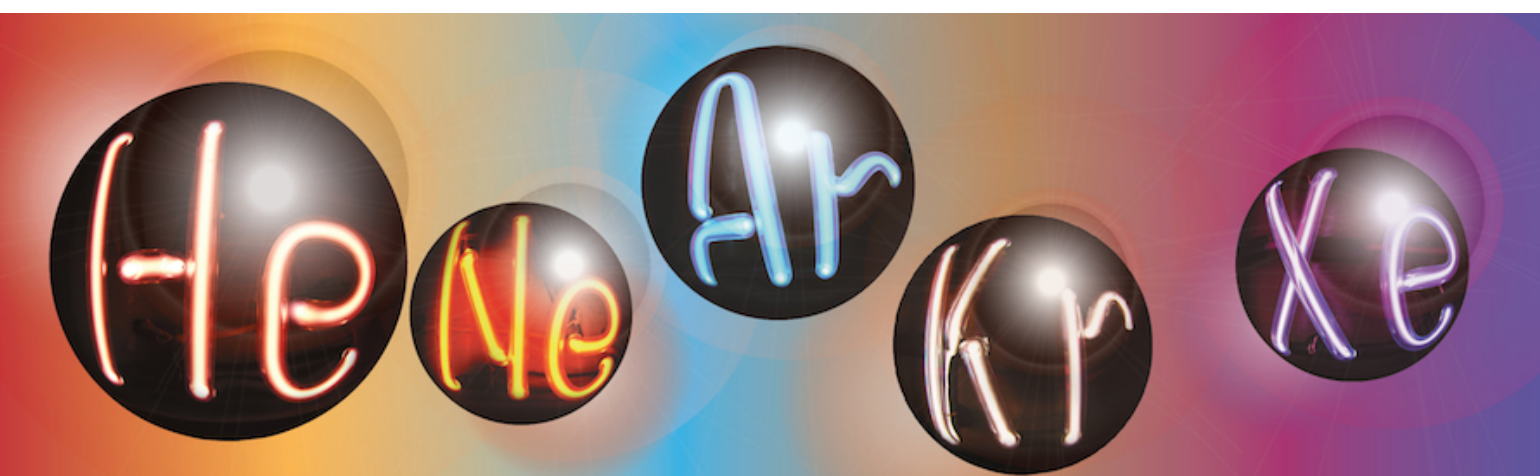


XENOSCOPE

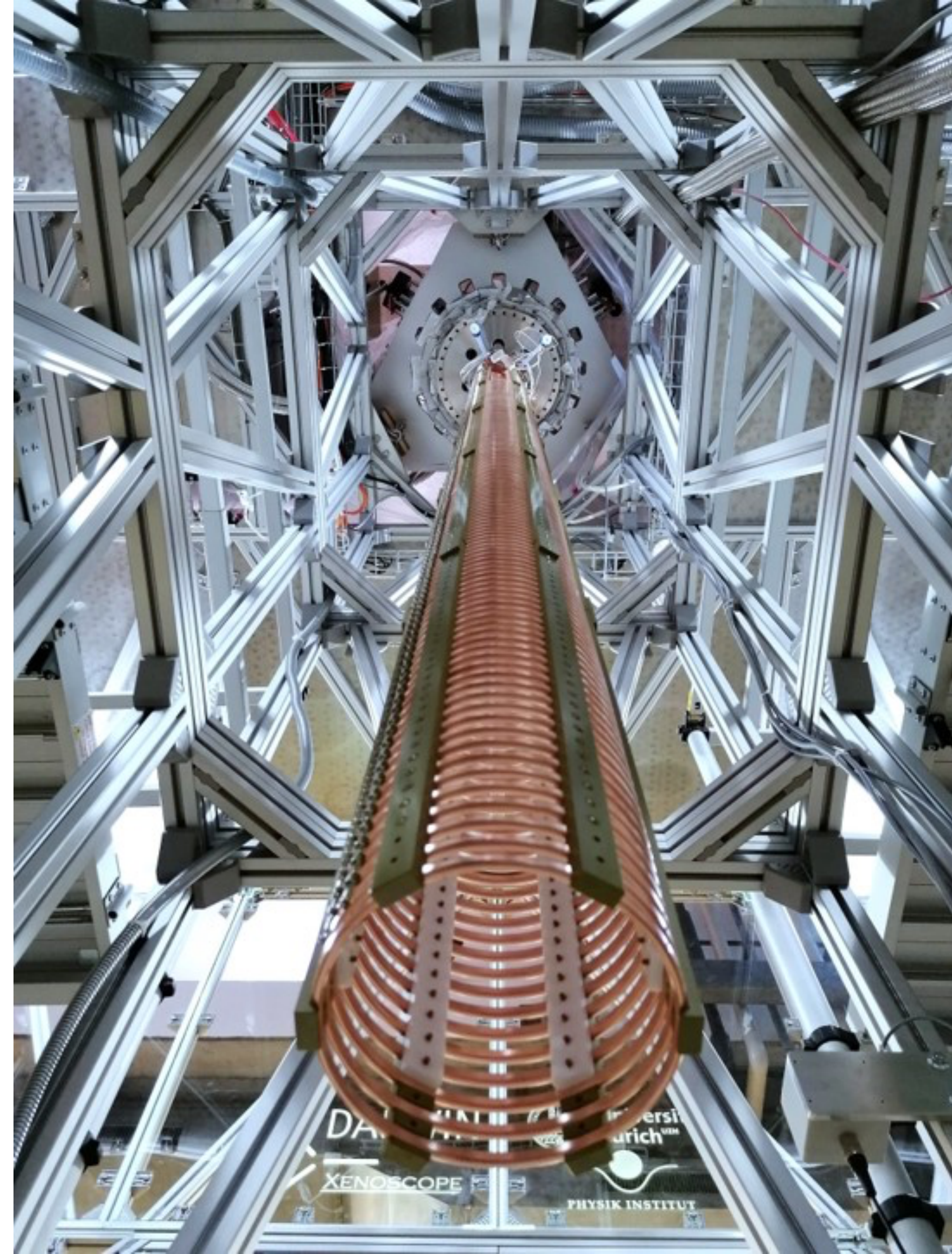
a vertical demonstrator
for the XLZD observatory

Chiara Capelli (University of Zurich)

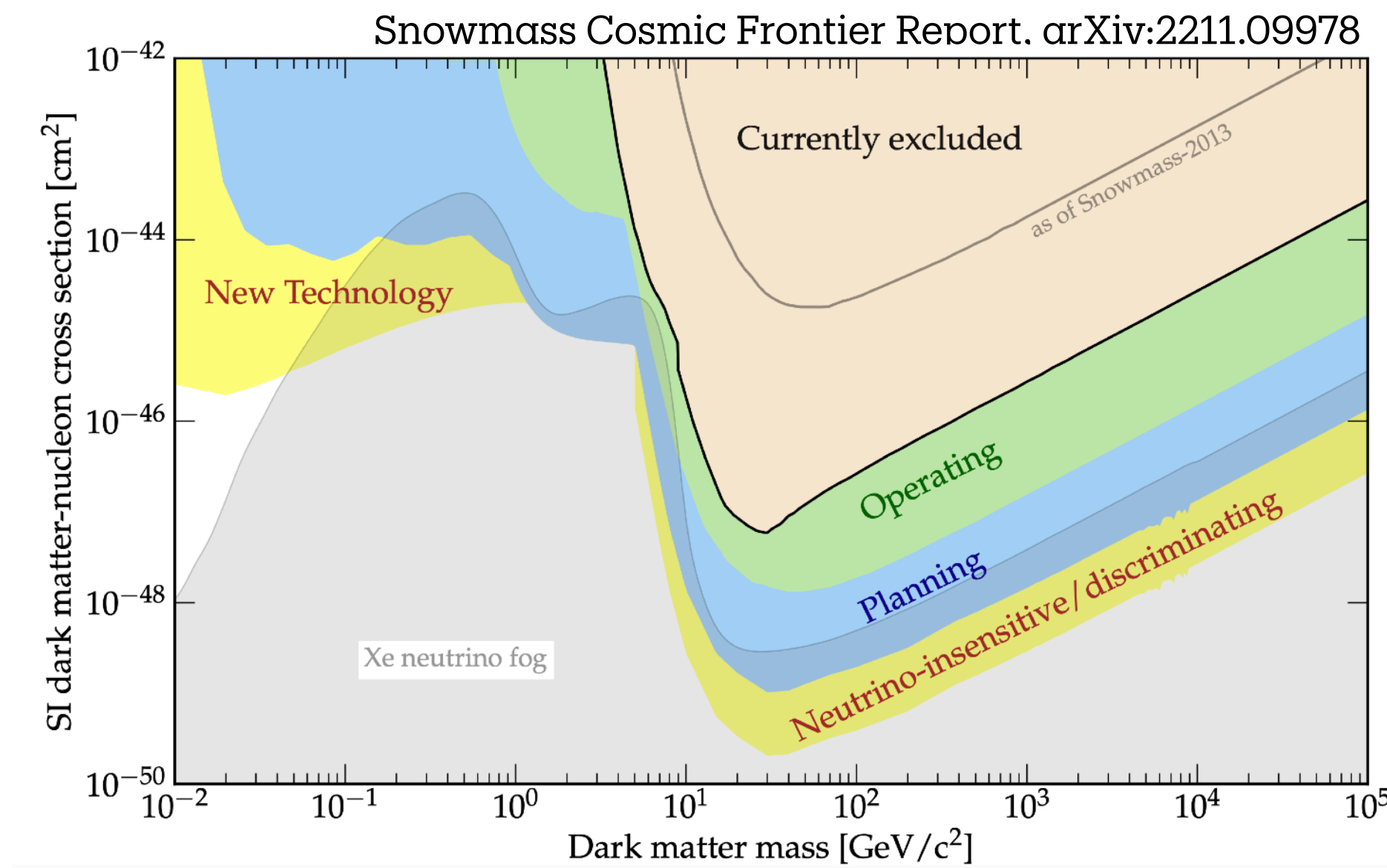
On behalf of the Xenoscope team



LIDINE conference
Hong Kong
October 21-24, 2025



The XLZD observatory



XLZD: XENON-LZ-DARWIN

- WIMP search down to the neutrino floor
- Neutrino Physics
- Multi-channel observatory

- Current experiments $\mathcal{O}(10 \text{ t})$ LXe and 1.5 m dimensions, 1:1 ratio
- Next generation to increase SI-WIMP sensitivity by one order of magnitude $\sim 10^{-48} \text{ cm}^2 \rightarrow \sim 10^{-49} \text{ cm}^2$

Dark Matter

WIMPs
Sub-GeV
Inelastic
Axion-like particles
Planck mass
Dark photons

arXiv: 2410.17137
J.Phys.G 52 (2025) 4, 045102

Neutrino nature

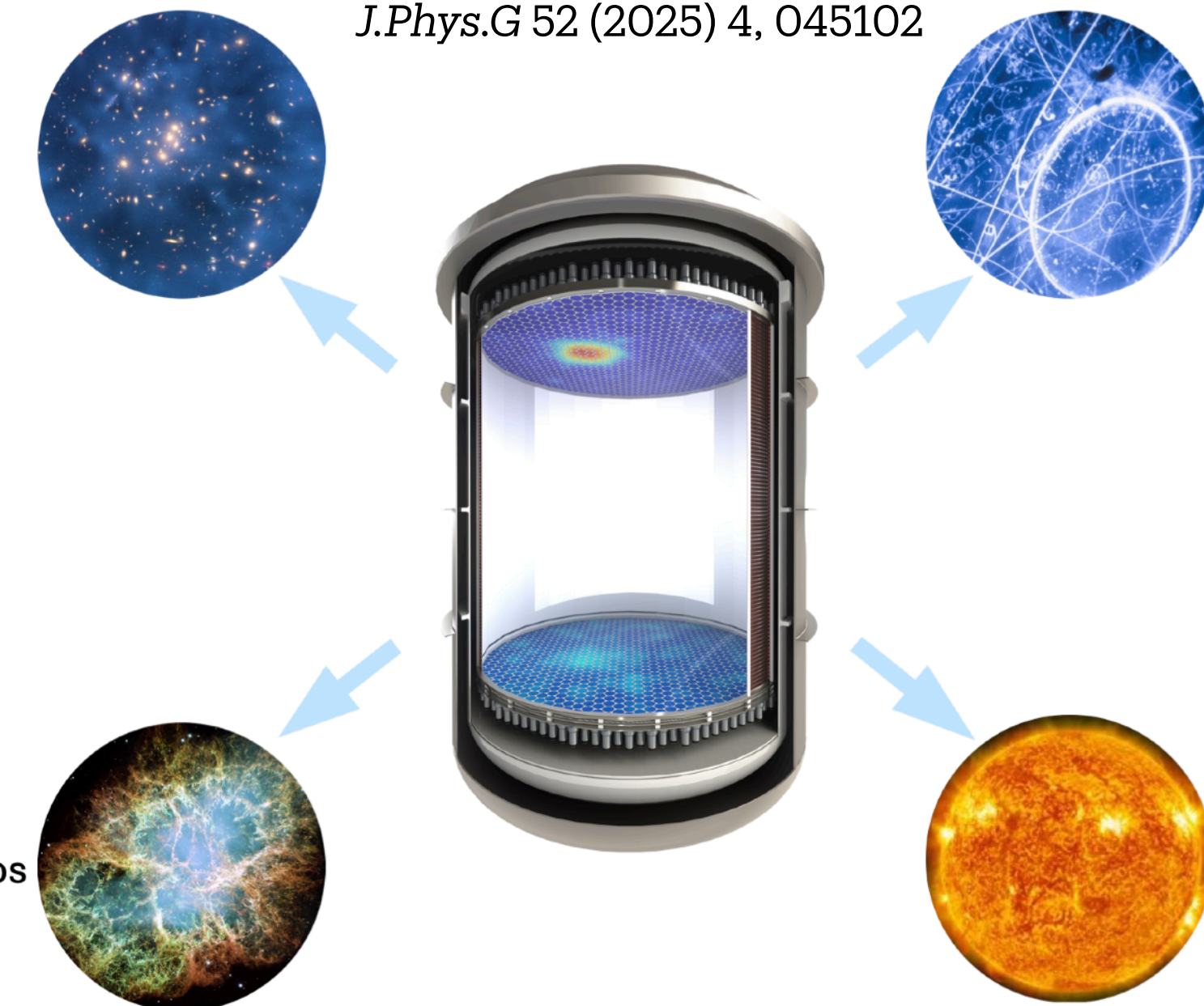
Neutrinoless double beta decay
Neutrino magnetic moment
Double electron capture

Supernovae

Early alert
Supernova neutrinos
Multi-messenger astrophysics

Sun

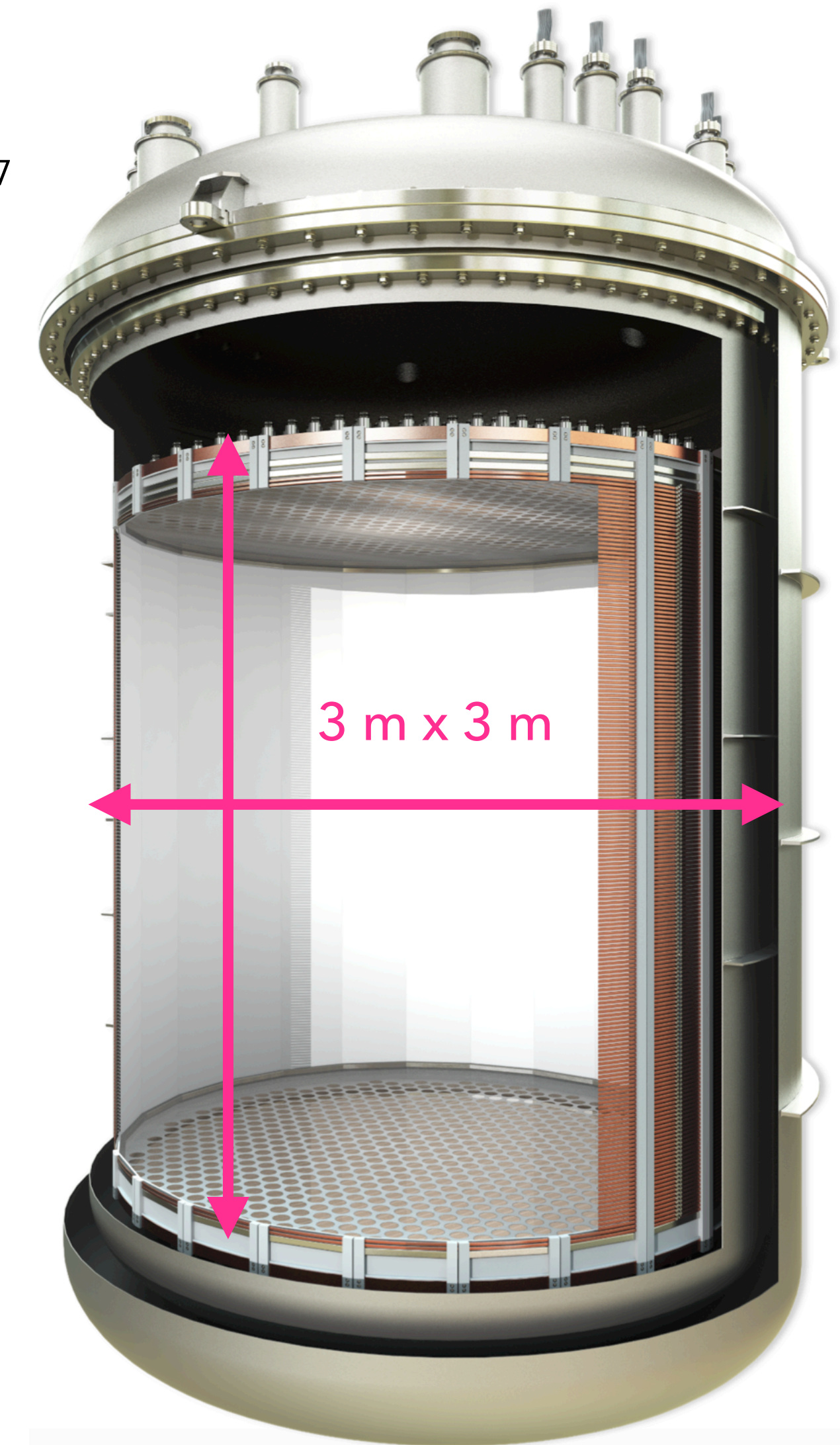
pp neutrinos
Solar metallicity
 ${}^7\text{Be}$, ${}^8\text{B}$, hep



