ELI Beamlines:

Status of the user facility development

High-Energy Beam Pillar
of the pan-European Research Infrastructure ELI

EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

Outline

- ELI
- ELI Beamlines
  - Project
  - Lasers
  - Experiments
- Eupraxia at ELI
- Conclusions

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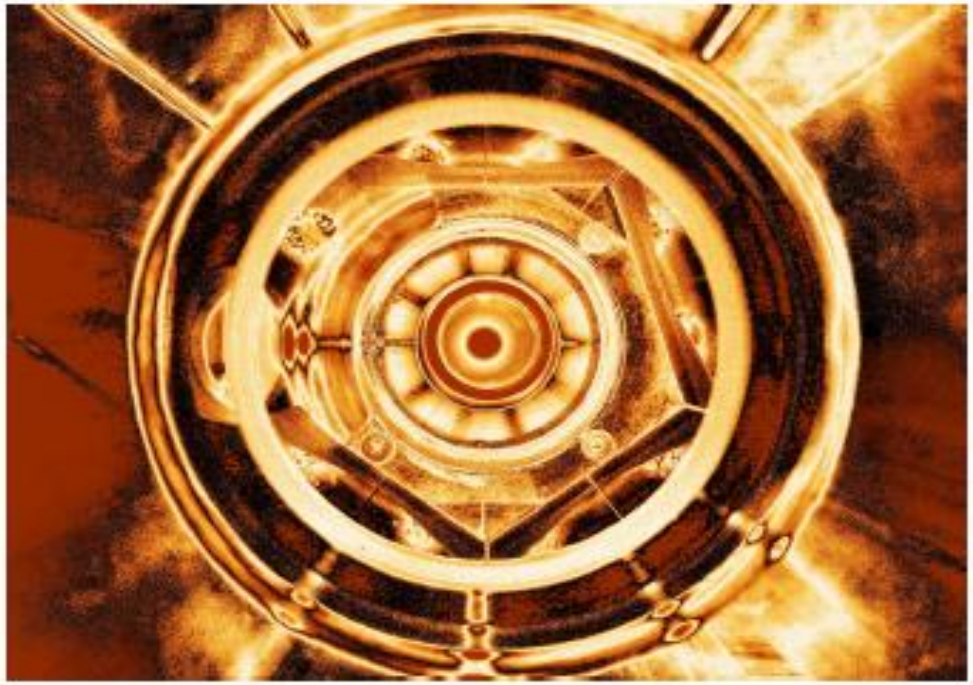
The Science Case

ELI – Extreme Light Infrastructure

Science and Technology with Ultra-Intense Lasers

WHITEBOOK



Editors

Gérard A. Mourou

Georg Korn

Wolfgang Sandner

John L. Collier

530 pages of Science, Technology and implementation strategies of ELI

www.eli-beams.eu

The Extreme Light Infrastructure
European Project

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New science, unique research opportunitites

ELI: a truly international laser research infrastructure

Attosecond Laser Science

- new regimes of time resolution (***ELI ALPS*, Szeged, HU**)

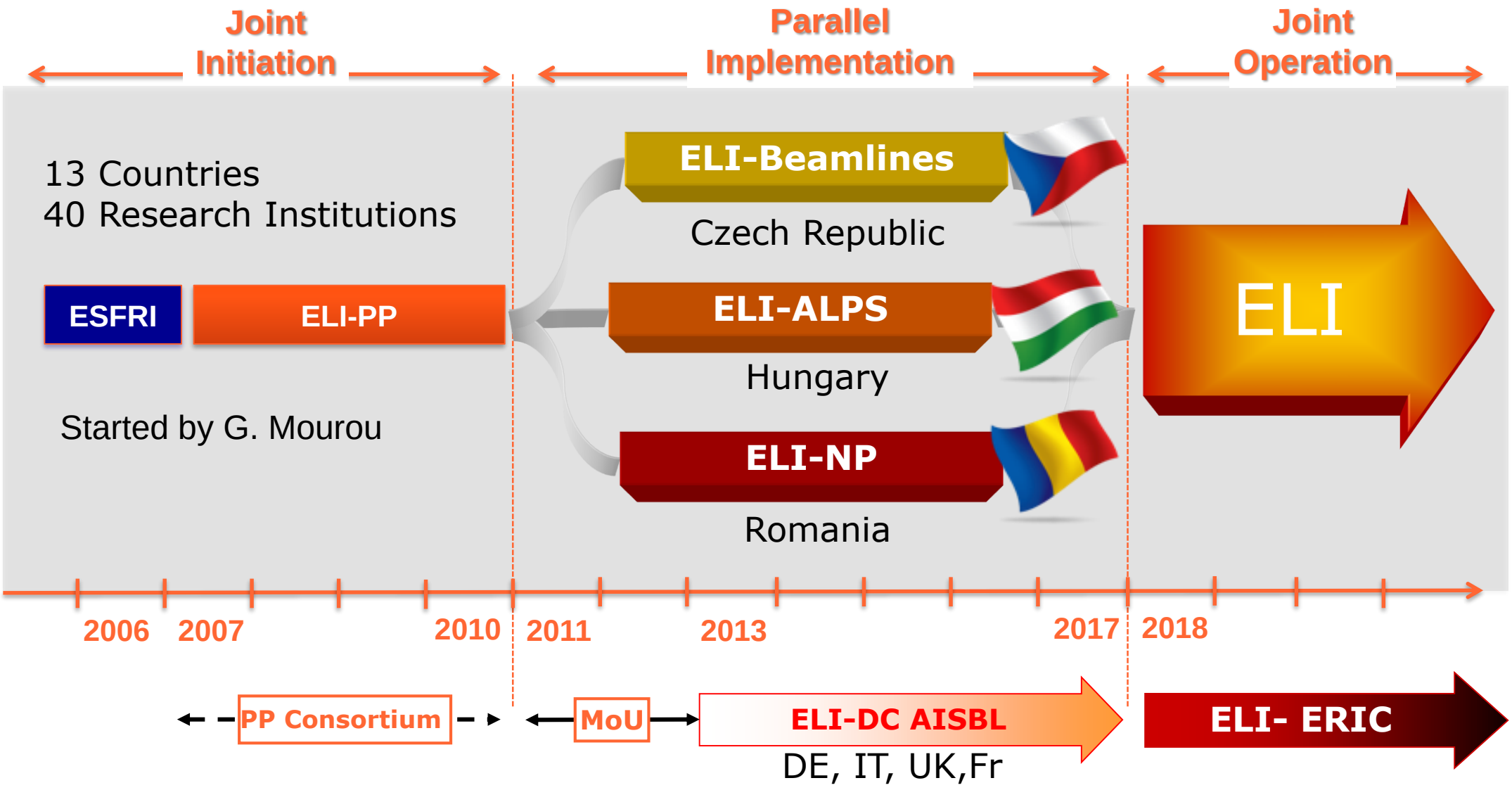
High-Energy Beam Facility

- development and application of ultra-short pulses of high-energy particles and radiation stemming from relativistic and later ultra-relativistc interaction (***ELI Beamlines*, Prague, CZ**)

Nuclear Physics Facility

- ultra-intense lasers and gamma beams < 19 MeV
- enabling brilliant neutron beam generation with controlled variety of energies (***ELI NP*, Magurele, RO**)

ELI = European Project



ELI Beamlines

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The Science Case

Fundamental science & User applications

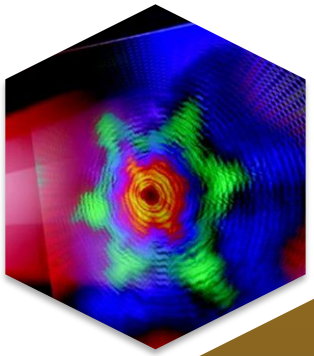
BIOCEV

Lasers

PW

kHz

B. Rus



ELIBIO

Prof. J. Hajdu

J. Nejdl

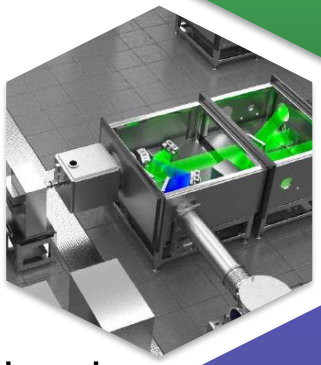
X-ray sources

Lab astrophysics

Plasma optics

S. Weber

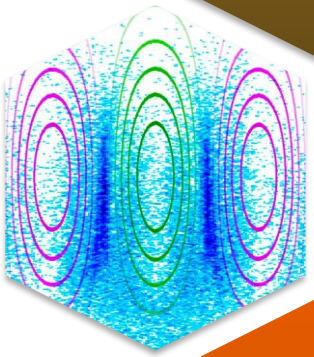
High energy density



Particle acceleration

p, e^-

D. Margarone



High field physics

Theory

Towards

10^{23} W/cm^2

S. Weber

Molecular

Biomedical

Material

J. Andreasson

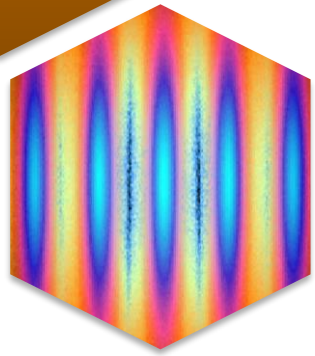
Applications

Fusion and plasma

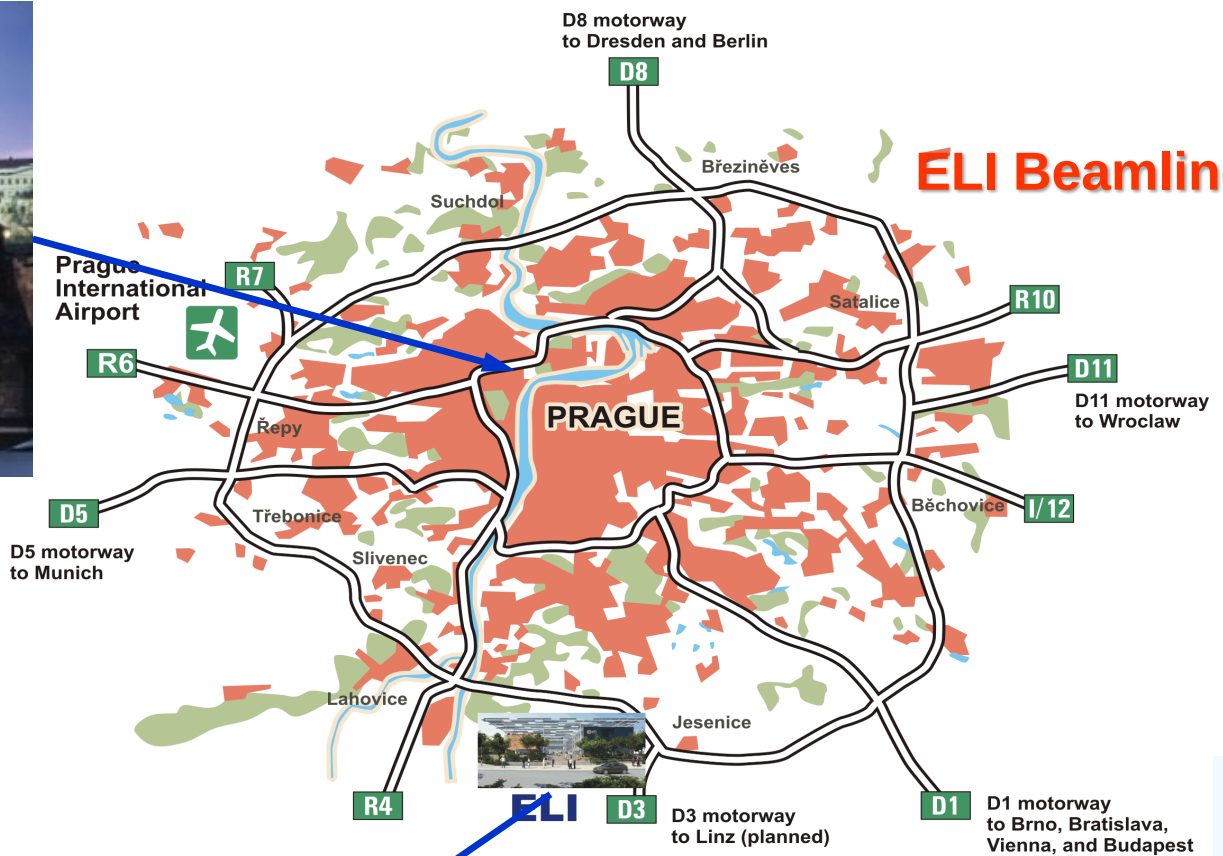
Prof. S. Bulanov

Prof. Tichonchuk

HIFI group



ELI Beamlines location



International airport (25 min drive)

