Multi-laser accelerator facility ELI Beamlines: Laser Safety Challenges

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FZÚ

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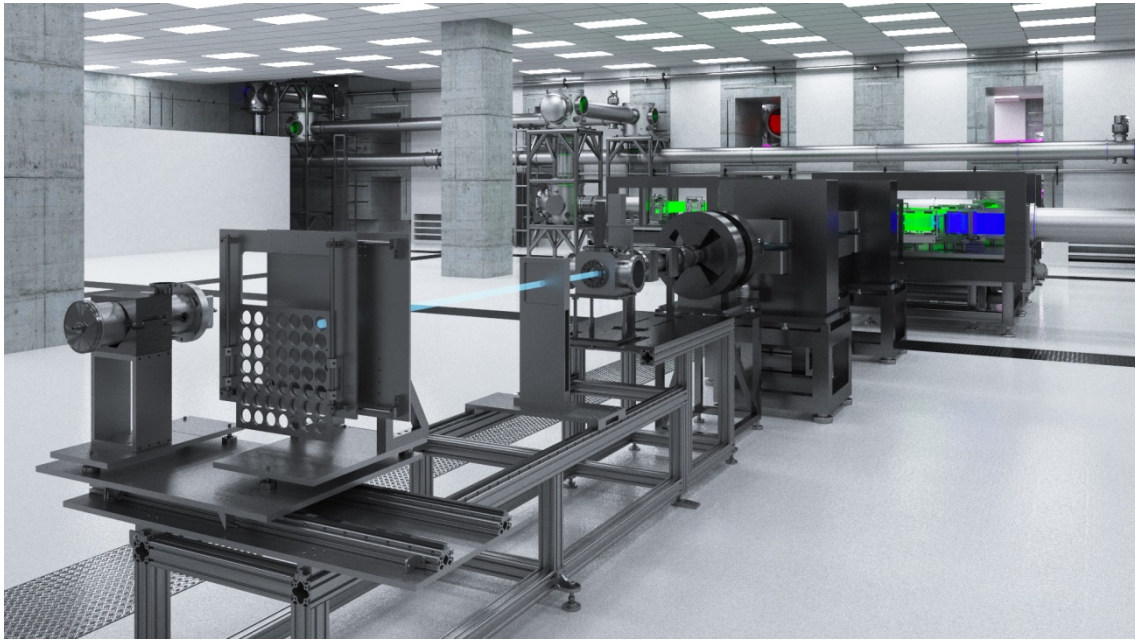
ELI Beamlines facility in Prague



- 4 major high power laser systems (up to 10PW).
- 8 main workstations under development in 5 target areas.
- Electron and ion acceleration, X-ray and plasma physics stations.
- Independently operated and driven by all laser systems via beam transport.
- Construction completed – technology to be installed – operation: end of 2017.

- Areas with various combined hazards and laser safety challenges.

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Facility Layout

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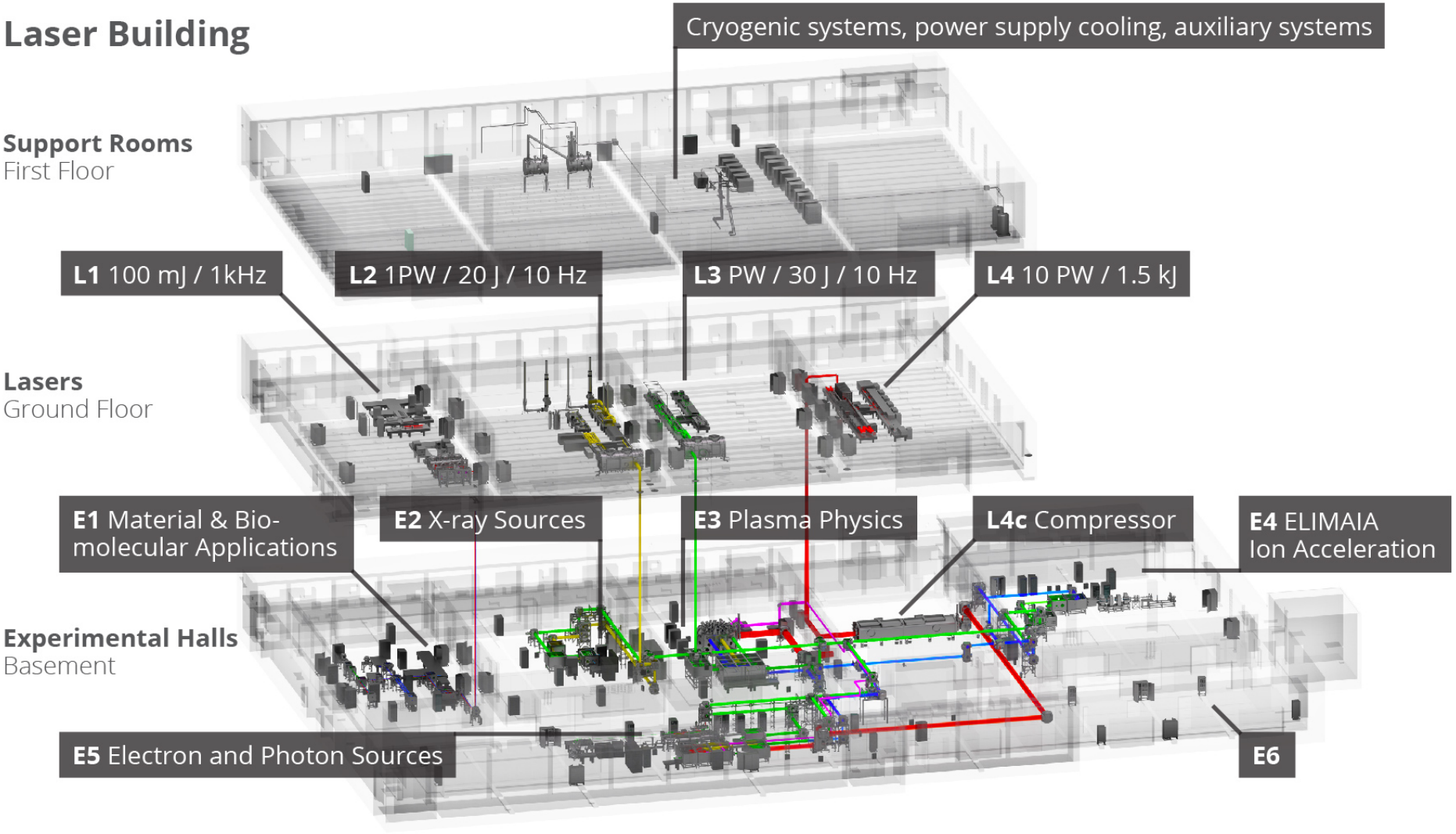
Facility Layout



