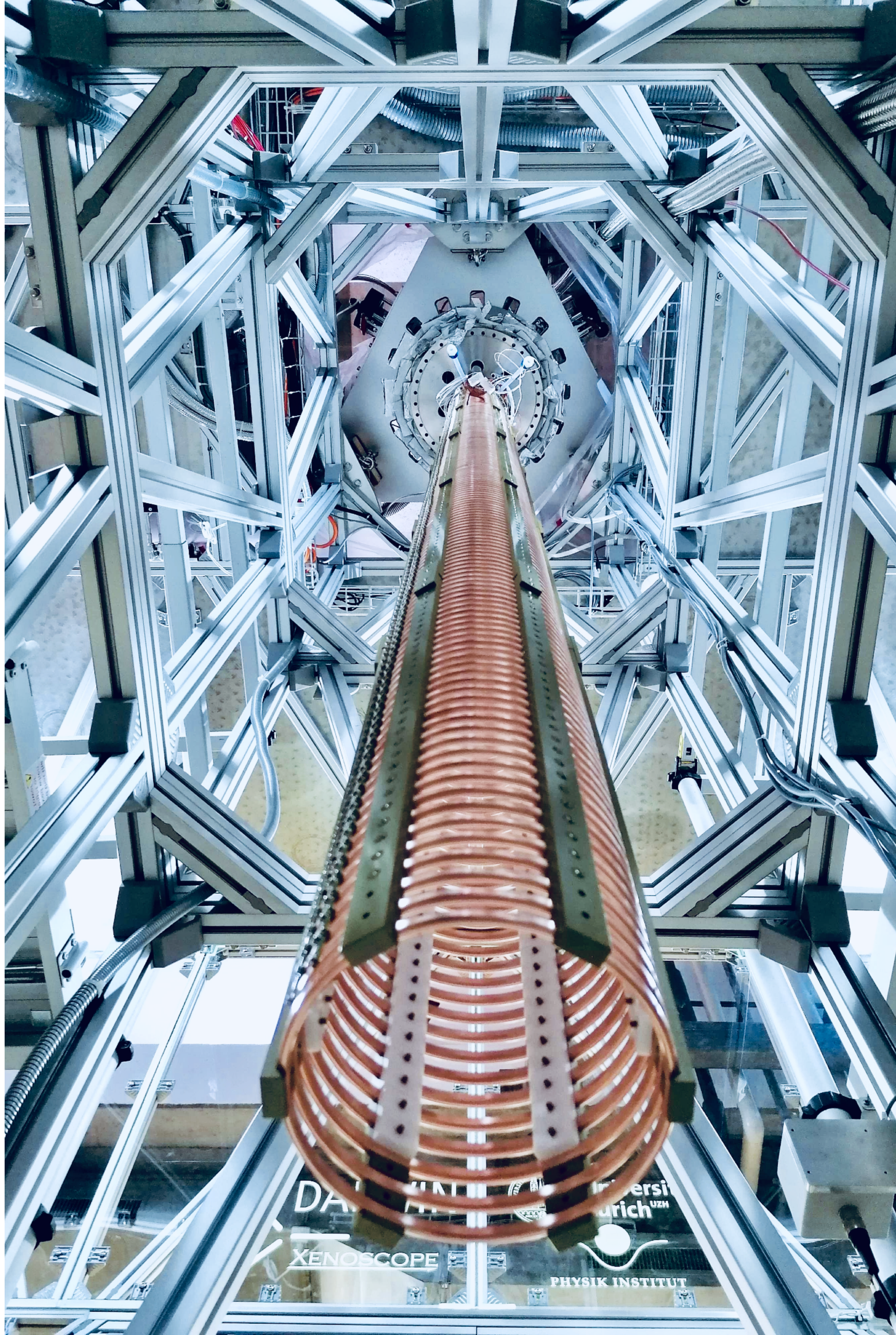
University of Zurich[UZH]

Xenoscope – A full-scale vertical demonstrator for the DARWIN observatory

LowRAD Symposium

Münster | June 30 2023

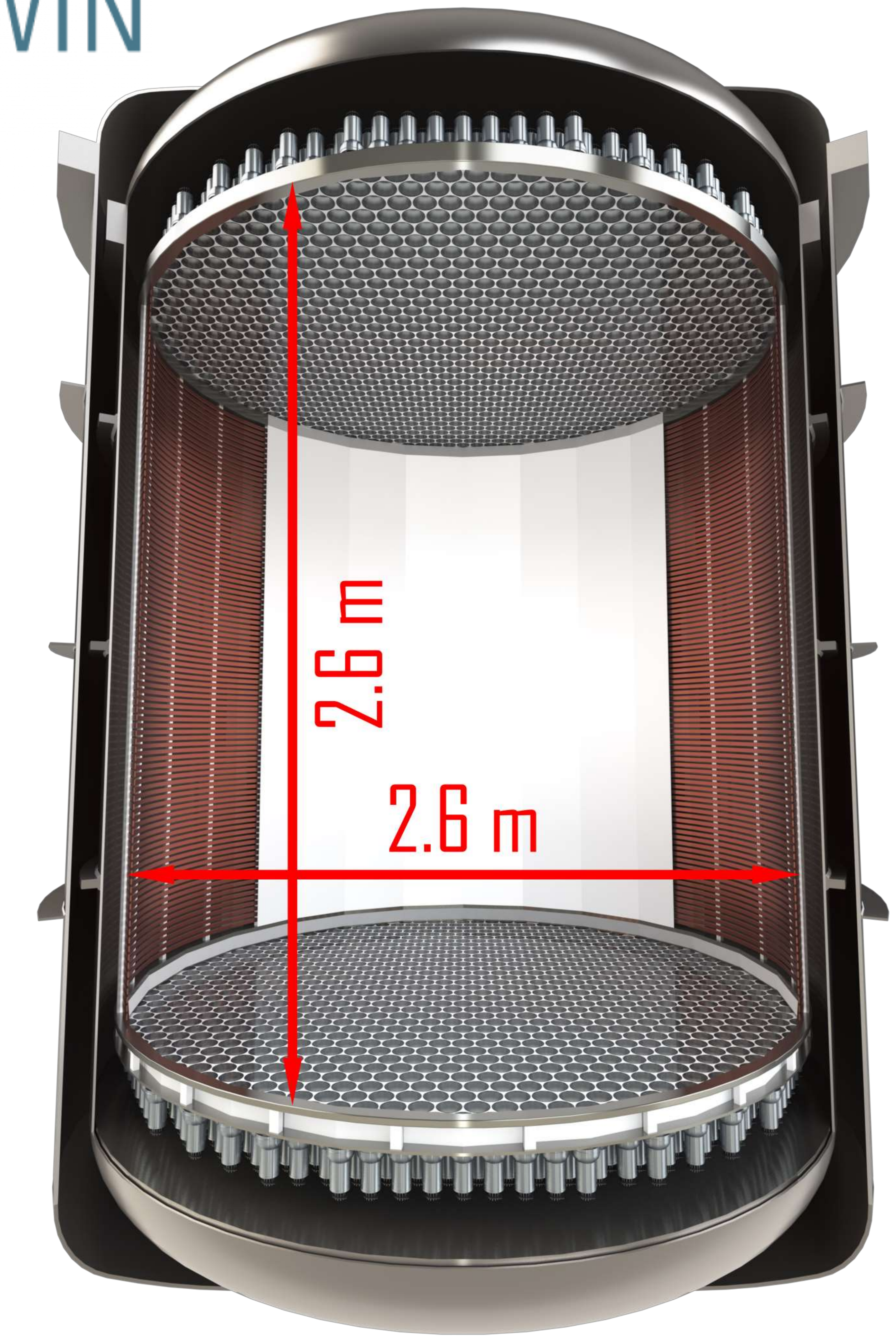
Christian Wittweg on behalf of the Xenoscope team:
Marta Babicz, Laura Baudis, Alexander Bismark, Yanina Biondi, Jose Cuenca García, Paloma Cimental, Michelle Galloway, Frédéric Girard, Andrej Marrafino, Sana Ouahada, Ricardo Peres, Mariana Rajado Silva, Diego Ramírez García, Patricia Sanchez-Lucas, Kevin Thieme, Christian Wittweg



Challenges for DARWIN

- Electrode manufacturing, quality and sagging
- Long electron drift:
  - HV delivery
  - Electrons captured by impurities
  - Longitudinal and transverse diffusion
  - Stronger impact of optical properties for long light paths
- Stringent background requirements:
  - Radiopurity
  - New photosensors needed?
  - Radon emanation
  - Active removal of radiogenic impurities
- …

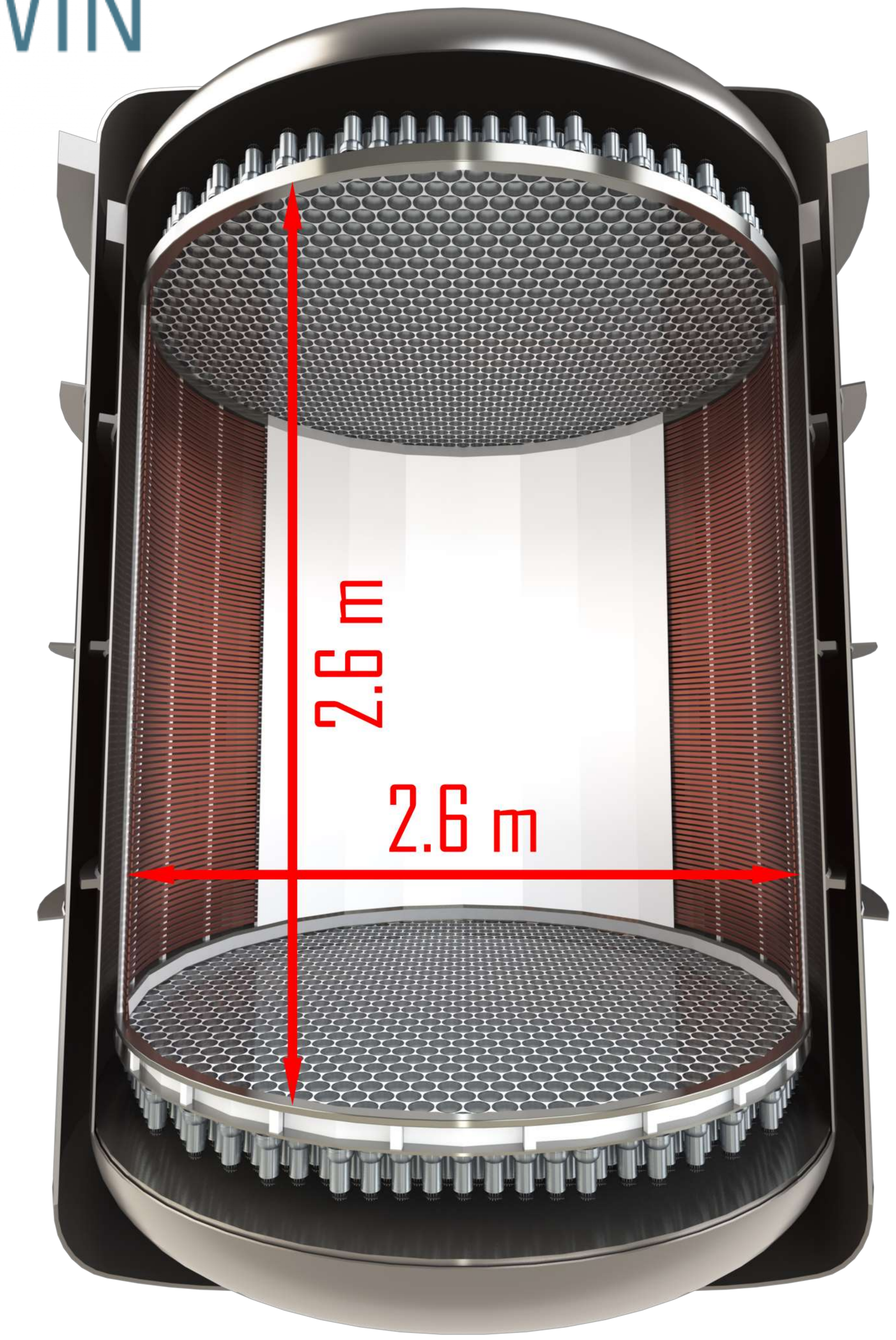
DARWIN



Challenges for DARWIN

- Electrode manufacturing, quality and sagging
- **Long electron drift:**
  - **HV delivery**
  - **Electrons captured by impurities**
  - **Longitudinal and transverse diffusion**
  - **Stronger impact of optical properties for long light paths**
- Stringent background requirements:
  - Radiopurity
  - New **photosensors** needed?
  - Radon emanation
  - Active removal of radiogenic impurities
- …

DARWIN



The DARWIN demonstrators

Pancake @ Uni Freiburg

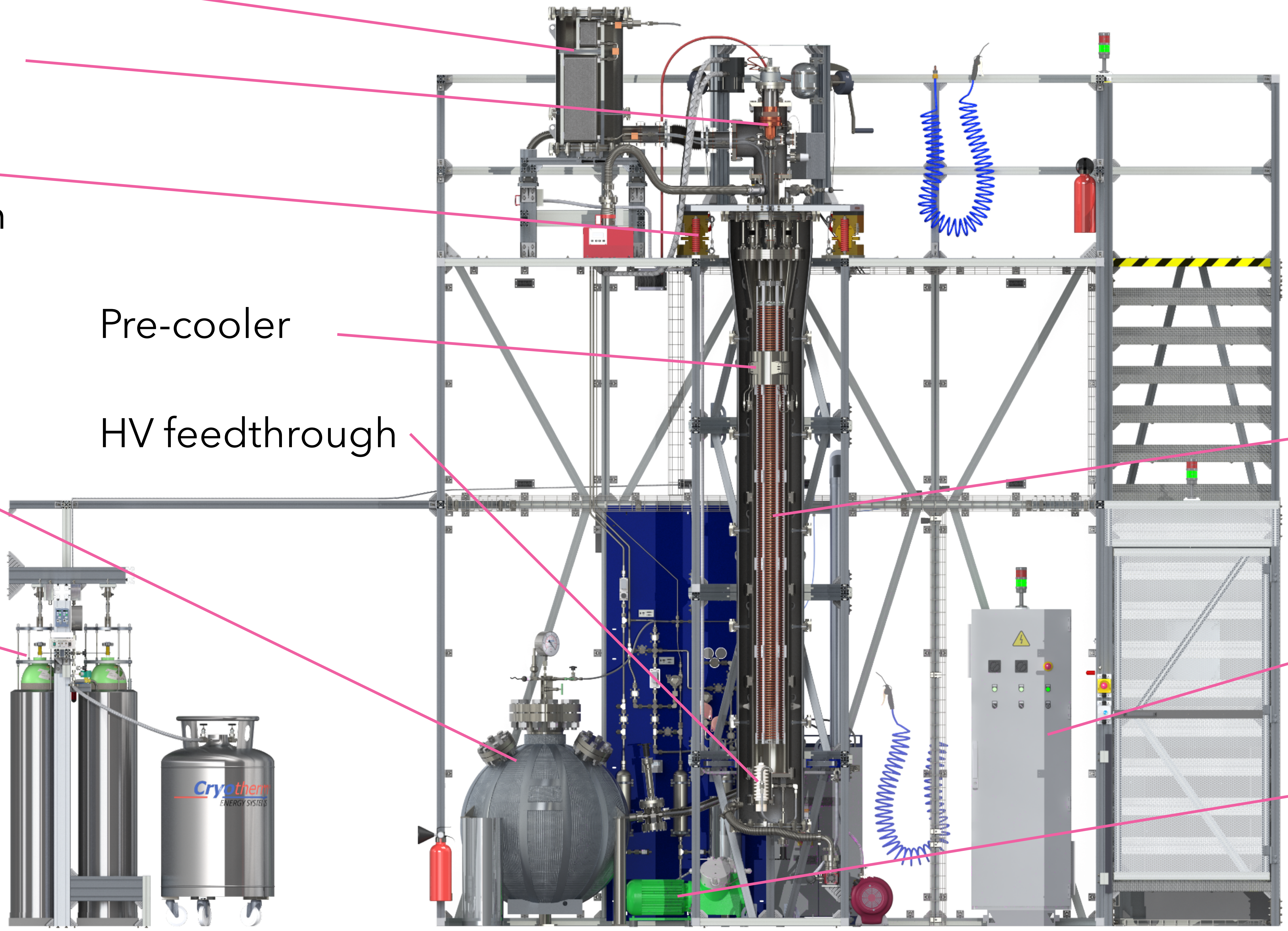
- Test full size DARWIN electrodes in ~300 kg of liquid xenon
- Test any flat detector component up to ø of 2.75 m

Xenoscope @ UZH

- Proof of principle: electron drift over 2.6 m LXe
- Study of electron cloud diffusion
- Purification, photosensor and HV R&D

The Xenoscope facility

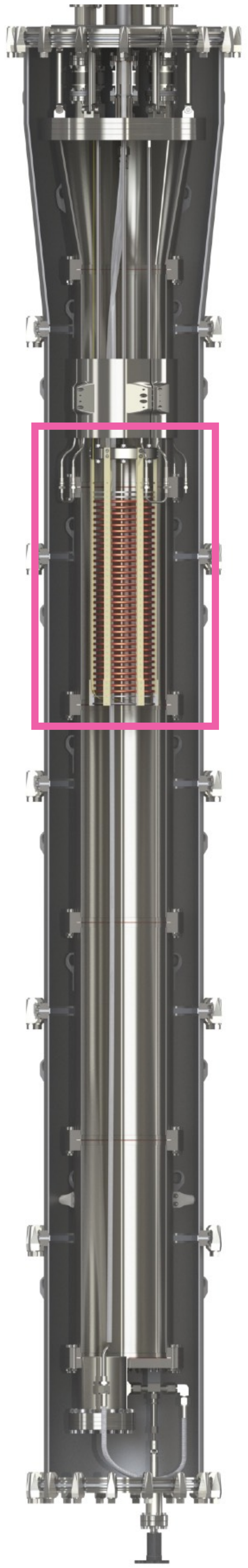
JINST 16 P08052 (2021)

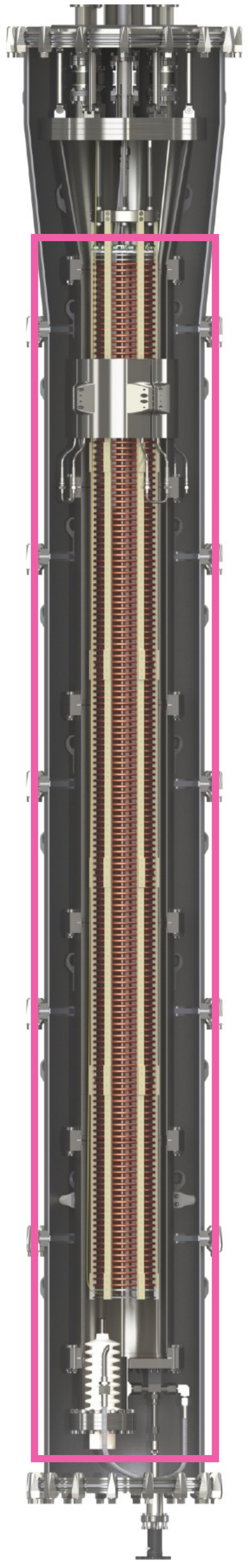


Phased approach for Xenoscope

Phase 1: Purity monitor (2022)

- Purity monitor with charge readout and ≈50 cm drift
- Measure electron lifetime, drift velocity and longitudinal diffusion
- Demonstrate stable operation for ≈ 3 months
- Test new cryostat pre-cooler and liquid xenon recuperation with BoX



