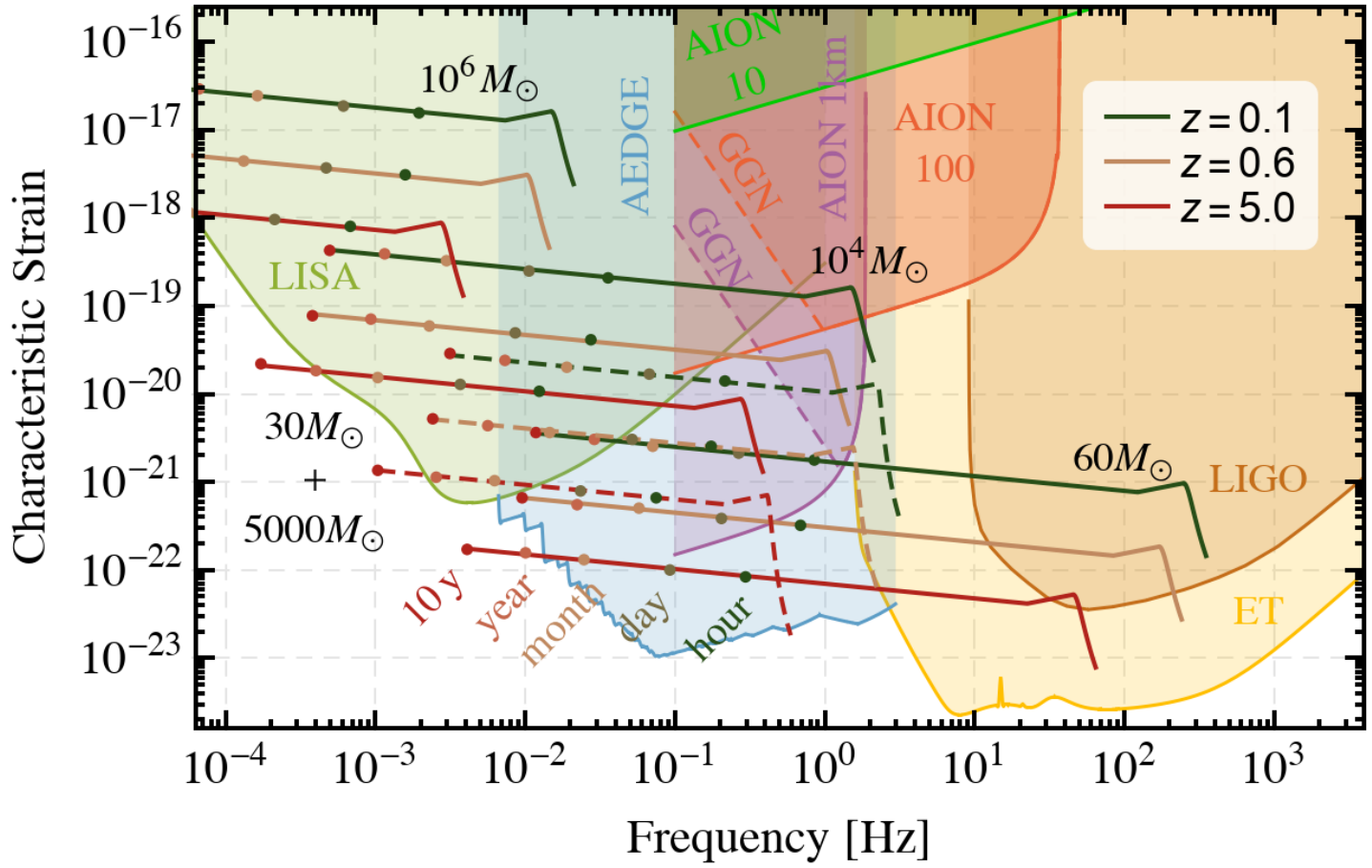
A Vertical Atom Interferometer at CERN LHC Point 4

Sergio Calatroni on behalf of the Feasibility Study Group

14.03.2023

Motivation for atom interferometer

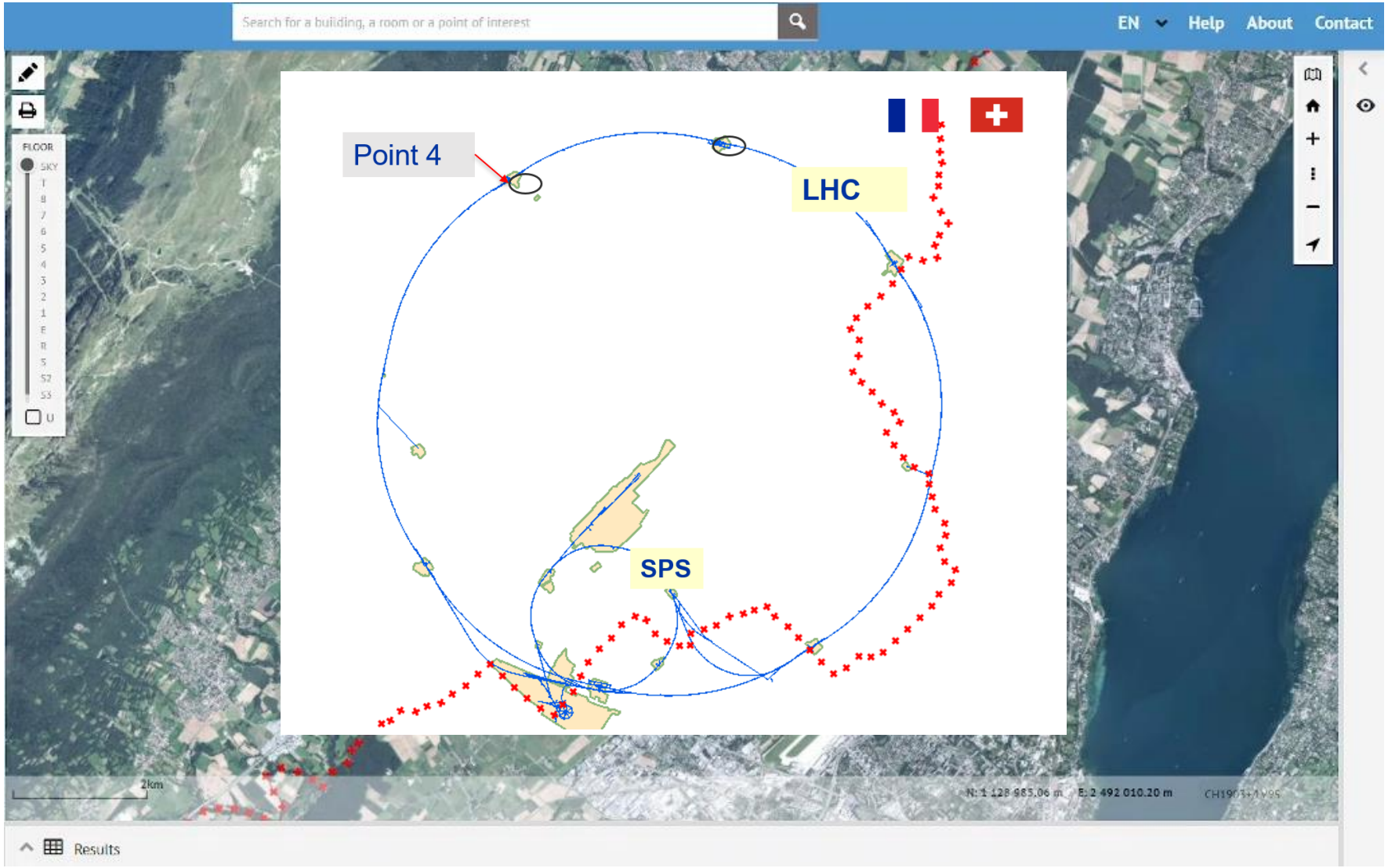


Motivation

- Identify location for a vertical AI ~100 m deep at CERN
- Site already part of a large international laboratory and experimental facility
- Assess technical feasibility and impact from presence of LHC machine
- Based on AION-100 technical requirements as guideline

- “A Long-Baseline Atom Interferometer at CERN: Conceptual Feasibility Study”
- CERN-PBC-REPORT-2023-002, https://cds.cern.ch/record/2851946

