Current Status of ELI-Beamlines

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Laser Leptonics with High-intensity Facilities, FNSPE-CTU Prague, 7-8 October, 2013

Outlines

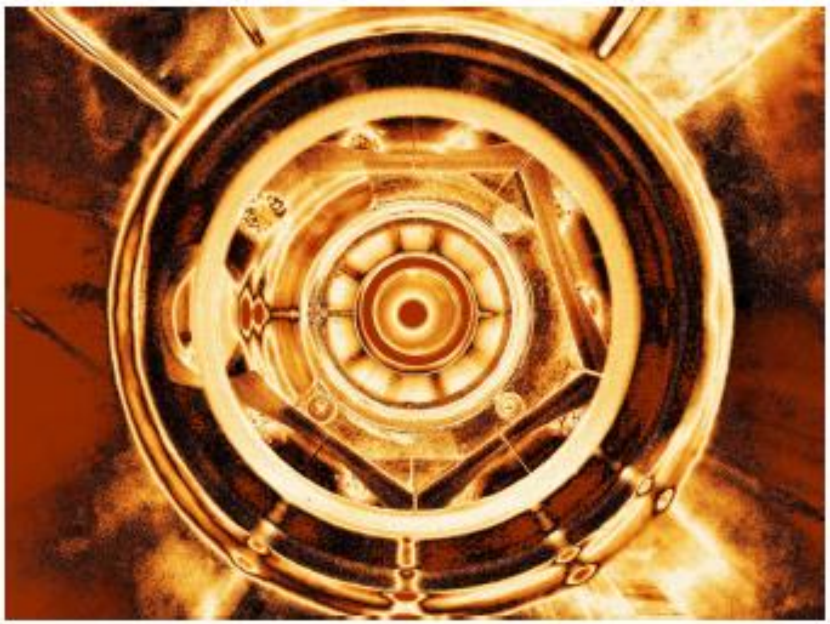
- ✓ ELI pillars and ELI-Beamlines
- ✓ Facility layouts
- ✓ Lasers (RP1)
- ✓ Beam transport and switchyard
- ✓ Experiments (RP2-RP6)

The ELI White Book

ELI – Extreme Light Infrastructure

Science and Technology with Ultra-Intense Lasers

WHITEBOOK



Editors

Gérard A. Mourou
Georg Korn
Wolfgang Sandner
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530 pages of Science, Technology and implementation strategies of ELI

www.eli-beams.eu

The Extreme Light Infrastructure European Project

Authors

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Site selection decision on 1.10.2009

Czech Republic
Prague

Hungary
Szeged

Romania
Bucharest - Magurele

Structure of implementation of the ELI project

Location	Facility		Research area
Prague	Beamlines facility	→	High-brightness sources of X-ray radiation & particles
Szeged	Attosecond facility, ALPS	→	Attosecond XUV/X-ray physics
Magurele	Photonuclear facility , NP	→	Laser-induced nuclear physics
	200 PW facility (?)	→	Frontier physics by exawatt lasers

ELI-Beamlines project mission: fundamental & applied research

- High-repetition rate and high average power lasers using diode-pumping
- Ultra-high peak power of 10 PW, focused intensities up to 10^{24} Wcm^{-2}

1. Generation of rep-rated femtosecond secondary sources of radiation and particles

- XUV and X-ray sources (monochromatic and broadband)
- Accelerated electrons (2 GeV 10 Hz rep-rate, 100 GeV low rep-rate),
  protons (200-400 MeV 10 Hz rep-rate, >3 GeV low-rep-rate)
- Gamma-ray sources (broadband)

2. Programmatic applications of rep-rated femtosecond secondary sources

- Medical research including proton therapy
- Molecular, biomedical and material sciences
- Physics of dense plasmas, laser fusion, laboratory astrophysics

3. High-field physics experiments with focused intensities 10^{23}-10^{24} Wcm^{-2}

- "Exotic" physics, non-linear QED: sophisticated pump-probe capabilities

4. Development & testing new technologies for multi-PW laser systems

- Generation and compression of 10-PW ultrashort pulses, coherent superposition, etc.

Science Case at ELI-Beamlines

ELI-Beamlines bid: balance between fundamental science and applications

ELI-Beamlines will be international user facility, partnership experiments & projects

Research Program 1
Lasers generating rep-rate ultrashort pulses & multi-petawatt peak powers

Research Program 2
X-ray sources driven by rep-rate ultrashort laser pulses

Research Program 3
Particle acceleration by lasers

Research Program 4
Applications in molecular, biomedical, and material sciences

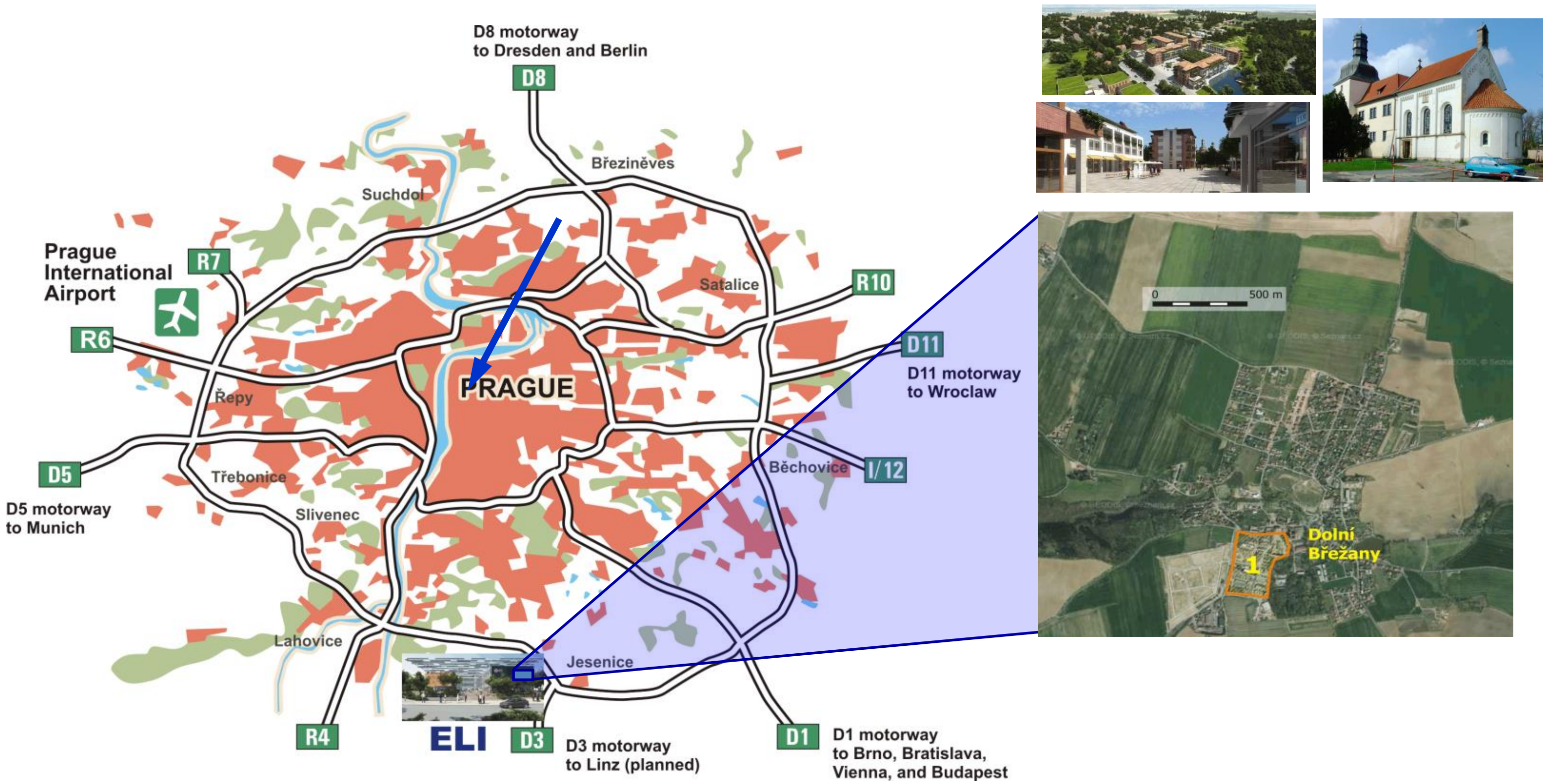
Research Program 5
Laser plasma and high-energy-density physics

Research Program 6
High-field physics and theory (steps to 10^{23}W/cm^2, radiation reaction plays role)

ELI-Beamlines Milestones

Apr 2011	ELI-Beamlines funding approved by EC
Aug 2011	Funding (278 mil. Euro) signed by the CZ's Ministry of Education
Dec 2011	Technical Design Report completed
July 2012	Building documentation completed
Sept 2012	Site excavations start
May 2013	Construction start
Sept 2015	Start of installation of laser systems
Dec 2015	Phase I completed: two laser units + support installed
2016-2017	Phase II: lasers & experiments installed: facility commissioned!

ELI-Beamlines location



• Proximity of international airport (15 min drive), enjoyable surroundings, behind the border of Prague (funding issues)

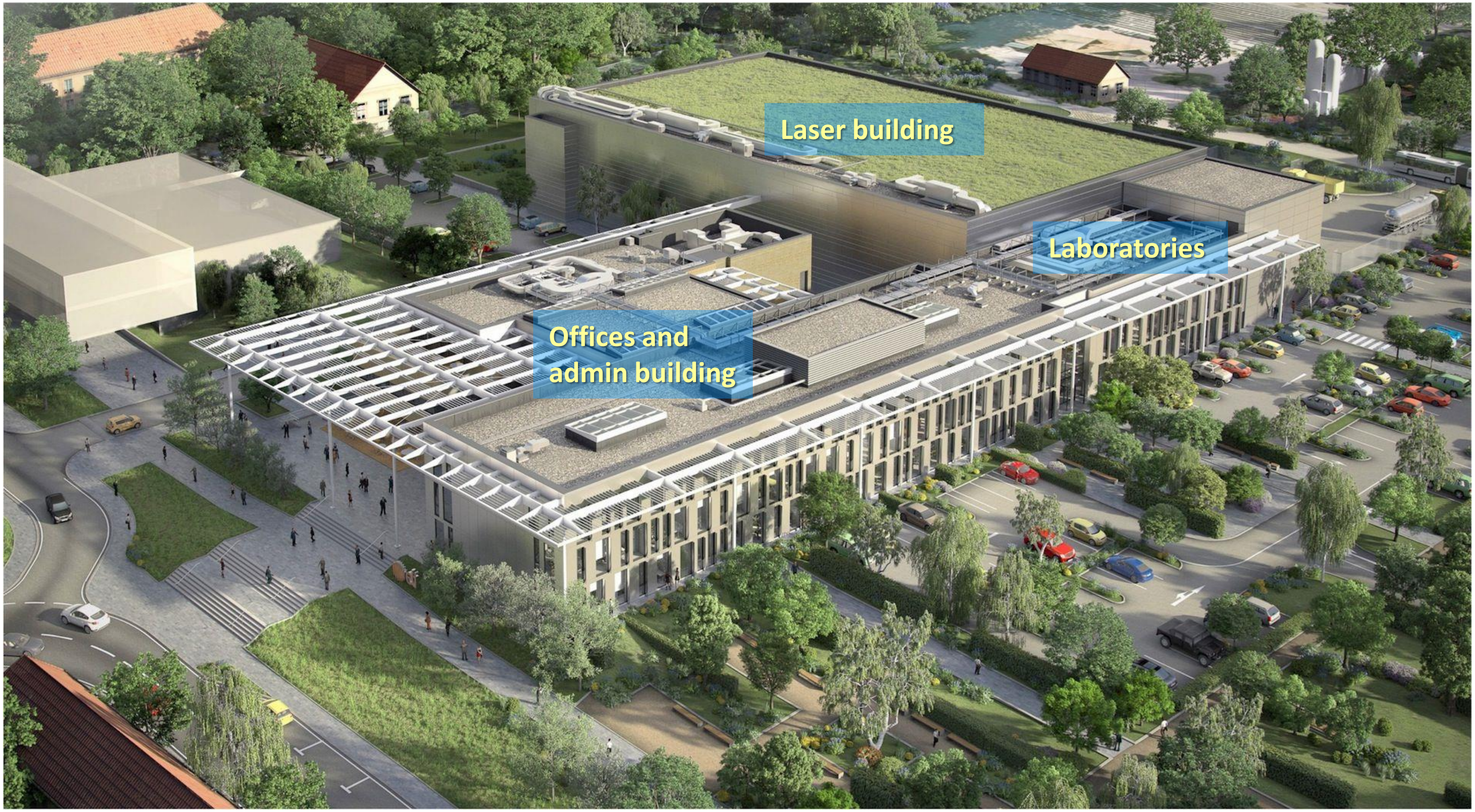
• Synergy with planned large biotechnology center BIOCEV (2 km distance)

• Direct connection to Prague outer ring and the European motorway network

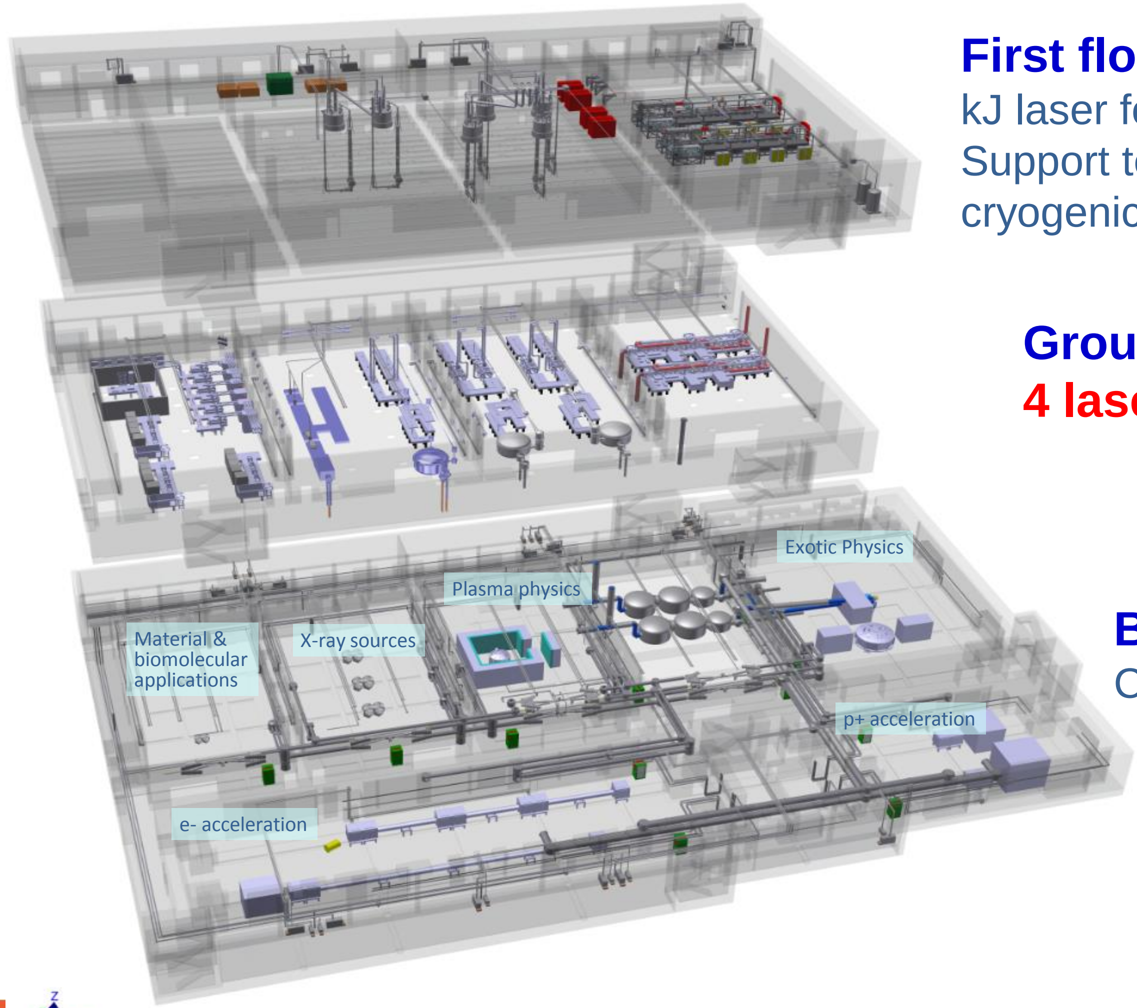
Ground breaking ceremony 9th of October 2012

Prime Minister Necas, Minister of Education Fiala, President of Academy, Representative of Church praying for good photons!

