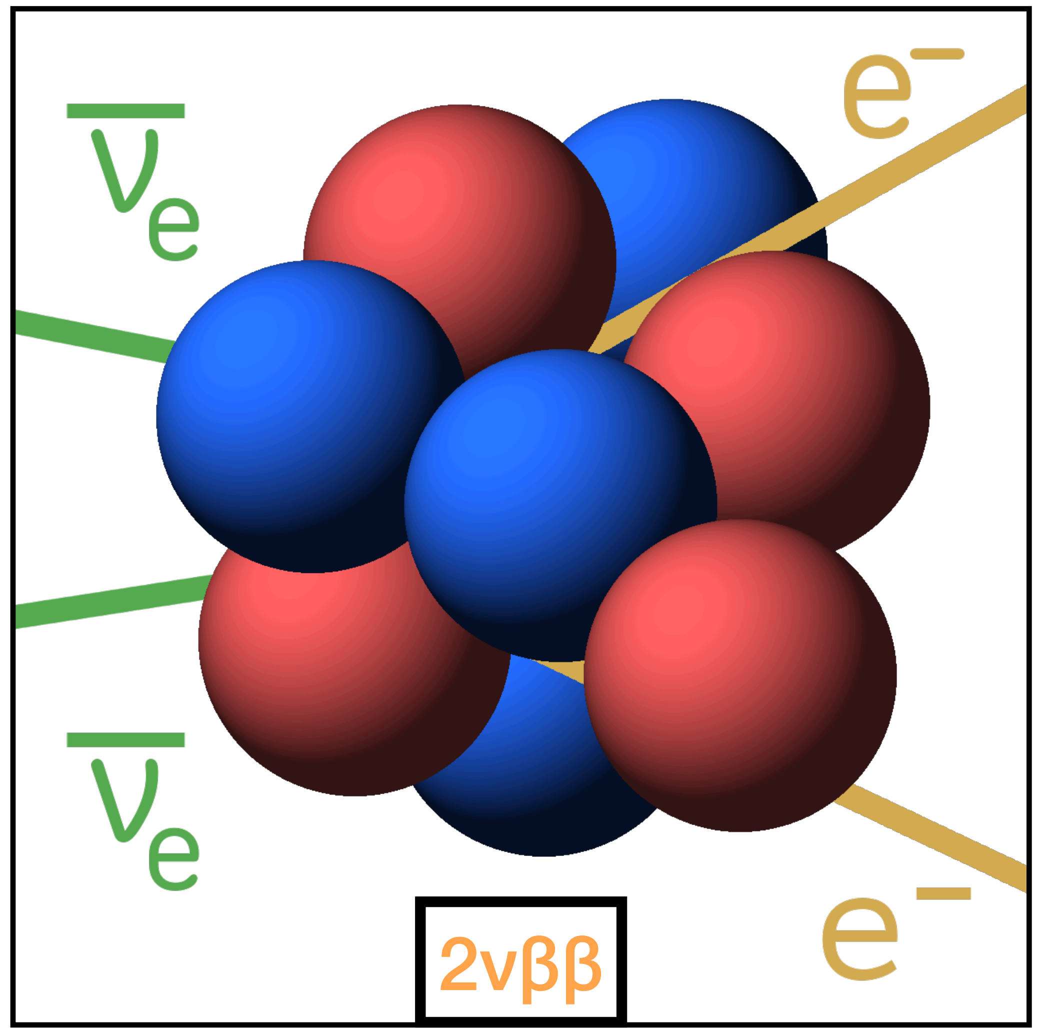
R2D2
Rare Decays with Radial Detector

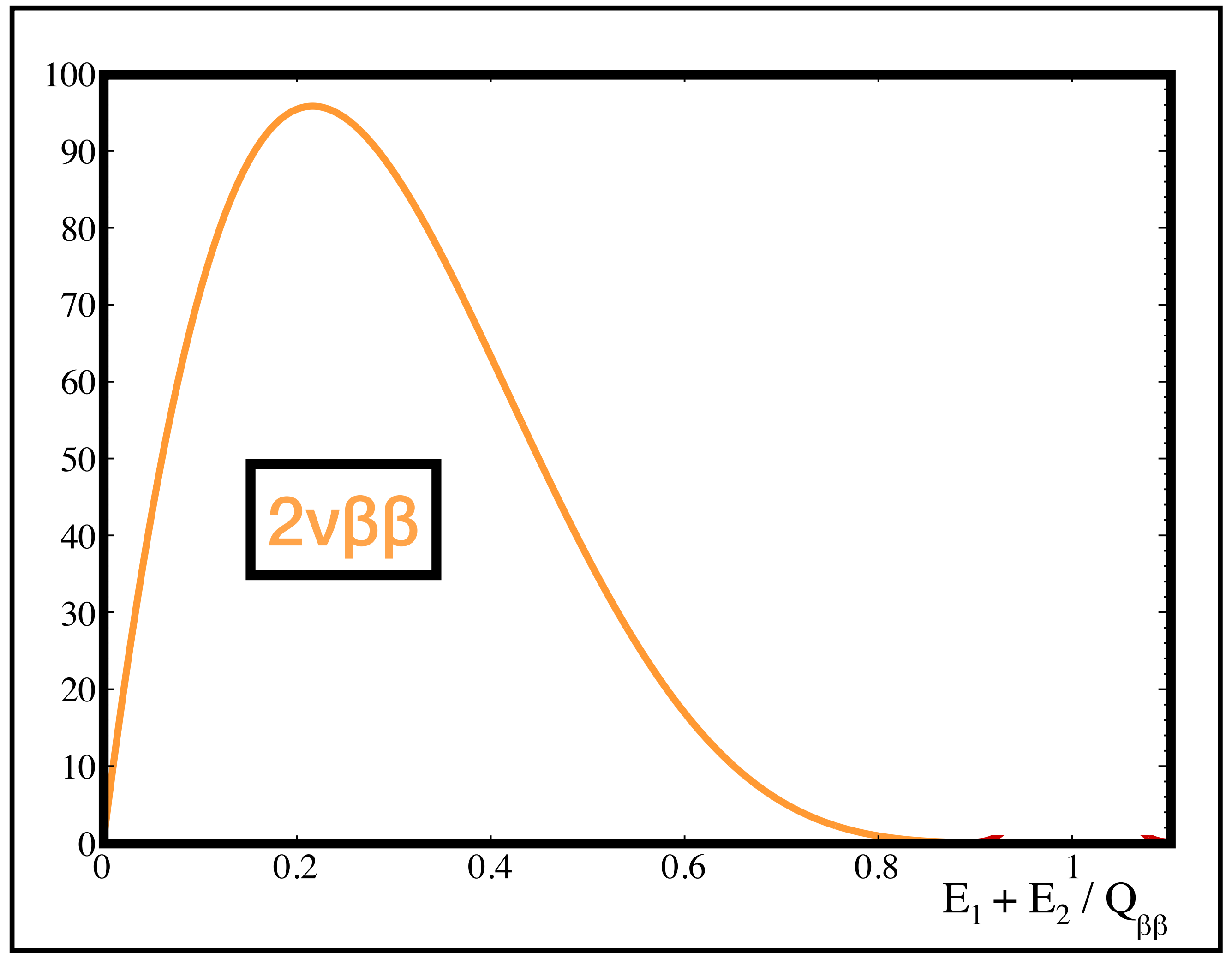
Neutrino Nature and ββ Decay

- Since the confirmation of neutrinos oscillations, neutrino research has been one of the leading way in the exploration of physics beyond the Standard Model. The neutrinos nature, Dirac or Majorana, is driving global efforts and resources.

- The current most sensitive experimental proof of the Majorana nature of neutrinos is the observation of the 0νββ decay.

  - 2νββ decay : $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$ first direct observation in 1987.



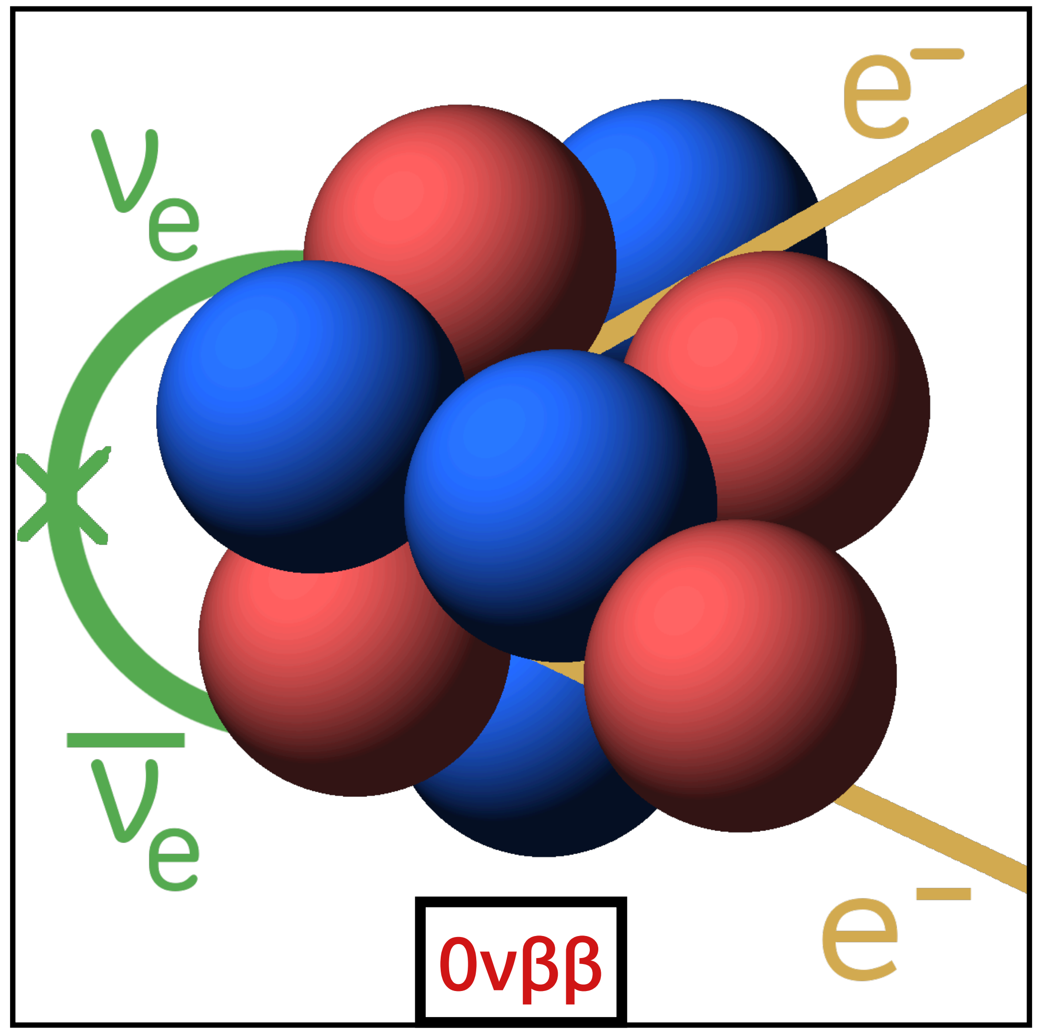


Neutrino Nature and ββ Decay

- Since the confirmation of neutrinos oscillations, neutrino research has been one of the leading way in the exploration of physics beyond the Standard Model. The neutrinos nature, Dirac or Majorana, is driving global efforts and resources.

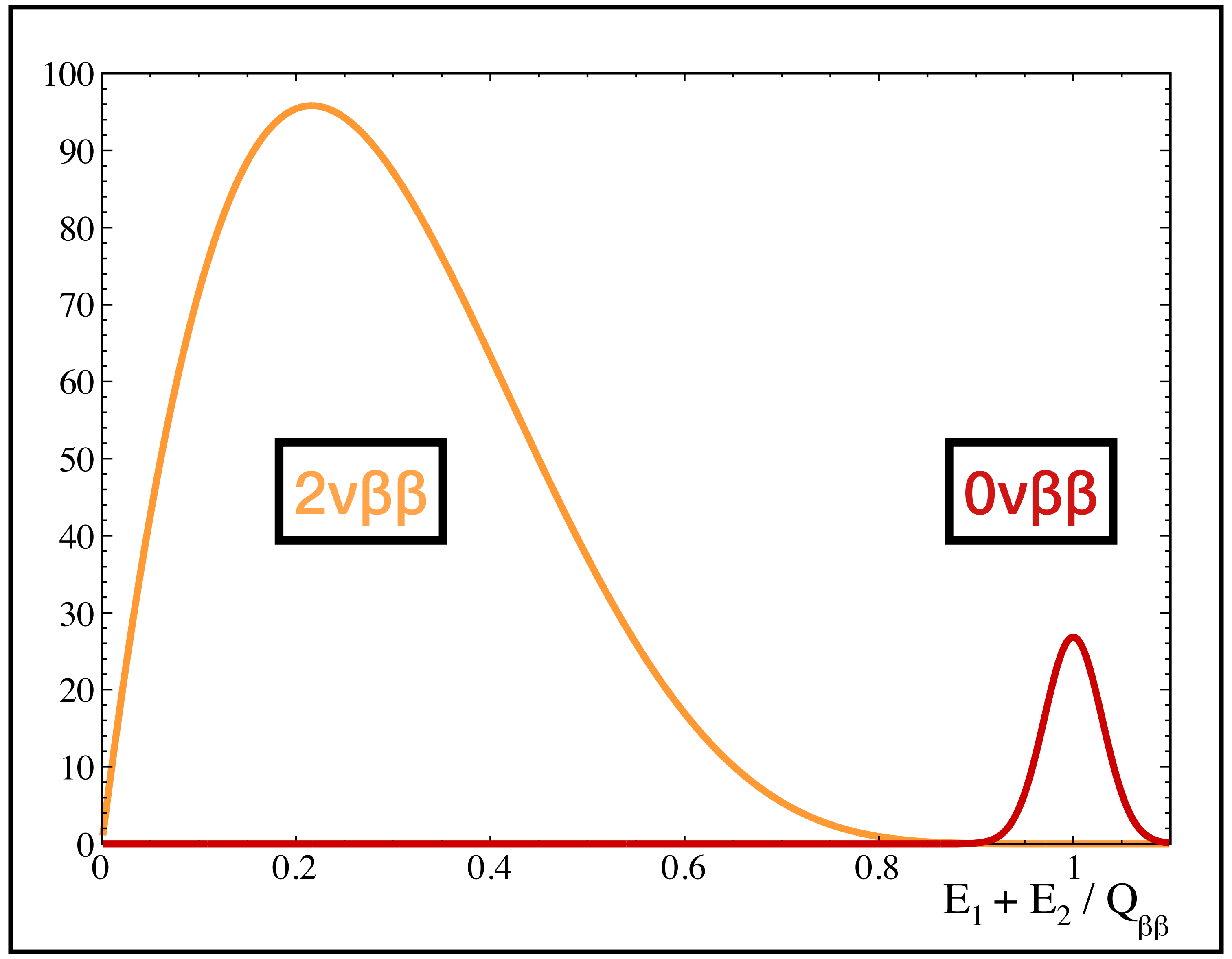
- The current most sensitive experimental proof of the Majorana nature of neutrinos is the observation of the 0νββ decay.

  - 2νββ decay : $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\overline{\nu}_e$ first direct observation in 1987.
  - 0νββ decay : $(A, Z) \rightarrow (A, Z+2) + 2e^-$ postulated in 1939.
    - Only possible if neutrino are Majorana particles
    - Violation of total lepton number
    - Total decay energy, $Q_{\beta\beta}$, shared by the two electrons.



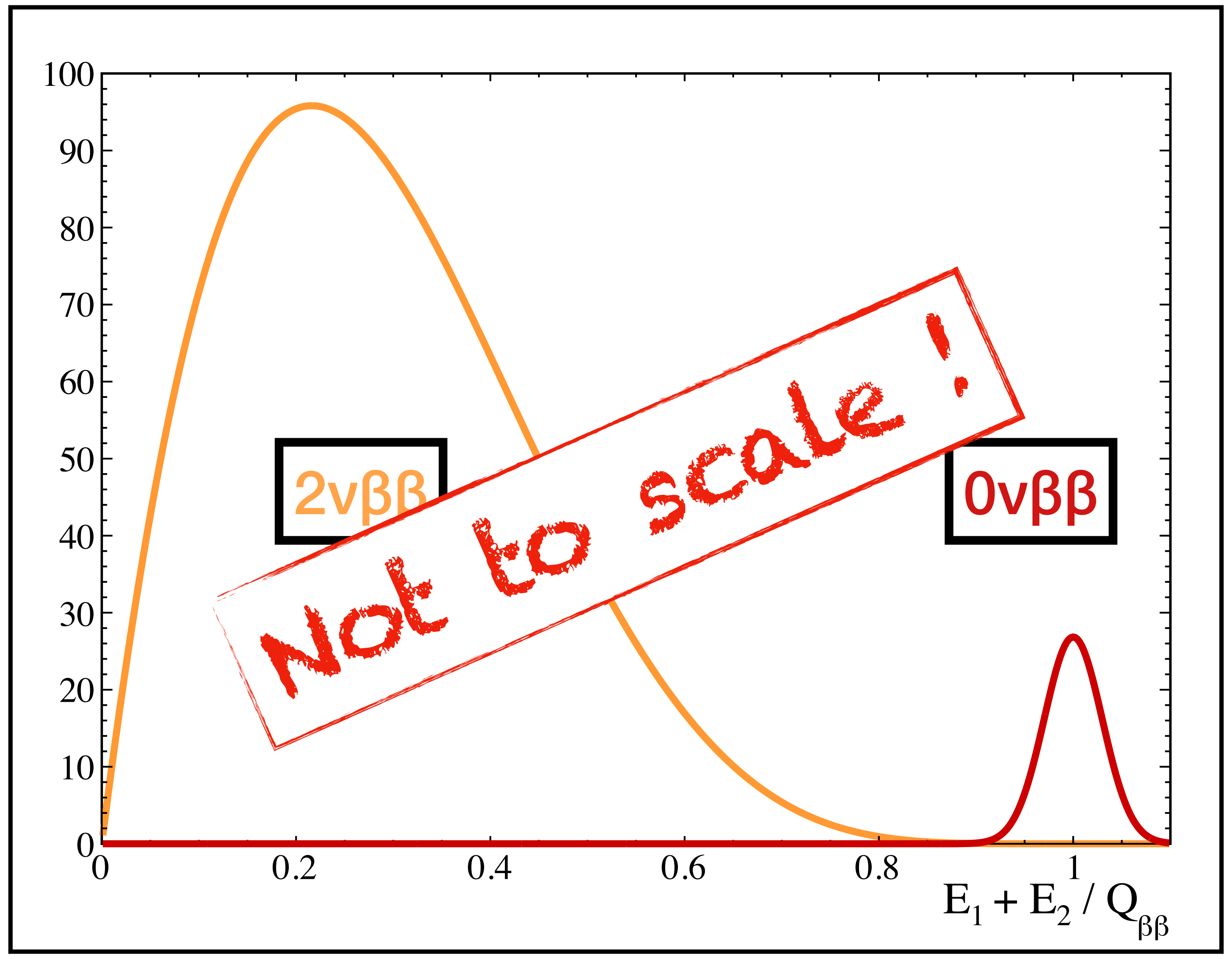
0νββ Observation

- Several isotopes are ββ emitter: ^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{136}Xe, ^{150}Nd
  - $T^{2\nu}_{1/2} \sim 10^{18-21}$ years, $T^{0\nu}_{1/2} > 10^{21-26}$ years.
- This observation could consists in the measurement of a narrow peak at the end of the two electron energy distribution, i.e the $Q_{\beta\beta}$ of the ββ decay.

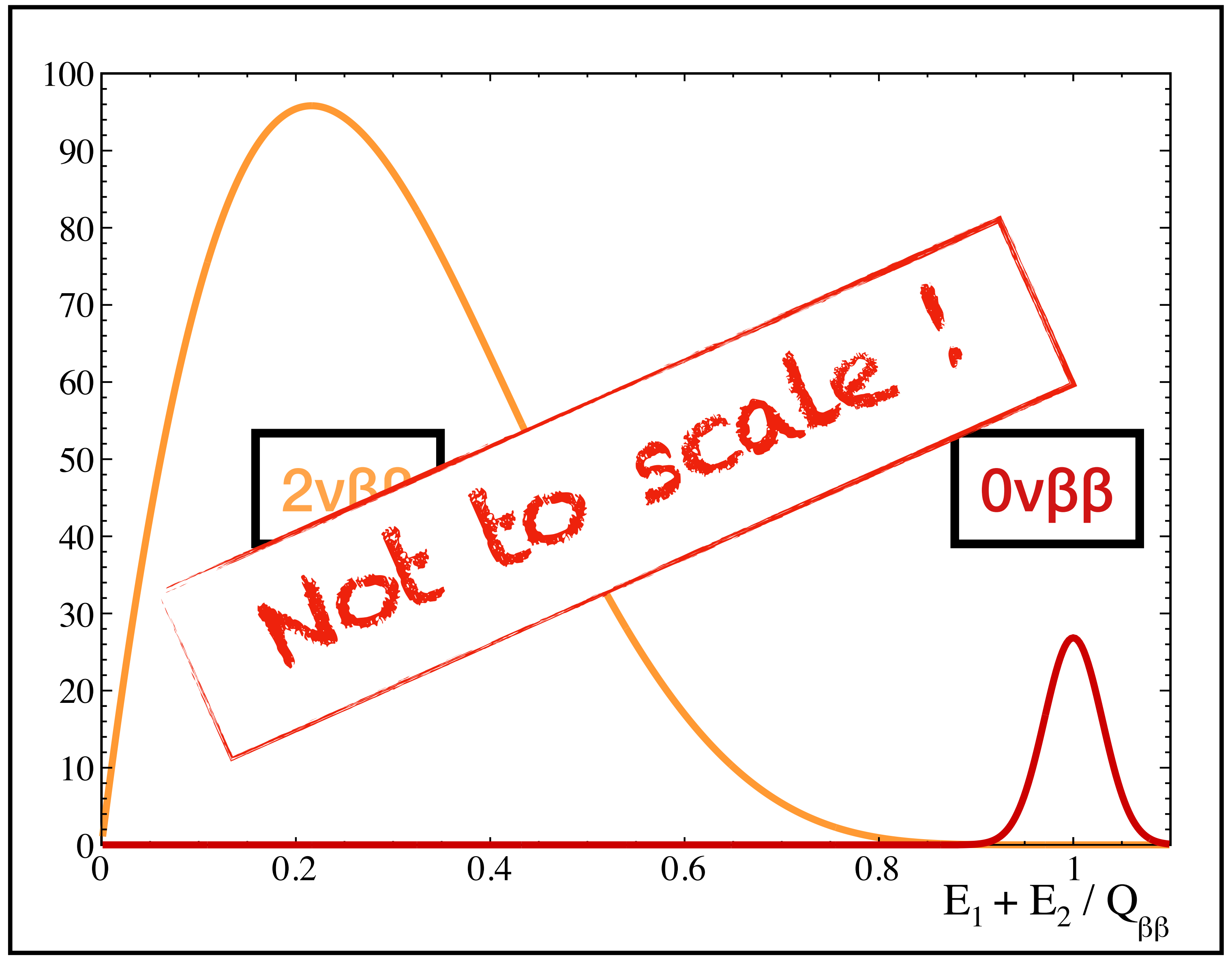


0νββ Observation

- Several isotopes are ββ emitter: ^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{136}Xe, ^{150}Nd
  - $T_{1/2}^{2\nu} \sim 10^{18-21}$ years, $T_{1/2}^{0\nu} > 10^{21-26}$ years.
- This observation could consists in the measurement of a narrow peak at the end of the two electron energy distribution, i.e the $Q_{\beta\beta}$ of the ββ decay.

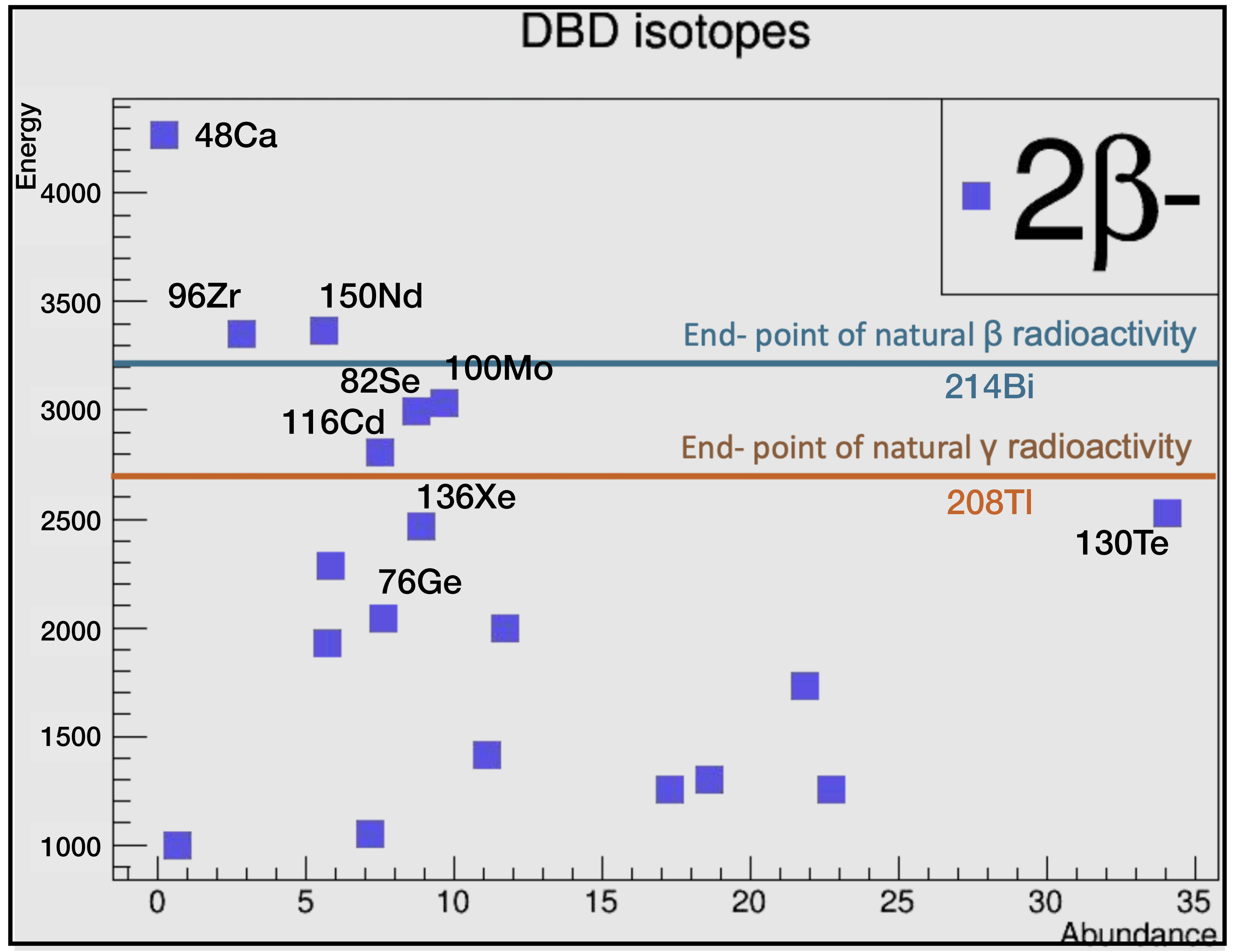


Requirements



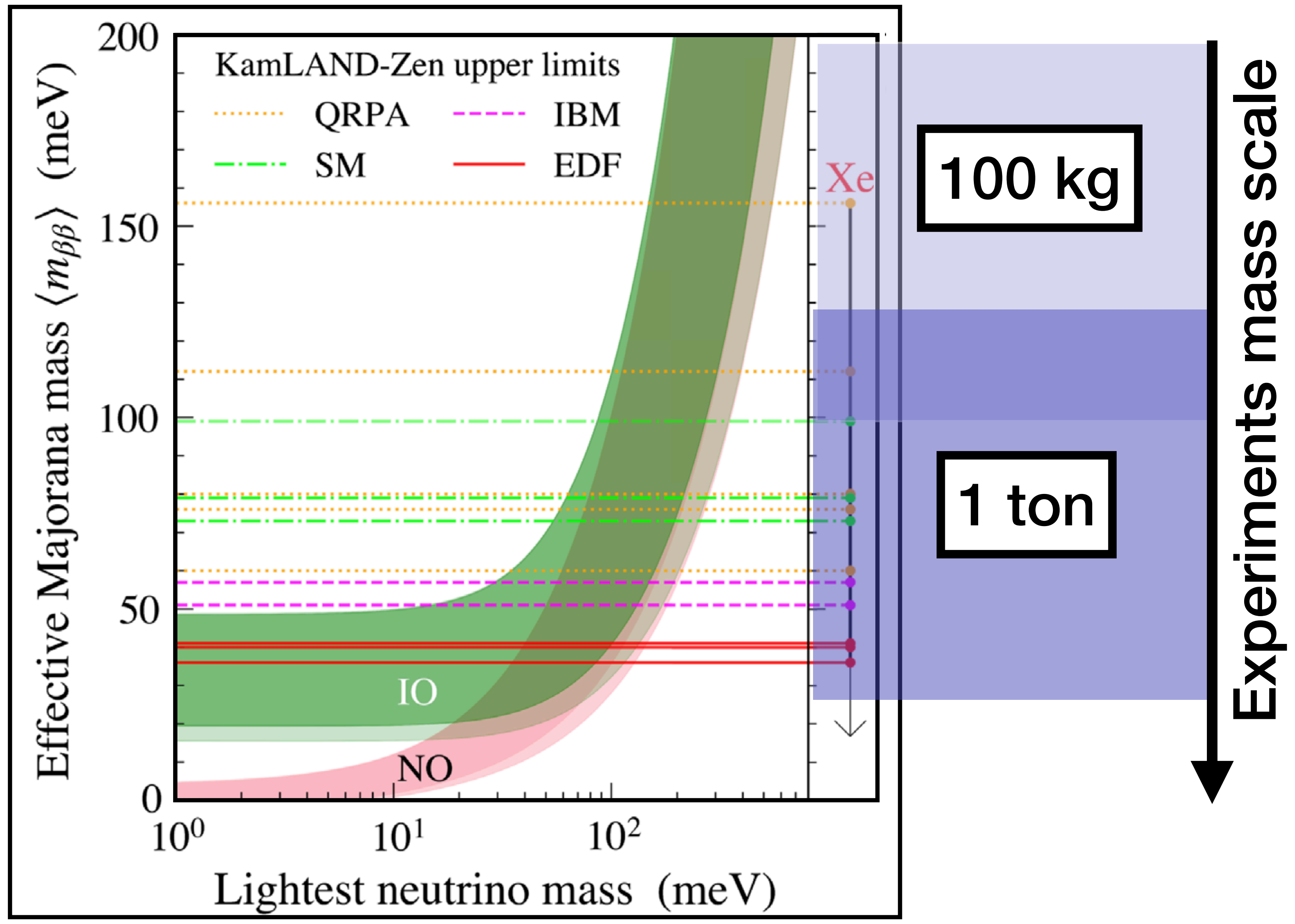
- Excellent energy resolution.
  - Current factor of at least 10^3 years between 2νββ half-life and 0νββ half-life limits.
- Low (zero) background.
  - The region of interest is surrounded by natural radioactivity. Ex: ^{136}Xe $Q_{\beta\beta}$ is 2.458 MeV and ^{208}Tl gamma is at 2.615 MeV or 3.27 MeV β from ^{214}Bi.
- Ton scale experiment.
  - Ton scale experiment is required to fully cover the inverse mass hierarchy region.
  - $$\left(T^{0\nu}_{1/2}\right)^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)\left|M^{0\nu}\right|^2 \left\langle \frac{m_{\beta\beta}}{m_e} \right\rangle^2$$

Requirements



- Excellent energy resolution.
  - Current factor of at least 10^3 years between 2νββ half-life and 0νββ half-life limits.
- Low (zero) background.
  - The region of interest is surrounded by natural radioactivity. Ex: ^{136}Xe $Q_{\beta\beta}$ is 2.458 MeV and ^{208}Tl gamma is at 2.615 MeV or 3.27 MeV β from ^{214}Bi.
- Ton scale experiment.
  - Ton scale experiment is required to fully cover the inverse mass hierarchy region.
  - $$\left(T^{0\nu}_{1/2}\right)^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)\left|M^{0\nu}\right|^2 \left\langle \frac{m_{\beta\beta}}{m_e} \right\rangle^2$$

Requirements



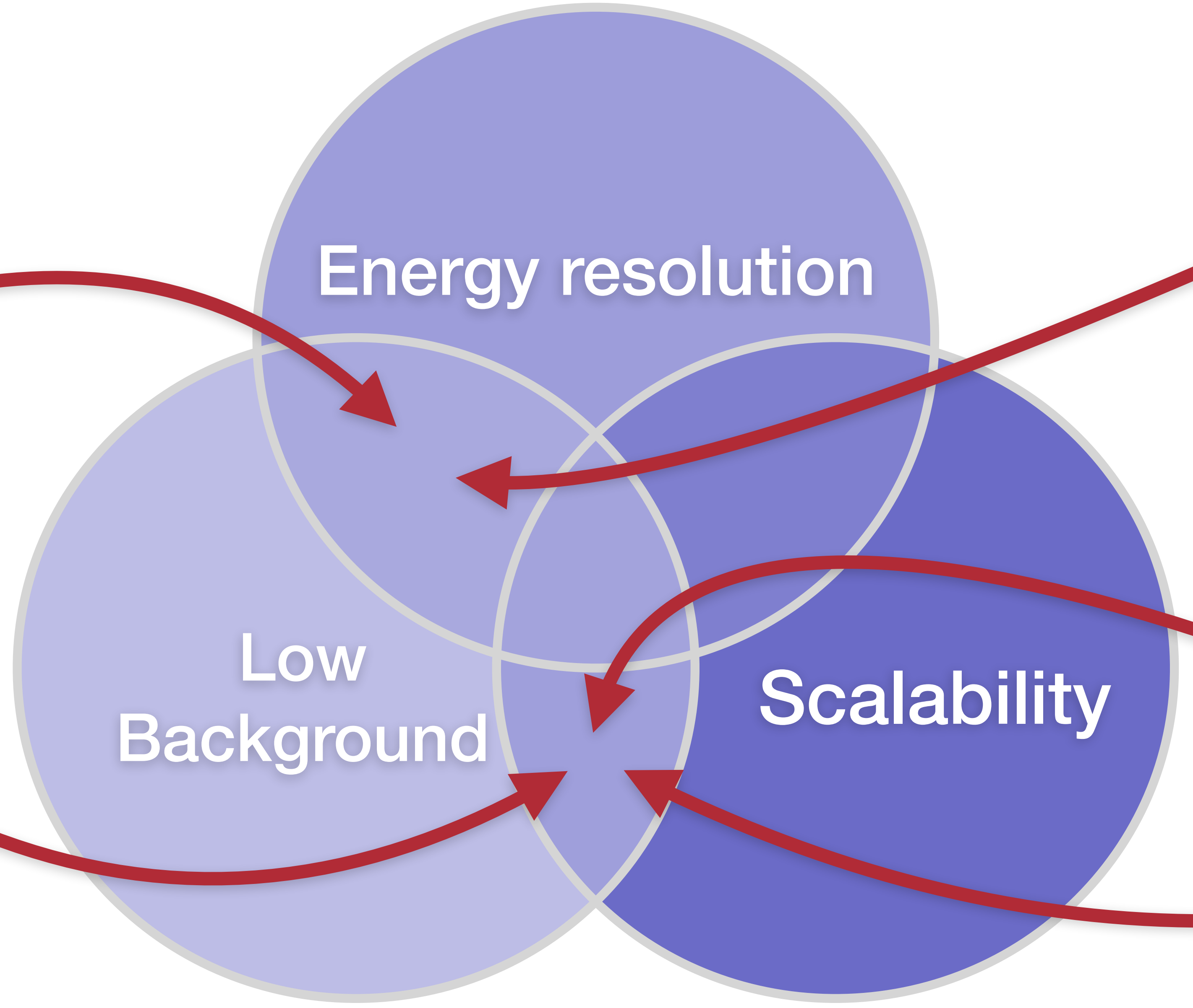
- Excellent energy resolution.
  - Current factor of at least 10^3 years between 2vββ half-life and 0vββ half-life limits.
- Low (zero) background.
  - The region of interest is surrounded by natural radioactivity. Ex: ^{136}Xe $Q_{\beta\beta}$ is 2.458 MeV and ^{208}Tl gamma is at 2.615 MeV or 3.27 MeV β from ^{214}Bi.
- Ton scale experiment.
  - Ton scale experiment is required to fully cover the inverse mass hierarchy region.
  - $$\left(T_{1/2}^{0\nu}\right)^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)\left|M^{0\nu}\right|^2 \left\langle \frac{m_{\beta\beta}}{m_e} \right\rangle^2$$

General Goals

R2D2 is an R&D that explores a single anode HP-TPC[1] solution for ^{136}Xe $0\nu\beta\beta$ search.

