Current status of Xenoscope, a full-scale vertical demonstrator for the DARWIN observatory

Nagoya Workshop on Technology and Instrumentation in Future Liquid Noble Gas Detectors, 2024.

Jose Cuenca-García, on behalf of the Xenoscope team.

15.02.2024

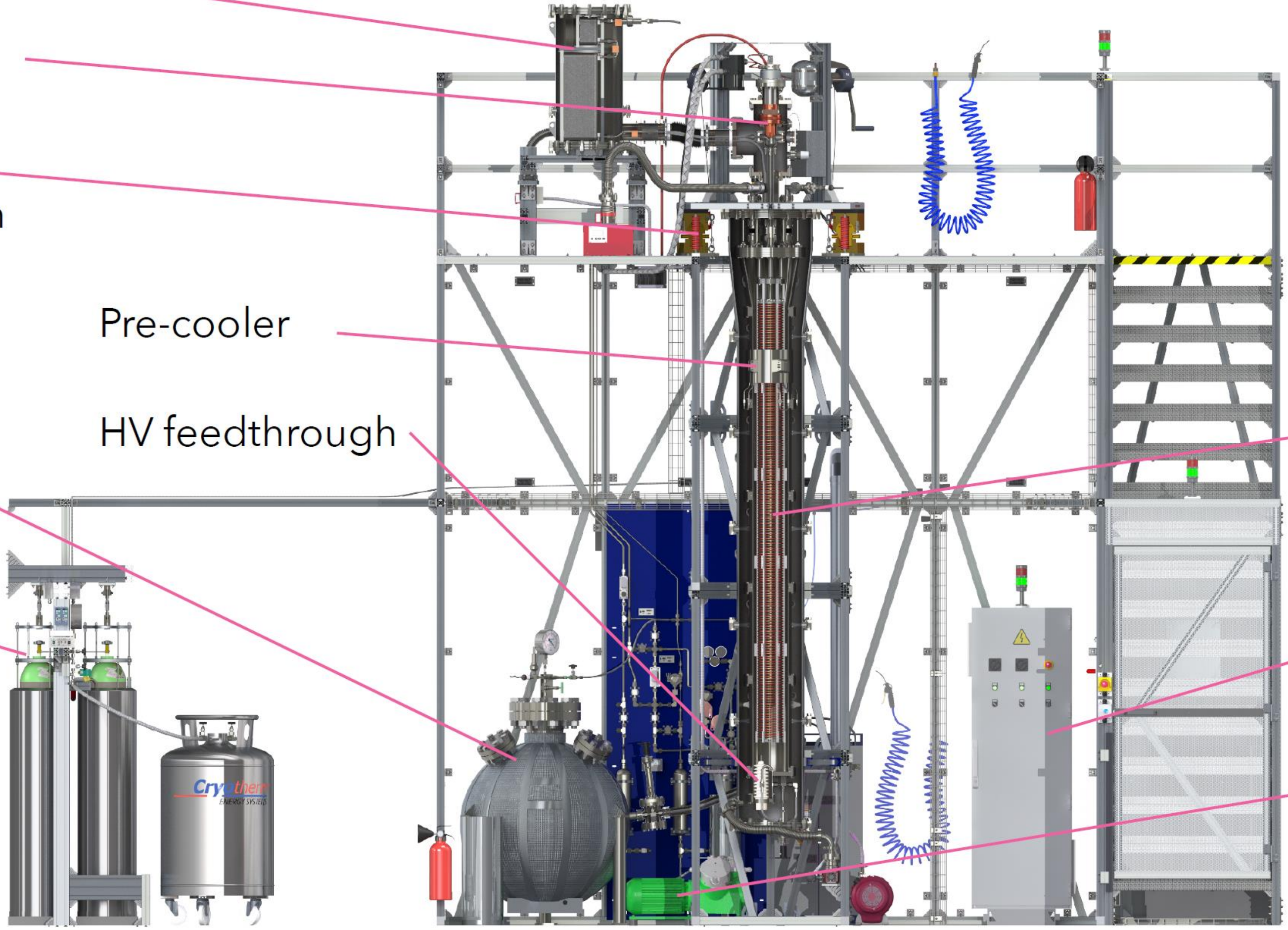
Two demonstrators for DARWIN

Pancake (Freiburg)

Xenoscope (Zurich)

Xenoscope

JINST 16 P08052 (2021)



Heat exchanger

Cooling tower

Mechanical levelling system

Pre-cooler

HV feedthrough

BoX liquid recuperation

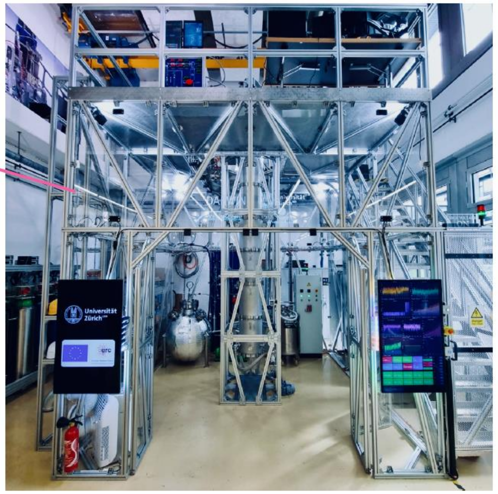
Xenon bottle storage for a 400 kg inventory

Cryostat with time projection chamber

SAES Getter

Diaphragm pump from KNF for 100 SLPM gas circulation

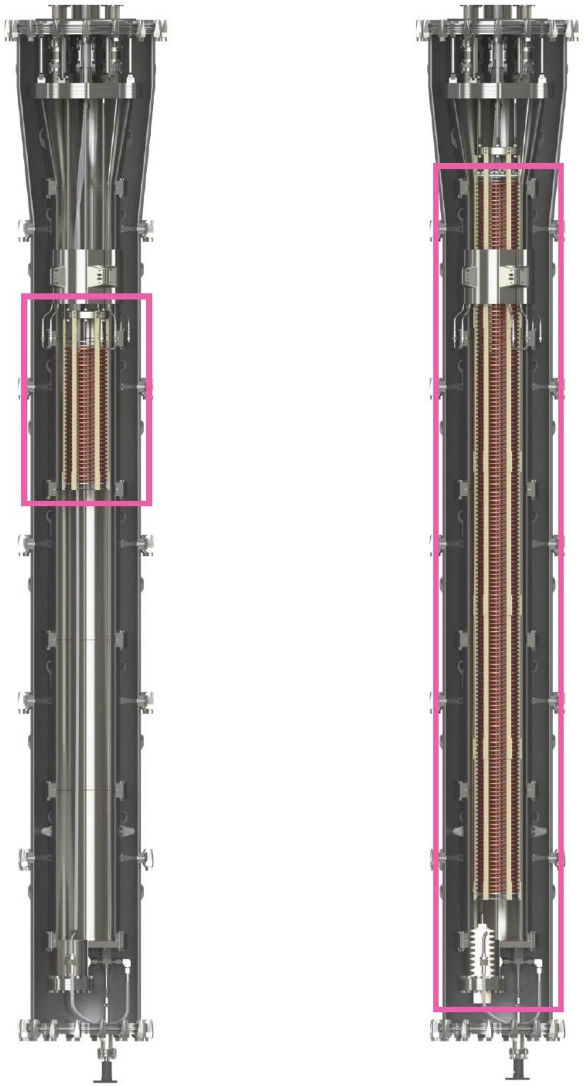
Provisional cleanroom



The plan

Phase 1: purity monitor

- Stable operation for 3 months
- Test cryostat systems (pre-cooler)
- Test of liquid recuperation to BoX
- Model electron lifetime as a function of purification speed/conditions
- Model electron transport properties for different electric fields

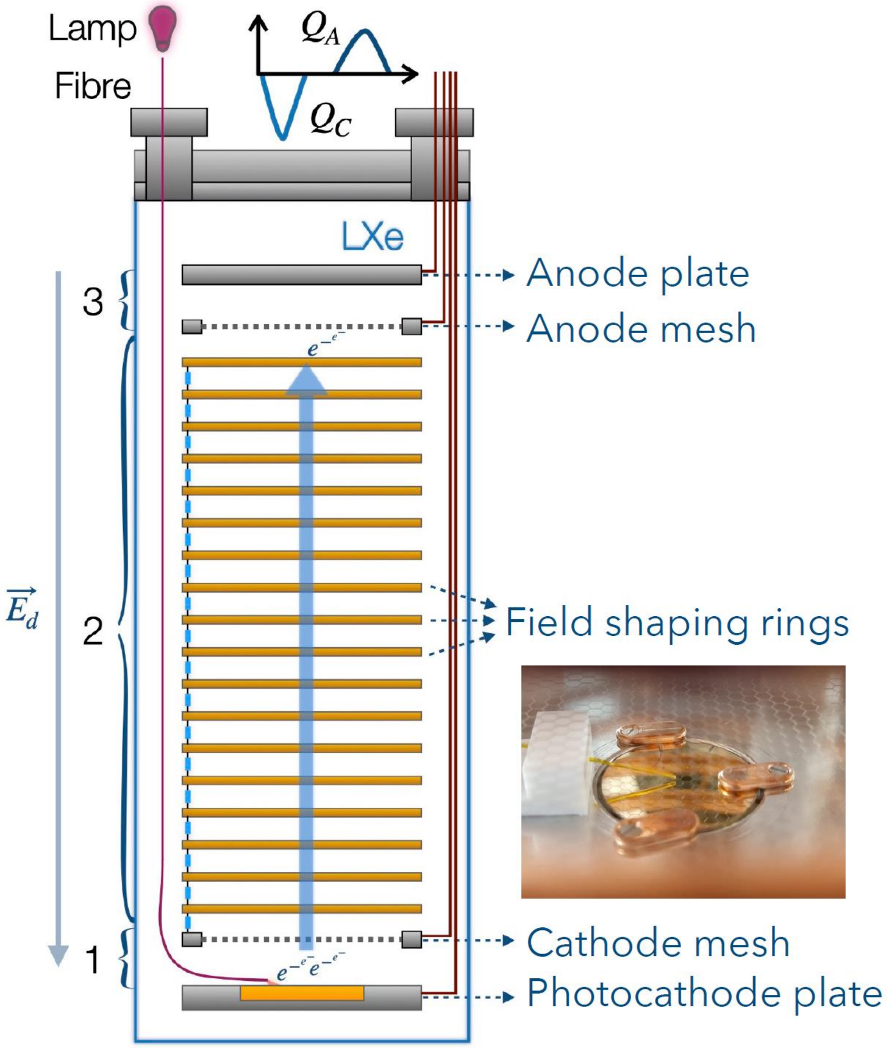


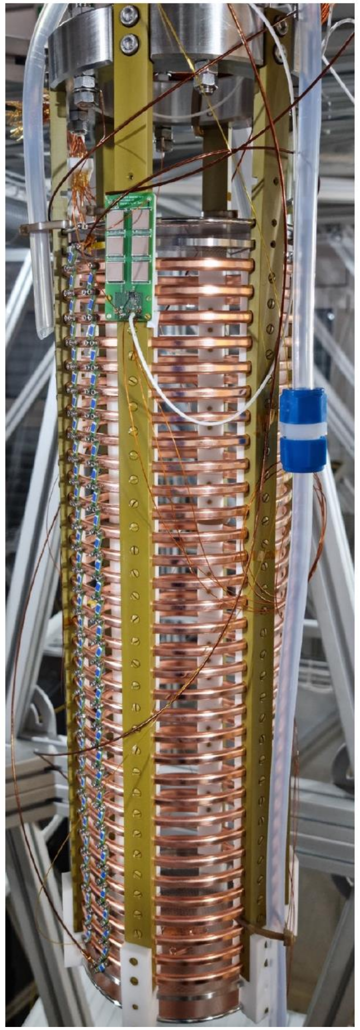
Phase 2: 2.6-m Time Projection Chamber

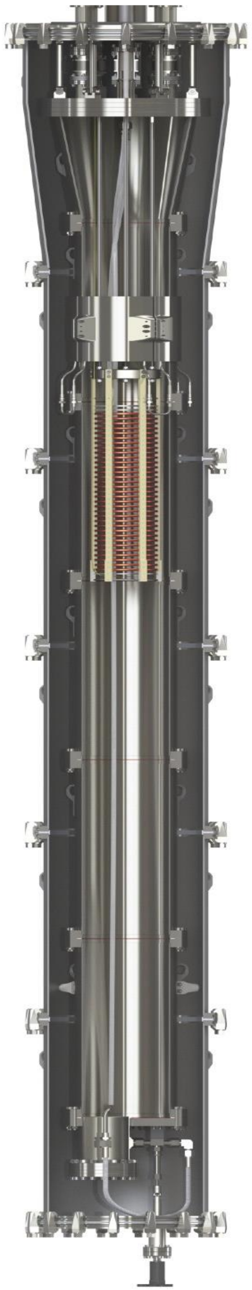
- High-voltage up to 50 kV
- SiPM array on top to detect S2 light
- Liquid level control
- Additional calibration sources (muons, external sources) to further improve our models