At European motorway network

Castle transformed into 4*Hotel

Research campus

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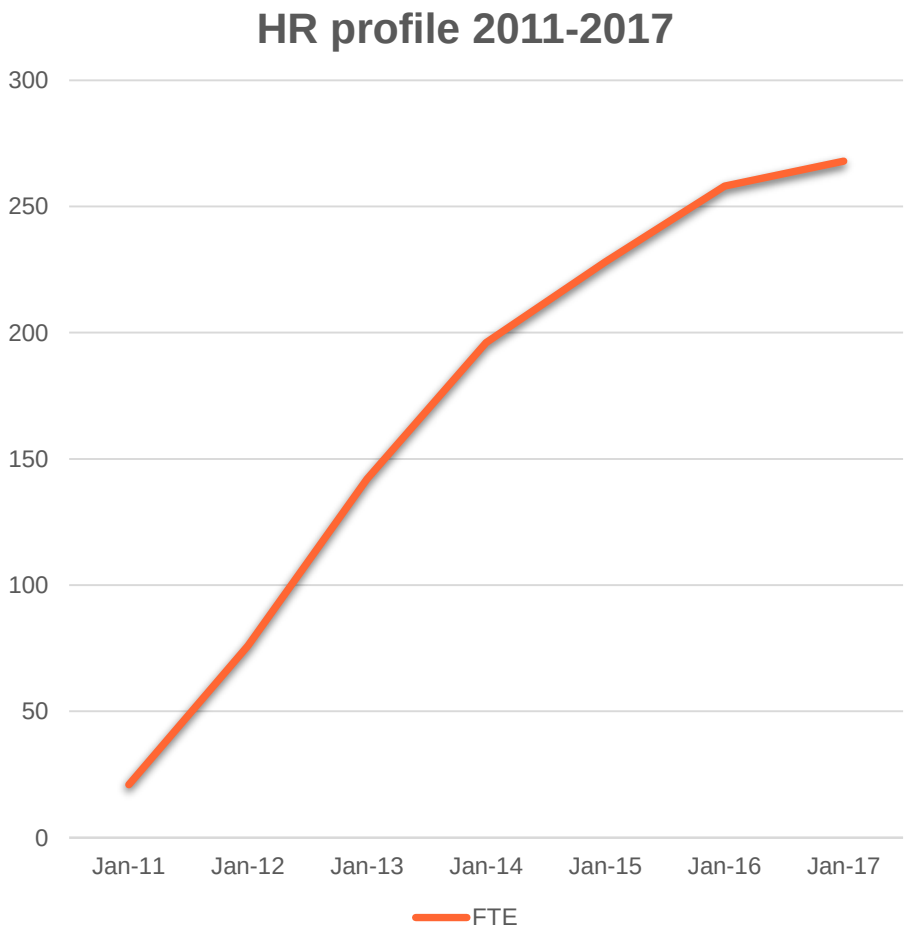
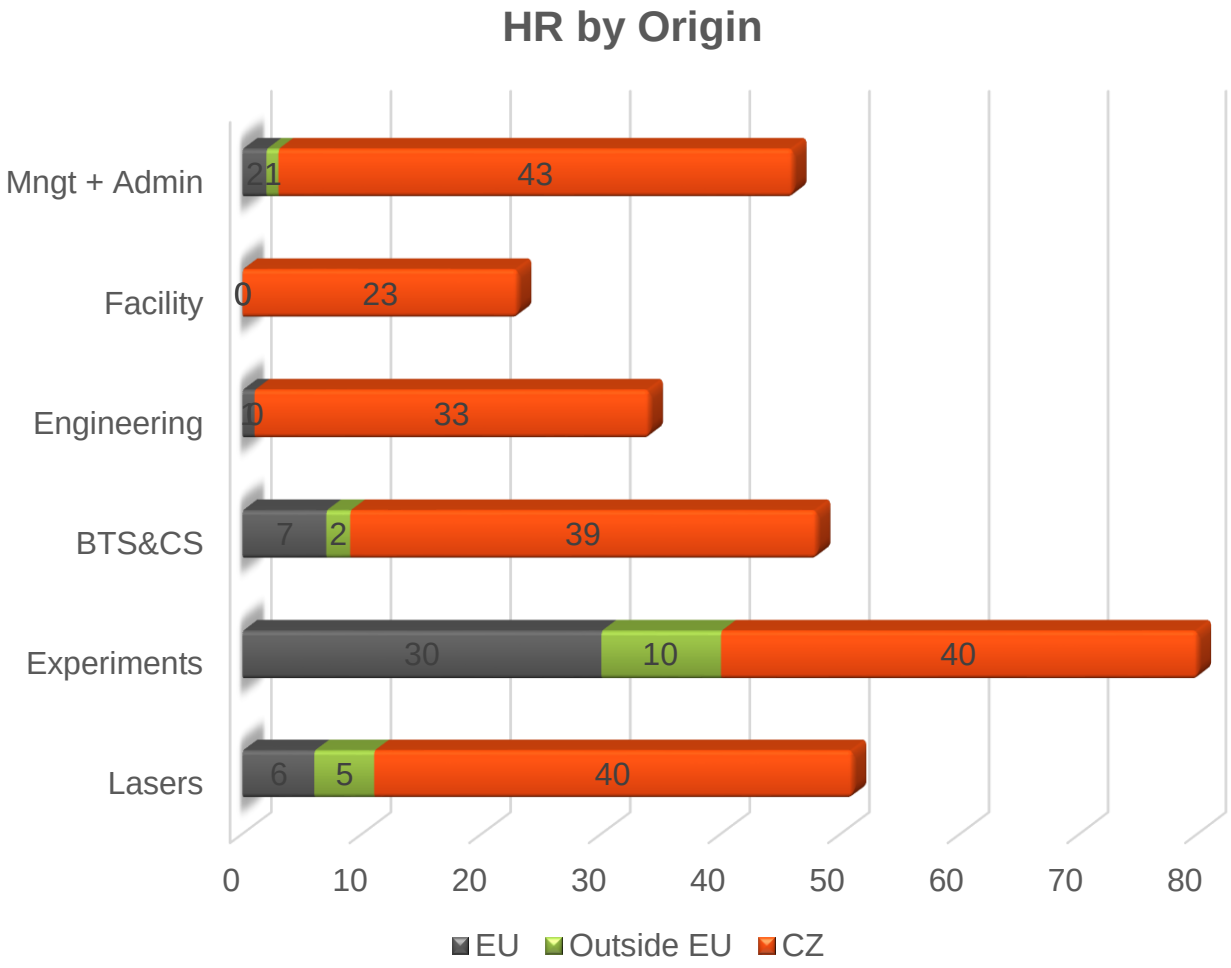
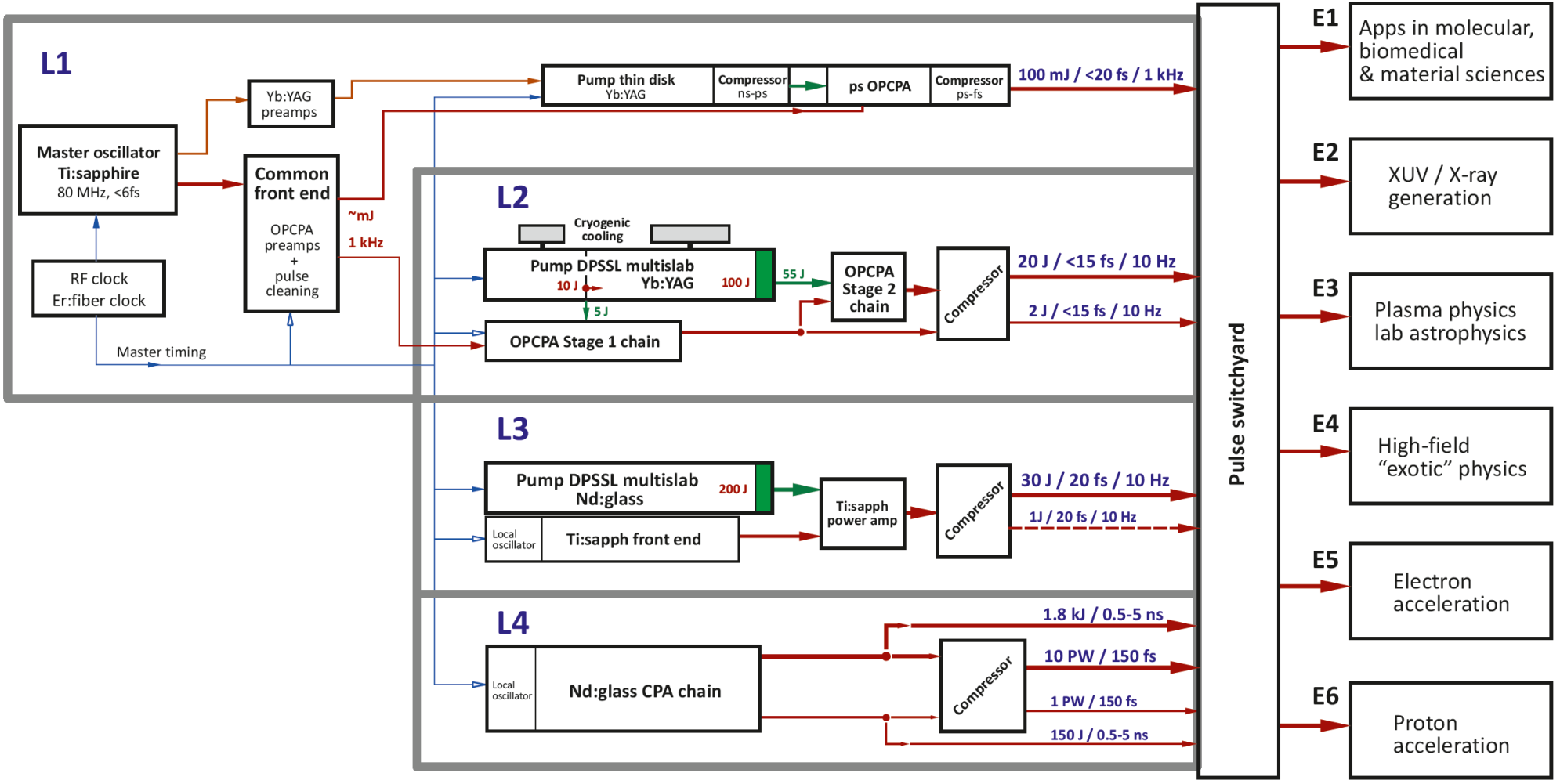
ELI colleagues

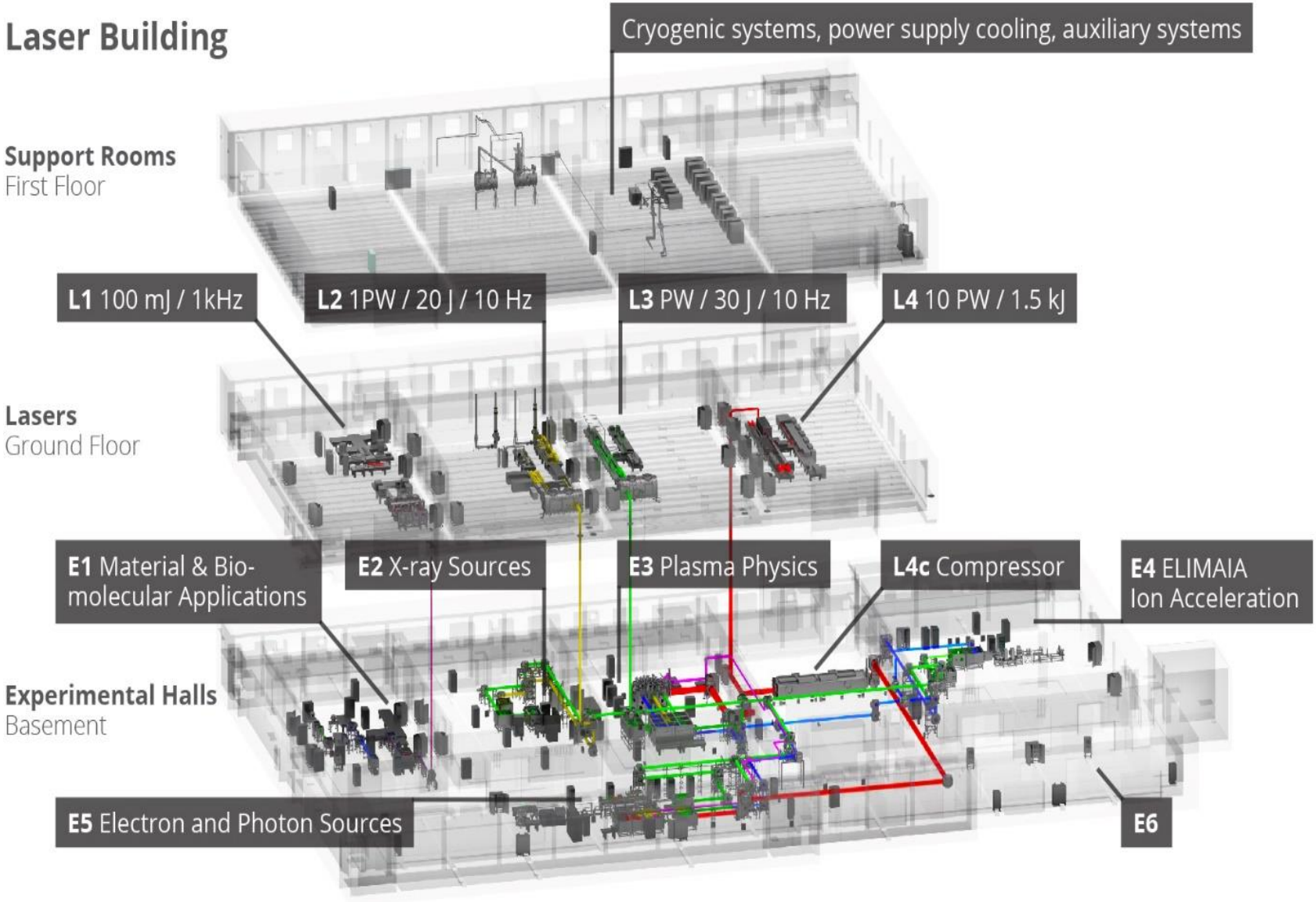




ELI Beamlines master scheme



Lasers and experiments



Pavel Bakule et al.

L1

100 mJ / <20 fs / 1 kHz laser beamline

Picosecond OPCPA pumped by Yb:YAG thin-disk lasers

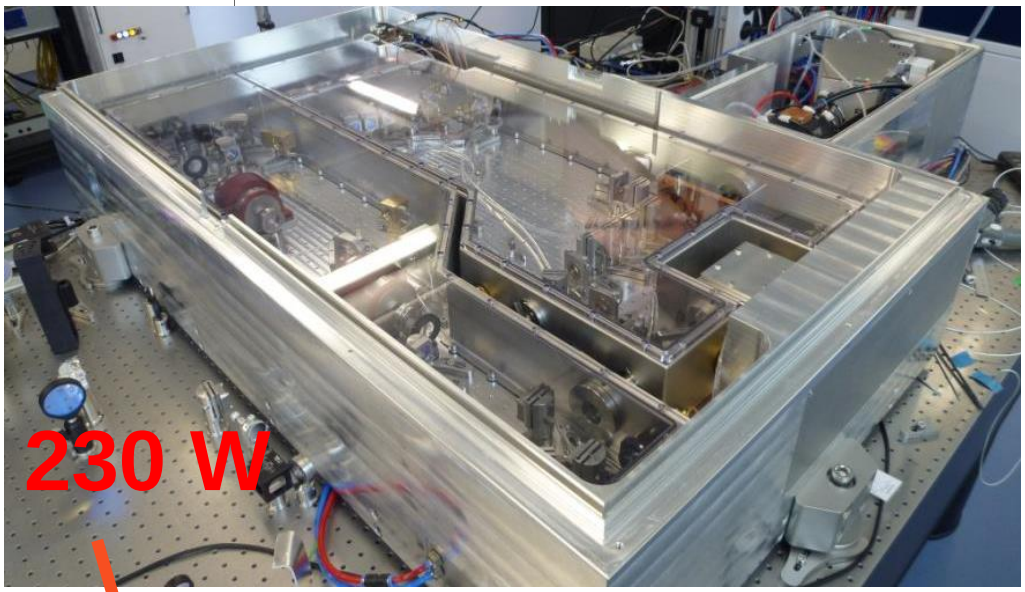
Upgradable to 200 mJ or more

In house development and integration by ELI Beamlines

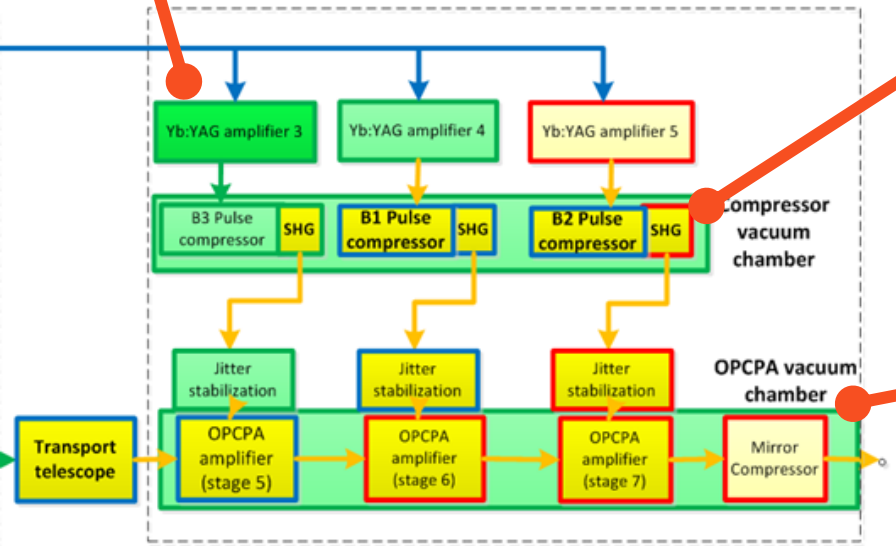
Pump thin-disk lasers supplied by TRUMPF, DPSSL Technology

100 mJ to be achieved by end 2019

L1 main amplifier subsystems

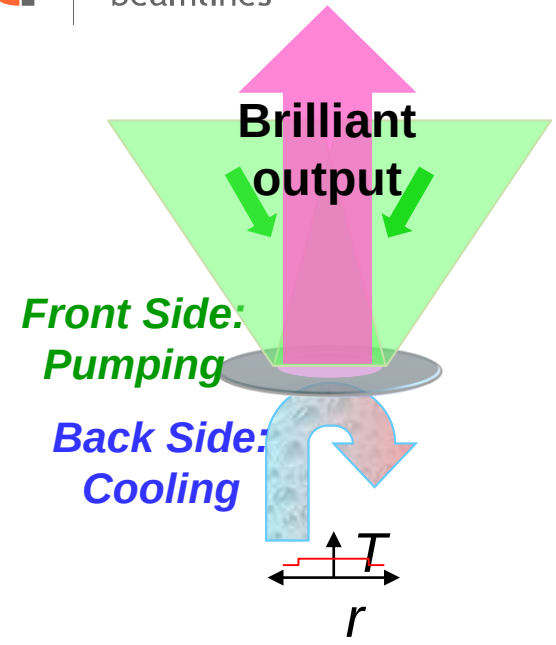


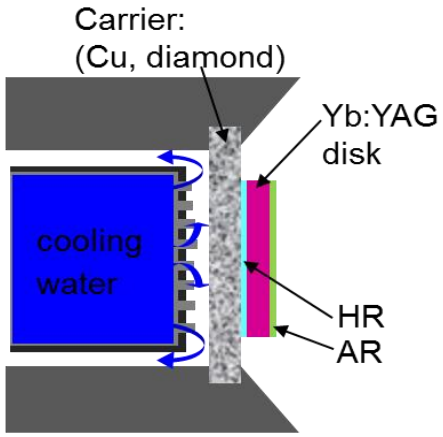
Pavel Bakule et al.