R2D2 Goals and features:

- 1% FWHM at ^{136}Xe $Q_{\beta\beta}$ of 2.458 MeV.
- Low material budget.
- Low detection Threshold.
- One readout channel.
- Simple geometry.



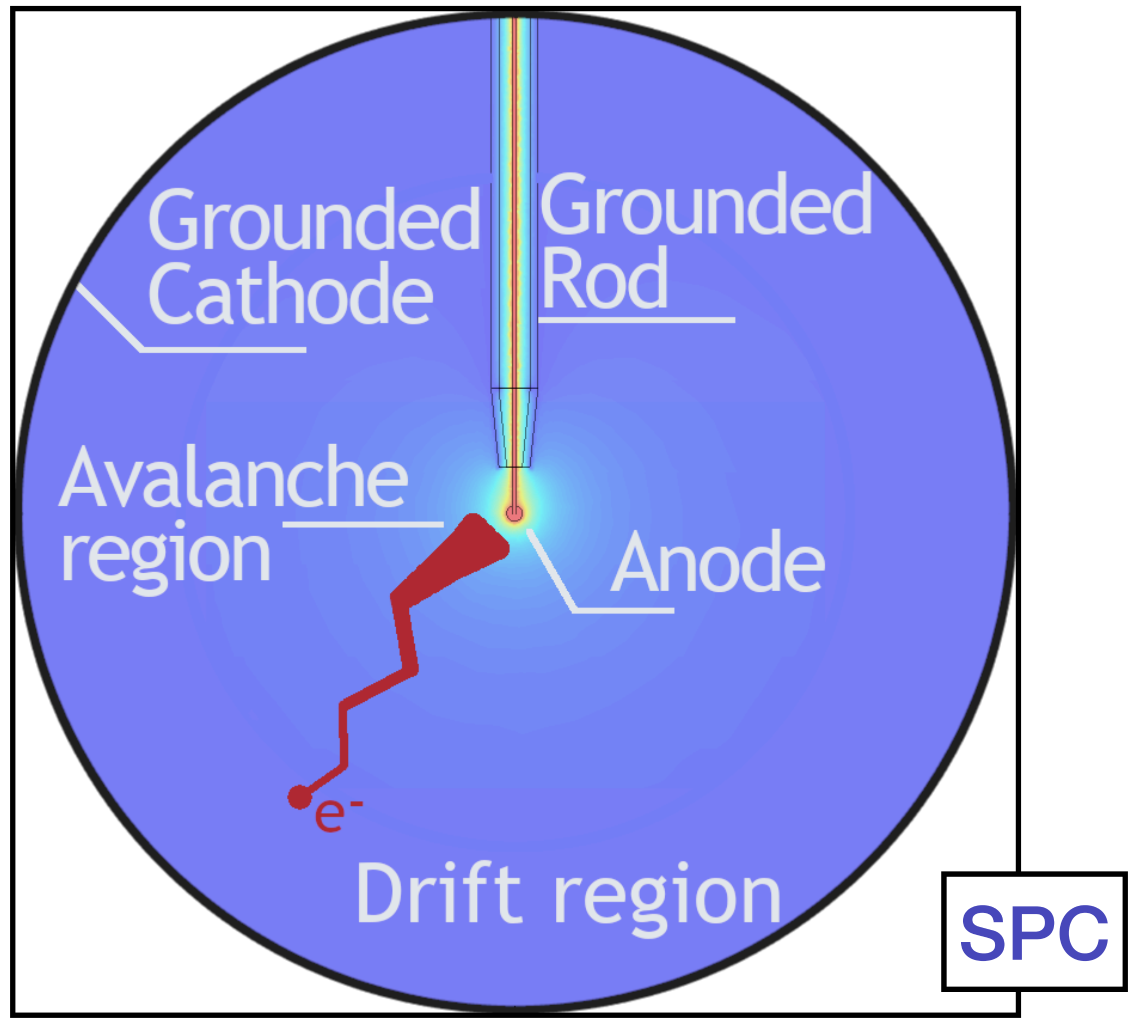
^{136}Xe assets:

- $T^{2\nu}_{1/2} = 2.16 \pm .02 \cdot 10^{21}$ years.
- $T^{0\nu}_{1/2} > 2.30 \pm .02 \cdot 10^{26}$ years.
- One of the most abundant (8.86 %) and easiest to enrich.

>10^5 years !

[1] HP-TPC: High Pressure Time Projection Chamber

Detectors

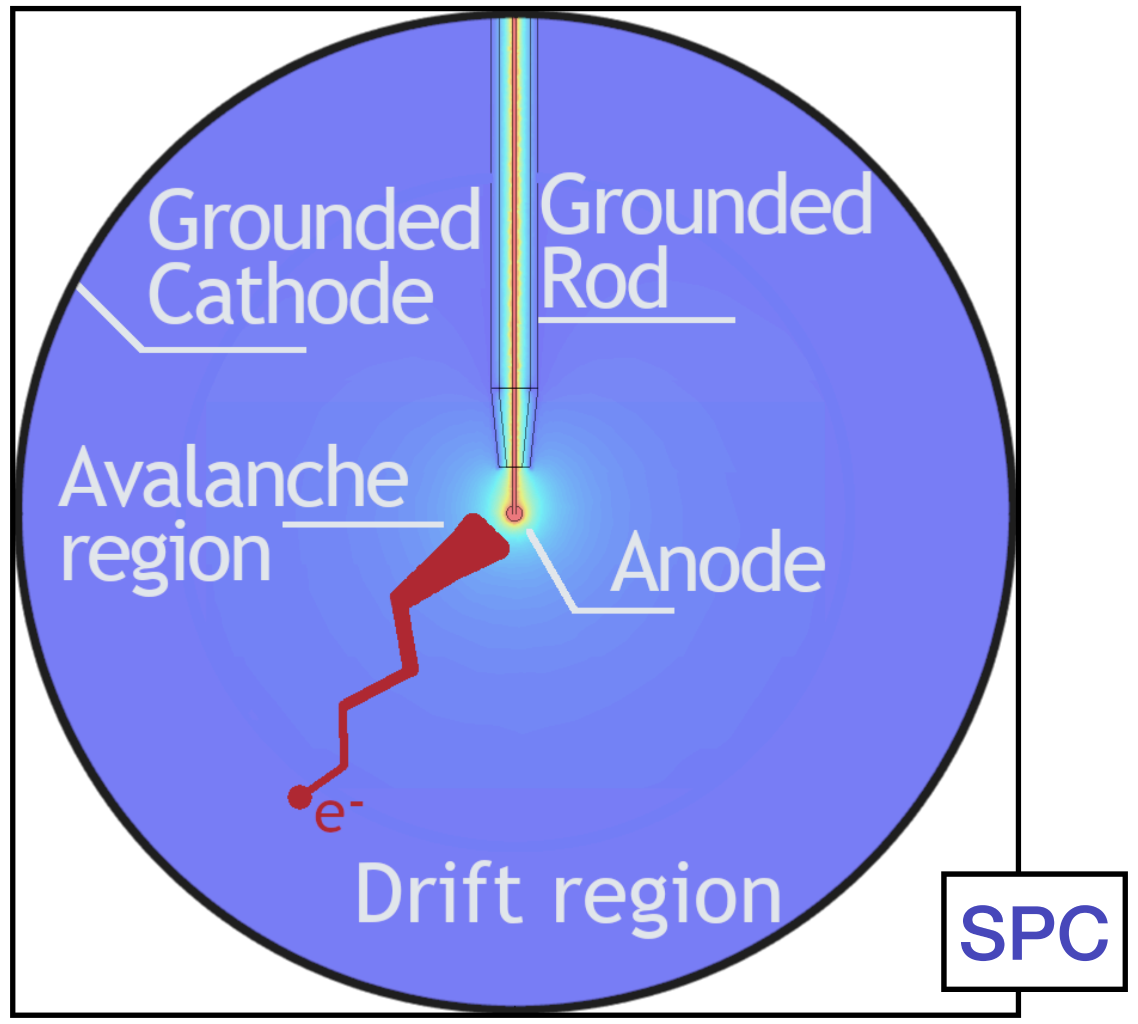


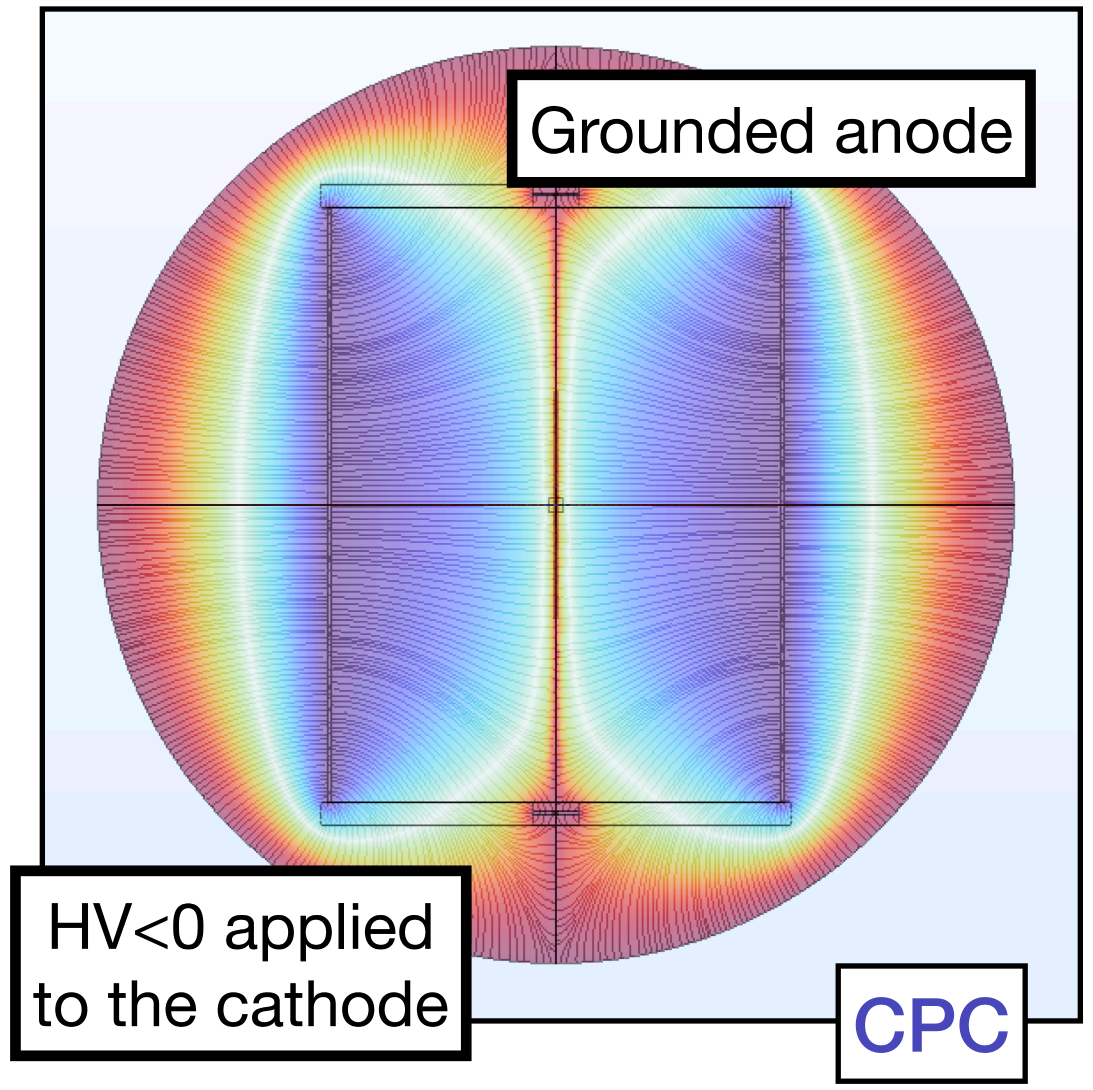
Design based on dark matter experiment

The R&D is currently considering two detectors options:

- Spherical Proportional Counter (SPC):
  - A grounded spherical cathode with a positively bias central anode readout.
  - Both signal and tension go through the anode.
  - Electric Field: $\propto \frac{1}{r^2}$

Detectors





The R&D is currently considering two detectors options:

- Spherical Proportional Counter (SPC):
  - A grounded spherical cathode with a positively bias central anode readout.
  - Both signal and tension go through the anode.
  - Electric Field: $\propto \frac{1}{r^2}$
- Cylindrical Proportional Counter (CPC):
  - A grounded central anode readout and a negatively bias cylindrical cathode.
  - Signal is read through the anode and discoupled from tension applied to the cathode.
  - Electric Field: $\propto \frac{1}{r}$

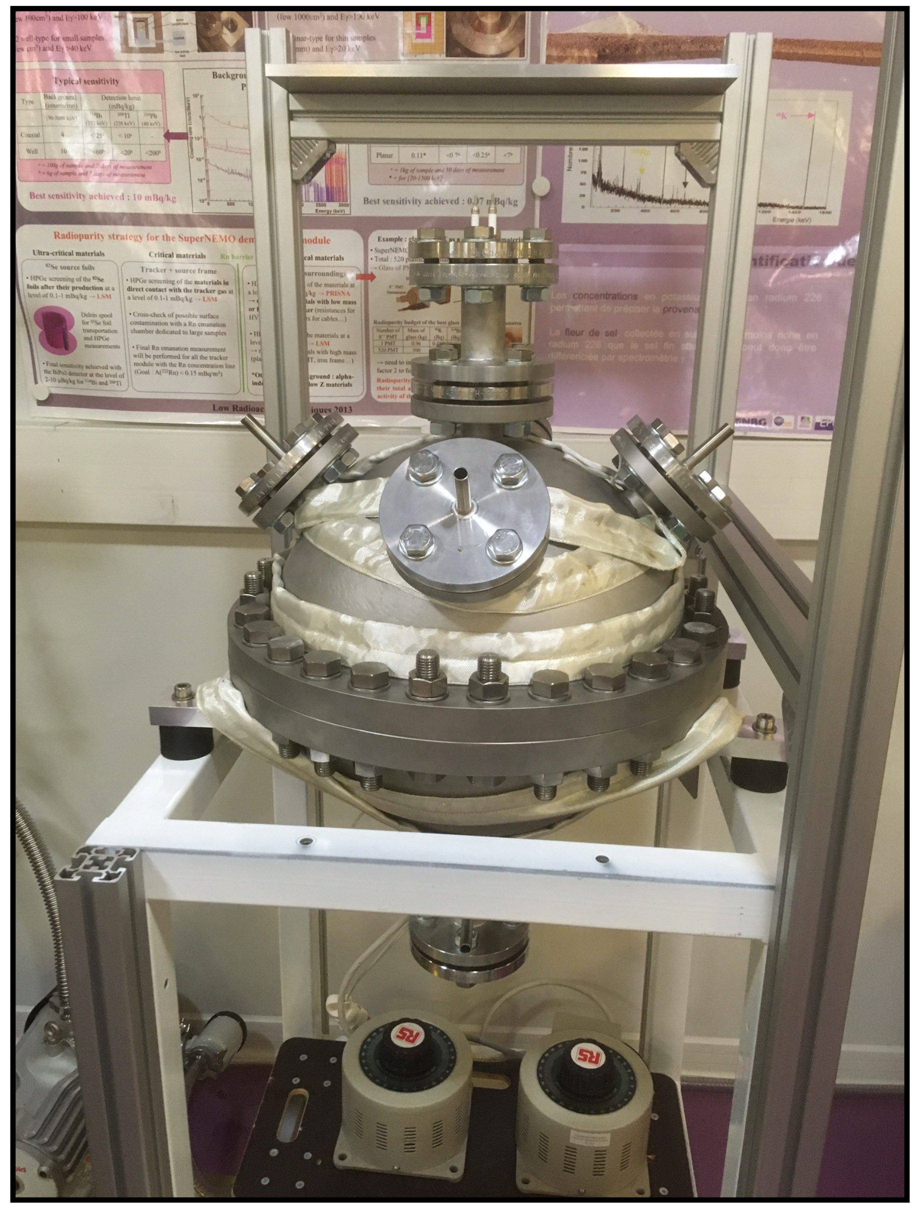
Current R&D Experimentations

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

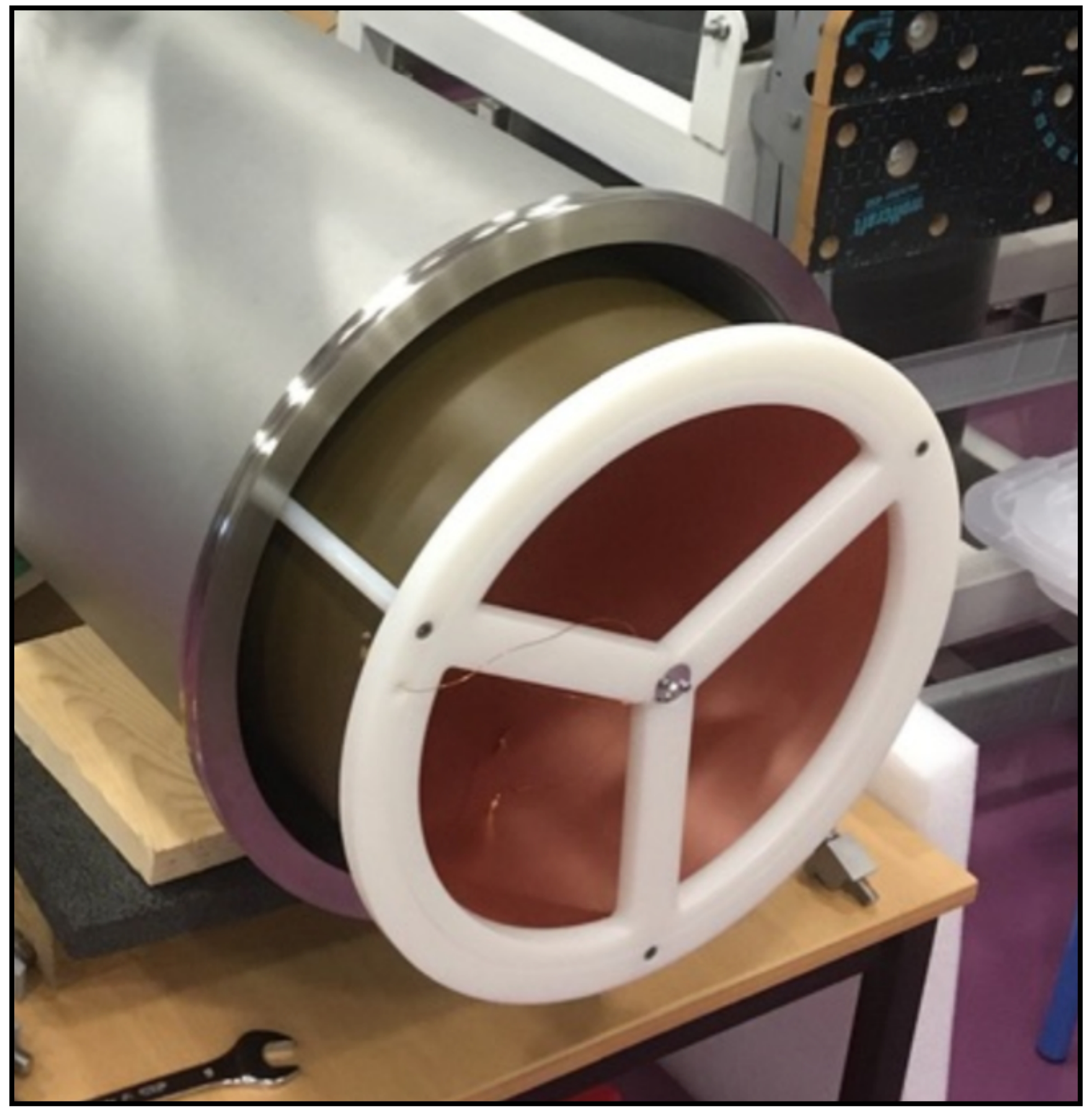
- Radioactive sources: α from ^{210}Po and ^{222}Rn.
- Point-like events response: ^{210}Po is fixed, and ^{222}Rn is scattered over the cathode.
- Gas types: Argon and Xenon.
- Gas purity development.
- Gas recirculation and recovery.
- Sensor characterisation and improvement.
- Exploring ionisation and proportional mode.
- Electronics and data acquisition.
- Signal processing development.
- …

Prototype Setup Evolution At LP2I Bordeaux

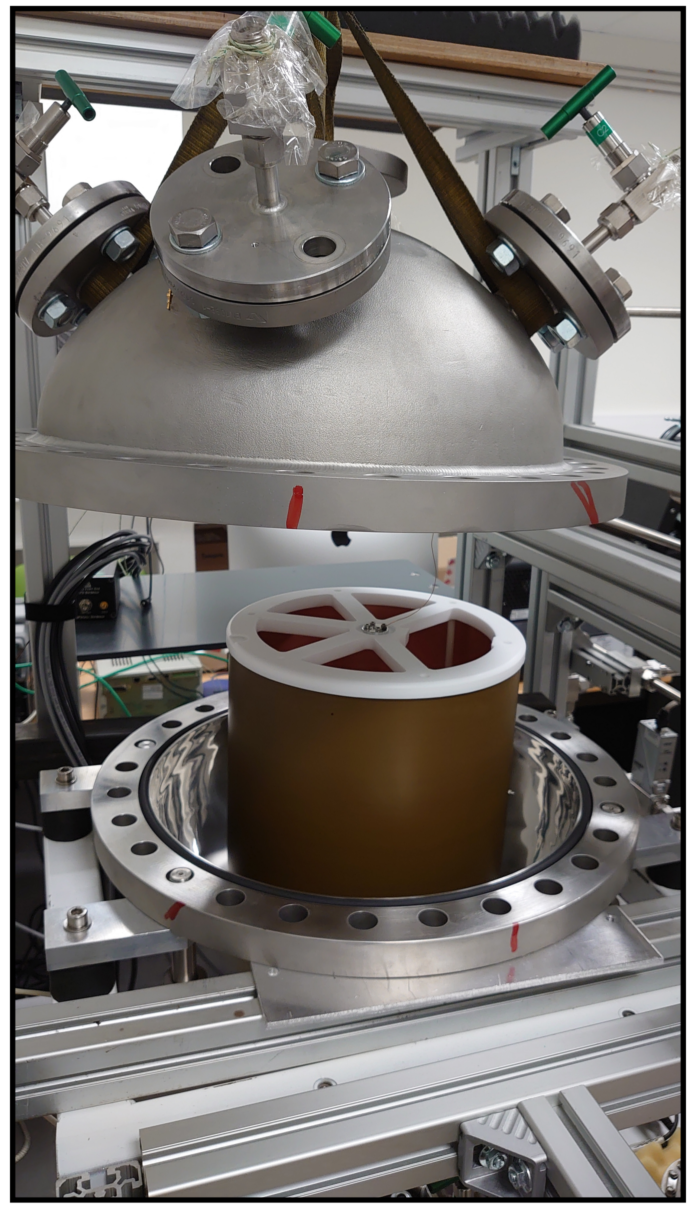
SPC-1 (2018)
40 cm ⌀
Up to 1 bar[1]



SPC-2 (2021)
40 cm ⌀
Up to 40 bar[2]



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



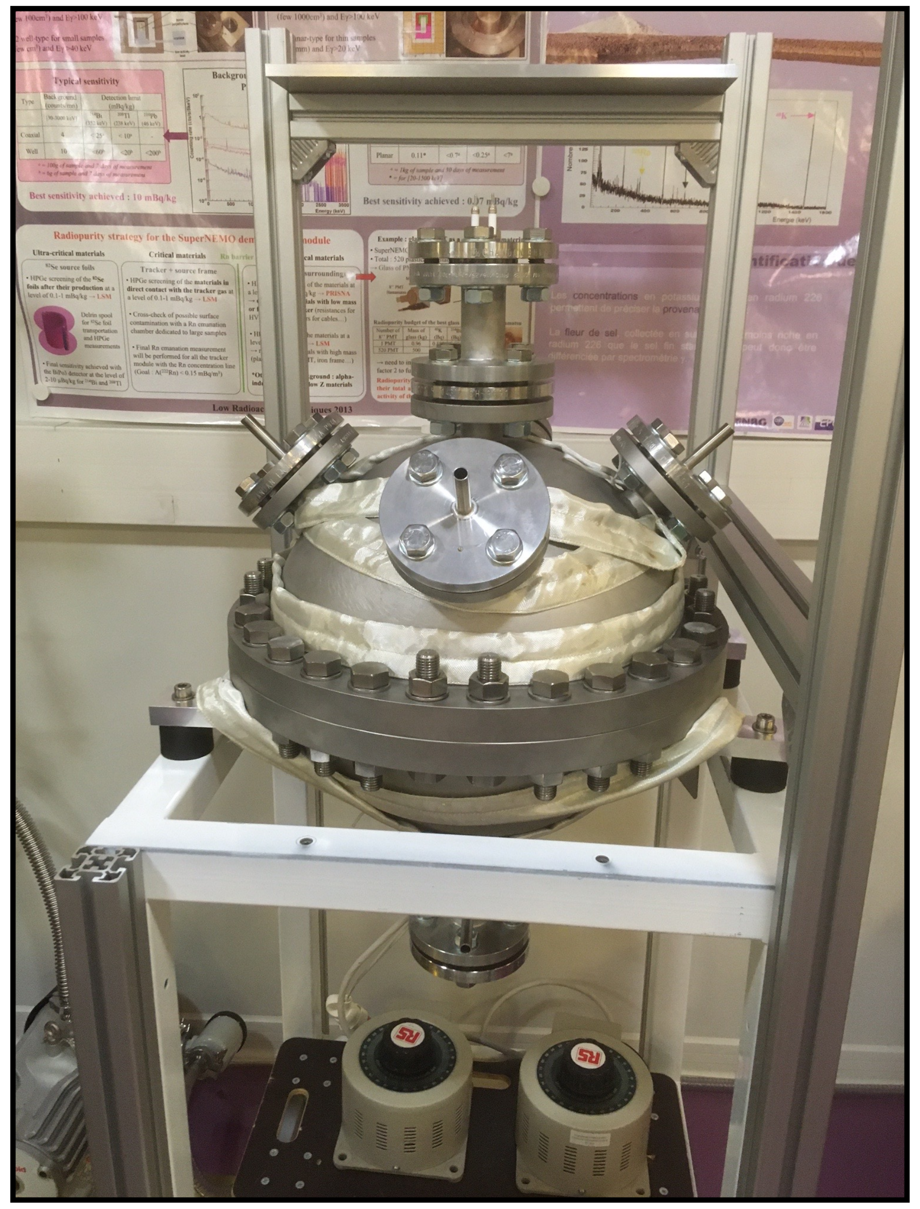
CPC-2 (2023)
27cm x 20 cm ⌀
Up to 40 bar[2]

