# R2D2
# Rare Decays with Radial Detector

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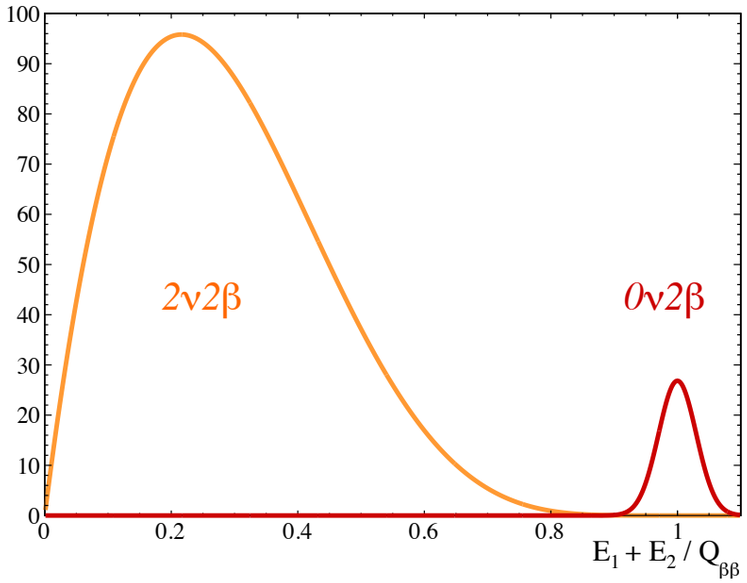
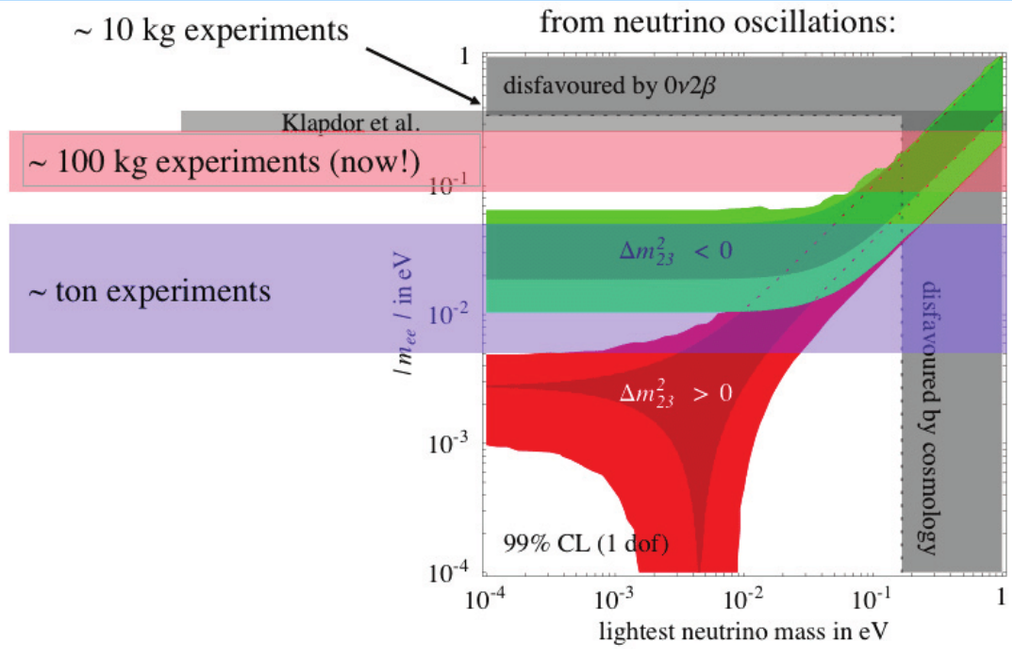
24/05/2023

# Introduction

- To demonstrate the Majorana nature of neutrino the most sensitive experimental way is an observation of the so called **0νββ decay**.
- The measurement relies on the observation of a peak in the distribution of the energy of the two electrons corresponding to the $Q_{\beta\beta}$ of the reaction.
- Experiments so far are just hitting the inverted mass hierarchy region and to fully cover it we need a ton scale experiment.




**Requirements**

**Excellent energy resolution**

**Low background**

**Large masses of isotopes**

# Status

- Presently used technologies do not meet all the requirements at the same time.

| | Energy resolution | Low background | Large isotope masses |
|---|---|---|---|
| Solid state detectors | **Extremely good (0.1% at Q value)** | **Extremely low (zero background)** | **Large number of crystals/ electronics channels Difficult scalability to large masses** |
| Liquid Xenon experiments | **Order of 4% at Q value** | **Far from zero background** | **Ton scale easily achievable** |
| Gaseous Xenon experiments | **Order of 1% at Q value** | **Far from zero background** | **Complex detector Feasible at ton scale?** |

**Can we meet all the requirements at the same time?** → **goal of R2D2**

**Can we additionally perform PID and tracking?**

**R2D2 is an R&D program aiming at the development of a zero background ton scale detector to search for the neutrinoless double beta decay.**