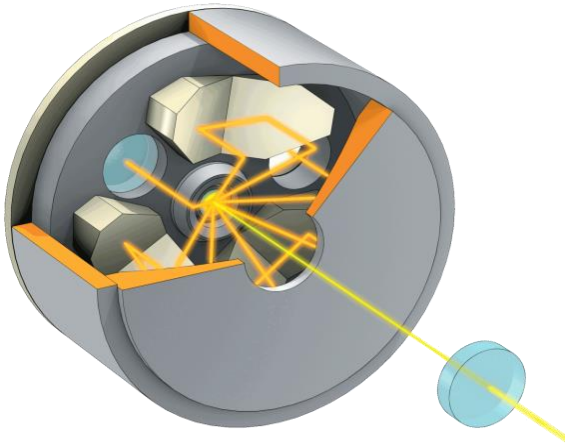


L1 Main Amplifier

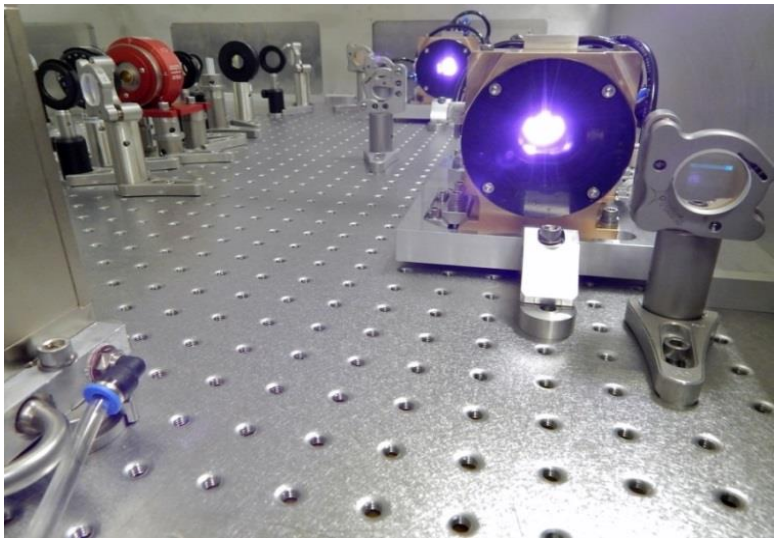
Thin disk 1 kH pump lasers







Courtesy of T. Metzger, TRUMPF-Scientific



225 mJ 1 kHz
Regen unit for L1
developed by TRUMPF-Scientific

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Bedrich Rus et al.

L3

1 PW 10 Hz repetition rate beamline

All laser amplifiers pumped by DPSSL technology

High pulse-to-pulse stability, robustness, low maintenance, high level of automation, scalability to higher peak power and rep rate

Supplier: LLNL

Collaborative effort of ELI-Beamlines on development of the PW compressor, PW diagnostics, control & timing systems

PW workhorse of the ELI-Beamlines facility

Installations finish July 2018

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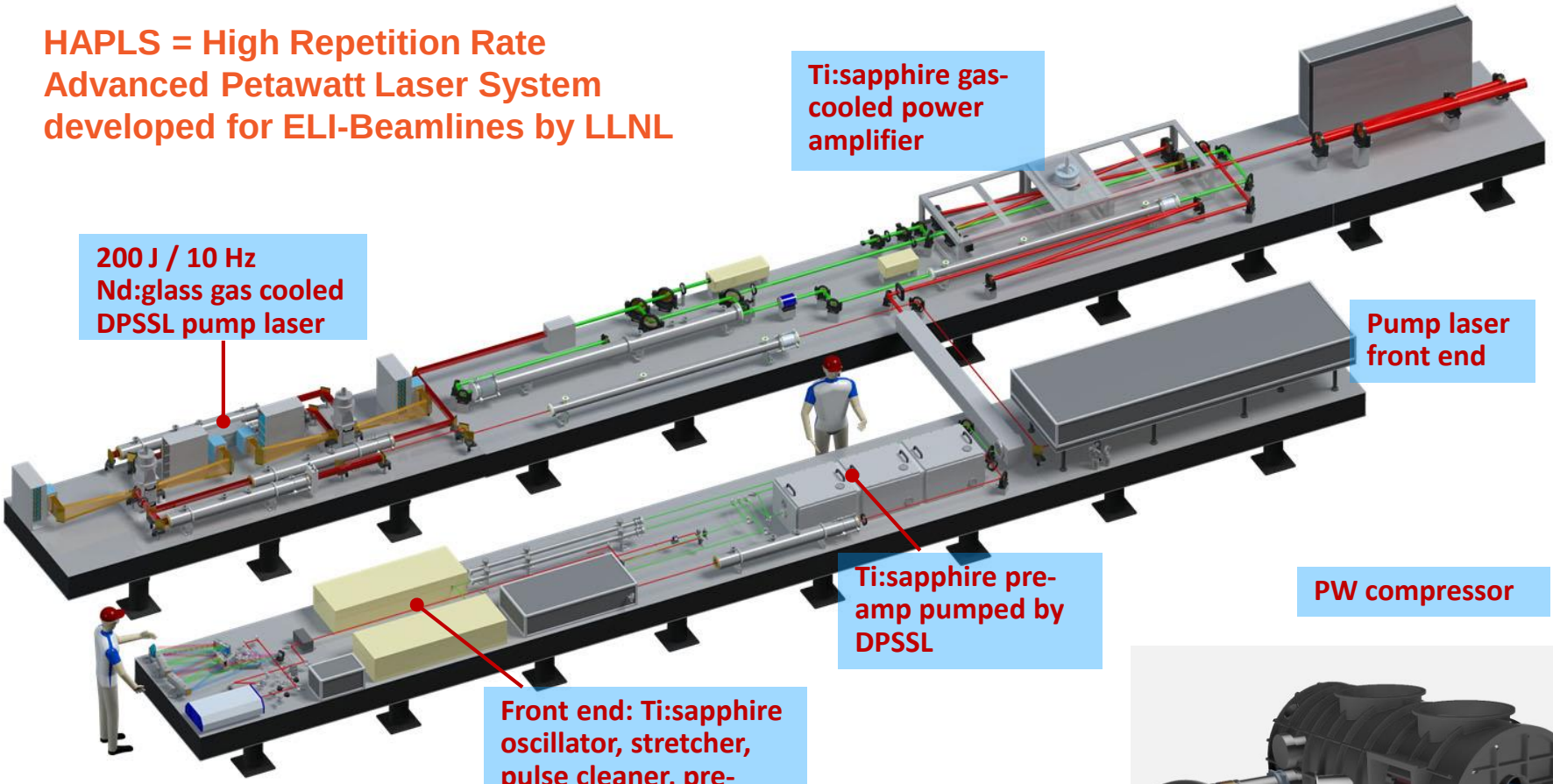
L3 = HAPLS + PW compressor & Diagnostics

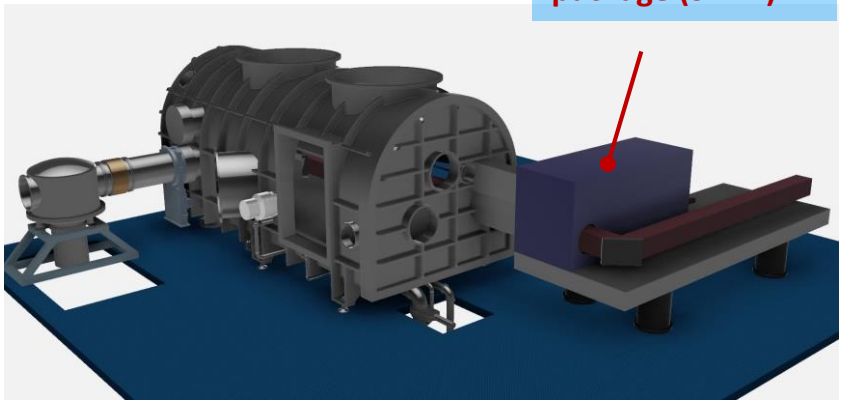
Bedrich Rus et al.

HAPLS = High Repetition Rate Advanced Petawatt Laser System developed for ELI-Beamlines by LLNL



PW compressor

Short pulse diagnostics package (SPDP)



PW compressor & diagnostics developed by Inst. of Physics

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L3 compressor chambre at ELI

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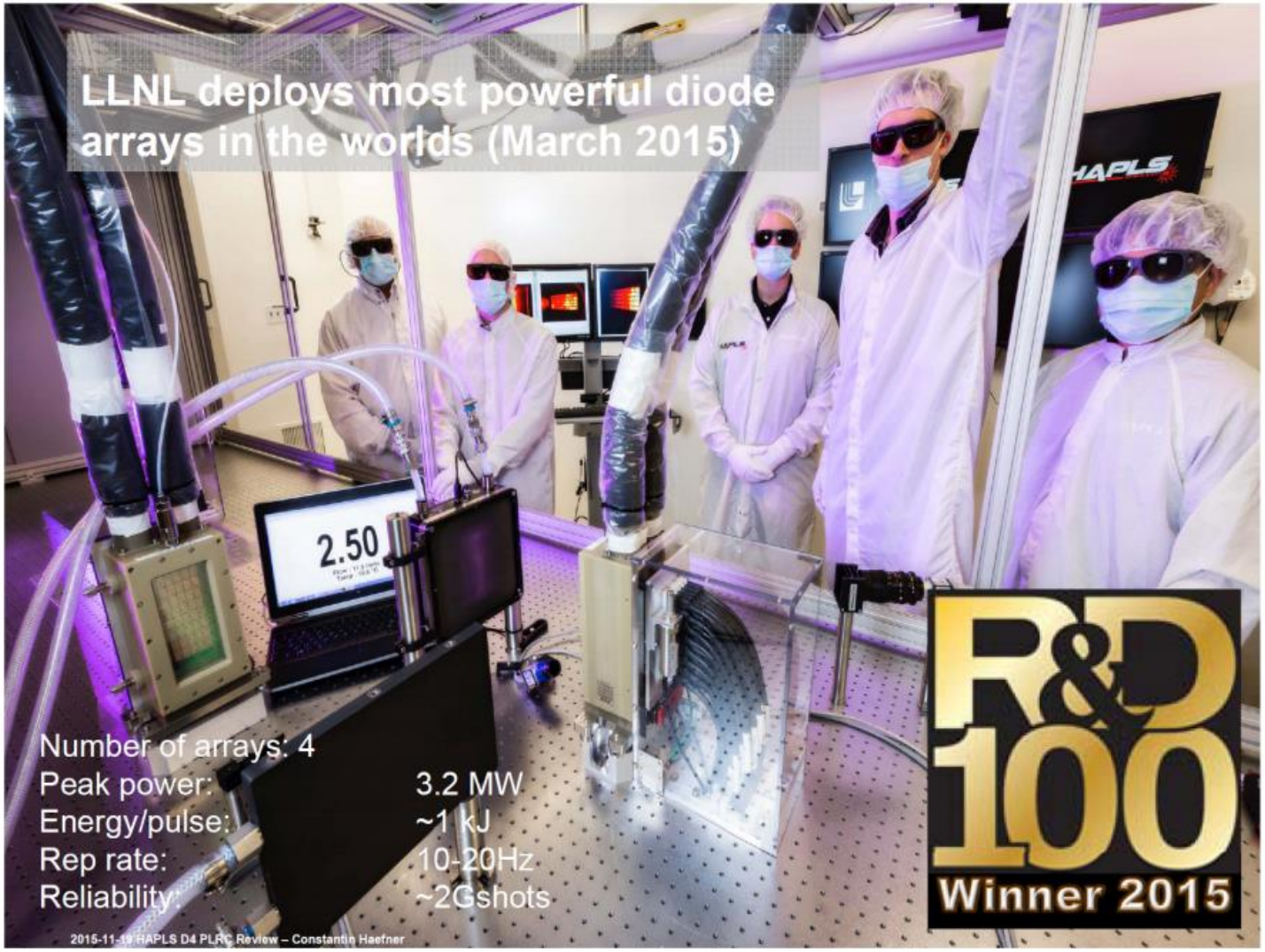
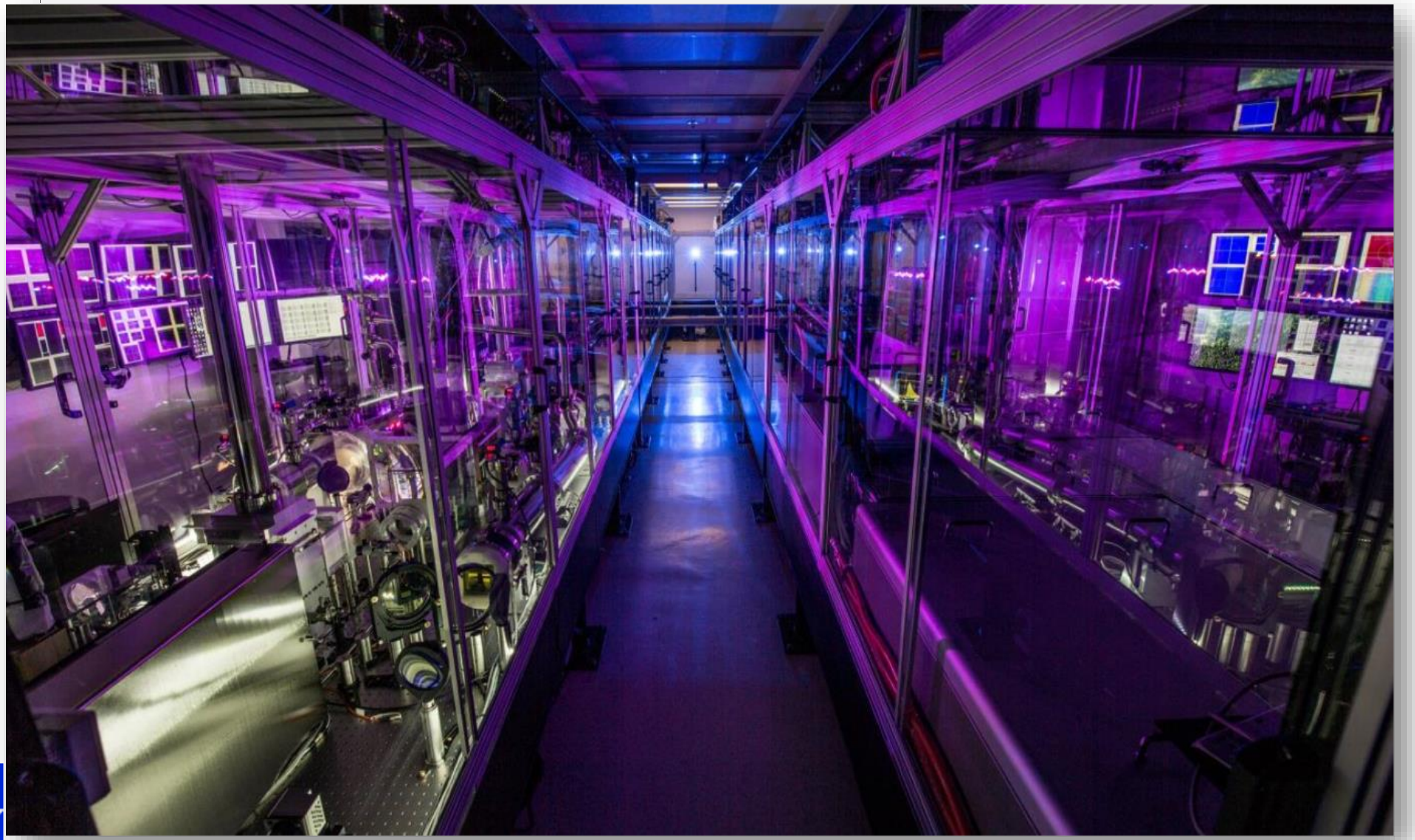
Laser L3 High-Power Intelligent Laser Diode-System (HILADS)

LLNL, LaserTel, https://www.rd100conference.com/awards/winners-finalists/5360/an-intelligent-laser/



Capable to run fs laser with 600 W average power (30 J, 20 Hz).

Laser L3



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Bedrich Rus, Daniel Kramer et al.

