CLPU Centro de Láseres Pulsados

LA³NET

3rd School on Advanced Laser Applications and Accelerators

Salamanca 3rd October 2014

ELI-Extreme Light Infrastructures: An overview

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CLPU Centro de Láseres Pulsados

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Centro de Láseres Pulsados. Edificio M5. Parque Científico de la USAL. c/ Adaja, 8. 37185 Villamayor de la Armuña. Salamanca

Facilities

Big scientific facilities during last decades:

CLF - RAL

GSI – Phelix

LOA – Saclay

CILEX

MBI Berlin

CELIA

BESSY II

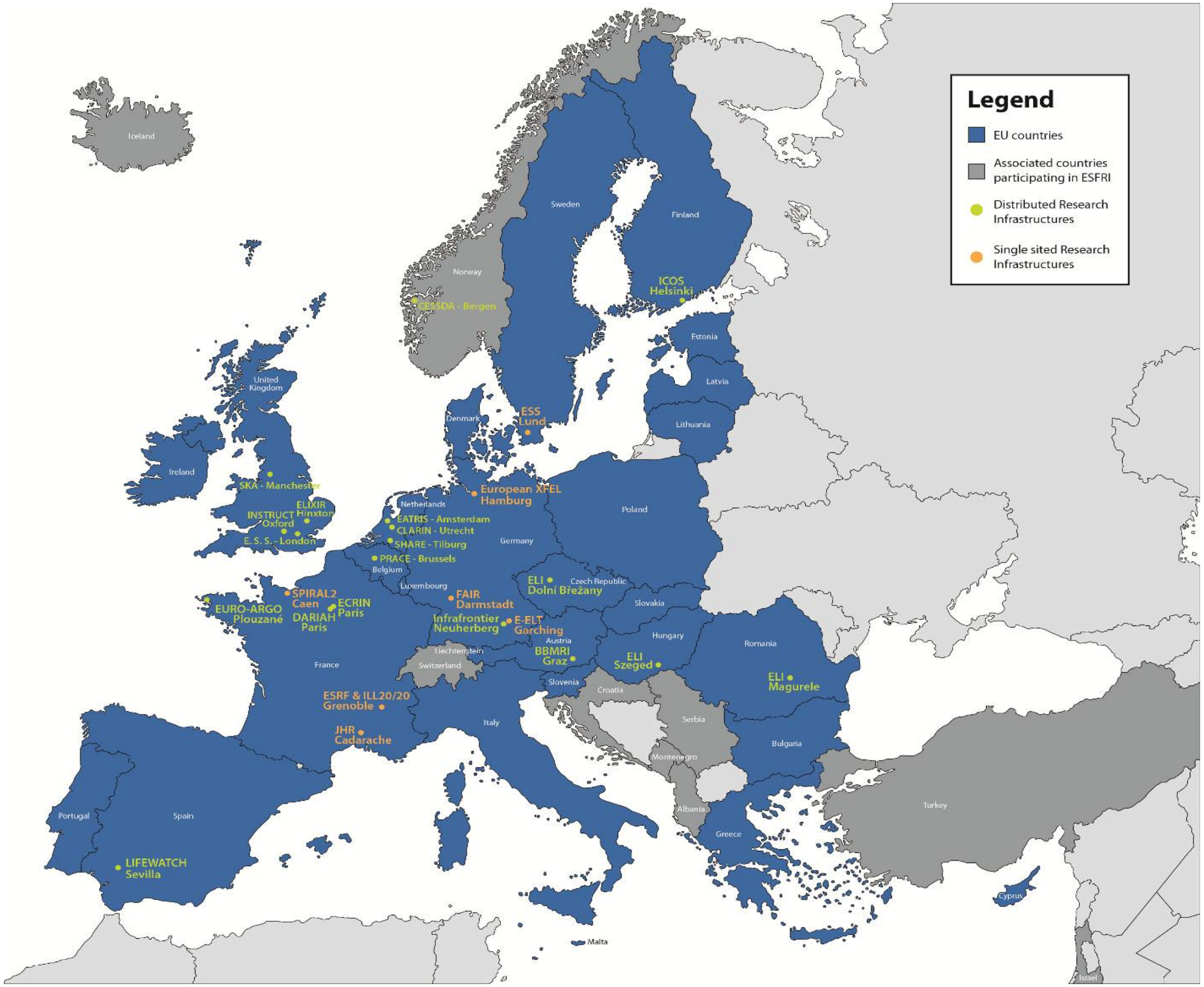
DESY

CERN

JUPITER – OMEGA

and more …

ESFRI map



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Leading-edge research based on advanced laser sources. This activity aims at furthering the integration of state-of-the art laser technology enabling a wide range of novel applications with high industrial and social impact, such as bio-and nanophotonics, (bio)material analyses, (bio)medical diagnosis and treatment, communication and data processing. Synergies with relevant ESFRI Infrastructures, such as European XFEL, EUROFEL and ELI, should be duly exploited.

LaserlabEurope

Laserlab Europe

The "**Integrated Initiative**" of European Laser Infrastructures
in the 7th Framework Programme of the European Union

30 leading institutions in laser-based inter-disciplinary research from 16 countries

Aligning one of the Ultra laser systems at CLF

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

UNIÓN EUROPEA
FONDO EUROPEO DE DESARROLLO REGIONAL
"Una manera de hacer Europa"

CLPU CENTRO DE LÁSERES PULSADOS

LaserLab IV proposal

An Integrating Activity shall combine, in a closely co-ordinated manner:
(i) **Networking activities**, to foster a culture of co-operation between research infrastructures, scientific communities, industries and other stakeholders as appropriate, and to help developing a more efficient and attractive European Research Area;
(ii) **Trans-national access or virtual access activities**, to support scientific communities in their access to the identified research infrastructures;
(iii) **Joint research activities**, to improve, in quality and/or quantity, the integrated services provided at European level by the infrastructures.

JRA proposal:
1 Biomedical Optics for Life Science Applications (BIOAPP)
2 Innovative Laser Technologies (ILAT)
3 Photonic Techniques for Material Analysis, Nano-science and Sensing (PHOTMAT)
4 Laser-driven High Energy Photon and Particle Sources towards Industrial and Societal Applications (LEPP)

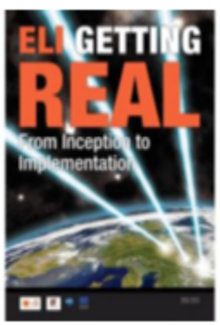
History of ELI

2005: Idea of an Extreme Light Infrastructure (ELI) by G. Mourou

eli extreme light infrastructure

2007: ELI enters PP and ESFRI roadmap

13 countries; >300 projects



2010: ELI-PP Gives over to ELI-NP/ELI-ALPS/ELI-BEAMS

2011 — eli beamlines

2012 — eli Nuclear Physics

2013 — ELI-ALPS

→ eli delivery consortium

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The ELI Project

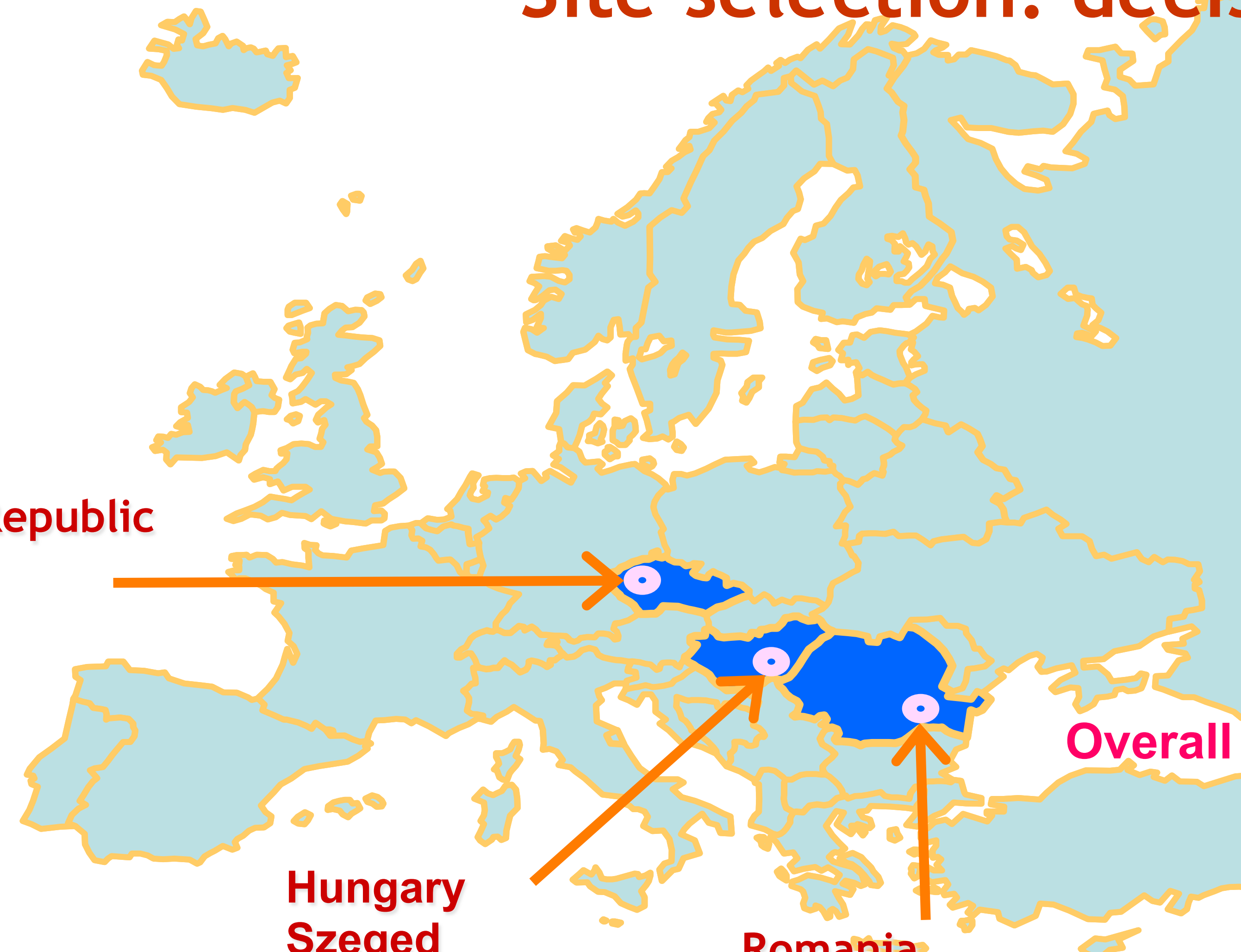
ELI will be the world's first international laser research infrastructure, pursuing unique science and research applications for international users.

ELI will be implemented as a distributed research infrastructure based initially on 3 specialised and complementary facilities located in the Czech Republic, Hungary and Romania.

ELI is the first ESFRI project to be fully implemented in the newer EU Member States.

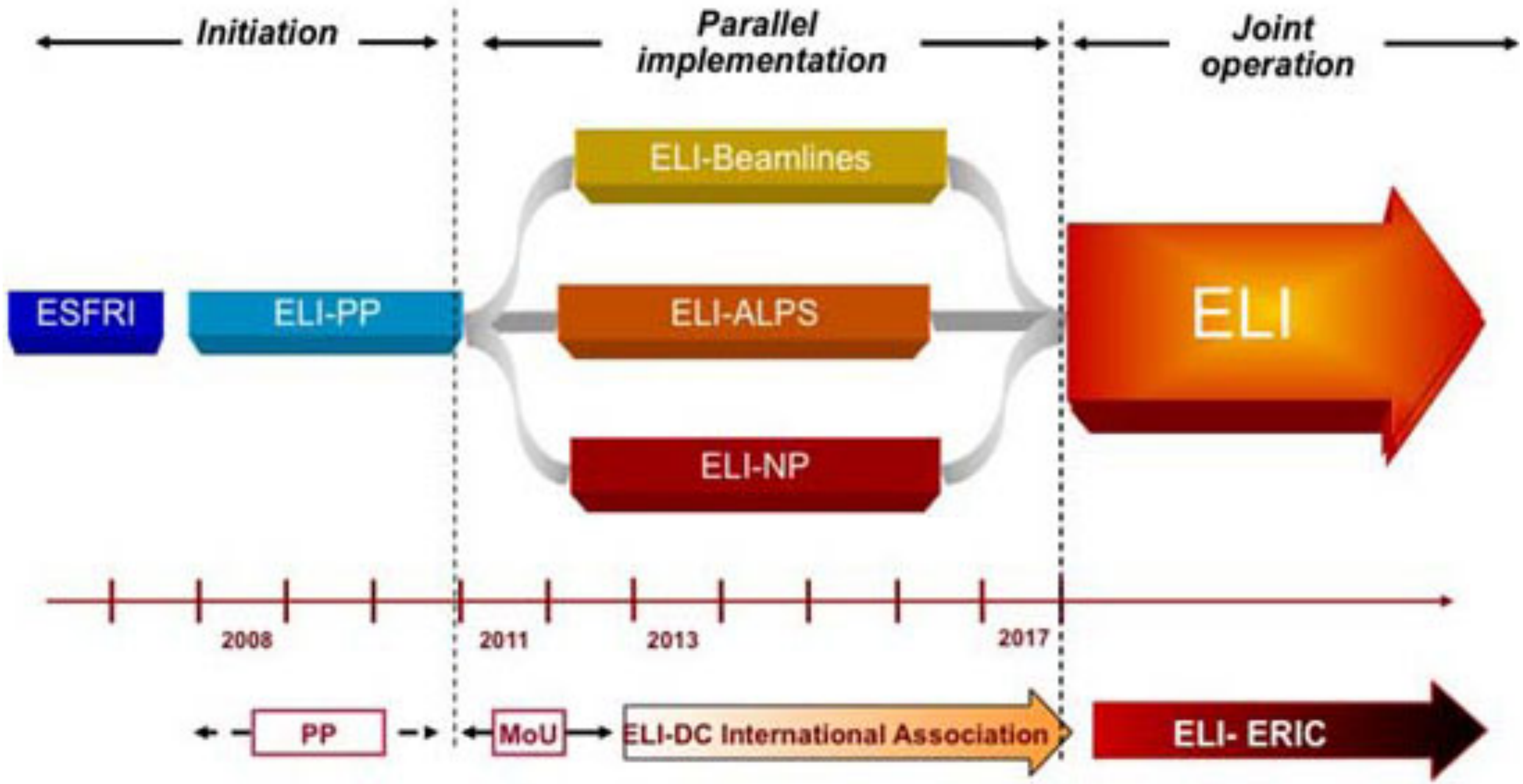
ELI is pioneering a novel funding model combining the use of EU structural funds (ERDF) for the implementation, and member contributions to a yet to be established European Research Infrastructure Consortium ERIC for the operation.

Site selection: decision on 2011

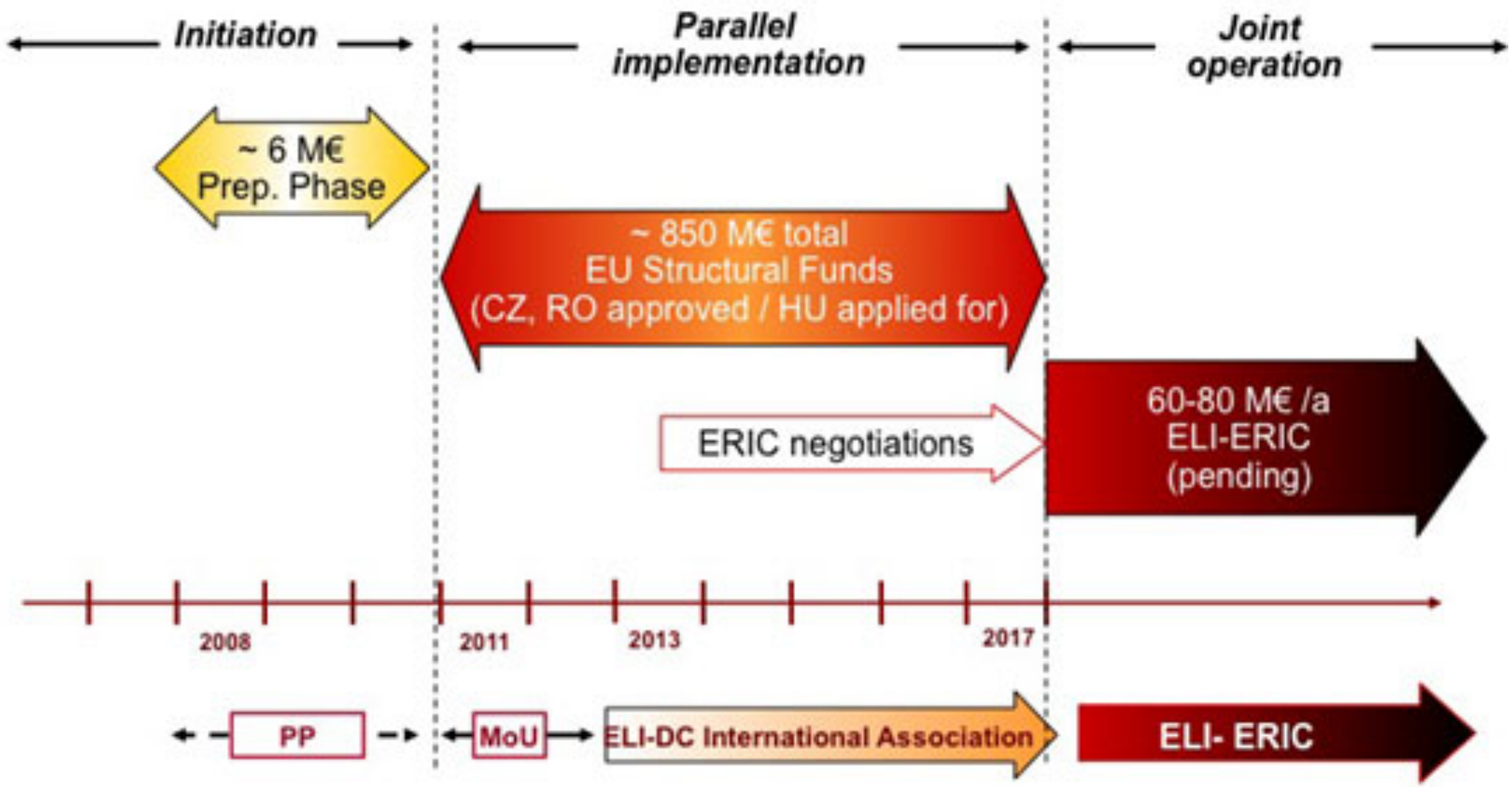


Overall cost: ≈850M€

Timeline of ELI



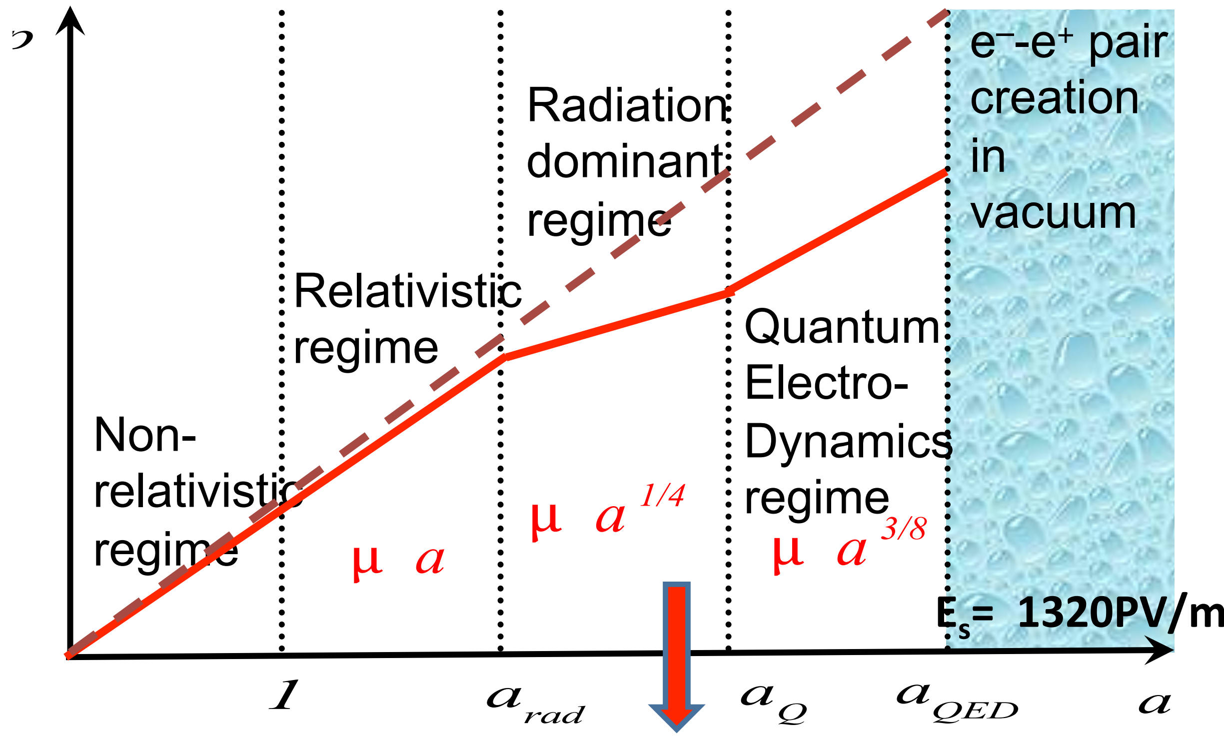
Budget evolution for ELI



CENTRO DE LÁSERES PULSADOS

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

Amplitude $\left[a_0 = \frac{eE_0}{m_e c\omega}\right]$	Intensity $\left[\frac{W}{cm^2}\right]$	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^-



Currently
$I_{max} = 10^{22}$ W/cm²
ELI pushes the limits by more than 2 orders

$a^c_{rad} = 408 \quad \gamma = 70$ MeV

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

CENTRO DE LÁSERES PULSADOS

WhiteBook

530 pages
Science, technology and implementation strategies of ELI

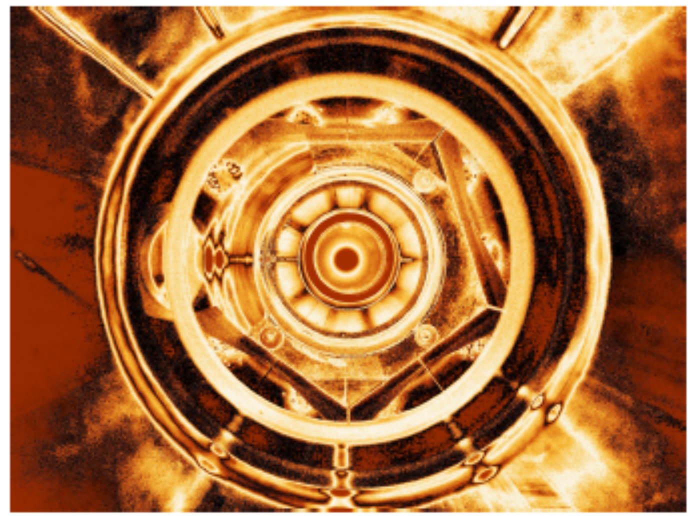
> 170 authors

http://cswiki.eli-beams.eu/public/ELI_White_Book-092010.pdf

ELI – Extreme Light Infrastructure

Science and Technology with
Ultra-Intense Lasers

WHITEBOOK



Editors
Gérard A. Mourou
Georg Korn
Wolfgang Sandner
John L. Collier

CLPU CENTRO DE LÁSERES PULSADOS

ELI pillars

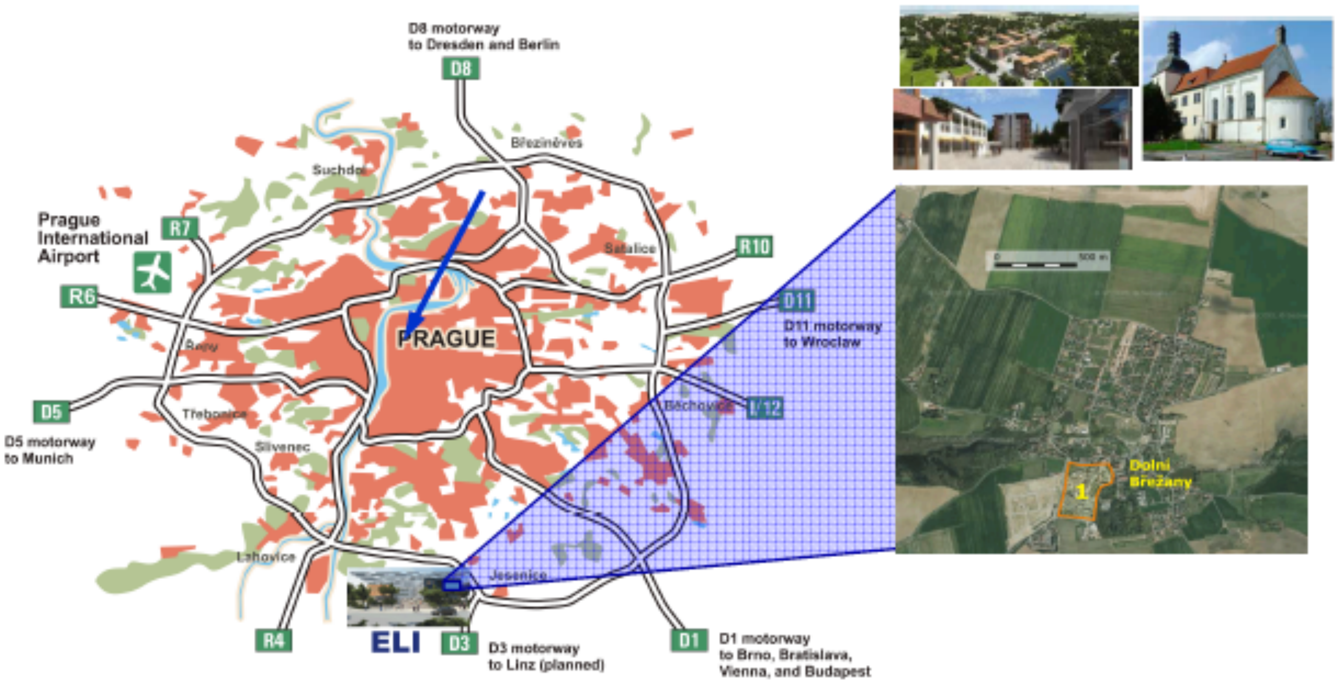
ELI-ALPS, Hu → Attosecond XUV/X-ray physics
Applications in material sciences and biology

ELI-Beamlines, Cz → High-brightness sources of X-rays & particles
Molecular & biomedical sciences, particle acceleration, dense plasma physics, exotic physics

ELI-NP, Ro → Laser-induced nuclear physics
Photonuclear science and applications

Site to be determined — **High-intensity development** → Exawatt-class laser technology
High-intensity laser technologies for frontier physical research

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

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.

Fyzikální ústav
Akademie věd ČR, v. v. i.
projekt podporovaný:
EVROPSKÁ UNIE
EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ
INVESTICE DO VAŠÍ BUDOUCNOSTI
OP Výzkum a vývoj pro inovace

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, B. Rus

Research Program 2
X-ray sources driven by rep-rate ultrashort laser pulses, S. Sebban

Research Program 3
Particle acceleration by lasers, D. Margarone

Research Program 4
Applications in molecular, biomedical, and material sciences, J. Andreasson

Research Program 5
Laser plasma and high-energy-density physics, S. Weber

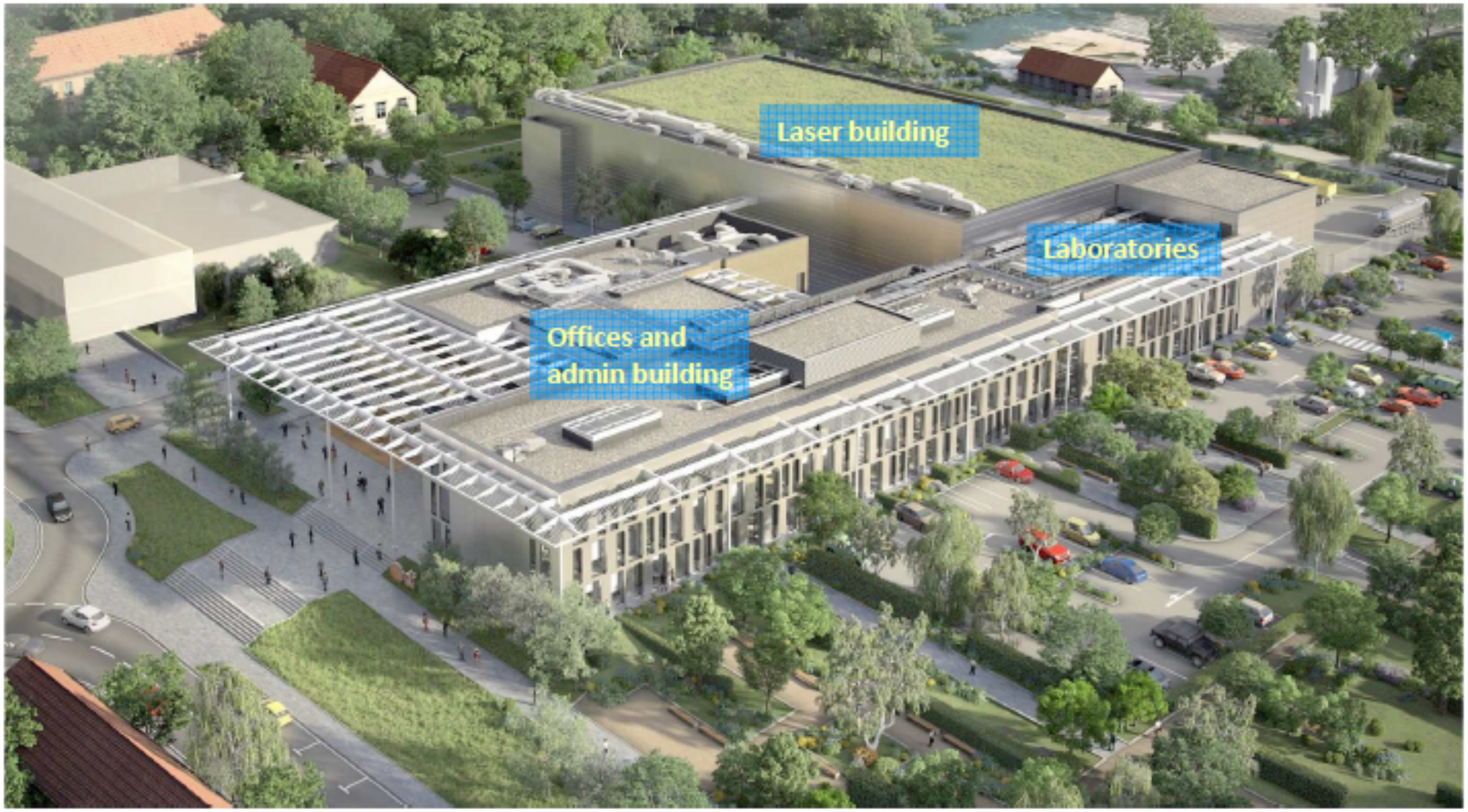
Research Program 6
High-field physics and theory (steps to 10^{23}W/cm^2, radiation reaction plays role)

eli beamlines

ELI project background

May 2010	ELI-Beamlines pre-approved for funding
Apr 2011	ELI-Beamlines funding approved by EC
Aug 2011	Funding (278 M€) signed by the Czech Rep's Ministry of Education, Sports and Youth
Dec 2012	Agreement from EC to deliver facility after 2015 European Regional Development Fund (infrastructural funds)
May 2013	Facility 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
2018	Facility commissioning and start of user action