The XLZD TPC

- ~3 m diameter x ~3 m height
- 78 t/60 t LXe mass/active target → up to 80 t active mass depending on xenon supply market
- Two arrays of photosensors → baseline design with ~2400 3" PMTs
- Double-walled low-background Ti cryostat + LXe “skin” around the TPC
- Drift field of 240-290 V/cm and extraction field of 6-8 kV/cm for optimal discrimination between ER and NR
- Passive and active muon and neutron shielding
- Gadolinium loaded water tank to enhance neutron capture cross-section

arXiv: 2410.17137



Challenges and R&D

- Scaling up infrastructures
- High-voltage delivery:
 - Electrodes and HV feedthrough design
 - Electric field homogeneity
- Liquid xenon purity
- Background mitigation
- Light collection efficiency
- Photosensors performance



JINST 16, P08052 (2021)
Eur. Phys. J. C 83, 717 (2023)
JINST 20, P04013 (2025)



JINST 19 (2024) P05018

The Xenoscope facility

- Vertical demonstrator with goals:

- Vertical scaling up
- Electron drift over 2.6 m
- Electron cloud diffusion
- Xenon optical properties

- ~360 kg of xenon mass

- Phase 1: purity monitor → completed

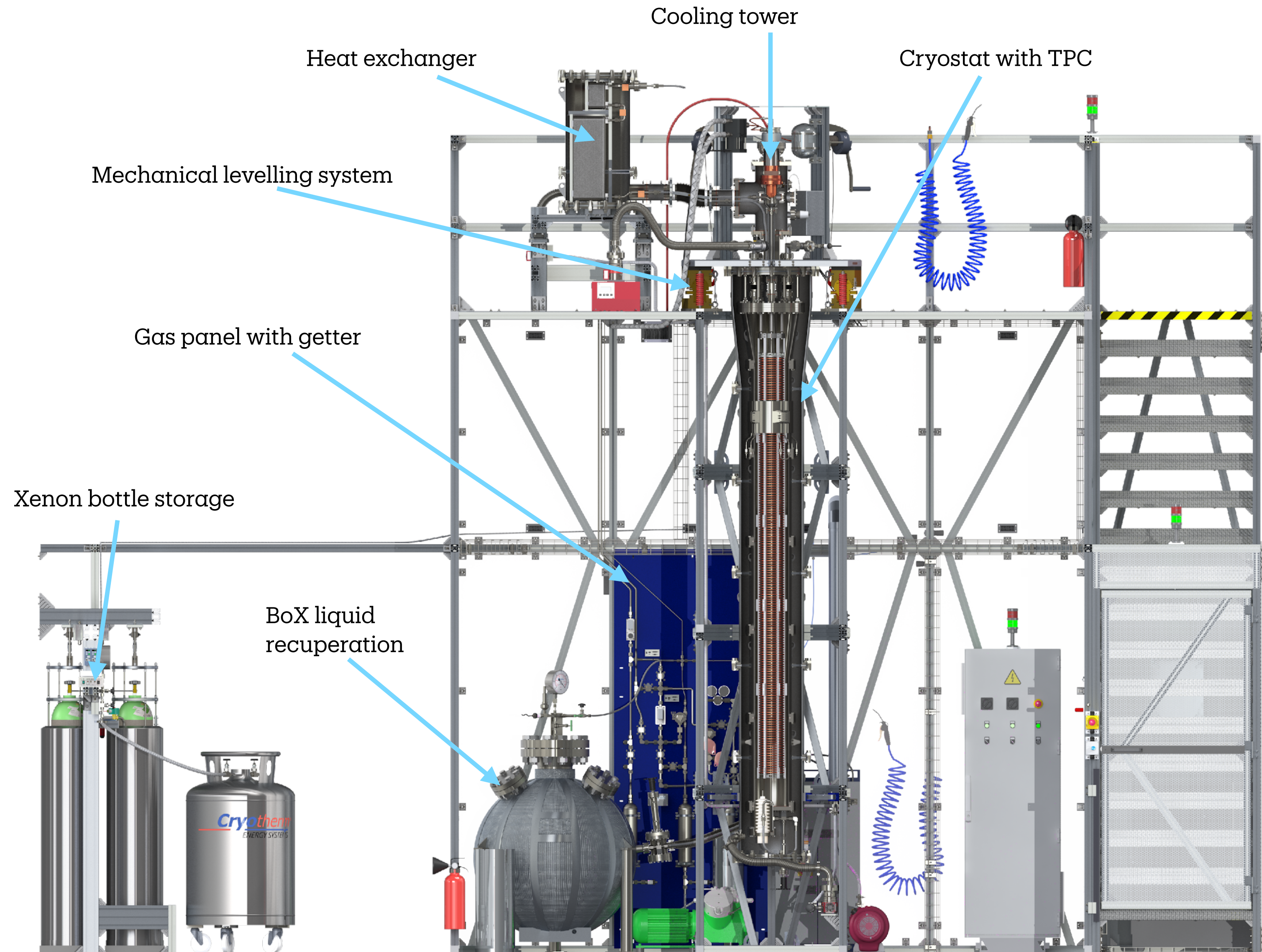
- Phase 2: modular TPC

- Commissioned
- Science runs and upgrades

JINST 16, P08052 (2021)

Eur. Phys. J. C 83, 717 (2023)

JINST 20, P04013 (2025)



The Xenoscope facility

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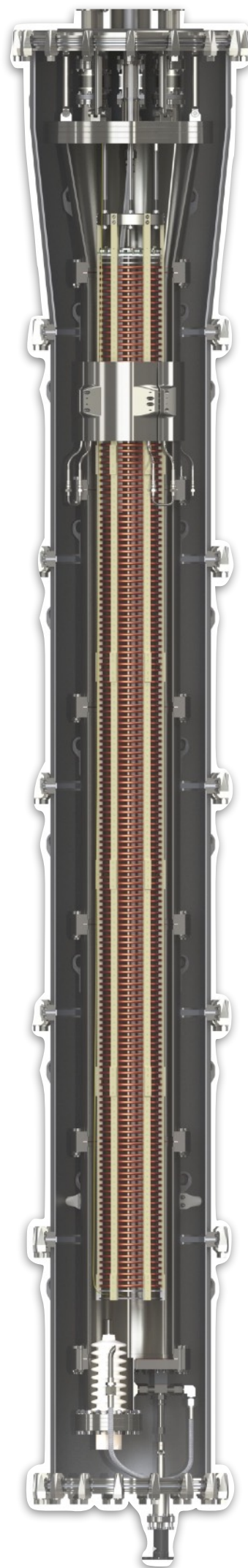
JINST 16, P08052 (2021)

Eur. Phys. J. C 83, 717 (2023)

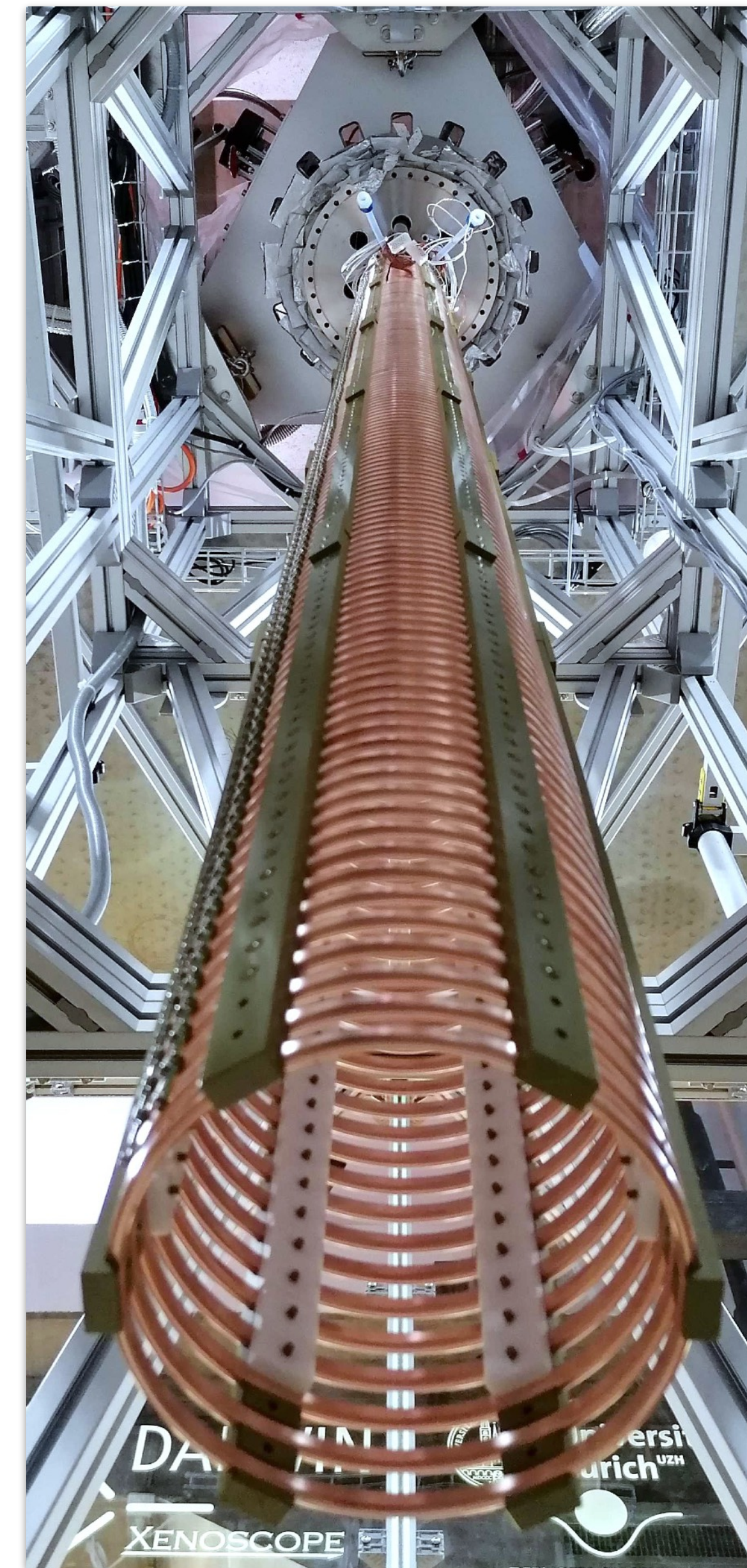
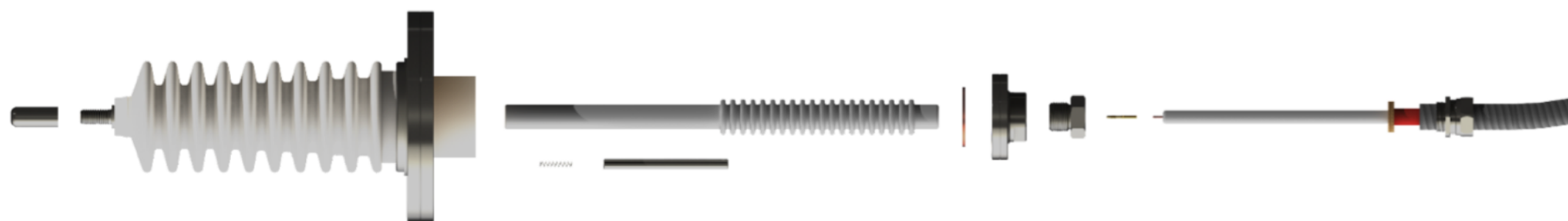
JINST 20, P04013 (2025)



Dual-phase TPC

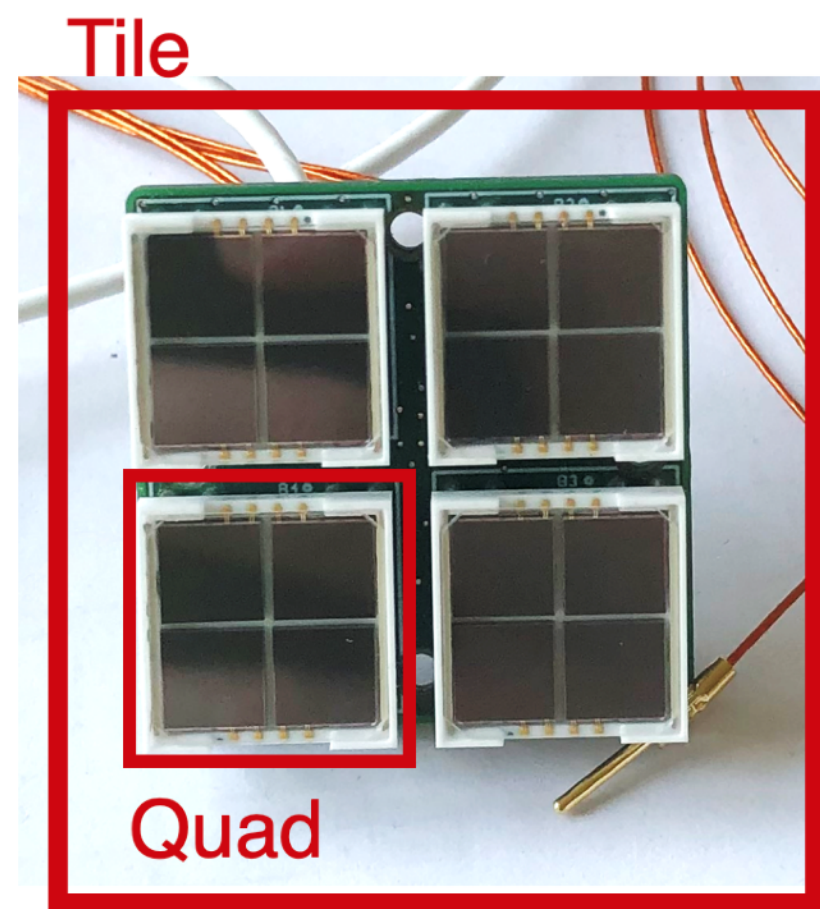
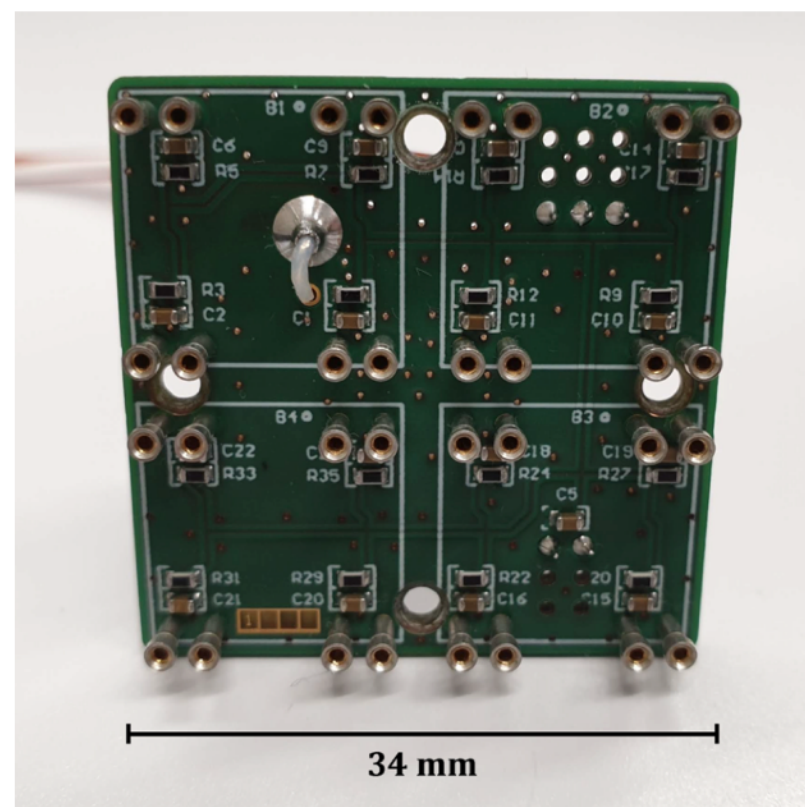
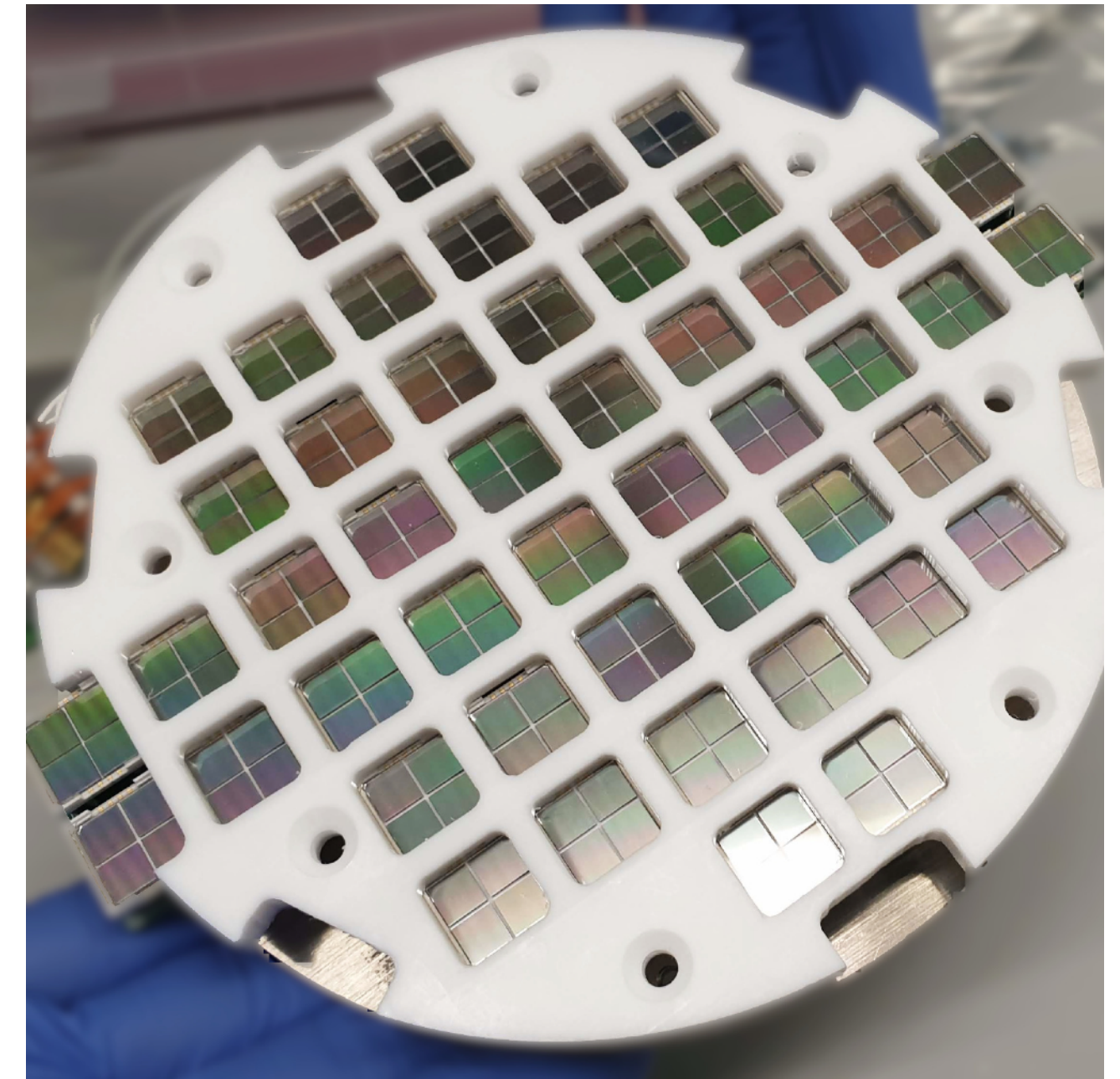