L4

10 PW kJ CPA laser: mixed Nd:glass providing spectral bandwidth for direct pulse compression to ≤150 fs

Nanosecond pulses with programmable temporal shape for sophisticated laser-plasma experiments

PW auxiliary beam for plasma probing

Possible future use as OPCPA driver for generation >10 PW power

Supplier:

- **NE-EKSPLA**
- **ELI-Beamlines co-develops: 10 PW compressor + diagnostics + timing system**

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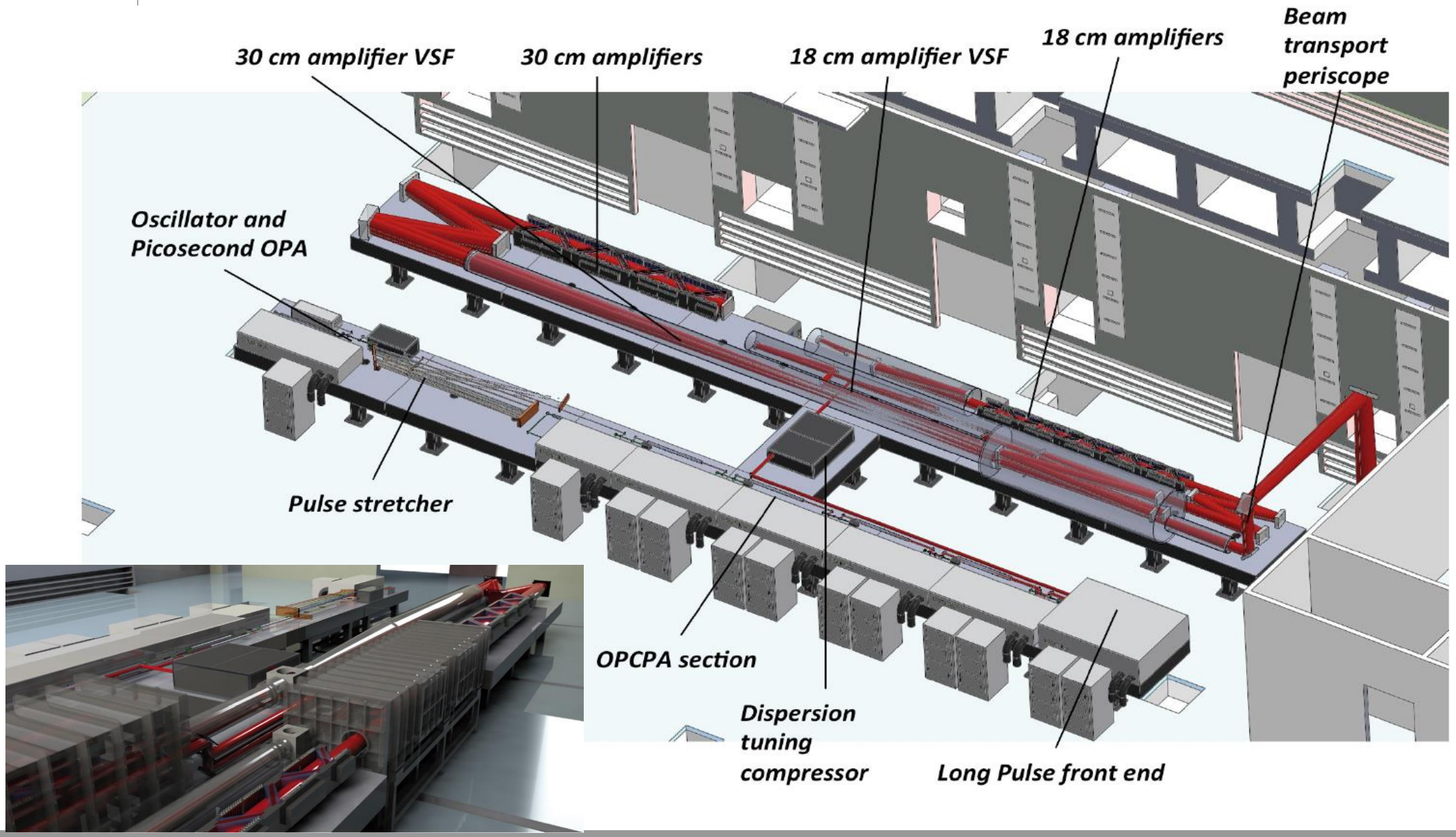
L4 laser chain



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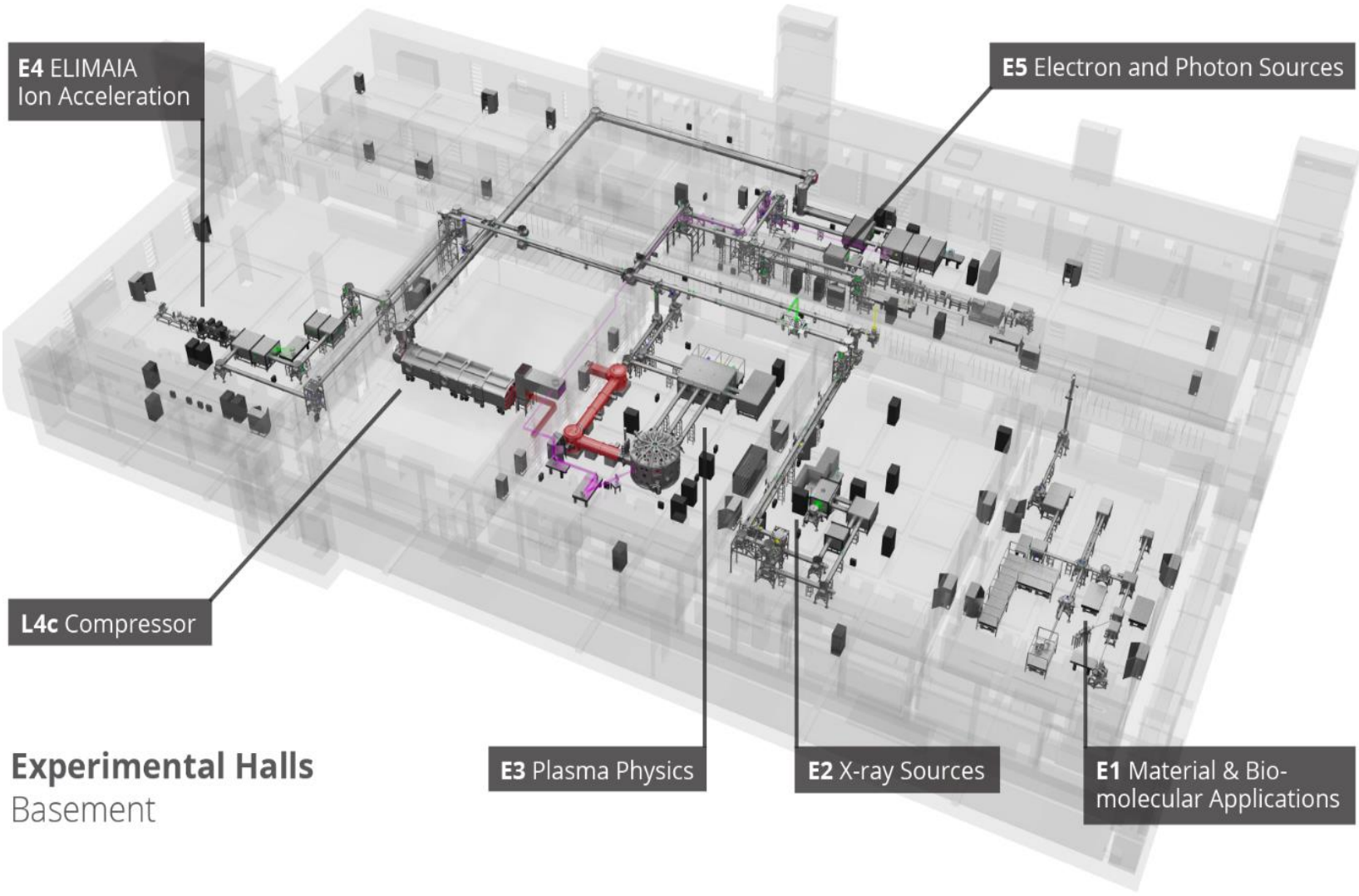
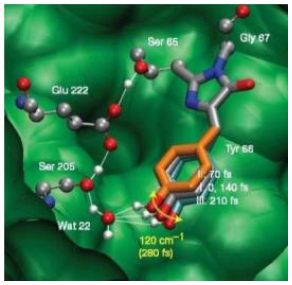
L4 laser front-end

Experiments



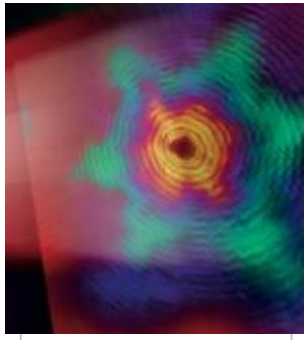
ELI Beamlines
Photon sources and Applications for life sciences

Jaroslav Nejdl et al., Jakob Andreasson et al.



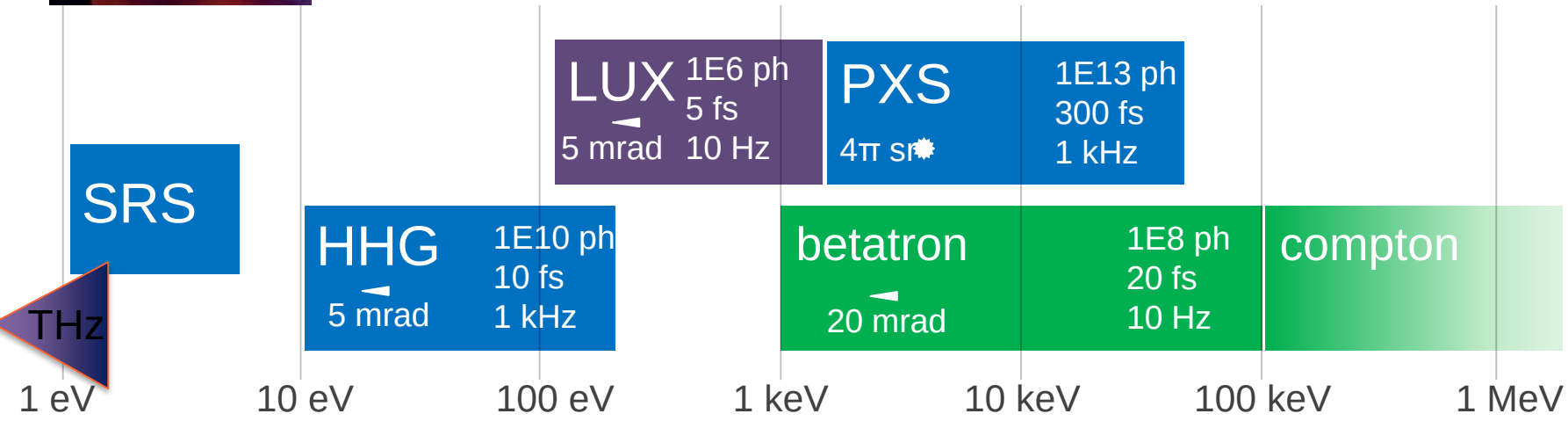
Stimulated Raman Station
Optical spectroscopy and molecular dynamics

Plasma X-ray Source
Hard X-ray diffraction
Spectroscopy and Imaging



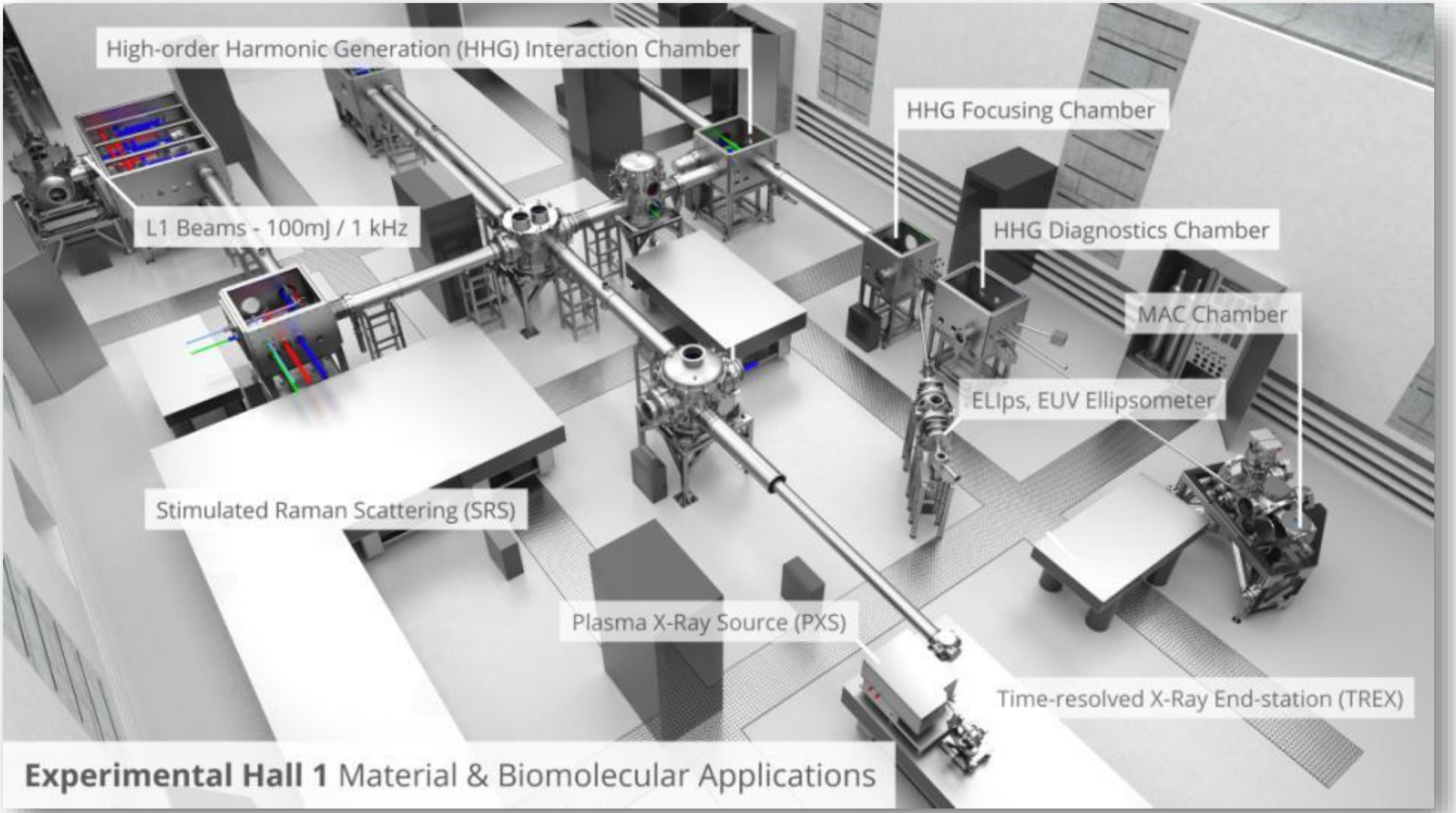
High Harmonics Generation
Coherent Diffractive Imaging
Atomic, Molecular and Optical Science
Material science – VUV ellipsometer

Photon science experiments in the THz to Hard X-ray range -fs to ms dynamics

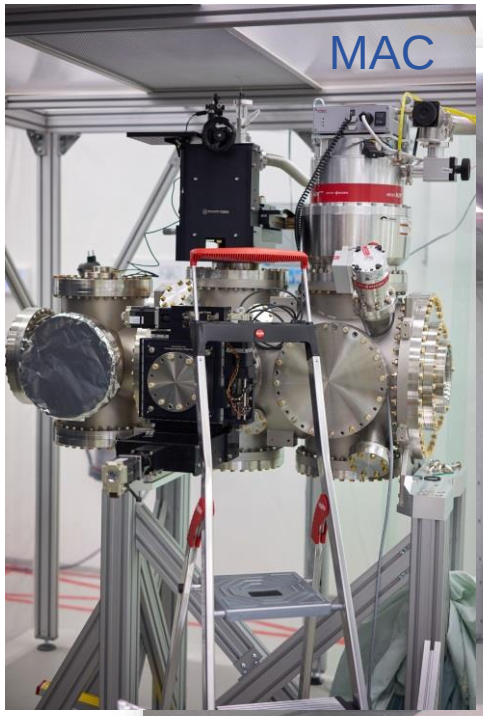


Experimental hall 1

OPCPA and 5fs probe beams available covering from UV to 20 μm for spectroscopy applications



E1 first experiments in February 2018



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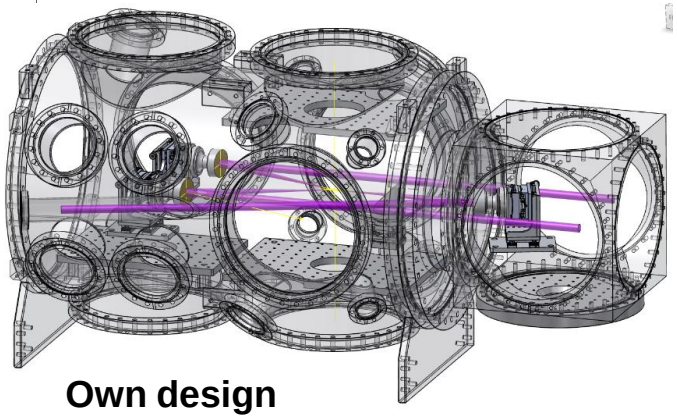
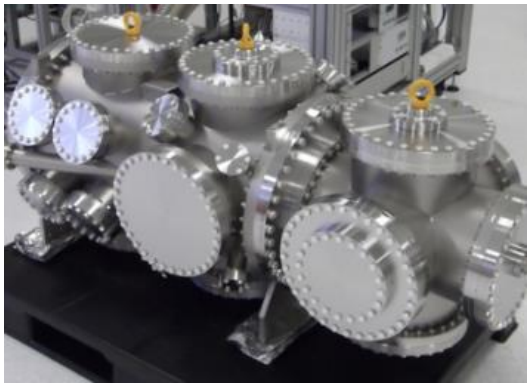
MAC: Multi purpose end station for Atomic, Molecular and Optical science and Coherent Diffractive Imaging.