ELI-Beamlines facility aerial view




2014-03-04 10:19:49 ELI ze sila smer HILASE

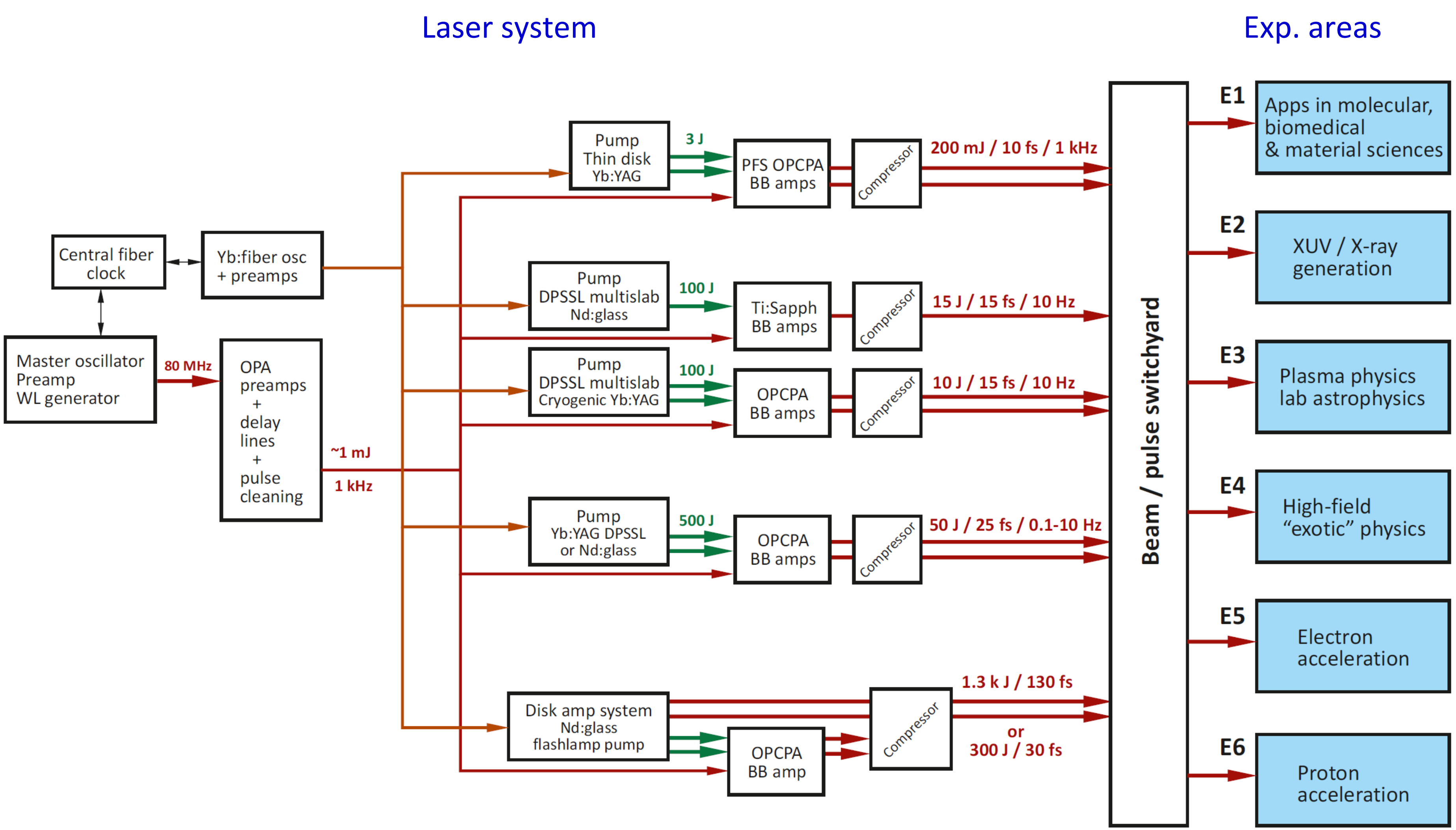

2014-03-04 10:21:51 ELI ze sila smer hriste

- ✓ ELI pillars and ELI-Beamlines
- ✓ Facility layouts
- ✓ **Lasers (RP1)**
- ✓ Beam transport and switchyard
- ✓ Experiments (RP2-RP6)
- ✓ RP3 (ion and electron acceleration)

Research Program 1 (Lasers) team: 42 people

11 Senior Researchers, 18 Junior Researchers, 9 Engineers/ Technicians, 4 Support

ELI Beamlines facility laser



Technologies of rep-rate pump lasers for ELI-Beamlines

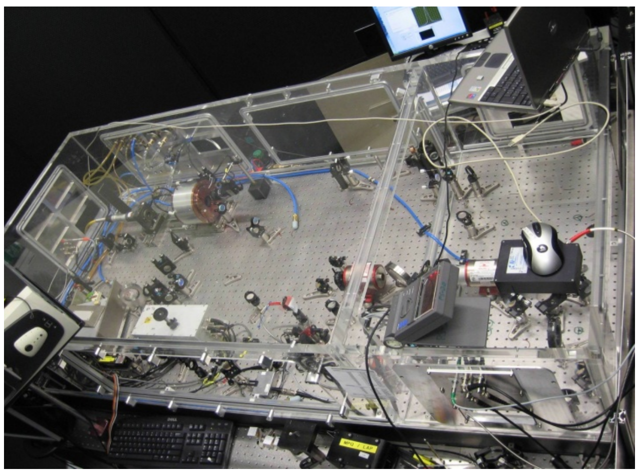
Thin disk pump technology

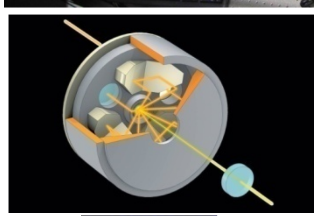
Development at MPQ/LMU/MBI

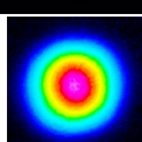
ELI: cooperation on scaling to >kW avg power
0.5 kW 1.5ps, 3kHz

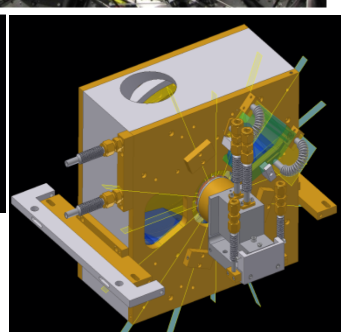
Multislab pump technology

LLNL - Mercury 60J/10Hz,
Development of cryogenic Yb:YAG at RAL
ELI: cooperation on dev't of 500 J/10 Hz cryogenic amps, HILASE

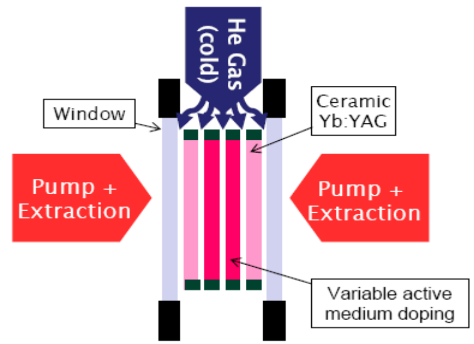


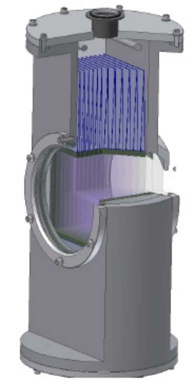


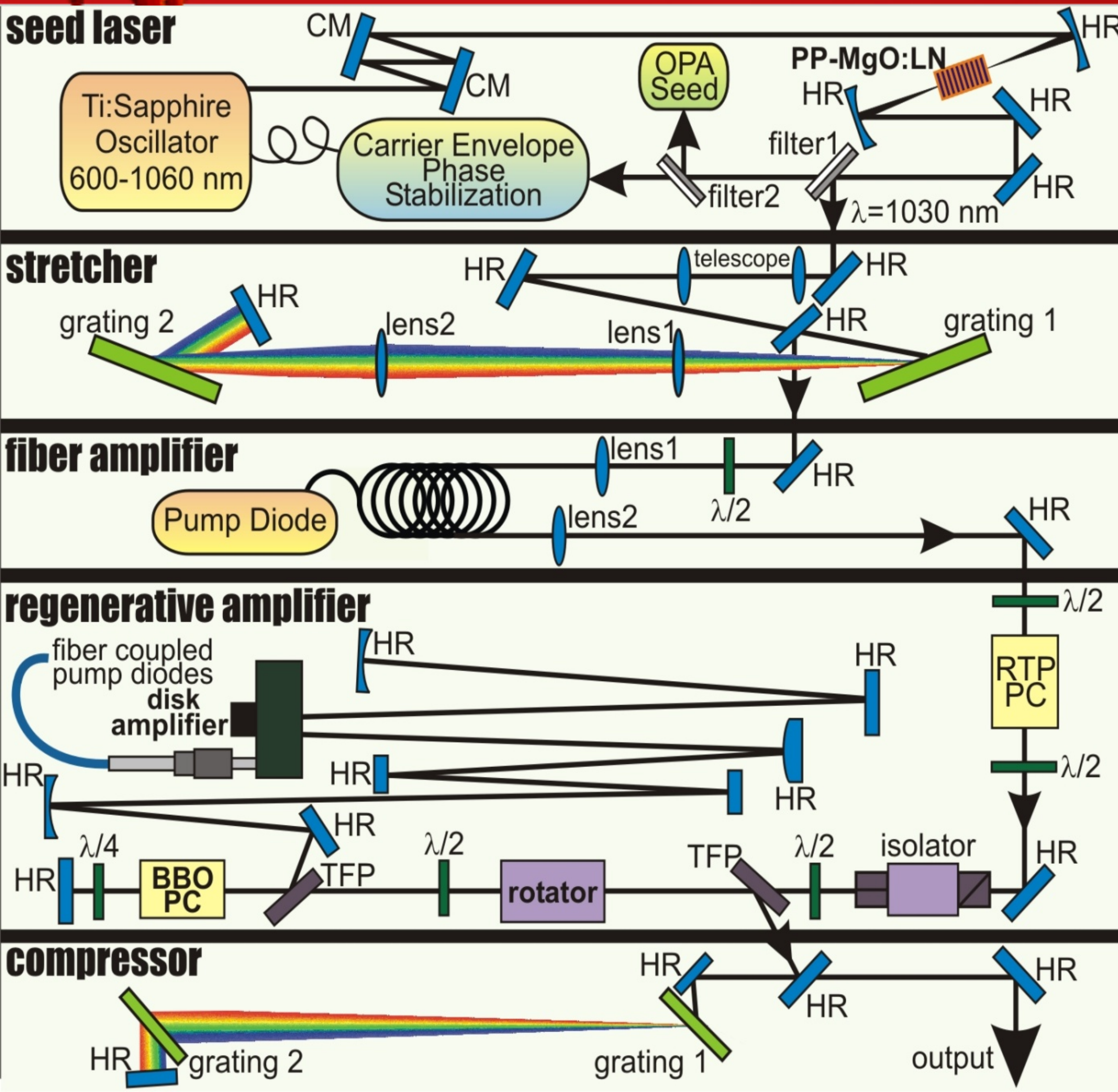




Design of 25 kW head

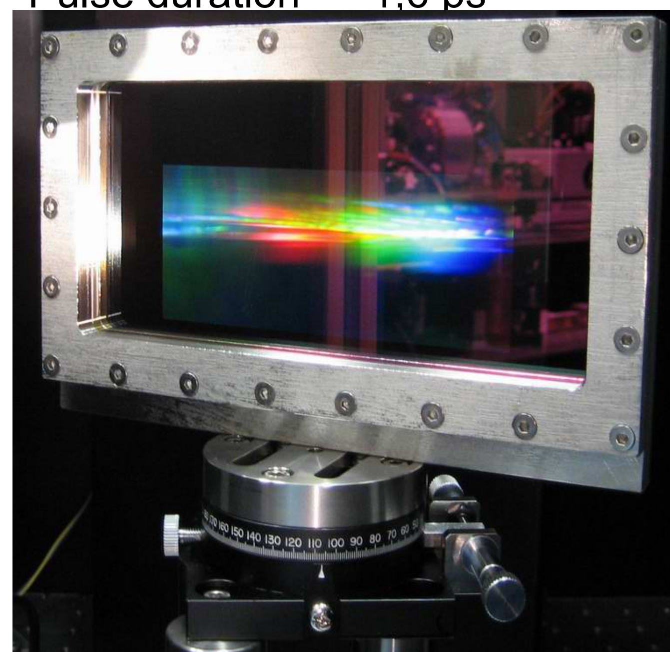






Compressor (negative GDD)
(Uni Jena 1400 Lines/mm):

Bandwidth	~1 nm @ 1030 nm
GDD	~ -10^{8} fs²
Efficiency	~ 77 %
Pulse duration	1,6 ps

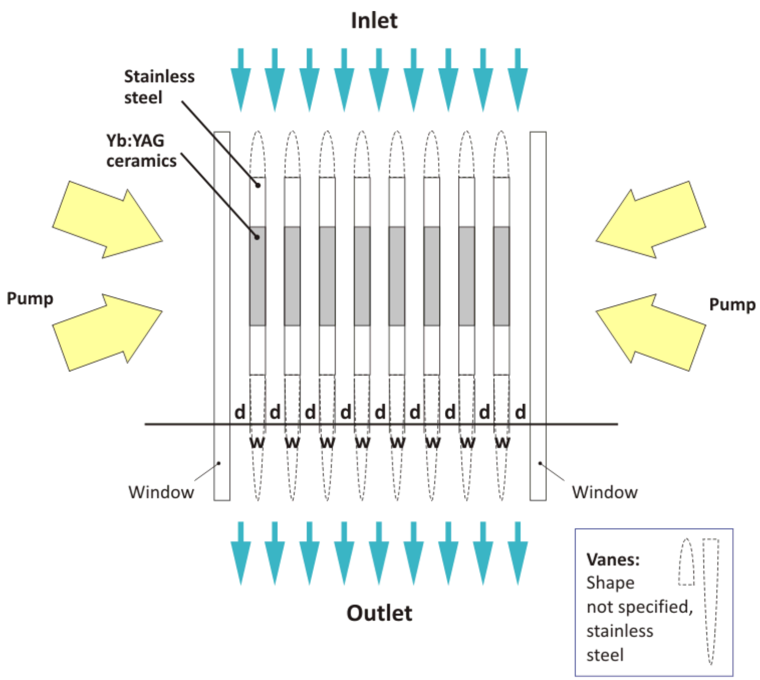


0.5 kW ; 1J-2 J, 1 kHz staging for pumping the OPCPA, 1 kHz, Common effort, MPQ, court.T. Metzger

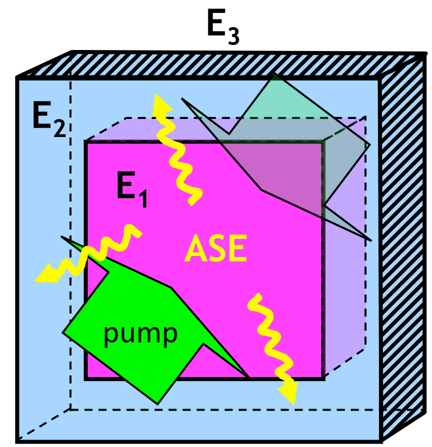
Modelling of ASE losses and energy budget in multislab lasers

Design phase of 500 J/ 10 Hz multislab amplifiers
(collaboration with Rutherford Appleton Laboratory)

Baseline model



8 Yb:YAG slabs, each 8 mm thick
Nominal operation temp. 170K



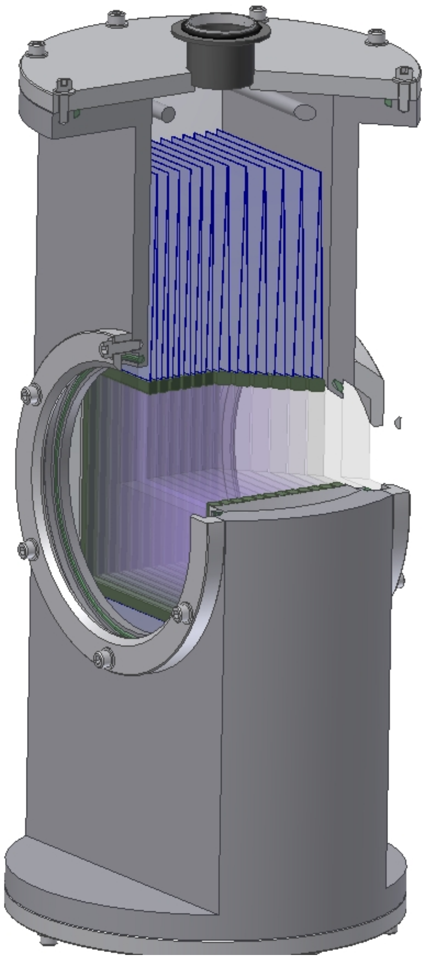
Heat sources in the crystal:

- Transition (>11 %):
  - Stokes defect
  - Quantum efficiency (non-radiative)
- Radiative (>35 %)
  - Absorption on impurities
  - Absorption on the ASE absorber
  - Higher orders effects (colective absorption)

- ASE losses can be limited by MLD absorptive coating or Cr:YAG absorber
- Heat conduction calculations predict < 4 K temperature non-uniformity

M. Divoký et al.   Numerical evaluation of heat deposition in cryogenically cooled multi-slab amplifier

Concept for 1 kJ DPSSL Amplifier, RAL design HILASE, HIPER



- Beam size 14 x 14 cm^2 ⇨ 5 J/cm^2 extraction fluence (safe?)
- 2 Amplifier heads
- Pump 5kW/cm^2 each side for 1 ms
- $\Delta\lambda_{pump}$ = 5 nm, $\lambda_{c,pump}$ = 939 nm
- Combined pump power 4 MW ⇨ need to reach 25% o-o efficiency
- 175 Kelvin (or lower)
- 12 slabs, variable doping
- ASE control: g_o*l < 3 along diagonal

HiLASE project

Institute of Physics AS CR

30 M € Diode pumped Lasers for applications

New lasers for industry and research

- High average power pulsed LASErs

- Czech national project on development of advanced solid-state laser technologies based on diode pumping

- Motivated by strong need for head-start laser technology development & prototyping for the next generation of high rep. rate laser facilities

- Potential of industrial applications using rep. rate, high-peak and high-average power lasers

- Implementation phase: 4 years (fully supported)
- Operational phase: ALAP (institutional/grants/contractual)

Electron acceleration (LWFA) with 10 PW laser pulses

Generating sub-TeV quasi-monoenergetic proton beam by an ultra-relativistically intense laser in the snowplow regime

F.L.Zheng,[1,2] H.Y.Wang,[1] X.T.He,[1,3,*] J.E.Chen,[1] Y.R.Lu,[1]
Z.Y.Guo,[1] G.Mourou,[4] T.Tajima,[5] and X.Q.Yan[1,†]

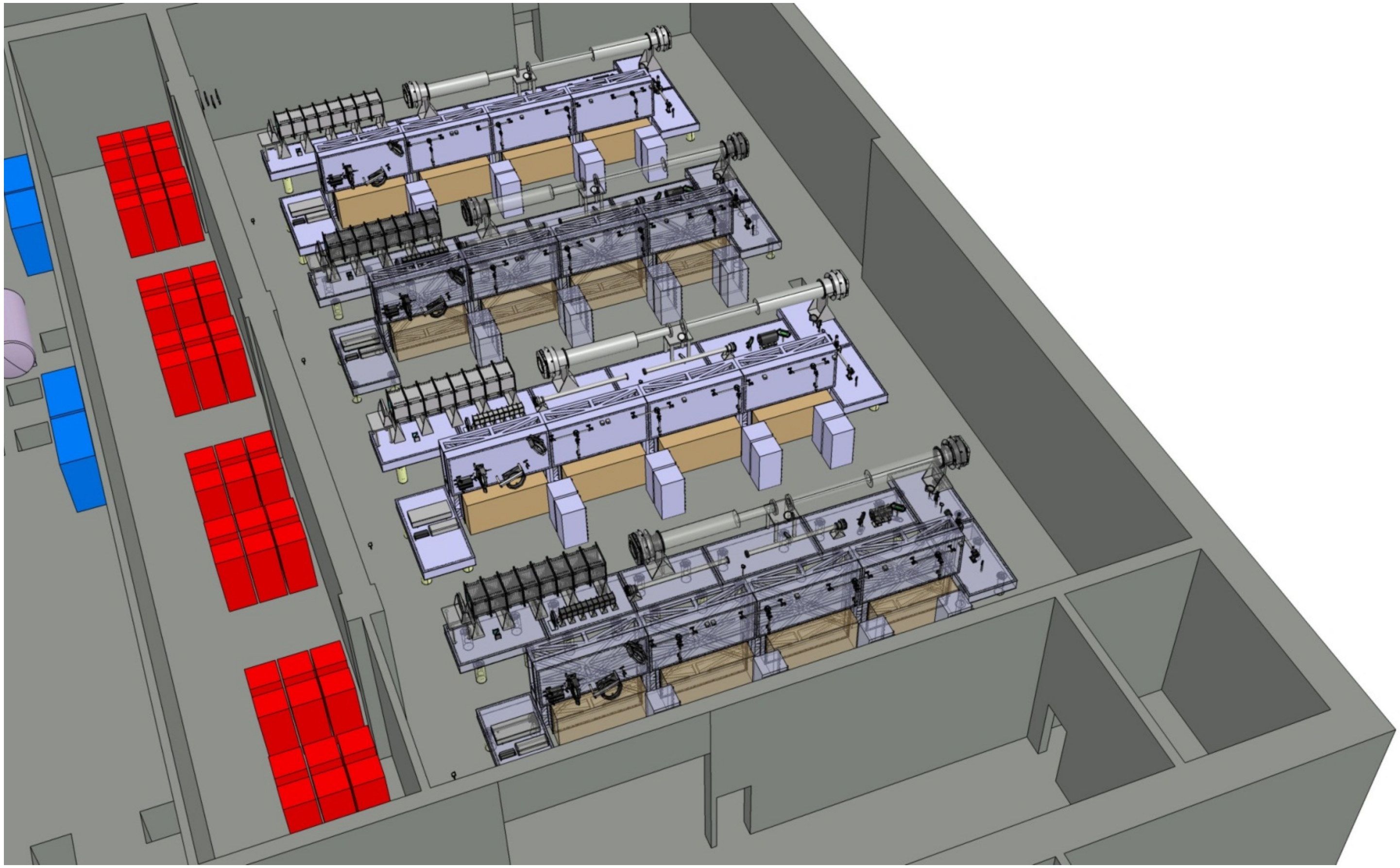
Abstract

Snowplow ion acceleration is presented, using an ultra-relativistically intense laser pulse irradiating on a combination target, where the relativistic proton beam generated by radiation pressure acceleration can be trapped and accelerated by the laser plasma wakefield. The theory suggests that sub-TeV quasi-monoenergetic proton bunches can be generated by a centimeter-scale laser wakefield accelerator, driven by a circularly polarized (CP) laser pulse with the peak intensity of 10^{23}W/cm^2 and duration of 116fs.

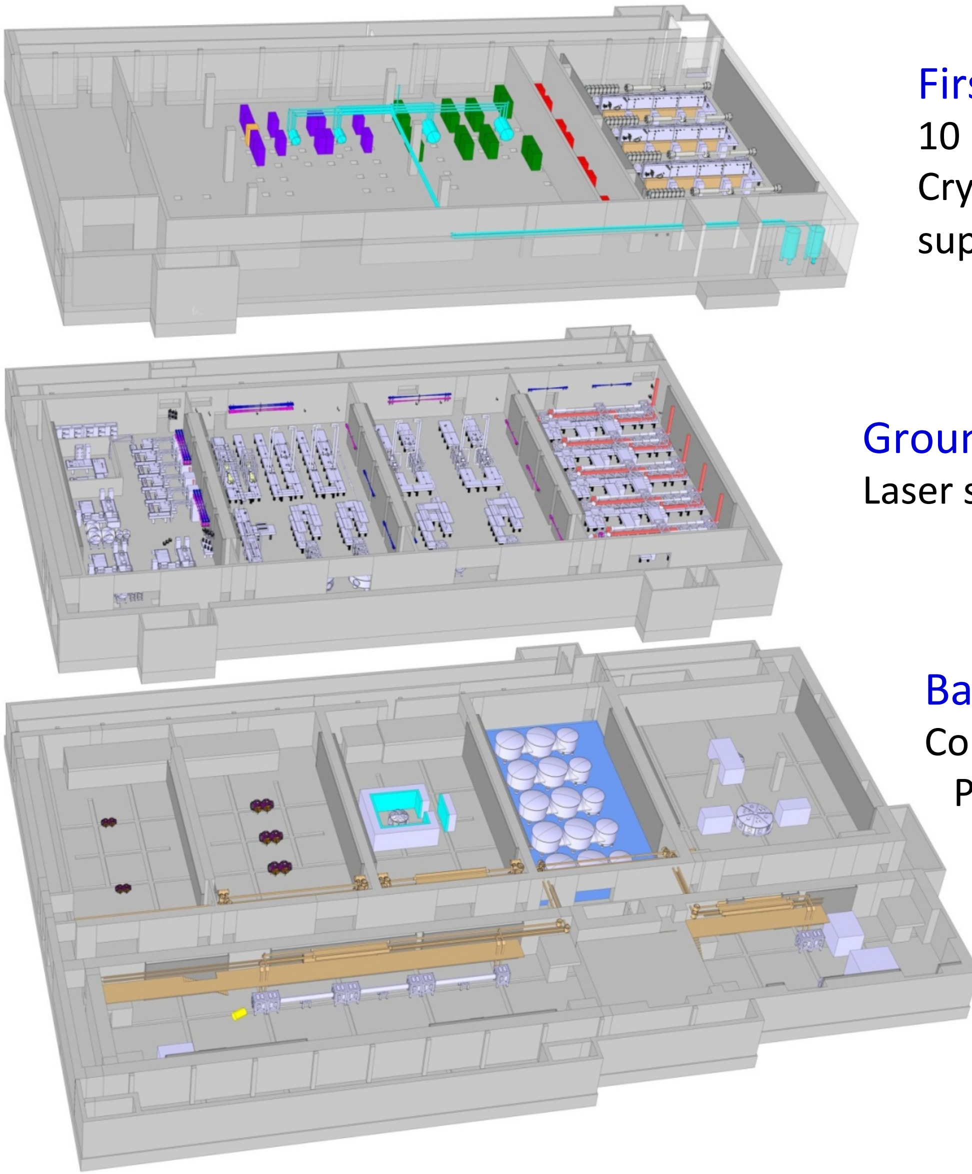
Submitted

10 PW pump lasers (1st floor)

If available, disk lasers providing kJ energy and bandwidth >12 nm (~130 fs pulses) would be an excellent choice for e- acceleration! Back up for OPCPA



ELI-Beamlines layout



First floor

10 PW pump lasers

Cryogenic & thermal management support systems

Ground floor

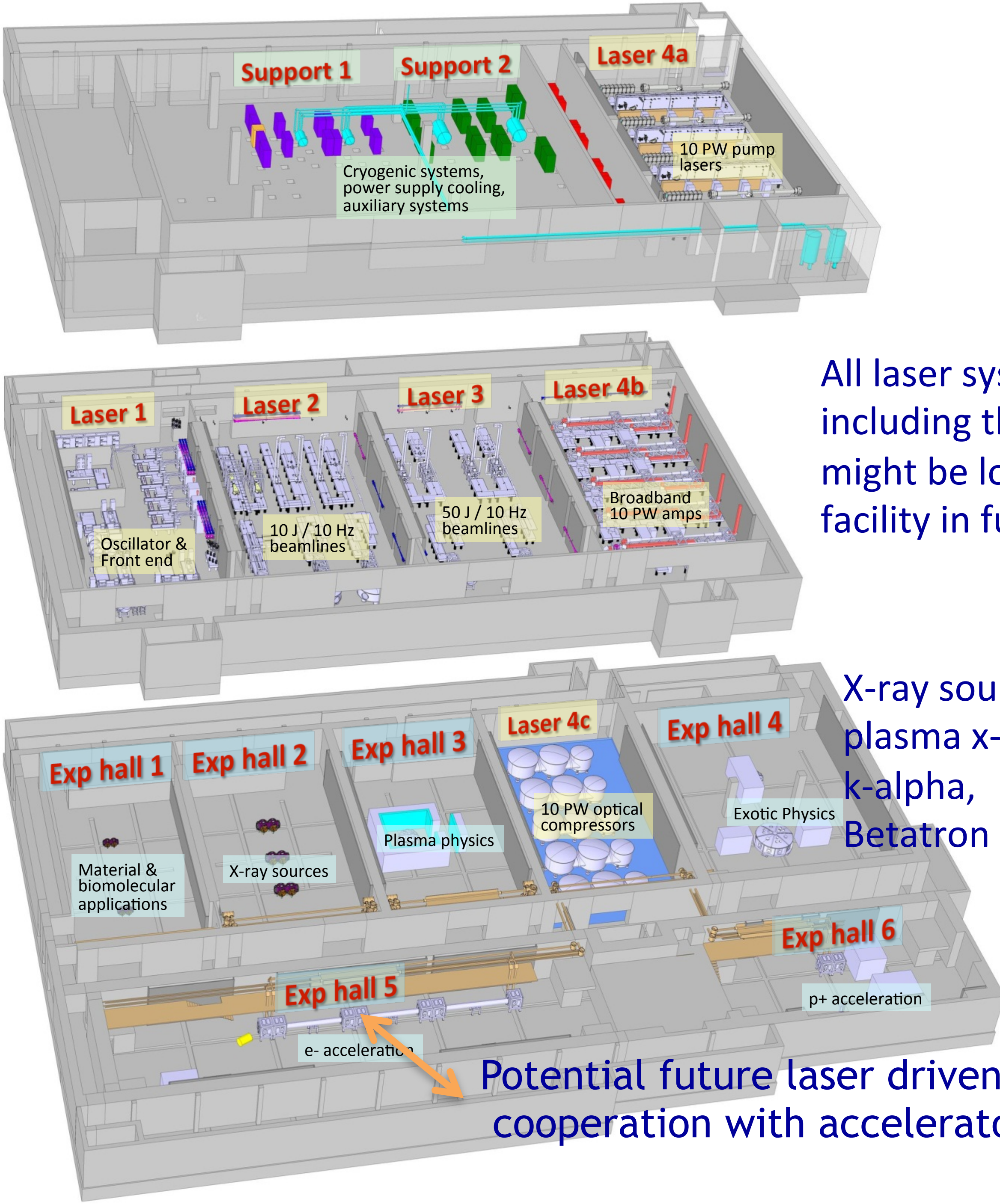
Laser systems

Basement

Compressor hall of 10-PW beamlines

Pulse distribution

6 dedicated experimental areas



All laser systems shown, including those which might be located at the facility in future

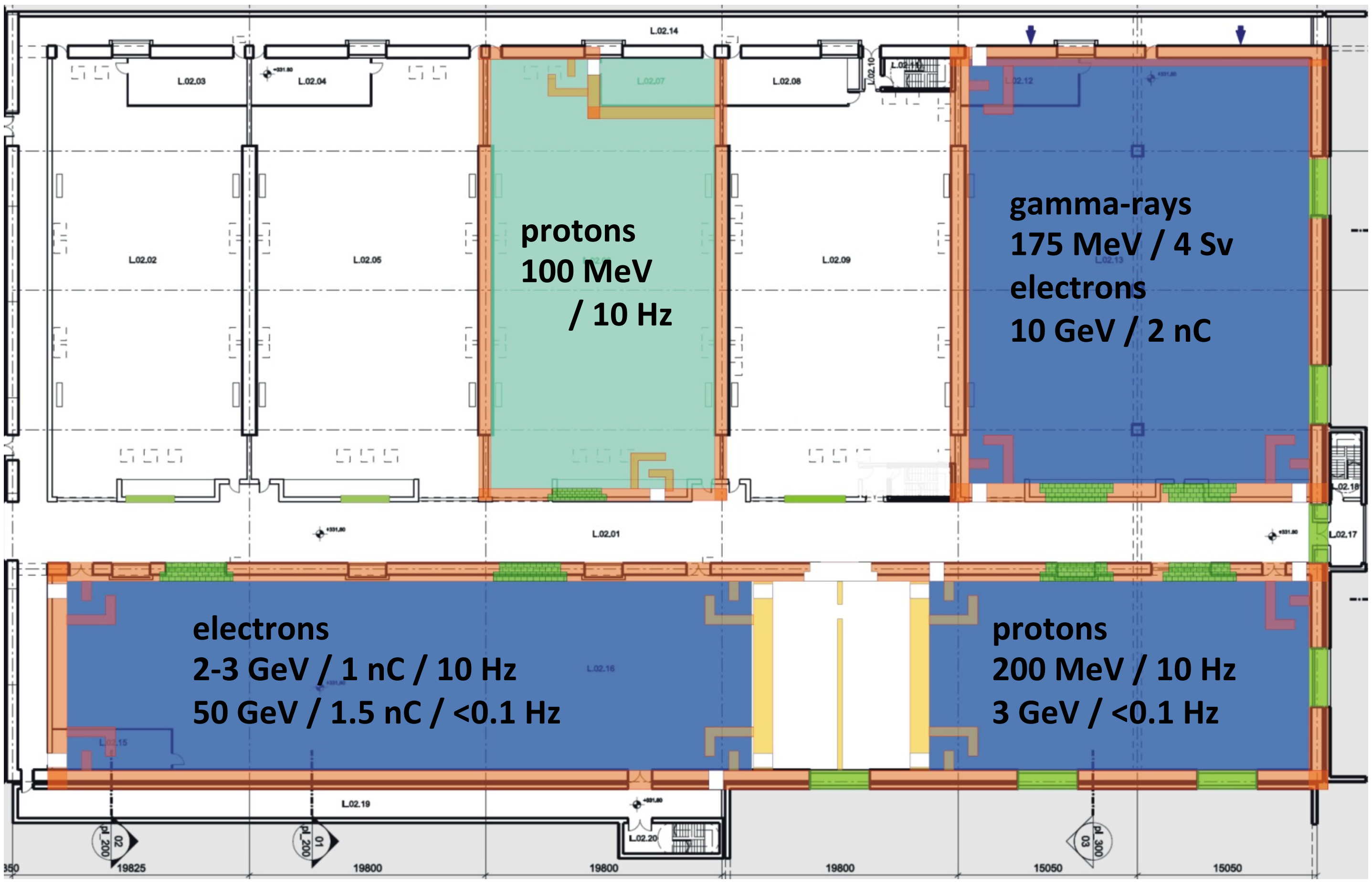
X-ray sources:
plasma x-ray laser (seeded),
k-alpha,
Betatron

