The 2.6 m-high Xenoscope TPC

Design, Assembly, and First Results

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on behalf of the Xenoscope Team

LIDINE 2024

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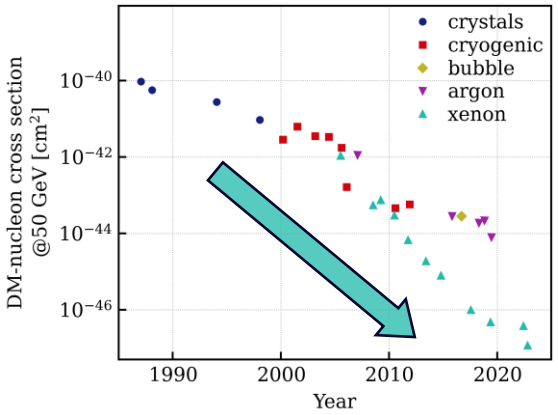
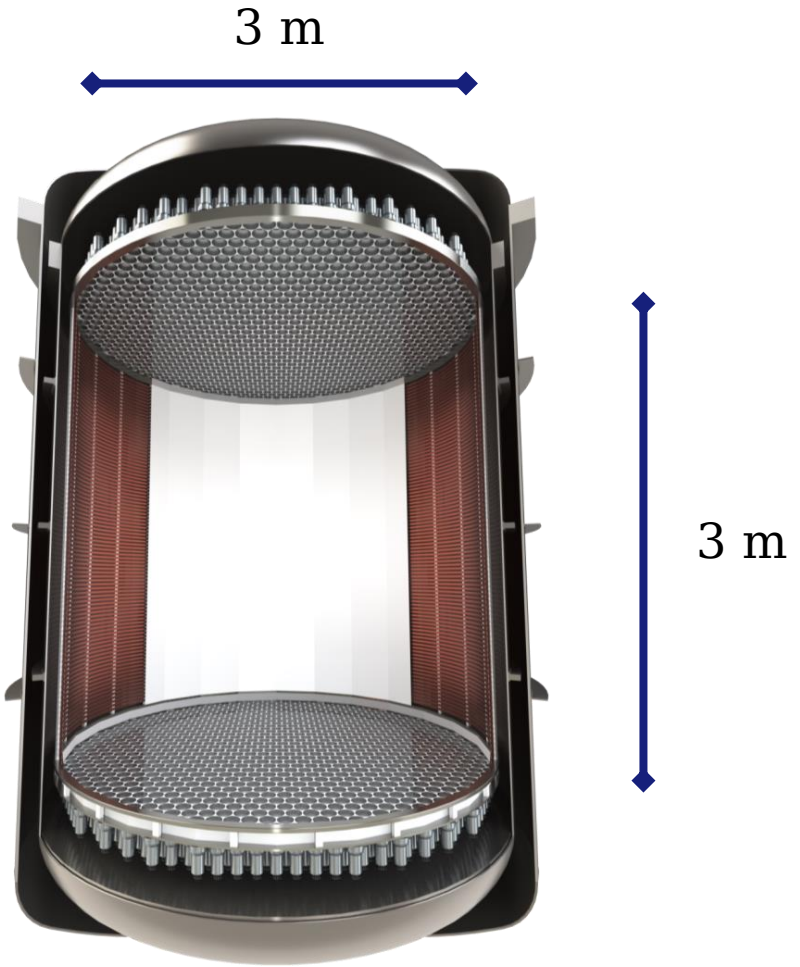
XLZD: the next generation LXe observatory

- Next-gen LXe observatory:
  - WIMP DM
  - Astrophysical neutrinos (solar, SN)
  - Neutrino properties
  - …
- Dual phase LXe TPC
  - 3 m diameter x 3 m height
- 60 – 80 t LXe active target
- Two arrays of photosensors (~2k 3” PMTs)
- PTFE reflector walls
- Double-walled Ti cryostat, 7 cm LXe “skin”
- Passive and active muon and neutron vetos





Scale up: a set of challenges

- Liquid xenon purity
- High-voltage delivery
- Electrodes design and operation at 3 m scale
- Electric drift field homogeneity
- Light collection efficiency throughout the TPC
- Background mitigation
- Photosensor performance
- …

XENONnT /LZ: ~8 t

XLZD: 60 – 80 t

R&D: full-scale demonstrators

Xenoscope
@Uni. Zurich

JINST 16 P08052 (2021)

PANCAKE
@Uni. Freiburg

JINST 19 P05018 (2024)

Xenoscope - a full-scale vertical demonstrator

- DARWIN/XLZD full-height demonstrator goals:
  - Electron drift ~2.6 m
  - Custom-made HV distribution
  - Electron cloud diffusion properties
  - Light attenuation measurements
  - R&D test platform

L. Baudis *et al* 2021 *JINST* **16** P08052

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L. Baudis *et al* 2021 *JINST* **16** P08052

Xenoscope - a full-scale vertical demonstrator

53 cm Purity Monitor

- 53 cm single phase PM
- Signal from Xe flash-lamp shining on a photocathode
- Direct charge readout from electrodes

Eur.Phys.J.C 83 8, 717 (2023)

Xenoscope - a full-scale vertical demonstrator

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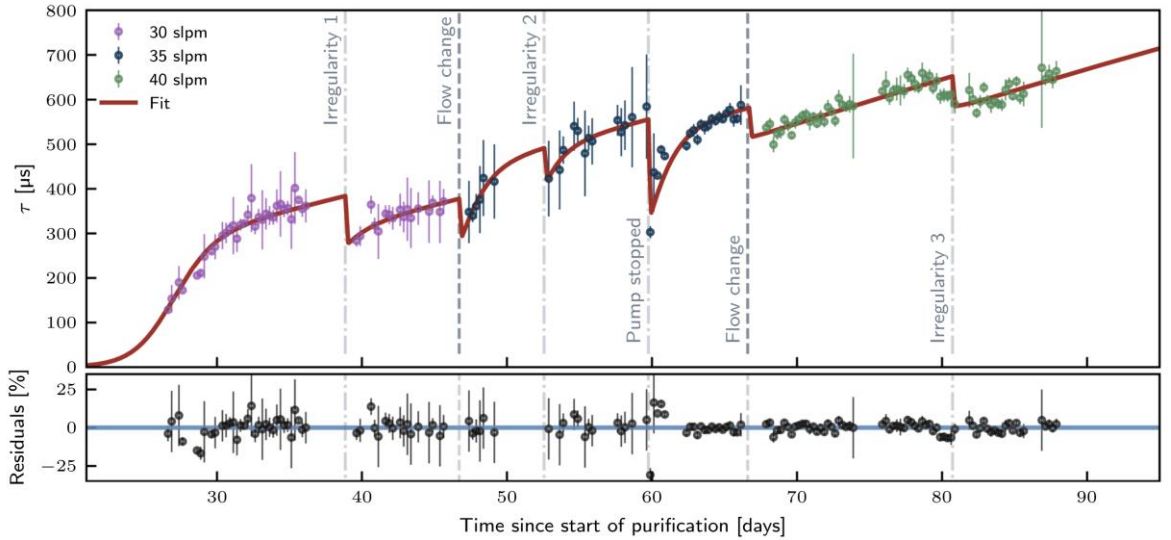
- Direct charge readout from electrodes
- Achieved 600 us e^- drift lifetime



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- Measured:
  - drift speed
  - longitudinal diffusion

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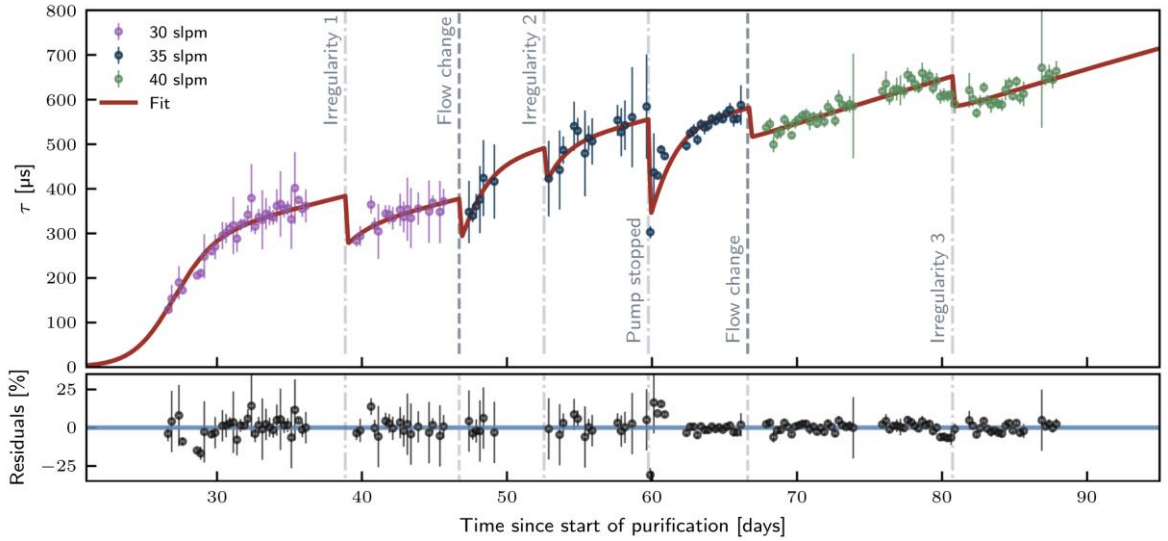
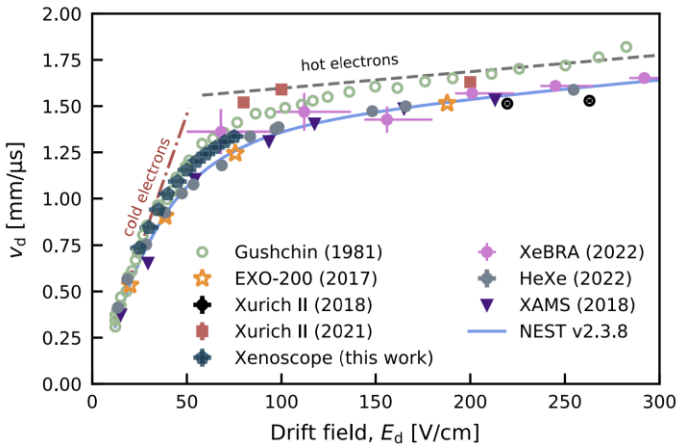
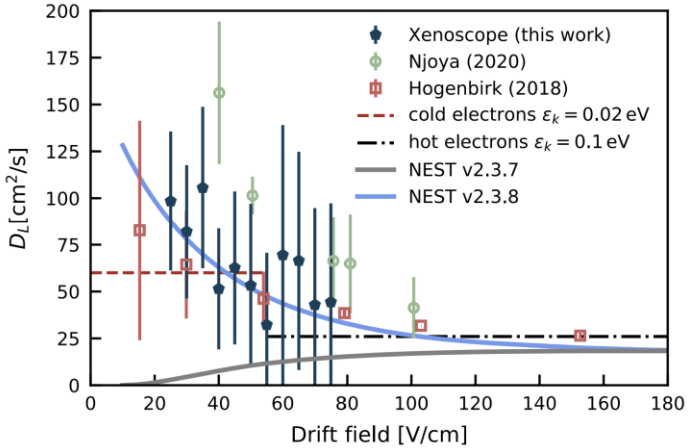
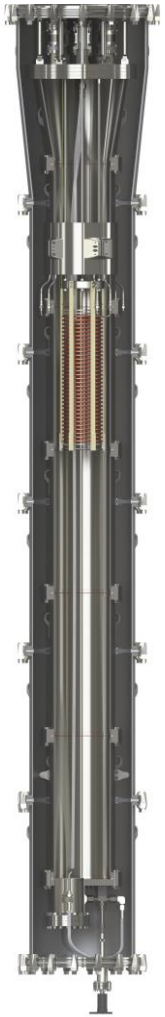






Xenoscope - a full-scale vertical demonstrator



53 cm Purity Monitor

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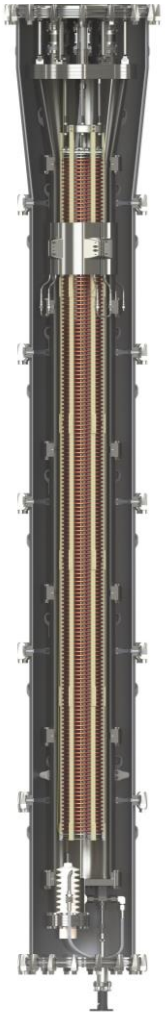
Eur.Phys.J.C 83 8, 717 (2023)



2.6 m dual-phase TPC

- Dual-phase time-projection chamber
- Drift length of 2.6 m
- Electron signal from:
  - Photocathode
  - Muons
  - Possibly internal and external sources
- Proportional scintillation light readout with a SiPM tiled array