ELI-Beamlines facility aerial view



Layout of ELI-Beamlines laser building



First floor (80 x 40 m)

kJ laser for L4

Support technologies, cooling systems, cryogenic systems

Ground floor (80 x 40 m)

4 laser halls (L1 to L4)

Basement (110 x 60 m)

Compressor(s) of L4 10-PW laser(s)

Vacuum pulse distribution

6 specialized experimental halls (E1 to E6)

eli beamlines

- ✓ ELI pillars and ELI-Beamlines
- ✓ Facility layouts
- ✓ **Lasers (RP1)**
- ✓ Beam transport and switchyard
- ✓ Experiments (RP2-RP6)

ELI-Beamlines laser baseline

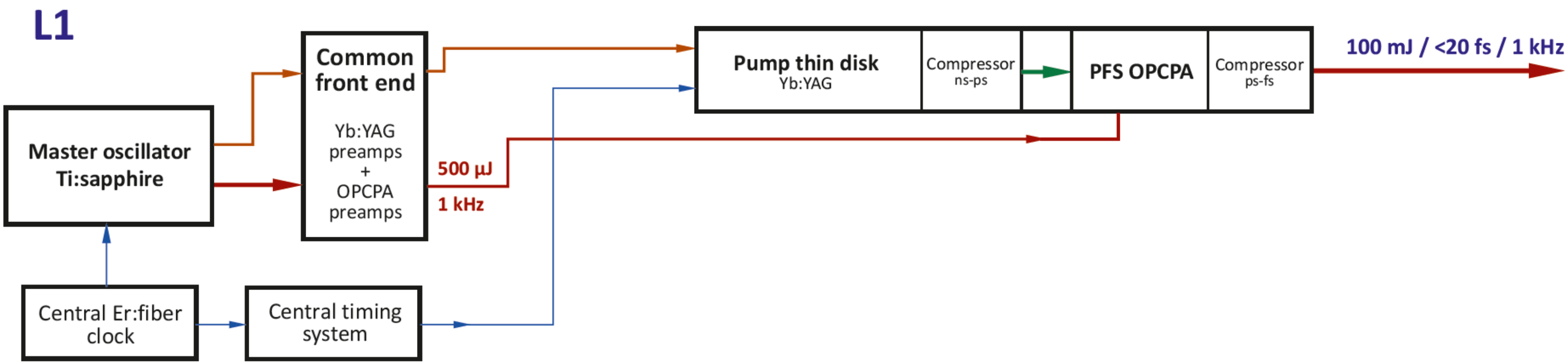
4 laser beamlines: L1, L2, L3 and L4

- **L1**: 10TW-class @ kHz
- **L2** and **L3**: PW @ 10 Hz
- **L4**: 10 PW (1shot/min) and high energy "kJ" beam

Beamlines based either on existing or newly developed technologies

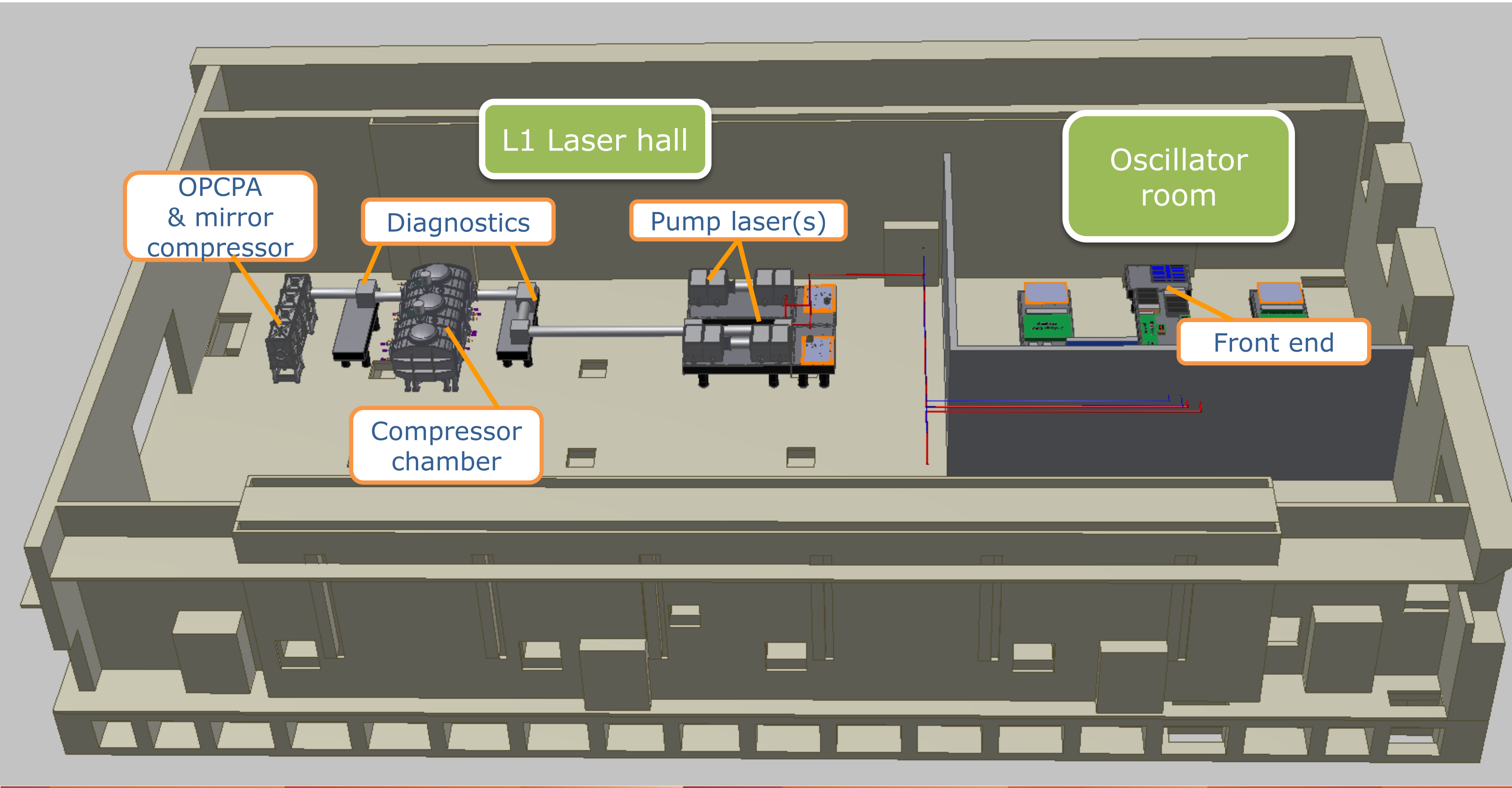
- DPSSL and flashlamp pumped
- OPCPA, Ti: Sapphire and mixed glass technologies
- Thin disk (MPQ, MBI and Trumpf Scientific)
- Multi slabs (Dipole – STFC, Mercury- LIFE- LLNL)
- Mixed glass (Texas PW laser, Apollon pump laser)
- Czech program for High Power Laser development "**HILASE**"

L1 beamline layout

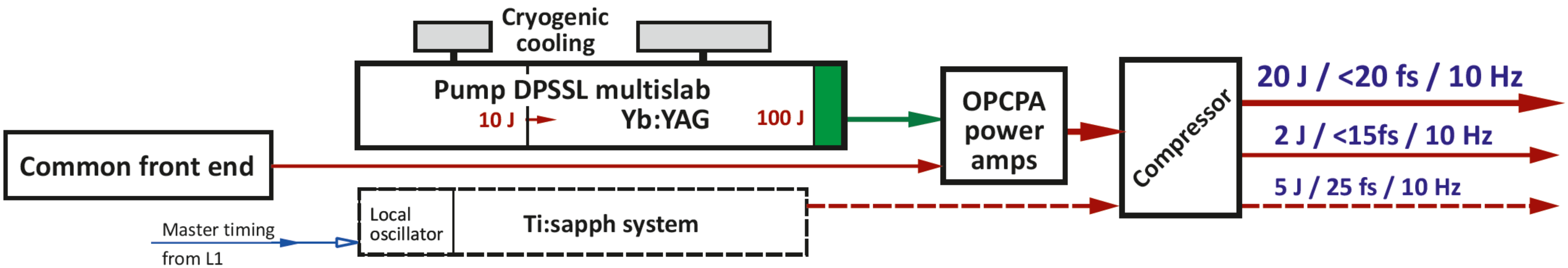


- kHz repetition rate laser-diode pumped using thin-disk pump technology
- Oscillator and common front end producing mutually synchronized seed pulses
- Capable to generate several seeds with central wavelengths from 800 to 900 nm
- Picosecond OPCPA system for L1 broadband amplification

L1 beamline conceptual design

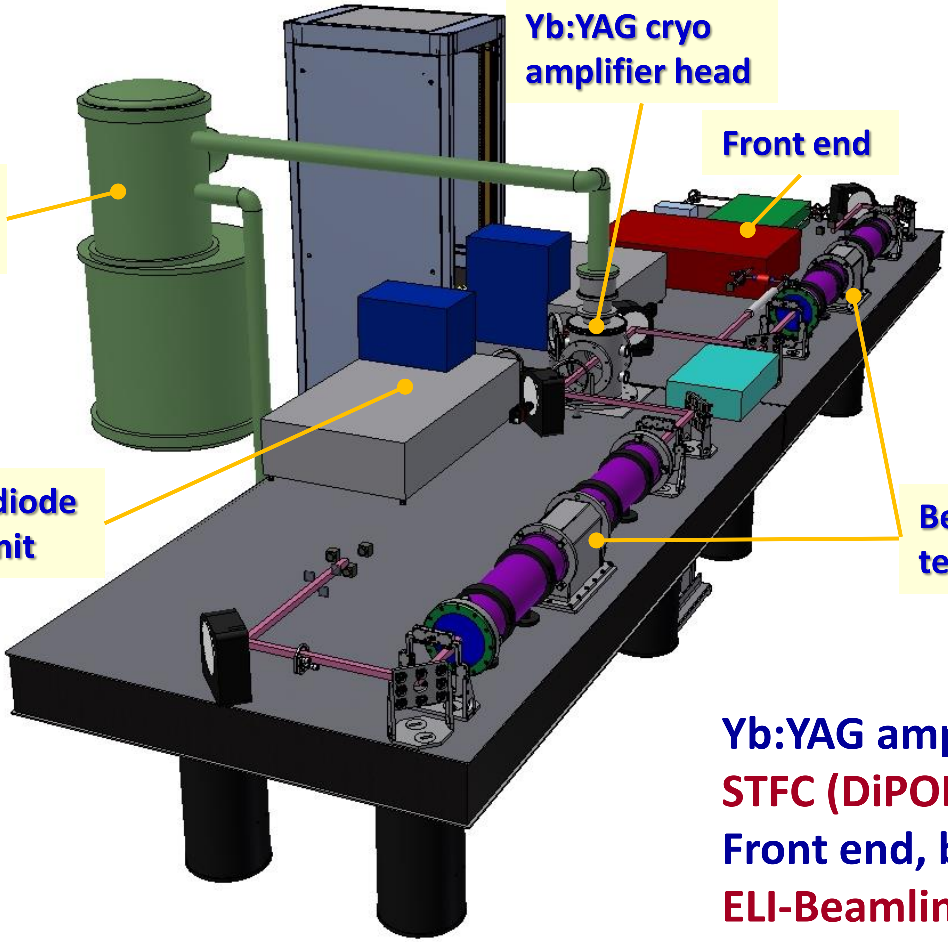


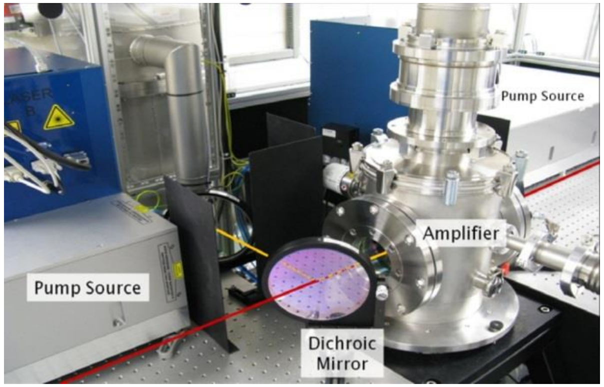
L2 beamline layout



- Cryogenic Yb:YAG laser-diode pumped multislab technology
- First stage (10J/10Hz) of the pump system being built (completion end 2013)
- Strong support from **HiLASE** project!
- OPCPA short-pulse amplifiers
- Optional 200-TW-class Ti:sapphire commercial system

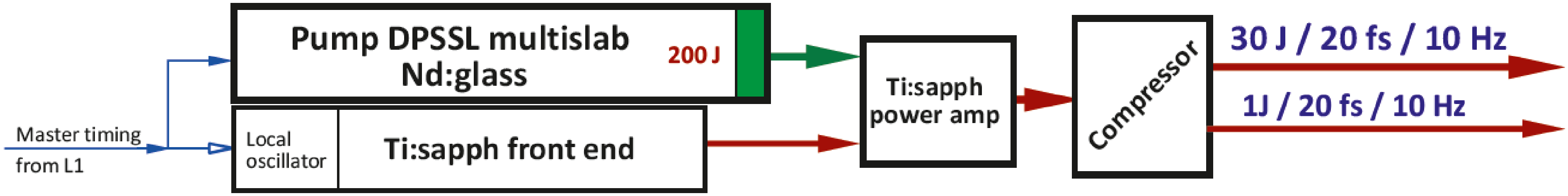
10J/10Hz Yb:YAG subsystem of the L2 pump laser