Phase 1: purity monitor

- Drift length of ≈ 50 cm
- Gold-coated quartz photocathode produced in house
- A xenon flash lamp (190 – 2000 nm) was used to iluminate the photocathode
- The FSR provide an homogeneous drift field of 25 - 75 V/cm
- No light: we measured the induced currents







Results on: Eur. Phys. J. C (2023) 83: 717

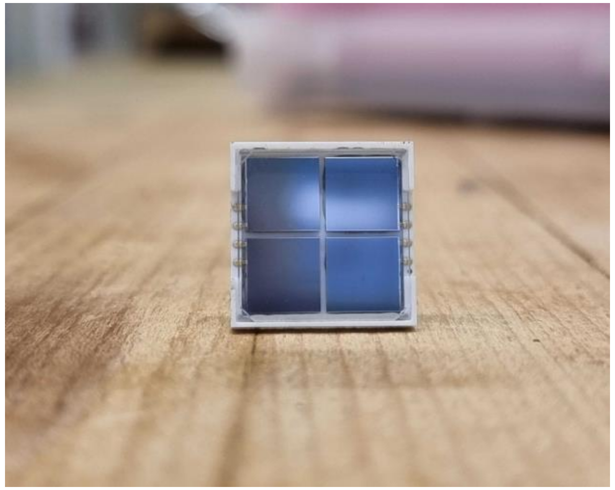
Jump to next step

Several upgrades were made from the purity monitor

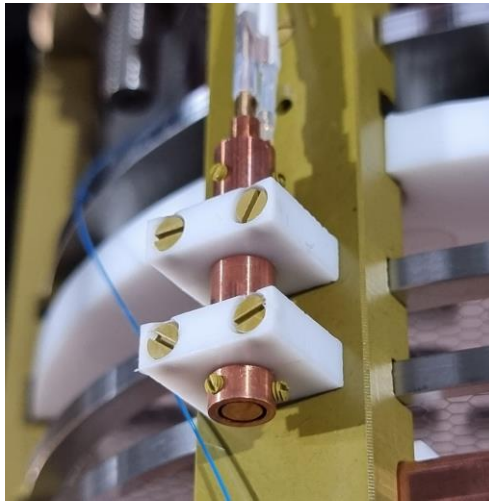
Field cage

High-voltage

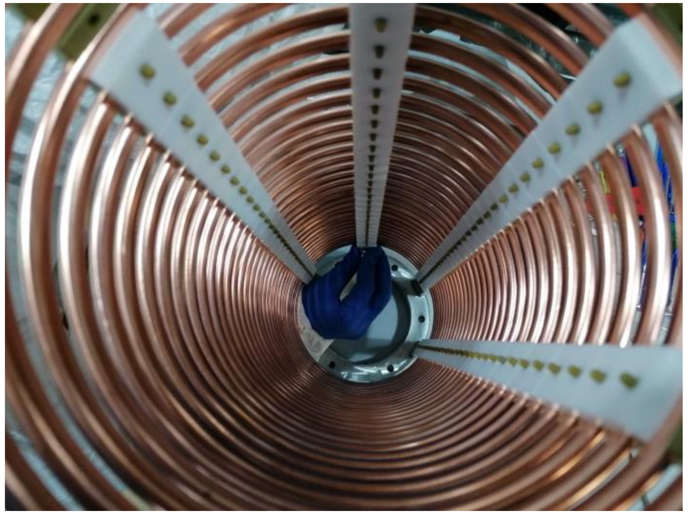
SiPM array



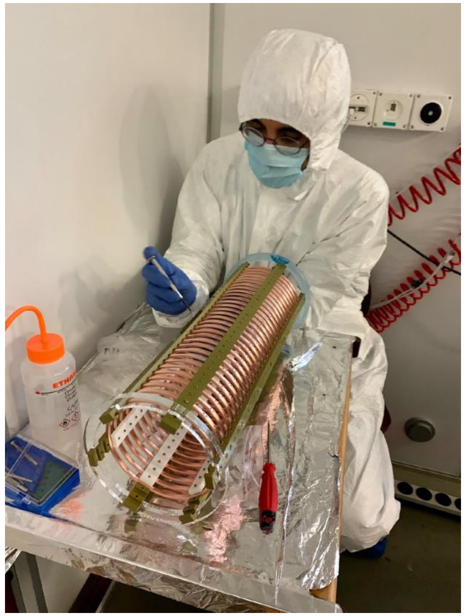
Liquid level control

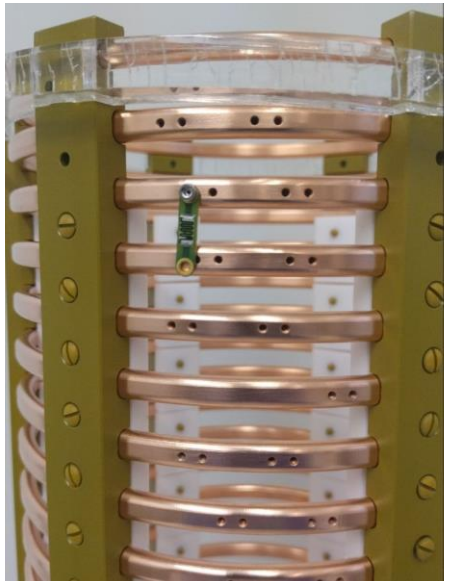


Upgrade: the field cage




- Divided into 5 independent modules (52 cm each)
- In total, we have 173 copper rings
- Pillars made of Torlon and PTFE inner connectors
- Two parallel 1 GΩ resistor chains (200 nA at 20kV)

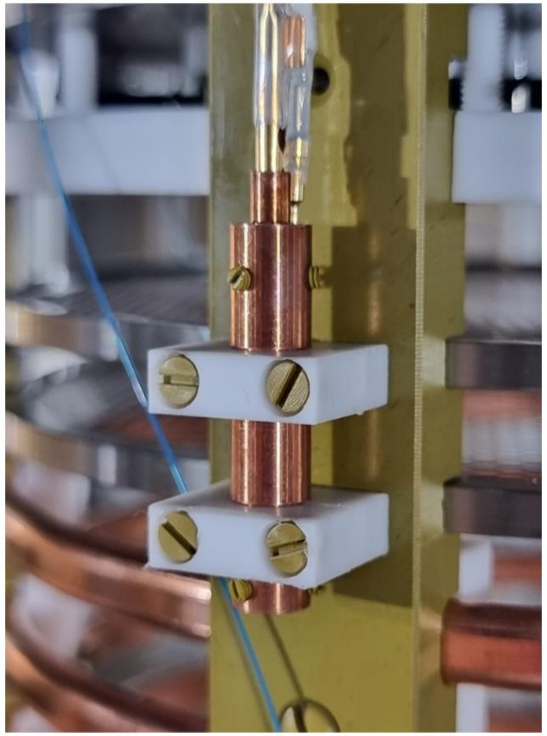




Upgrade: liquid level control

Long Level Meter (LLM)

Short Level Meter (SLM)

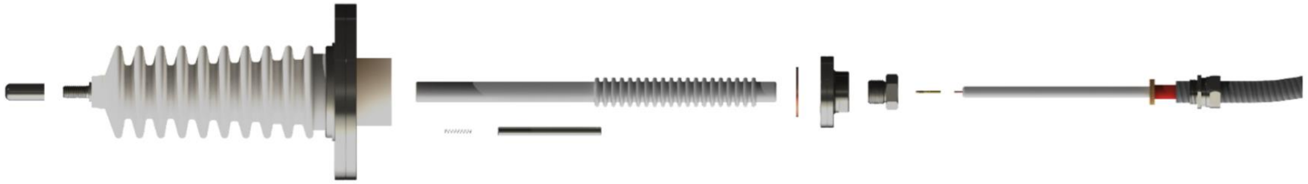


Weir

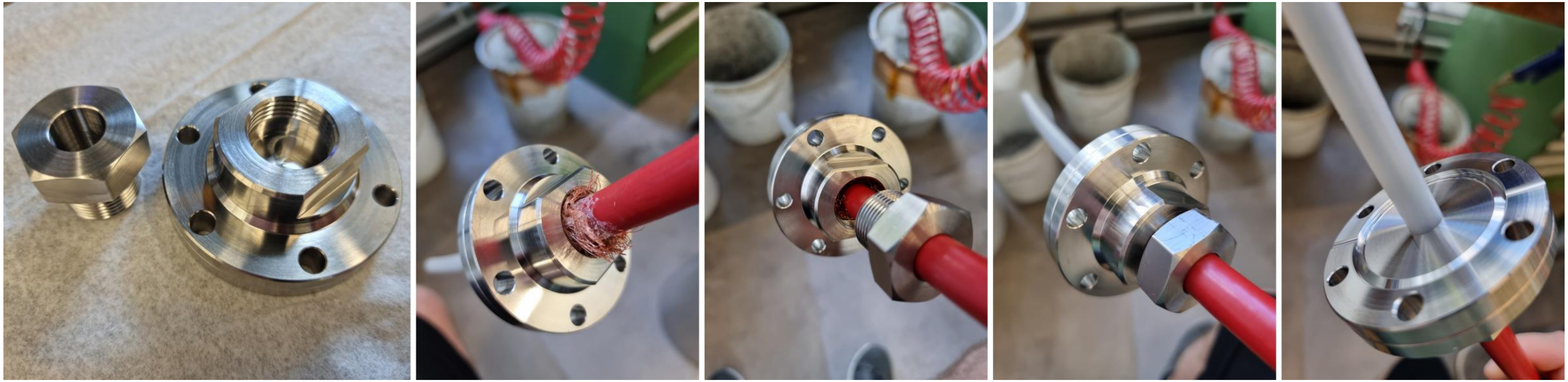
- Level-dependent capacitance of cylindrical level meters
- 3 SLMs + 2-piece segmented LLM
- Active level control with weir on motion feedthrough
- Plan to integrate it in SC readout

