# First Xenon Results With R2D2

# Overview

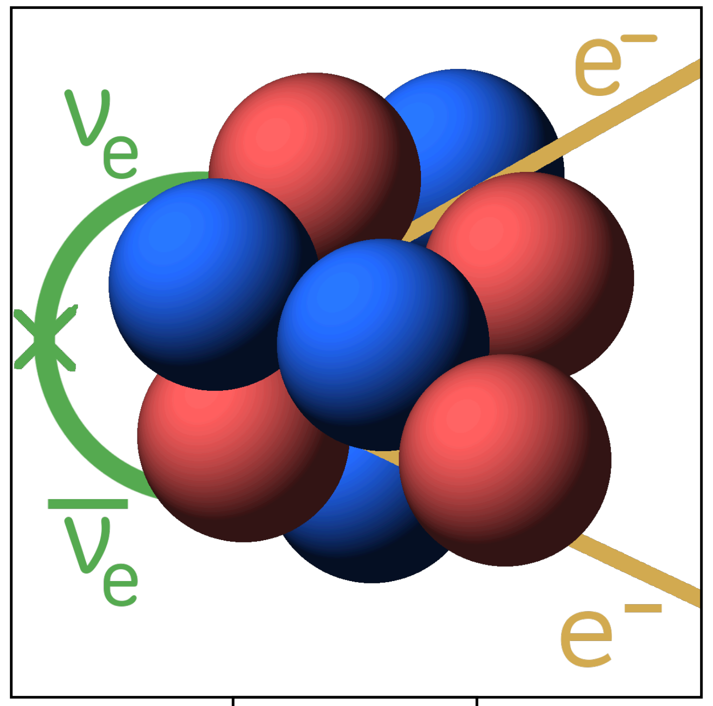
- Introduction
- Experimental Setup
- Latest Improvements And First Xenon Results
- Conclusions

# Motivations: R2D2 - Rare Decays with Radial Detector

R2D2 is an R&D project that explores a single anode HP-TPC[1] solution for ββ0ν search.

Preliminary simulations[2] have shown that a SPC[3] could reach competitive sensitivity for ββ0ν decay searches by matching the following requirements:

- Excellent energy resolution: 1% FWHM at $^{136}$Xe $Q_{\beta\beta}$ of 2.458 MeV
- Low (zero) background: below 0.1 event / year
- Large mass of isotope $^{136}$Xe: ton scale experiment



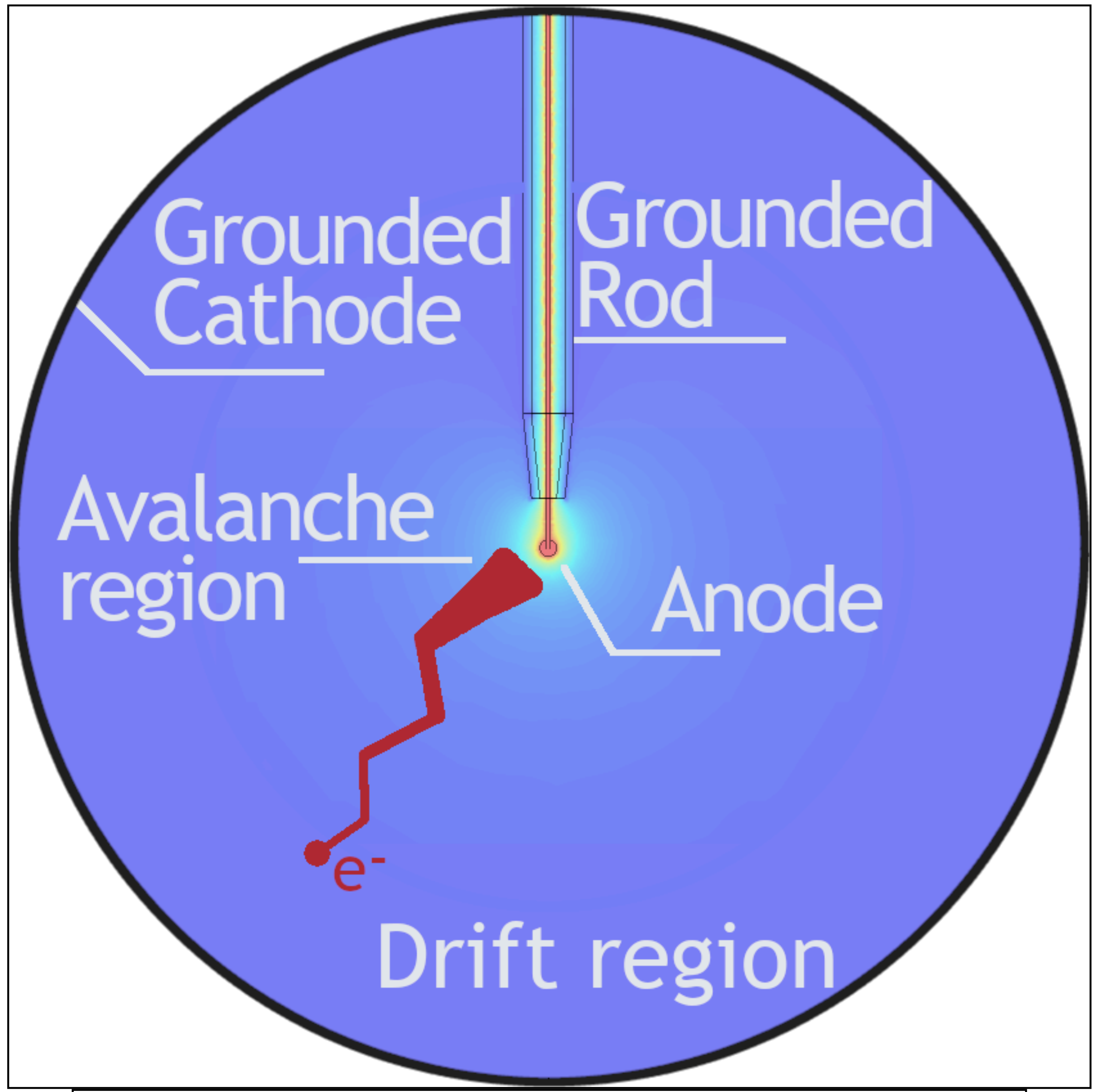
ββ0ν

[1] HP-TPC: High Pressure Time Projection Chamber
[2] JINST 13 (2018) no.01, P01009 [arXiv:1710.04536]
[3] SPC: Spherical Proportional Counter

# Principle And Advantages

- Excellent energy resolution[1].
- Low (zero) background.
  - Excellent background rejection.
  - Low material budget.
- Large mass of isotope $^{136}Xe$.
  - Easy isotope enrichment.

$^{136}Xe$ (ββ emitter) enriched gas as medium




SPC Principle diagram

[1] A. Bolotnikov and B. Ramsey, Nucl.Instrum.Meth.A 396 1997

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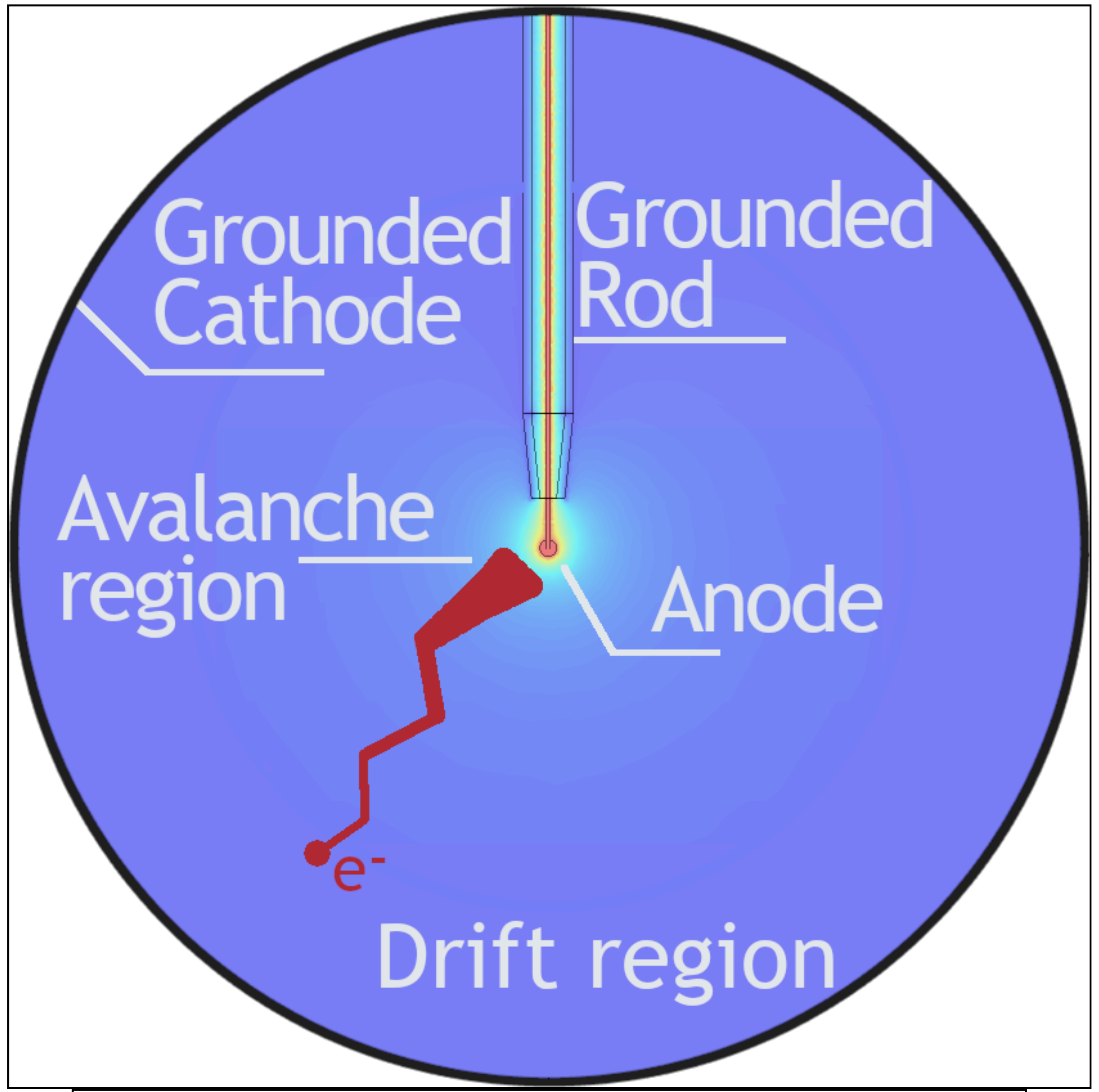


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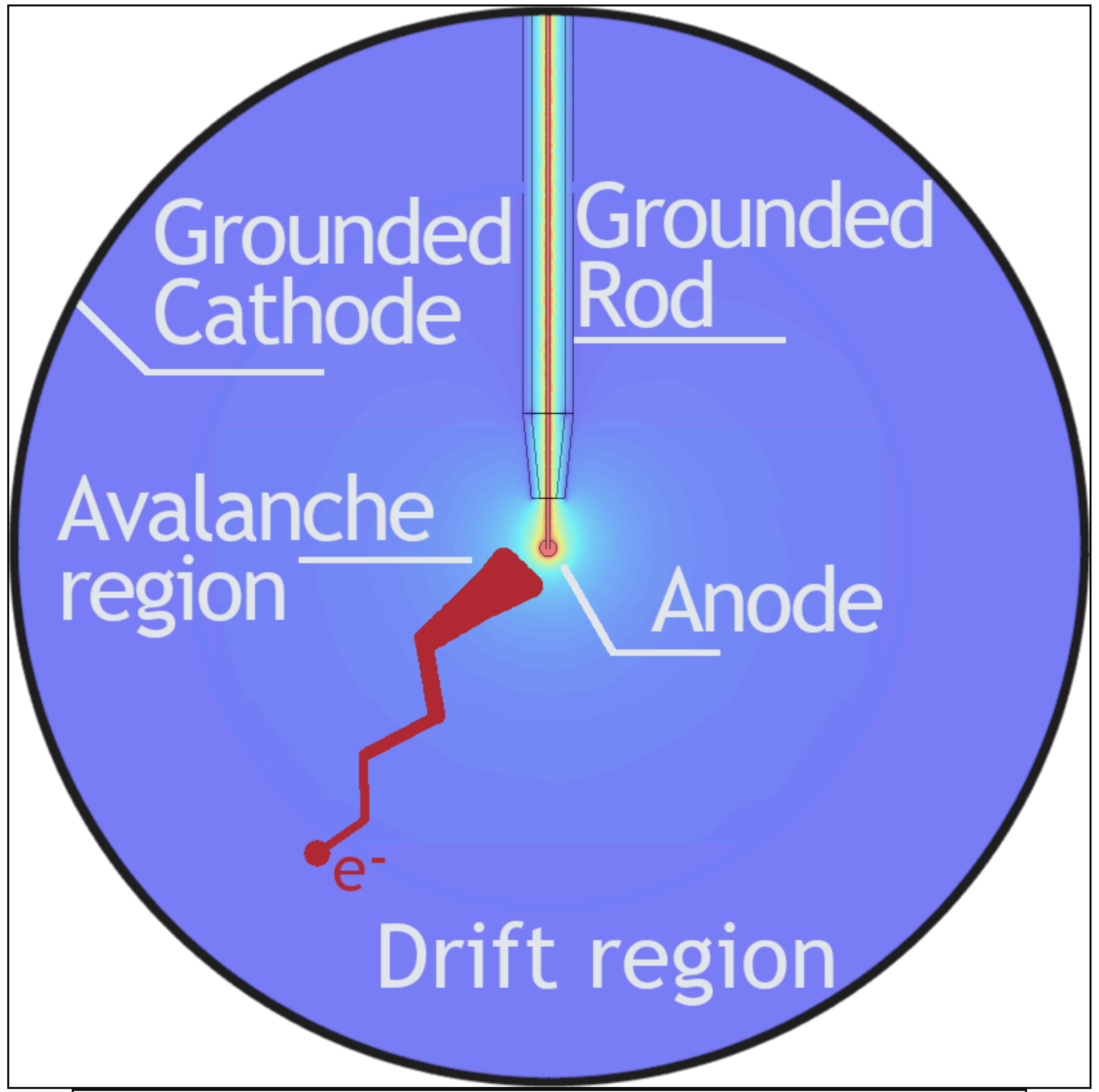