Xenoscope - a full-scale vertical demonstrator

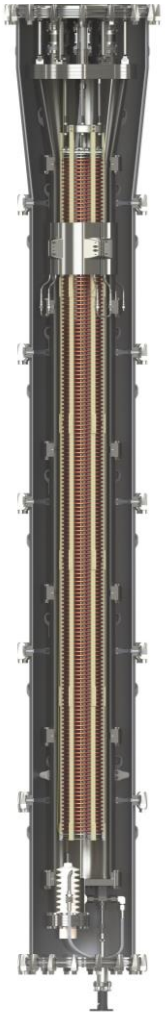
Cleaning and TPC assembly

SiPM array

Liquid level control

HV delivery

DAQ and Processing



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The Top Array of Xenoscope

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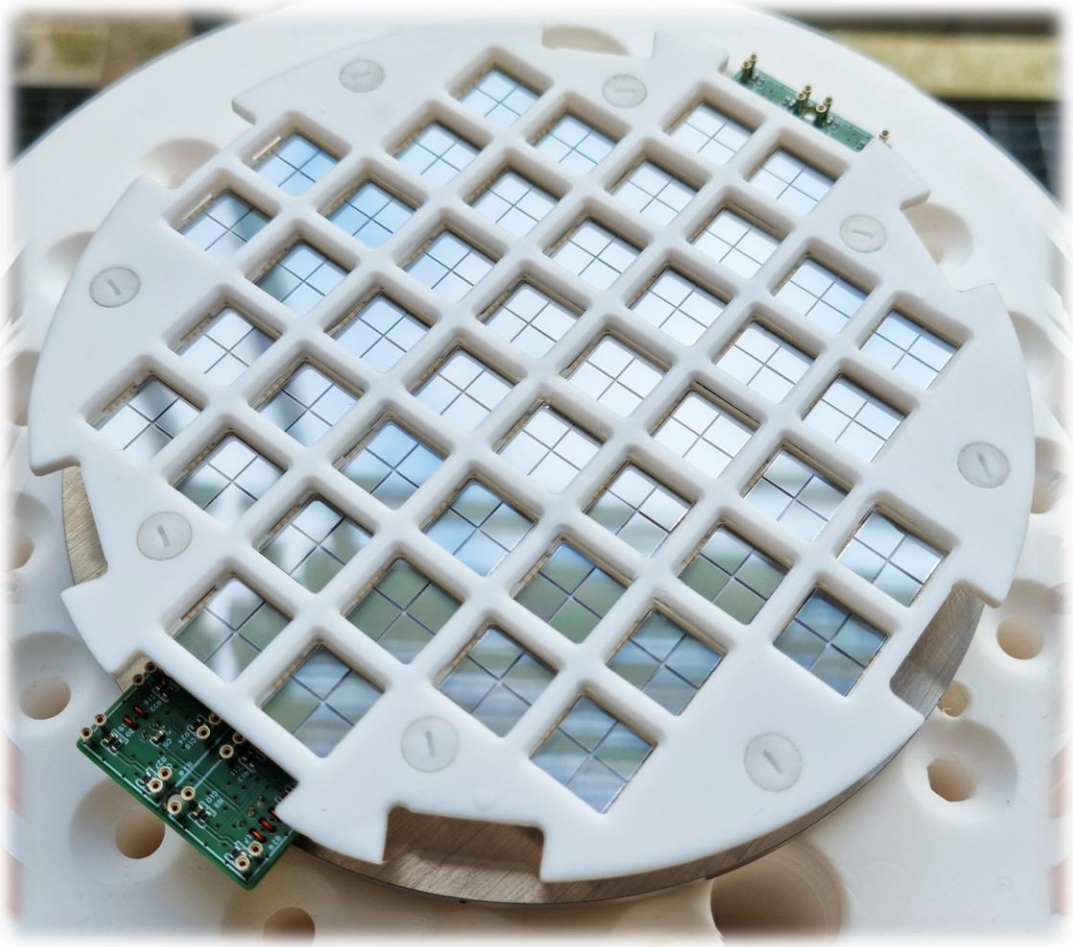
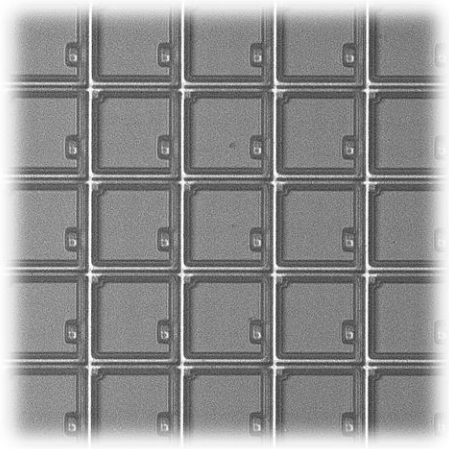
- Dimensions:
  - Back plate: ø160 mm
  - TPC/active area: ø150 mm
- Testing SiPMs on a large-scale dual-phase LXe TPC
- Total of 48 12×12 mm^2 VUV4 MMPCs from Hamamatsu
  - 192 6×6 mm^2 SiPMs

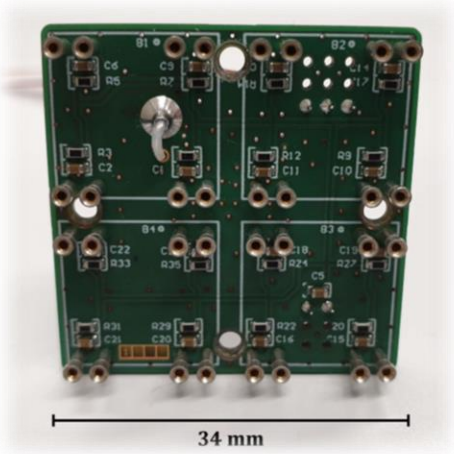
JINST 18 03, C03027 (2023)

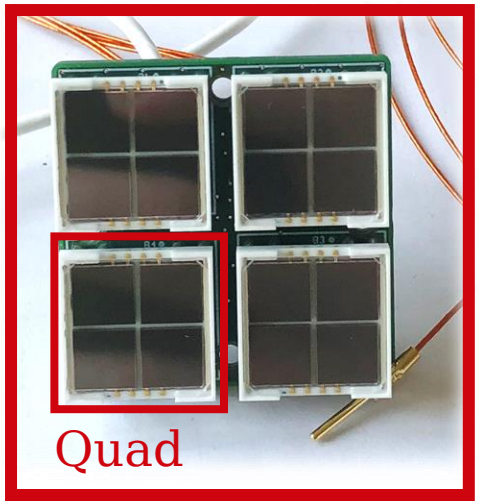


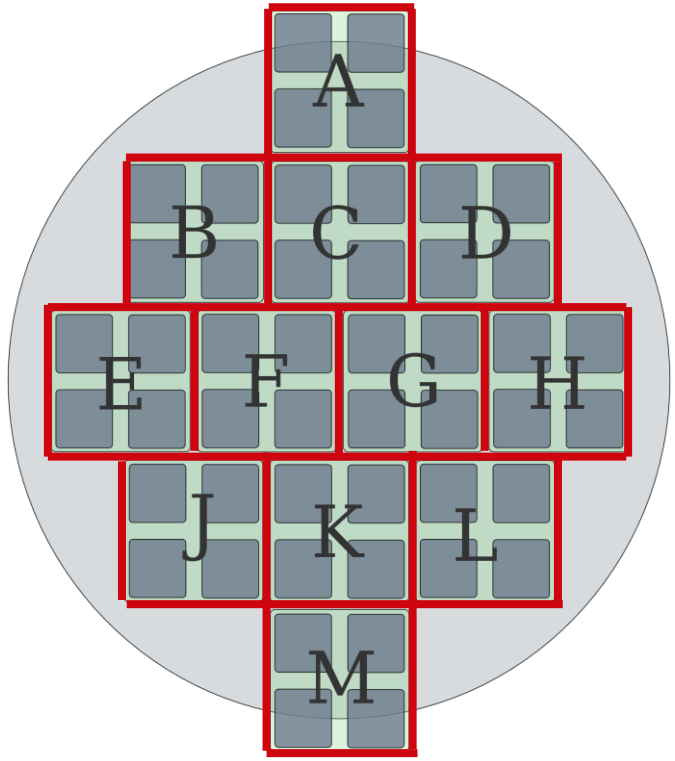
The VUV4 MPPCs and the summed readout

- VUV4 SiPMs from Hamamatsu Photonics (S13371-6050CQ-02)
- 50-µm pitch cells
- Tiled array with 4 12 × 12 mm^2 MPPCs
- Summed readout (parallel) with a x20 pre-amplifier circuit



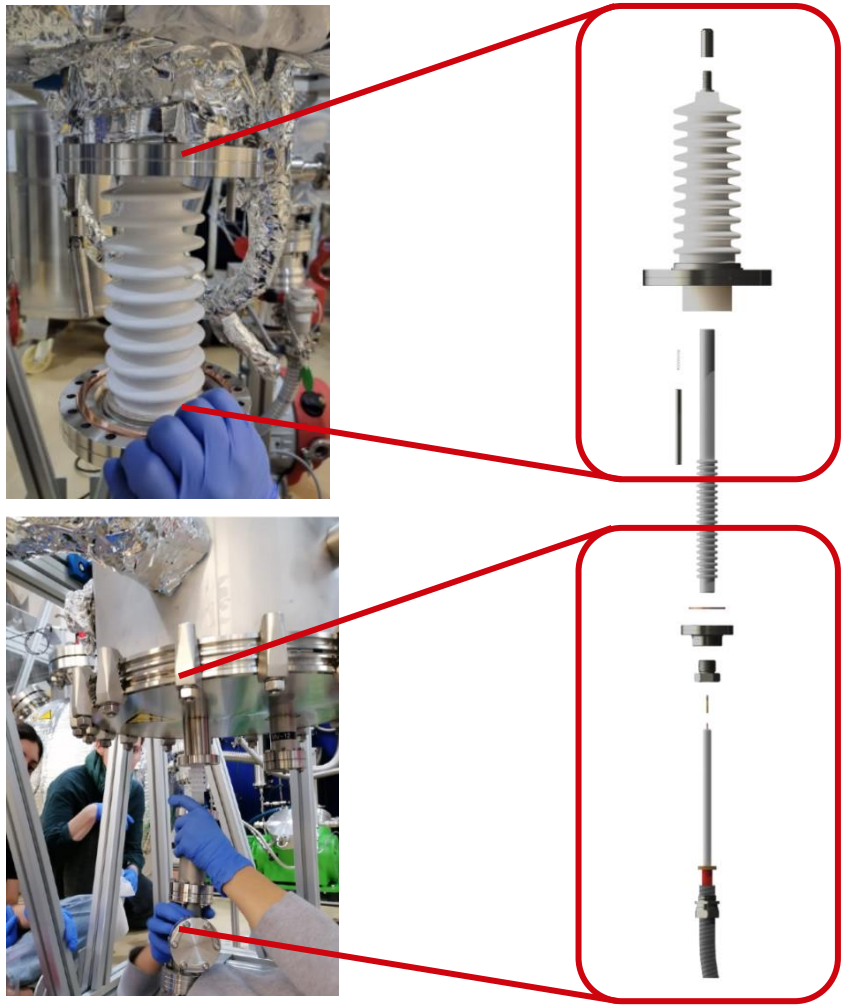






HV delivery

- 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



Liquid level control

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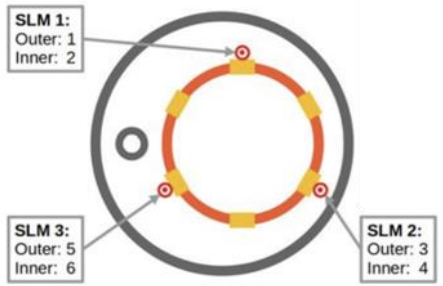
Long levelmeters (LLM)

- Monitor liquid level during filling and recuperation
- Two 1.44 m capacitive levelmeters segments (2.8 m total length)
- 5 PEEK equidistant spacer rings used for calibration

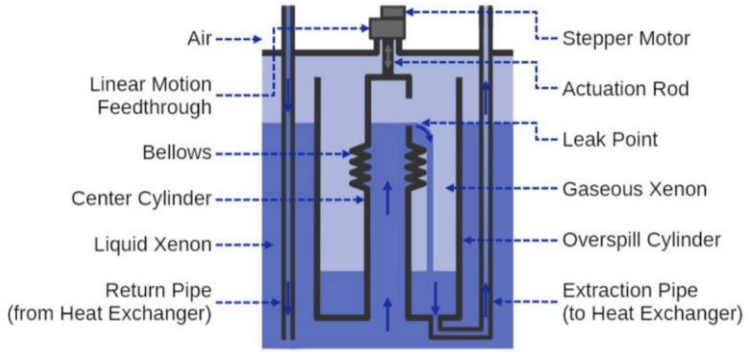
Short levelmeters (SLM)

- Three 3 cm capacitive levelmeters positioned around the top stack
- O(0.1)mm accuracy
- Initial capillary rise used for calibration, predicted to be 4.5 mm