Upgrade: high-voltage feedthrough

- 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
- Entire assembly was tested in vacuum at 120 K and ~4 bar overpressure
- The HVFT was successfully operated at 50 kV for over 4 days without sparks



The cryo-fitting



- The cable (Heinzinger HVC100) is stripped of the last three layers

- The white HMWPE insulator (Ø 10.7 mm) is cryo-fitted to the custom DN40CF flange

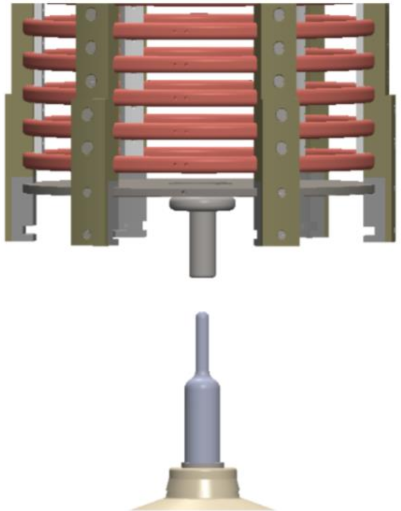
- The cable is slowly dipped in LN2 and cooled down to 77 K

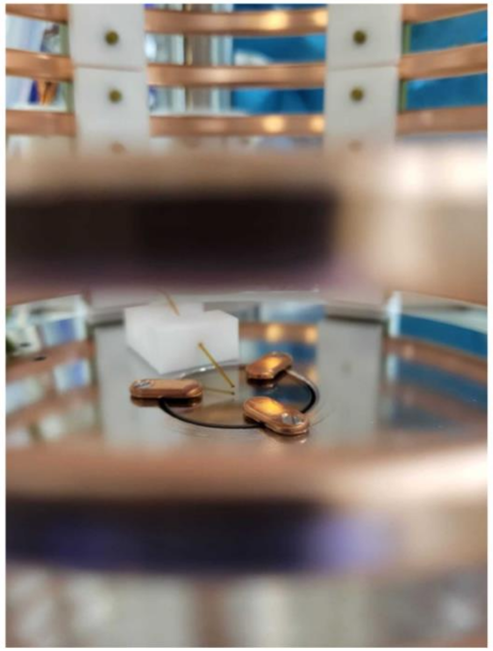
- When the cable warms up to room temperature, it gets cryo-fitted in the flange, making a vacuum tight seal

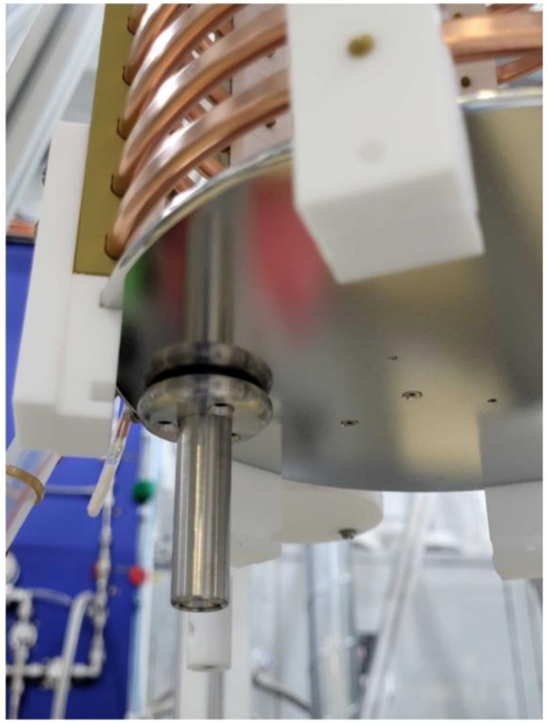
Photocathode and high-voltage connection

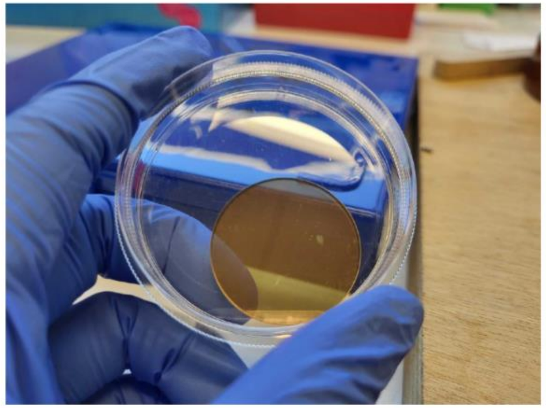
- New photocathode gold coated (50 nm thickness) on a quartz substrate (2 mm thick)
- Xe flash lamp pulse transmitted through optical fibre
- Round-edged HV terminal connected to the Ceramic FT delivers HV to cup & spring system
- Cup & spring system for HV transmission to the cathode

Q150T S automatic sputter coater

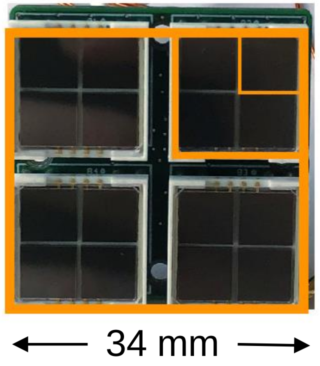




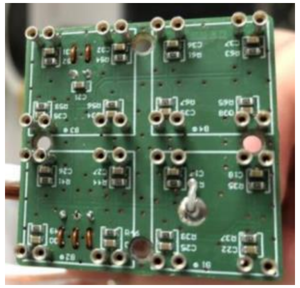


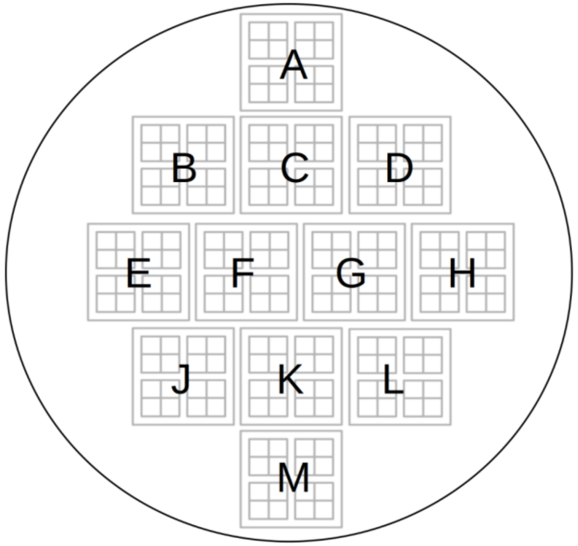


Upgrade: SiPM array

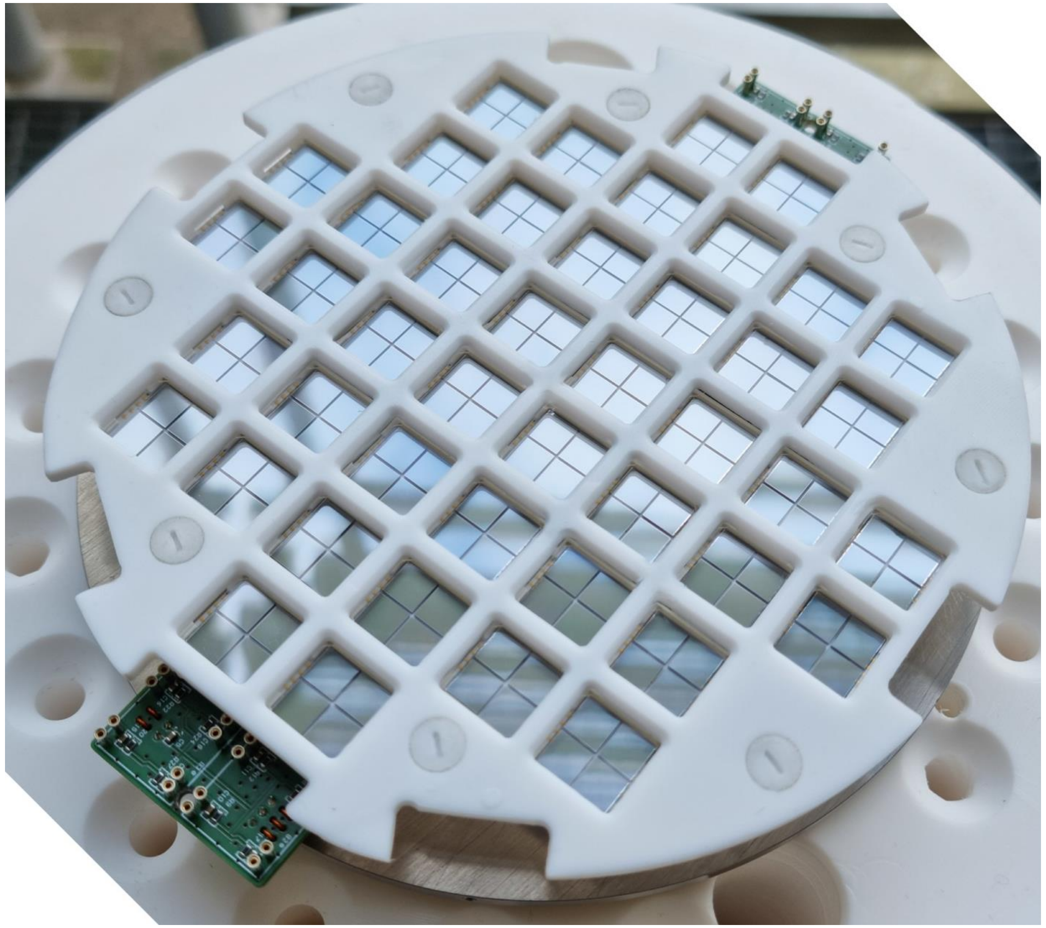


Cell = 6 x 6 mm^2
Quad = 4 cells
Tile = 4 quads



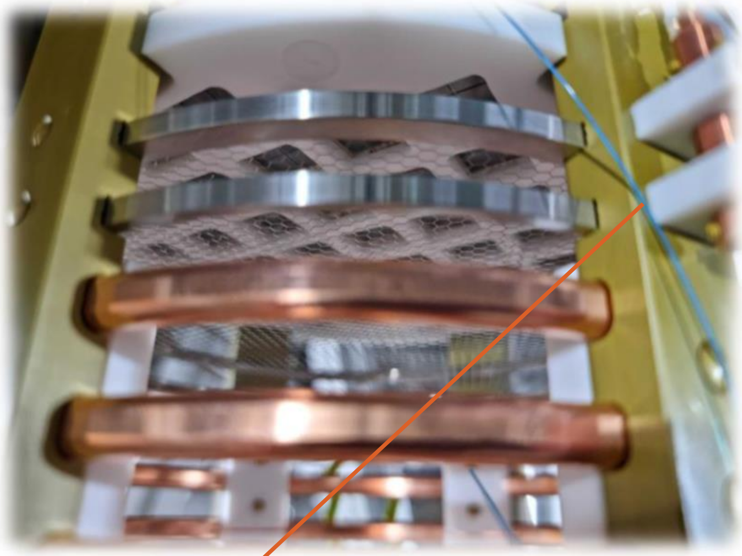


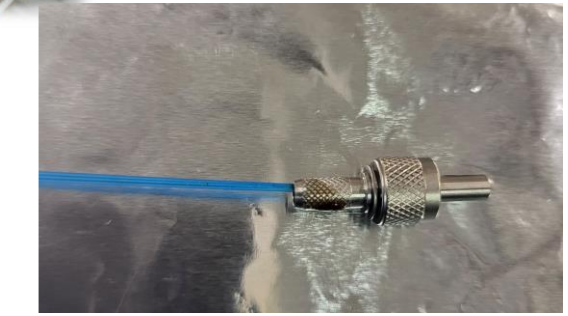
- Array = 12 tiles (or 192 SiPM cells) 12 x 12 mm^2 each
- Hamamatsu S13371-6050CQ-02 MPPC VUV SiPM
- Readout is made in parallel, so we have 12 channels
- 20x amplification per tile