Own design based on CAMP chamber

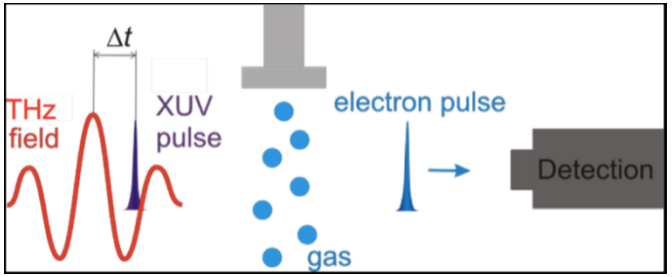


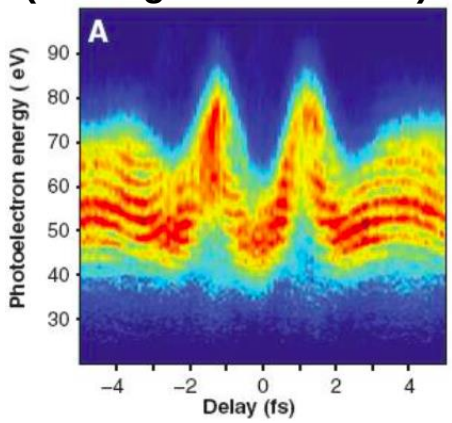
During pump tests at VACOM

Delivered but unpacked (waiting for clean area)

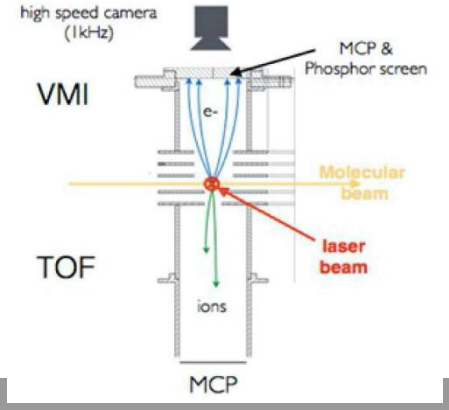
Jakob Andreasson et al.

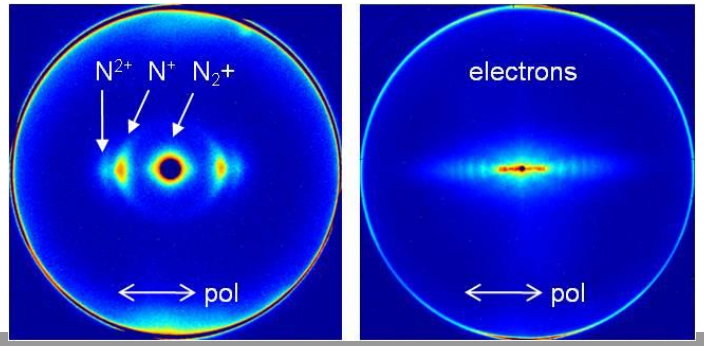
1) Time structure of photo electron events, electron streaking Time of Flight





2) Velocity map imaging (VMI) of fragmentation of molecules. Tracks electron dynamics in isolated sample particles
-Ion (left) and electron (right)





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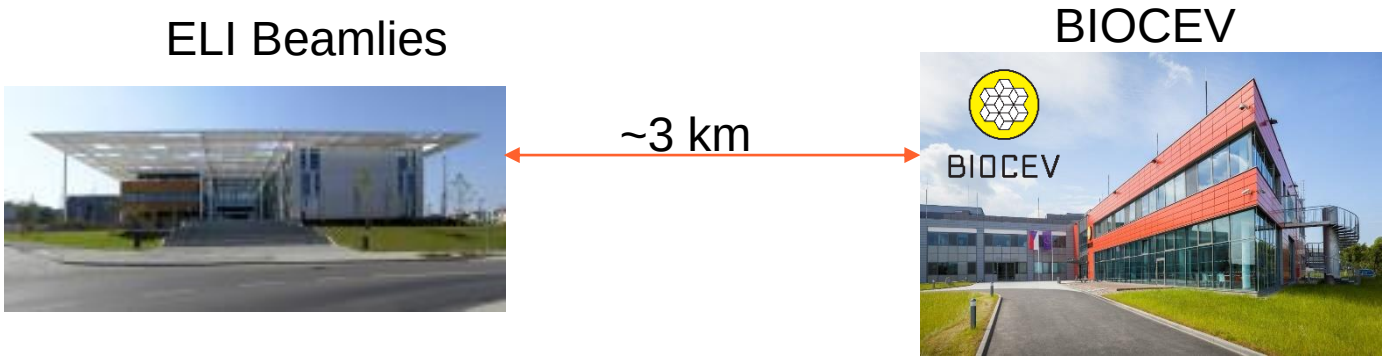
ELIBIO excellent research team

Janos Hajdu et al.

- **ELIBIO team at the interface between biology and laser science**
- Team size: Team leader + 15 researchers and 1 technician
- Includes funding to build a bio lab complex at ELI Beamlines



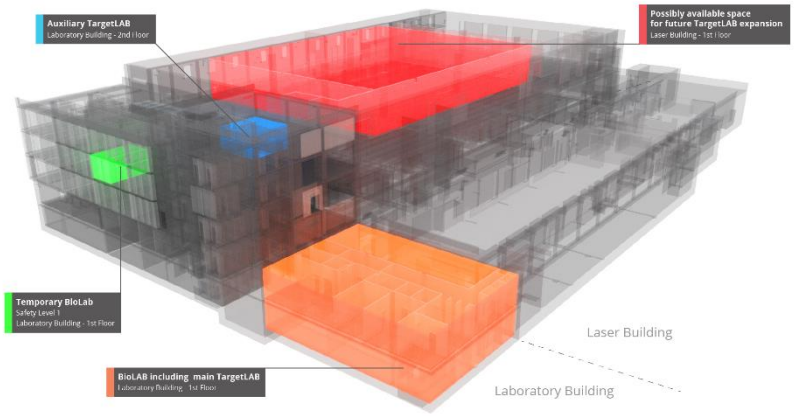
RP4	ELIBIO	IBT @ BIOCEV
User operation and independent research	Independent research at ELI, XFELs,synchrotrons, …	Independent research and user support

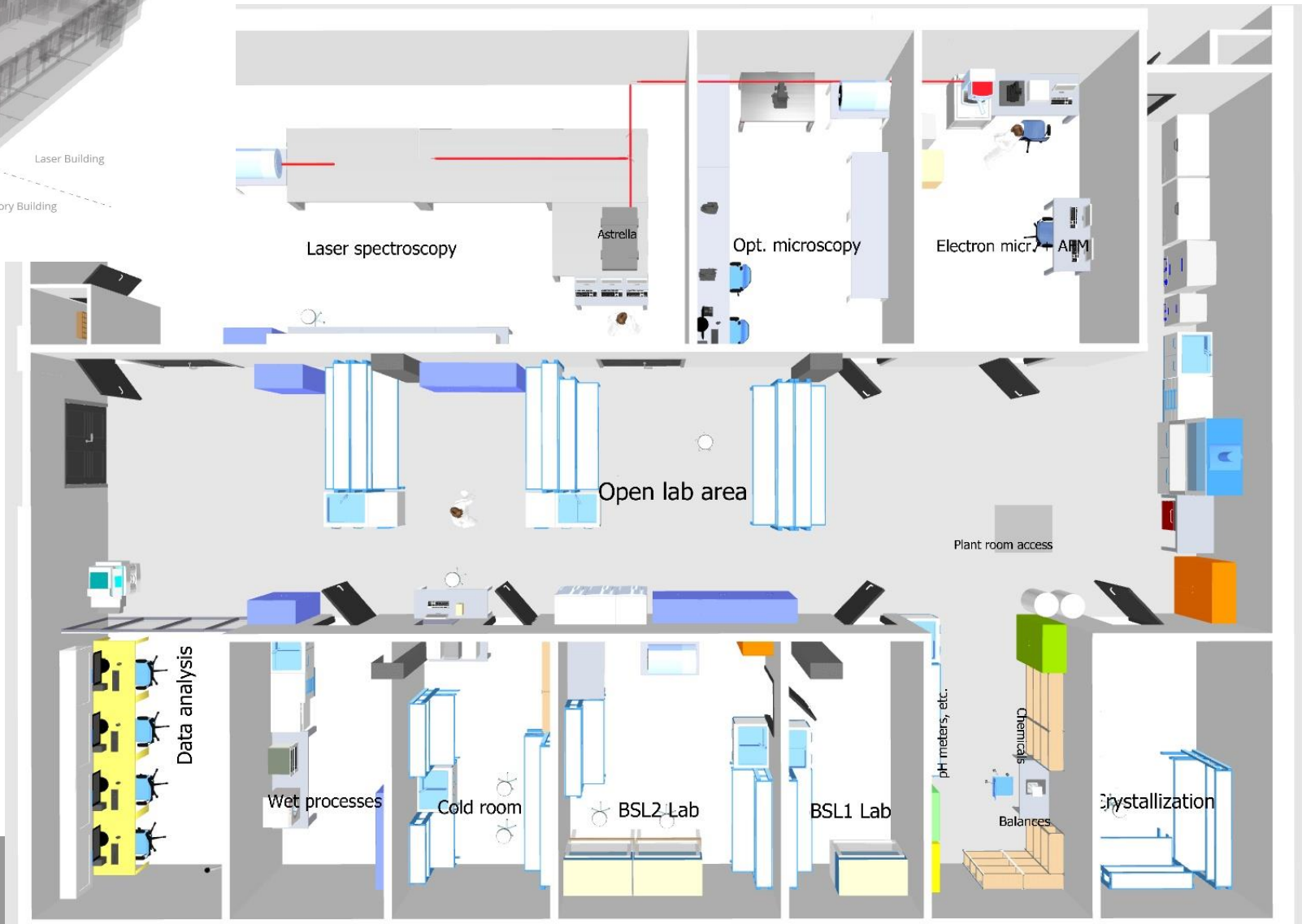
RP4/ELIBIO combination:

- Directly involves >25 researchers in bio/molecular/material/photon science
- Strong connection to sample preparation
- Strong connection to laser and source development
- Strong connection to other Research Institutes and user communities

ELI Biolab

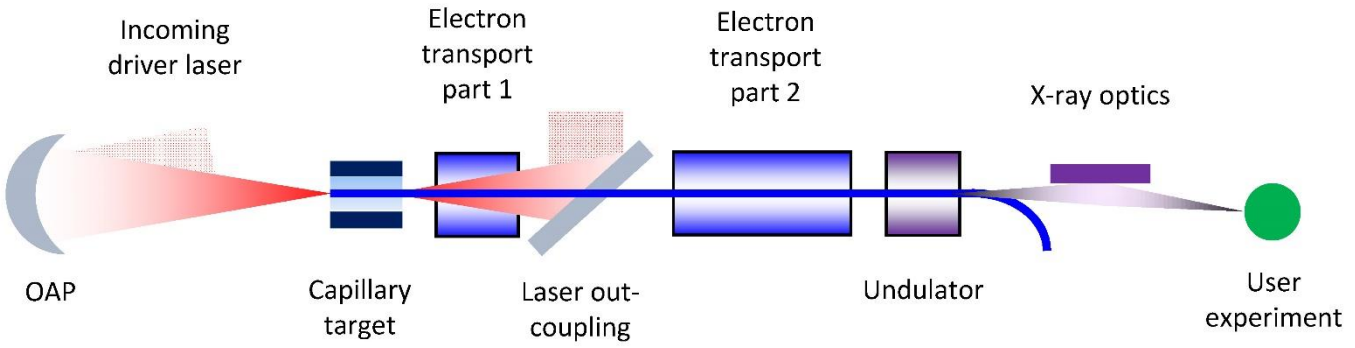
M. Přeček et al.





lukas.pribyl@eli-beams.eu

Laser Undulator X-ray source



Electron energy	tuneable 400 MeV – 1200 MeV
El. bunch length	< 10 fs
Photon wave length	< 4.5 nm
Repetition rate	limited by the laser (~5 Hz)

Goals:
- Reaching **stability** for user experiment operation
- Development towards **laser-driven soft X-ray FEL**