[1] No Pressure certification
[2] Pressure certified

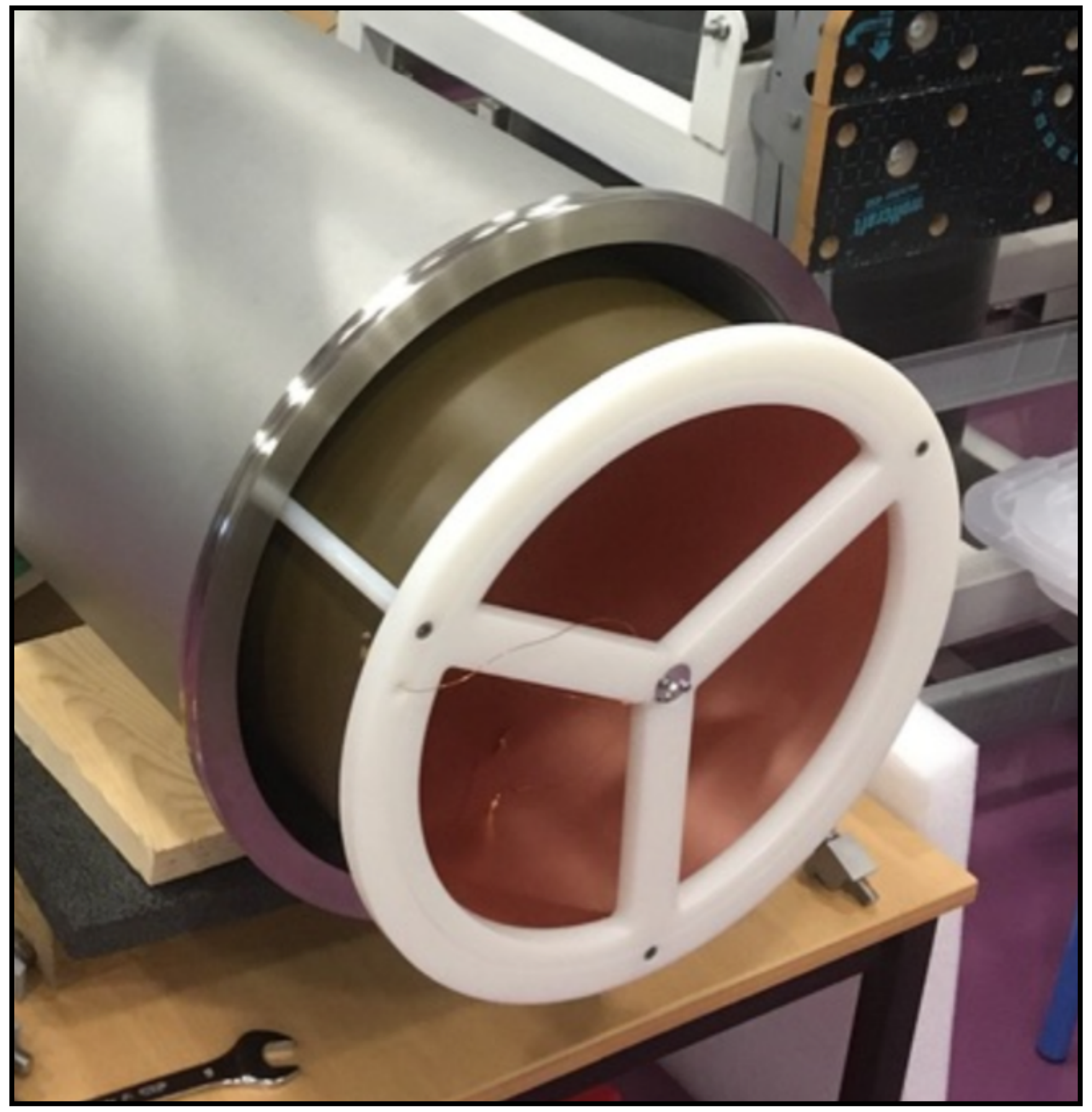
CPC Made at Subatech

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]



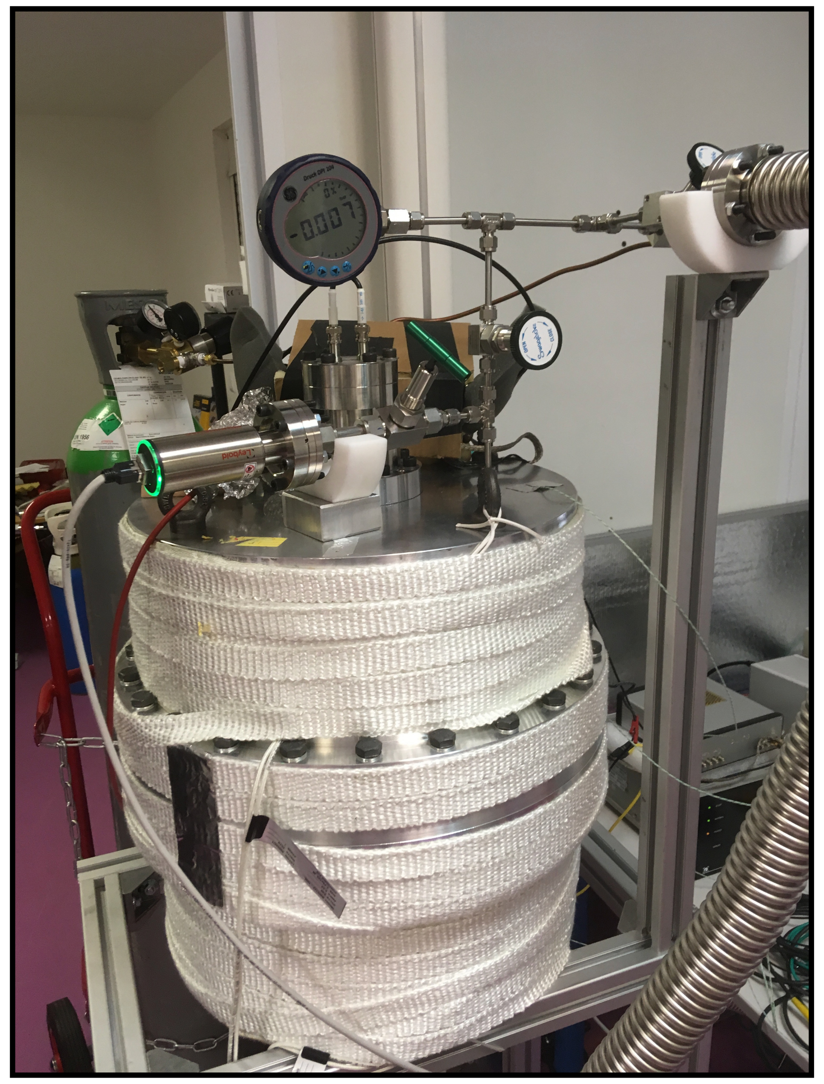
CPC-1 (2022)
1m x 37 cm ⌀
Up to 1 bar[1]

CPC-2.5 (2023)
27cm x 20 cm ⌀
Up to 40 bar[2]

CPC Made at Subatech

1 No Pressure certification
2 Pressure certified

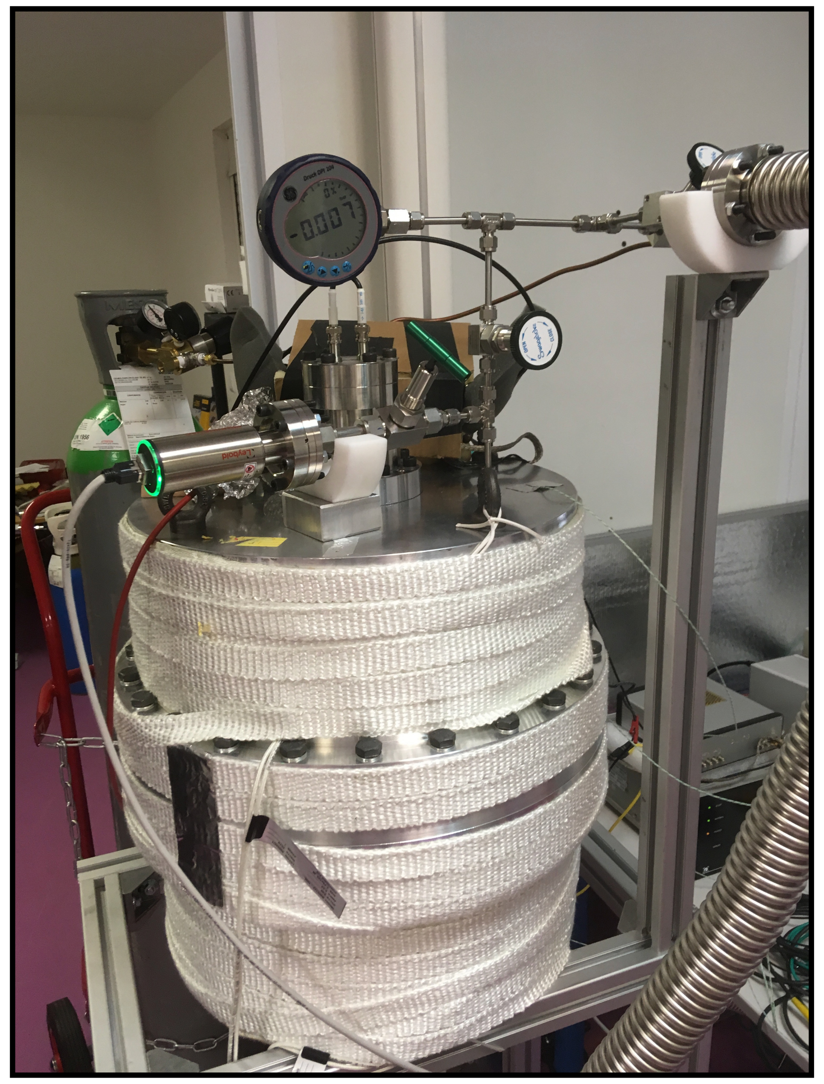
1st SPC Prototype

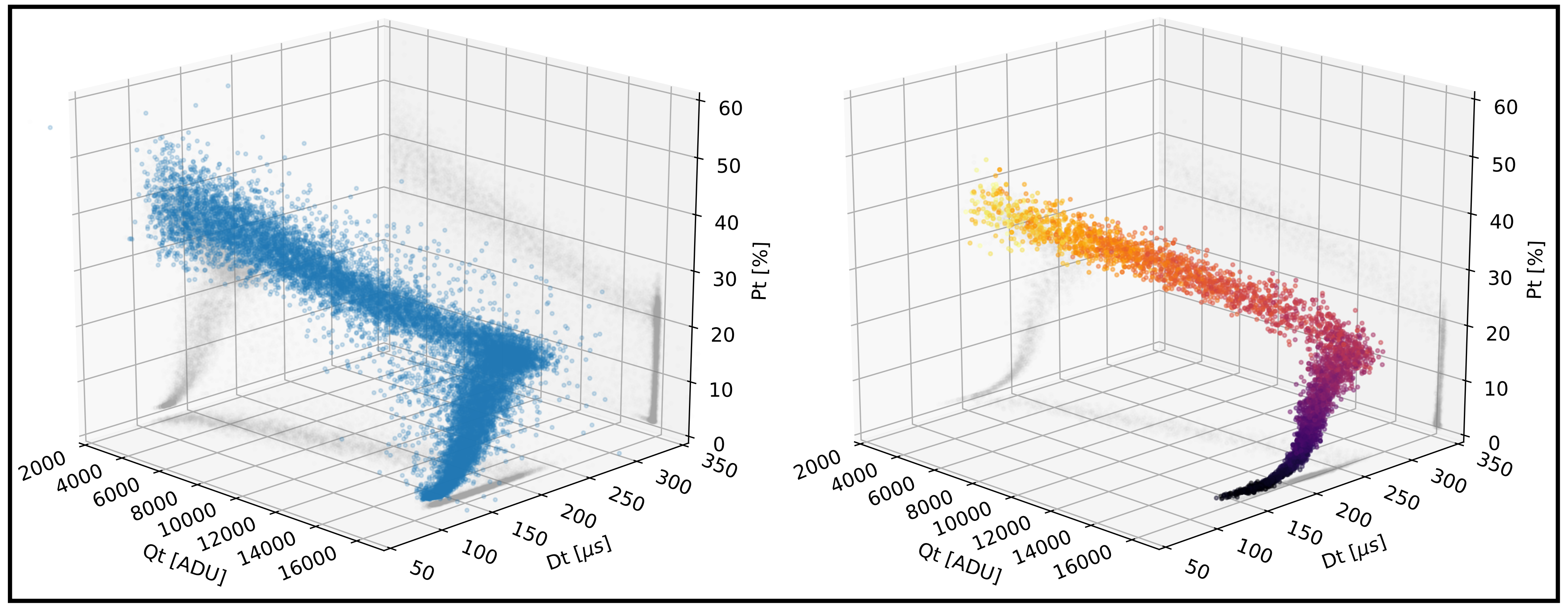


- In 2018 the R2D2 was funded as R&D by the IN2P3: 1st SCP prototype was built.
- A 20 cm radius sphere made of Aluminium (i.e. no low background but much cheaper) was built at LP2IB and a custom made low noise electronics (OWEN project) was developed.
- The detector was commissioned and was operated with ArP2 at LP2IB at pressures up to 1.1 bar. First resolution and localisation in proportional mode results were published[1].

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

1st SPC Prototype



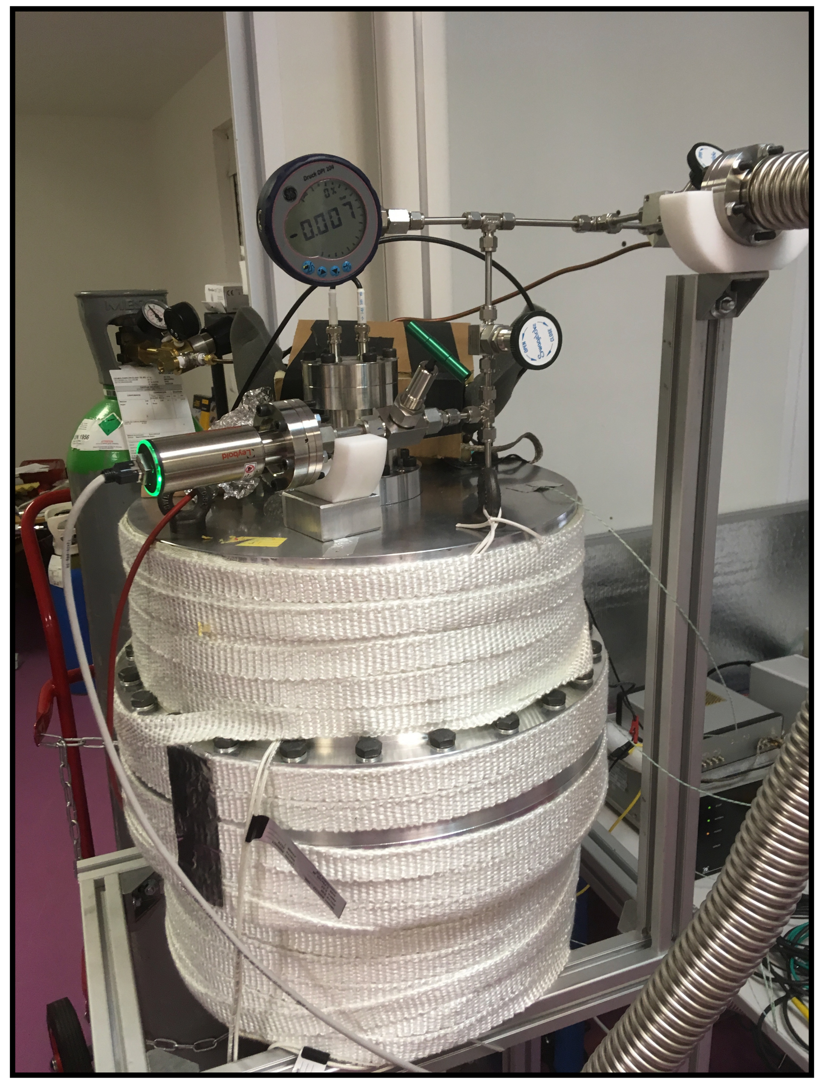


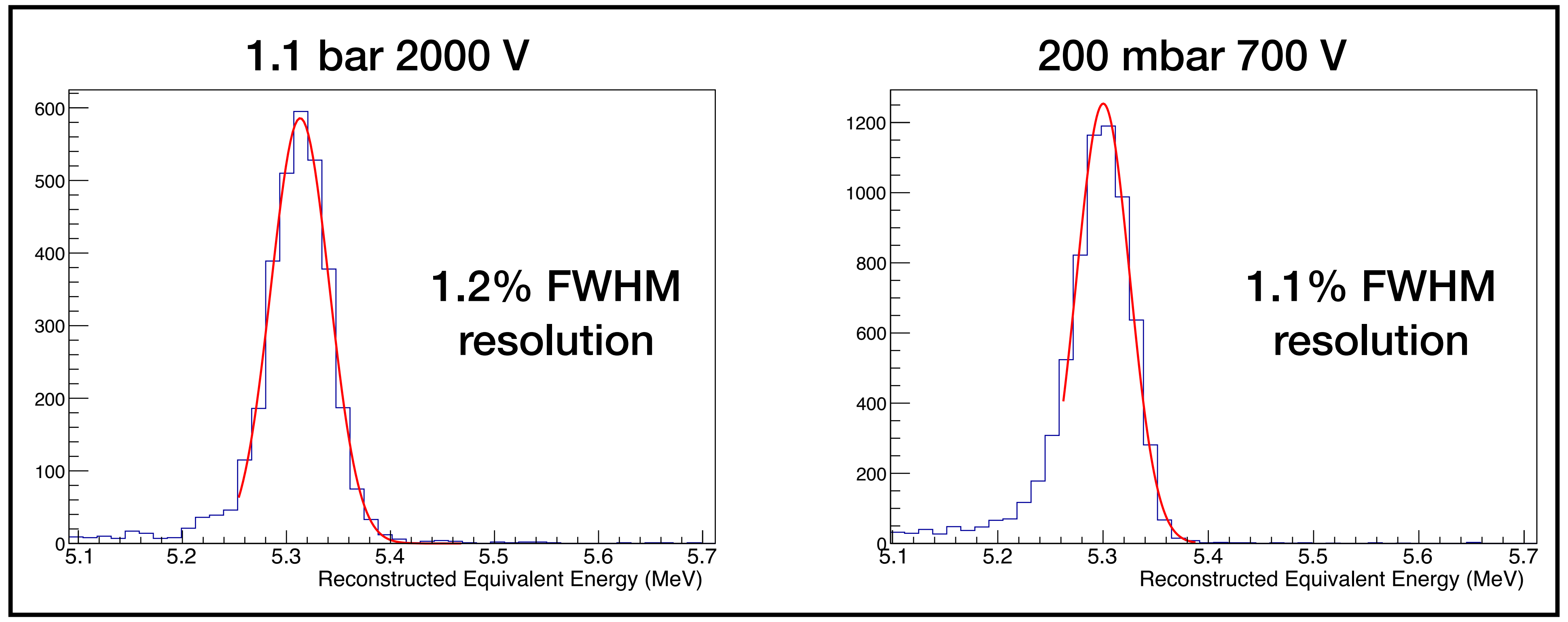
Proportional mode

- In 2018 the R2D2 was funded as R&D by the IN2P3: 1st SCP prototype was built.
- A 20 cm radius sphere made of Aluminium (i.e. no low background but much cheaper) was built at LP2IB and a custom made low noise electronics (OWEN project) was developed.
- The detector was commissioned and was operated with ArP2 at LP2IB at pressures up to 1.1 bar. First resolution and localisation in proportional mode results were published[1].
- A detailed simulation has confirmed our detector understanding: the agreement between data and simulation is very good and the detector behaviour is well understood.

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

1st SPC Prototype



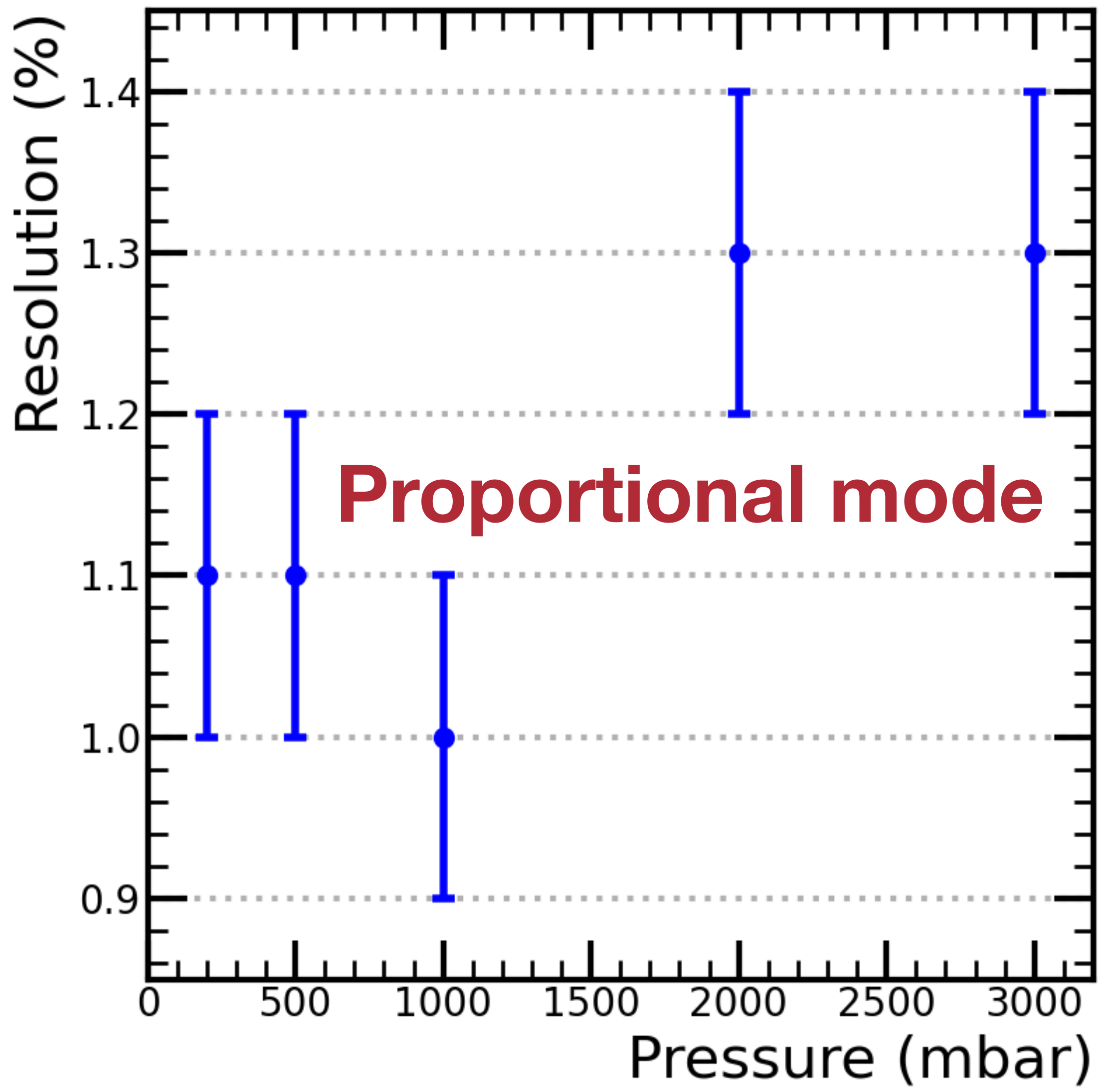


Proportional mode

- In 2018 the R2D2 was funded as R&D by the IN2P3: 1st SCP prototype was built.
- A 20 cm radius sphere made of Aluminium (i.e. no low background but much cheaper) was built at LP2IB and a custom made low noise electronics (OWEN project) was developed.
- The detector was commissioned and was operated with ArP2 at LP2IB at pressures up to 1.1 bar. First resolution and localisation in proportional mode results were published[1].
- A detailed simulation has confirmed our detector understanding: the agreement between data and simulation is very good and the detector behaviour is well understood.
- The resolution was computed at 200 mbar and 1.1 bar in proportional mode: we obtained a similar resolution showing no impact due to the length of the tracks (from 3-4 cm at 1.1 bar to 15-20 cm at 200 mbar).

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

2nd SPC Prototype

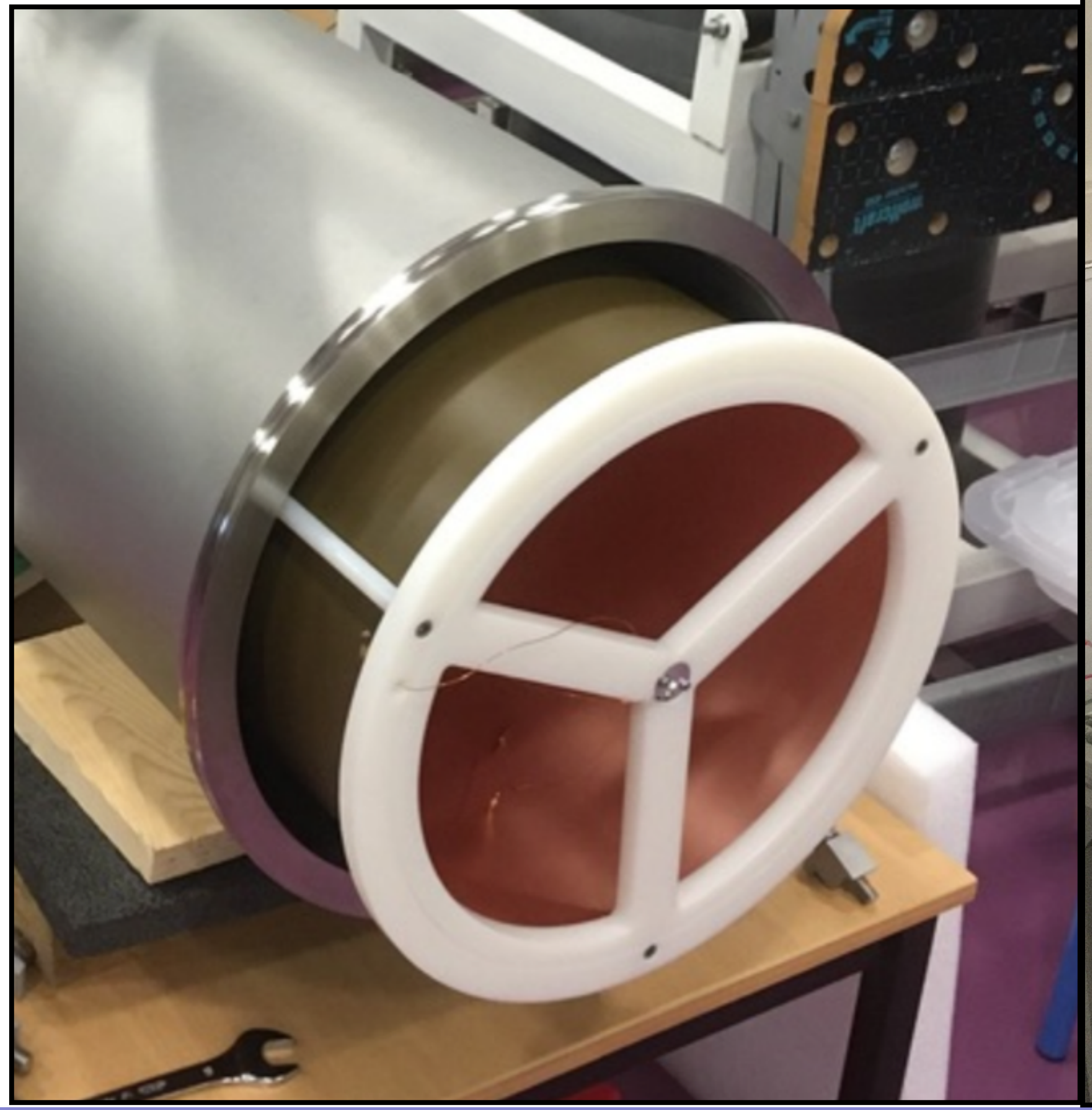


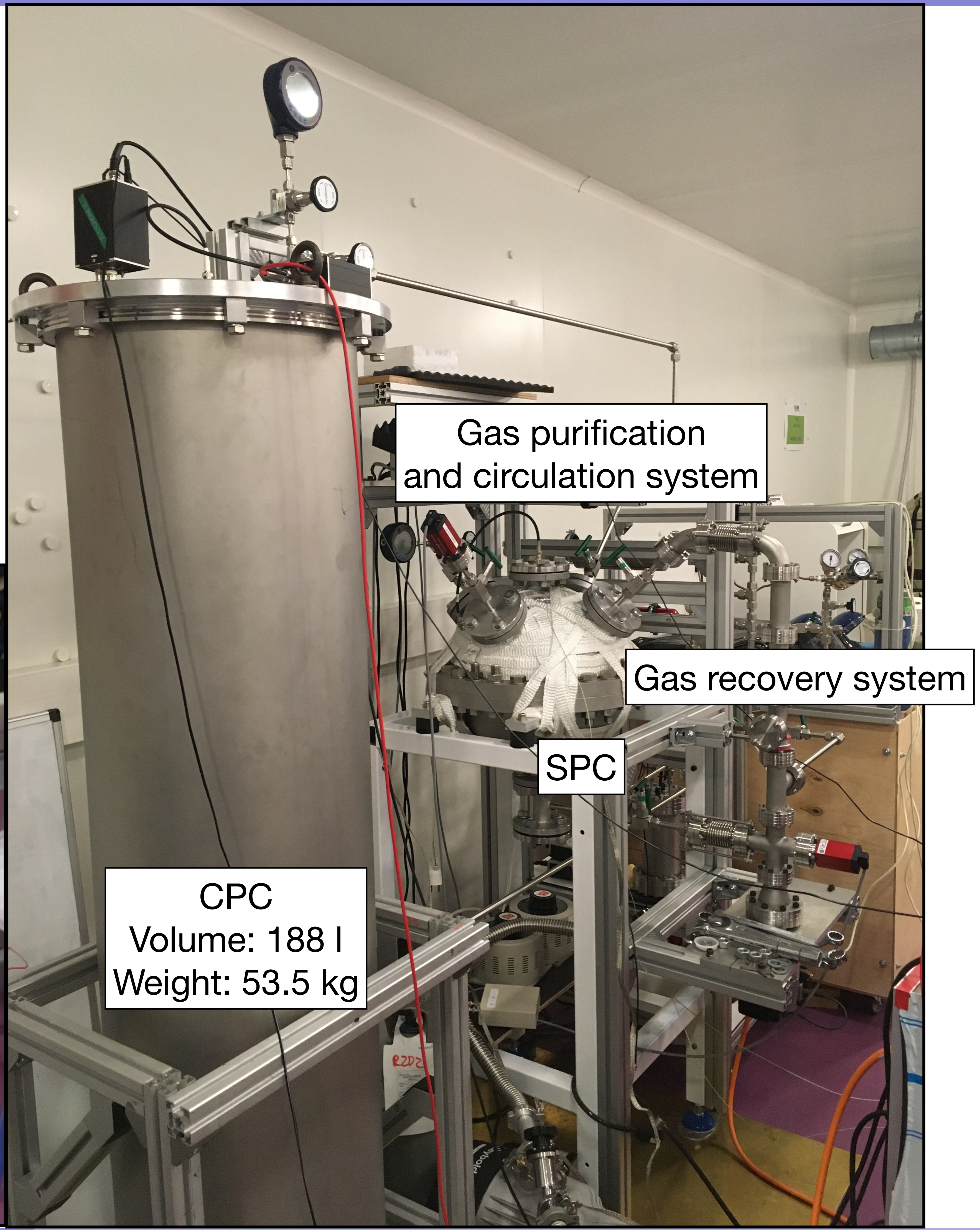
- In 2021 the second SPC prototype, certified to be operated up to 40 bar, was built by an external company.
- In the meantime the xenon recirculation and recuperation system was finalized and commissioned.
- In 2022 the detector was operated with ArP2 with pressures up to 3 bar. A set of measurement was carried out with a resolution below 1.4% up to 3 bar.