Potential future laser driven FEL
cooperation with accelerator people (import

Underground target areas with shielding

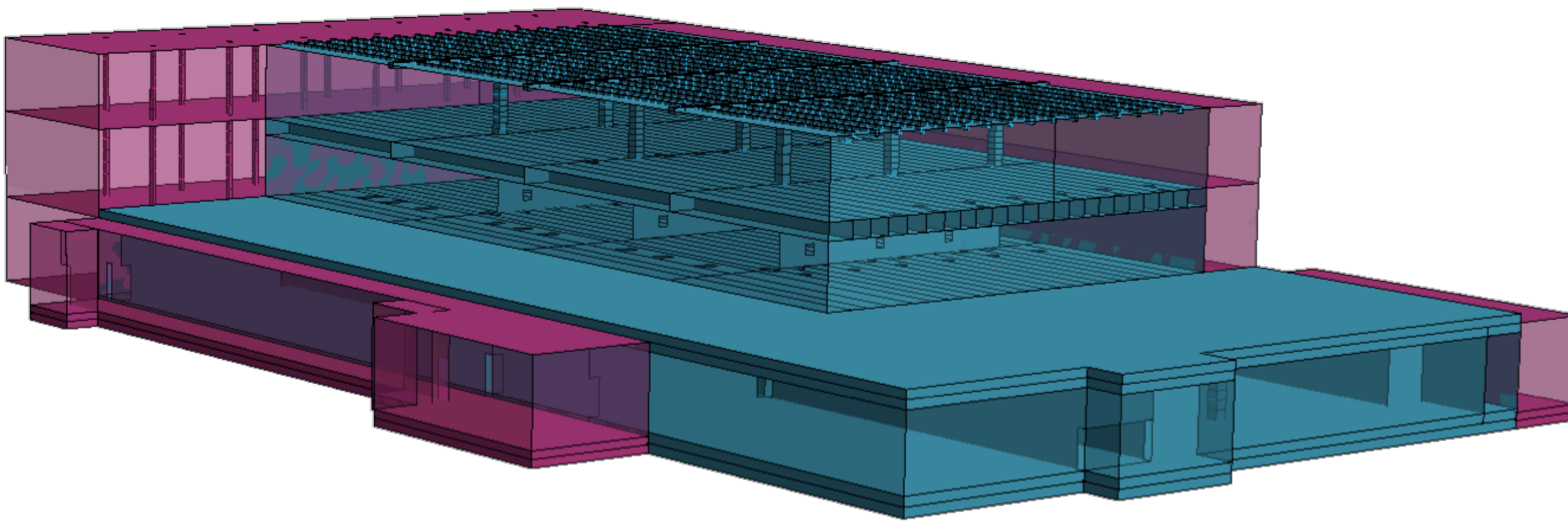
Combination of bulk shielding and local shielding (beam dumps)

Radiological classification: Control rooms are class R1, accumulated annual dose <1mSv



Vibration analysis of the laser building

Master structural model



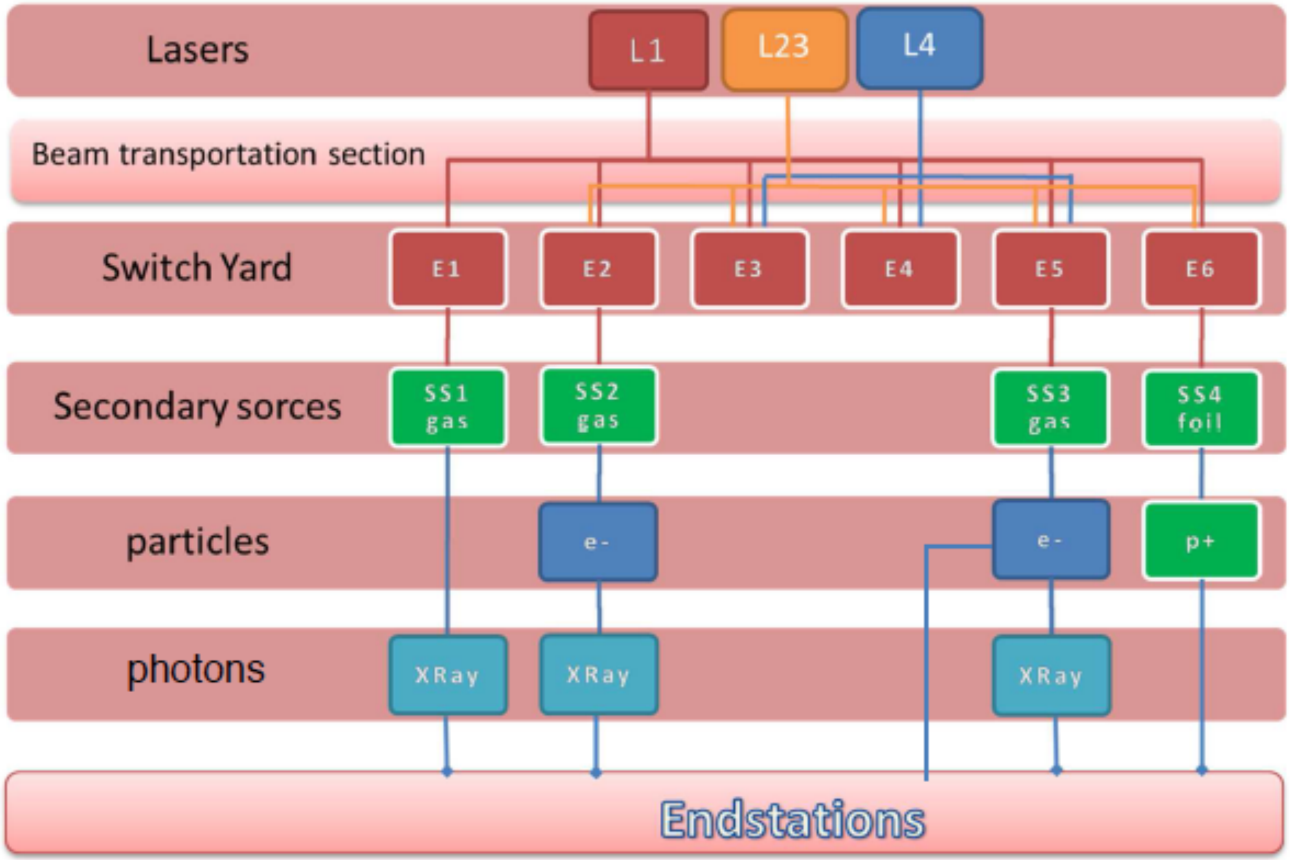
Monolithic structure (laser and experimental areas)

Supporting technologies (air conditioning, vacuum pumps, etc.) **& auxiliary laboratories**

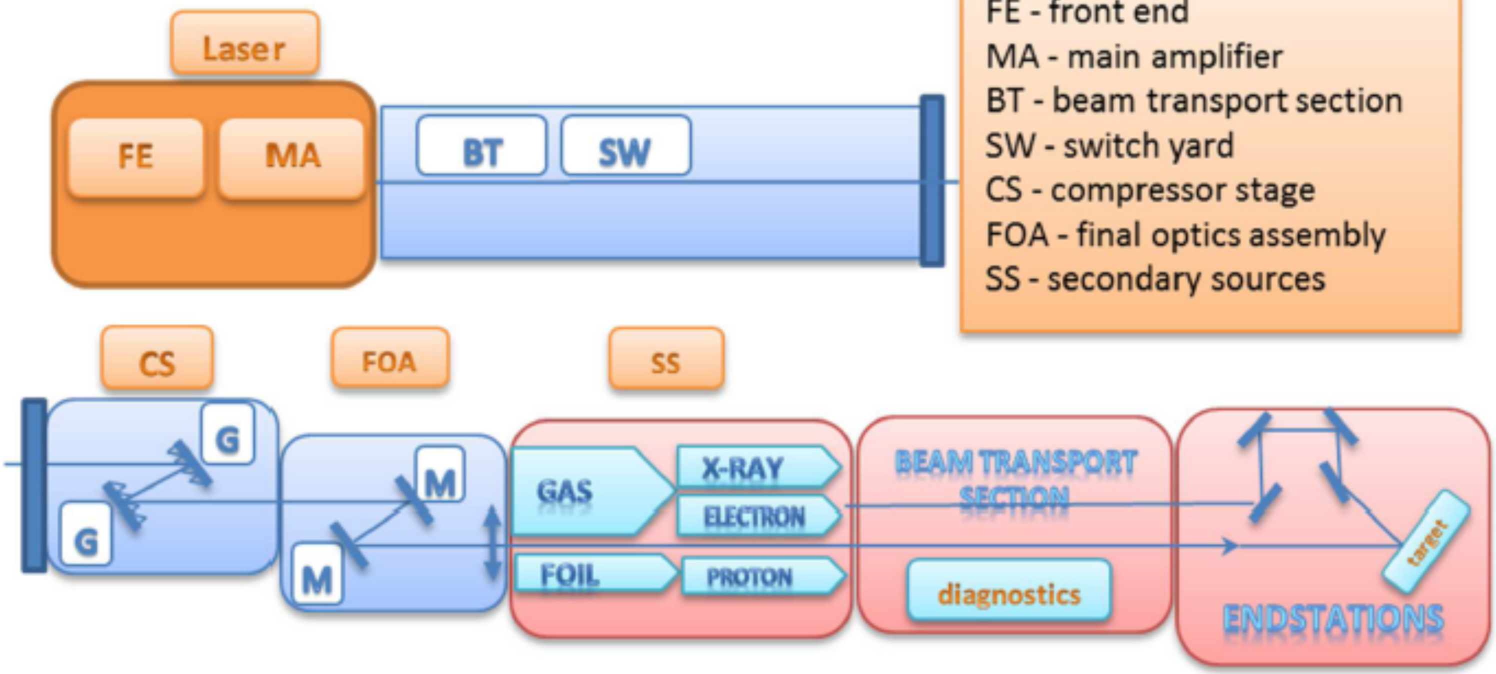
The analysis accounts for actual sources of vibration measured on the site

- ✓ ELI pillars and ELI-Beamlines
- ✓ Facility layouts
- ✓ Lasers (RP1)
- ✓ **Beam transport and switchyards**
- ✓ Experiments (RP2-RP6)
- ✓ RP3 (ion and electron acceleration)

Facility general layout



Beamline general layout

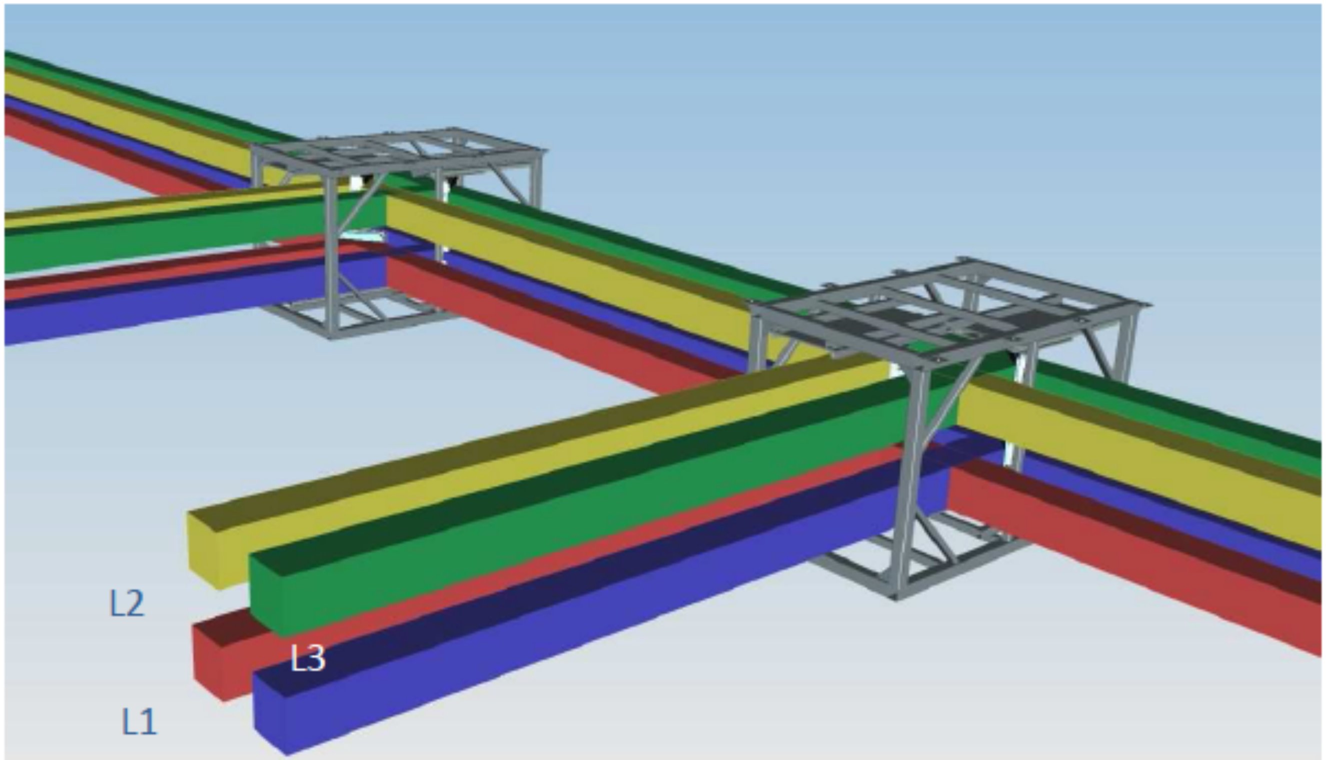


FE - front end
MA - main amplifier
BT - beam transport section
SW - switch yard
CS - compressor stage
FOA - final optics assembly
SS - secondary sources

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

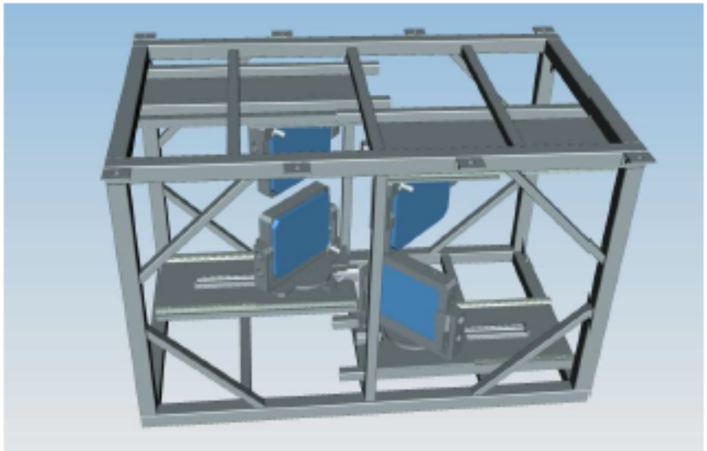
Beam transport and switchyards

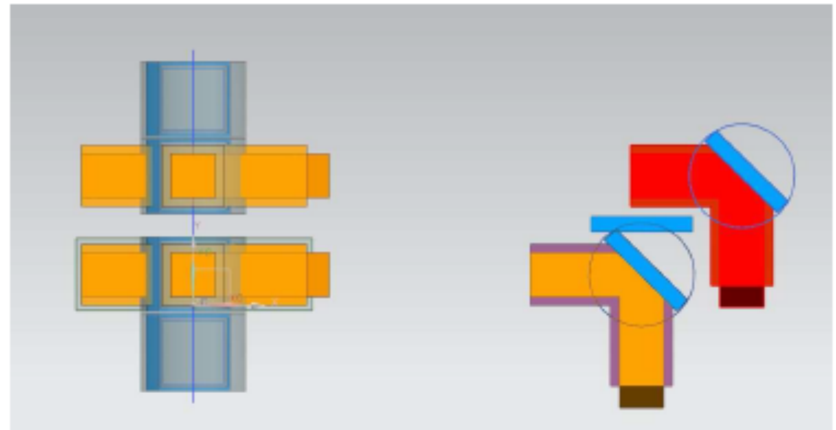
All laser beamlines can be delivered to any of the experimental rooms!

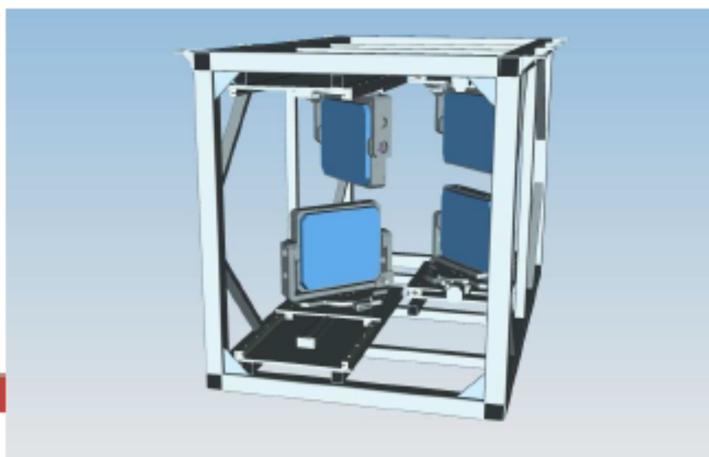


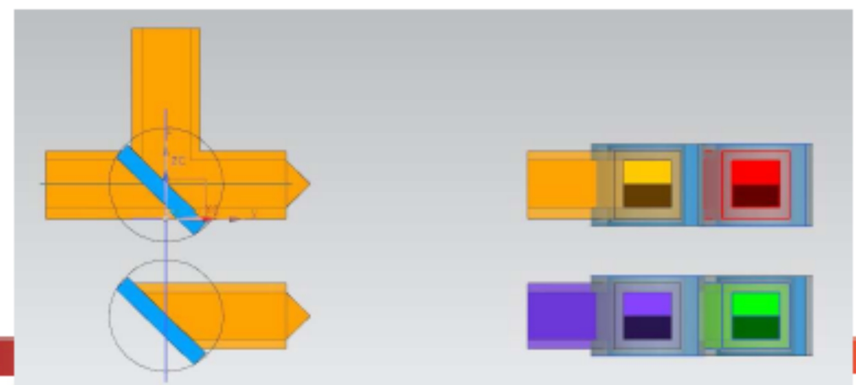
eli beamlines

Beam transport and switchyard 1





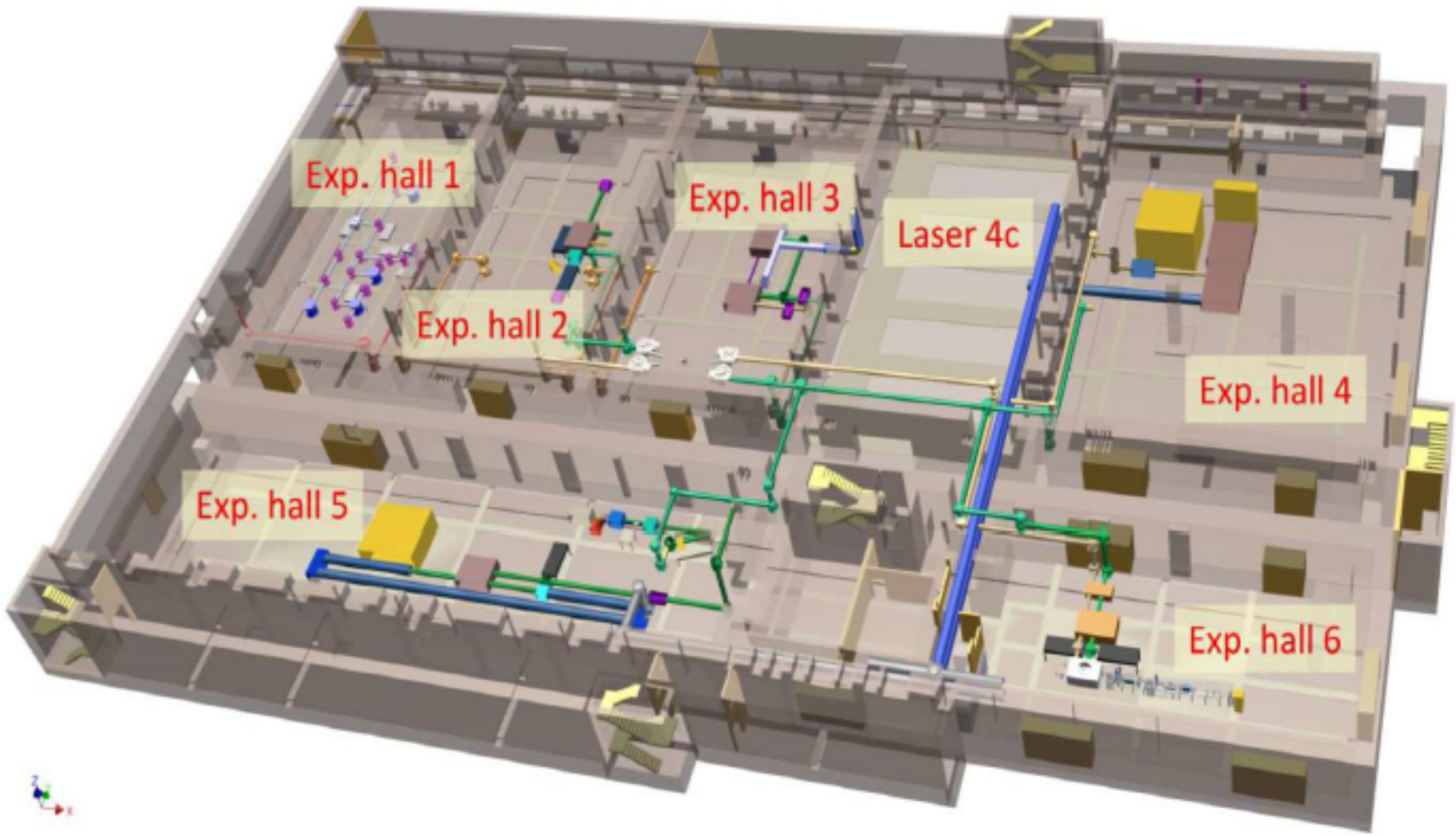




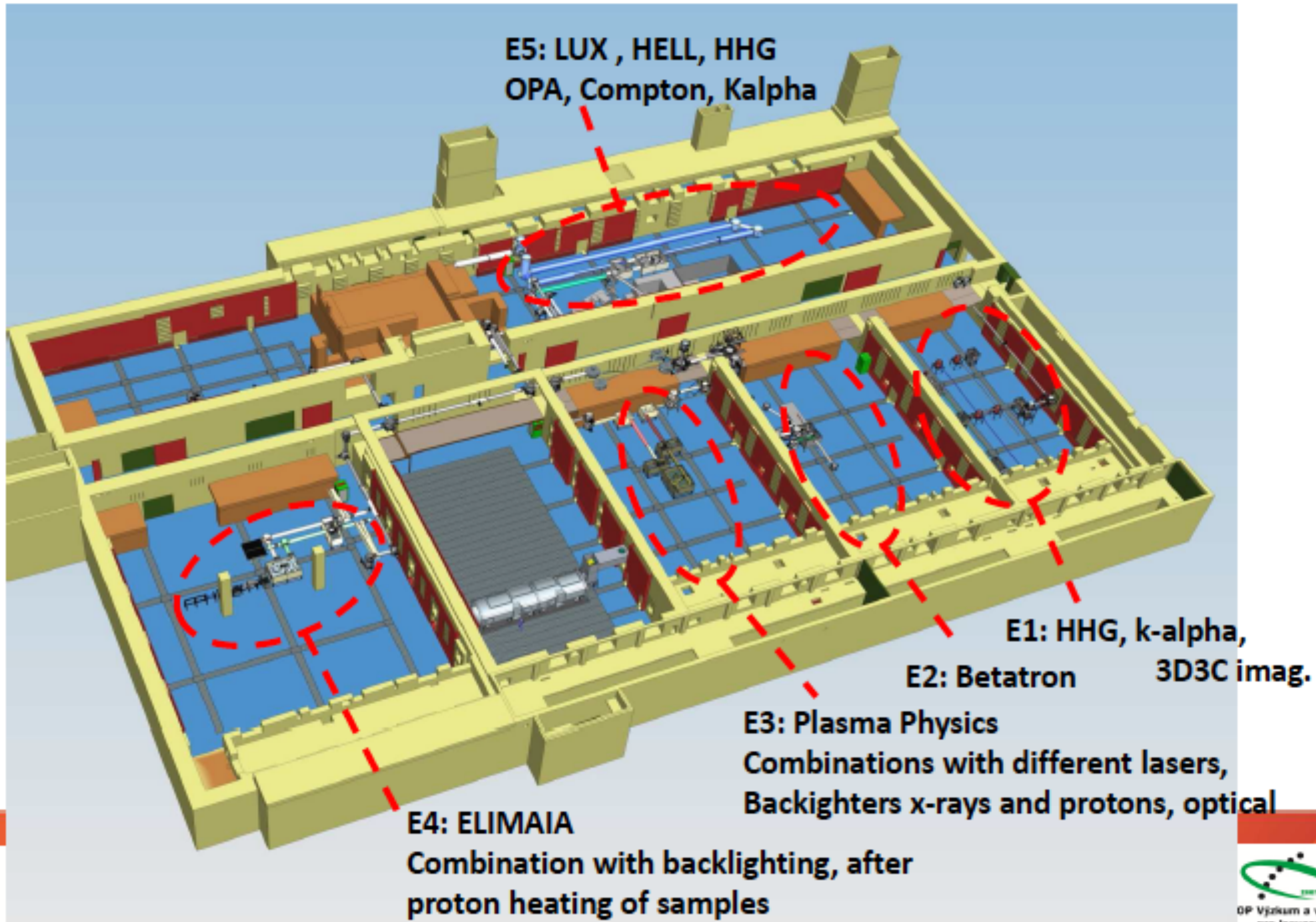
eli beamlines

- ✓ ELI pillars and ELI-Beamlines
- ✓ Facility layouts
- ✓ Lasers (RP1)
- ✓ Beam transport and switchyards
- ✓ Experiments (RP2-RP6)
- ✓ RP3 (ion and electron acceleration)

Experimental Area (ground floor)



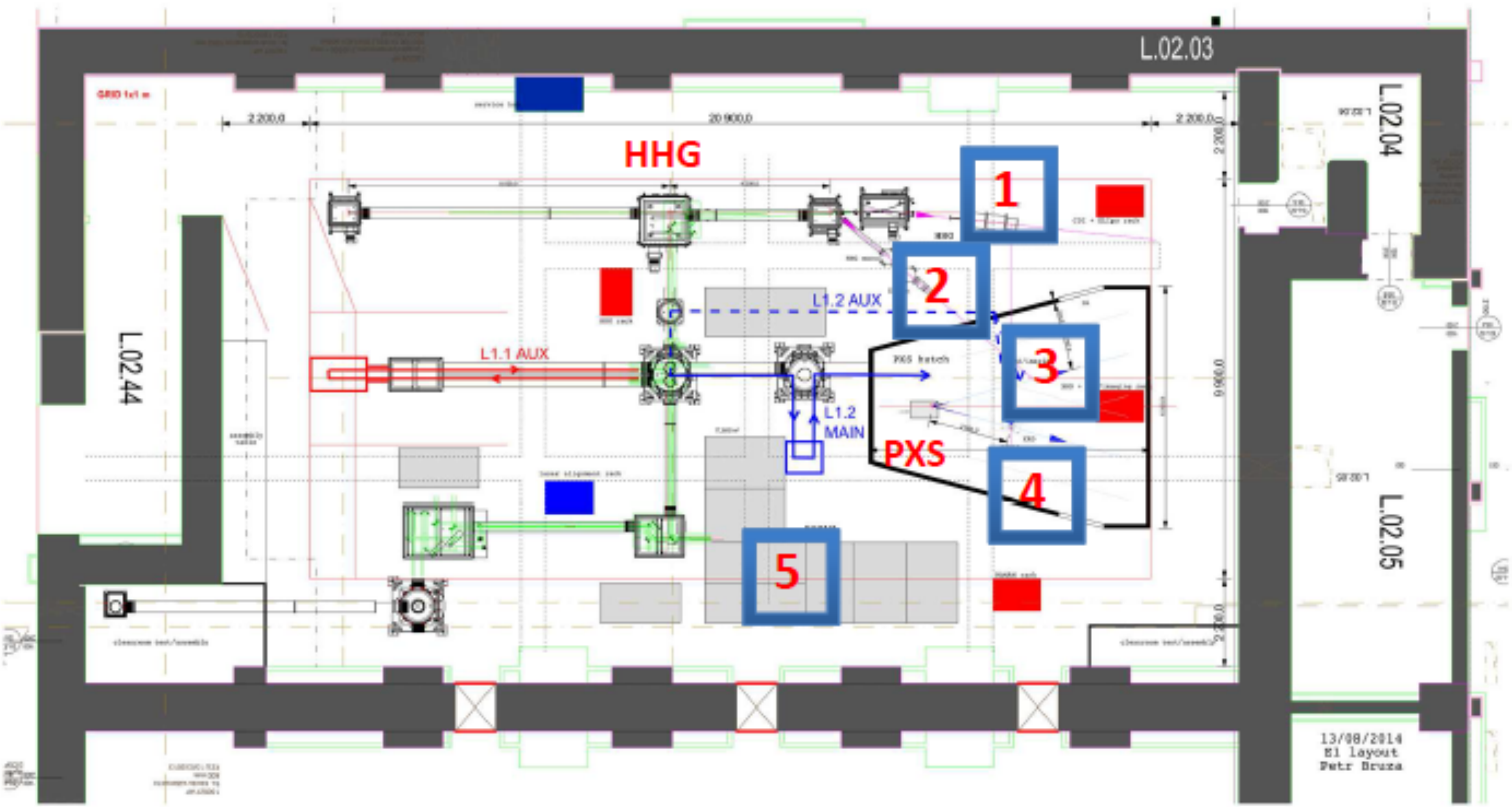
Experimental Areas, Basement floor



E1 layout, beam distribution and experimental stations

4 beams from the L1 laser allows complex time-resolved experiments

- 2 secondary sources: Higher Harmonics Generation (HHG) for soft X-rays and a Plasma X-ray Source (PXS) for hard X-rays
- 5 Experimental end-stations where experiments are performed



eli beamlines

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

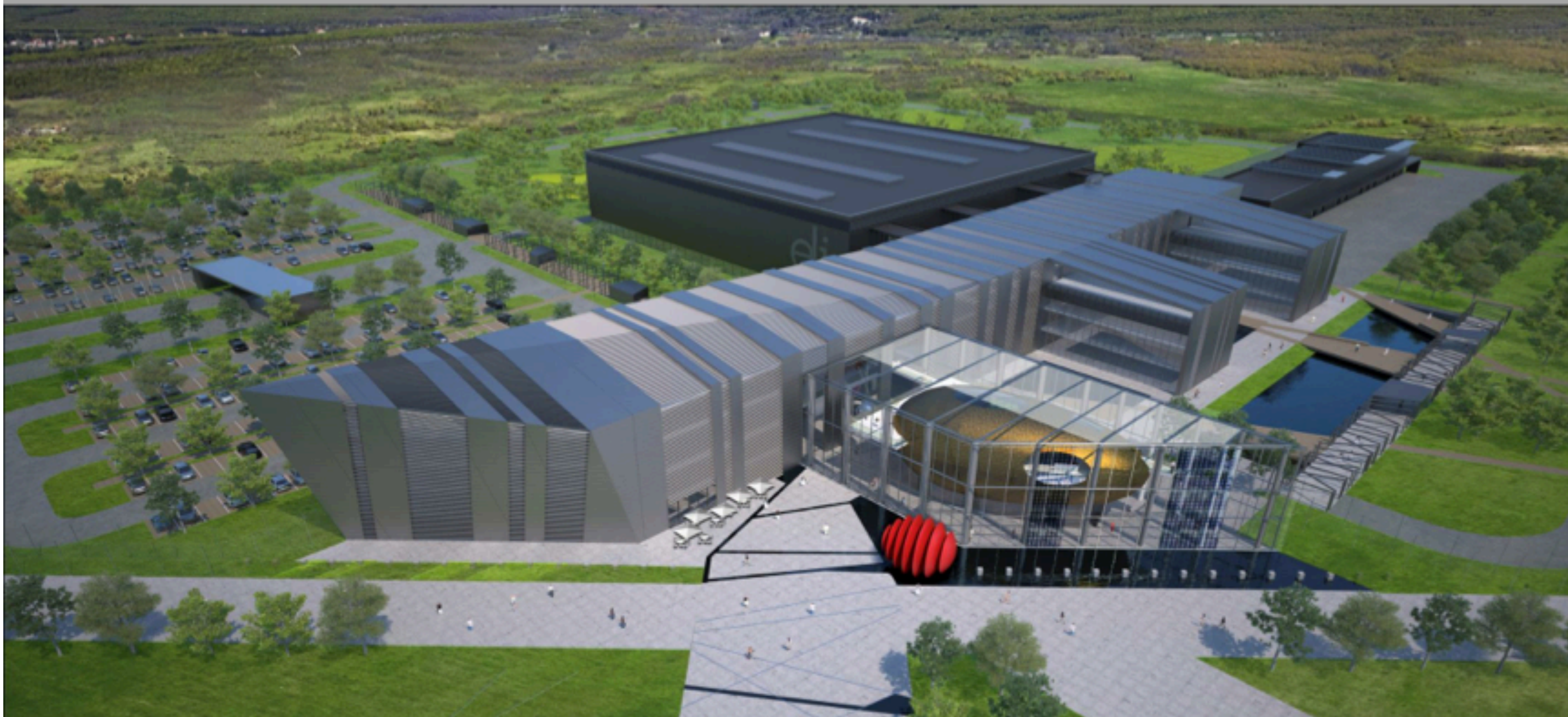
EVROPSKÁ UNIE

OP Vzdělávání pro konkurenceschopnost

INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

OP Výzkum a vývoj pro inovace

Eli – attosecond Hungary



National Development Agency
www.ujszechenyiterv.gov.hu
06 40 638 638

HUNGARY'S RENEWAL

The projects are supported by the European Union and co-financed by the European Regional Development Fund.