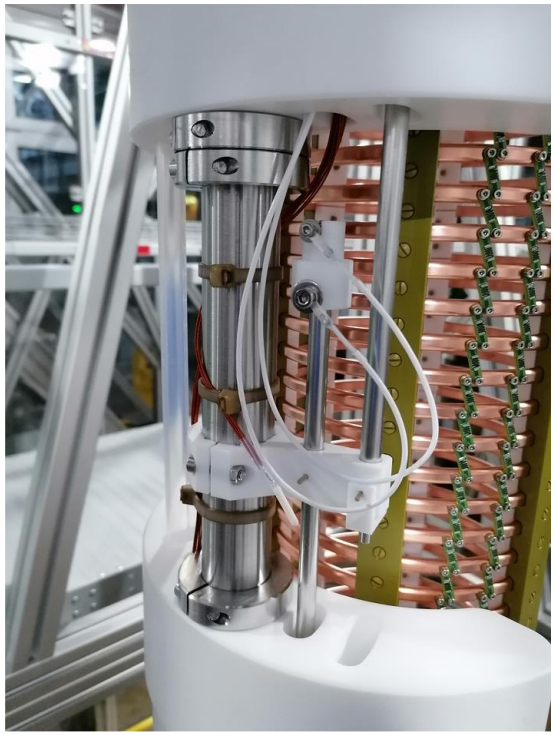
Weir

- Cylindrical weir actuated by a motion feedthrough
- Total capacity: ~2.3 kg

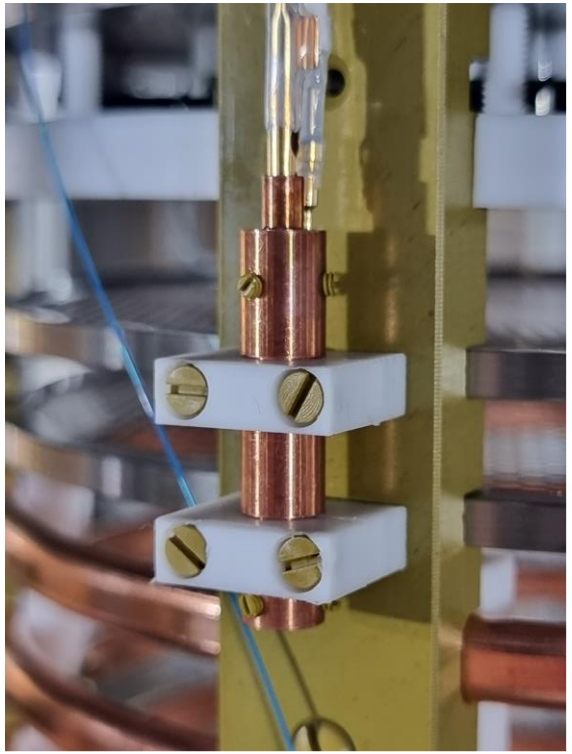


Liquid level control

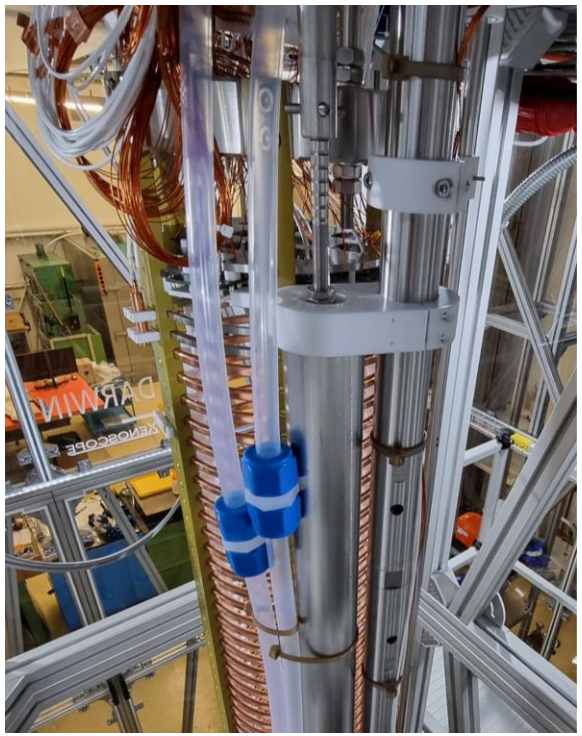
LLM



SLM

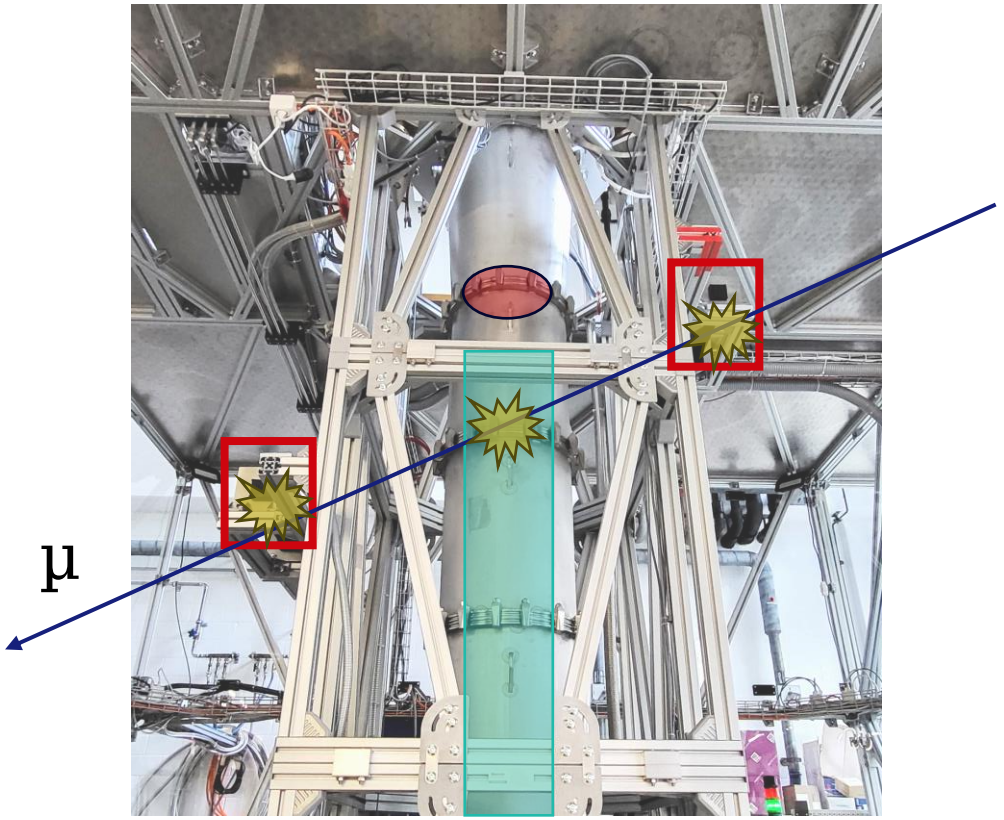


Weir



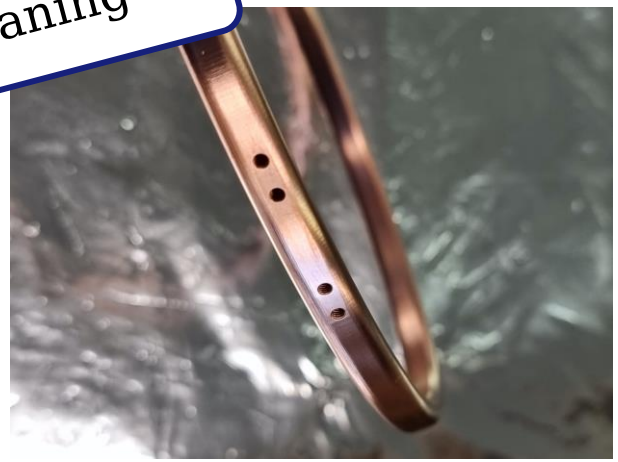
DAQ, data handling, processing

- Data taking modes:
  1. LED light for SiPM calibration
  2. **Muon-coincidence from two scintillator panels and PMTs** ($35.5 \times 5.3 \times 5.3\ cm^3$)
  3. Channel coincidence for signal (S2) monitoring
  4. Xenon flash-lamp (delayed) trigger
- Two CAEN v1724 digitisers in external trigger setting
- Custom open-source software:
  - Acquisition: XeDAQ
  - Processing: PyLArS

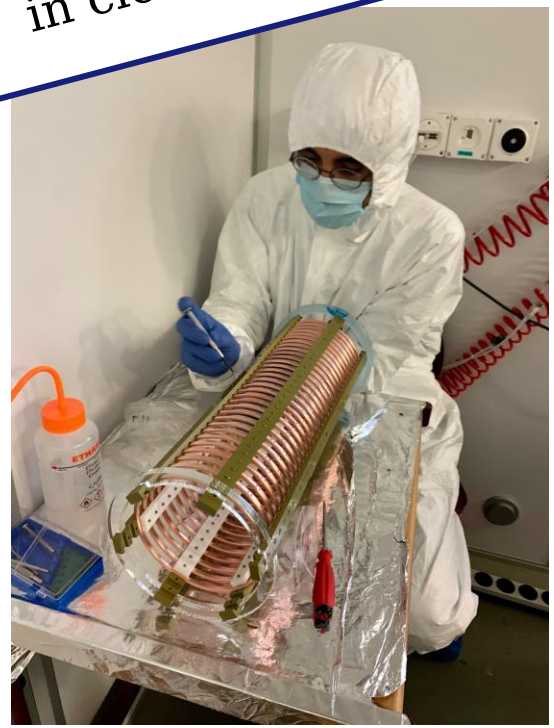


Field cage assembly

Cleaning



Modules assembly in cleanroom

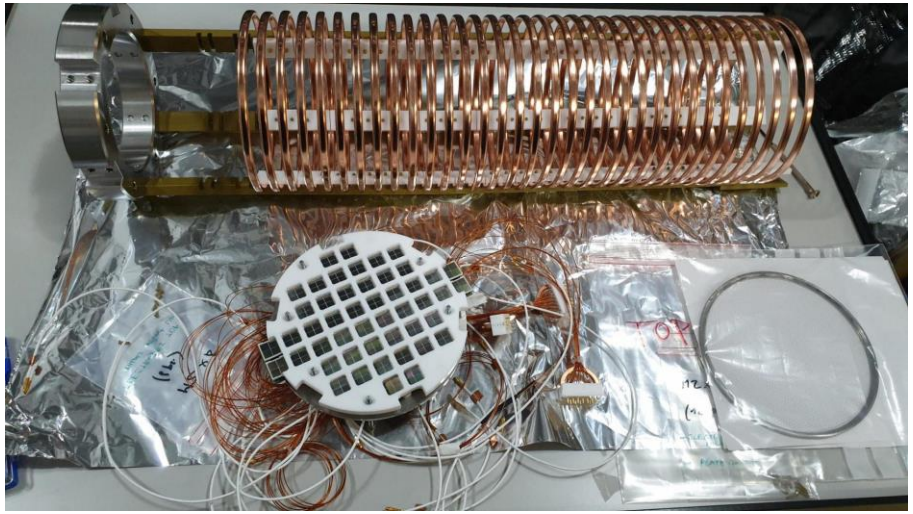


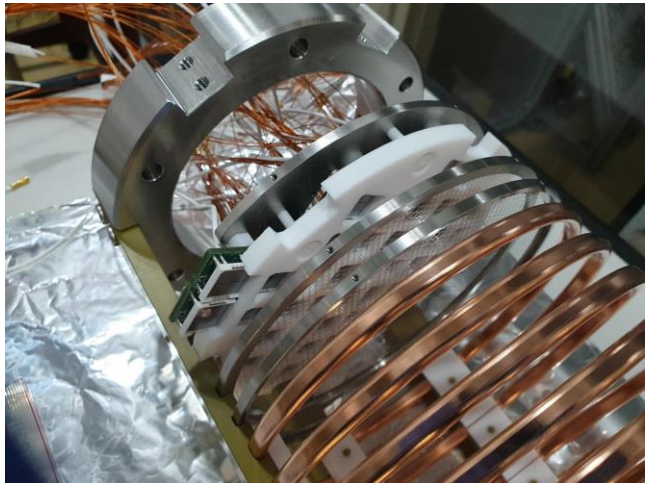
173 OFHC copper rings

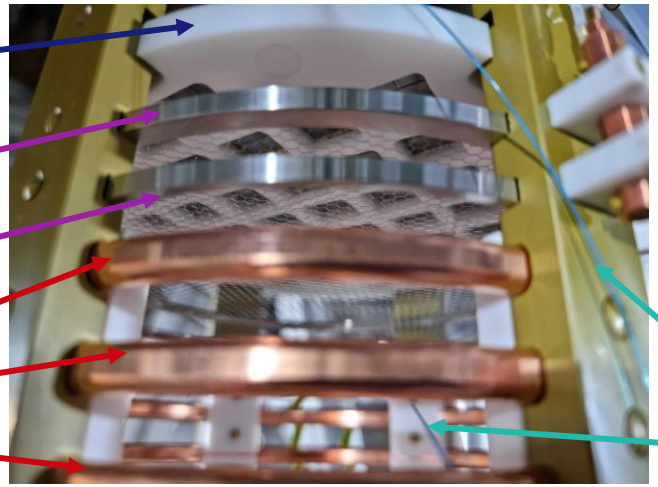
Two redundant resistor chains 1GΩ resistors

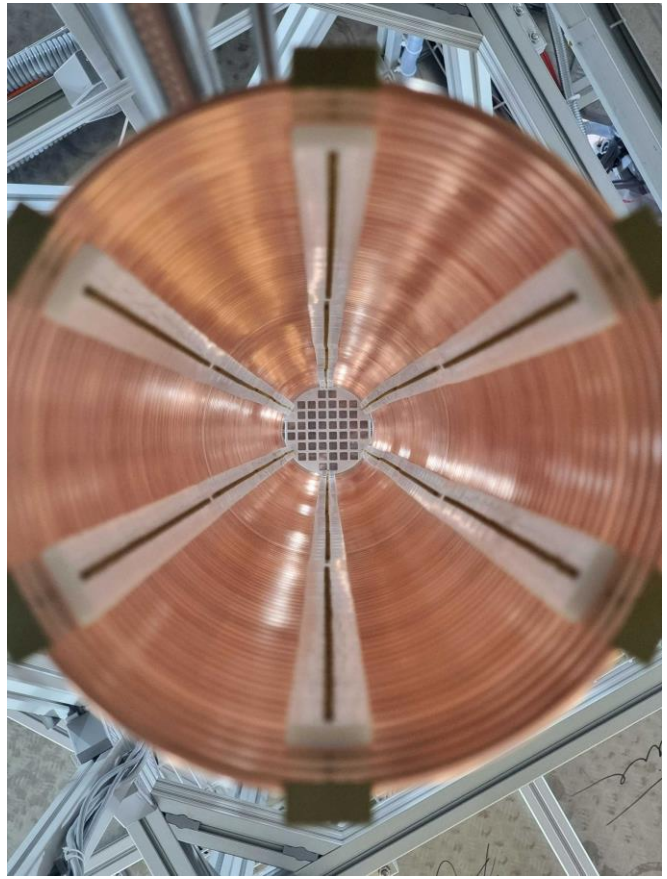
6 poliamide-imide (Torlon) pillars PTFE connectors inside

SiPM array assembly









SiPM array

13.7 mm

Anode

12 mm

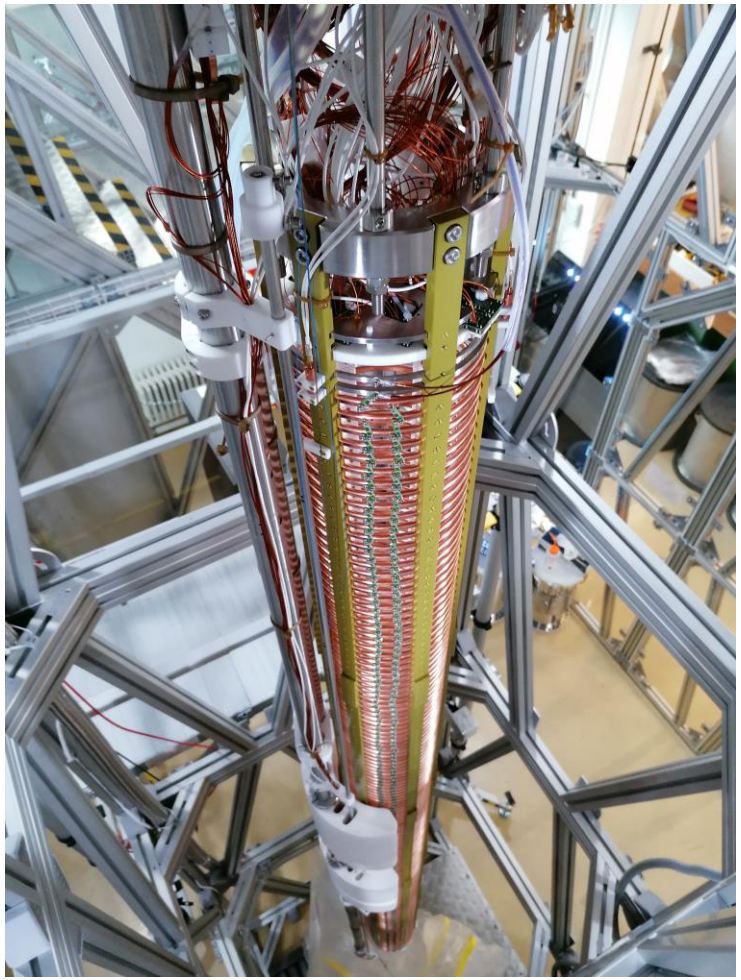
Gate

Field cage

LED fibre

Full TPC assembled

- ✓ 5 field-cage modules
- ✓ 3 electrodes
- ✓ SiPM array + LED fibres
- ✓ Weir
- ✓ 2 LLMs + 3 SLMs
- ✓ Photocathode + fibre
- ✓ 6 PTFE “fillers”
- ✓ HV feedthrough



