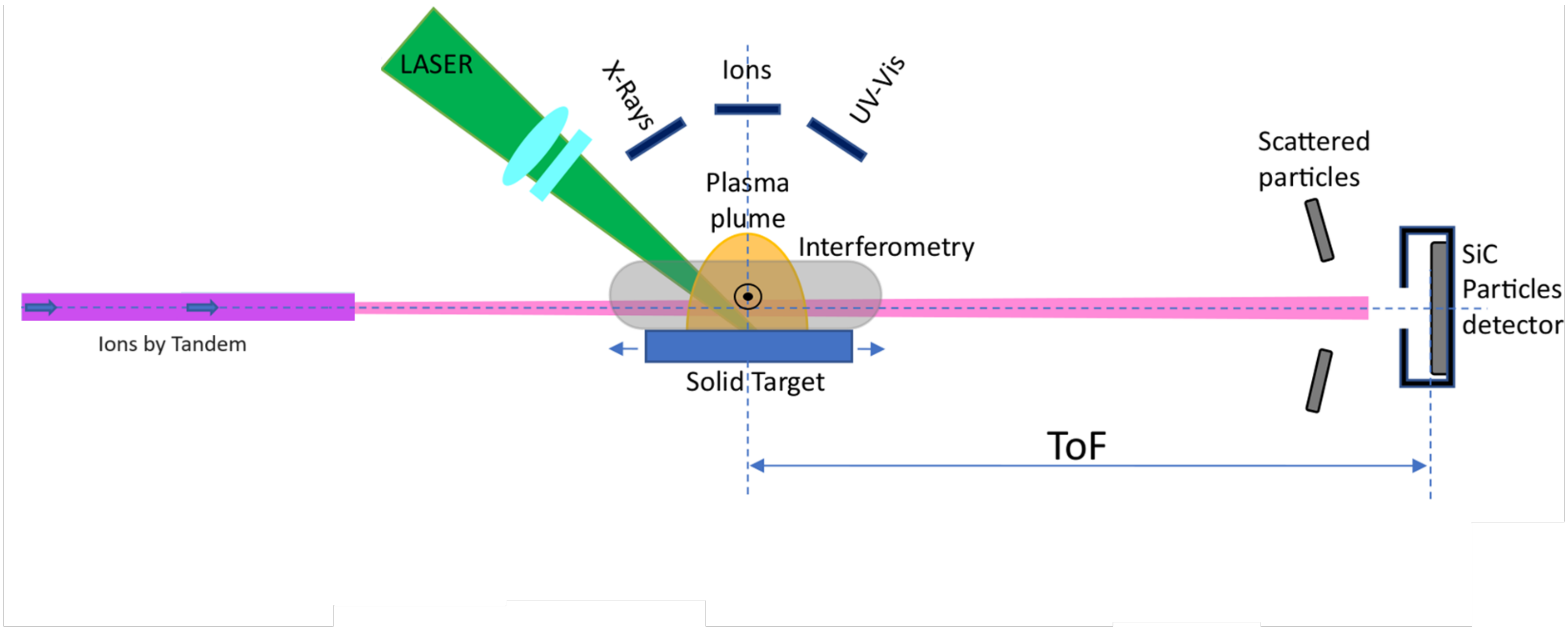
- Inertial Confinement Fusion
- Astrophysics and Nuclear Astrophysics
- High-energy Density Physics
- Plasma strippers
- Solid State Physics

Characterization of ions stopping power in plasma at I-LUCE facility

Collaboration: C. Altana, G. Castro, S. Cavallaro, C. Ciampi, G.A.P. Cirrone, R. De Angelis, S. De Luca, G. Lanzalone, L. Malferrari, F. Odorici, L. Palladino, G. Pasquali, A. Russo, A. Trifirò and S. Tudisco

