I-LUCE @ INFN-LNS
INFN Laser inUCEd radiation production

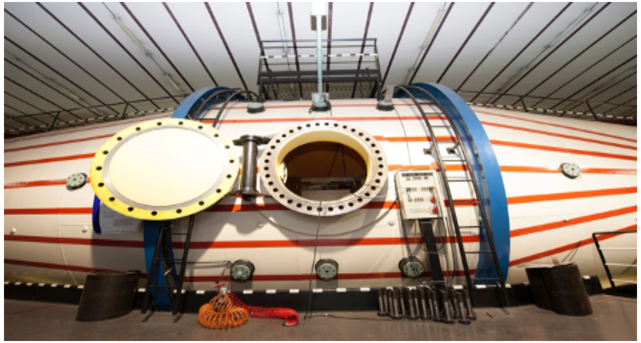
A facility for new radiation sources at LNS

Pablo Cirrone

Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (Italy)

Accelerators and laser at LNS

I-LUCE goals: increase the number of radiations sources at INFN-LNS and generate plasma states for basic-physics studies



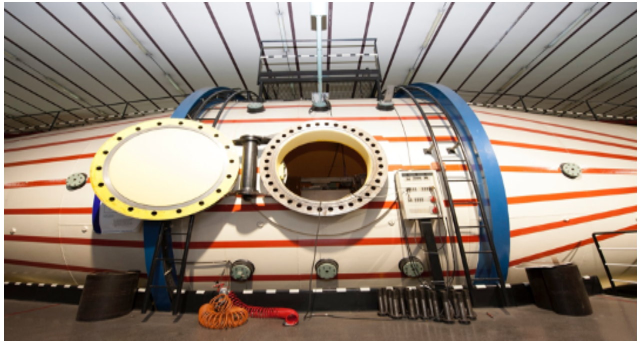
Length: 25 m
Weight: 120 t
Max voltage: 15MV

TANDEM	
Negative ions	Injected beam intensity [nA]
1H	1500
2D	1500
6Li	250
….	
197Au	700

Height: 28 m
Weight: 176 t
Max magnetic field: 4.8 T

Superconducting cyclotron	
${}^{a}X$	E [MeV/amu]
H2+	62, 80
H3+	30,35,45
2D+	35,62,80
…	
208Pb	10

I-LUCE goals: increase the number of radiations sources at INFN-LNS and generate plasma states for basic-physics studies



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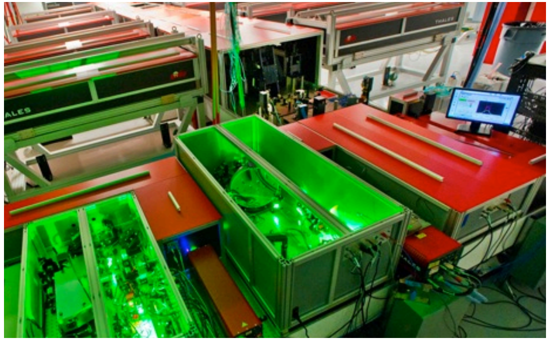


Fitting in a room 9x13 m2
Power: 0.5 PW scale
Weight:

High power laser	
Radiation	E [MeV/amu]
Protons/ions	up to 60 MeV
Electrons	up to 2 GeV
Neutrons	Positrons
Gamma/X	Others

Main ingredients of a laser-plasma radiation production

What ingredients do we need to produce radiation?

What ingredients do we need to produce radiation?

A laser

High power (TW - PW)

Short pulse duration (ps - fs)

A Target: thin/thick solid/liquid/gassous …

Other useful things

High contrast laser

High quality target fabrication

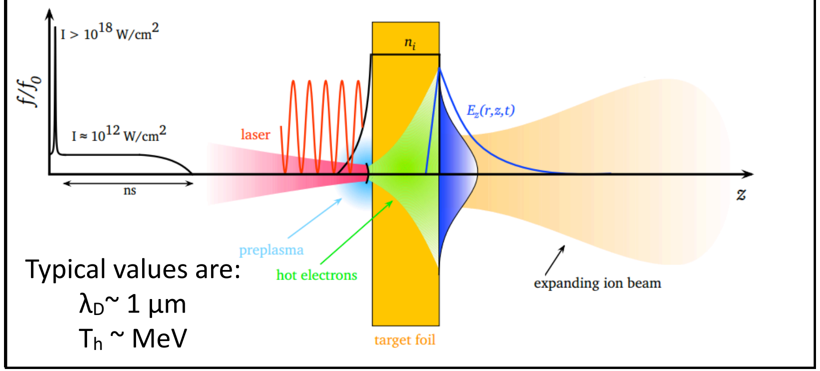
High quality wave front-end

…..

See talks by Daniele Margarone, Tadzio Levato, Luca Labate

Ions, electrons, neutrons, gamma, positrons, ……

Ions acceleration



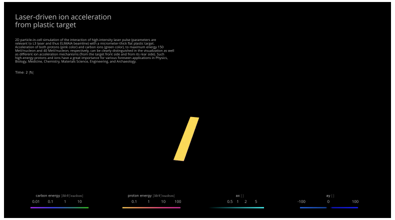
Typical values are:

$\lambda_D \sim 1\ \mu m$

$T_h \sim MeV$

$$E(0) = \frac{KT_h}{e\lambda_D} = \sqrt{\frac{n_h KT_h}{\varepsilon_0}}$$

$$E(0) = \frac{10^6 V}{10^{-6} m} \sim TV/m$$



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Ions, electrons, neutrons, gamma, positrons, ……

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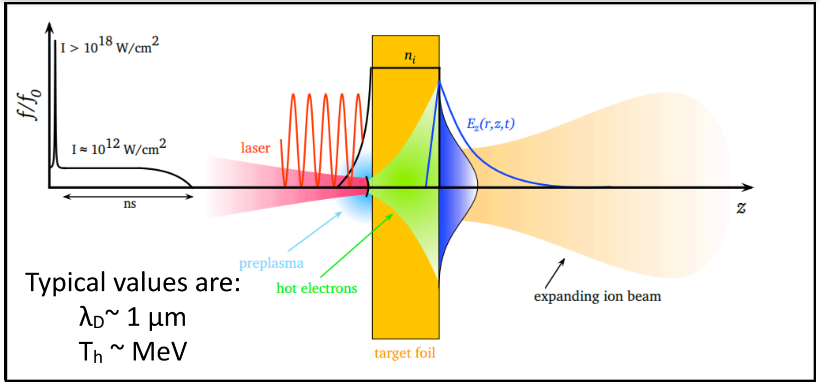

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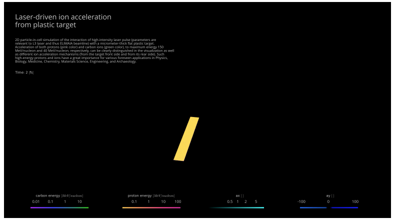

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Ions, electrons, neutrons, gamma, positrons, ……

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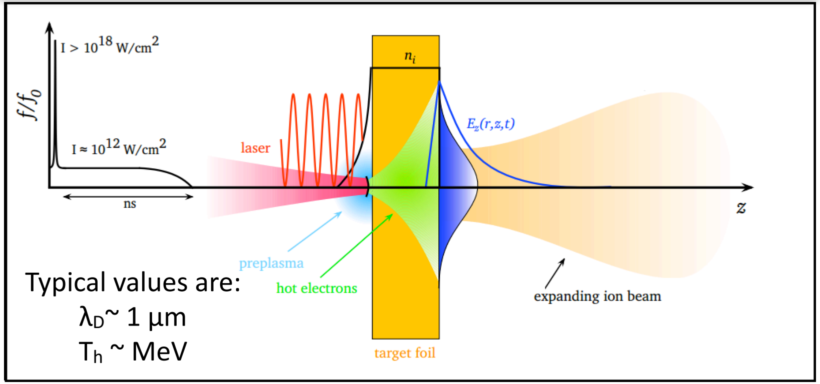
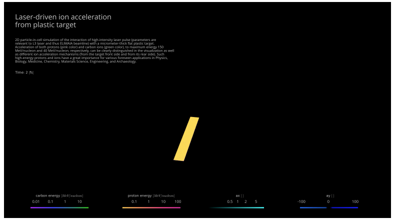


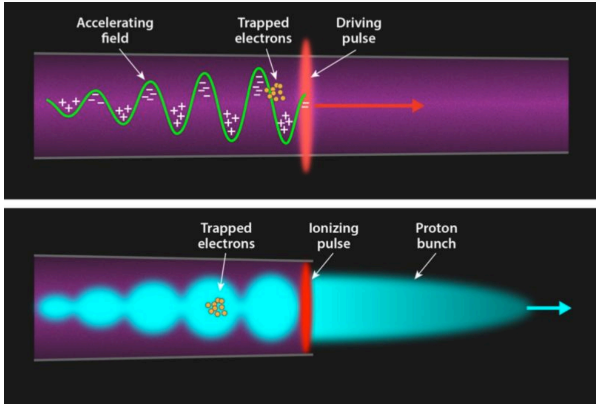
Typical values are:
λ_D ~ 1 µm
T_h ~ MeV

$$E(0) = \frac{KT_h}{e\lambda_D} = \sqrt{\frac{n_h K T_h}{\varepsilon_0}}$$

$$E(0) = \frac{10^6\,V}{10^{-6}\,m} \sim TV/m$$



Electrons acceleration



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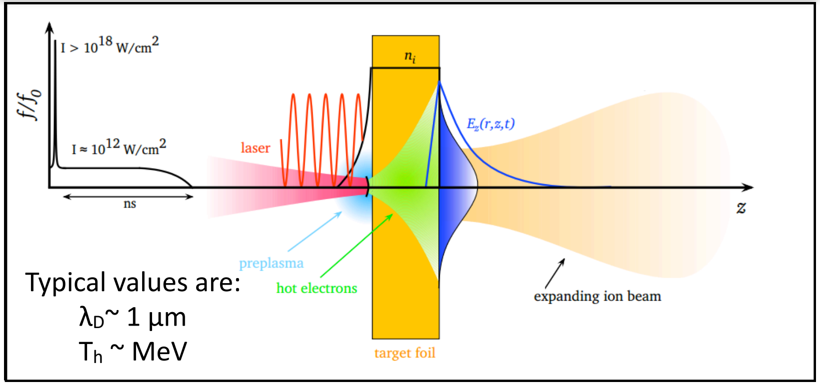
Ions acceleration



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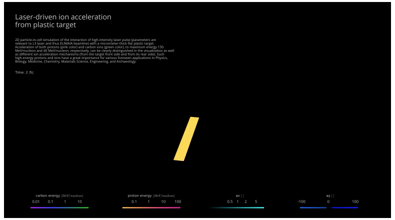
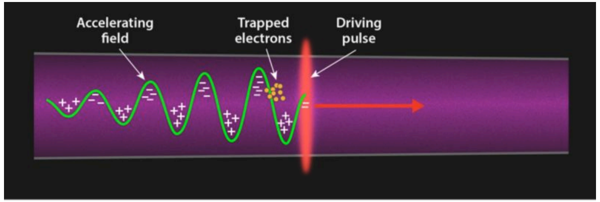
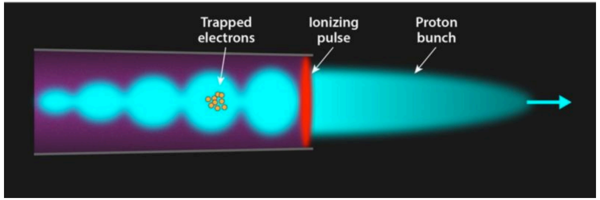
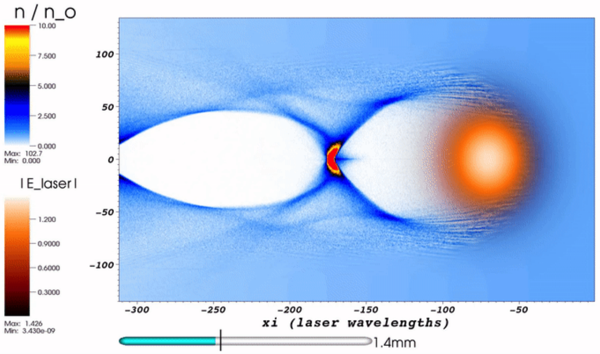