Subsystem testing and filling

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Run Objectives

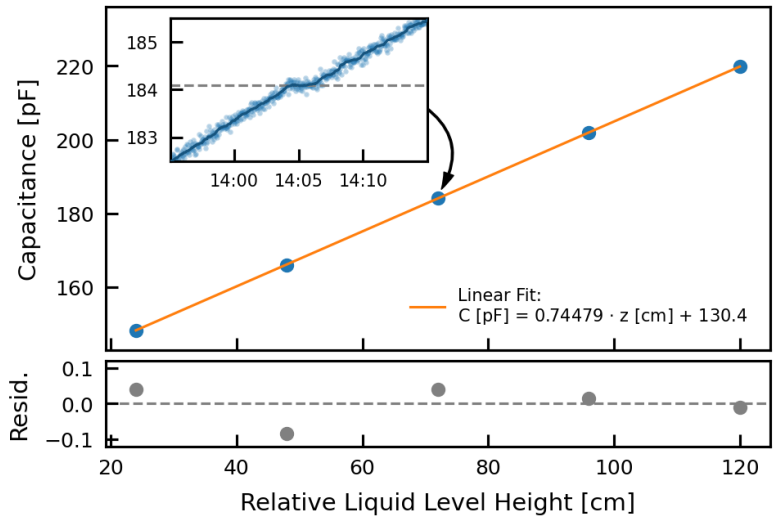
- Fill and circulate the full xenon inventory
- Commission and benchmark the installed subsystems

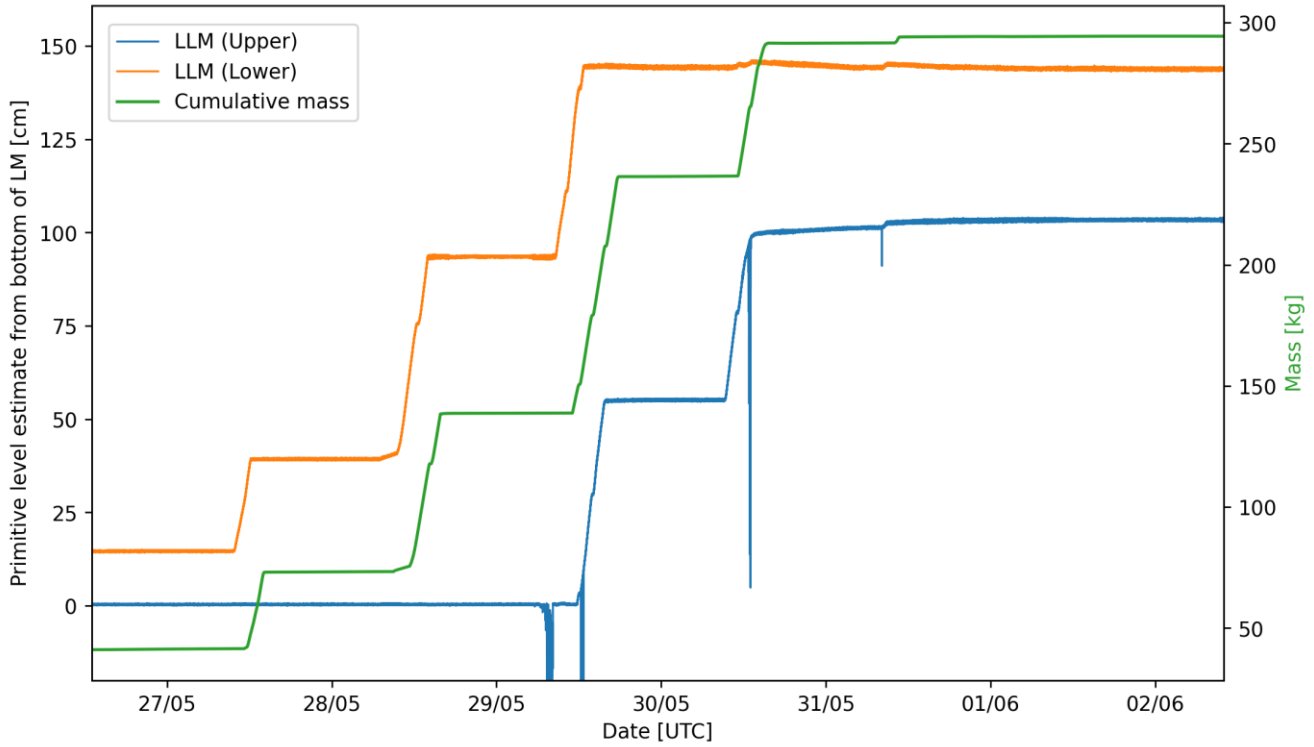
Run Caveats

- Getter is not operational
  - No full drift expected!
- Compressor and gas system updates further in the pipeline

Level monitoring and setting

- Liquid level monitored throughout the filling process and correlated with the integrated flow
- Lower levelmeter saturated
- Calibration rings identified and capacitance to height calibrated

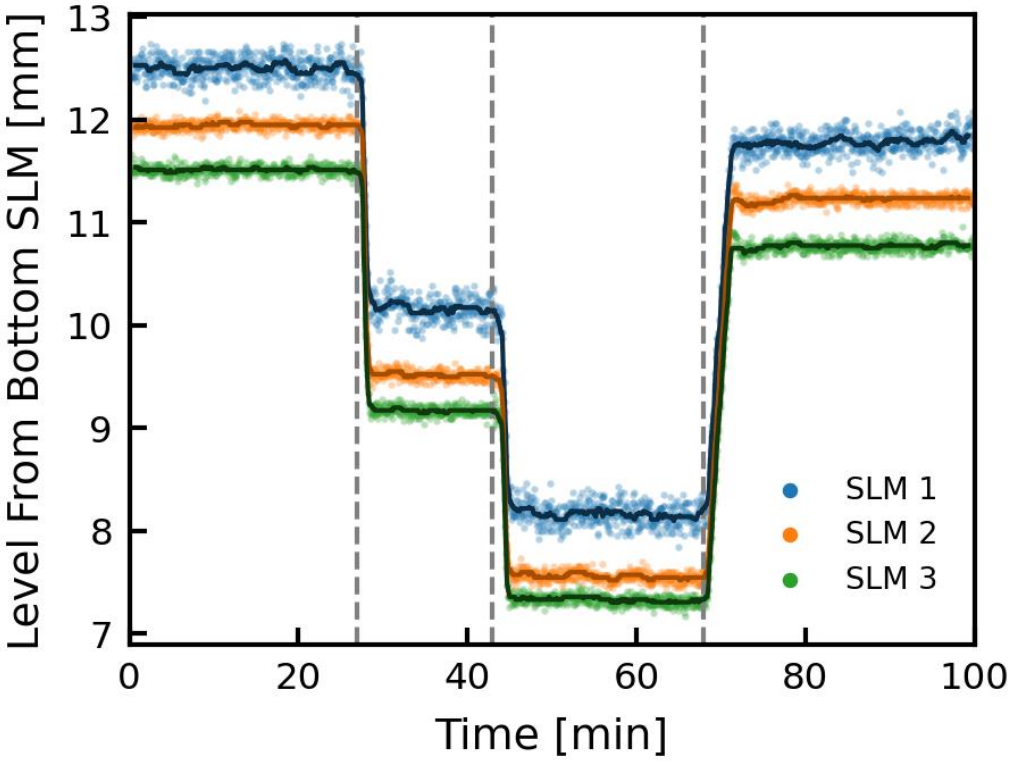




Total of ~360 kg filled!

Level monitoring and setting

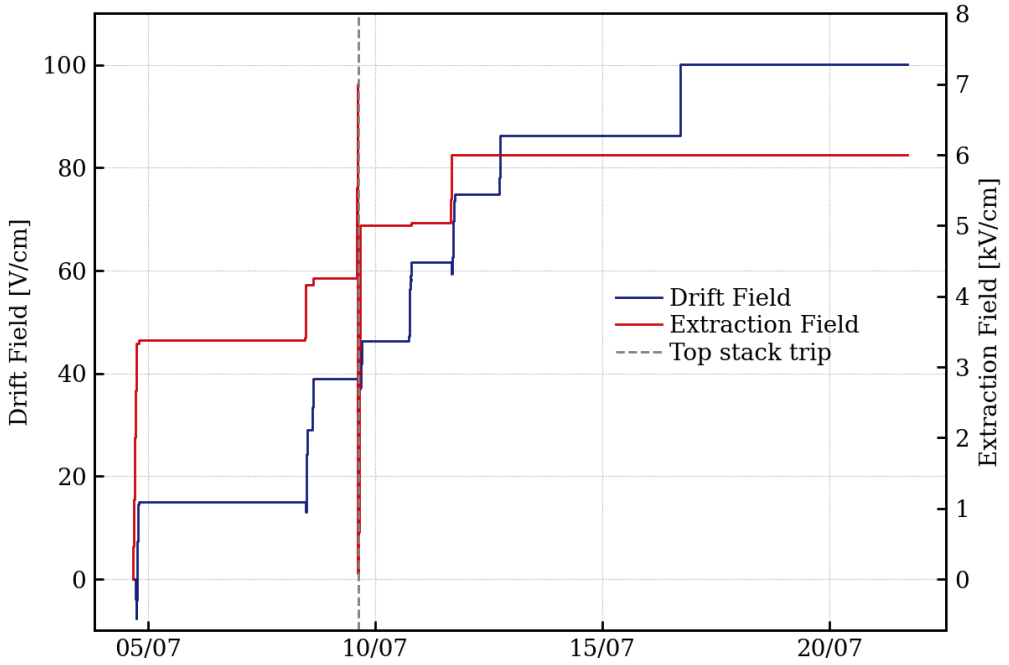
- Weir commissioned by overfilling and recuperating excess
- All 3 SLMs worked as expected
- Tested linearity and hysteresis effects by lowing and raising several times



HV ramp-up

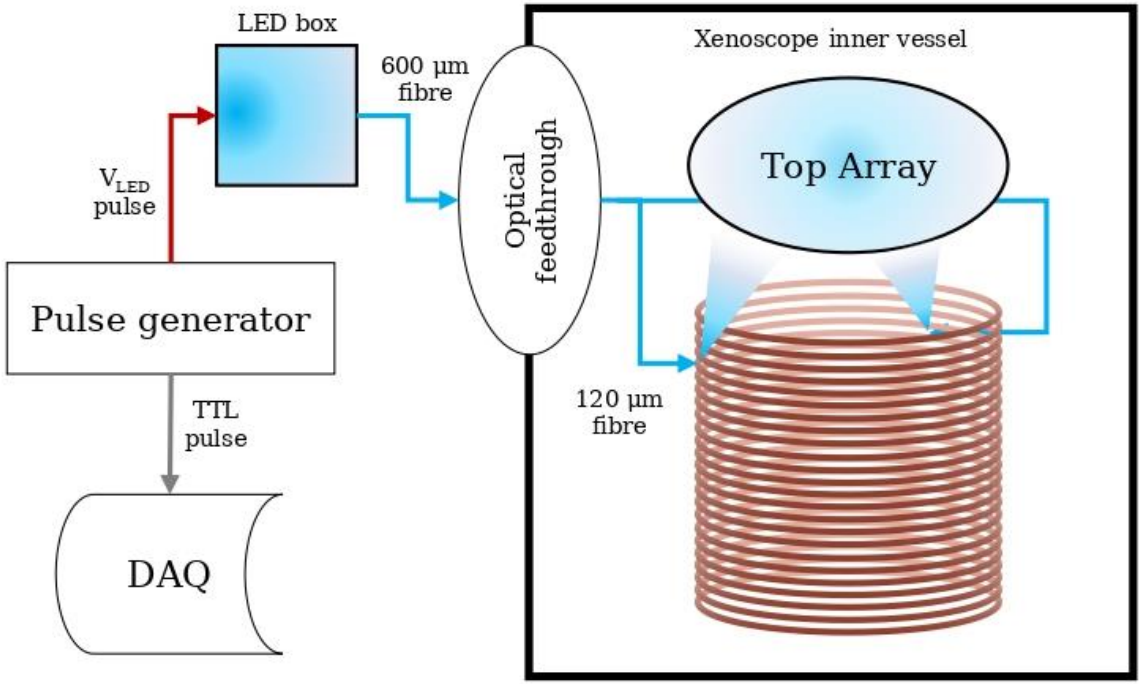
- Power supplies:
  - Anode and cathode: CAEN NDT1470 4CH
  - Cathode: Heinzinger PNC 100000
- Ramped up through several weeks to monitor stability
- Final configuration reached:
  - Anode: 3.6 kV
  - Gate: -3.6 kV
  - Cathode: -29 kV

Extraction field: 6kV/cm
Drift field: ~100 V/cm



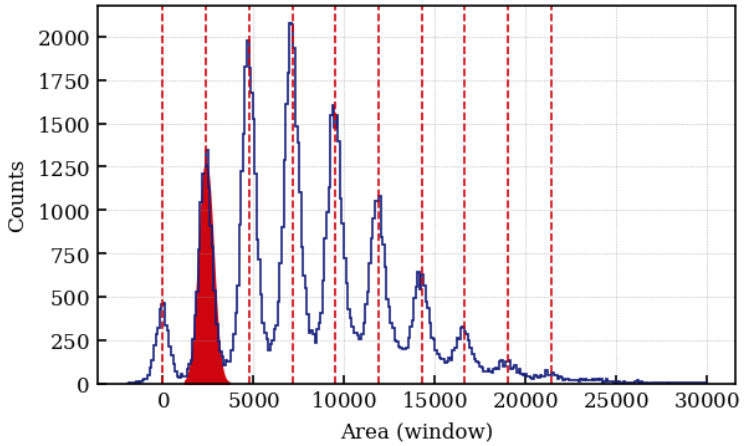
LED calibration

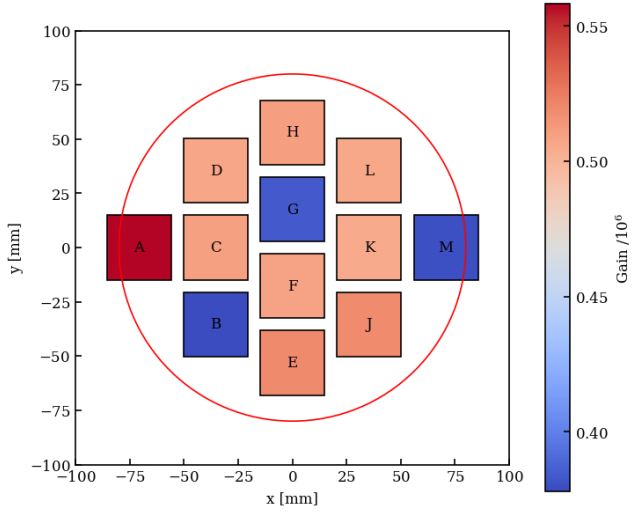
- Blue LED ($\lambda \approx 400\,nm$) triggered by pulse generator connected to DAQ
- LED box connected to inner vessel through optical feedthrough
- Light comes out of two fibers (~180º separation) that point to array
- Gain determination from fit of SPE peak