LHC Point 4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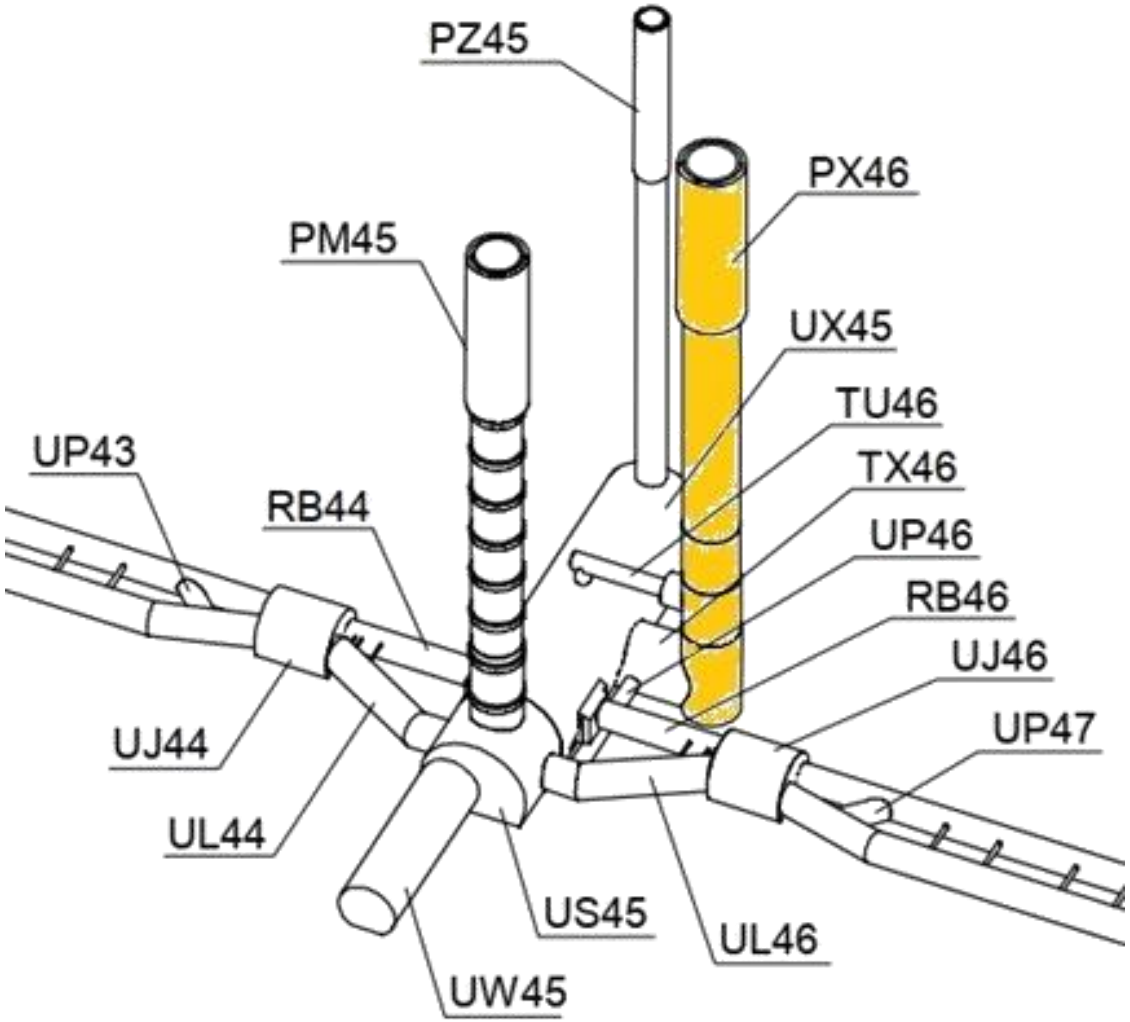
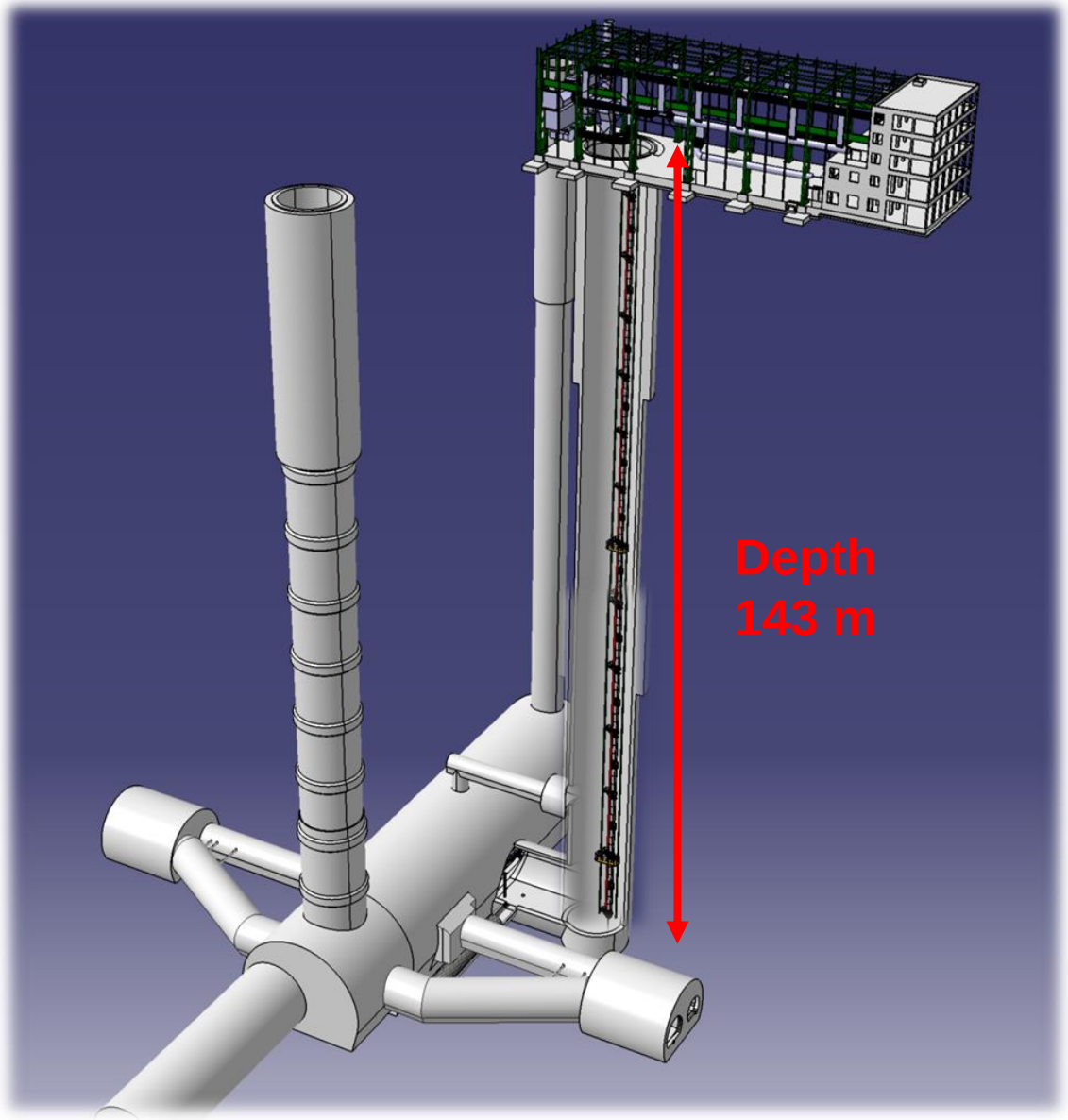
Selected location: PX46