1st CPC Prototype

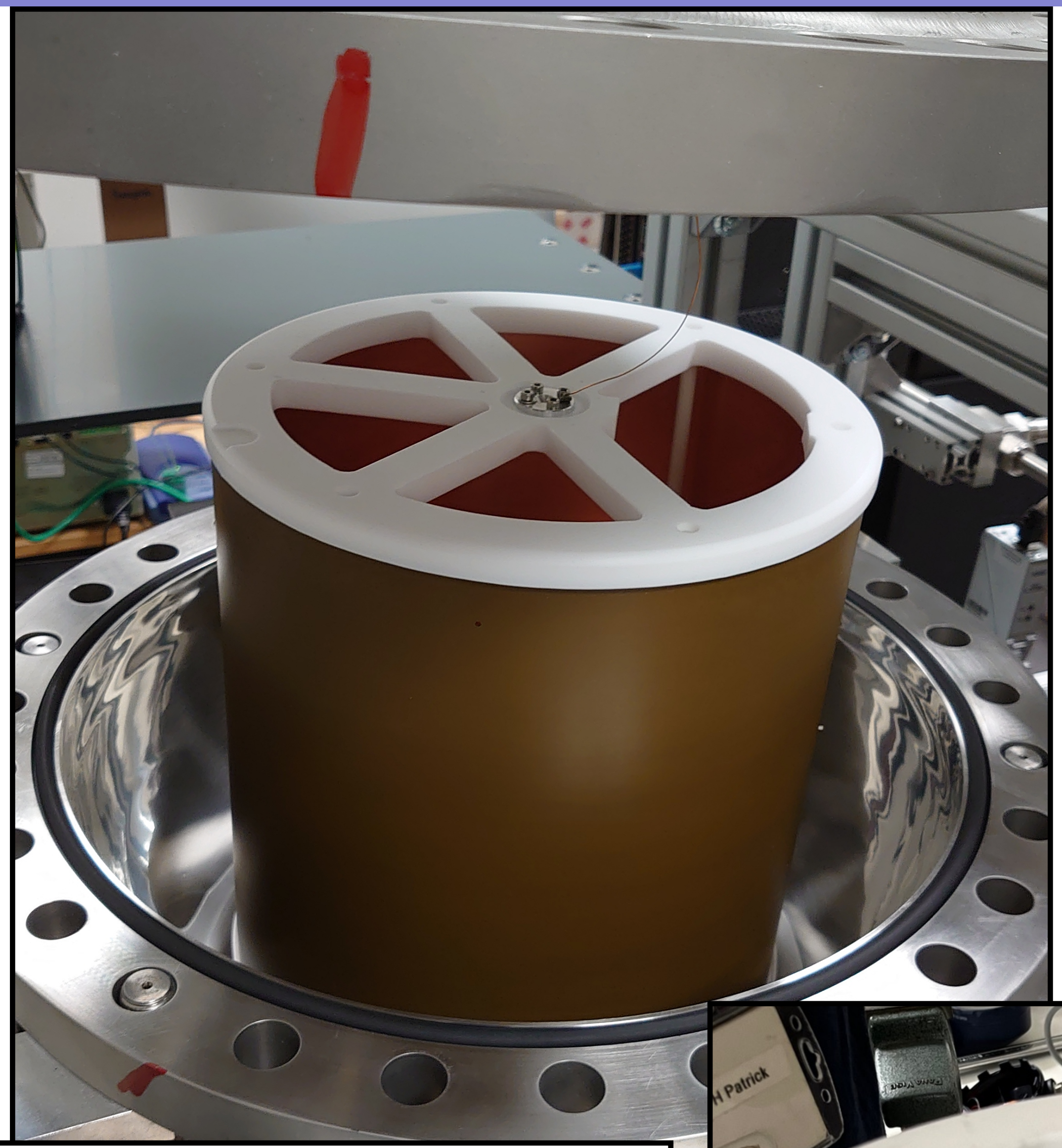
May 2022, new CPC detector is installed.First validation in ArP2 showed a resolution comparable with SPC, 1.2% at 1 bar in proportional mode but at lower voltage.

- Inox Tube: 1m50 x 40cm ø.
- Copper cathode: 1m x 35 cm ø.
- Tungsten anode: 50 µm ø.
- ^{210}Po source.





2nd CPC Prototype

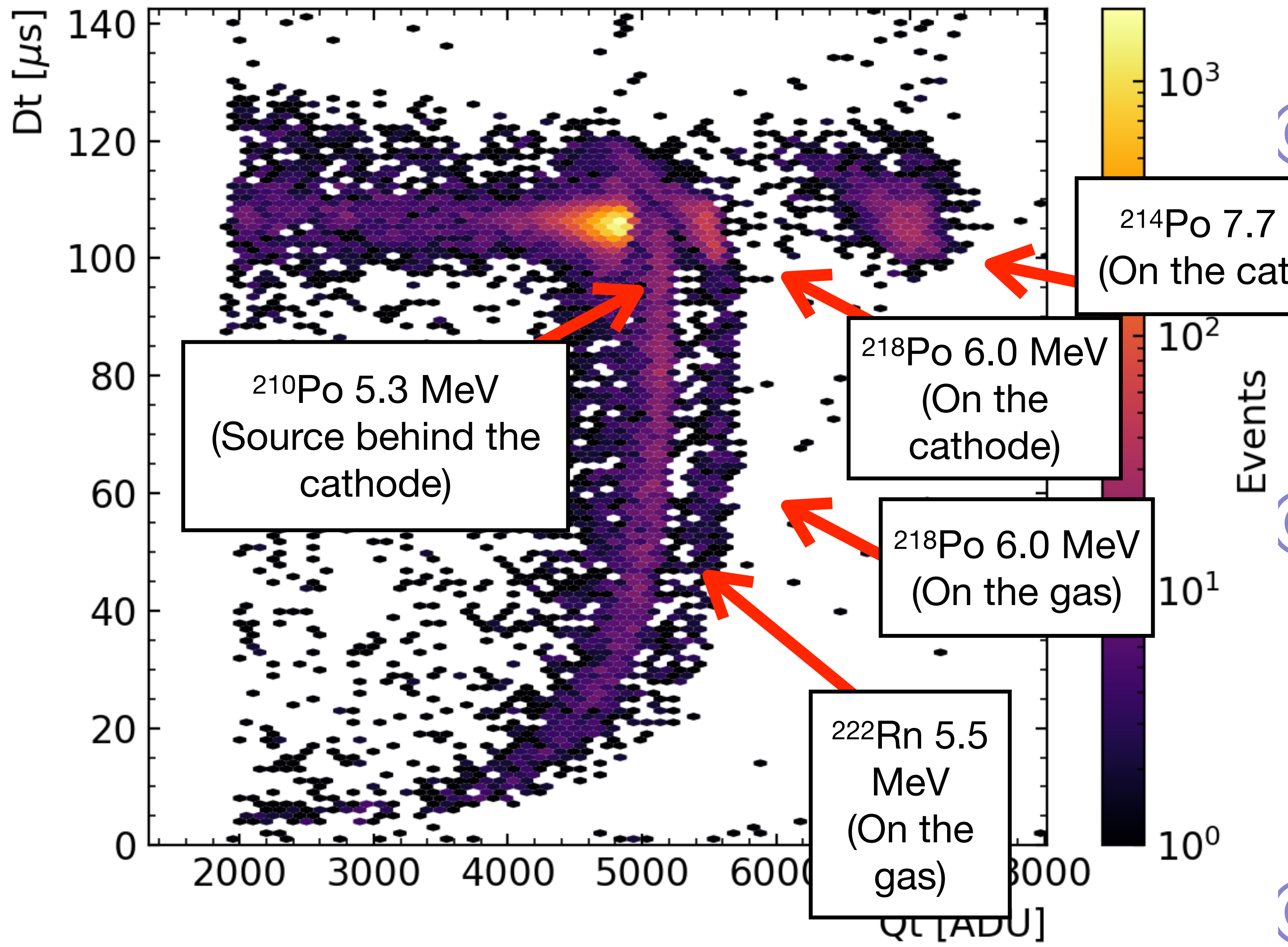


CPC 2.0 - Wire - 50µm⌀

CPC 2.5 - Rod - 1.2mm⌀

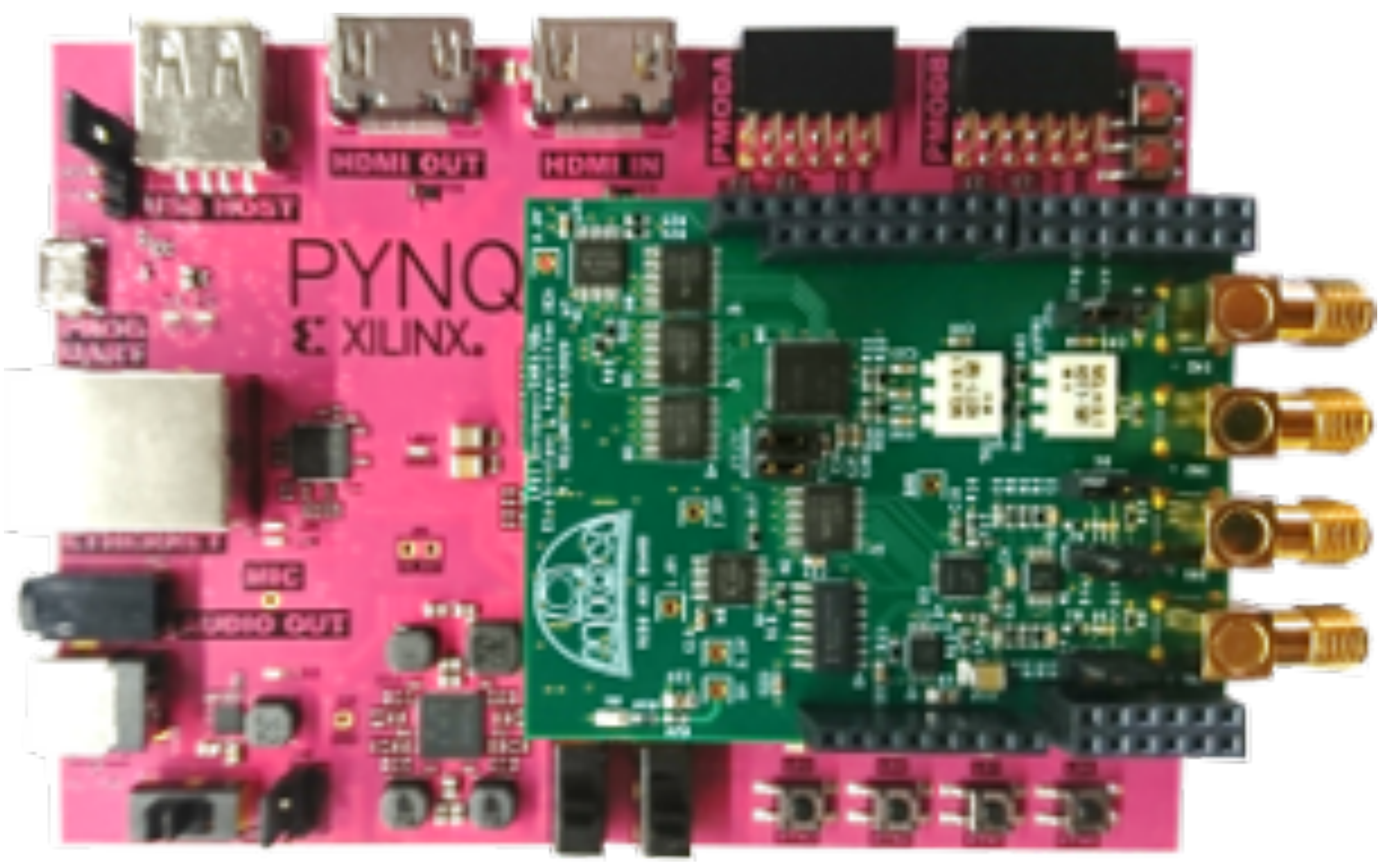
- Early 2023 the second prototype for CPC was conceived and built at Subatech.
- The CPC is designed to be operated inside the sphere (SPC 2nd prototype) in order to test the detector at high pressure.
- First test in Ar showed a good behavior of the CPC up to 10 bars in ionisation mode. Tests in xenon were carried out up to 6 bars in ionisation mode as well.
- The technical limits of the current purification (hot getter: 10 bar max) and recovery (gas recovery bottle) setup has been reached.

2nd CPC Prototype



- Early 2023 the second prototype for CPC was conceived and built at Subatech.
- The CPC is designed to be operated inside the sphere (SPC 2nd prototype) in order to test the detector at high pressure.
- First test in Ar showed a good behavior of the CPC up to 10 bars in ionisation mode. Tests in xenon were carried out up to 6 bars in ionisation mode as well.
- The technical limits of the current purification (hot getter: 10 bar max) and recovery (gas recovery bottle) setup has been reached.

Electronics and DAQ



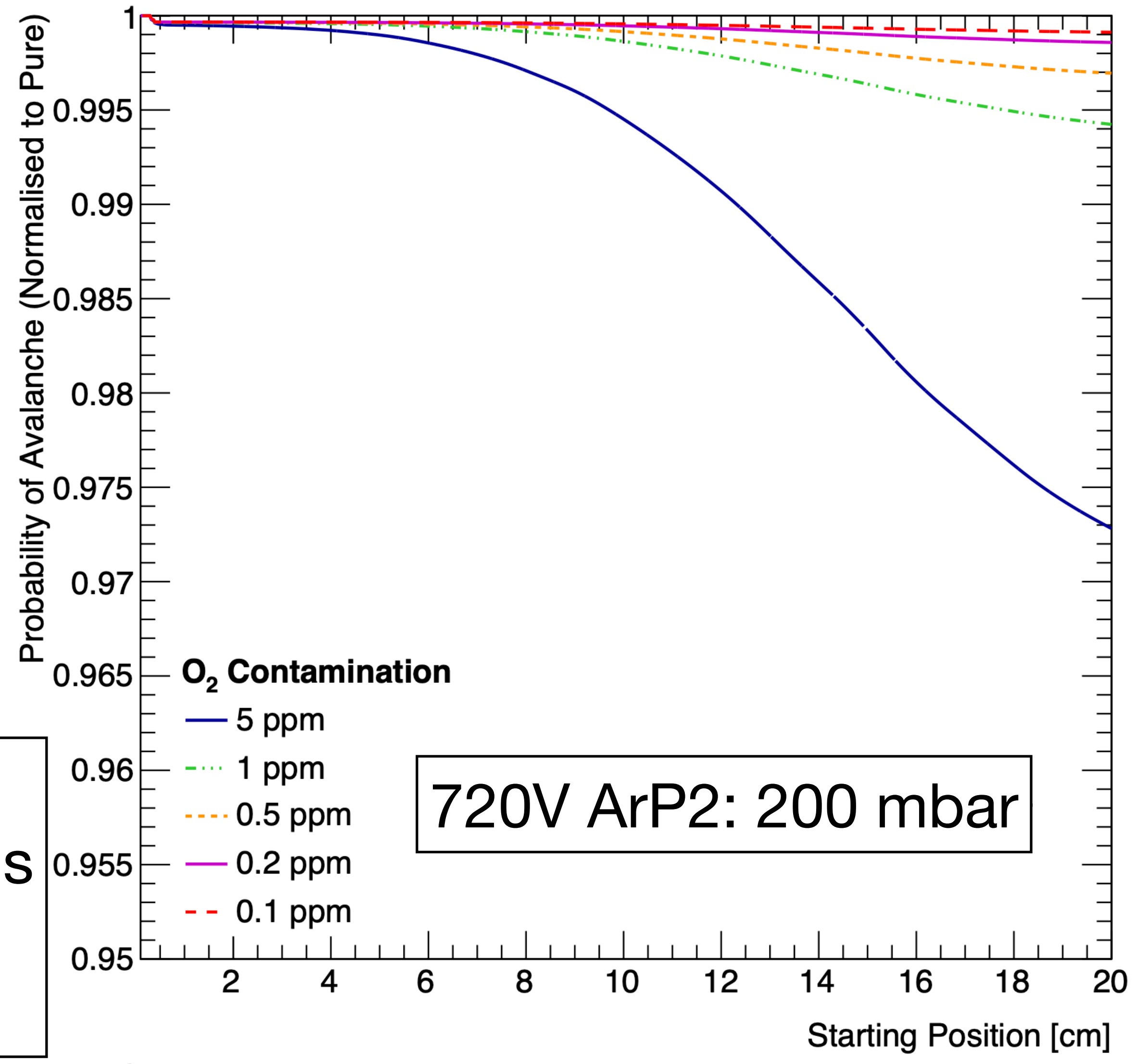
WEN
Optimal Waveform recognition Electronic Node

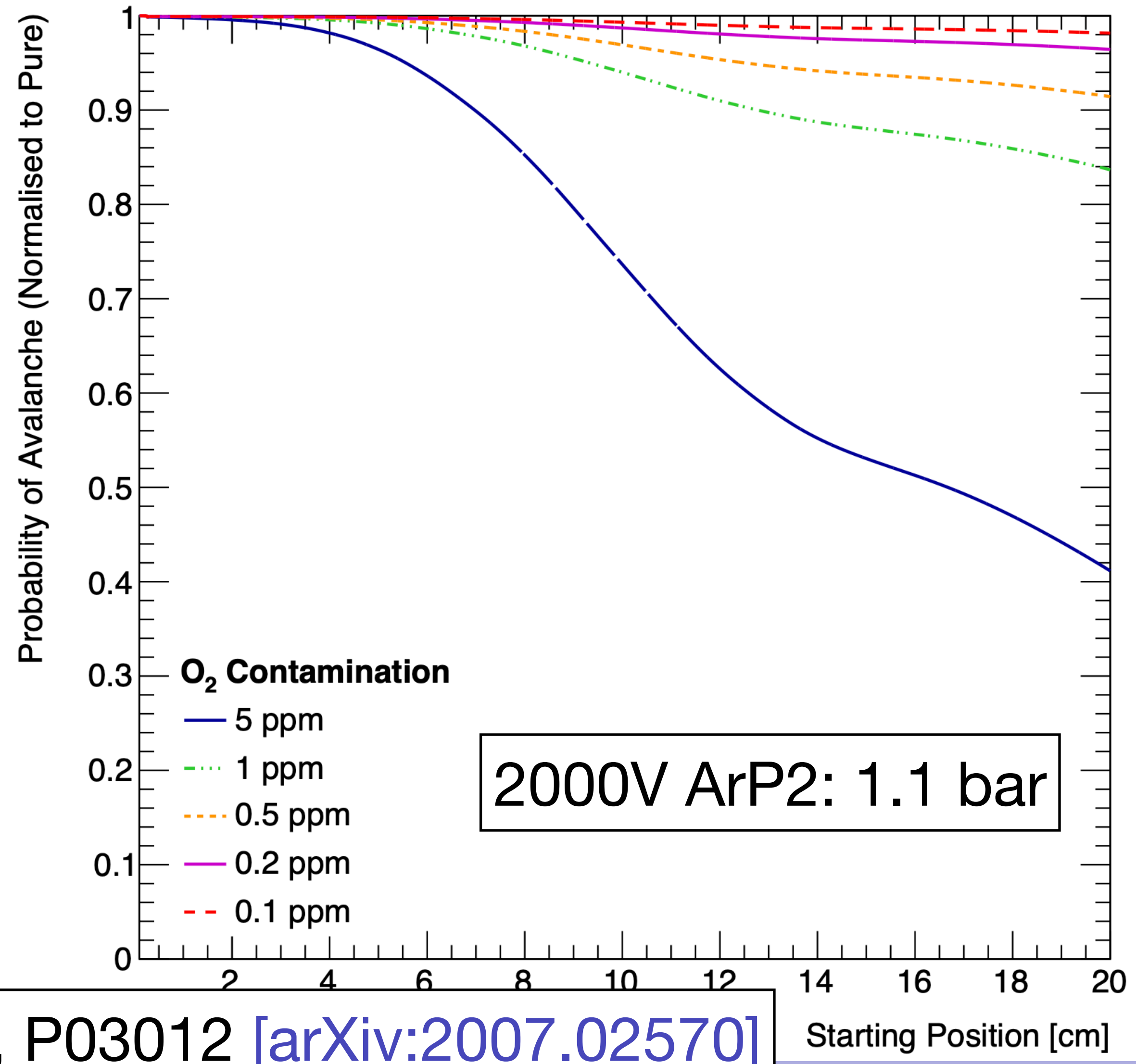
- To achieve the energy resolution requirement, a dedicated low noise electronics chain is essential.
- A low noise preamplifier was developed and a DAQ chain is under development (foreseen for end-2023) while we use in the meantime the CALI card developed for EDELWEISS and used today in NEWS-G.
- This work is carried out in the framework of the OWEN project (IdEX Emergence Université Bordeaux) which includes a dedicated development of onboard technology for a fast data processing.
- The use of a new specific and low noise FEE for resistive anode is in development. It will enables longitudinal localisation by reading both end of the anode.

Gas Purity And Recirculation

- Purification:
  - High purity is a strong requirement.
  - Circulation inside getters.
- Recirculation:
  - Recirculation system.
  - Controlled flow.
- Recovery:
  - Implementation of a cryopumping system.
  - Pressure controlled valve.

Garfield Simulation.
Cathode: 20 cm radius
Anode: 1 mm radius
Proportional mode

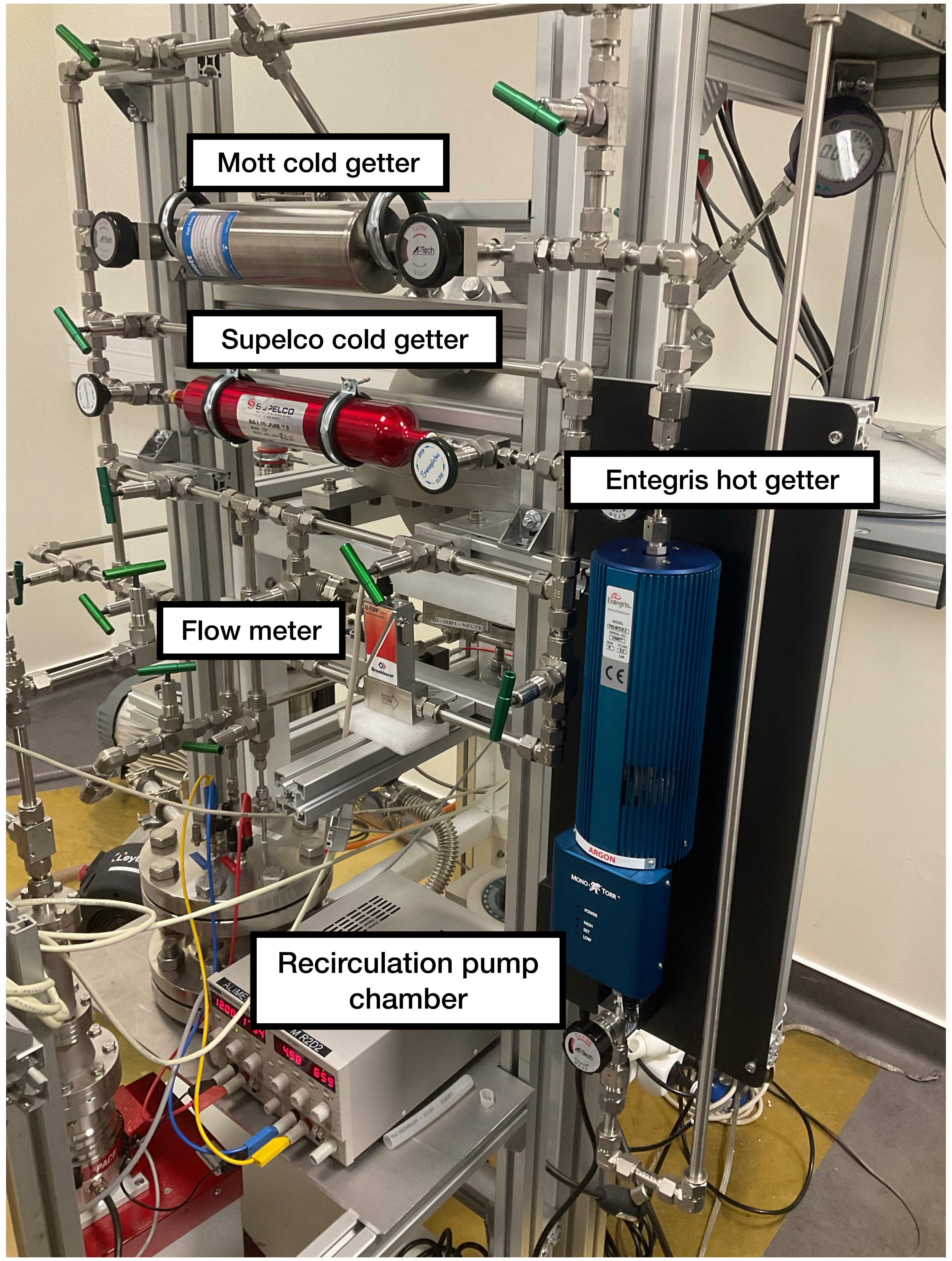




JINST 16 (2021) 03, P03012 [arXiv:2007.02570]

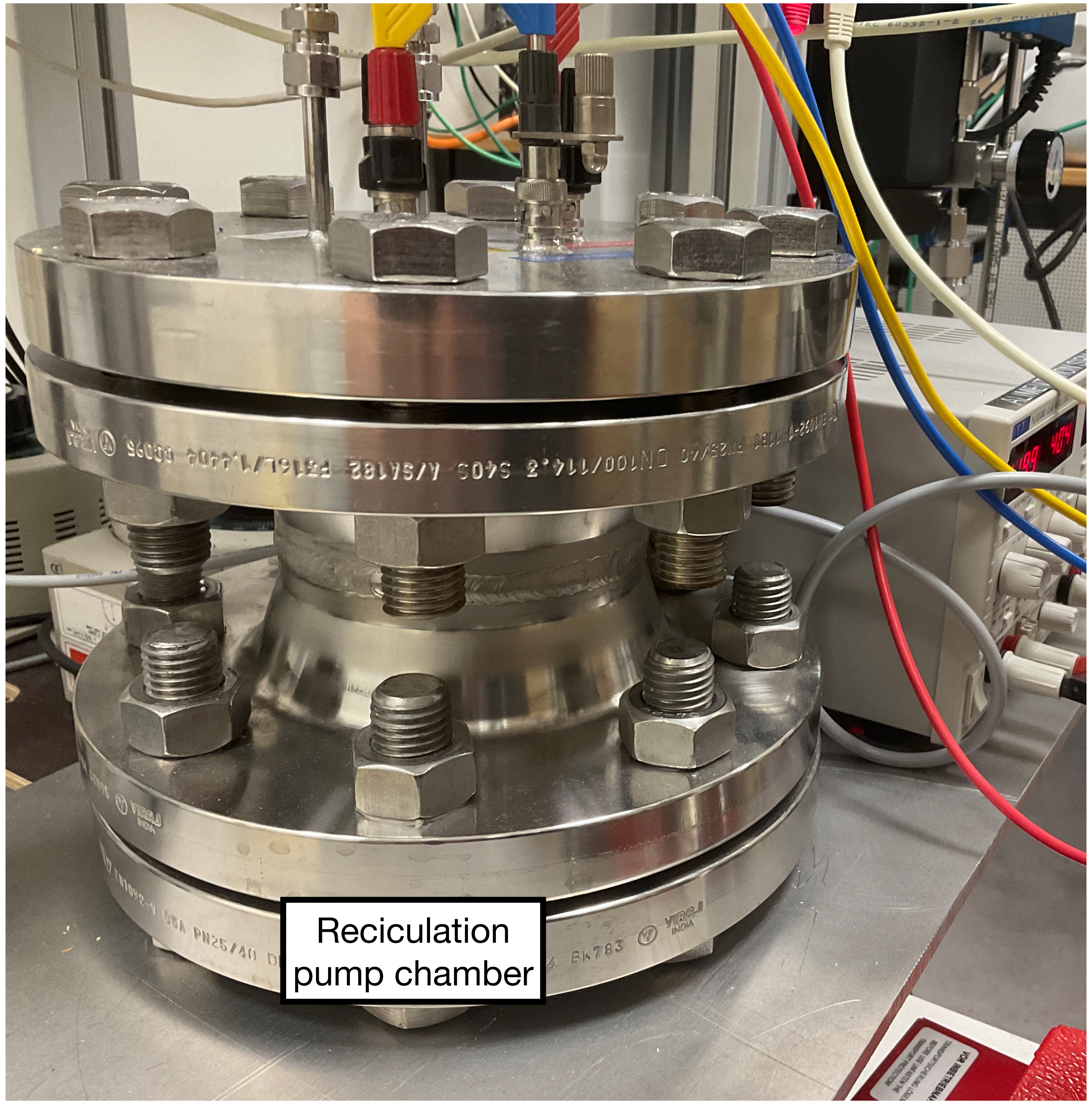
Gas Purity And Recirculation

- Purification:
  - High purity is a strong requirement.
  - Circulation inside getters.
- Recirculation:
  - Recirculation system.
  - Controlled flow.
- Recovery:
  - Implementation of a cryopumping system.
  - Pressure controlled valve.



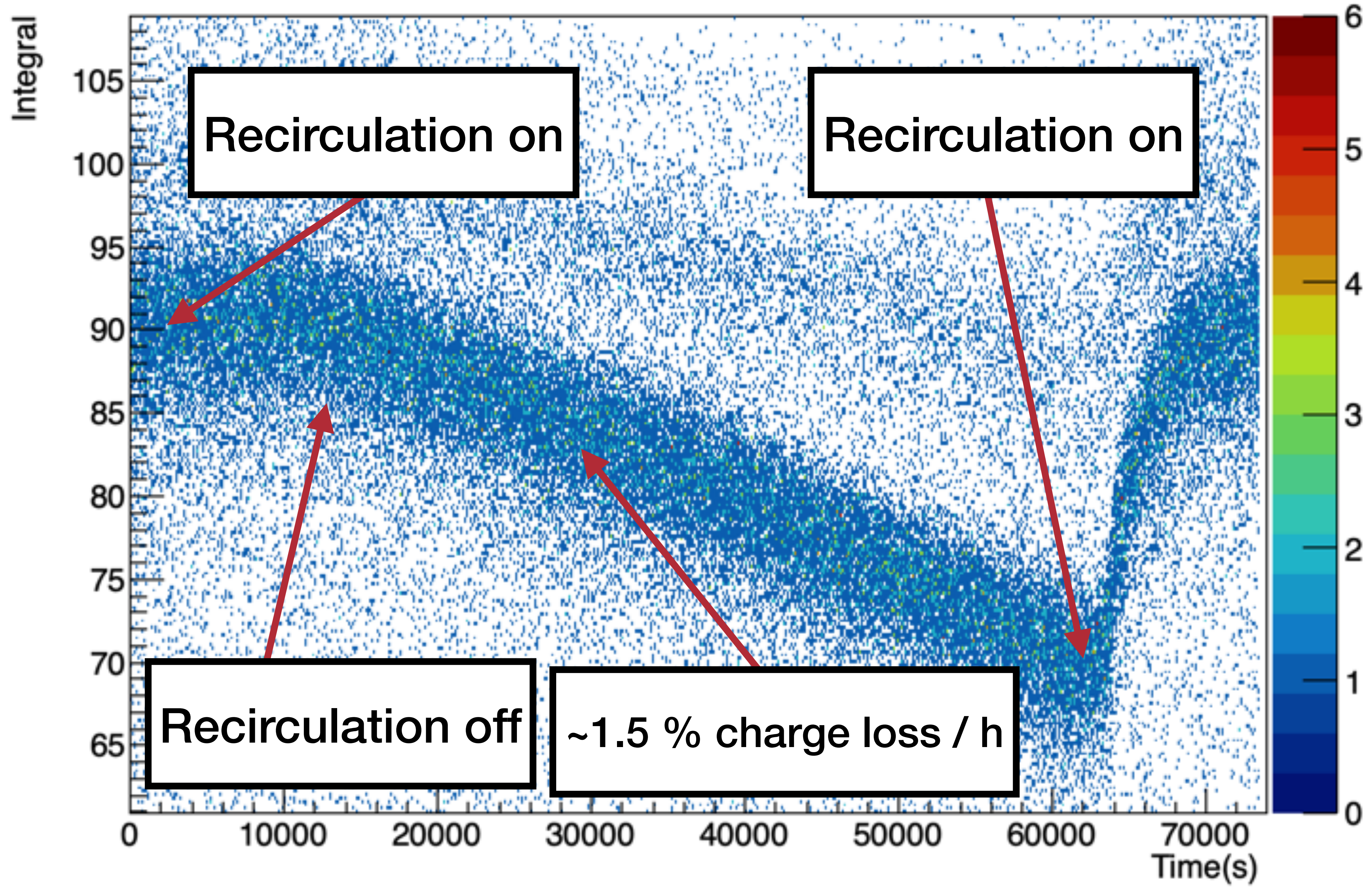
Gas Purity And Recirculation

- Purification:
  - High purity is a strong requirement.
  - Circulation inside getters.
- Recirculation:
  - Recirculation system.
  - Controlled flow.
- Recovery:
  - Implementation of a cryopumping system.
  - Pressure controlled valve.