Location of ELI-ALPS and a planned Scientific Park

Major missions of ELI-ALPS

1) To generate X-UV and X-ray fs and atto pulses, for temporal investigation at the attosecond scale of electron dynamics in atoms, molecules, plasmas and solids.
   ATTOSECOND Beamline & User Facility

2) To contribute to the technological development towards 200PW
   HIGH INTENSITY beamline

Design of ELI-ALPS I

NEW SZÉCHENYI PLAN

ELI-PP
Mission
Basic scientific directions

ELI-ALPS
July 2010 – Dec 2010
Feasibility study for the Scientific Case of ELI-ALPS

March 2011 – June 2011
Planned research Activities of ELI-ALPS

Feasibility study of ELI-ALPS – part of project application to the EU.
Completed: June, 2012

Design of ELI-ALPS II

NEW SZÉCHENYI PLAN

Conceptual Design Report
by the international community

Part I (sources, sci. IT) is completed
SAC approved

Research institutes and Universities

Part II (labs, workshops)
is due Q2 2014

Technical design (TDR)
by the contractors

Part I is due by Q3 2014

Mainly industrial partners

CLPU CENTRO DE LÁSERES PULSADOS

Phasing and financing

NEW SZÉCHENYI PLAN

Phase 1 (-2015)

Building:	cc. 18,2 bln HUF	64.1 M EUR
Research equip:	cc. 16, 2 bln HUF	57 M EUR
Services:	cc. 2,6 bln HUF	9.2 M EUR
Total:	**cc. 37,0 bln HUF**	**130.4 M EUR**

Phase 2 (-2017)

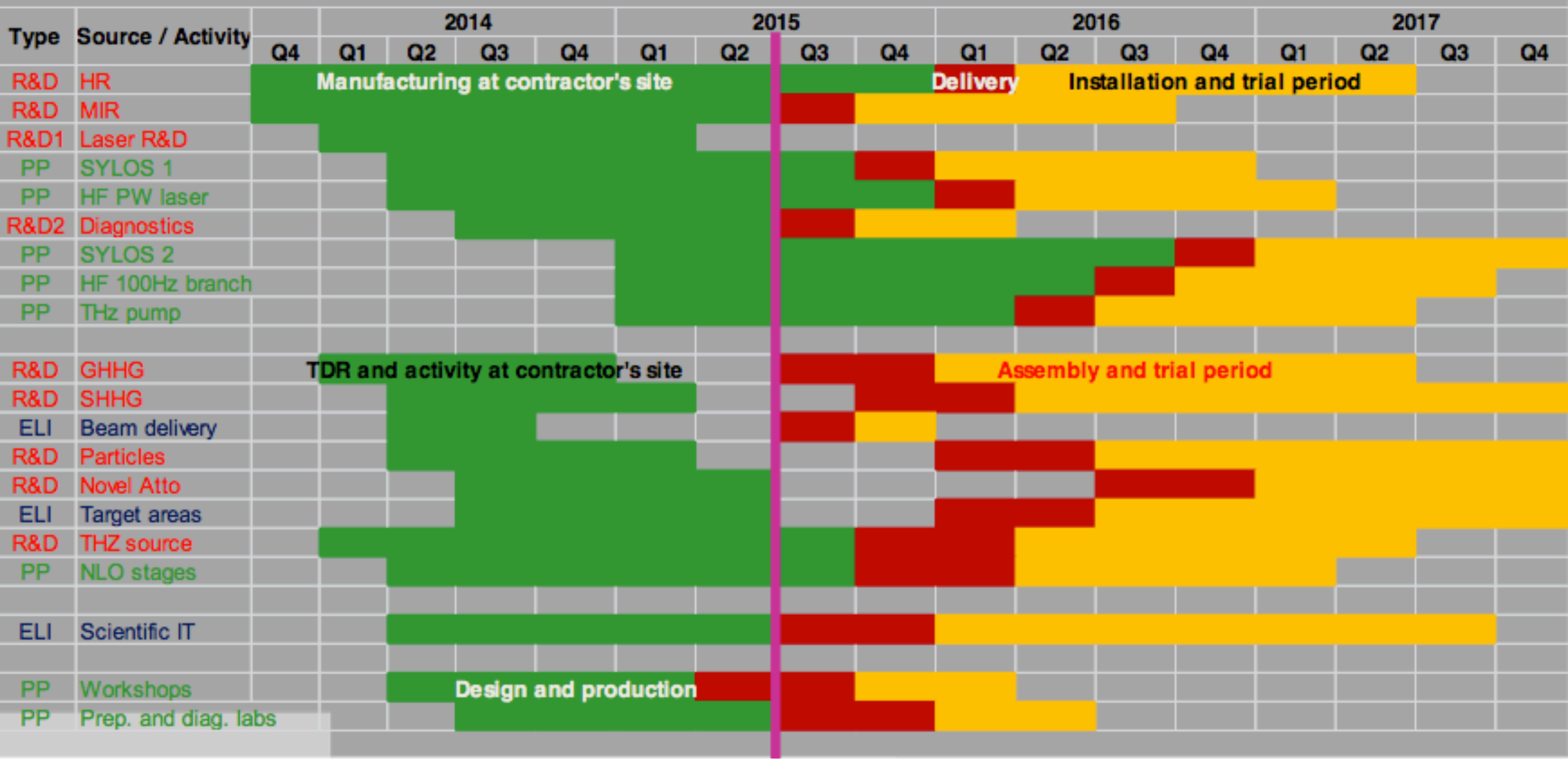
Building:	cc. 4,7 bln HUF	16.6 M EUR
Research equip.:	cc. 17,2 bln HUF	60.6 M EUR
Services:	cc. 2,4 bln HUF	8.5 M EUR
Total:	**cc. 24,3 bln HUF**	**85.6 M EUR**
Grand total:	**cc. 61.3 bln HUF**	**216 M EUR**

(+Preparation: 2,434 bln HUF)

CLPU CENTRO DE LÁSERES PULSADOS

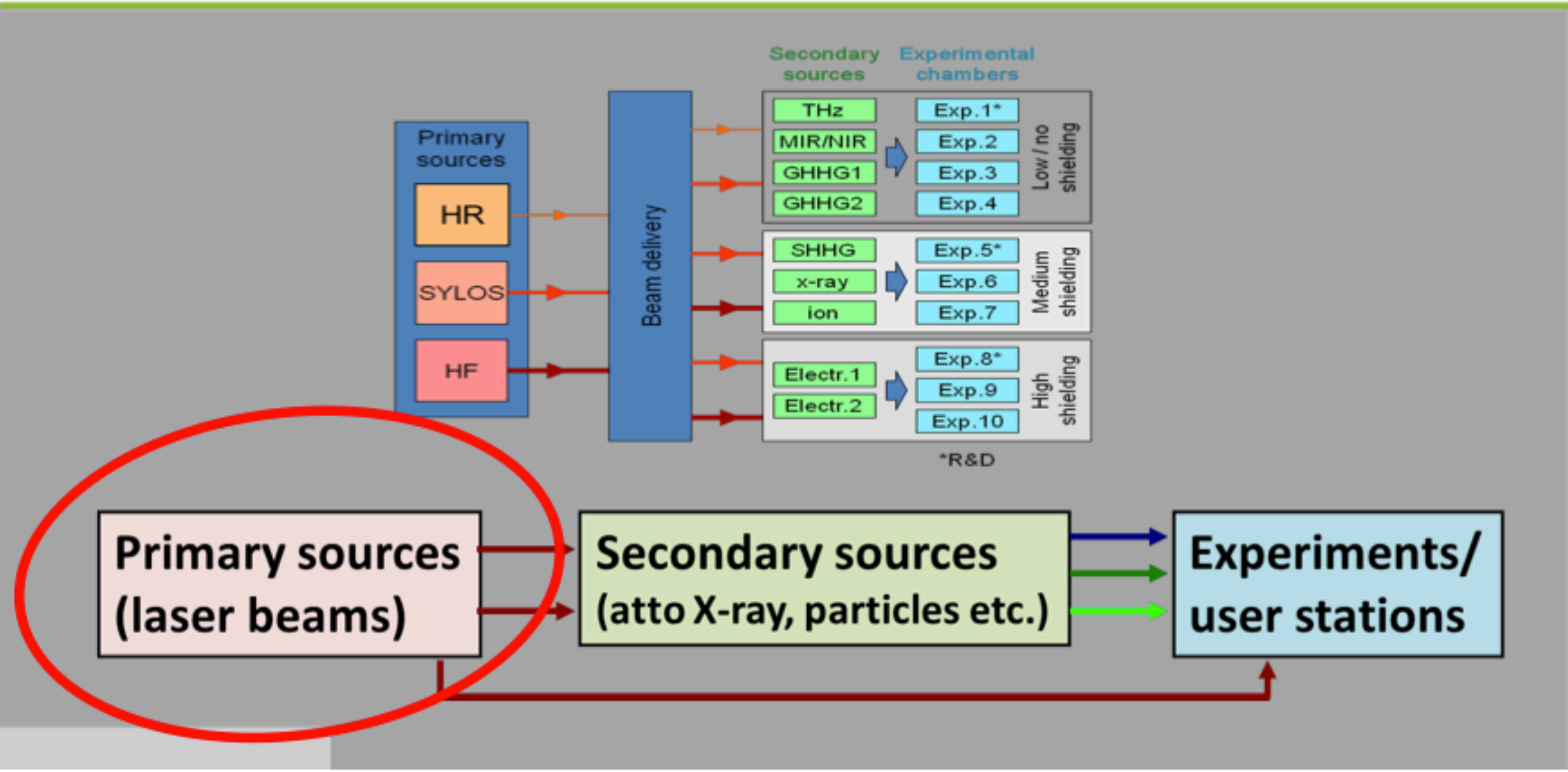
Implementation plan - Overview

NEW SZÉCHENYI PLAN



CLPU CENTRO DE LÁSERES PULSADOS

Schematics of ELI-ALPS



Implementation of the lasers I

NEW SZÉCHENYI PLAN

1 Via R&D projects

ALPS HR laser

100kHz, >4TW, <20fs, VIS-NIR, CEP

ALPS MIR laser

100kHz, 0,1mJ, <6 cycle, MIR

Q1 2016 Delivery to the site Q3 2015

Submission deadline of the R&D proposals is 27th November, 2013.

ALPS Mid-Infrared Source (MIRS)

100kHz, >100µJ, few cycle, @ 3µm

CLPU CENTRO DE LÁSERES PULSADOS

Implementation of the lasers II

NEW SZÉCHENYI PLAN

2 Public procurement – Q4 2013

ALPS Sylos 1 laser
1kHz, >4TW, <20fs, VIS-NIR, CEP

ALPS HF PW laser
≤5Hz, >2PW, <20fs, NIR

Q4 2015 — Delivery to the site — Q1 2016

3 Laser R&D projects for elimination of technological bottlenecks

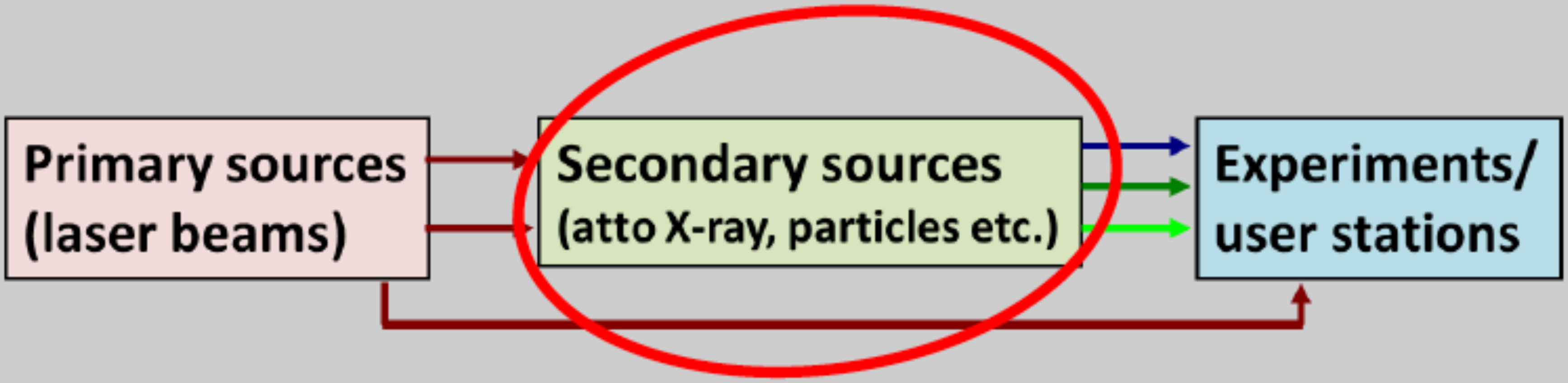
4 Public procurement – Q4 2014

ALPS Sylos 2 laser
1kHz, >20TW, 5fs, VIS-NIR, CEP

ALPS HF 100 laser
100Hz, >40TW, <12fs, NIR

Q4 2016 — Delivery to the site — Q3 2016

Schematics of ELI-ALPS



Secondary sources

NEW SZÉCHENYI PLAN

Gas High Harmonic Generation and Attosecond Pulses

1kHz-100kHz, 4-400eV, up to 10 μJ

Solid High Harmonic Generation and Attosecond Pulses

5Hz – 1kHz, 10eV – 5keV, up to mJ

Electron and Ion Acceleration

e^-: 1-2GeV, 0.2nC; p^+: up to 160MeV, up to 1nC

THz sources

3MV/cm – 100MV/cm, up to 1mJ

New Concepts for HHG and Attosecond Pulse Generation

CLPU CENTRO DE LÁSERES PULSADOS

Implementation of the secondary sources

NEW SZÉCHENYI PLAN

Via R&D projects – Q4 2013

TDR of the beamlines
TDR of the target areas

Delivery I: Q2 2014
Delivery II: Q1 2015

Public procurements – Q2 2014

Hardware for the beamlines
Hardware for the target areas

Delivery I: Q2 2015
Delivery II: Q1 2016

By the same groups / contractors
+ ELI-ALPS workforces

Via R&D projects – Q4 2013

Implementation of the beamlines
Implementation of the target areas

Delivery I: Q1 2016
Delivery II: Q4 2017

CLPU CENTRO DE LÁSERES PULSADOS

Layout – Scientific areas

- Laser hall: 1350 m²
- Target areas: 2100 m²

- Optics labs: 330 m²
- Biology/chemistry/medical labs: 320 m²
- Diagnostics labs: 110 m²

- Mechanical workshops: 530 m²
- Electric / IT workshop: 200 m²

Eli nuclear physics Romania

The EuroGammaS Association

Plus 4 Industrial Partners:
ACP (Amplitue Group, France), Alsyom (Alcen Group, France),Comeb (Italy), ScandiNova Systems (Sweden)

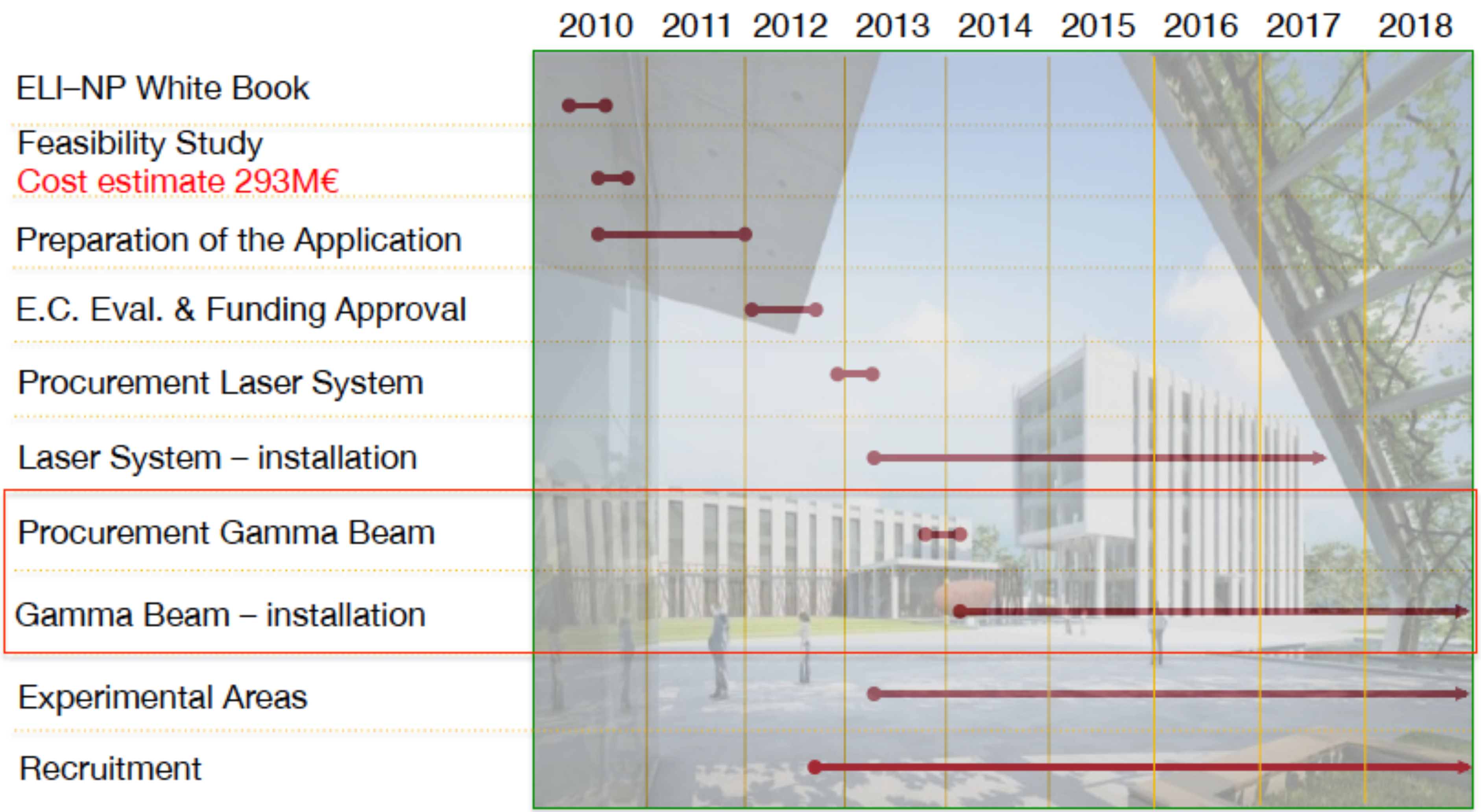
and several Sub-Contractors:
Alba (Spain), Cosylab (Slovenia), Danfysik (Denmark), IT (Slovenia), M+W Group (Italy), Menlo Systems (Germany), RI (Germany)

The Challenge : to design the *most advanced Compton* Gamma Beam Source based on *state–of–the–art* components, to be commissioned and delivered to users *by mid 2018*, reliable, cost-effective (67 *M€*), compatible with ELI-NP building

ELI-NP Gamma Beam Source: Bright, Monochromatic (0.3%–0.5%), High Spectral Flux (10,000 ph/sec·eV), Tunable (0.2-20 MeV), Polarized

TDR – arXiv:1407.3669 [physics.acc-ph]

ELI–NP Implementation Timeline



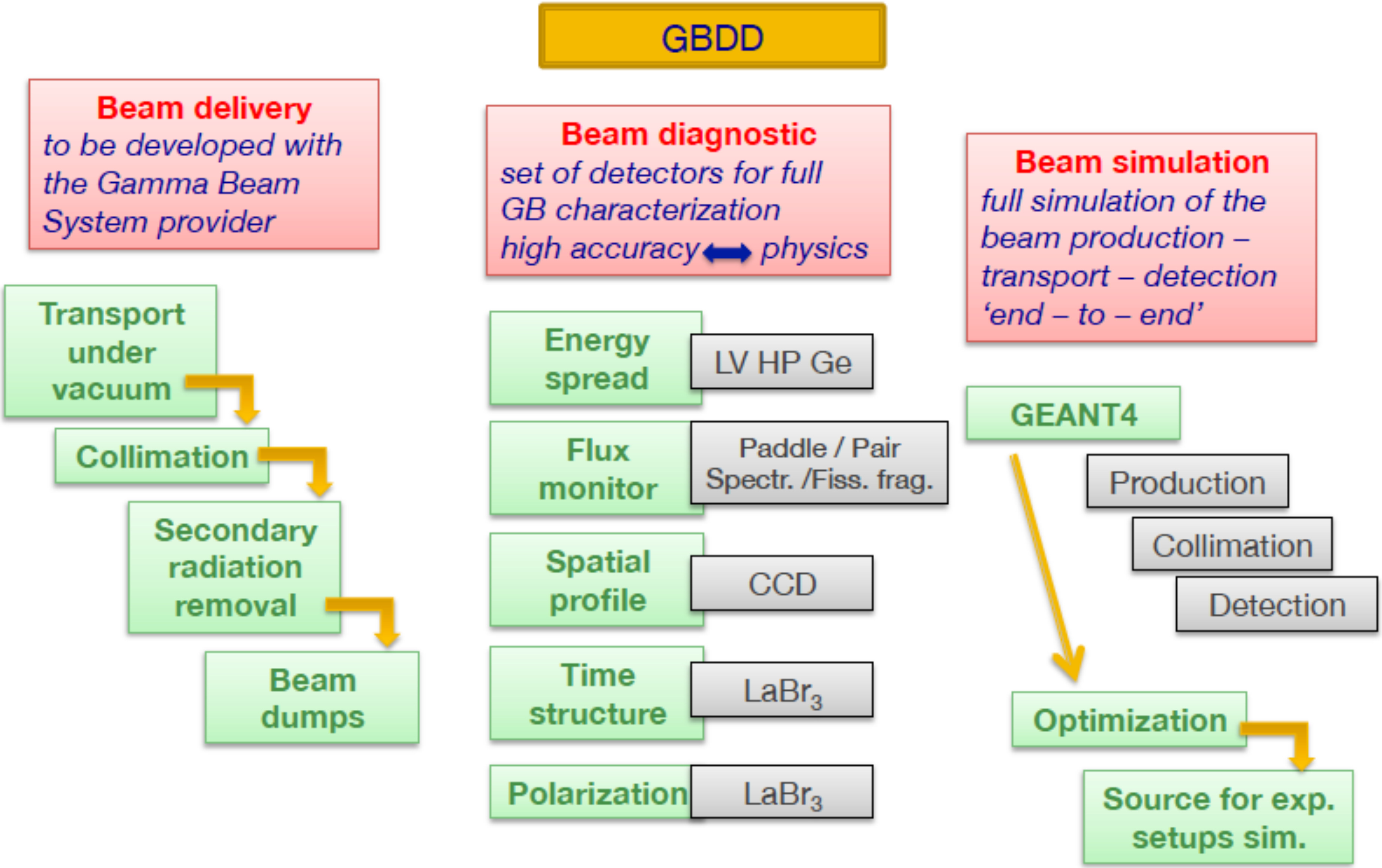
ELI–NP Gamma Beam System

If the Physics of Inverse Compton Scattering is straightforward….

The Challenge of making a Compton Gamma Beam System out of an electron–photon beam Collider, and maximizing the spectral flux of the gamma ray beam generated, Is a completely different Issue!

L.Serafini

The ELI–NP GBDD



What are appropriate solutions for the 2 x 10-PW laser system implementation at ELI-NP:

- Laser development approach?
- Technical solution?

We considered:

- Previous experience and human resources
- Nature of the ELI-NP project
- State of the art in the field of high power femtosecond laser systems

CENTRO DE LÁSERES PULSADOS

Possible solutions for 2 x 10-PW ELI-NP laser

A) OPCPA based laser system (910-nm central wavelength)*:
- Front-End: very broad-band signal radiation at 910-nm central wavelength
- High power OPCPA in large aperture DKDP crystals

B1) Hybrid laser system at ~ 800 nm central wavelength**:
- Front-End based on OPCPA in nonlinear crystals (BBO)
- High energy amplification in Ti:sapphire crystals

or

B2) Ti:sapphire amplifiers at ~ 800 nm central wavelength*** :
- Front-End based on Ti:sapphire amplification
- High energy amplification in Ti:sapphire crystals

Basic solution proposed for ELI-NP laser

C) Hybrid laser system with Front-End based on OPCPA in BBO crystals and high energy amplification in mixed silicate/phosphate Nd-doped glasses near 1 µm wavelength****

Alternative solution for ELI-NP laser

*RAL, Annual Report, 2009.
**J. P. Chambaret, "The Extreme Light Infrastructure Project ELI and its prototype APOLLON/ ILE. The associated laser bottlenecks", LEI Conference, Brasov, October 2009.
***Commercial companies solutions (Thales, Amplitude Technologies)
****Erhard W. Gaul et al., "Demonstration of a 1.1 petawatt laser based on a hybrid optical parametric chirped pulse amplification/mixed Nd:glass amplifier", Appl.Opt. 49 (9), 1676 (2010).

Key principle of OPCPA:

A broad bandwidth linearly chirped signal pulse is amplified with an energetic and relatively narrow-band pump pulse of approximately the same duration

Distinct features of laser medium amplification (CPA) and OPCPA

Laser medium amplification (CPA)	OPCPA
Amplification during the existence of the inverted population (energy accumulated on the upper laser level) For Ti:sapphire: ~ 1 μs after the pump pulse 10-100 ns precision of pump and signal pulse synchronization (*non-critical*)	***Amplification only during the pump and signal pulse temporal overlapping*** Pump and signal pulse of the same duration Pump-signal pulse synchronisation <(pump/signal pulse duration)/10 For ps OPCPA, optical synchronization is necessary
Thermal loading $h\nu_p > h\nu_L$ Part of the pump energy (~ 33% in case of Ti:sapphire) is dissipated in the amplifying medium	***No thermal loading*** Nonlinear crystals are transparent for the interacting beams wavelength

Advantages and Drawbacks of OPCPA compared to CPA

Advantages:

- No spectral band narrowing and red-shifting
- Ultra-broad bandwidth (ultrashort re-compressed pulses)
- Negligible thermal loading
- High signal gain
- High signal - noise contrast ratio
- Available large non-linear crystals, no transversal lasing
- No transversal lasing

Drawbacks:

- Precise time/space required synchronization of signal and pump pulses
- High intensity and high temporal/spatial quality pump beams required
- Sensitive to the angle variation between seed and pump pulses
- Difficulties related to building laser devices able to generate short (ps-ns) pump pulses at high energy level
- No matured technique at high energy level of amplification

Advanced techniques and fabrication technologies used in the ELI-NP 2 x 10 PW laser (HPLS)

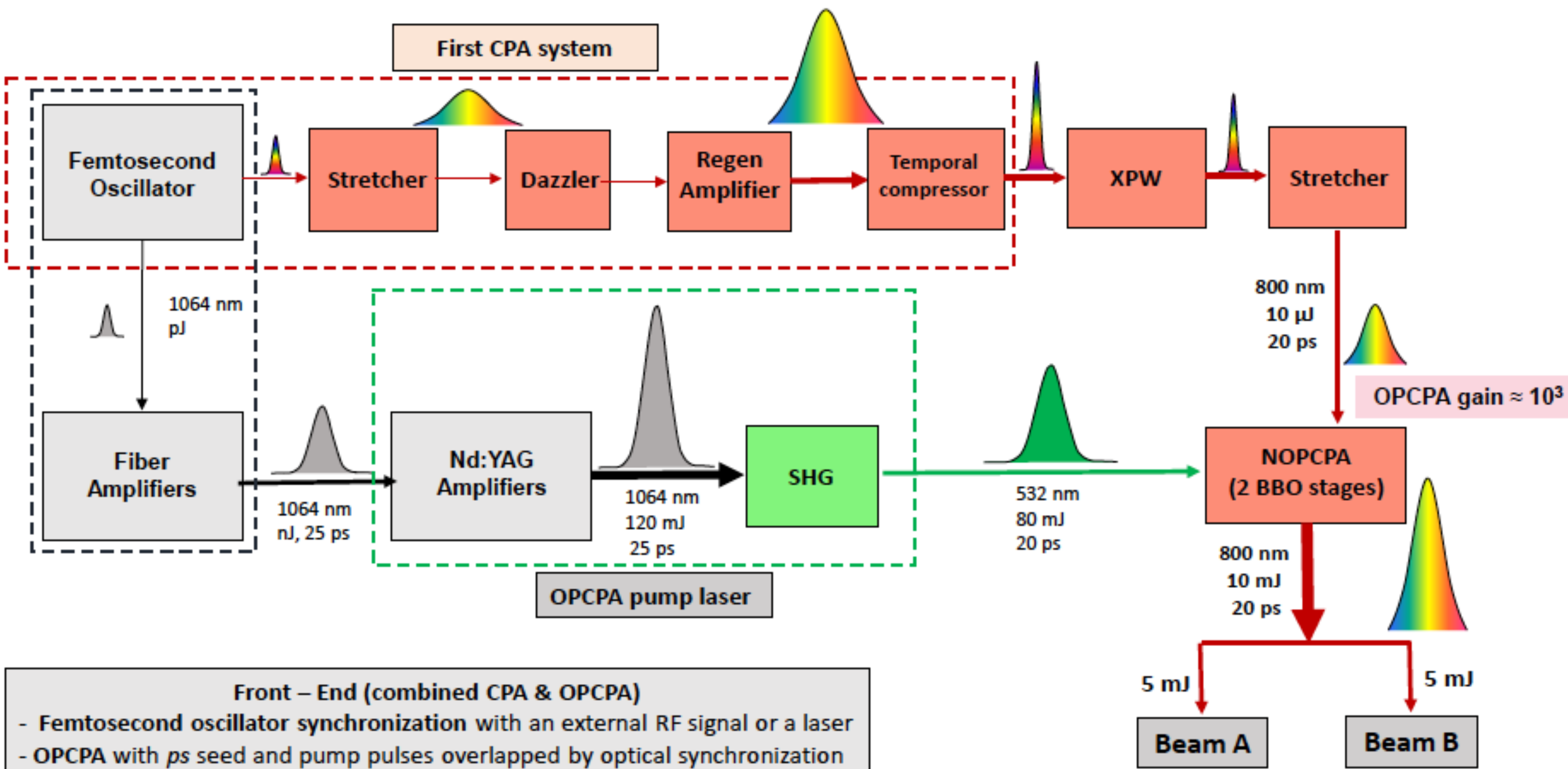
Front – End (combined CPA & OPCPA)

- **Femtosecond oscillator synchronization** with an external RF signal or a laser
- **OPCPA** with *ps* seed and pump pulses overlapped by optical synchronization for contrast increasing and large bandwidth preserving
- **XPW filter** for intensity contrast increasing and spectrum broadening
- **Dazzler** for spectral phase and spectral amplitude control

High energy Ti:sapphire CPA & temporal compressor

- Large aperture Ti:sapphire crystals (~200 mm diameter)
- Large size diffraction gratings (~ 0.6 m x 1 m)
- Large size (~0.6 m x 0.85 m), large bandwidth mirrors
- High energy green pump lasers (100 J) – ATLAS type (THALES)
- **Spectrum management** using selective reflective mirrors
- **Parasitic lasing suppression**
- **Large size adaptive** optics for wavefront control

HPLS Front - End



Front – End (combined CPA & OPCPA)

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Fiber amplifiers for OPCPA pump laser

Femtosecond oscillator

1064 nm, ~ 10 nm, pJ

Ytterbium doped optical fiber (YDOF) amplifier 1

T ~ 10 ps , ~ 10 nm, nJ

Fiber Bragg Grating

T ~ 25 ps , ~ 0.066 nm, ~ 10 pJ

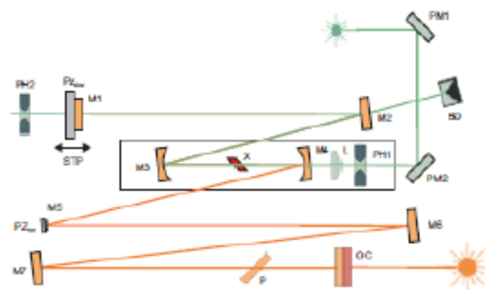
YDOF amplifier 2

T ~ 25 ps , ~ 0.066 nm, ~ 1 nJ

To Nd:YAG bulk amplifiers

▸ **PZ - Piezo-Controlled Option**

If required for synchronization experiments, the VENTEON | PULSE : ONE laser cavity can be equipped with a special piezo transducer / stepper-motor combination that allows for a resonance-free locking of the repetition frequency in a bandwidth up to 30kHz to a suitable microwave standard. This **Piezo-Controlled Option** includes two piezo-mounted resonator mirrors that enable an external voltage-controlled f_{rep}-scanning or fine-tuning. The small load of the fast piezo mirror allows for a rapid response up to an exceptional high resonance frequency of more than 30 kHz. Slow drifts can be controlled using the second piezo with a higher travel range. For long-term operation a stepper-motor can expand the full travel even more.

