EuAPS - High Power Laser program at LNS

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Laser-driven particle acceleration and LNS experience

Outline

Laser-driven particle acceleration and LNS experience

WP3: High Power laser beamline

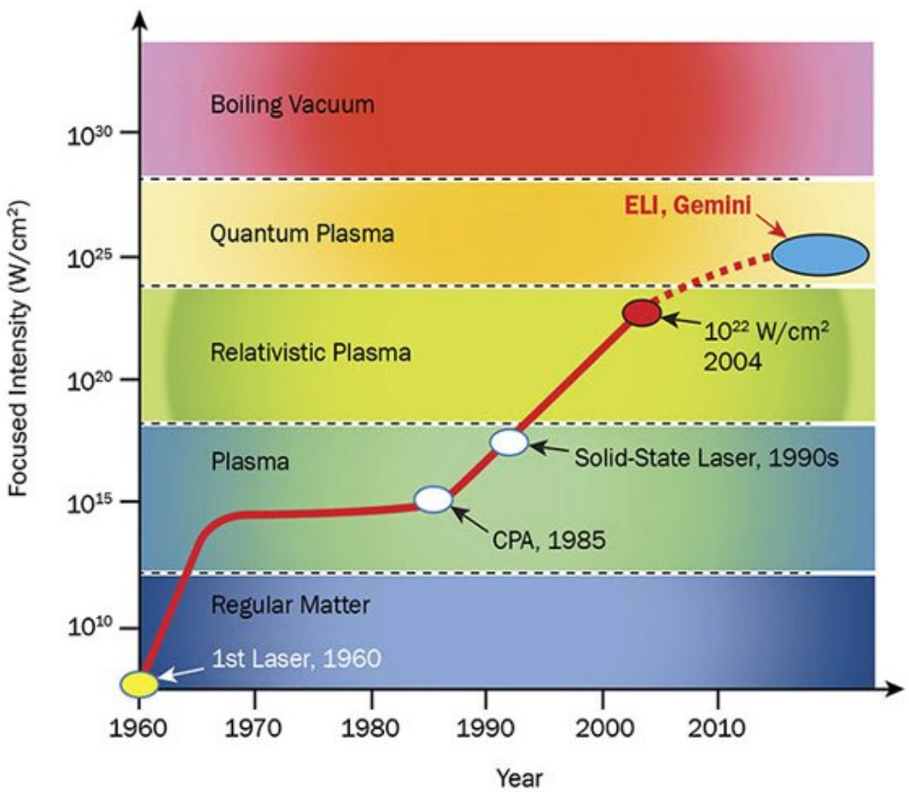
I-LUCE @INFN-LNS

Laser-driven particles acceleration

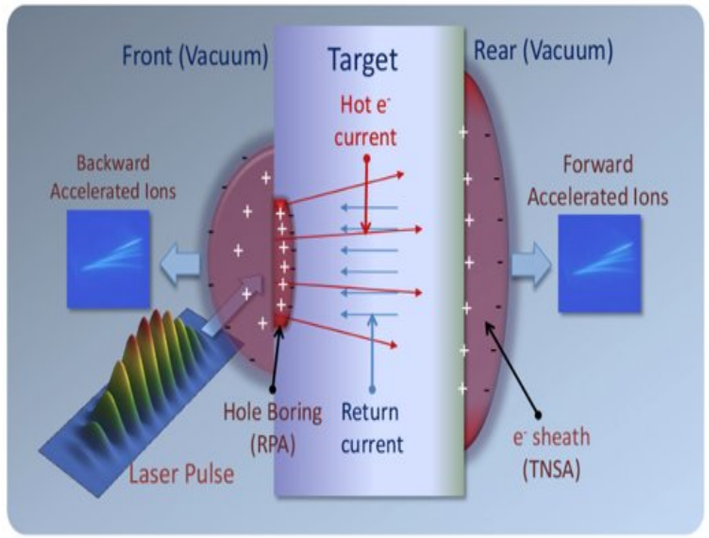
Nowadays approaches for electrons and ions acceleration are different but both based on some high-power laser interacting with some material (gas for electrons and solid for ions)

Laser-driven particles acceleration

LASER SYSTEMS	High energy CPA systems	Ultrashort CPA systems
Technology	Nd: Glass	Ti:Sa
Energy	100's J	10's J
Pulse duration	>100's fs	10s fs
Intensity [W/cm2]	10^{21} Wcm2	10^{21} Wcm2
Rep rate	1 shot/hours	1-10 Hz



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 ~ 98 MeV

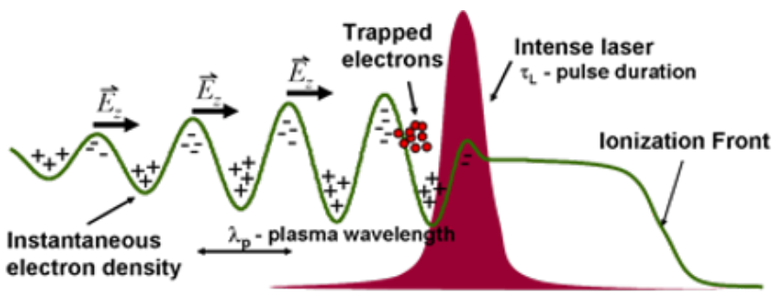
Pulse duration ≈ 10s fs - 100s ps

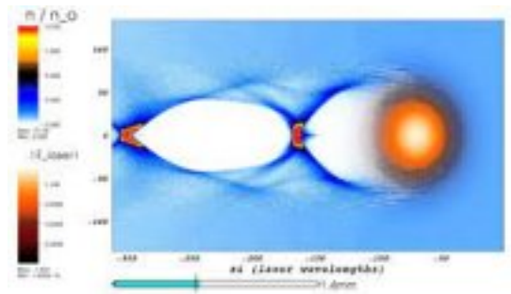
ppb ≈ 108-1011

Broad energy spectra (100%)

Wide angular divergence (≈ 10°-20°)