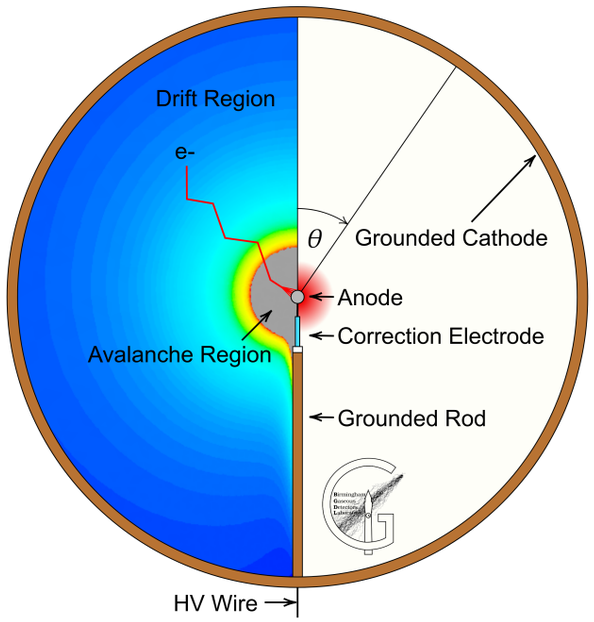
# Detector

- **Two options** (**NEW since last CS**) are considered in the R&D: a spherical Xenon gas proportional counter (SPC) as proposed by Giomataris et al. and used today in the NEWS-G collaboration for the search of dark matter, and a cylindrical proportional counter (CPC).
- Both setups have the critical feature for the search of $\beta\beta0\nu$.

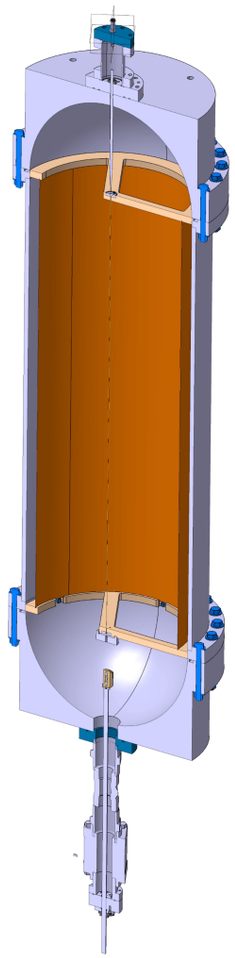
**To be validated**
**Main goal of R2D2 R&D**

**Detector features**

- High energy resolution (goal of 1% FWHM at $^{136}Xe$ $Q_{\beta\beta}$)
- Extremely low background due to the very low material budget.
- Scalability to large isotope masses.
- Low detection threshold at the level of 30 eV i.e. single electron signal.
- Simplicity of the detector readout with only one (or few in the upgraded version) readout channels.




**SPC**



**CPC**

# 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.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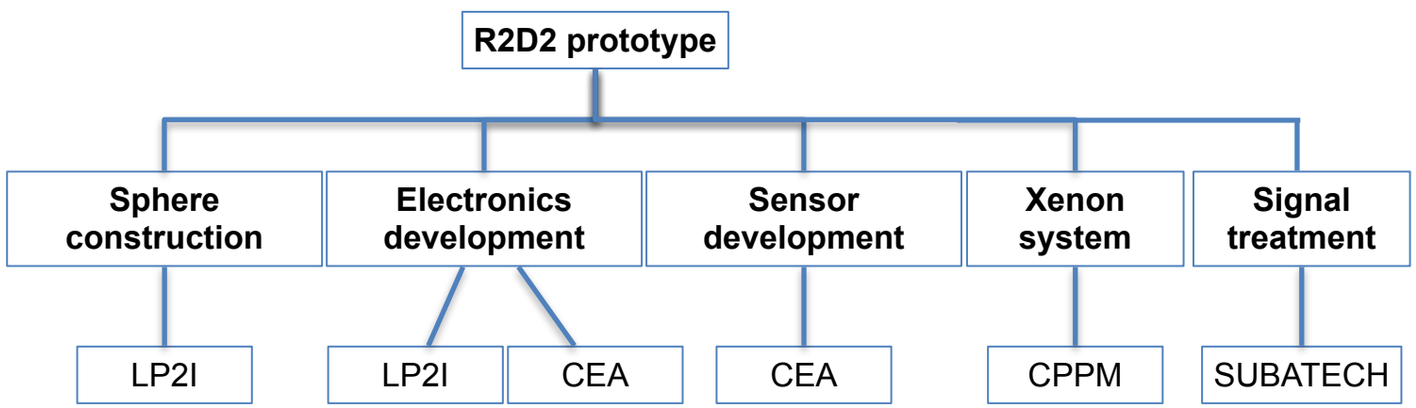


# Sensitivity studies

- 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.