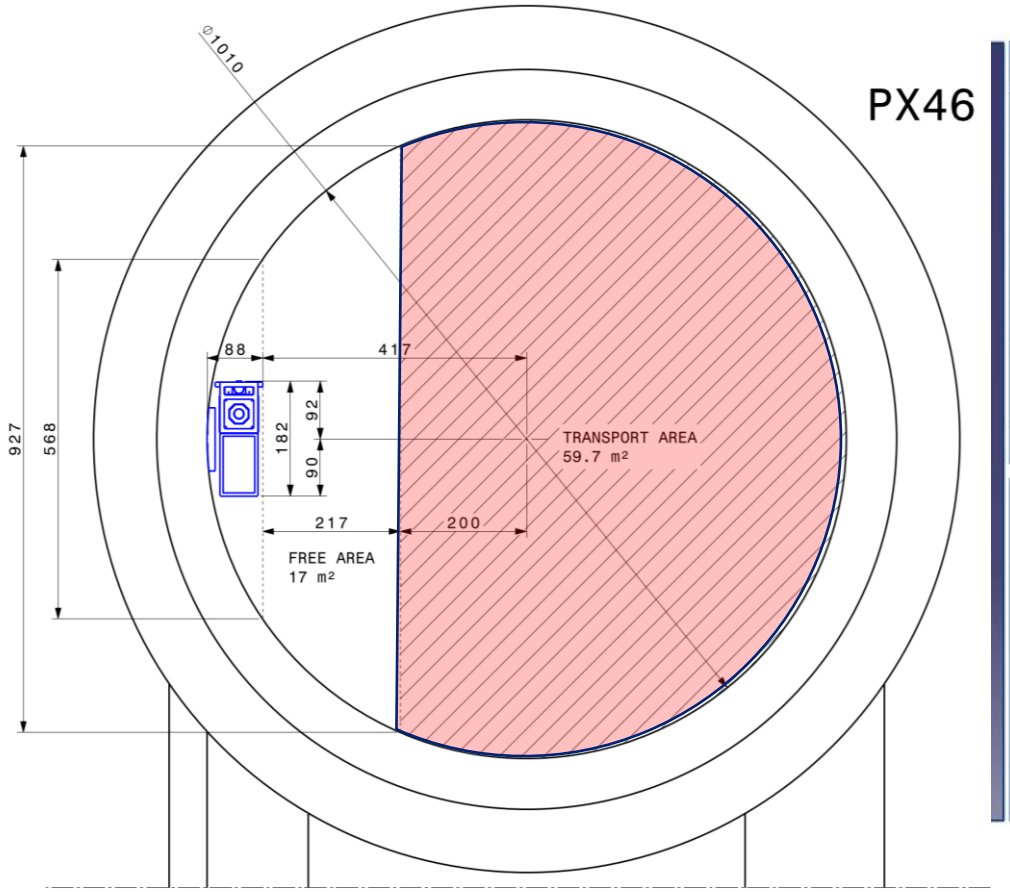


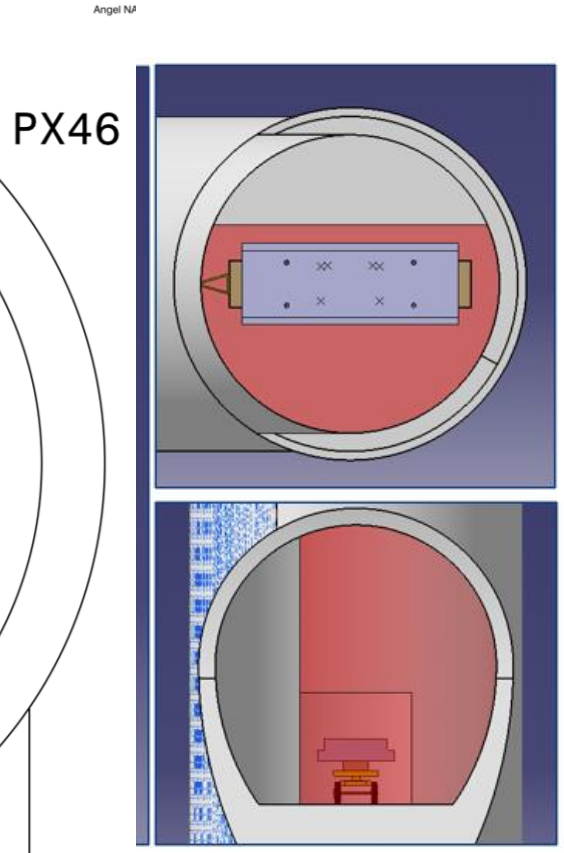
Selected location: PX46

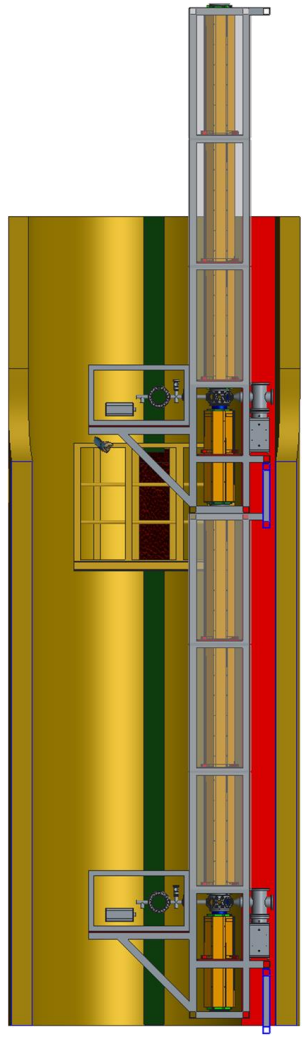
Views at the surface

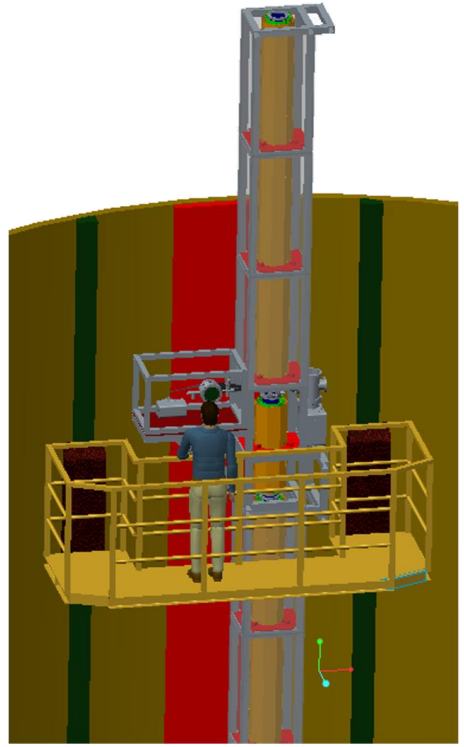
View from below

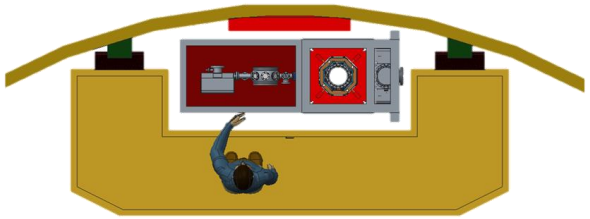
Transport of LHC components and proposed layout







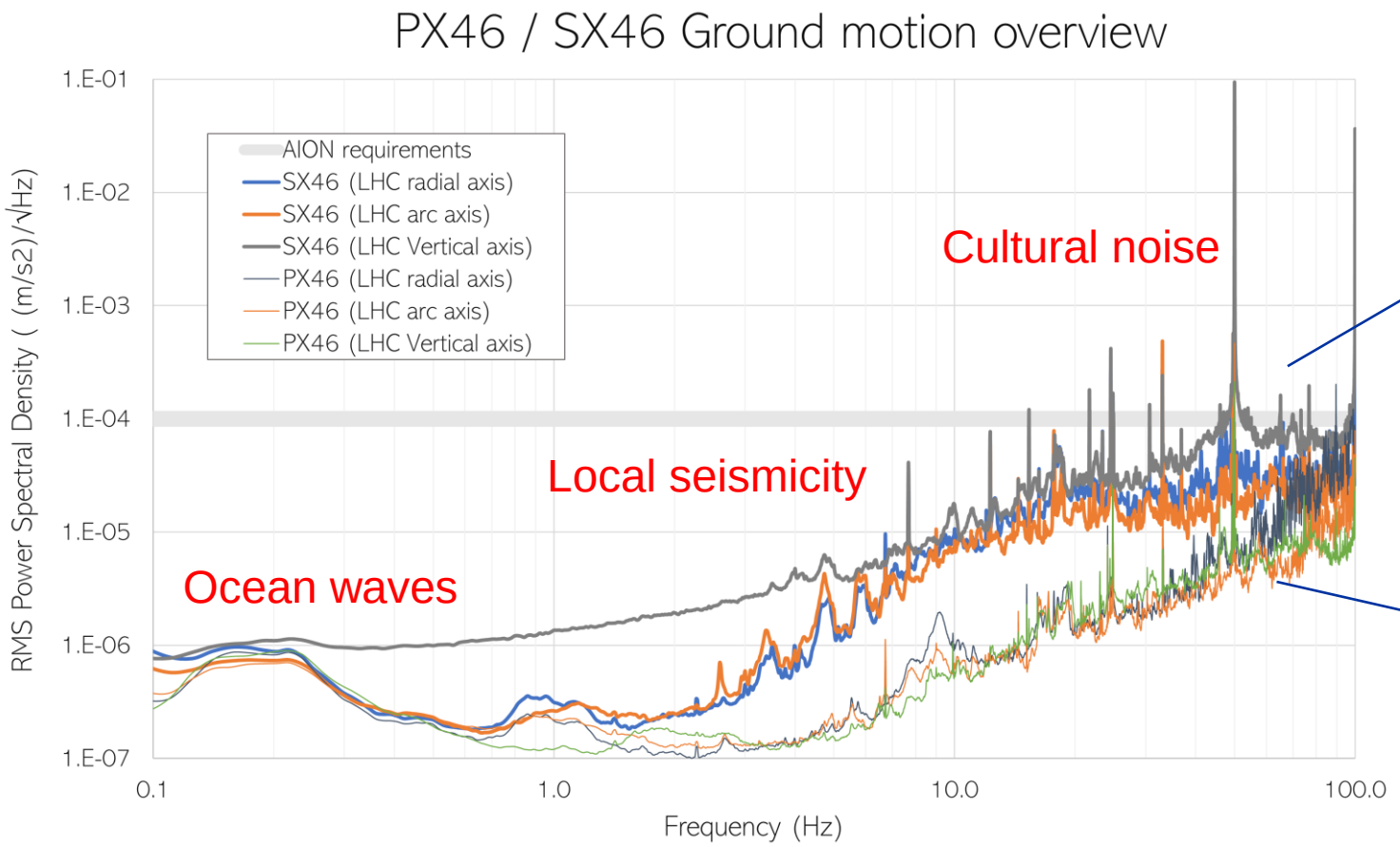




Evaluation of PX46 as suitable site for an AI

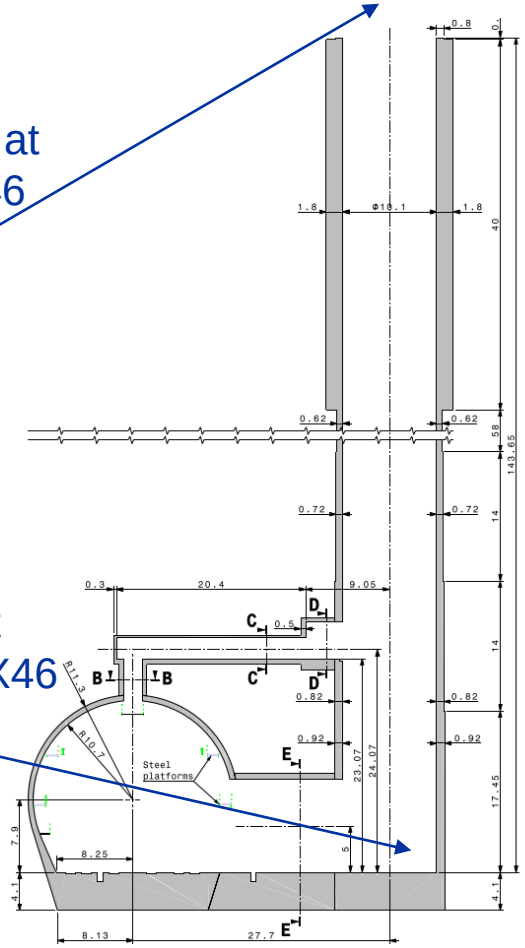
- **Compatibility with technical requirements for an AI – influence of the LHC**
  - Vibrations, seismic noise and local geology
  - EM noise
  - Radiation protection
  - Fire safety
  - He release hazards
  - Access control
- **Available infrastructure**
  - Electrical supply, network, etc.
  - HVAC

Vibrations and seismic noise



Measured at top of PX46

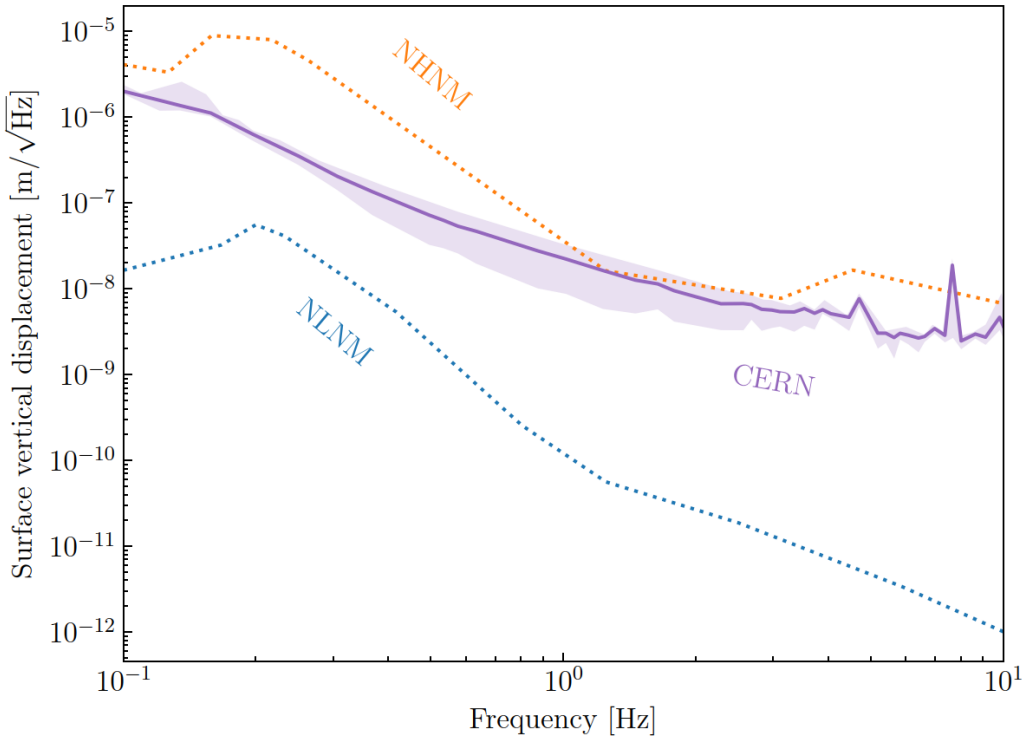
Measured at bottom of PX46



RMS power spectral density (time block 64s, averaged over the worst day)