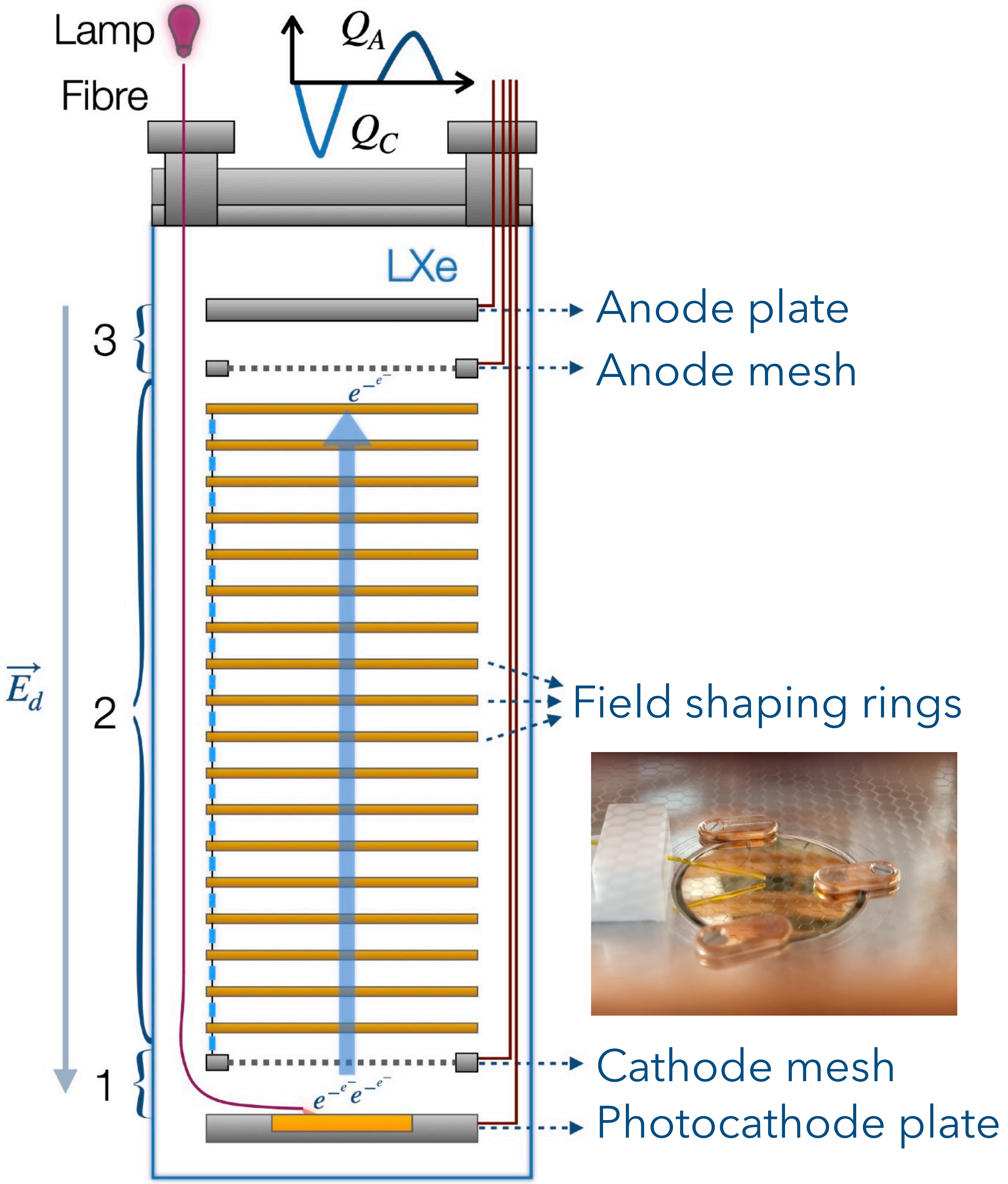


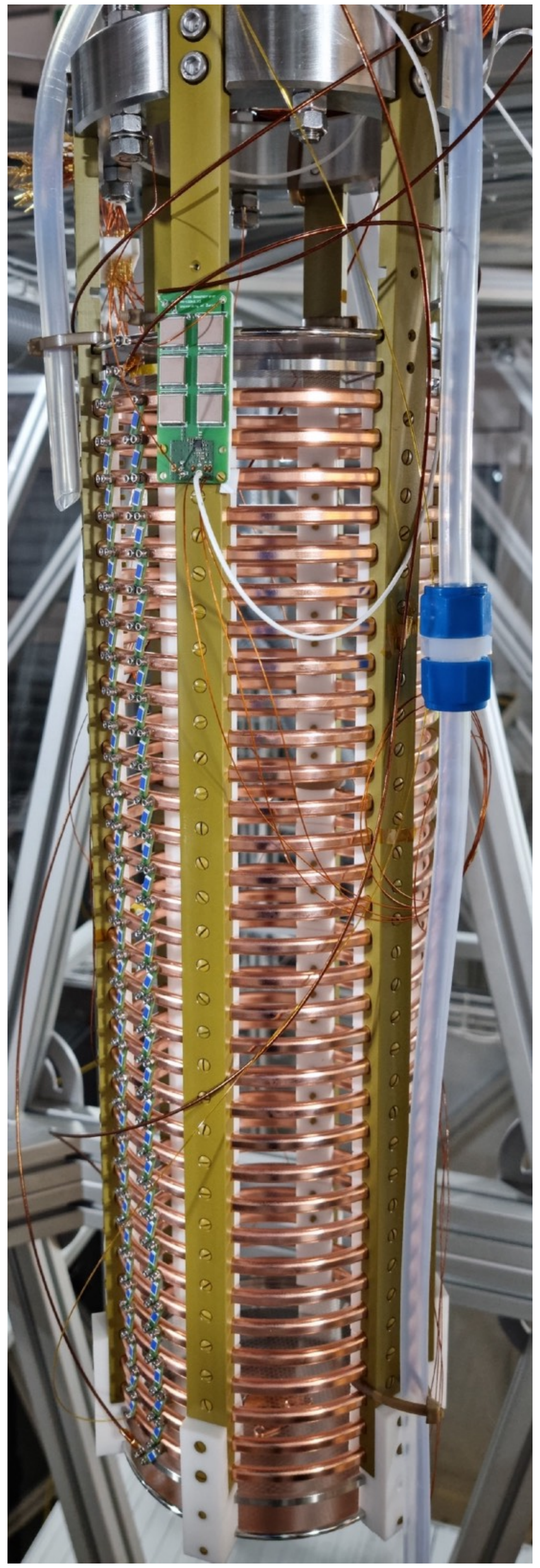
Phase 2: Dual-phase time projection chamber (2023)

- 2.6 m drift length
- Light readout with SiPM array
- High voltage up to 50 kV
- Liquid level measurement and active control
- External calibration sources and cosmic muons in addition to xenon flash lamp

Phase 1: Purity monitor

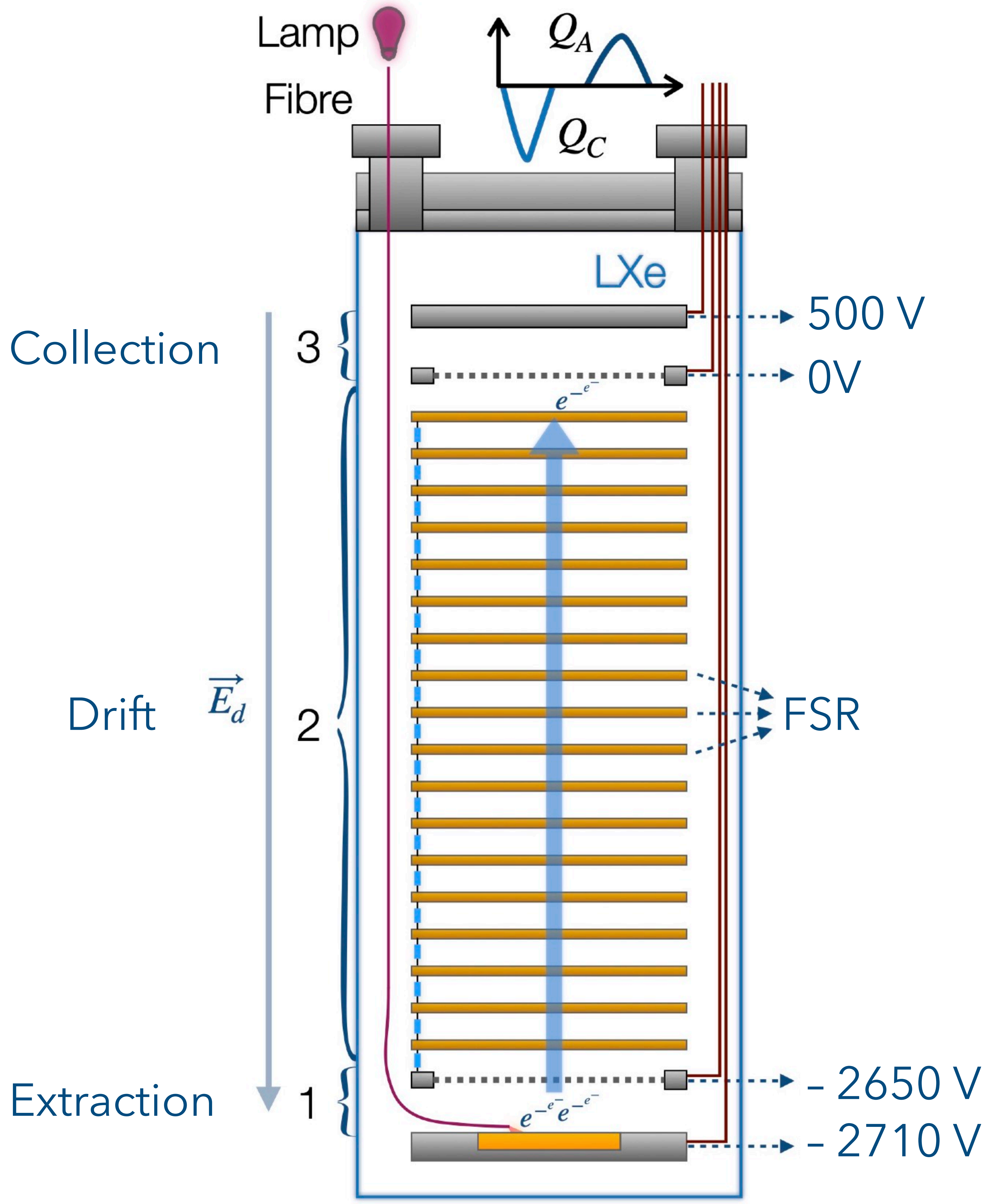
- Drift length of ≈50 cm
- Gold-coated quartz substrate photocathode produced at UZH Physics Institute
- Light from xenon flash lamp (190 – 2000 nm) injected via optical fiber
- Hexagonally etched stainless steel meshes
- Field-shaping rings for homogeneous drift fields of 25 – 75 V/cm
- Measure induced currents from electron clouds, convert to voltage signals and integrate to obtain anode and cathode charges





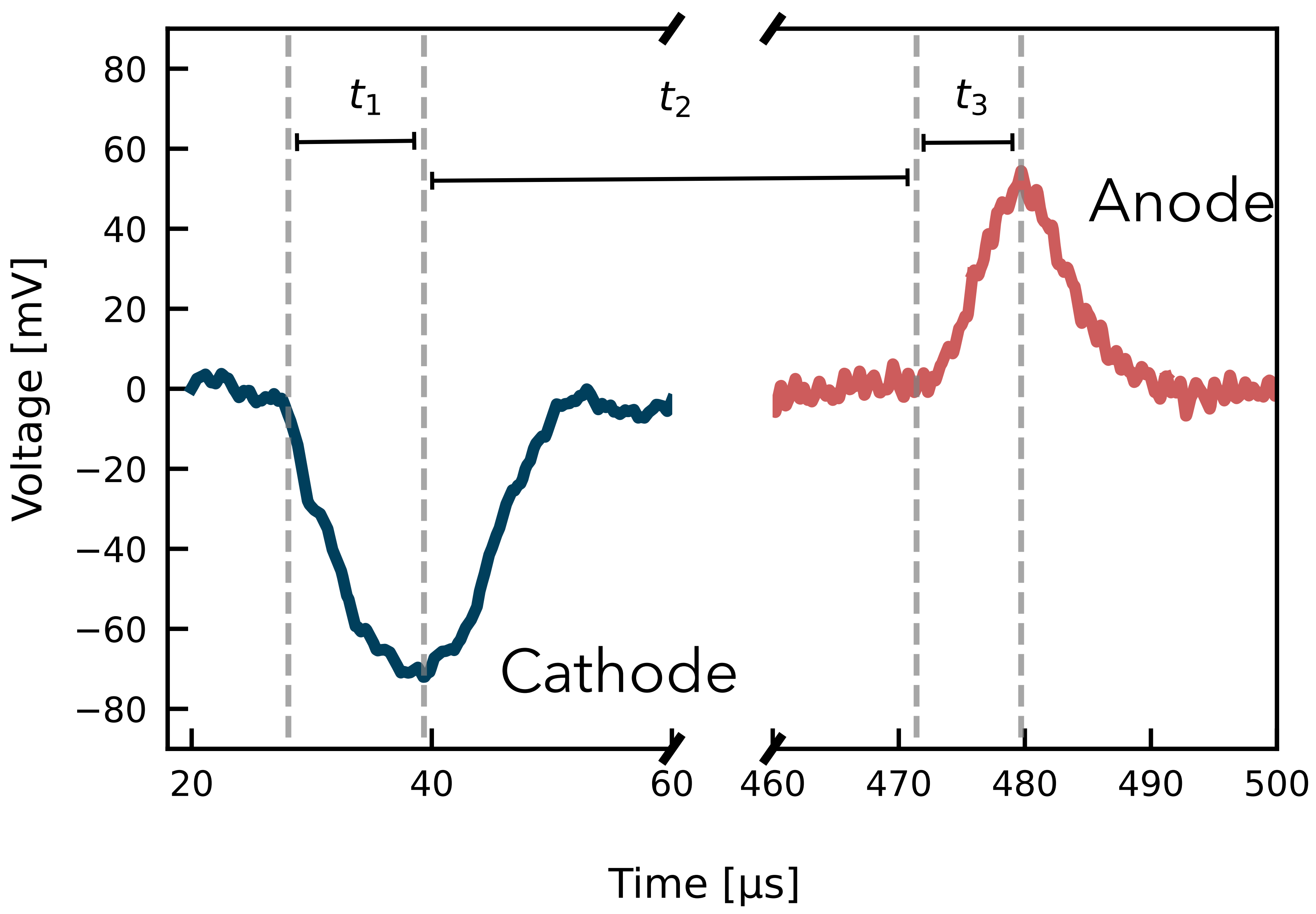
arXiv:2303.13963

Purity monitor signals



- 343 kg of xenon
- Measurements at (2.05±0.01) bar and (177.6±0.1) K
- Illumination at 1 Hz
- First observable waveforms after 26.5 days of purification

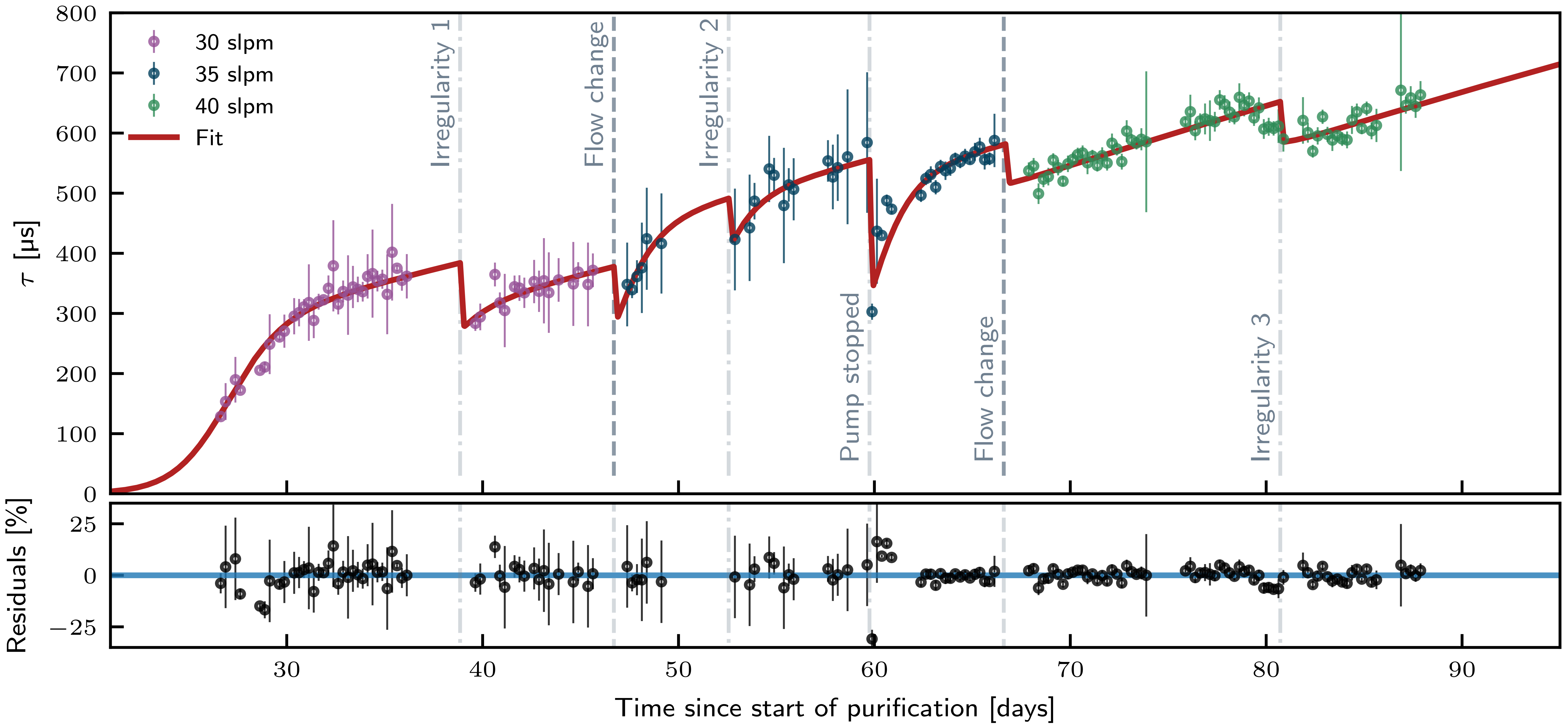
$$\frac{Q_A}{Q_C} = \frac{t_1}{t_3} e^{-(t_1+t_2+t_3)/\tau} \frac{(e^{t_3/\tau} - 1)}{(e^{-t_1/\tau} - 1)}$$



- Pulse delay: **drift velocity**
- Relative pulse area: **electron drift lifetime**
- Pulse shape: **longitudinal electron cloud diffusion**

Purification performance

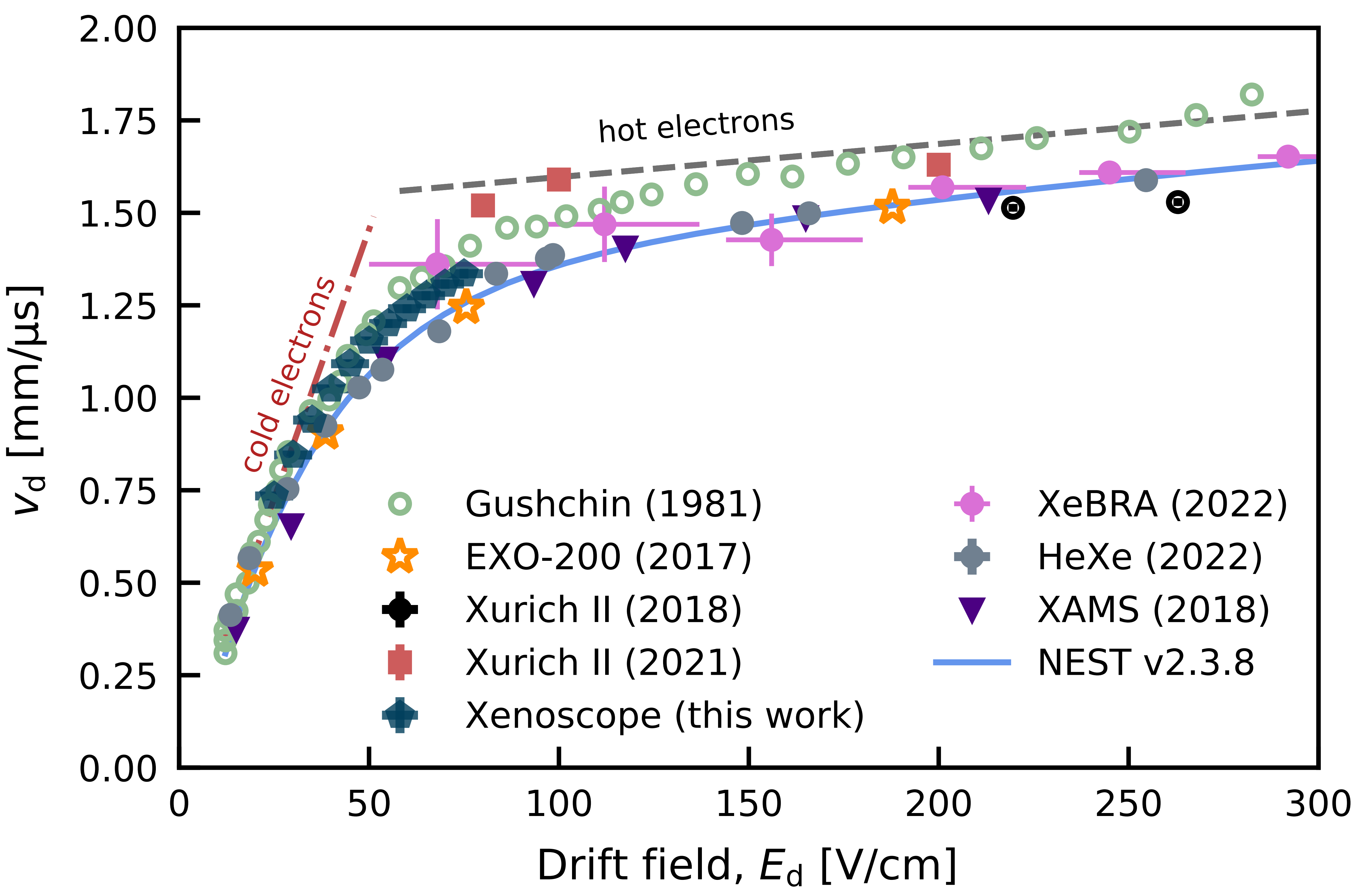
- Maximum flux limited to 40 slpm during purity monitor phase
  - 30 slpm: 46.6 d
  - 35 slpm: 20.0 d
  - 40 slpm: 21.2 d
- Electron drift lifetime drops during flow changes due to liberation of trapped impurities at the LXe surface collar
- Reached **(664 ± 23) μs** comparable to LUX and XENON1T
- Expect to reach > 2 ms with gas phase purification and 80 slpm



$$M_\mathrm{l}\frac{\mathrm{d}I_\mathrm{l}}{\mathrm{d}t}^{(j)} = -F_\mathrm{l}\rho I_\mathrm{l} + \left(\frac{\Lambda_{\mathrm{l},0}}{1+\frac{t-\Delta t_l^{(j)}}{T_{1/2,l}}} + C_\mathrm{l}\right) - \frac{\varepsilon_1 P_\mathrm{C} I_\mathrm{l}}{h} + \frac{\varepsilon_2 P I_\mathrm{g}}{h} + M_\mathrm{l}\Delta I_\mathrm{l}^{(j)}\int\delta\left(t-t^{(j)}\right)\mathrm{d}t$$