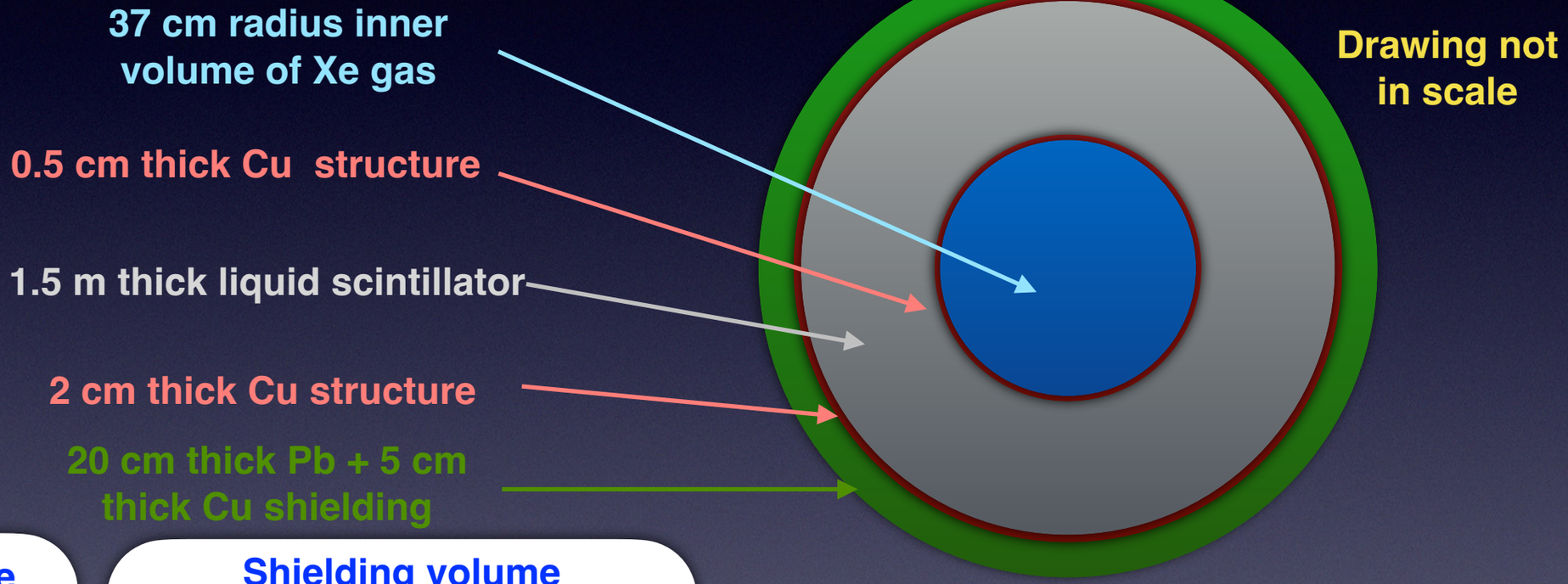
**Xenon active volume**

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.




**Liquid scintillator volume**

Thickness of 1.5 m

Assumed to be LAB

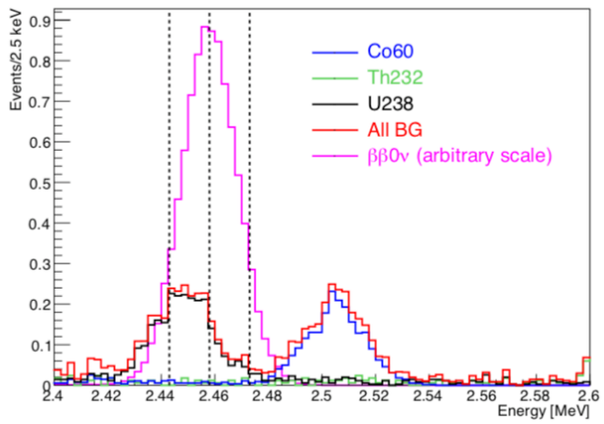
The thickness is chosen in order to have a background rate below 0.1 events per year from the $^{208}$Tl contamination of the liquid scintillator vessel.

**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*

# The R2D2 Roadmap

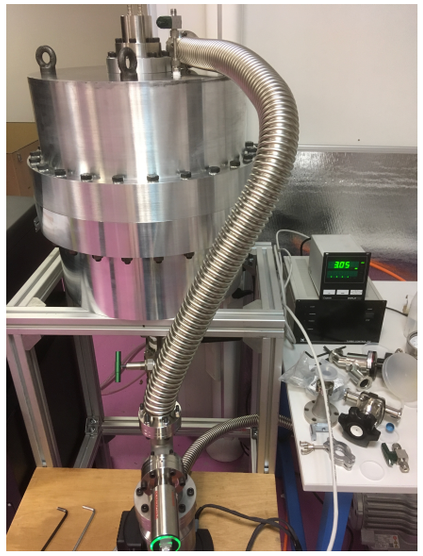
**Prototype 1**

**Running - Funded by IN2P3 R&D**

Up to 10 kg (40 bars) Xenon prototype (no low radioactivity) to demonstrate the detector capability in particular on the energy resolution