Laser Wake Field Acceleration (LWFA) for electrons

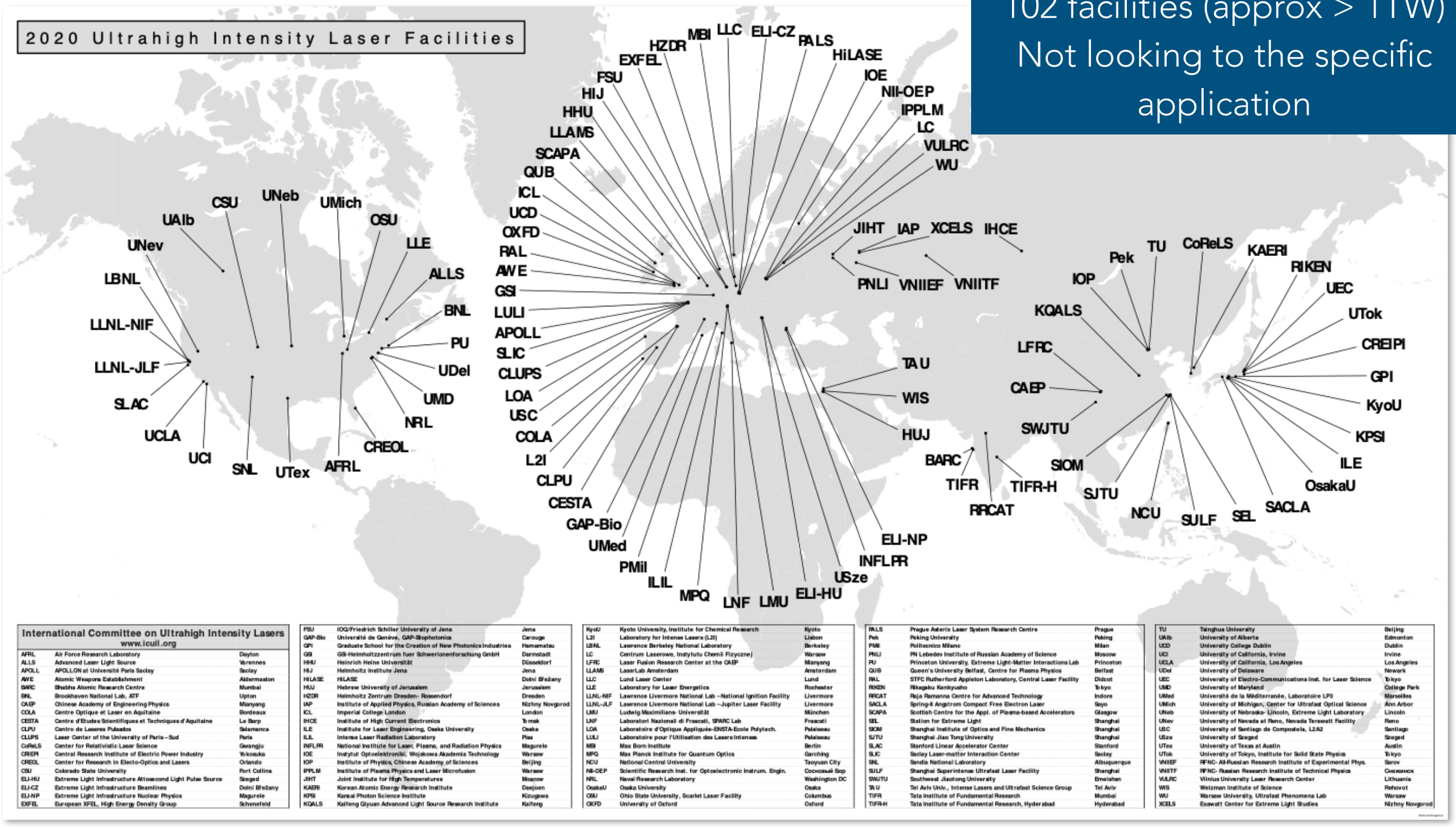




7.8 GeV have been reached at the BELLA (Berkeley Lab) in 2019 using two lasers

2020 world lasers facilities

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



International Committee on Ultrahigh Intensity Lasers www.icuil.org		
AFRL	Air Force Research Laboratory	Dayton
ALLS	Advanced Laser Light Source	Varennes
APOLL	APOLLON at Université Paris Saclay	Saclay
AWE	Atomic Weapons Establishment	Aldermaston
BARC	Bhabha Atomic Research Centre	Mumbai
BNL	Brookhaven National Lab, ATF	Upton
CAEP	Chinese Academy of Engineering Physics	Mianyang
COLA	Centre Optique et Laser en Aquitaine	Bordeaux
CESTA	Centre d'Etudes Scientifiques et Techniques d'Aquitaine	Le Barp
CLPU	Centro de Laseres Pulsados	Salamanca
CLUPS	Laser Center of the University of Paris–Sud	Paris
CoReLS	Center for Relativistic Laser Science	Gwangju
CREIPI	Central Research Institute of Electric Power Industry	Yokosuka
CREOL	Center for Research in Electo-Optics and Lasers	Orlando
CSU	Colorado State University	Fort Collins
ELI-HU	Extreme Light Infrastructure Attosecond Light Pulse Source	Szeged
ELI-CZ	Extreme Light Infrastructure Beamlines	Dolni Břežany
ELI-NP	Extreme Light Infrastructure Nuclear Physics	Magurele
EXFEL	European XFEL, High Energy Density Group	Schenefeld

FSU	IOQ/Friedrich Schiller University of Jena	Jena
GAP-Bio	Université de Genève, GAP-Biophotonics	Carouge
GPI	Graduate School for the Creation of New Photonics Industries	Hamamatsu
GSI	GSI-Helmholtzzentrum fuer Schwerionenforschung GmbH	Darmstadt
HHU	Heinrich Heine Universität	Düsseldorf
HIJ	Helmholtz Institute Jena	Jena
HILASE	HILASE	Dolní Břežany
HUJ	Hebrew University of Jerusalem	Jerusalem
HZDR	Helmholtz Zentrum Dresden- Rossendorf	Dresden
IAP	Institute of Applied Physics, Russian Academy of Sciences	Nizhny Novgorod
ICL	Imperial College London	London
IHCE	Institute of High Current Electronics	Tomsk
ILE	Institute for Laser Engineering, Osaka University	Osaka
ILIL	Intense Laser Radiation Laboratory	Pisa
INFLPR	National Institute for Laser, Plasma, and Radiation Physics	Magurele
IOE	Instytut Optoelektroniki, Wojskowa Akademia Technology	Warsaw
IOP	Institute of Physics, Chinese Academy of Sciences	Beijing
IPPLM	Institute of Plasma Physics and Laser Microfusion	Warsaw
JIHT	Joint Institute for High Temperatures	Moscow
KAERI	Korean Atomic Energy Research Institute	Daejoen
KPSI	Kansai Photon Science Institute	Kizugawa
KQALS	Kaifeng Qiyuan Advanced Light Source Research Institute	Kaifeng