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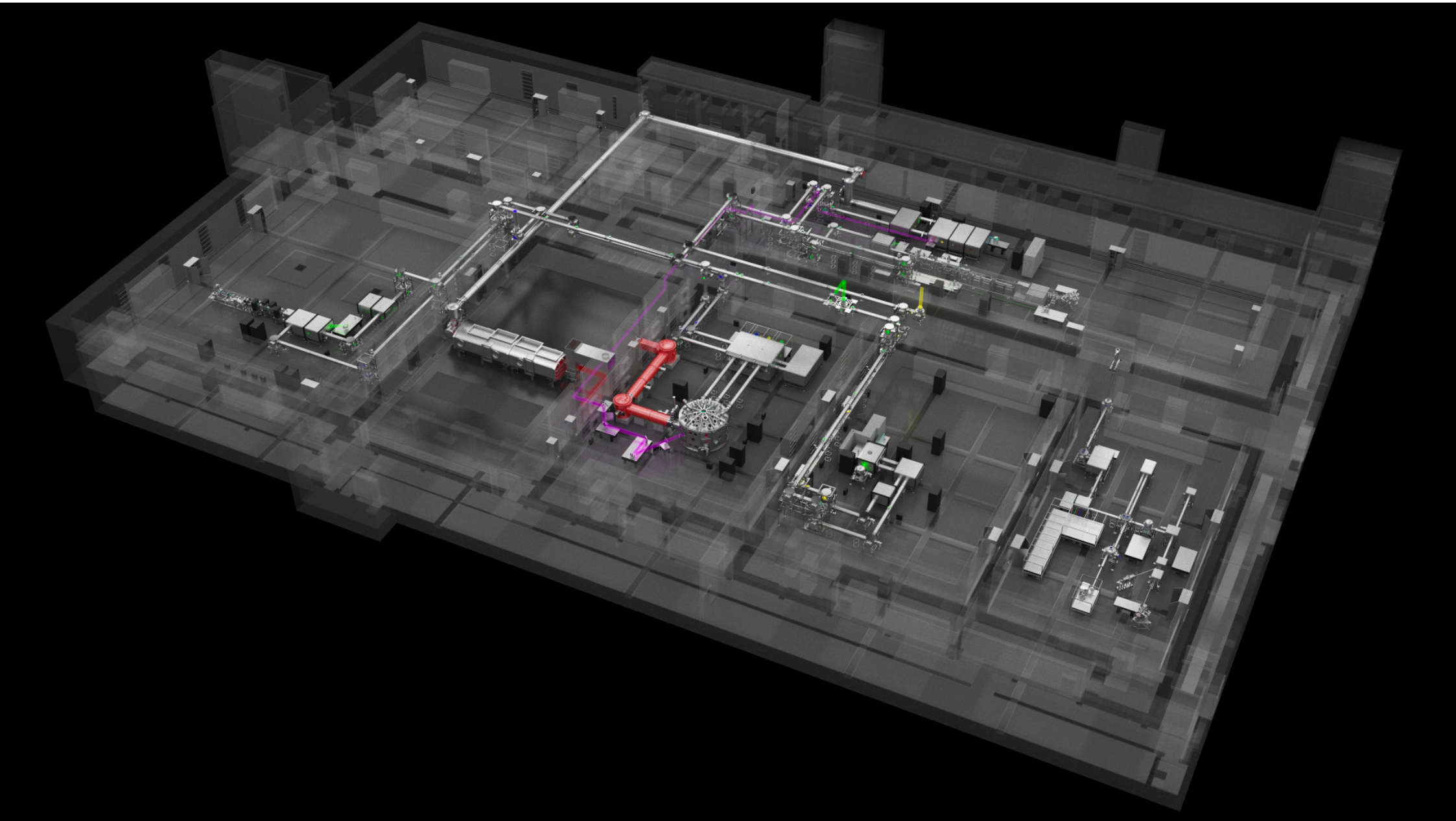
eli beamlines

Facility in 3D



Laser Systems

Laser System	L1	L2	L3	L4	Astrella
Peak power	>5 TW	1 PW	≥1 PW	10 PW	TW
Energy in pulse	100 mJ	≥15 J	≥30 J	≥1.5 kJ	15 mJ
Pulse duration	<20 fs	≤15 fs	≤30 fs	≤150 fs	<40 fs
Rep rate	1 kHz	10 Hz, >10 Hz	10 Hz	1 per min	1 kHz
Wavelength	850 nm	850 nm	820 nm	1050 nm	700-900 nm
Produced	In-house	In House and Purchased (STFC)	LLNL	National Energetics, EKSPLA	Coherent

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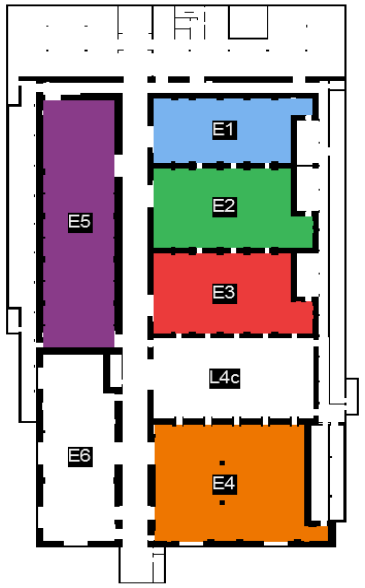

What users get

end-stations

L1

- **PXS** — 1E13 ph, 300 fs, 1 kHz, 4π sr
  - X-ray phase contrast imaging
  - X-ray Diffraction
  - X-ray absorption spectroscopy
- **HHG** — 1E10 ph, 10 fs, 1 kHz, 5 mrad
  - Coherent Diffractive Imaging
  - Atomic, Molecular and Optical Science
  - Soft X-ray Materials Science
- **SRS** — + pump, beams
  - Pulsed Radiolysis,

L2

- **LUX** — 1E6 ph, 5 fs, 10 Hz, 5 mrad
  - WW pump-probe (station development)

L3

- **Betatron** — 1E8 ph, 10 fs, 10 Hz, 20 mrad
  - X-ray Phase contrast imaging
  - X-ray fluorescence
  - Absorption spectroscopy,

L4

- **P3 Plasma Phy. Platform**
  - WDM@10Hz,
- **ELIMAIA Ion accel.**
- **Hell electron.**

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Hazard Analysis

- **Preliminary Hazard Analysis**[1]
- **Hazards identified:**
  - Ionizing radiation,
  - **Laser radiation**,
  - High voltage systems,
  - Flammable and toxic gases,
  - Oxygen depleting gases,
  - Vacuum,
  - Pneumatics,
  - Ozone,
  - Biohazards,
  - Nanomaterials,
  - Chemicals,
  - Electromagnetic pulse (EMP),
  - Magnetic field,
  - Cryogenics,
  - Robotics,
  - Radioactive materials.

Identification:

- Failure
- Causes and consequences
- Controls: Engineering vs. Administrative
- Affected areas

Figure 29 Doors to be PSI controlled in L.02.25 (E6) (floor 098)

6.2.3. Preliminary hazard analysis of ionizing radiation

Failure	Cause	Consequence	Controls
Ionizing radiation in experimental halls (E2-E6, L4c)	1. Intended use of laser in experimental halls.	1. Irradiation of personnel inside the halls during the experiment. 2. Material activation.	- Halls shall be PSI controlled areas. - Access denied into these halls during the experiments. - Proper design of equipment in a way to minimize the activation. - Access restricted after the experiment until the dose rates reach preset levels.