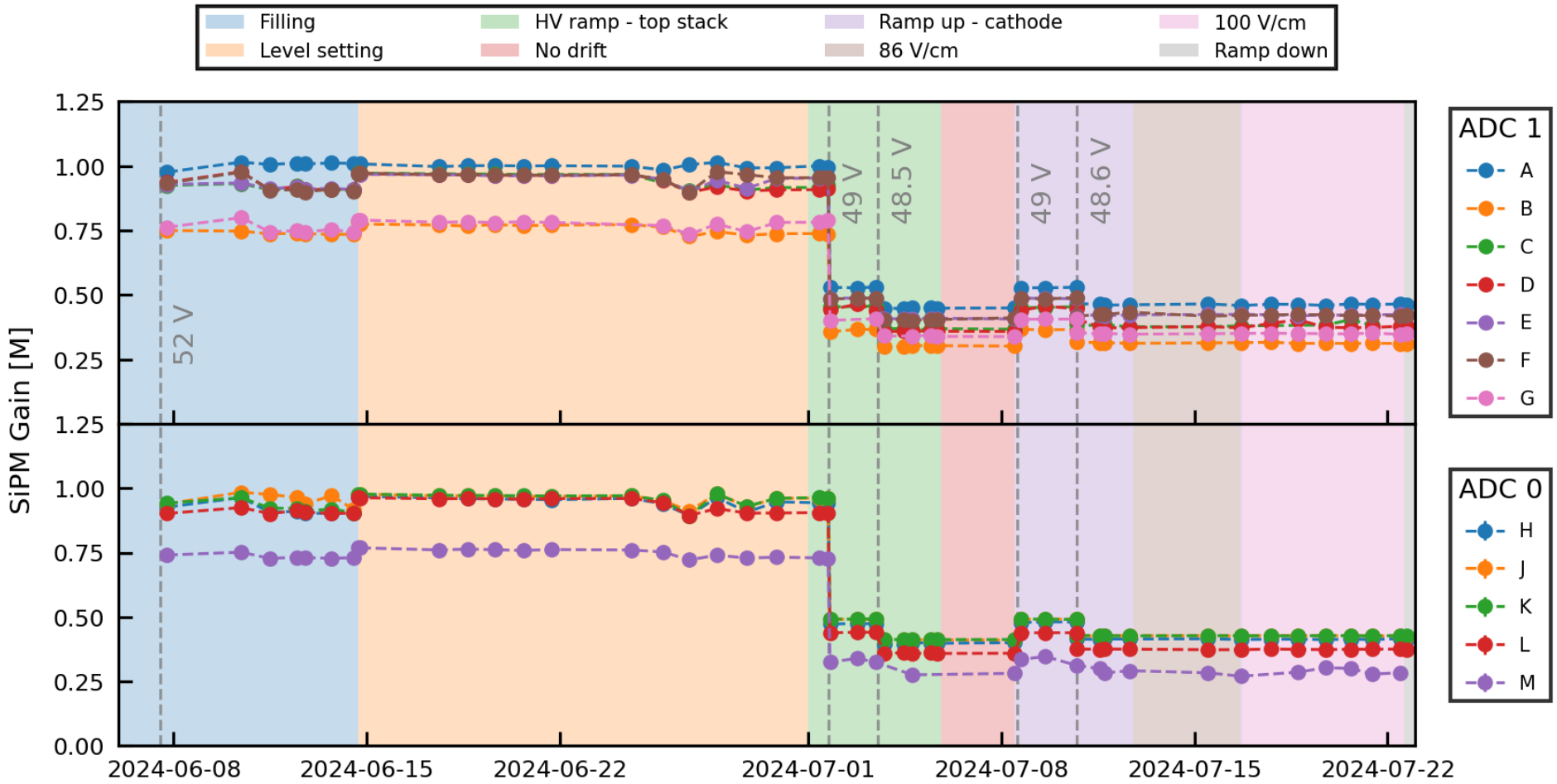
SiPM gain calibration

- Daily LED calibration with 5 light levels for gain monitoring (2 used in the final gain model)
- All 12 channels acquired simultaneously
- LED signal integrated over a 0.5 us window containing the full peak
- Gain determined by fit of the SPE peak in charge spectrum
- SiPM bias voltage changed throughout the run to avoid signal saturation





SiPM gain evolution



S1 and S2 signals

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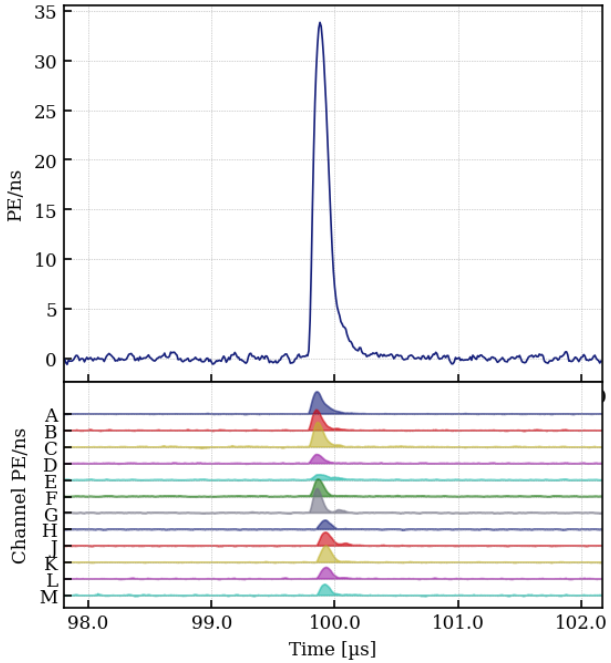
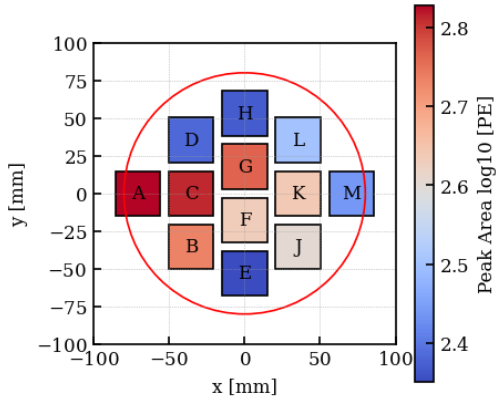
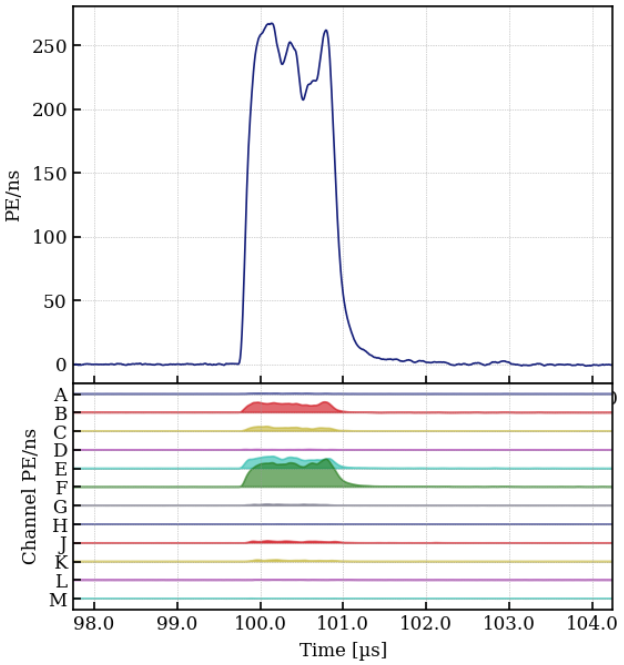
S1-like

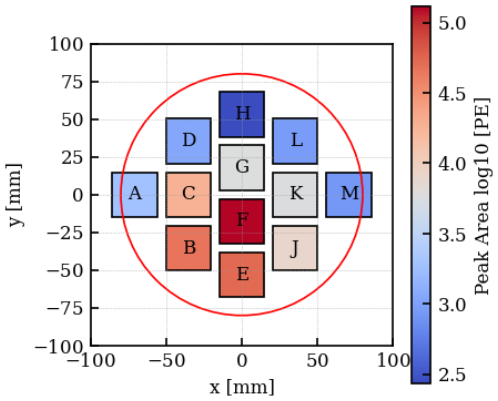




Area: 4995.24 PE
Length: 0.37 µs
Position: 99.80 µs
Amplitude: 33.83 PE/ns

S2-like



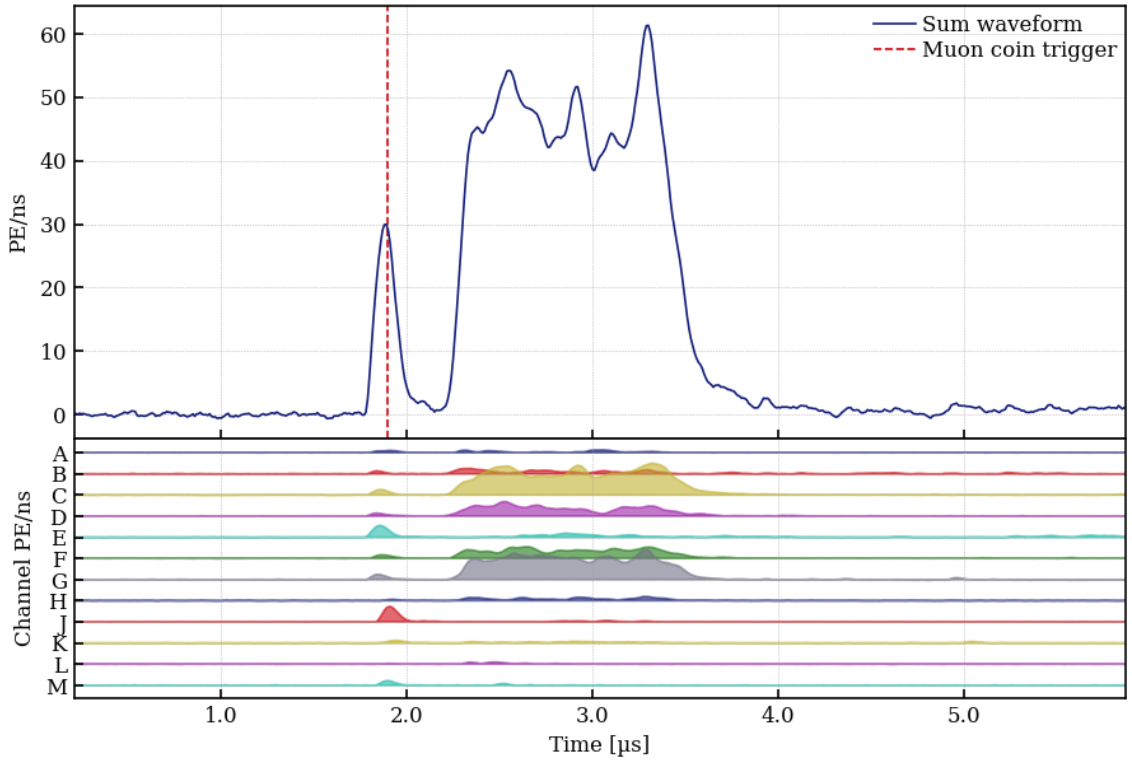


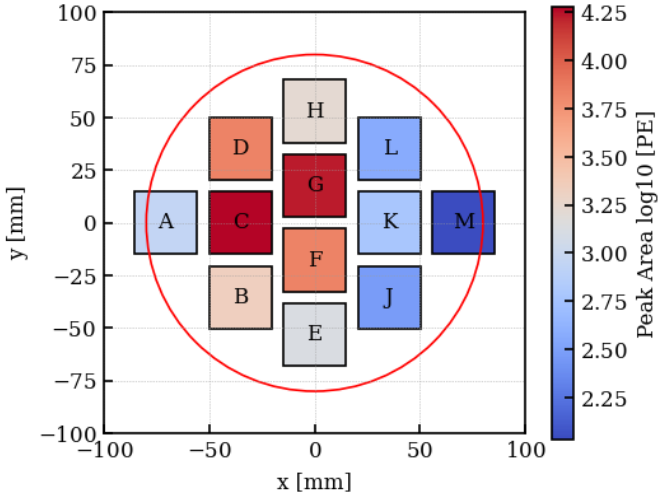
Area: 274941.92 PE
Length: 2.50 µs
Position: 99.75 µs
Amplitude: 267.20 PE/ns

S1 and S2 signals

University of Zurich[UZH]

S1-S2 event

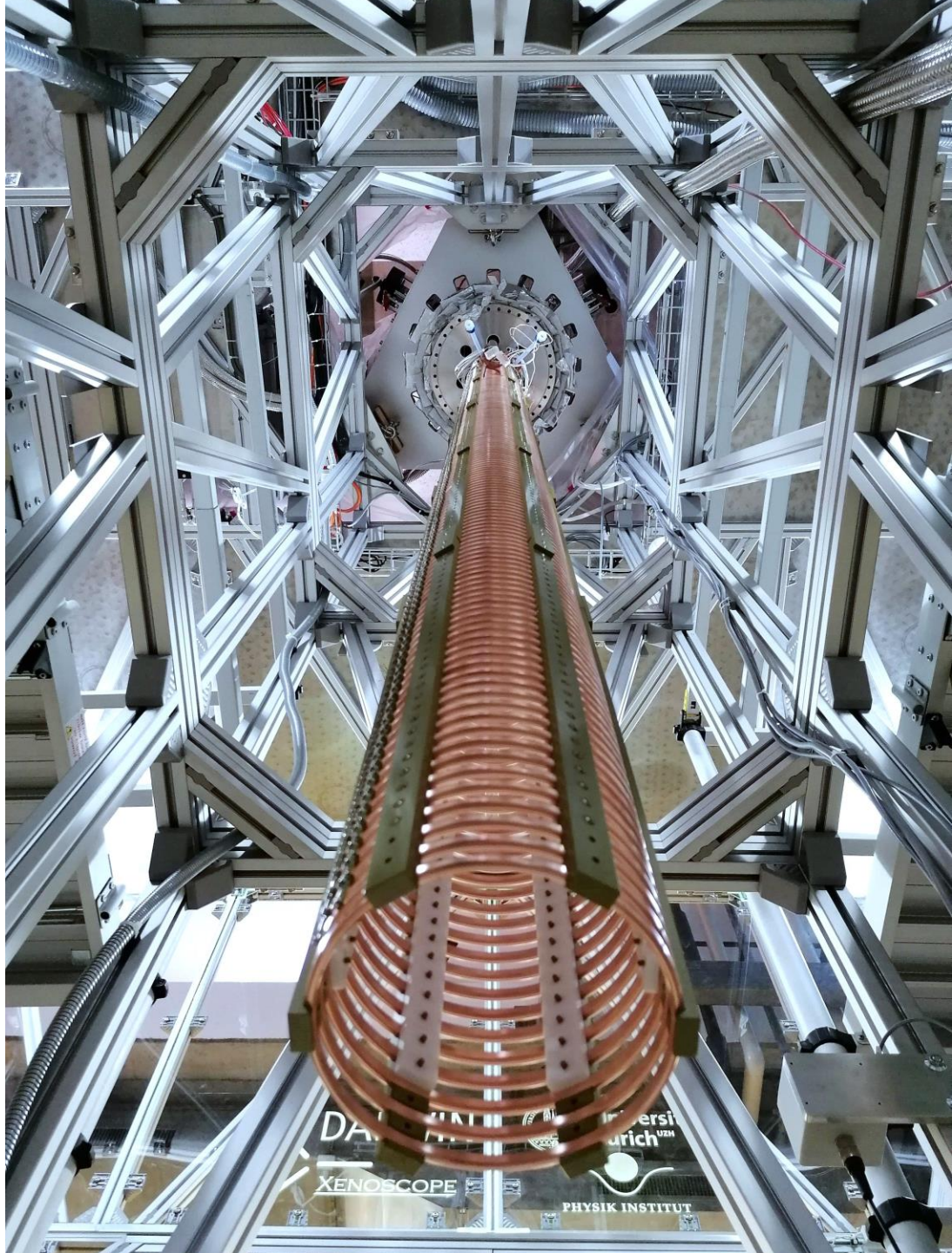




Area: 57318.53 PE
Length: 1.66 µs
Position: 2.21 µs
Amplitude: 61.30 PE/ns

Summary and Outlook

- 2.6 m dual-phase LXe assembled
- All subsystems successfully commissioned
  - LLMs
  - Weir + SLMs
  - HV delivery
  - SiPM array
  - DAQ + processing
- S1-S2 events observed!