- 2.6 m tall TPC - 5 modules of 52 cm each
- Field cage with 173 OFHC copper rings $\varnothing 160$ mm
 - Two redundant resistor chains - 1 G Ω resistors
 - Six polyamide-imide (Torlon) pillars reinforced inside with PTFE
- Electrons extracted from photocathode at the bottom
- 3 electrodes for drift and extraction fields
 - Custom-made cathode HV delivery system rated up to 100 kV
- SiPM array at the top to detect light
- Levelmeters + weir for liquid level control

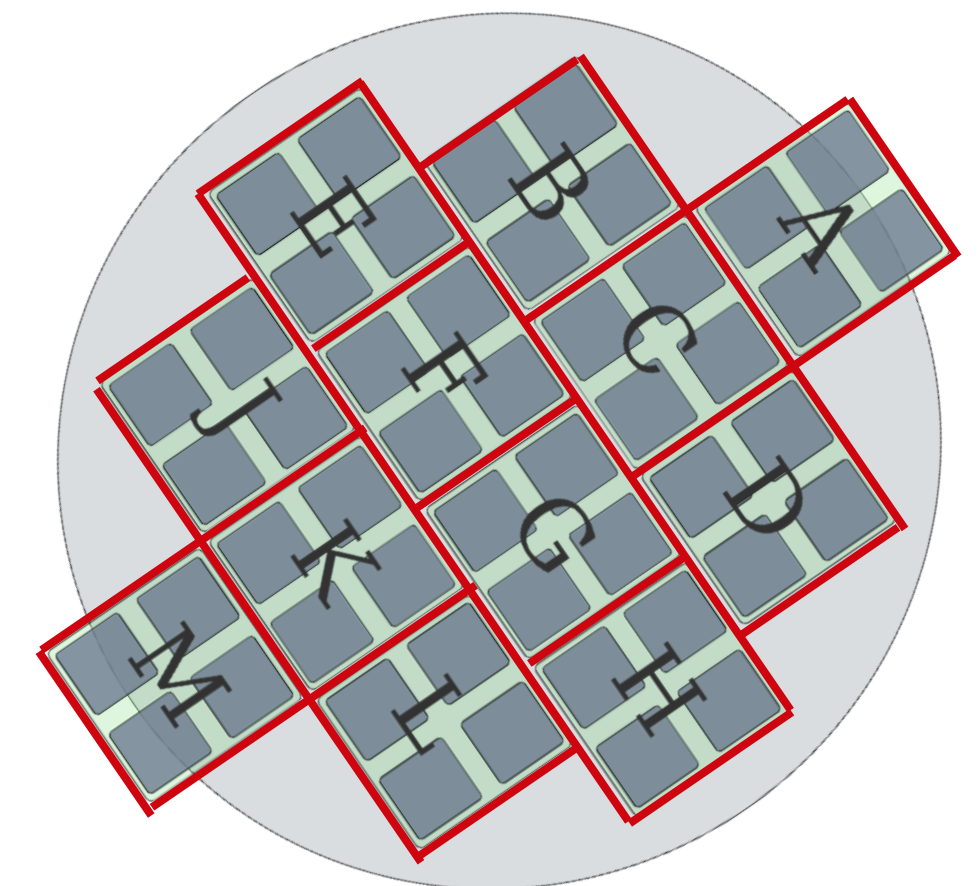


SiPM array

- Array with 48 12x12 mm² MPPCs (192 6x6 mm² SiPMs)
 - VUV4 SiPMs from Hamamatsu Photonics (S13371-6050CQ-02)
 - 50- μ m pitch cells
 - Summed readout (parallel) with a x20 pre-amplifier circuit
 - Dimensions: $\varnothing$ 160 mm, with TPC active area of $\varnothing$ 150 mm



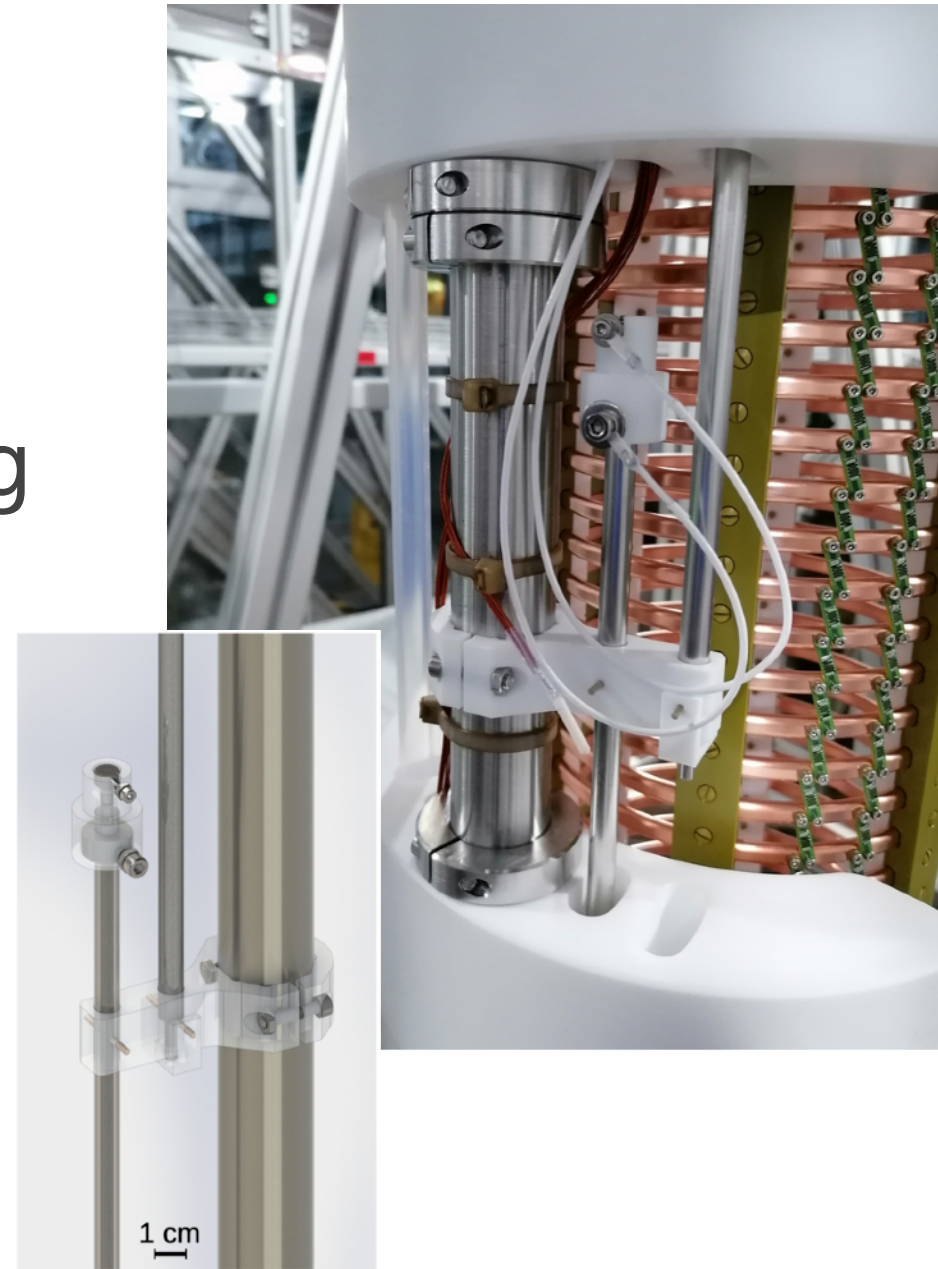
- $\sim 3 \times 10^6$ gain at 52 V_{bias}, 190K
- SPE resolution: $(4.38 \pm 0.44) \%$
- Dark count rate: ~ 3 Hz/mm²
- Cross talk probability: $\sim 15\%$



Liquid level control

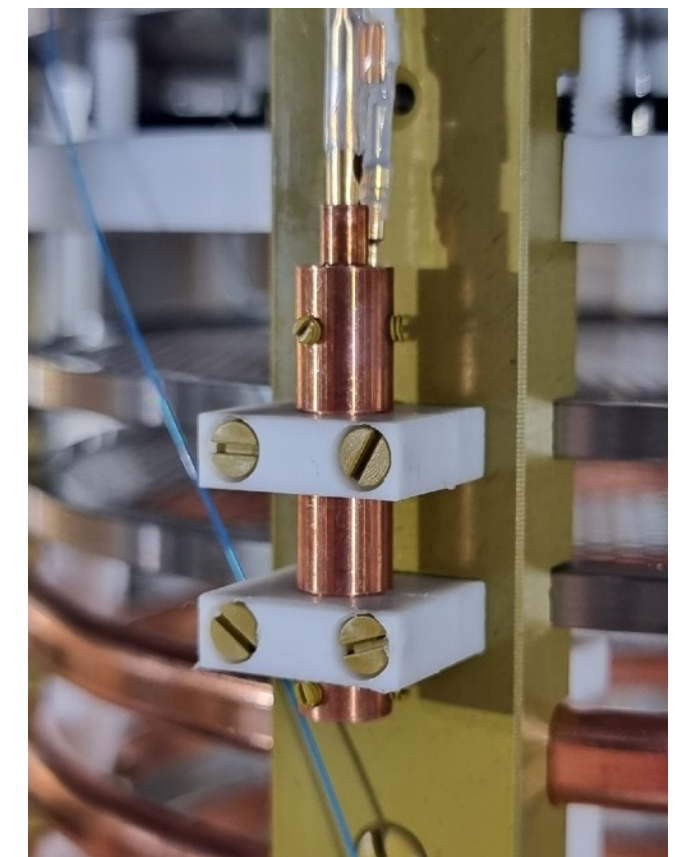
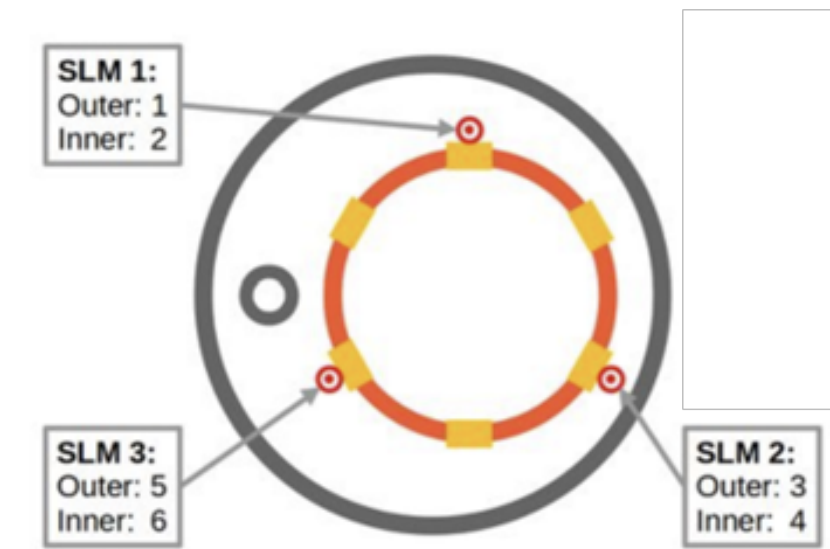
Long Levelmeters (LLM)

- Monitor liquid level during filling and recuperation
- Two 1.44 m capacitive levelmeters segments (2.8 m total length)



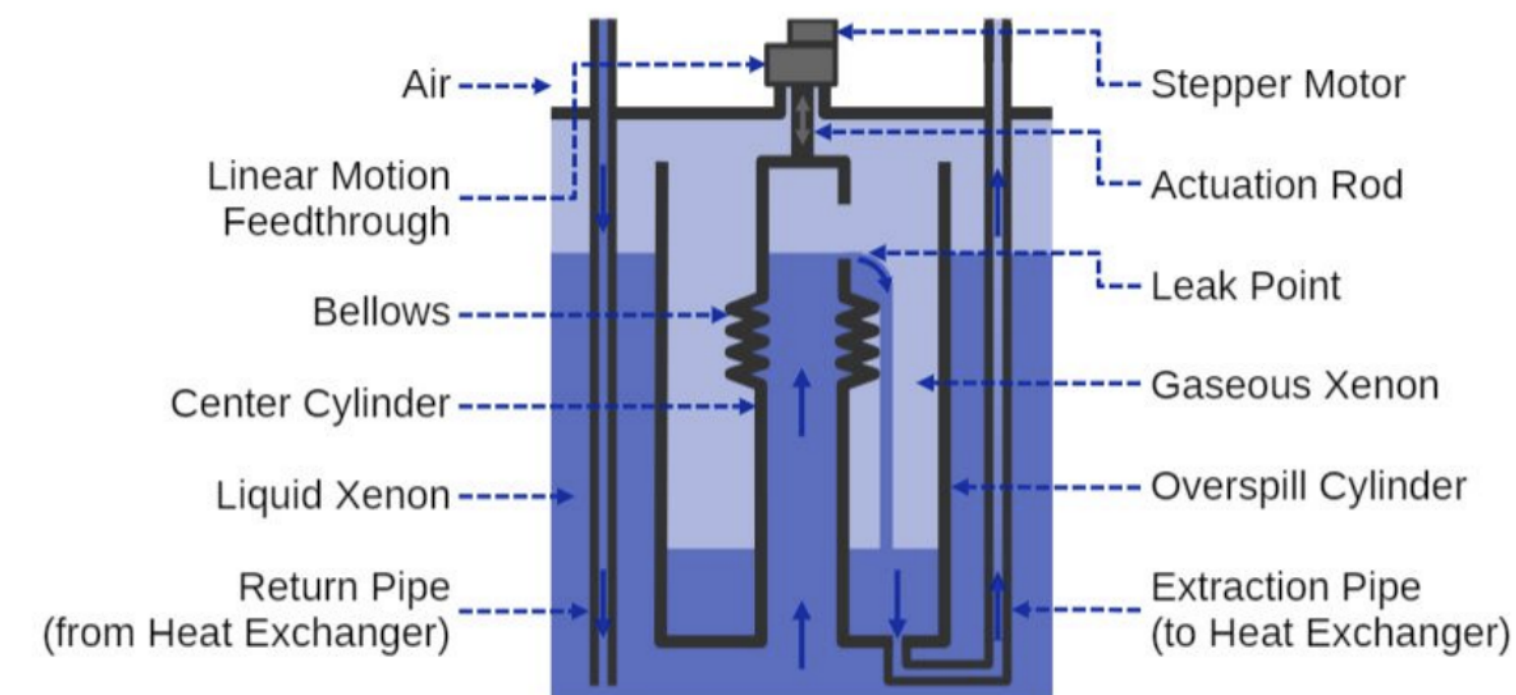
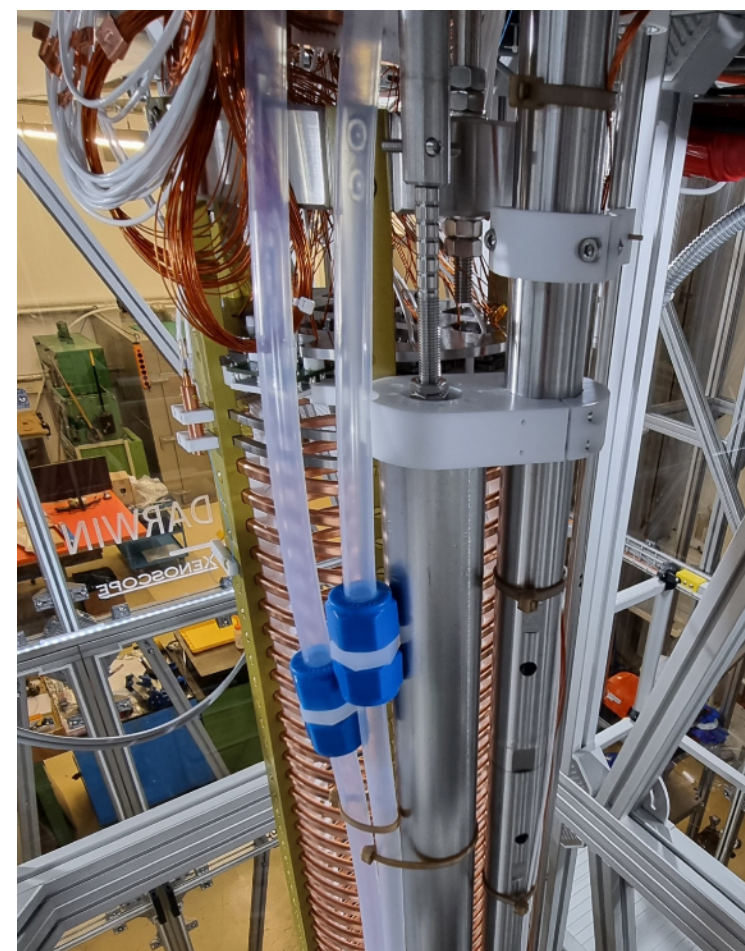
Short Levelmeters (SLM)

- Fine tuning monitor for liquid level and tilting of the TPC
- Three 3 cm capacitive levelmeters positioned around the top stack
- O(0.1)mm accuracy