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Ionizing radiation exceeds preset level in experimental hall E1	1. Wrong experiment arrangement or design. 2. Different laser been quality than requested by experiment designer. 3. Wrong alignment of the laser beam.	1. Irradiation of personnel inside the E1 hall.	- Implementation of monitoring system in the hall. - Immediate process termination in the case of dose rates in control rooms, corridors, and laser halls exceeding the preset level. - Additional shielding of the most powerful ionizing radiation shielding. - Proper laser beam diagnostics and alignment procedures. - Installation of E-STOP to immediately terminate the process.
Ionizing radiation leaks to the plant rooms (mentioned in Chapter 6.2.2)	1. Design of the building (plant rooms are not shielded)	1. Serious injury to death of personnel present in the plant room	- Plant rooms to be controlled by PSI and PSI area modes shall be established. - Installation of E-STOP to immediately terminate the process.
Ionizing radiation leaks to Control rooms	1. Ionizing radiation beam with parameters exceeding / are different than presumed parameters. 2. Wrong ionizing radiation beam alignment. 3. Wrong position of beam dump.	1. Irradiation of personnel in the control rooms that can result in health damage.	- Implementation of monitoring system in the control rooms. - Immediate process termination in the case of dose rates in control rooms, corridors, and laser halls exceeding the preset level. - Installation of E-STOP to immediately terminate the process.
Ionizing radiation leaks to corridors	1. Ionizing radiation beam with parameters exceeding / are different than presumed parameters. 2. Wrong ionizing radiation beam alignment. 3. Wrong position of beam dump. 4. Focused laser beam in the beam distribution hits the pipe and ionizes the metal.	1. Irradiation of personnel in the corridors that can result in health damage.	- Implementation of monitoring system in the corridors. - Immediate process termination in the case of dose rates in control rooms, corridors, and laser halls exceeding the preset level. - Installation of E-STOP to immediately terminate the process.

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[1]CCPS. Guidelines for Hazard Evaluation Procedures, 3rd Edition. 2008

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Laser safety challenges

- Ultra short pulsed laser system – eyewear selection challenge
- Complex laser beam transport system – flexibility increases but safety becomes more complicated
- Laser beam transport system complexity brings more safety requirements on its parts (switchyards etc.) to reach appropriate safety level.
- Up to 3 different laser systems (L2, L3, L4) are to be used simultaneously in the Experimental Halls – more complicated safety system
- Laser beam parameters set limits to the material choice for shutter gates

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Laser safety controls and measures: General

- Physical barriers:

  - Enclosures, curtains, walls, tubes, shutters

- Control and safety systems:

  - Integrated Safety System, Machine Safety System, Monitoring System

- Regime:

  - various safety modes of the room to ensure personnel safety

- Administrative controls:

  - clear procedures and manuals, different levels of training, PPEs

- Responsibilities:

  - appointment of LSO, responsibility distribution (to manage to works and operate Integrated Safety System

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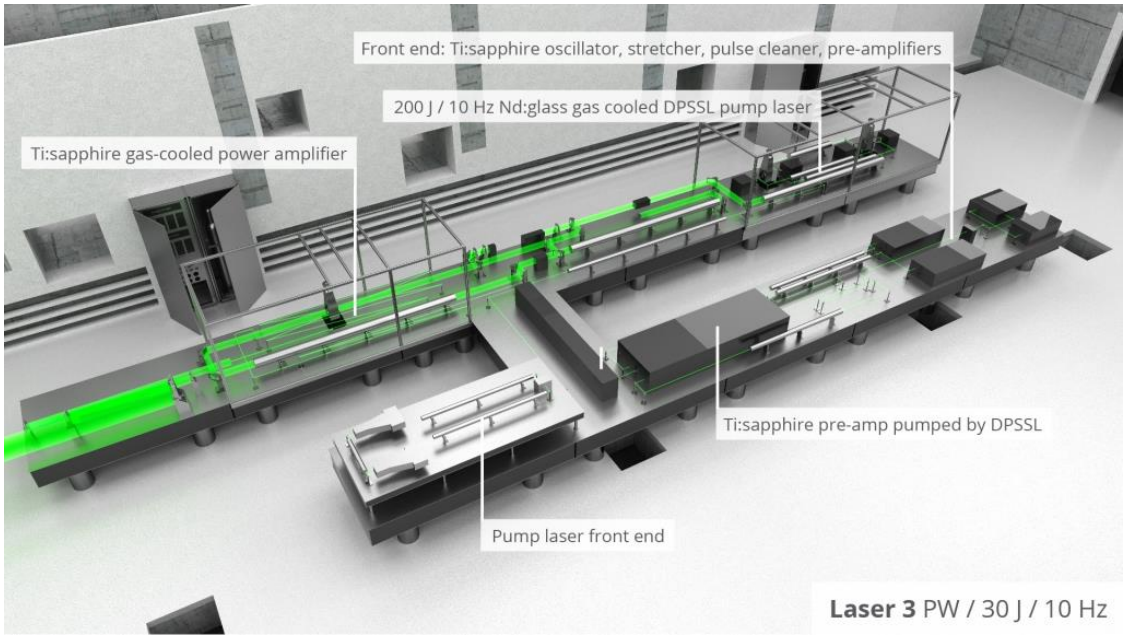
L3: HAPLS - High-Repetition-Rate Advanced Petawatt Laser System



- HPW mode: ≥1 PW, ≥30 J, ≤30 fs, 10 Hz, λ=820 nm
- Laser Hall 3
- Drives stations:
  - Betatron – e^- (E2)
  - Plasma Physics Platform (E3)
  - ELIMAIA – p^+ (E4)
  - HELL – e^- (E5)
  - LUX – e^- (E5)
- Complex beam transport system
- 3 switchyards, 1 injection chamber

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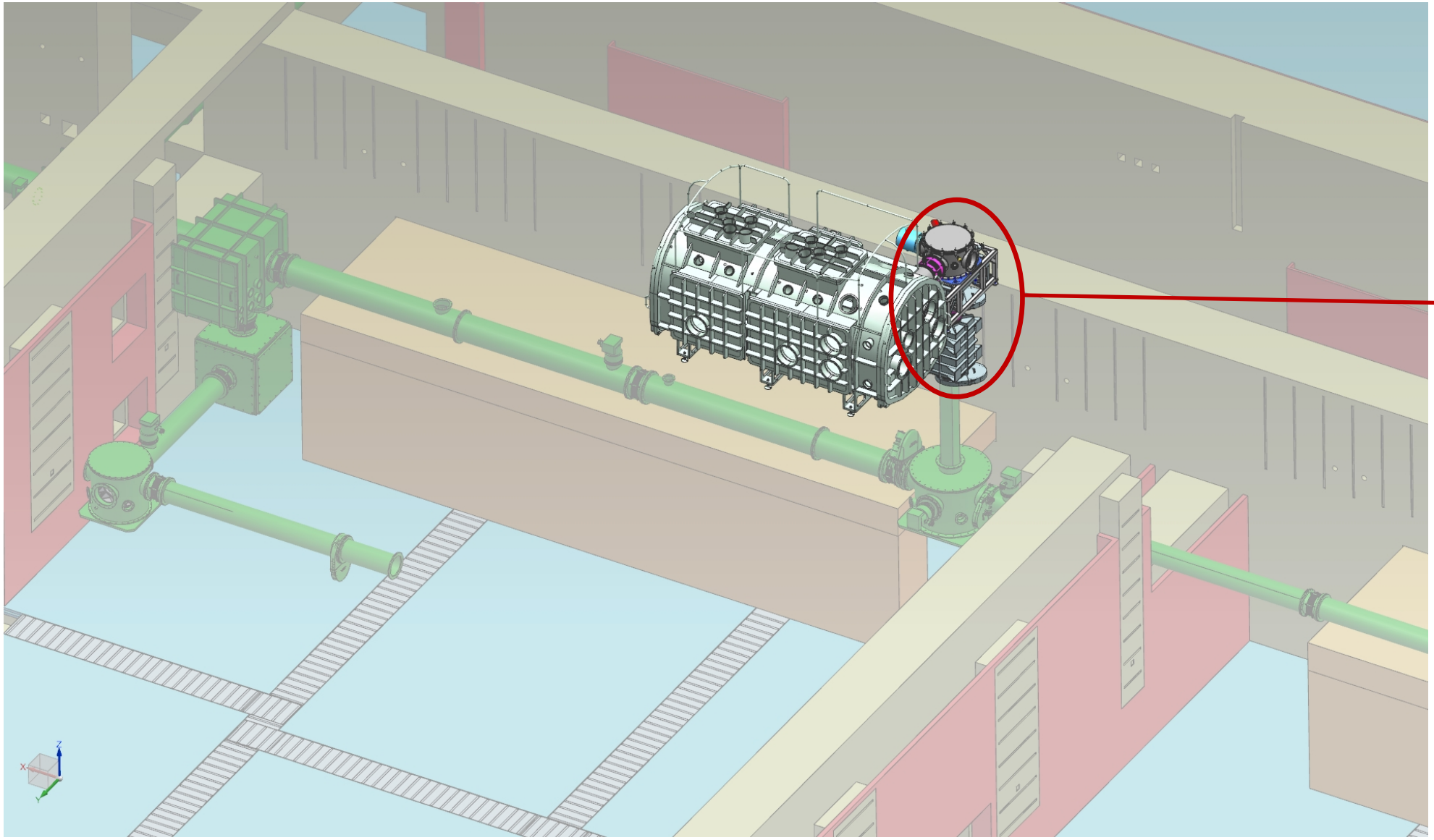
L3 Beam Transport System: optical compressor and injection