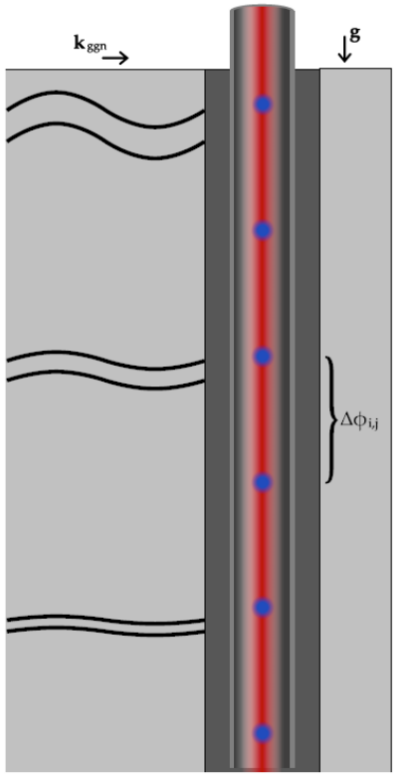
✓ Measured values within acceptable limits

Effect of local geology: gravity gradient noise

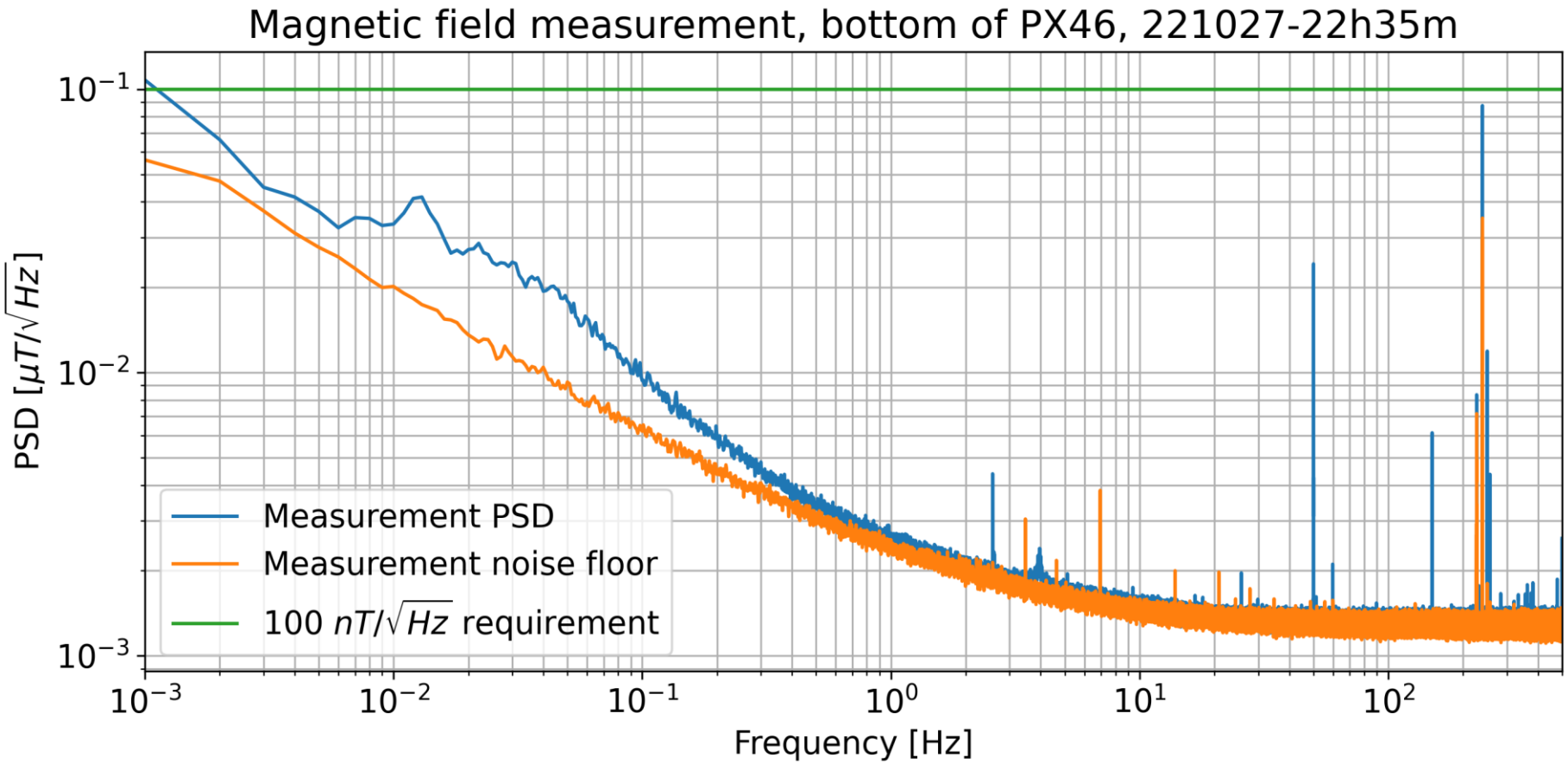


Seismic gravity gradient noise (GGN): seismic waves disturb local mass distribution, cause oscillating gravity gradient that is a noise background (especially important at lower frequencies)

Calculated using RMS spectral density of surface vertical displacement measurements, the shaded band corresponds to the difference between the minimum and maximum daily measurements. Compared with the New High and Low Noise Models (NHNM and NLNM: USGS seismic models for hypothetical quiet and noisy sites).