Electrons acceleration







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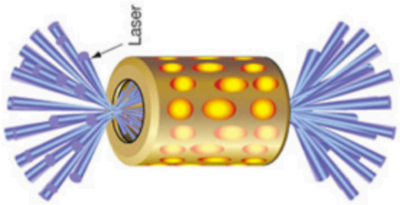
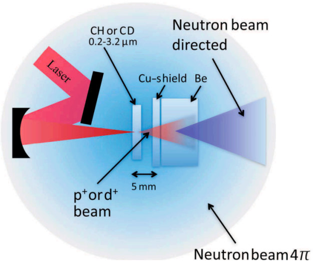
Ions, electrons, neutrons, gamma, positrons, ……

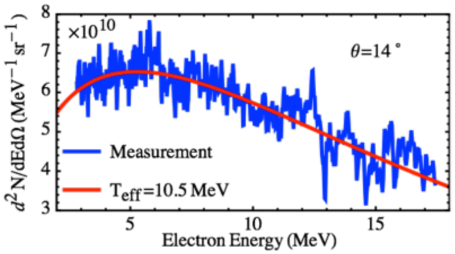
Neutrons productions

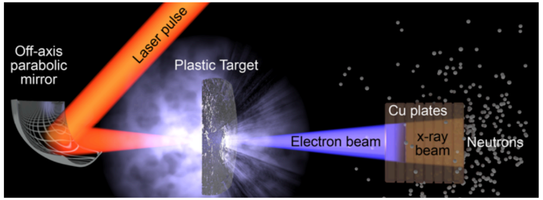
Inertial fusion processes





Electron driven





I. Pomerantz, et al., Phys. Rev. Lett. 113, 184801 (2014)

M. Roth, et. al., Phys. Rev. Lett. **110**, 044802 (2013)
D. Jung, et. al., Phys. Plasmas **20**, 056706 (2013)
Nature Research Highlights vol. **494**, 9 (2013)

C. Zulick, et al. Appl. Phys. Lett. **102**, 124101 (2013)

M. Storm, et al. Phys. Plasmas **20**, 053106 (2013)

I. Pomerantz, et al. Phys. Rev. Lett. 113, 184801 (2014)

Y. Arikawa, et al.
Plasma and Fusion Research 10, 2404003 (2015)

S. Kar, et al. arXiv:1507.04511 [physics.plasm-ph] (2015)

I-LUCE

L Torrisi, S Gammino, G Cuttone, A Anzalone,
S Tudisco, G Lanzalone, A Bonasera, D Margarone, D Mascali e molti altri

2000 | 2009 | 2012 | 2018 | 2023

ECLISSE PLAIA PLATONE PLEIADI LILIA ELIMED L3IA FUSION

PLANETA

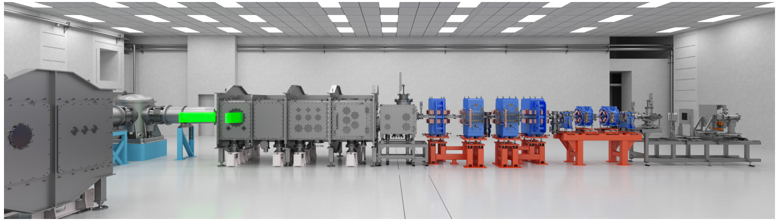
Discussion groups for an high-power laser acquisition (L Calabretta et al)

2000 is a breakthrough year

ELIMED contract

BCT e PNNR projects

	Laser intensity [W cm-2]	Number of protons	Max proton energy [MeV]
Maksimchuk et al., 2000	3*E18	> 1E9	1.5
Clark et al., 2000	5E+19	1E+12	18
Snavely et al., 2000	3E+20	2E+13	58



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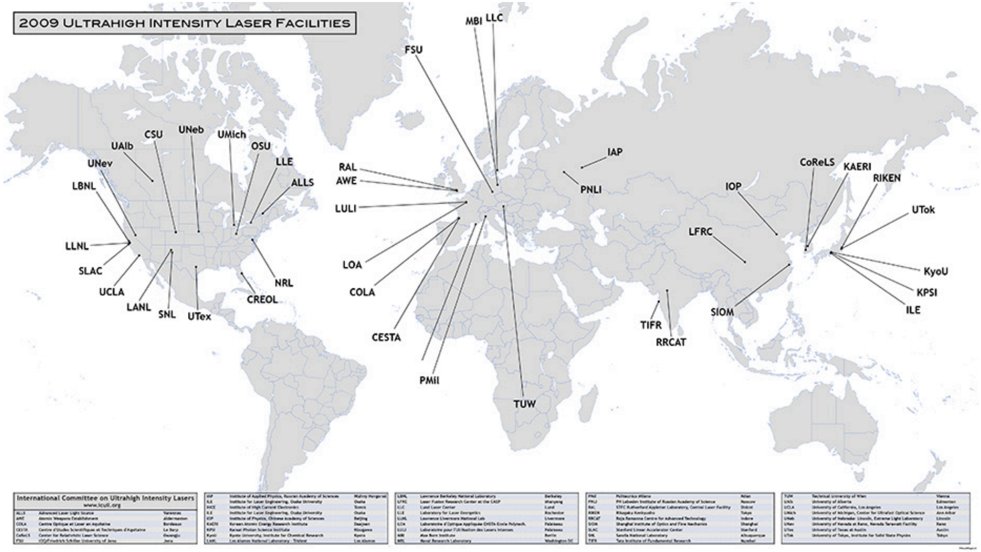
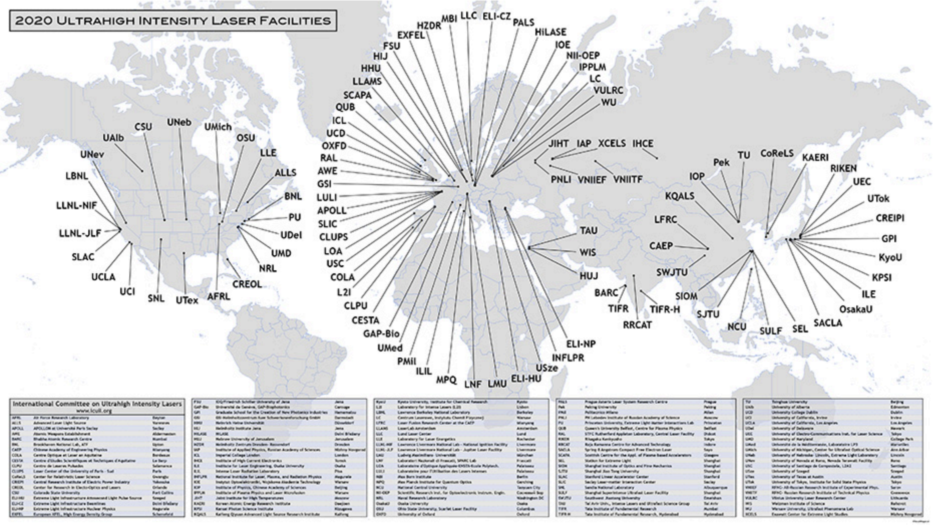