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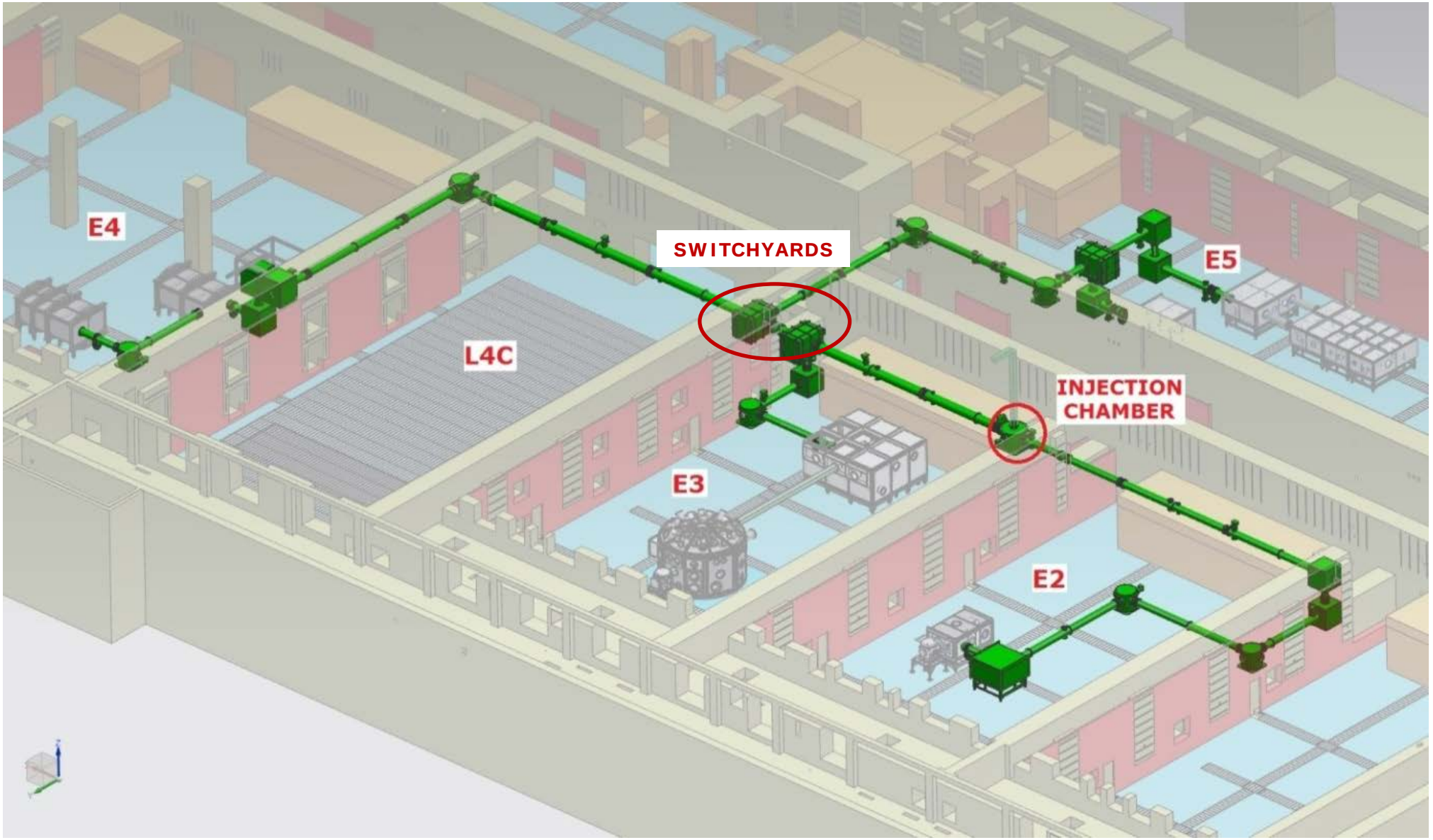
L3 Beam Transport System



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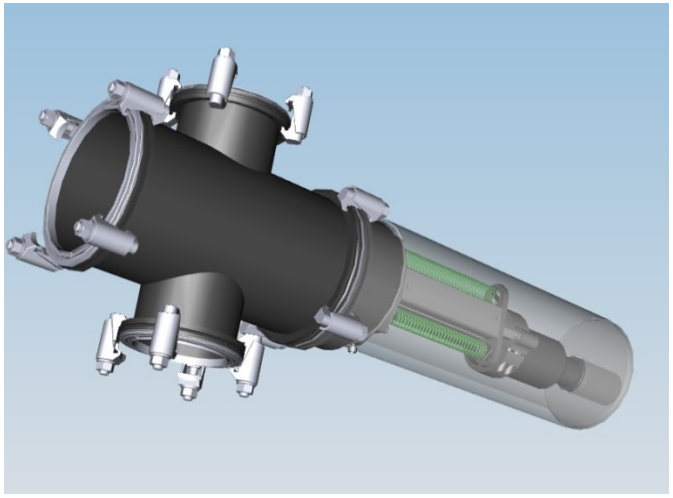
L3 Beam Transport Shutters

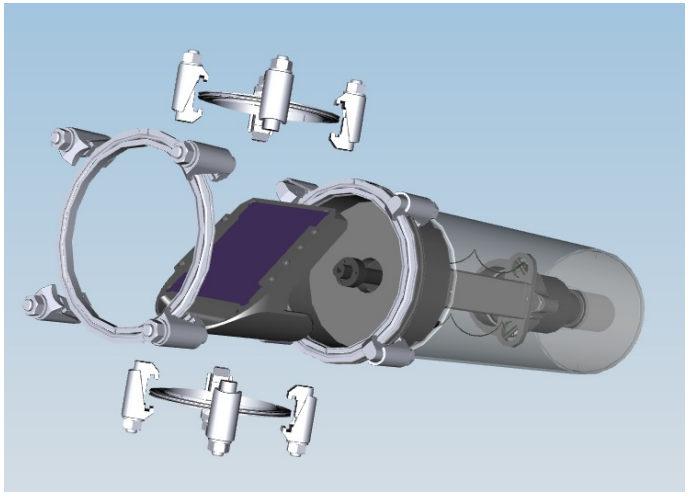
- Used to separate the rooms from the beam distribution during the operation.
- Two types:

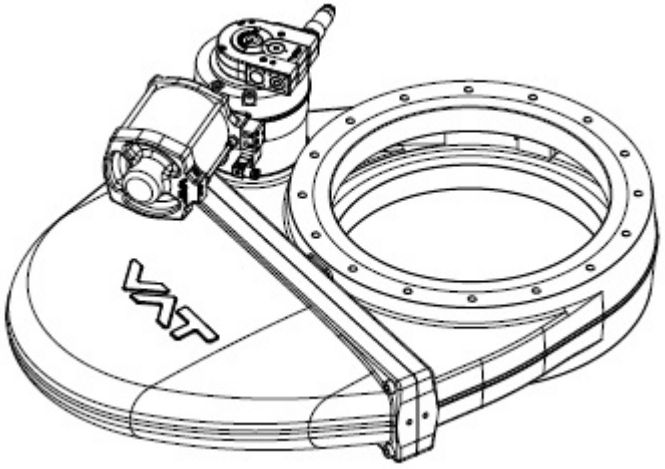
  - "mirror" type with beam dump (**fast**) – L3 Hall

  - vacuum valve (**slow**) – beam transport system in Experimental Halls

- Not safety device – **operated by control system**
- Safety sensors connected to integrated safety system – **monitored by safety system**







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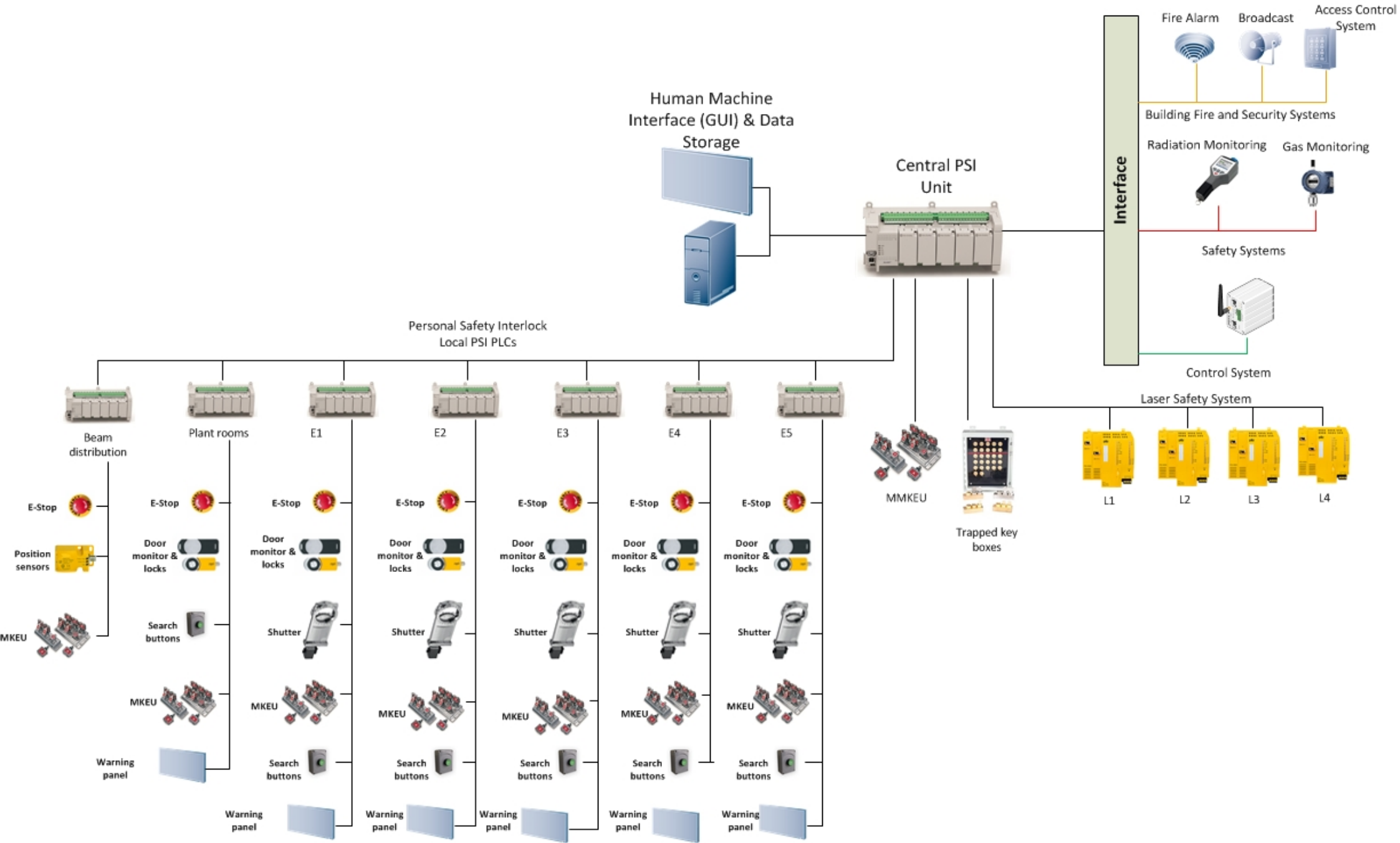
Integrated Safety System - Scheme



Area modes in corresponding experimental halls

- Area safety modes: E-Stop, "Closed", **Safe**, **Alignment**, Search, **High power**, Post-experimental
- Safe mode:
  - no laser hazard
  - no eyewear required
- Alignment mode:
  - low power laser hazard (however Class IV): L3 alignment mode or CW alignment laser
  - eyewear required
- High power mode:
  - laser hazard: ≥1 PW, ≥30 J, ≤30 fs, 10 Hz, λ=820 nm
  - ionizing radiation hazard – ACCESS DENIED

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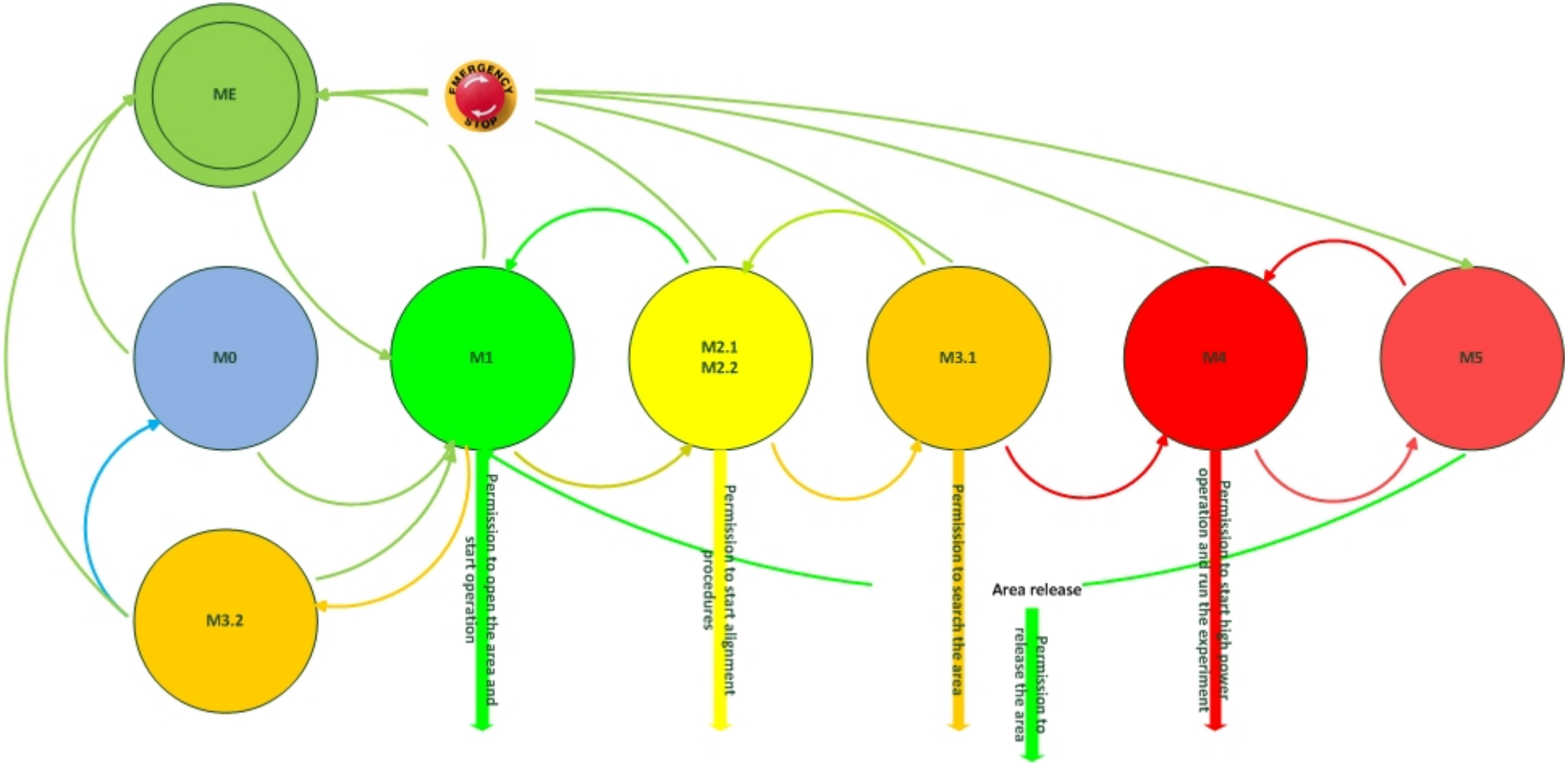
Integrated Safety System: State machine