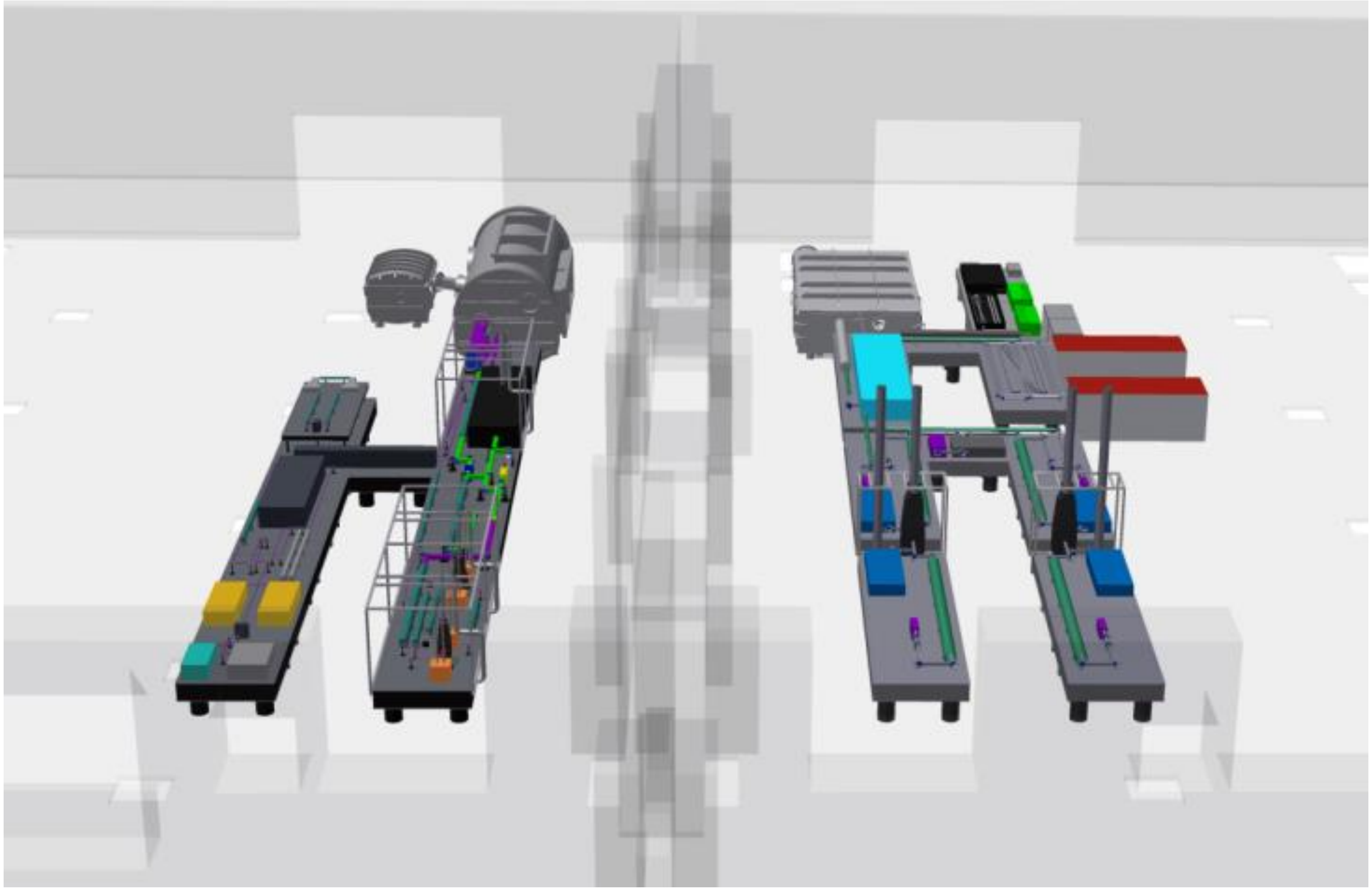
Yb:YAG amp head & pump diode lasers:
STFC (DiPOLE)
Front end, beam transport & cryo unit:
ELI-Beamlines

L3 beamline layout

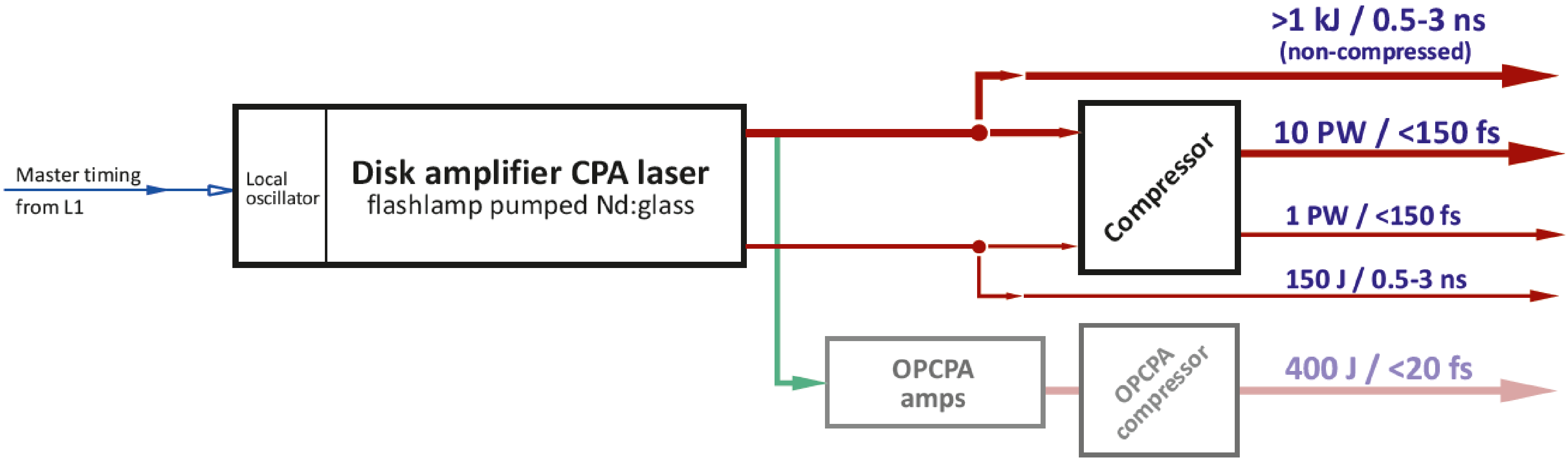


- <u>Nd:glass laser-diode pumped multislab technology</u>
- **Planned to become PW workhorse of the ELI-Beamlines facility**
- Pump engine based on diode pumped technology
- Nd:glass active medium
- Operation at near room temperature

L3 & L2, 10 Hz, PW beamlines conc. design



L4 beamline layout



- <u>kJ, 120-150fs, CPA Nd:glass laser</u>
- Nanosecond kJ pulses required for laser plasma experiments
- Spectral bandwidth for direct compression down to 120-150 fs
- <u>Auxiliary beam for generation of “long” PW probe pulses</u> (e- and ion acc.)
- Prospects for future OPCPA upgrade

- ✓ ELI pillars and ELI-Beamlines
- ✓ Facility layouts
- ✓ Lasers (RP1)
- ✓ **Beam transport and switchyards**
- ✓ Experiments (RP2-RP6)

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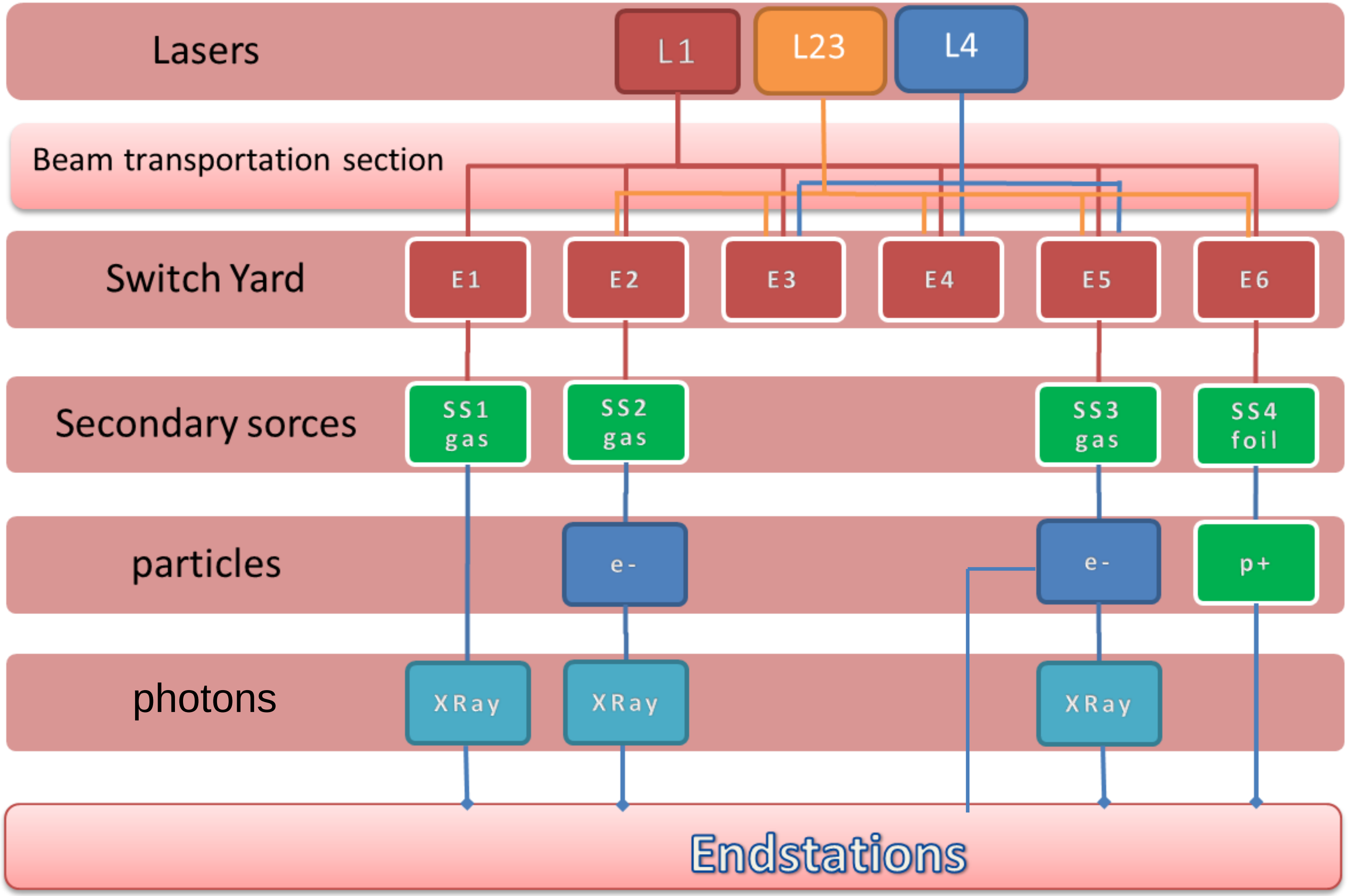
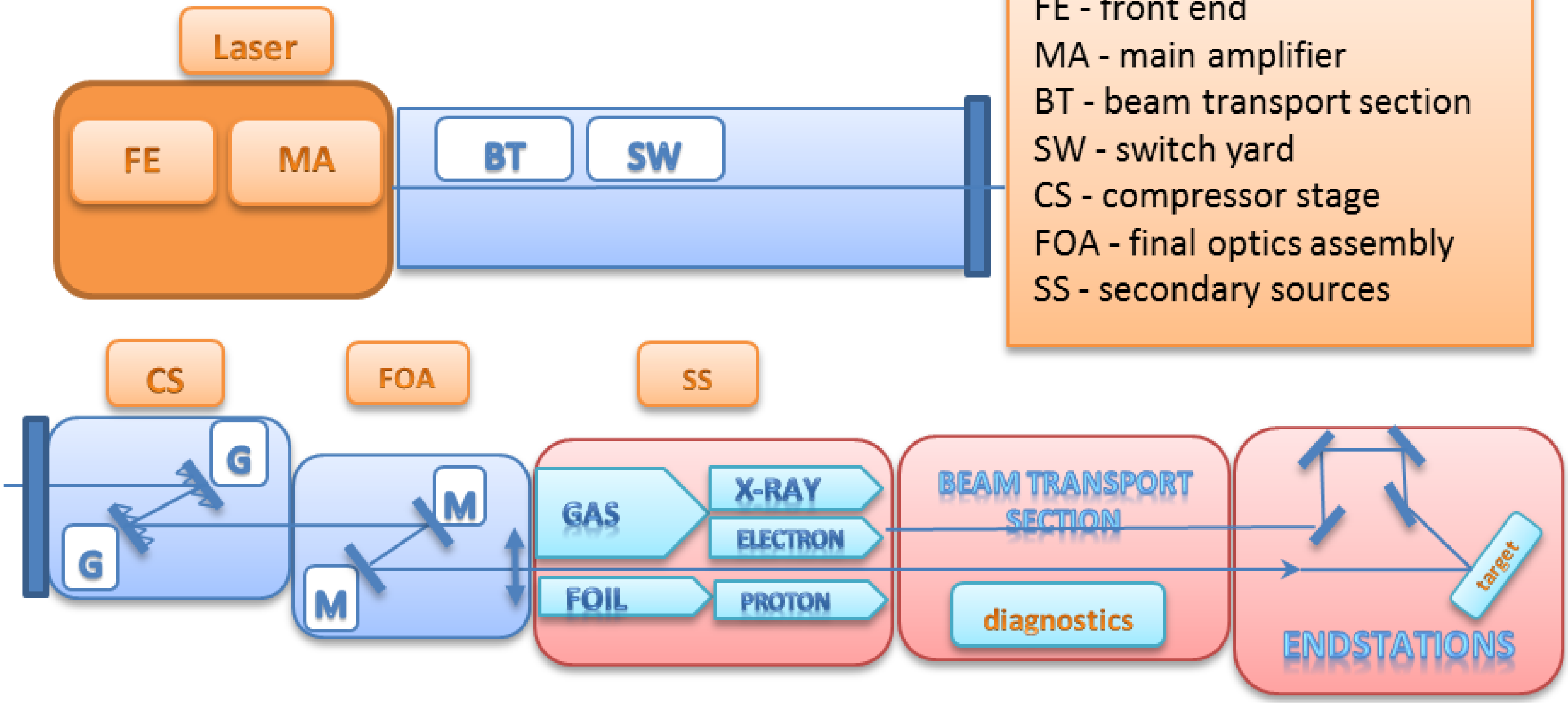
Facility general layout