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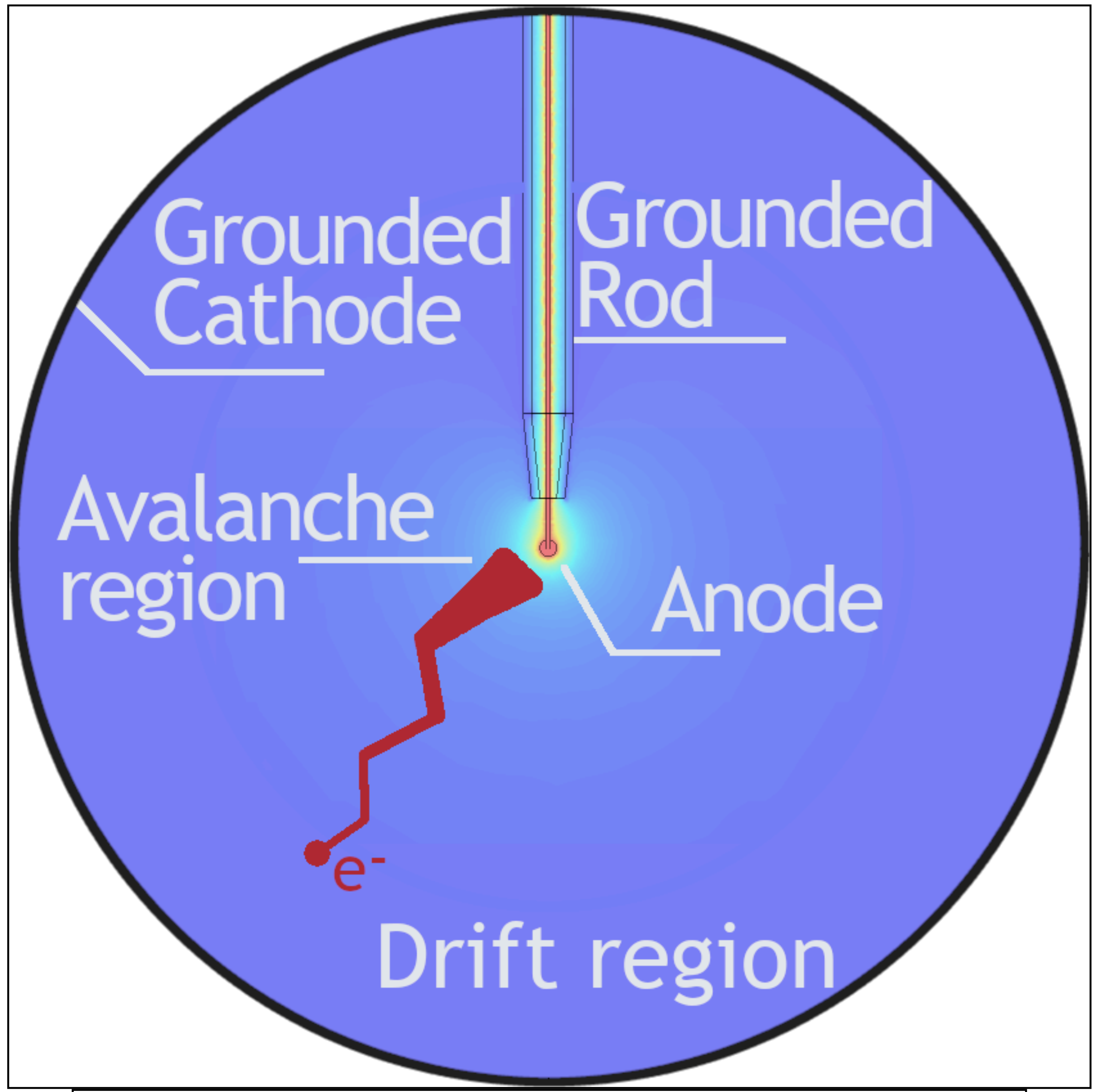


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# Current Phases

Current prototype goal: Achieve 1% FWHM energy resolution at 2.458 MeV, $^{136}Xe$ $Q_{\beta\beta}$.

- First phase with Argon as detector medium and $^{210}Po$ as α source.
  - Electronics and data acquisition
  - Sensor characterisation and improvement
  - Light readout[1]
- Second phase with Xenon as detector medium and $^{210}Po$ as α source.
  - Gas purity development
  - Gas recirculation and recovery
  - Exploring CPC[2] solution

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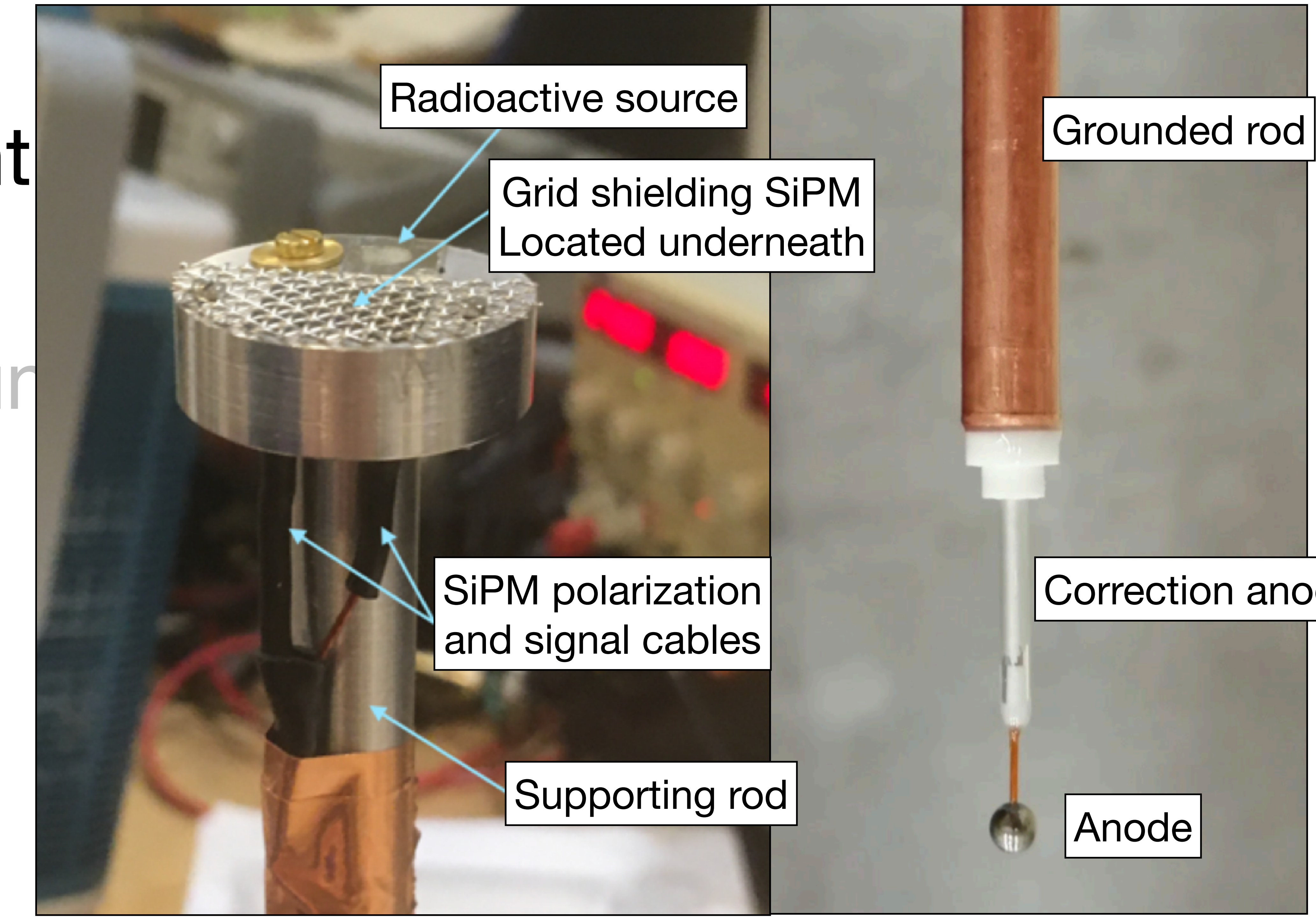


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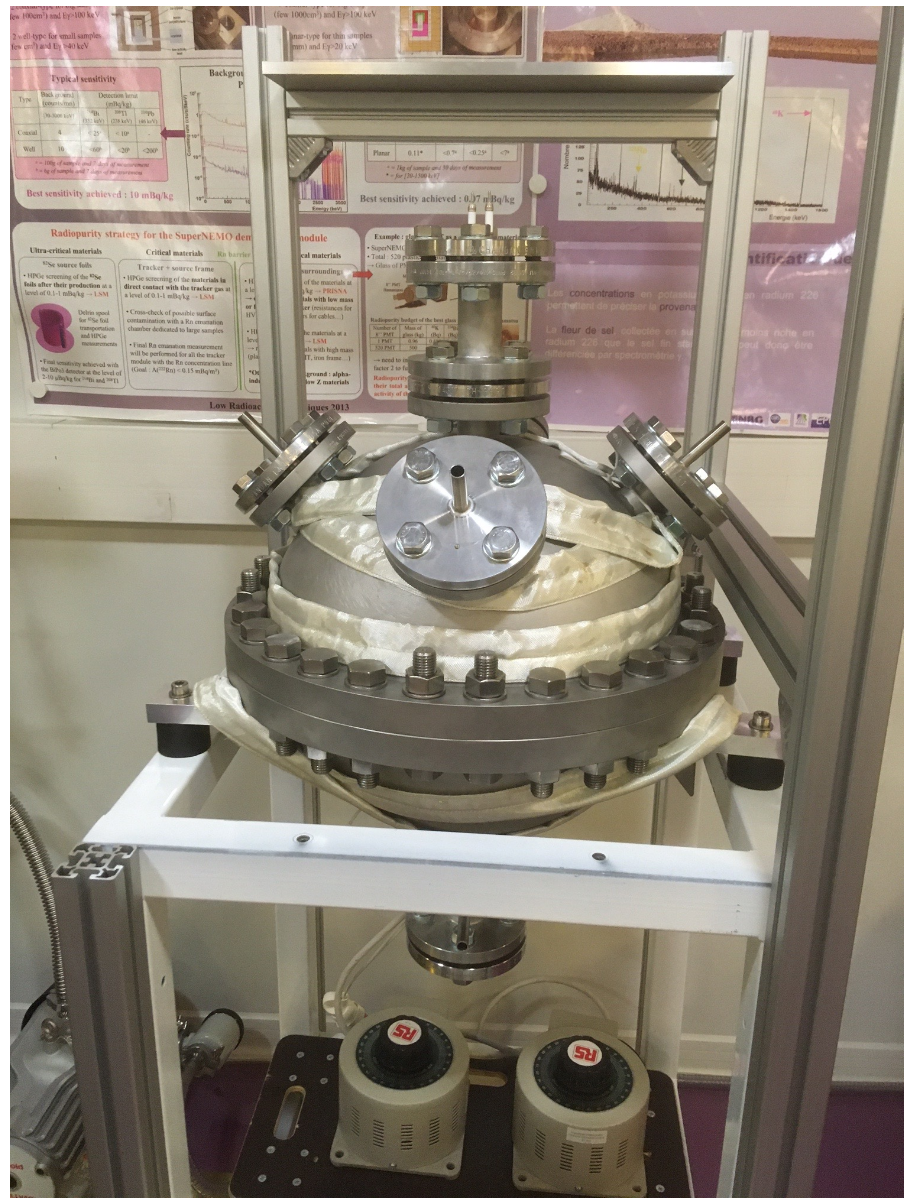
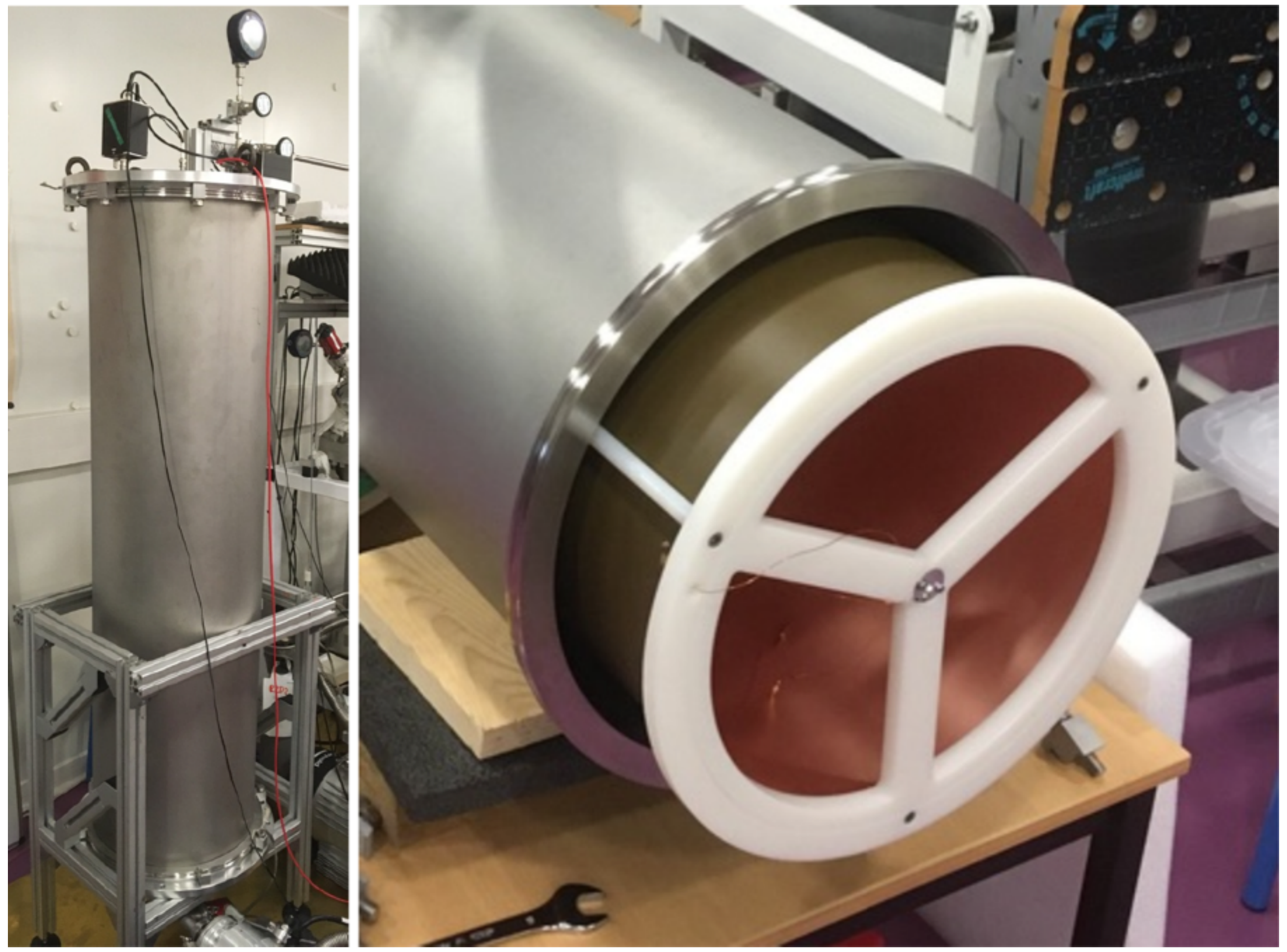
# Prototype setup evolution at LP2I Bordeaux