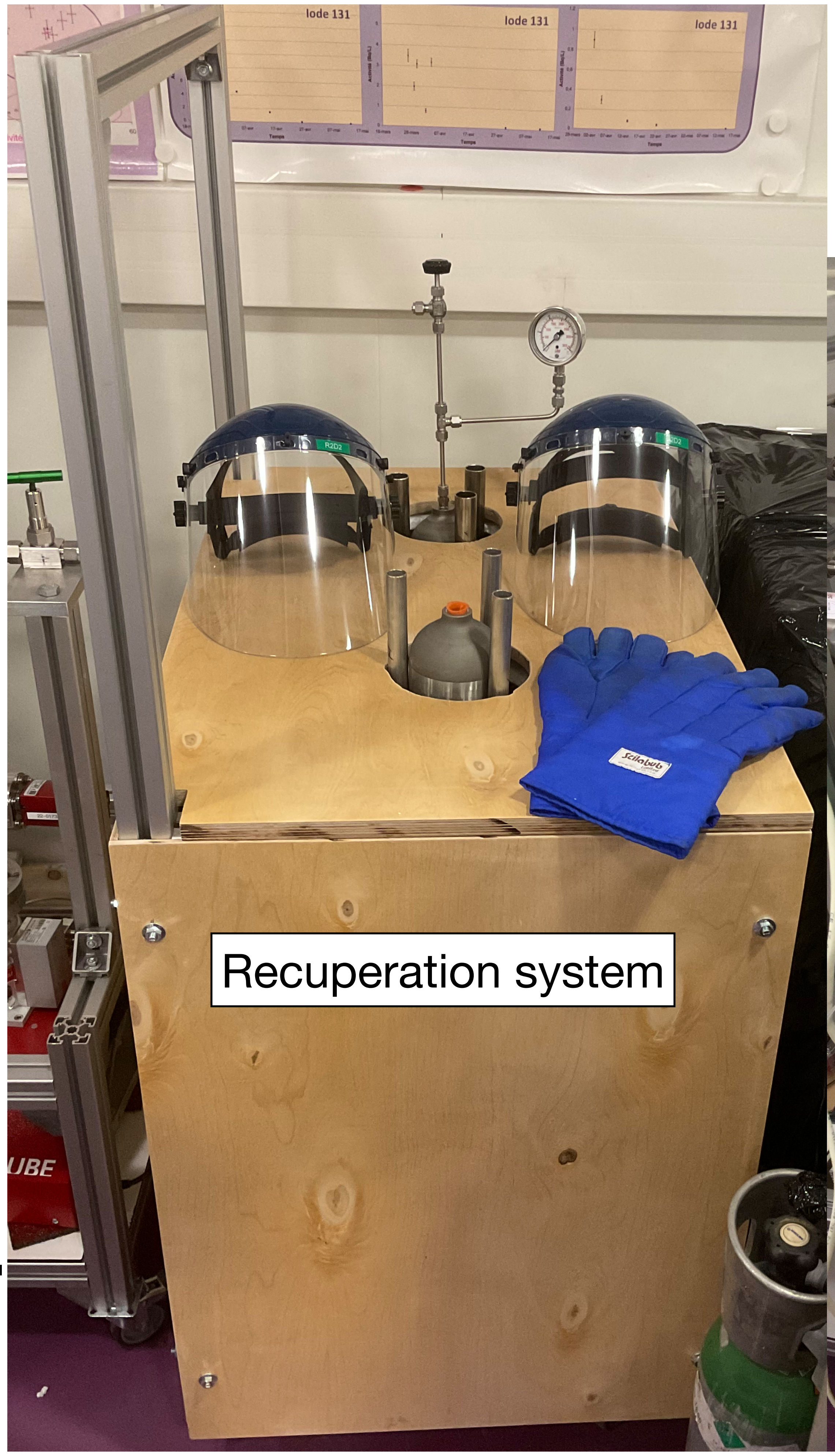
Gas Purity And Recirculation

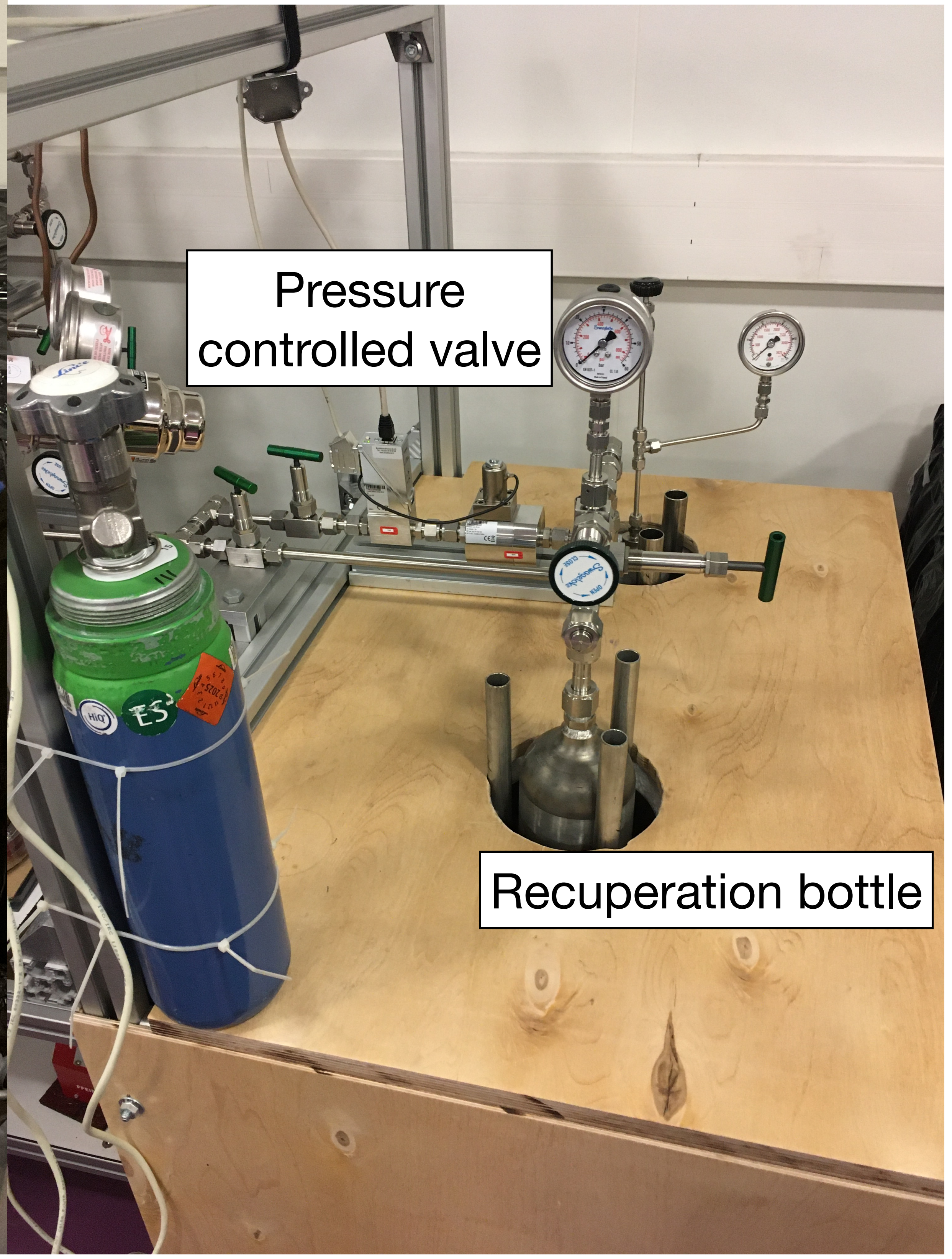
- Purification:
  - High purity is a strong requirement.
  - Circulation inside getters.
- Recirculation:
  - Recirculation system.
  - Controlled flow.
- Recovery:
  - Implementation of a cryopumping system.
  - Pressure controlled valve.



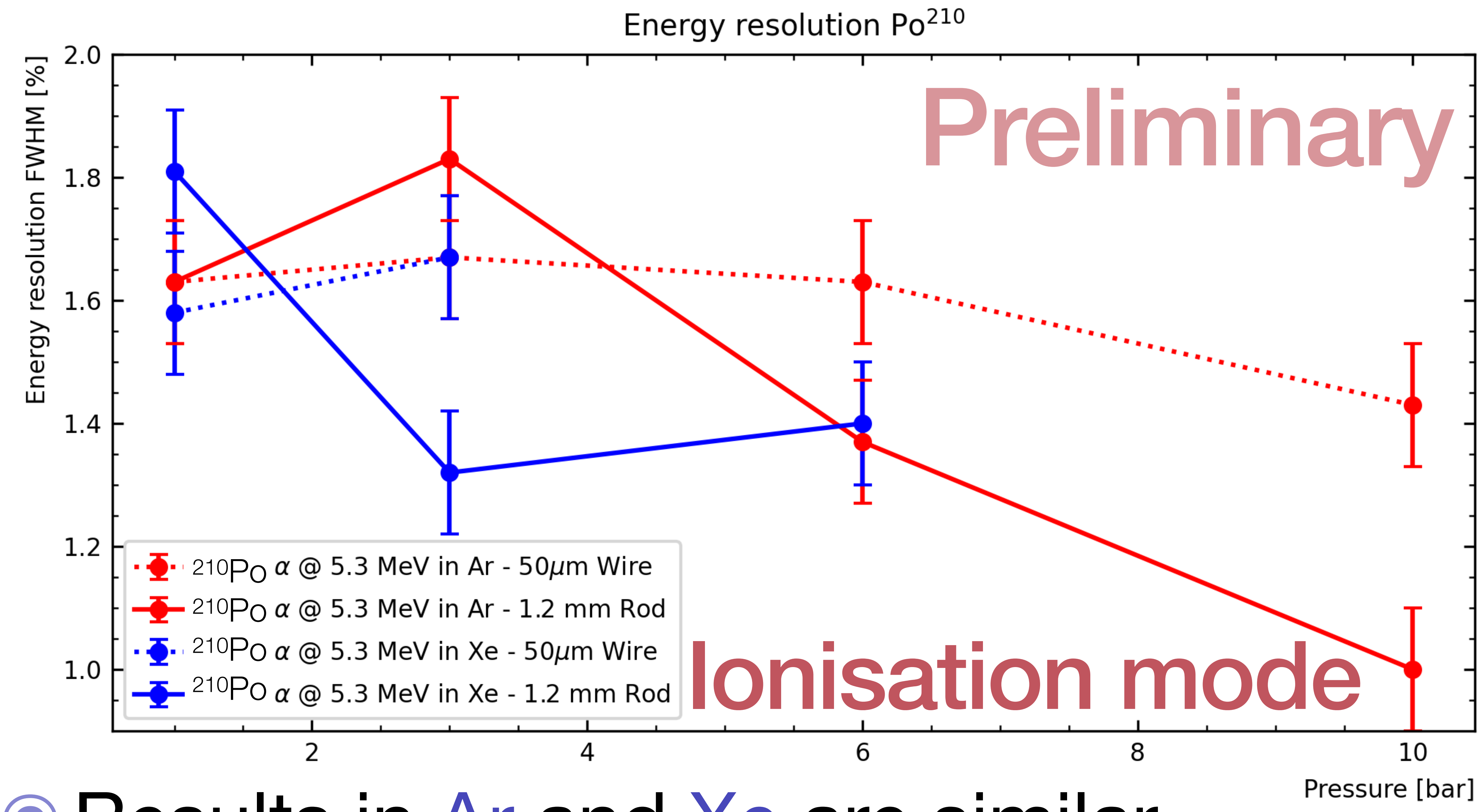
Gas Purity And Recirculation

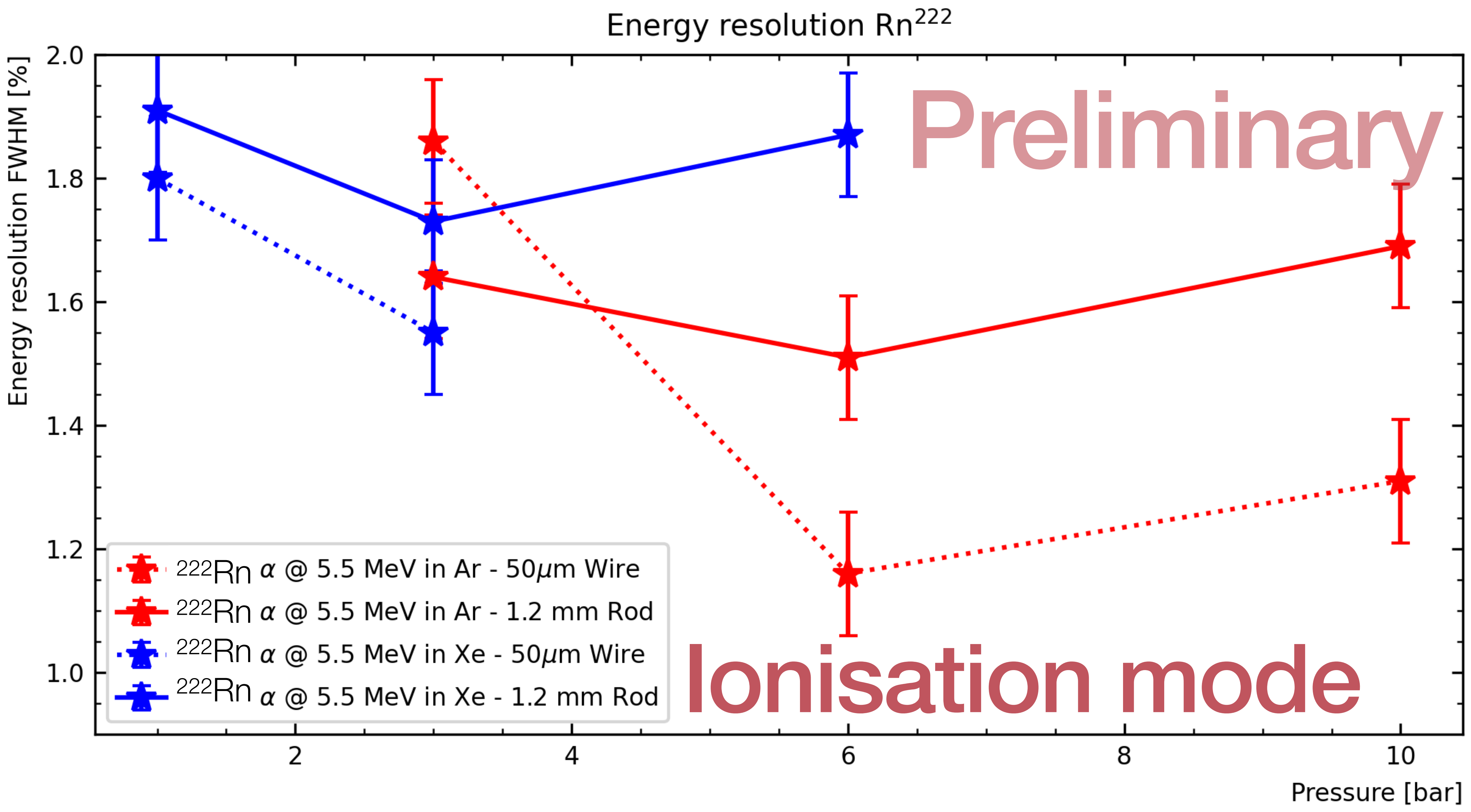
- Purification:
  - High purity is a strong requirement.
  - Circulation inside getters.
- Recirculation:
  - Recirculation system.
  - Controlled flow.
- Recovery:
  - Implementation of a cryopumping system.
  - Pressure controlled valve.





Preliminary resolution Results

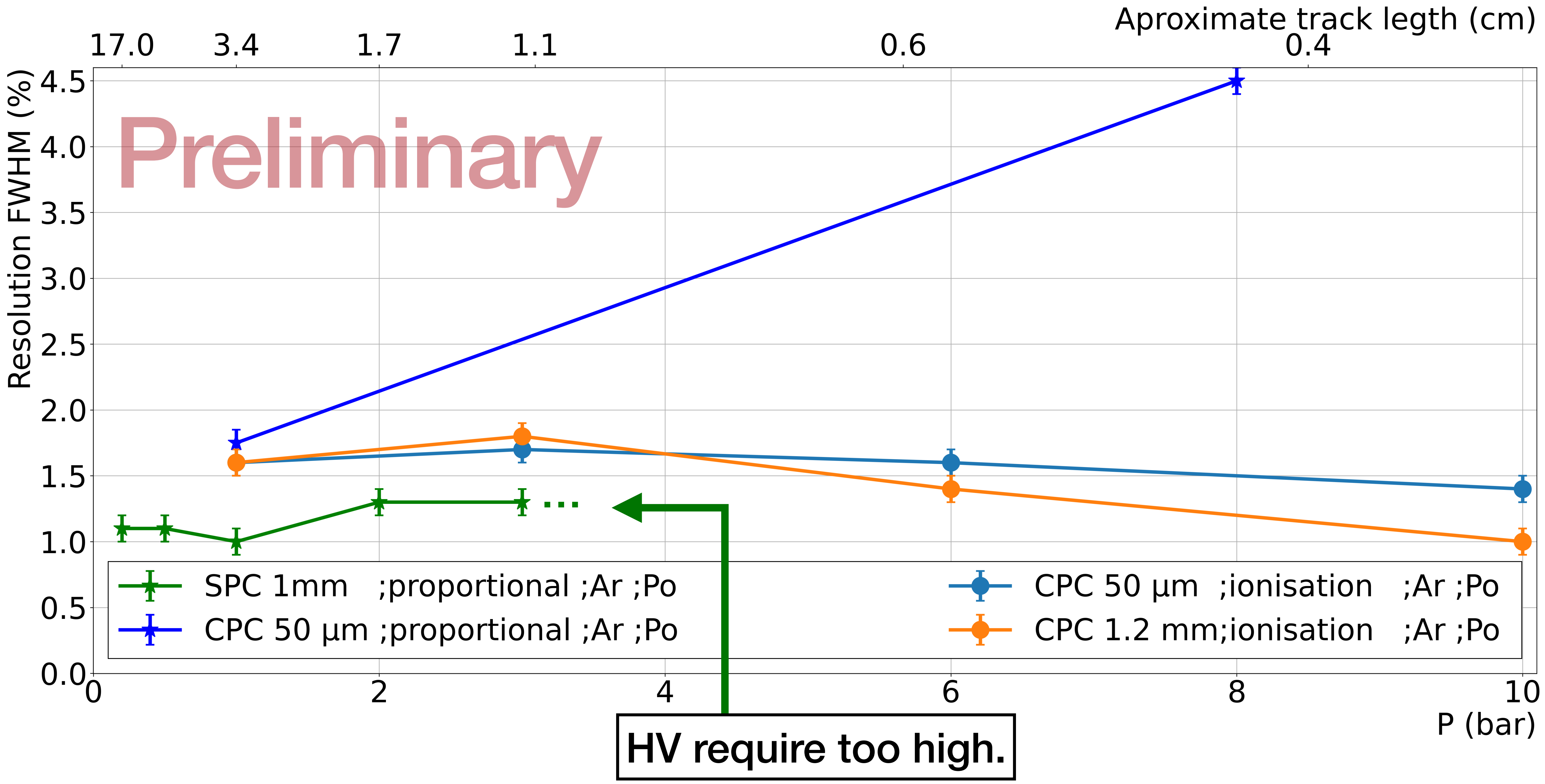




- Results in Ar and Xe are similar.
- Current result are dominated by noise.
- Resolution remain steady over 10 bar for Ar or 6 bar for Xe (technical limits).
- Resolution remain steady for point-like event on fix (Po) or scatter (Rn) sources.

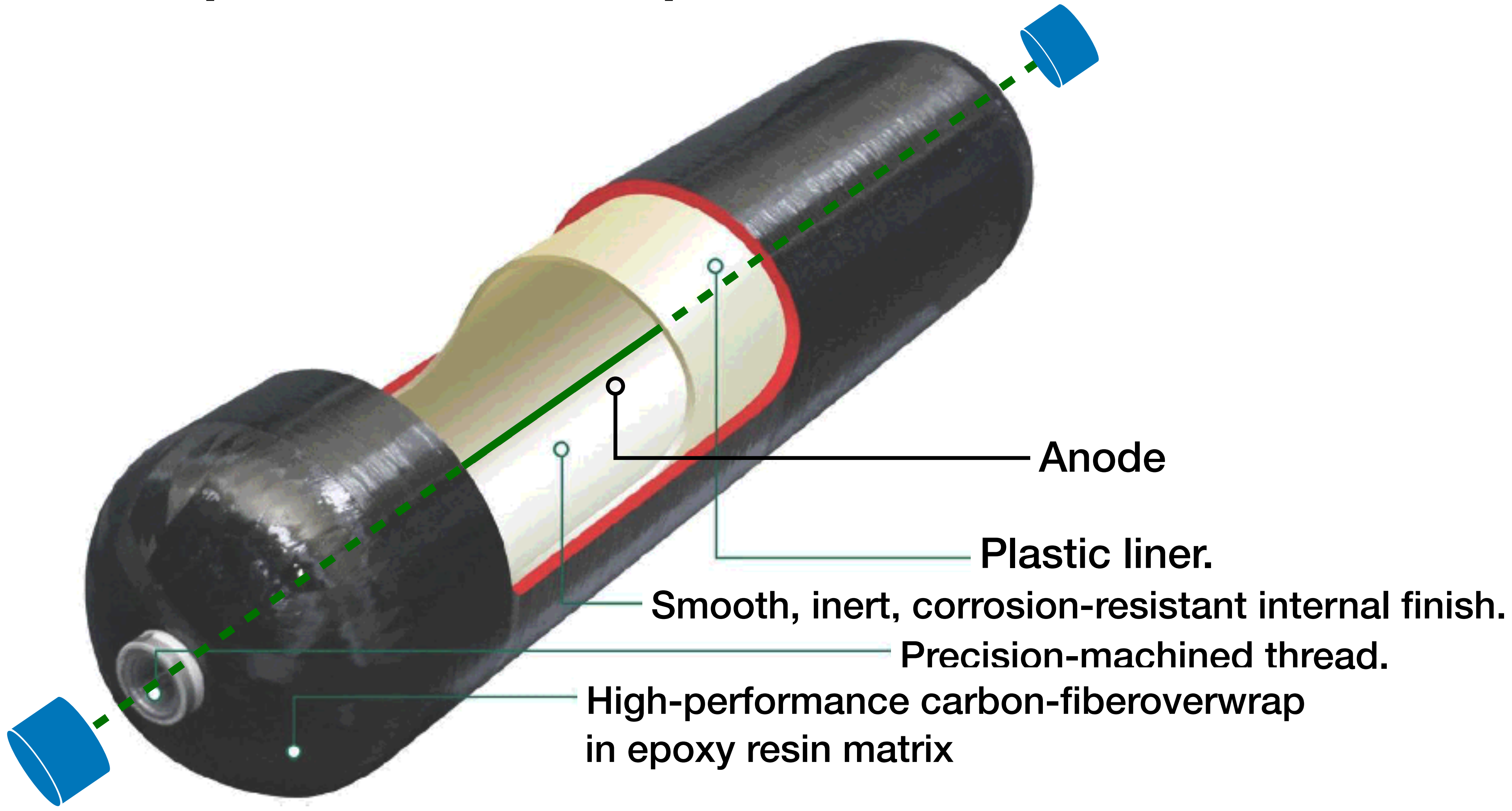
Ionisation & Proportional

- The CPC allows exploration of the ionisation mode, which has several benefits. Among them:
  - Ionisation require a lower high voltage.
  - Lower high voltage produce fewer electronic noise.
  - No avalanche fluctuations.
- Such advantages are the reason for the use ionisation mode for futur detector.



Options For Constructing

- Closed tank
  - New option: Composite H_2 tank.



- Solved issues:
  - Anode.
  - End-caps.
- Remaining uncertainties:
  - Radioactive background.
  - Cathode layer.

- Open tank
  - Backup conventional option.

Independant CPC inserted in the tank, like PANDA-X III.

Conclusion

- The R2D2 R&D primary goal is considered reached.
- Those efforts have led to the validation of the detector resolution stability from 200 mbar up to 10 bar in Ar and up to 6 bar in Xe.
- Several important results and developments where not or barely mention in this talk such as signal processing and event localisation.
- Several new improvements are already in development. A dedicated low noise FEE and a new tank technology.

The End

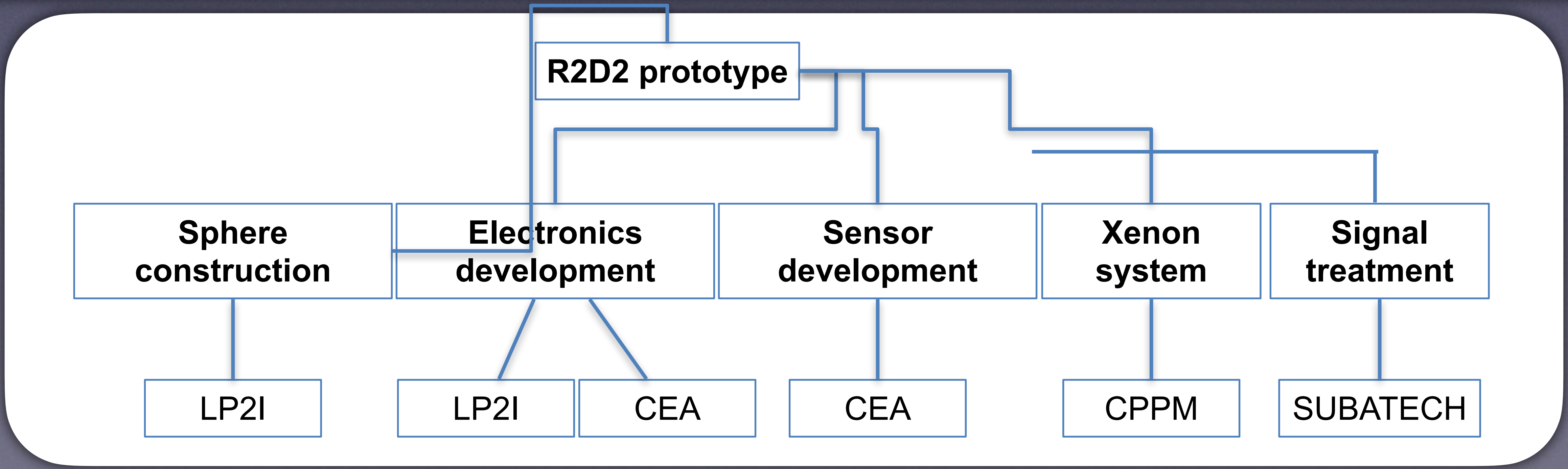
Backups

R2D2 collaboration

- A proto-collaboration has been formed (Czech colleagues from Prague joined R2D2 in April 2023).
- R2D2 is today approved as IN2P3 R&D to assess in particular the possibility to reach the desired energy resolution which is the major showstopper.

R. Bouet,[a] J. Busto,[b] V. Cecchini,[a] C. Cerna,[a] P. Charpentier,[a] A. Dastgheibi-Fard,[c] F. Druillole,[a] C. Jollet,[a,1] P. Hellmuth,[a] I. Katsioulas,[d] P. Knights,[d,e] I. Giomataris,[e] M. Gros,[e] P. Lautridou,[f] A. Meregaglia,[a] X. F. Navick,[e] T. Neep,[d] K. Nikolopoulos,[d] F. Perrot,[a] F. Piquemal,[a] M. Roche,[a] B. Thomas,[a] R. Ward[d]

[a] *LP2I Bordeaux, Université de Bordeaux, CNRS/IN2P3, F-33175 Gradignan, France*
[b] *CPPM, Université d'Aix-Marseille, CNRS/IN2P3, F-13288 Marseille, France*
[c] *LSM, CNRS/IN2P3, Université Grenoble-Alpes, Modane, France*
[d] *School of Physics and Astronomy, University of Birmingham, B15 2TT, United Kingdom*
[e] *IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France*
[f] *SUBATECH, IMT-Atlantique, Université de Nantes, CNRS-IN2P3, France*



Sensitivity studies

- A **full Monte Carlo simulation** was developed to assess our capability to reject background and to evaluate the possible sensitivity on the searched signal.
- We considered a geometry including active and passive veto and a small mass of 50 kg of xenon corresponding to the foreseen prototype.

Xenon active volume

Mass of 50 kg

Radius of 37 cm

Pressure of 40 bar

This choice, based on the results of a pressure and radius scan, is driven by the need of containing at least 80% of the $\beta\beta0\nu$ electrons.

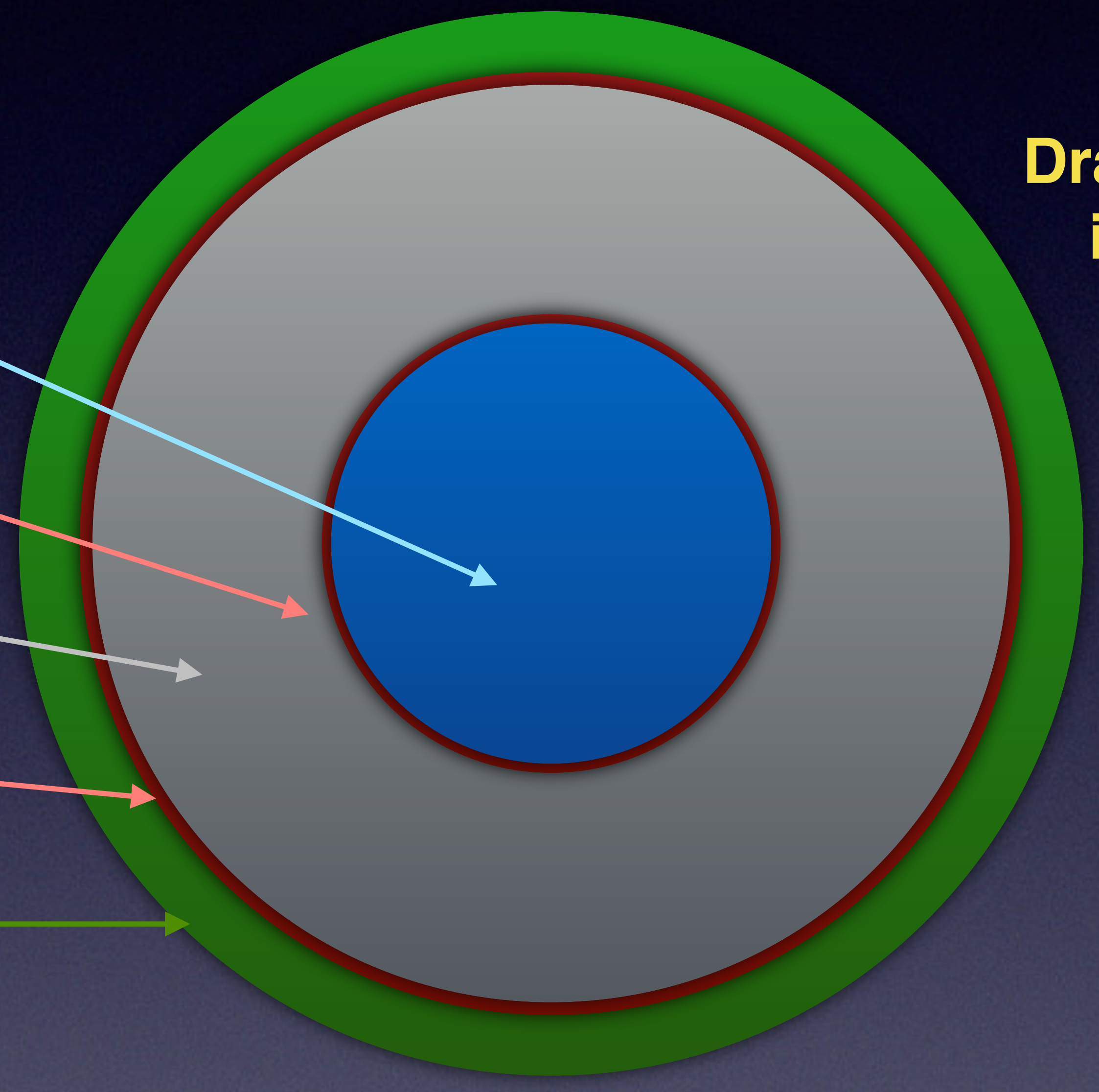
37 cm radius inner volume of Xe gas

0.5 cm thick Cu structure

1.5 m thick liquid scintillator

2 cm thick Cu structure

20 cm thick Pb + 5 cm thick Cu shielding



Drawing not in scale

Liquid scintillator volume

Thickness of 1.5 m

Assumed to be LAB

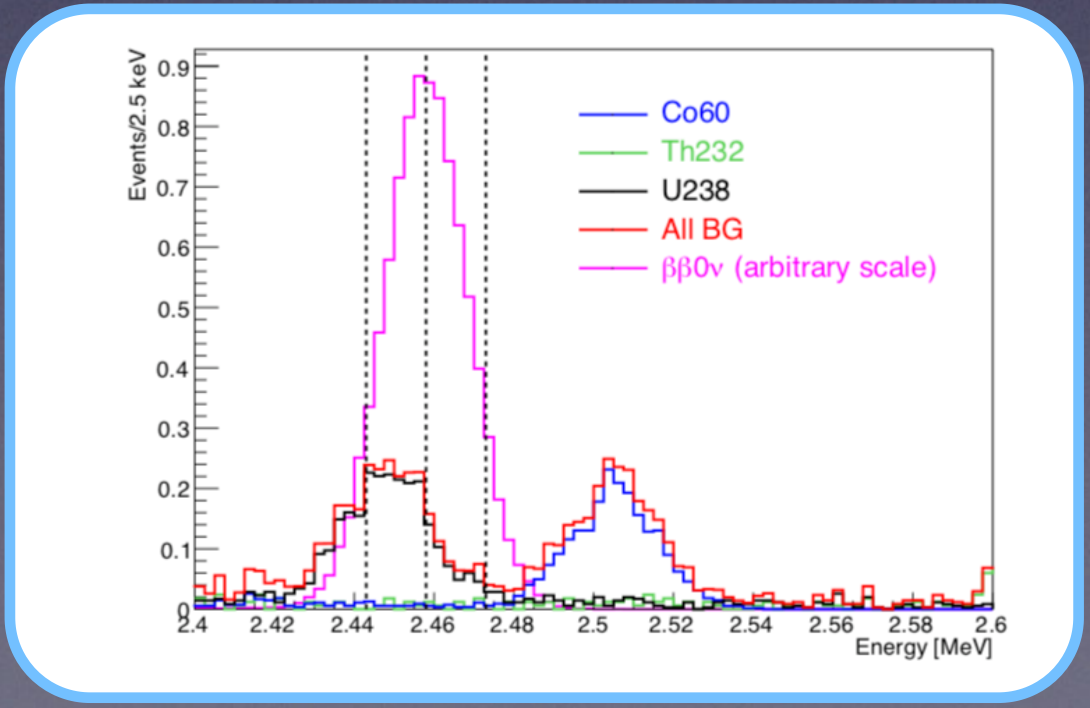
The thickness is chosen in order to have a background rate below 0.1 events per year from the ^{208}Tl contamination of the liquid scintillator vessel.