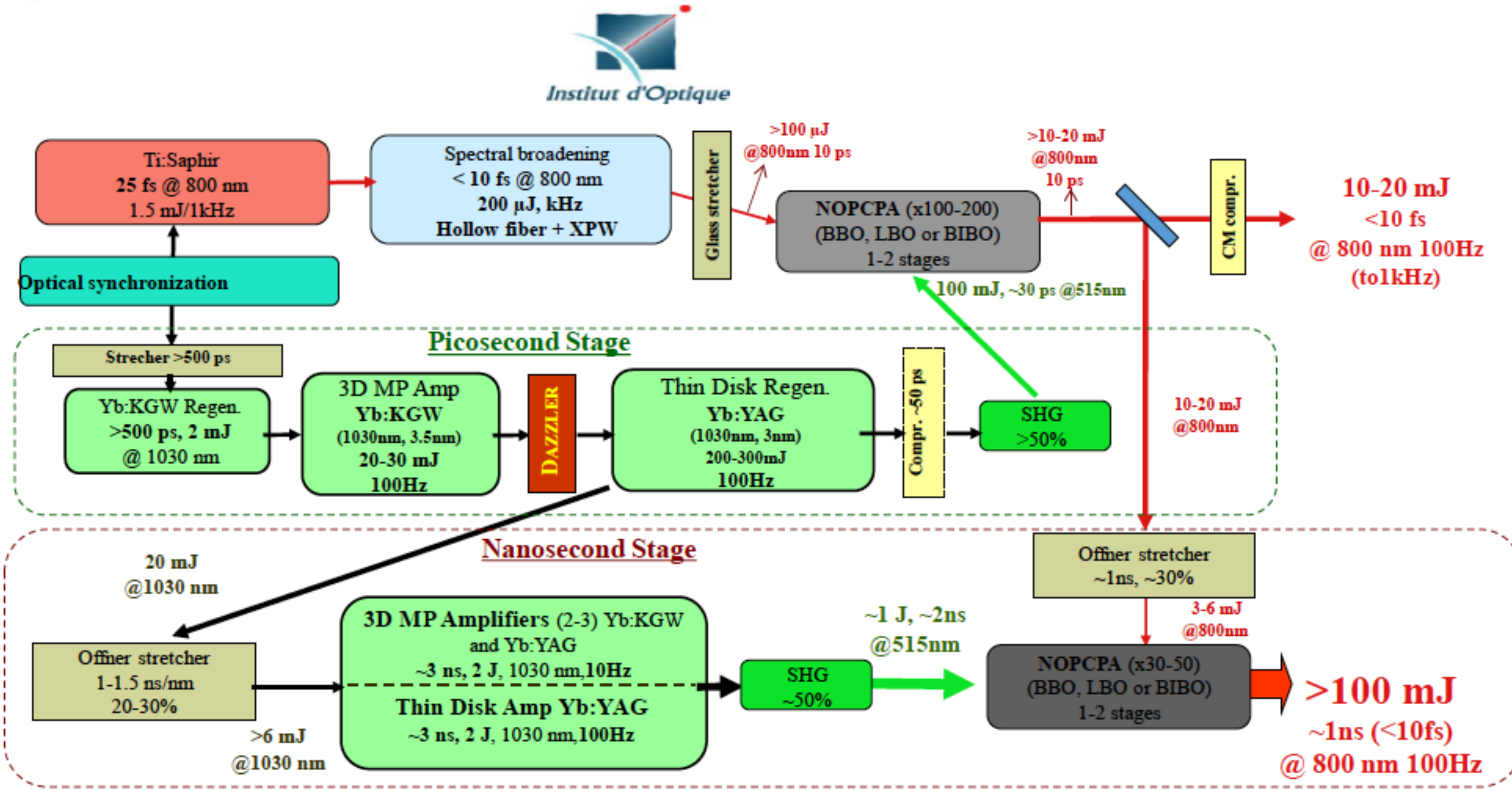


▸ Optical setup of a VENTEON cavity equipped with two piezos (PZ_{fast} @ mirror M5 and PZ_{slow} @ mirror M1) and one stepper-motor (STP).

Condition for synchronization with a RF external signal, f_{RF}:

Fs laser Rep-Rate = f_{RF}/N

The ILE APOLLON 10PW Front End ps/ns strategy

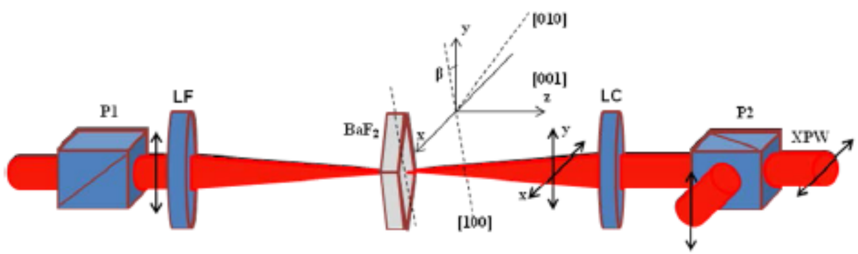


Courtesy: J. P Chambaret, LEI Conference , Brasov (RO) October 21rst, 2009

Intensity contrast improvement inside amplifier chain

Background radiation intensity must be < 10^11 W/cm^2

Cross-polarized wave (XPW) generation



Contrast improvement: 10^3-10^5

Spectral broadening by $\sim\sqrt{3}$

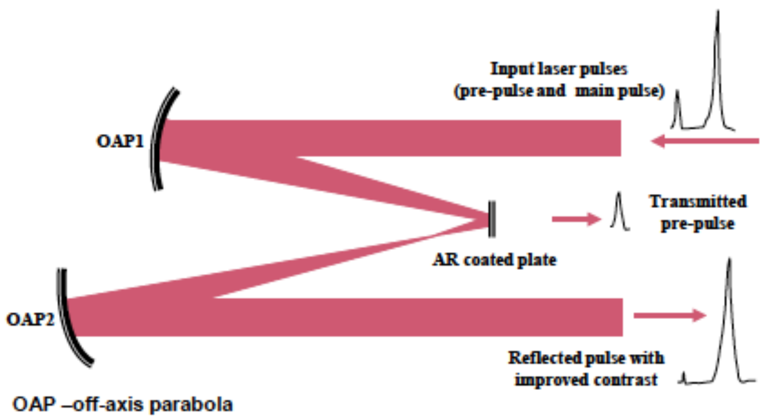
$\omega - \omega + \omega \rightarrow \omega$ $\quad XPW_{efficiency} \sim \sigma I^3$ where I is the laser intensity

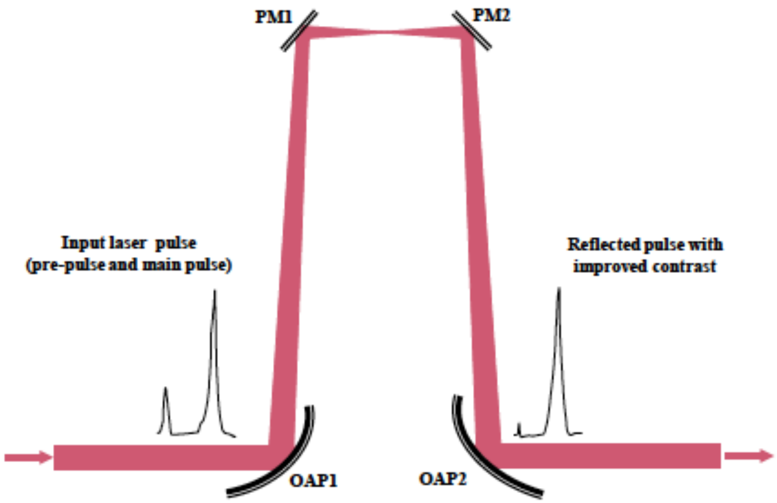
$\sigma \sim$ Anisotropy of the $\chi^{(3)}$ third order susceptibility tensor

BaF_2 cubic crystal isotropic to linear optical properties → perfect phase and group-velocity matching of two orthogonally polarized waves

[1] N. Minkovski, G. I. Petrov, S. M. Saltiel, O. Albert, J. Etchepare, J. Opt. Soc. Am. B **21** (9), 1659 (2004).
[2] Aurélie Jullien, Olivier Albert, Frédéric Burgy, Guy Hamoniaux, Jean-Philippe Rousseau, Jean-Paul Chambaret, Frédérika Augé-Rochereau, Gilles Chériaux, Jean Etchepare, Nikolay Minkovski, Solomon M. Saltiel, Opt. Lett **30** (8), 920 (2005).
[3]. L. Canova, O. Albert, N. Forget, B. Mercier, S. Kourtev, N. Minkovski, S.M. Saltiel, and R. Lopez Martens, "Influence of spectral phase on cross-polarized wave generation with short femtosecond pulses", Appl. Phys. B **93**, 443–453 (2008).
[4]. A. Jullien, S. Kourtev, O. Albert, G. Cheriaux, J. Etchepare, N. Minkovski, S.M. Saltiel, Appl. Phys B **84**, 409 (2006).
[5]. A. Jullien, J. P. Rousseau, B. Mercier, L. Antonucci, O. Albert, G. Chériaux, S. Kourtev, N. Minkovski, and S. M. Saltiel, "Highly efficient nonlinear filter for femtosecond pulse contrast enhancement and pulse shortening," Opt. Lett. **33** (20), 2353–2355 (2008).
[6]. A. Jullien, L. Canova, O. Albert, D. Boschetto, L. Antonucci, Y.-H. Cha, J. P. Rousseau, P. Chaudet, G.Cheriaux, J. Etchepare, S. Kourtev, N. Minkovski, and S. M. Saltiel, Appl. Phys. B **87**, 595 (2007).

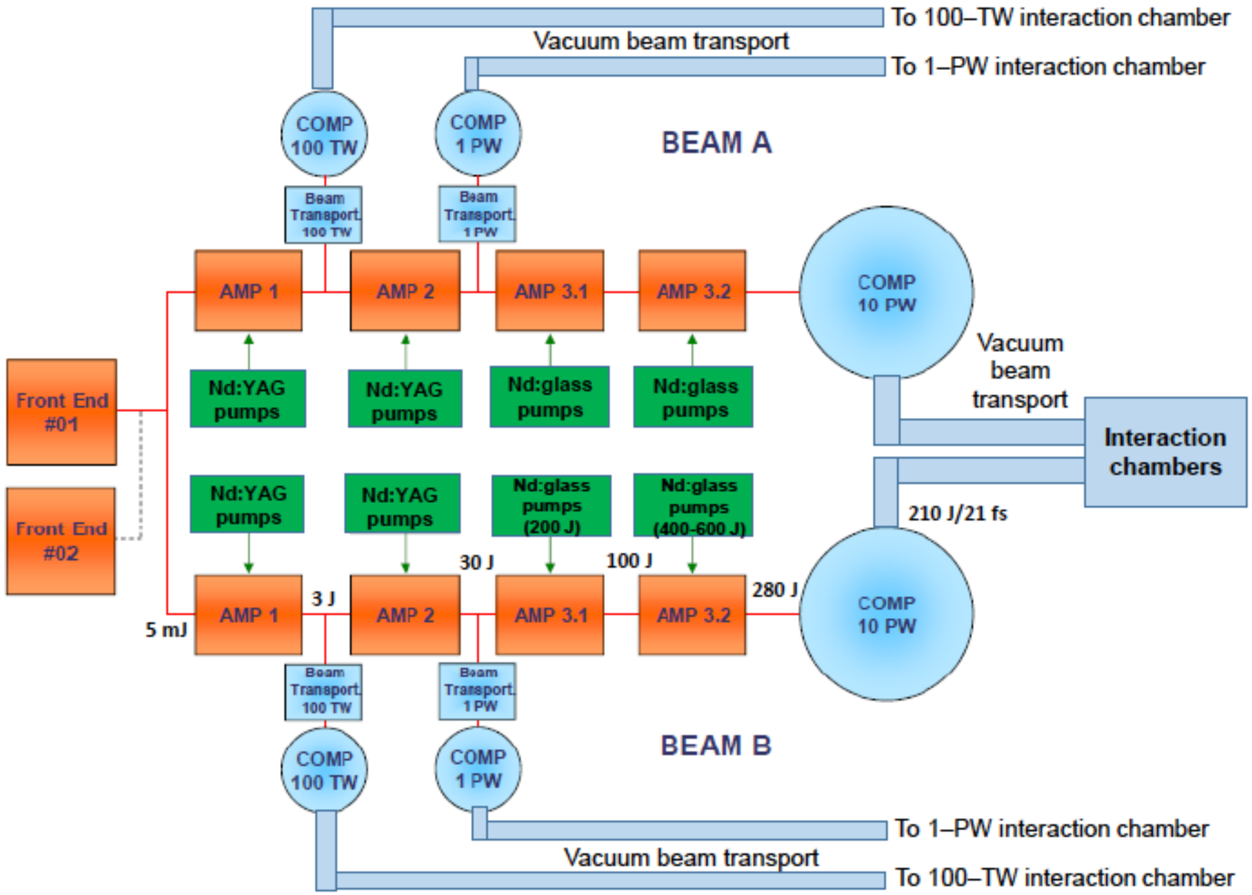
Contrast improvement after amplification and temporal compression: Plasma mirrors



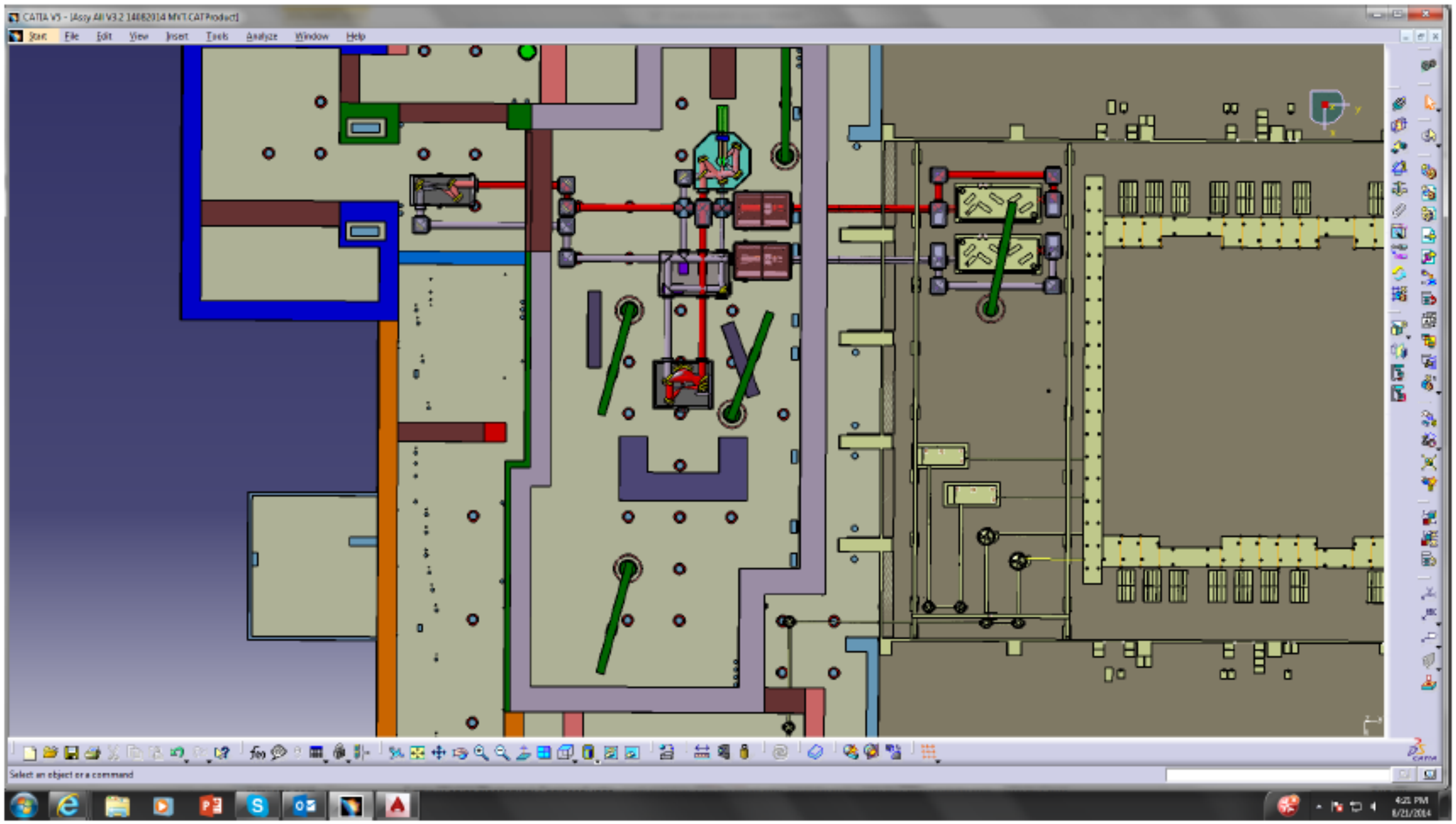


Plasma mirror principle

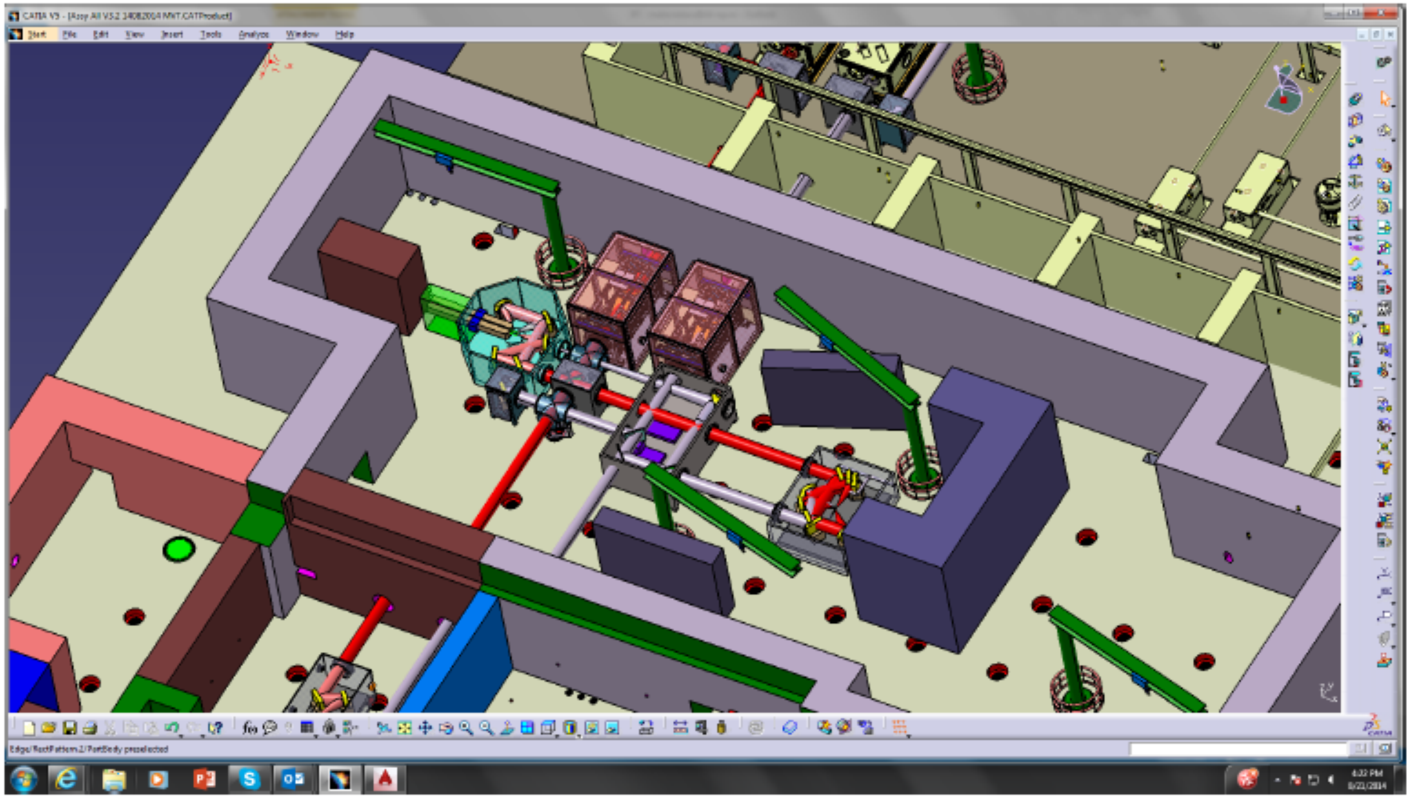
Schematic drawing of ELI-NP HPLS



Laser beam delivery and interaction chambers (top view)

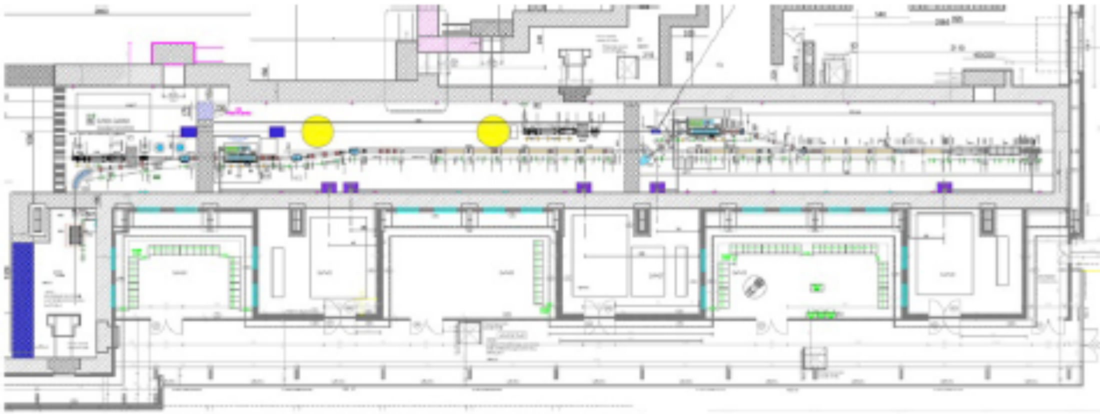


Laser beam delivery



ELI–NP GBS

Main components

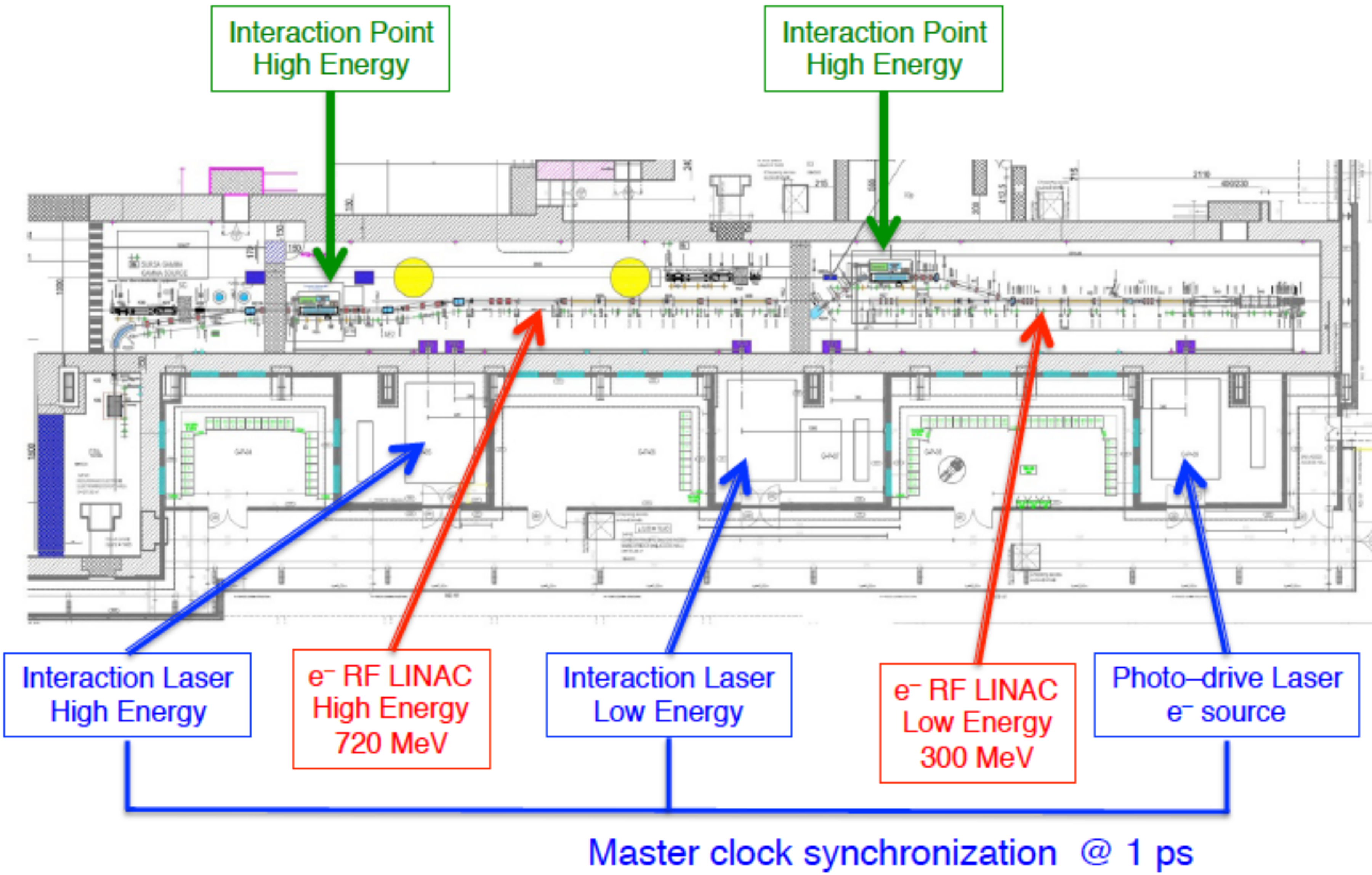


1) Warm RF Linac as for Linear Collider and FEL's machines (max rep rate, multi–bunch, max phase space density per average beam power)
   - two acceleration stages

2) High average power, high quality J–class 100 Hz psec Collision Laser (strategic investment in new Yb:YAG laser technology)
   - two lasers

3) Laser recirculation with μm and μrad and sub–psec alignment/synchronization (metrology/interferometry optical cavities)
   - two interaction points

Gamma Beam System – Layout



Phases of GBS & Parameters

Quantity	Symbol	Unit	Specification Full	Specification Stage 2	Footnote
Minimum Photon Energy	E_γ	[MeV]	≤ 0.2	≤ 0.2	
Maximum Photon Energy	E_γ	[MeV]	≥ 19.5	≥ 3	
Tunability of the Photon Energy			Steplessly variable	–	b)
Linear Polarization of Gamma-Ray Beam	P_γ	[%]	≥ 95	–	b)
Minimum Frequency of Gamma-Ray Macropulses	$\Omega_{\gamma,M}$	[Hz]	$\geq 1.0 \times 10^2$	–	b)
Divergence	$\Delta\theta$	[rad]	$\leq 2.0 \times 10^{-4}$	$\leq 2.0 \times 10^{-3}$	b)
Average Diametral Full Width Half Maximum of Beam Spot	σ_r	[m]	$\leq 1.0 \times 10^{-3}$	$\leq 1.0 \times 10^{-2}$	a,b)
Average Bandwidth of Gamma–Ray Beam	W		$\leq 5.0 \times 10^{-3}$	$\leq 5.0 \times 10^{-2}$	a,b,c)
Gamma–Ray Beam Time–Average Spectral Density at Peak Energy	F	[1/(s•eV)]	$\geq 5.0 \times 10^3$	$\geq 5.0 \times 10^2$	d)
Time–Average Brilliance at Peak Energy	B_{av}	[1/(s•mm²•mrad² •0.1%W)]	$\geq 1.0 \times 10^{11}$	$\geq 1.0 \times 10^{10}$	a,d)
Peak–Brilliance at Peak Energy	B	[1/(s•mm²•mrad² •0.1%W)]	$\geq 1.0 \times 10^{19}$	–	a,d)
Average Spectral Off–Peak Gamma–Ray Background Density	$\Phi_{\gamma,bkgr}$	[1/(s•eV)]	$\leq 1.0 \times 10^{-2}$	–	a,b,c)

1. Eγ > 1 MeV (***Demonstrator***)
    a. Expandable to the full system
    b. Deadline 31.10.2015
2. Intermediate parameters
    a. Deadline 28.02.2017
3. Full system
    a. Deadline (after 54 months)
    b. Two beams: stage 2 and stage 3

a) At reference–point located at approximately 10 m downstream of the Compton–collision point for gamma–ray production

b) For all gamma–ray energies between minimum and maximum photon energy

c) At all points within the FWHM of the beam spot

d) At gamma–ray energy of 2 MeV (for the first part of the electron accelerator) and 10 MeV (for the full electron accelerator)