State machine for Experimental Halls E2 – E5



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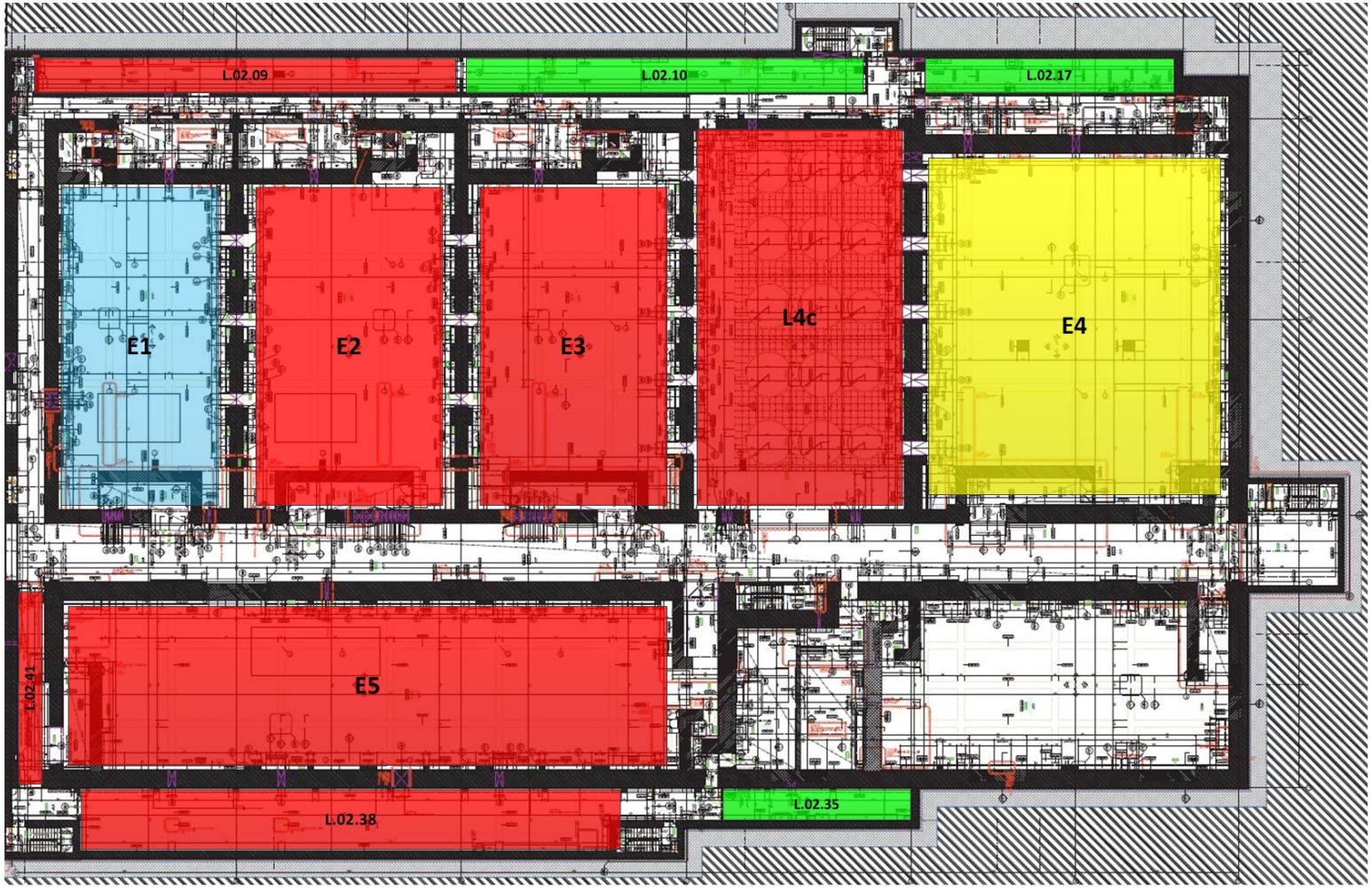
Integrated Safety System – Operation

E3 Operation – M4 (High Power Mode): Error



FAILURE
AREA CLOSED – ACCESS DENIED
NO HAZARD
WARNING LASER HAZARD
SEARCH IN PROGRESS – ACCESS DENIED
LASER HAZARD
IONIZING RADIATION
ACCESS DENIED
IONIZING RADIATION
AUTHORIZED PERSONNEL ONLY