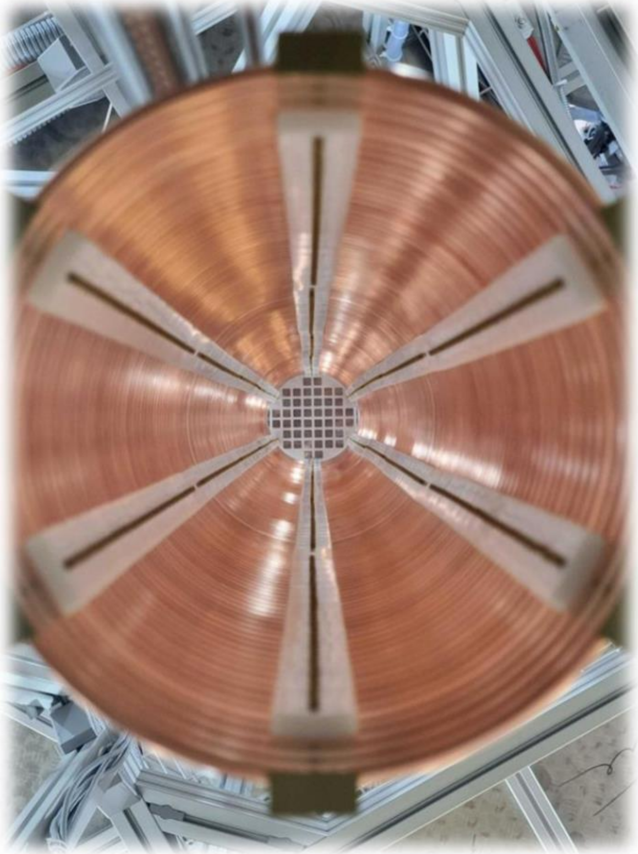


JINST 18 C03027 (2023)

Installing the array in Xenoscope





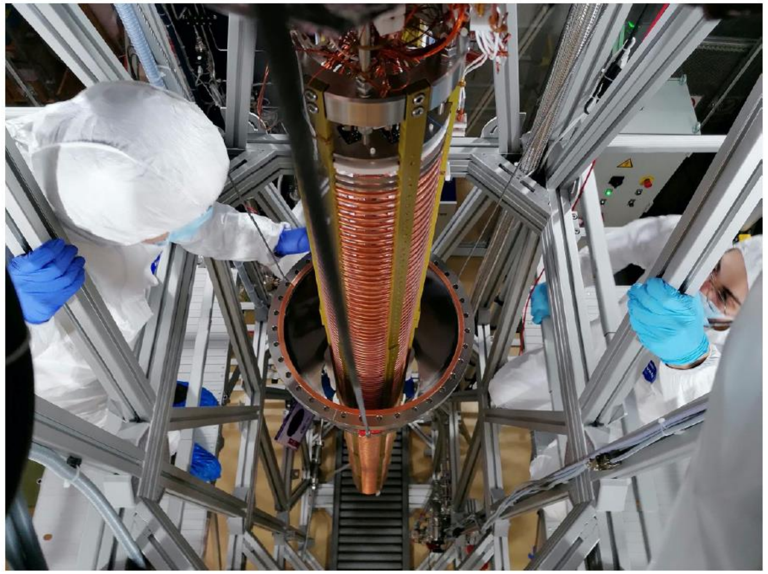


Calibration system:

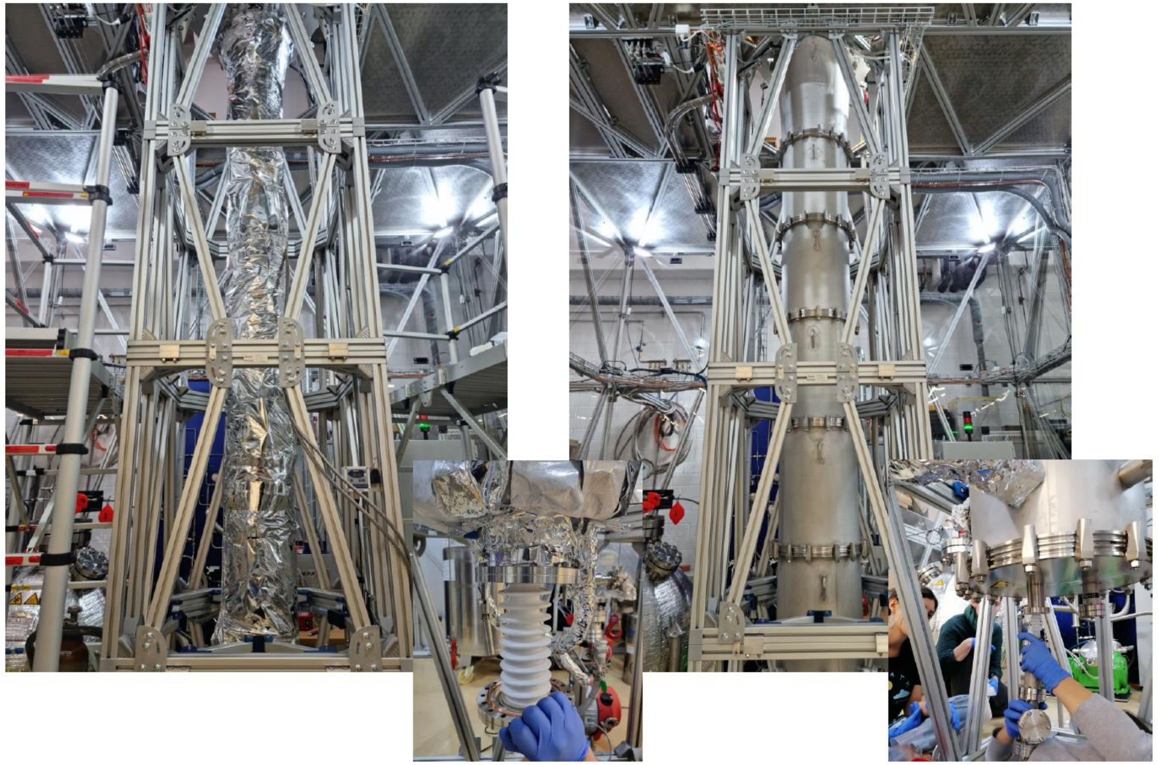
- Blue light emitting diode (~460 nm) inside black box on air side
- Light transmited via optical silica fibre

➡ We have 2 fibres (180º)

Putting all together



Connect all modules, cables, sensors…and close inner cryostat



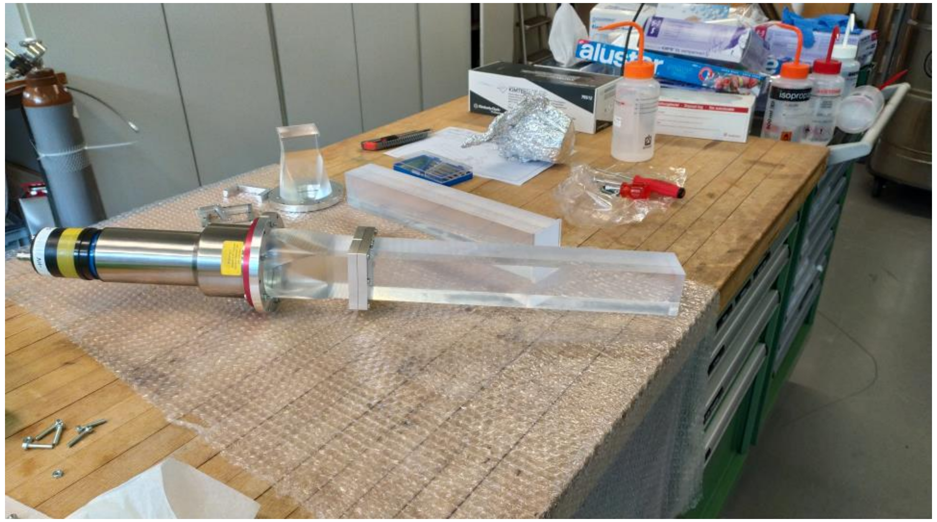
Insulate with mylar and install the vacuum-to-LXe feedthrough

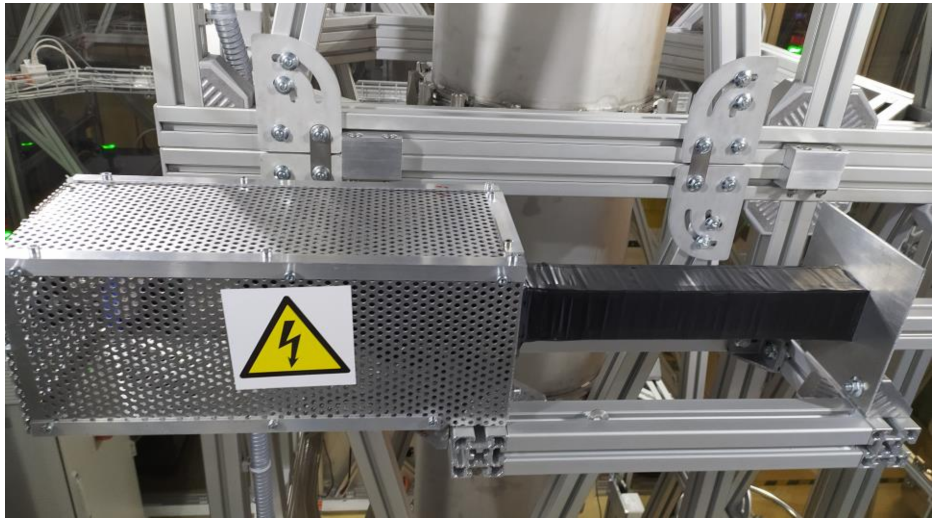
Close the outer cryostat and install high-voltage