SPC-1 (2018)
40 cm ⌀
Up to 1 bar[1]



SPC-2 (2021)
40 cm ⌀
Up to 40 bar[2]



CPC-1 (2022)
1m x 37 cm ⌀
Up to 1 bar[1]

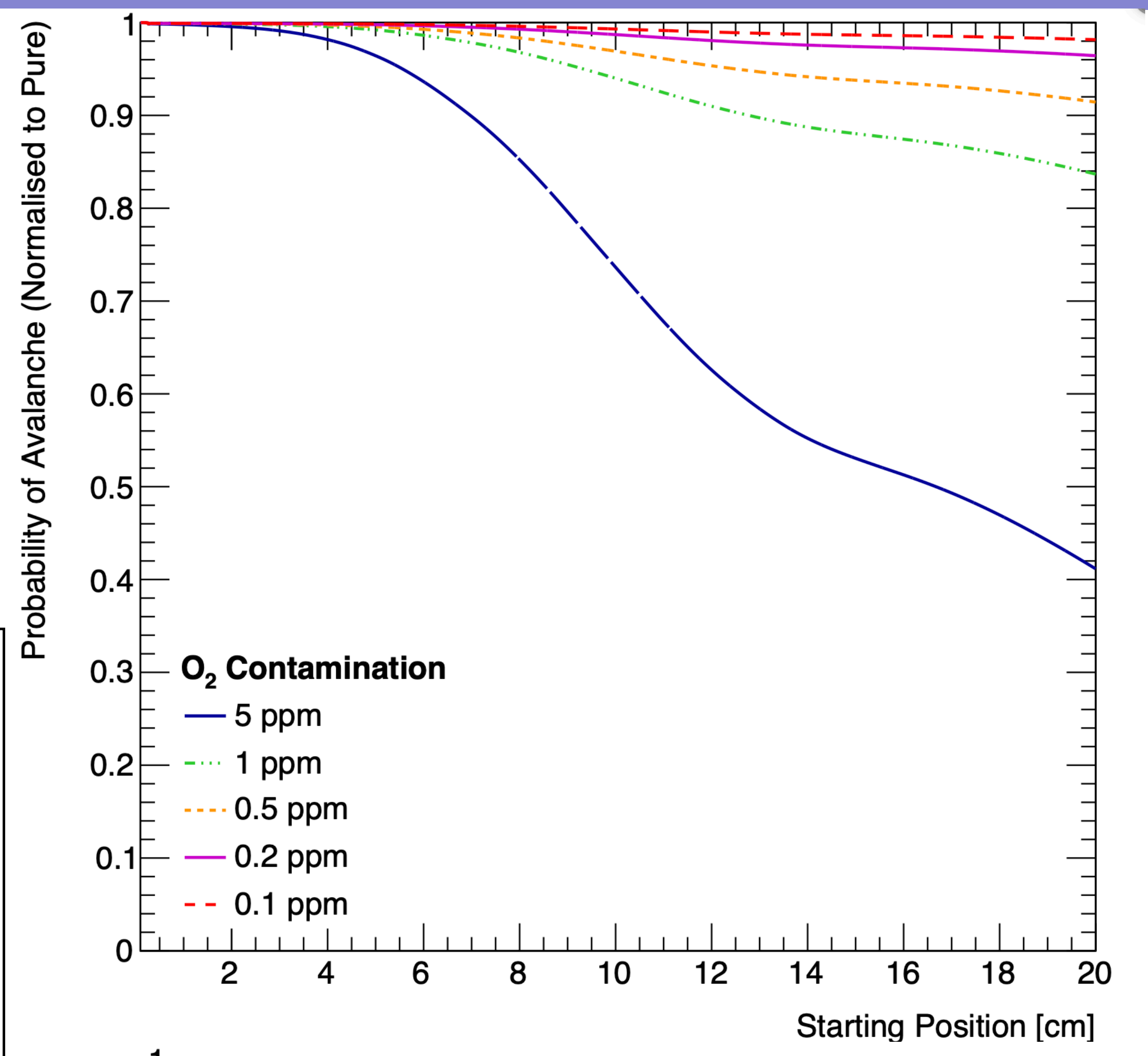
Made at Subatech

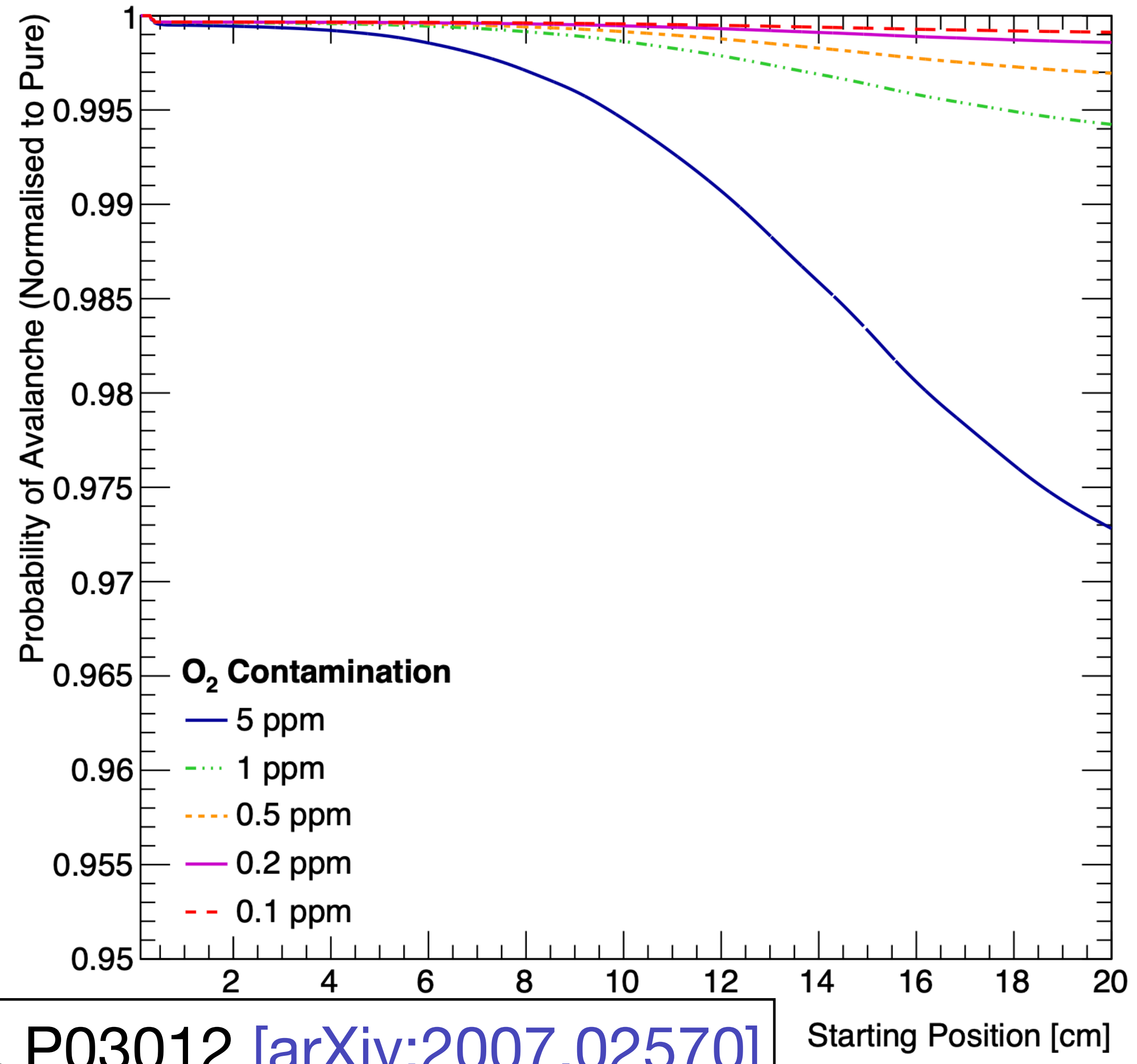
[1] No Pressure certification
[2] Pressure certification

# Latest Setup Improvements

- Purification:
  - High purity is a strong requirement.
  - Circulation inside cold getters.
- Recirculation:
  - Recirculation system.
  - Controlled flow.
- Recovery: First design by
  - Creation of a cryopumping system.
  - Pressure controlled valve.

Simulation
Cathode: 20 cm radius
Anode: 1 mm radius; 2000V
ArP2: 1.1 bar ↑
Anode: 1 mm radius; 720V
ArP2: 200 mbar ↓




JINST 16 (2021) 03, P03012 [arXiv:2007.02570]

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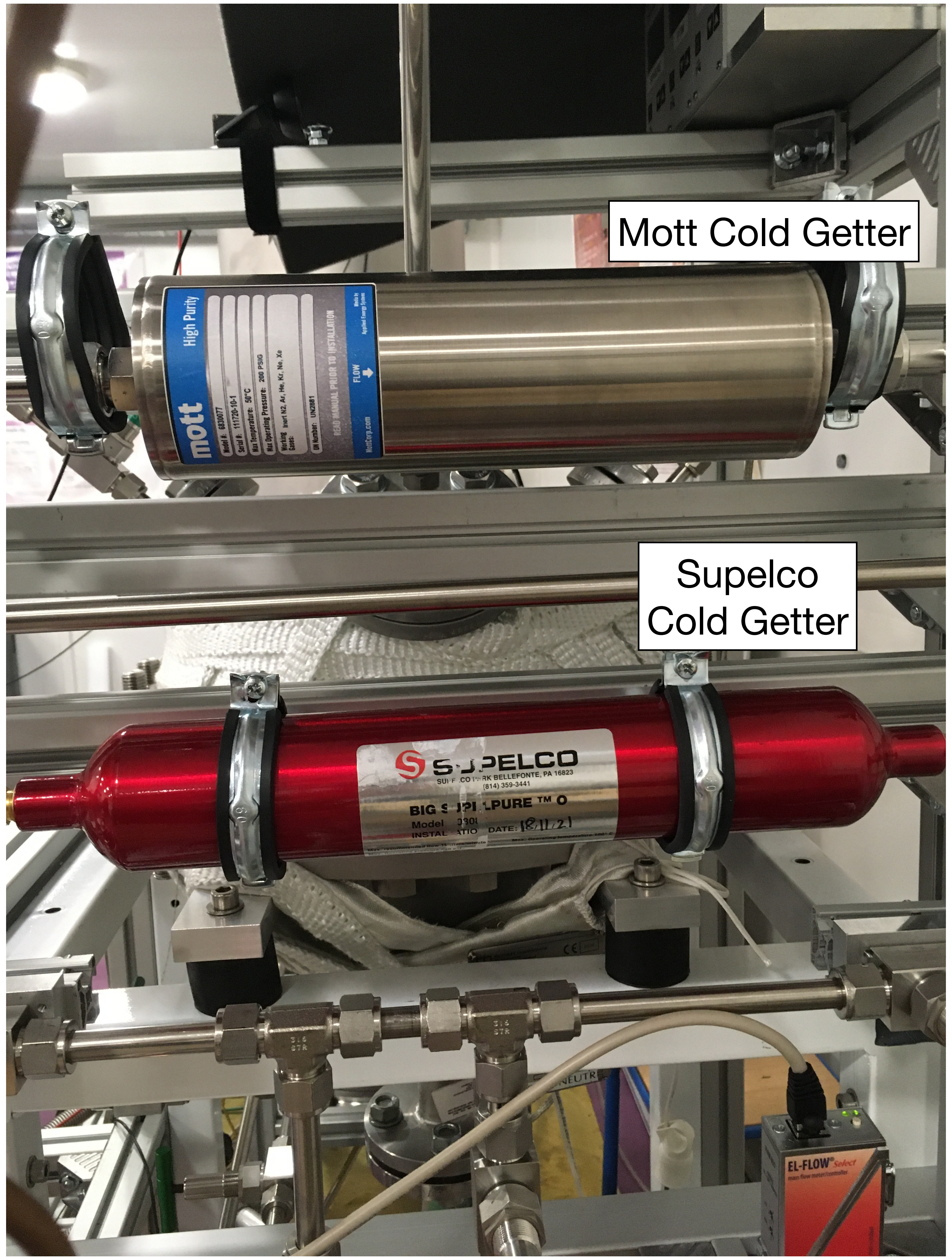

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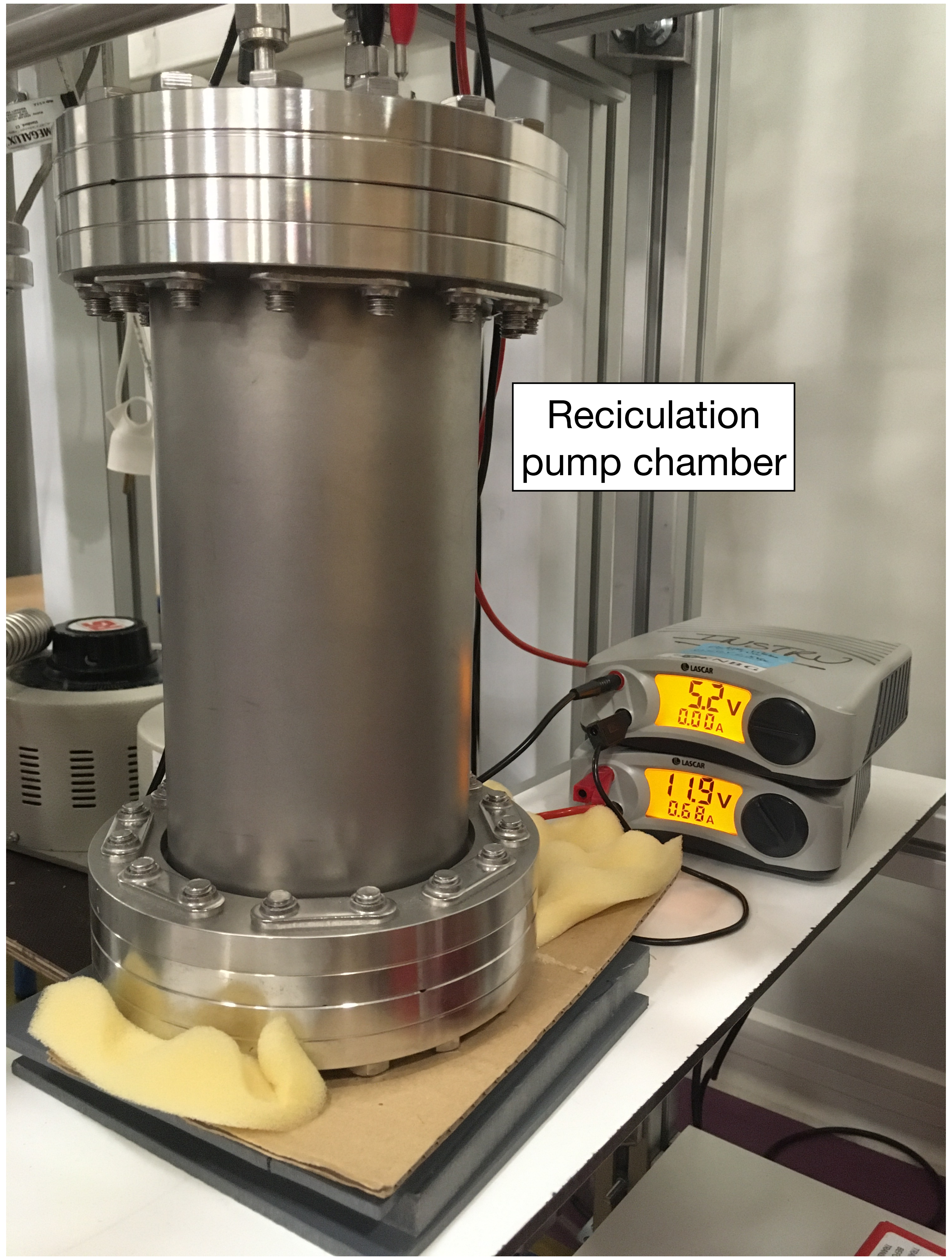