Beamline general layout

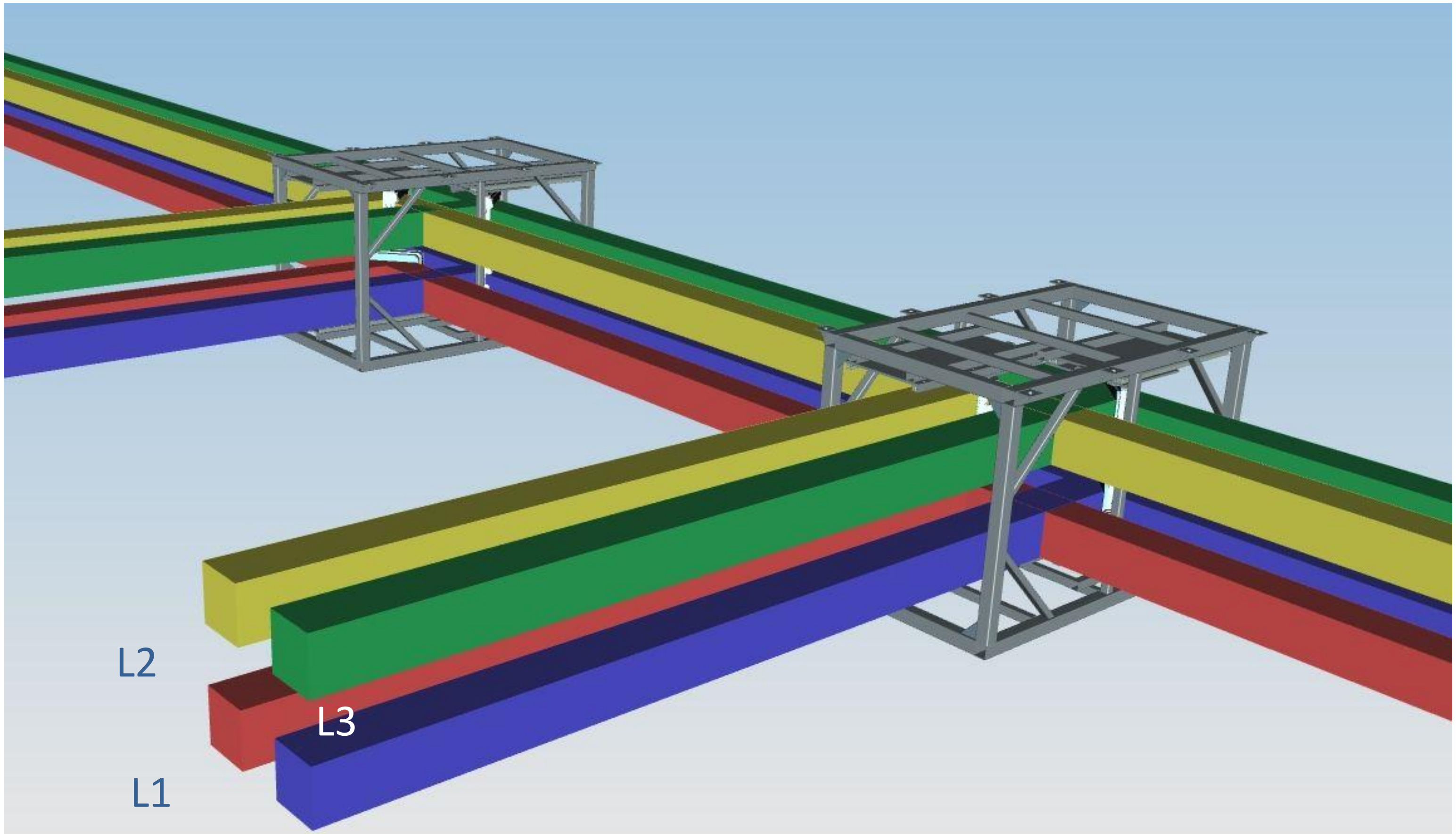


FE - front end
MA - main amplifier
BT - beam transport section
SW - switch yard
CS - compressor stage
FOA - final optics assembly
SS - secondary sources

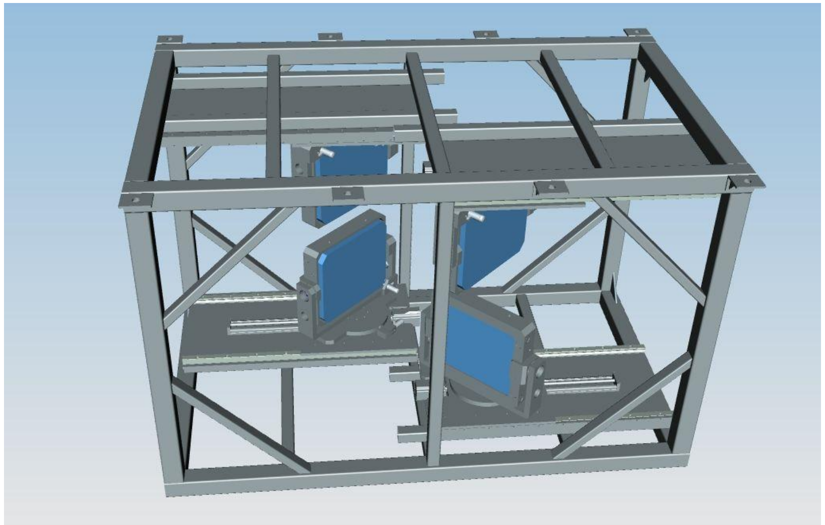
ELI-Beamlines will provide synchronized beams of short pulse optical photons, x-rays, electrons, ions to be used by users (including pump-probe experiments)

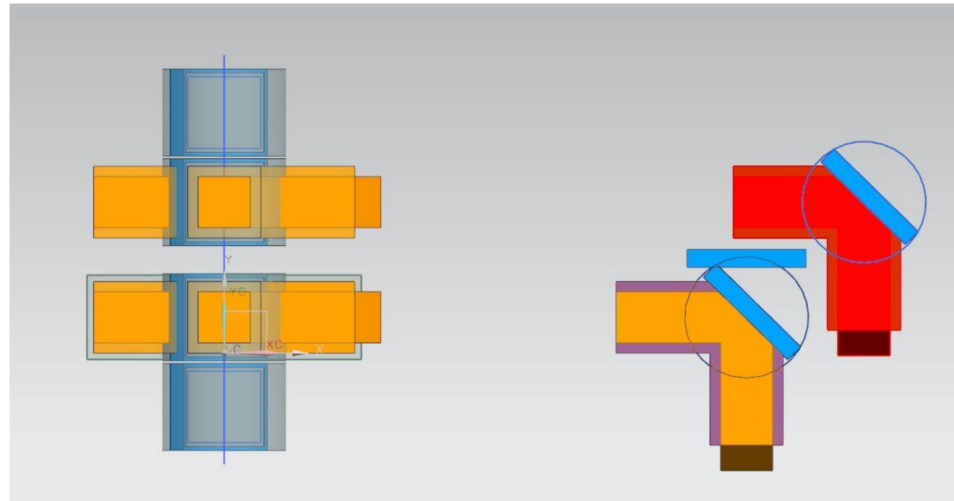
Beam transport and switchyards

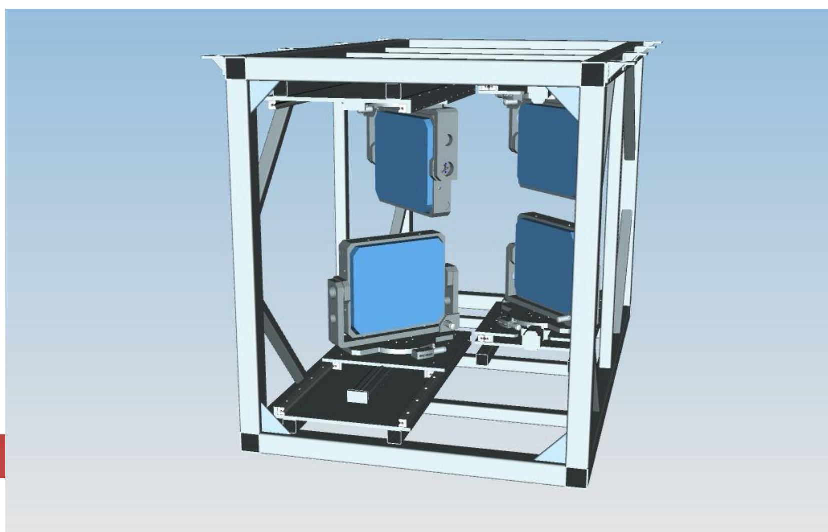
All laser beamlines can be delivered to any of the experimental rooms!

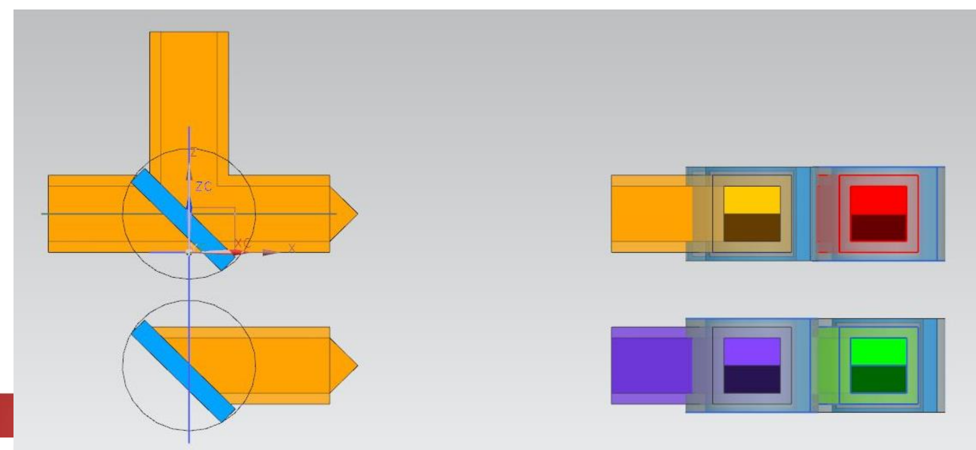


Beam transport and switchyard 1



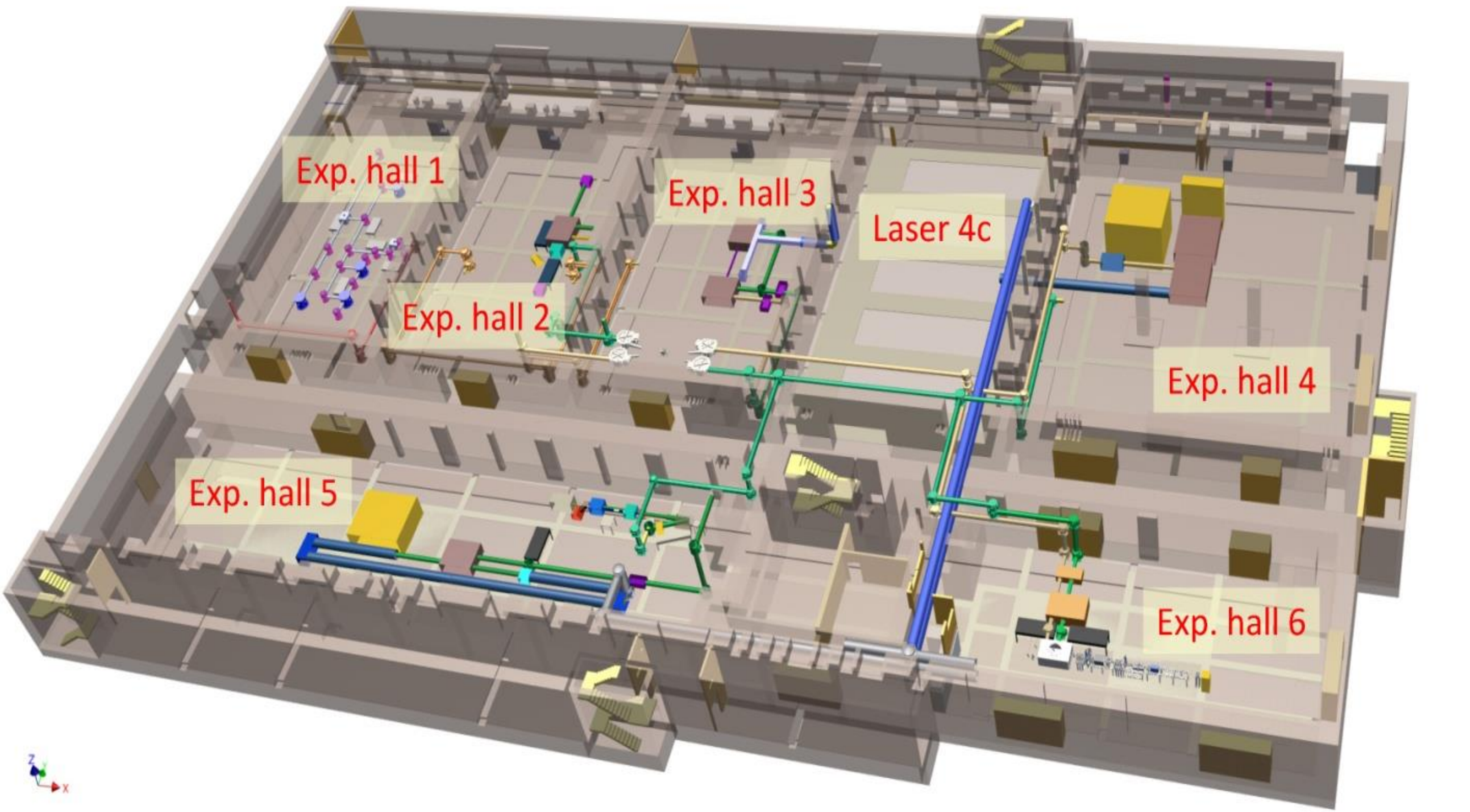






- ✓ ELI pillars and ELI-Beamlines
- ✓ Facility layouts
- ✓ Lasers (RP1)
- ✓ Beam transport and switchyards
- ✓ Experiments (RP2-RP6)

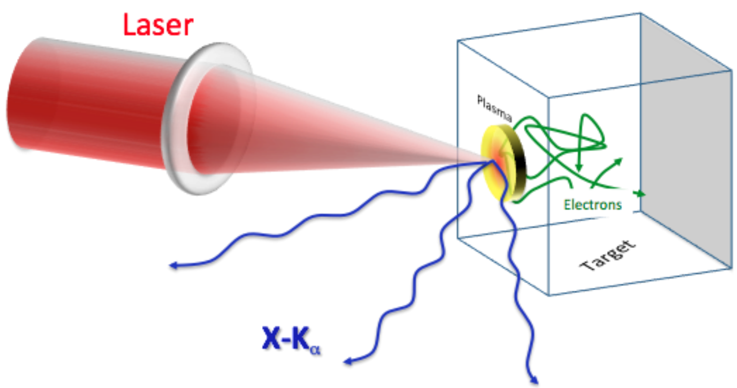
Experimental Area (underground floor)