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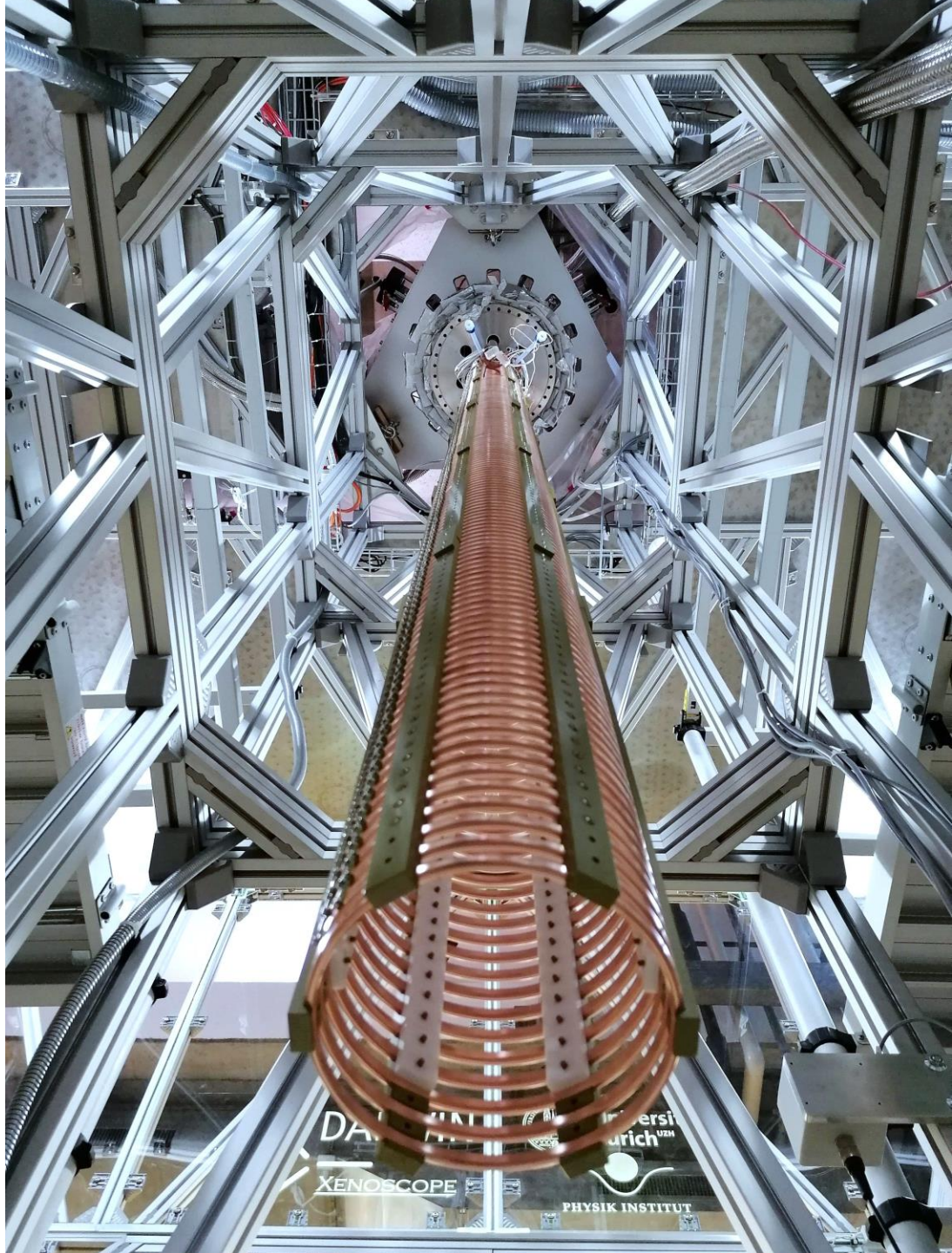
- All subsystems successfully commissioned
  - LLMs
  - Weir + SLMs
  - HV delivery
  - SiPM array
  - DAQ + processing
- S1-S2 events observed!

- Next run in preparation
  - Several updates to compressor and gas system to allow variable xenon purification
  - Getter ON
  - Photocathode and external calibration sources

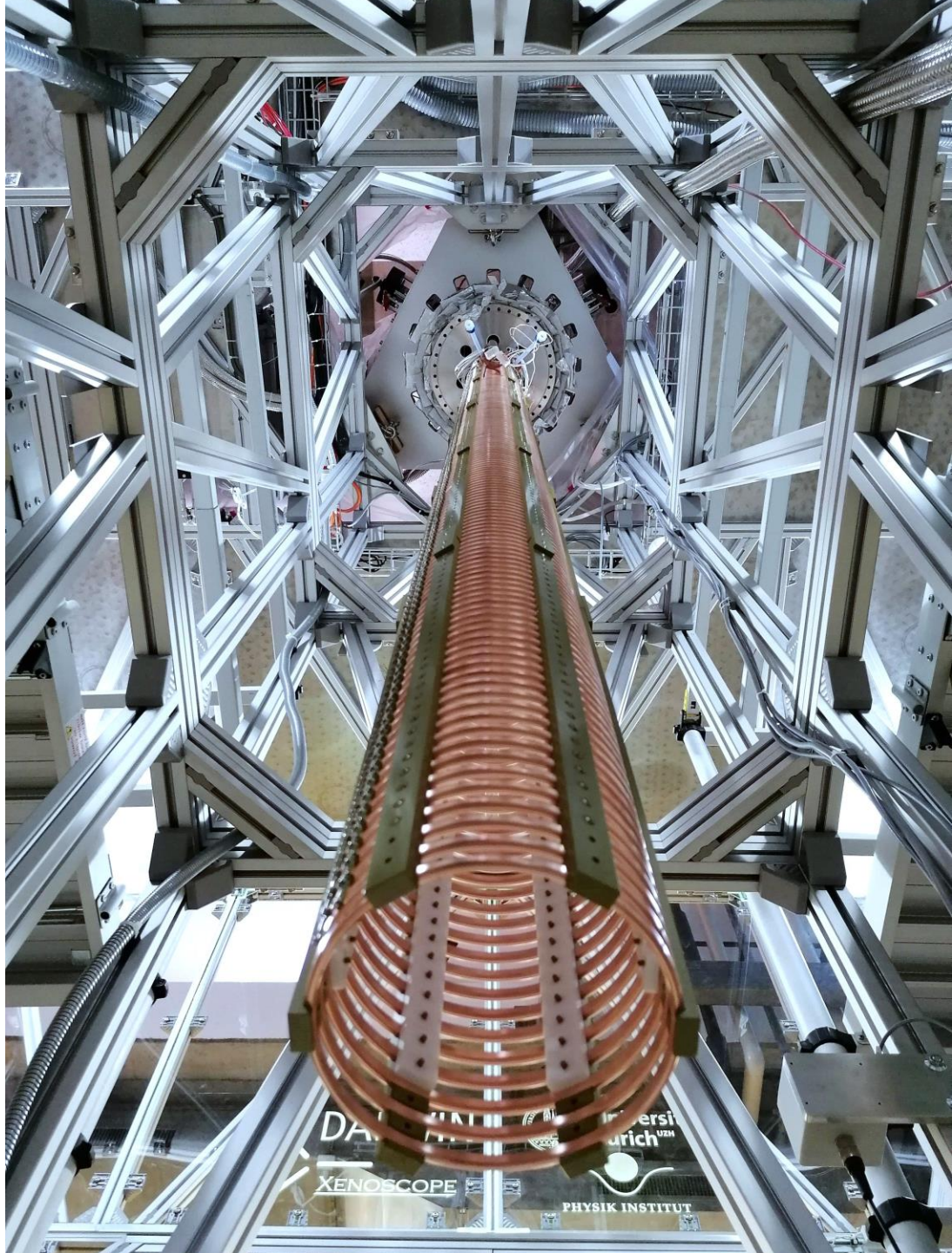


Summary and Outlook

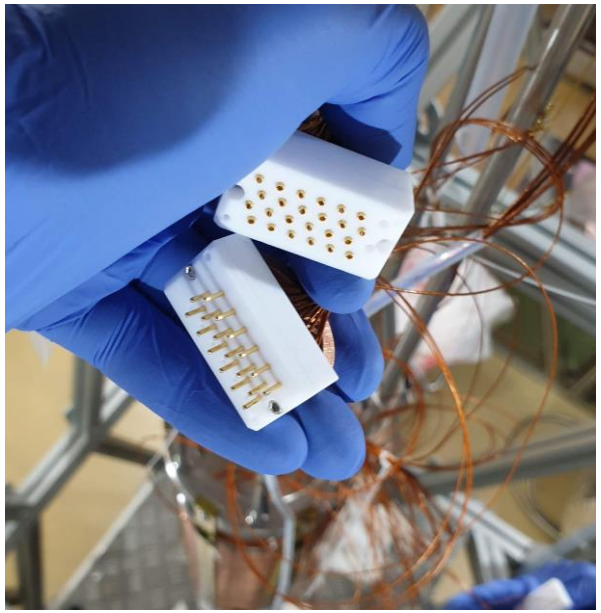
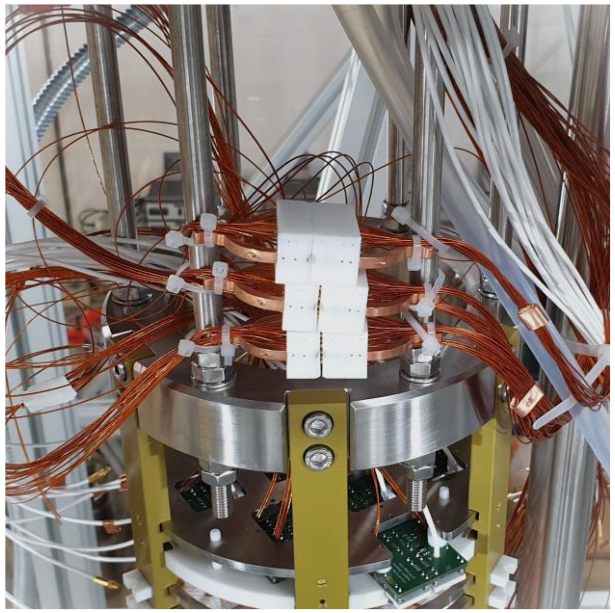
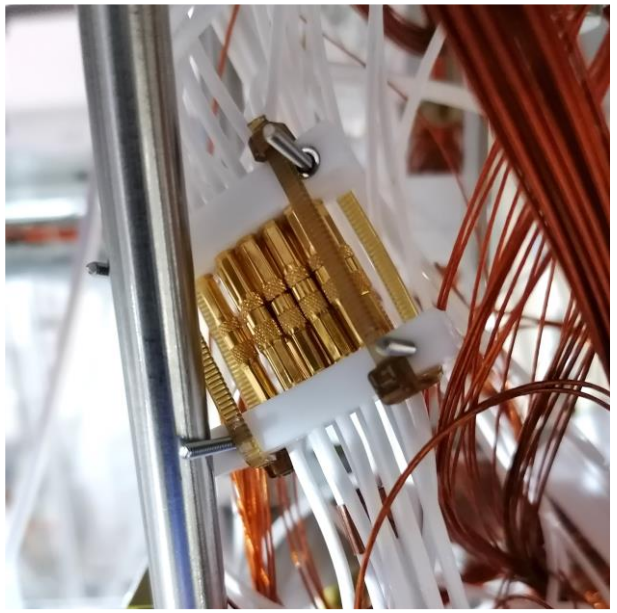
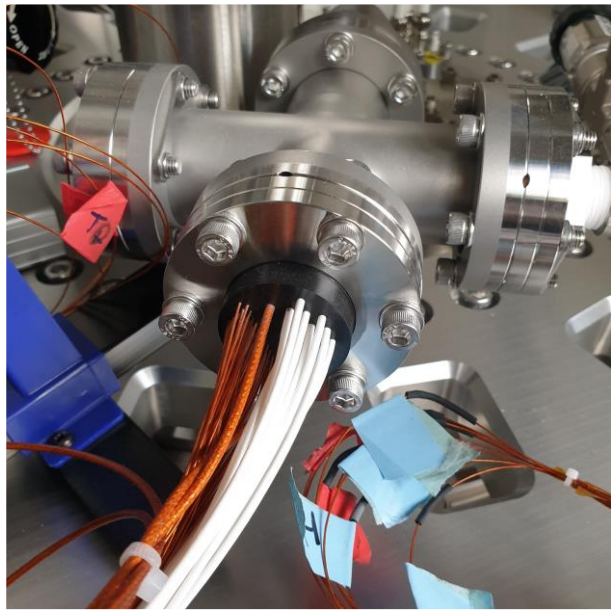
- 2.6 m dual-phase LXe assembled
- All subsystems successfully commissioned
  - LLMs
  - Weir + SLMs
  - HV delivery
  - SiPM array
  - DAQ + processing
- S1-S2 events observed!