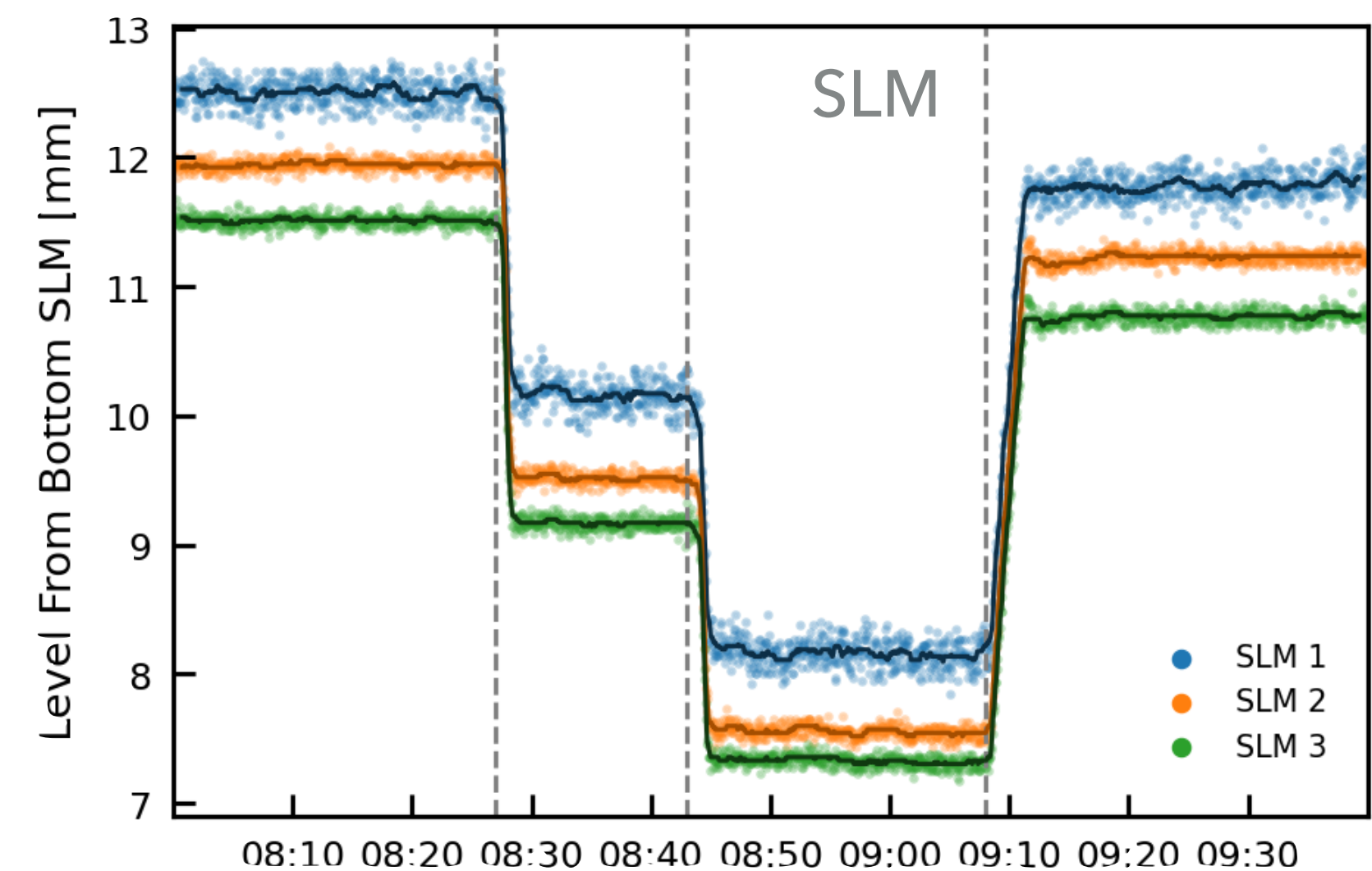
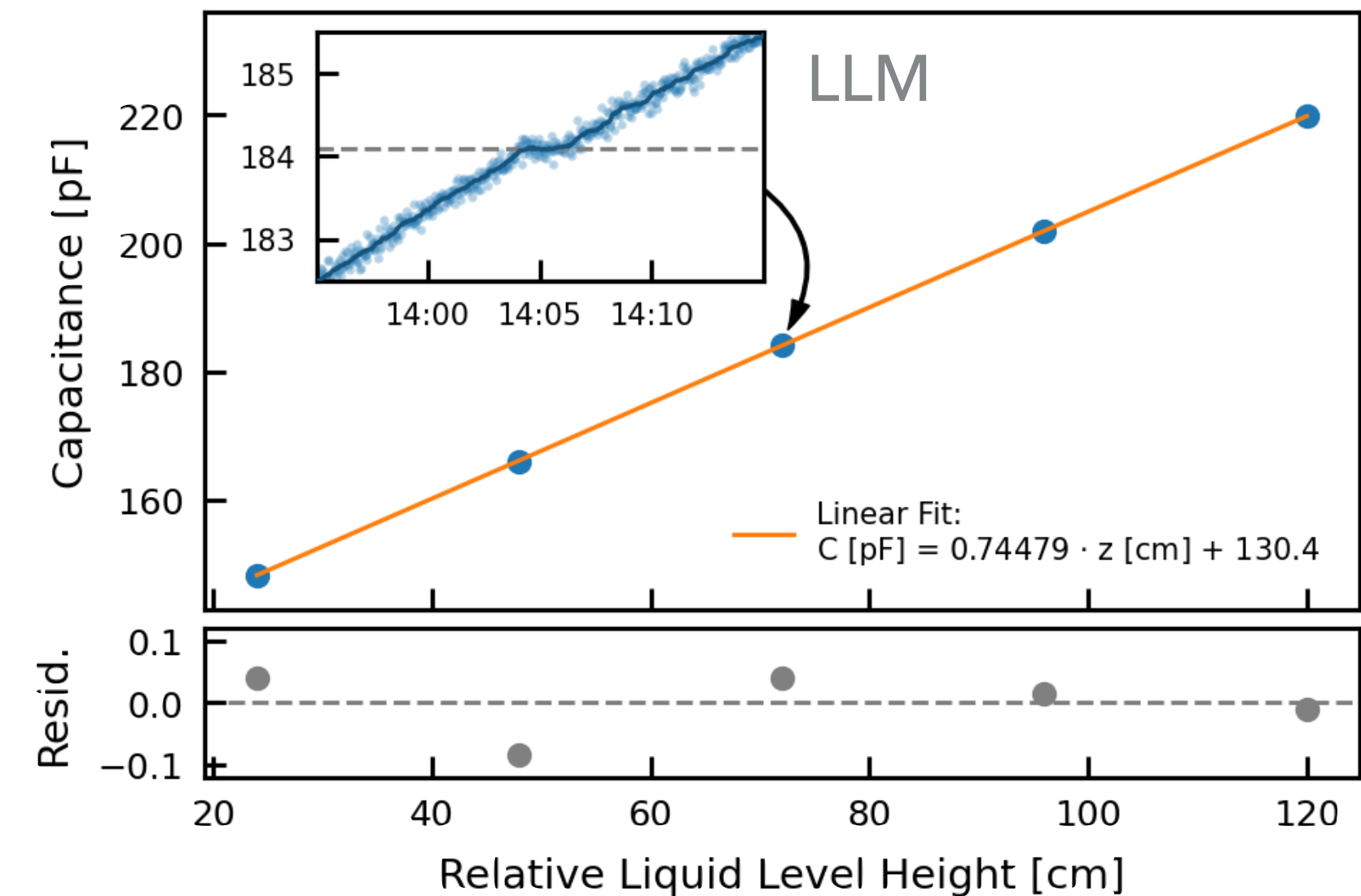
Weir

- Keep liquid level stable
- Cylindrical weir actuated by a motion feedthrough
- Total capacity: ~2.3 kg



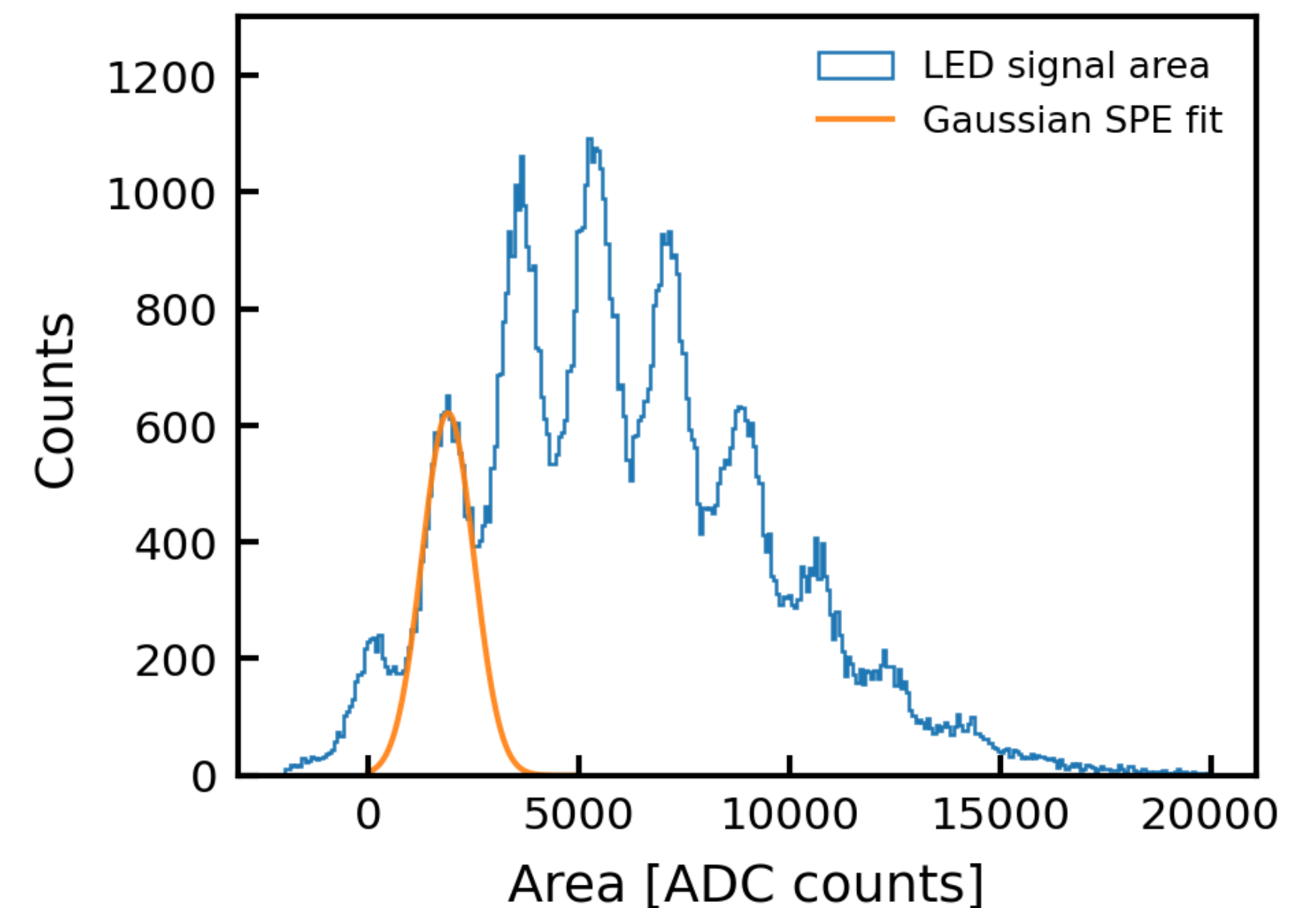
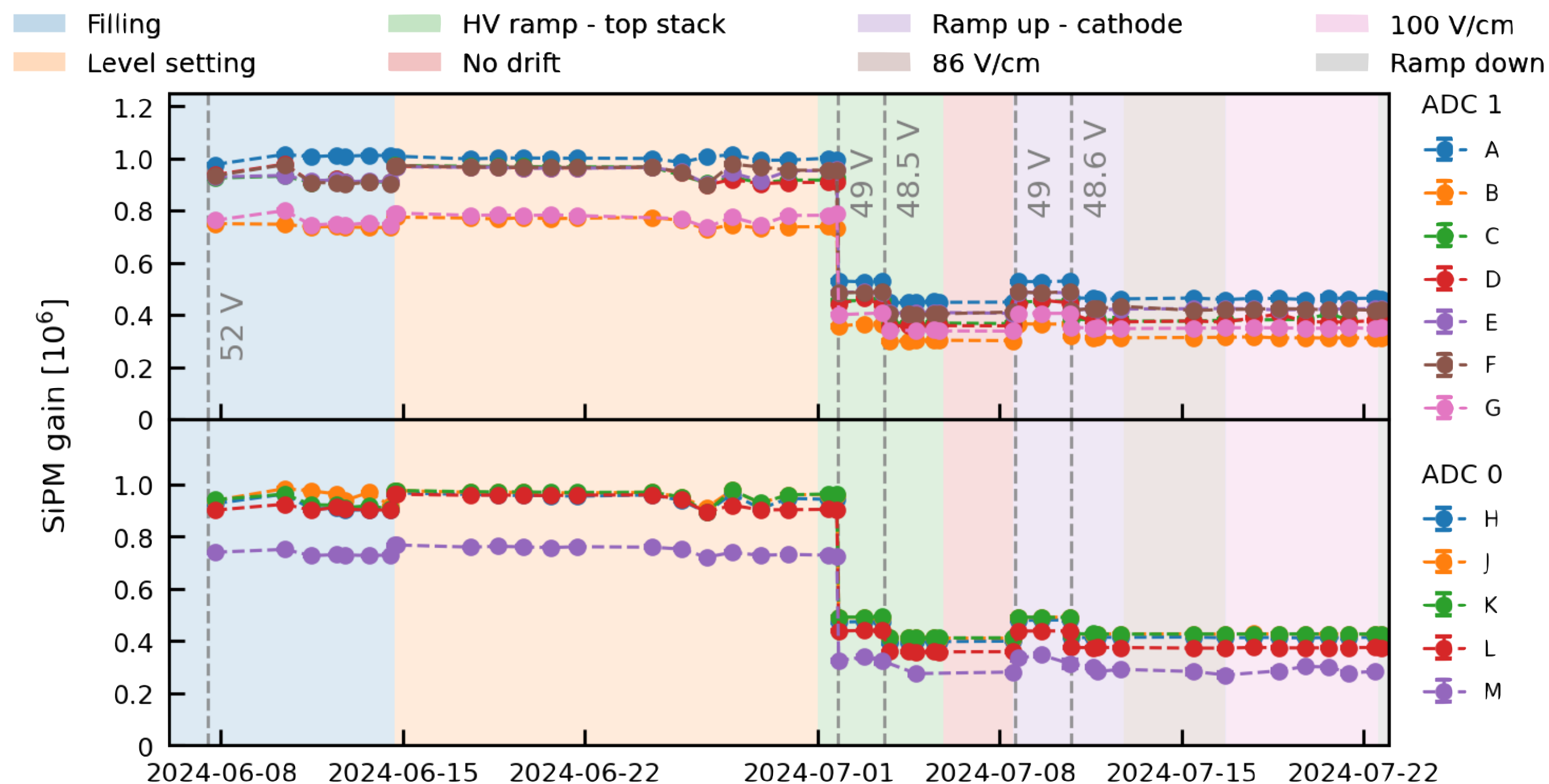
Commissioning run

- Tested recirculation and filling correlated with integrated xenon flow at ~50 slpm → Filled ~360 kg of xenon
- Five spacer rings along each LLM used as calibration points
- Weir commissioned by varying the liquid level and monitoring it through the SLM
- Getter not operation during commissioning → no purity for science data
- HV ramp gradually up to monitor stability and set to:
 - Drift field: ~100 V/cm
 - Extraction field: 6 kV/cm