2009: 19 facilites

https://www.icuil.org/index.php

The International Committee on Ultra-High Intensity Lasers

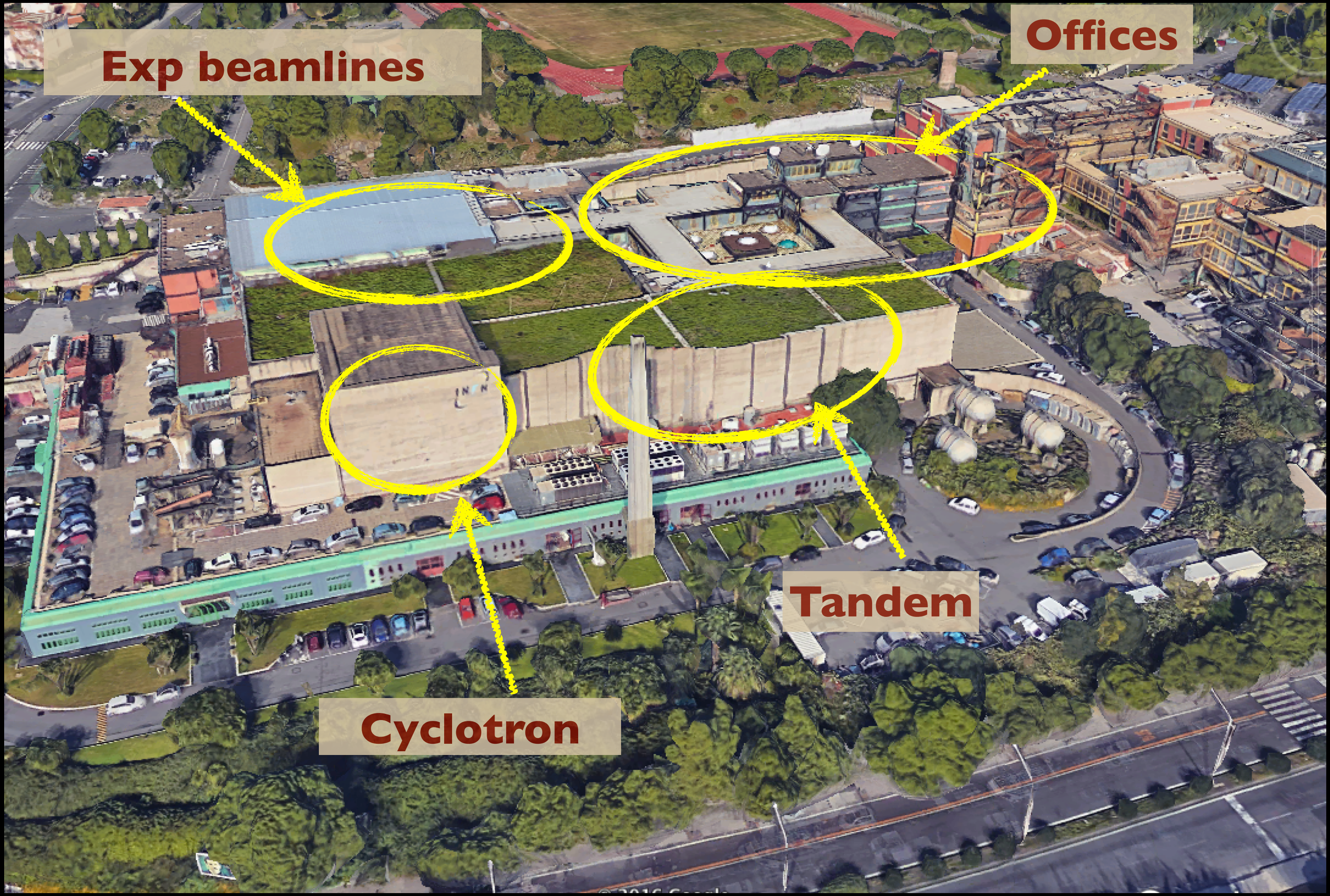
2020: 90 facilities

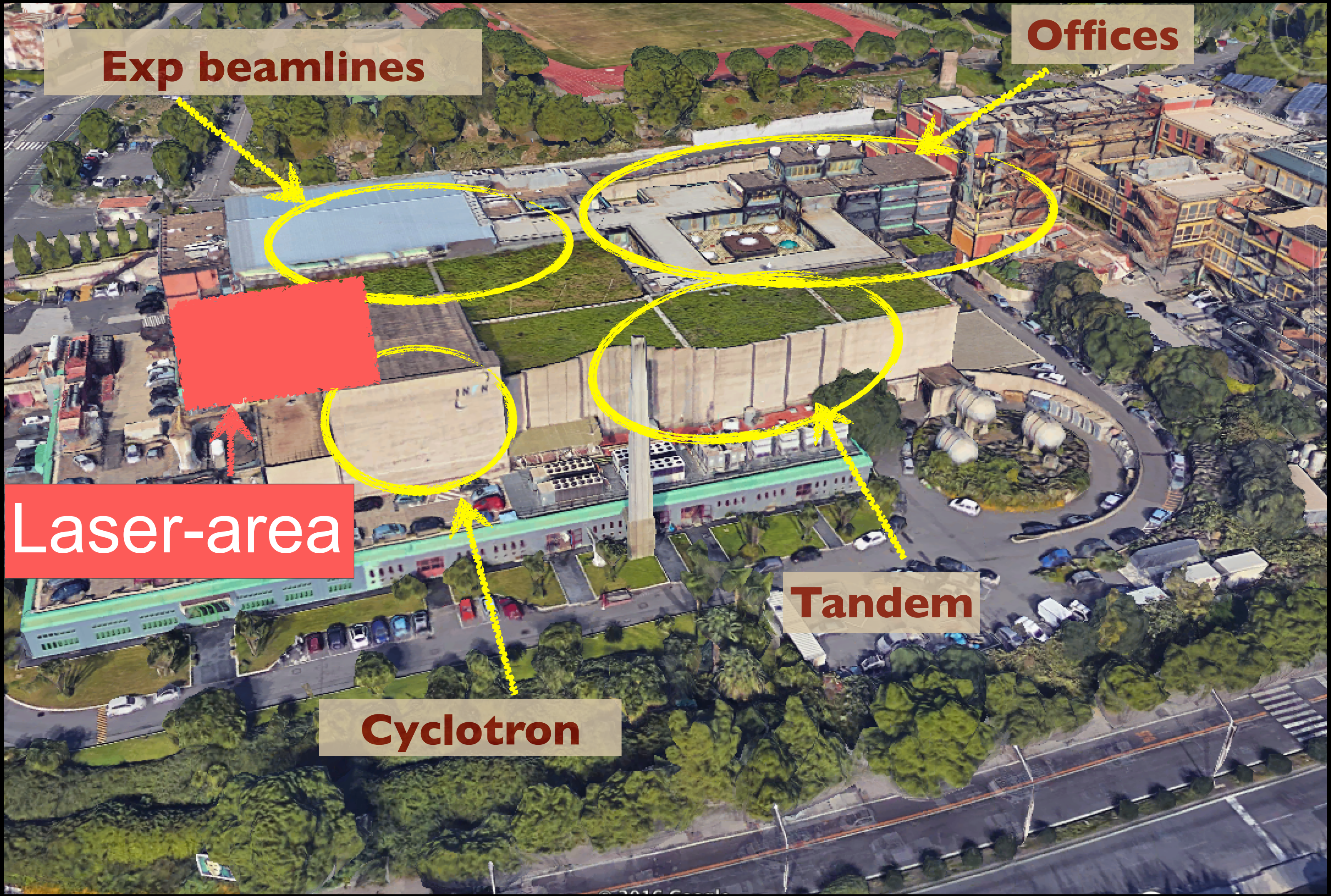


I-LUCE

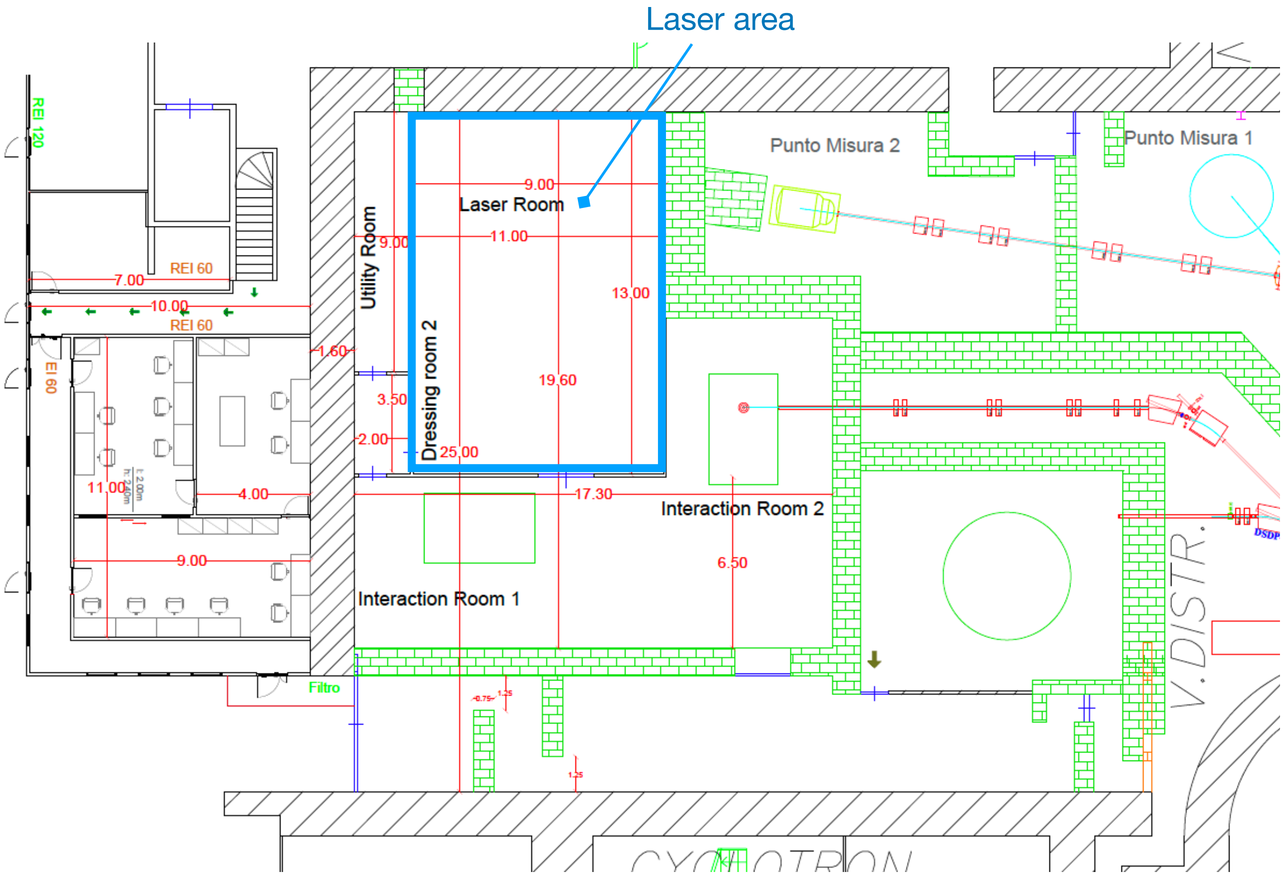
INFN - Laser indUCEd radiation production