Destination: Experimental Hall E5
Operations start: 2018/08

LUX Collaboration

Group F. Grüner

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

DESY

LAOLA
Laboratory for Laser- and beam-driven plasma Acceleration

CFEL SCIENCE

A. Maier

M. Schnepp

N. Delbos

S. Jolly (ELI)

P. Messner

M. Trunk

C. Werle

V. Leroux (ELI)

S. Jalas

M. Kirchen

P. Winkler

Group G. Korn

eli beamlines

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

L. Přibyl

A. Molodozhentsev

K. Kruchinin

D. Kocoň

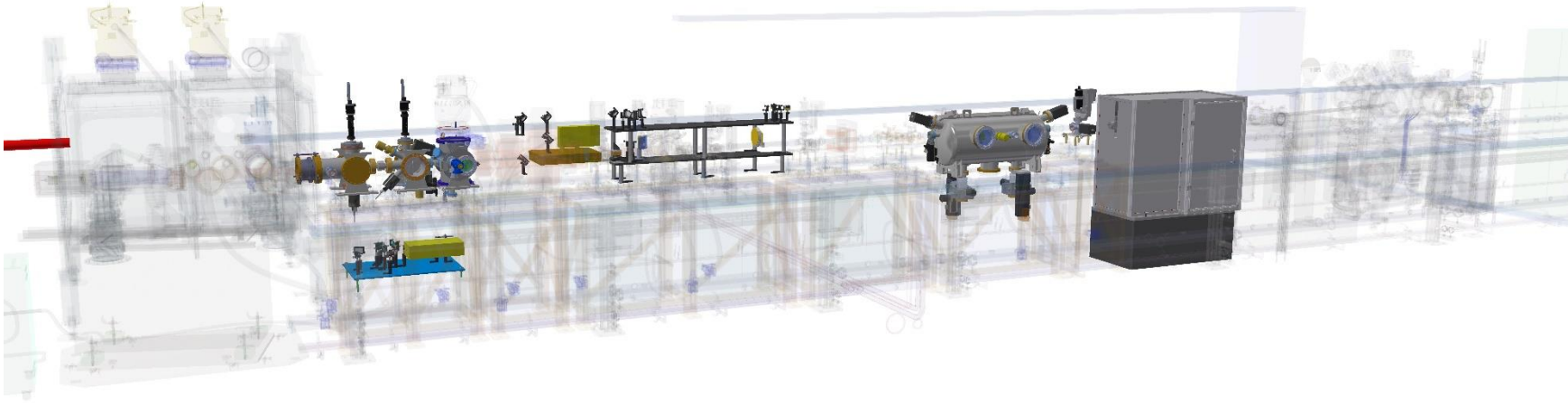
V. Leroux

S. Jolly

LUX in E5

A. Maier et al.

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG



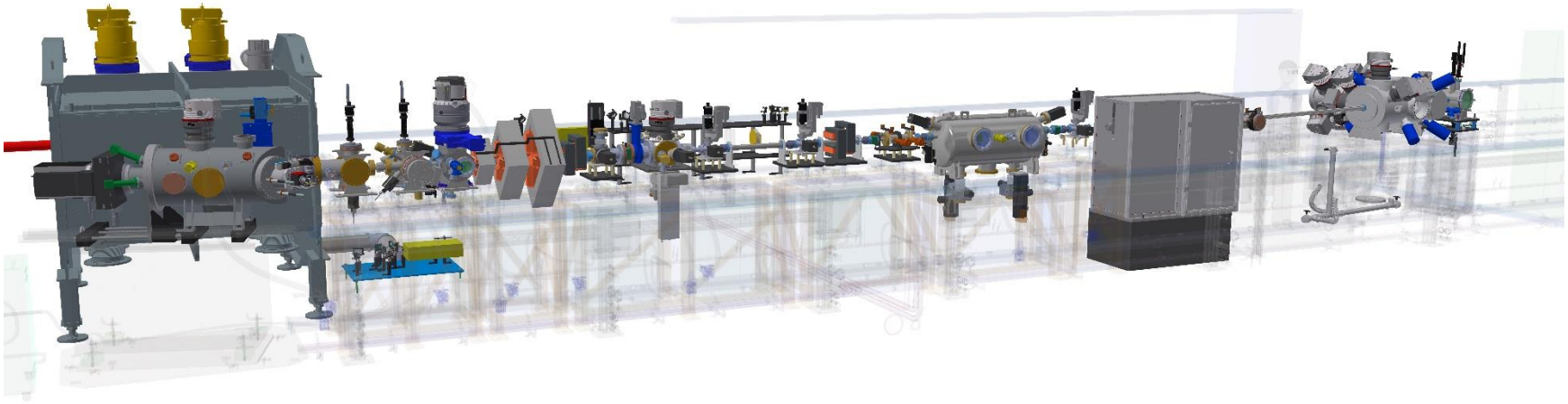
Dariusz Kocoň

LUX in E5

A. Maier et al.

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

L. Přibyl et al.



Dariusz Kocoň

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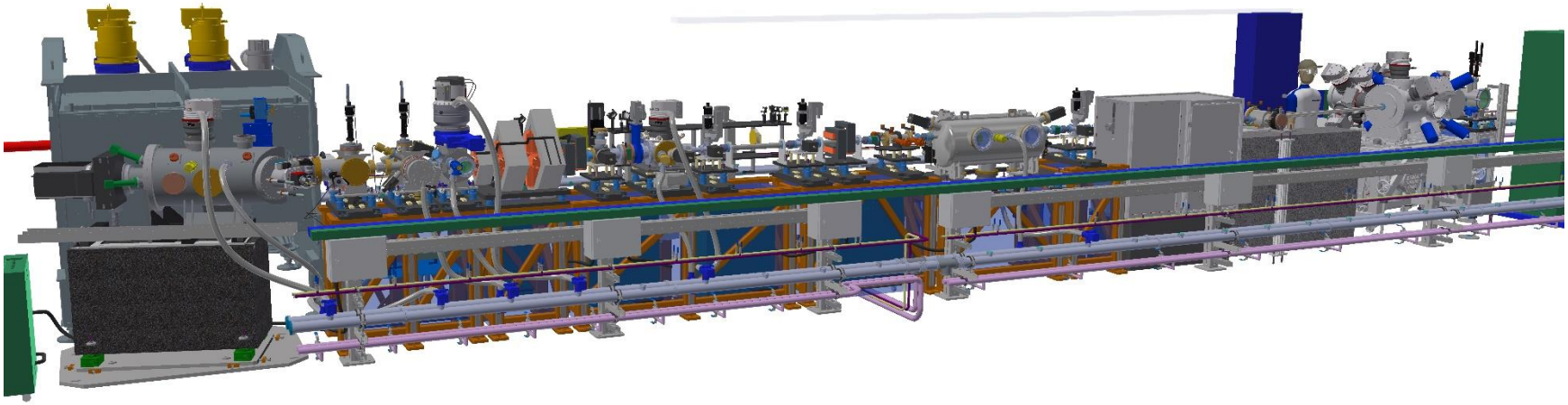
YOUTH AND SPORTS

LUX in E5

L. Přibyl et al.



Dariusz Kocoň

- First user experiment end of 2018
- Reaching **stability** for user experiment operation
- Development towards **laser-driven soft X-ray FEL**

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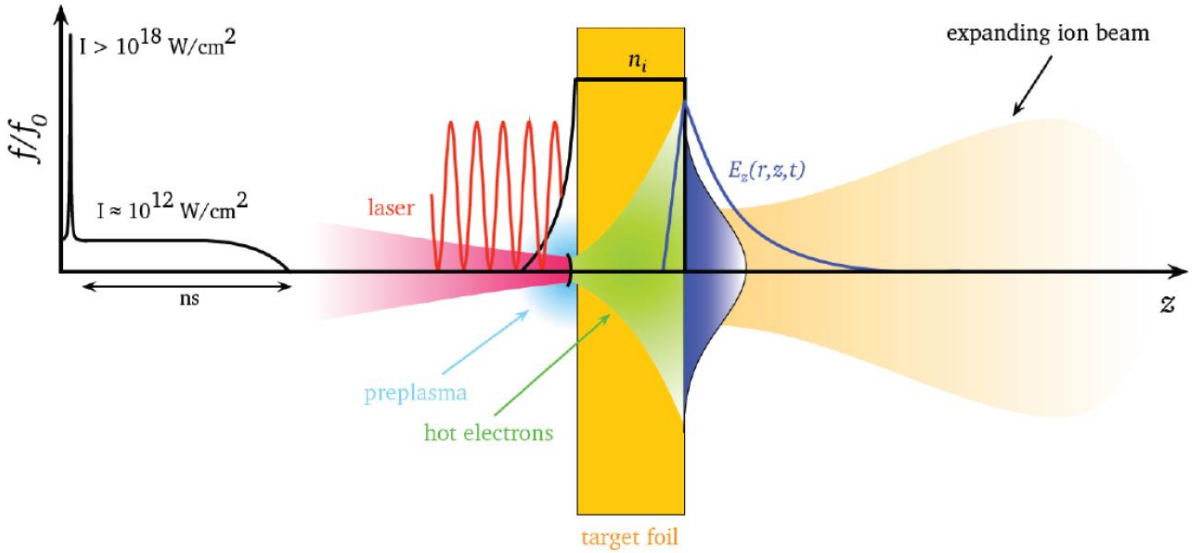
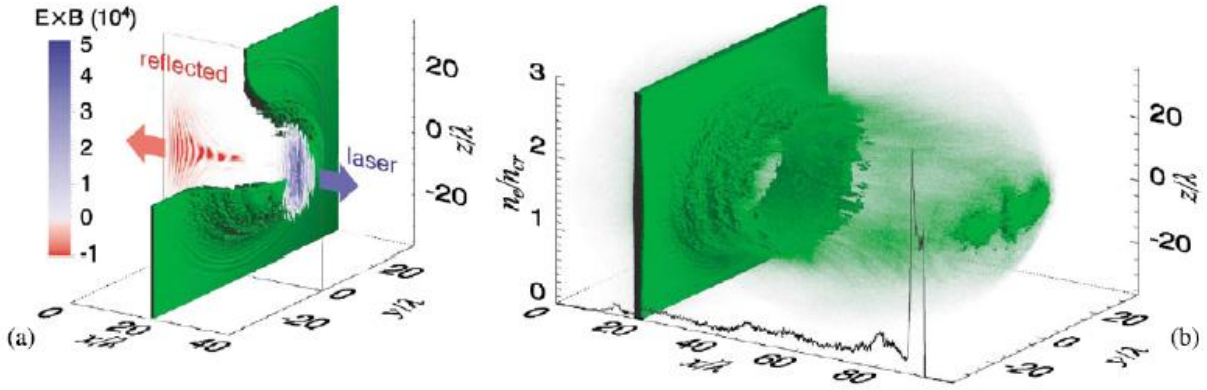
ELIMAIA – an ion user beamline

D. Margarone et al.



Target normal sheath acceleration

Up to 60 to 250 MeV



Radiation pressure acceleration

Above 250 MeV

High intensity required

Courtesy S. V. Bulanov

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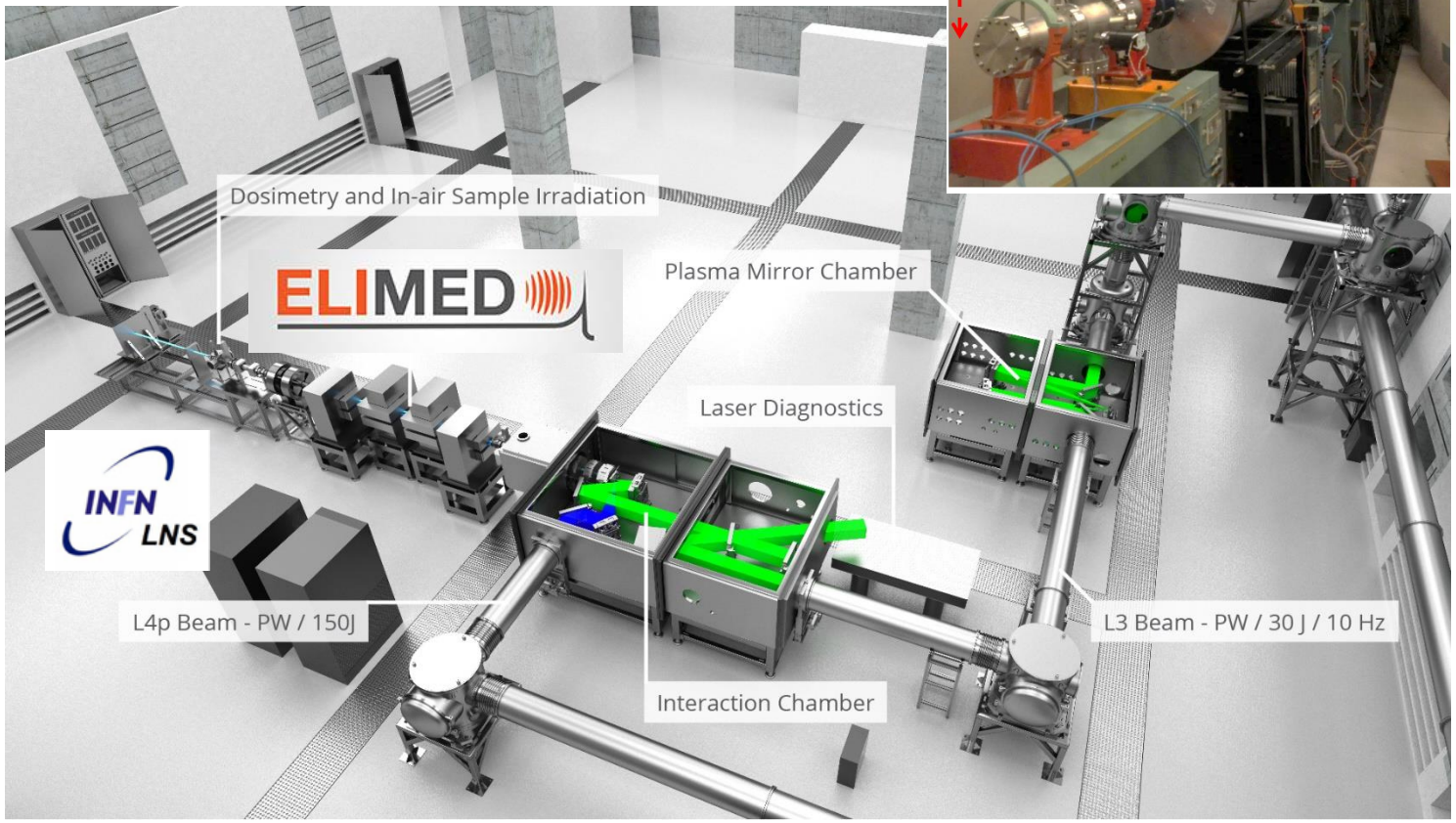
ELIMAIA – an ion user beamline

D. Margarone et al.

ELI Multidisciplinary Applications of laser-Ion Acceleration



ELIMED prototype @ INFN-LNS

Summary of main ELIMAIA equipment

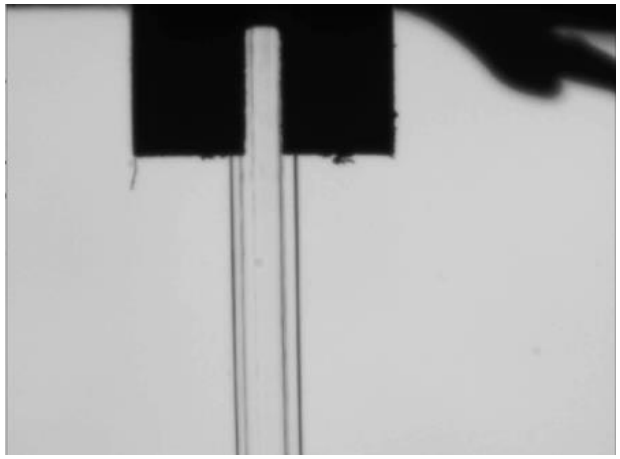
- Focusing optics (OAP): f/1.5 (L3), f/3 or f/4 (L4-PW)
- Estimated laser intensity: 10^{20}-10^{22} W/cm^2
- Targets (1-10 Hz): Thin foils (0.01-10 μm); cryogenic H (5-100 μm)
- Diagnostics (1-10 Hz): TP spectrometer, TOF detectors, optical interferometer, ion beam transport devices, ion beam dosimeters (Faraday cup, ionization chamber, SEM)
- Diagnostics (single shot): RCF stack; CR39

ELI Beamlines
Particle acceleration - ions

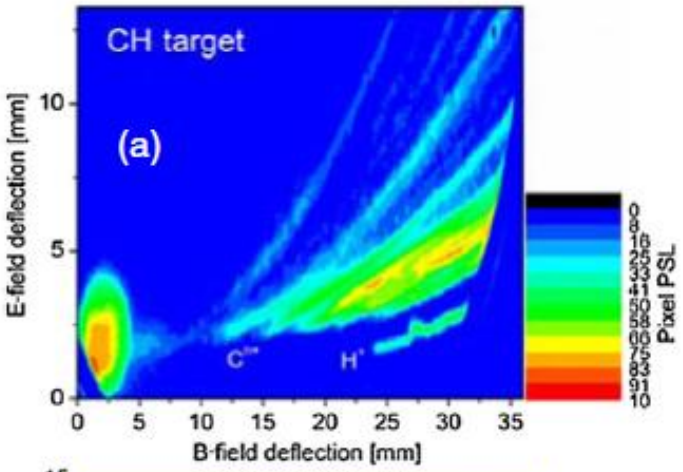
Daniele Margarone et al.