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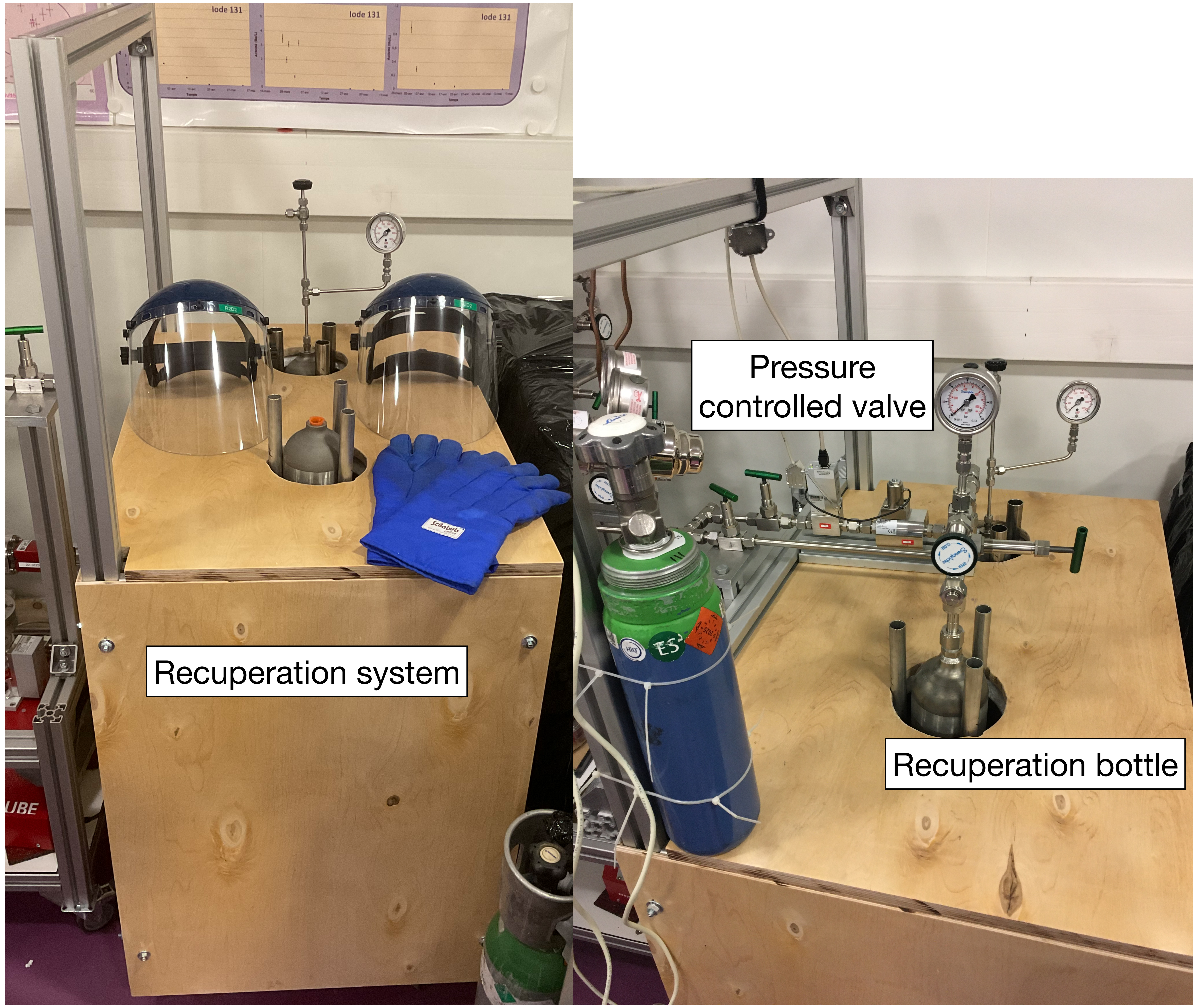

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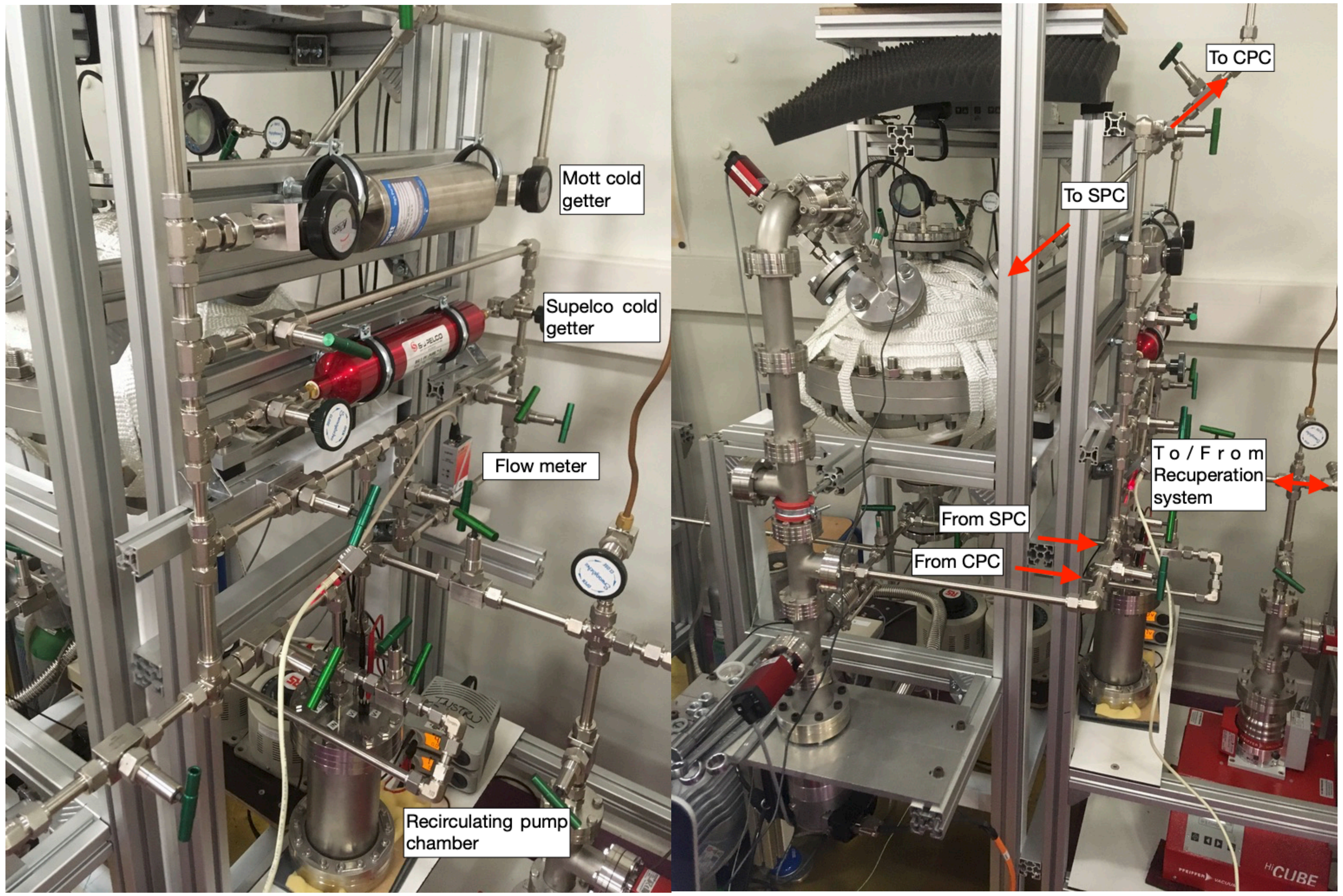



Hot getter coming in 2023 …

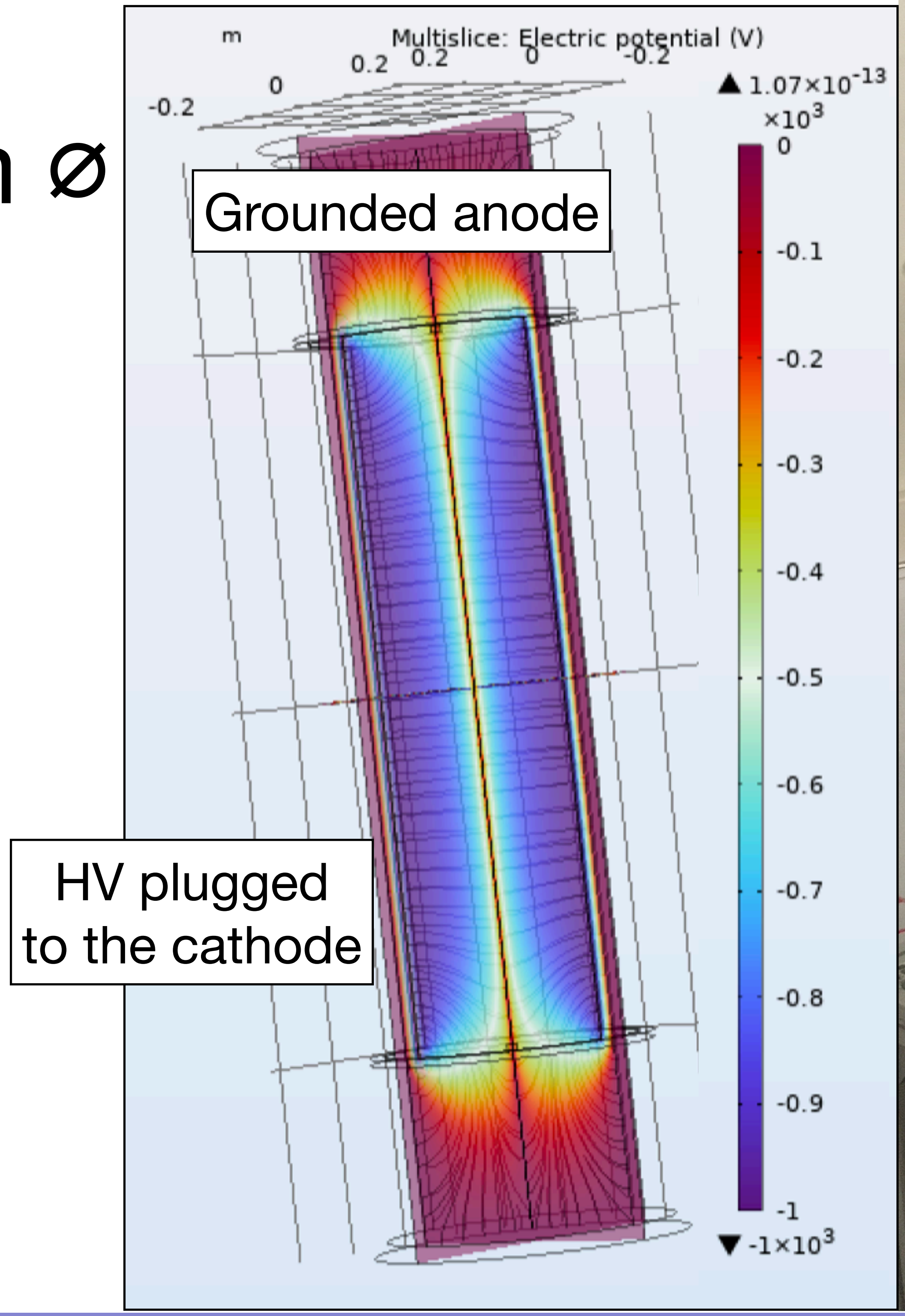
# CPC

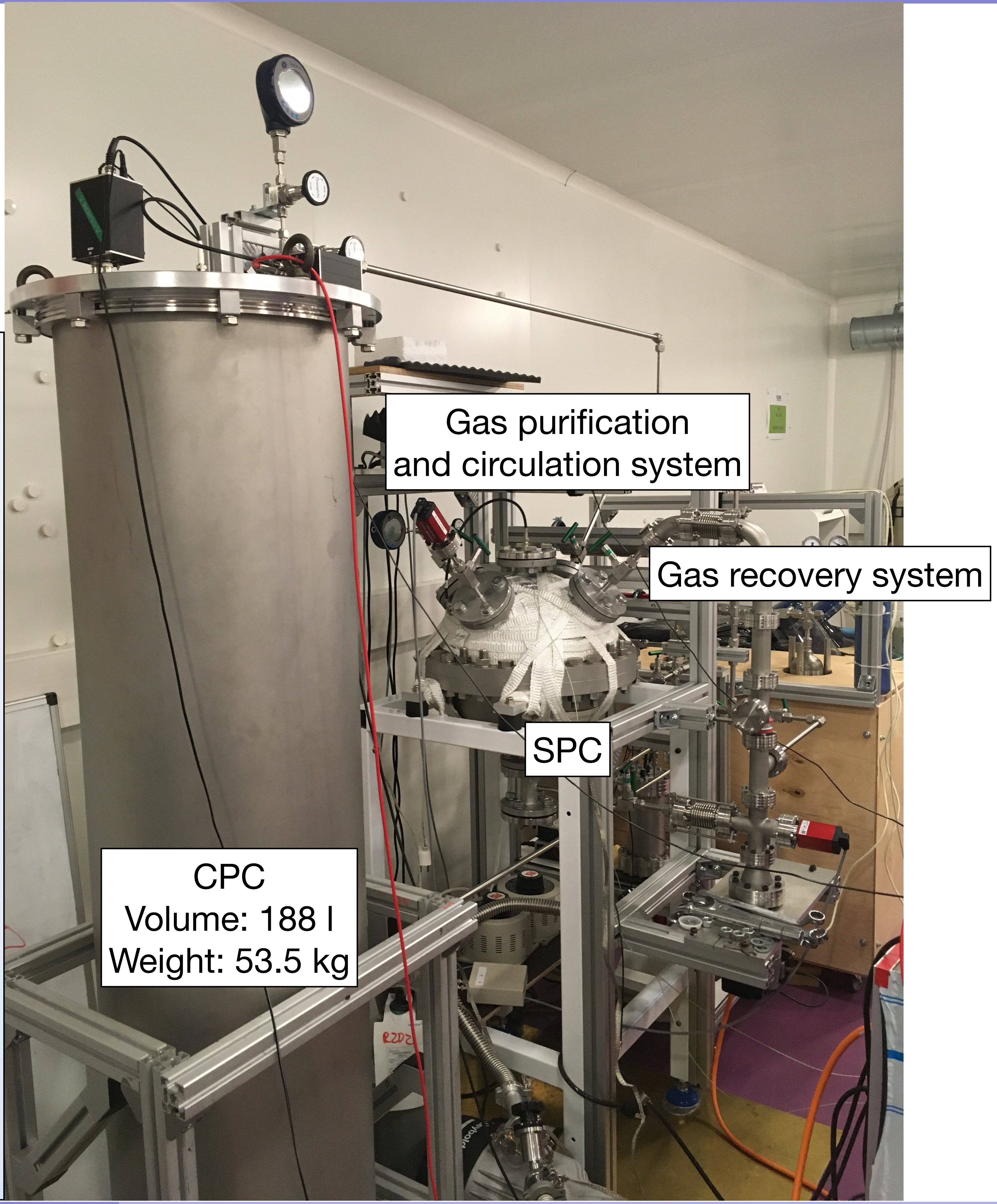
Since May 2022 a new prototype is under study. A CPC exploiting the existing electronic chain, pumping and gas management system.