Purification | Outgassing | Gas-liquid impurity exchange | Discontinuities

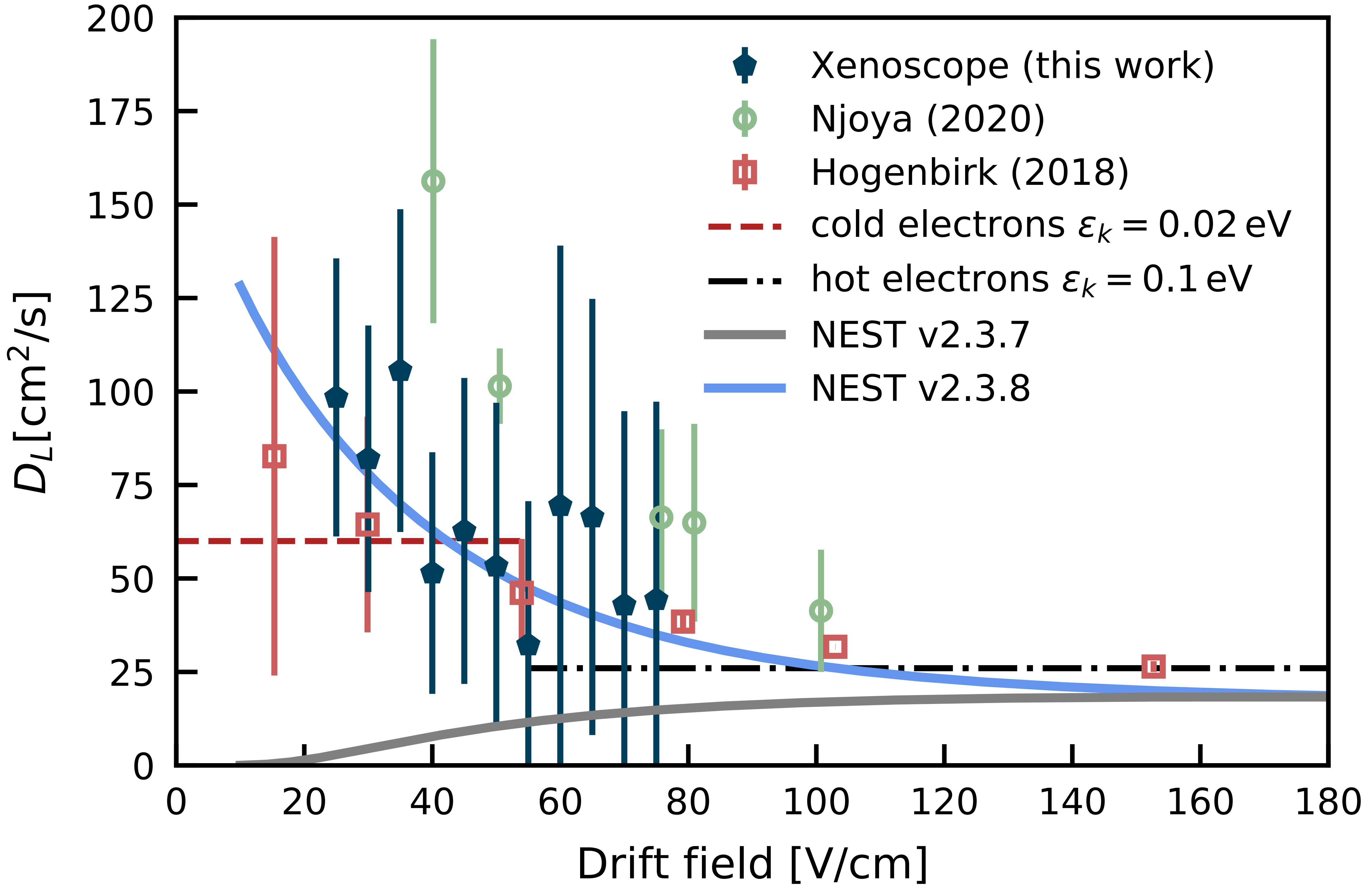
Electron drift velocity



$$v_d = \mu E_d = \frac{d}{t}$$

- Drift velocity measured from ***E*$_d$ = 25 - 75 V/cm**
- Measurement at the end of the purification campaign at constant electron lifetime
- Electron mobility ***μ*** gives time between elastic collisions of electrons with xenon (and impurities, also inelastic)
- Depends on temperature, density and electron energy
- Impurities can offer more efficient energy loss than scattering on xenon leading to higher mobility

Longitudinal diffusion



Anode Gaussian peak width

$$\sigma^2 = \frac{D_L 2t^3}{d^2} + \sigma_0^2$$

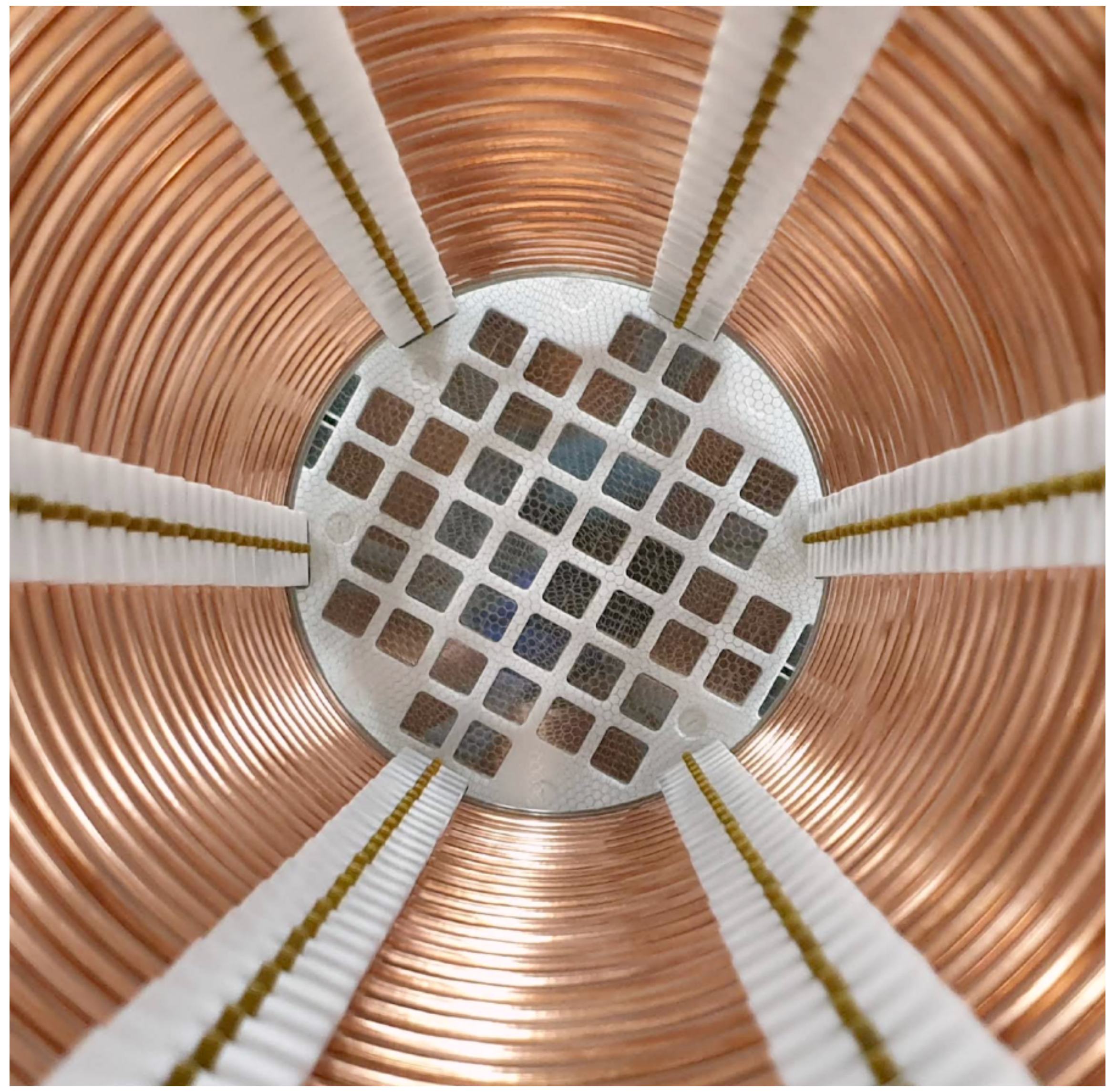
Cathode Gaussian peak width

Diffusion coefficient, drift length, drift time

$$D_L = \frac{(\varepsilon_T + \varepsilon)}{e}\mu$$

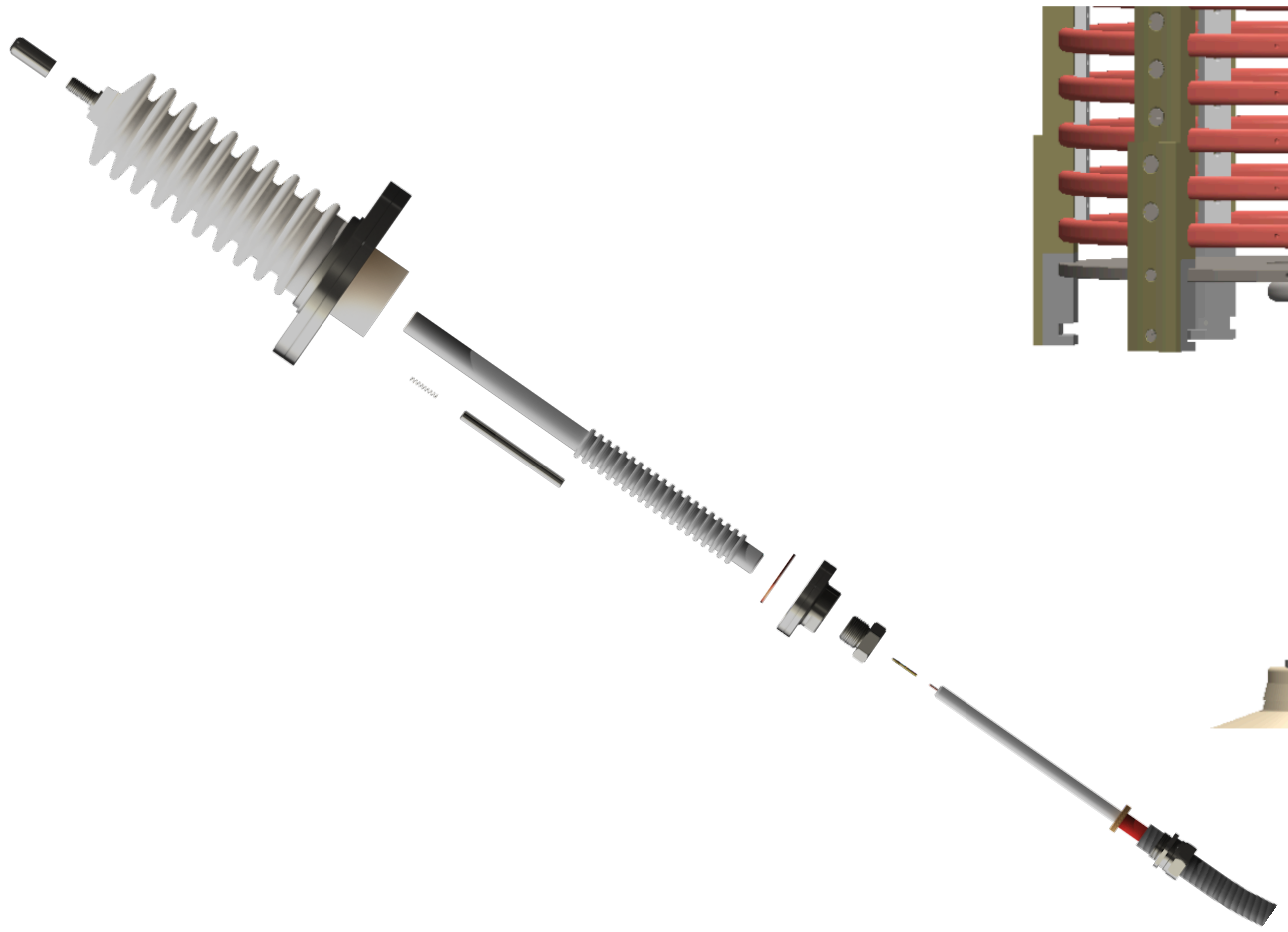
Systematic effect	Treatment and uncertainty
Measured	
Anode signal width, σ	Gaussian plus sine fit, $2-3\%$.
Drift time, t_2+t_3	Time interval between extrema of the cathode and anode signal fits.
Initial signal width	Introduced by the lamp pulse. Measurements in vacuum and in LXe, $(2.4\pm0.2)\,\mu$s.
Electronics	RC time constant calculation from a square pulse, $0.2\,\mu$s.
Drift length, d_2+d_3	Drift distance of the electron cloud, taken as (513 ± 7) mm when accounting for the potential contraction of the components at 177 K with an assumed 1% thermal contraction, and the position of the centre of the cloud distribution in drift regions with respect the extrema of the signals.
Filtering and processing	Maximum 4% of anode signal width.
Simulated	
Detector response	COMSOL 3D model of the detector to derive the weighting potential, 10% uncertainty in the response.
Assumed	
Coulomb repulsion	Calculated with empirical model from [48], assumption of additional 5% uncertainty in the initial signal spread.
Electron attachment	Neglected, 4th-order correction: $\frac{D_L}{(v_d \cdot d)} \ll 1$.

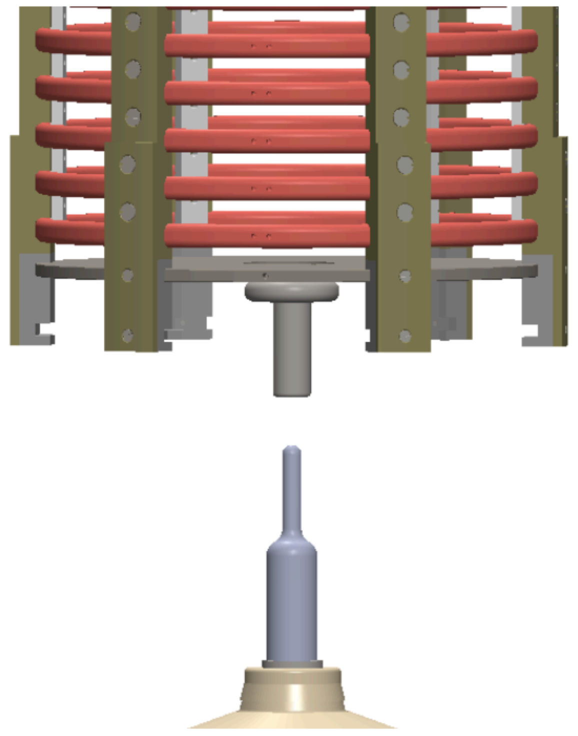
Phase 2: Dual-phase TPC



SiPM array

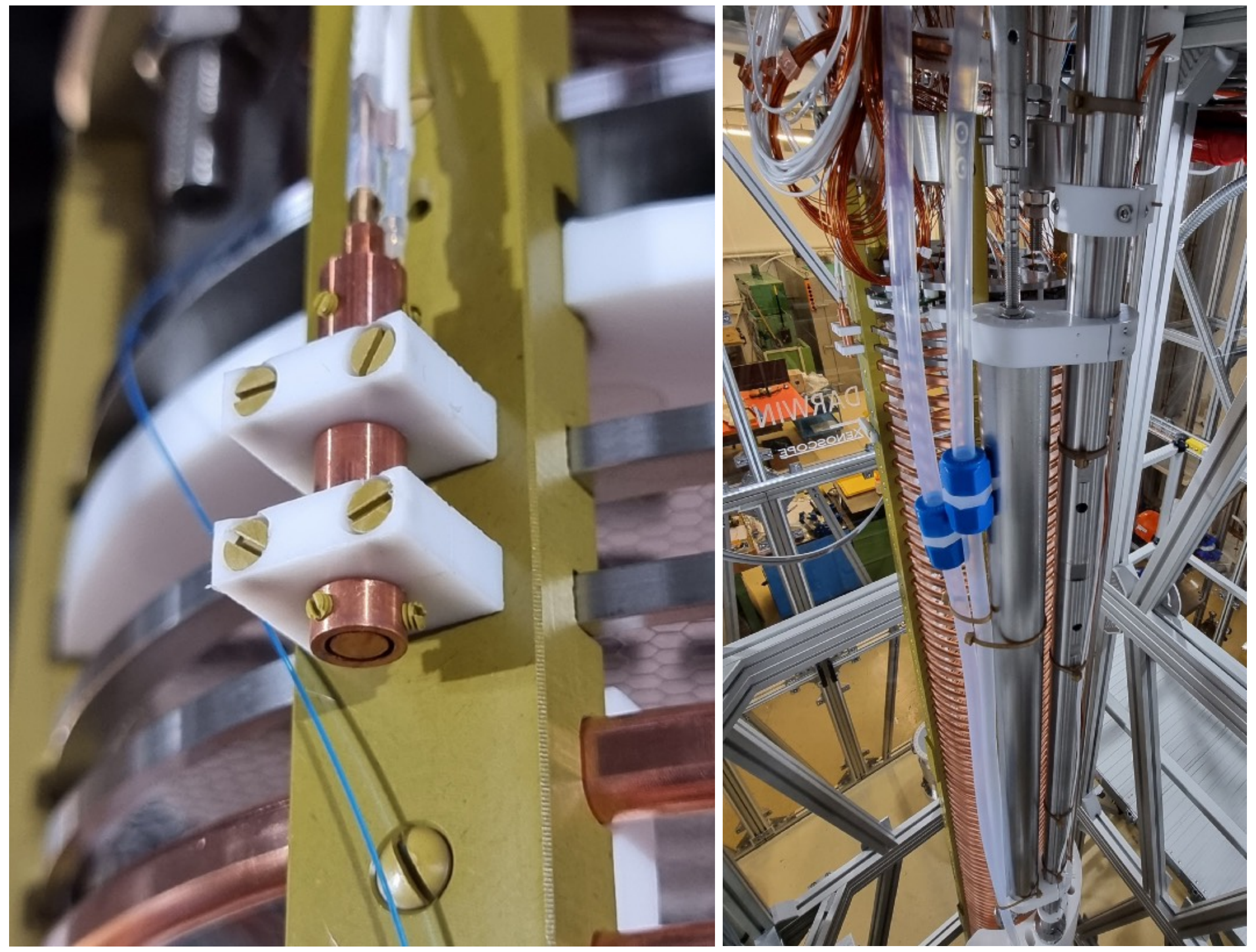
Xenon VUV light readout by 192 6x6 mm^2 SiPM cells read out in 16 channels.