Additional subsystems: 1.Muon detectors

For trigger in coincidence

Here they are





2. Liquid xenon recuperation: BoX (Ball of Xenon)

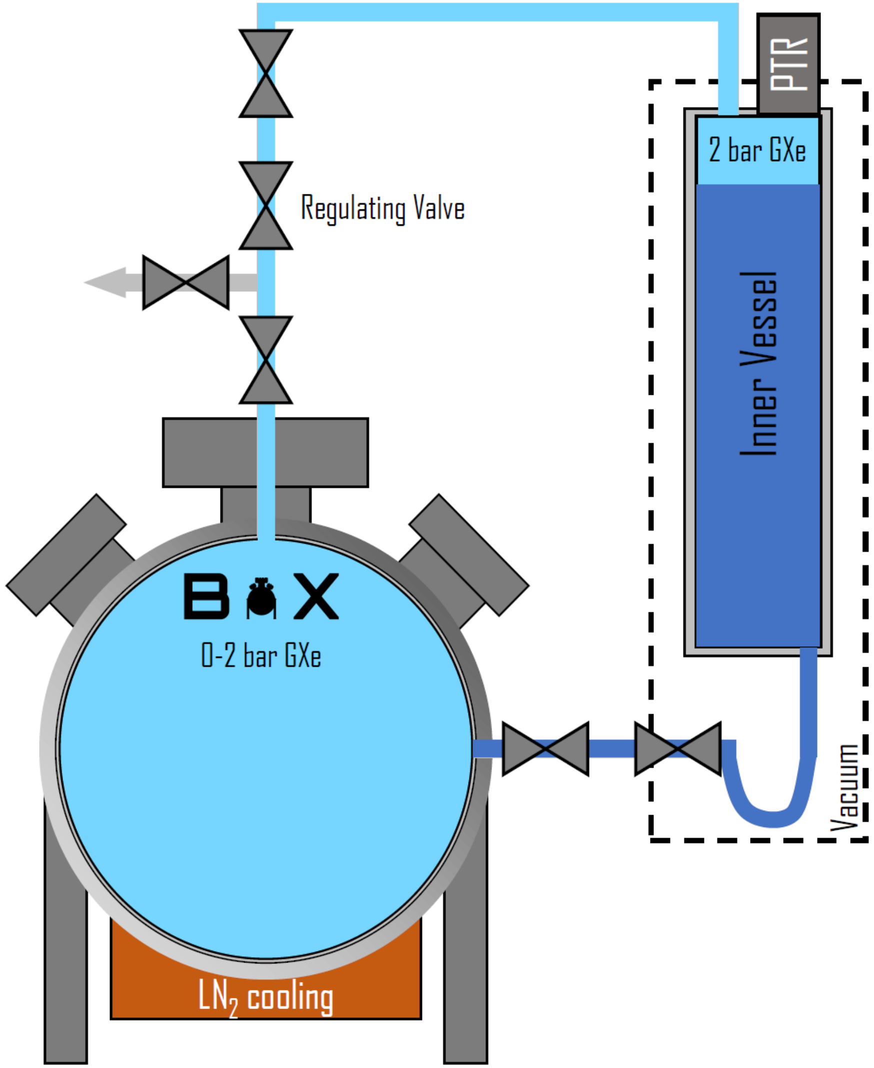
- Stainless Steel spherical vessel
- Gravity-assisted LXe recuperation system
- It can hold 450 kg of xenon at room temperature (max. pressure of 90 bar)

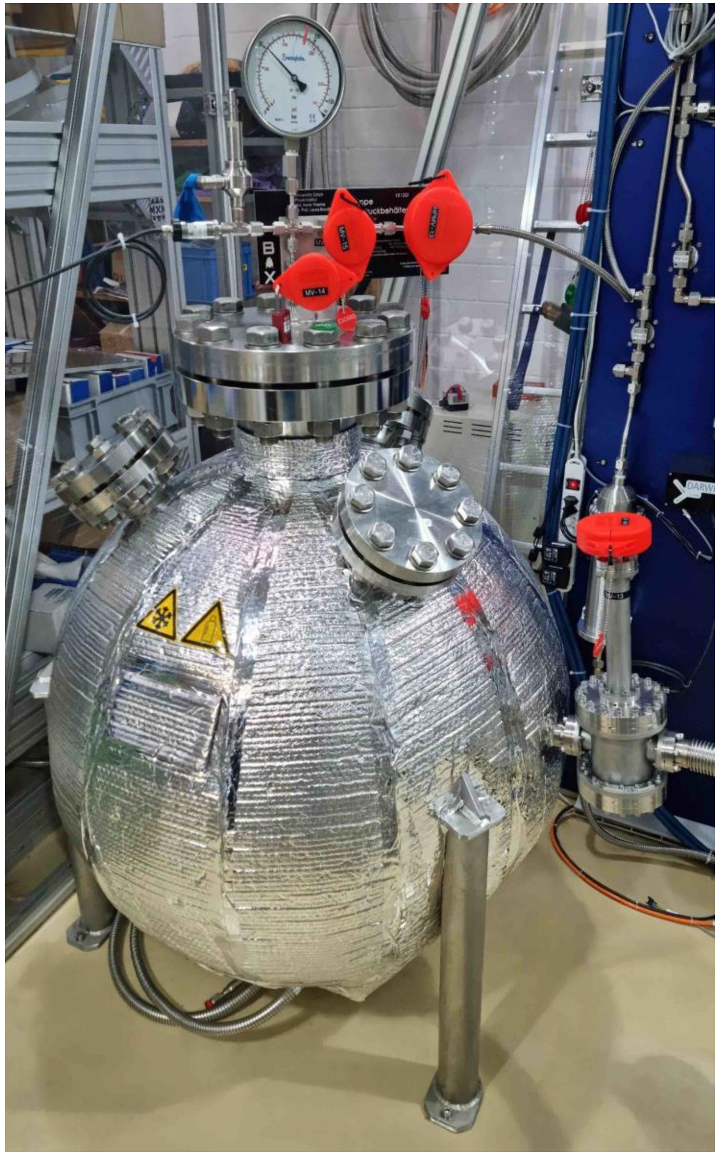
The recuperation speed is ~51 kg/h (only using gas phase ~19 kg/h)

For reference:

Using BoX the entire system (350 kg) was recuperated in 12 h (including LN2 cooling process)

Without BoX it takes two-three days

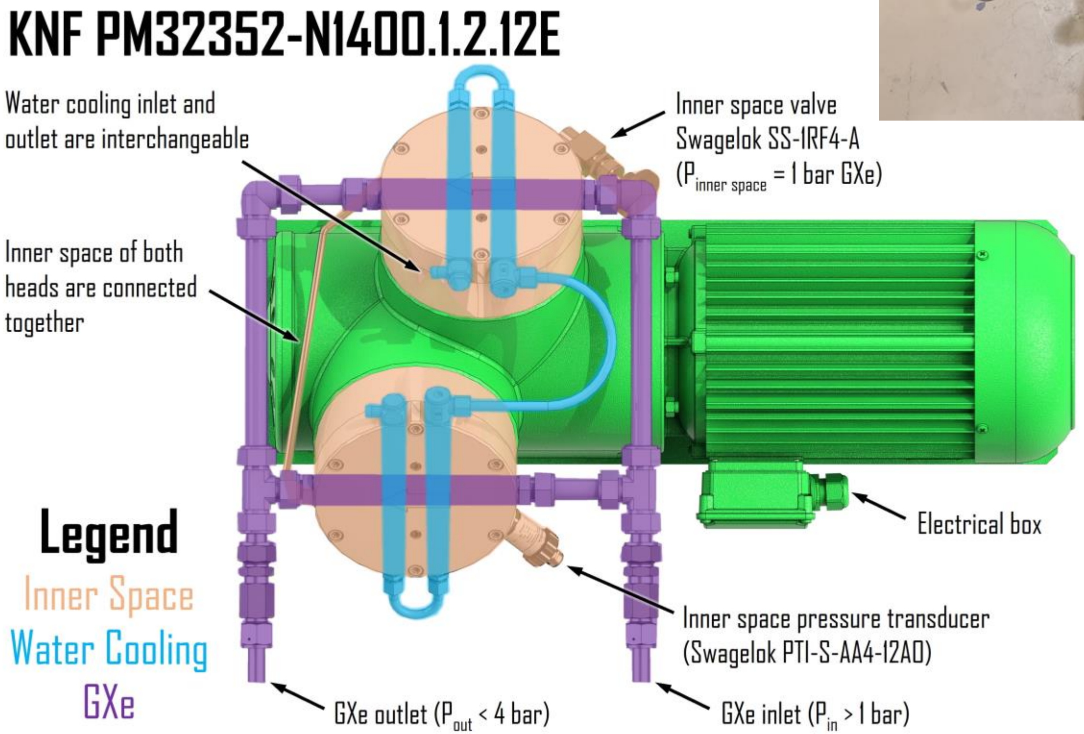




3. Moving Xenon: the compressor

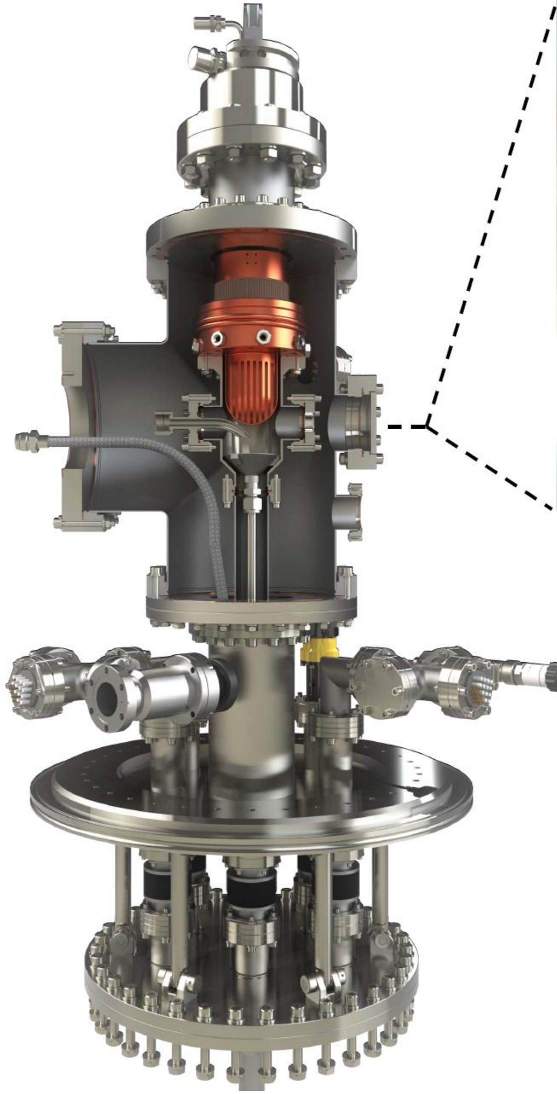
Double diaphragm KNF compressor:

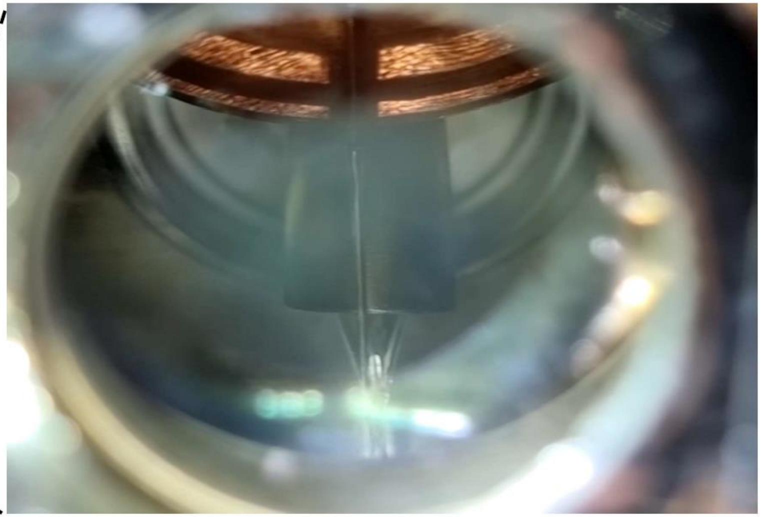
- Modified to operate at 100 slpm
- Should be operated with **at least** 1 bar abs. at the inlet
- Too much heat can be induced in the heads, causing the degradation of the diaphragm membranes



4. Cooling things

- Iwatani PC-150 PTR (~200 W cooling) and heater (~180 W heating)
- LN2 pre-cooler attached to the inner vessel for additional cooling power:
  - Filling w/o pre-cooler: 4 kg/h
  - Filling with pre-cooler: 17 kg/h
- 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