Shielding volume

20 cm Lead

5 cm Copper

The choice was made to match the shielding used in measurements performed at LSM to have a reliable and less complicated MC.



JINST 13 (2018) no.01, P01009

Released results

- We have published 4 papers and recently submitted a new one on the first results on xenon.

PAPERS

- **"Performance of a spherical high pressure gas TPC for neutrino magnetic moment measurement"** R. Bouet et al. JINST 18 (2023) 03, P03031 " [arXiv:2201.12621] ← **Sensitivity to neutrino magnetic moment**
- **"Simultaneous scintillation light and charge readout of a pure argon filled Spherical Proportional Counter"** R. Bouet et al. Nucl.Instrum.Meth.A 1028 (2022) 166382 "[arXiv:2201.12621] ← **Observation of scintillation light**
- **"R2D2 spherical TPC: first energy resolution results"** R. Bouet et al. JINST 16 (2021) 03, P03012 "[arXiv:2007.02570] ← **First results in ArP2**
- **"Study of a spherical Xenon gas TPC for neutrinoless double beta detection"** A.Meregaglia et al. JINST 13 (2018) no.01, P01009 "[arXiv:1710.04536] ← **First sensitivity studies**

- We have presented the obtained results at various international conferences.

TALKS

- **Journé Matière Sombre France 2017 - Paris - 2017**: "The R2D2 project" A.Meregaglia
- **Double Beta France workshop - Paris - 2018**: "Status of the R2D2 project" A.Meregaglia
- **GET workshop - Bordeaux - 2018**: "The R2D2 project" A.Meregaglia
- **9th Symposium on Large TPCs for low-energy rare event detection - Paris - 2018**: "A new neutrinoless double beta decay experiment: R2D2" A.Meregaglia
- **Low Radioactivity Techniques - Canfranc - 2019**: "A new neutrinoless double beta decay experiment: R2D2" A.Meregaglia
- **TAUP 2019 - Toyama - 2019**: "A new neutrinoless double beta decay experiment: R2D2" C.Jollet (Talk given by G.Gerbier)
- **ICHEP2020 - Prague - 2020**: "First results of the R2D2 project" A.Meregaglia
- **XIX International workshop on Neutrino Telescopes - Venice - 2021**: "Latest results of the R2D2 project" T.Neep
- **TIPP2021 - Virtual - 2021**: "Latest results of the R2D2 project" A.Meregaglia
- **TAUP2021 - Virtual - 2021**: "Status of the R2D2 project A future $0\nu\beta\beta$ experiment" I.Katsioulas
- **10th LTPC symposium - Paris - 2021**: "R2D2: An R&D program for the research of 2b0n decay with a SPC" P.Lautridou
- **XeSAT2022 - Coimbra - 2022**: "R2D2: a xenon TPC for neutrinoless double beta decay search" A.Meregaglia

POSTERS

- **Neutrino2020 - Chicago - 2020**: "R2D2: a spherical high pressure TPC for the neutrinoless double beta decay search" V.Cecchini
- **Neutrino2022 - Seoul Virtual - 2022**: "R2D2: a xenon TPC for the neutrinoless double beta decay search" P.Charpentier

Technical developments

High Voltage

- High voltages at the level of more than 20 kV might be needed when working at 40 bars (a possible back up option is to work in ionisation mode).
- At the moment we need however a feed through with several features:
  - Good for vacuum and high pressure
  - Good up to 10 kV (possibly more in the future)
  - Good for temperatures up to 100 degrees for detector heating.
  - Low noise
- We tested several commercial options but **each feed through has to be welded by a certified company and the behavior in terms of noise is not guarantee to be the same after and before**.
- Discussion ongoing with AXON company (already collaborating in JUNO) and prototype expected in 2023.

Leakage current

Not shielded (noise)

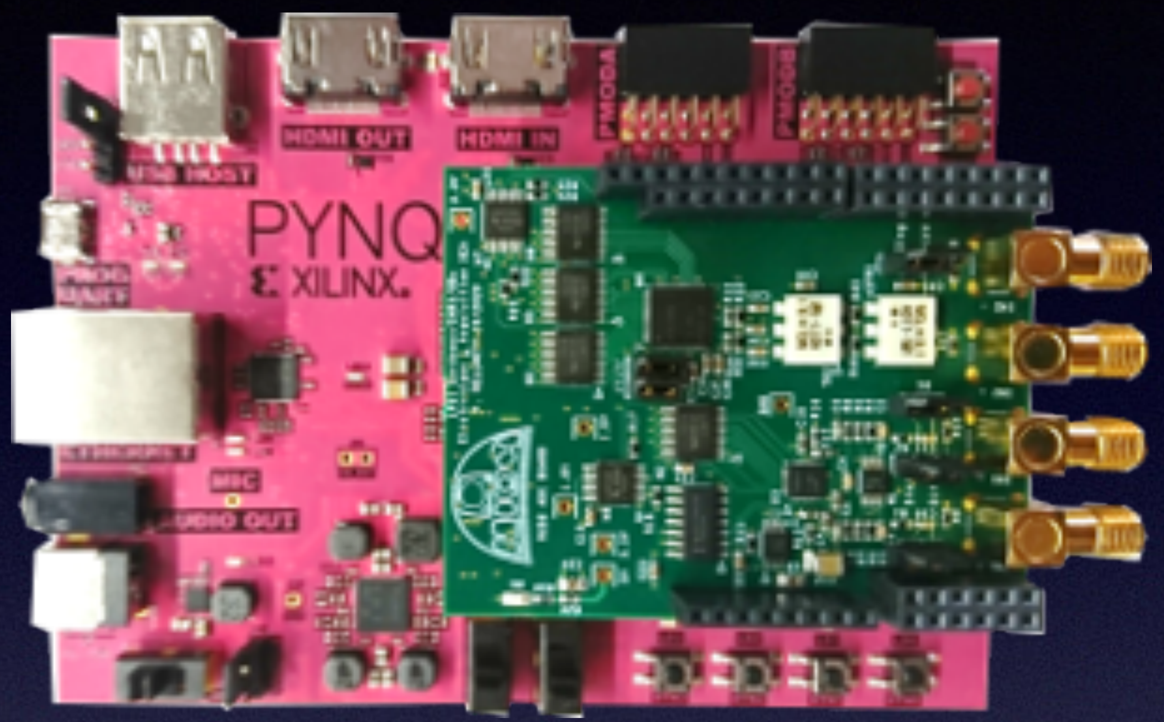
Not certified for HP

Note: This is an issue only for SPC

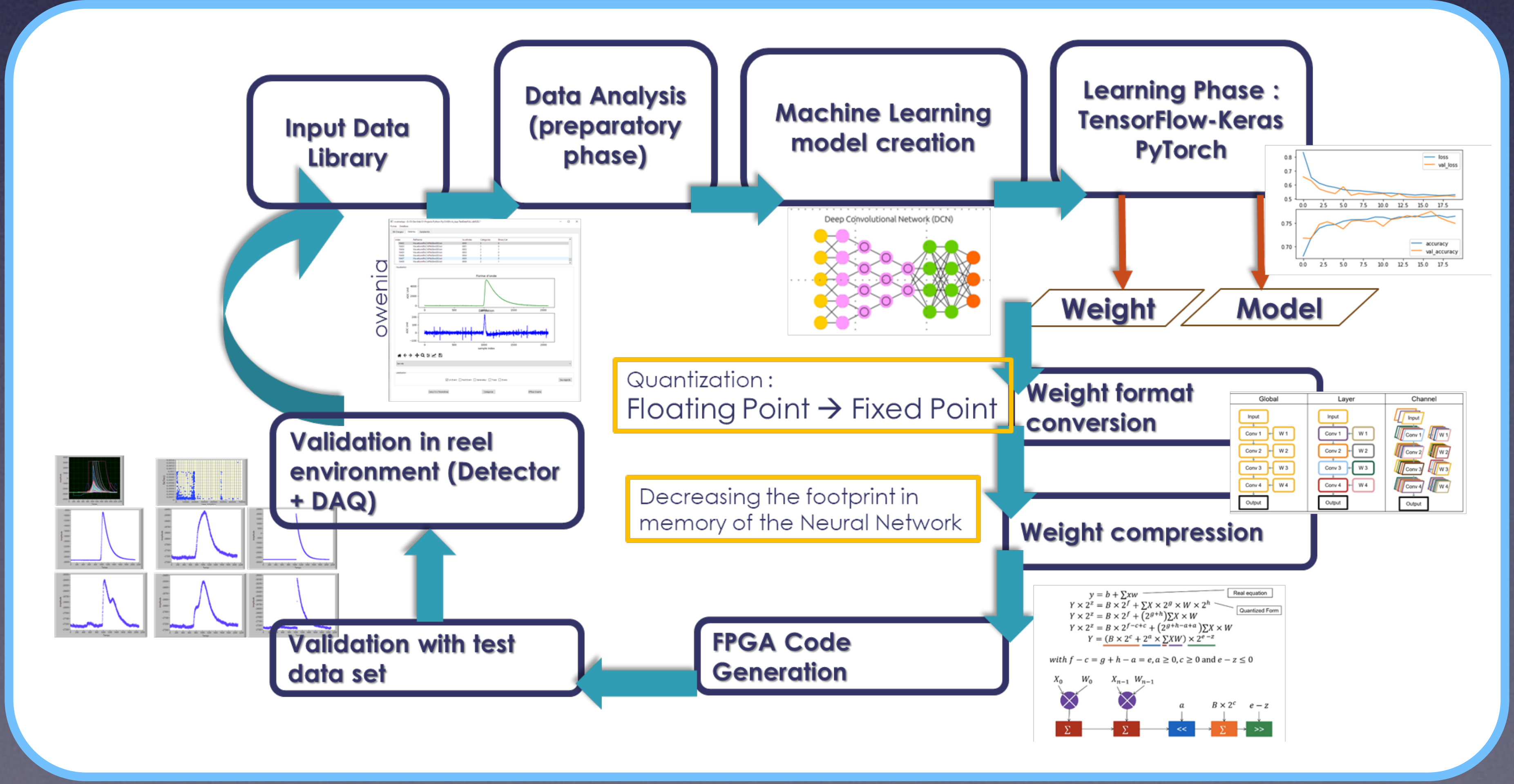
OWEN

Optimal Waveform recognition Electronic Node

- **Hardware developments**:
  - Very low noise front end
  - Optimized waveform digitization with High resolution (18 bits)
  - Embedded processor in integrated shape @ 1Gb/s



- **On-Line Embedded Artificial Intelligence:**
  - Offline classification waveform (classic AI) to possibly reconstruct two-electrons track signature
  - Research of a good neural network architecture to fulfill R2D2 needs
  - Research of a process to integrate AI algorithm in embedded system
  - Digital signal processing to tag events online (with embedded AI)

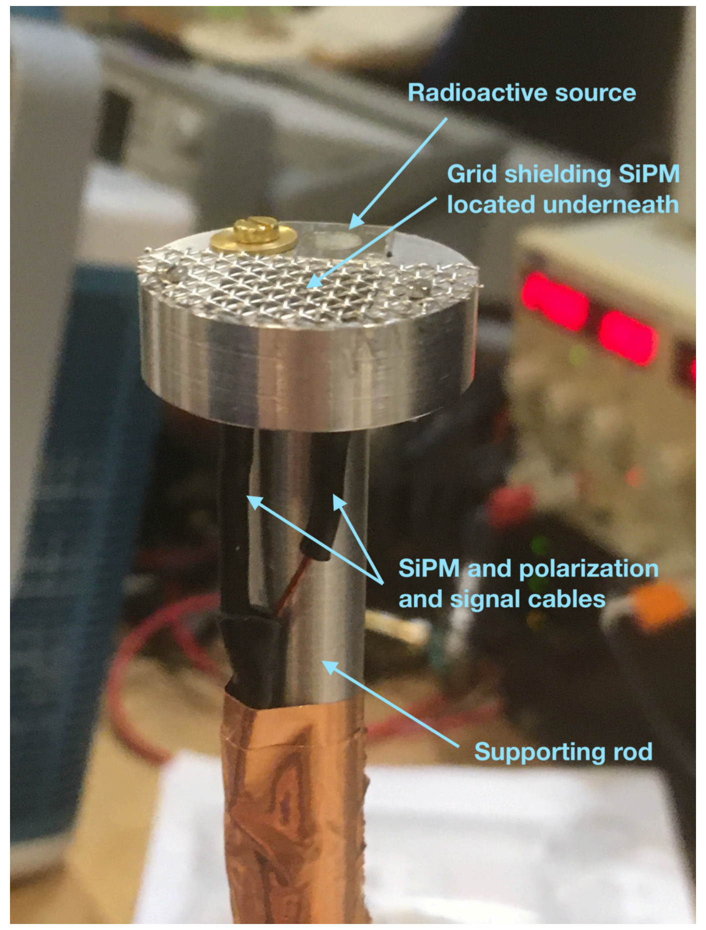


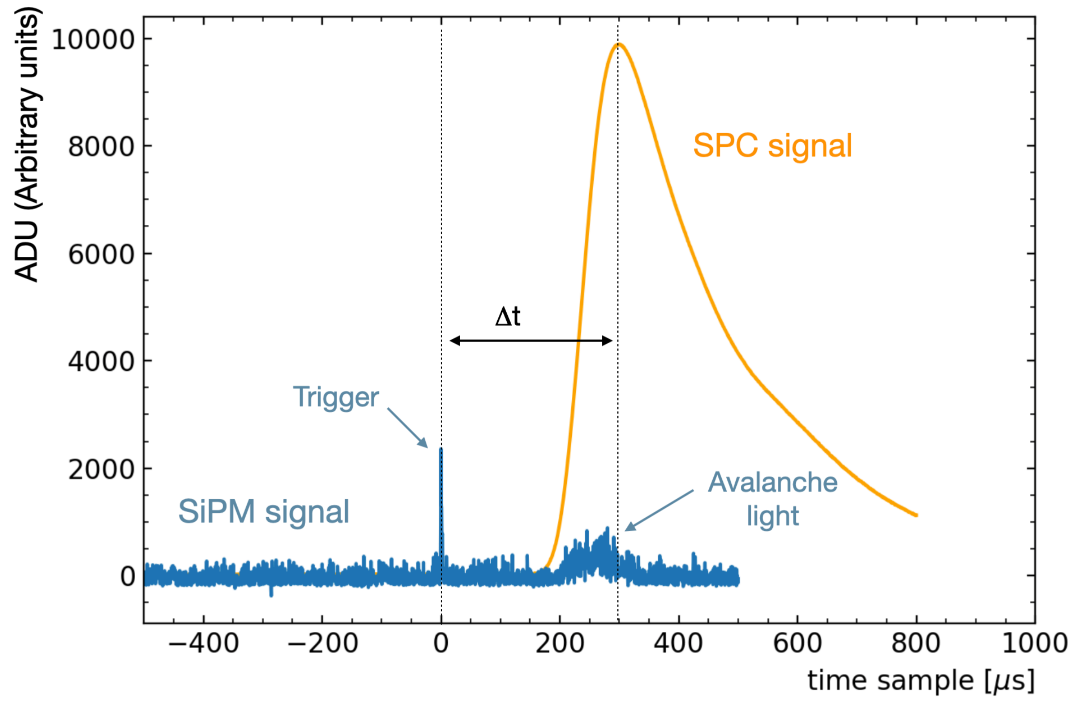
Full system expected to be ready for experiments in 2023

Technical developments

Light readout

- So far spherical TPC (NEWS-G or SEDINE detectors) used the waveform rise time to reconstruct the radial position of the deposited energy with a precision of the order of few cm.
- Having an event trigger (T_0) and knowing the drift velocity a sub-cm precision can be reached which is important for any fiducialization of the volume or to identify multiple energy depositions (electron/gamma rejection).
- We run the detector in pure argon to observe the scintillation light and use it as trigger for the first time in a SPC detector.
- We used a 6x6 mm^2 SiPM from Hamamatsu with a 15% QE at 128 nm.
- We observed two signals on the SiPM: a trigger given by the scintillation light (S1) and a second signal on time with the SPC signal due to the light emitted in the avalanche (S2).
- The time between the S1 and S2 gives the electrons drift time and can be used to validate the Garfield++ simulation. An **excellent agreement is found for alphas emitted at about 19 cm** from the anode as expected.

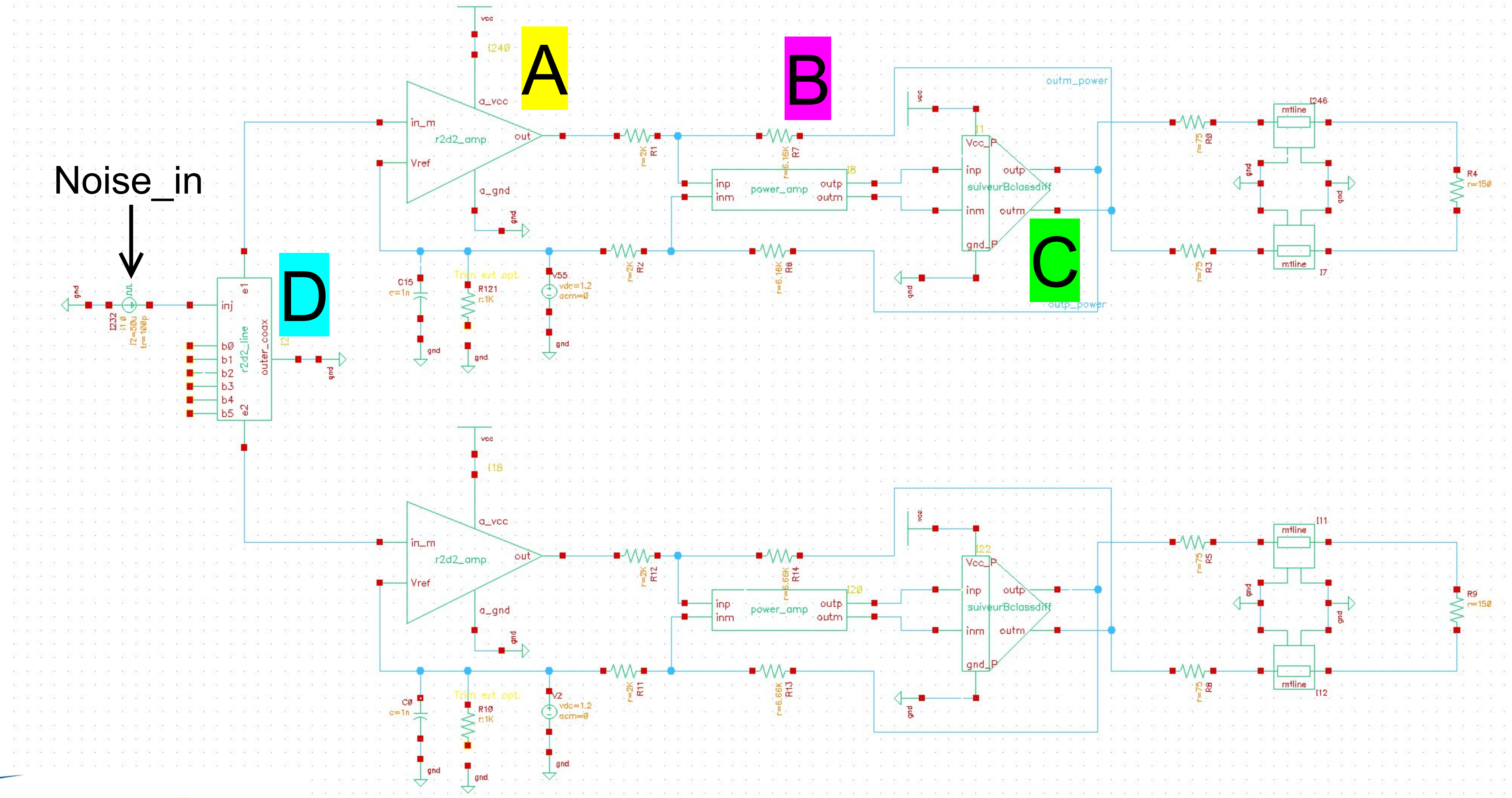




Nucl.Instrum.Meth.A **1028 (2022) 166382**

LOW NOISE TRANSIMPEDANCE AMPLIFIER

- **"R&T BiCMOS"**, projet transverse de **l'IN2P3** : ~5 building blocks dont 1 TIA pour R2D2
- 1 Fonderie en technologie **SiGe:C**, IHP 130nm
- HBT Transistor ==> **low flicker noise**, high intrinsic gain
- TIA optimized for detectors D with Rdet from 2kΩ to 5kΩ, Zc_det=415Ω ,Ldet=2m
- Architecture:
  - A : **TIA**, 33kΩ gain
  - B : **single to diff amplifier** : gain 3V/V
  - C : **B-class** differential power amp, +/- 2Vp on 300Ω diff. load
    - ==> **low consumption :** tot ~ 25mW
    - **matched** 150ohm load thru twinax cable ==> allow **> 10m length** to diff ADC
- Noise : **82% noise detector dominated** for 5kΩ det. (92% for 2kΩ det.)



Rdet	N_in* pA/√Hz	-1dB_BW	Gain tot
5k @ **0°K**	1.7 @ 1MHz		
	1.9 @ 100Hz		
5k@300°K	**4** @ 1MHz	11 MHz	**50kΩ** matched (100kΩ highZ)
	4.1 @ 100Hz		
2k@300°K	**6.2** @ 1MHz	40 MHz	idem
	6.3 @ 100Hz		

*current source at **middle detector** , 1/2 for LNA input : **<1pA/√Hz**

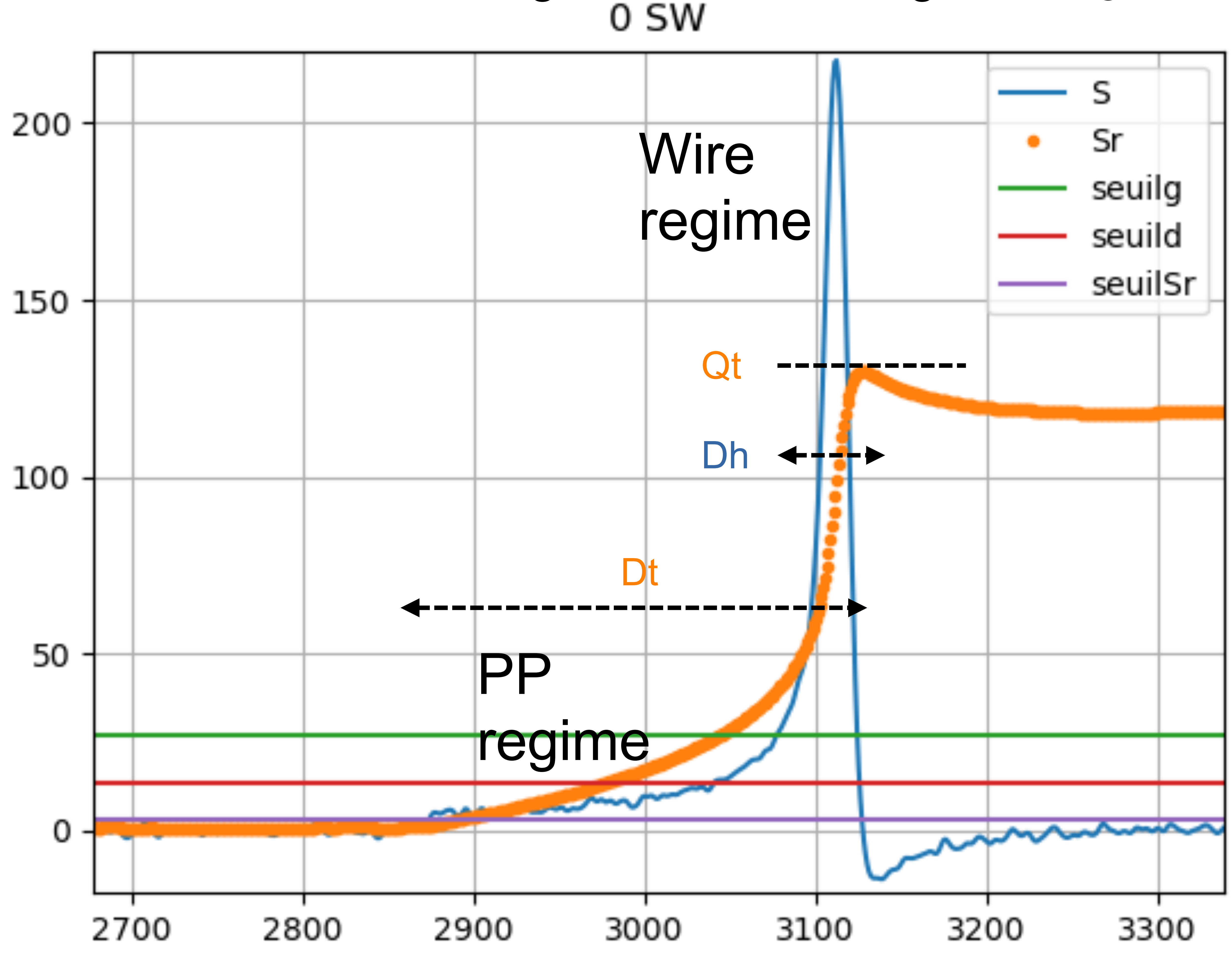
contact : didier.charrier@subatech.in2p3.fr

Signal & Observables

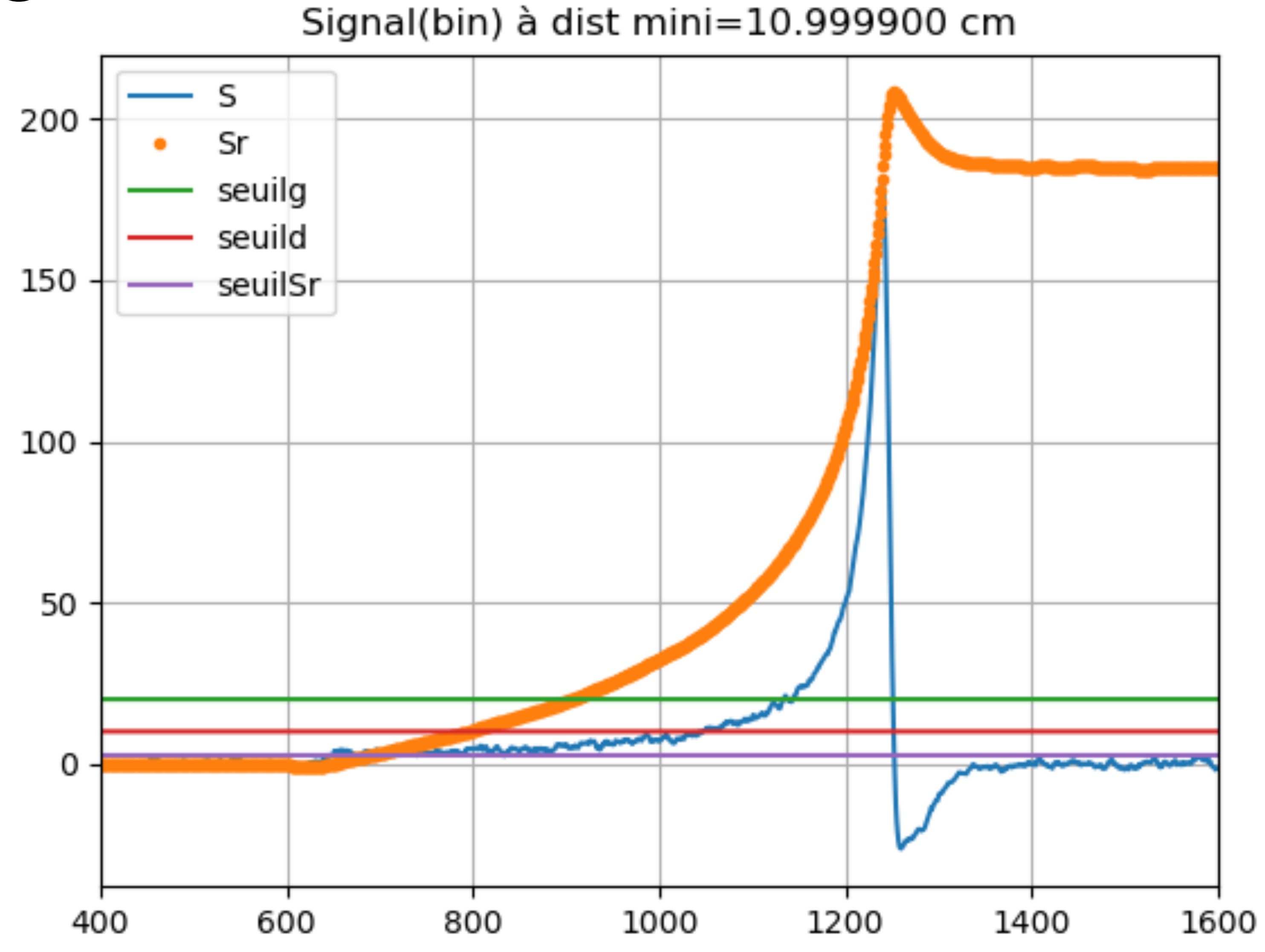
Experimental signal

With Mini-CPC
Anode: D=1,2mm)
Gas: Xe, 3bar
HV: 3000V
FEE: Ortec 142PC
Mode: Ionization