HV delivery

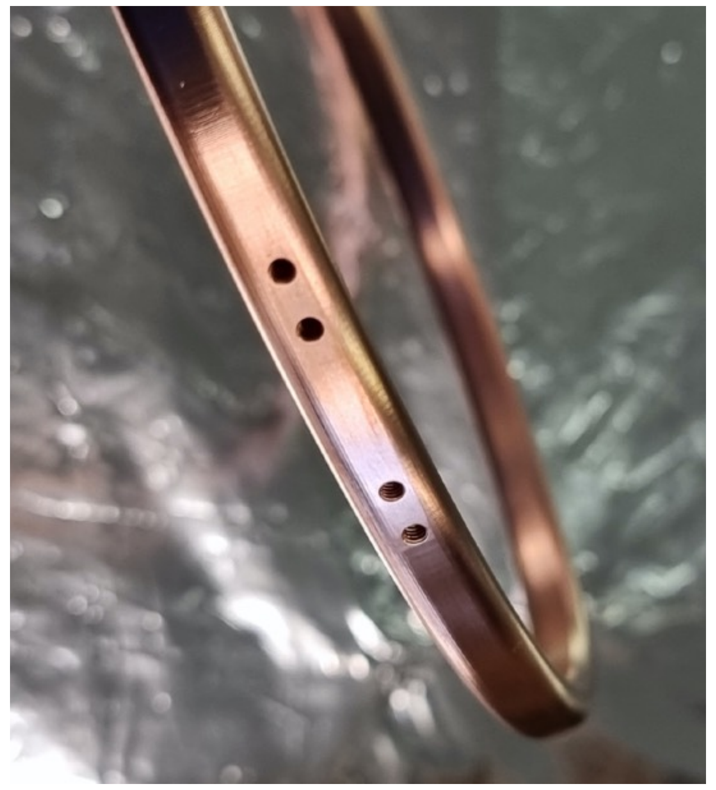
Custom cryofitted air-to-vacuum feedthrough, commercial vacuum-to-xenon feedthrough and in-house designed cathode connection.

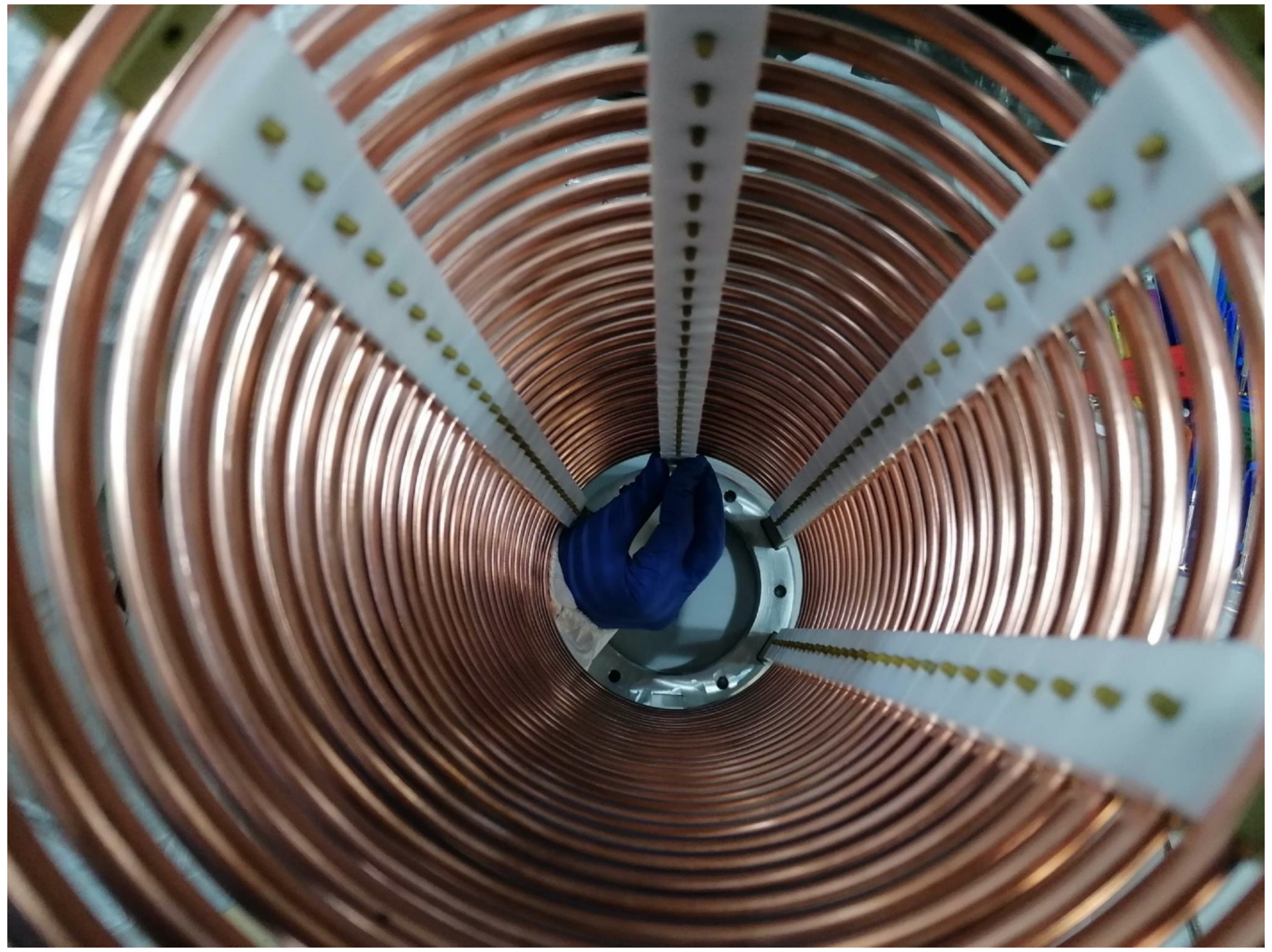


Liquid level control

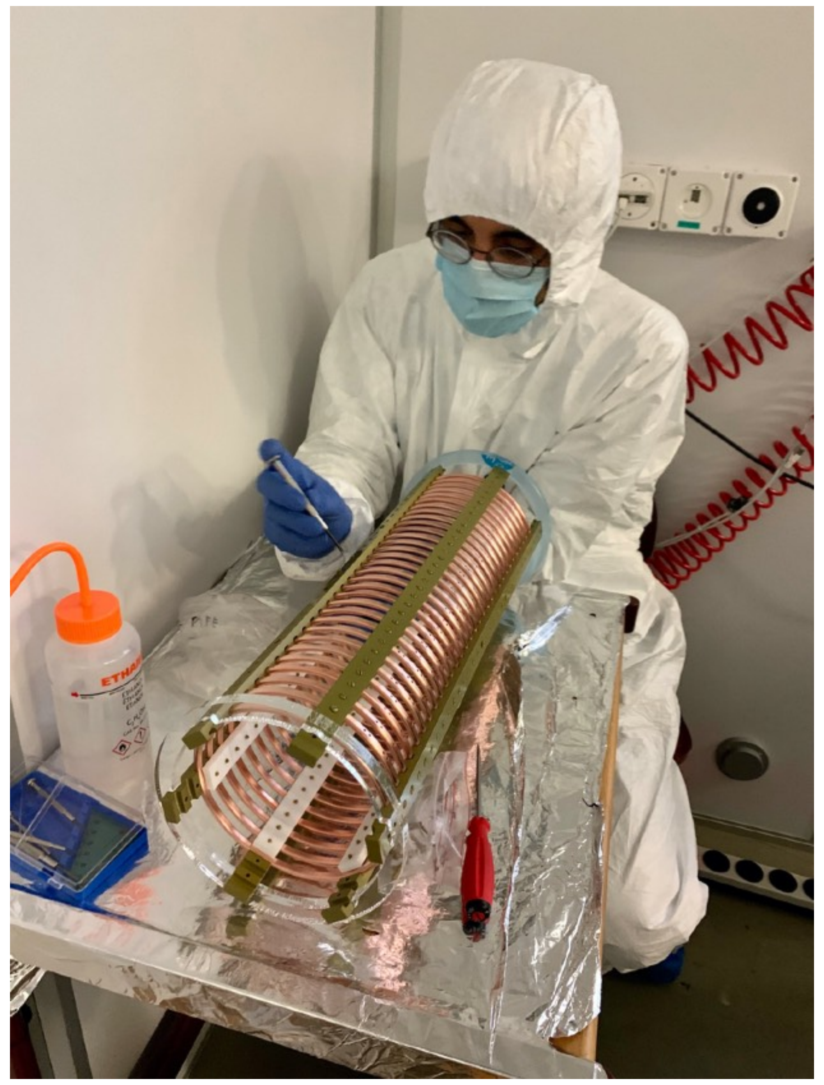
Real time monitoring of liquid level with three small capacitive level meters. Active level control with weir on motion feedthrough.

Field cage assembly

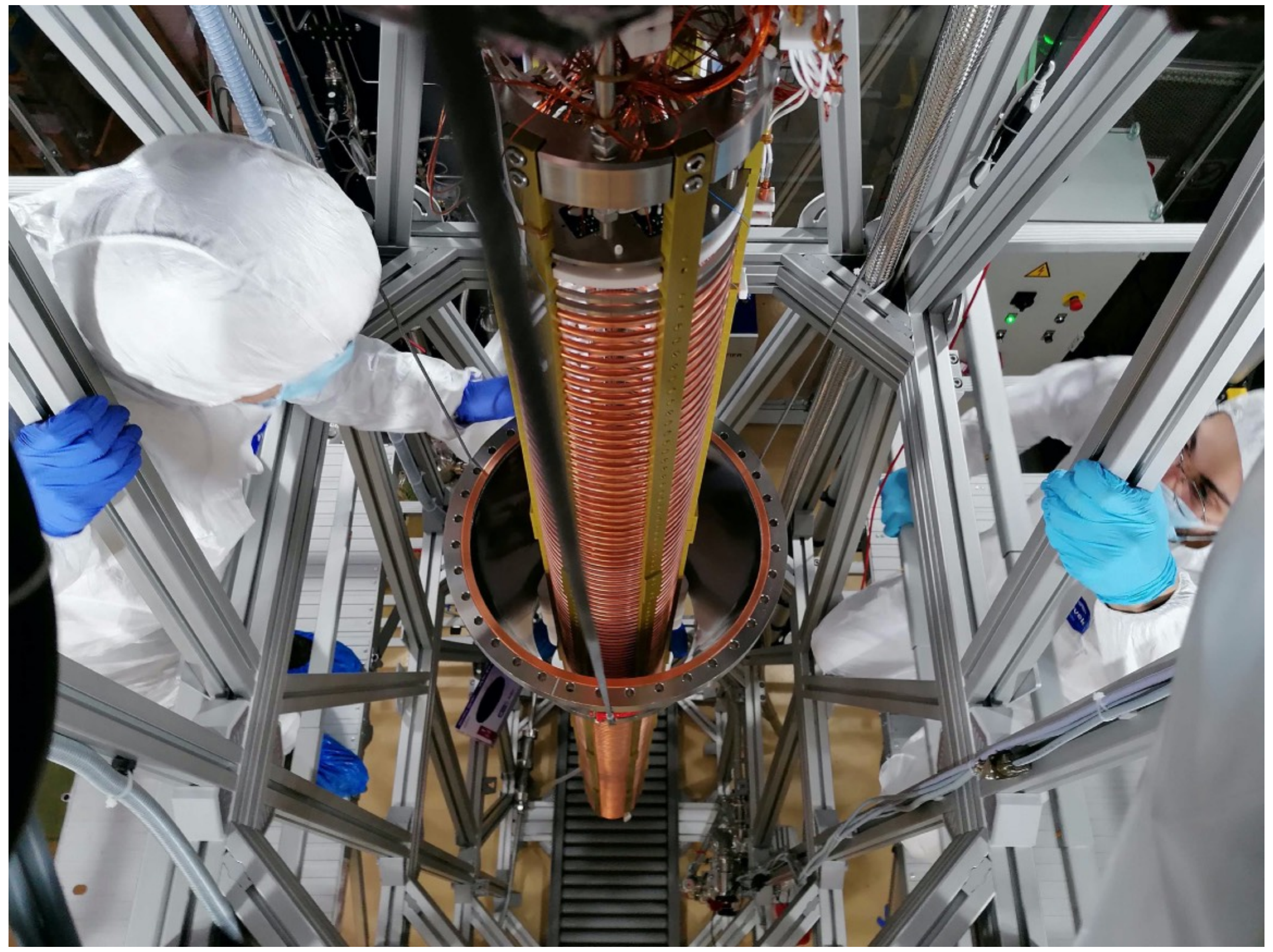




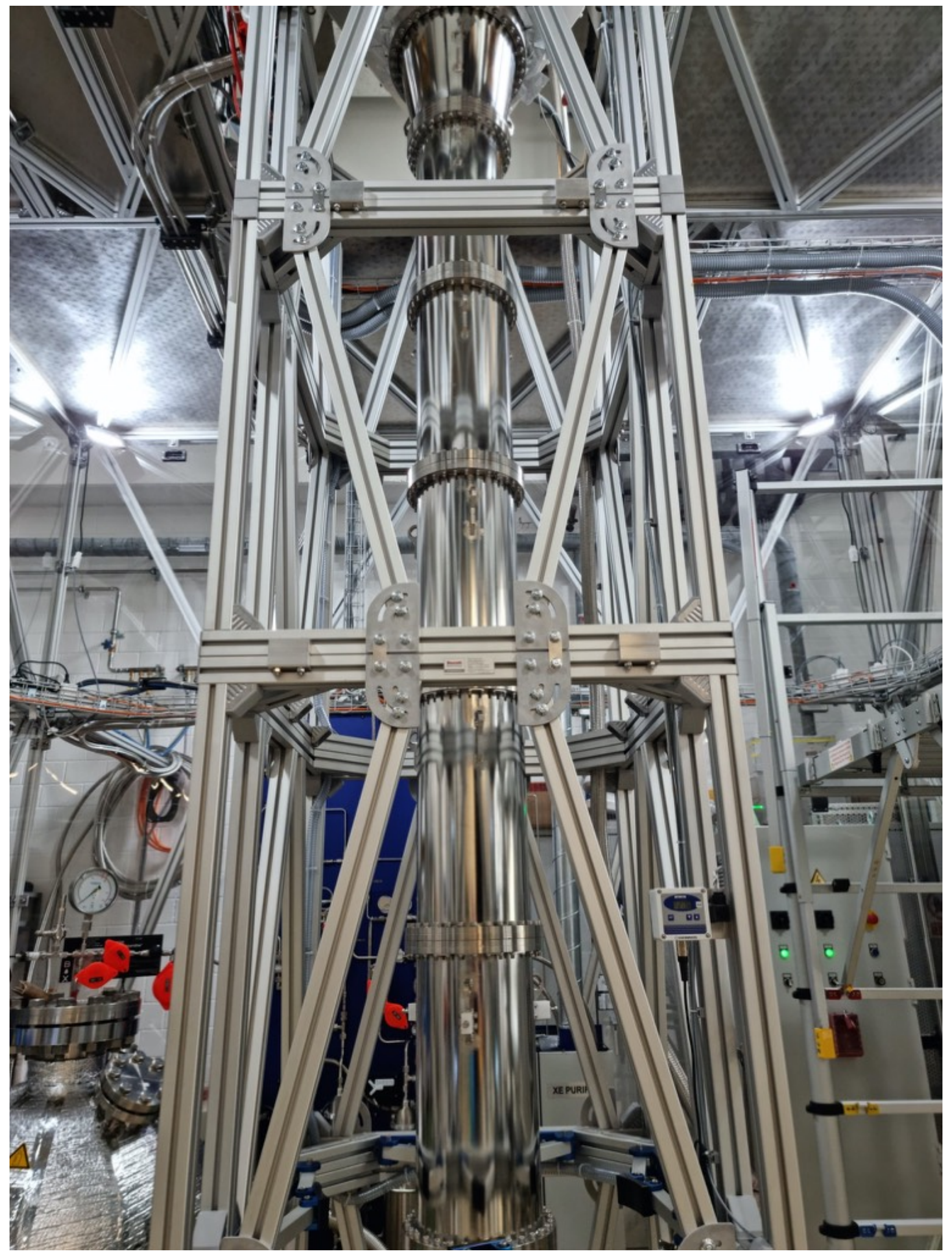
- Clean and electropolish 173 rings with 16 cm inner ø
- Two parallel 1 GΩ resistor chains (200 nA at 20 kV)
- 6 Torlon pillars with PTFE connectors
- Assemble modules in clean room, bag and install in Xenoscope provisional cleanroom.