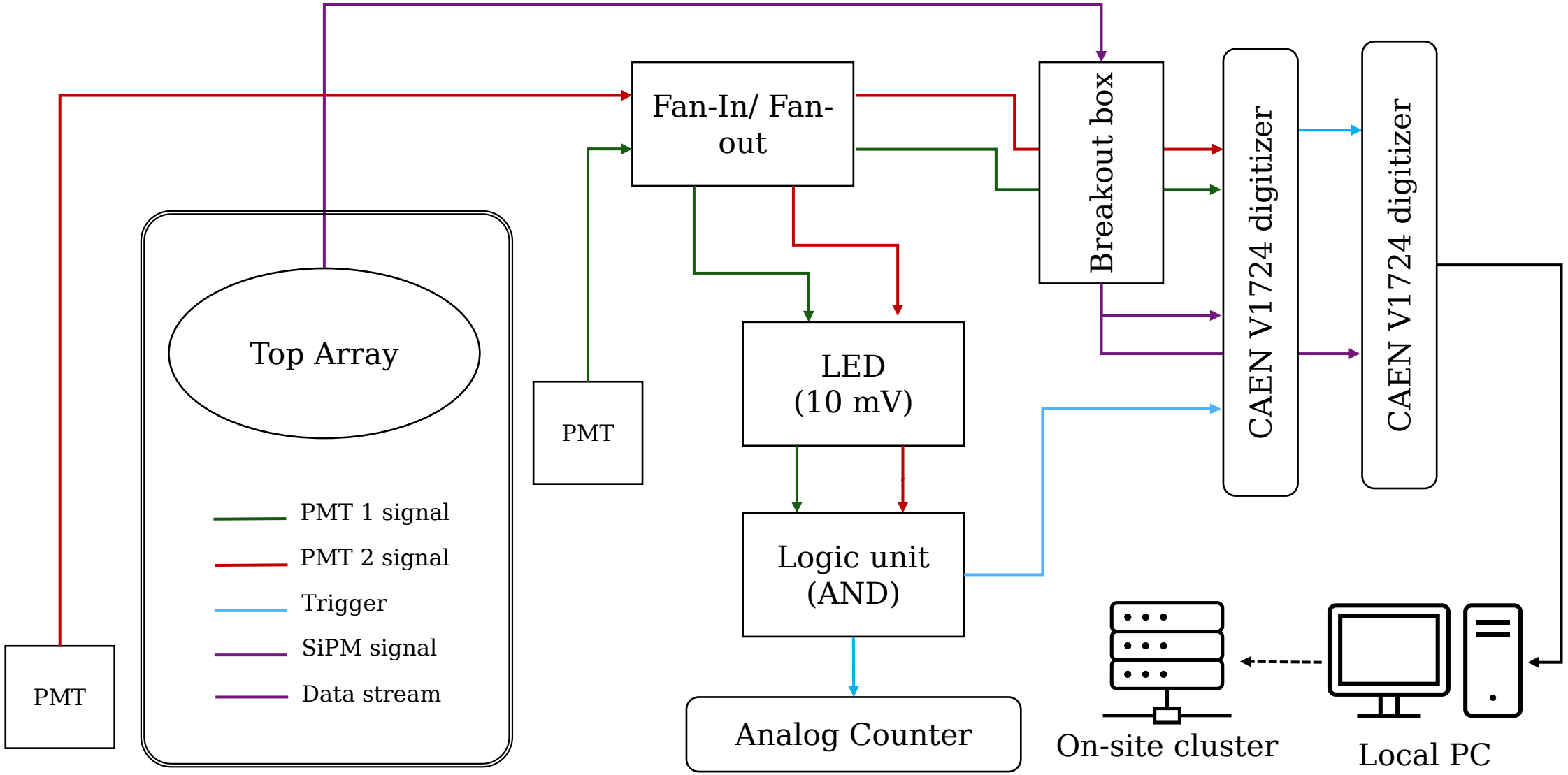
- Next run in preparation
  - Several updates to compressor and gas system to allow variable xenon purification
  - Getter ON
  - Photocathode and external calibration sources

Thank you!



Cabling

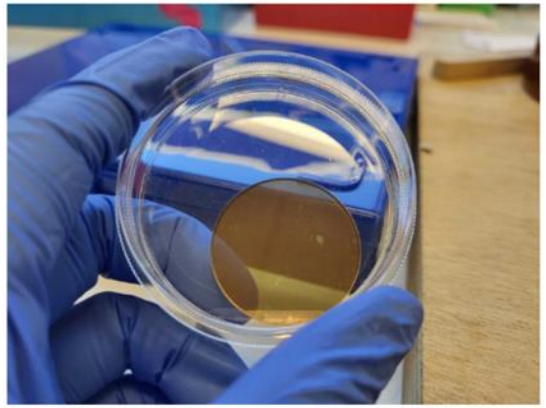





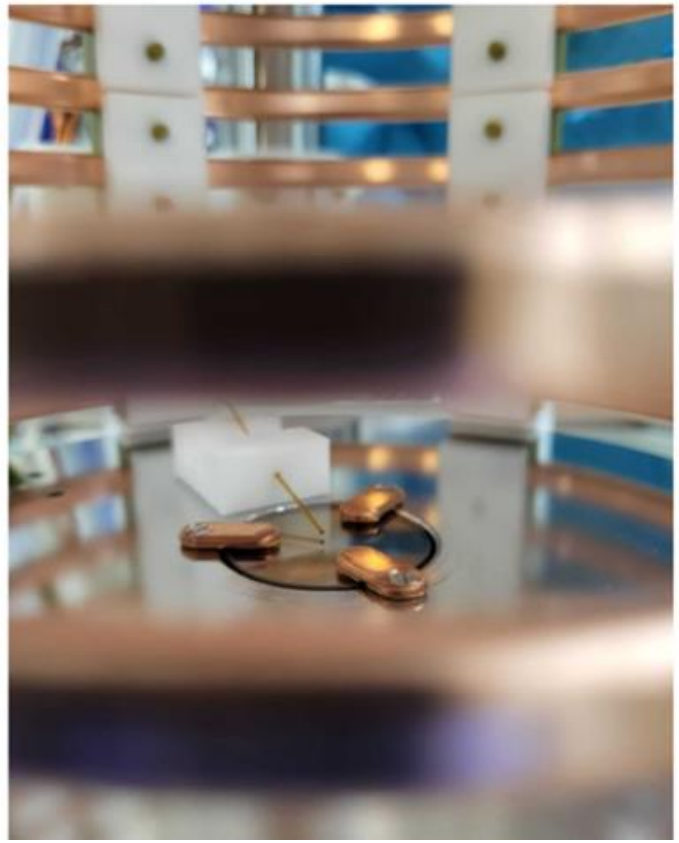

Fan-In/ Fan-out
Breakout box
CAEN V1724 digitizer
CAEN V1724 digitizer
Top Array
PMT
LED (10 mV)
PMT
Logic unit (AND)
PMT 1 signal
PMT 2 signal
Trigger
SiPM signal
Data stream
Analog Counter
On-site cluster
Local PC

Photocathode and high-voltage connection

- New photocathode gold coated (50 nm thickness) on a quartz substrate (2 mm thick)
- Xe flash lamp pulse transmitted through optical fibre

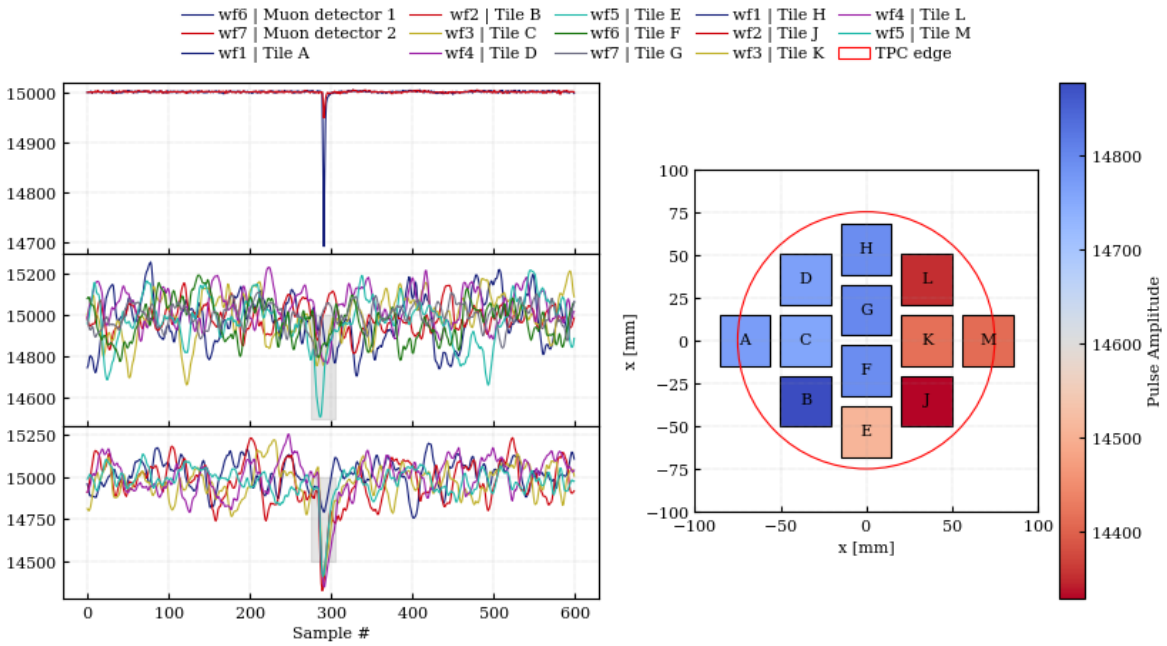
Q150T S automatic sputter coater

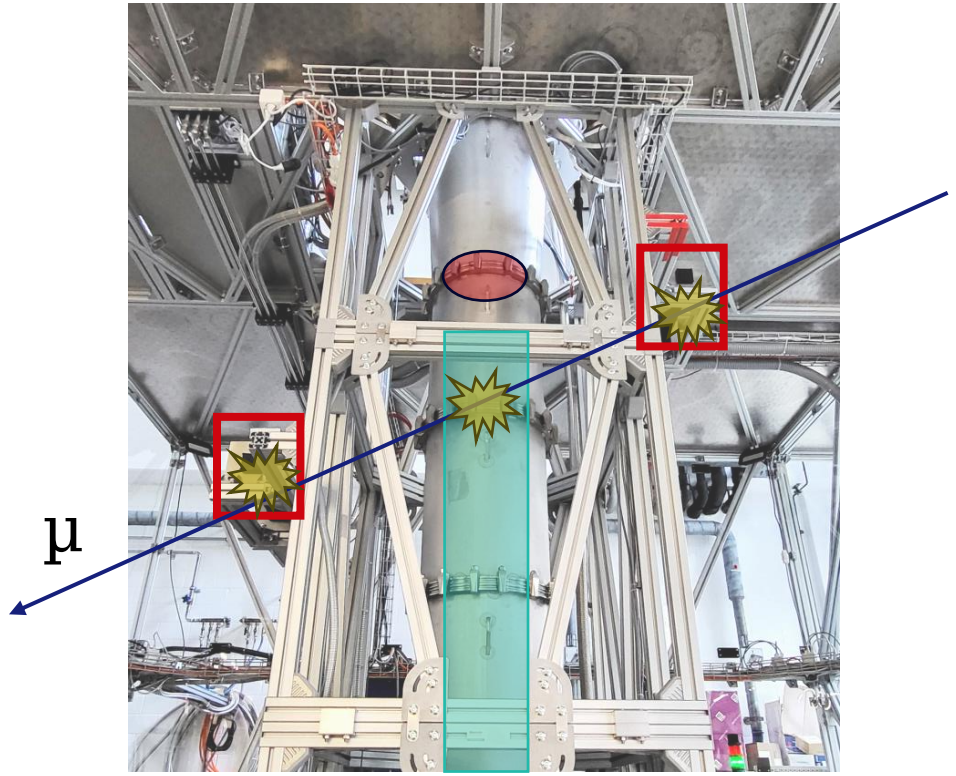




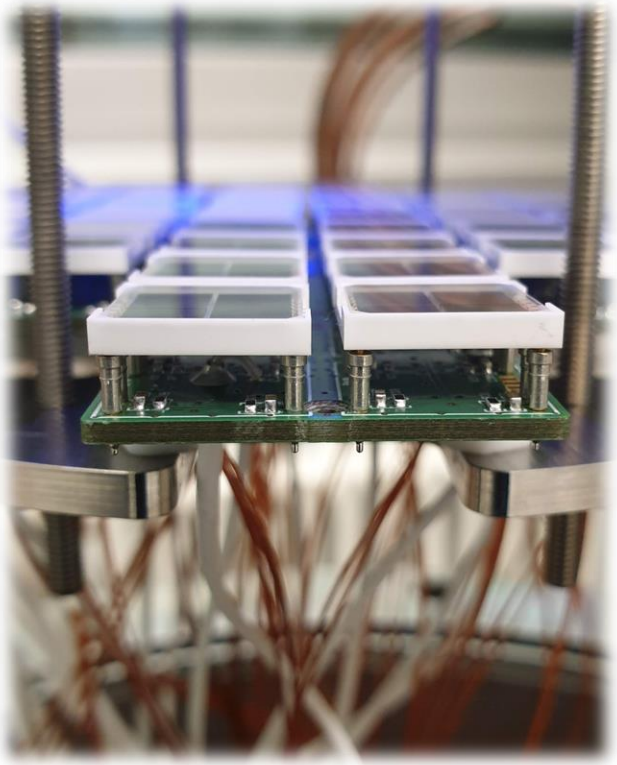
SiPM array test in warm

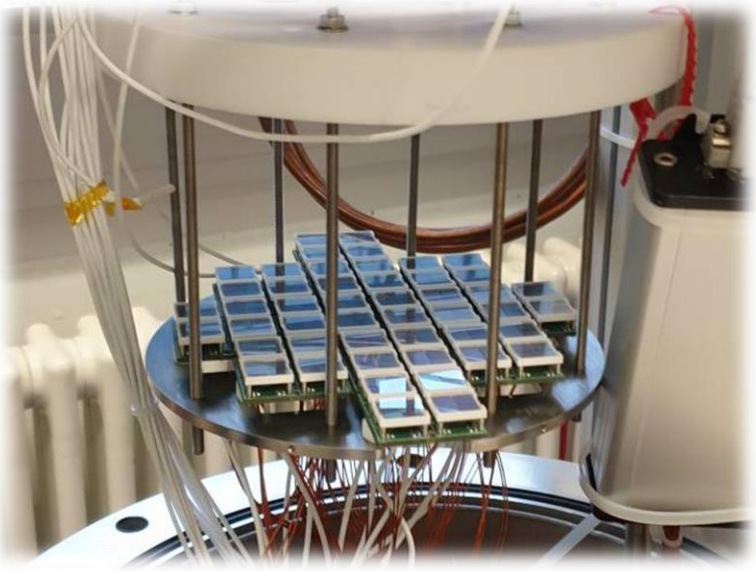
- LED in warm
- Gxe fill – 2 bar
- Muon coincidence data