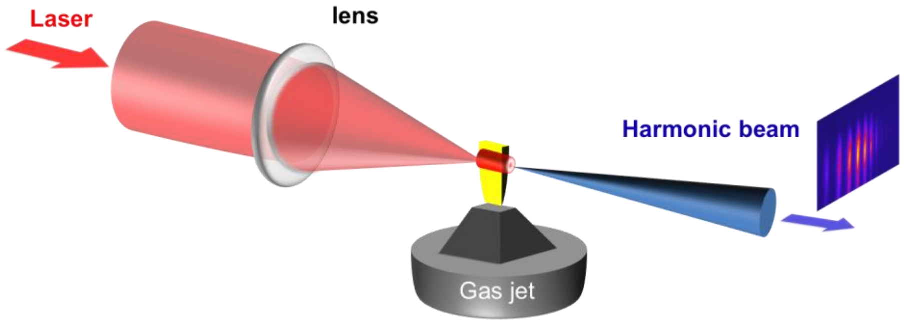
eli beamlines

RP2: Laser-driven X-ray sources

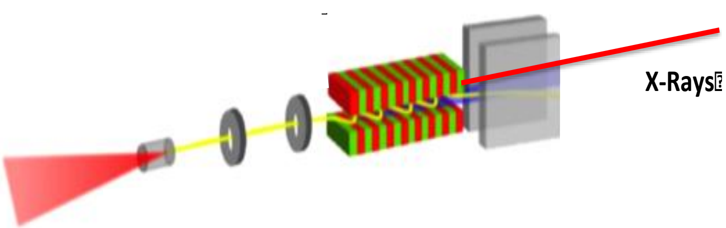
Plasma sources



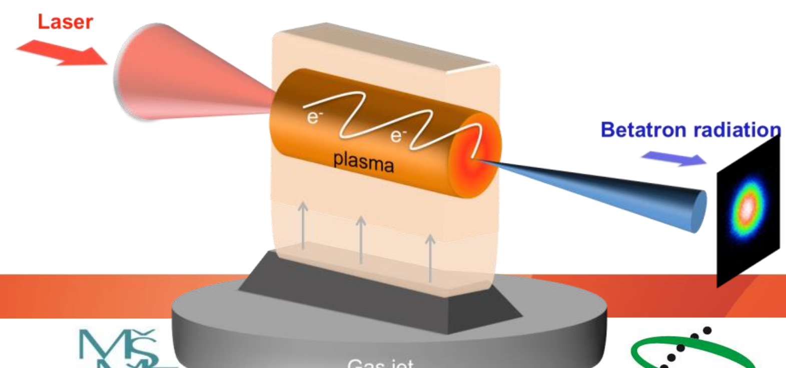
Harmonics (gas)



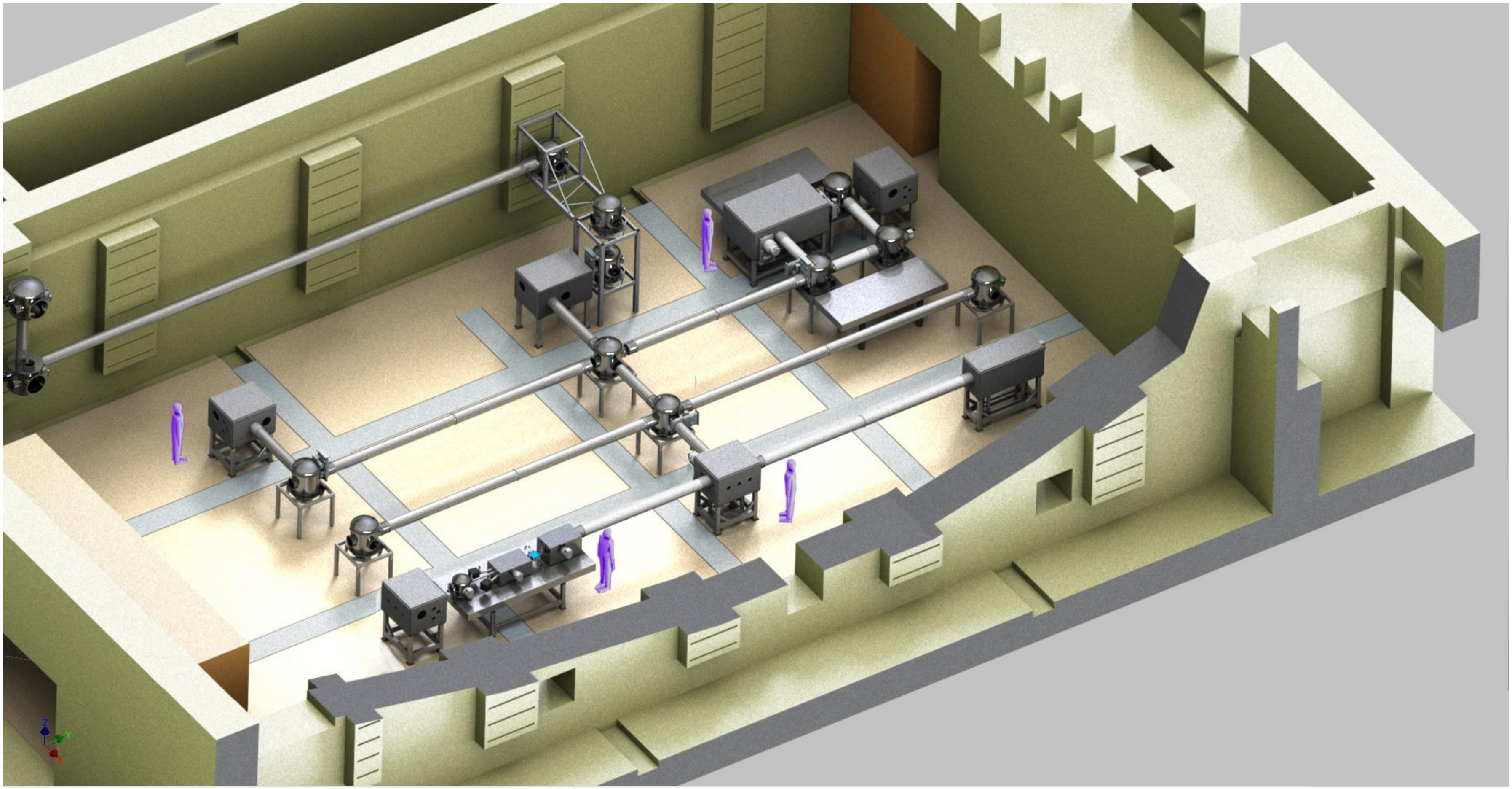
LUX/XFEL



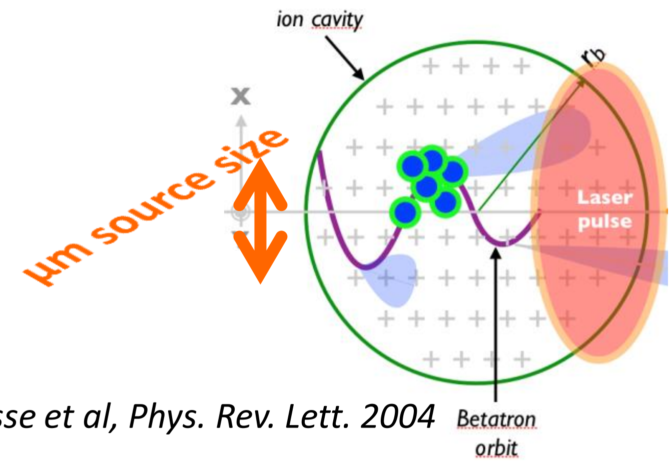
X-rays from relativistic e-beams



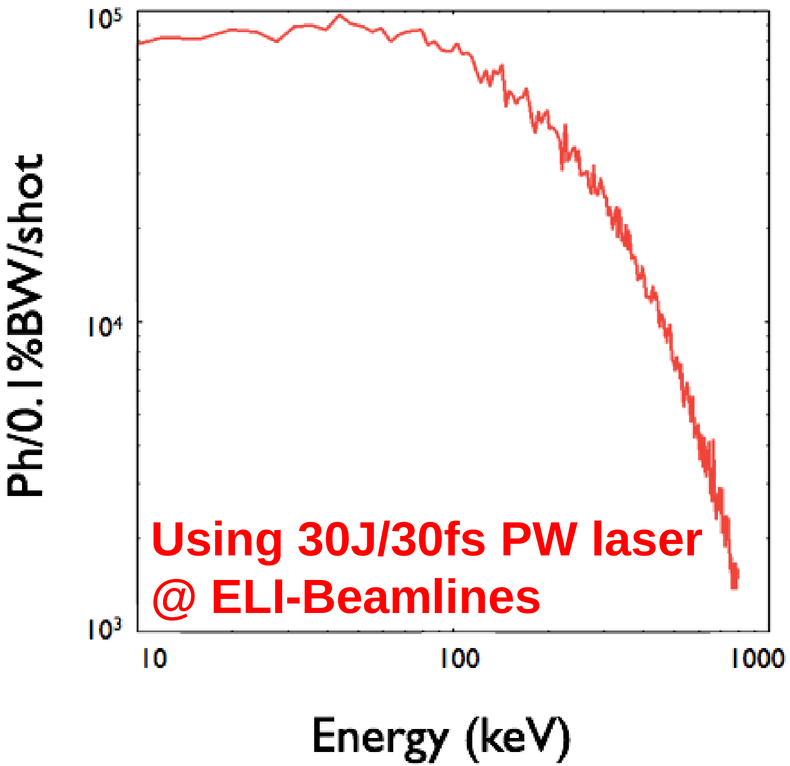
X-ray beamlines in E1

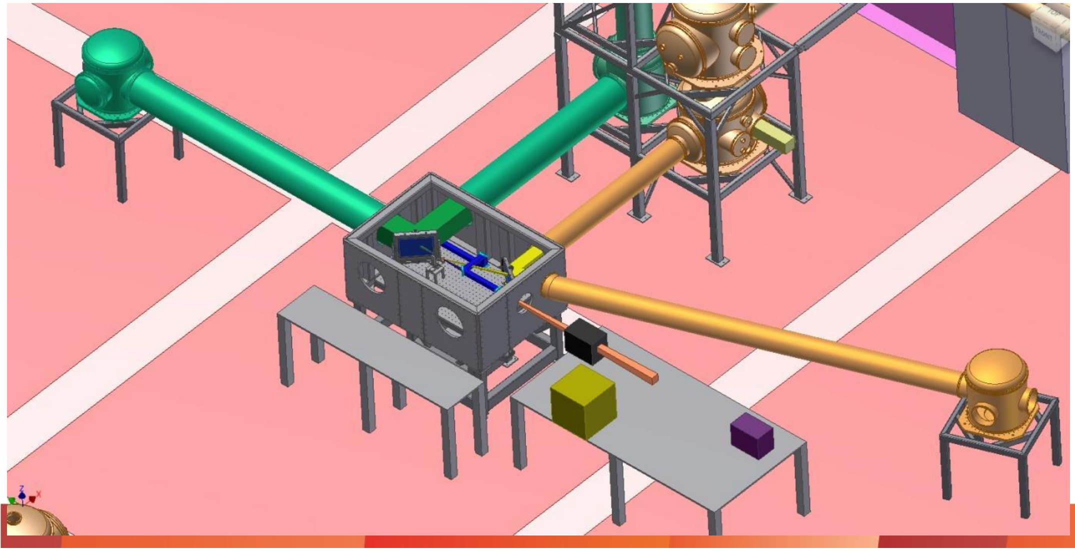


Betatron & Compton sources in E2



A. Rousse et al, Phys. Rev. Lett. 2004





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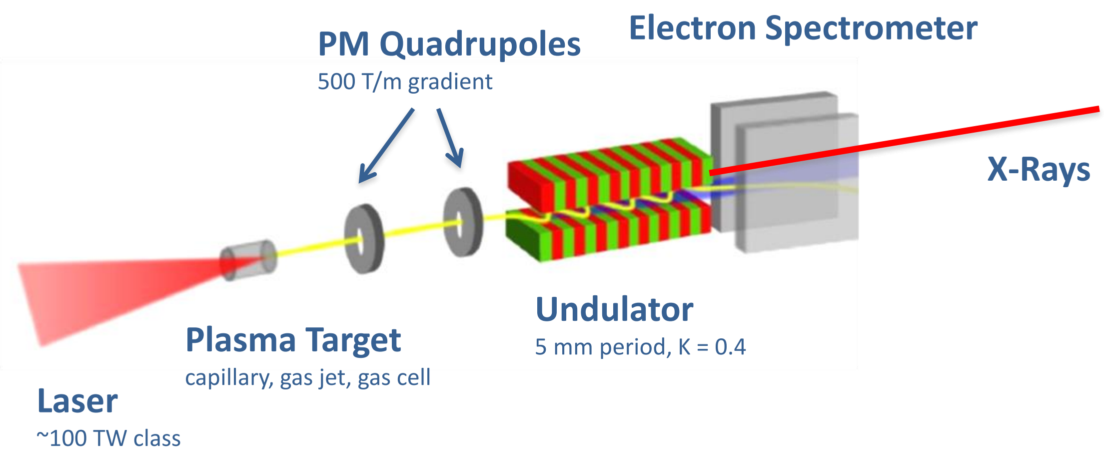
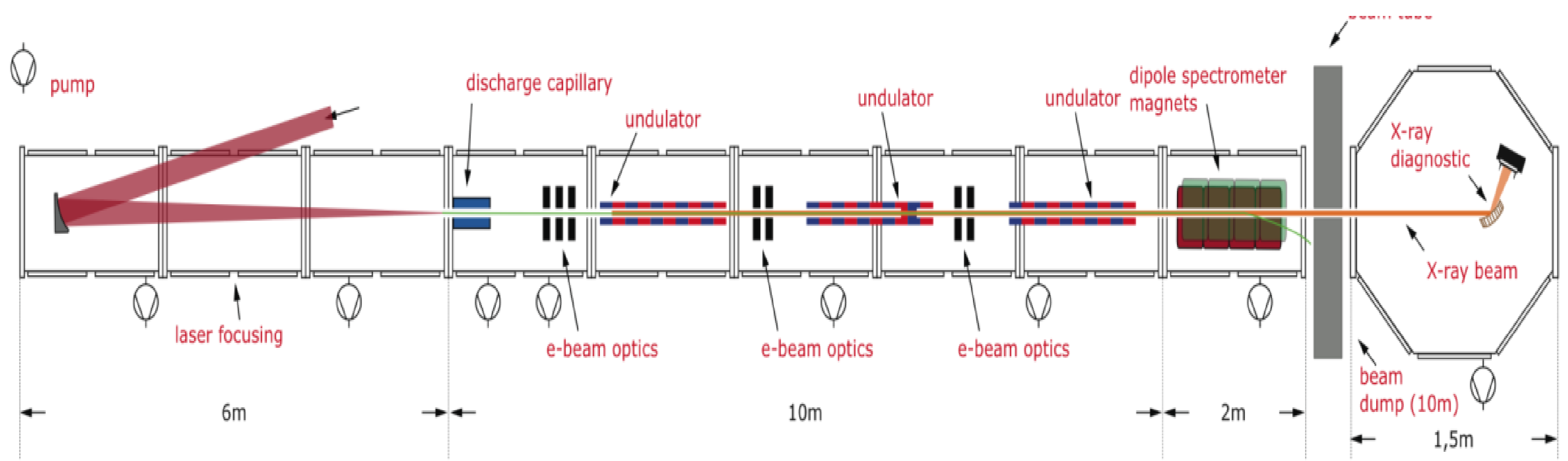
LUX (Laser Undulator X-ray) beamline

- Development in collaboration with Hamburg University (F. Gruner) and DESY
- Water window wavelength range with sub-5fs pulse duration
- Future extension to laser driven X-FEL with more undulators (5 keV, short and tunable x-ray pulses)