S: Deconvolved signal - Sr : Reintegrated signal

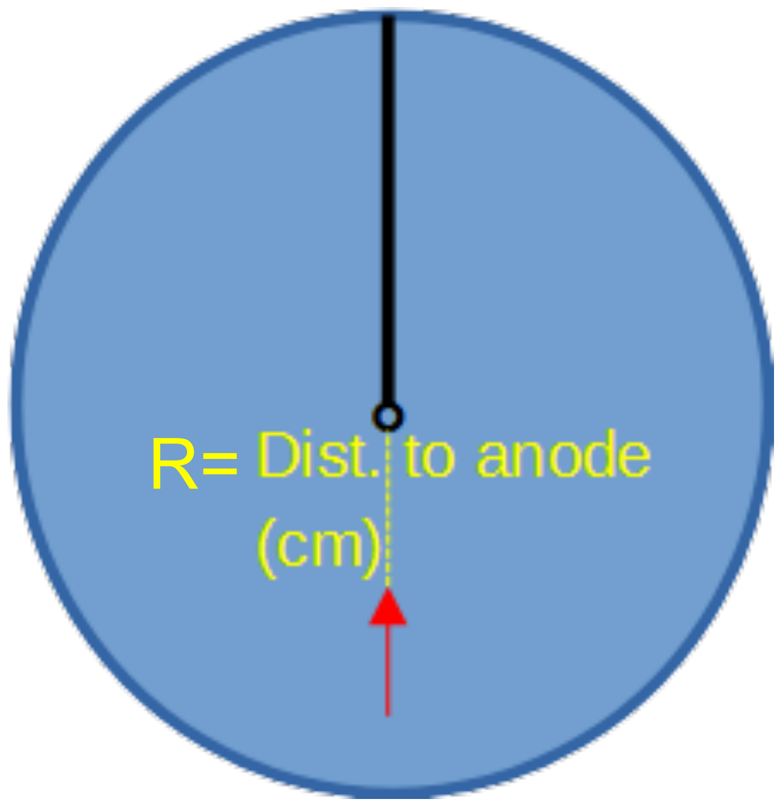


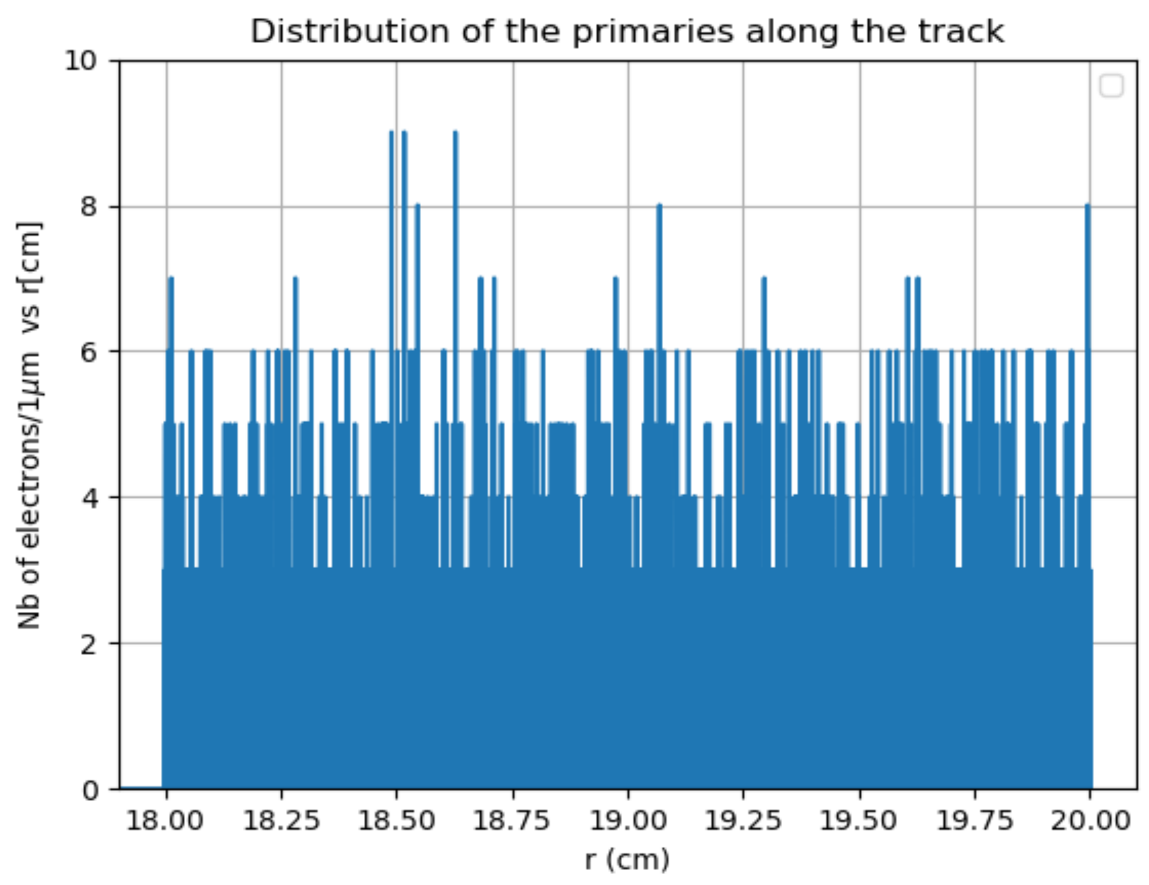
Signal simulation

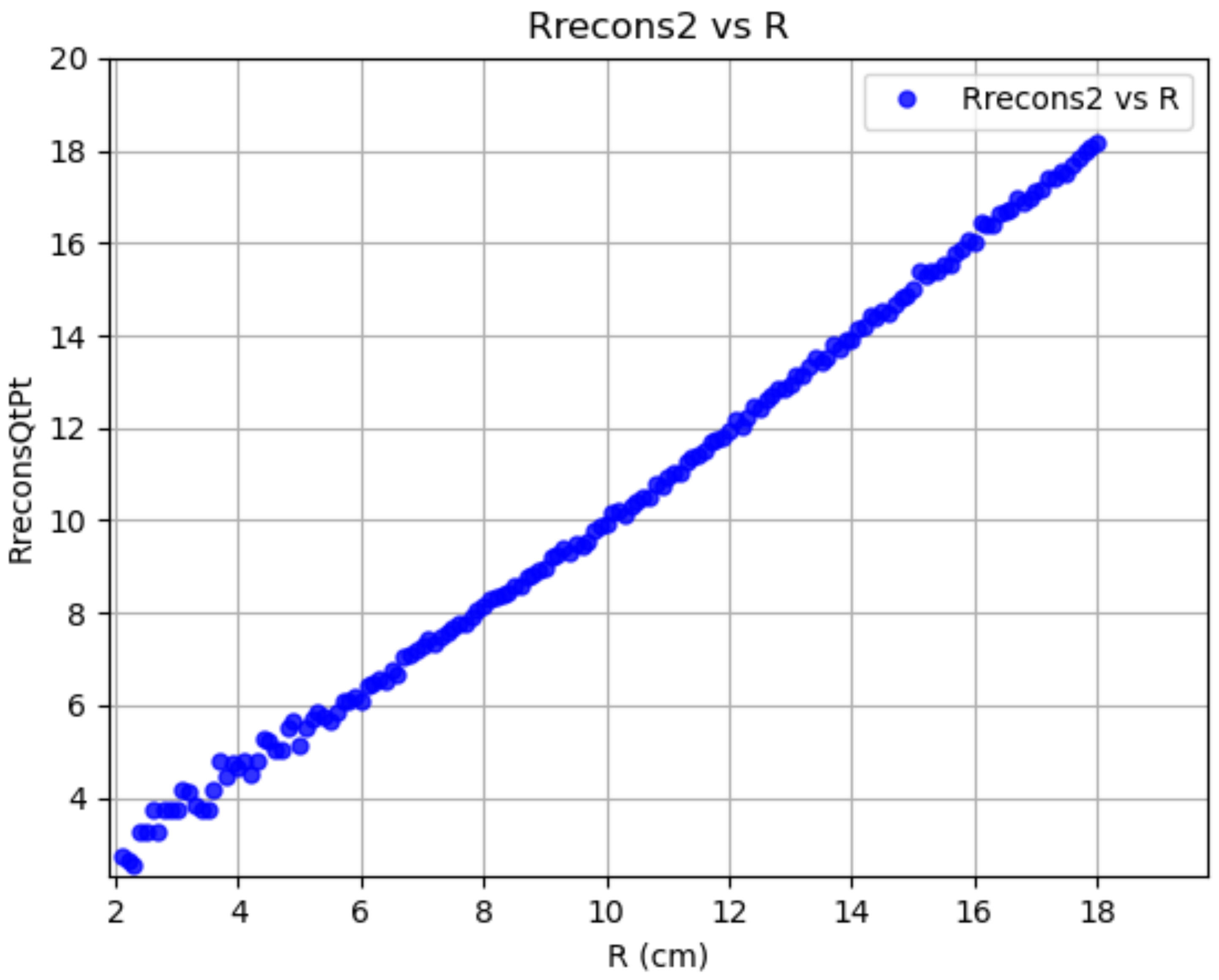


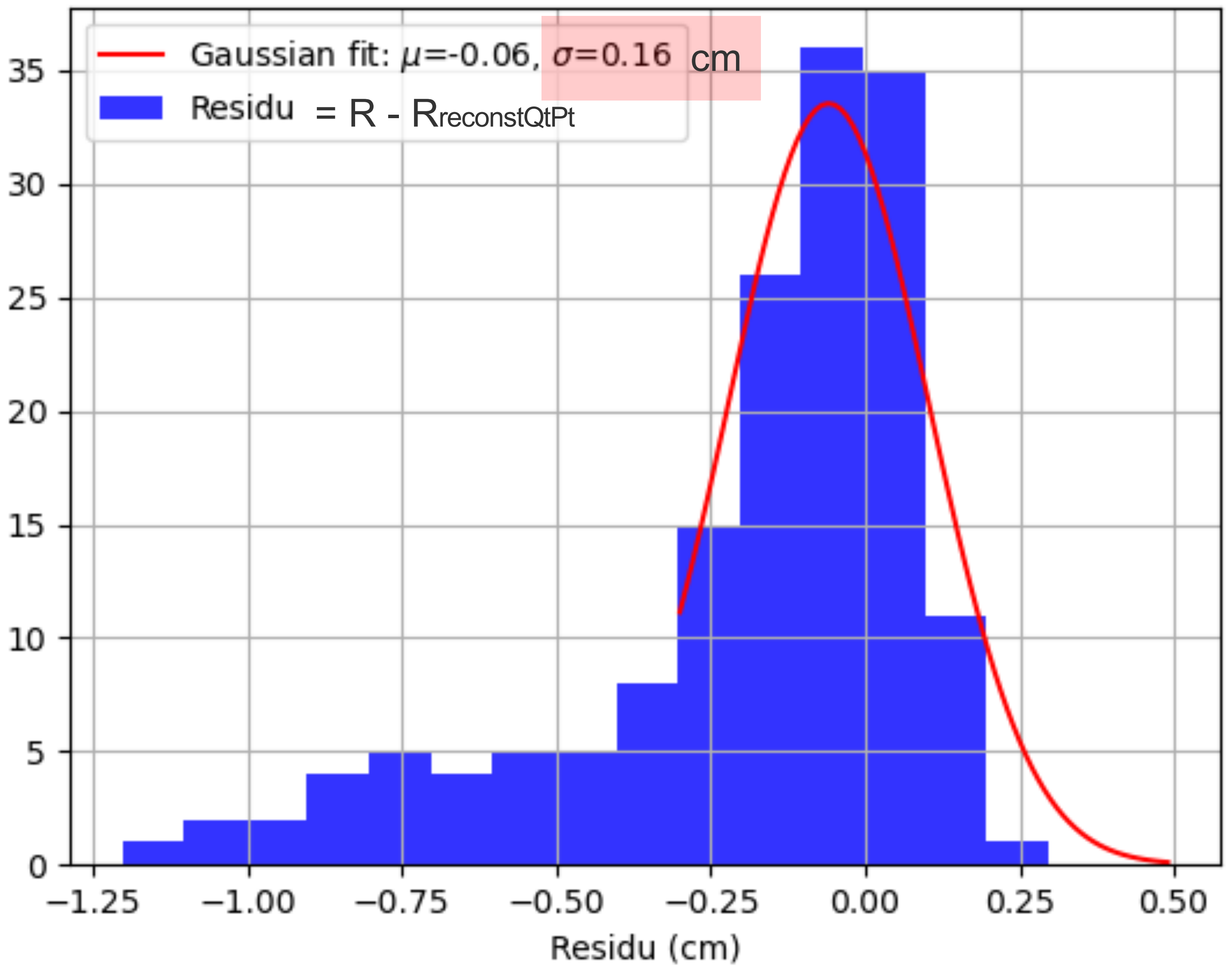
Radial localization

SPC simulation with
track length of 2 cm - non-uniform ionization (clusters)
- 10000 e⁻ - ArP2 gas - prop. mode (G=8)





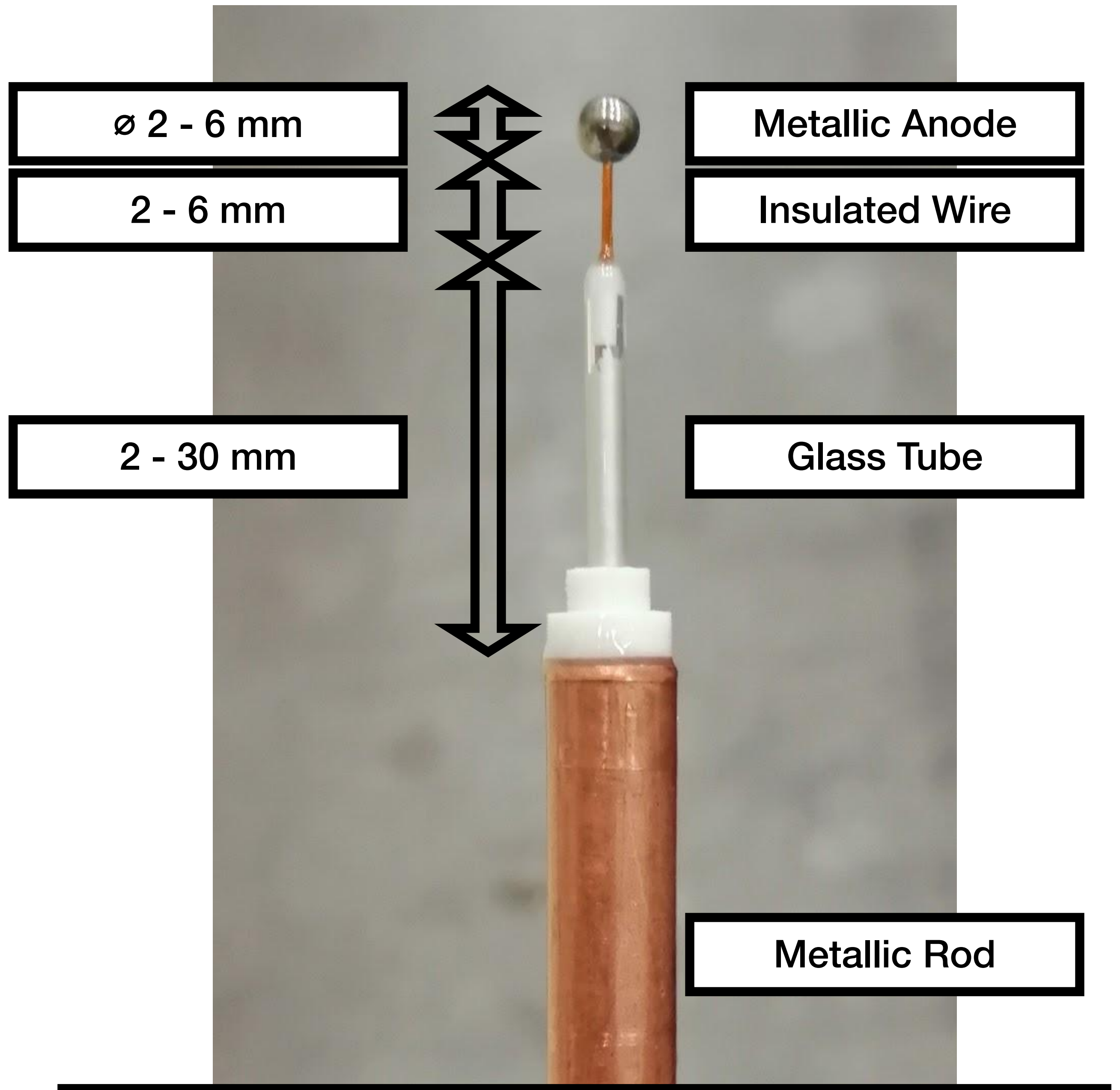




- Pt_{max}, Pt are deduced from plot (Qt, Pt)
- RreconsQtPt = $r_{max} * (Pt / Pt_{max})^{1/a}$ is then compared to the initial distance R set for the simulated event through residues analysis

=> Second result of the simulation: A track localization can be obtained.

SPC Sensor

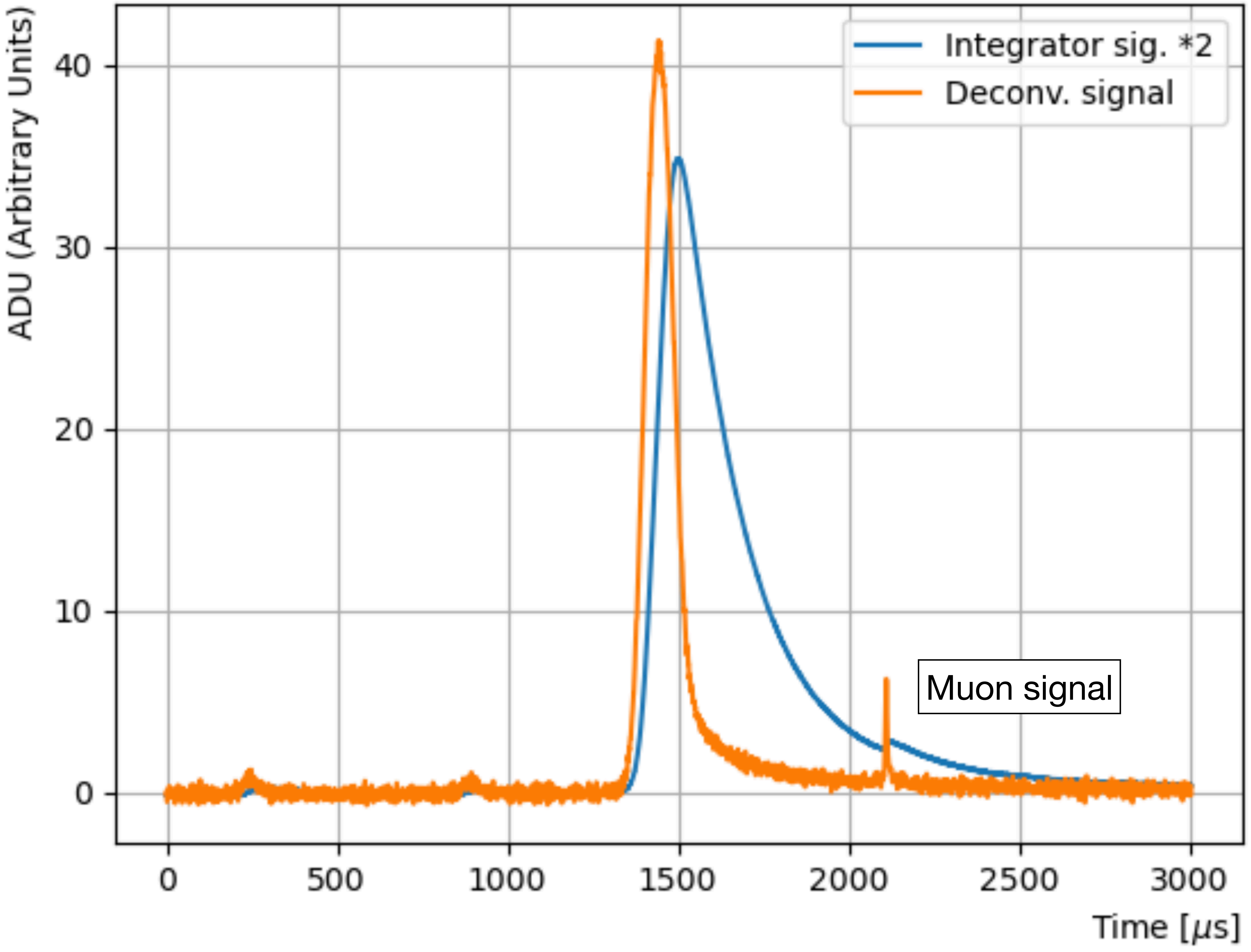


J. Instrum. 13 (2018), (11):P11006
[arXiv: 1809.03270]

- The sensor is the key point of the SPC detector.
- With the ongoing R&D we learned a lot from the detector functioning and we tested different option modifying the distance between the anode and the supporting rod.
- The anode soldering to the wire is still a critical point since any imperfection results into a field distortion.
- Multi channel sensor (Achinos) was also tested but channel equalisation is currently an issue for resolution.

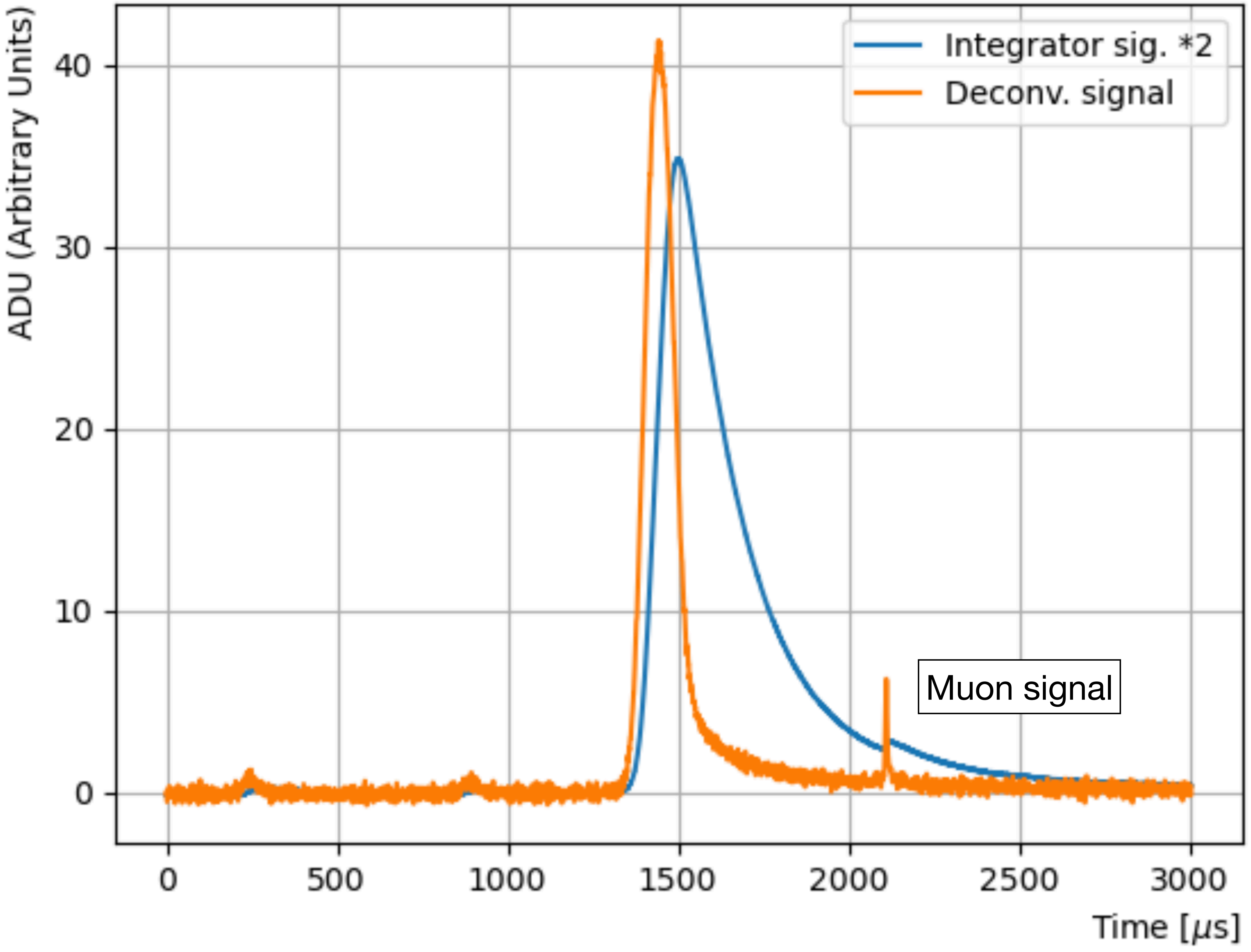
CPC Xenon: Cosmic Background

- 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.



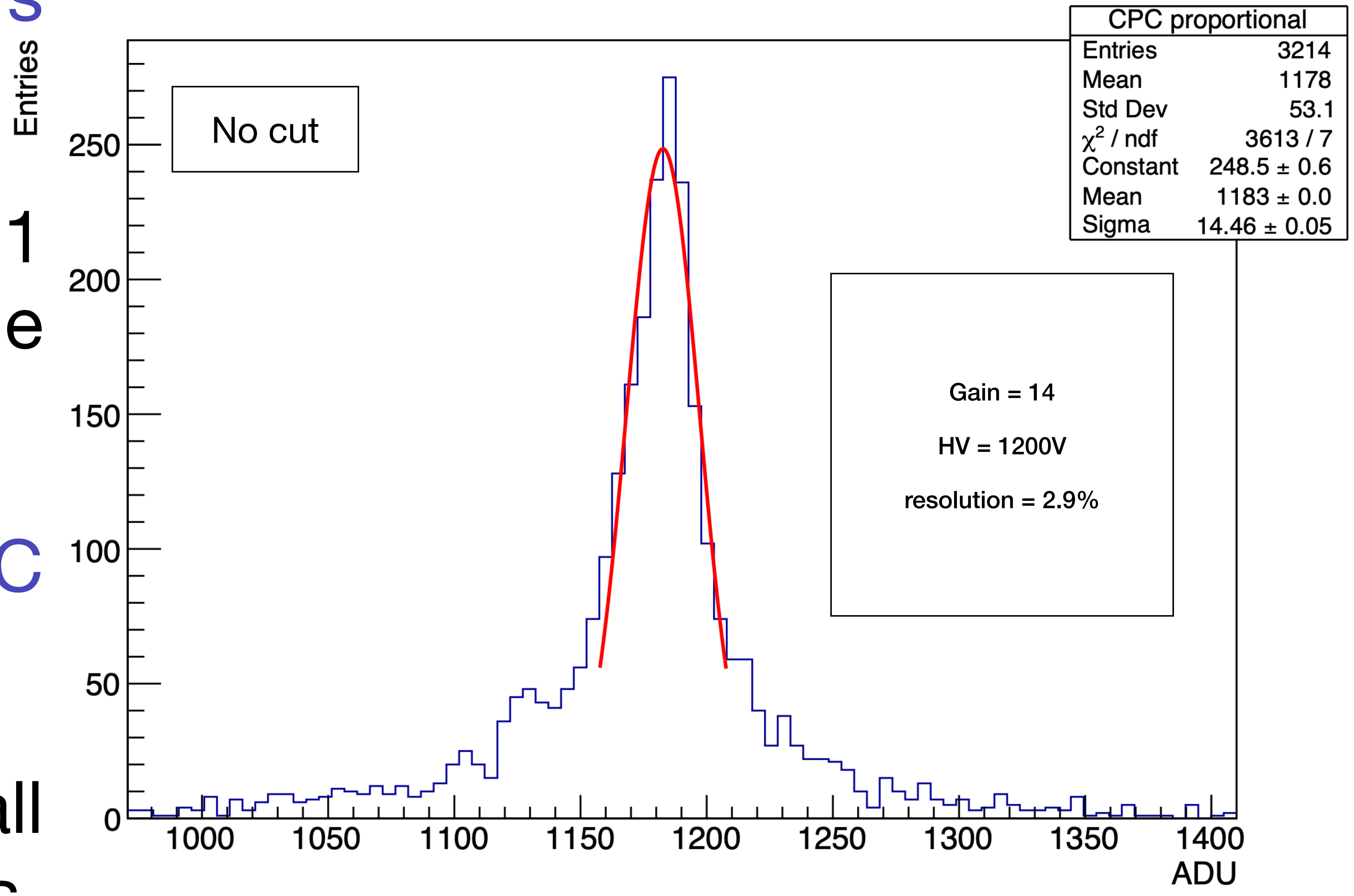
CPC Xenon: Cosmic Background

- 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.