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

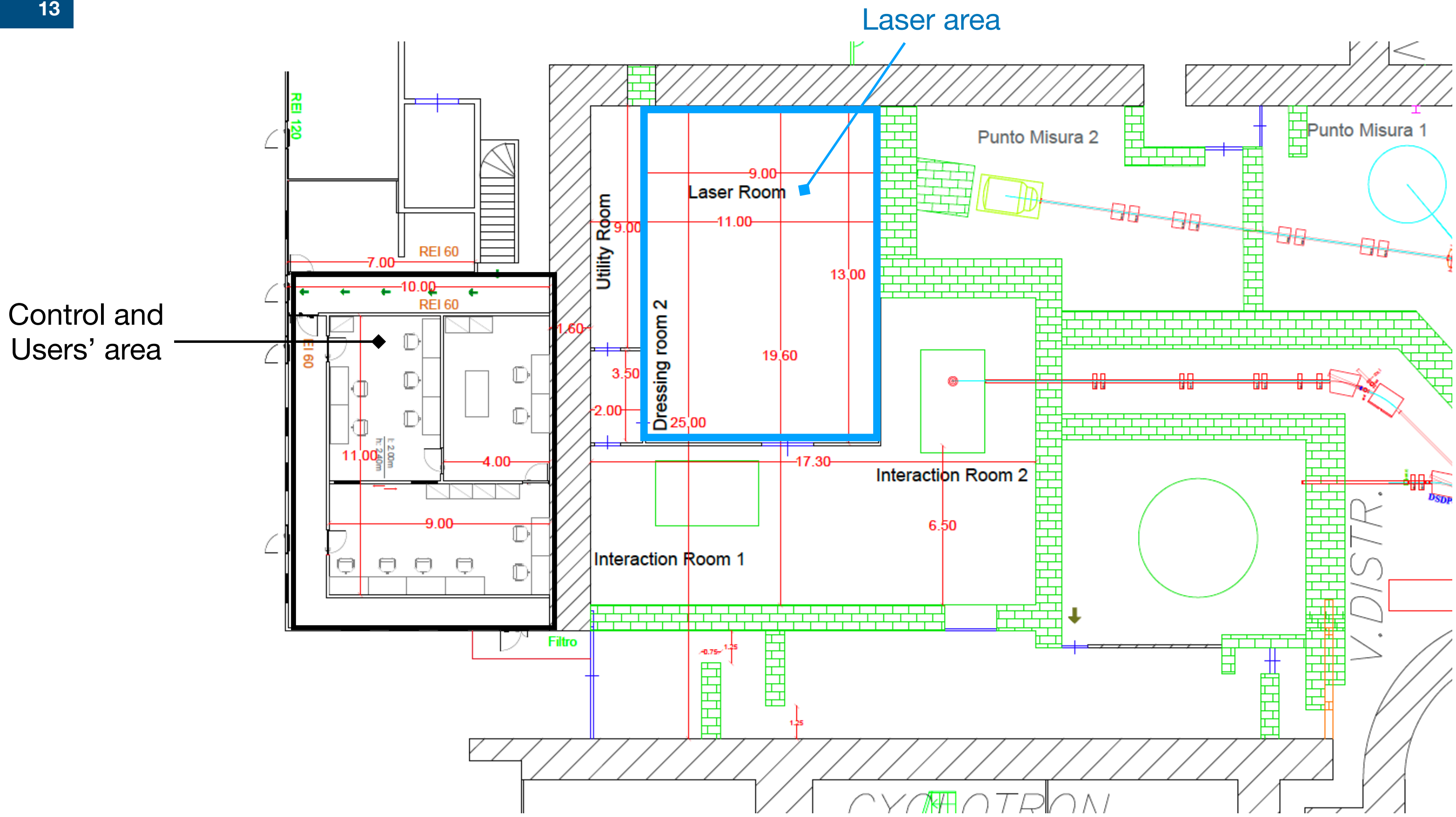

Exp beamlines
Offices
Tandem
Cyclotron


Exp beamlines
Offices
Laser-area
Tandem
Cyclotron

I-LUCE layout



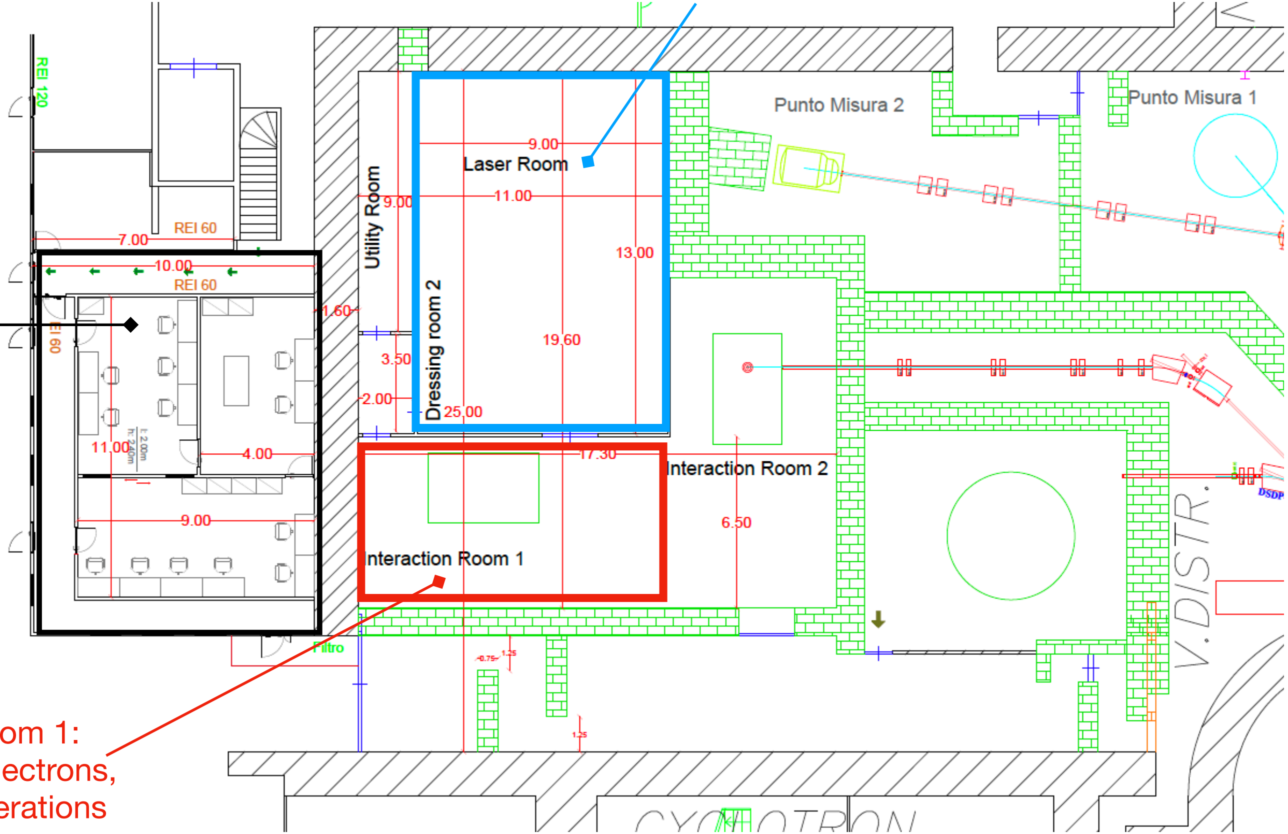
I-LUCE layout



I-LUCE layout

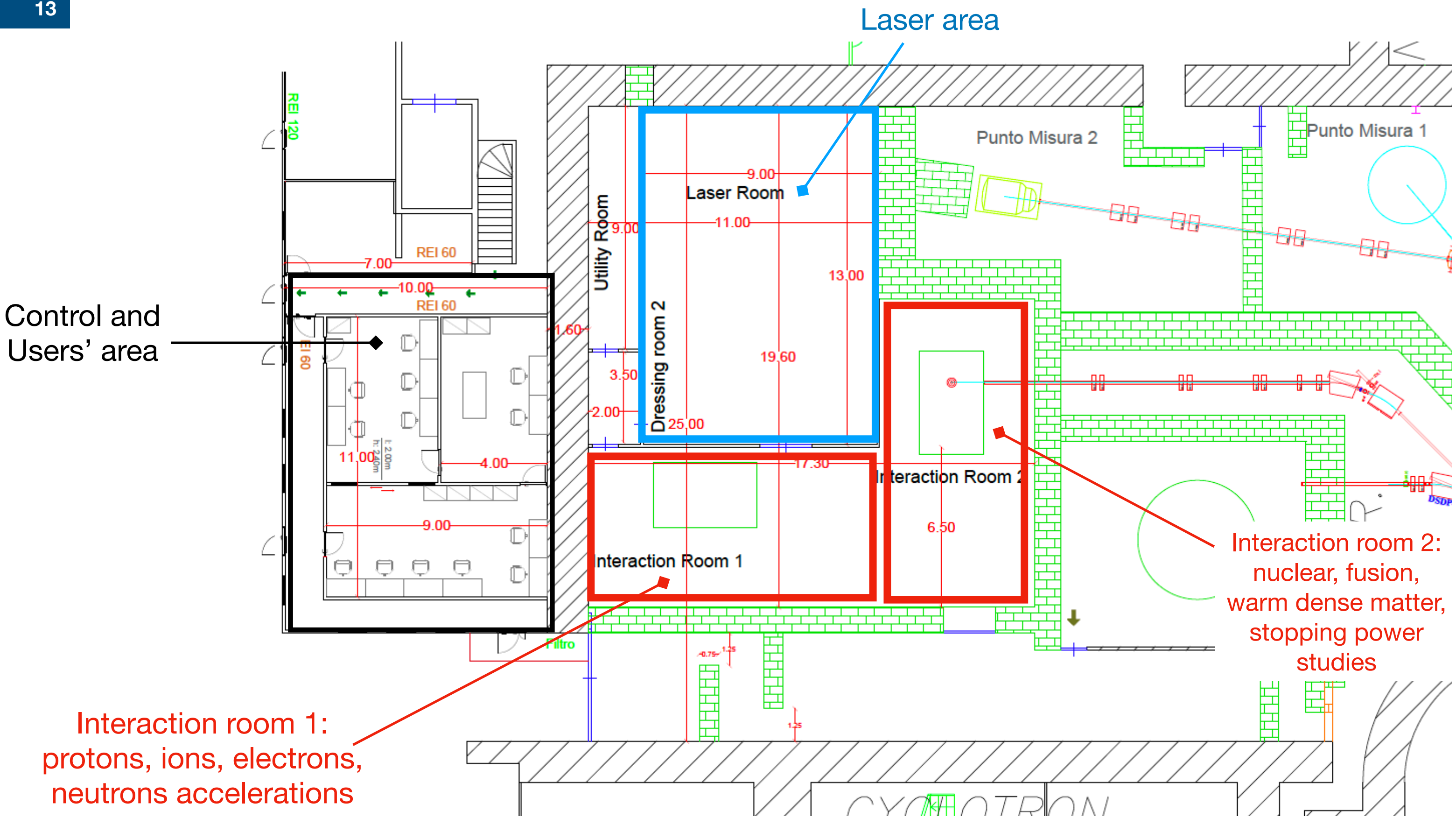
Laser area

Control and Users' area

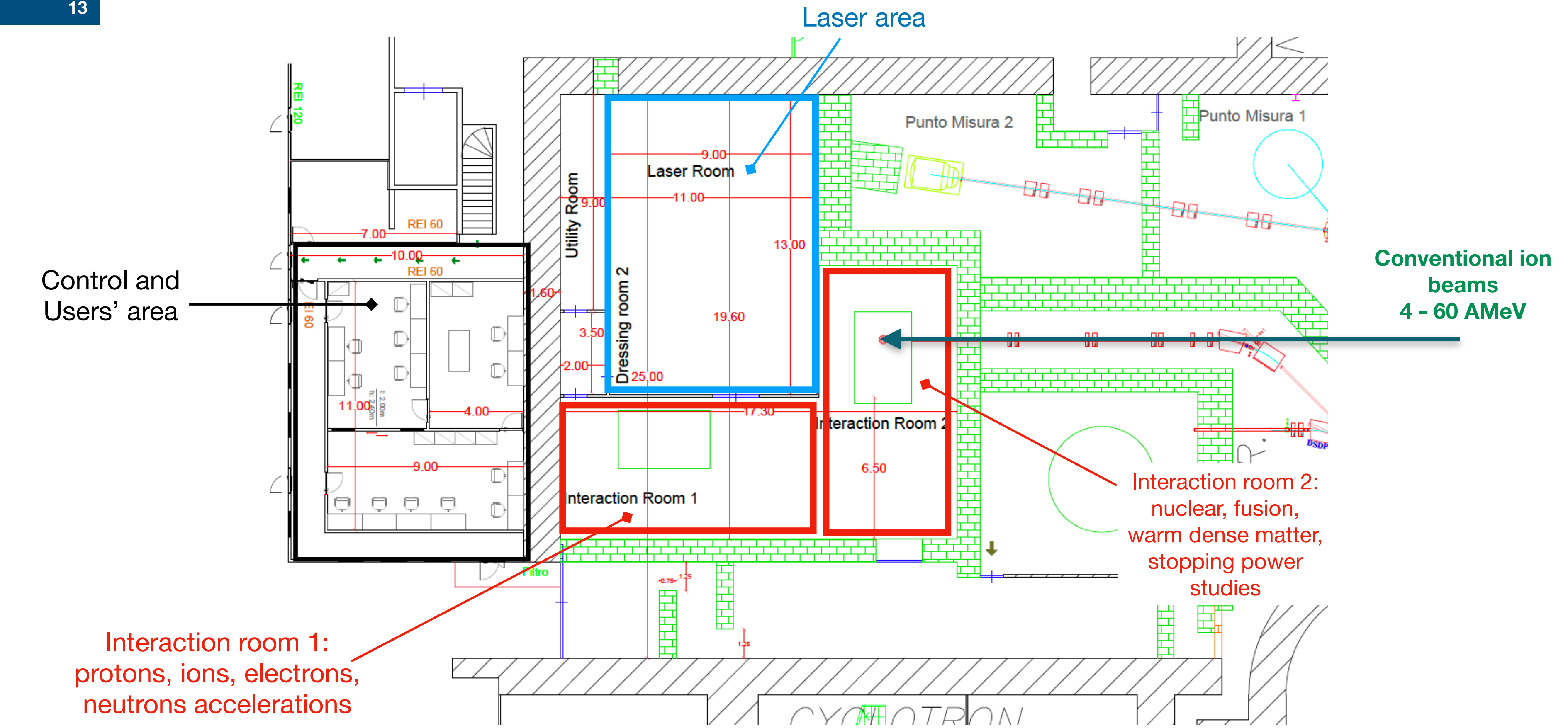


Interaction room 1: protons, ions, electrons, neutrons accelerations

I-LUCE layout



I-LUCE layout



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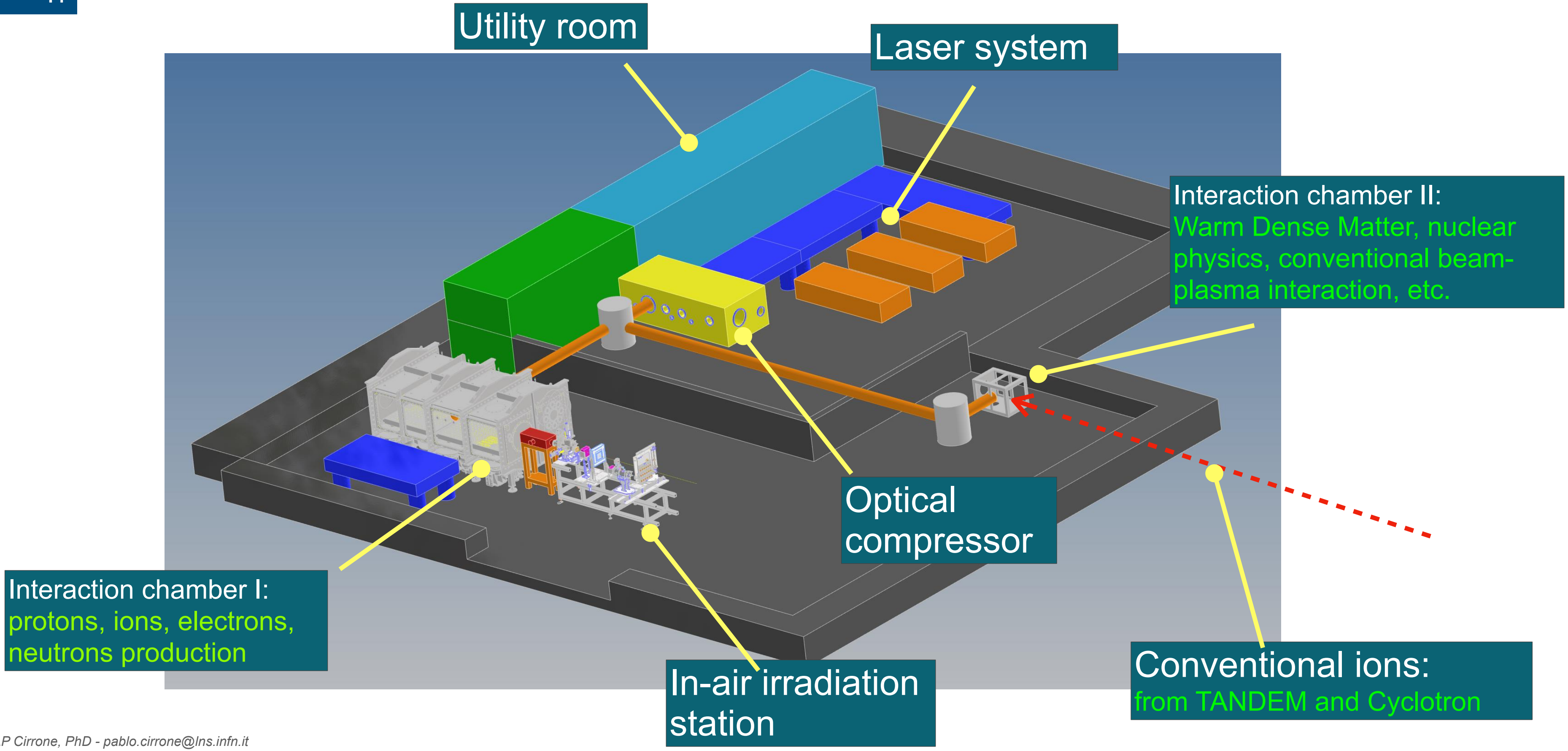
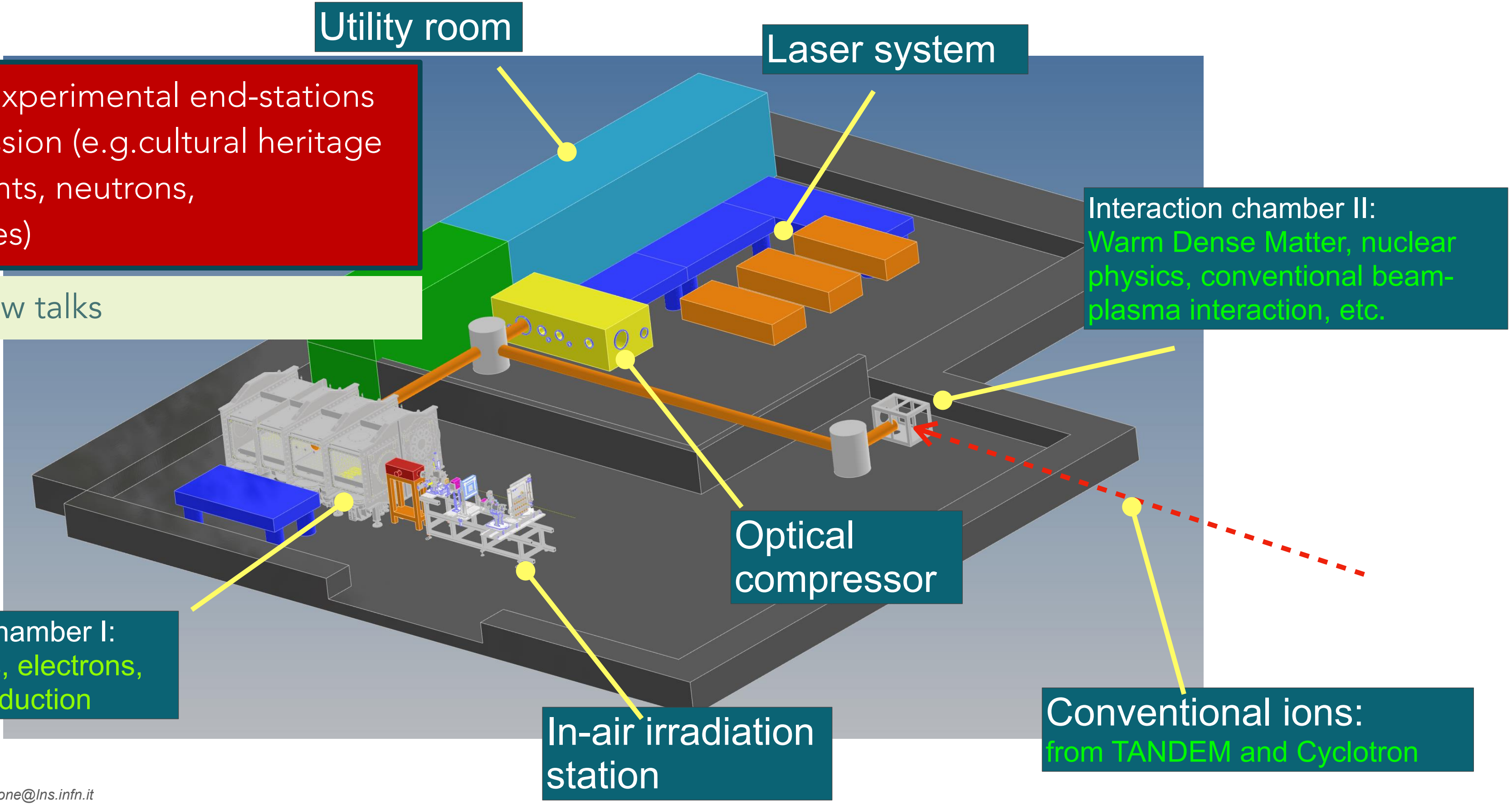

Utility room
Laser system
Interaction chamber II:
Warm Dense Matter, nuclear physics, conventional beam-plasma interaction, etc.
Optical compressor
Interaction chamber I:
protons, ions, electrons, neutrons production
In-air irradiation station
Conventional ions:
from TANDEM and Cyclotron

I-LUCE

Additional experimental end-stations are in discussion (e.g.cultural heritage measurements, neutrons, radioisotopes)

See tomorrow talks



The facility layout (first phase) - summary

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€)

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 ropabgation 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:

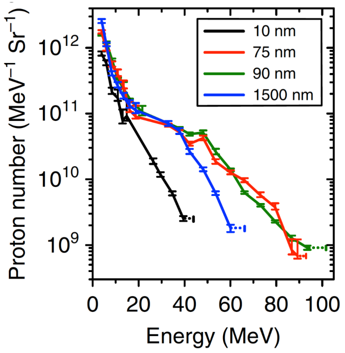
— *Decay studies*
— *Stopping powers studies*
— *WDM characterisation*

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

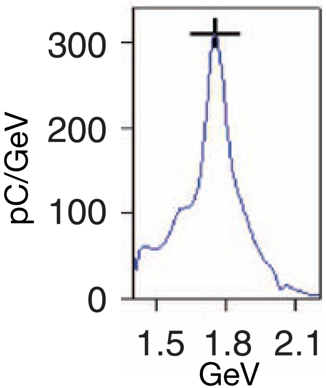
High-power modality: 350 TW

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 breemsstrahlung	
	Energy	up to 80 MeV
	Beam divergency	Directionality in the beam ropabgation

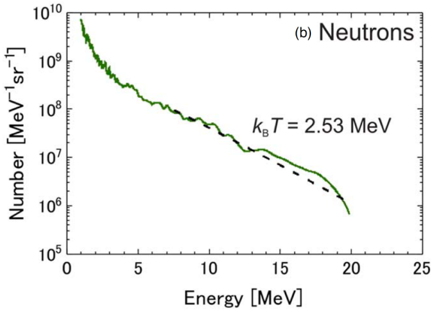
Protons spectra from A. Higginson et al. "Near-100 MeV protons via a laser-driven transparency-enhanced hybrid acceleration scheme", NATURE COMMUNICATIONS | (2018) 9:724