ELI–NP GBS Layout

Accelerator and Equipment
in ELI-NP Building

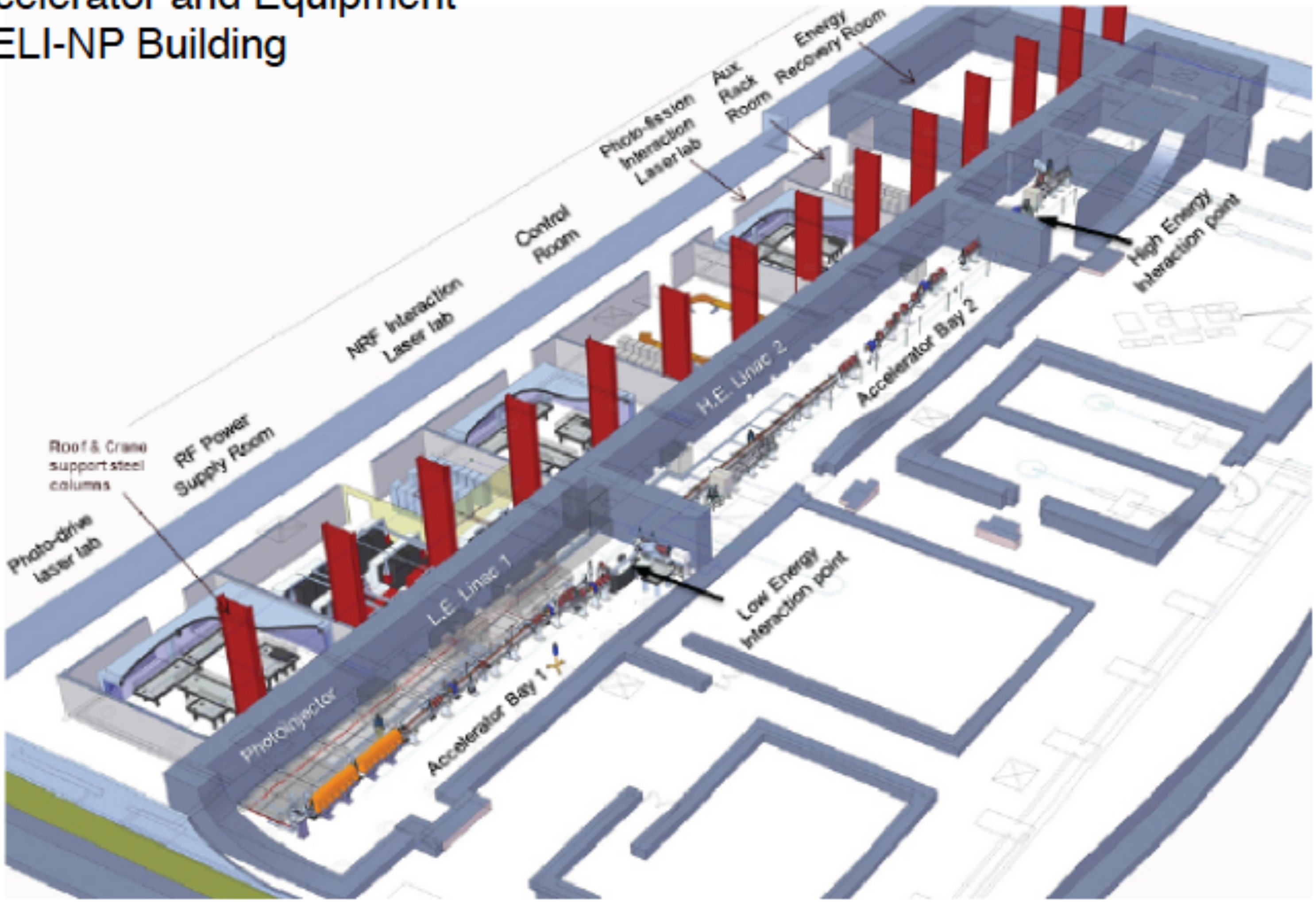
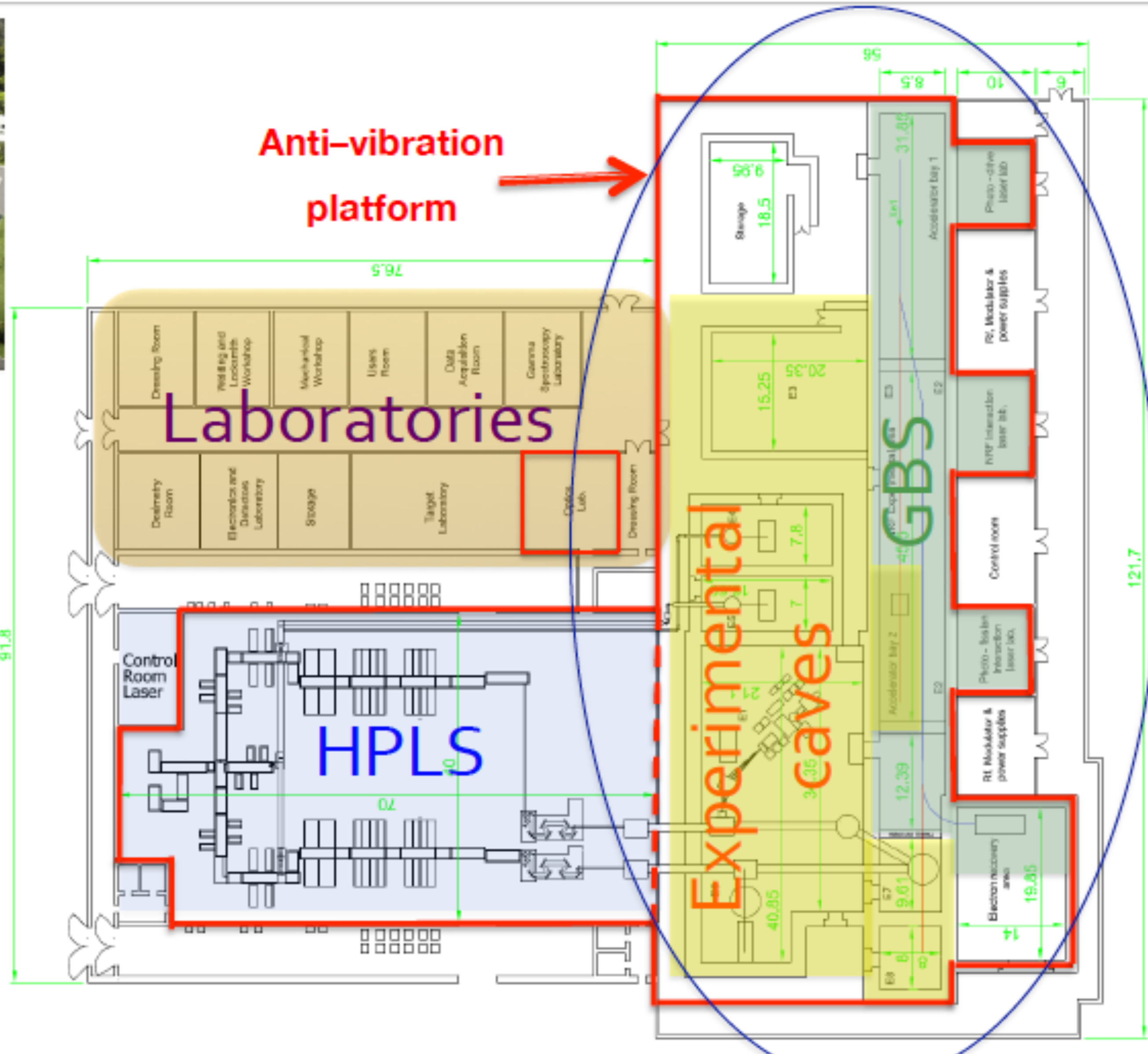


Fig. 197. Isometric 3D view of Building Layout of the Accelerator Hall & Experimental Areas

EuroGammaS Technical Design Report

ELI–NP Experiment Building

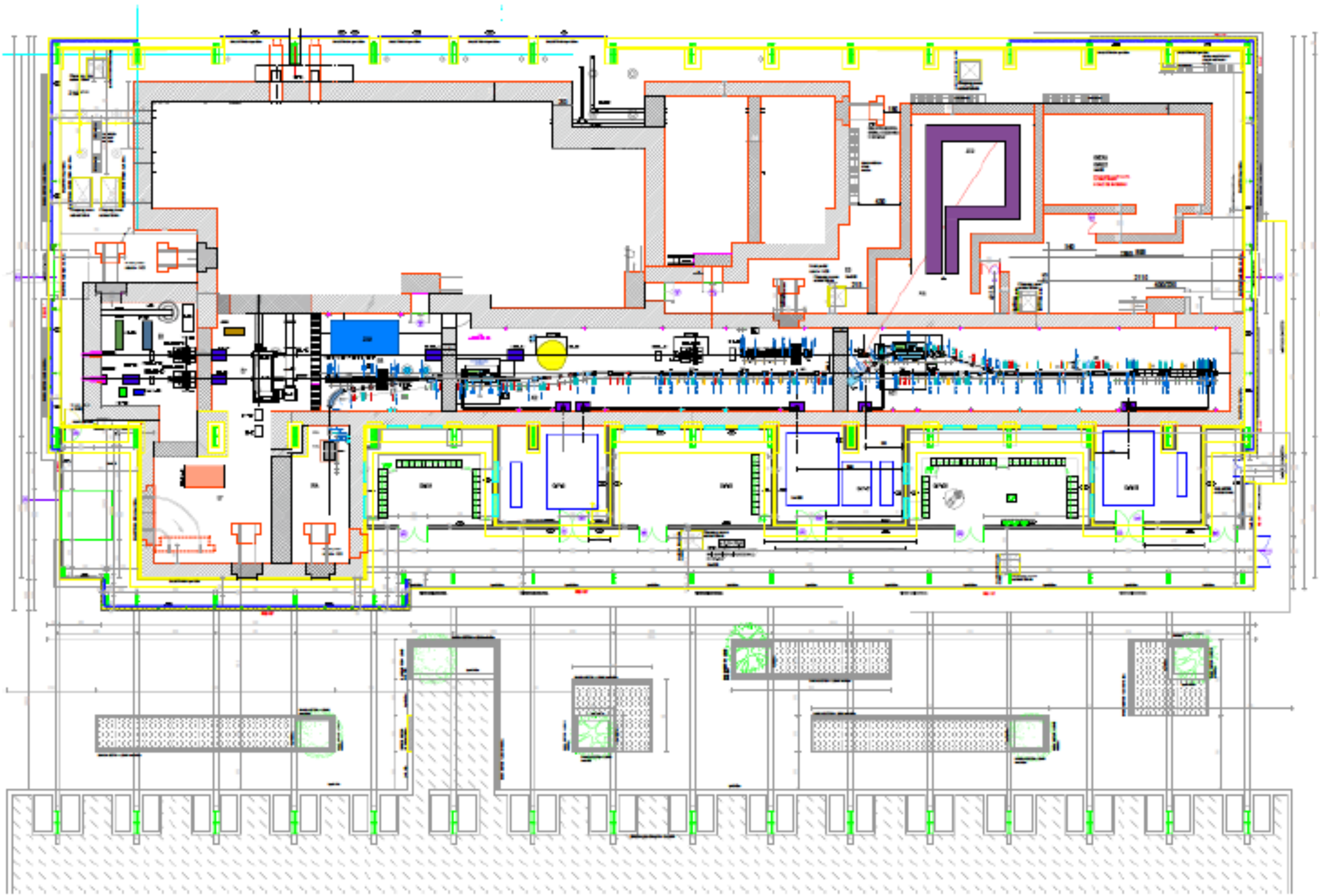


Platform vibrations

±1 μm @ < 10 Hz

- supported on dampers

ELI–NP Experiment Building



Experiment TDRs with GBS

Nuclear Physics

1. Gamma Beam Delivery & Diagnostics
2. NRF Experiments
3. Photo–fission experiments
4. (γ,n) experiments – above the neutron threshold
5. (γ,charged particles) experiments
6. Positron source for material science
7. Applications

Gamma Beam Diagnostics Stages

Accelerator commissioning stage (2016)

- bremsstrahlung spectra measurement
  - large NaI(Tl) detector
- energy profile measurements (gamma rays with < 3 MeV)
  - large volume HPGe detector with anti–Compton shield or large volume $LaBr_3$ detector

Low–energy stage (beginning 2017) $\geq$ 3 MeV & BW $\leq 5 \times 10^{-2}$

- in–beam measurements
  - high count rate → reduction of photon number
    - high precision absorbers
  - flux counter detector

High–energy stage (end of 2018) $\geq$ 19.5 MeV & BW $\leq 5 \times 10^{-3}$

+ characterize the time structure of the gamma beam
  - $LaBr_3$ detector for fast timing (2”x 2”) $\leq$ 0.5 ns
+ polarization measurements
  - ^{232}Th NRF
  - ^{2}D break–up (neutrons and protons)

GBS – Experimental Setups

Nuclear Physics eli

E3: Positron spectroscopy

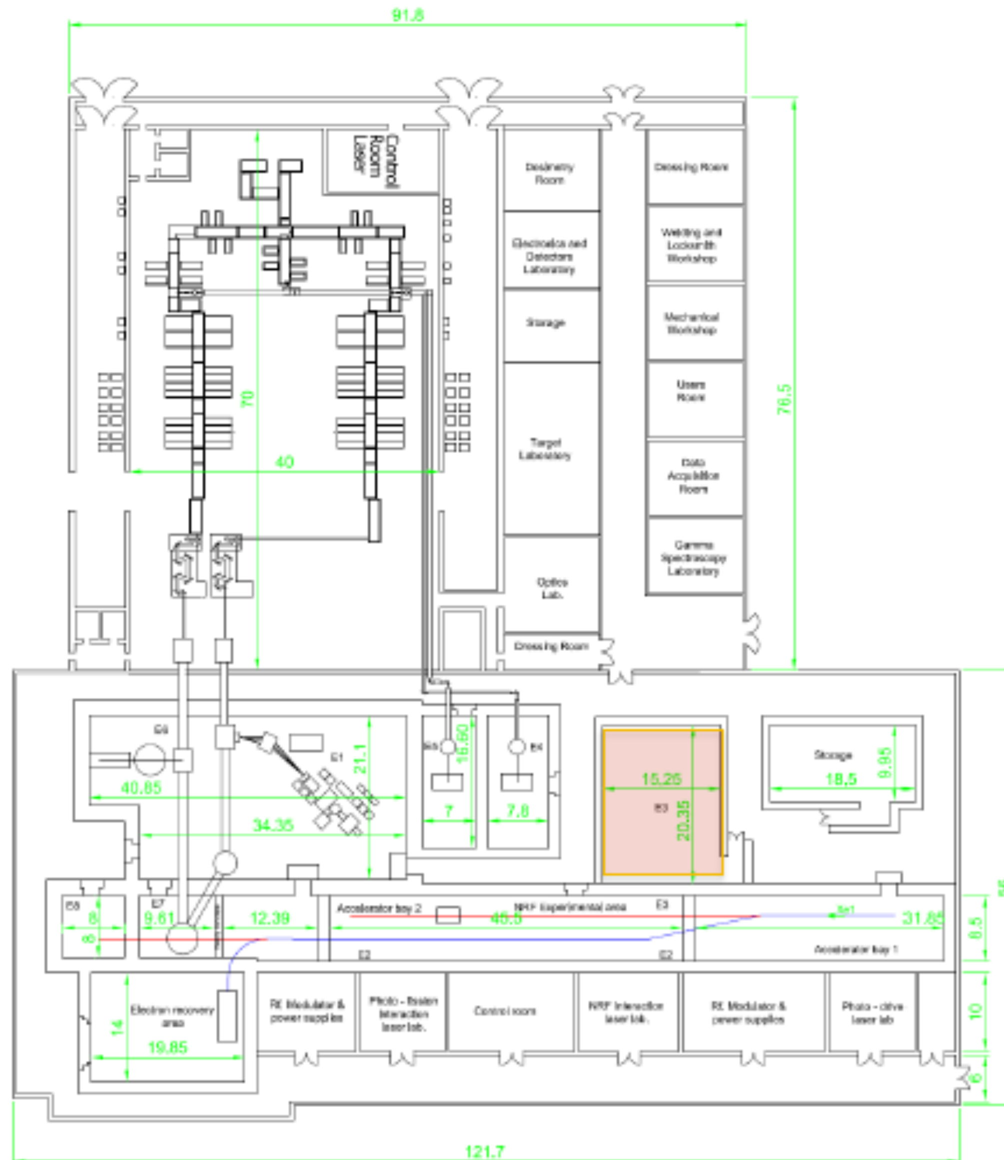
E2: Low energy gamma vault

- Nuclear Resonance Fluorescence
- Isotope-specific material detection, assay and imaging
- Medical isotopes

E8: High energy gamma vault

- (γ,*n*) cross sections
- (γ,*charged particles*) astrophysics
- NRF
- Photofission

E7: Experiments with combined laser and gamma beams



GBS – Experimental Setups

E3: Positron spectroscopy

E2: Low energy gamma vault

- Nuclear Resonance Fluorescence
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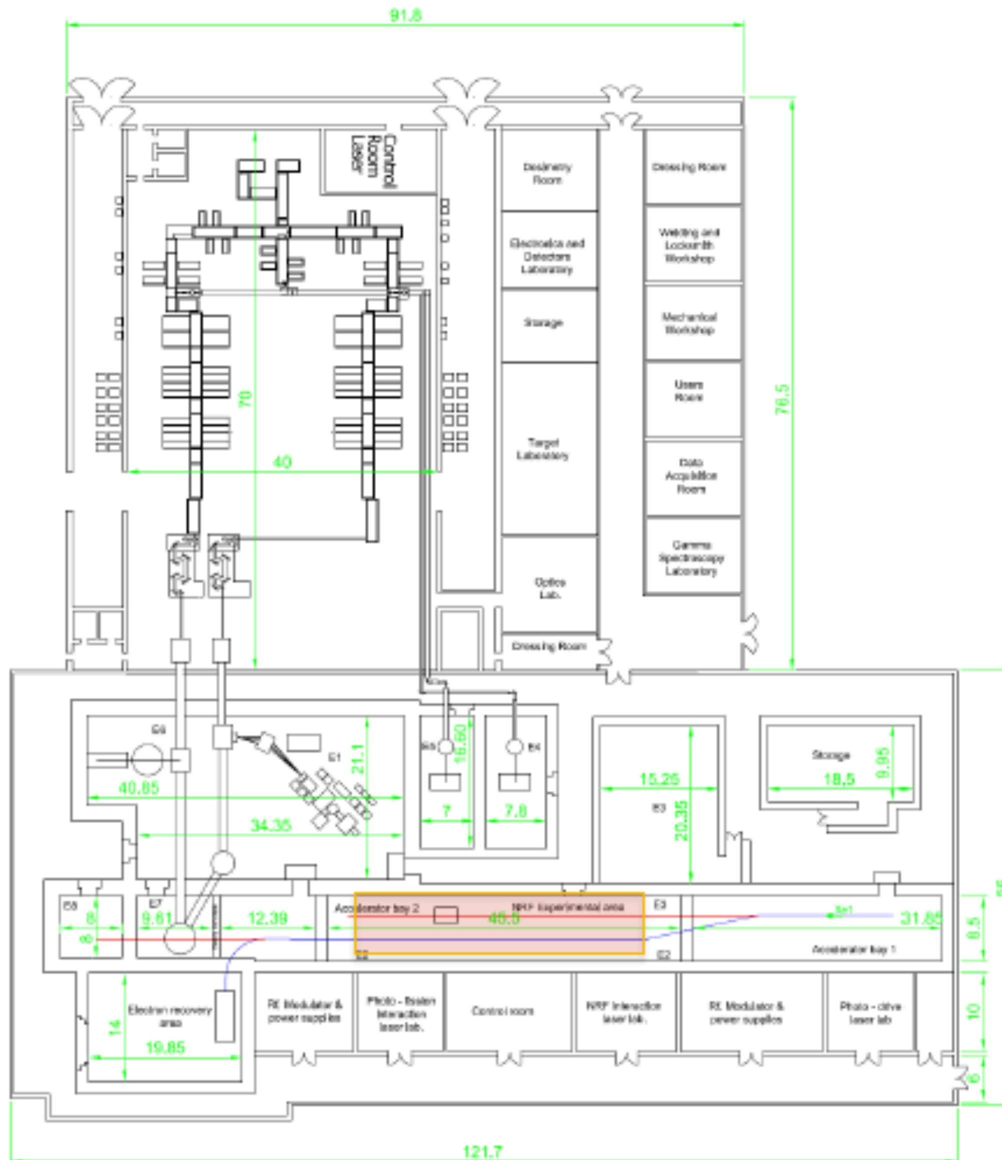

GBS – Experimental Setups

eli Nuclear Physics

E3: Positron spectroscopy

E2: Low energy gamma vault

- Nuclear Resonance Fluorescence
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E8: High energy gamma vault

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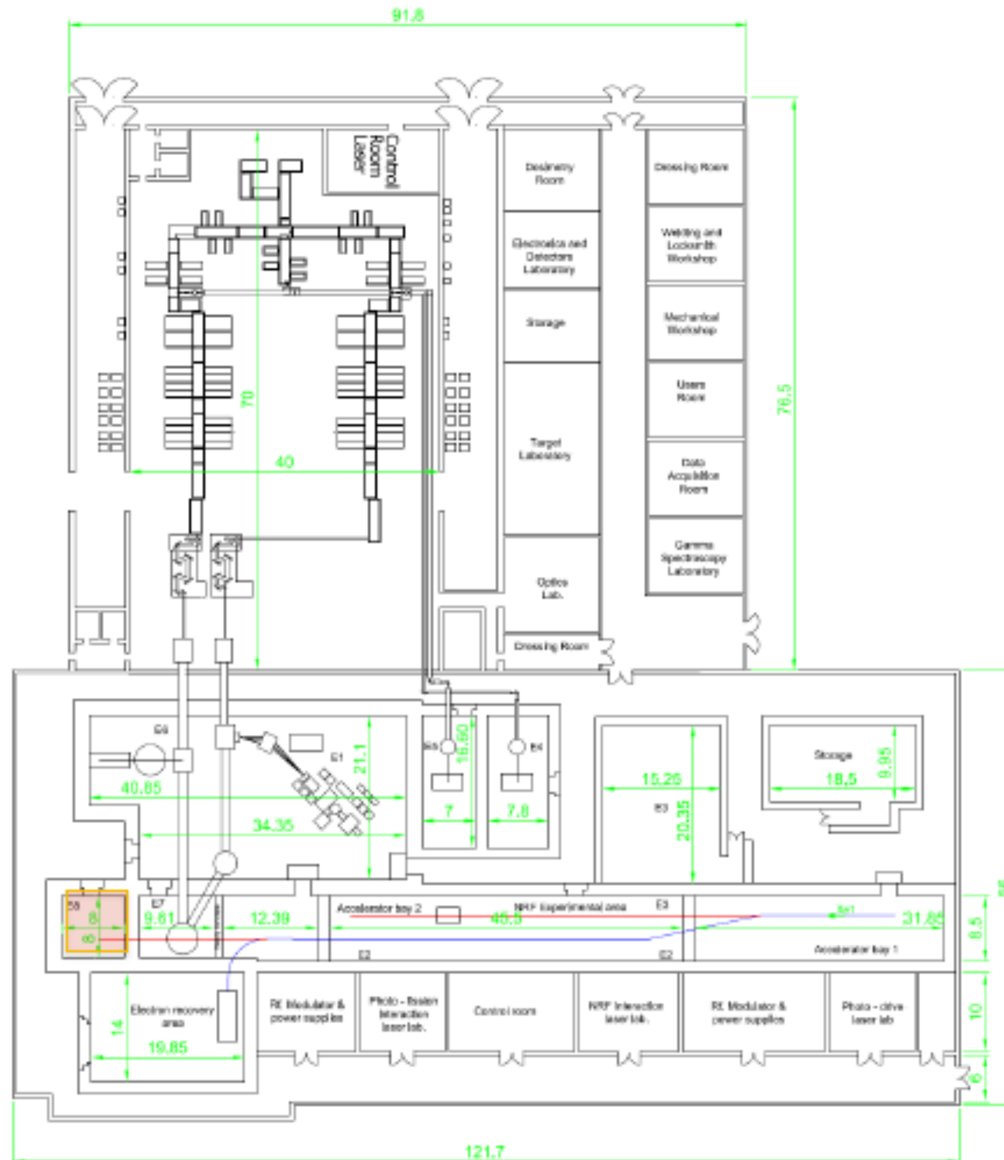
E7: Experiments with combined laser and gamma beams



GBS – Experimental Setups

Nuclear Physics

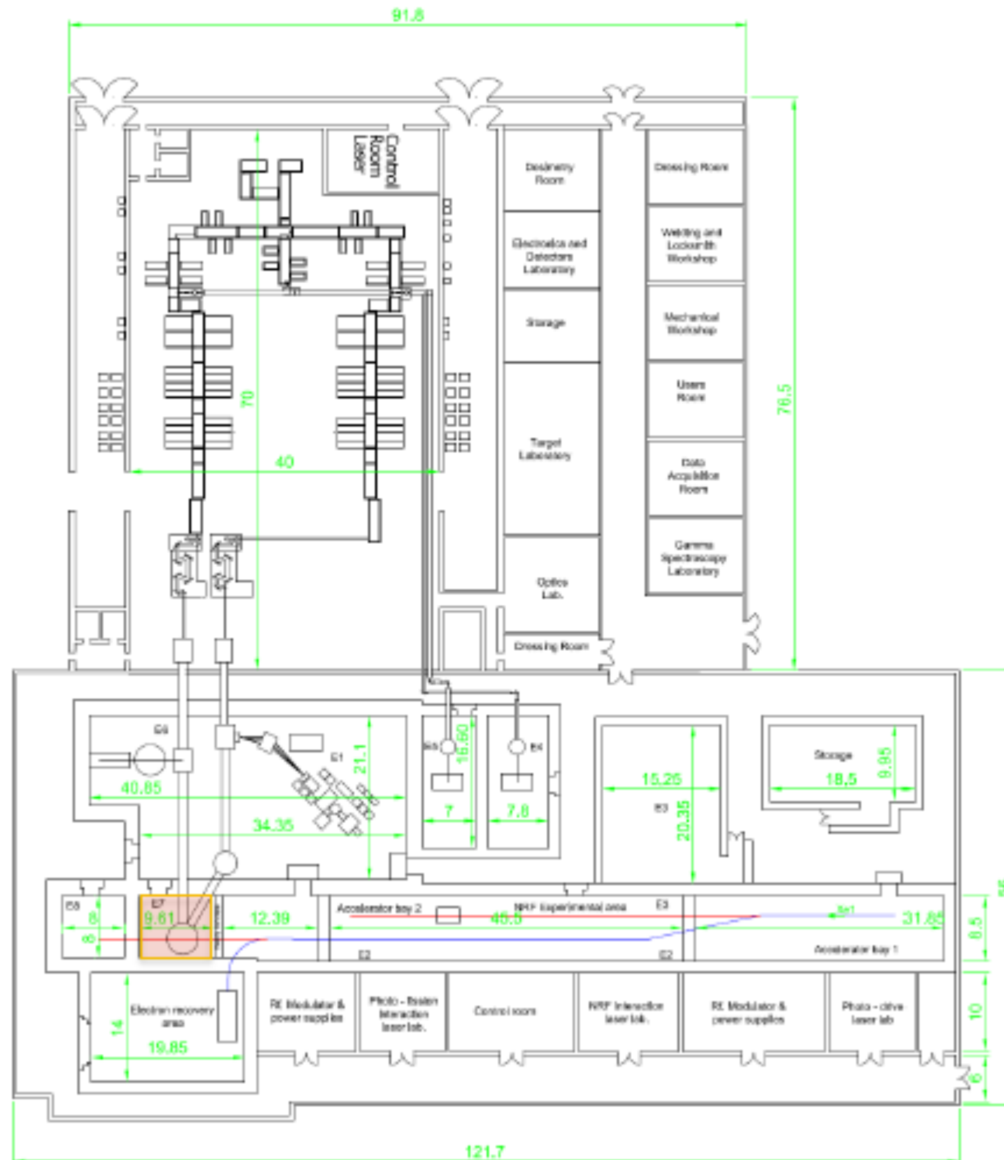
E3: Positron spectroscopy

E2: Low energy gamma vault

- Nuclear Resonance Fluorescence
- Isotope-specific material detection, assay and imaging
- Medical isotopes

E8: High energy gamma vault

- (γ,*n*) cross sections
- (γ,*charged particles*) astrophysics
- NRF
- Photofission



E7: Experiments with combined laser and gamma beams

Acknowledges for info:

Georg Korn eli-beamlines
Karoly Osavy eli-alps
Razvan Dabu eli-np
Calin A. Ur eli-np

Thanks

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Centro de Láseres Pulsados.
Edificio M5. Parque Científico de la Universidad de Salamanca.
c/ Adaja, 8. 37185 Villamayor de la Armuña.
Salamanca. Spain

- ✓ ELI pillars and ELI-Beamlines
- ✓ Facility layouts
- ✓ Lasers (RP1)
- ✓ Beam transport and switchyards
- ✓ **Experiments (RP2-RP6)**
- ✓ RP3 (ion and electron acceleration)

Relativistic Nonlinear Optics

2 sources of Nonlinearity

1. relativistic mass change
2. Pondermotive Pressure

Relativistic Optics

$$\vec{F} = q\left(\vec{E} + \left(\frac{\vec{v}}{c} \wedge \vec{B}\right)\right)$$

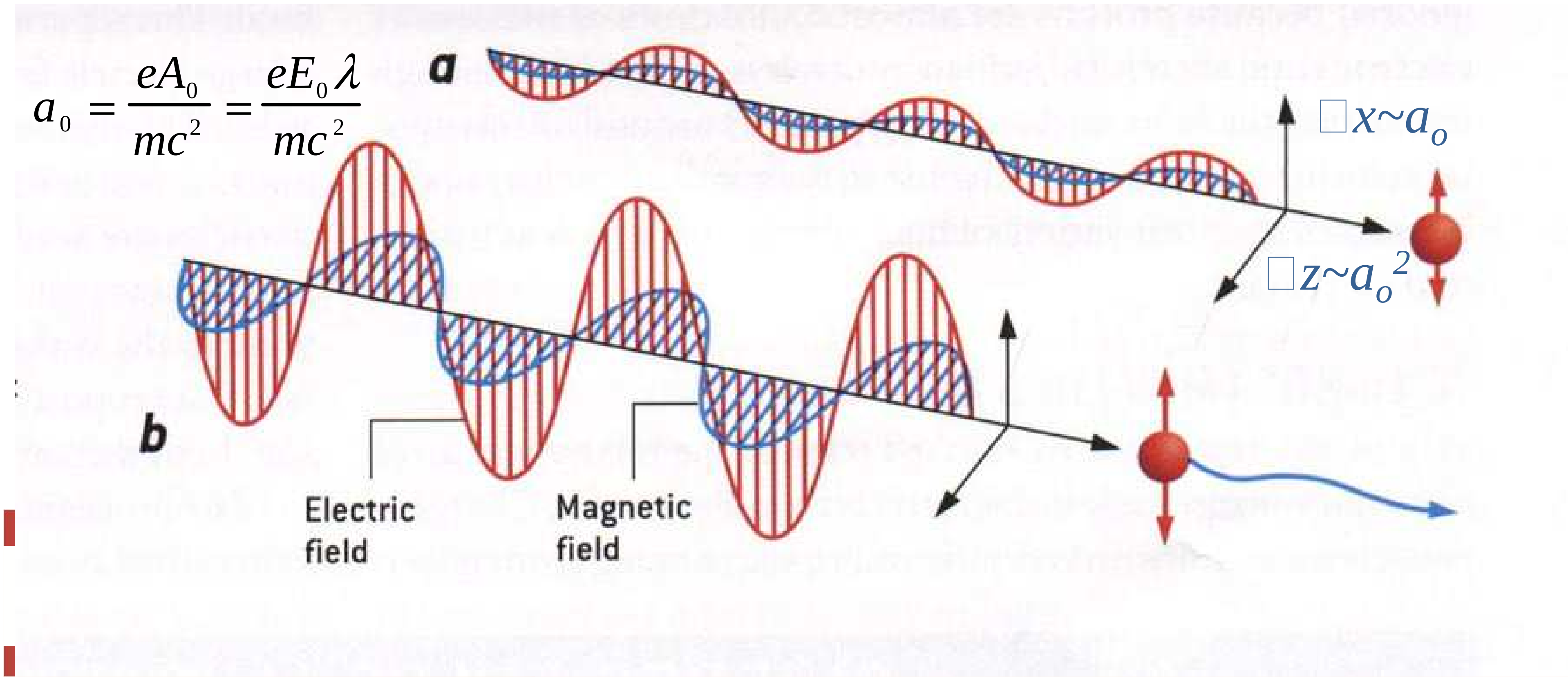
a)Classical optics v<<c,

$a_0 << 1,\ a_0 >> a_0^2$

b) Relativistic optics v~c

$a_0 >> 1,\ a_0 << a_0^2$

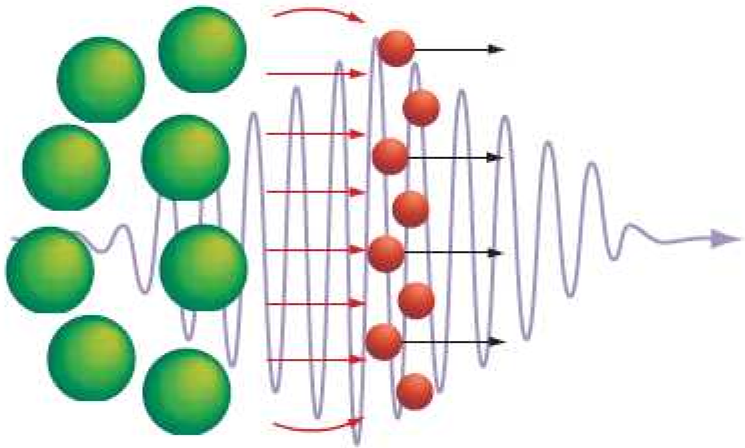
$$a_0 = \frac{eA_0}{mc^2} = \frac{eE_0\lambda}{mc^2}$$

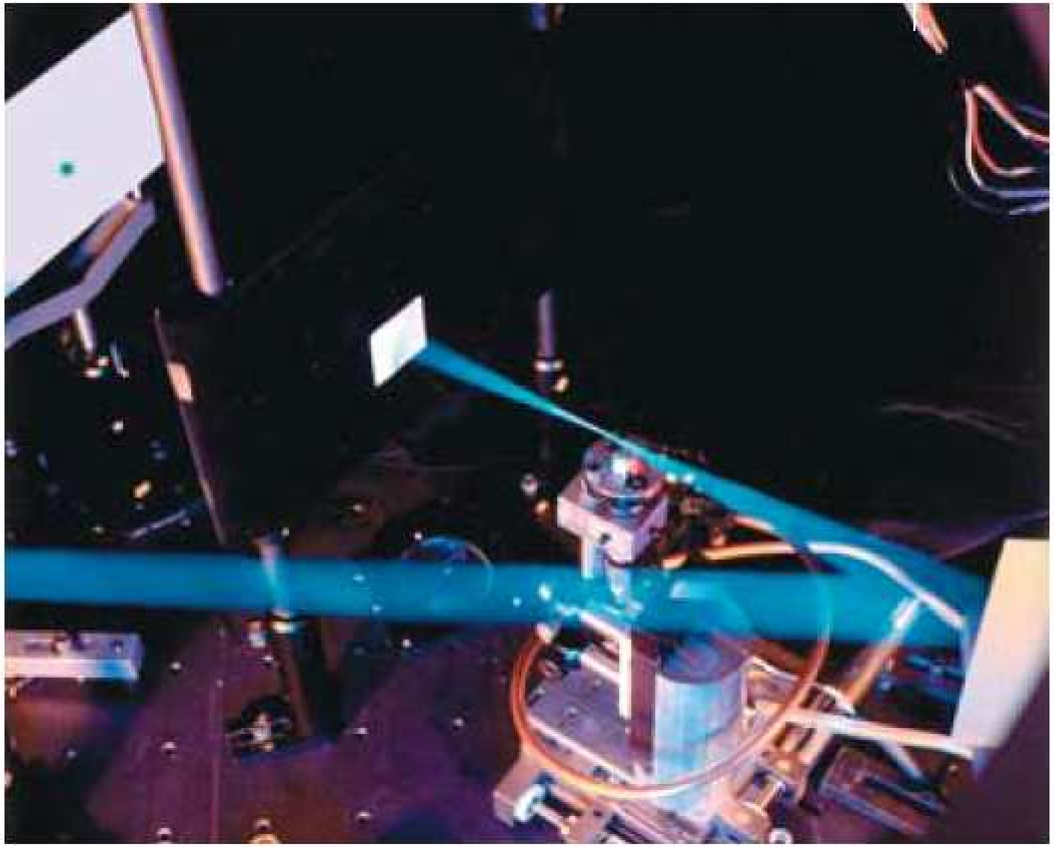


See talk of D. Margarone, electron and ion acceleration

WAKE-FIELD ACCELERATION

HIGH-INTENSITY LIGHT striking a plasma (*below*) pushes the electrons to very high speeds, leaving the heavier positive ions (*green*) behind and producing a powerful electric field (*red lines*) between these separated charges. This separation of charges and the associated electric field trails along in the wake of the light and can accelerate other charged particles to very high energy.