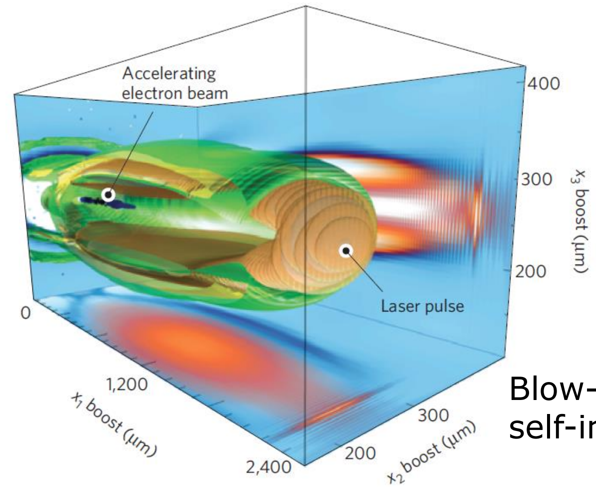




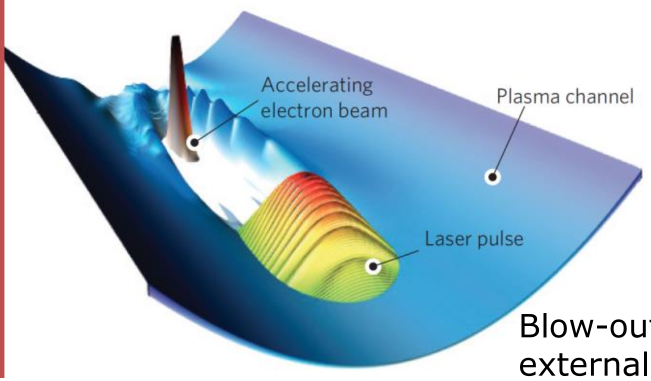
RP3: Electron Acceleration (Scaling Laws)

Electron Beam Parameters

- **PW-class** beamline (30J/30fs, 0.01-10 Hz): **L3**
  - ✓ Bubble regime
    - Energy: **few GeV**
    - Charge: **several nC**
    - Divergence: **>>1 degree**
  - ✓ Blow-out regime/self-guided
    - Energy: **several GeV**
    - Charge: **~1 nC**
    - Divergence: **<1 degree**
  - ✓ Blow-out regime/external-guided
    - Energy: **>10 GeV**
    - Charge: **<1 nC**
    - Divergence: **<1 degree**
- **10 PW-class** beamline (1.3kJ/130fs, <0.01 Hz): **L4**
  - ✓ Phase 3
    - Energy: **100 GeV**
    - Charge: **>1 nC**
    - Divergence: **<1 degree**



Blow-out self-injection



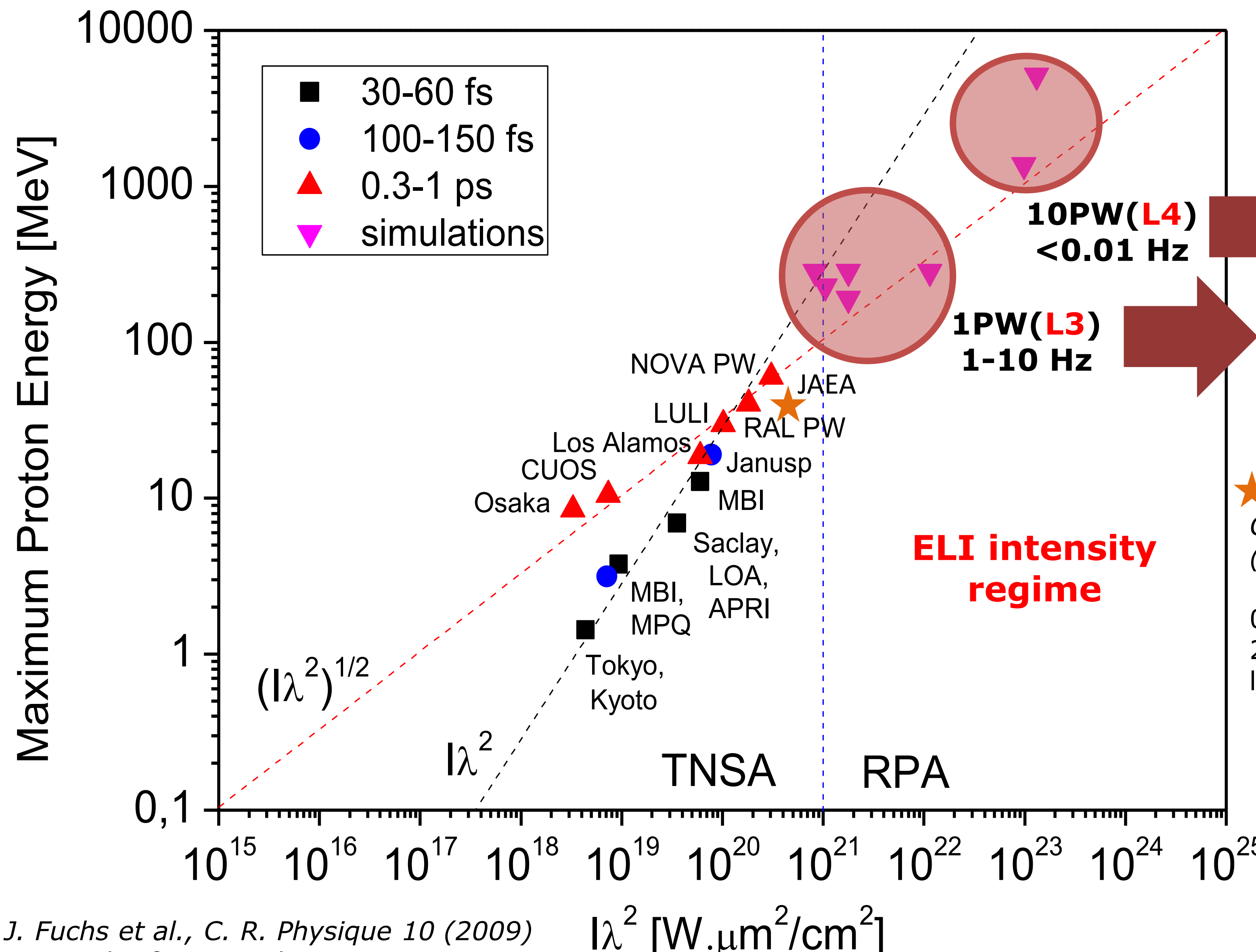
Blow-out external-injection

Scaling laws:
S. V. Bulanov et al., Phys. Plasmas (2012)

$$E_e = k m_e c^2 \frac{P}{P_{cr}}$$

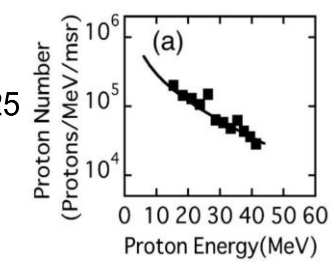
OSIRIS PIC simulations:
S.F. Martins, R.A. Fonseca, W. Lu, V.W. Mori and L.O. Silva, Nature Physics 6 (2010) 311

RP3: Ion Acceleration (Scaling Laws)



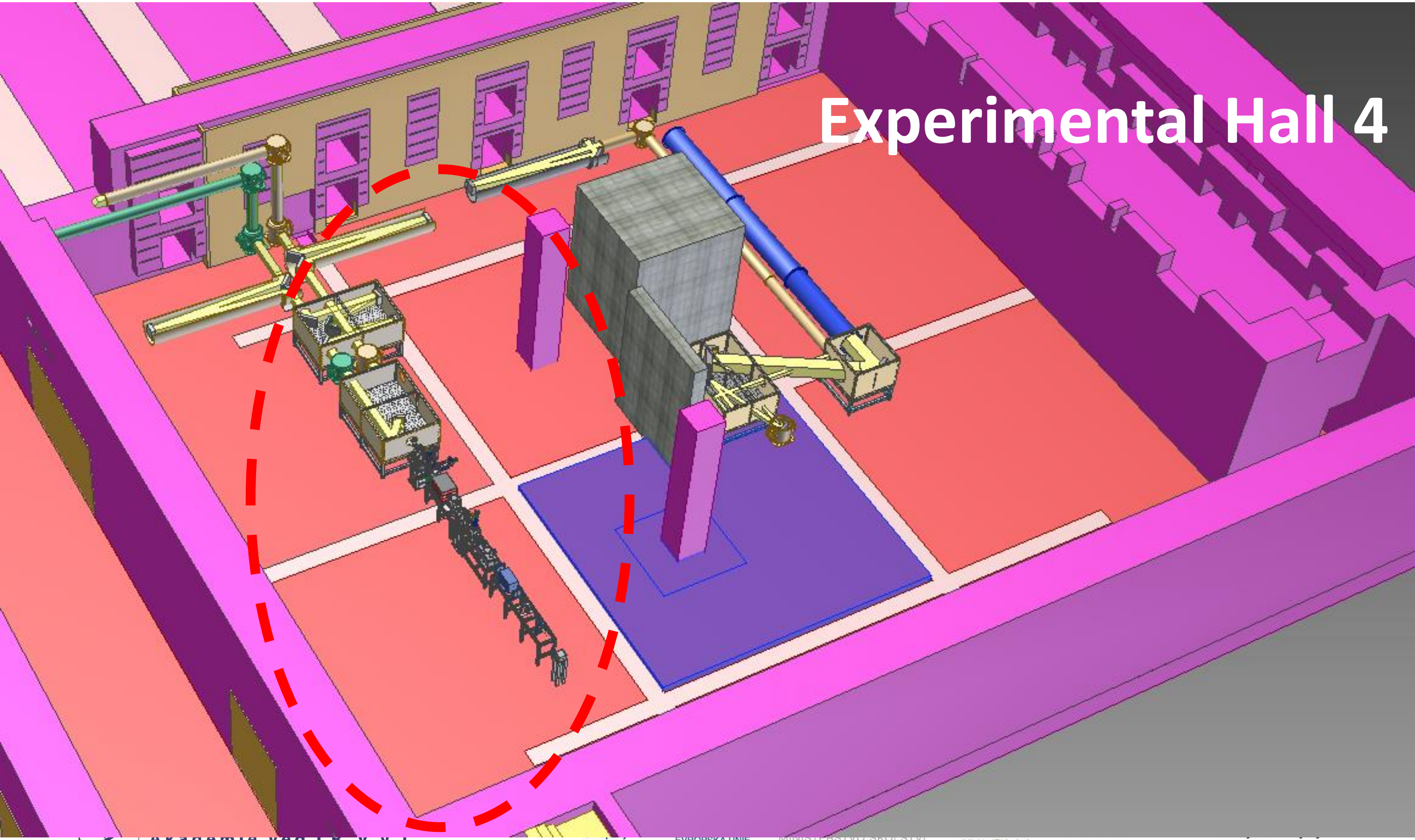
★ *K. Ogura et al., Optics Letters 37 (2012) 2868*

0.8 μm Al target;
200 TW (8J/40fs)
laser

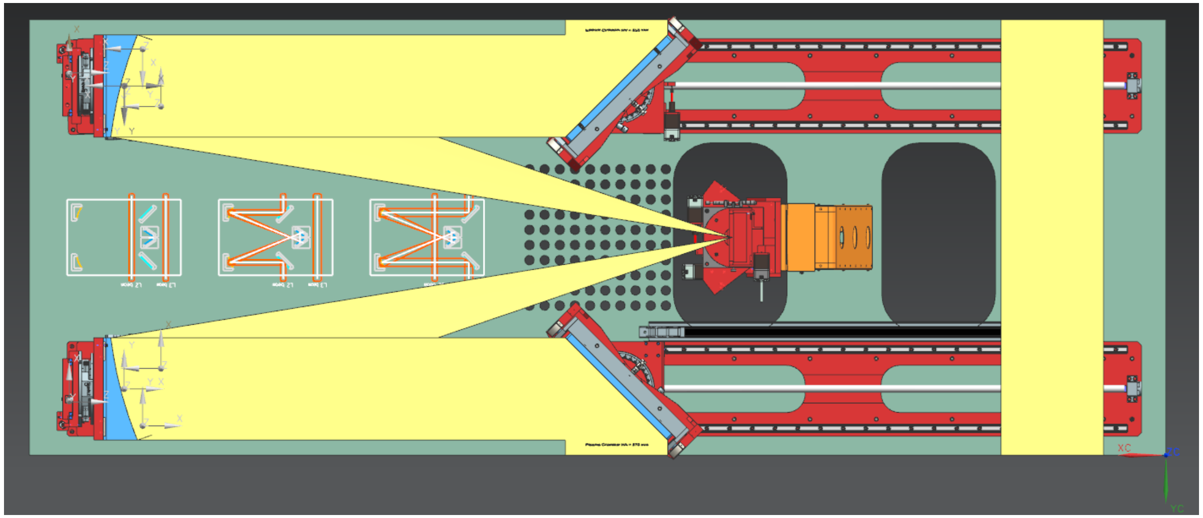


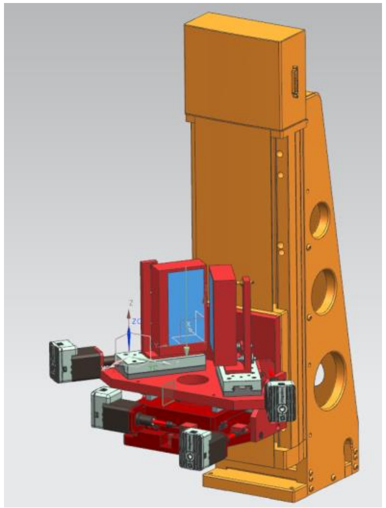
J. Fuchs et al., C. R. Physique 10 (2009) 176 and references therein

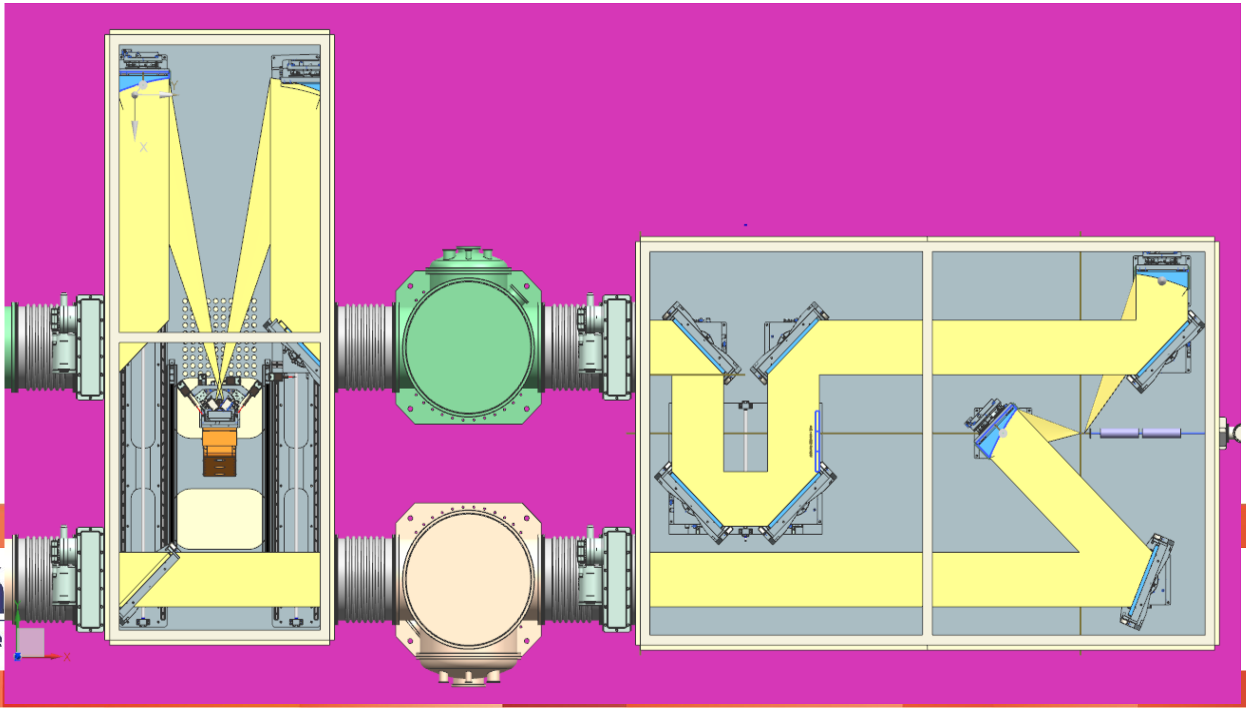
The ELIMIAA beamline: ELI-beamlines Multidisciplinary Ion Acceleration Applications