E1 – M0 E2 – M4 E3 – M4 E4 – M2.1
E5 – M4

L4c – Permissive

L.02.09 – M4
L.02.10 – M1
L.02.17 – M1
L.02.41 – M4
L.02.38 – M4
L.02.35 – M1

L4 requested to E3
ERROR: L.02.10 in M1 – PERMIT NOT GRANTED

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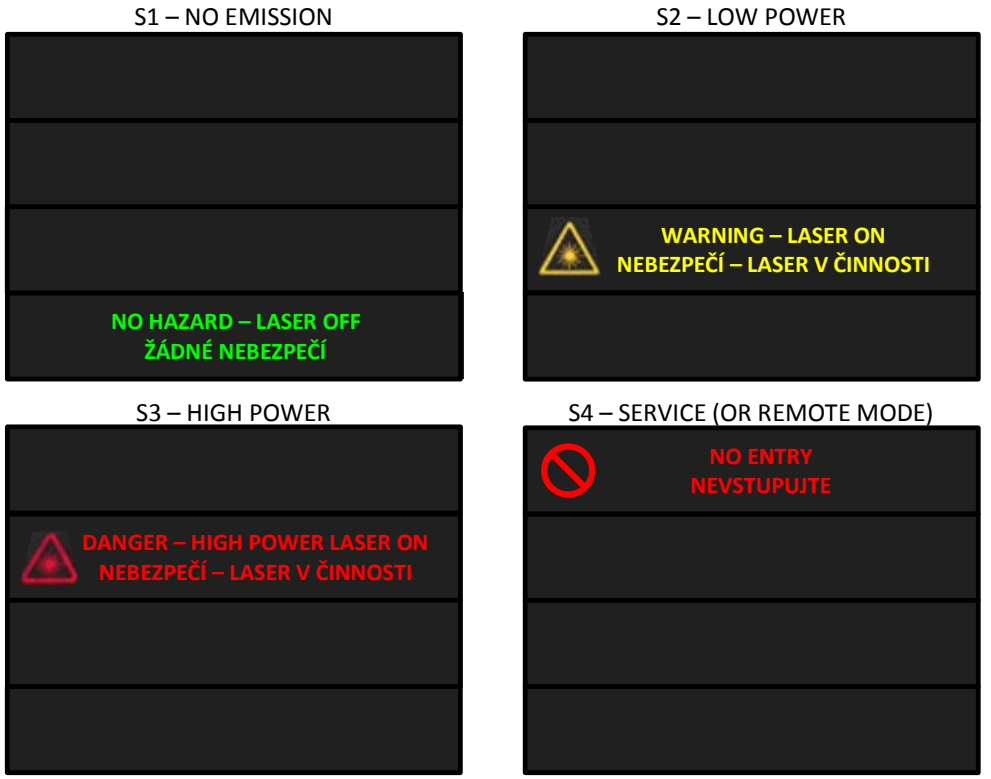
Laser Safety System in L3 Hall

- Safety Modes:
  - -No emission
  - - Low power
  - - High power (confined)
  - - Service mode (high power laser hazard unconfined)
- Integrated with facility Integrated Safety System
- Pilz PLC based



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Conclusions

- Eyewear:
  - proper eyewear selection – Experimental Halls
  - restricted access – Laser Halls (based on safety modes)
- Laser beam transport:
  - robust Integrated Safety System that will still enable to operate comfortably
  - cautious design of the system
- Shutters:
  - proper selection of shutter gates (coating, design etc.)
  - integration of non-safety devices into Integrated Safety System

HiLASE laser laboratory

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Acknowledgement

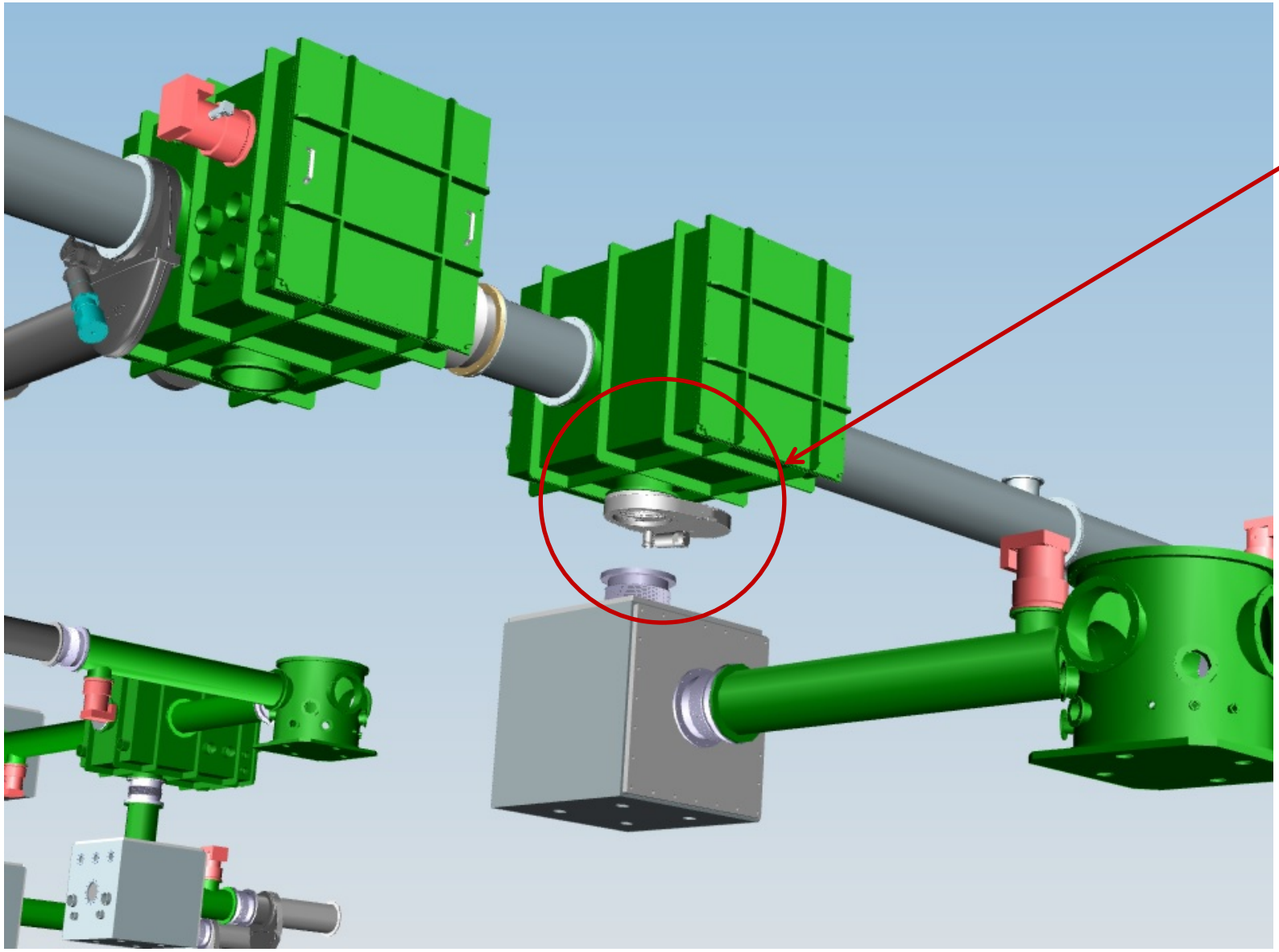
- Supported by the project ELI - Extreme Light Infrastructure – phase 2 (CZ.02.1.01/0.0/0.0/15_008/0000162) from European Regional Development Fund.

- Cooperation and support:
  - ELI Beamlines EHS Team, Jakub Grosz (ELI Beamlines), Jiri Vyskocil (ELI Beamlines), ELI Beamlines Laser, Experimental, and Engineering Teams, Ken Barat (Laser Safety Solutions)

Questions?