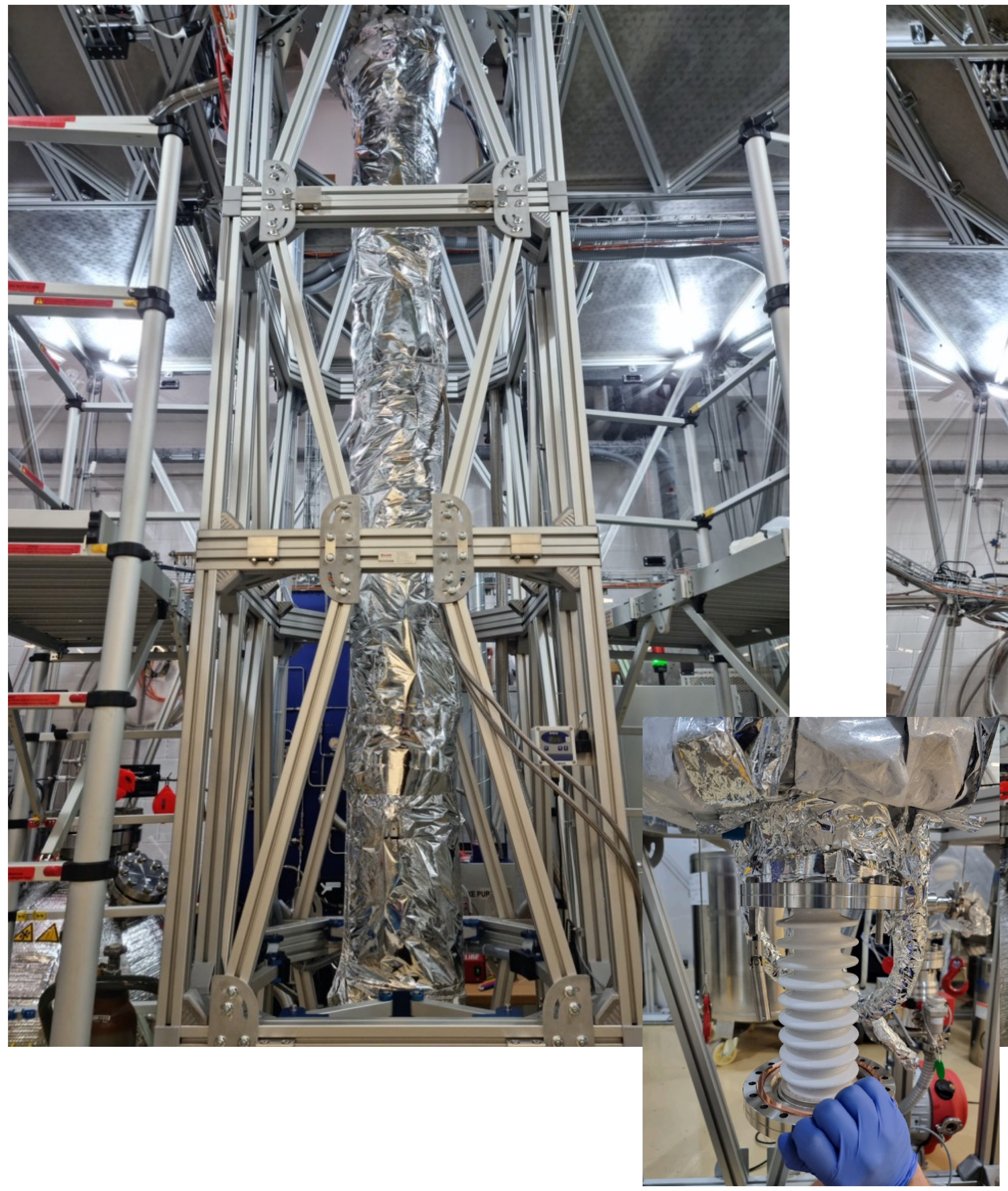
Closing time



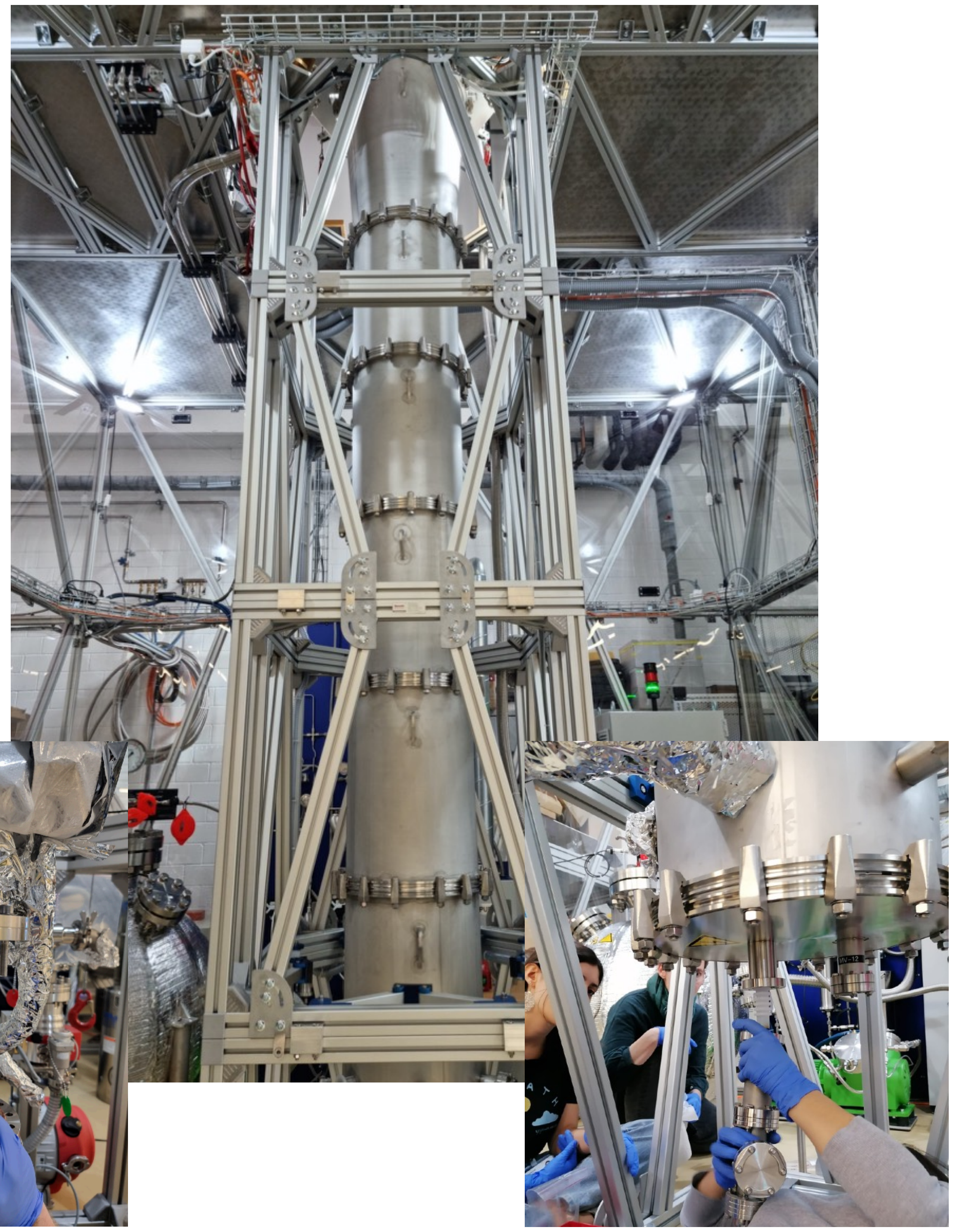
Full TPC installed.
Close section by section (… and do not forget the gasket).



Inner cryostat fully closed.



Add mylar insulation, install vacuum to LXe feedthrough.

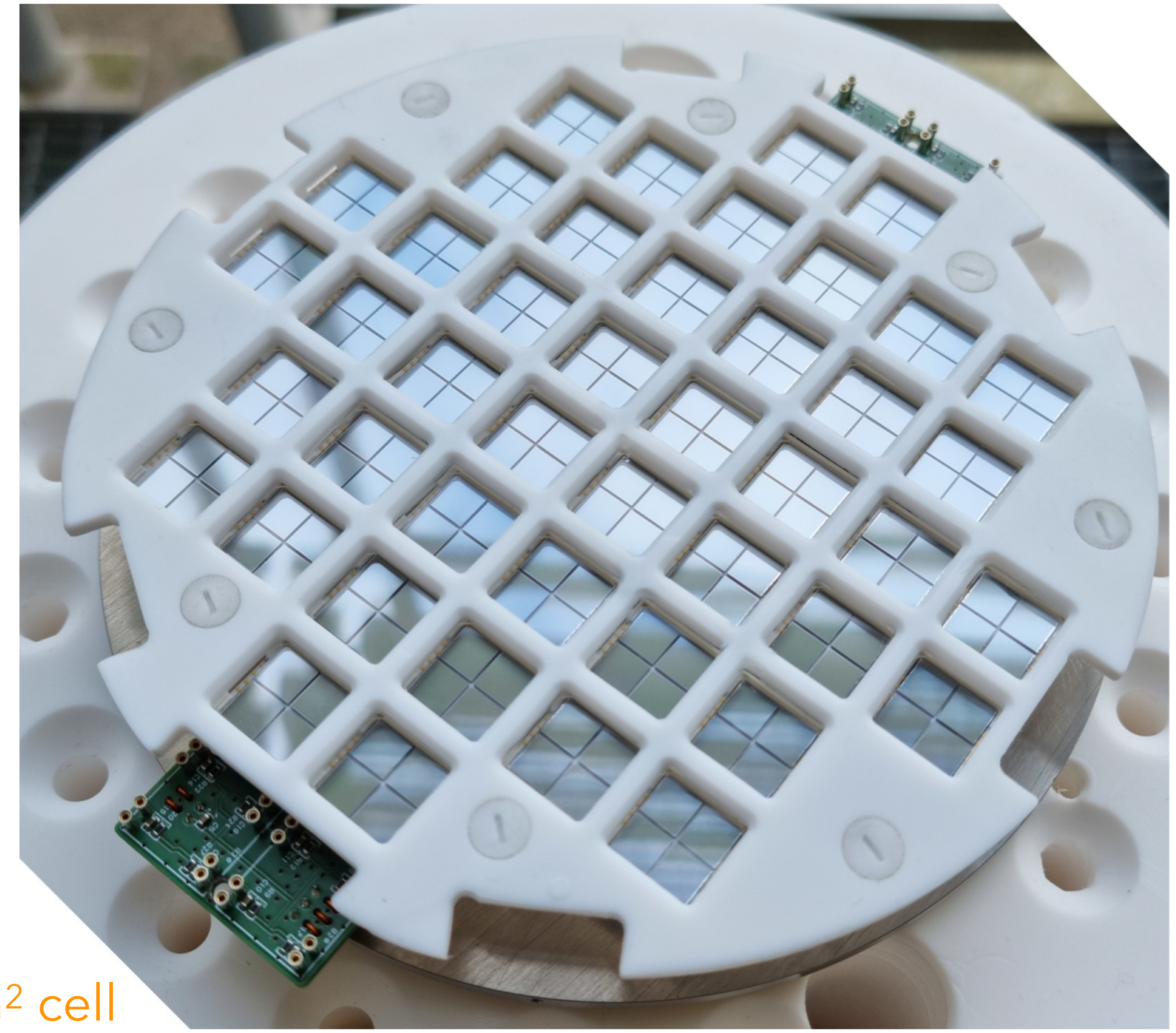


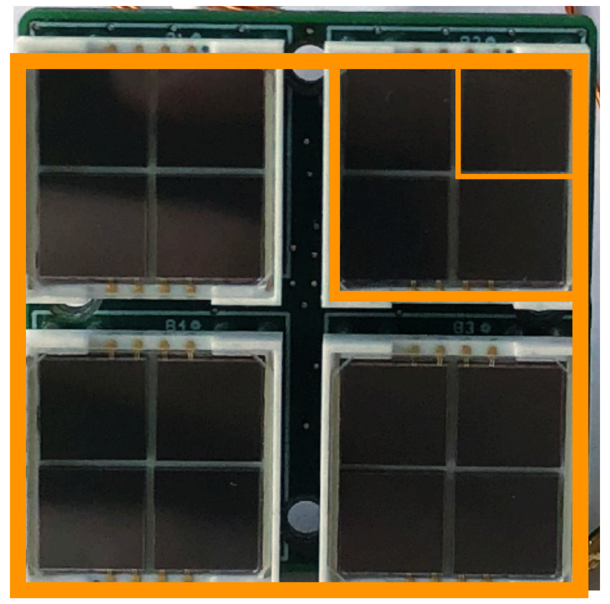
Close outer cryostat section by section, connect box, install HV feedthrough.

SiPM array

- SiPMs characterized individually with LED in dark box before array assembly
- 192 SiPM cells
- 48 VUV4 MPPCs by Hamamatsu (**quads**)
- The array has 12 **tiles**. Each tile consists of four 12×12mm2 VUV SiPMs from Hamamatsu (S13371-6050CQ-02 MPPC)
- 20x amplification per tile
- Parallel readout per tile => 12 channels
- Two optical fibers for calibration

JINST 18 C03027 (2023)





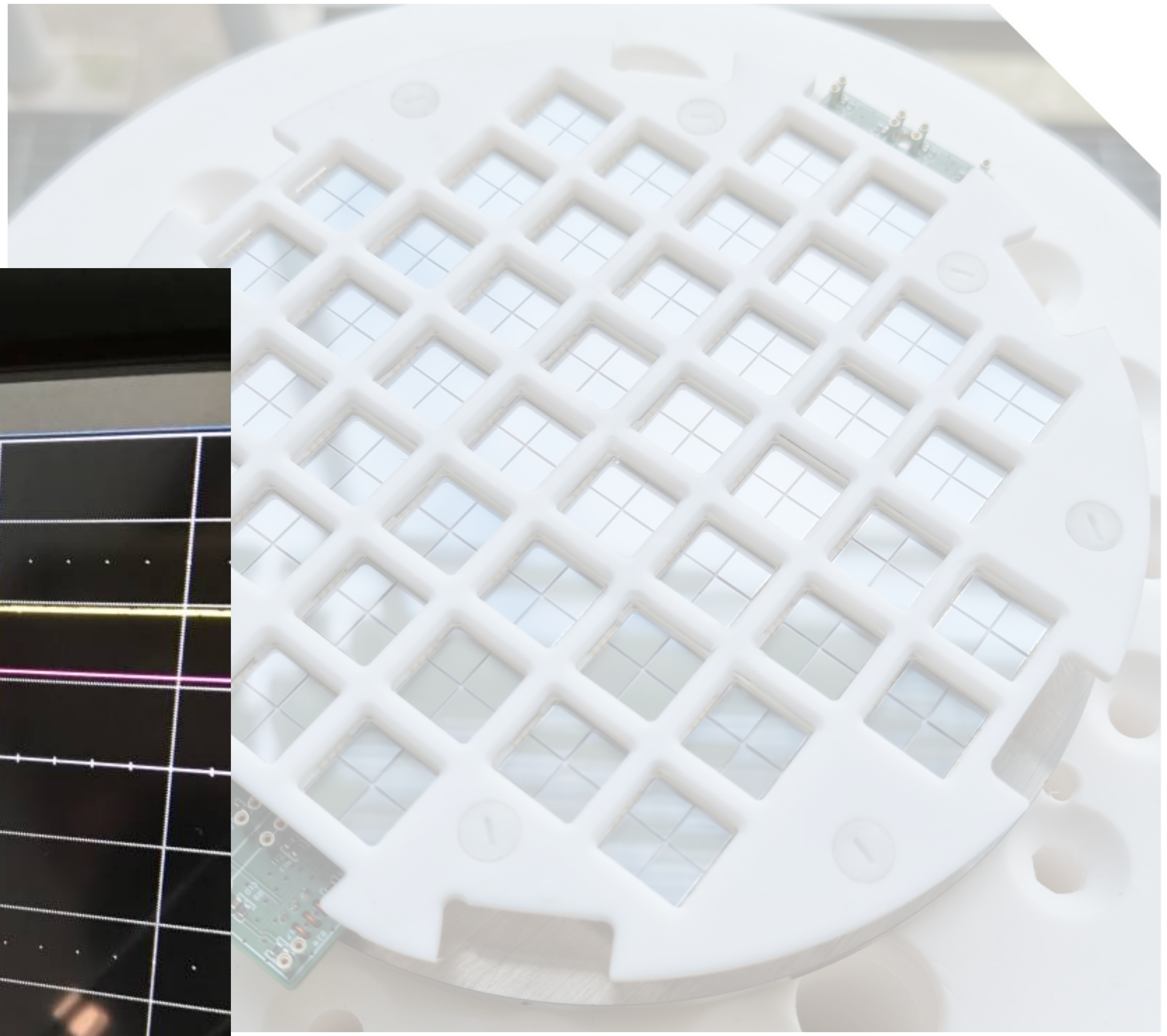
6x6 mm^2 cell

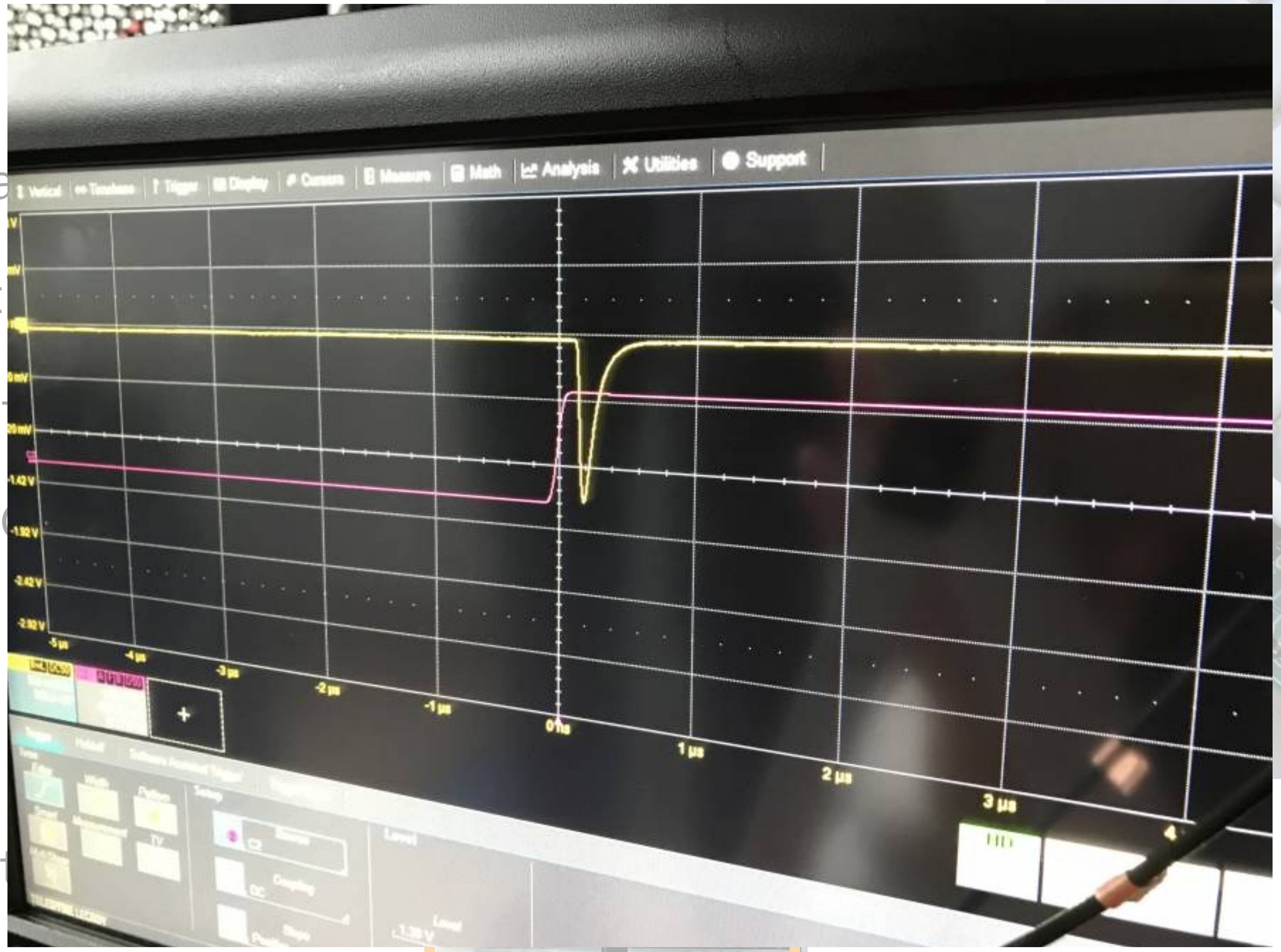
Quad = 4 cells

Tile = 4 Hamamatsu VUV4 quads

SiPM array

- SiPMs characterized individually with LED in dark box before array assembly
- 192 SiPM cells
- 48 VUV4 MPPCs by Hamama
- The array has 12 **tiles**. Each t four 12×12mm2 VUV SiPMs Hamamatsu (S13371-6050C
- 20x amplification per tile
- Parallel readout per tile => 1
- Two optical fibers for calibrat