Plasma mirror and target chambers design







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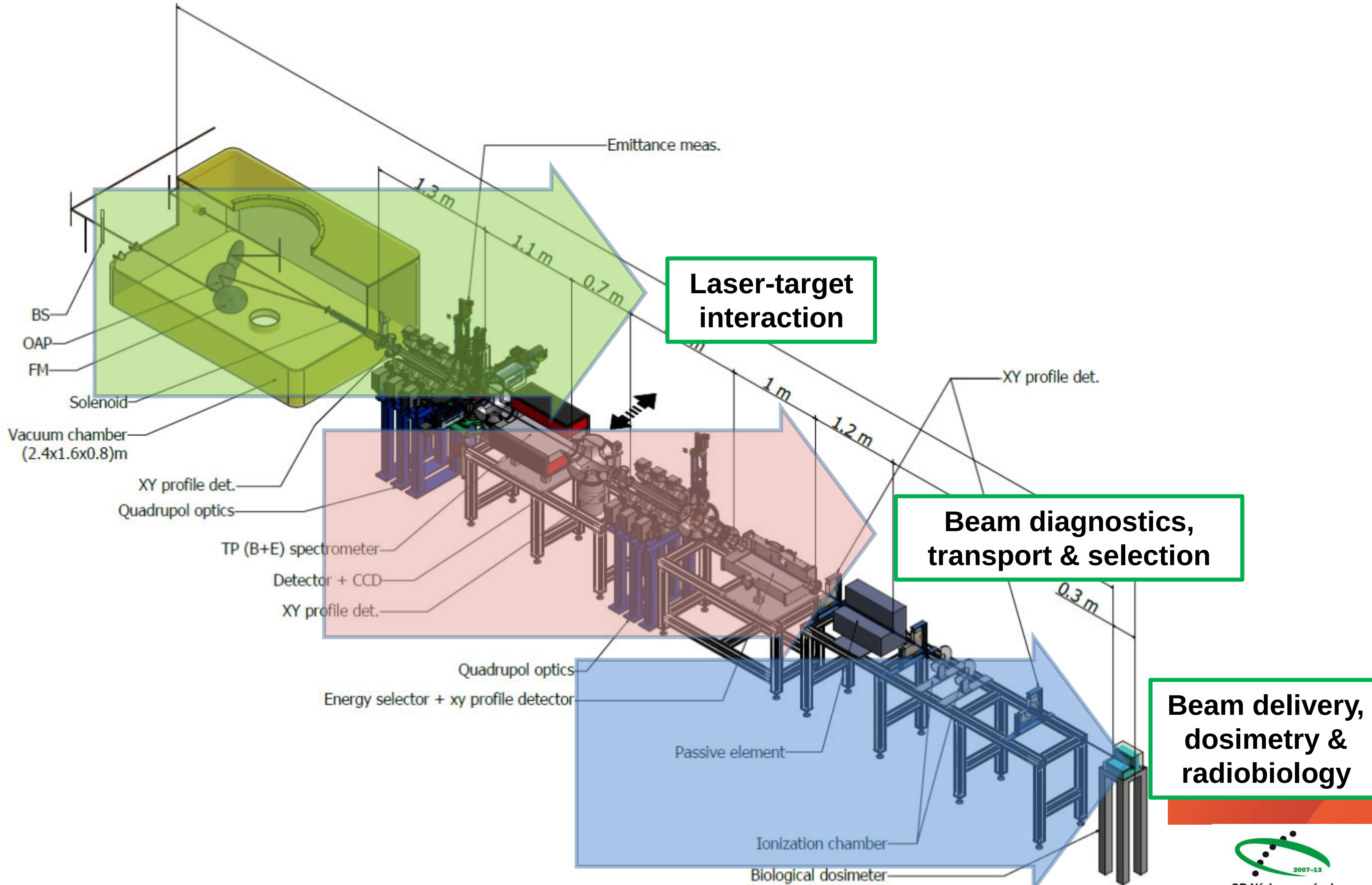
The ELIMIAA Beamline



The ELIMED international cooperation

TÉCNICO LISBOA

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

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Fyzikální ústav Akademie věd ČR, v. v. i.

2nd ELIMED Workshop and Panel,
18-19 October 2012 @ INFN-LNS, Catania

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Università degli Studi di Catania

Azienda Ospedaliero Universitaria "Policlinico - Vittorio Emanuele" Catania Presidio "Gaspare Rodolico"

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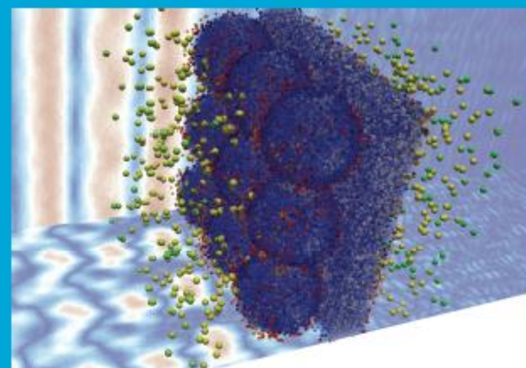
Volume 1546

Conference collection

2nd ELIMED Workshop and Panel



Catania, Italy
18-19 October 2012

Editors
Daniele Margarone, Pablo Cirrone, Giacomo Cuttone and Georg Korn

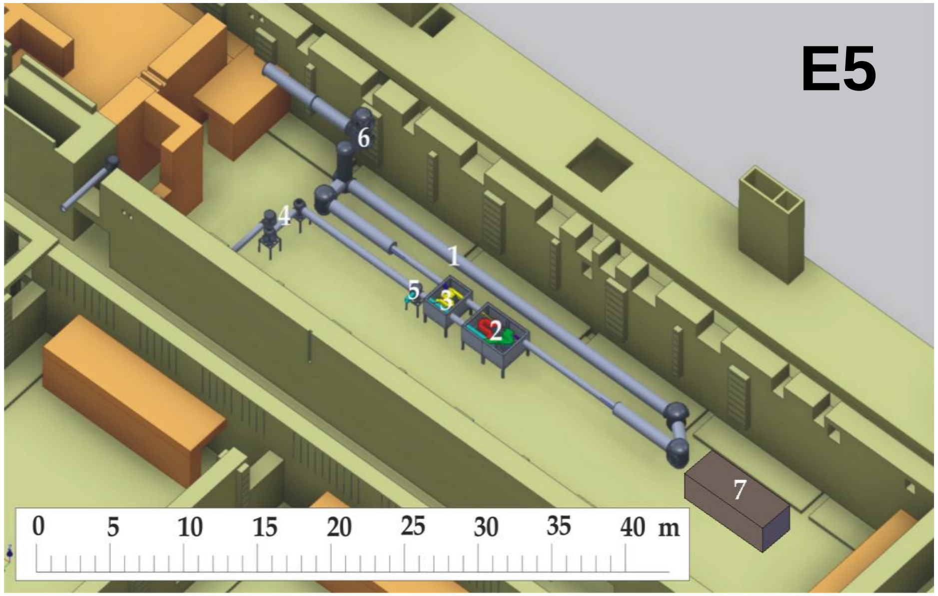
AIP | Proceedings

proceedings.aip.org

Fyzikáln
Akademie vě

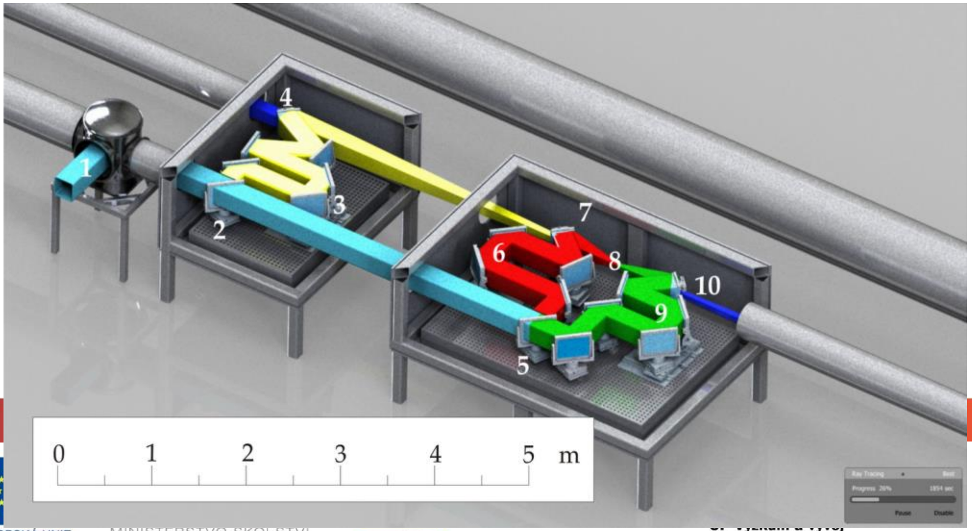
2007–13
OP Výzkum a vývoj pro inovace

HELL (High-energy ELectron-acceleration by Lasers)



Flexible platform for laser-plasma accelerators with **PW-class** and **10PW-class** lasers **(L3 & L4)**

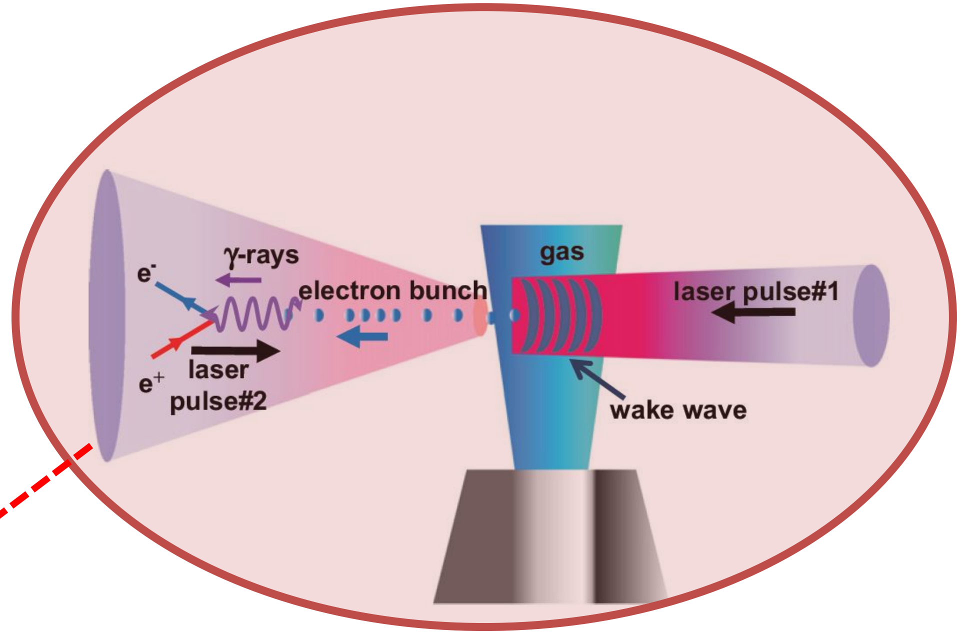
Synergy with RP6 (gas target)

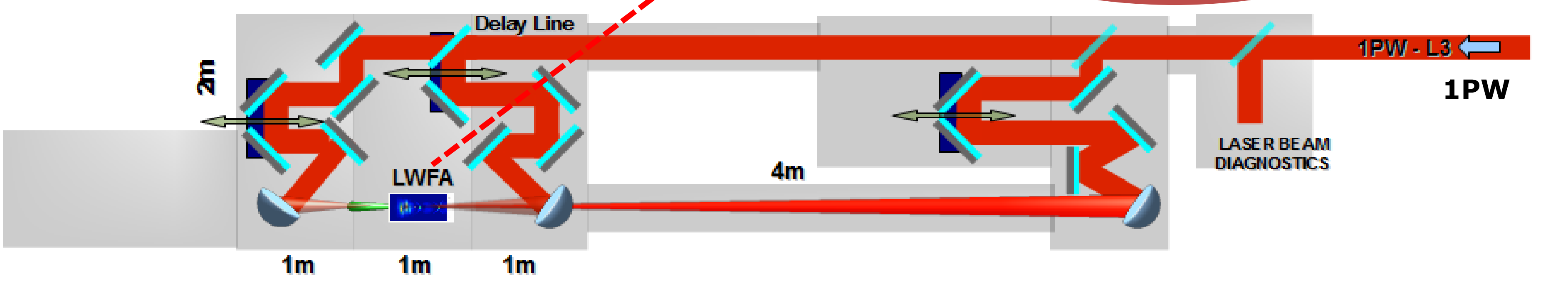


Electron Acceleration & Counter Propagation

- stable acceleration with 1-2PW laser
- inverse Compton scattering (counter-propagating setup) with 1-2PW laser
- Flying mirror type experiments wih 1-2PW
- similar experimental setups for 10PW

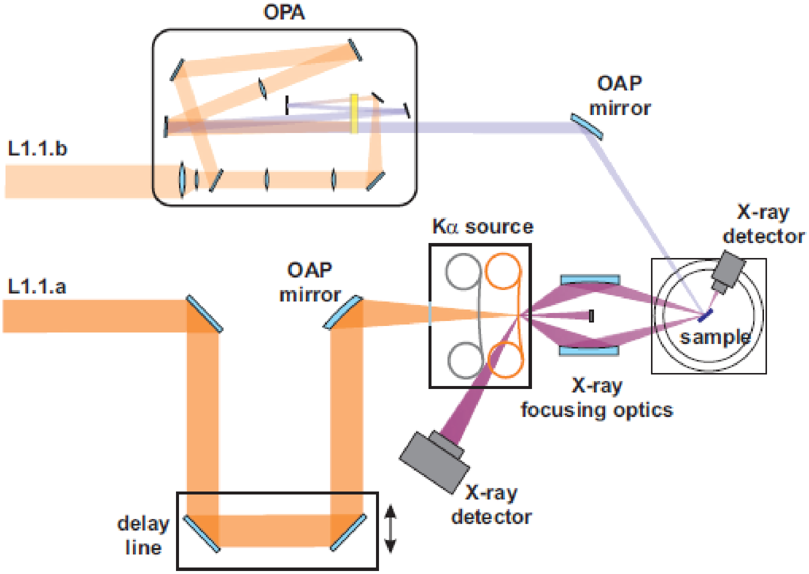
S.V. Bulanov, ... G.Korn, Nuclear Instruments and Methods in Physics Research A 660 (2011) 31–42