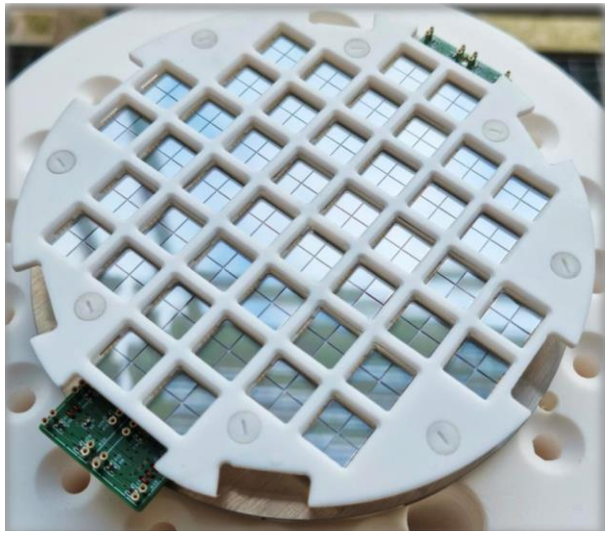




LXe condensing on the cold head

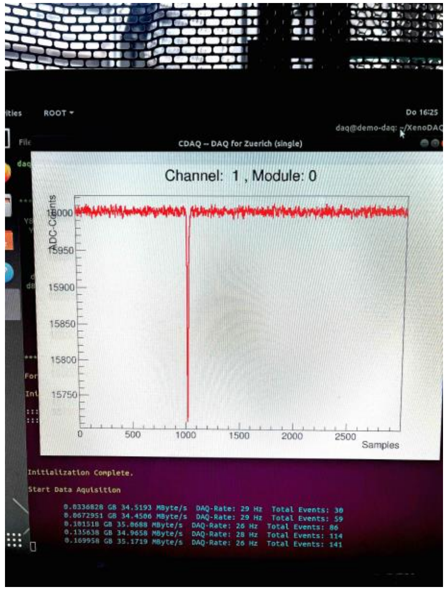
Pre-cooler

5. Taking data



12 signal channels

- CAEN V1724
- Two 8-channel boards daisy-chained
- 14 bits
- 100 MS/s
- 0-2.25 V Dynamic range

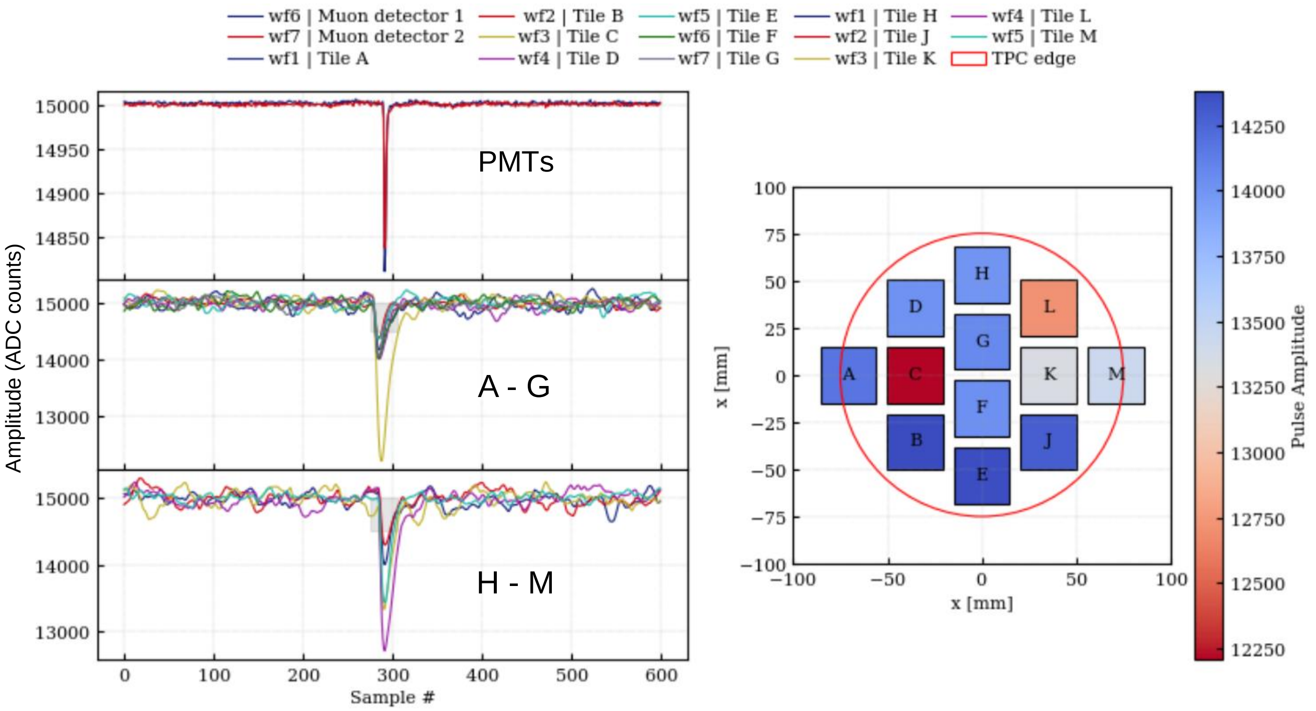


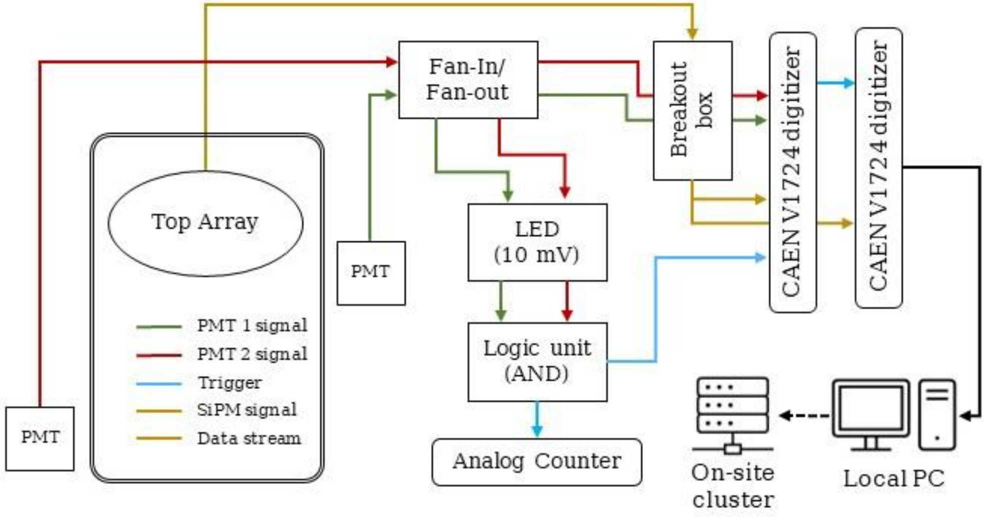
```
Initialization Complete.

Start Data Aquisition

        0.0336828 GB 34.5193 MByte/s  DAQ-Rate: 29 Hz  Total Events: 30
        0.0672951 GB 34.4506 MByte/s  DAQ-Rate: 29 Hz  Total Events: 59
        0.101518 GB 35.0688 MByte/s  DAQ-Rate: 26 Hz  Total Events: 86
        0.135638 GB 34.9658 MByte/s  DAQ-Rate: 28 Hz  Total Events: 114
        0.169958 GB 35.1719 MByte/s  DAQ-Rate: 26 Hz  Total Events: 141
```

- DAQ interface configured through a XML file
- Output data in ROOT format
- Data sent to local cluster for storing

First test of the system: muon coincidence in gas

- The system was filled with 2 bar of GXe at room temperature
- Data acquired with a dual-coincidence trigger between the two PMTs coupled to the scintillators
- The total acquired livetime was 21 days





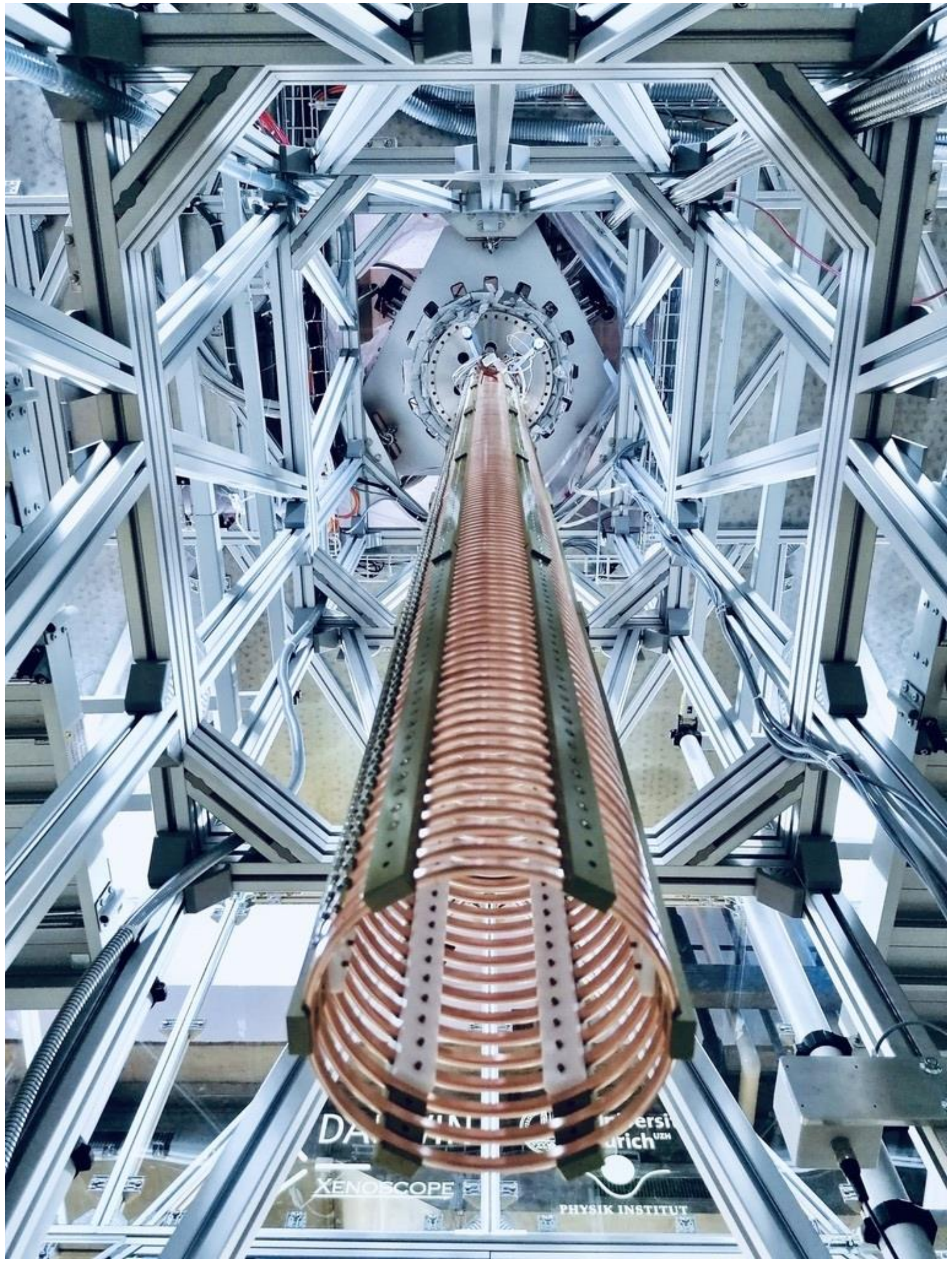
It works!