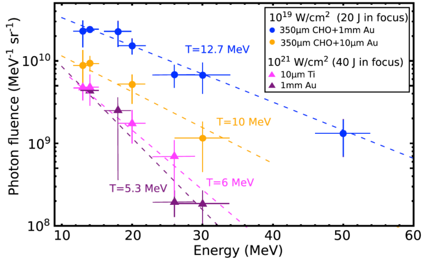
Electrons spectra from X. Wang et al. "Quasi-monoenergetic laser-plasma acceleration of electrons to 2 GeV", NATURE COMMUNICATIONS, 4:1988 2018 DOI: 10.1038/ncomms2988



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)



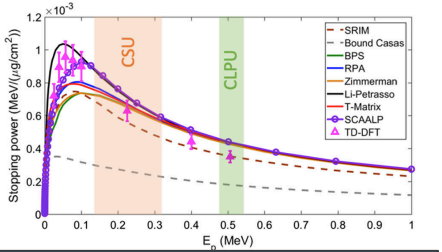
Gamma spectra from M. M. Günther et al "Forward-looking insights in laser-generated ultraintense γ-ray and neutron sources for nuclear application and science" NATURE COMMUNICATIONS | (2022) 13:170



Nuclear physics mid-term plan

18

Chapter 6.2 Laser applications



Stopping power in plasma

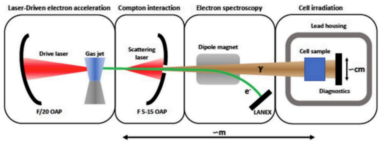
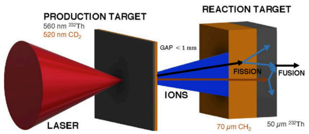
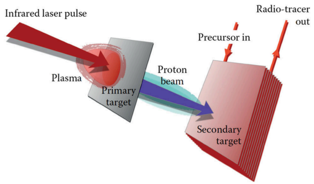


Fig. 48 Setup for the high-brilliance γ production via inverse Compton-scattering (from Sarri et al. [371])

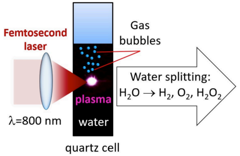
Positrons generation



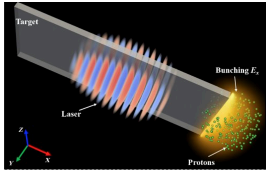
Nuclear reaction schemes



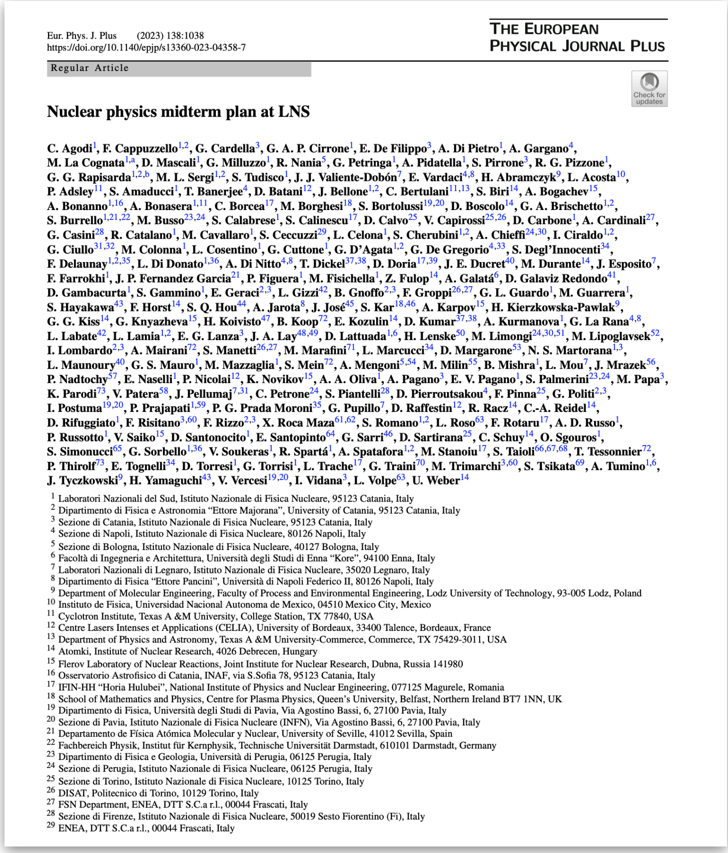
Radioisotopes



Hydrogen generation



Protons and electrons generation



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

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Nuclear physics midterm plan at LNS

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

I-LUCE organisation

WP	Activity	Responsible
1	Laser systems and management	Josè Suarez
2	Laser transport and interaction	Carmen Altana
2a	Protons/ions production	Giada Petringa and Roberto catalano
2b	Electrons productions	Sahar Arjmand
3	Secondary beam transport, diagnostic, dosimetry, analysis	Alfio Pappalardo
4	Control system	Giada Petringa
5	Electromagnetic pulse and its mitigation	Danilo Bonanno
6	Tenders and personnel	Roberto Catalano

Giuseppe Angemi, Giovanni Cantone, Enrico Caruso, Orsola Giampiccolo, Alessandro Pizzino with the BCT project, supporting the experimental activity