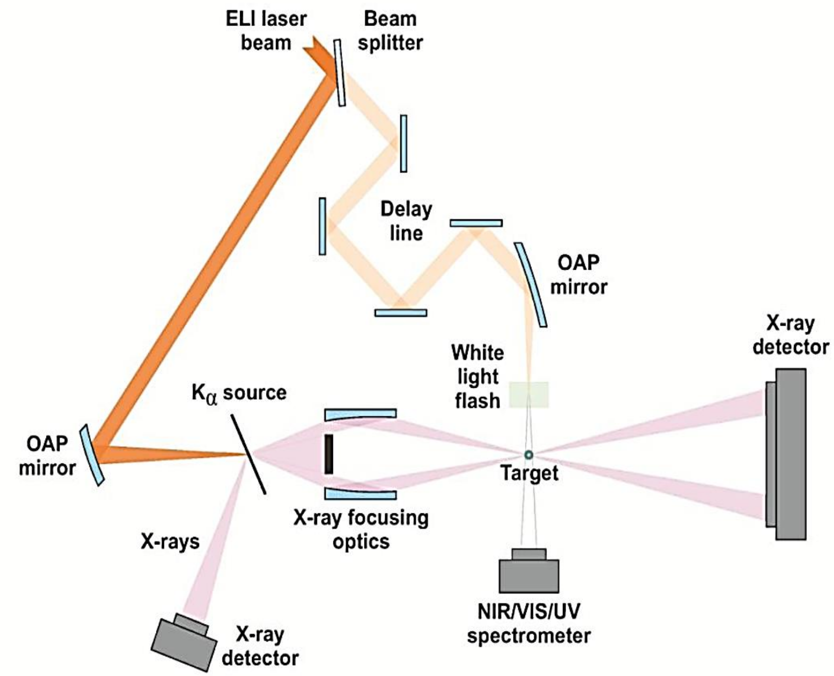


RP4: applications in molecular, biomedical, and material sciences

- User end-stations
- “flexible” end-stations will be available @ ELI-Beamlines
- few examples are identified



Layout of the X-diffraction “pump-probe” end-station

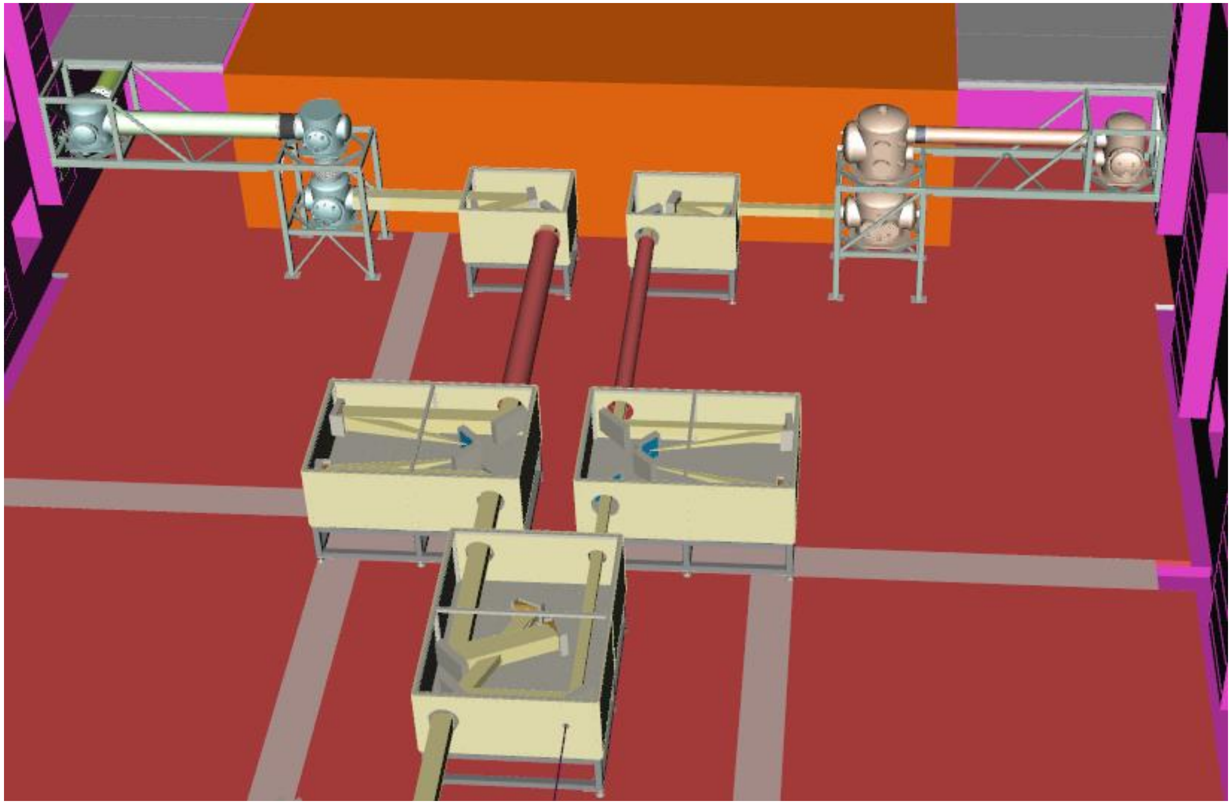


Layout of the pulse radiolysis end station using plasma X-ray pulse and laser probe transient absorption

RP5: Laser plasma and high-energy-density physics

- X-ray diagnostics for E3
- Target chamber design
- Radiation protection in a PW-laser environment
- The ELI Virtual Beamline
- Laser-plasma interaction for shock-ignition approach to ICF
- Amplification of short light pulses
- WDM investigations
- Laboratory Astrophysics
- Proton and X-ray plasma radiography….

Plasma Physics Target Area (E3)



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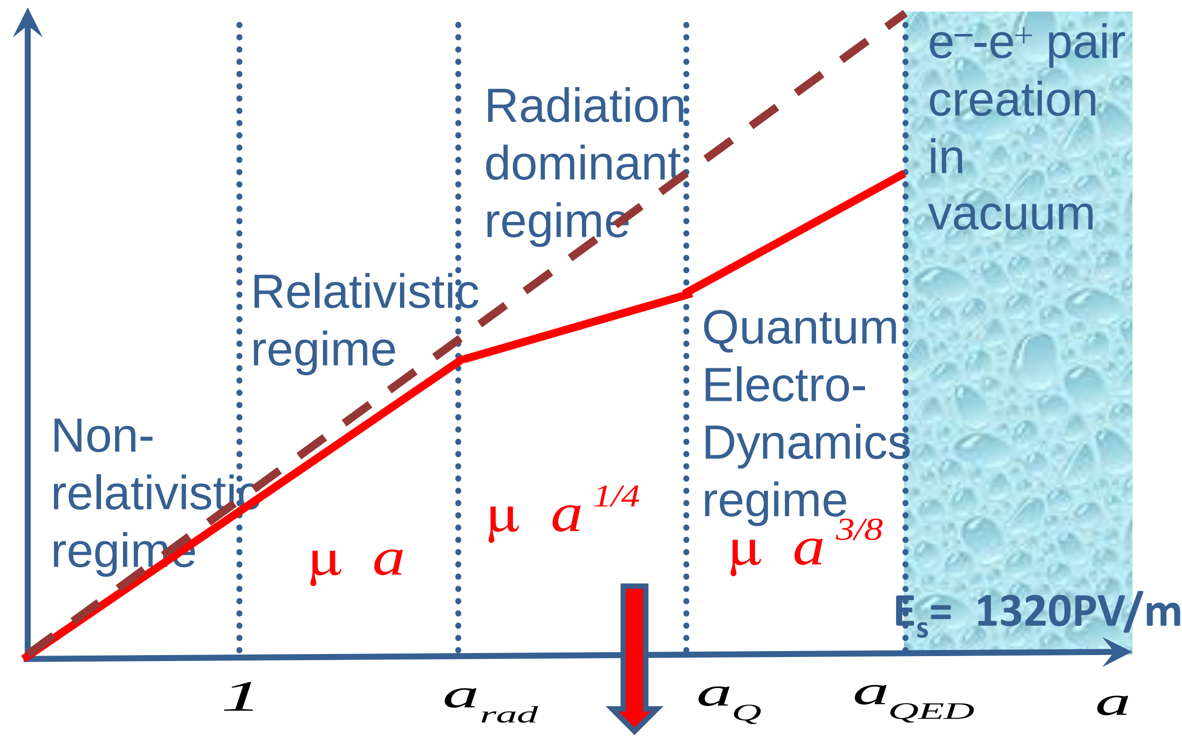
RP6: Exotic Physics

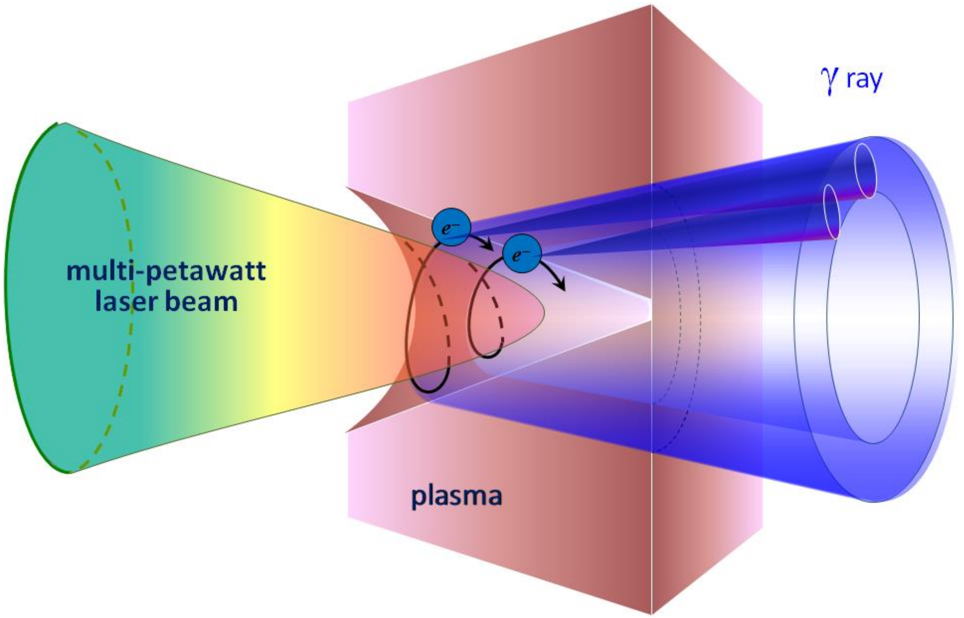
Amplitude $\left[a_0 = \frac{eE_0}{m_e c\omega}\right]$	Intensity $\left[\frac{\text{W}}{\text{cm}^2}\right]$	Regime
$a_{QED} = \frac{m_e c^2}{\hbar\omega}$	2.4×10^{29}	e^+, e^- in vacuum
$a_{QM} = \frac{2e^2 m_e c}{3\hbar^2\omega}$	5.6×10^{24}	quantum effects
$a_p = \frac{m_p}{m_e}$	1.3×10^{24}	ultra - relativistic p
$a_{rad} = \left(\frac{3\lambda}{4\pi r_e}\right)^{1/3}$	1×10^{23}	radiation damping
$a_{rel} = 1$	1.3×10^{18}	relativistic e^-

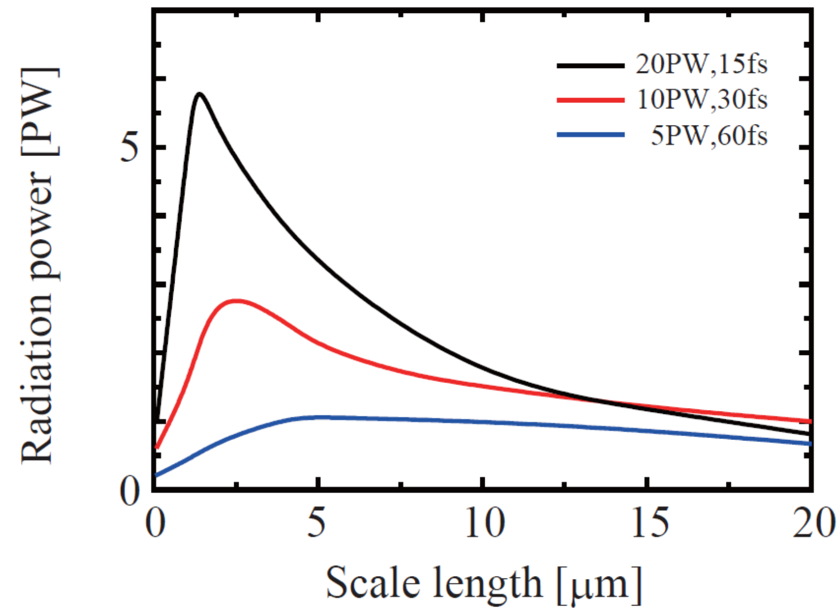
Summary of Laser-Plasma Interaction in "Radiation-Dominant" Regimes



Ultrarelativistic ELI
$a_0 > 2000$, E= 4 PV/m

Concept of high power gamma-flash generation





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High-Power γ-Ray Flash Generation in Ultraintense Laser-Plasma Interactions

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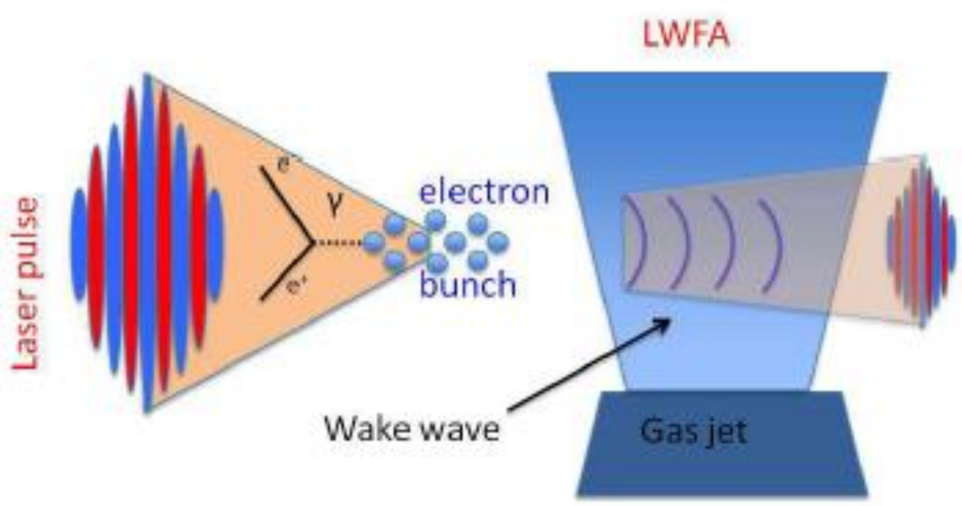
Laser-induced Nonlinear QED

Quantum description is necessary when the recoil due to photon emission is of the order of the electron energy → 10^{21} Wcm^{-2} for 10 GeV electrons



Stepan Bulanov et al, AAC 2012

Thank you for your kind attention!

For more info about the ELI Beamlines facility see http://www.eli-beams.eu