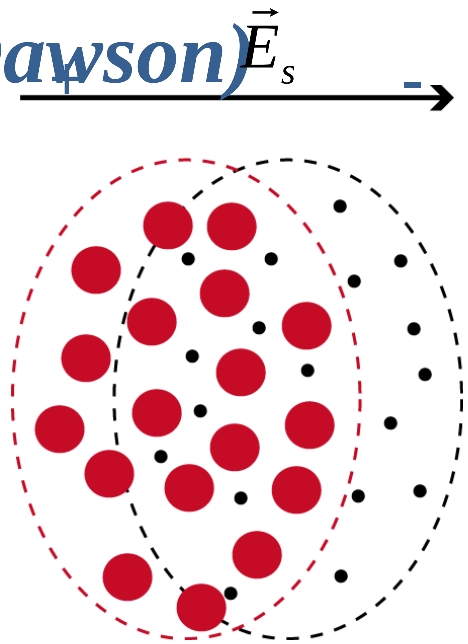


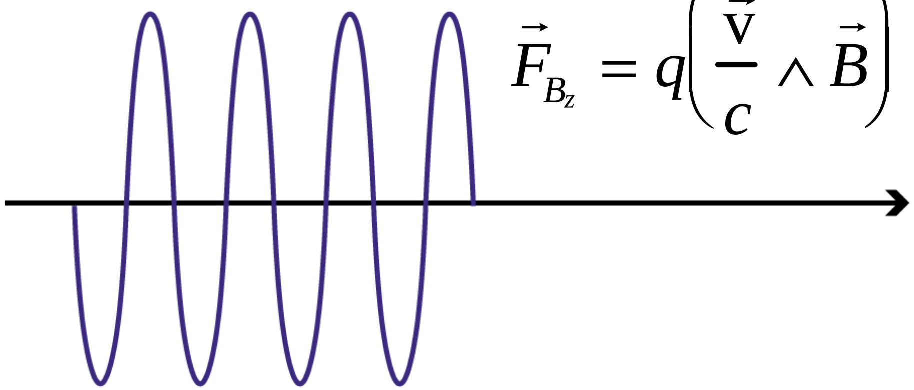


ULTRAHIGH-INTENSITY LASER PULSE (*added in blue*) focused on a jet of helium gas by a parabolic mirror accelerates electrons from the gas to 60 MeV in one millimeter. A fluorescent screen (*upper left*) detects the high-energy electron beam.

Relativistic Rectification

(Wake-Field Tajima, Dawson)





$$\vec{F}_{B_z} = q\left(\frac{\vec{\mathrm{v}}}{c} \wedge \vec{B}\right)$$

1) $\vec{\mathrm{v}} \wedge \vec{B}$ pushes the electrons.

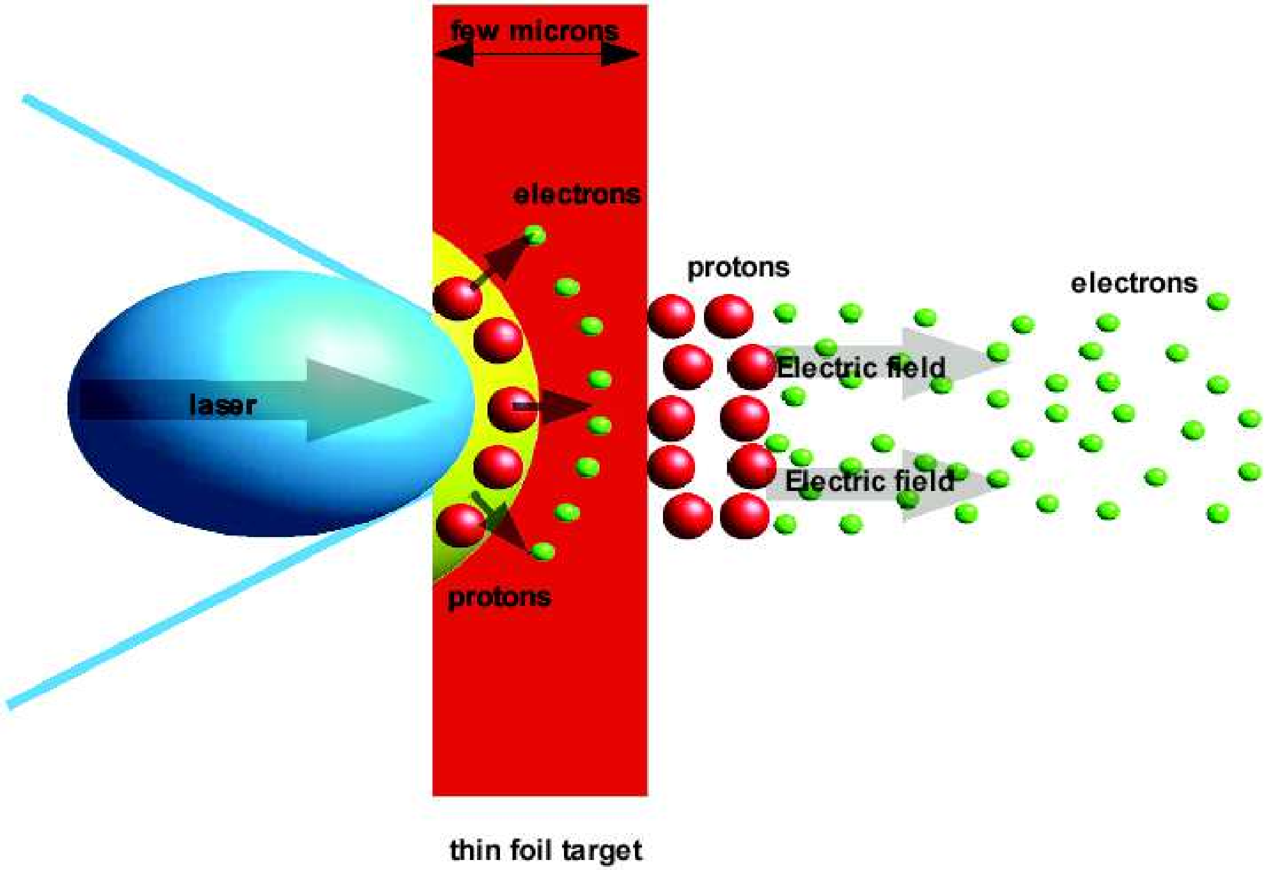
2) The charge separation generates an electrostatic longitudinal field. (Tajima and Dawson: Wake Fields or Snow Plough)

$$E_s = \frac{c\gamma m_o \omega_p}{e} = \sqrt{4\pi\gamma m_o c^2 n_e}$$

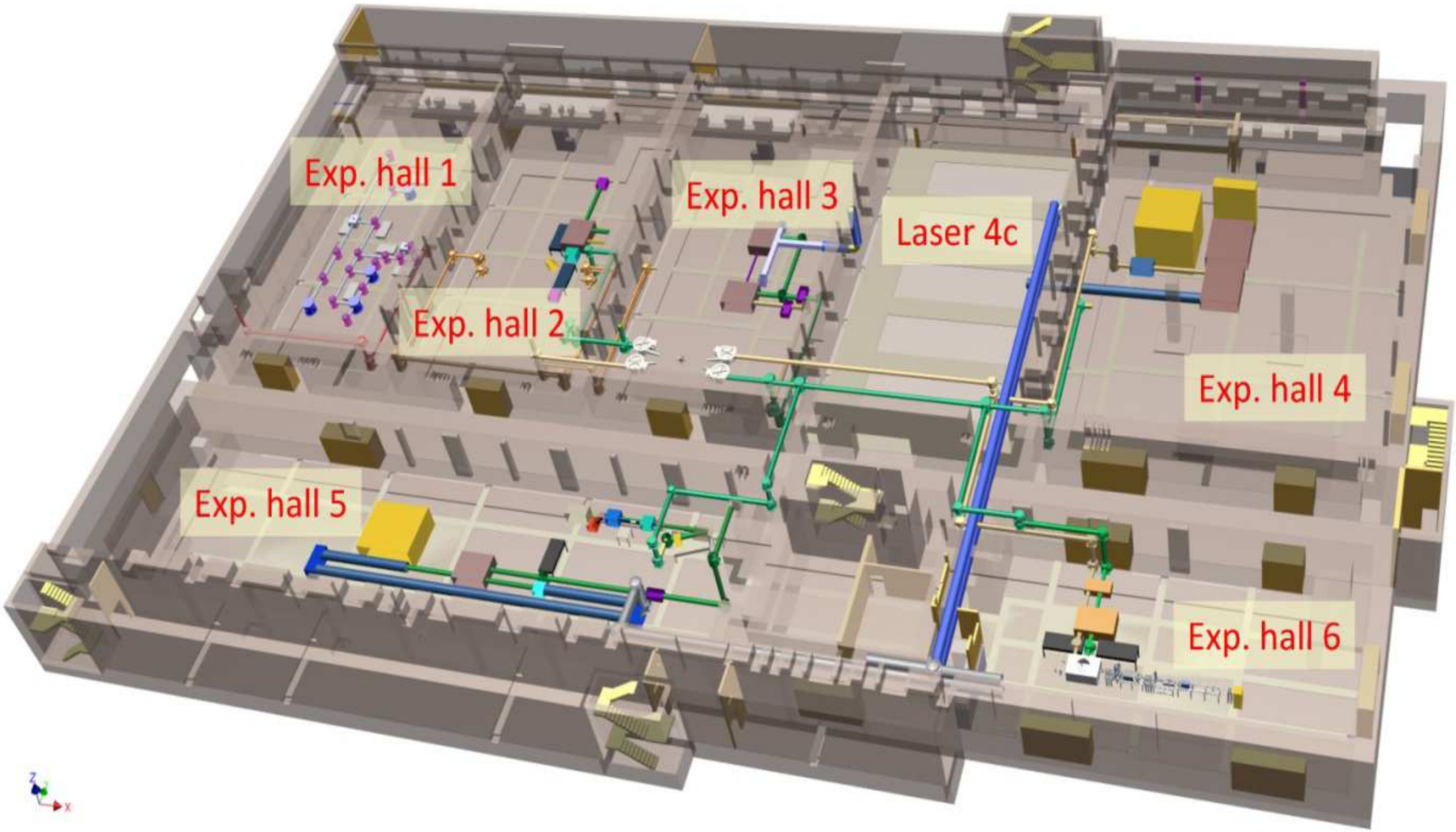
3) The electrostatic field $E_s \approx E_L$

Compact accelerators

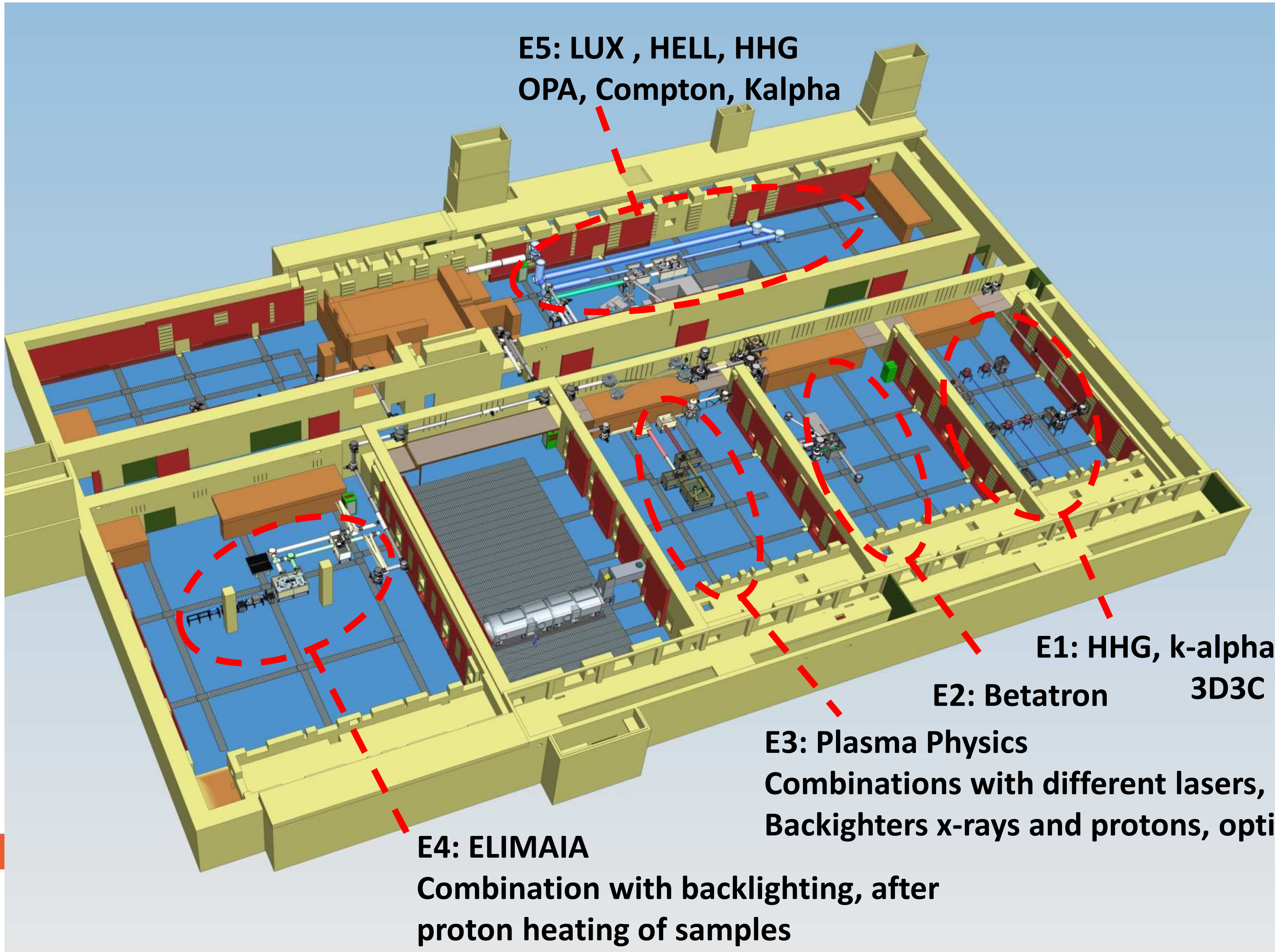
Proton Acceleration mechanism (TNSA)



Experimental Area (ground floor)

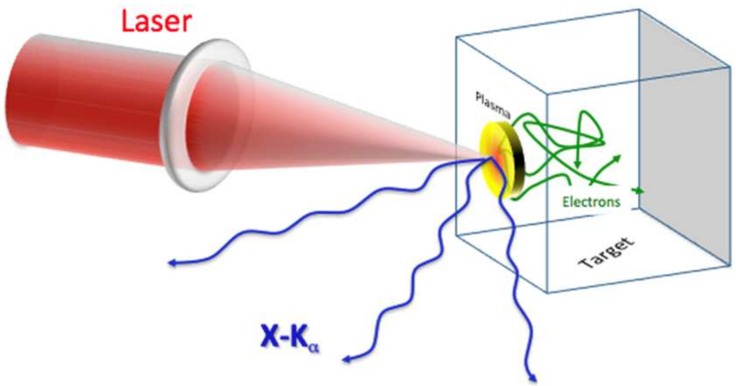


Experimental Areas, Basement floor

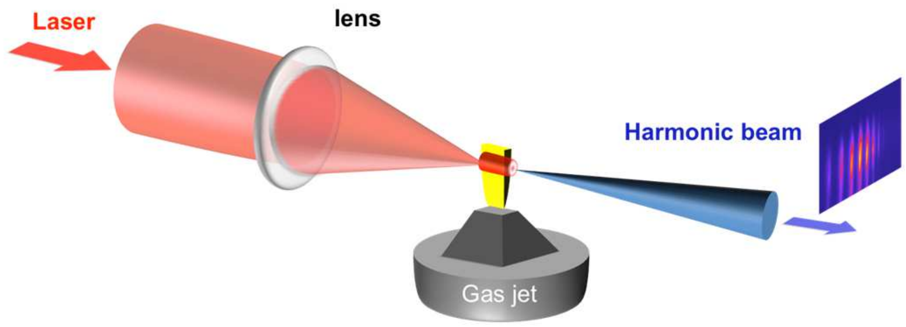


RP2: Laser-driven X-ray sources
S. Sebban

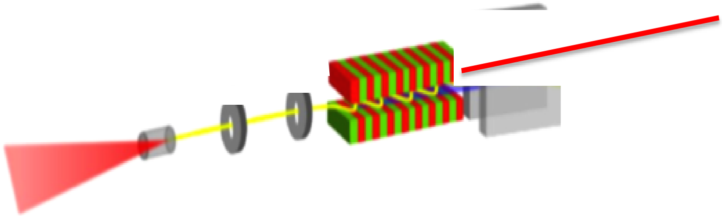
Plasma sources



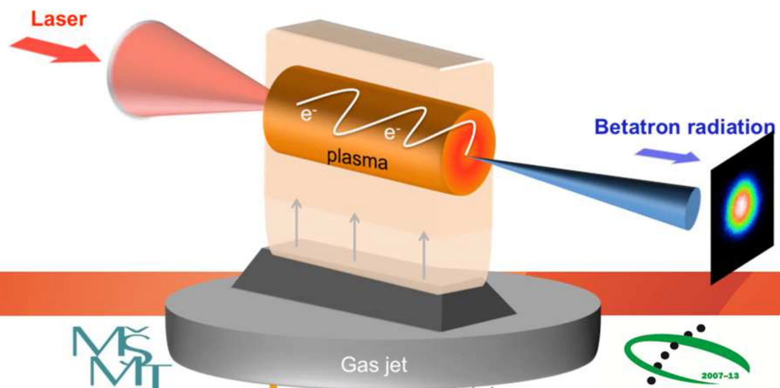
Harmonics (gas)



LUX/XFEL



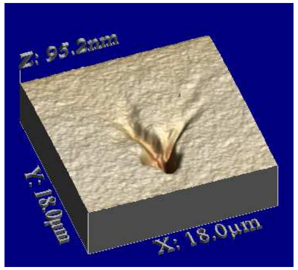
X-rays from relativistic e-beams



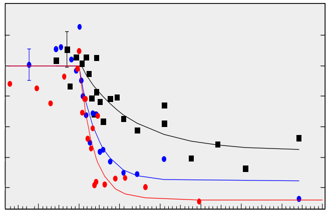
eli beamlines

Motivations : brigth fs sources for applications
See Talk of J. Andreasson

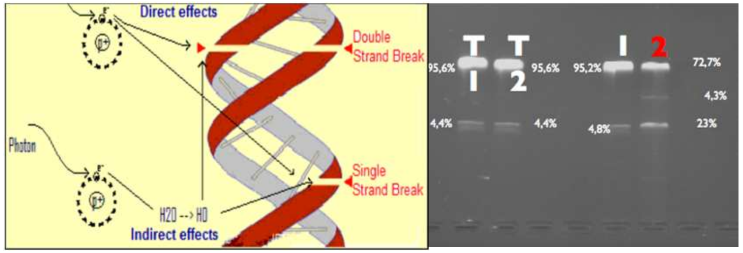
Ablation



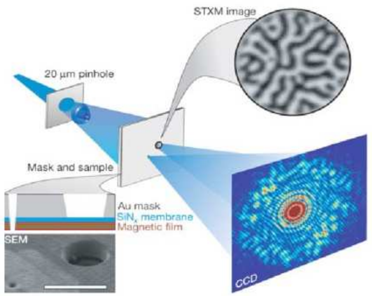
Phase transitions



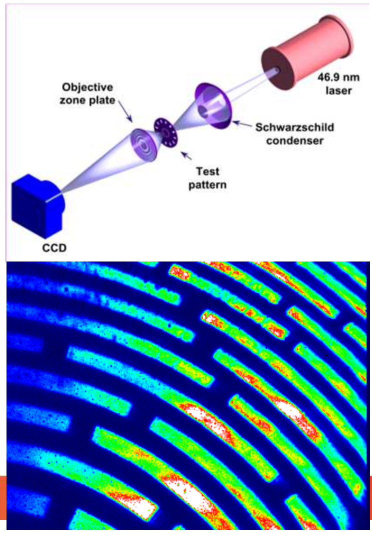
Bio structures, damage



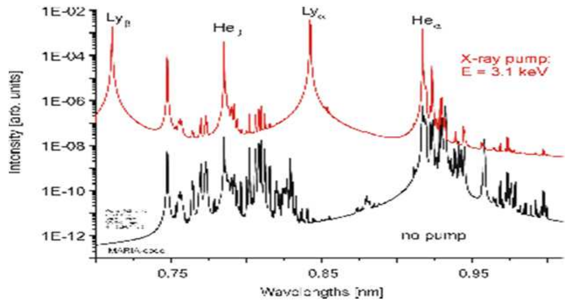
Magnetism



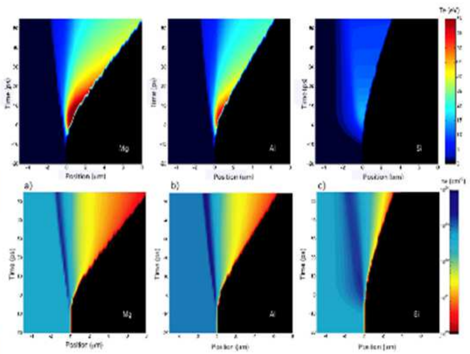
X-ray microscopy



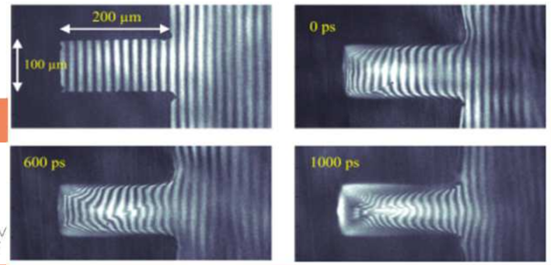
Atomic physics



Warm dense matter



Plasma diagnostics



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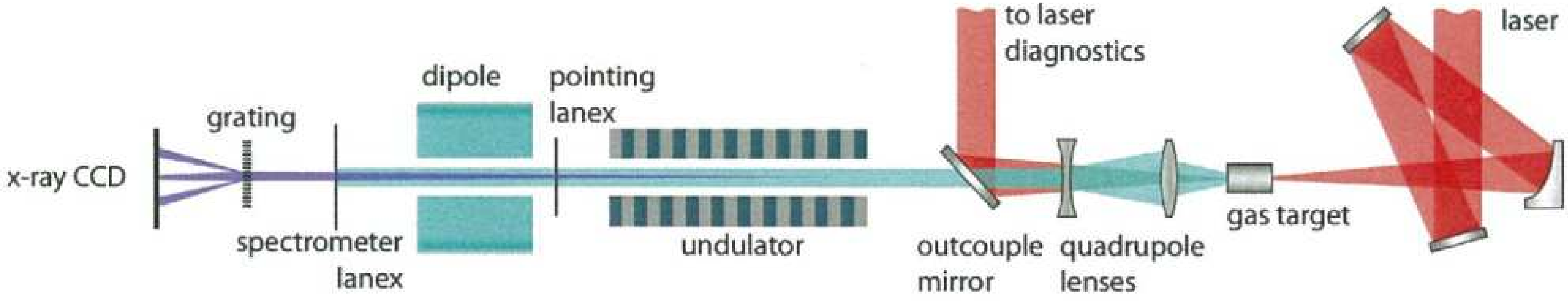
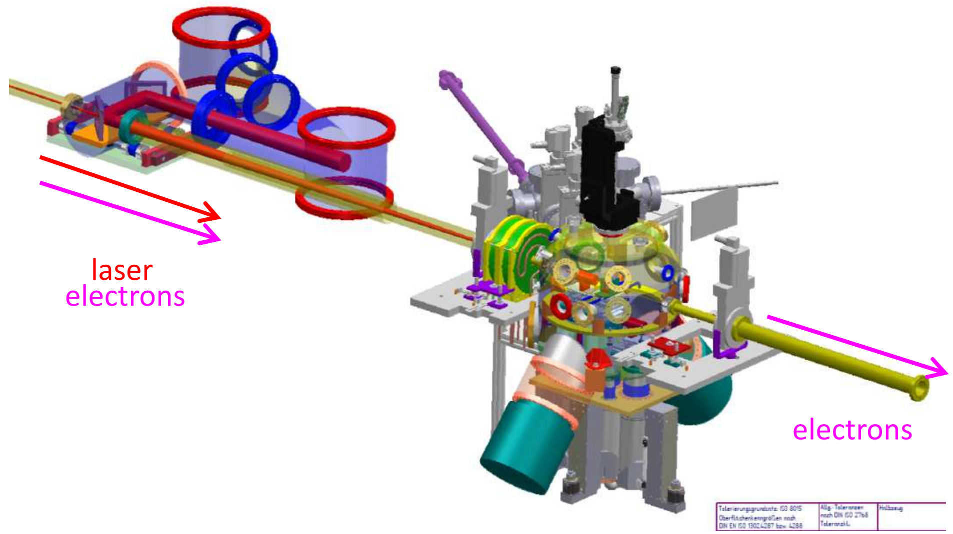
LUX (Laser Undulator X-ray) beamline
F. Gruener

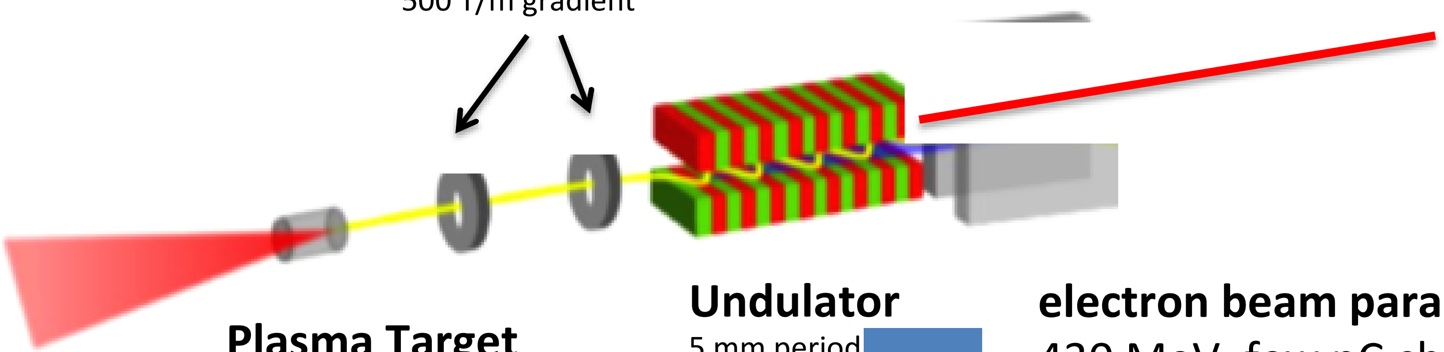


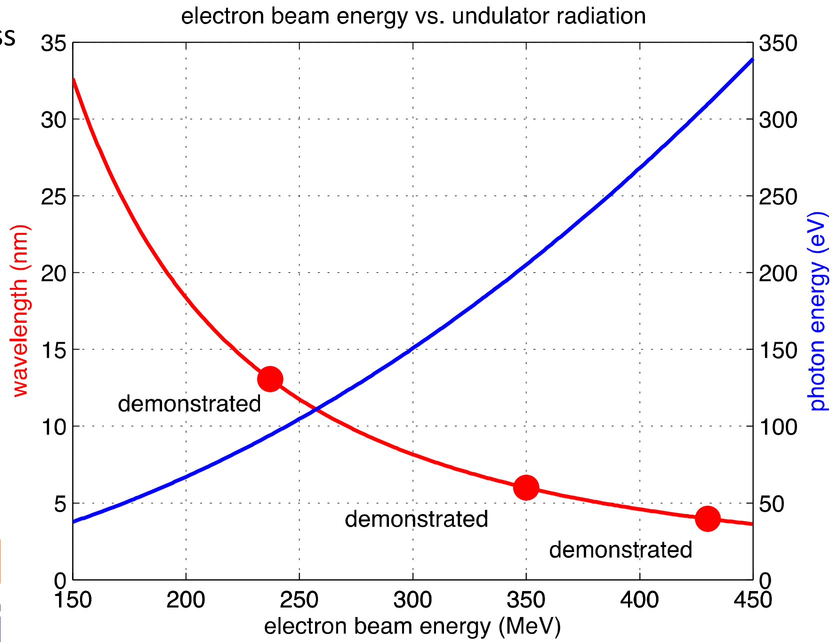
- Development in collaboration with Hamburg University (F. Gruner) and DESY
- Water window wavelength range with sub-5fs pulse duration
- Future extension to laser driven X-FEL with more undulators (water window and 5 keV, short and tunable x-ray pulses)



REGAE beamline (Hamburg) CAD model

LUX beamline





electron beam parameters:
430 MeV, few pC charge
0.2 mm.mrad norm emittance

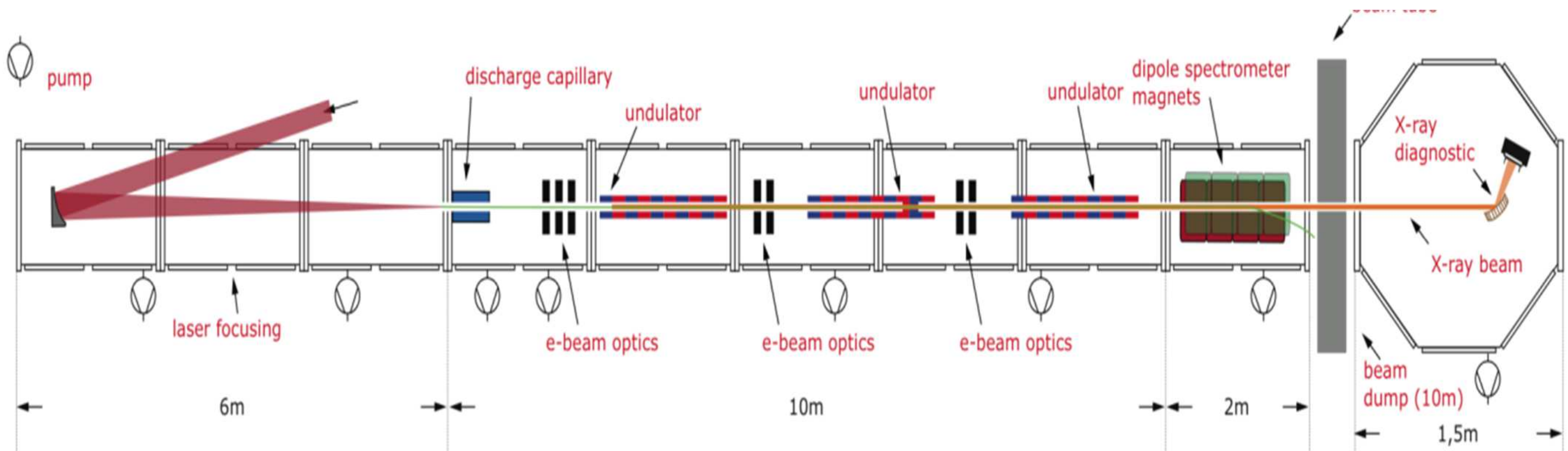
photons (2016)