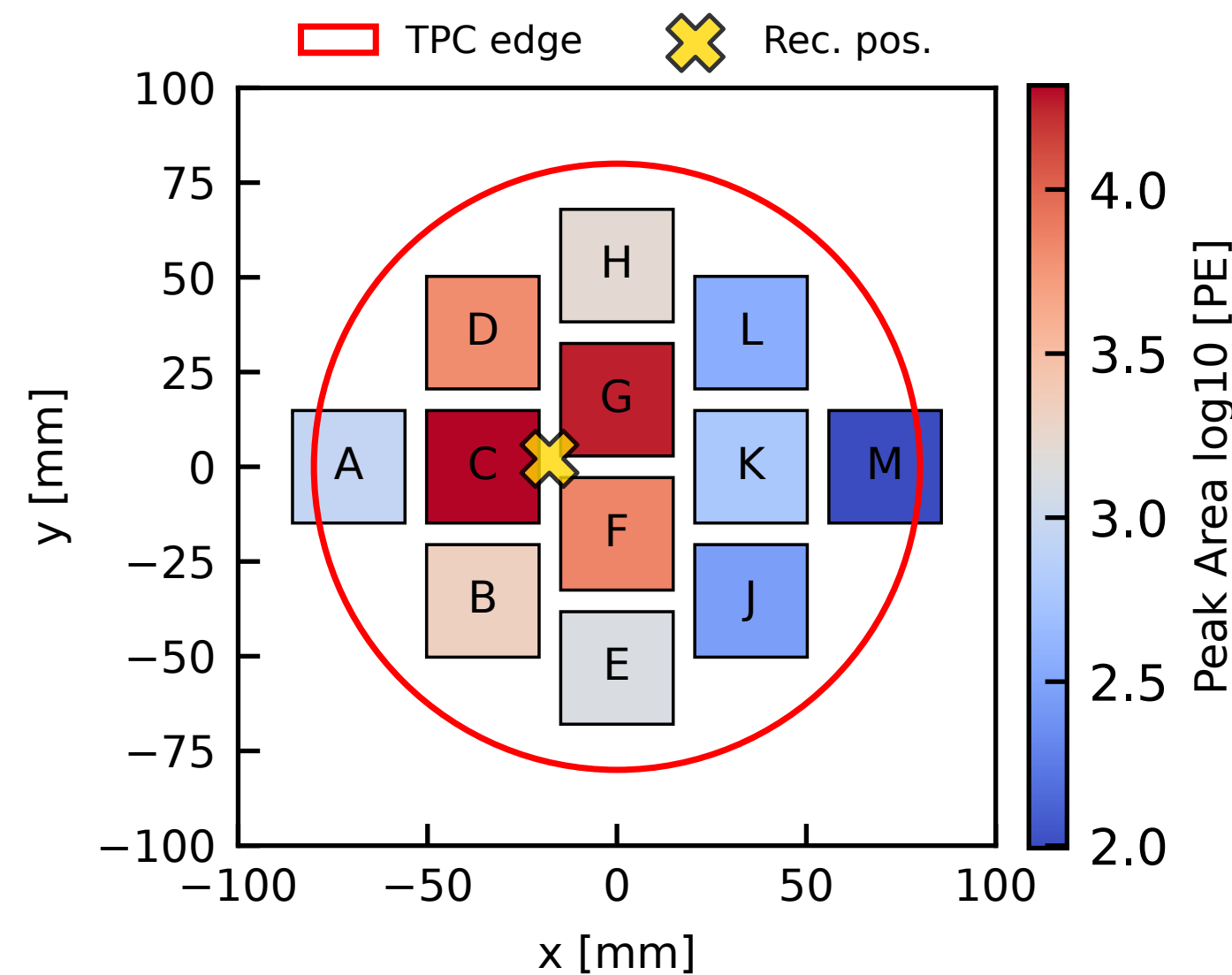
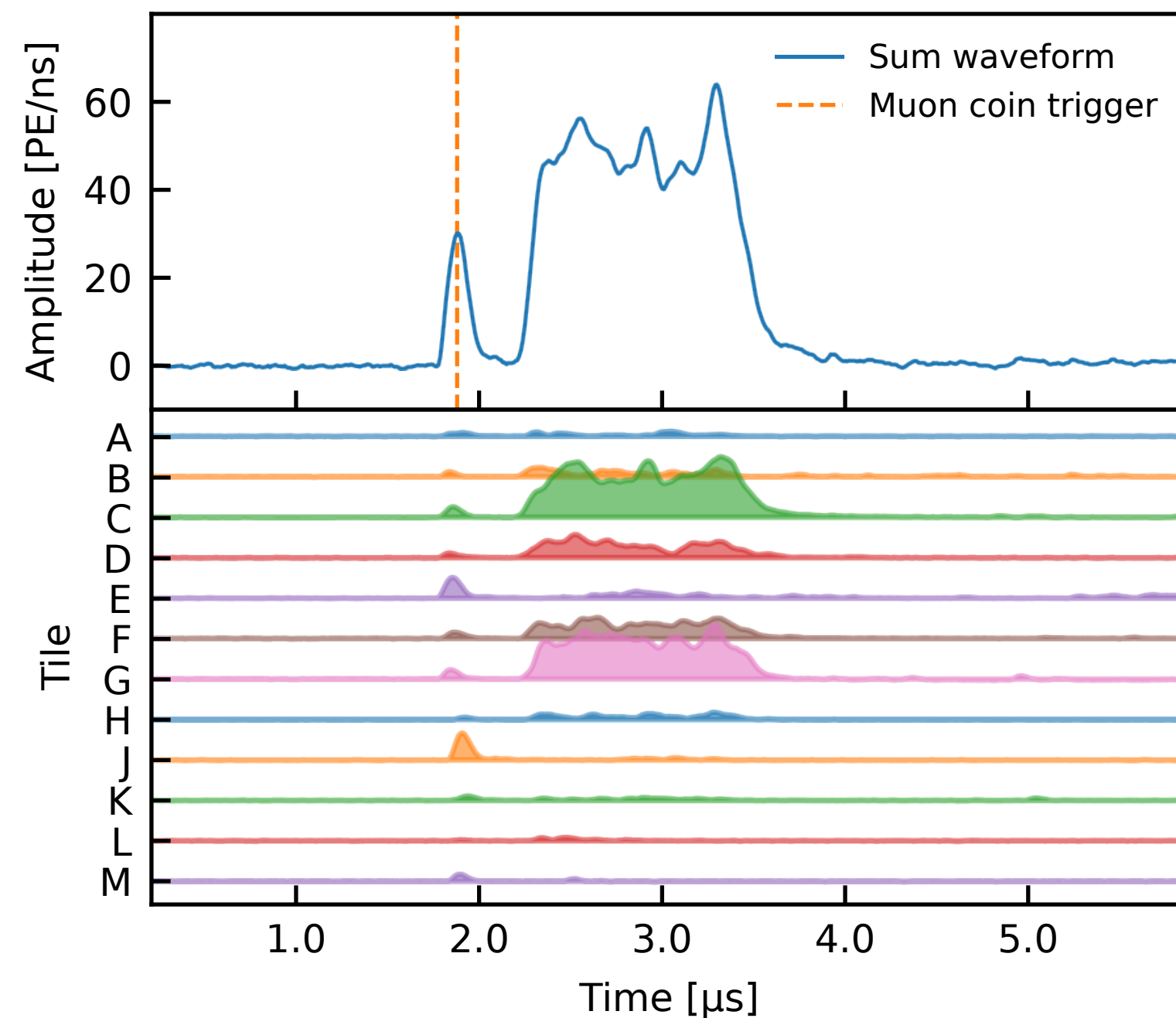
Commissioning run

- SiPM array performance monitored with low intensity blue LED light $\lambda \approx 400$ nm routed by two fibres directed toward the array
- Different illumination level to account for non-uniformity of light
- The mean value of the single photoelectron (SPE) peak fit is used to calculate the gain
- SiPM bias and gain adjusted to avoid saturation



Commissioning run

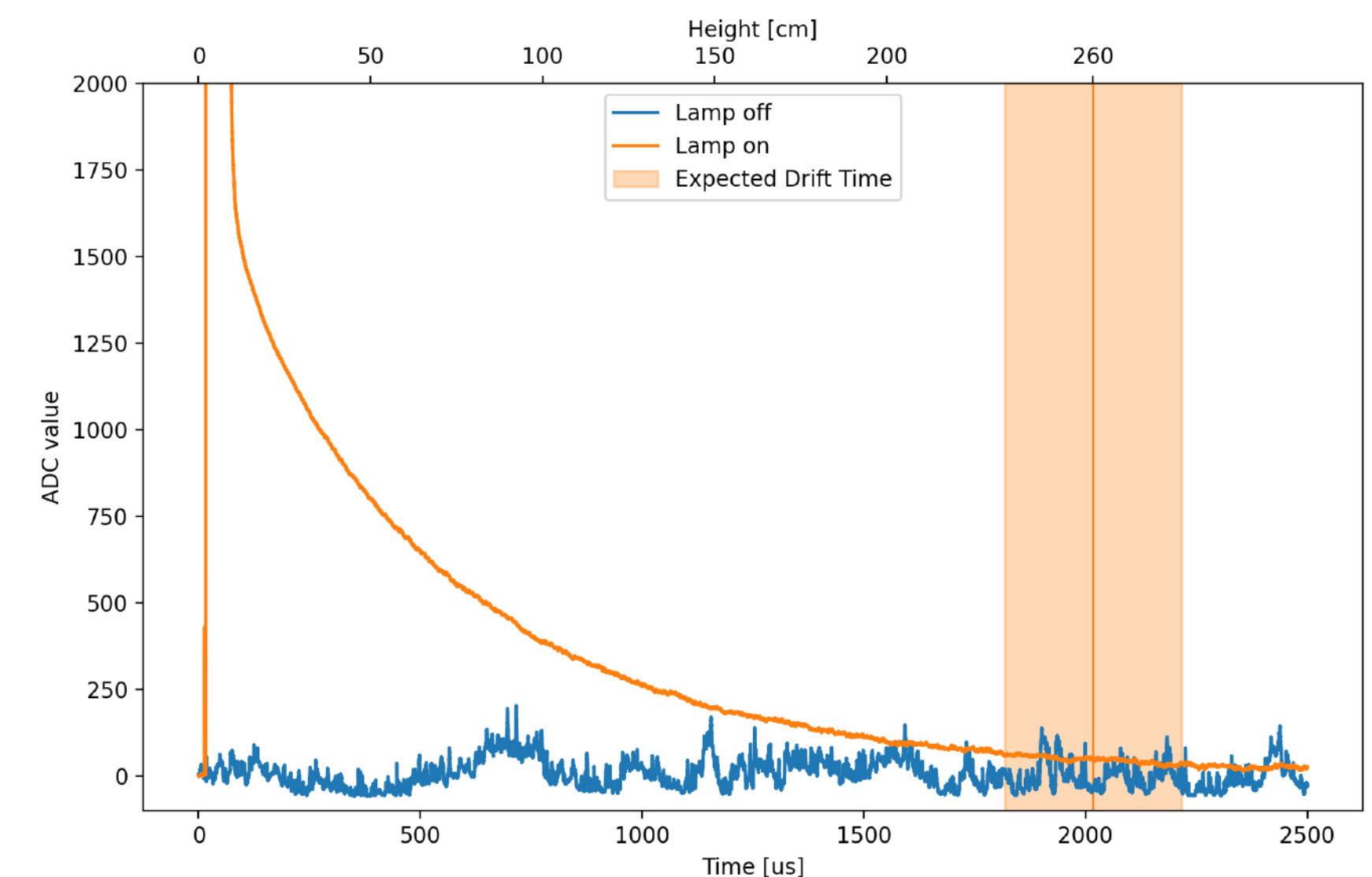
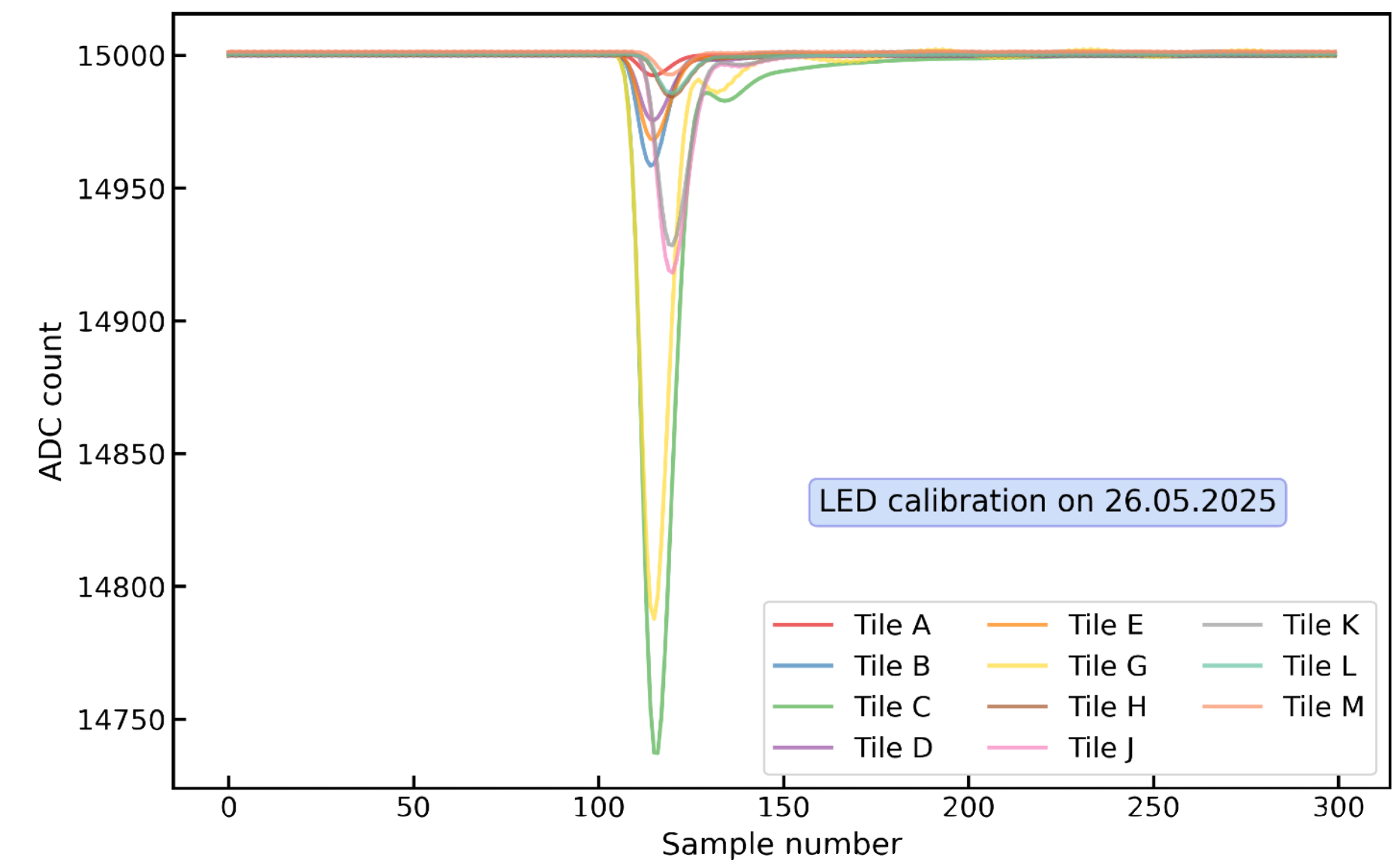
- Acquired cosmic muons crossing the top of the LXe (drift $<10\ \mu\text{s}$ - no purification)
- 2 scintillator panels with 3" PMTs in coincidence to trigger the event
- S1 in coincidence with the muon trigger system



Position reconstruction given by the centre of gravity algorithm based on the relative area of the S2 signal in each tile

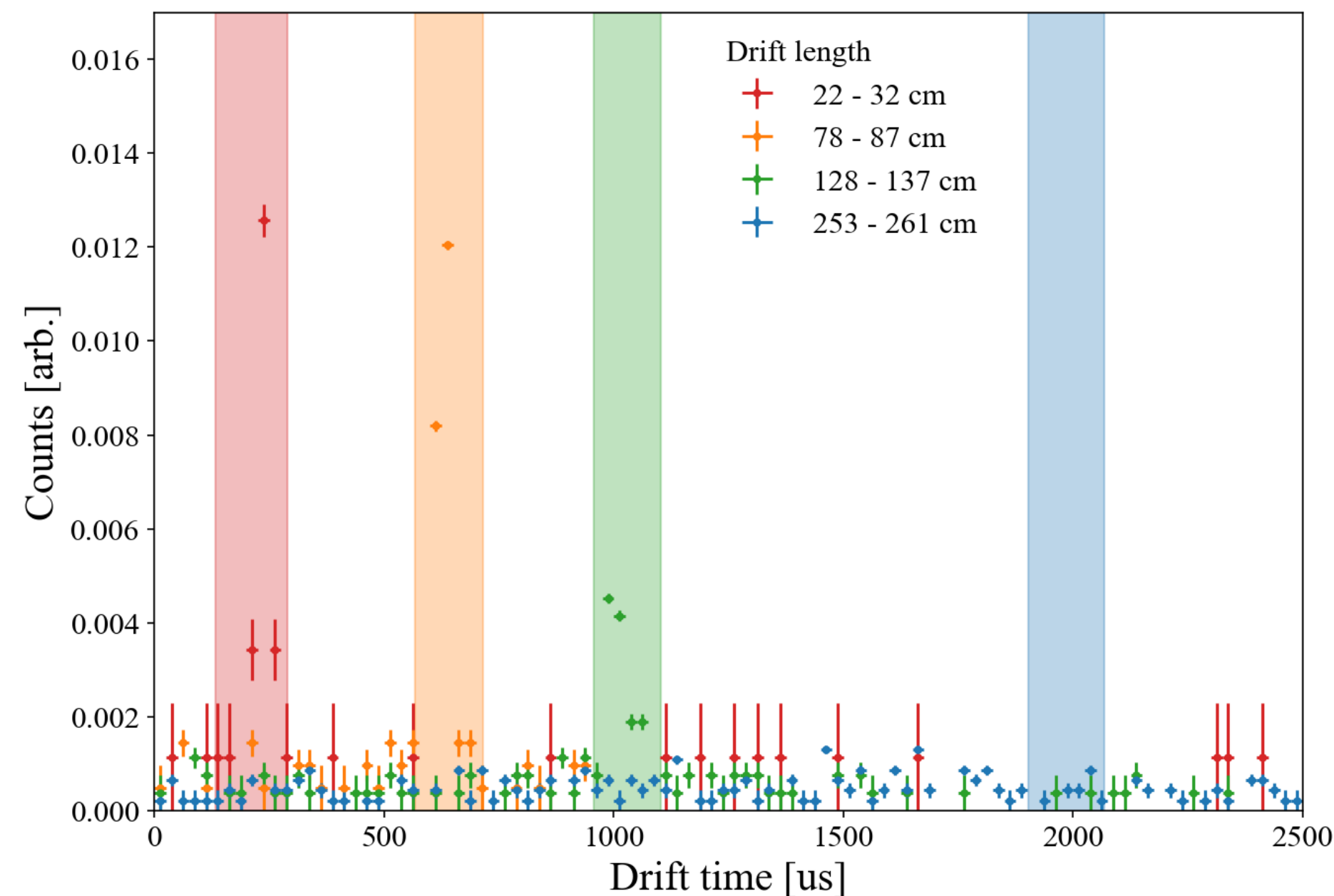
First science run

- Upgrades to the gas system for xenon purification:
 - New getter and filters
 - Variable frequency driver to adjust compressor speed
- Filling and monitoring procedures were successful
- Observed spark on the HV → field setting:
 - Drift field: ~ 80 V/cm
 - Extraction field: 8 kV/cm
- LED calibration: stable gain in agreement with commissioning but tile C and G show excessive light collection → likely from optical fiber displacement
- Shining xenon lamp on photocathode to extract electrons: not visible but a lot of light coming from it → likely fiber displacement and light not hitting the photocathode

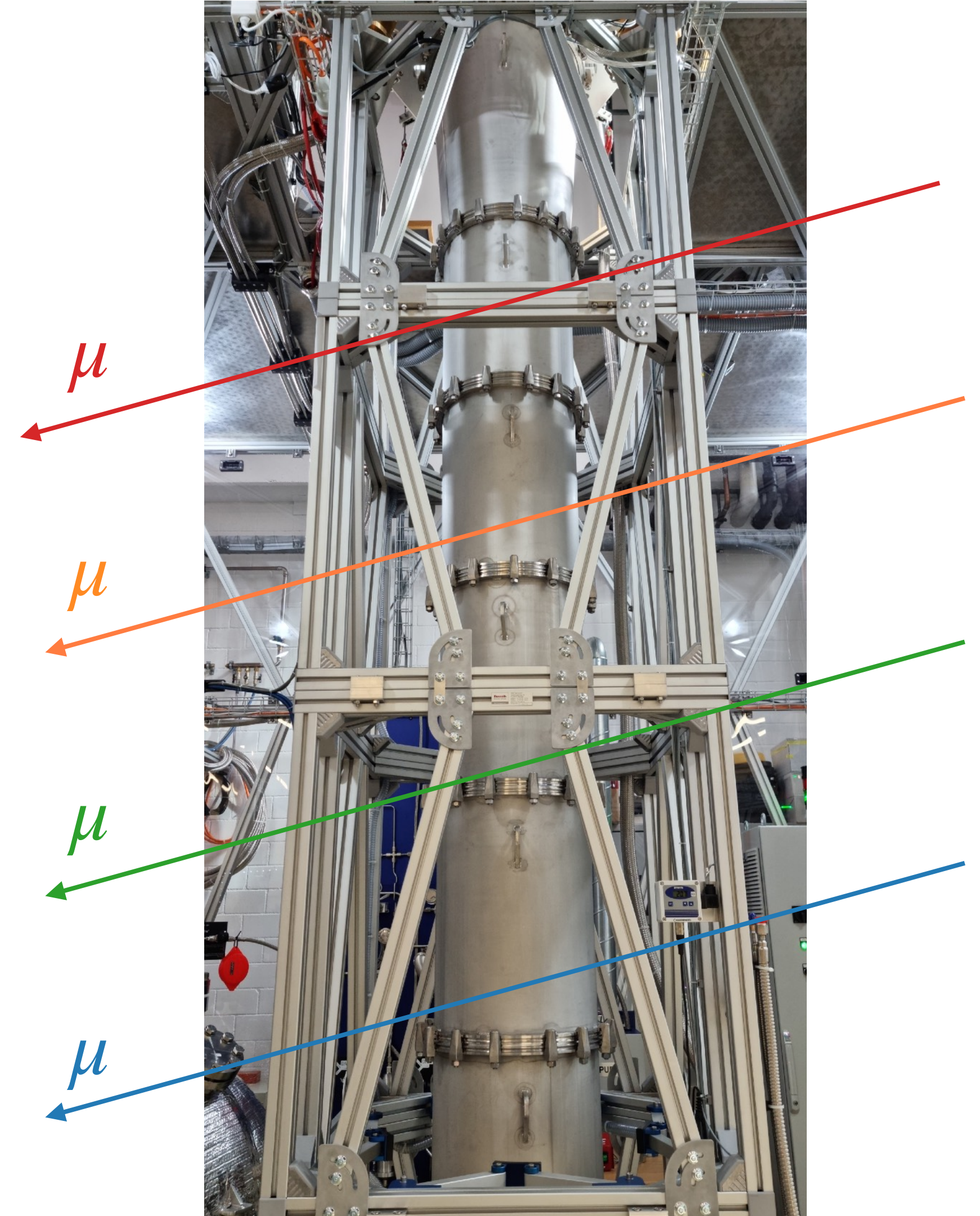


First science run

- Acquired cosmic muons at 4 positions along the TPC height
- Drifted events visible in positions 1, 2, and 3
- Limited statistic due to small scintillator area, angle and pump lifetime → not enough to be sensitive to the drifted events in the lowest position