Financial support

Roma TV, LNF, Pisa CNR, LNS
15 M€

7.9 M€ WP3 High-Power lasers

Infrastructure

Laser system and interaction chambers

Electrons and ion acceleration

GAP Cirrone

S Tudisco

0.8 M€

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

Anthem

Advanced technologies for Human Centred Medicine

23 Istituti; Spoke 4: Caserta, Pavia, INFN

GAP Cirrone, G Cuttone

1.3 M€

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

BCT

Breast Cancer Therapy

G Cuttone, GAP Cirrone

2.0 M€

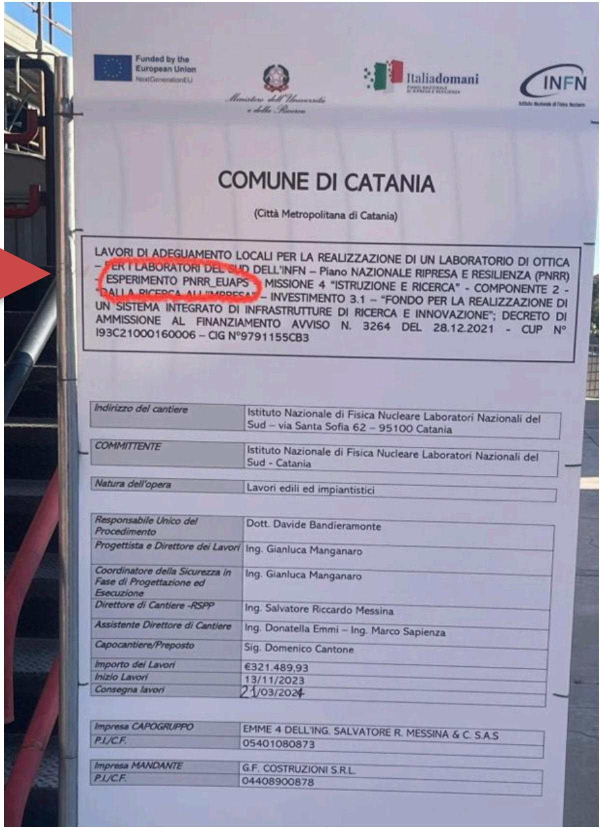
Ottimizzazione nella selezione di fasci di protoni per applicazioni mediche

See talks by Giacomo Cuttone

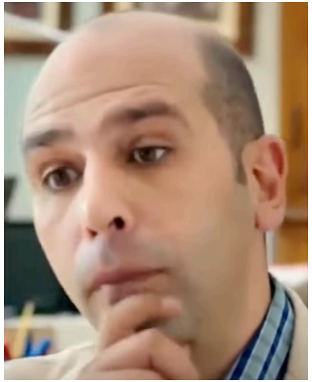
Status

Tender	Status	Project
Control room and optical laboratory	Assigned/working ongoing	EuAPS
Laser system	Assigned (contract to be signed)	EuAPS
Interaction chamber for radiation production	Assigned (contract to be signed)	EuAPS
Clean rom and interaction area	Waiting for the assignment	EuAPS
Target tower for proton acceleration	Tender started	SAMOTHARACE
Optical tables	tbd	EuAPS
Laser beam transport design	Technical specifications under definition	SAMOTHARACE
Laser beam transport realisation	Technical specifications under definition	SAMOTHARACE
Target system for electron acceleration	Technical specifications under definitions	ANTHEM
…..	…..	……

Control room and optical laboratory are almost ready!



Take-to-home message



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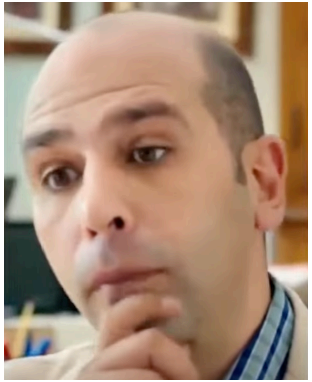

LUCE

New radiation beams, complementary to the existing ones

New basic physics studies complementary to other apparata in realisation (ex PANDORA)

A new European facility with unique features

Thanks to ...

Daniele (ELI), Fabrizio (ENEA), Marco (QUB), Domenico (QUB e ELI), Tadzio (INO), Lorenzo (ELI), Luca (INO-CNR), Luca (CPLU), Leo (INO-CNR), Antonino (FBK), Joseph (AVCR-CAS), Roberto (ELI), and many others

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The LNS with its Directors and Divisions and all the colleagues that participated to the activities
… and are participating, indeed

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Marco La Cognata et coll.
Salvo Tudisco et coll.

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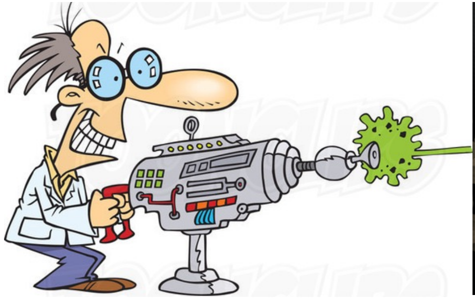
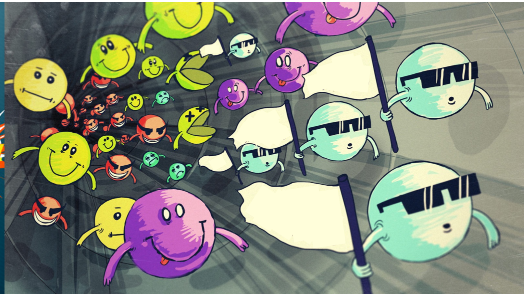
Thanks for listening



Studio della Warm Dense Matter dalla interazione ioni (anche/soprattutto di bassa energia) e plasma

Fisica del plasma: informazioni sul comportamento delle particelle cariche in questo stato e sulle proprietà globali del plasma stesso.

Fusione nucleare: l'interazione di fasci di ioni con un plasma può essere utilizzata per studiare la fusione nucleare controllata. La fusione nucleare è una possibile fonte di energia nel futuro e coinvolge la fusione di nuclei leggeri per formare nuclei più pesanti, rilasciando una grande quantità di energia. Lo studio dell'interazione dei fasci di ioni con un plasma può contribuire alla comprensione delle condizioni necessarie per raggiungere e mantenere una reazione di fusione nucleare stabile.

Fisica delle collisioni atomiche: l'interazione tra ioni di bassa energia e plasmi può fornire informazioni sulla fisica delle collisioni atomiche. Ciò include lo studio delle collisioni tra ioni e atomi neutri nel plasma, nonché le collisioni tra particelle cariche all'interno del plasma stesso. Questi studi possono rivelare importanti informazioni **sulle sezioni d'urto di collisione, l'energia di eccitazione e ionizzazione degli atomi**, i processi di scambio di energia e quant'altro.

Processi di scattering:. questi processi coinvolgono la deviazione di particelle cariche da parte di altre particelle o campi all'interno del plasma. L'analisi del processo di scattering può fornire informazioni sulla struttura interna del plasma, nonché sulle forze elettriche e magnetiche che agiscono sulle particelle.

Ionizzazione e ricombinazione: lo studio di questi processi può fornire informazioni sulle sezioni d'urto di ionizzazione e ricombinazione, nonché sulle rate di reazione in diverse condizioni di plasma.

Eccitazione atomica e spettroscopia: studio della eccitazione degli atomi nel plasma e la conseguente emissione di radiazione. Questo può includere lo studio della spettroscopia di emissione del plasma, che fornisce informazioni sulla struttura atomica e molecolare all'interno del plasma stesso.

Una possibilità unica per la fisica dei nostri Laboratori

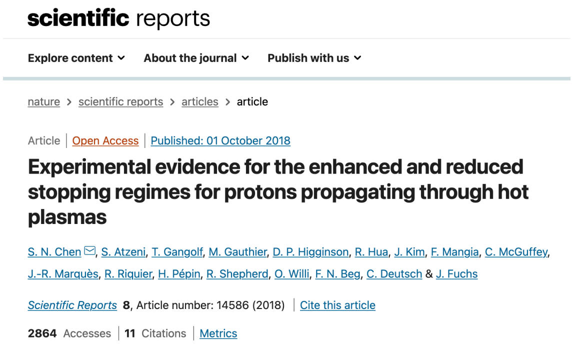
Studio della Warm Dense Matter dalla interazione ioni (anche/soprattutto di bassa energia) e plasma

Eccitazione atomica e spettroscopia: l'interazione tra ioni di bassa energia e plasmi può essere utilizzata per studiare l'eccitazione degli atomi nel plasma e la conseguente emissione di radiazione. Questo può includere lo studio della spettroscopia di emissione del plasma, che fornisce informazioni sulla struttura atomica e molecolare all'interno del plasma stesso.

Risonanze di plasma: gli ioni nel plasma possono interagire con le onde elettromagnetiche generate dal plasma stesso. Queste interazioni possono portare alla formazione di risonanze di plasma, in cui l'energia viene scambiata tra le particelle cariche e l'onda elettromagnetica. Lo studio di queste risonanze può fornire informazioni sulle proprietà del plasma e sulle interazioni particella-onda.

Oscillazioni elettrostatiche: gli ioni nel plasma possono partecipare a oscillazioni elettrostatiche, come le onde di Langmuir, in cui le particelle cariche si muovono sincronicamente sotto l'influenza delle forze elettriche. Lo studio di queste oscillazioni può contribuire alla comprensione delle proprietà di trasporto e delle caratteristiche dinamiche del plasma.

Onde elettromagnetiche: l'interazione tra ioni e plasmi può portare alla generazione e alla propagazione di onde elettromagnetiche nel plasma. Queste onde possono includere onde di plasma, onde di Langmuir, onde di Alfvén e onde elettromagnetiche più complesse. Lo studio di queste onde può fornire informazioni sulle proprietà del plasma, sull'assorbimento e sulla dispersione delle onde elettromagnetiche e sulle interazioni con le particelle cariche.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Experimental evidence for the enhanced and reduced stopping regimes for protons propagating through hot plasmas

S. N. Chen, S. Atzeni, T. Gangolf, M. Gauthier, D. P. Higginson, R. Hua, J. Kim, F. Mangia, C. McGuffey, J.-R. Marquès, R. Riquier, H. Pépin, R. Shepherd, O. Willi, F. N. Beg, C. Deutsch & J. Fuchs

Scientific Reports **8**, Article number: 14586 (2018) | Cite this article

2864 Accesses | **11** Citations | Metrics

I fondi PNRR a nostra disposizione

Supporto per la costruzione e il mantenimento di I-LUCE

Divisione Ricerca

- Reparto Gestione e manutenzione apparati sperimentali
- Reparto Laboratorio di tecniche chimico fisiche
- Reparto Elettronica e rivelatori

Divisione Acceleratori

- Reparto Vuoto
- Reparto Elettronica, convertitori di potenza, diagnostica ed automazioni
- Reparto Sistemi informatici
- Reparto dispositivi meccanici
- Reparto operazione e conduzione degli acceleratori
- Reparto progettazione meccanica
- Reparto metrologia, linee di fascio e allineamenti

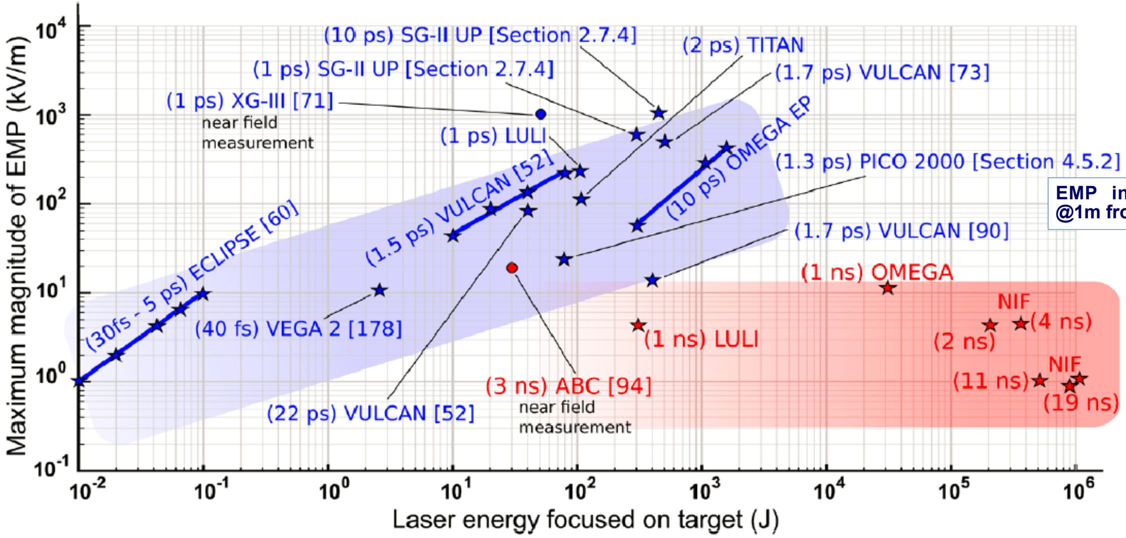
Divisione Tecnica

Gestione laser	2 Tecnologi
Trasporto del laser ed interazione	2 Tecnologi
Diagnostica di plasma e di fasci, preparazione esperimenti	2 Tecnologi
Elettronica e acquisizione	Servizi e reparti LNS
Allineamenti, laser management	
Sviluppo target	
Rumore elettromagnetico e mitigazione	Gruppo lavoro I
Sistema di controllo	Gruppo lavoro II
	Gruppo lavoro X