- Inox Tube: 1m50 x 20cm ⌀
- Copper cathode: 1m x 17.5 cm ⌀
- Tungsten anode: 20 µm ⌀
- $^{210}$Po source

Electric Field:

- SPC: $\propto \frac{1}{r^2}$
- CPC: $\propto \frac{1}{r}$ (far from the edges)



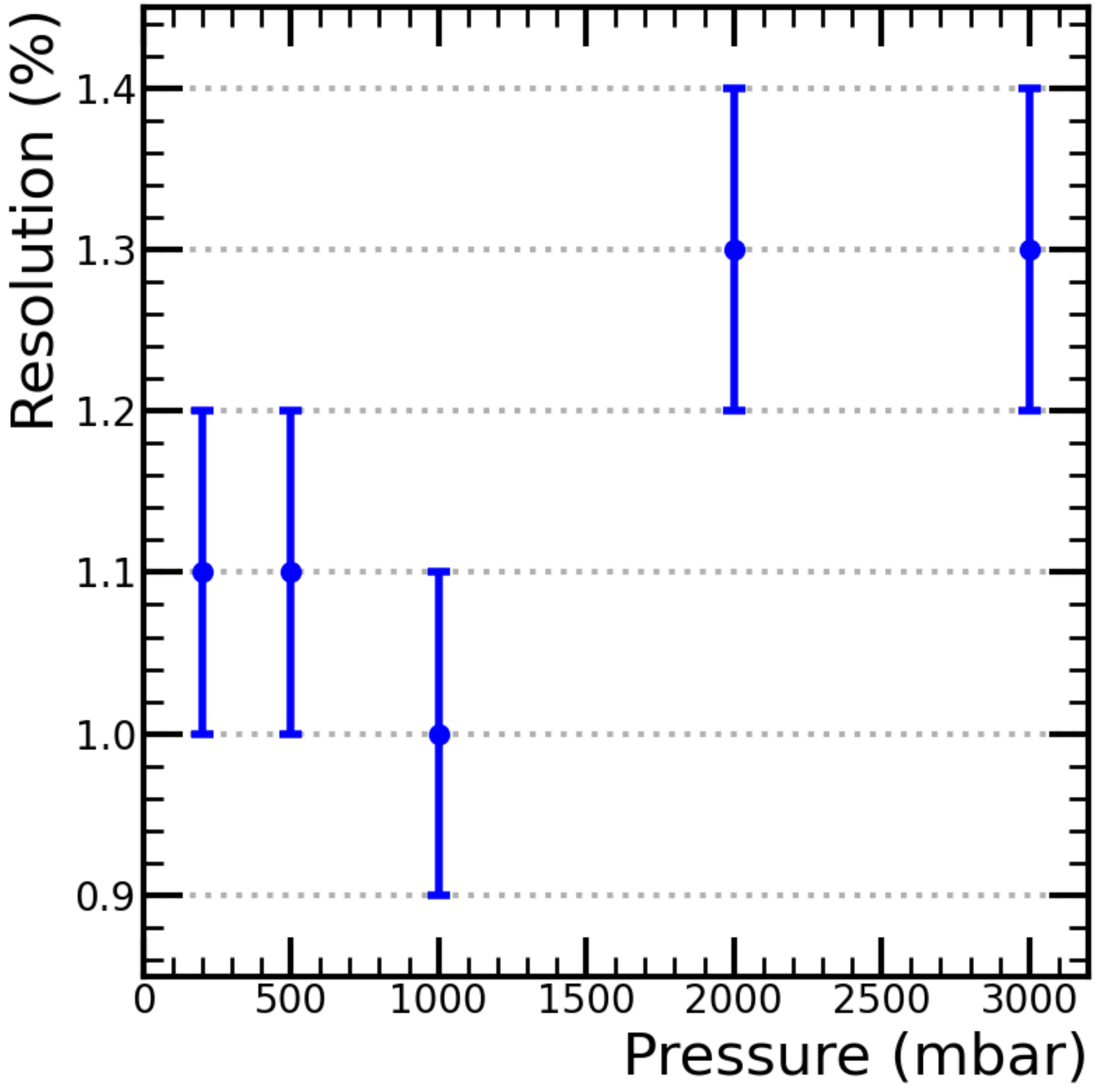



# Updated Argon Result: SPC — Proportional

Former published[1] measurement with SPC-1 in ArP2[2] spanned from 200 mbar to 1.1 bar using $^{210}$Po α of 5.3 MeV.

New measurement with SPC-2:

- Measurement up to 3 bar in proportional mode.
- Resolution between 1% and 1.3%.
- Anode radius: 1 mm.
- Limits:
  - HV: with small radius anode the electric field is too weak to collect all electrons at the cathode.
  - Gas purity: at higher pressure even small electronegative impurities induce important signal reduction.




[1] JINST 16 (2021) 03, P03012 [arXiv:2007.02570]

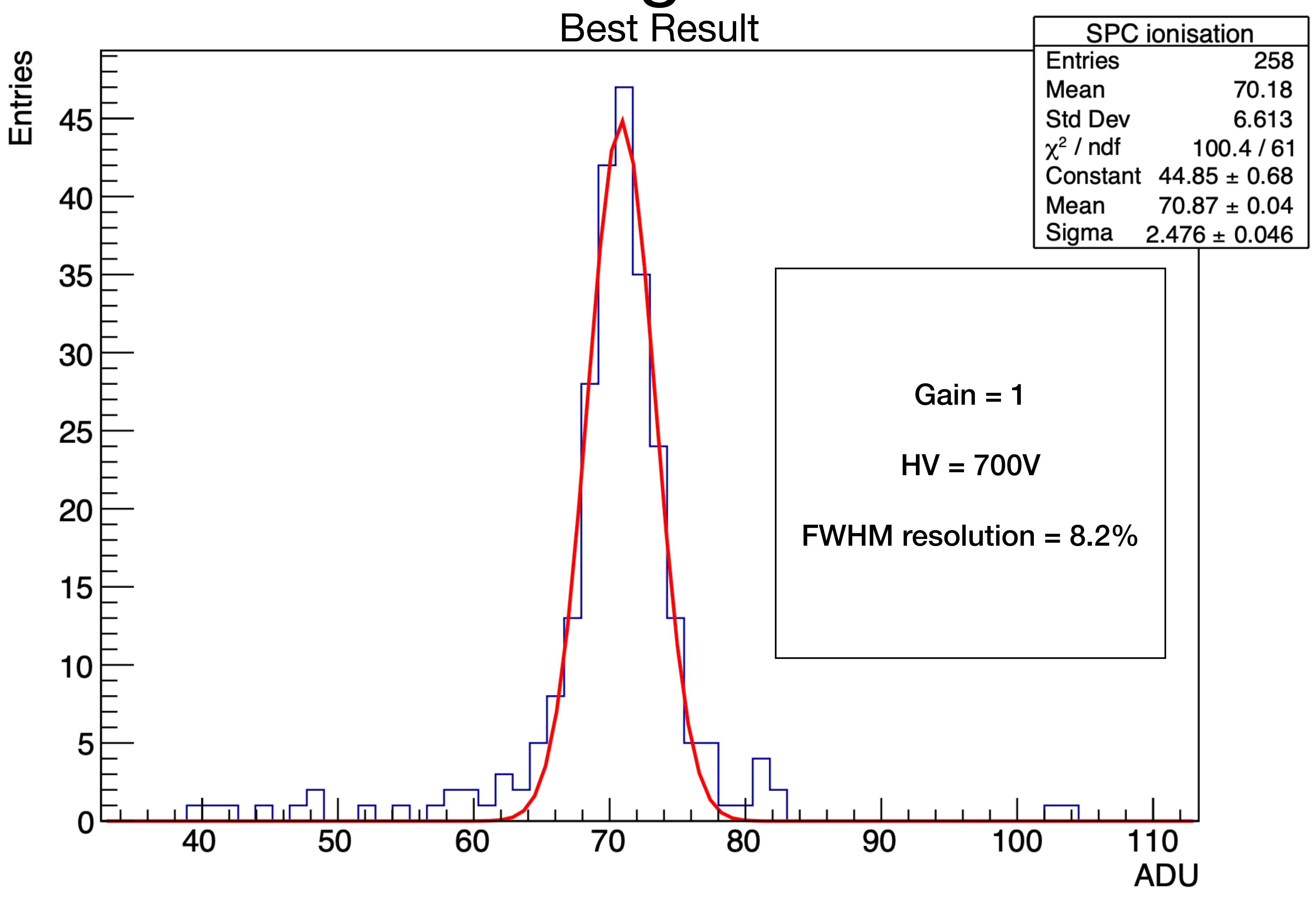
[2] ArP2: Argon (98%) and $CH_4$ (2%) mix

# Updated Argon Result: SPC — Ionisation

SPC-2: Resolution measure for $^{210}$Po α of 5.3 MeV.

The electric field at the cathode is too weak to collect all the charges. A workaround is to use a larger sensor tip.

The downside is a lower gain on the signal and thus a ionisation working mode.

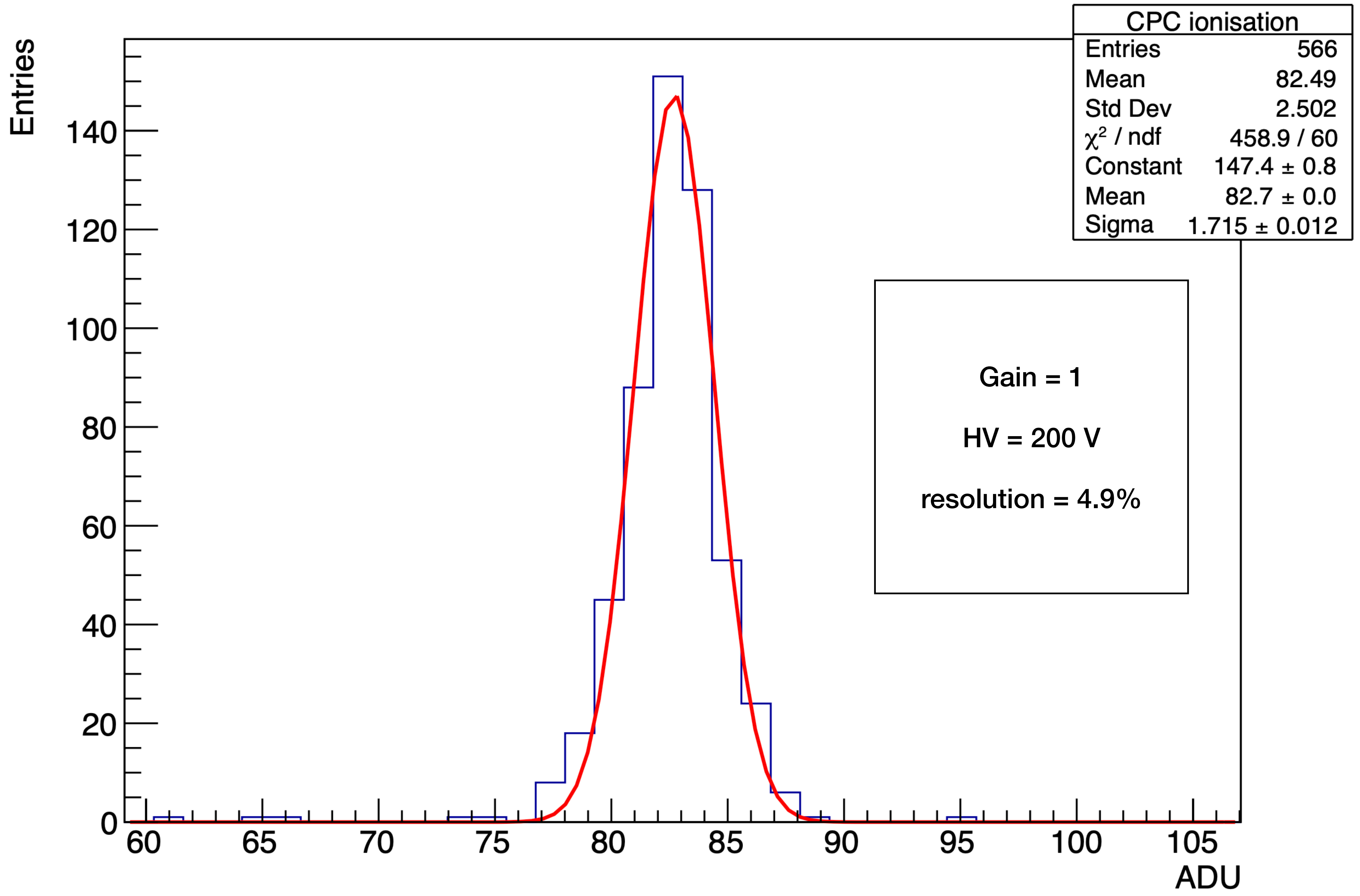



Anode with 3 mm radius at 1 bar:

- HV: 700 V instead of 1900 V in proportional
- Spread: 2.5 ADU → DAQ limitation
- Integral: ~70 ADU → resolution ~8% FWHM independently of the gas pressure

# CPC Argon result

First tests with ArP2 show a much lower noise due to the separation of the signal from the HV. The 1/r electric field dependence results in a higher field at the cathode for the same HV compared to the SPC.




First measurement
in proportional mode (1 bar, 900 V):

- 1.2% resolution FWHM.