1. drift length 22-32 cm
2. drift length 78-87 cm
3. drift length 128-137 cm
4. drift length 253-261 cm



Opening and detector inspection

Issues found:

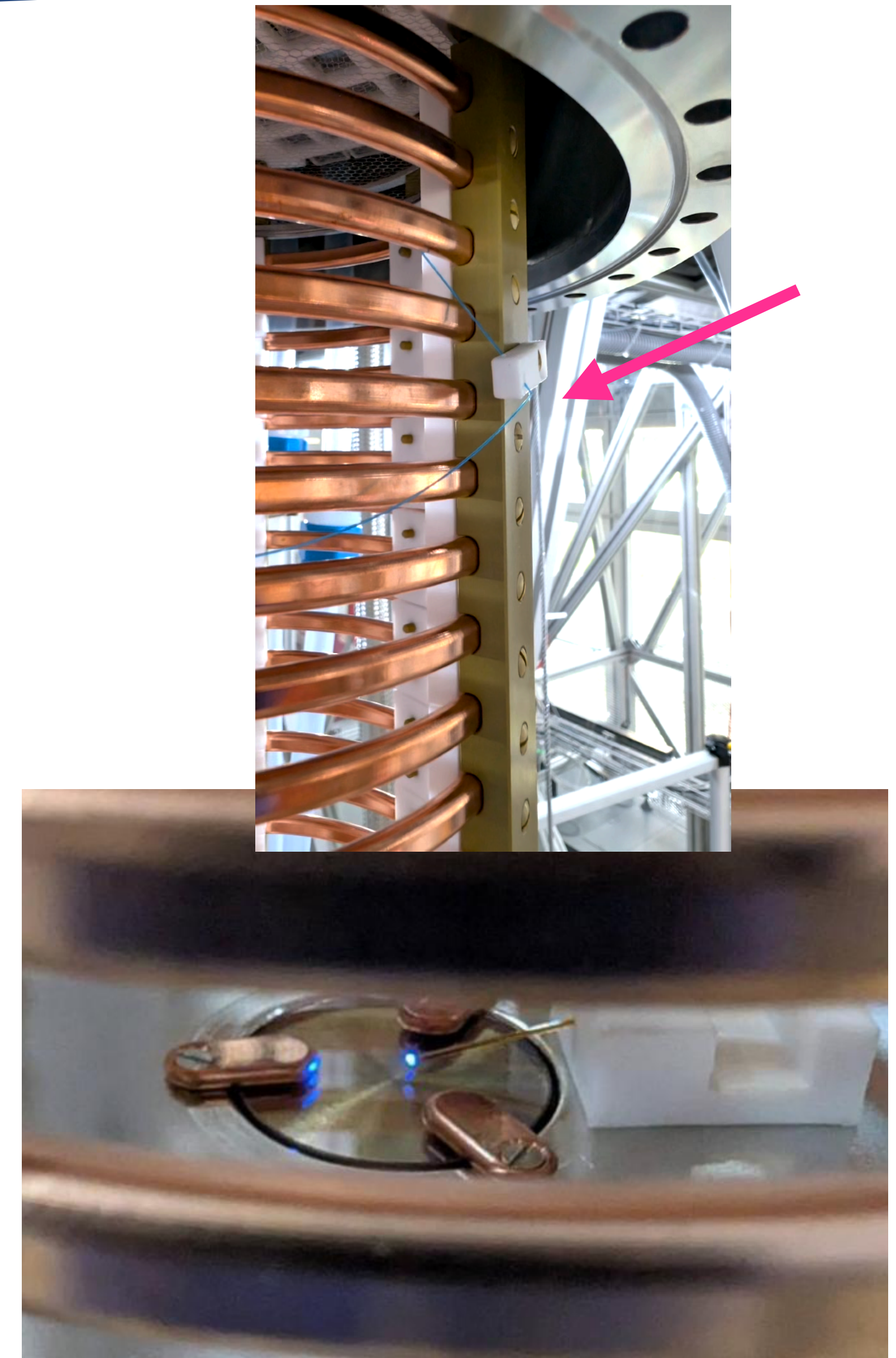
- Optical fibers: one broken and one moved close to the array
- Xenon lamp fiber: moved and pointing to copper holder

⇒ Displacement due to filling?

Plans:

- replace the optical fibres and change the xenon lamp fibre design
- Improve the gas system to allow for longer pump lifetime

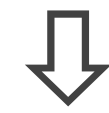
⇒ Reference system inside and outside the cryostat showed a mismatch of 7 cm → position 4 had scintillators for muon coincidence below the LXe volume



Upgrades to the gas system

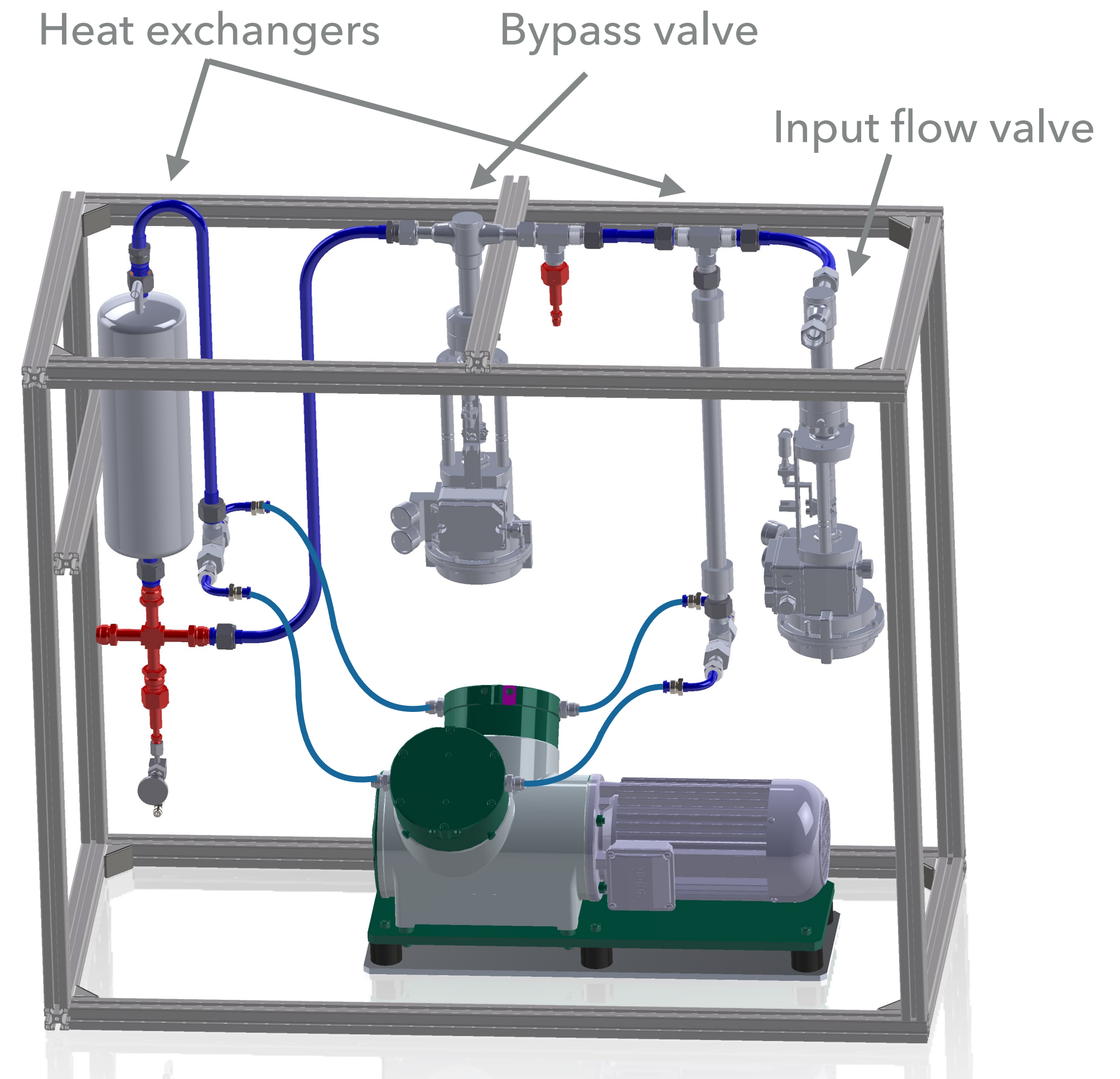
Goal: increase xenon mass flow to stable ~100 slpm

What we need: control pump input pressure and overheating, and reduction of impedance in the line



New chiller line to route 5 °C water to recirculation system:

- Cooling of the pump heads
- Xenon gas cooling with input and output heat exchanger
- Bypass line between pump output and input to bring cooled xenon gas to the input and reduce the pressure



Work almost completed!

Upgrades to the gas system

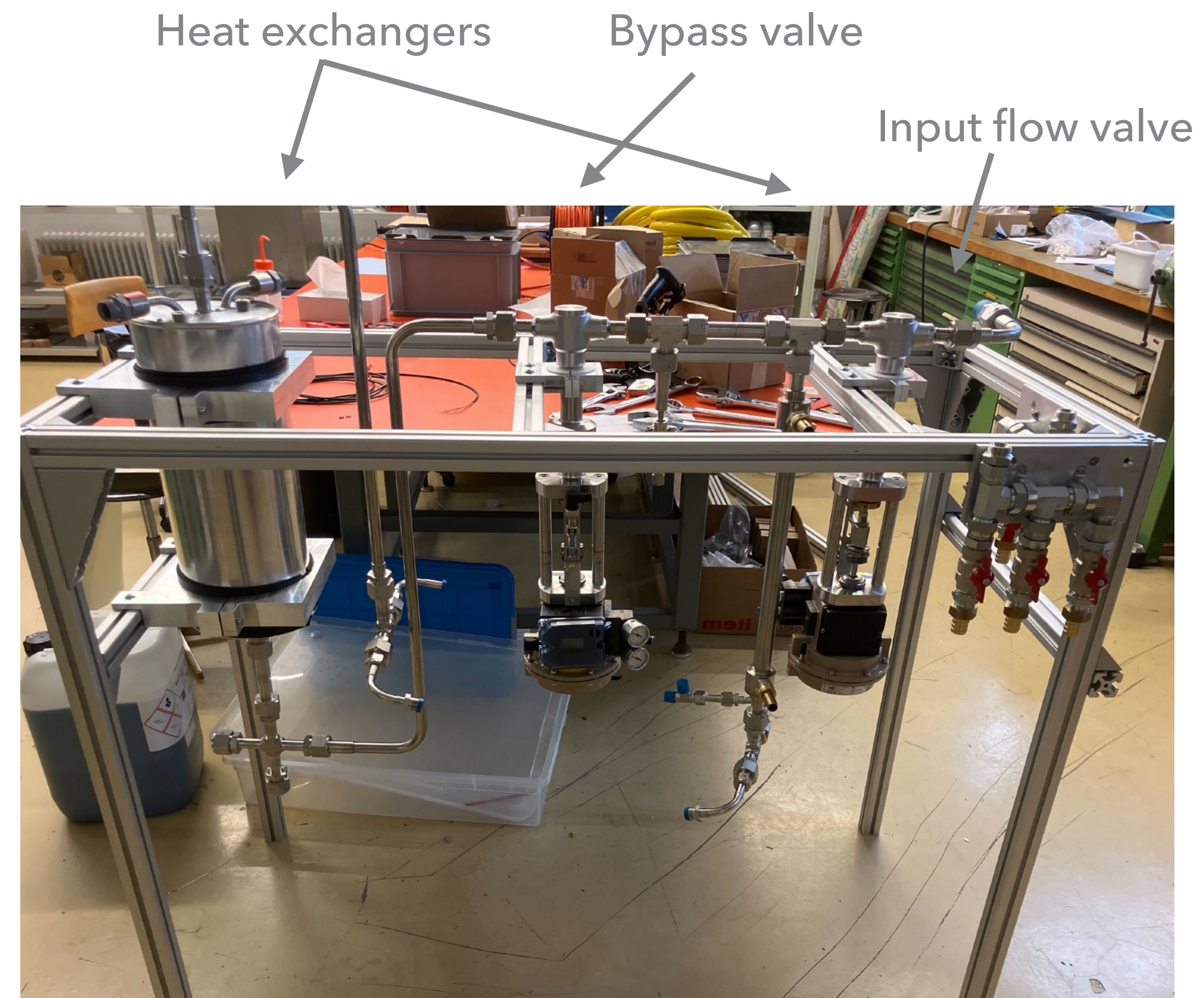
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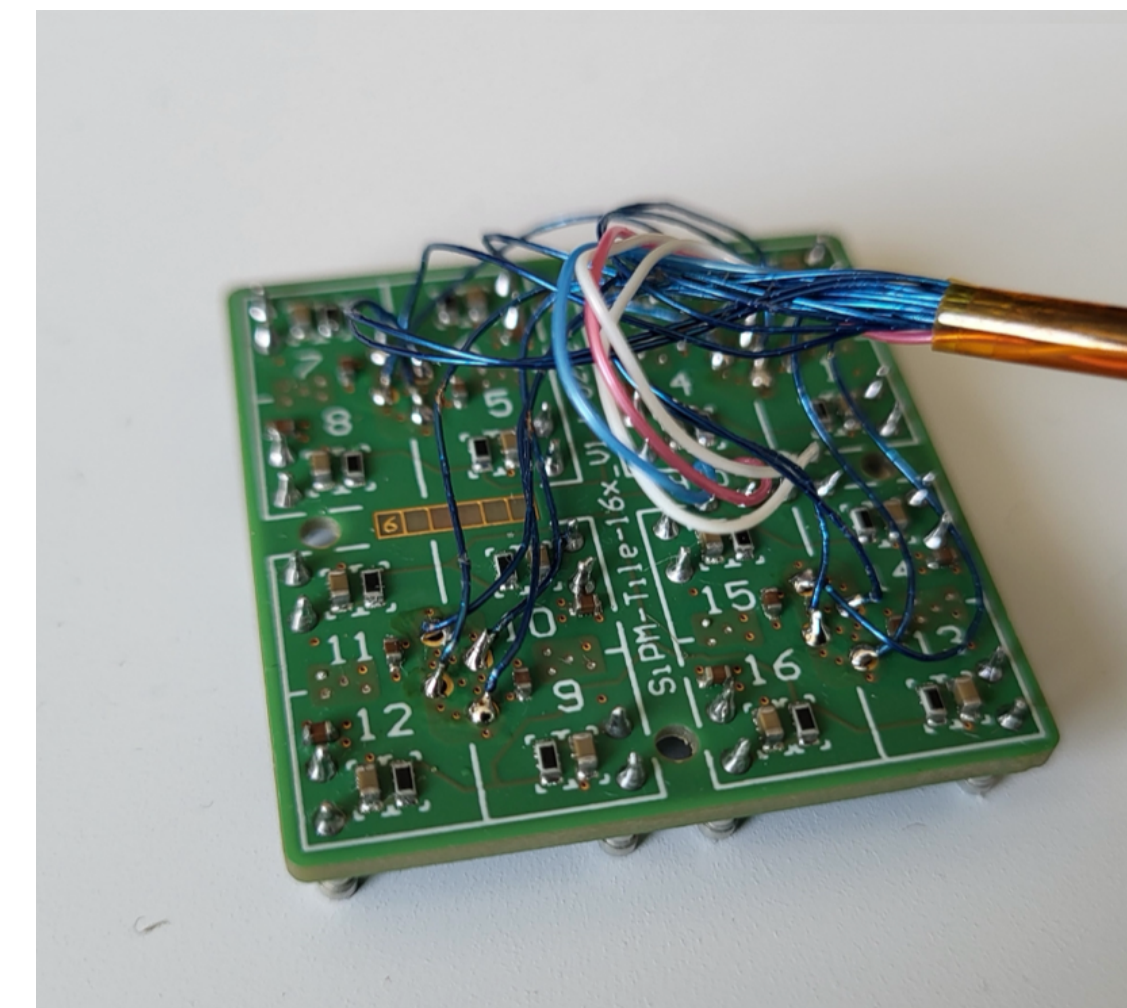
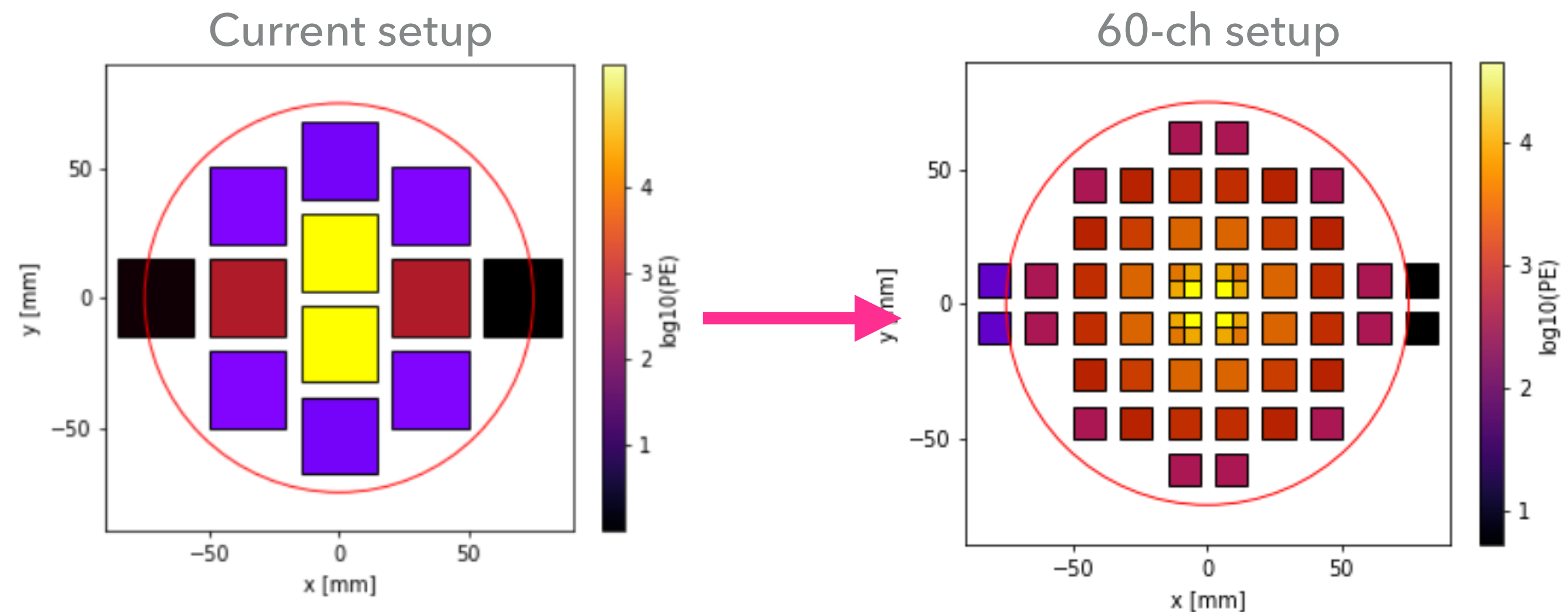
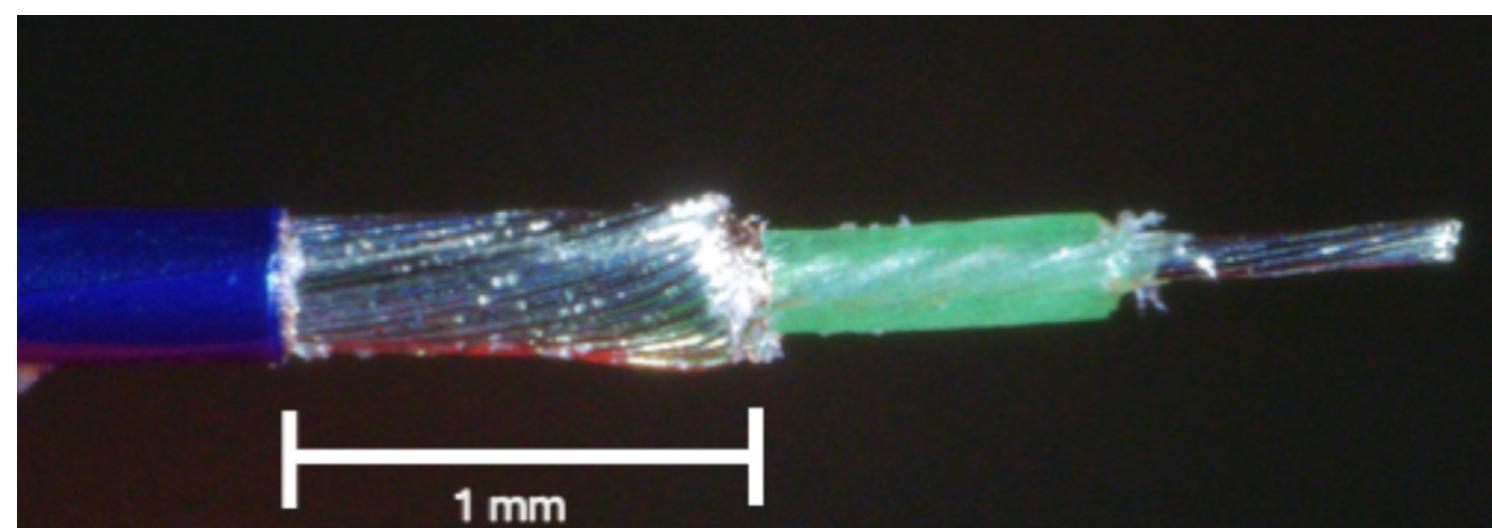
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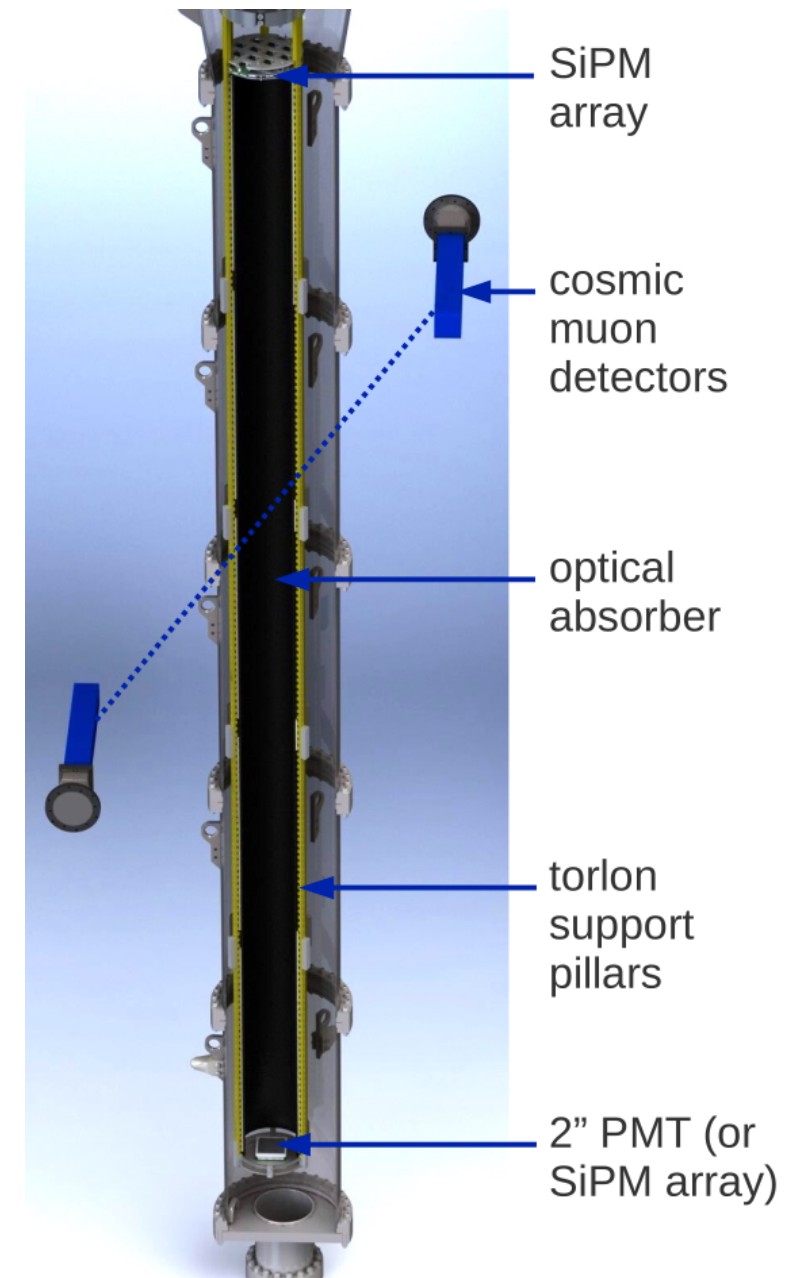
High granularity SiPM array