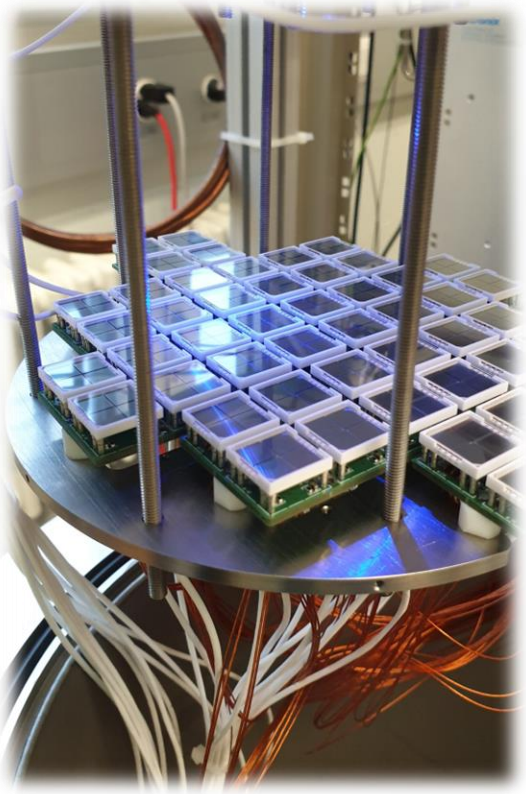




The LArS Test Setup

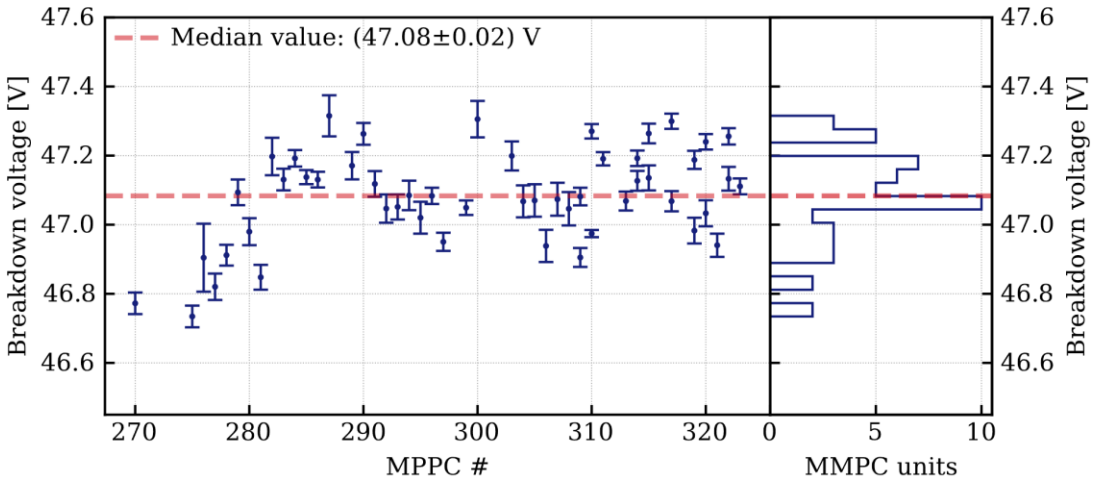


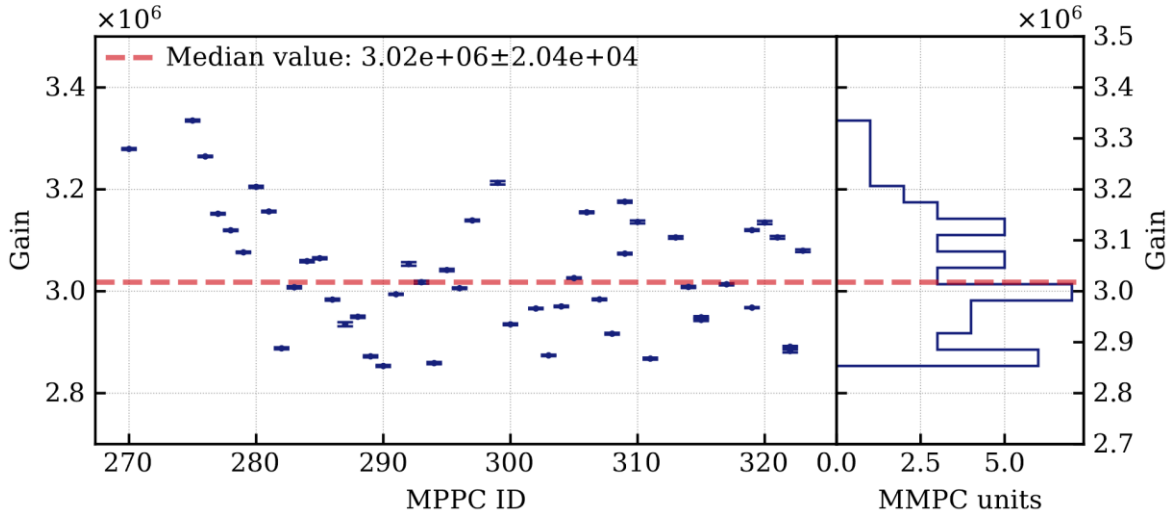




Gain and Breakdown Voltage

@52 V, 190 K

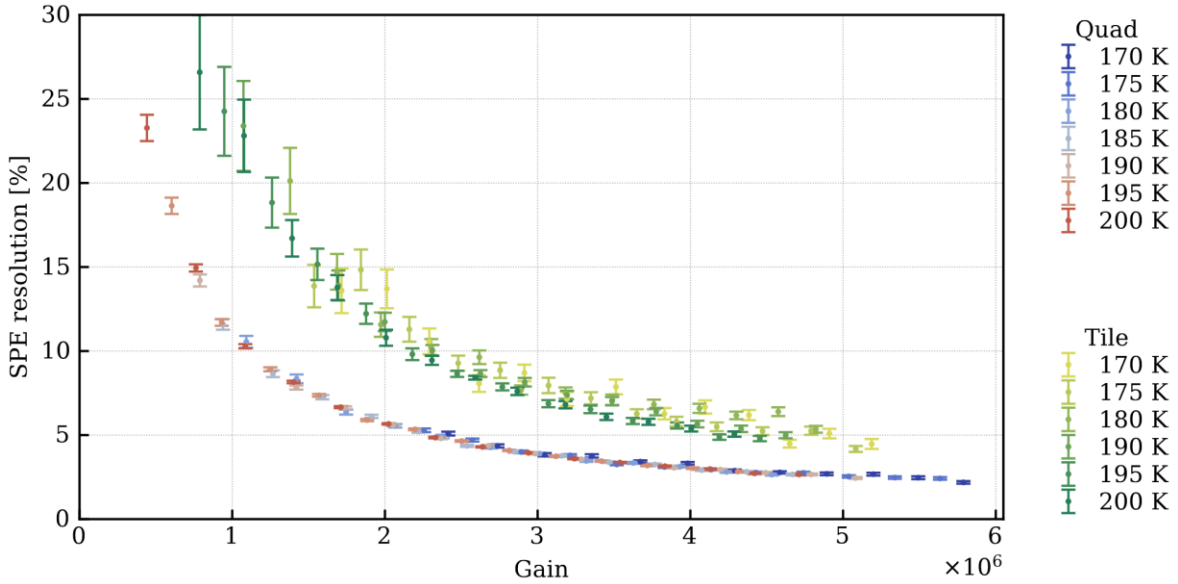




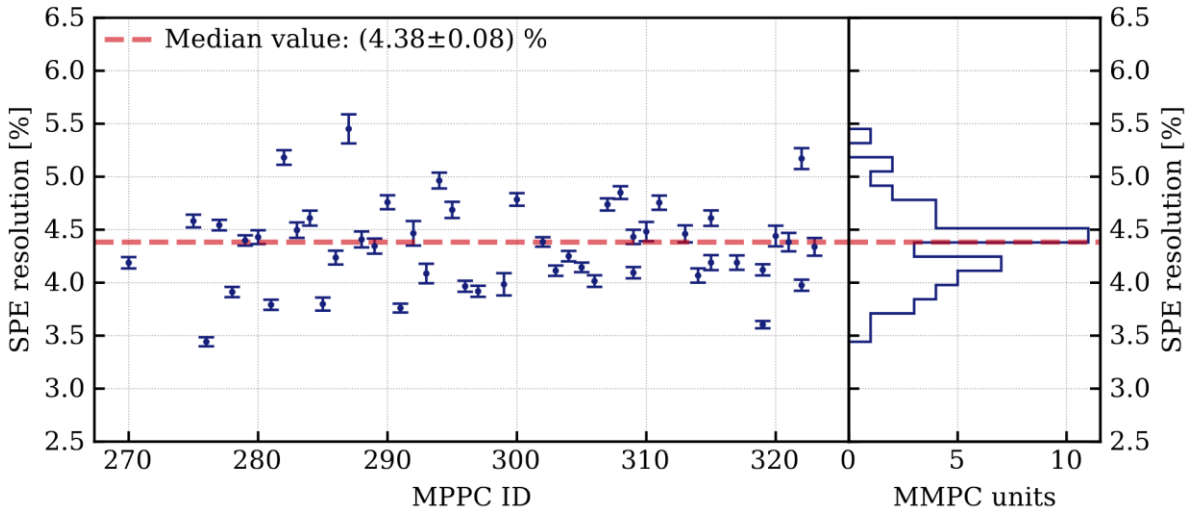
BV: 47.08 ± 0.13 V

Gain: $(3.02 \pm 0.12) \times 10^6$

SPE Resolution



@52 V, 190 K

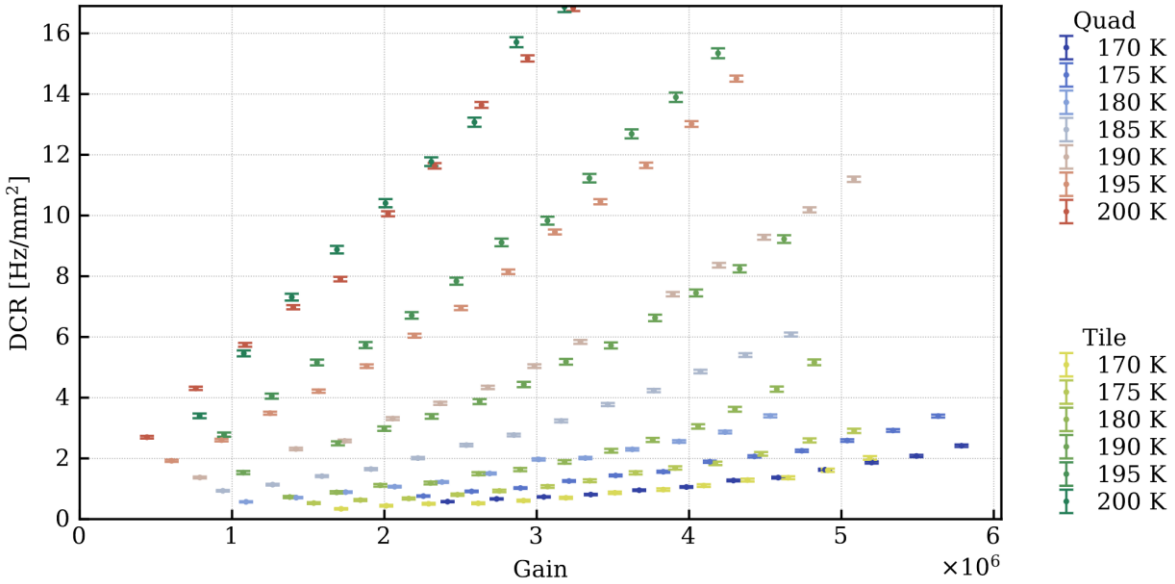


Tile ~2x worse than single quad

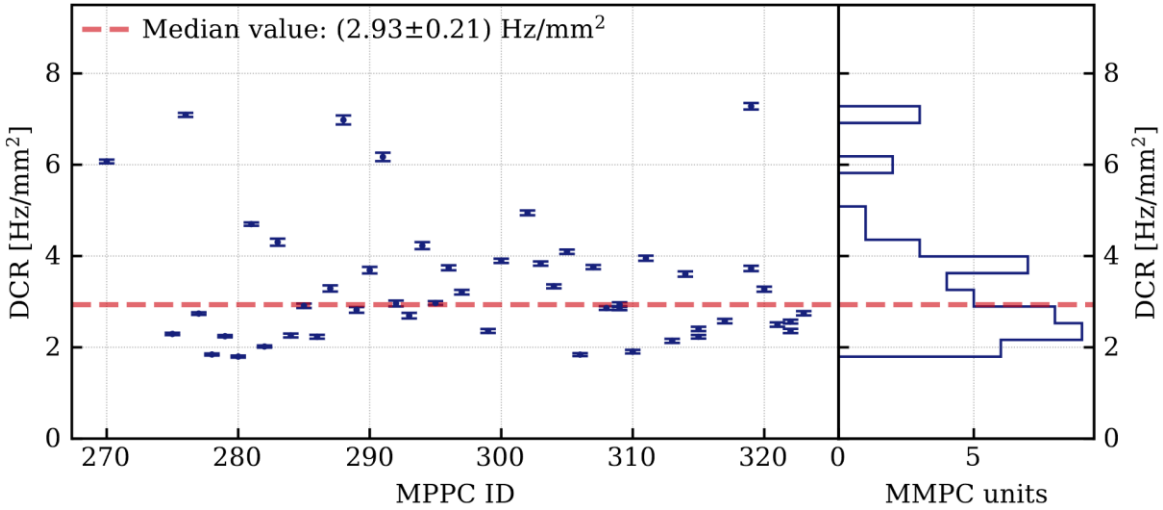
Improvable by gain matching

SPE: (4.38 ± 0.44) %

Dark Count Rate



@52 V, 190 K



Tile and quad show same behaviour

Each tile: ~1.69 kHz

Full array: ~20.25 kHz

DCR: (2.93 ± 1.2) Hz/mm²

Looking ahead: simulating signals in Xenoscope

- Xe light at photocathode / alpha source at bottom
- Electron drift and diffusion
- Diffusion sensitivity study incoming
  - hybrid granularity solution