Test in ionisation mode (1 bar, 200 V):

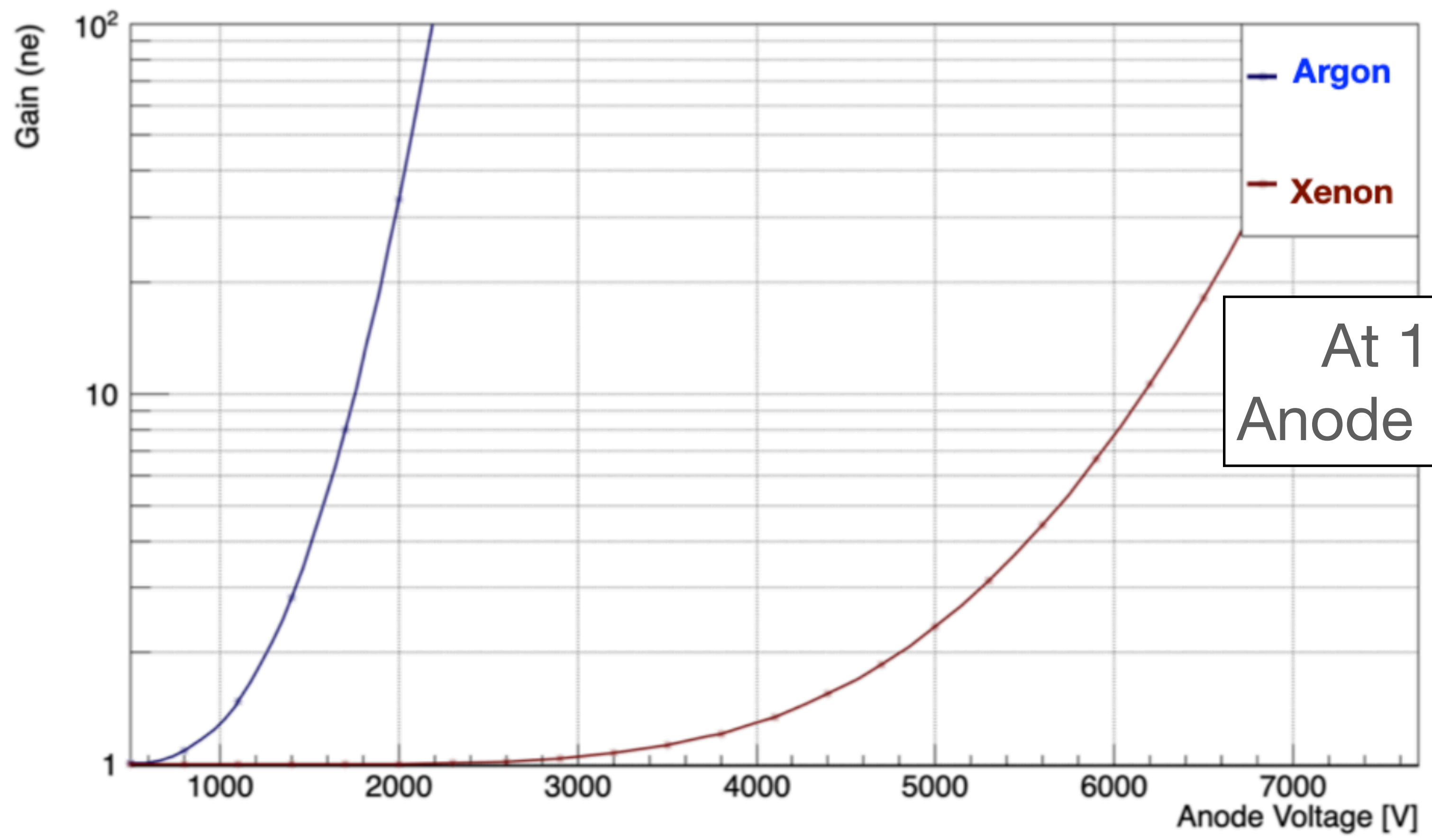
- 4.9% resolution FWHM.

This result is better with respect to the SPC since such resolution is dominated by baseline fluctuation which is much smaller by decoupling HV and signal.

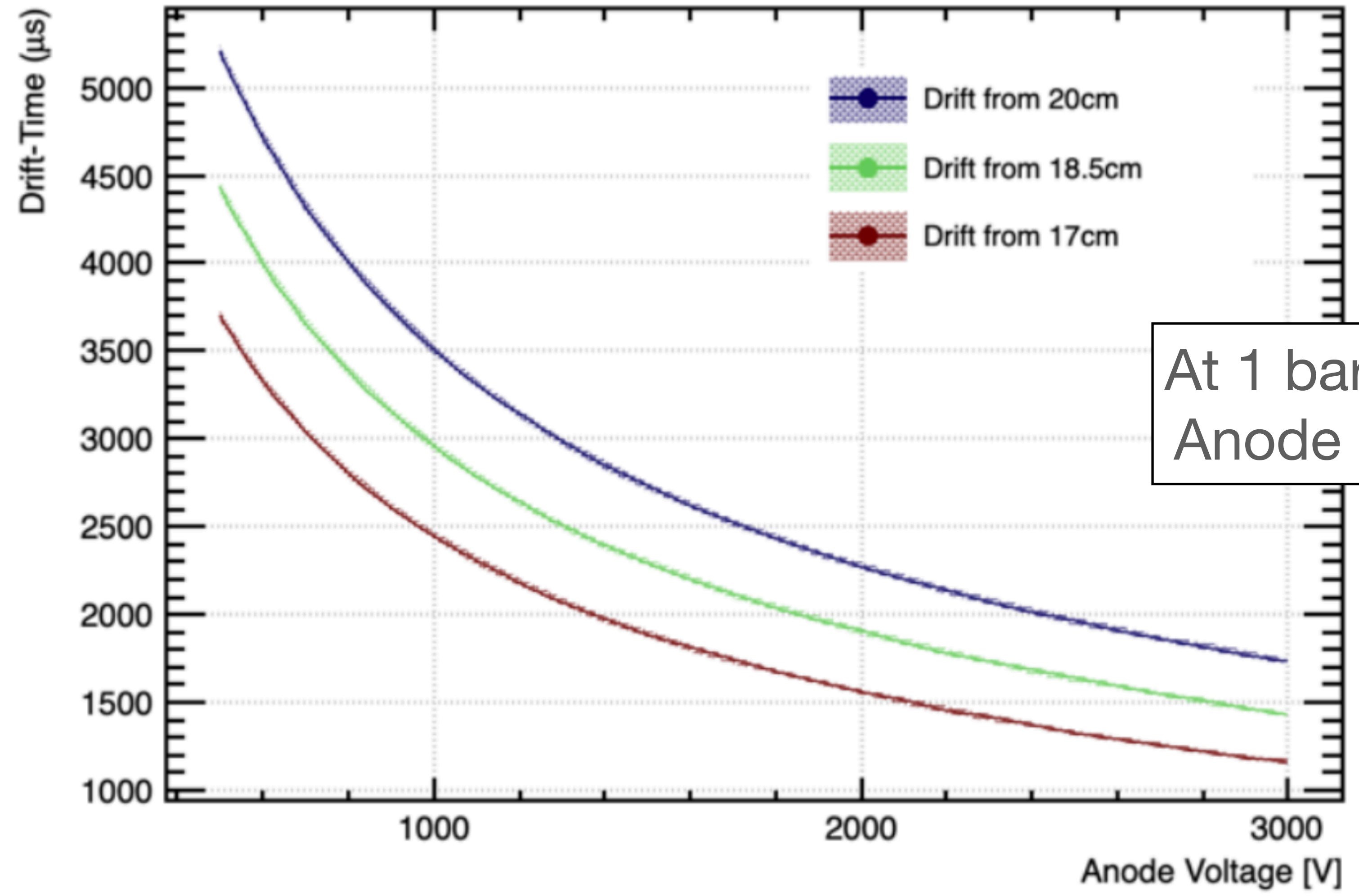
# SPC Xenon: Main Difficulties

Switching from Ar to Xe implied a lot of challenges to overcome. Aside from the previously discussed technical consideration:

- Xe electrons drift time is one order of magnitude larger than Ar.
- Electronegative impurities become more critical. Purity is paramount.
- A stronger electric field is needed across the whole medium.
  - Higher HV → higher noise.
  - Larger anode → Ionisation mode only.




At 1 bar
Anode 6mm ⌀




At 1 bar Xenon
Anode 6mm ⌀

# SPC Xenon: First measures

250 mbar

- HV scan: 800 V up to 1400 V
- Optimal: 1300 V
  - Integral: 118 ADU
  - Sigma: 1.9 ADU
  - Resolution: 3.8%

900 mbar

- HV scan: 1300 V up to 2200 V
- Optimal: 2000 V
  - Integral: 85 ADU
  - Sigma: 2.5 ADU
  - Resolution: 7%

Higher pressure measurement would require a gas purity level that is not achieved yet with the current setup. Even after several days of recirculation through the getters, electron attachment is still present.

# CPC Xenon: First measures

First measurement: 500 mbar; 900 V; 24 hours of recirculation.

- Still dominated by attachment issue…
- … But 2.3% of resolution in proportional mode.
- Down to 1.8% if a rise time cut is applied to reject α particles with partial deposit.

Second measurement: 1 bar; 1200 V; 48 hours of recirculation.

- Attachment reduced, thus integral has increased and it is less direction dependent.
- 2.9% of resolution. Down to 1.8% if a rise time cut is applied

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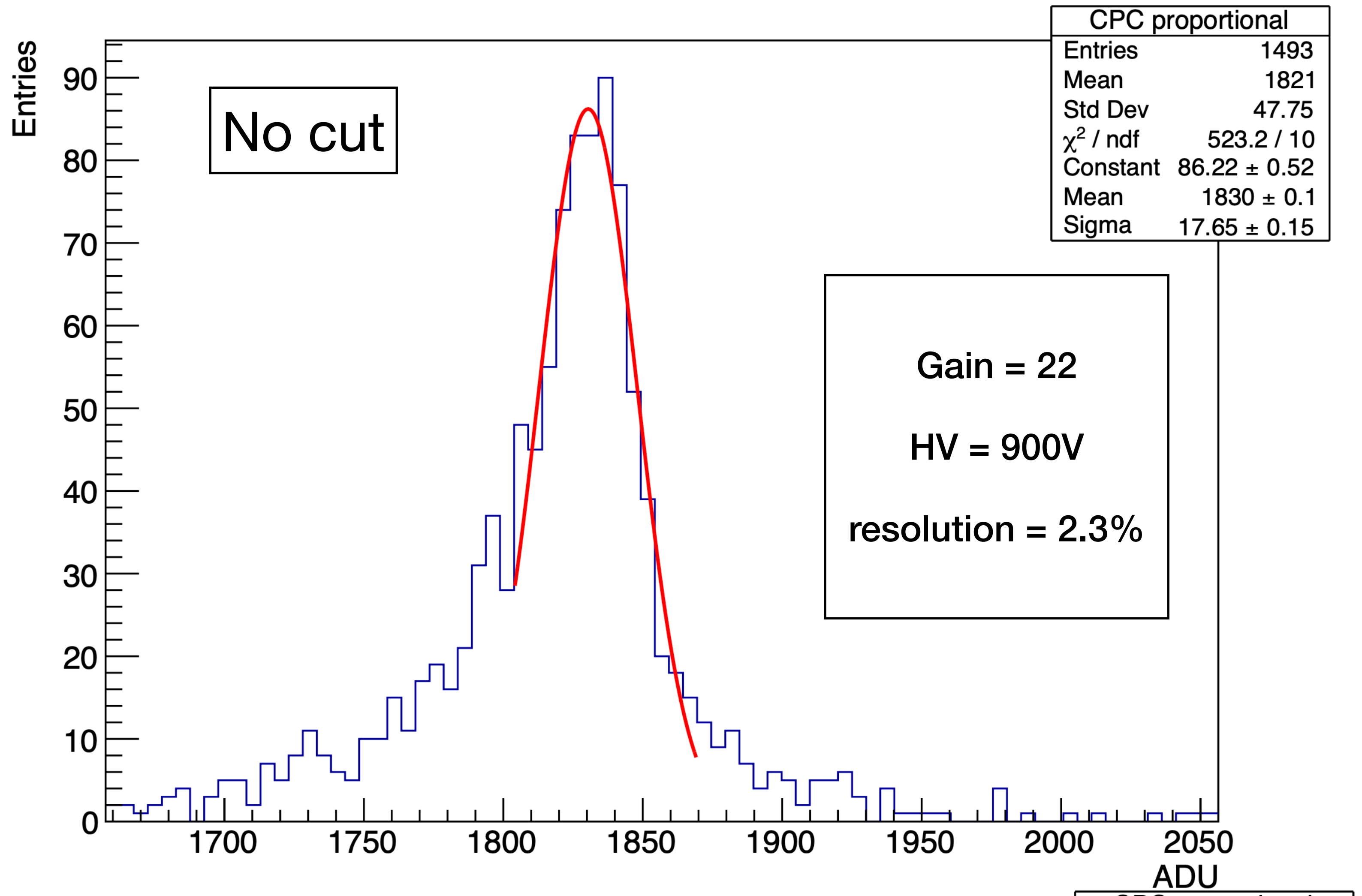