- For 2 ms drift length expected transverse diffusion width of ~ 6.6 mm
- Preliminary study - 60 ch as optimal tradeoff between position resolution and number of channels
- Ongoing upgrade for readout PCB board, cabling and readout
 - Up to 16 independent 6×6 mm² per board - new dual-channel amplifier
 - Micro-coaxial cables AWG40 - 0.09mm



Optical measurements

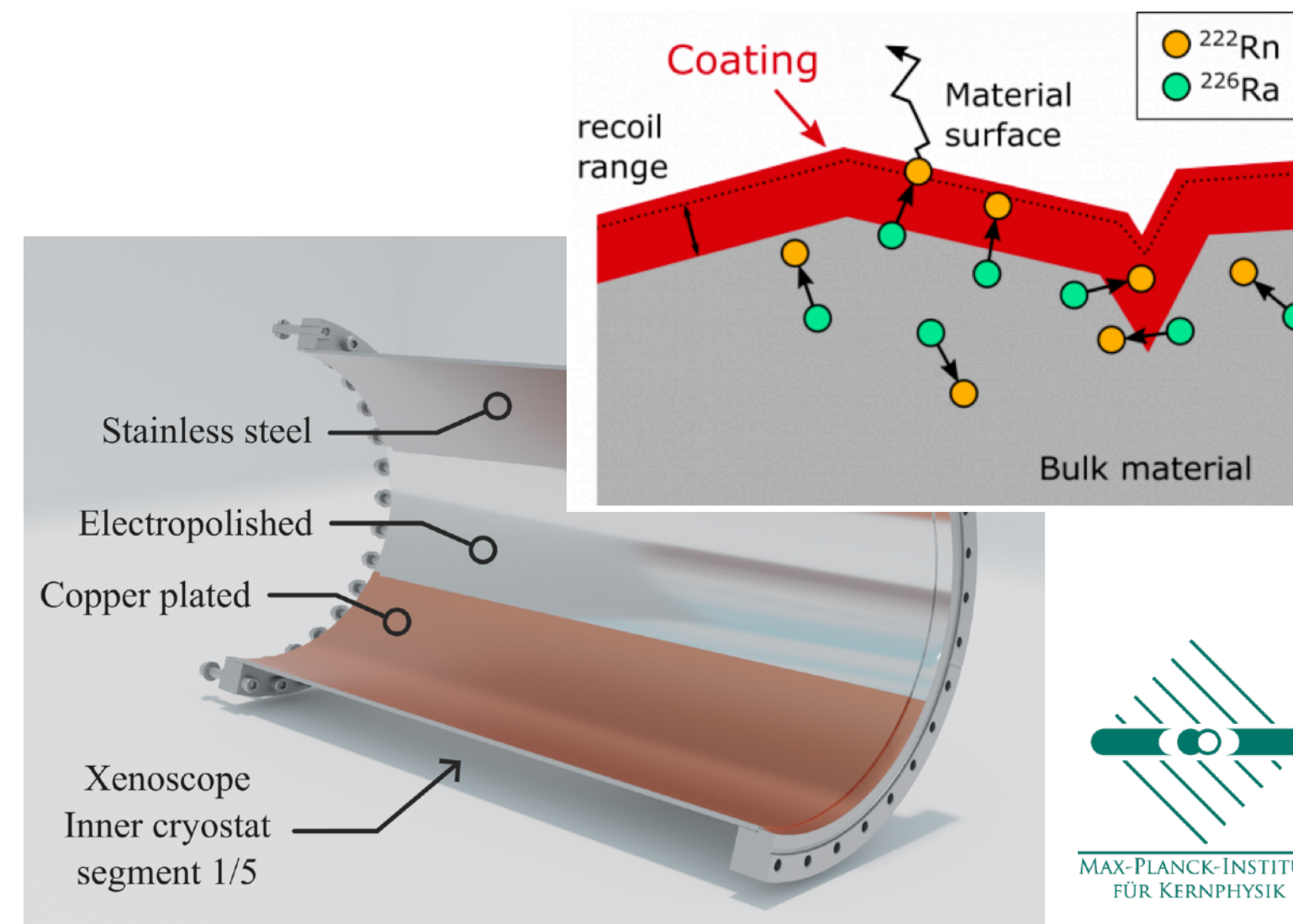
- Light attenuation in LXe with large setup
- Disentangle absorption and Rayleigh scattering



- Hodoscope with muon scintillators
- Measure refractive index from group velocity

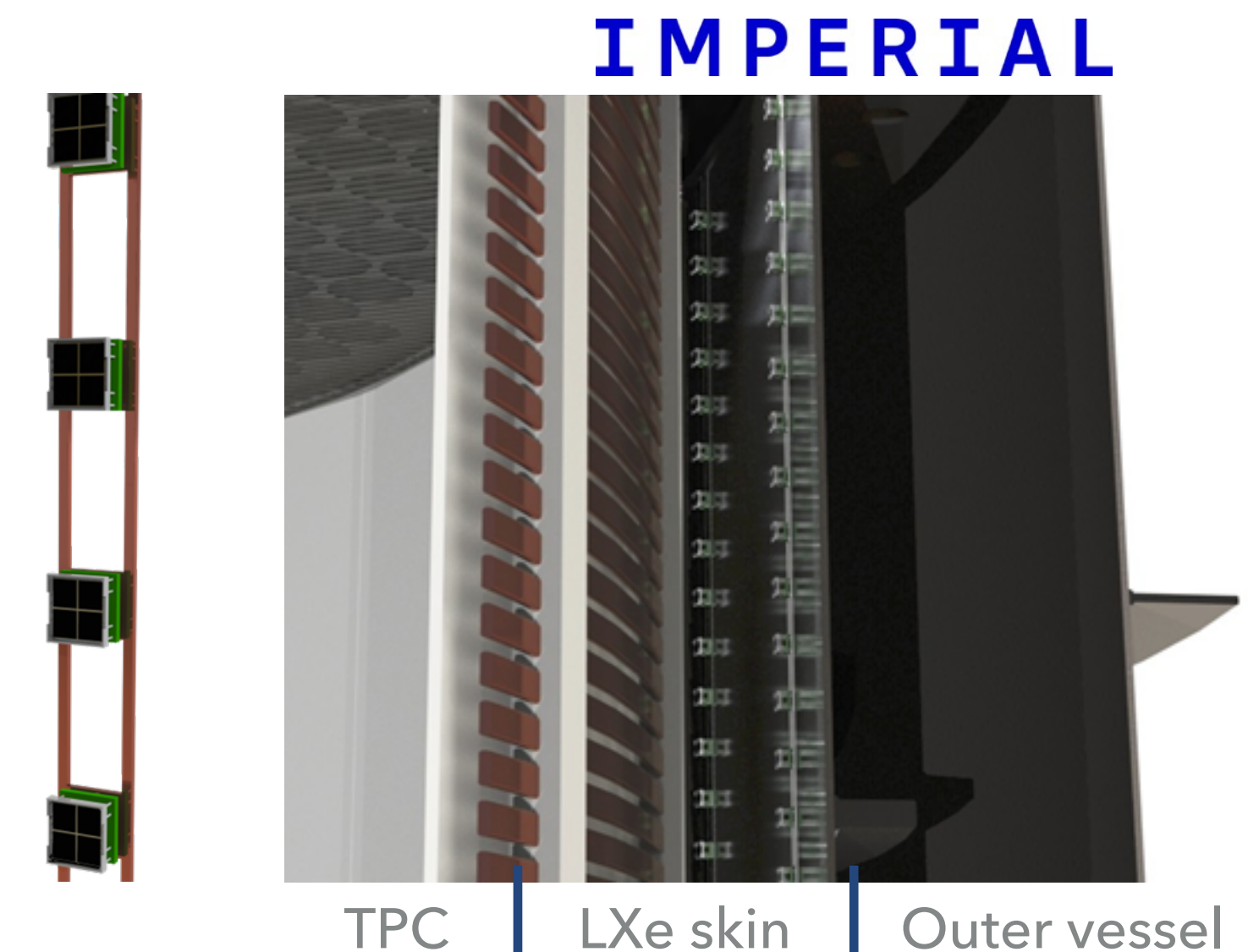
Radon mitigation

- In collaboration with MPIK Heidelberg
- ~5 μm electrodeposited copper surface coating on the inner cryostat
- verify cryogenic and xenon purity demands



LXe skin tagging

- Joint UZH-Imperial R&D for the LXe skin
- Chains of SiPMs to improve light collection



Conclusion and outlook

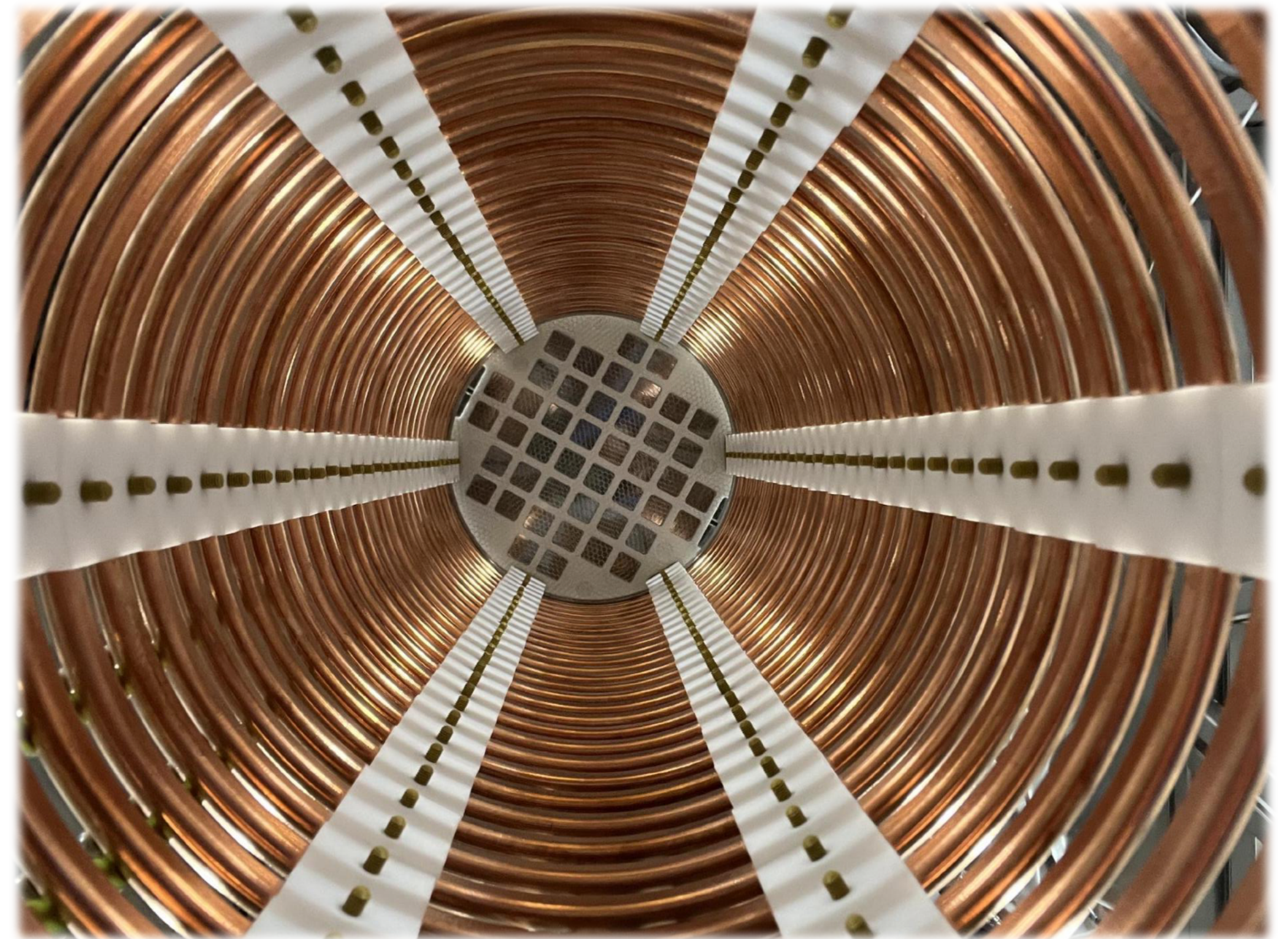
Xenoscope facility for XLZD scale R&D

- All subsystems commissioned
- First science run showed some issues that were identified by following detector inspection
- Preparing for next science run
- Planned upgrades and future R&Ds

Open platform for XLZD collaborators

DRD2 large scale testing facility

Thank you!