KyoU	Kyoto University, Institute for Chemical Research	Kyoto
L2I	Laboratory for Intense Lasers (L2I)	Lisbon
LBNL	Lawrence Berkeley National Laboratory	Berkeley
LC	Centrum Laserowe, Instytutu Chemii Fizycznej	Warsaw
LFRC	Laser Fusion Research Center at the CAEP	Mianyang
LLAMS	LaserLab Amsterdam	Amsterdam
LLC	Lund Laser Center	Lund
LLE	Laboratory for Laser Energetics	Rochester
LLNL-NIF	Lawrence Livermore National Lab –National Ignition Facility	Livermore
LLNL-JLF	Lawrence Livermore National Lab –Jupiter Laser Facility	Livermore
LMU	Ludwig Maximilians- Universität	München
LNF	Laboratori Nazionali di Frascati, SPARC Lab	Frascati
LOA	Laboratoire d'Optique Appliquée-ENSTA-Ecole Polytech.	Palaiseau
LULI	Laboratoire pour l'Utilisation des Lasers Intenses	Palaiseau
MBI	Max Born Institute	Berlin
MPQ	Max Planck Institute for Quantum Optics	Garching
NCU	National Central University	Taoyuan City
NII-OEP	Scientific Research Inst. for Optoelectronic Instrum. Engin.	Сосновый Бор
NRL	Naval Research Laboratory	Washington DC
OsakaU	Osaka University	Osaka
OSU	Ohio State University, Scarlet Laser Facility	Columbus
OXFD	University of Oxford	Oxford

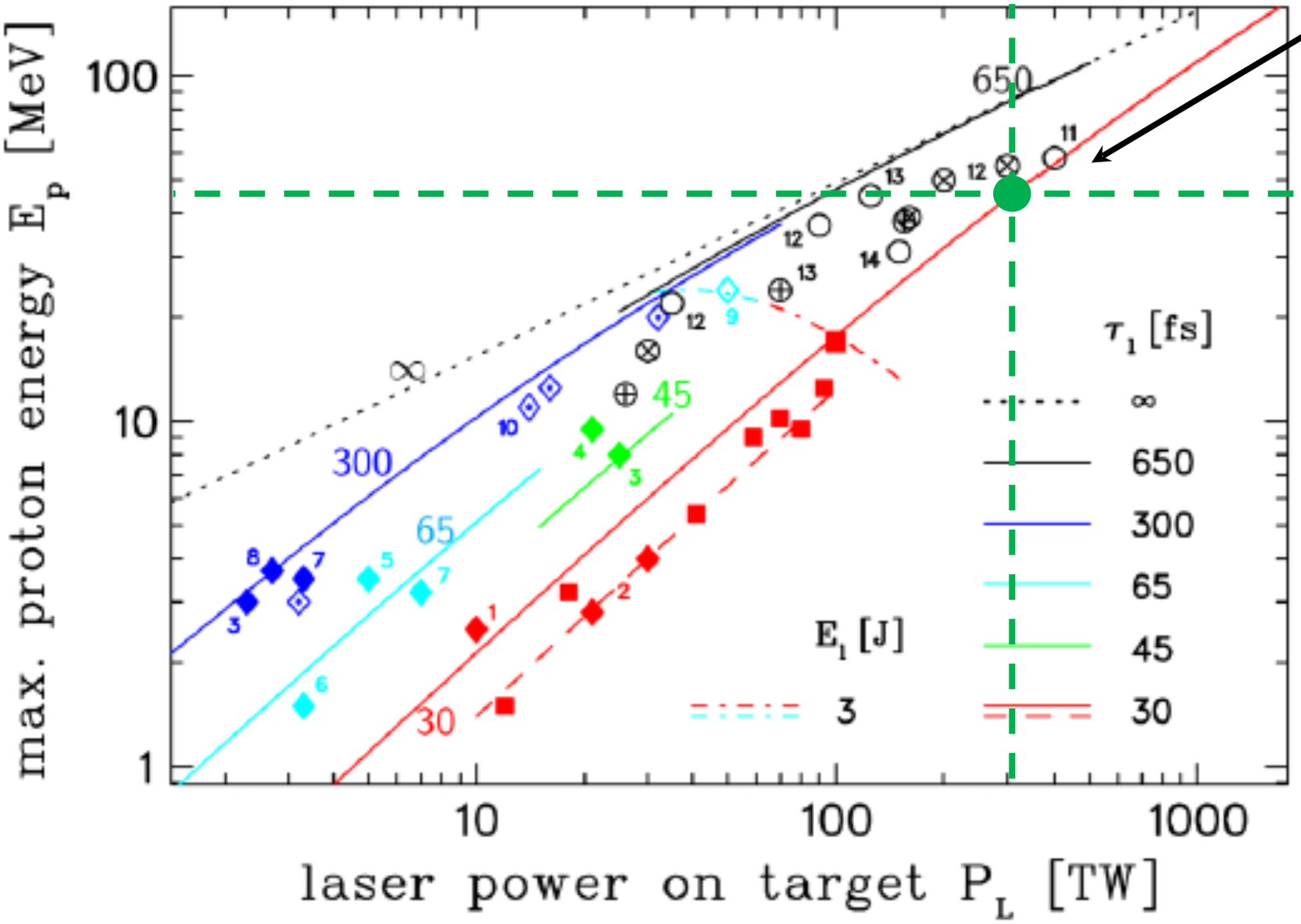
PALS	Prague Asterix Laser System Research Centre	Prague
Pek	Peking University	Peking
PMil	Politecnico Milano	Milan
PNLI	PN Lebedev Institute of Russian Academy of Science	Moscow
PU	Princeton University, Extreme Light-Matter Interactions Lab	Princeton
QUB	Queen's University Belfast, Centre for Plasma Physics	Belfast
RAL	STFC Rutherford Appleton Laboratory, Central Laser Facility	Didcot
RIKEN	Rikagaku Kenkyusho	Tokyo
RRCAT	Raja Ramanna Centre for Advanced Technology	Indore
SACLA	Spring-8 Angstrom Compact Free Electron Laser	Sayo
SCAPA	Scottish Centre for the Appl. of Plasma-based Accelerators	Glasgow
SEL	Station for Extreme Light	Shanghai
SIOM	Shanghai Institute of Optics and Fine Mechanics	Shanghai
SJTU	Shanghai Jiao Tong University	Shanghai
SLAC	Stanford Linear Accelerator Center	Stanford
SLIC	Soliey Laser-matter Interaction Center	Saclay
SNL	Sandia National Laboratory	Albuquerque
SULF	Shanghai Superintense Ultrafast Laser Facility	Shanghai
SWJTU	Southwest Jiaotong University	Emeishan
TAU	Tel Aviv Univ., Intense Lasers and Ultrafast Science Group	Tel Aviv
TIFR	Tata Institute of Fundamental Research	Mumbai
TIFR-H	Tata Institute of Fundamental Research, Hyderabad	Hyderabad