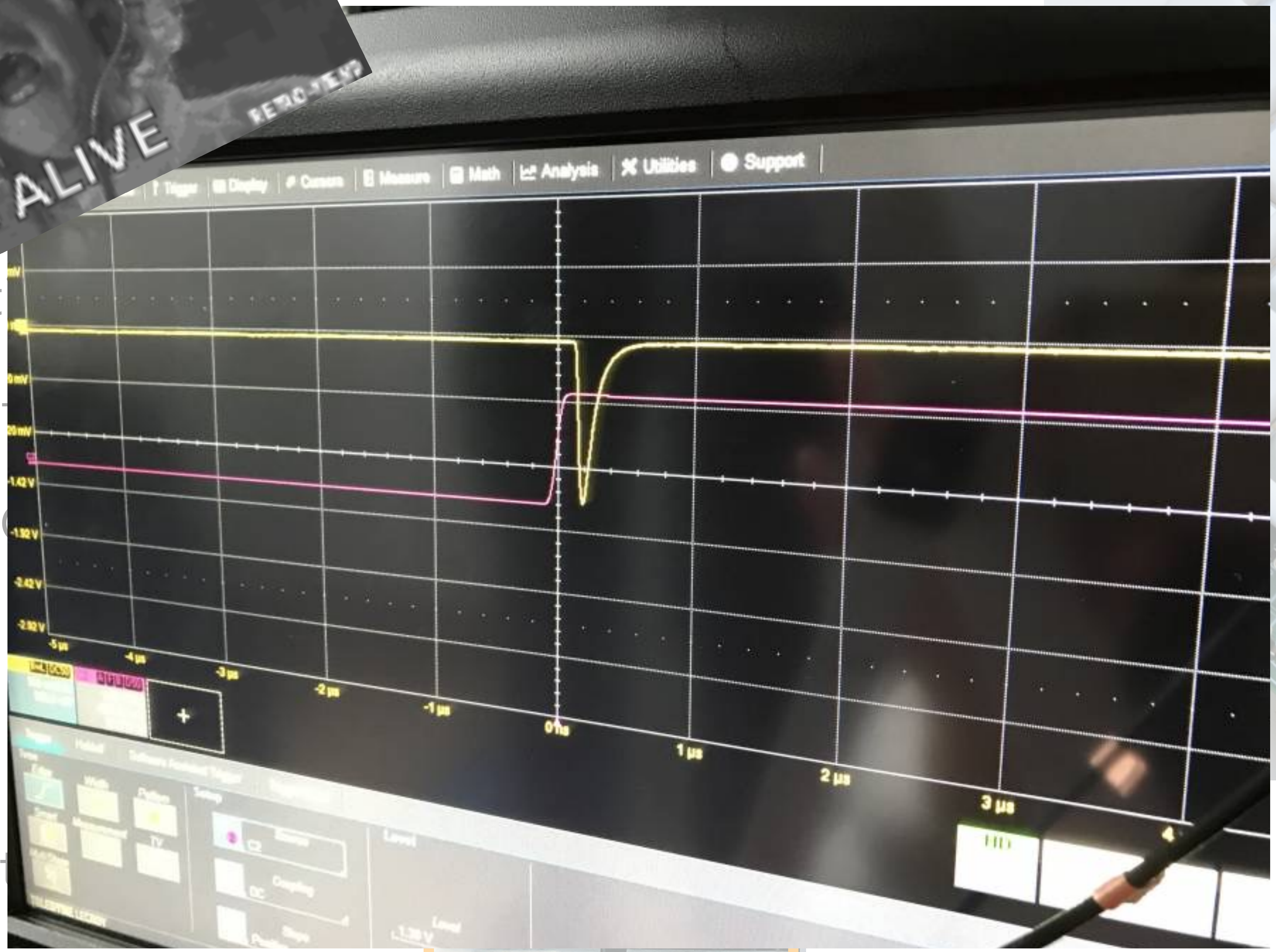


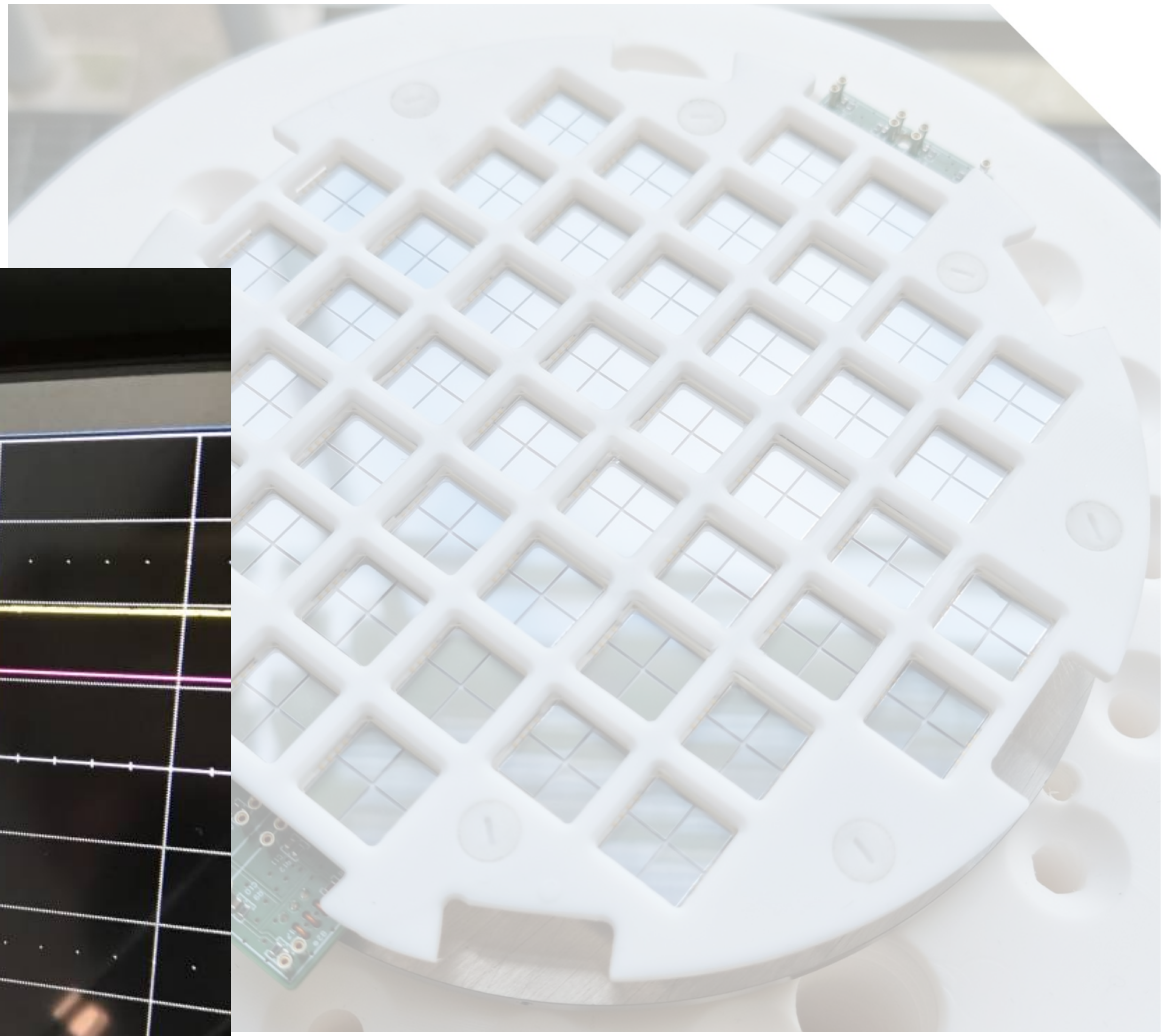
Tile = 4 Hamamatsu VUV4 quads

JINST 18 C03027 (2023)

SiPM array

- SiPMs characterized individ… ED in dark box before array assem…
- 192 SiPM ce…
- 48 VUV4 MPP…
- The array has 12 … ach t… four 12×12mm2 VUV SiPMs … Hamamatsu (S13371-6050C…
- 20x amplification per tile
- Parallel readout per tile => 1…
- Two optical fibers for calibrat…

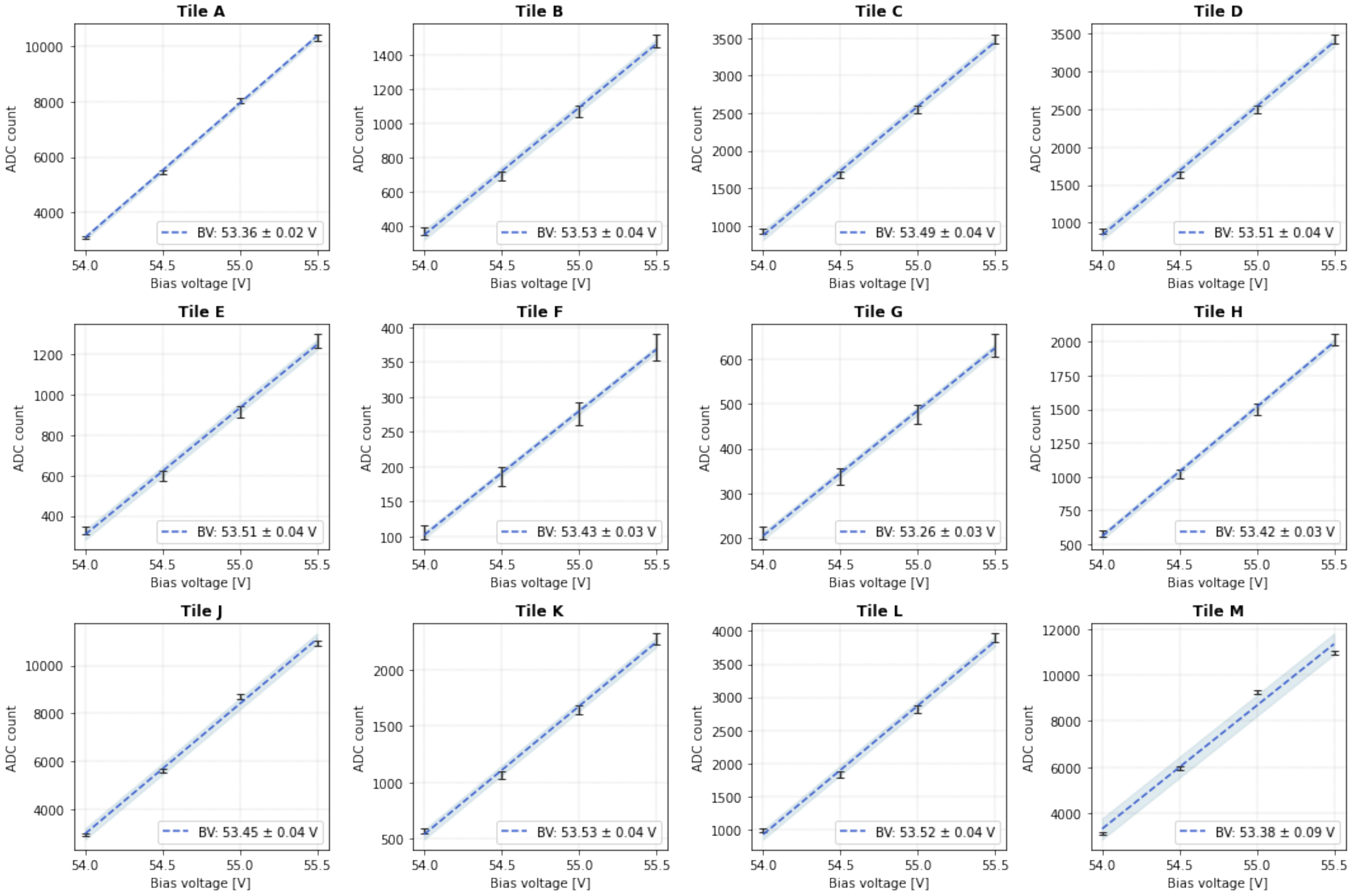


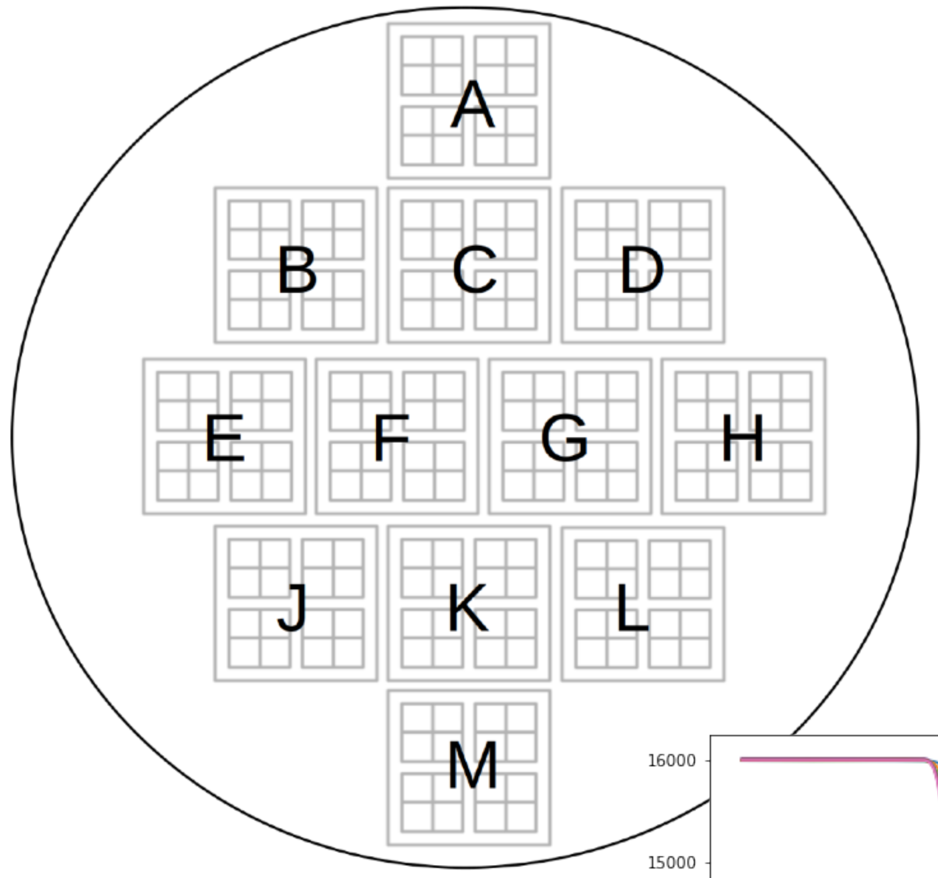


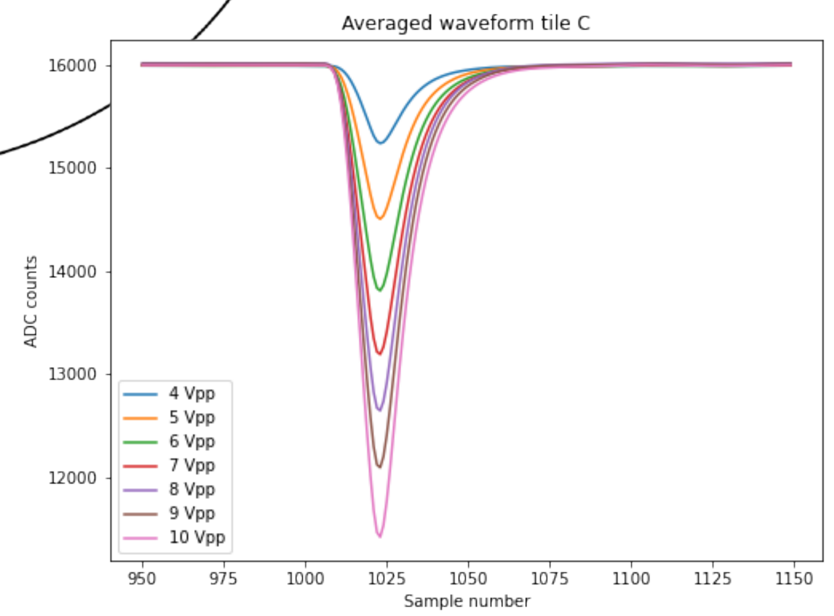
JINST 18 C03027 (2023)

Tile = 4 Hamamatsu VUV4 quads

SiPM array tests in vacuum







- Data-taking for constant LED light level and varying bias voltages.
- Measured breakdown voltages agree with dark box characterization.

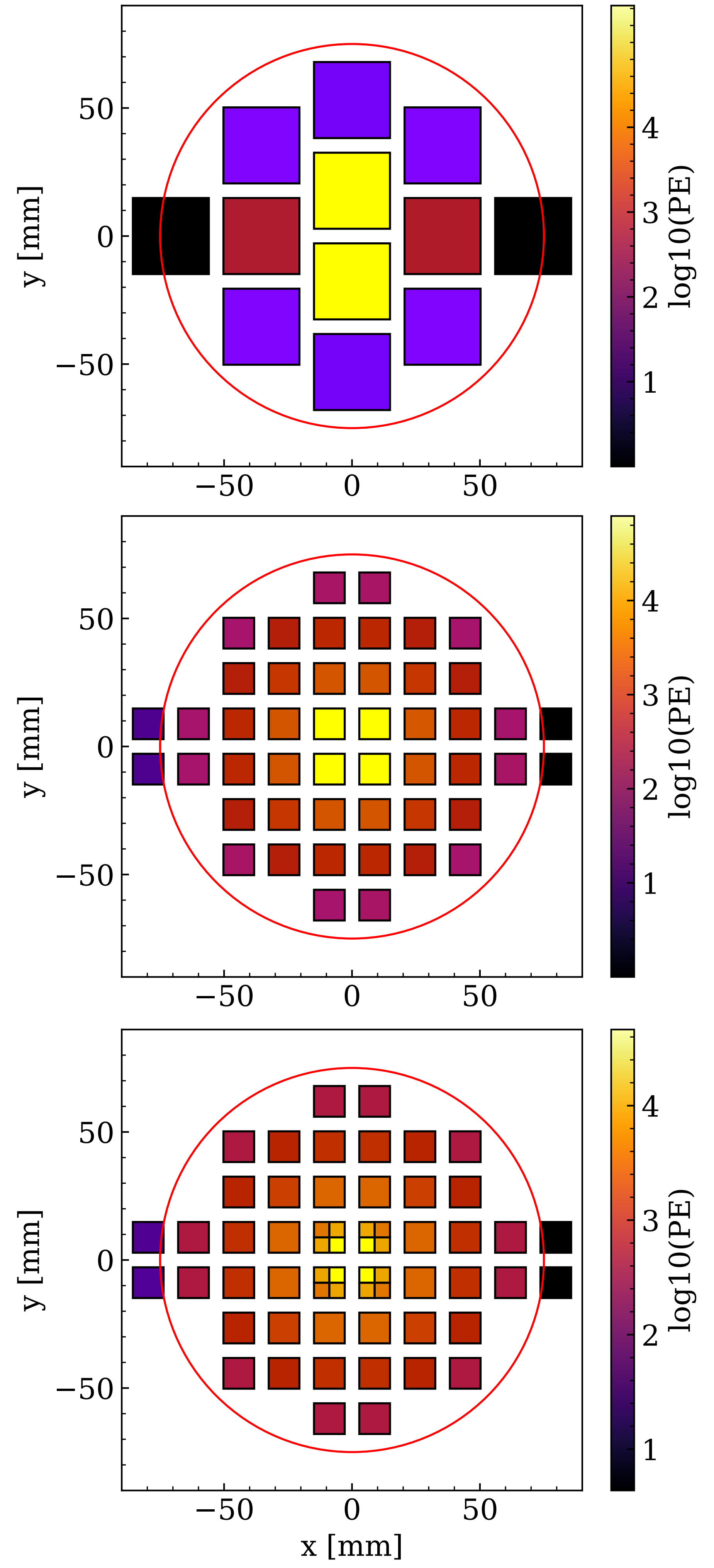
Future plan

Soon:

- Filling of the dual-phase TPC
- Combined purification of gas and liquid phase
- Detection of first S2s
- Electron lifetime measurements
- Position reconstruction
- Test of external sources
- Longitudinal and transverse diffusion measurements

Less soon:

- Measurements of xenon's optical properties
- Gain matching of SiPM quads per tile
- SiPM array readout with finer granularity for better transverse diffusion measurements
- Make Xenoscope available as test platform to the entire collaboration



Summary

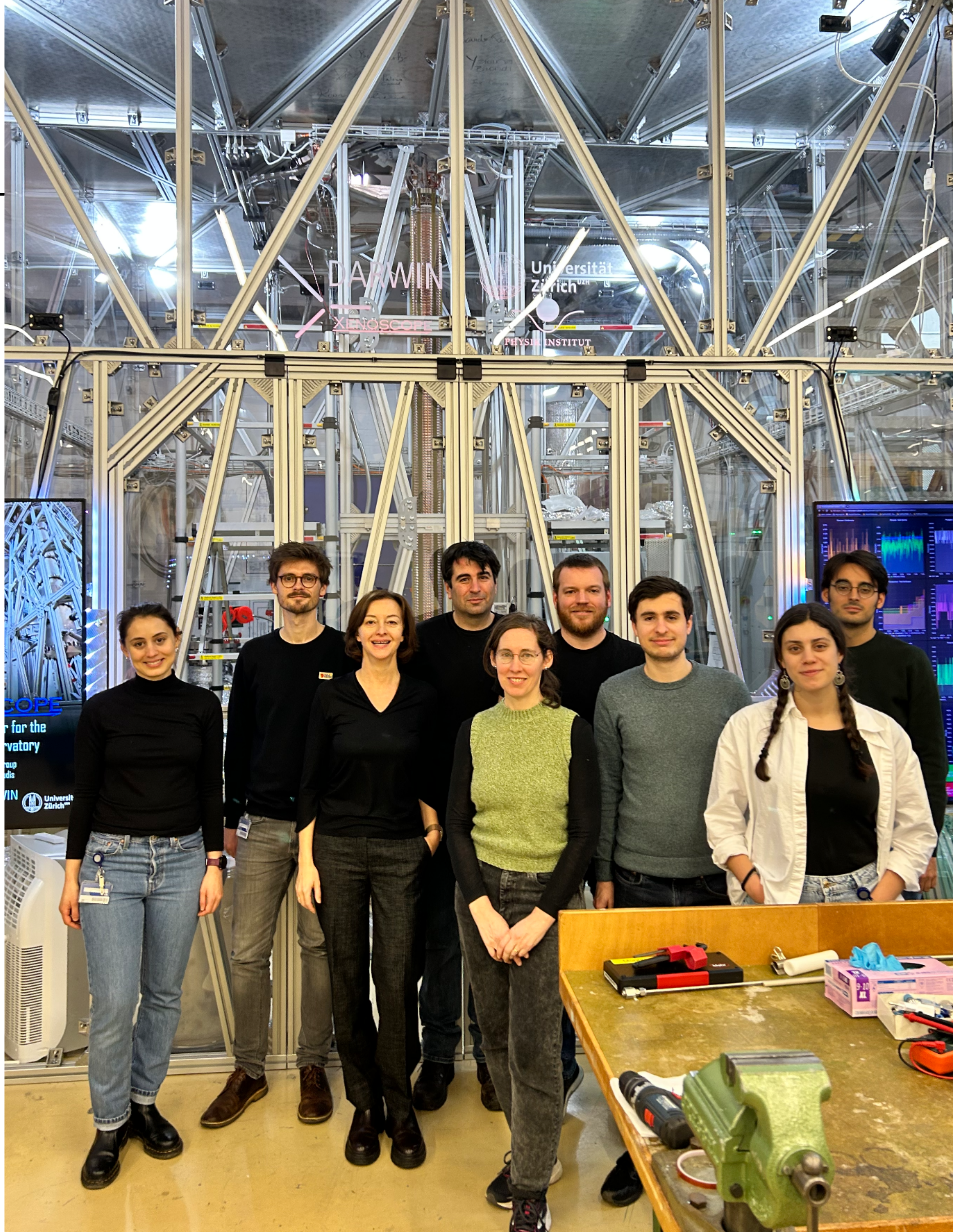
University of Zurich[UZH]

- Xenoscope is one of the two demonstrators for R&D on technical challenges for DARWIN such as:
  - Electron transport
  - Purification
  - Photosensor R&D
- First electron measurements were carried out with a purity monitor.
- Second phase with dual-phase TPC and full 2.6 m drift will start soon.