Backups

Impulsi elettromagnetici generati da interazione laser materia

- Impulsi elettromagnetici (electromagnetic pulses: EMPs) sono classicamente generati da interazioni laser materia ad alta intensità, con impulsi laser dal nanosecondo giù fino al femtosecondo
- Si ottengono intensità fino all'ordine del MV/m e anche oltre, alla distanza dal target di 1 m, e un ampio range di frequenze che vanno dall'ordine del MHz fino al THz
- Sono pertanto riconosciuti come un serio pericolo per l'elettronica, i computer, gli strumenti di diagnostica impiegati nella camera sperimentale, ma anche fuori. E ovviamente è importante confinarli adeguatamente perché non agiscano sul personale



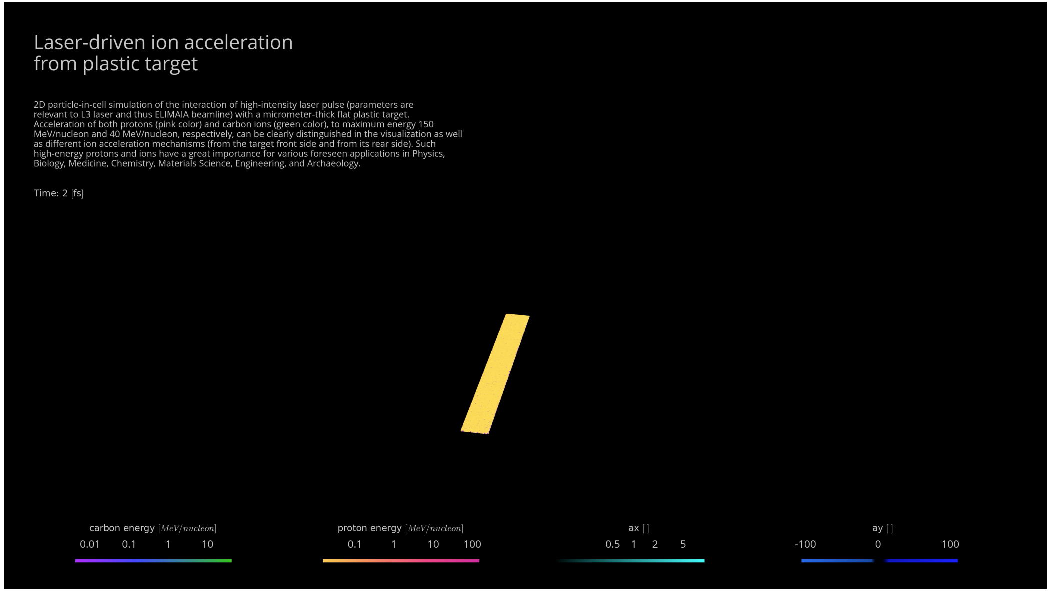
EMP intensity normalized @1m from target

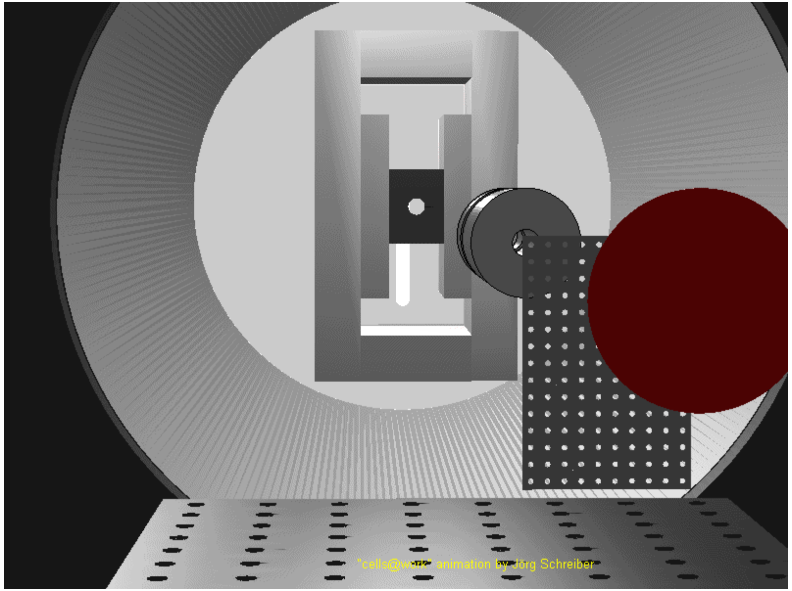
F. Consoli et al, High Power Laser Science and Engineering 8, e22 (2020)

Impulsi elettromagnetici generati da interazione laser materia

- E’ quindi di estrema importanza
  - definire delle metodologie per minimizzare tali campi elettromagnetici
  - implementare delle soluzioni che
    - confinino il più possibile i campi in zone in cui non ci sia personale
    - minimizzino le intensità dei campi nelle zone in cui il personale è presente, per rispettare i valori di soglia della normativa
    - consentano il corretto funzionamento dell’elettronica e dei dispositivi di diagnostica impiegati
      - a tal fine la minimizzazione dei campi è certamente di primaria importanza
      - impiegando elettronica e dispositivi con alta schermatura ai campi elettromagnetici
  - Impiegare sensori calibrati che garantiscano il monitoraggio del rispetto delle soglie della normativa per il personale e per le condizioni sostenibili dall’elettronica impiegata.
- E’ possibile provvedere in maniera adeguata alle operazioni elencate per la protezione del personale e dell’elettronica, come fatto dalle facility laser ad alta intensità operanti oggigiorno nel panorama mondiale e per quelle al momento in fase di costruzione
- È importante provvedere ben prima della costruzione della facility alla parallela definizione ed implementazione di metodologie di adeguata schermatura e minimizzazione dei campi elettromagnetici

Come avviene l'accelerazione dei protoni e degli ioni





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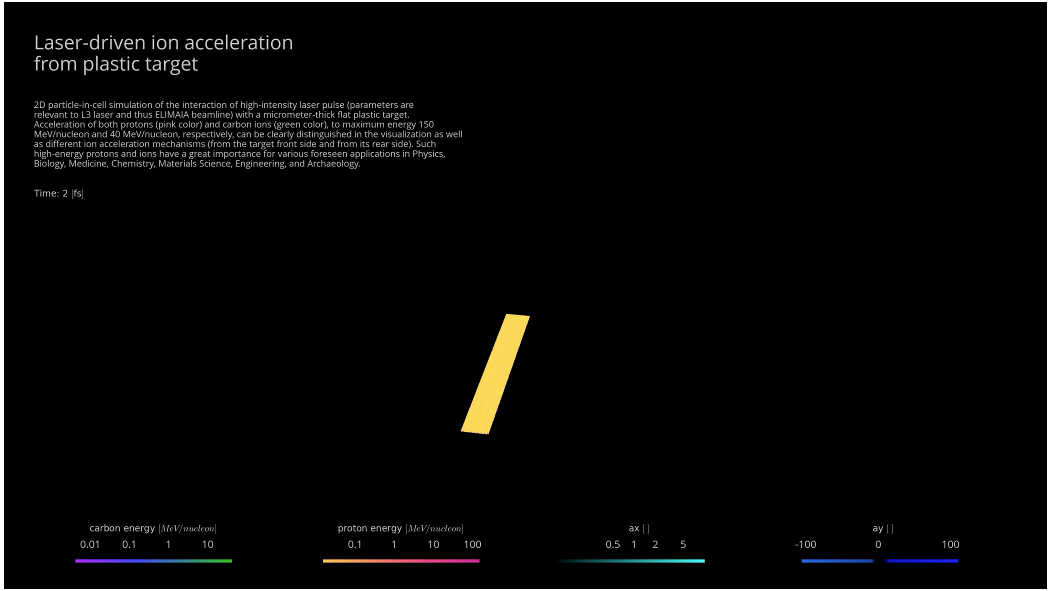
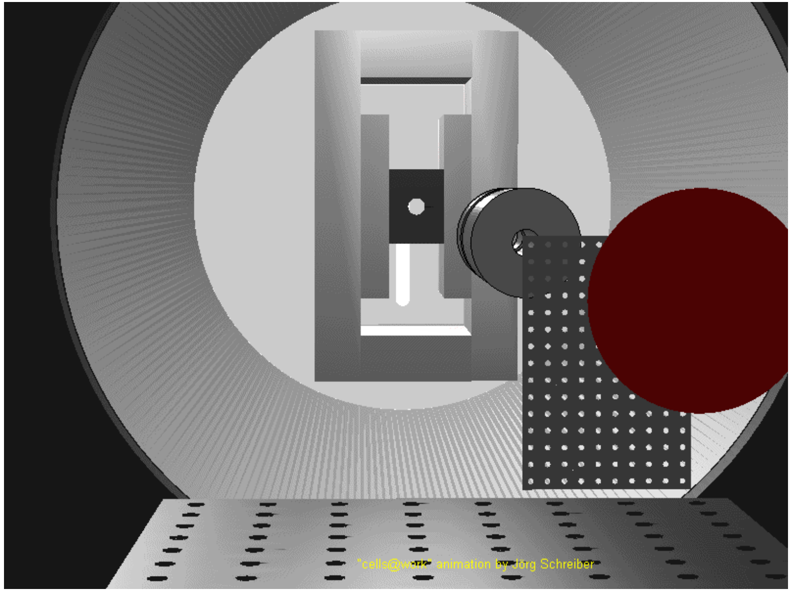
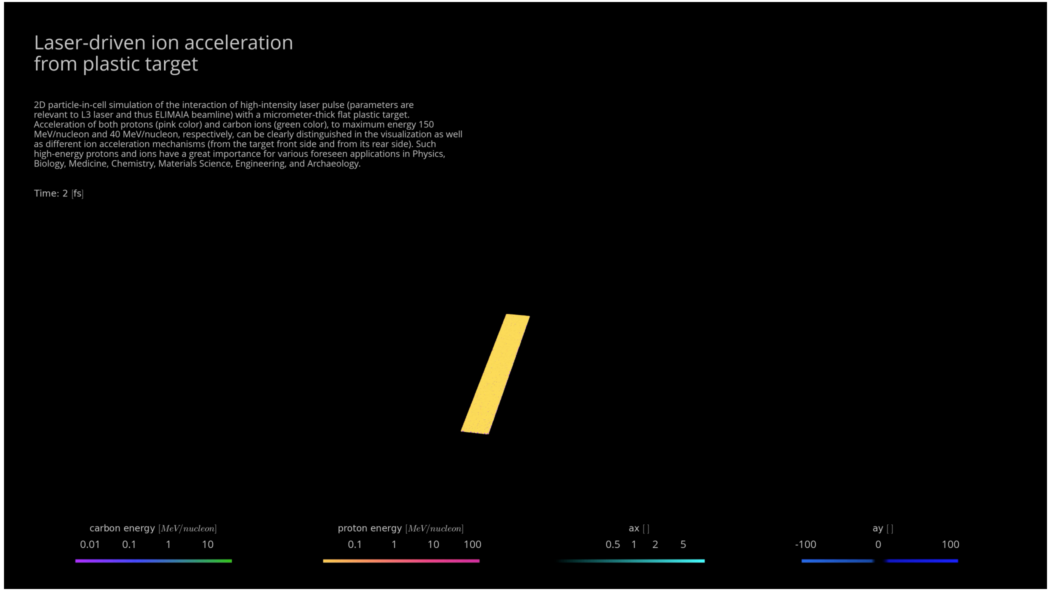
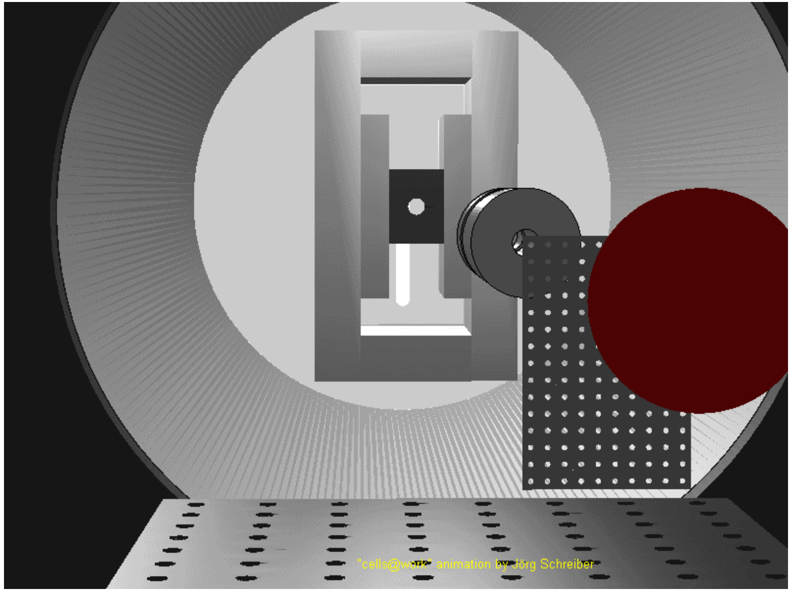