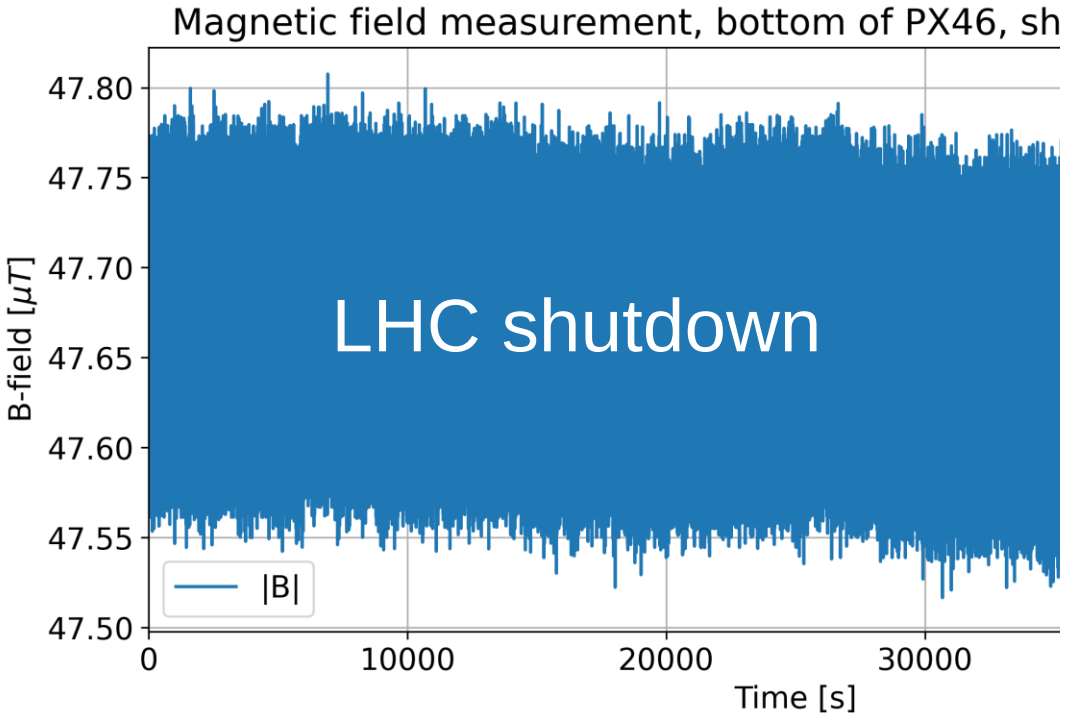
EM noise

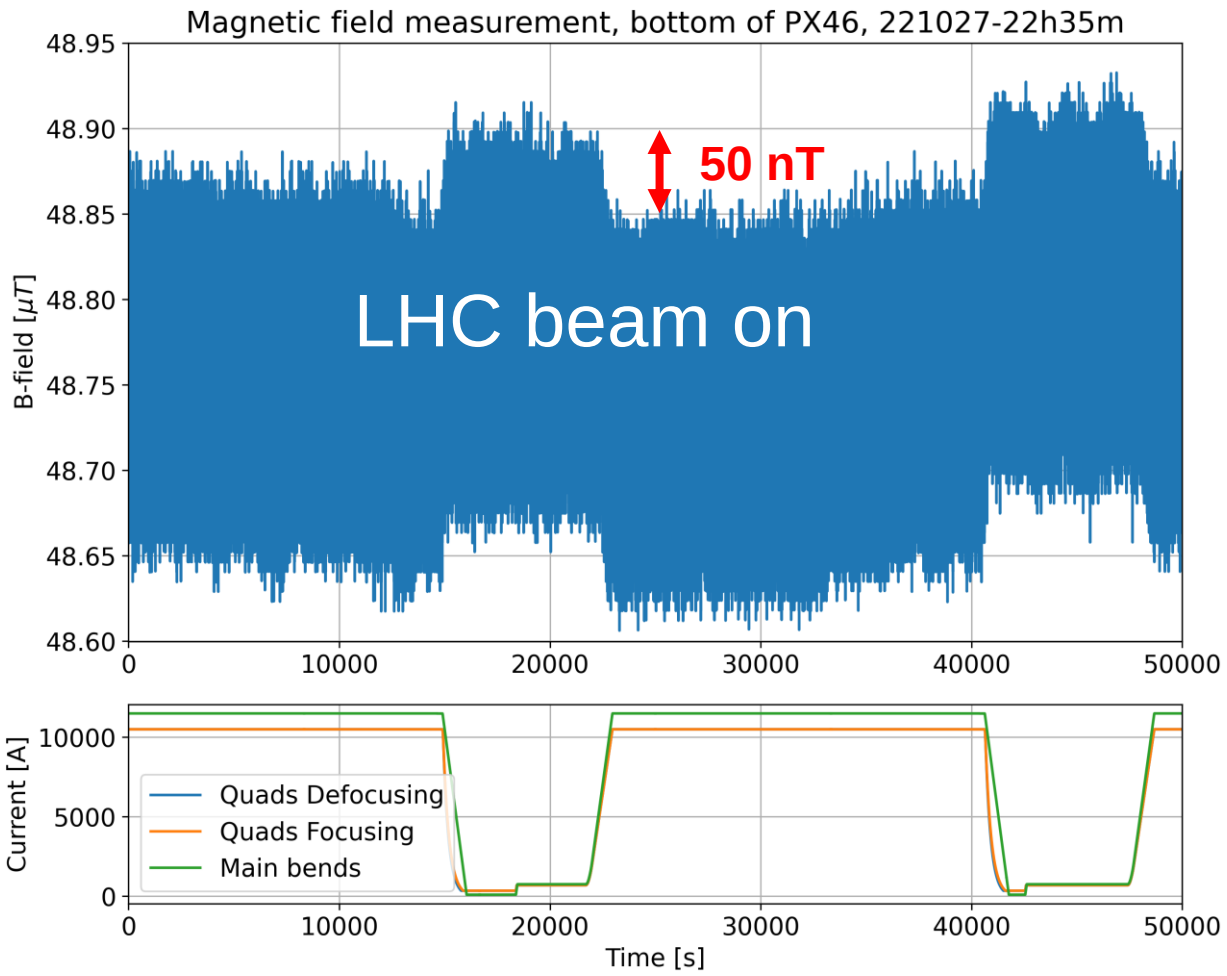


Power spectral density low-frequency magnetic field measurement

✓ Measured values within acceptable limits

Effect of LHC magnets

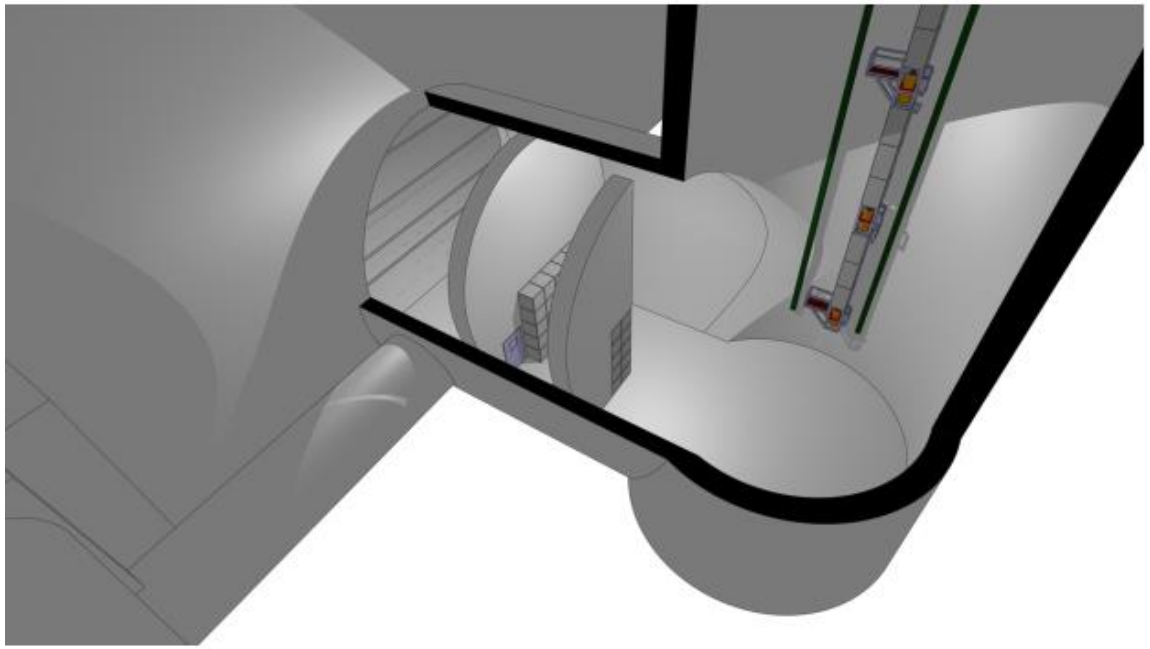




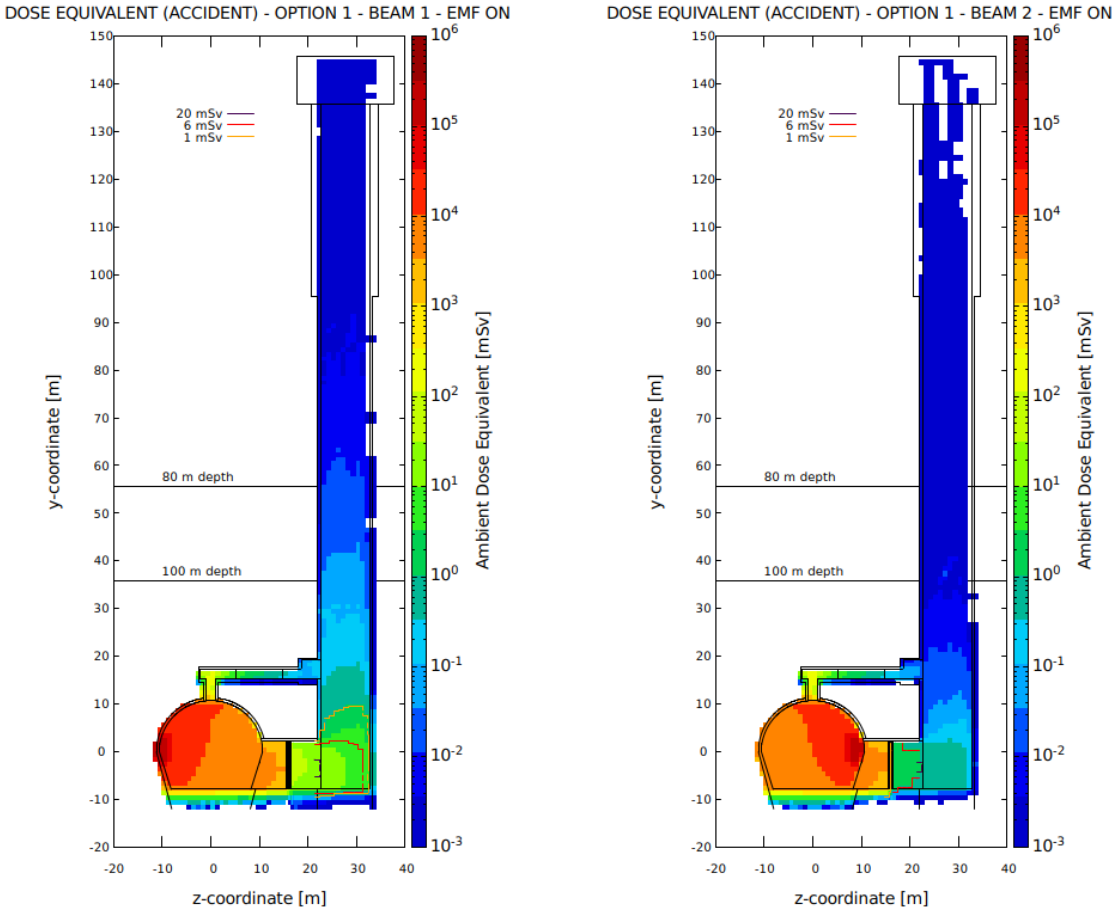
Drift or steps in magnetic field of ≳50nT are a potential concern for the side-arms and the detector.

➢ Measured values within acceptable limits

Radiation protection



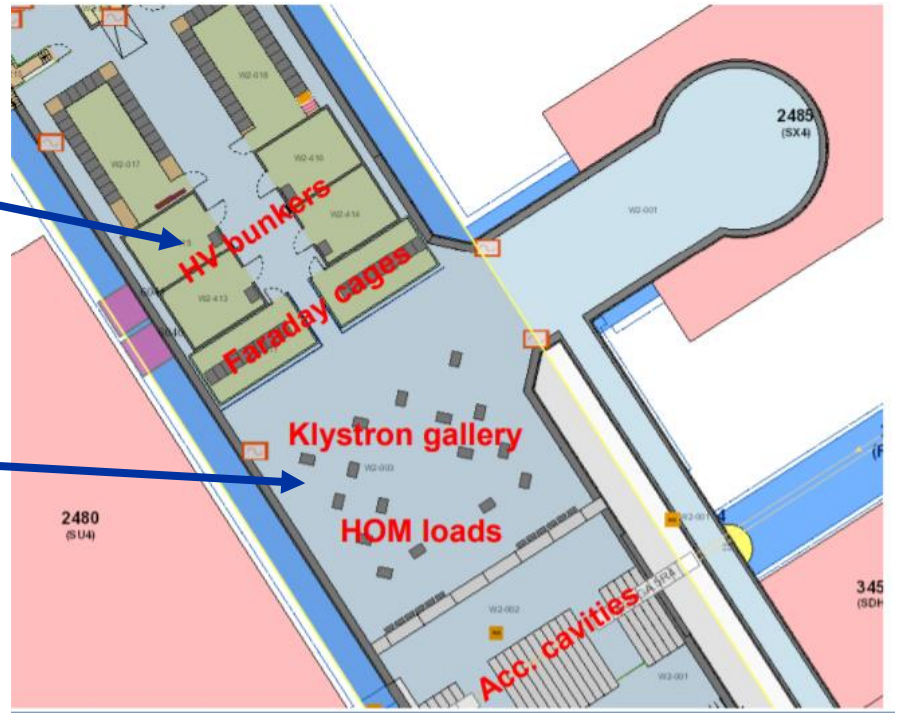
Beam loss in RUX45 with 0.8 m shielding in TX46