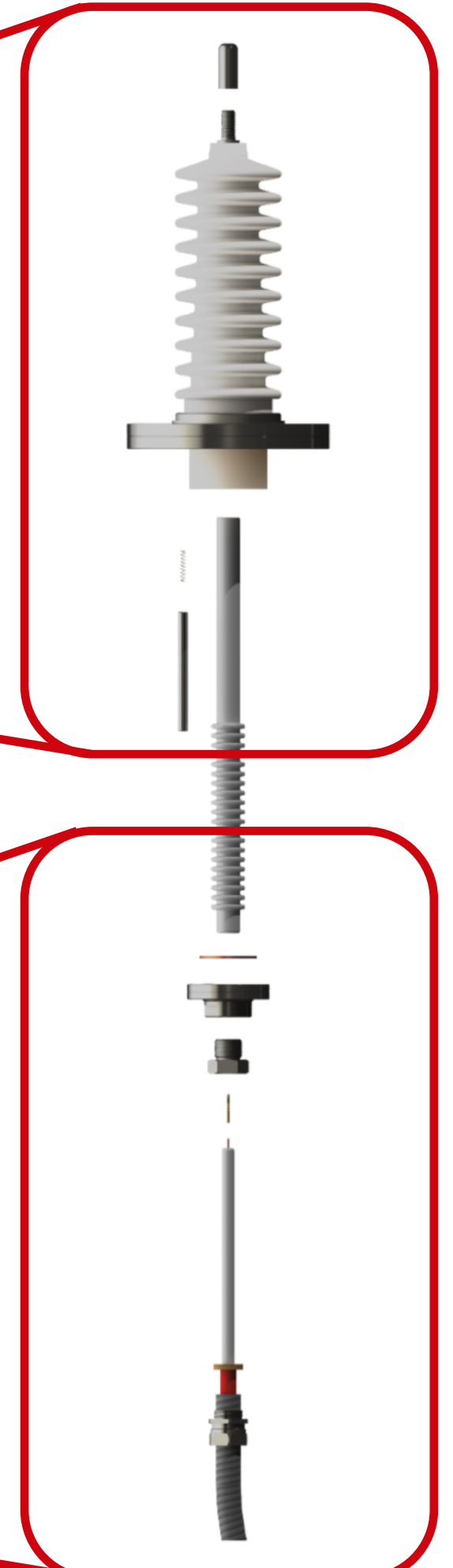
Xenoscope team:

Maximino Adrover, Nicolas Angelides, Marta Babicz, Erin Barillier, Laura Baudis, Harvey Birch, Alexander Bismark, Chiara Capelli, Jose Cuenca García, Paloma Cimental, Sebastian George, Rebecca Hampp, Luisa Höttsch, Florian Jörg, Knut Morå, Margherita Noia, Sana Ouahada, Björn Penning, Francesco Piastra, Diego Ramírez García, Christian Wittweg

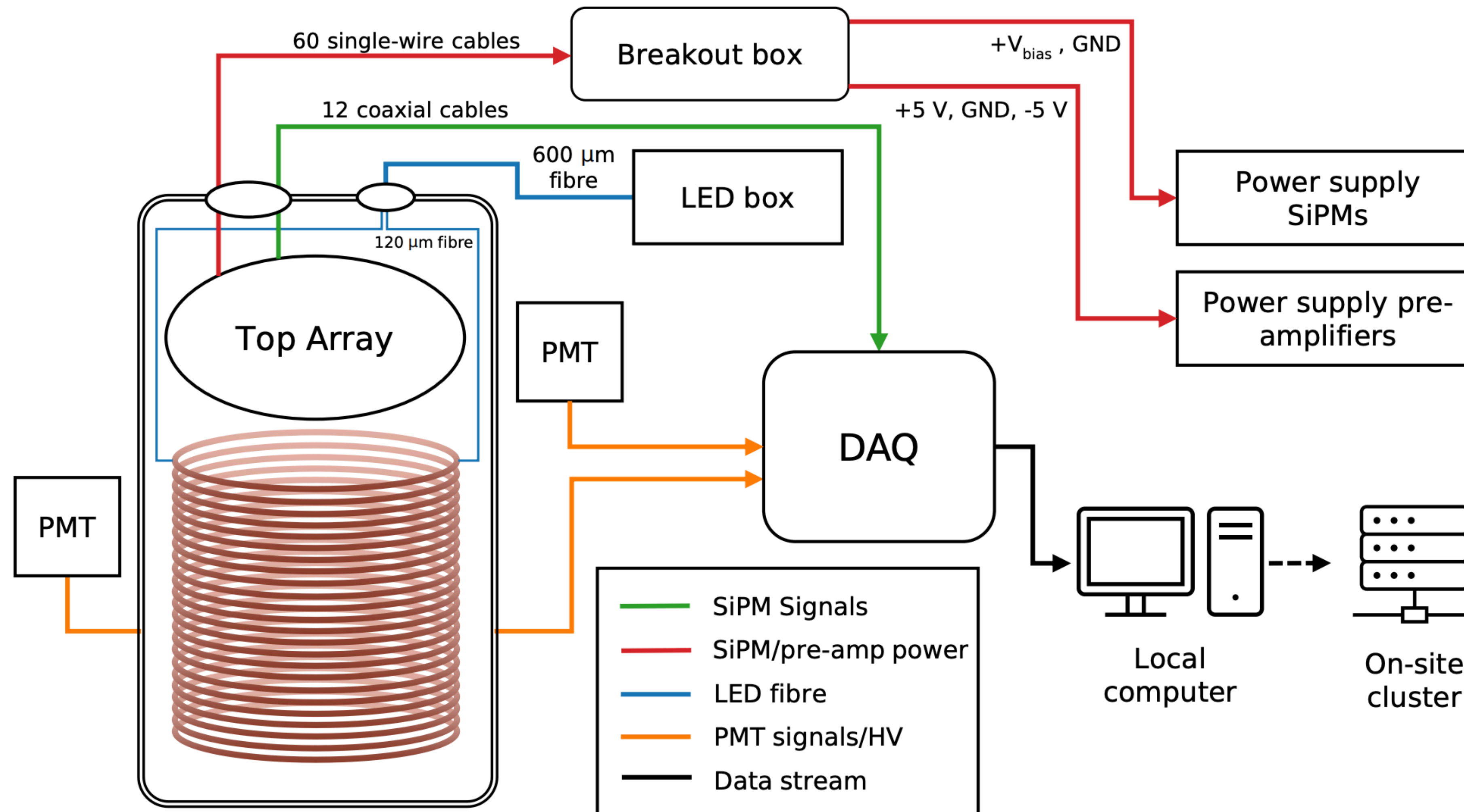
Backups

Cathode HV delivery system

- HV enters the TPC from the bottom (bending radius ~ 28 cm)
- Commercial Ceramseal (CeramTec) FT, rated 100 kV. Inhouse cryofitted air-to-vacuum FT
- HV rating improved by conditioning, HMWPE insulation elongation, surface treatment
- Tested in vacuum at 120 K and ~ 4 bar overpressure
- The HVFT was successfully operated at 50 kV for over 4 days without sparks
- Power supplies:
 - Anode and cathode: CAEN NDT1470 4CH
 - Cathode: Heinzinger PNC 100000

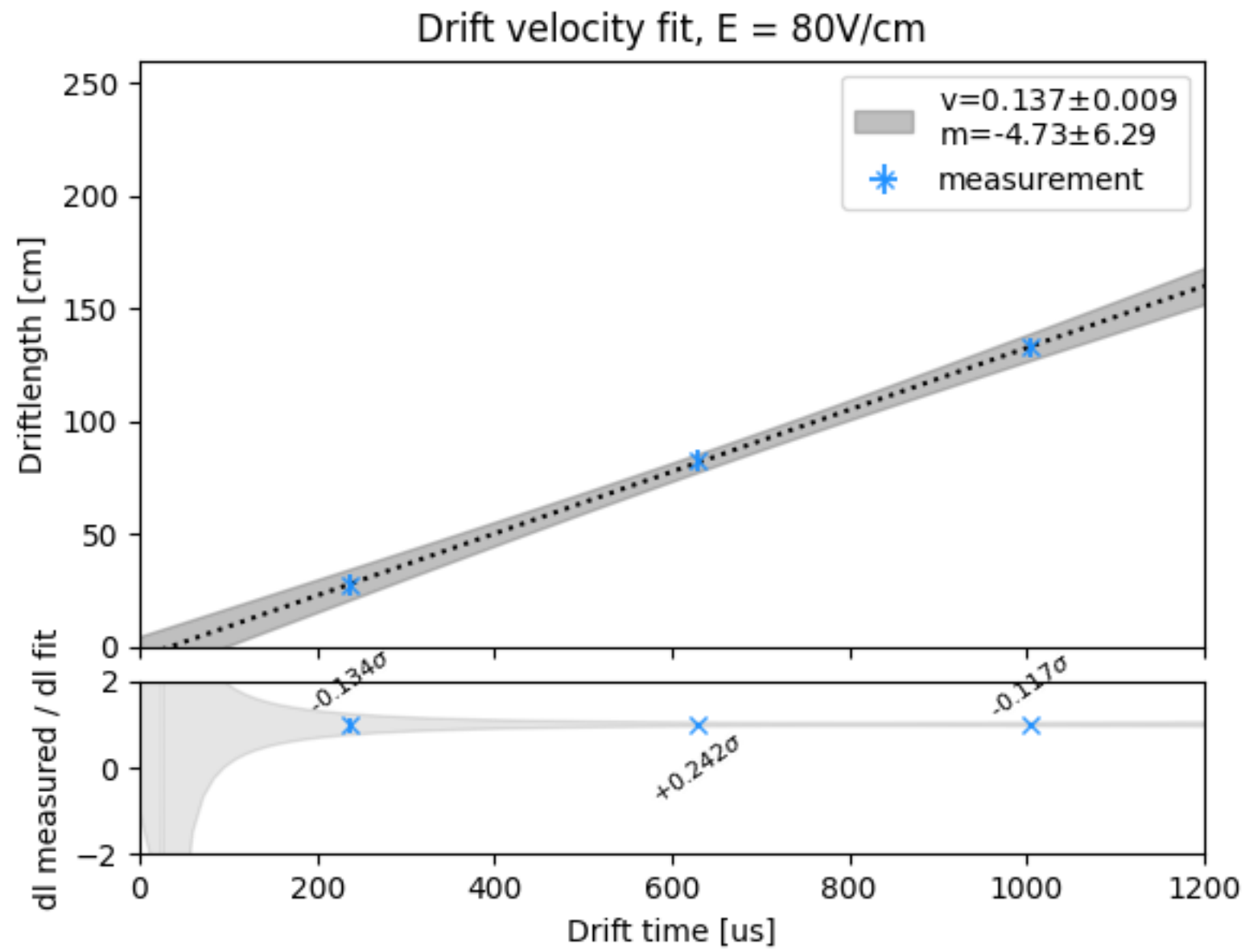
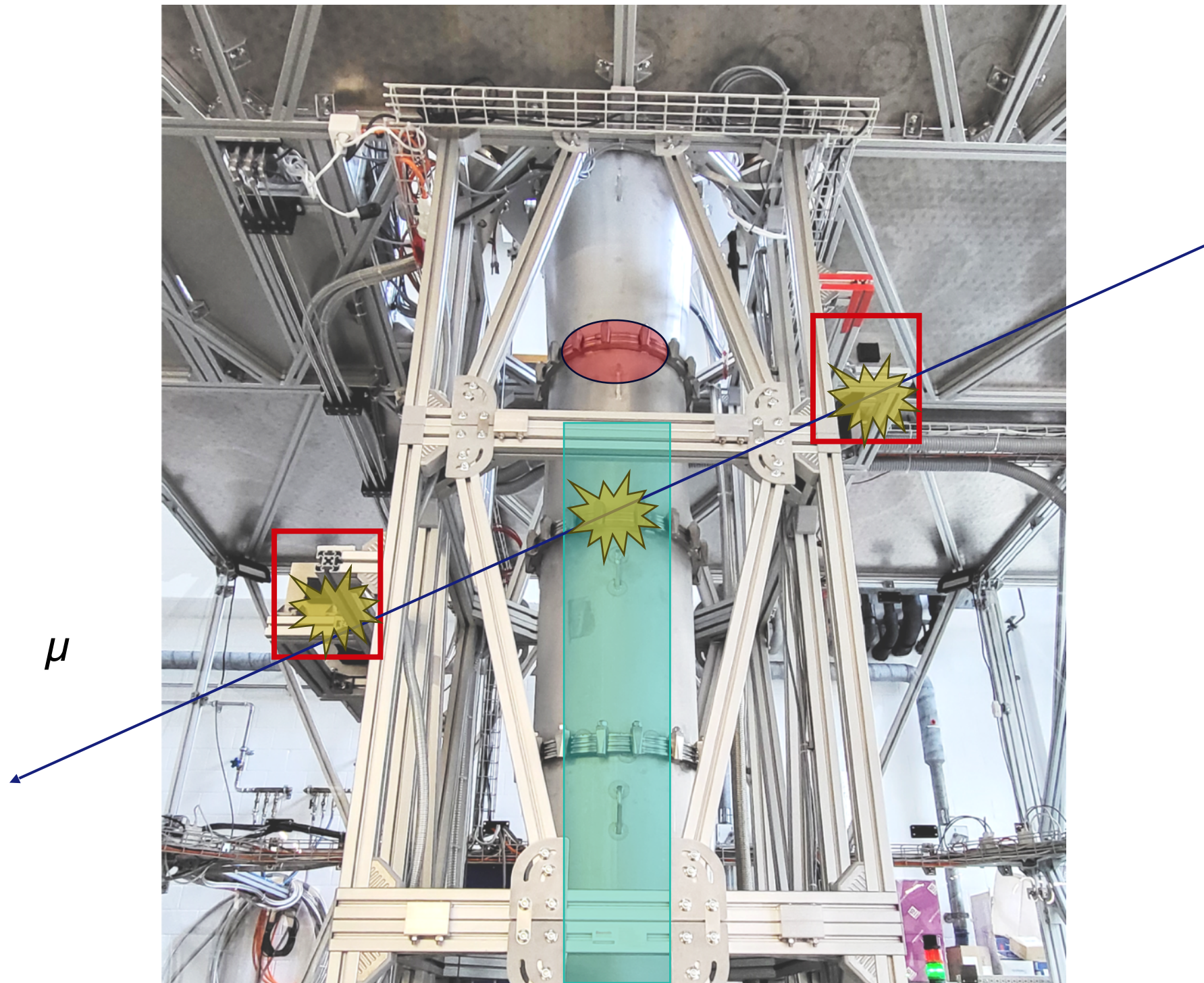


DAQ system

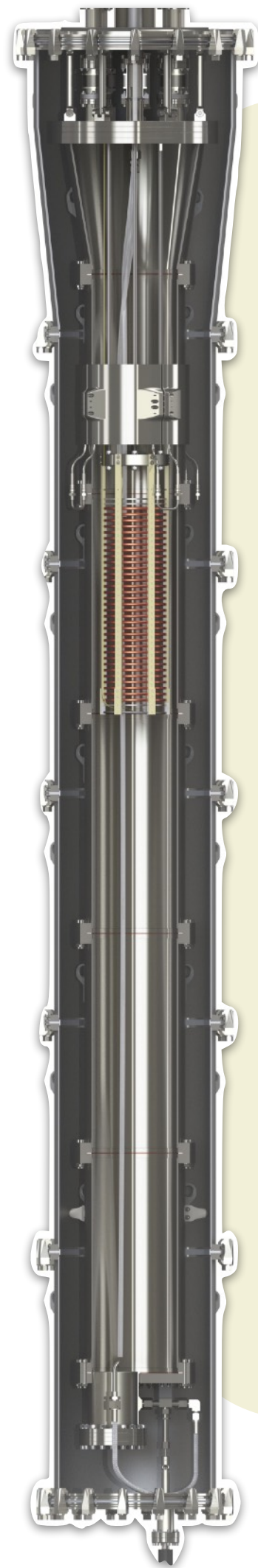


Muon data analysis

Position	Drift length [cm]	Angle	maximal vertical track [cm]	intrinsic width [us]	diffusion width [us]
Position 1	22 - 32	16.4°	3.8	~30	~1
Position 2	78 - 87	13°	2.9	~23	~2
Position 3	128 - 137	12.2°	2.7	~21	~2
Position 4	253 - 261	11.8°	2.5	~19	~3



Xenoscope purity monitor



Purity monitor

Spring 2022

- Dedicated setup to measure **electron lifetime** and **electron transport properties in LXe**:
 - 53 cm drift length with charge readout
 - 343 kg of LXe
 - Signal from a xenon flash lamp on photocathode
- After ~2 months of continuous purification and stable operation:

Electron lifetime: $(664 \pm 23)\mu\text{s}$