TU	Tsinghua University	Beijing
UAlb	University of Alberta	Edmonton
UCD	University College Dublin	Dublin
UCI	University of California, Irvine	Irvine
UCLA	University of California, Los Angeles	Los Angeles
UDel	University of Delaware	Newark
UEC	University of Electro-Communications Inst. for Laser Science	Tokyo
UMD	University of Maryland	College Park
UMed	Université de la Méditerranée, Laboratoire LP3	Marseilles
UMich	University of Michigan, Center for Ultrafast Optical Science	Ann Arbor
UNeb	University of Nebraska- Lincoln, Extreme Light Laboratory	Lincoln
UNev	University of Nevada at Reno, Nevada Terawatt Facility	Reno
USC	University of Santiago de Compostela, L2A2	Santiago
USze	University of Szeged	Szeged
UTex	University of Texas at Austin	Austin
UTok	University of Tokyo, Institute for Solid State Physics	Tokyo
VNIIEF	RFNC- All-Russian Research Institute of Experimental Phys.	Sarov
VNIITF	RFNC- Russian Research Institute of Technical Physics	Chesenevk
VULRC	Vilnius University Laser Research Center	Lithuania
WIS	Weizman Institute of Science	Rehovot
WU	Warsaw University, Ultrafast Phenomena Lab	Warsaw
XCELS	Exawatt Center for Extreme Light Studies	Nizhny Novgorod

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

Scaling law for proton acceleration

EUAPS
I-LUCE @ LNS



The two data set are related to two different 'family' of laser system

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

INFN contribution in high power lasers-plasma interaction

Istituto Nazionale di Fisica Nucleare

1997-1998 -- ECLISSE proposal for an hybrid source and first MoU with PALS laboratory (CZ)

2010 – the LILIA project (INFN Committee V)

Ion acceleration at FLAME

MoU with ELI-Beamlines Institute (Z)

2013 – ELIMED project (INFN Committee V)

Development of transport devices and dosimetric systems for laser driven beams up to 30 MeV

2014 – ELIMED tender (Competitive project after a tender published by ELI-beamlines)

Development of transport devices and dosimetric systems for laser driven proton/ion up to 200 MeV

Beamline installed at running at the ELI-Beamline facility

2016 to 2022 L3IA and LP2A projects (INFN Committee V)

Laser-driven transport, dosimetry and radiobiology

2020 – IMPULSE project (H2020)

Innovative detectors for laser-driven and FLASH beams in collaboration with many European laser facilities

2022 – EUAPS and I-LUCE

ELIMED - installation in E4 (June-July 2018)

Istituto Nazionale di Fisica Nucleare

ELI Multidisciplinary Applications of laser-Ion Acceleration

	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

G.A.P. Cirrone, G. Cuttone, A. Amato, A. Russo, G. La Rosa, R. Leanza, E. Zappalà, G. Messina, L. Allegra, F. Schillaci, V. Scuderi, F. Romano, G. Milluzzo, G. Petringa

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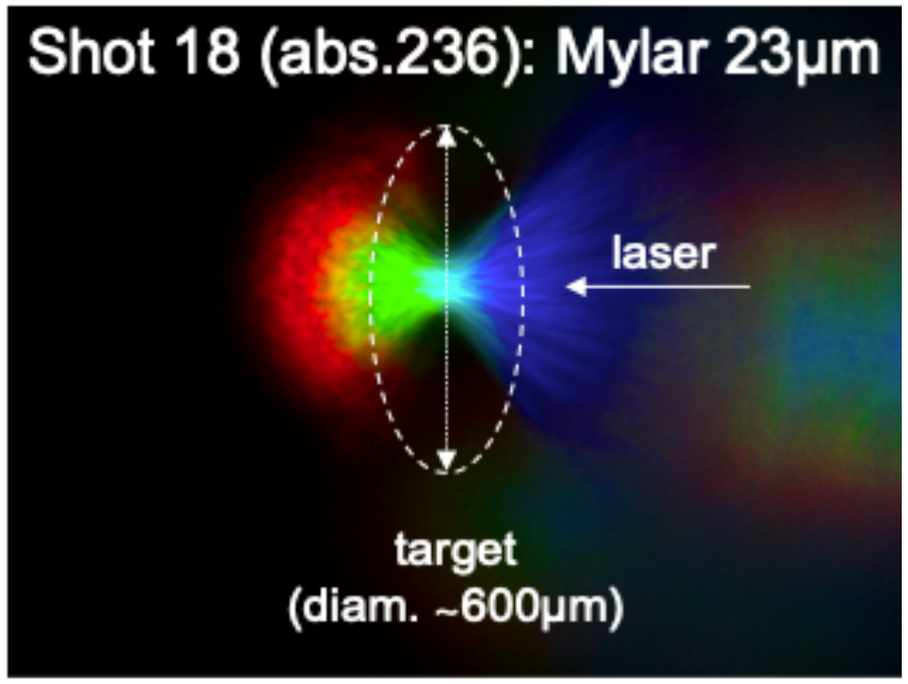
September 2021: pre-commissioning phase @ELIMAIA!