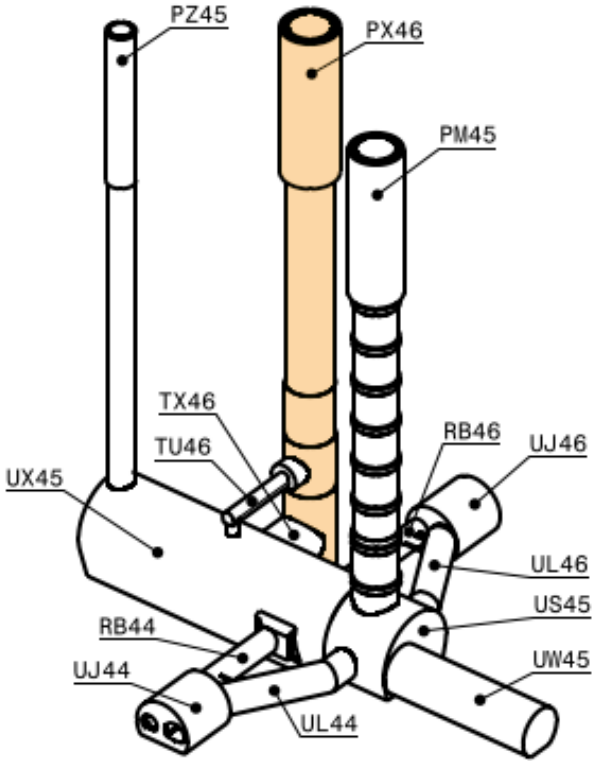


Area	Annual dose limit E [mSv] year	Assuming 20% working time: Ambient dose equivalent rate $\dot{H}^*(10)$ [μSv/h] permanent occupancy	low occupancy
Non-designated	1	0.5	2.5
Supervised	6	3	15

- No concern during normal LHC beam operations
- In case of beam loss, radiation levels remain within acceptable limits (supervised area)
- Thickness of shielding wall to be optimized

Fire safety

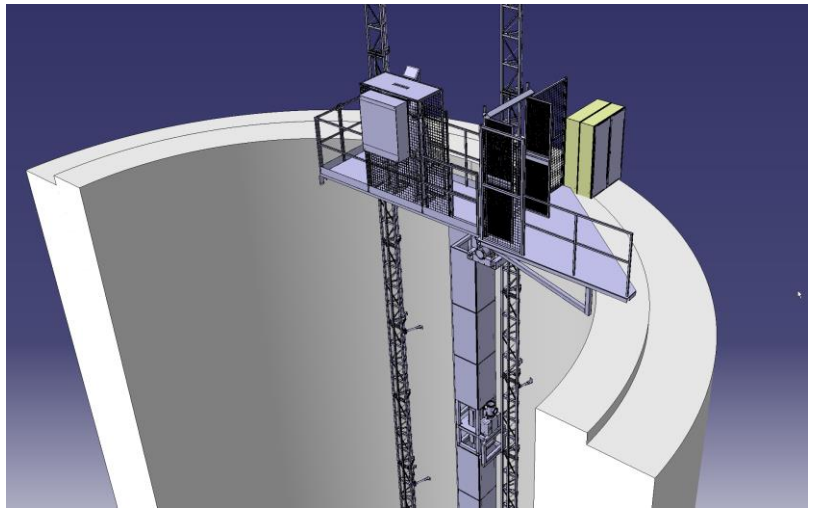


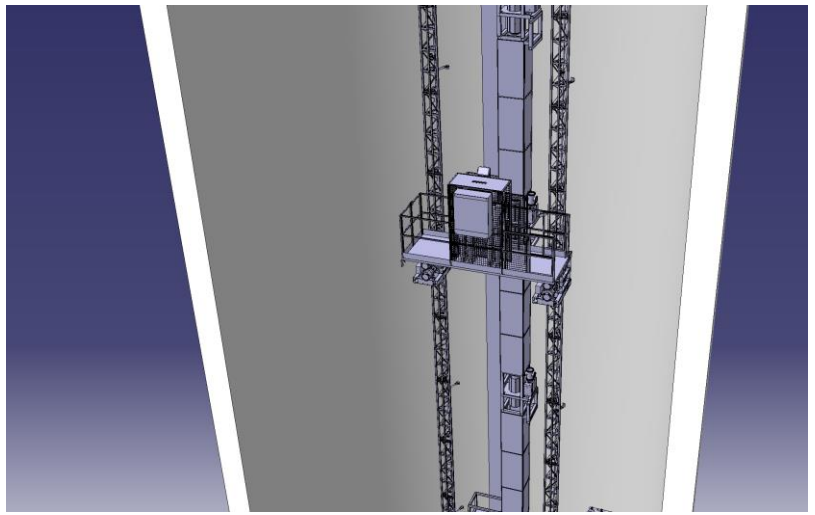


In case of a fire in UX45 (klystron gallery):

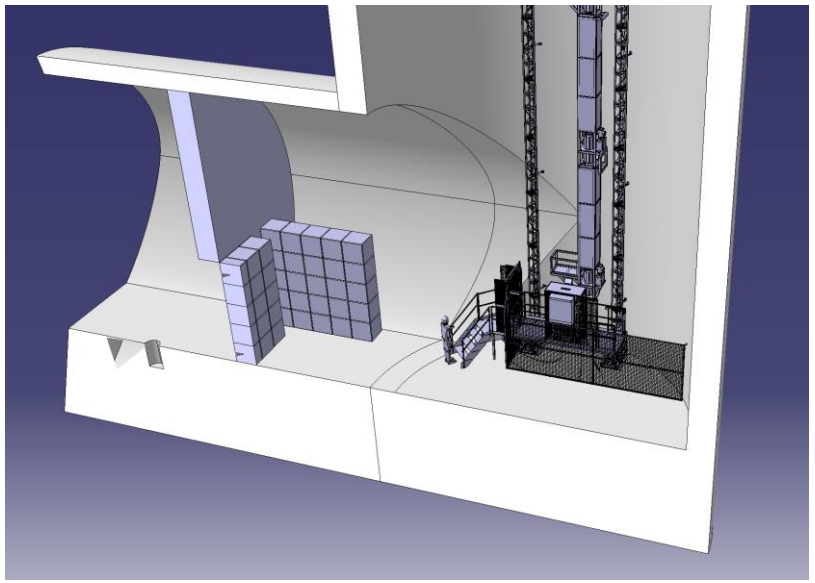
- Smoke detection -> Alarms -> Evacuation with elevator in ~2 min via top of PX46
- In case of systems failure: controlled descent in ~2 min to bottom of PX46 and exit via PM45 or PZ45

Elevator: from artist view to conceptual design

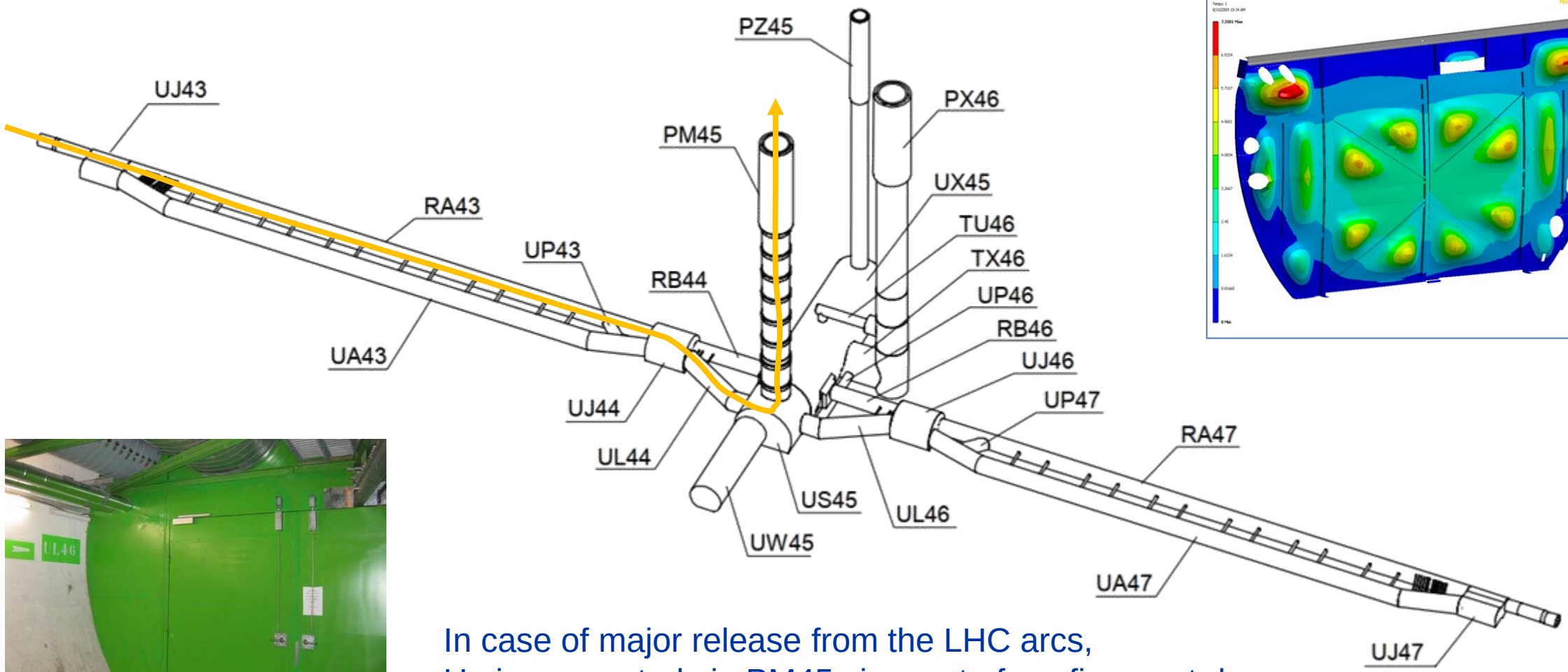




A design that complies with all requirements is technically feasible as demonstrated by an external consultant