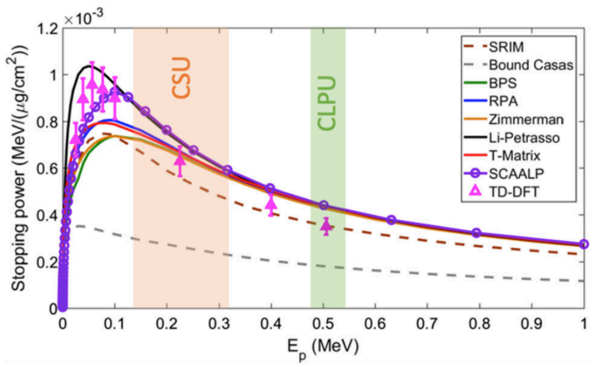
Partecipating INFN sections: Catania, LNS, LNGS, Bologna, Firenze

Stopping powers in plasma

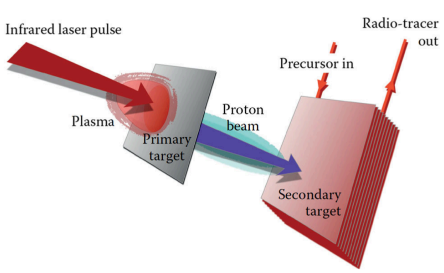


LNS has the only possibility, together with GSI, to deliver a beam with low energy by Tandem accelerator that cross a plasma plume generated under vacuum by a laser beam interacting with a solid target.

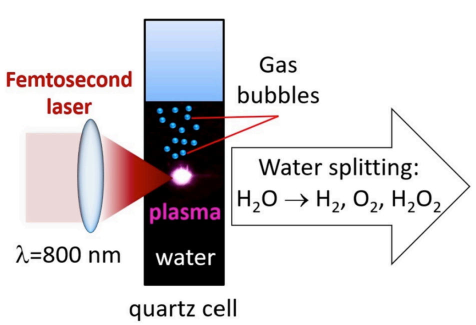
Nuclear physics mid-term plan



Stopping power in plasma



Radioisotopes



Hydrogen generation

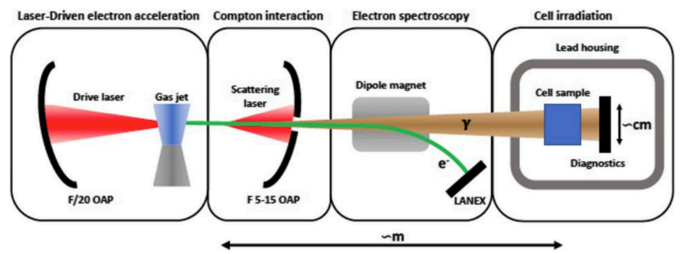
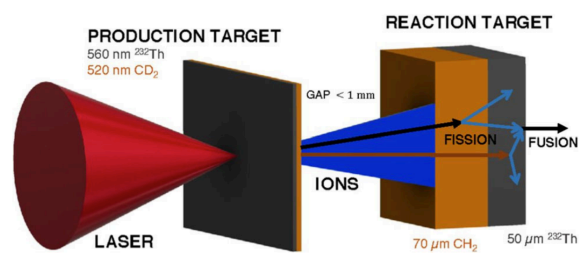
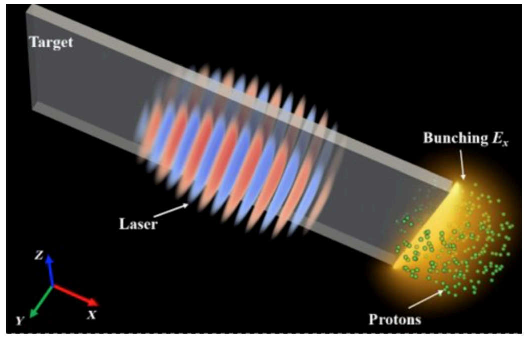


Fig. 48 Setup for the high-brilliance γ production via inverse Compton-scattering (from Sarri et al. [371])

Positrons generation



Nuclear reaction schemes



Protons and electrons generation

Chapter 6.2 Laser applications

Eur. Phys. J. Plus (2023) 138:1038
https://doi.org/10.1140/epjp/s13360-023-04358-7

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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Take-to-home message

Take-to-home message

New radiation beams, complementary to the existing ones

New basic physics and multidisciplinary studies (also complementary to other apparata in realisation, i.e PANDORA)

A new European facility with unique features

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

Thanks to everyone