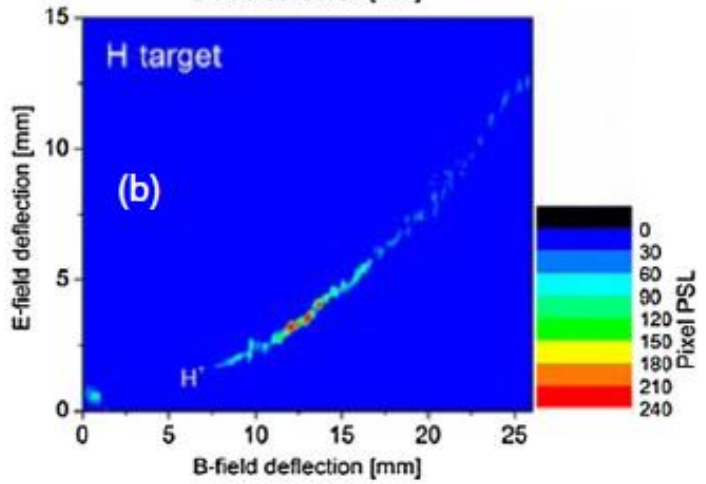
Solid Hydrogen target

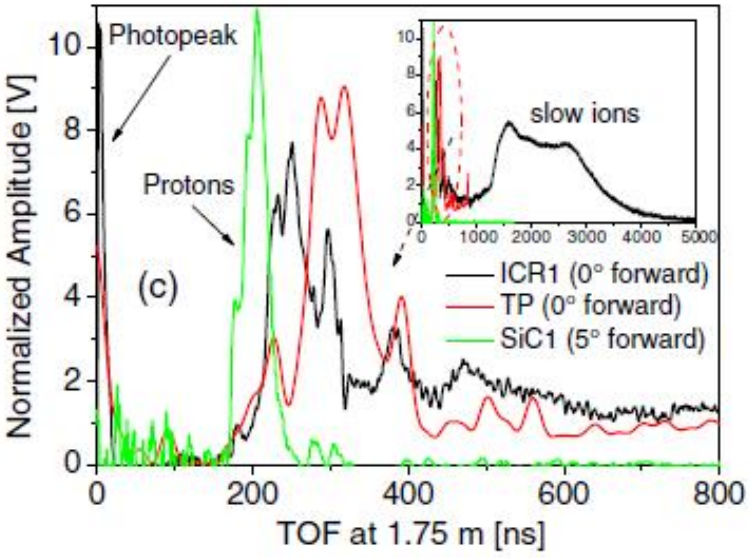
Tested at PALS, Prague
600 J, 300 ps, 1315 nm pulse
H_2 ribbon 62 μm thick



D. Margarone et al., Phys. Rev. X 6, 041030 (2016)



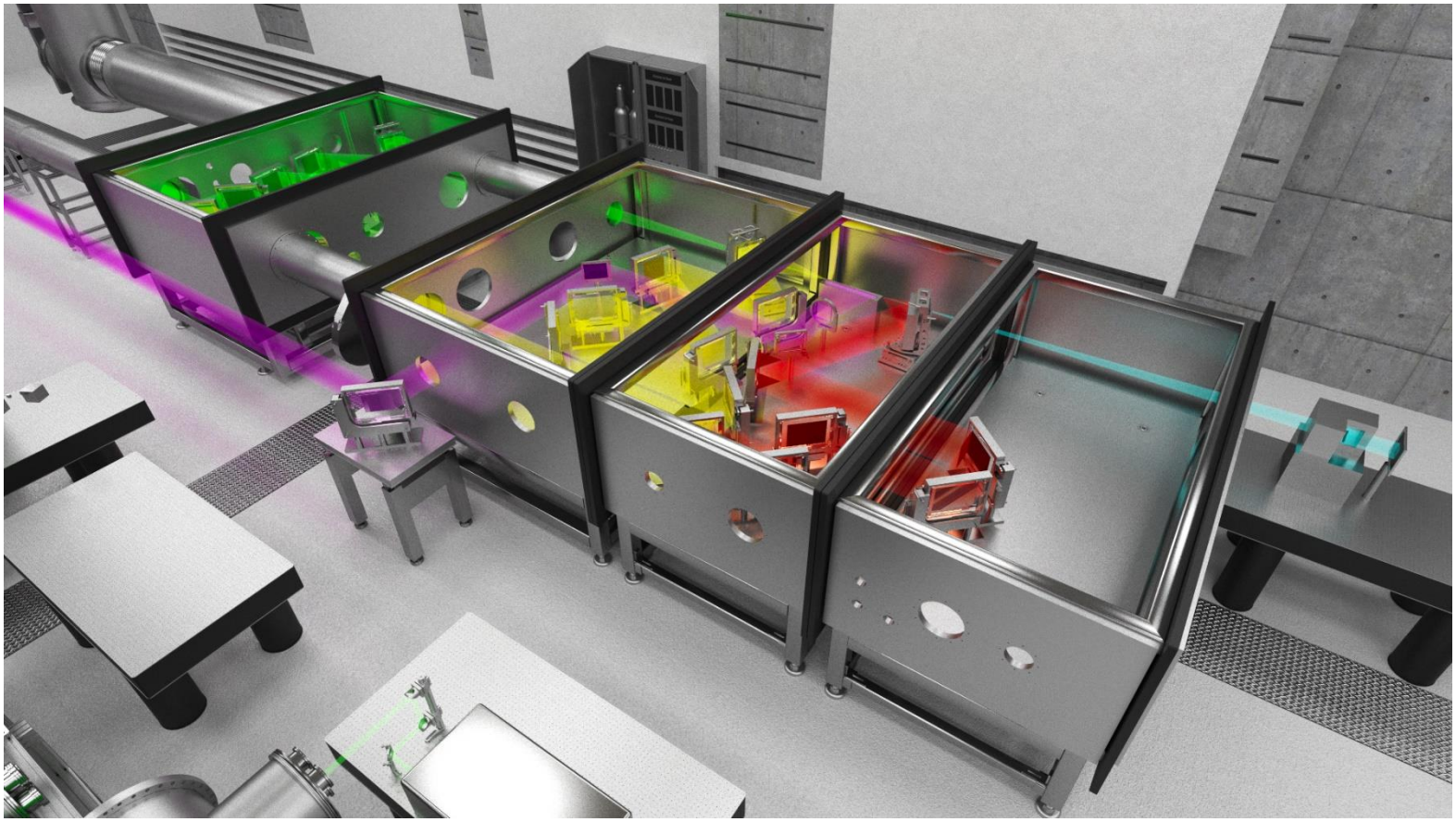


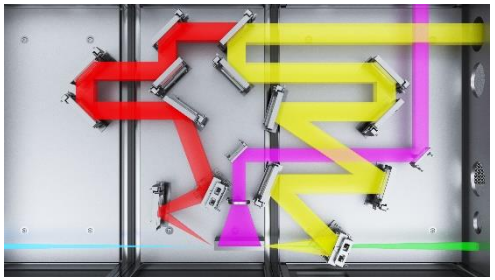


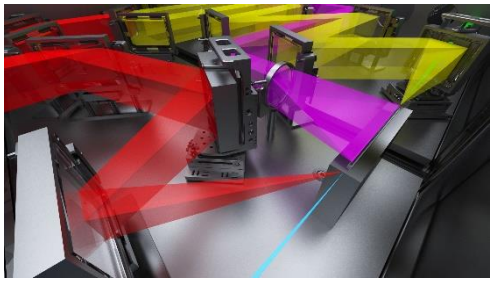
HELL electron acceleration

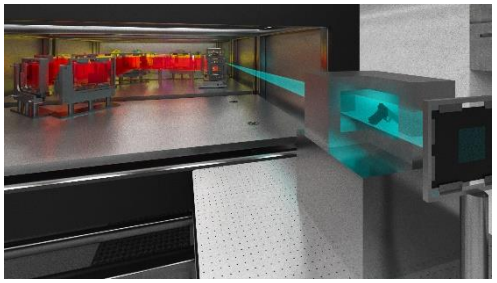
T. Levato et al.

The High-energy Electron by Laser Light





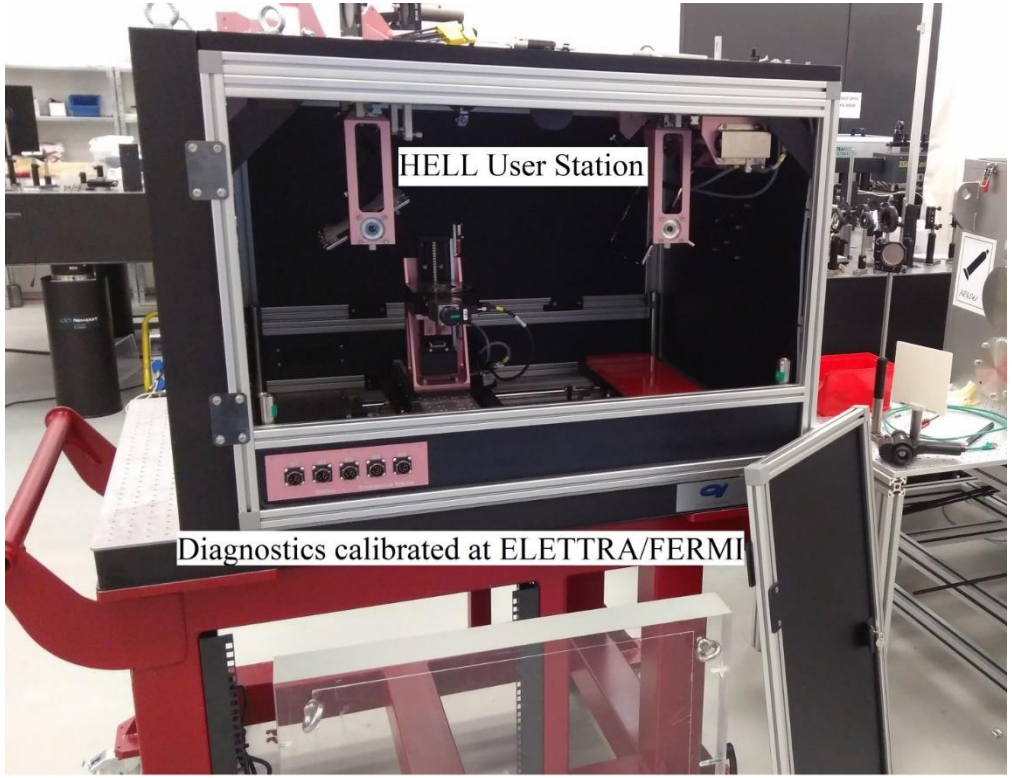




High flexibility for advanced setups

HELL electron acceleration

tadzio.levato@eli-beams.eu



Courtesy of ELETTRA/FERMI

Courtesy of Fantini SUD

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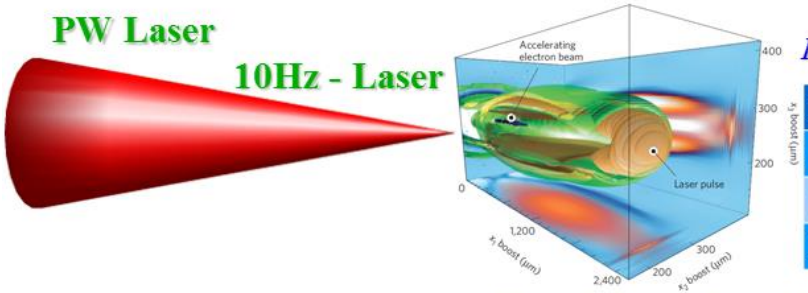
HELL scope

T. Levato et al.

Interaction regimes and parameters with L3 and L4



*Flat plasma: **not-guided regime***

Energy (GeV)	0.1 - 2
Charge (nC)	0.1 - 100
Energy spread (%rms)	1 - 10
Bunch duration* (fs)	1-10*

*Preformed plasma-channel: **guided regime***

Energy (GeV)	1 - 5
Charge (nC)	0.01 – .1
Energy spread (%rms)	0.1 – 1
Bunch duration* (fs)	1-10*

Laser-Electron COLLIDER

	Electron	Laser	X/Gamma
Energy	.1 – 5 GeV	**J** and **kJoule**	MeV
Duration	1-10 fs	20 – 150 fs	10 – 1000 fs
Rep.rate	10Hz	10Hz	10Hz

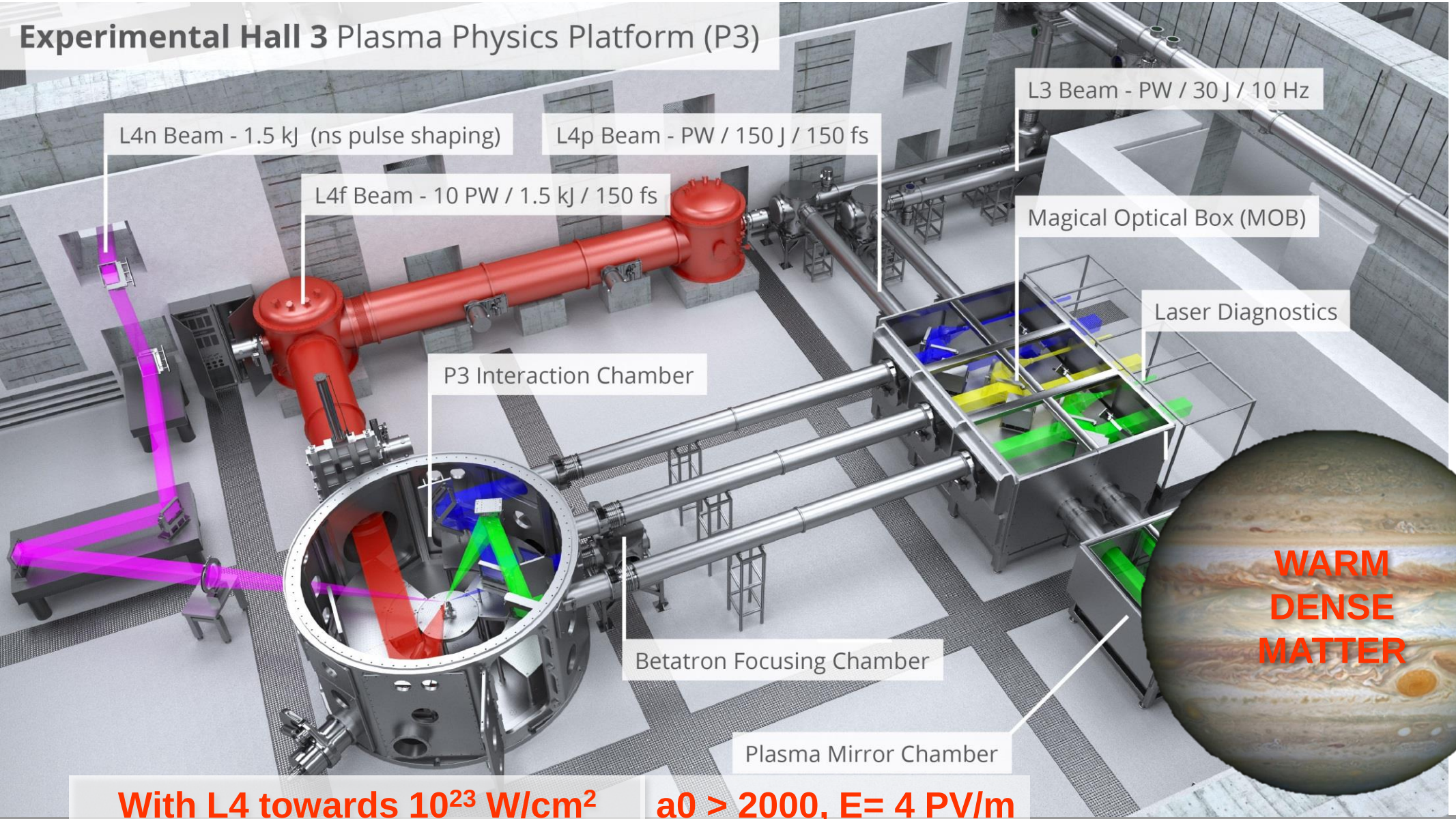
Diagnostics available:

- electrons spectrometer
- hard x-ray spectrometer
- plasma interferometry
- plasma shadowgraphy
- plasma optical imaging
- plasma xray imaging
- full laser diagnostics

Adaptive mirror, loop for correction

Stefan Weber et al.