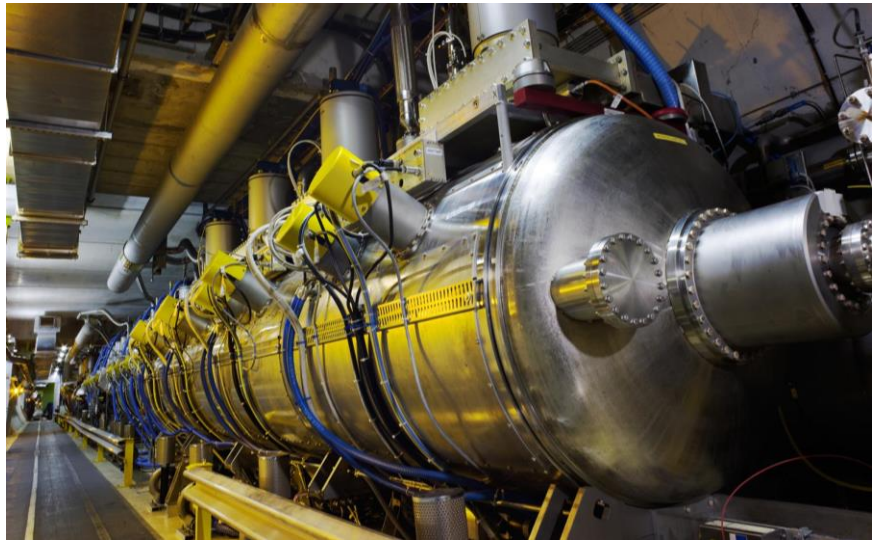
Helium release safety: LHC arcs

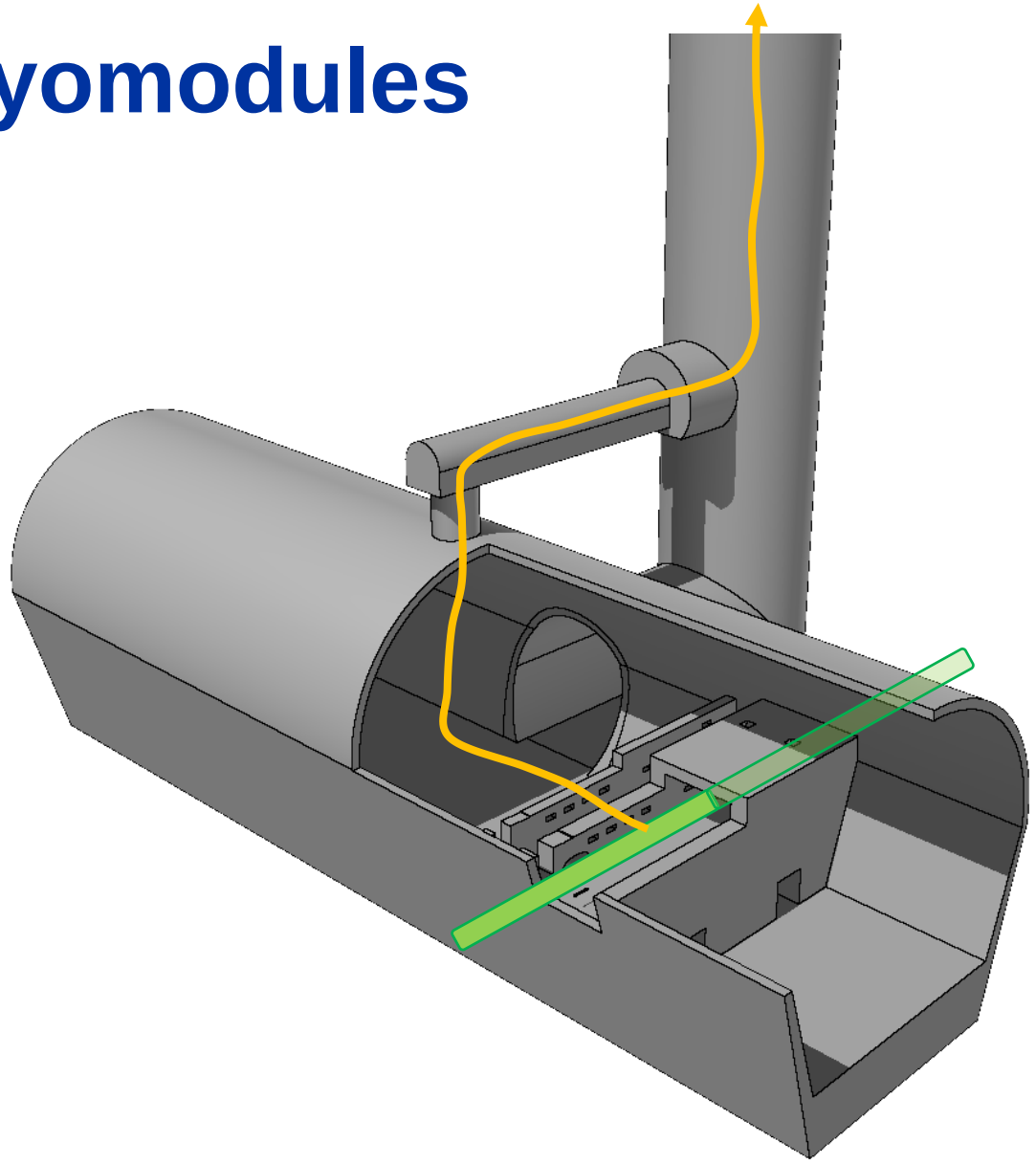


In case of major release from the LHC arcs,
He is evacuated via PM45 via a set of confinement doors

- No hazard in PX46 from He release in the LHC arcs

Helium release safety: RF cryomodules





- RF cryomodules contain 320 x 4 liters of liquid He; in case of release it is evacuated via PX46
- Flow restrained by the small openings (RF waveguides)
- 970 m^3 of gas compared to 18000 m^3 of the cavern (<~ 20%), oxygen deficiency hazard is limited

➢ Recently measured: no change in O_2 % in TU46 due to He release from RF cryomodules

Access control

End-of-zone door of the LHC Access Safety System (LASS), for emergency exit at the bottom of PX46
Red in color and including an emergency opening handle on both sides

Standard LHC Access Control System (LACS) door.
Probably a lightweight solution could be installed at the top platform of PX46, since access to the AI will NOT be an access to the LHC.
Availability and use of oxygen-generating self-rescue masks to be assessed

Technical requirements

Requirement	Laser Lab	Interferometry region	Side-arm (per side-arm)
Volume	Floor area $> 50\,\mathrm{m}^2$	$1\,\mathrm{m}^2$ cross-sectional area	$1\,\mathrm{m} \times 1\,\mathrm{m} \times 2\,\mathrm{m}$
Mains power	$\sim 35\,\mathrm{kW}$ (three- and single-phase outlets)	$\mathcal{O}(100\,\mathrm{W})$ diagnostic and monitoring electronics	$\mathcal{O}(10\,\mathrm{kW})$
Control cables	Ethernet, fibre, coaxial	Magnetic coils, diagnostic and monitoring electronics	optical fibres, coaxial, high-power steel-clad fibers
Temperature stability	$22\,^\circ\mathrm{C}$ w/ $\pm\,1\,^\circ\mathrm{C}$ pk-pk	$< 1\,^\circ\mathrm{C}\,\mathrm{h}^{-1}$	Temperature controlled, NEMA rated enclosure, $< 0.5\,^\circ\mathrm{C}$ pk-pk
Water cooling	$30\,\mathrm{kW}$ cooling capacity	n/a	$5\,\mathrm{kW}$ cooling capacity, $< \pm 1\,^\circ\mathrm{C}$ stability
Laser safety	Engineering (enclosures, interlocks); admin (training); PPE (glasses)	Already safe (enclosed)	Engineering (enclosures); admin (training); PPE (glasses)
Gases	Helium, compressed air, Argon	n/a	Helium for commissioning
Cryogenics	n/a	n/a	n/a
Ventilation	Air-handling unit capable of temp. spec.	Air-flow to maintain temp. spec.	Air-flow to move $5\,\mathrm{kW}$ of heat
Access	Year-round (> 12 hrs/day)	Access for maintenance (more access during calibration and commissioning)	Year-round ~ 12 hrs/day (more R& D for fully autonomous atom sources)
Smoke detector	Yes	Yes	Yes
Oxygen depletion monitor	Yes	During maintenance	n/a
Hoisting equipment	n/a	Modular sections $< 907\,\mathrm{kg}$	n/a