Demonstrator

**If prototype 1 successful and prototype 2 funded**



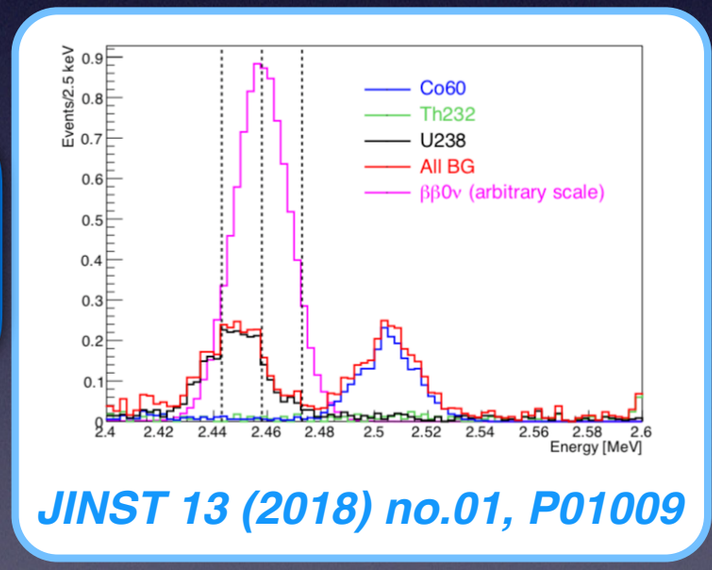
**Prototype 2**

**Sensitivity studies carried out**

50 kg Xenon detector (low radioactivity) with LS veto for first physics results to demonstrate the almost zero background

$m_{\beta\beta}$ < 160 - 330 meV

**Depending on the results and fundings**




*JINST 13 (2018) no.01, P01009*

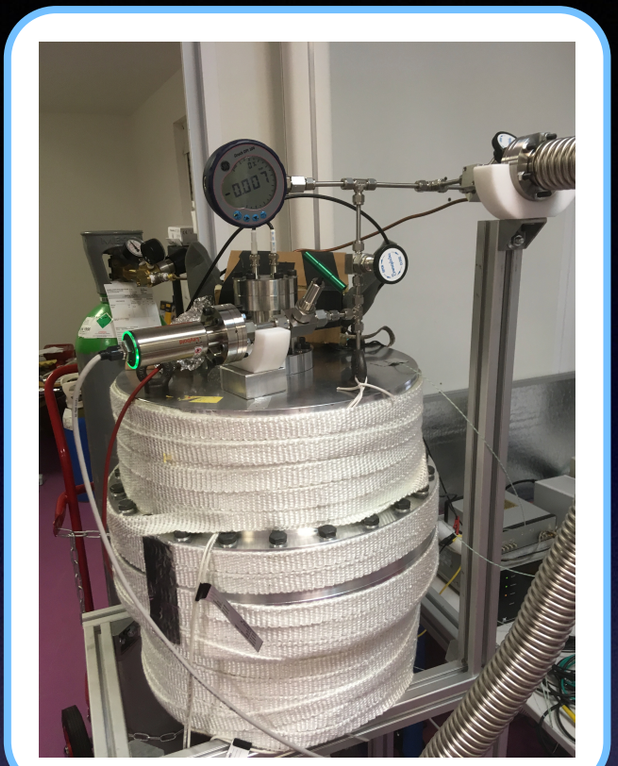
**Experiment**

Going towards a 1 ton background free detector

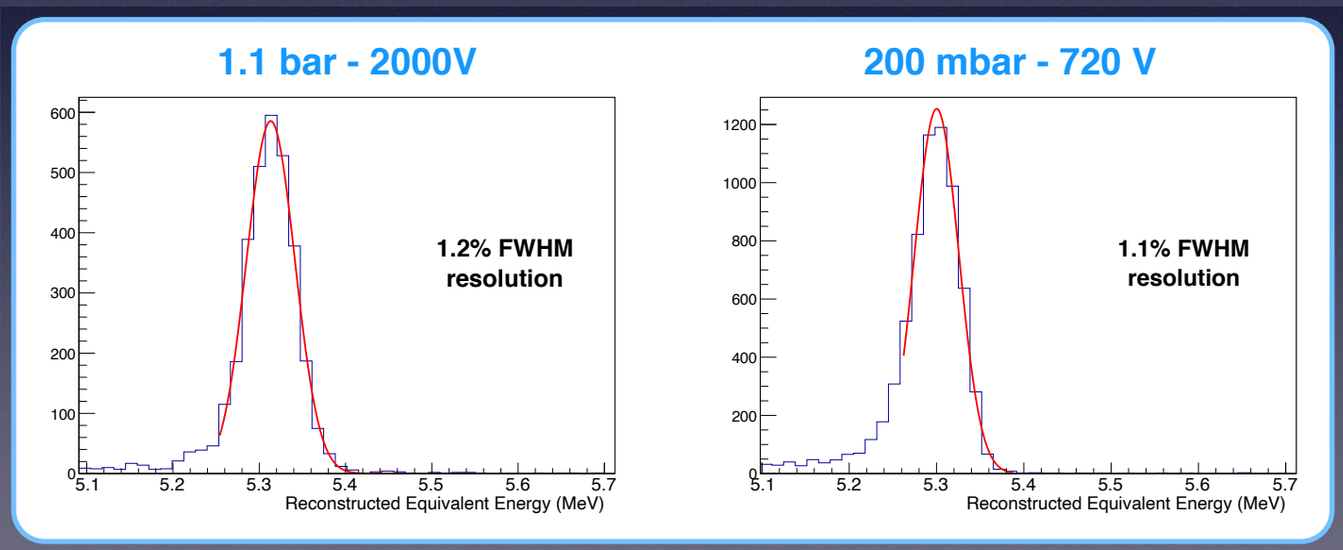
$m_{\beta\beta}$ < 10 meV (I.H. covered)