plasma imaging

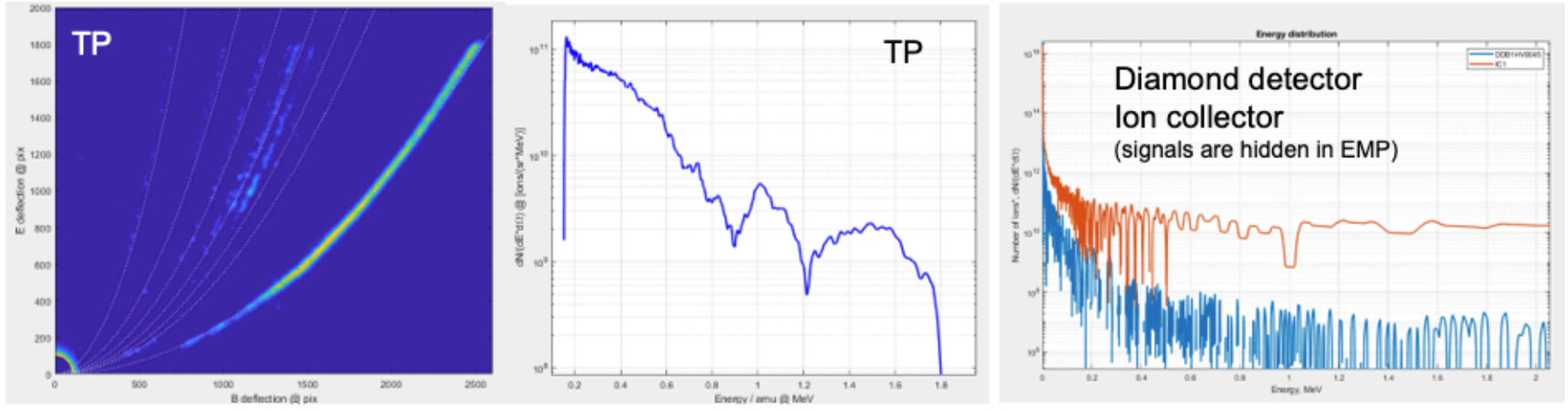


Timofej Chagovets, Pablo Cirrone,Lorenzo Giuffrida, Filip Grepl,Valeria Istokskaia,Vasiliki Kantarelou, Georg Korn, Tadzio Levato, Daniele Margarone, Giada Petringa, Francesco Schillaci, Stanislav Stancek,Marco Tosca, Maksym Tryus, Andriy Velyhan,Martina Zakova

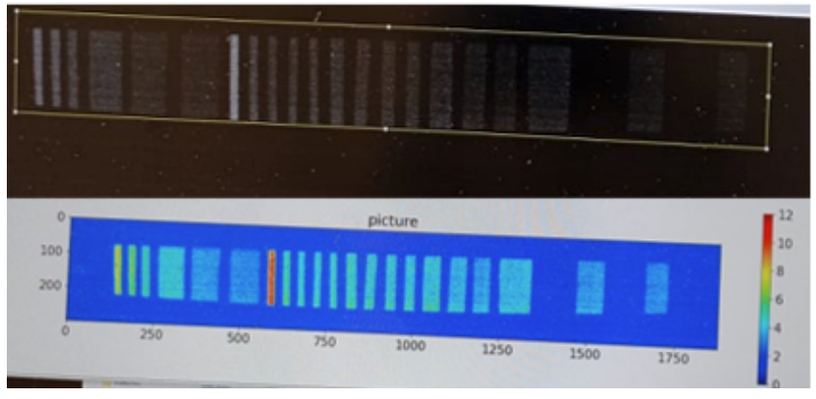
More than 20 online diagnostics working @1Hz repetition rate!

charged particles, neutrons, xrays, eletromagnetic pulse, electrons, plasma, laser on target

Thompson Parabola, Time Of Flight detectors and Ion Collectors



Calorimeter for gamma emission



Courtesy of D. Margarone, QUB (UK) and ELI-Beamline

WP3: High Power Laser beamline

WP organization

T3.1 Clean room realization

T3.2 Laser design and realization

T3.3 Target system for high repetition rate (up to 10 Hz)

T3.4 Plasma Diagnostics

T3.5 Secondary beam diagnostic

WPs organization

WP 3	High Power Laser beam line (INFN-LNS)						
Task		Deliverables			Milestones		
3.1	Clear room realisation	D3.1.1	Infrastructure realisation	M24	M3.1.1	Clean room design	M4
					M3.1.2	Procurement and first payment	M10
					M3.1.3	Second payment	M14
					M3.1.4	Third payment	M20
					M3.1.5	Assembling, commissioning and fourth payment	M24
3.2	Laser design and realisation (PW scale/10 Hz)	D3.2.1	Laser design procurement and installation	M30	M3.2.1	Laser Design	M6
					M3.2.2	Procurement and first payment	M10
					M3.2.3	Second payment	M16
					M3.2.4	Third payment	M24
					M3.2.5	Assembling, commissioning and fourth payment	M30
3.3	Target system for high repetition rate (up to 10 Hz)	D3.3.1	Design and realisation of the target system	M30	M3.3.1	Design and procurement	M24
					M3.3.2	Realization and test	M30
3.4	Plasma diagnostic	D3.4.1	Plasma diagnostic: acquisition and installation	M10	M3.4.1	Design and procurement	M10
3.5	Secondary beam diagnostic	D3.5.1	Secondary beam diagnostic: acquisition and installation	M30	M3.5.1	Design, procurement and mechanical realisations of diagnostic	M18
					M3.5.2	Calibration under conventional beams	M30

Budget

Fixed term personnel	150.000 €
Scientific instrumentation and technological equipment	*5.900.000 €*
Civil infrastructures and related systems	1.300.000 €
Indirect costs, including running costs	514.500 €
Training activities	*0,00*
Total	*7.864.500 €*

High power laser system
Charged particles diagnostic system
Laser and plasma diagnostic syste
Clean room