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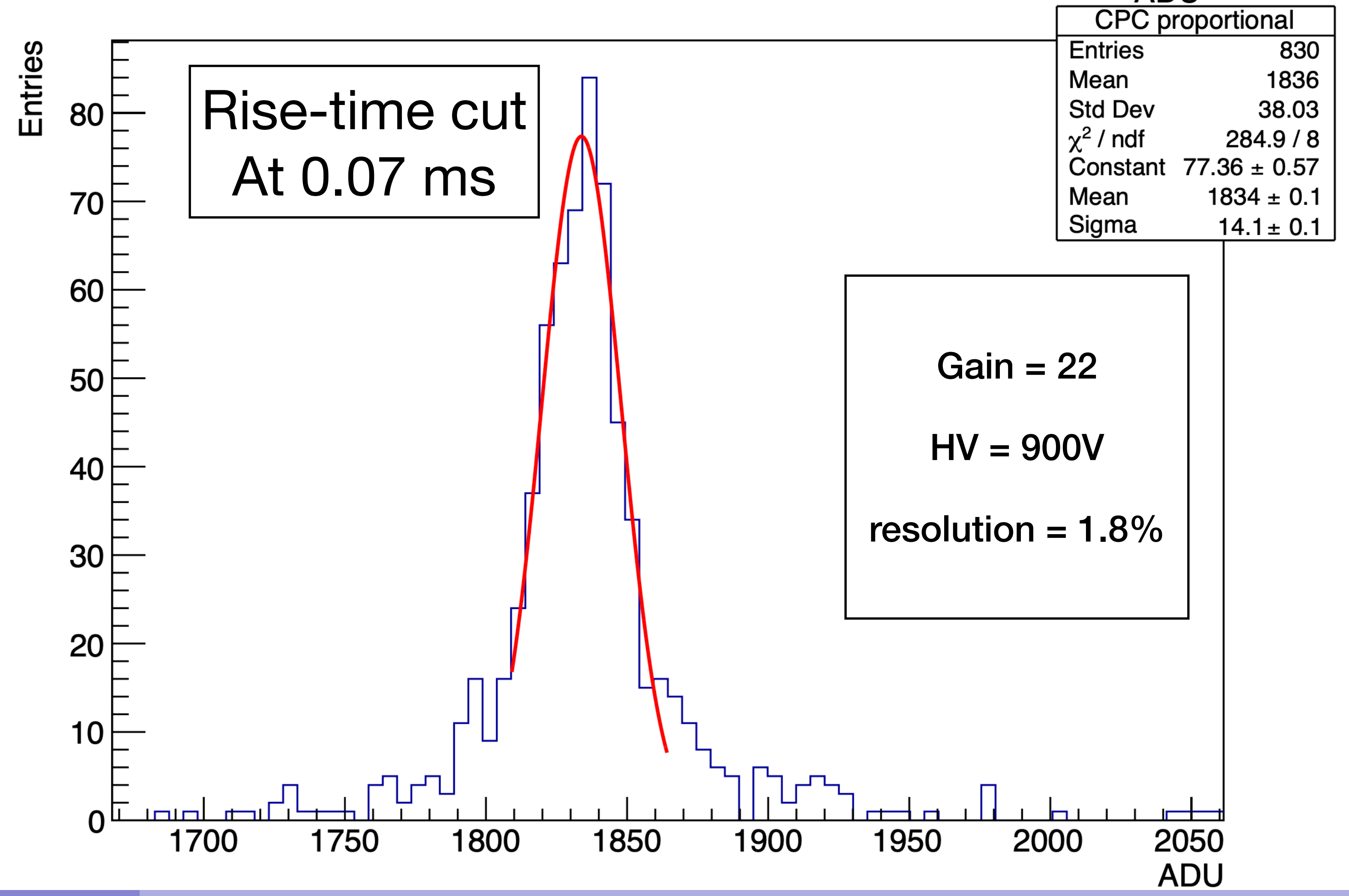

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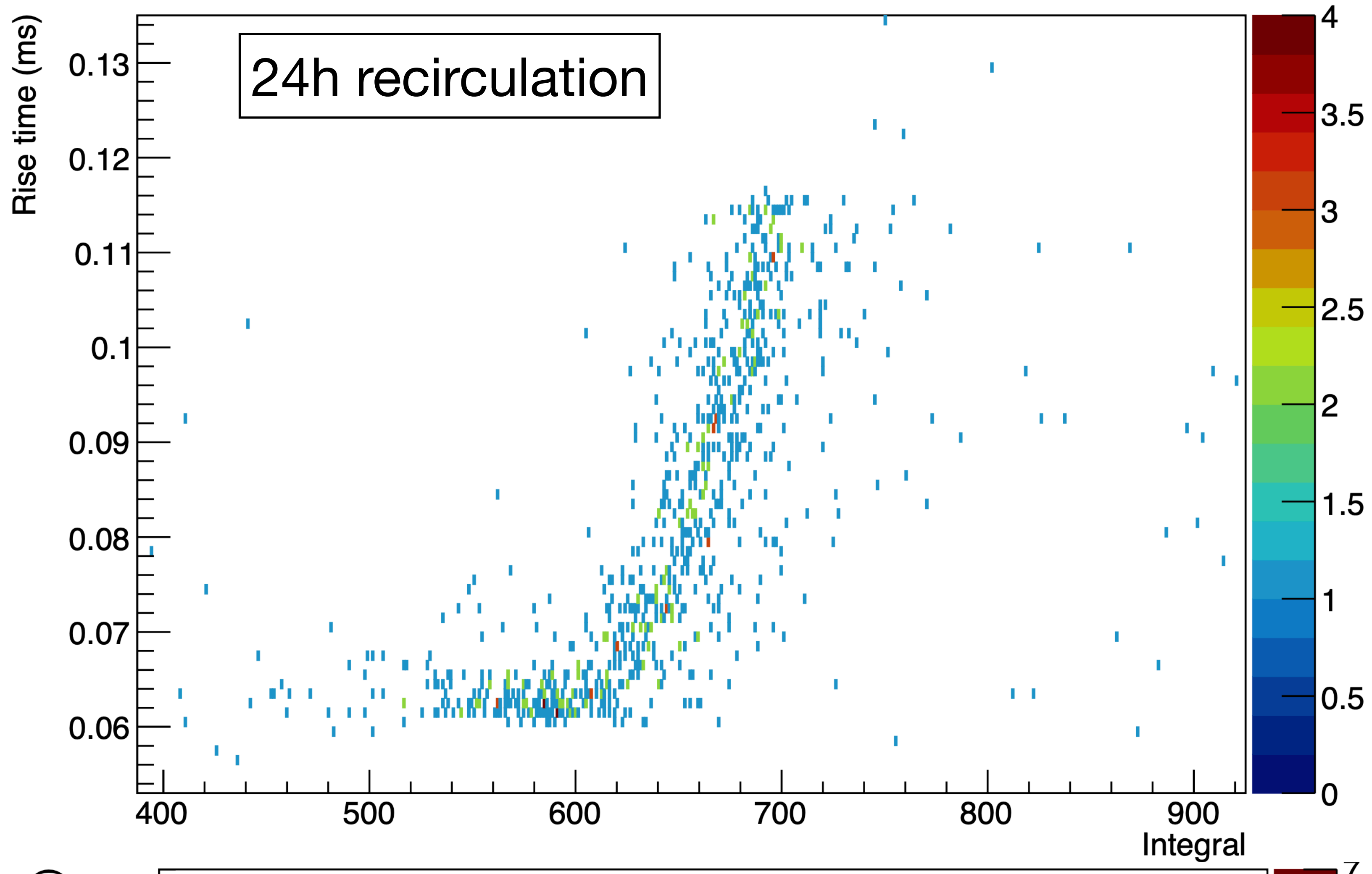