# Milestones: Prototype S1.0

- In 2018 the R2D2 was funded as R&D by the IN2P3: **prototype S1.0 for a SPC 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 Ar (98%) + $CH_4$ (2%)** at LP2IB at **pressures up to 1.1 bar**. First resolution results were published (*JINST* 16 (2021) 03, P03012).



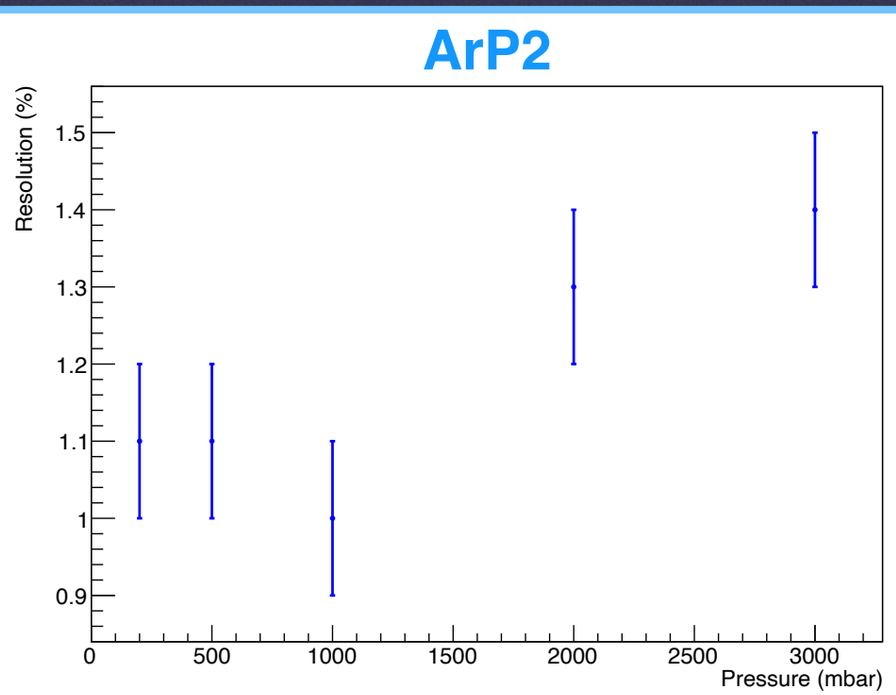
- A detailed simulation was setup to confirm our detector understanding: the **agreement between data and simulation is very good** and the detector behaviour is well understood.
- The resolution was computed at 200 mbar and 1.1 bar: we obtained a similar resolution showing **no impact due to the length of the tracks** (from 3-4 cm at 1.1 bar to 15-20 cm at 200 mbar).