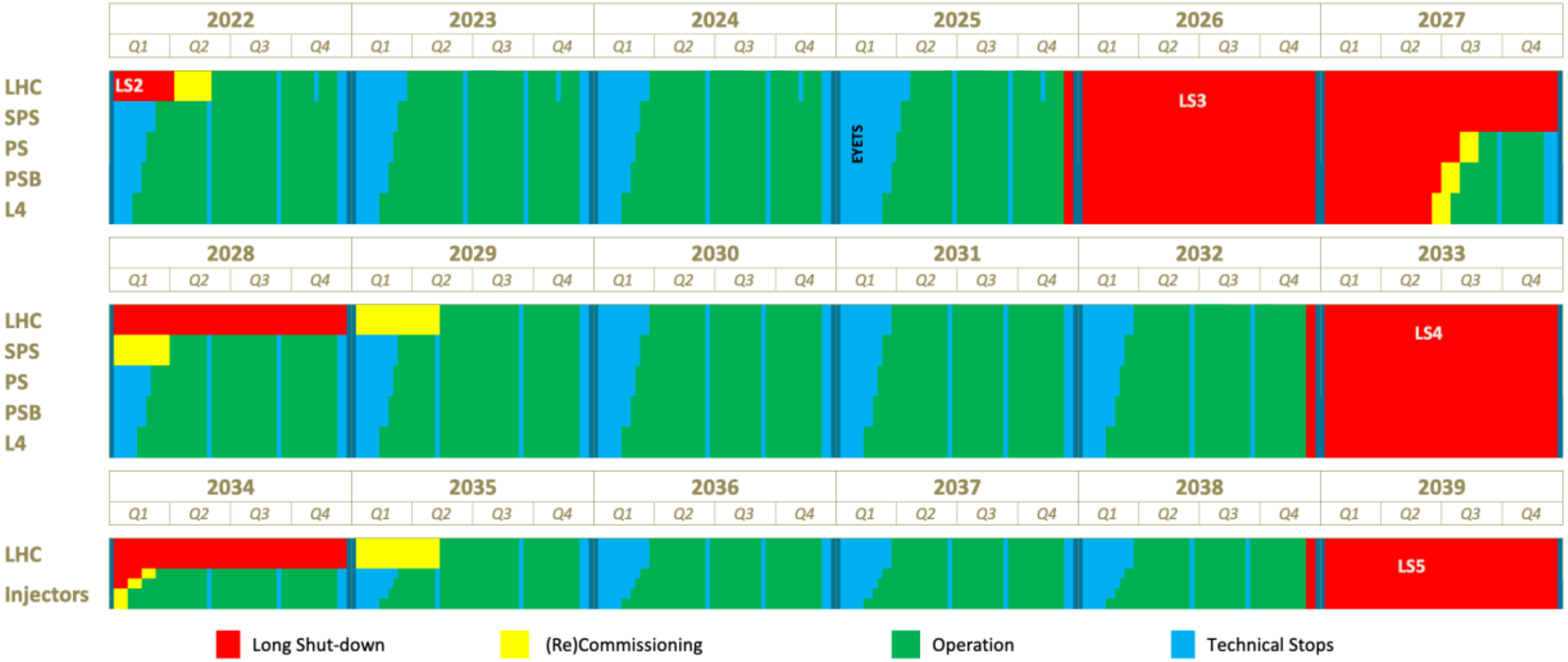
Conclusions and perspectives

- **No showstoppers identified for installing an AI at LHC Point 4**
  - Environmental noise measurements comply with requirements of an AI
  - Mitigation measures related to LHC environment identified (RP, helium, etc.)
  - HVAC, electricity and other relevant services are available
- **Expected ~1.5 MCHF cost for making the site infrastructure available for an AI**

CERN can propose PX46 at LHC point 4 as a candidate site for a vertical AI

- **Next steps**
  - Detailed technical design
  - Creation of an experimental collaboration aimed at constructing and running the AI
- **Target installation of shielding wall, elevator and access control: LS3 or LS4**

CERN accelerator complex master schedule

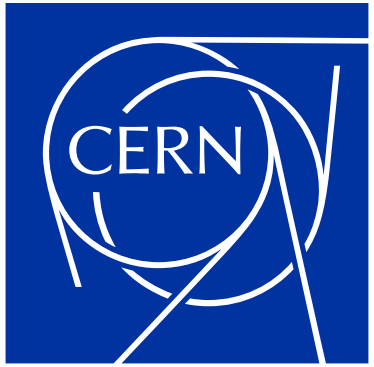


Acknowledgements

CERN-PBC Report-2023-002

A Long-Baseline Atom Interferometer at CERN: Conceptual Feasibility Study

G. Arduini[1,], L. Badurina[2], K. Balazs[1], C. Baynham[3], O. Buchmueller[3,4,*], M. Buzio[1], S. Calatroni[1,*], J.-P. Corso[1], J. Ellis[1,2,*], Ch. Gaignant[1], M. Guinchard[1], T. Hakulinen[1], R. Hobson[3], A. Infantino[1], D. Lafarge[1], R. Langlois[1], C. Marcel[1], J. Mitchell[5], M. Parodi[1], M. Pentella[1], D. Valuch[1], H. Vincke[1]*



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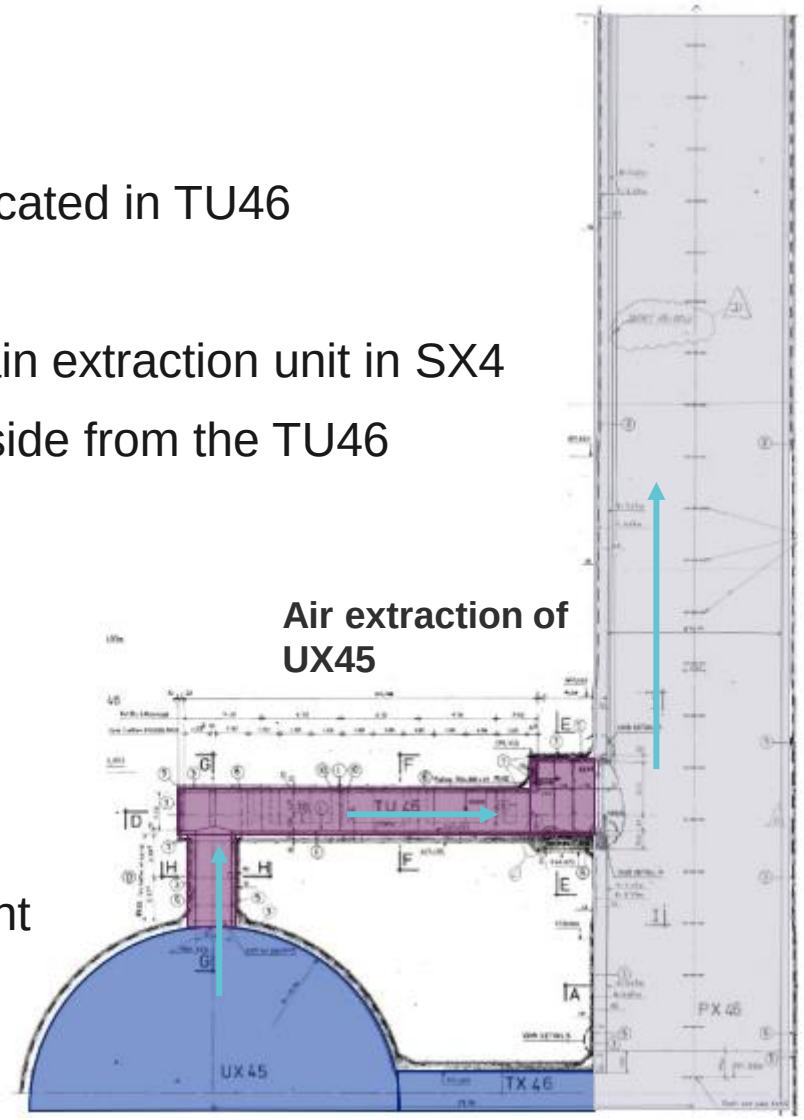
PX46 - Existing conditions: HVAC

Ventilation

- Air extraction from the UX45 is done at the top of the cavern by unit located in TU46
- Extracted air is then directly supplied in PX46 (no ducts in PX46)
- In surface, a duct is connected to the cap to collect extracted air to main extraction unit in SX4
- Existing CV platform at 24m from the bottom of the shaft, openable inside from the TU46
- All ventilation units are stopped if a fire is detected

Cooling

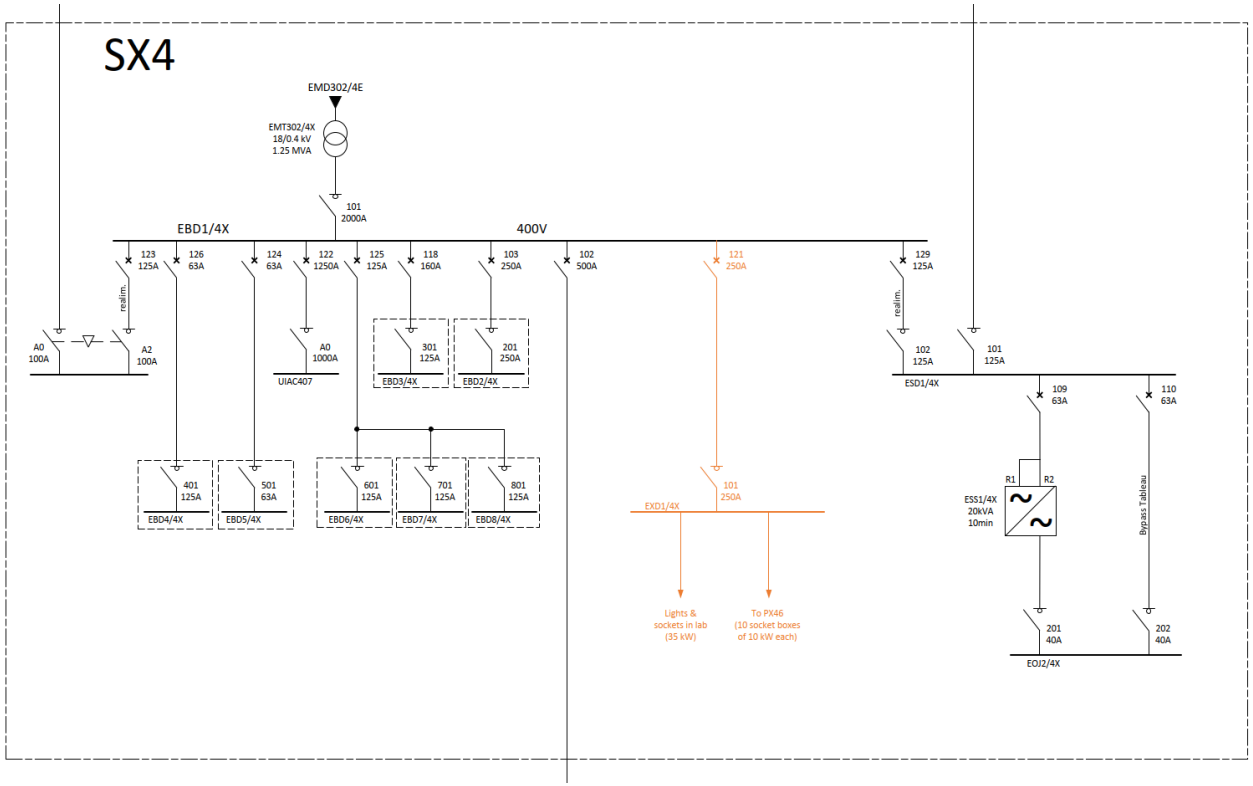
- Cooling system will be located on the surface and
- Water will be distributed to each side-arm
- Distribution piping will be installed along the full height of the experiment



Courtesy of R. Langlois

PX46 - Existing conditions: electricity

- **About 160 kW needed: interferometer + laser laboratory + elevator**
- **About 1.25 MVA available at the transformer in SX4 in front of a present consumption of 85 kVA**
- **As a consequence, no modifications of the electrical power distribution network are expected**



New preliminary single line diagram of SX4, with the new feeder of EBD1/4X, the new switchboard EXD1/4X and its feeders in orange