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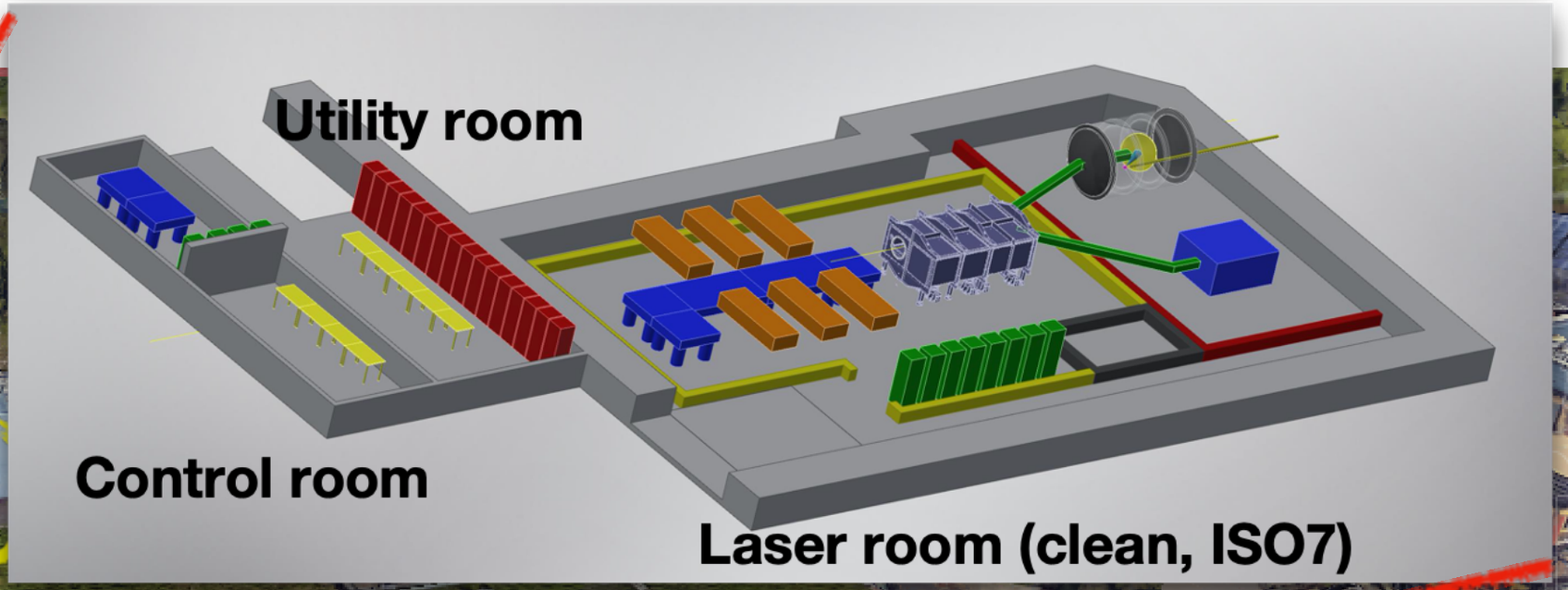
I-LUCE
@ INFN-LNS