Xenoscope facility:
JINST 16 P08052 (2021)

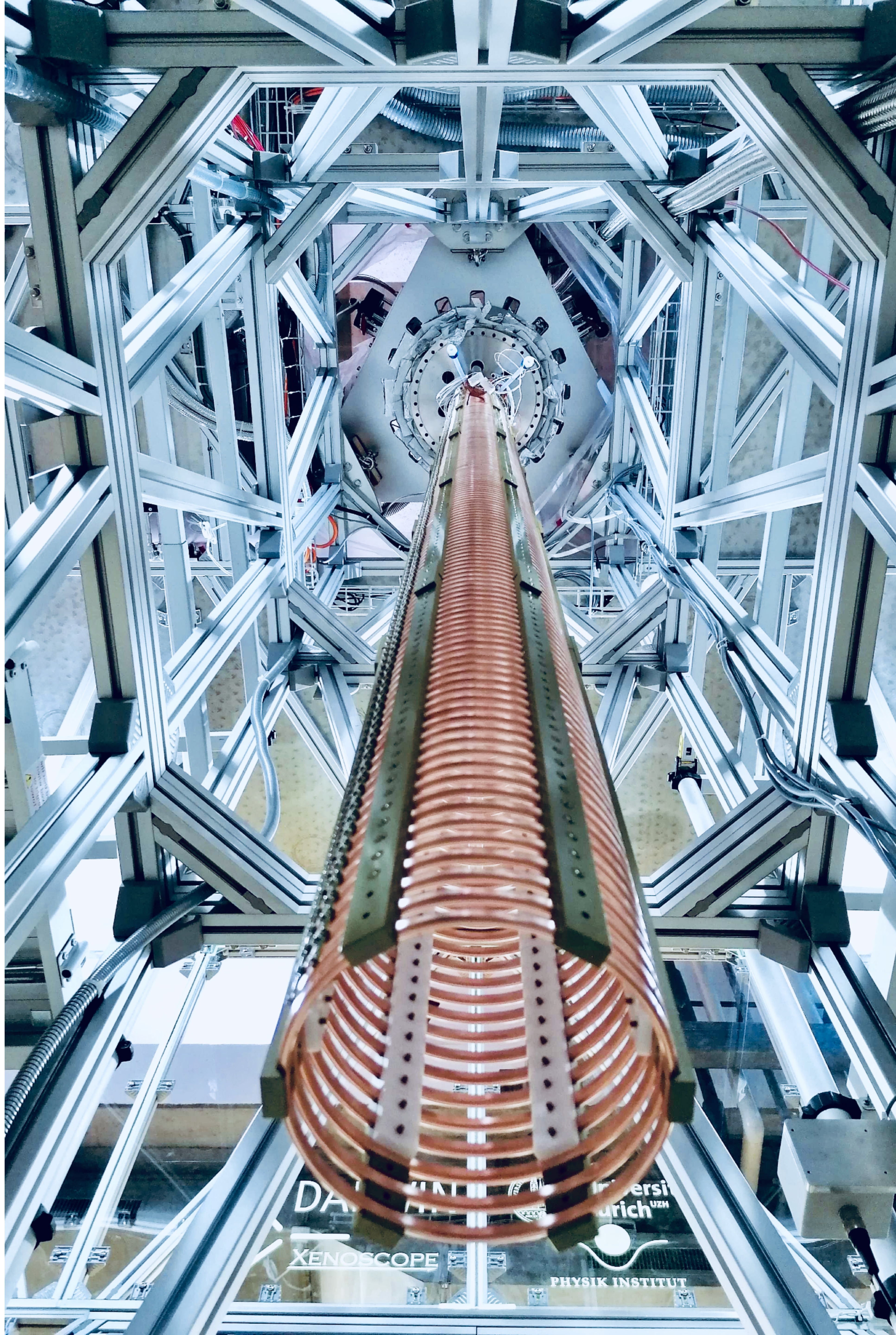
SiPM array:
JINST 18 C03027 (2023)

Electron transport measurements:
arXiv:2303.13963



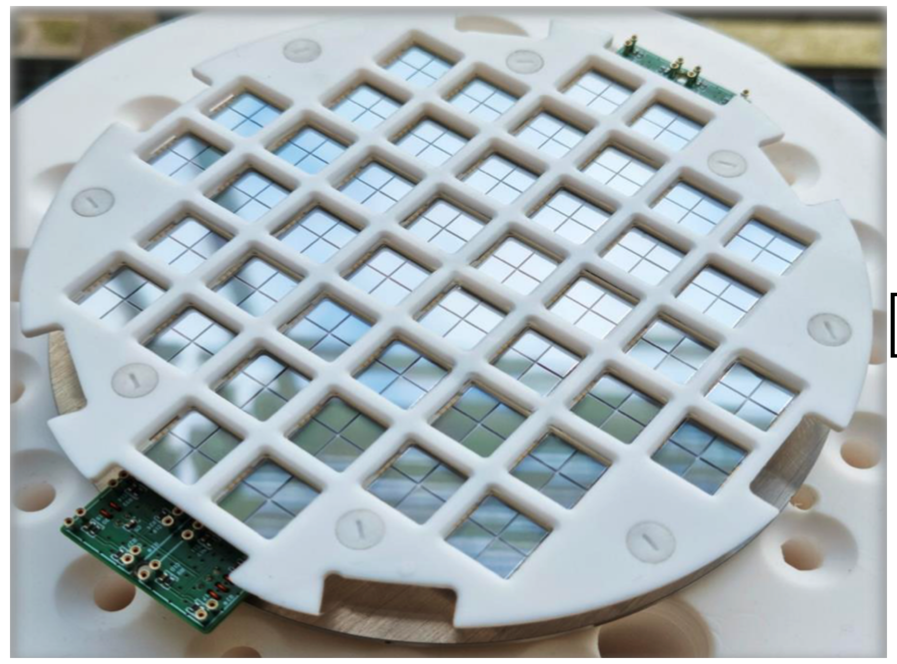
University of Zurich[UZH]

Backup



Data acquisition

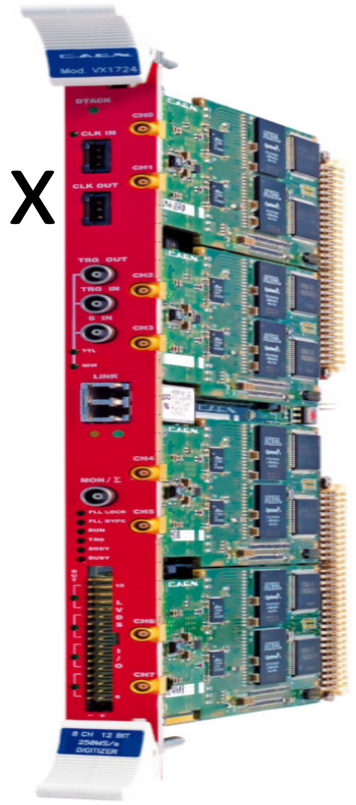
SiPM array



- 12 signal channels read out
- On-tile 20x amplification

CAEN V1724

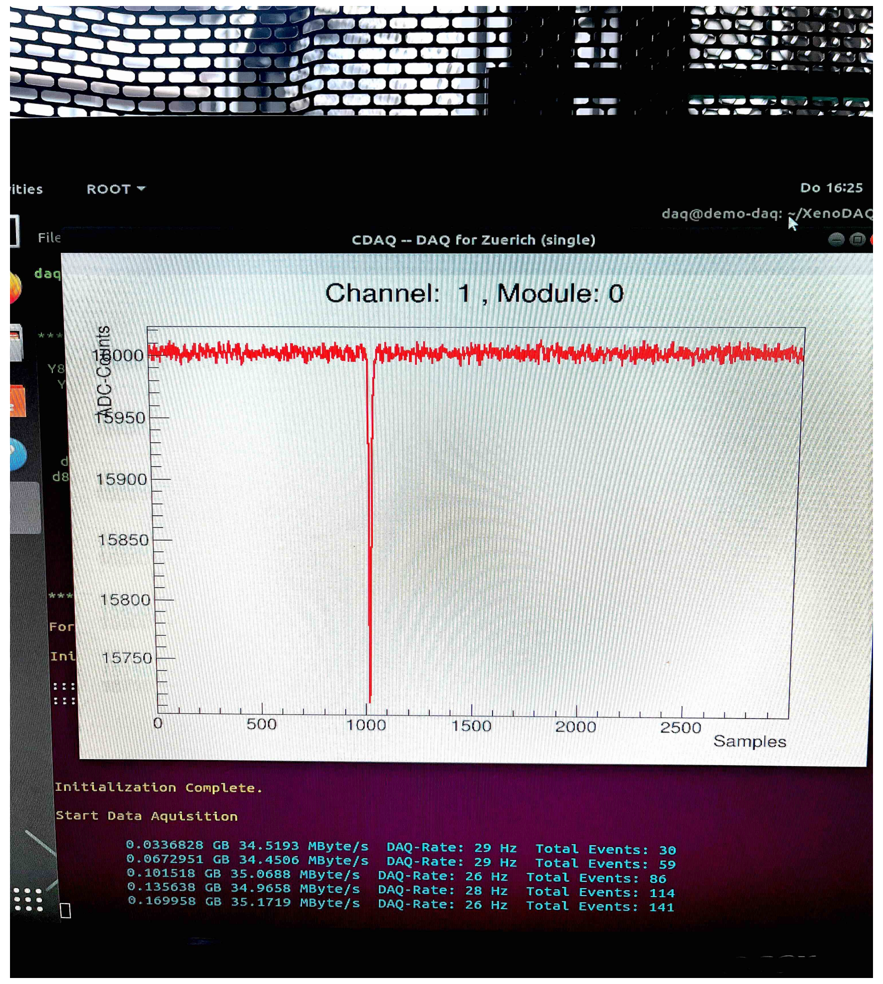
2 x



- Two 8-channel boards daisy-chained
- 14 bits
- 100 MS/s
- 0 – 2.25 V dynamic range
- Software, external or channel auto-trigger modes

PC

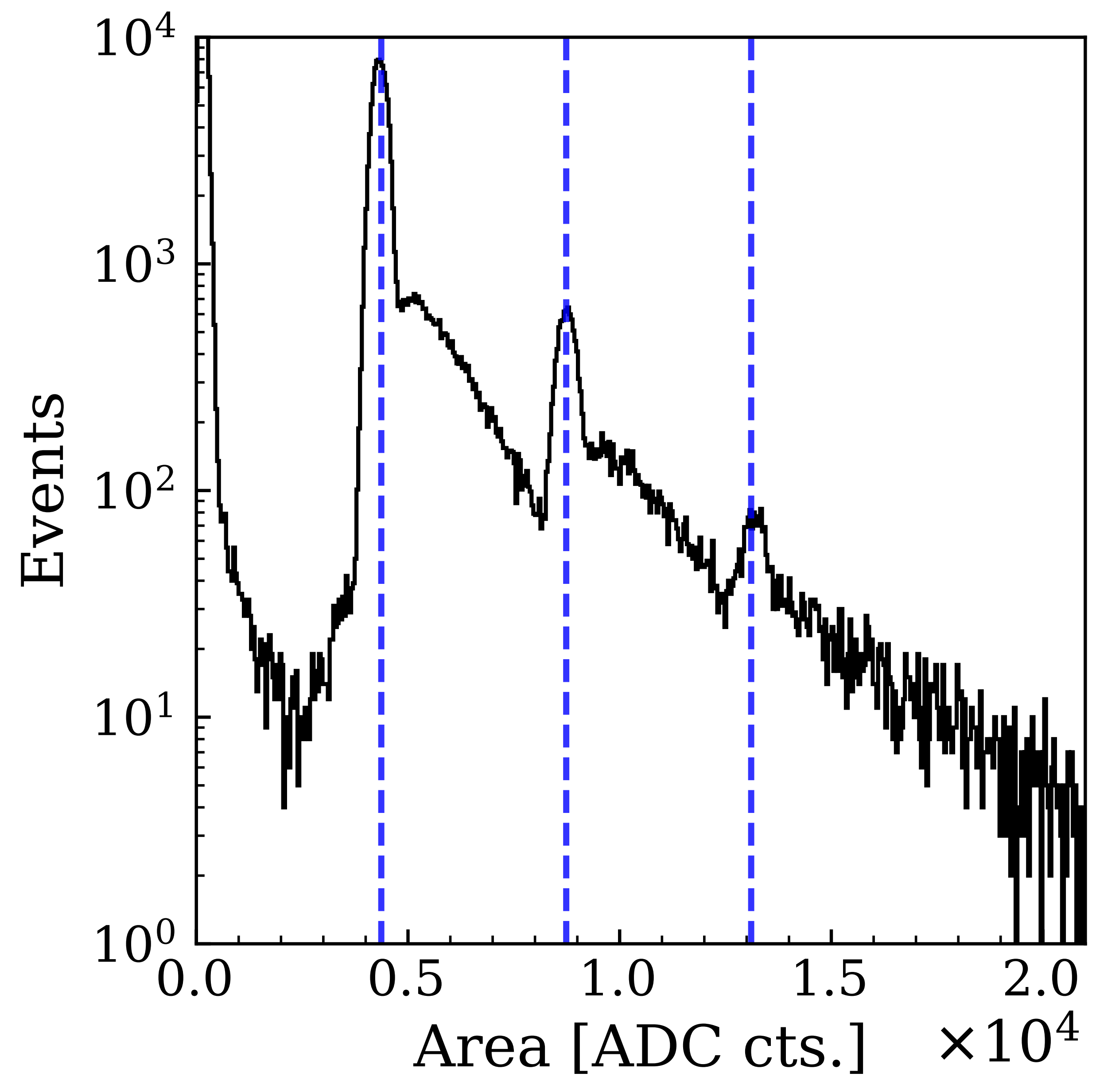
- A318 optical link connection to PC

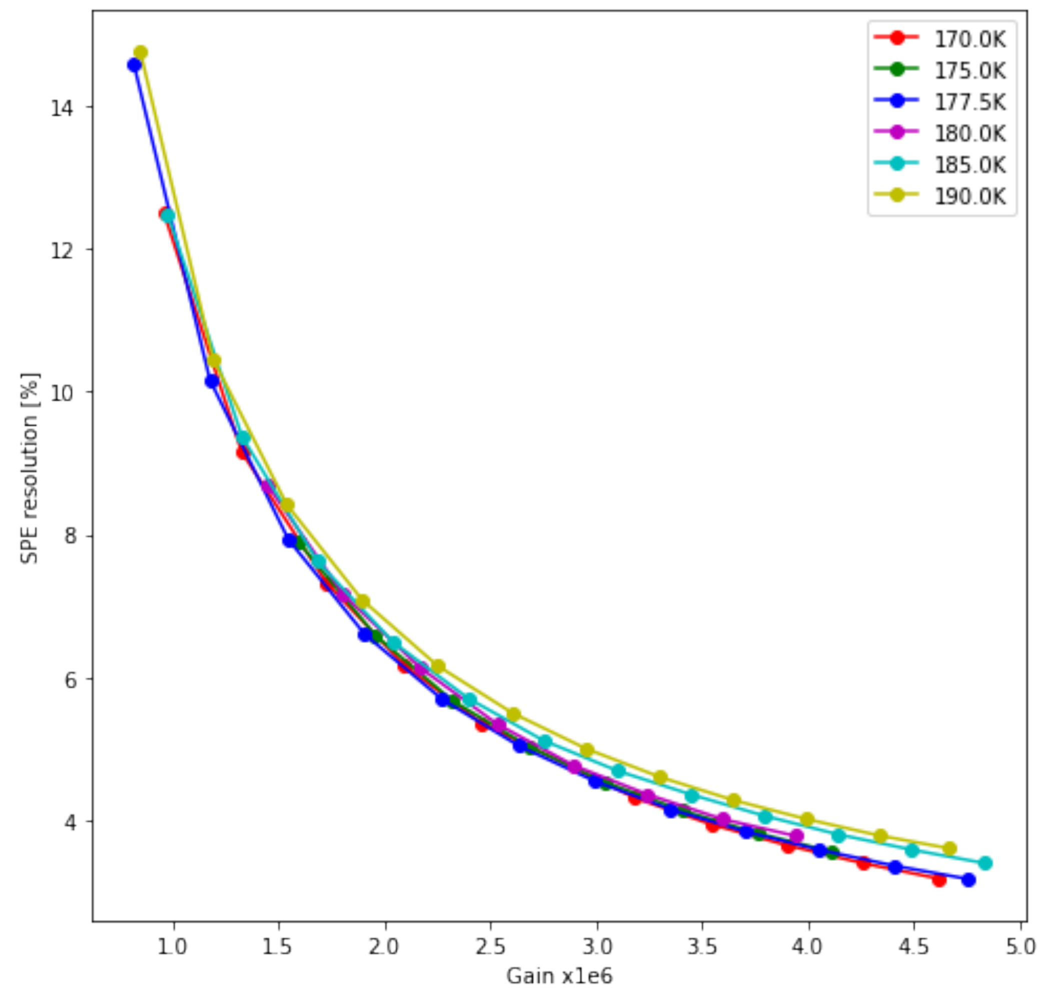


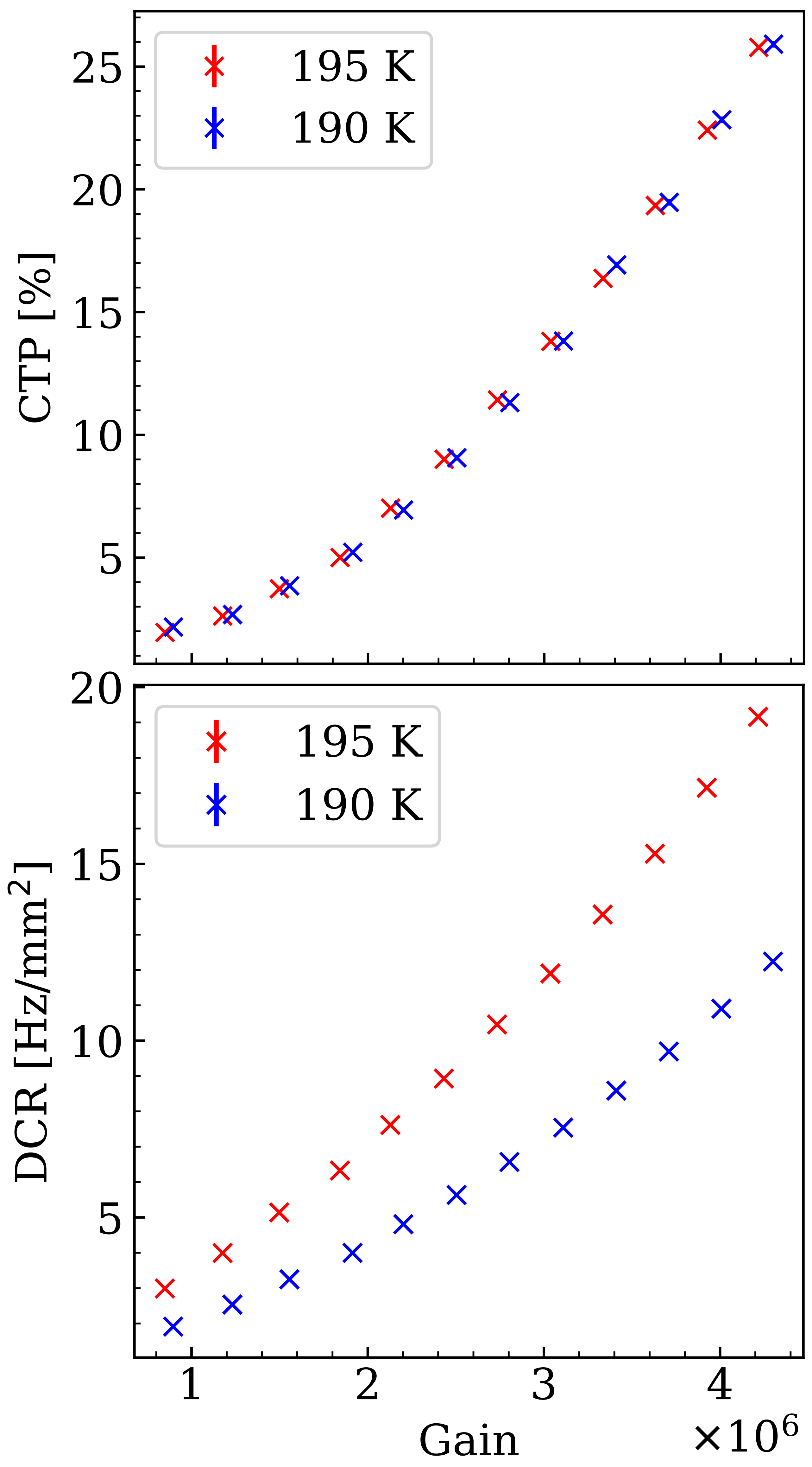
- DAQ interface via XML files
- Oscilloscope and multi-channel analyzer modes
- Output data in ROOT format