***JINST 16 (2021) 03, P03012***

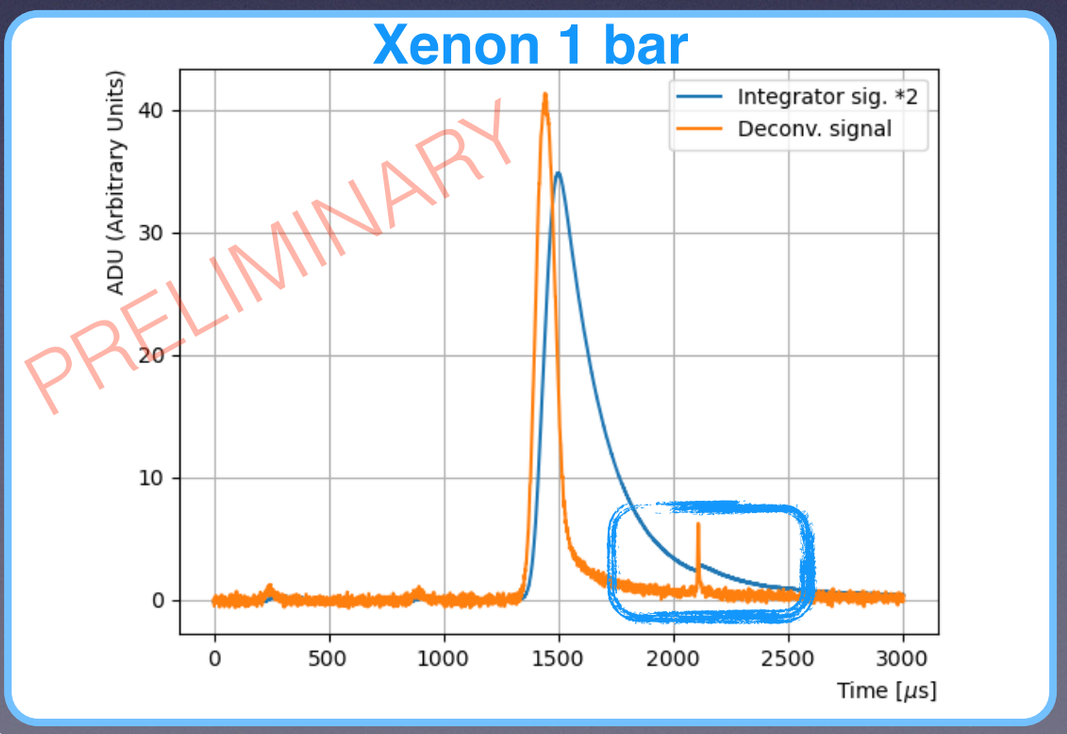
# Milestones: Prototype S2.0

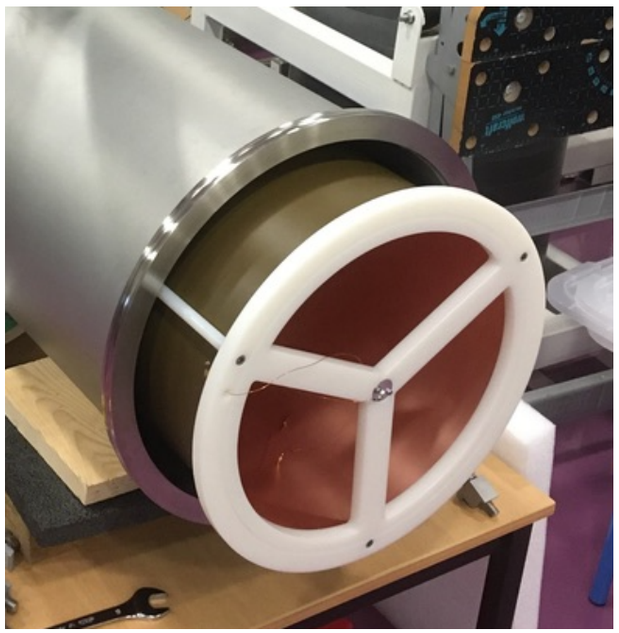
- In 2021 the second prototype (**prototype S2.0 for SPC**) certified to be operated up to 40 bar was built by RAVANAT company.
- In the meantime the xenon recirculation and recuperation system was finalized and commissioned.
- In 2022 the detector was **operated with Ar (98%) + $CH_4$ (2%)** at LP2IB at **pressures up to 3 bar**. A set of measurement was carried out with a **resolution below 1.4% up to 3 bar**.
- The limit of 3 bar is given by the actual limit on the HV of 5 kV (power supply, filters and central sensor).
- First **signals were also observed in xenon up to 1 bar**.
- Gas purity is still an issue (no hot getter) and larger anode is needed however this limits the SPC to work in ionization mode and resolution is limited by the noise.



# Milestones: Prototype C1.0

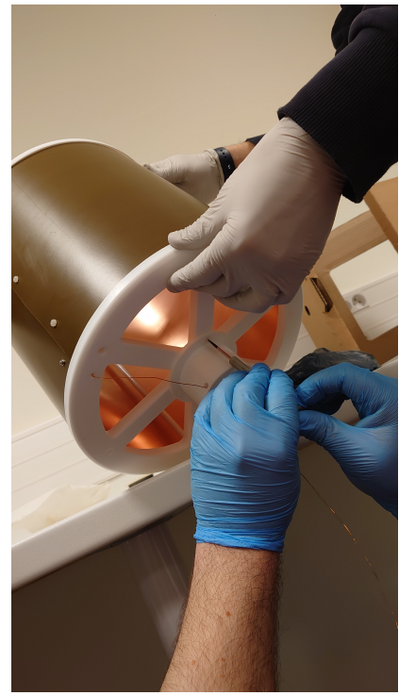
- In 2021 the first prototype for CPC was conceived and built at SUBATECH (**prototype C1.0 for CPC**).
- A 10μm radius grounded wire is in the middle and the cathode is set to negative HV.
- First validation in ArP2 showed a **resolution comparable with SPC (1.2% at 1 bar)** at lower voltage.
- The setup was filled with **xenon** at 1 bar and clean signals were observed. **A resolution of 1.8% was achieved** dominated by gas purity and the presence of cosmic muons creating pile up (1.4% in a sample cleaned from cosmics).