- bandwidth stabilized to 2%
- pointing stabilized
- $10^{5...6}$ photons per pulse
- down to 3 nm
- pump-probe experiments

M. Fuchs et al., *Nature Physics* ***5****, 826 (2009)*

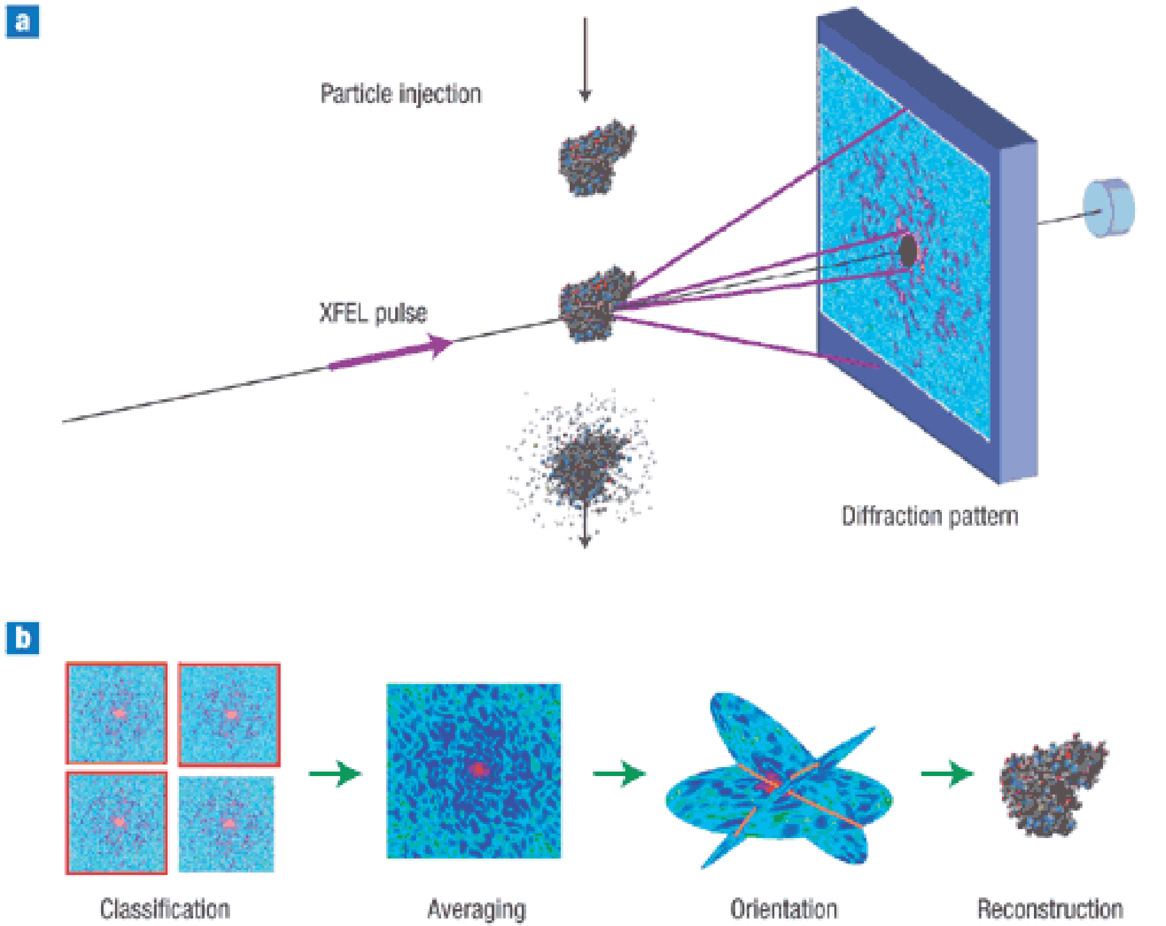
eli beamlines

Laser driven LUX and x-FEL (F. Grüner et al.)
Long term vision, ELI-white book
200 TW -1 PW @ 5-10 Hz, L2, L3
Cooperation with DESY using accelerator know-how, injection with synchronized relativistic electron gun



Water window FEL needs 400 MeV
2 GeV electrons, 5 keV, short and tunable x-ray pulses

Time-resolved single-particle diffraction imaging of biological molecules without crystallization, J. Andreasson



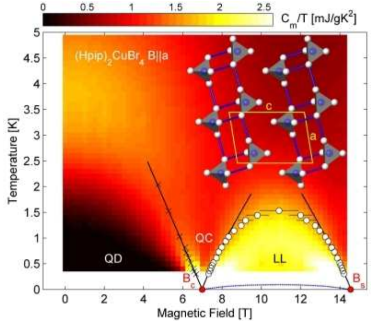
Kirz,Nature Physics 2, 799 - 800 (2006)

eli beamlines

Scientific programmes under development in RA4

1: Coherent Diffractive Imaging (CDI) and Atomic, Molecular and Optical (AMO) Science

@ the direct beamline of the HHG source

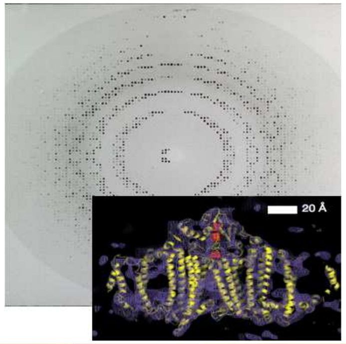


2: Soft X-ray Materials Science

@ the monochromator beamline of the HHG source

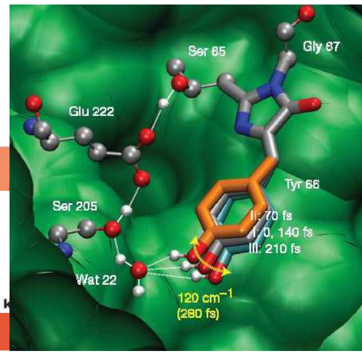
3: X-ray Absorption Spectroscopy (XAS) and Incoherent X-ray Imaging

@ one of the PXS beamlines



4: X-ray Diffraction

@ the other of the PXS beamlines



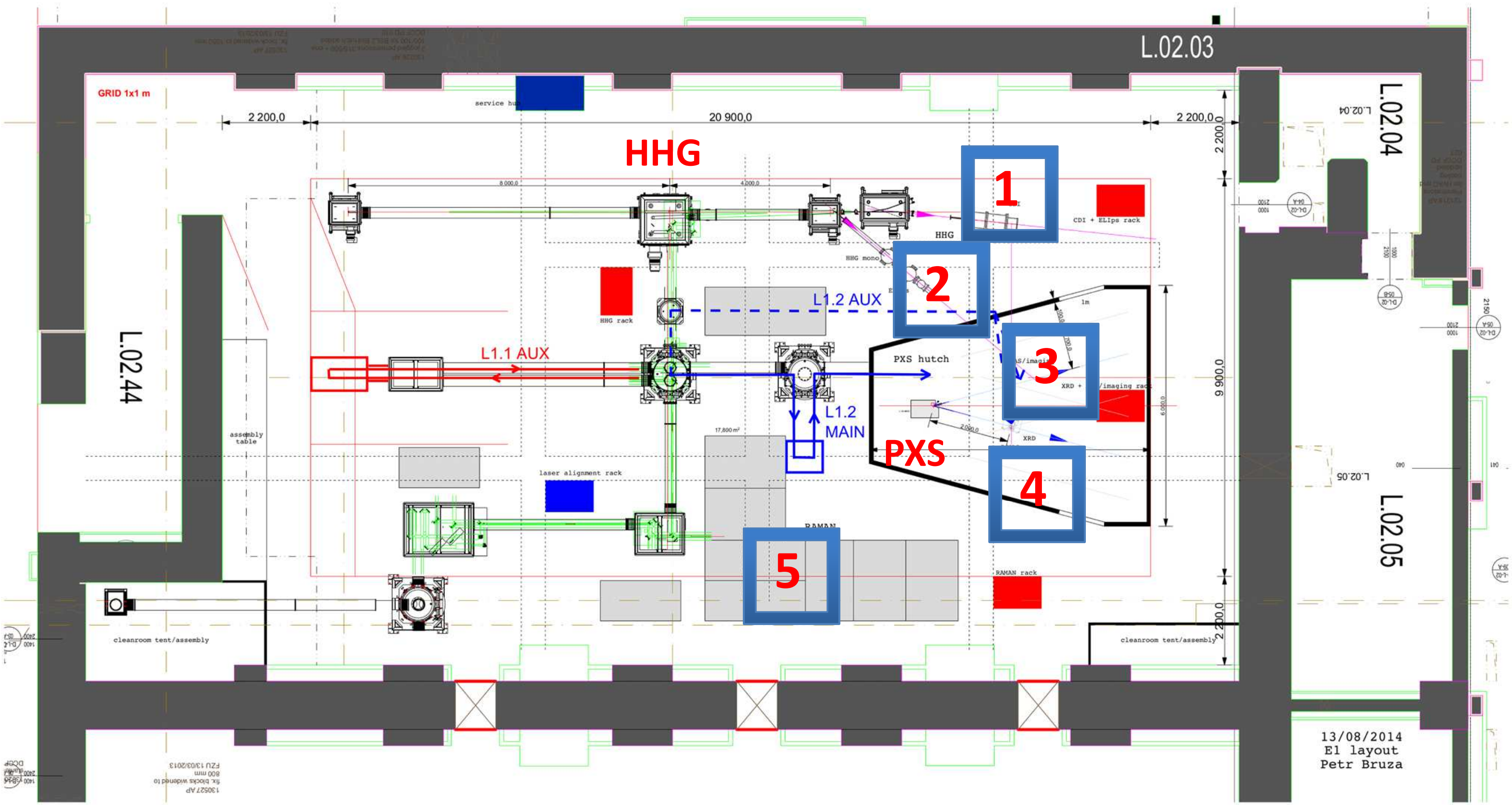
5: Optical Spectroscopy and Molecular Dynamics

@ the optical spectroscopy stations

E1 layout, beam distribution and experimental stations

4 beams from the L1 laser allows complex time-resolved experiments

• 2 secondary sources: Higher Harmonics Generation (HHG) for soft X-rays and a Plasma X-ray Source (PXS) for hard X-rays
• 5 Experimental end-stations where experiments are performed



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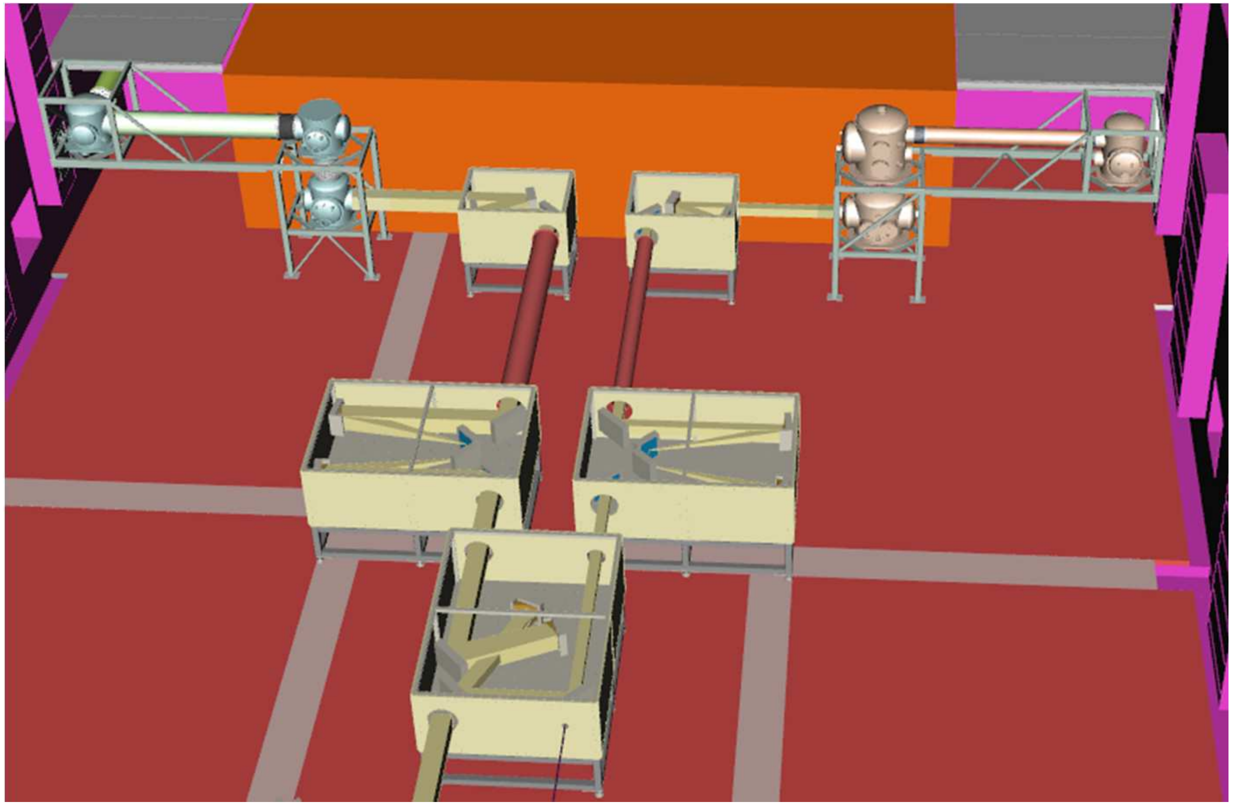
RP5: Laser plasma and high-energy-density physics, S. Weber

- 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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Fundamental intensity dependent regimes of interaction

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^-

$$e\lambda E_{rel} = m_e c^2$$

$$e\lambda E_{ultrarel} = m_p c^2$$

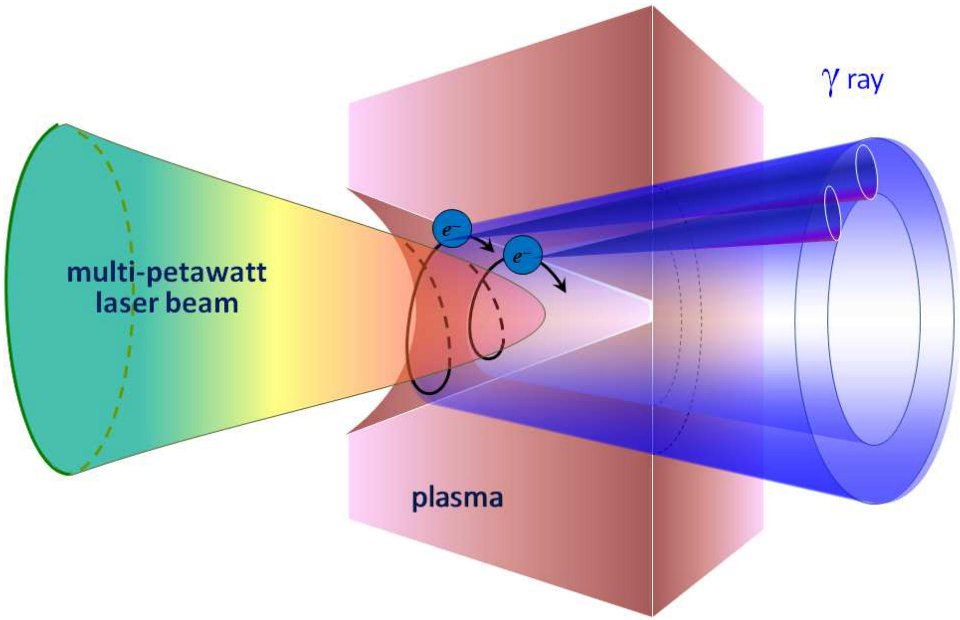
$$e\lambda_{comp} E_{rel} = m_e c^2$$

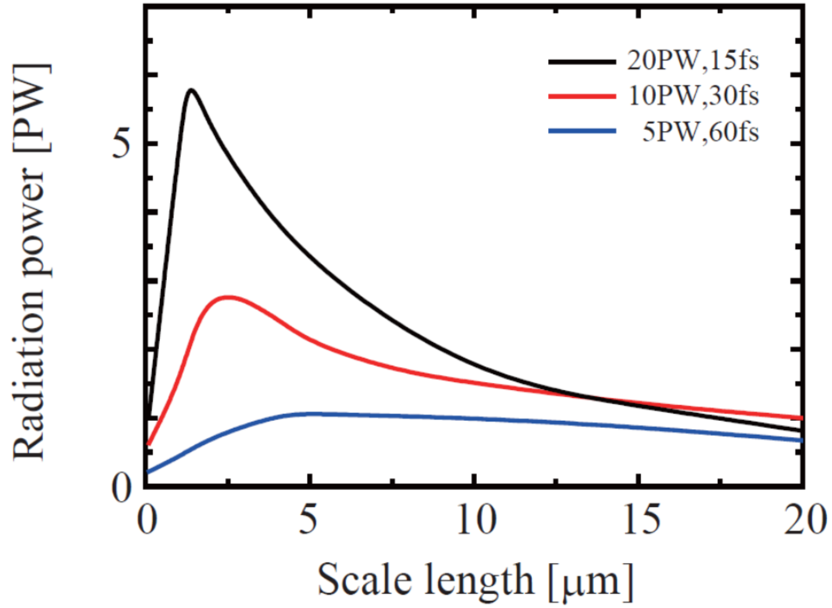
$$\lambda_{comp}(electron) = 2.4x10^{-6}\,\mu m$$

$$E_0[\text{V}/\text{cm}] = 19\sqrt{I[\text{W}/\text{cm}^2]}$$

Very compact accelerators can be built

Concept of high power gamma-flash generation





PRL **108,** 195001 (2012) PHYSICAL REVIEW LETTERS week ending 11 MAY 2012

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

Tatsufumi Nakamura,[1] James K. Koga,[1] Timur Zh. Esirkepov,[1] Masaki Kando,[1] Georg Korn,[2,3] and Sergei V. Bulanov[1,4]

[1]*Kansai Photon Science Institute, Japan Atomic Energy Agency, Kizugawa, Kyoto, Japan 6190215*

[2]*Max-Planck-Institut für Quantenoptik, Garching, Germany 85748*

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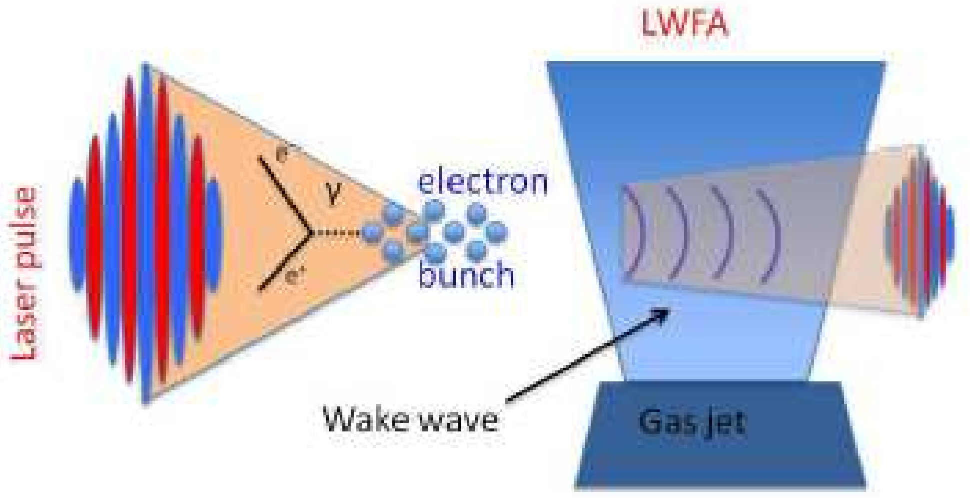
(Received 23 November 2011; revised manuscript received 10 February 2012; published 9 May 2012)

Laser-induced Nonlinear QED

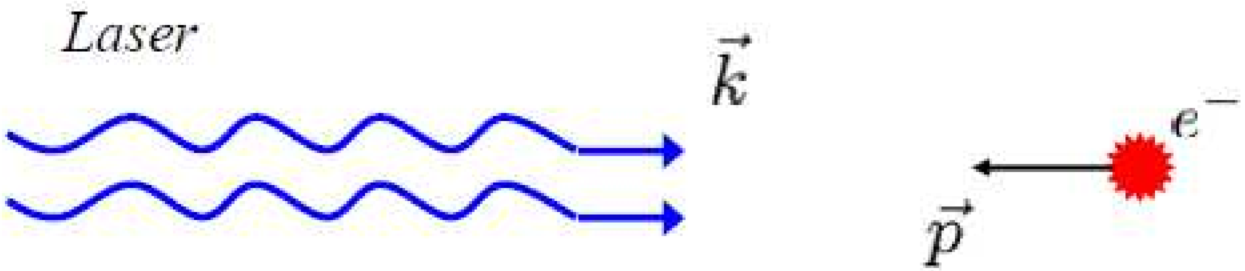
Quantum description is necessary when the recoil due to photon emission is of the order of the electron energy → 10^{21} Wcm^{-2} for 10 GeV electrons



Stepan Bulanov et al, AAC 2012

Laser-Induced Nonlinear QED

For head-on collision at laboratory reference frame:



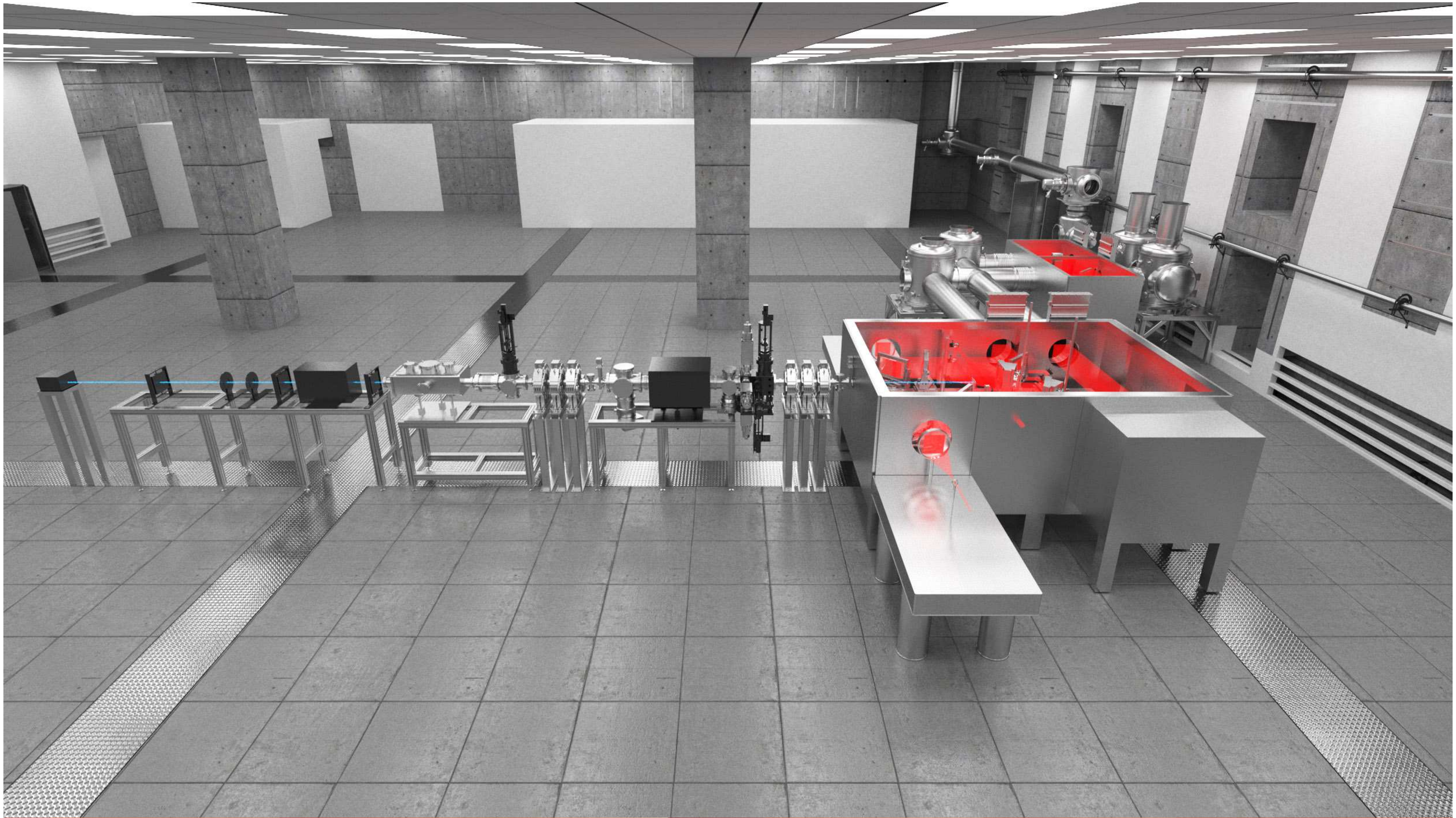
$$E_R = E_L \sqrt{\frac{1+v/c}{1-v/c}}, \qquad v = pc/\varepsilon$$ - electron velocity

for ultrarelativistic particle $1 - v/c \ll 1$, or

$$\gamma = \frac{1}{\sqrt{1-v^2/c^2}} = \varepsilon/mc^2 \gg 1 \qquad E_R \approx 2\gamma E_L$$

- ✓ ELI pillars and ELI-Beamlines
- ✓ Facility layouts
- ✓ Lasers (RP1)
- ✓ Beam transport and switchyards
- ✓ Experiments (RP2-RP6)
- ✓ RP3 (ion and electron acceleration)

«Virtual» ELIMAIA...



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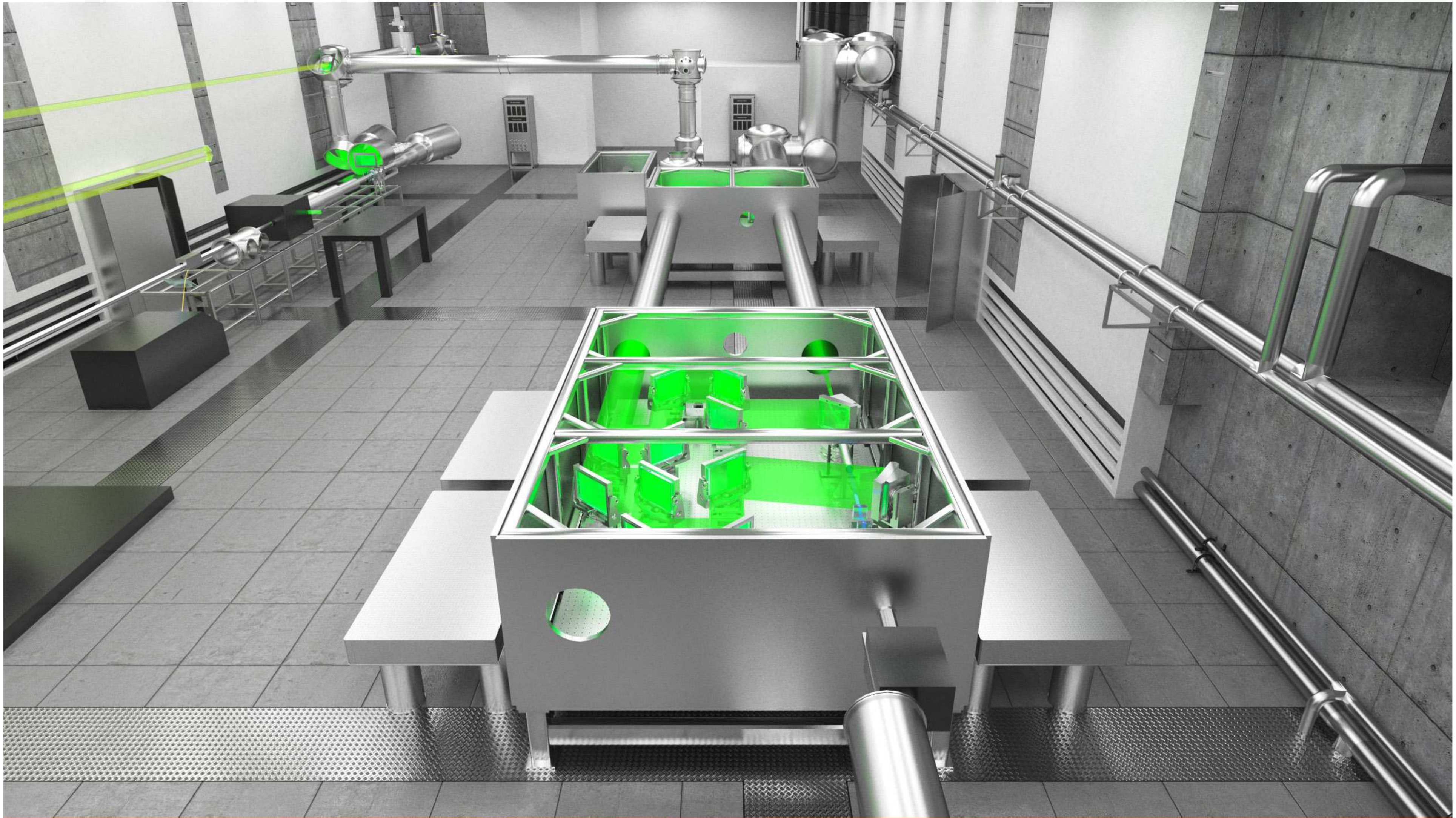

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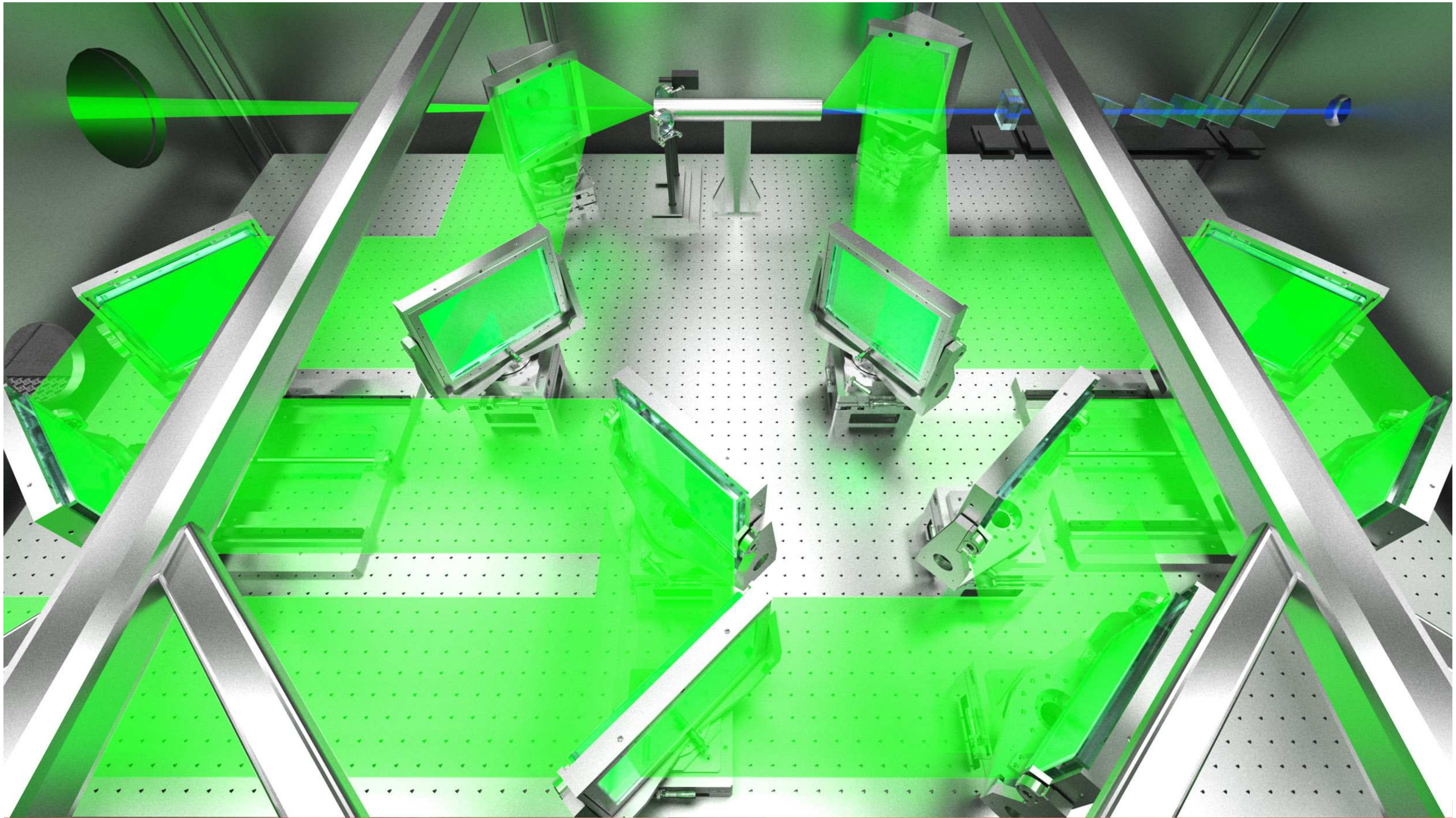

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