Back up slides

Shutters



Shutter in E3:

- line to P3 chamber
- Directly under the switchyard

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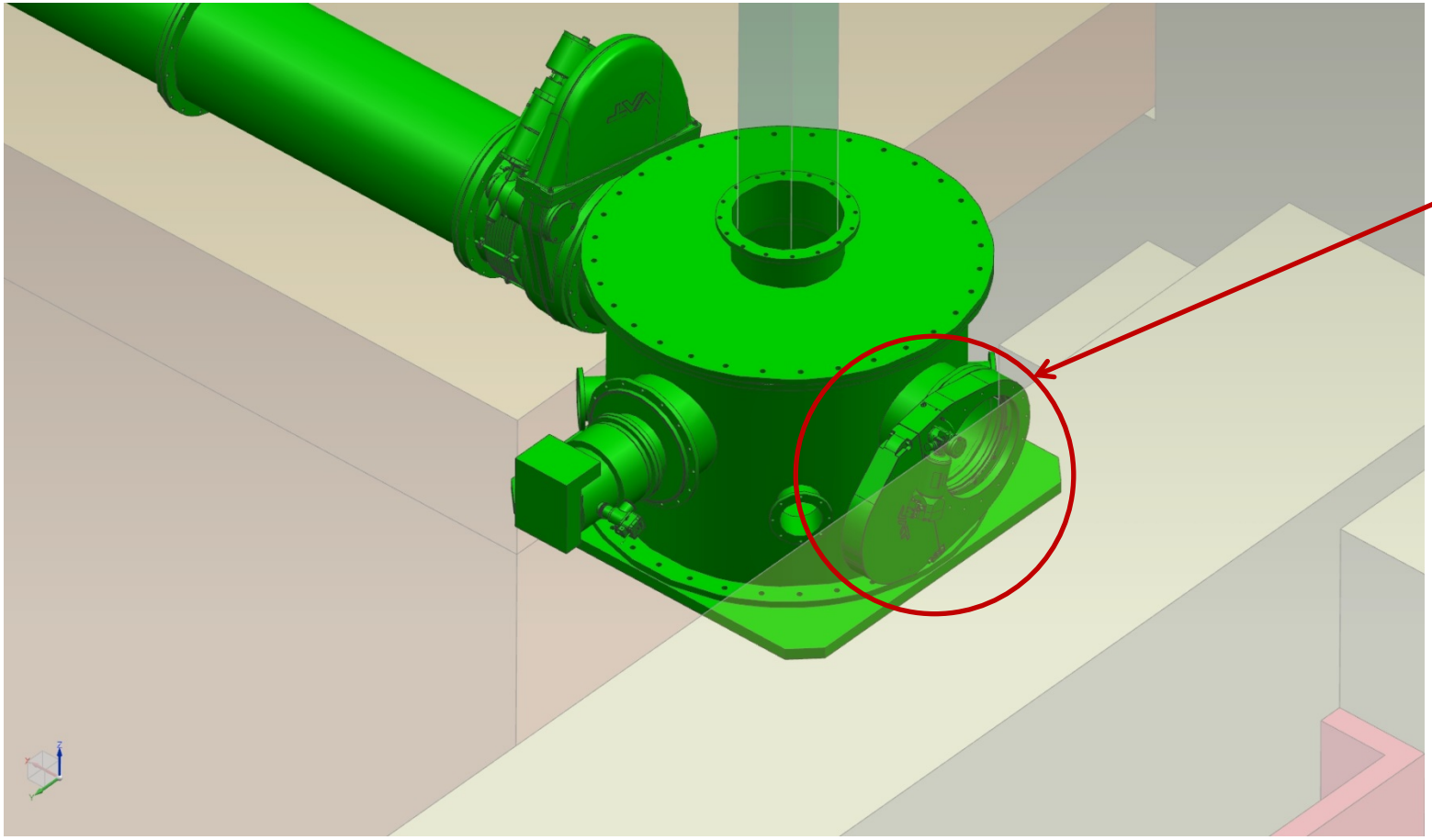
Shutters



Shutter in E3:

- line to E2
- Pendulum valve

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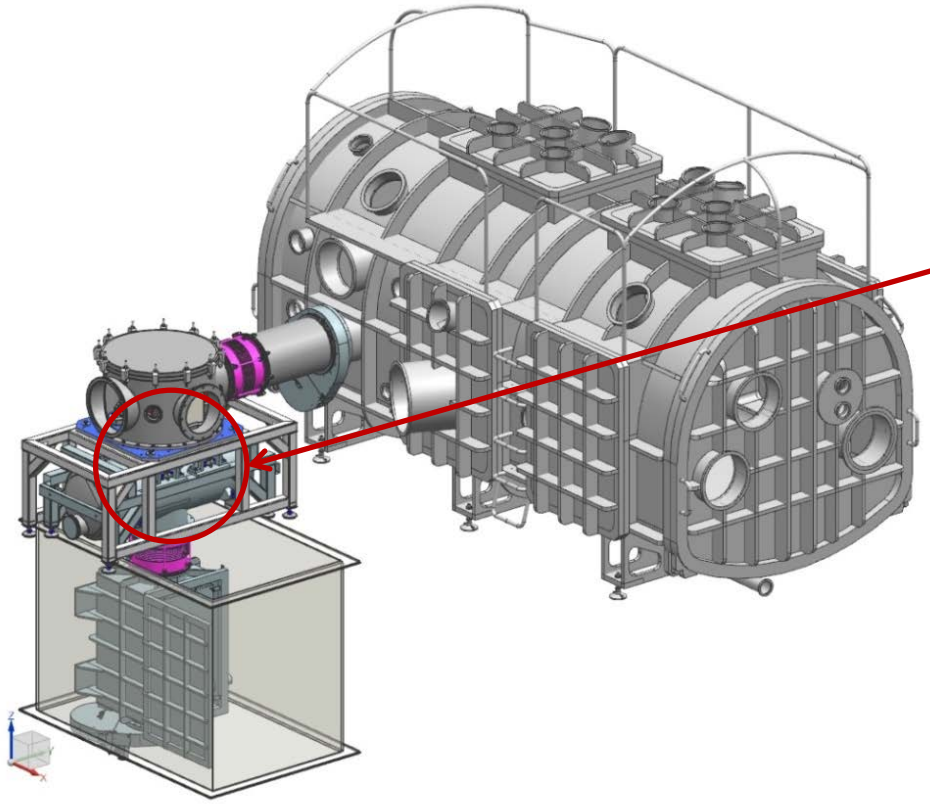
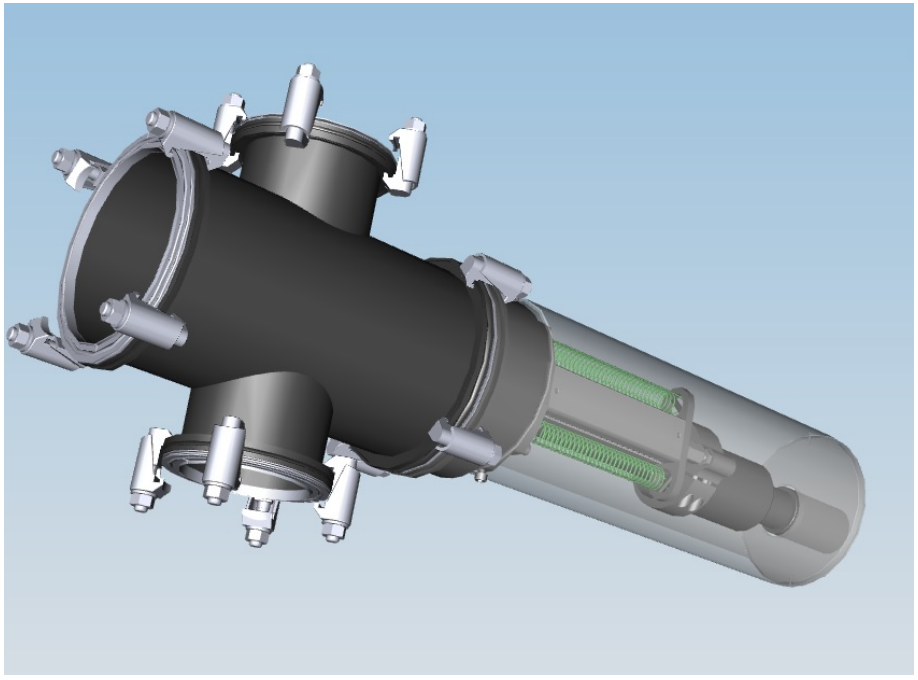
Shutters



Shutter in L3:

- line to E3
- mirror



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