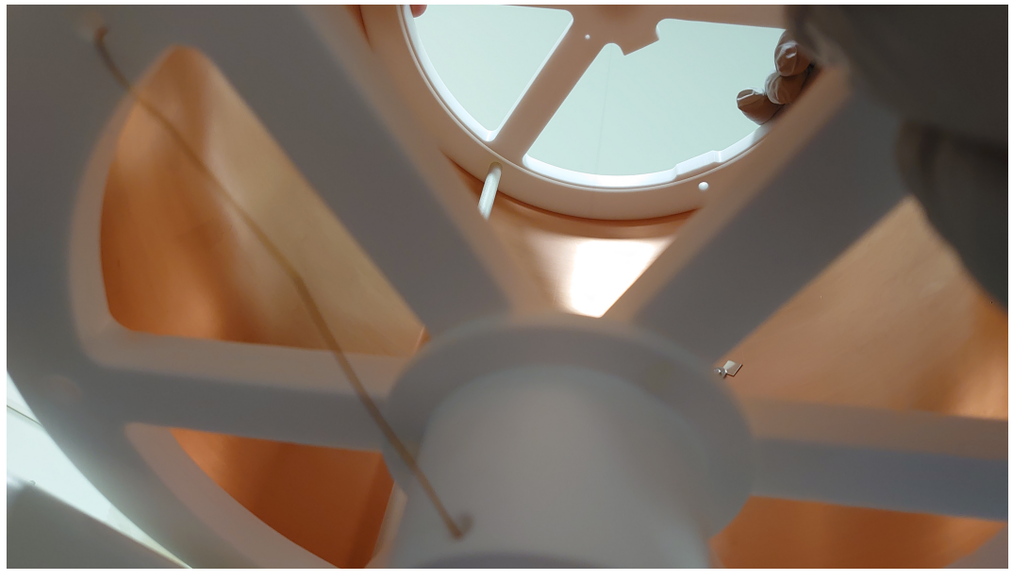


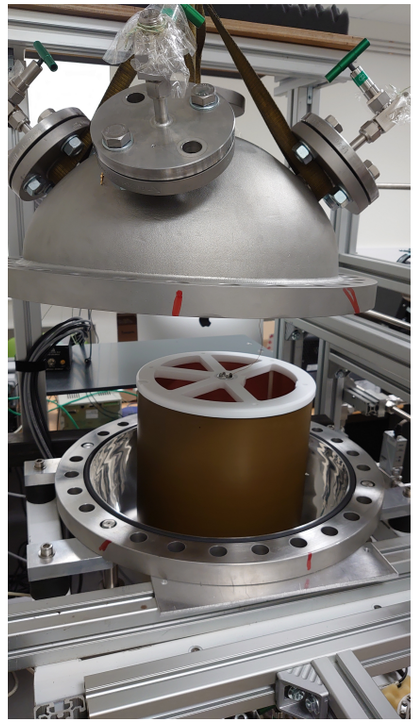



# Milestones: Prototype C2.0

- In 2023 the second prototype for CPC was conceived and built at SUBATECH (**prototype C2.0 for CPC**).
- It consists of a small CPC to be operated inside the sphere (S2.0) in order to test the detector at high pressure.
- First test in ArP2 showed a good behavior of the **CPC up to 15 bars**. Tests in xenon were carried out up to 3 bars as well.
- The limiting factor right now is the gas purity. The hot getter was received in May 2023 and should solve this issue.







# Results summary

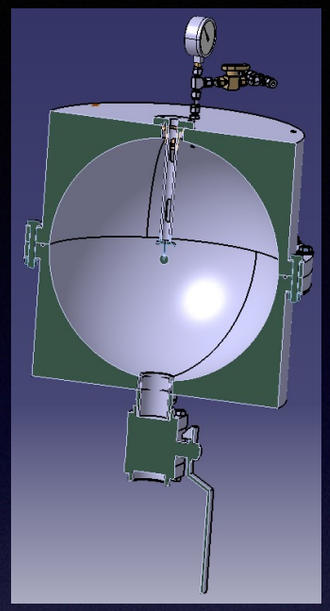
- SPC in proportional mode is limited at HV since noise increases with HV. In ionization mode the limit is given by the electronic noise.
- Noise in the CPC is smaller (independent on the HV) and resolution in ionization mode is better.
- CPC in proportional mode requires smaller HV and resolution is good enough. At high pressure the limit is given by the gas purity.