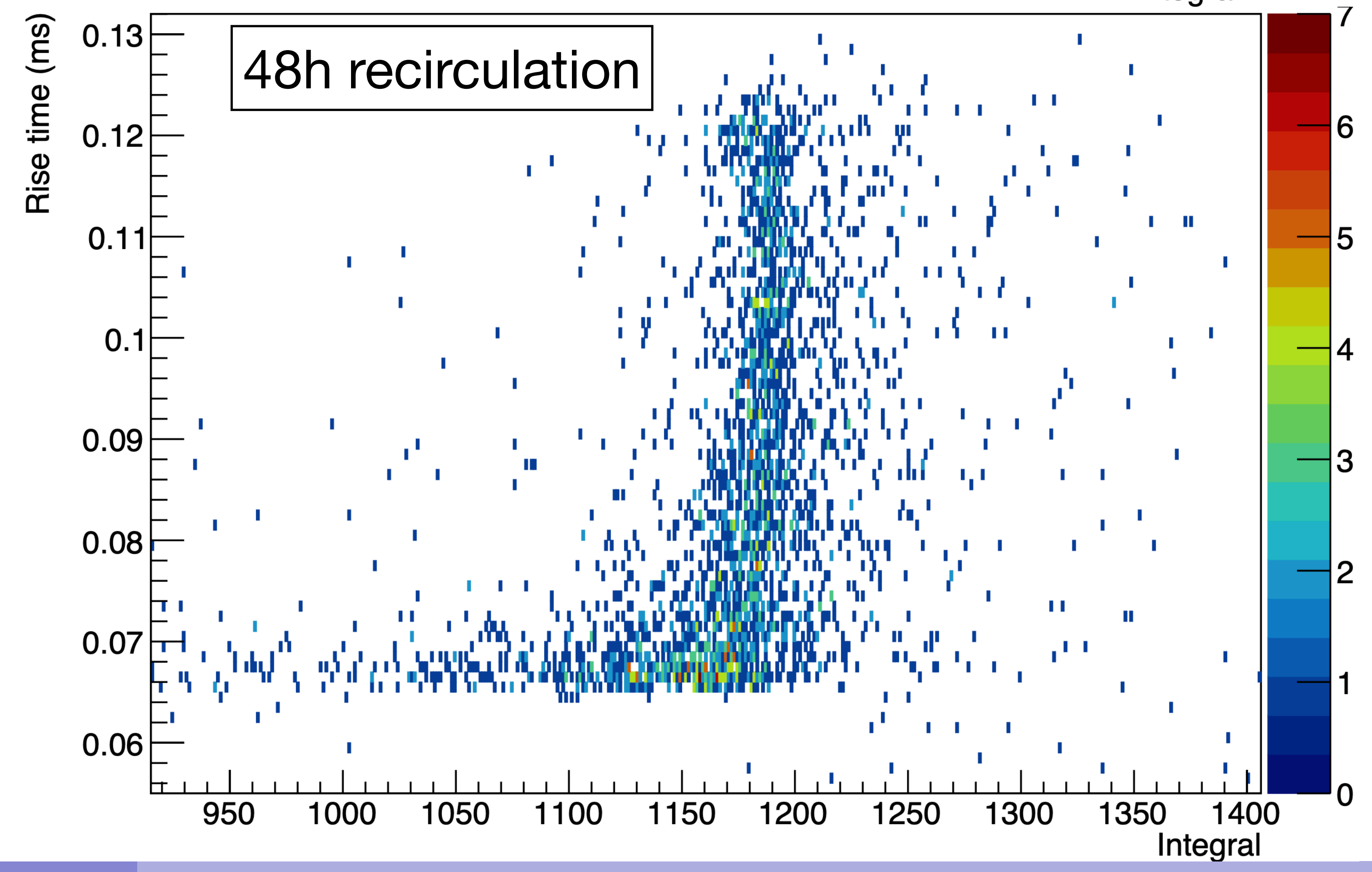


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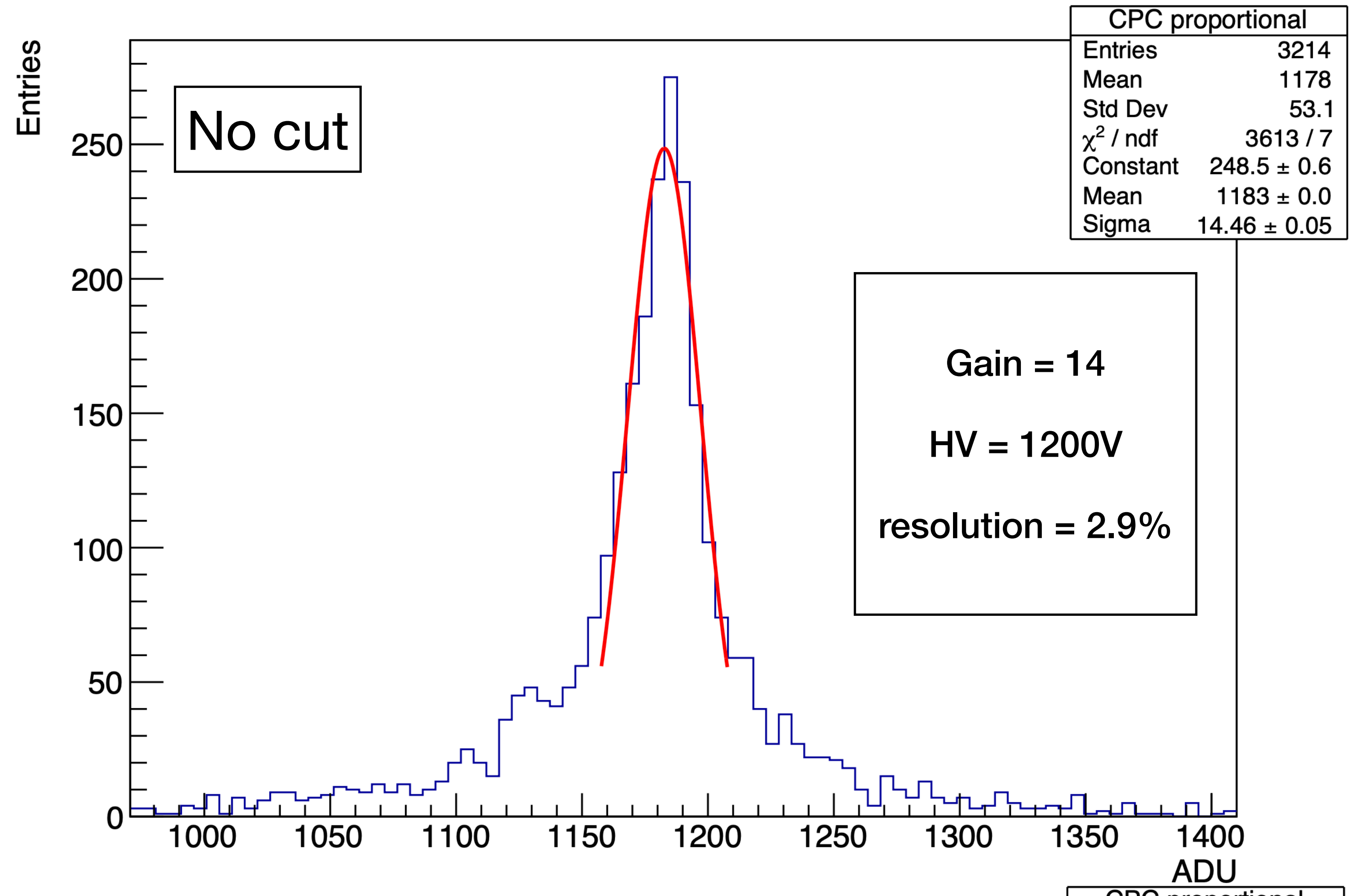
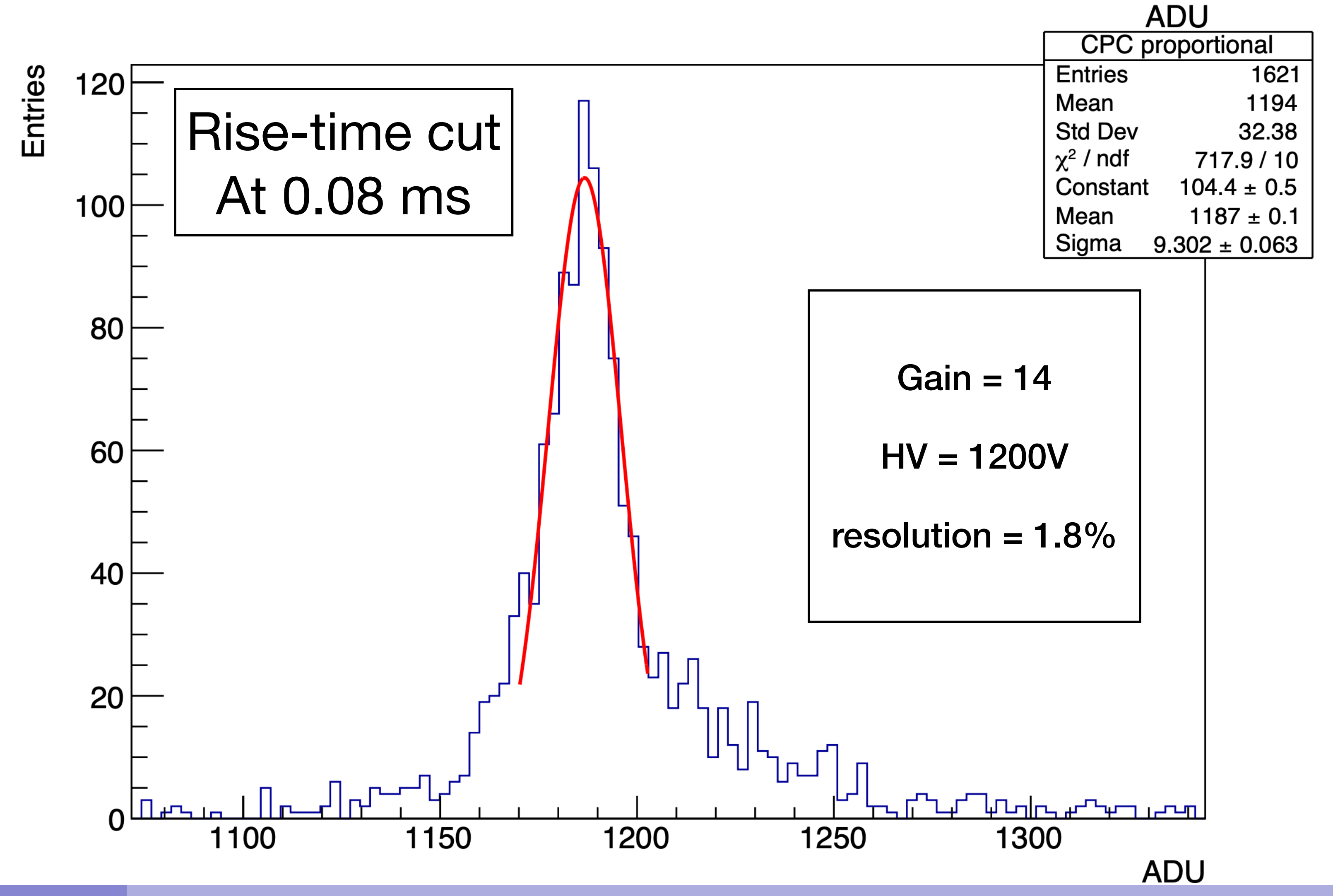
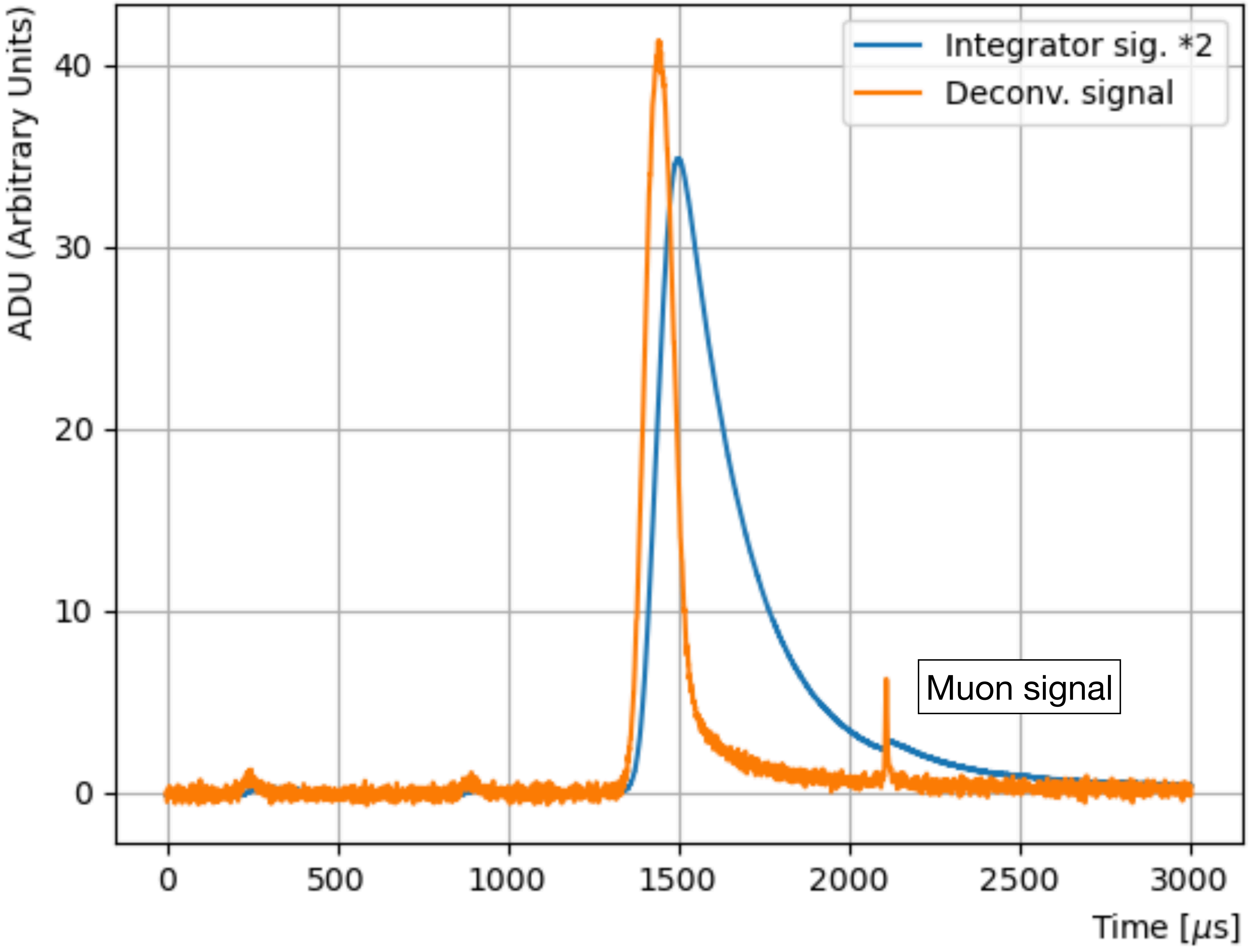


# CPC Xenon: Cosmic Background

- Unlike our current SPC, the geometry and orientation of our CPC prototype makes it more sensible to cosmic muons background.
- The energy deposit of a muon in Xe at 1 bar is significantly enough degrade the energy resolution of the α particles.
- This explain the right hand tail of the CPC reconstructed integral distribution.
- Nevertheless the final experiment shall take place in underground facilities, avoiding such inconveniences.



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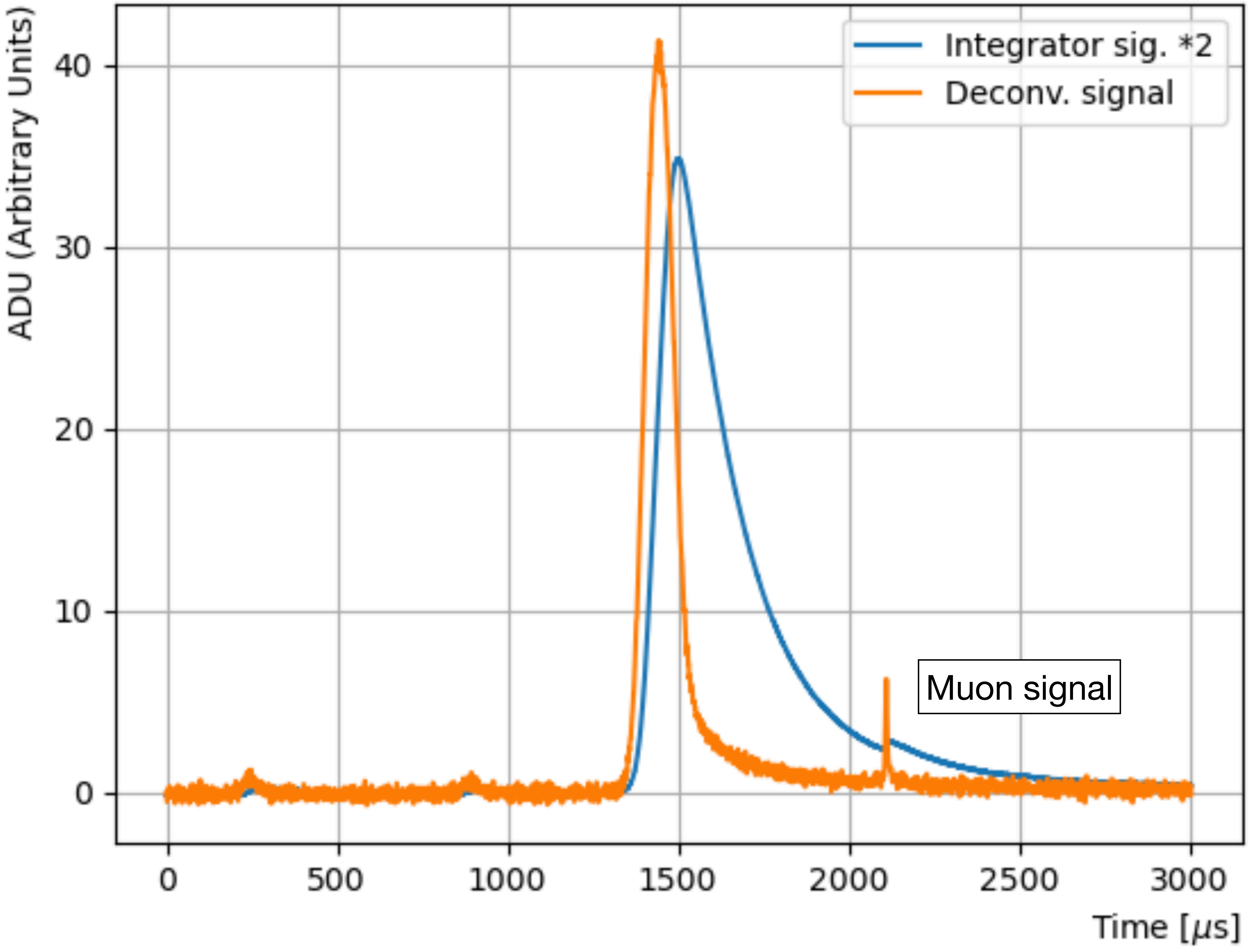

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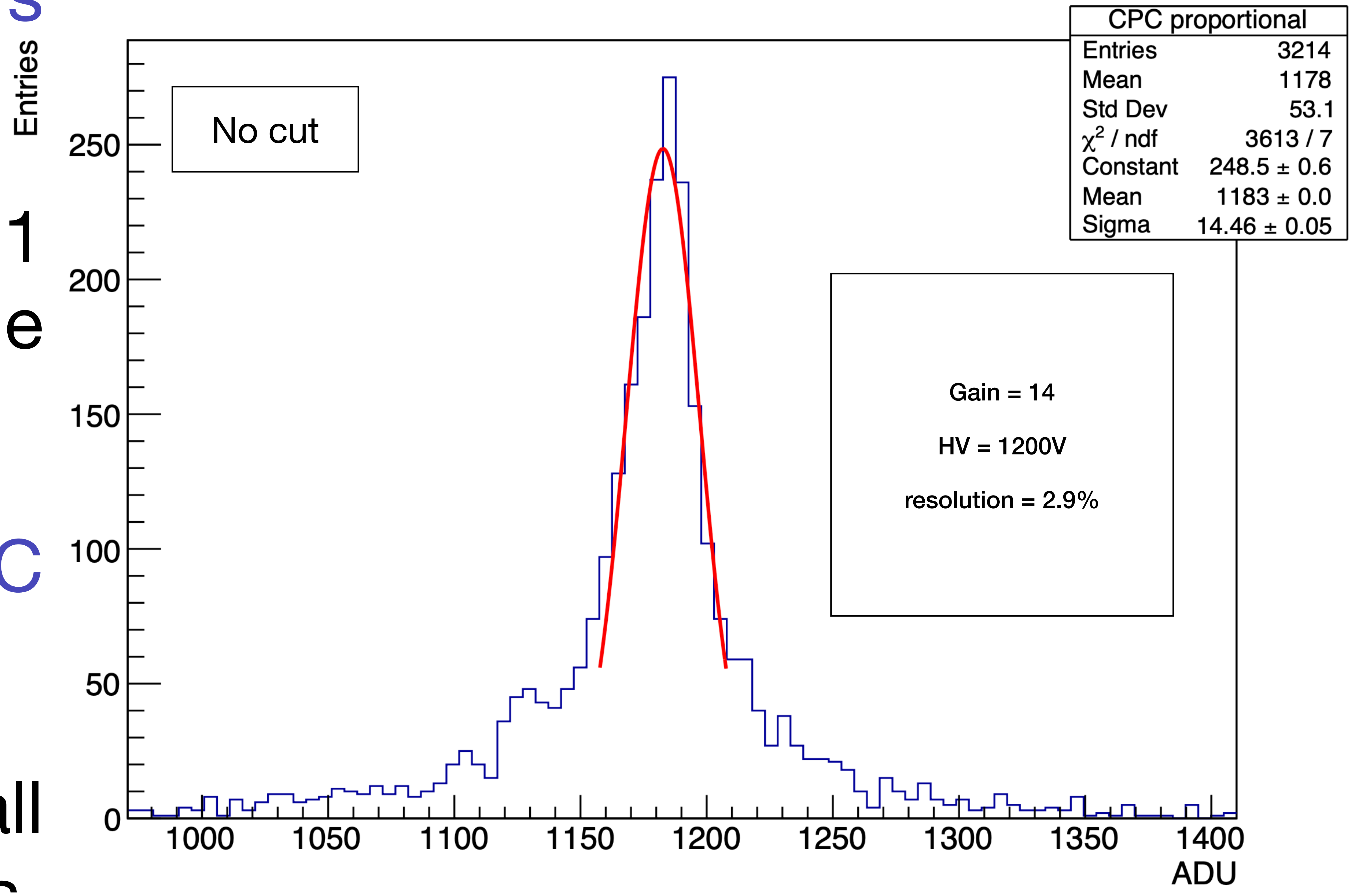

# Conclusions

- The SPC and CPC geometries were tested and compared in both Ar and Xe.
- R2D2 new SPC setup allows to obtain resolution under 1.4% in Ar up to 3 bar while the CPC has reached 1.2% up to 1 bar.
- The first measurement in Xenon were performed with success and resolution of 1.4 % is obtained at 1 bar in CPC.
- Some efforts remain, especially concerning gas purity which is crucial for the 1% resolution goal. Hot getter coming in 2023.
- Test of a small CPC up to 40 bar in Xenon in 2023.

# The End


More infos: https://r2d2.in2p3.fr