SiPM characterization

- Array characterized with blue LED in dark box before integration into Xenoscope
- Observation of single-, double- and triple-photoelectron pulses
- Measurements between 170 and 200 K
- Gain of 3 x 10^6 observed at 4.5 V overvoltage (above breakdown)
- Cross-talk probability of ~15 %
- SPE resolutions of 5 – 5.5 % mainly dependent on gain



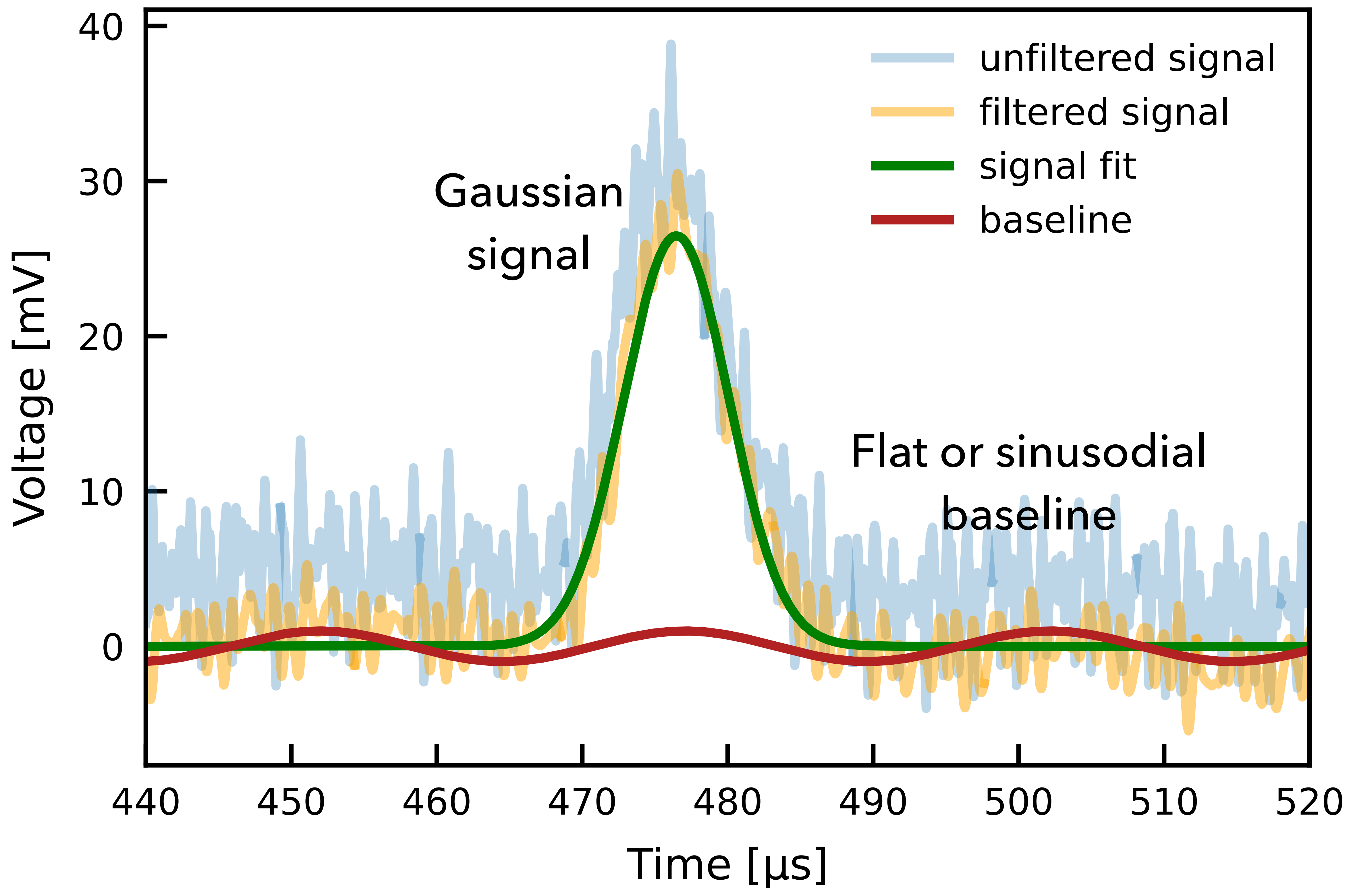




JINST 18 C03027 (2023)

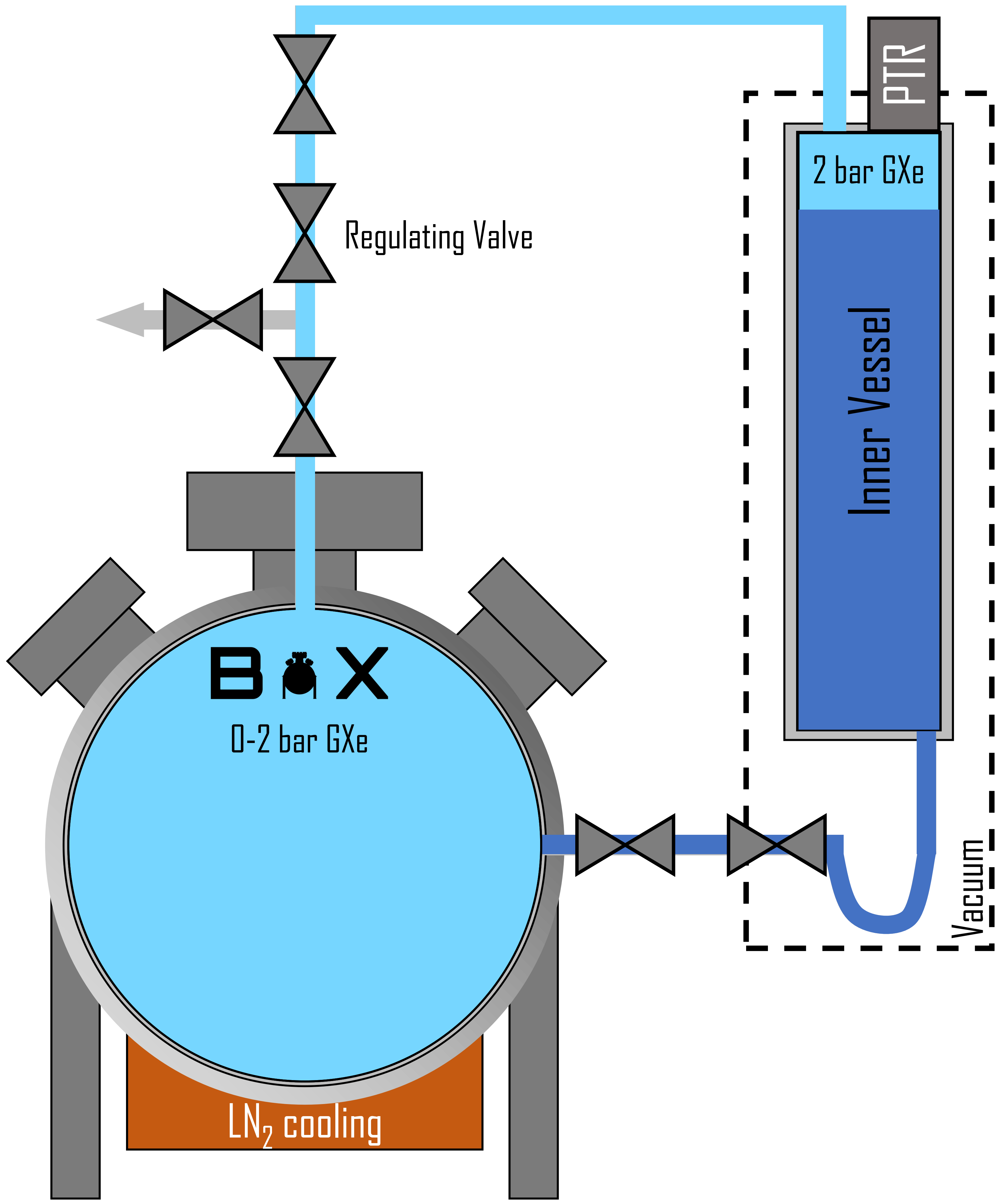
Purity monitor measurements

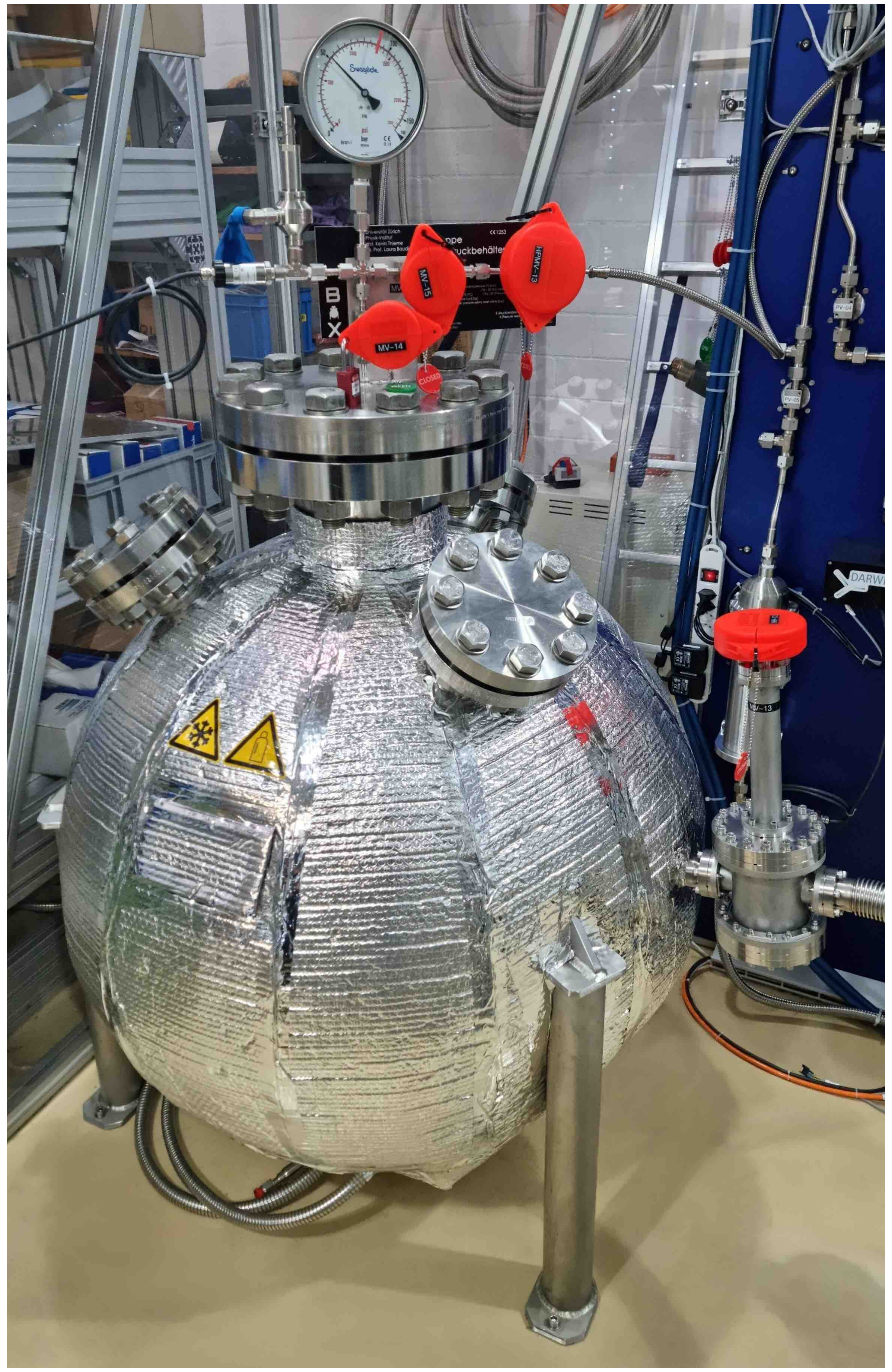
- Read-out voltage proportional to instantaneous current
- Low-pass filter (< 800 kHz) in order to remove electronic noise from lamp, temperature sensors and UPS
- Data recorded with CAEN v1724 ADC and Teledyne LeCroy Waverunner 6104A oscilloscope
- Averaging over 1000 recorded waveforms (~17 minutes) minimizes baseline noise



Ball of Xenon (BoX)

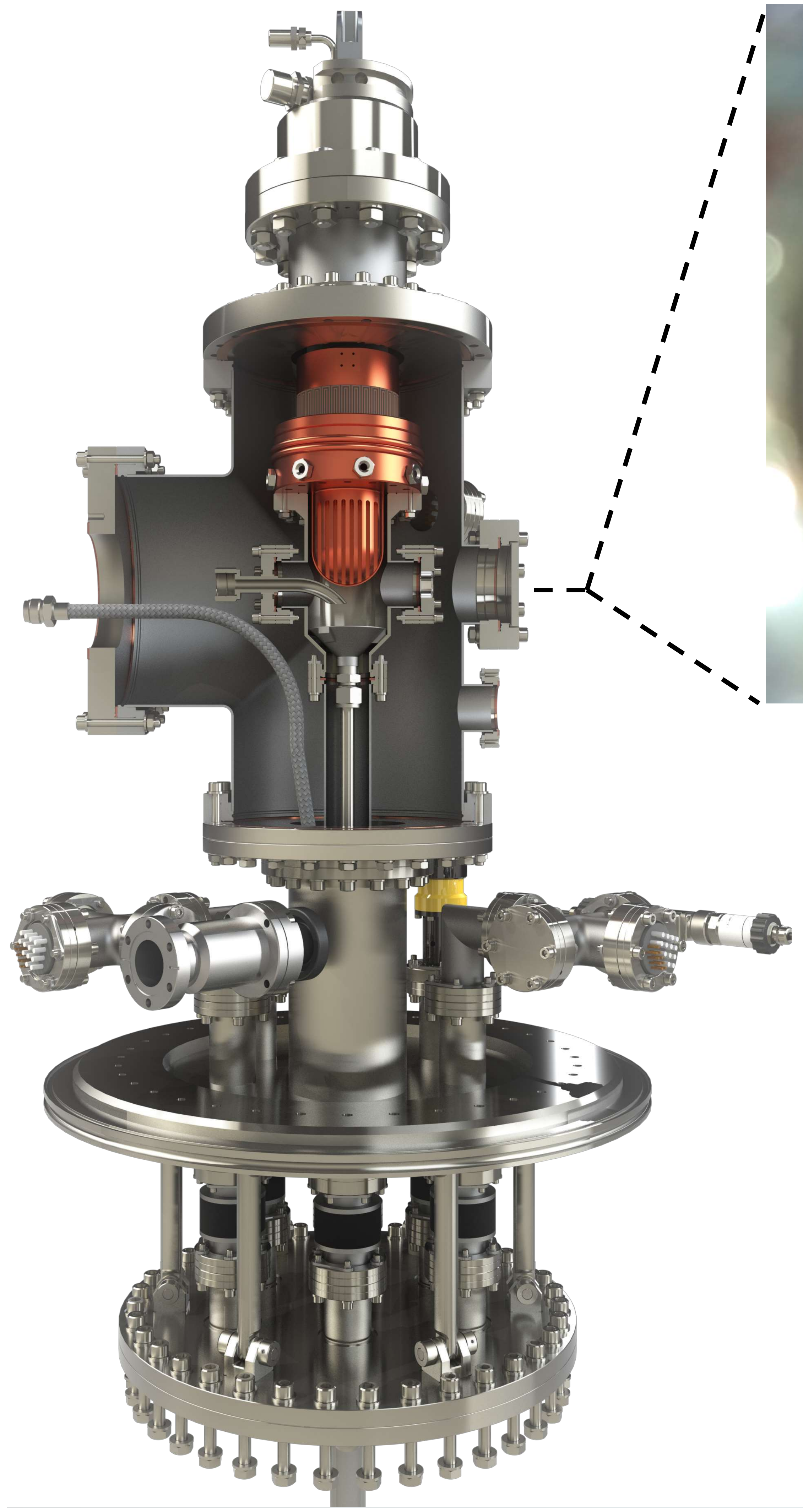
- Stainless steel pressure vessel rated at 90 bar for up to 450 kg LXe at room temperature
- Gravity-assisted LXe recuperation
- LN2 pre-cooler at the bottom
- Recuperation speed (with 160 kg): Avg: 19 kg/h (up to 51 kg/h)

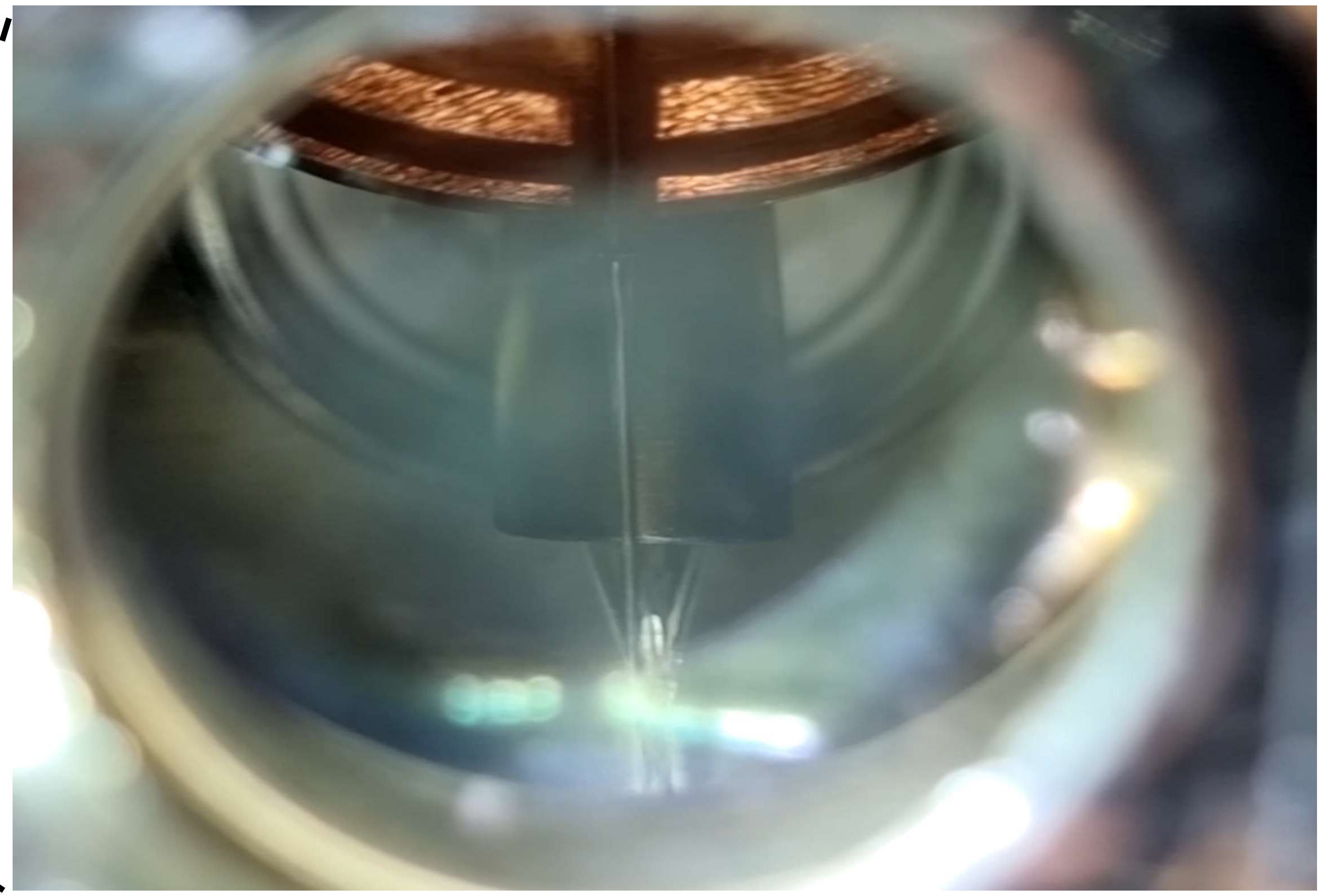




Cooling tower and pre-cooler

- Iwatani PC-150 PTR (~ 200 W cooling) and heater (~180 W heating)
- LN2 auxiliary cooling coil
- Unpurified Xe extracted from the top of the inner vessel
- LXe condensing on the cold head
- Funnel carries purified Xe to the bottom of the inner vessel
- Stress-free thermal contraction of the top flange thanks to swivel arms
- LN2 pre-cooler on inner vessel for additional cooling power:
    - Without pre-cooler filling at ~4 kg/h
    - With pre-cooler fillig at ~17 kg/h





LXe condensing on the cold head

Pre-cooler