Summary

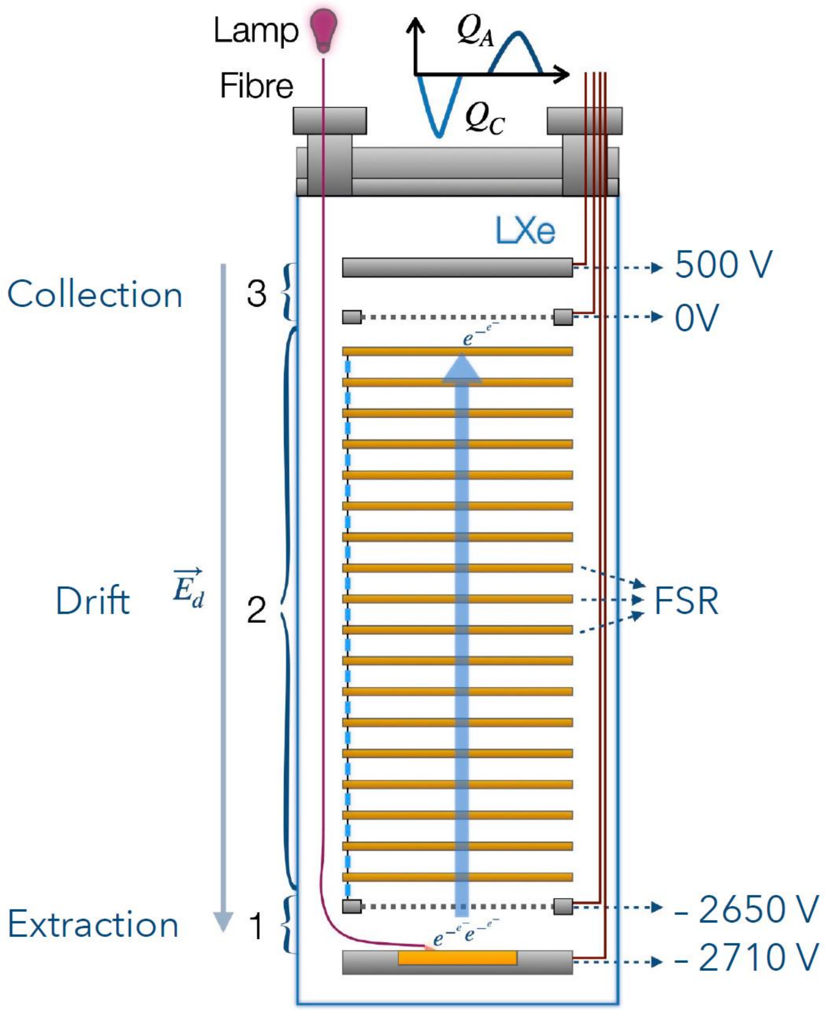
- We have built Xenoscope, a full-height DARWIN vertical demostrator
- One first run (purity monitor) was successfully conducted
- Several upgrades were done for the full 2.6-m TPC
- The SiPM array was successfully tested in GXe
- The system is ready to be operated soon in liquid

The Xenoscope team:

Marta Babicz, Laura Baudis, Alexander Bismark, Jose Cuenca García, Paloma Cimental, Ricardo Peres, Mariana Rajado Silva, Diego Ramírez García, Christian Wittweg.

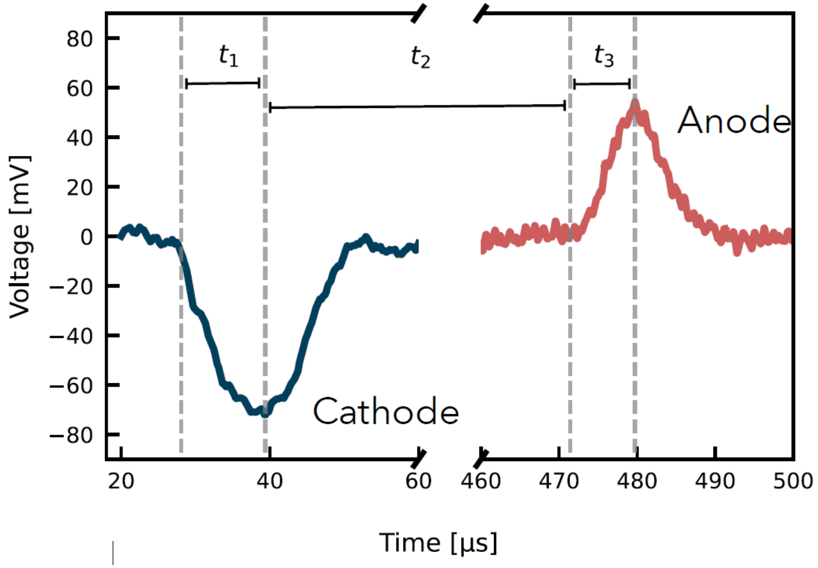


PM run: Form of the signals



- 343 kg of xenon
- Measurements at 2 bar and 177.6 K
- Illumination at 1 Hz
- First observable waveforms after 26.5 days of purification

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



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

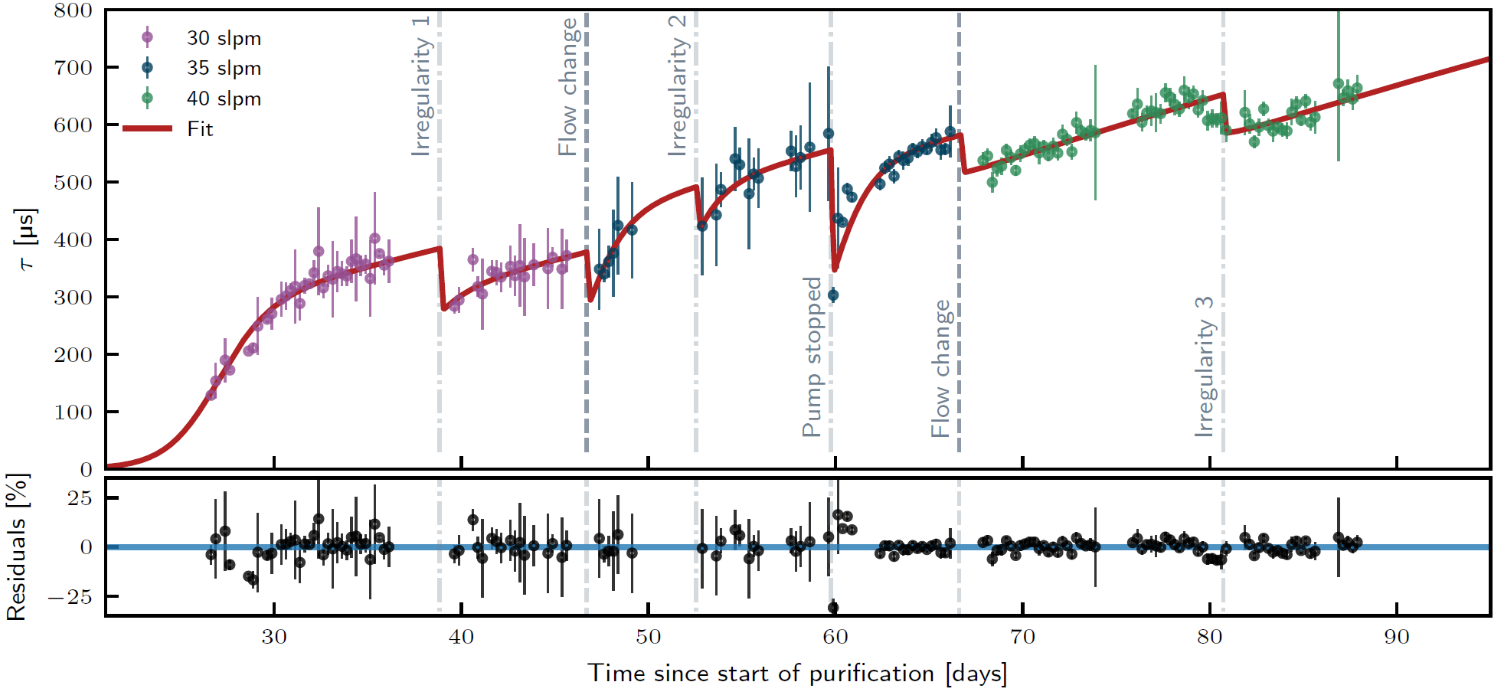
PM run: Purification performance

- Three different fluxes during the run:
    - 30 slpm (46.6 d)
    - 35 slpm (20.0 d)
    - 40 slpm (21.2 d)

- Electron drift lifetime drops during flow changes due to the liberation of of trapped impurities at the LXe surface collar.

- Reached **(664 ± 23) µs** comparable to LUX and XENON1T

- Expected to reach > 2 ms with gas phase purification and 80 slpm



$$M_l \frac{dI_l}{dt}^{(j)} = -F_l \rho I_l + \left(\frac{\Lambda_{l,0}}{1+\frac{t-\Delta t_l^{(j)}}{T_{1/2,l}}} + C_l \right) - \frac{\varepsilon_1 P_C I_l}{h} + \frac{\varepsilon_2 P I_g}{h} + M_l \Delta I_l^{(j)} \int \delta\left(t - t^{(j)}\right) dt$$