Beamlines



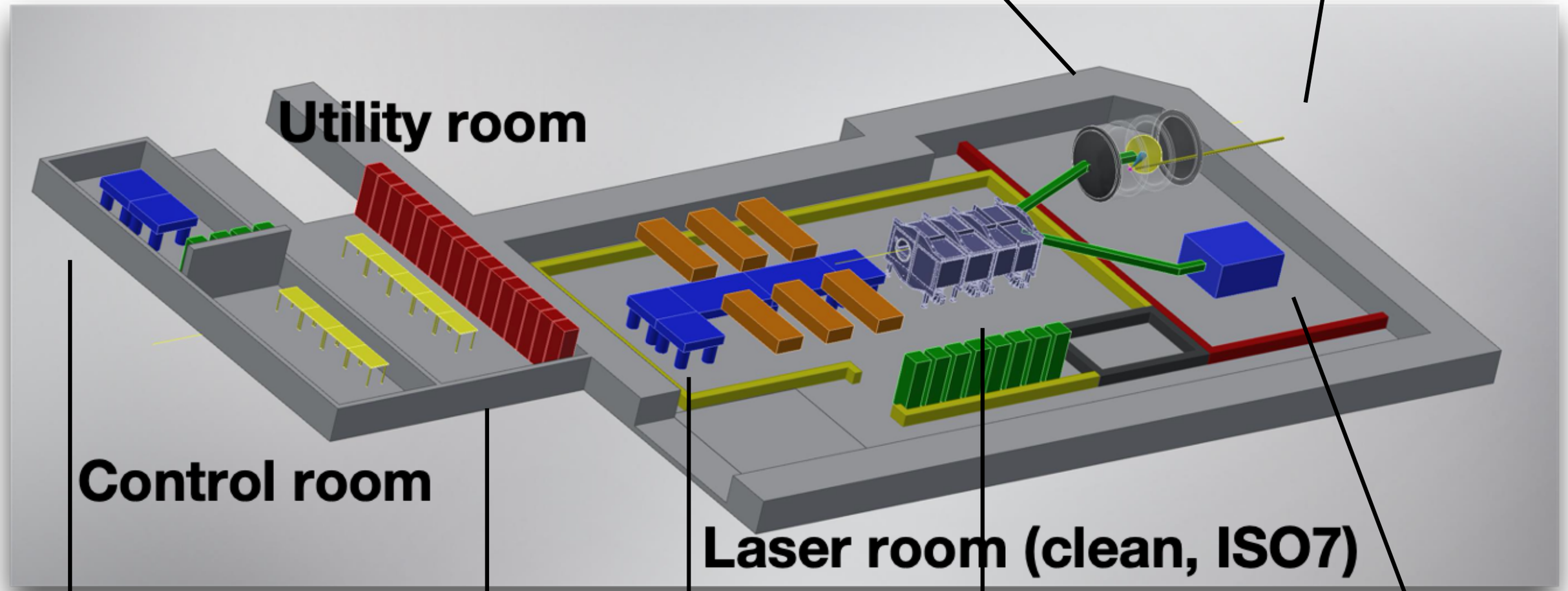
Laser-area

Cyclotron

Tandem accelerator

Plasma–ion interaction chamber; Plasma and nuclear physics studies

Ion beams from Cyclotron and Tandem



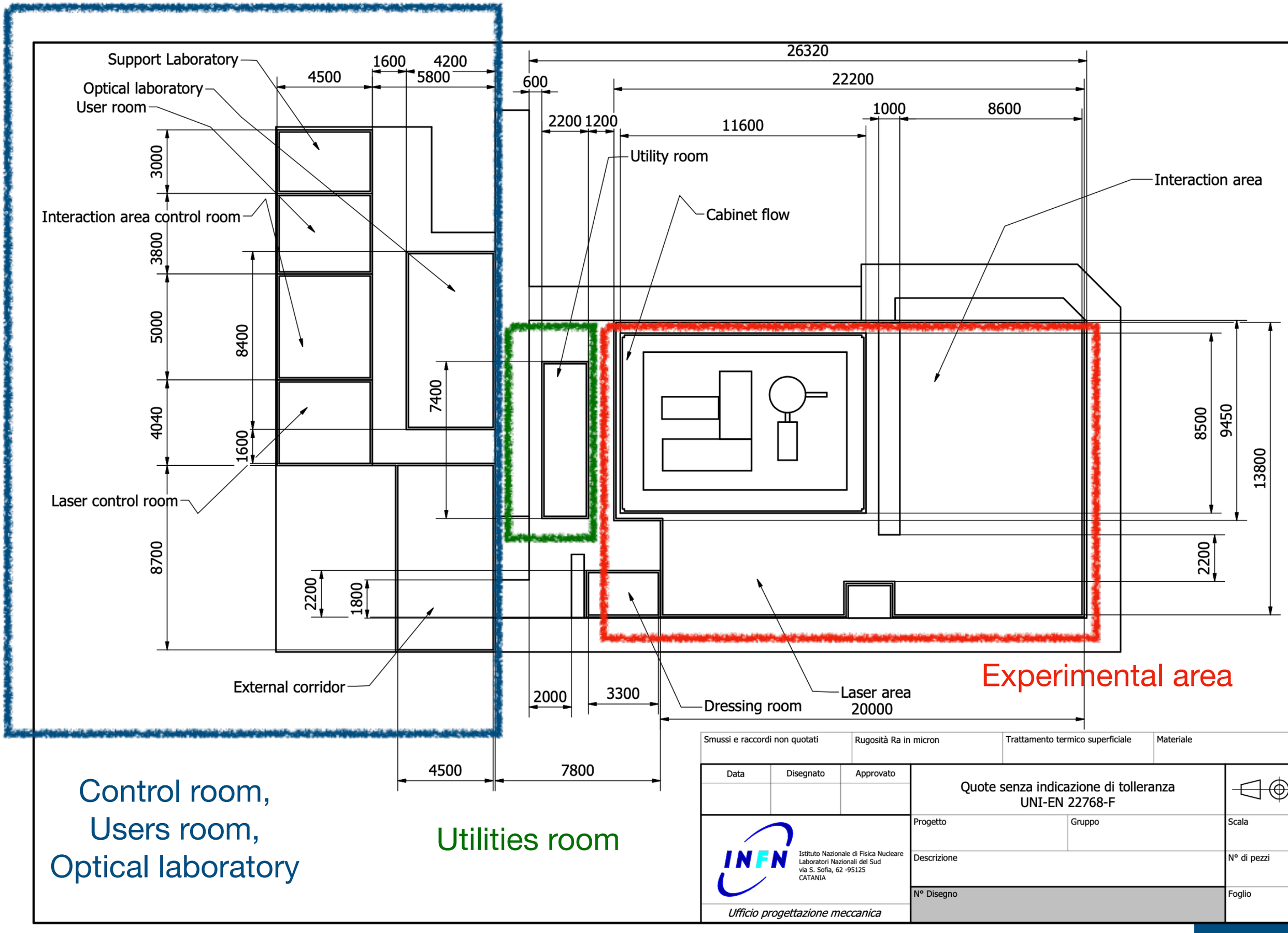
Optical laboratory

Pumps laser bias supplies

Laser system

Laser compressor chamber

Proton-, ion– and electron acceleration


Support Laboratory
Optical laboratory
User room
Interaction area control room
Laser control room
External corridor
4500
1600
4200
5800
3000
3800
5000
4040
8400
1600
7400
8700
2200
1800
2000
3300
4500
7800
26320
600
22200
2200
1200
11600
1000
8600
Utility room
Cabinet flow
Interaction area
Dressing room
Laser area
20000
8500
9450
13800
2200
Experimental area
Control room,
Users room,
Optical laboratory
Utilities room
Smussi e raccordi non quotati
Rugosità Ra in micron
Trattamento termico superficiale
Materiale
Data
Disegnato
Approvato
Quote senza indicazione di tolleranza
UNI-EN 22768-F
Progetto
Gruppo
Scala
Descrizione
N° di pezzi
N° Disegno
Foglio
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Sud
via S. Sofia, 62 -95125
CATANIA
Ufficio progettazione meccanica
IL CONTENUTO DI QUESTO FOGLIO È DI PROPRIETÀ DEI LABORATORI NAZIONALI DEL SUD - INFN. - OGNI FORMA DI RIPRODUZIONE, MODIFICA E DIVULGAZIONE, DEVE ESSERE PREVENTIVAMENTE AUTORIZZATA.

I-LUCE facility

I-LUCE: INFN Laser IndUced particle acCeleration

EUAPS will fund a 500TW laser system easily upgradable to 1 PW;

aim: electron, proton acceleration; nuclear reaction in warm dense matter; ion-plasma interaction studies

Peak power : 500 TW
Pulse duration: <25fs
Repetition rate: 1 Hz
System designed to be upgradable up to 1 PW