CPC Xenon: Cosmic Background

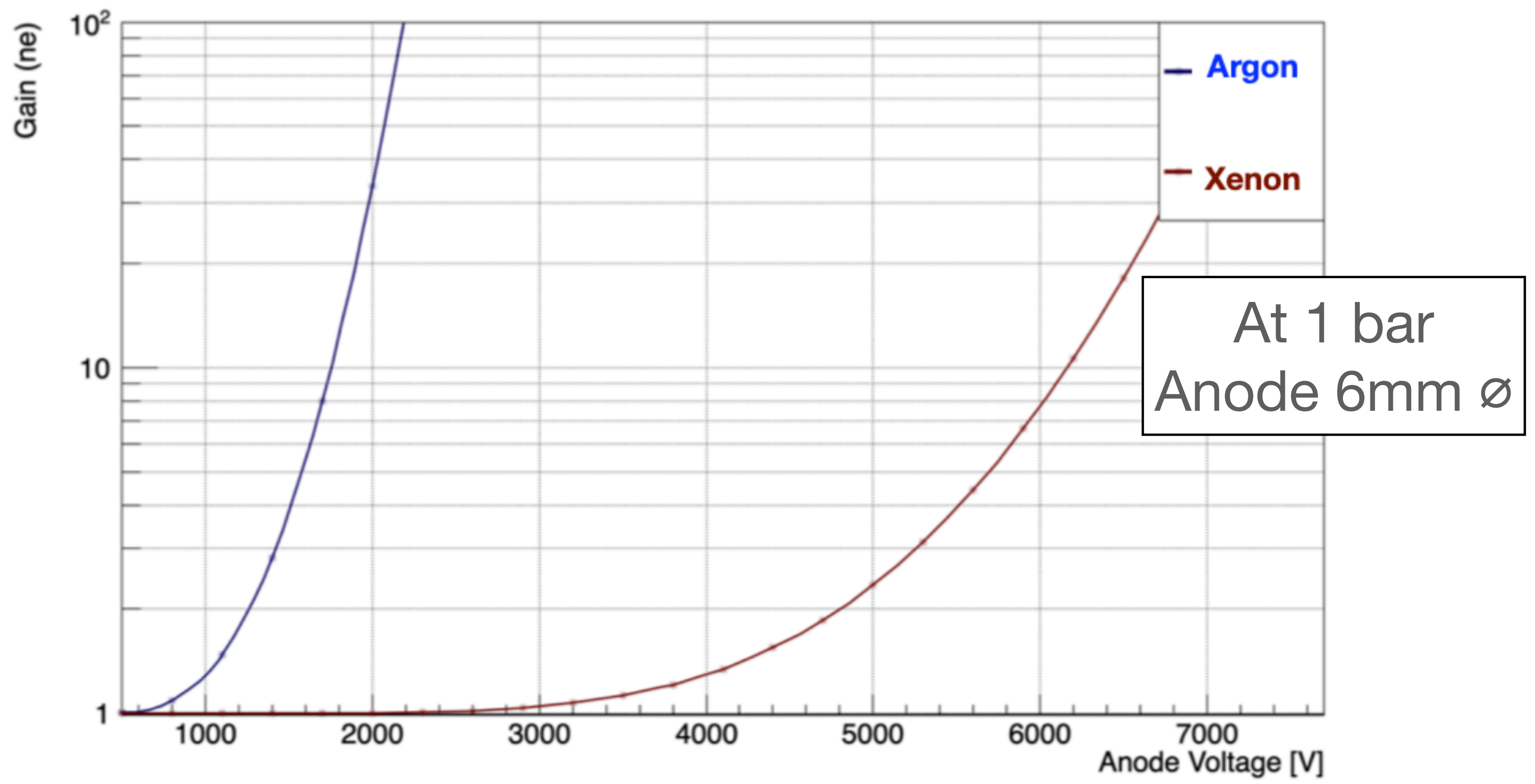
- Unlike our current SPC, the geometry and orientation of our CPC prototype makes it more sensible to cosmic muons background.
- The energy deposit of a muon in Xe at 1 bar is significantly enough degrade the energy resolution of the α particles.
- This explain the right hand tail of the CPC reconstructed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

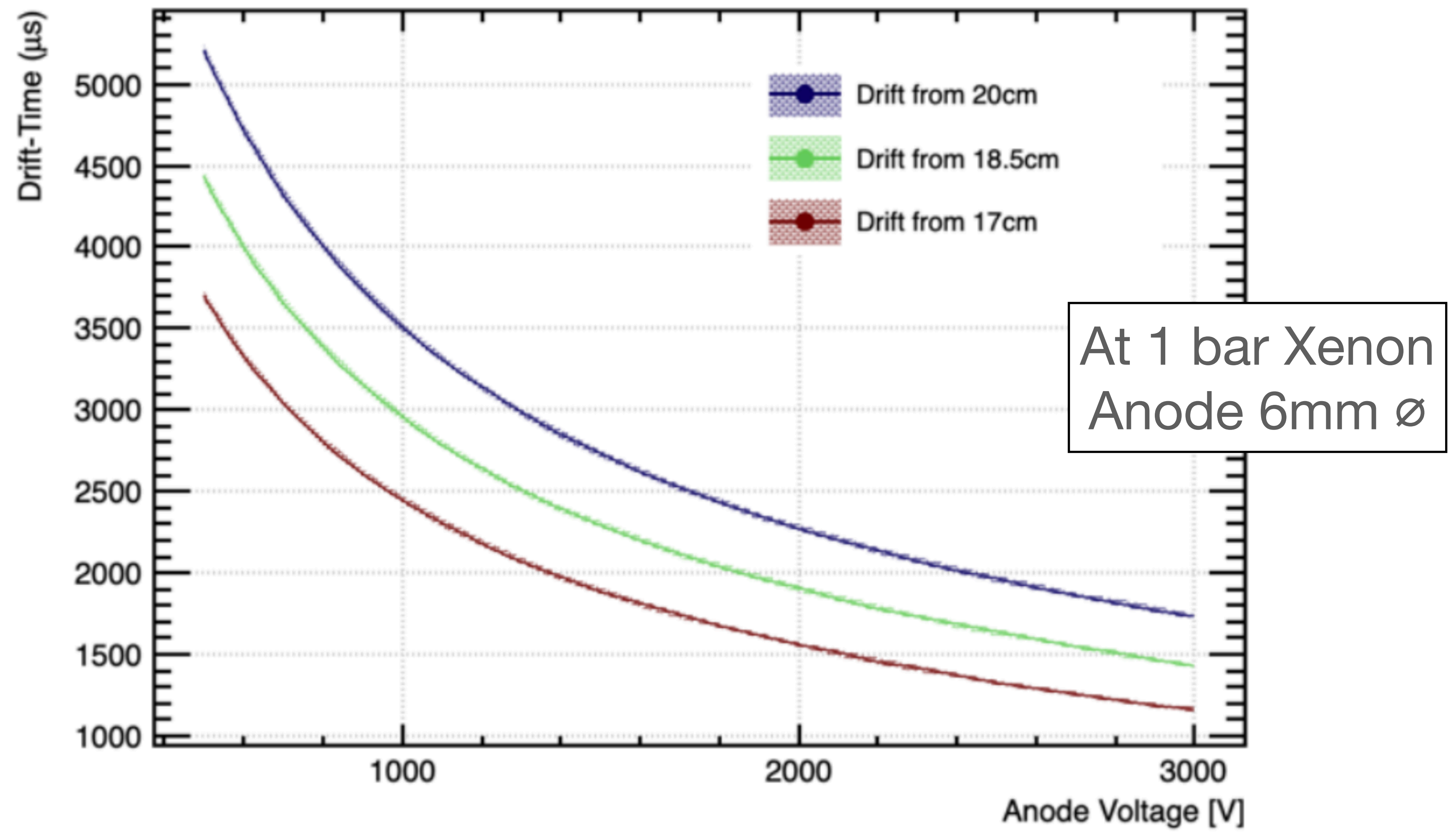


SPC Xenon: Main Difficulties

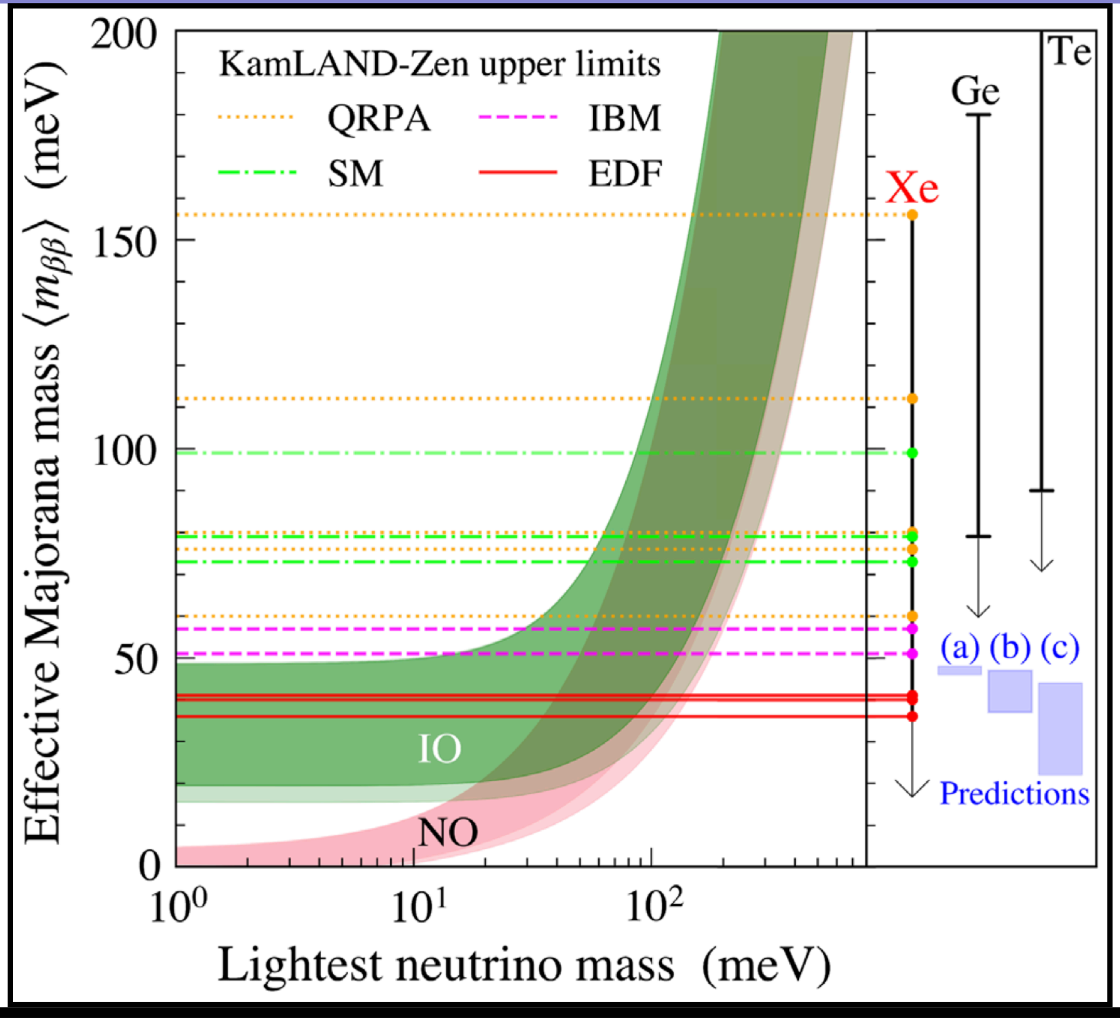
Switching from Ar to Xe implied a lot of challenges to overcome. Aside from the previously discussed technical consideration:

- 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.

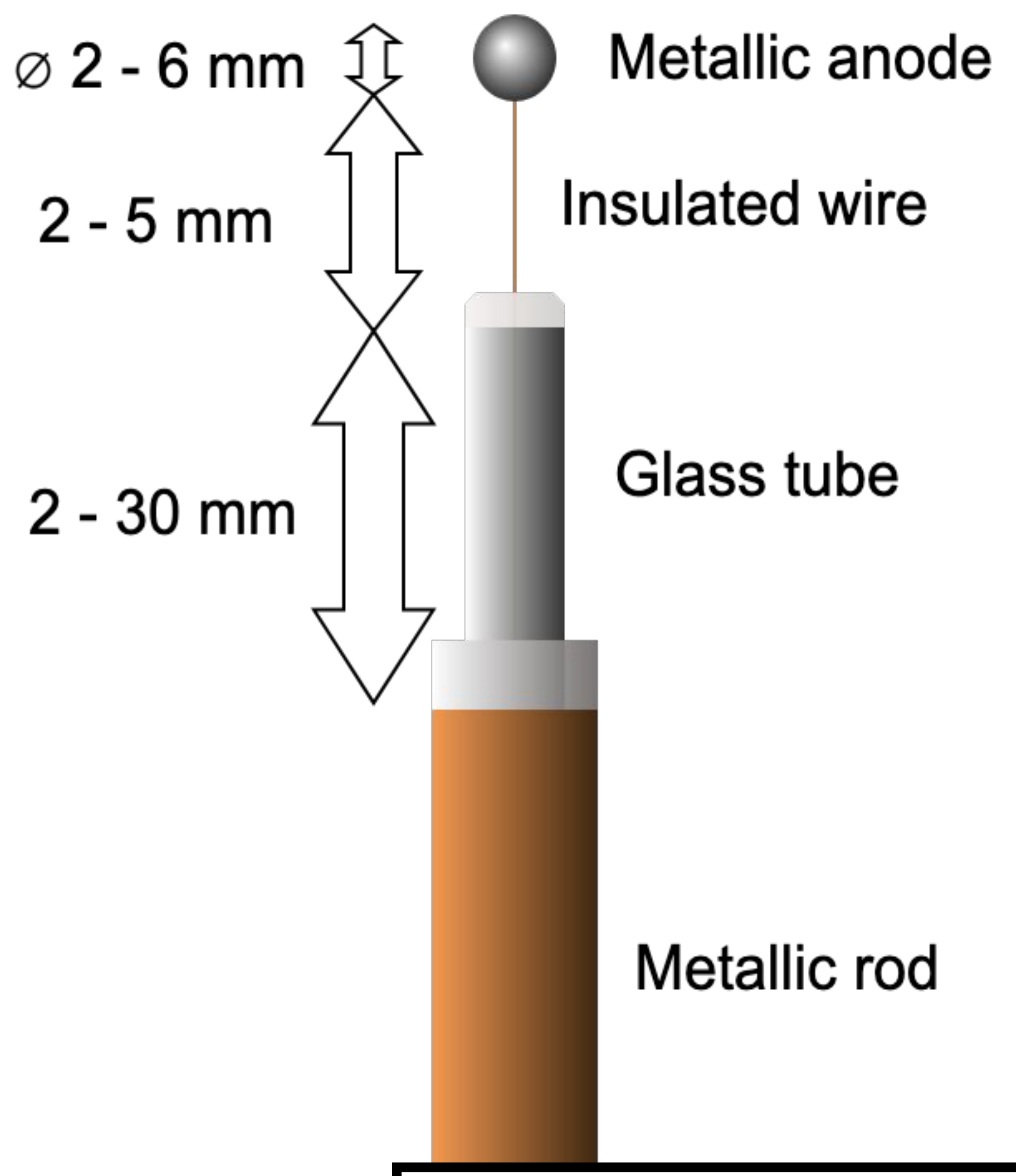




Références



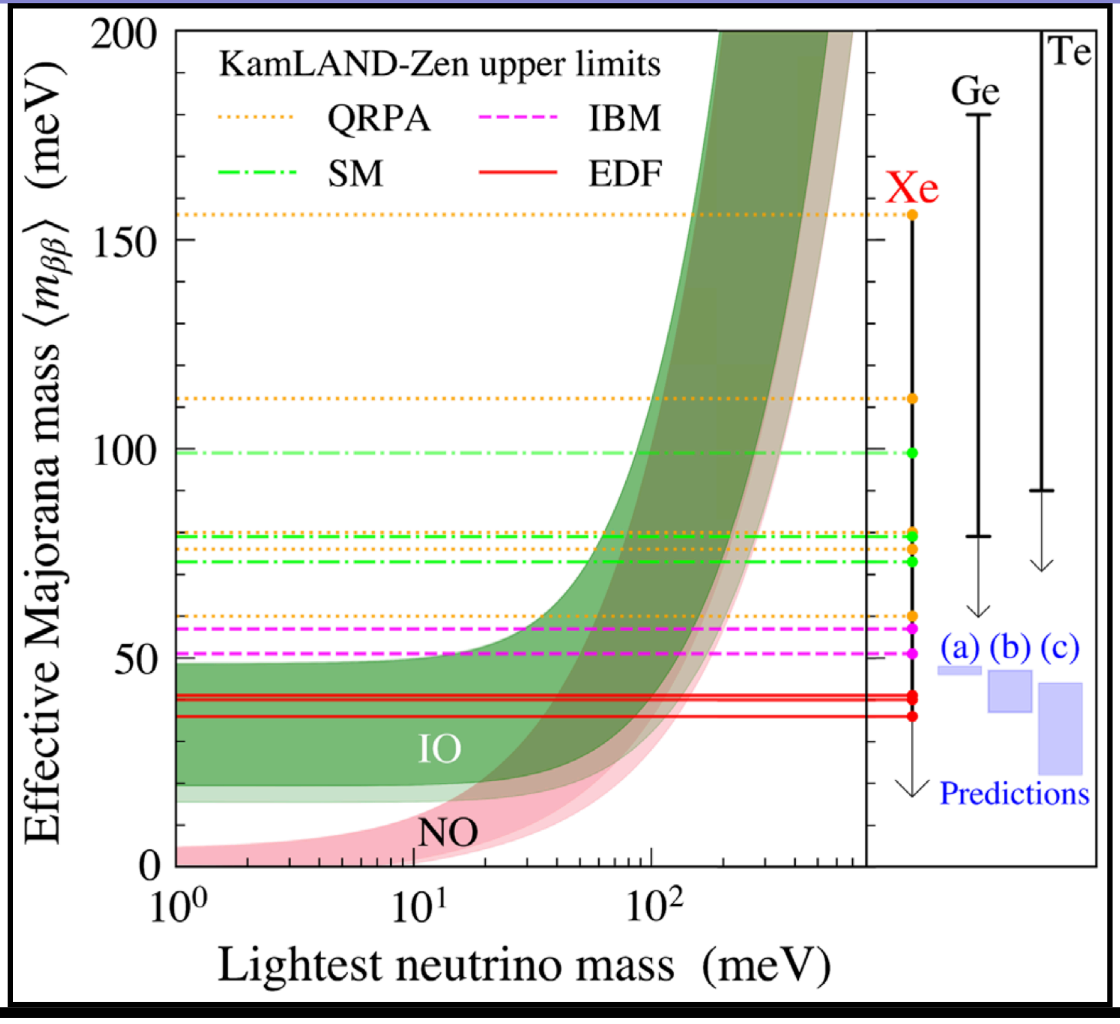
S. Abe et al. Phys. Rev. Lett. **130**, 051801



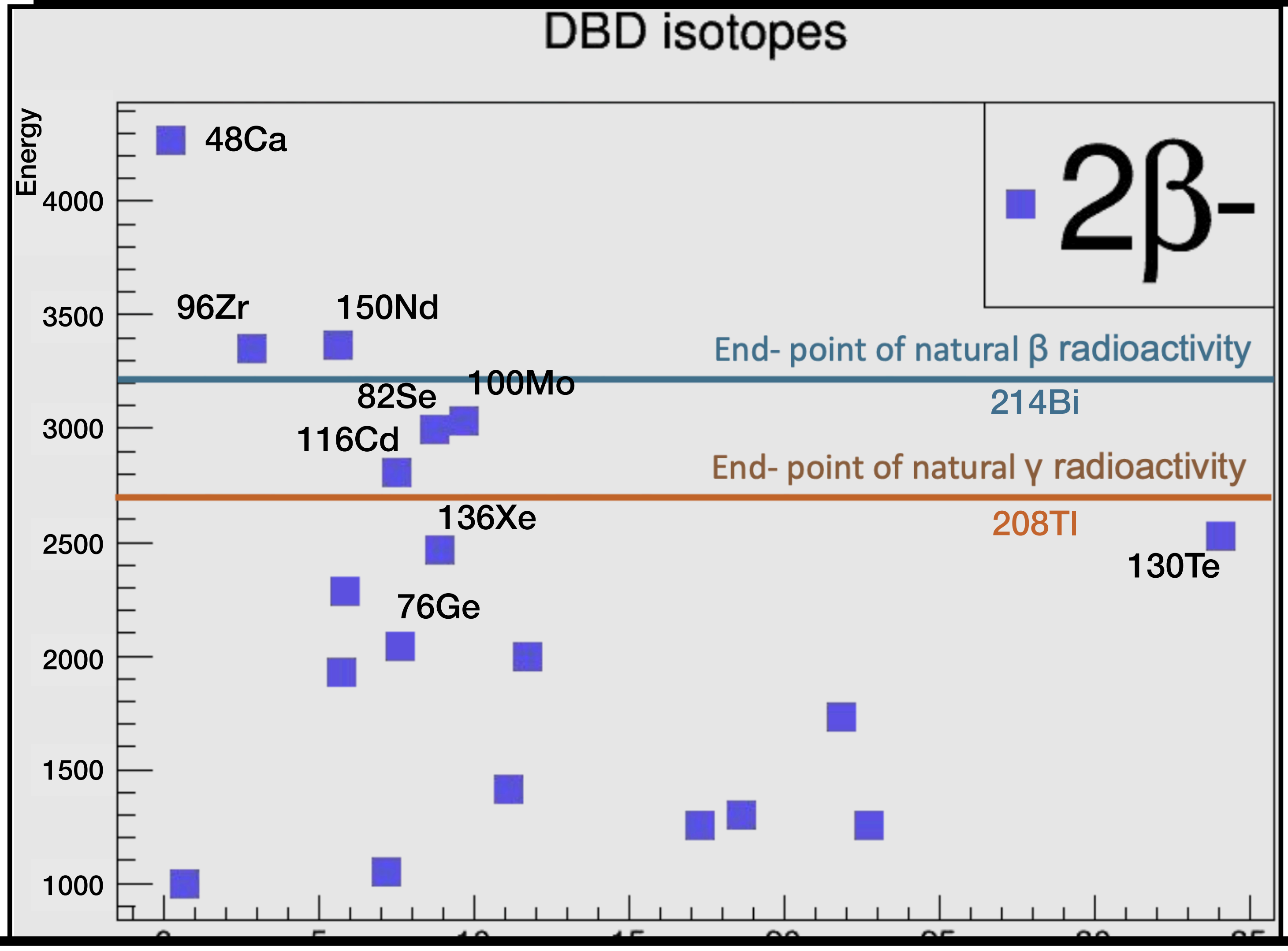
J. Instrum. 13 (2018), (11):P11006
[arXiv: 1809.03270]

EJC 2023 - Lecture on Double beta decay- Anastasiia Zolotarova

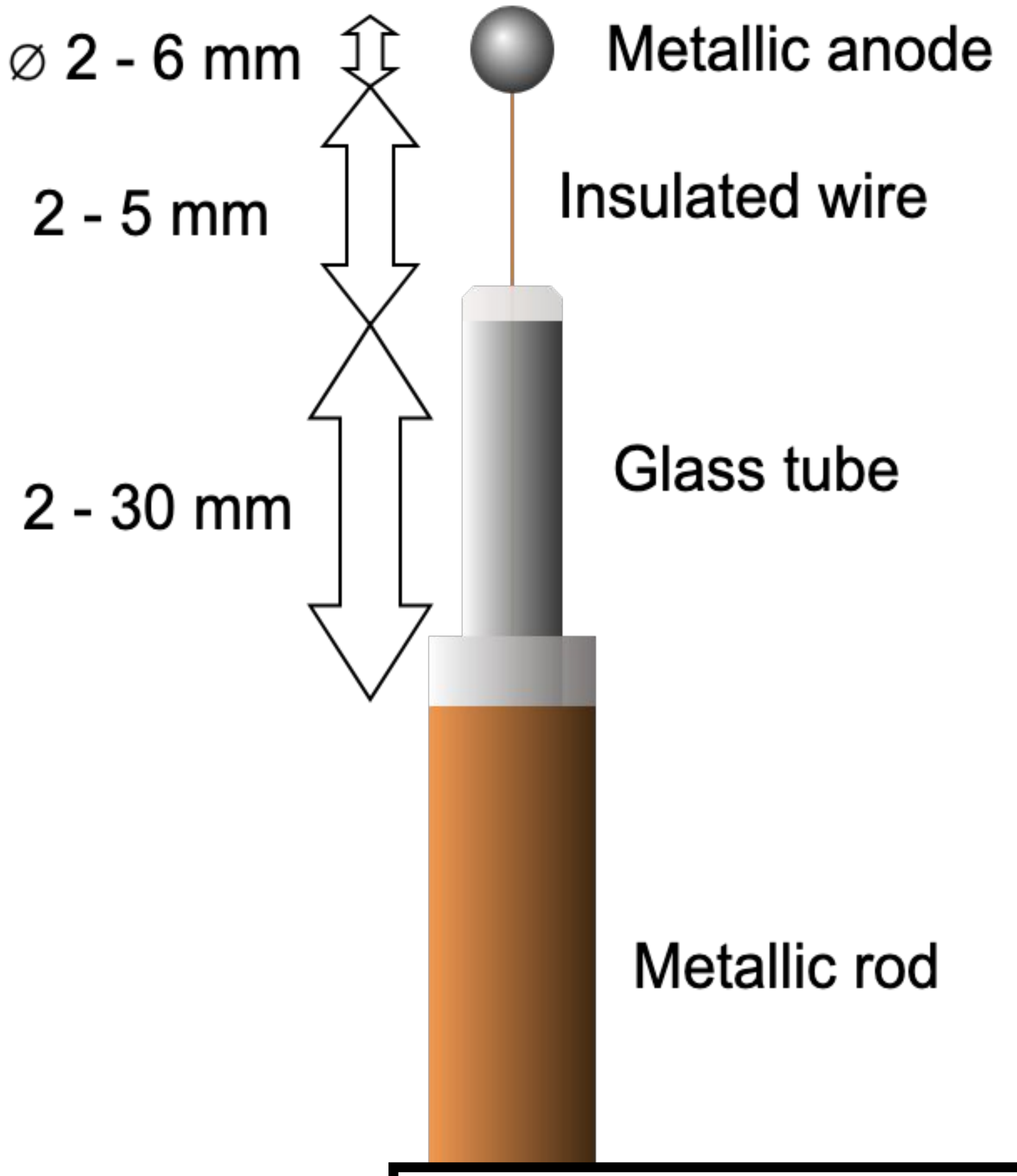
Références



S. Abe et al. Phys. Rev. Lett. **130**, 051801

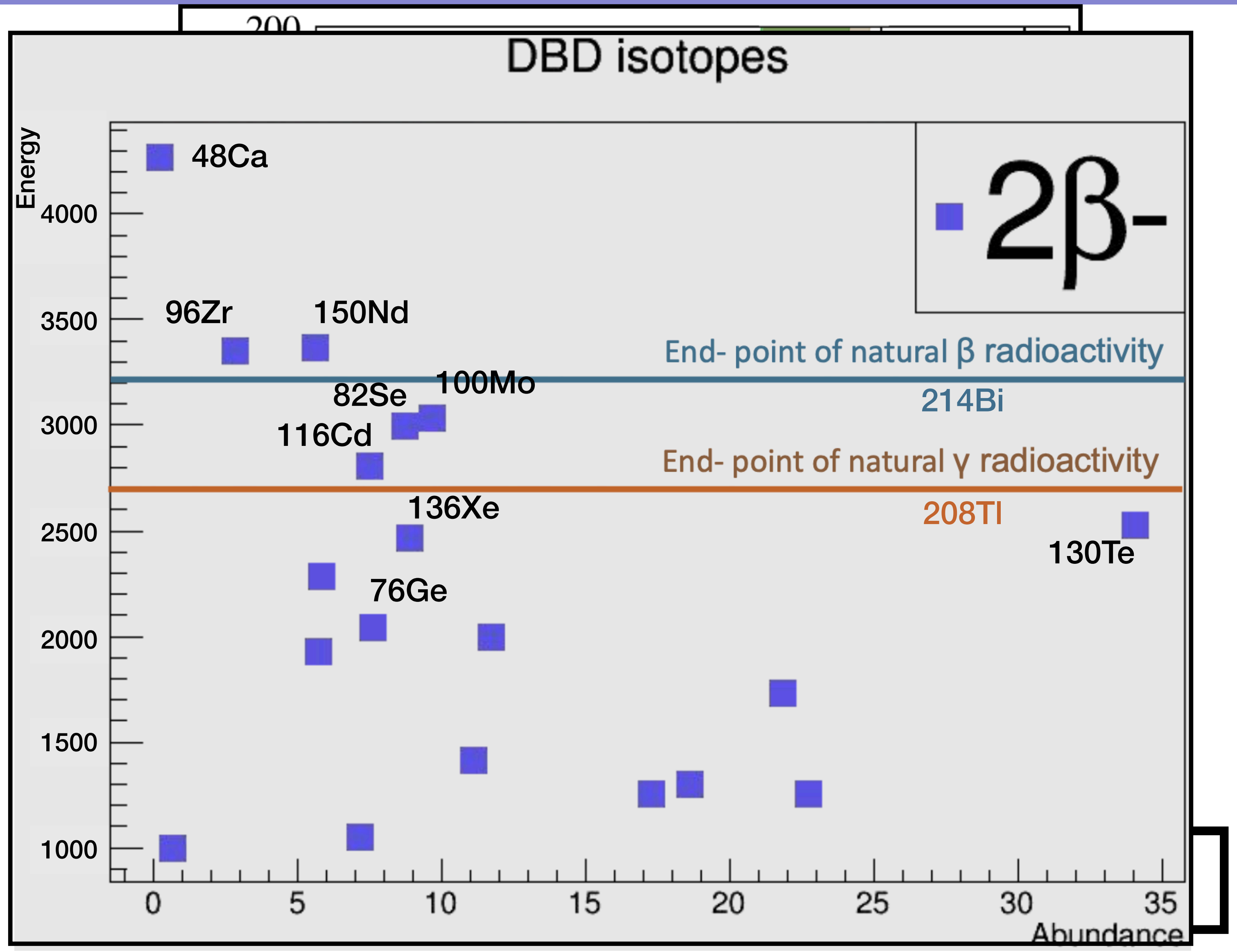


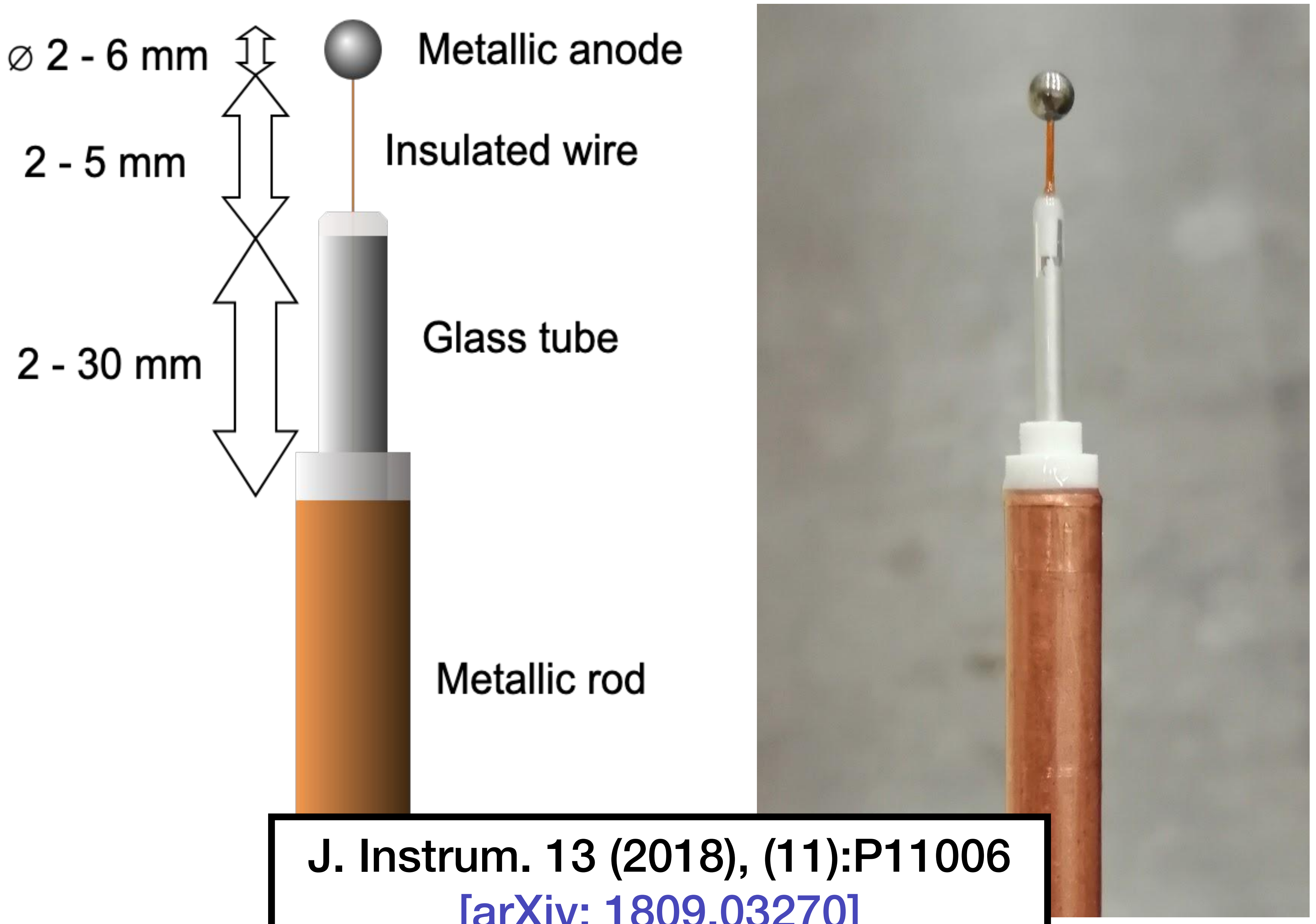
EJC 2023 - Lecture on Double beta decay- Anastasiia Zolotarova



J. Instrum. 13 (2018), (11):P11006
[arXiv: 1809.03270]

Références





J. Instrum. 13 (2018), (11):P11006
[arXiv: 1809.03270]

EJC 2023 - Lecture on Double beta decay- Anastasiia Zolotarova

Neutrinoless double beta decay rate

$$(T_{1/2}^{0\nu2\beta})^{-1} = G(Q,Z)\, g_A^4\, |NME|^2 \left\langle \frac{m_{\beta\beta}}{m_e} \right\rangle^2$$

Phase space factor

Effective Majorana mass, the unknown

Nuclear matrix elements

- Represent the distortion of the electronplane waves in the Coulomb field of the nucleus
- Can be calculated with high precision

$$G^{0\nu} \propto Q_{\beta\beta}^5$$

g_A is the coupling to the nucleon
hard to compute (lattice QCD) but can be measured in other decays: quenching is not defined well

- Represent nuclear structure of the initial and final nuclei
- To calculate it exactly we need the full wavefunction of the nucleus before and after the decay: $M \propto \langle N_f | J_1 J_2 | N_i \rangle$
- Main source of unsertanties for 0ν2β experiments sensitivity

$$\left(T_{1/2}^{0\nu2\beta}\right)^{-1} = G^{0\nu}(Q_{\beta\beta}, Z) \left| M^{0\nu2\beta} \right|^2 \left\langle \frac{m_{\beta\beta}}{m_e} \right\rangle^2$$

Enrichment capability

- Isotopic enrichmentby centrifugation - currently, the only viable large scale method
- Costs: 10-80 eur/g - big fraction of the total cost of the experiment
- Market of stable isotopes for medical applications
- Geopolitics impacts access to production: Russian agression in Ukraine impacts some DBD experiments directly