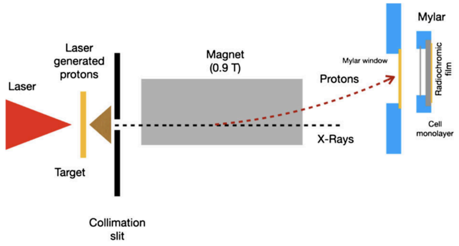


Come avviene l'accelerazione dei protoni e degli ioni





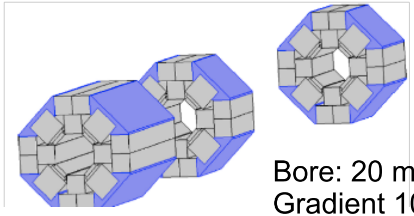
Soluzioni adottate per selezionare i fasci di protoni



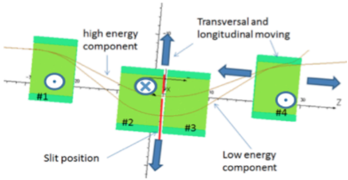
Dipole field: 0.9 T
Length: 100 mm
Energy selection:
up to 30 MeV proton

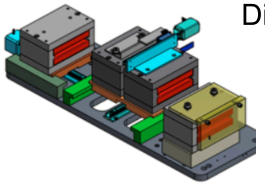
Single dipole for energy selection

F Hanton, et al.
Scientific Reports 9, 4471 (2019)



Bore: 20 mm;
Gradient 100 T/m

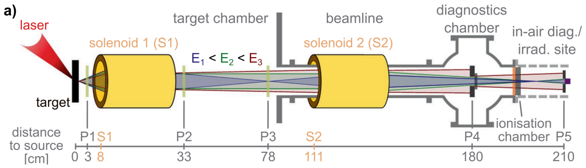




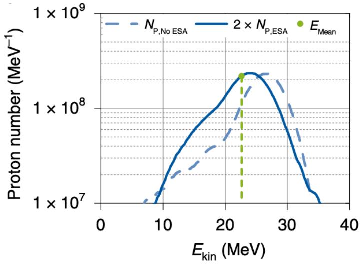
Dipole field: 0.8 T

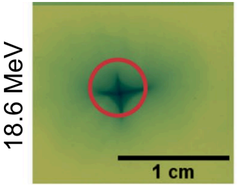
Quadrupoles + energy selector
Transport up to 30 MeV with an energy revolution of 5 %

F Schillaci, et al.
NIMA, 837, 80-87 (2016



On-axis magnetic field up to 19.5 T
Rep rate: up to 3 pulse per minute



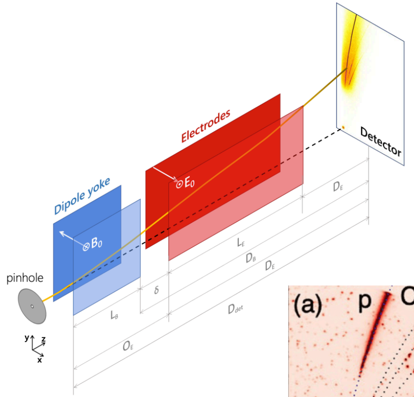


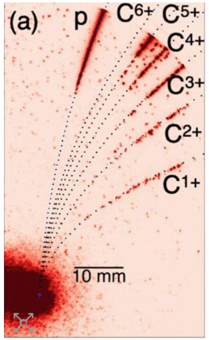
Pulsed solenoids

F Kroll et al. Nature Physics 18, 316–322 (2022)

Esempi di rivelatori attivi

Thomson-like spectrometer
Particle max energy
Plasma species detection
Energy spectra if properly calibrated

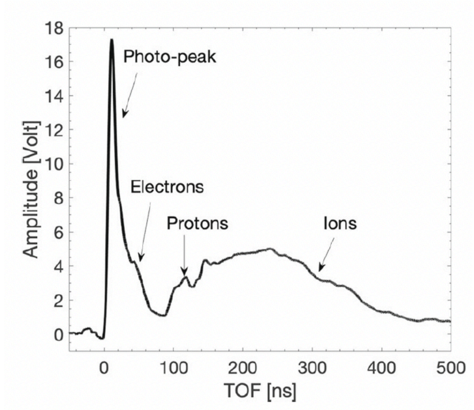




Principle:
Orthogonal Electric and magnetic fields
==>
charge separation and energy evaluation

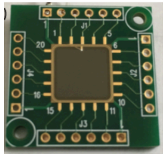
A Alejo et al.
JNIST 11 C10005 (2016)

TOF - approach detectors
Particle max energy
Energy spectra

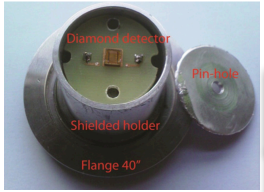


Typical Time of Flight spectra

Energy spectra can be derived



New generation of Silicon Carbide (left), Diamonds, Faraday Cups properly shielded for the EMP, are often used in this configuration



A diamond detector typically used in laser-driven experiments

M Marinelli et al.
JNIST 11 C10005 (2016)

G Milluzzo et al.
Review of Scientific Instruments 90, 083303 (2019);SI 11 C10005 (2016)

Scintillators both in single and stack configuration

Beam profile and energy spectra reconstruction

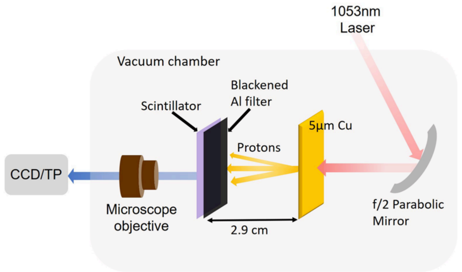
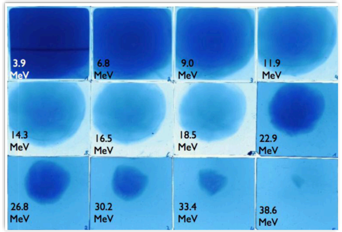


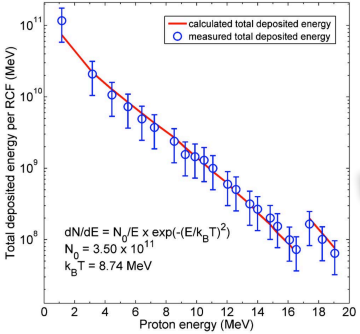
FIG. 1. A schematic of the experimental setup. A 1053 nm high intensity laser pulse is focused by a f/2 parabolic mirror onto a 5 μm Cu target to generate TNSA proton beams. The proton beam is measured either by the TP spectrometer to measure the energy spectrum or by the scintillator imaged onto a CCD with/without a microscope objective system to diagnose the spatial resolution.

H Tang et al.
Rev. Sci. Instrum. 91, 123304 (2020);

Esempi di rivelatori passivi

Radiochromic films
beam profile and energy spectra reconstruction



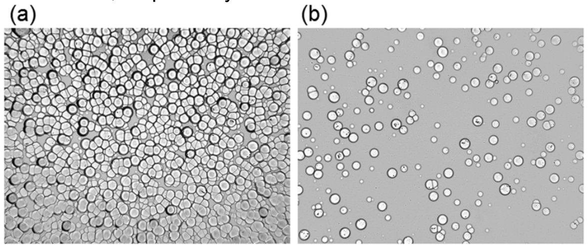


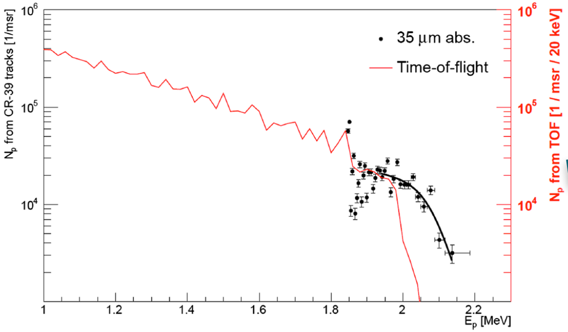
TRIDENT laser-driven protons
RAL (UK)

F Nürnberg, et al.
Review of Scientific Instruments 80, 033301 (2009);

CR39
Flux measure
Energy spectra

Microscopic images of CR-39 samples exposed to a single laser shot (example 3), covered with (a) 25 μm and (b) 35 μm of aluminum, respectively.

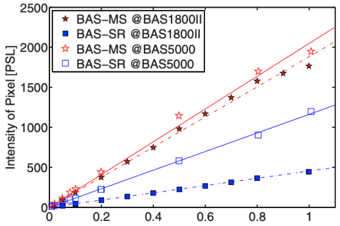


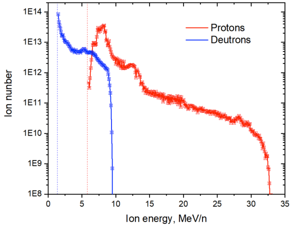


M Seimetz, et al.
Review of Scientific Instruments 89, 023302 (2018);

Image plate are photostimulable phosphor screen [BaFBr:Eu2+]
Flux measure
Energy spectra
Beam distribution

PSL: photo stimulated luminescence



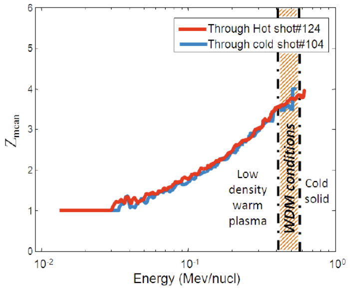


Laser -driven spectra of protons and deuterons

D O Gloving et al.
JINST 16 T02005 (2021);

Cos'altro possiamo fare?

Interaction of ion beams with plasmas (charge exchange, stopping, etc)



M. Gauthier, et al., Phys. Rev. Lett. **110**, 135003 (2013)

Thanks for Listening

Left to right:
Roberto Catalano, Davide Passarello, Pablo Cirrone, Emilio Zappalà, Nino Amato, Luciano Pandola, Giuliana Milluzzo, Michele Costa, Mariacristina Guarrera, Serena Fattori, Antonio Russo, Beatrice Cagni, Alma Kurmanova, Carmen Altana,Andrea Matamoros, Giuliana Navarra, Salvo Tudisco, Giacomo Cuttone, Giada Petringa, Gustavo Messina
INFN-LNS Medical Physics Group - Catania, April 30, 2021