→

Max energy
protons: 60 MeV
electrons: 800 MeV

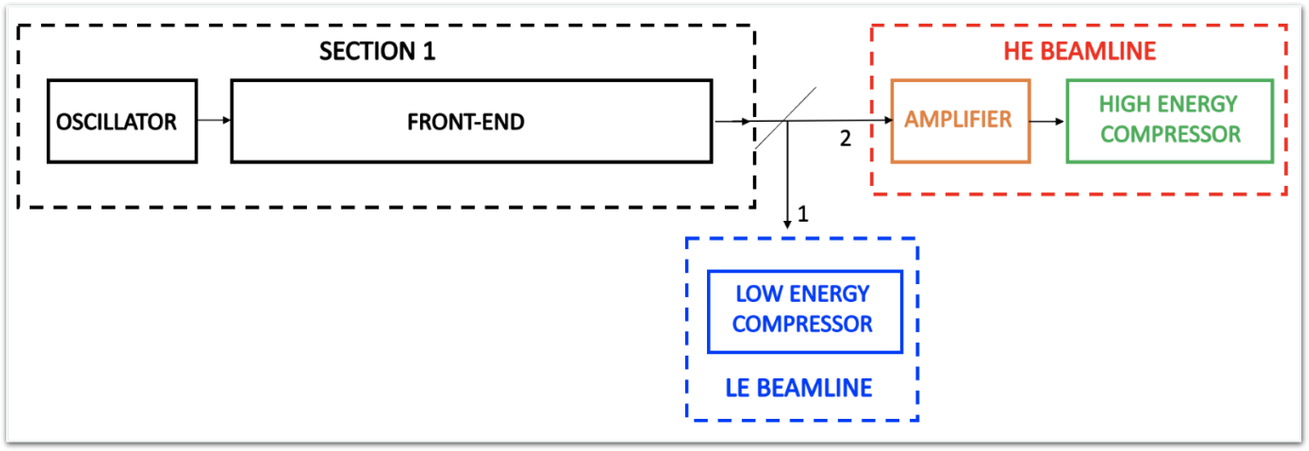
I-LUCE facility

Laser tender is starting

Middle 2024 the first experimental station

Two laser lines and three experimental stations:

- **Fusion studies**
- **Acceleration**
- **Plasma-ion interaction**



Laser Power	~ 1 TW
Energy per pulse	25-30 mJ
Pulse duration	**25-30 fs***
Contrast ratio ns	< 1*10-8
Contrast ratio @5 ps	> 10^5
Contrast ratio @100 ps (ASE)	> 10^{10}
Repetition rate	**10 Hz**

Laser Power	500 TW
Energy per pulse	≥ 10 J
Pulse duration	<= 25 fs
Contrast ratio ns	< 1*10-8
Contrast ratio @5 ps	> 10^5
Contrast ratio @100 ps (ASE)	> 10^{10}
Repetition rate	**1 Hz**
Path to upgrade up to 1PW	Compressor optics ready for the upgrade up to 1PW
Pointing stability	<50 μrad
Beam diameter (FWHM)	50-60 mm
Strehl ratio	>=0.65 (without deformable mirror) >=0.8 (with deformable mirror)

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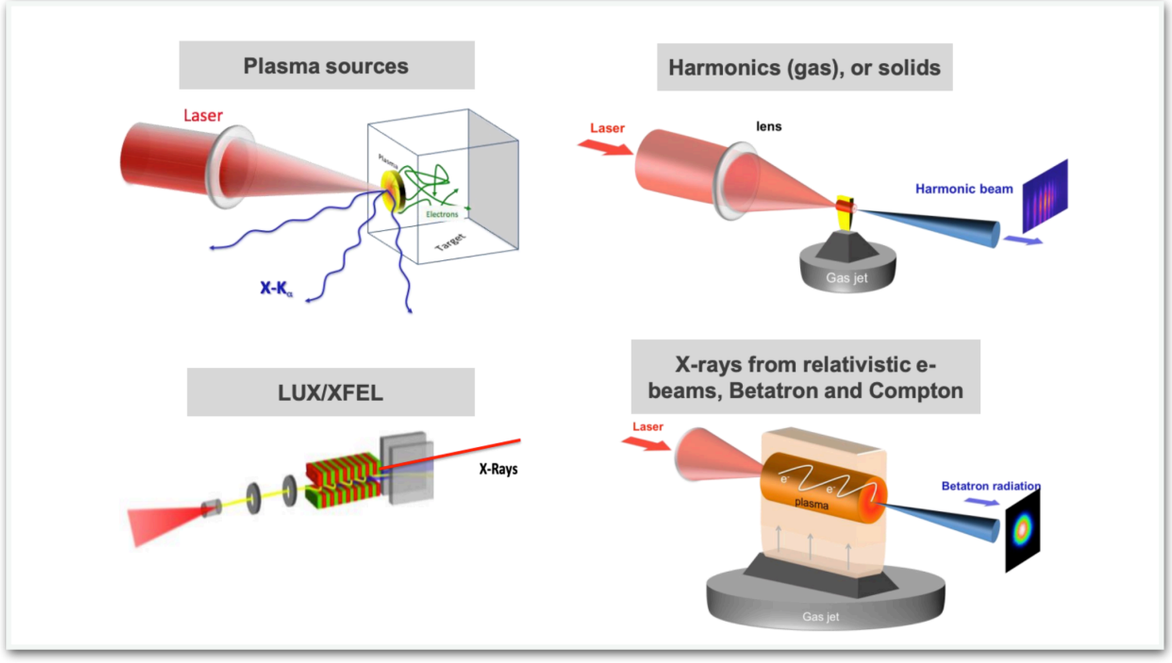
* we are discussing the possibility to increase the pulse duration

What we COULD do?

Ion-plasma interaction: **UNIQUE CAPBILITY OF INFN-LNS**

- ✓ **Proton and electron sources**
- ✓ **Neutron sources**
- ✓ **Free Electron Laser radiation**
- ✓ **Dosimetry and Radiobiology** of «FLASH» beams (electrons, protons, gamma)
- ✓ **Cultural Heritage:** PIXE studies with laser-driven protons
- ✓ **Space applications:** laser-driven beams could easily reproduce the space radiation quality
- ✓ **Radioisotopes production:** laser-driven beams could easily produce high intensity charged particles beams
- ✓ Imaging at the molecular level with **ultrafast X-Rays** (ex radiation chemistry of the radiolysis)
- ✓ **Stopping powers** in plasma
- ✓ Studies on **Nuclear Reaction** in plasma with particular focus on the pB reaction* (PROBONO Cost Action)
- ✓ Materials studies
- ✓ ..... Many other physics cases



Examples of X-rays production;
Curtesy of Georg Korn (ELI-Beamlines and Marvel Fusion GmbH)

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