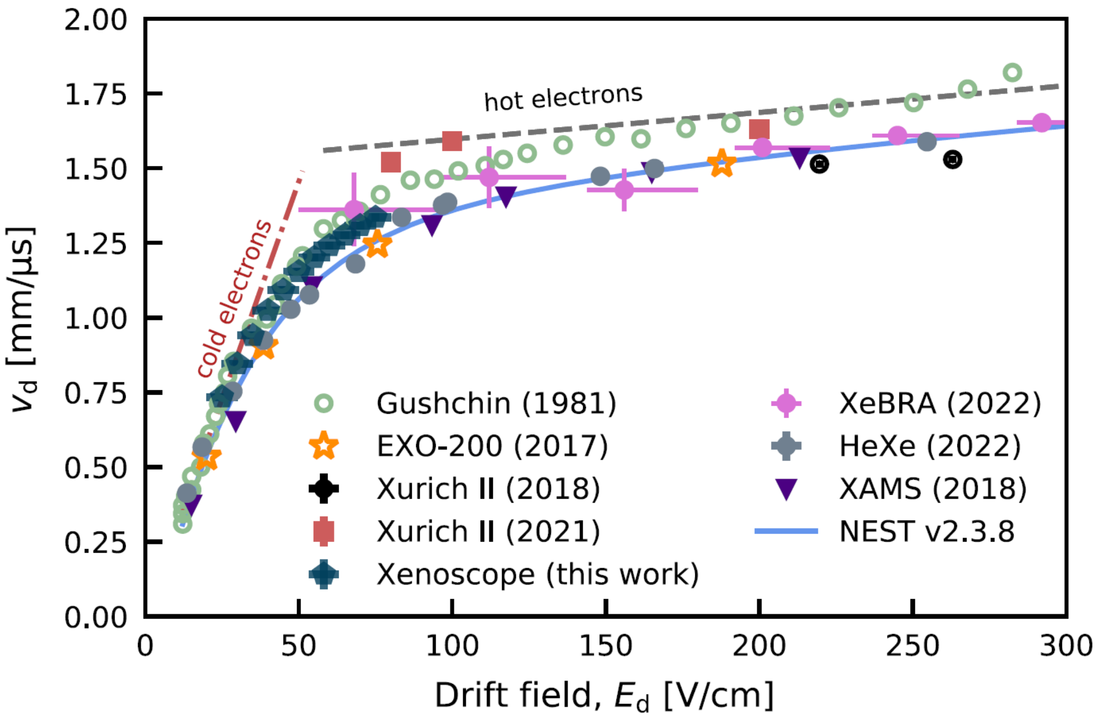
Purification

Outgassing

Gas-liquid impurity exchange

Discontinuities

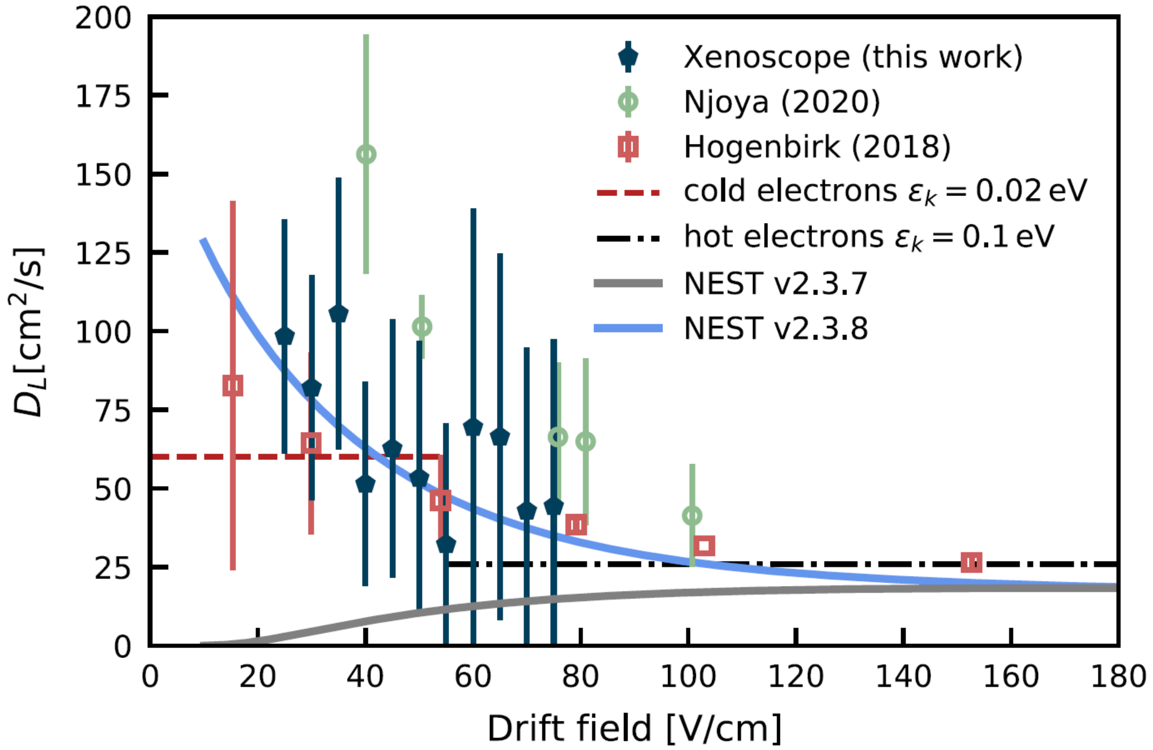
PM run: Electron drift velocity



$$v_\mathrm{d} = \mu E_\mathrm{d} = \frac{d}{t}$$

- Drift velocity from ***Ed* = 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

PM run: Longitudinal diffusion



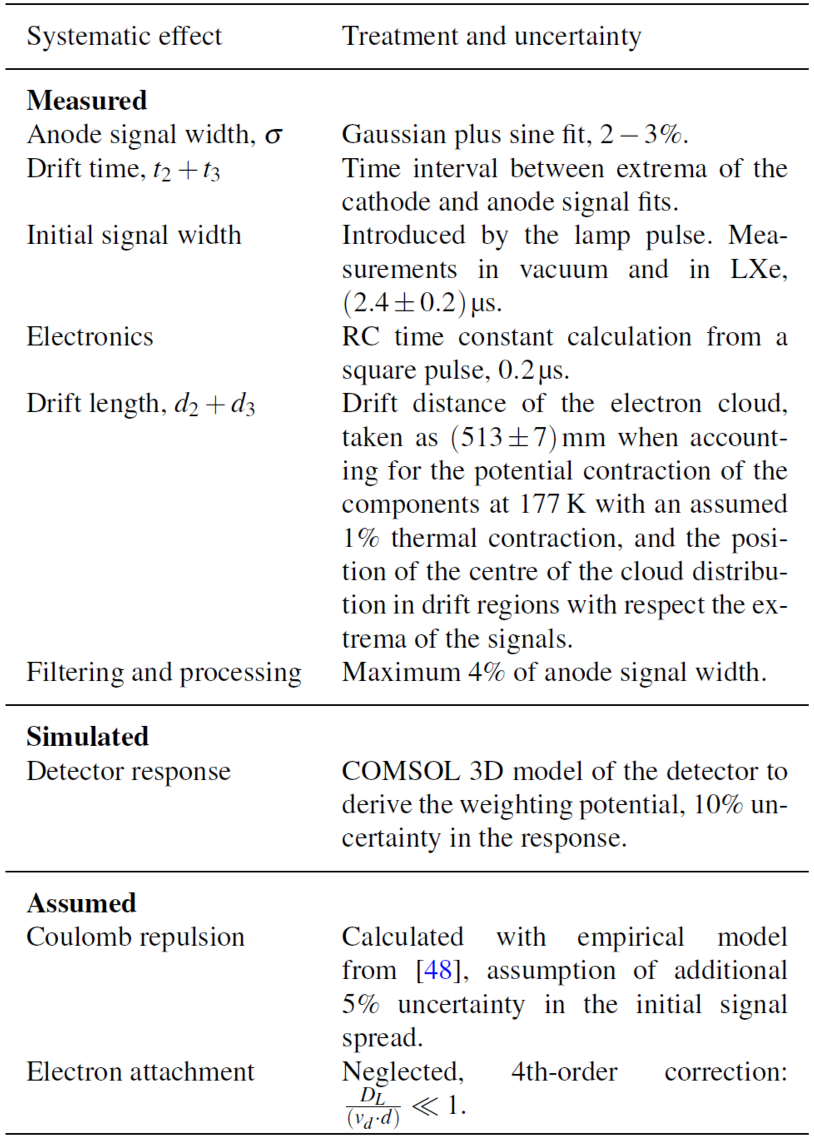
Anode Gaussian peak width

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

Cathode Gaussian peak width

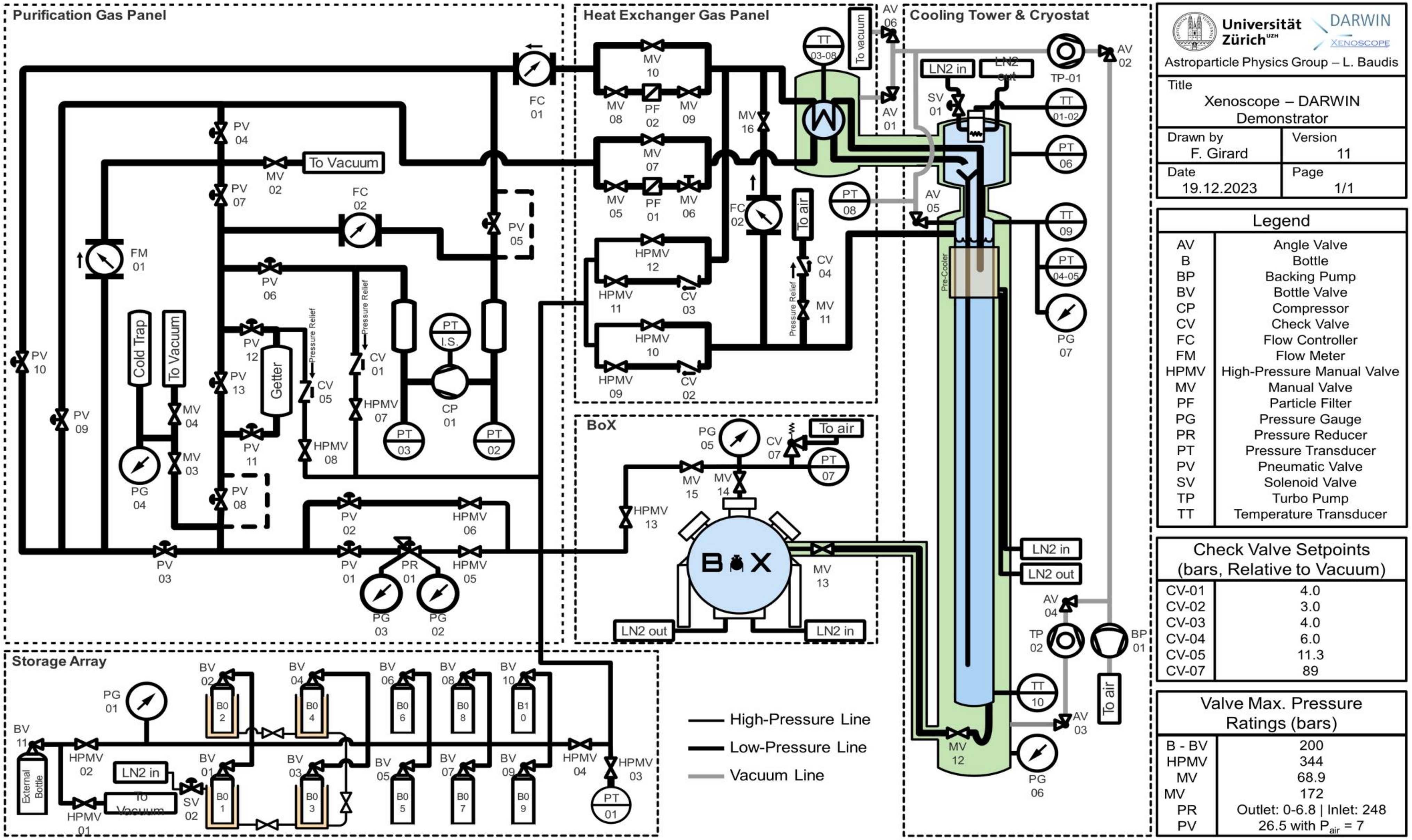
Diffusion coefficient, drift length, drift time

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



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 ± 0.2) µs.
Electronics	RC time constant calculation from a square pulse, 0.2 µs.
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: $\frac{D_L}{(v_d \cdot d)} \ll 1$.

P&ID



Universität Zürich^{UZH} DARWIN XENOSCOPE

Astroparticle Physics Group – L. Baudis

Title Xenoscope – DARWIN Demonstrator	
Drawn by F. Girard	Version 11
Date 19.12.2023	Page 1/1

Legend	
AV	Angle Valve
B	Bottle
BP	Backing Pump
BV	Bottle Valve
CP	Compressor
CV	Check Valve
FC	Flow Controller
FM	Flow Meter
HPMV	High-Pressure Manual Valve
MV	Manual Valve
PF	Particle Filter
PG	Pressure Gauge
PR	Pressure Reducer
PT	Pressure Transducer
PV	Pneumatic Valve
SV	Solenoid Valve
TP	Turbo Pump
TT	Temperature Transducer

Check Valve Setpoints (bars, Relative to Vacuum)	
CV-01	4.0
CV-02	3.0
CV-03	4.0
CV-04	6.0
CV-05	11.3
CV-07	89

Valve Max. Pressure Ratings (bars)	
B - BV	200
HPMV	344
MV	68.9
MV	172
PR	Outlet: 0-6.8 | Inlet: 248
PV	26.5 with P_{air} = 7

Current status of Xenoscope, Jose Cuenca-García