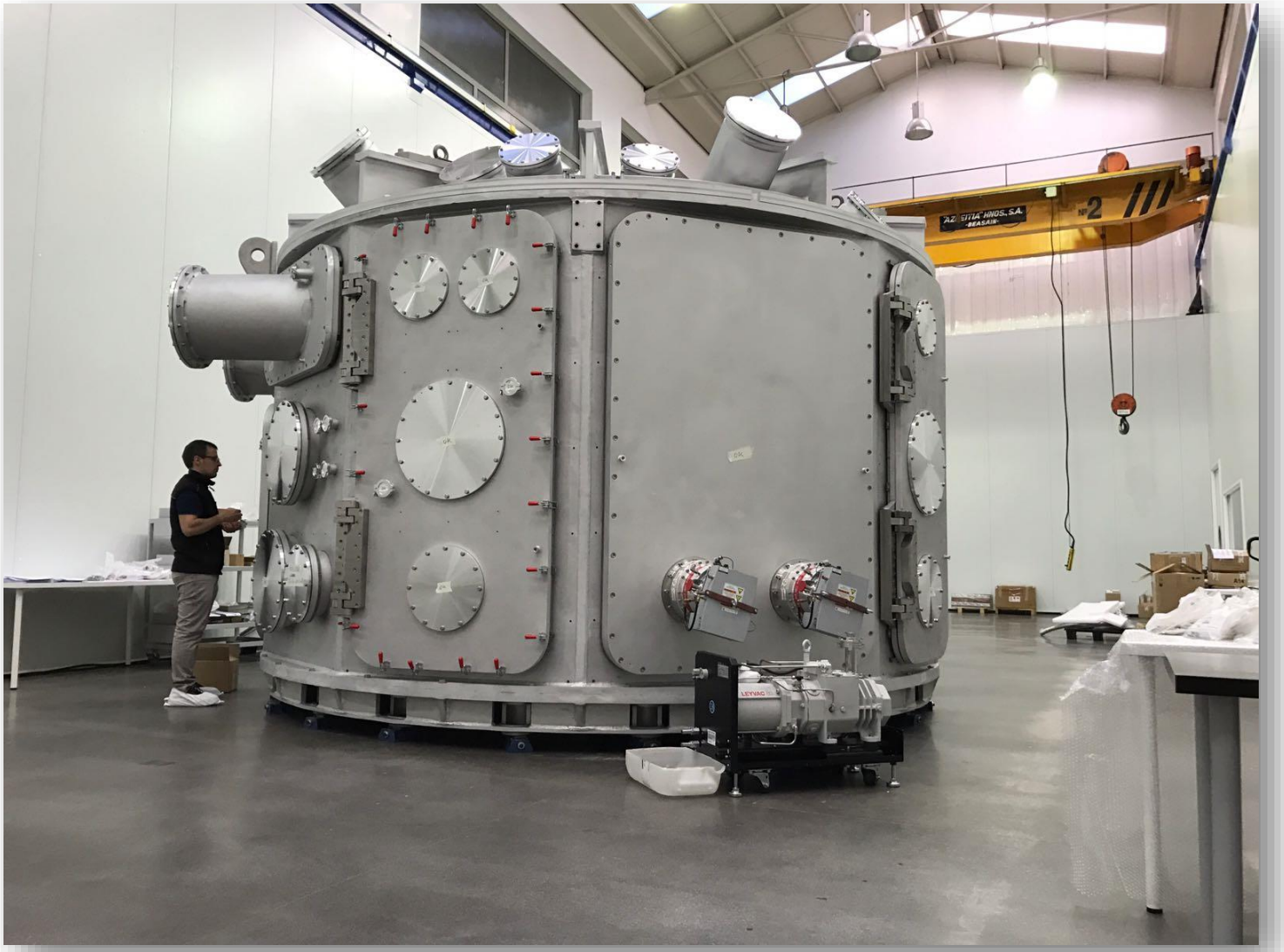
ELI Beamlines
High density plasma physics



With L4 towards 10^{23} W/cm^2 **a0 > 2000, E= 4 PV/m**

Chamber completed – Plasma and High Intensity Physics

Stefan Weber et al.



ELI-BL, LBNL & KIAM cooperation

S. Bulanov et al.

***1*. Development, validation, and support** of MARPLE3D computer code

***2*. Modelling** of (circular and square) **capillary discharge** in "ELI and BELLA relevant" regimes

***3*. Modelling** of **channels in gas targets formed by ns-laser heater** in "ELI relevant" regimes

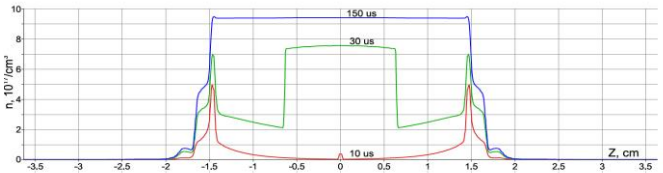
***4*.Modelling of plasma corona in solid targets** formed by ns-pedestal in "ELI relevant" regime

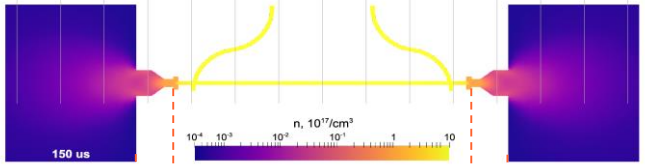
a) 3D simulation of capillary

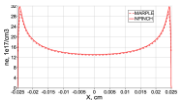
capillary

axial gas density at different instants of time

steady state 3D density

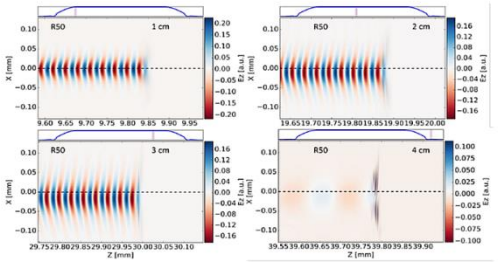




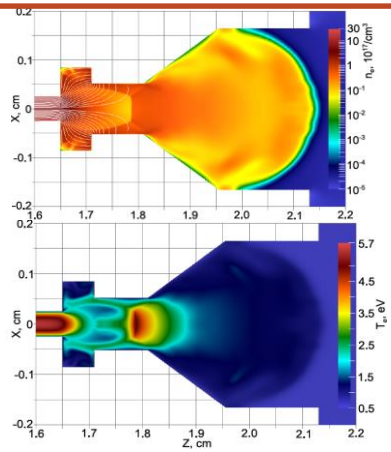


electrode insulator

wake wave Inside capillary



electron density and temperature distribution at capillary exit



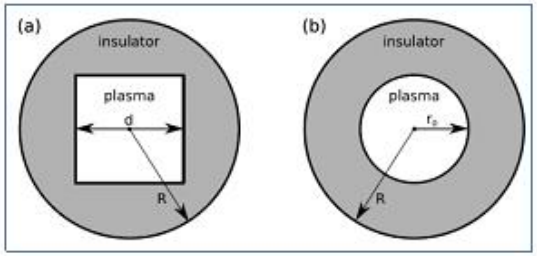
PUBLICATION

G. Bagdasarov, P. Sasorov, V. Gasilov, A. Boldarev, O. Olkhovskaya, C. Benedetti, S. Bulanov, A. Gonsalves, H. S. Mao, C. B. Schroeder, J. van Tilborg, E. Esarey, W. Leemans, T. Levato, D. Margarone, G. Korn, *Laser beam coupling with capillary discharge plasma for laser wakefield acceleration applications,* Physics of Plasmas **24**, 083109 (2017)

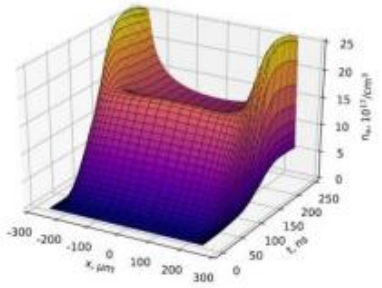
ELI-BL, LBNL & KIAM cooperation

S. Bulanov et al.

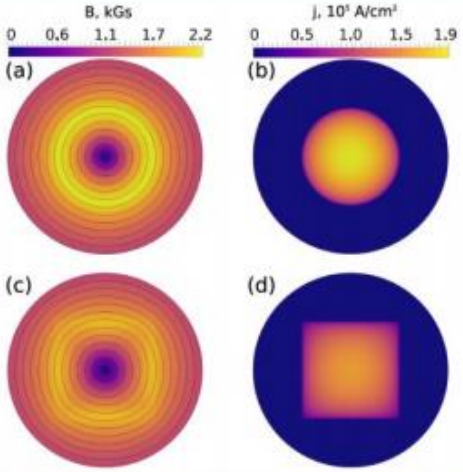
b) 2D simulation of various cross-section capillary discharges



electron density
vs *t* and *x*



magnetic field
and
electric current
density
at t=200 ns



electron density distribution in the vicinity of axis

$$n_e = n_e(0)\left[1 + a\cdot\left(\frac{r}{r_0}\right)^2 + b\cdot\left(\frac{r}{r_0}\right)^4 + \ldots\right] \quad \bigcirc$$

$$n_e = n_e(0)\left[1 + a\cdot\left(\frac{r}{r_0}\right)^2 + \left(b + c\cdot\cos 4\varphi\right)\cdot\left(\frac{r}{r_0}\right)^4 + \ldots\right] \quad \square$$

PUBLICATION

G. Bagdasarov, P. Sasorov, A. Boldarev, O. Olkhovskaya, V. Gasilov, A. Gonsalves, S. Barber, S. S. Bulanov, C. B. Schroeder, J. van Tilborg, E. Esarey, W. Leemans, T. Levato, D. Margarone, G. Korn, S. V. Bulanov, *Plasma Equilibrium inside Various Cross-Section Capillary Discharges*, Physics of Plasmas **24**, 053111 (2017)

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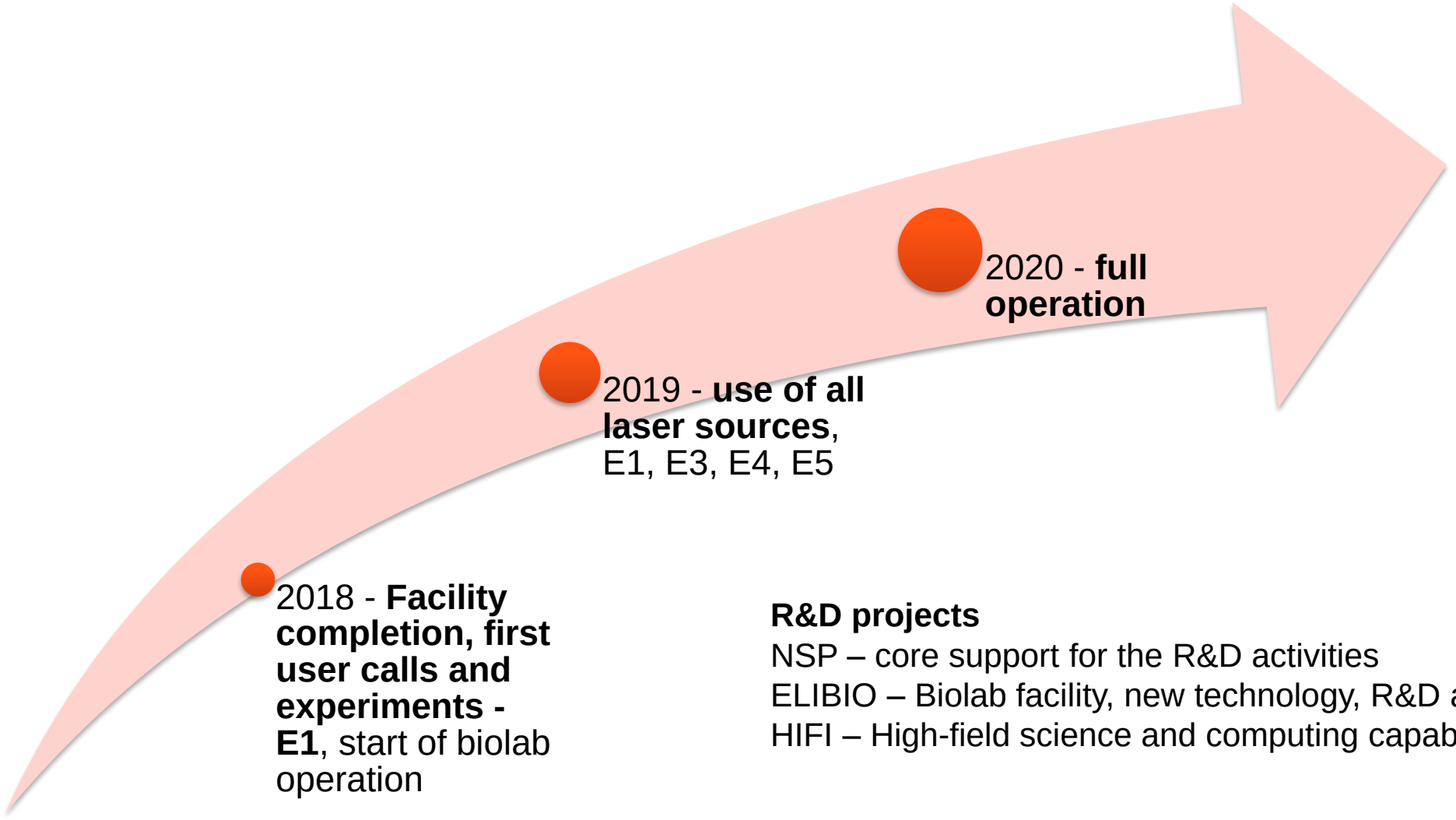
Facility completion and Mid-term outlook



R&D projects

NSP – core support for the R&D activities

ELIBIO – Biolab facility, new technology, R&D activities

HIFI – High-field science and computing capabilities

Eupraxia at ELI Beamlines

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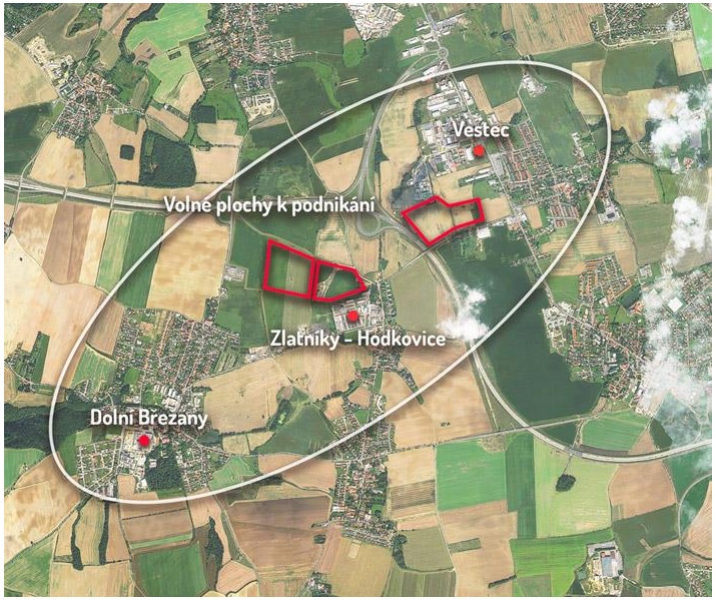
STAR
RESEARCH & INNOVATION CLUSTER

STAR Cluster
star-cluster.cz

eli beamlines

hilase
Power of light

BIOCEV



The region already attracts innovative companies…

EXBIO Antibodies

VIDIA …cesta ke správnému výsledku

Top-Bio

APRONEX BIOTECHNOLOGIES

Rigaku

A. Molodozhentsev

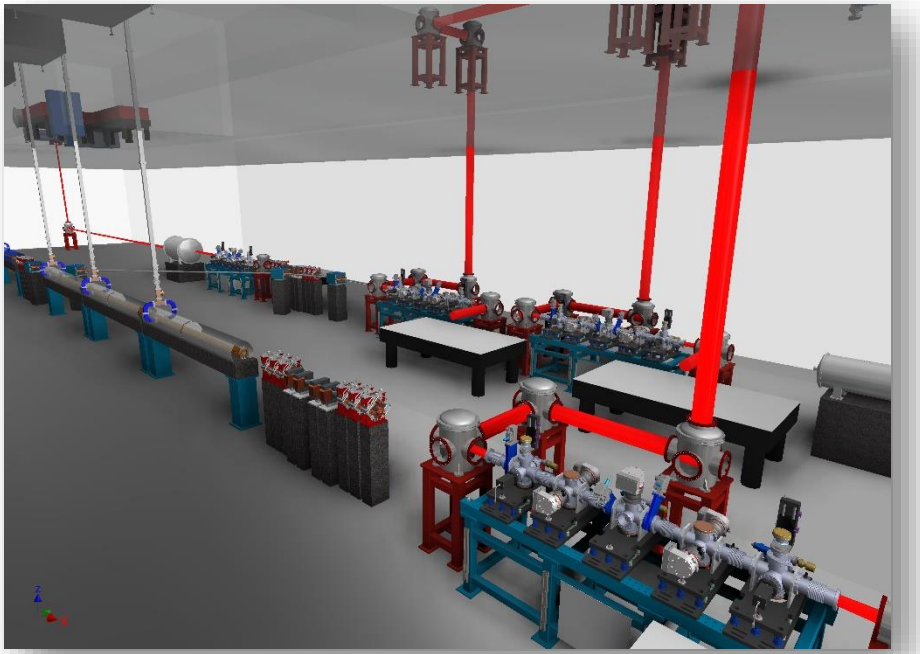
K. Kruchinin

L. Přibyl

Electron beam transport and diagnostics

D. Kocoň

Engineering



Conclusions

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Conclusions

- ELI Beamlines is approaching operations start.
- A range of its laser systems / sub-systems, beamlines and end-stations has been commissioned in partners labs.
- Installations are in full spin.
- First experiments within experimental hall starting in February 2018.
- A dynamic regional cluster of institutes and companies provides efficient support for further growth – and potentially for Eupraxia.
- We are looking forward for further collaboration!

Acknowledgements

Many thanks to:

Georg Korn
Dariusz Kocoň
Jakob Andreasson
Martin Přeček
Bedřich Rus
Pavel Bakule
Daniele Margarone
Tomáš Laštovička
Adam Wolf
Alexander Molodozhentsev
Konstantin Kruchinin
Zdeněk Svoboda

and others

Thank you for your kind attention !

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