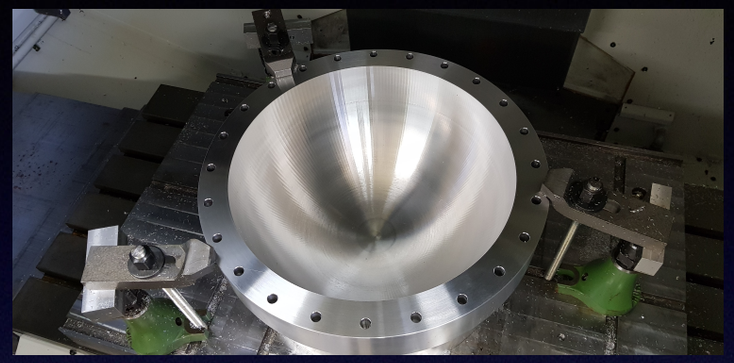
| Gas | Setup | Anode (radius) | Pressure | HV | Noise (ADU) | Gain | Resolution |
|---|---|---|---|---|---|---|---|
| ArP2 | SPC | 1 mm | 200 mbar | 800 | 4.3 | 45 | 1.1% |
| | | | 500 mbar | 1300 | 4.1 | 34 | 1.1% |
| | | | 1000 mbar | 1900 | 4.2 | 30 | 0.9% |
| | | | 2000 mbar | 2700 | 4.5 | 10 | 1.3% |
| | | | 3000 mbar | 3900 | 4.8 | 10 | 1.3% |
| | | 3 mm | 1000 mbar | 700 | 4.4 | 1 | 8.2% |
| | CPC | 10 $\mu$m | 1000 mbar | 200 | 3.6 | 1 | 4.9% |
| | | | 1000 mbar | 900 | 3.9 | 9 | 1.2% |
| Xe | SPC | 3 mm | 250 mbar | 1300 | 4.5 | 1.3 | 3.8% |
| | | | 900 mbar | 1300 | 4.4 | 1 | 7.2% |
| | CPC | 10 $\mu$m | 500 mbar | 900 | 3.8 | 20 | 1.8% |
| | | | 1000 mbar | 1200 | 3.9 | 14 | 1.8% |

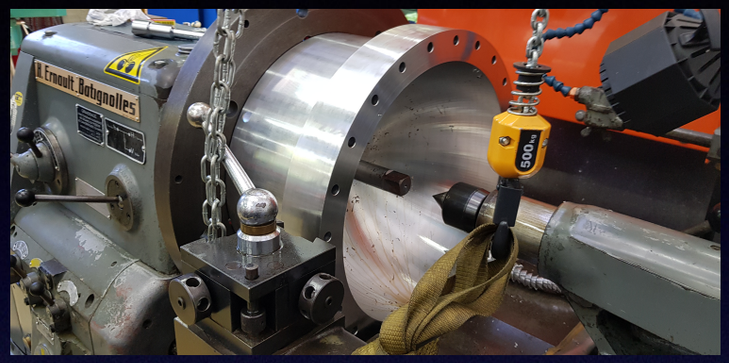
Table 1: *Summary of different experimental setup configurations and corresponding resolution obtained. Note that the cosmic reduction analysis is not accounted for in the table. The baseline noise in terms of ADU as well as the approximative operation gain are also stated.*

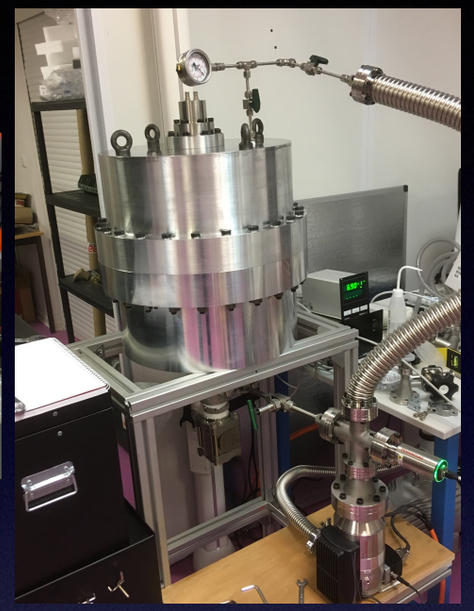
**CPC seems to be easier to operate and yields better results therefore it will be the design baseline for future steps**

# RH contribution at LP2I







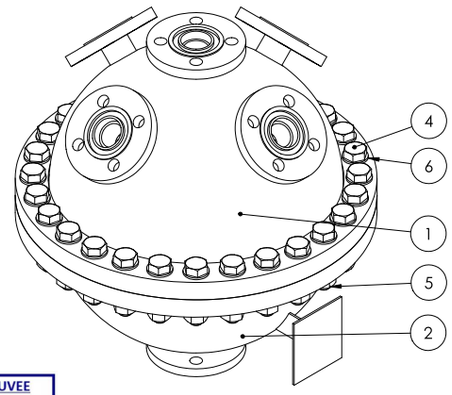
**Scientific coordinator: A. Meregaglia**
**Technical coordinator: P. Hellmuth**

- **Mechanics (M. Roche, F. Munoz, J. Outrequin, A. Tempel)**
  - Design, construction and installation of S1.0 detector (Aluminum sphere).
  - Support structure for the other prototypes.
- **Electronics (F. Druillole, P. Hellmuth, A. Rebii, R. Bouet)**
  - Construction splitter signal/HV, help on the noise reduction.
  - Custom electronics development.
  - DAQ development, A.I. development.
- **Instrumentation (B.Thomas, G.Claverie)**
  - Conception of detector concerning vacuum and high pressure, recirculation and recuperation, and help on the commissioning of the detector.

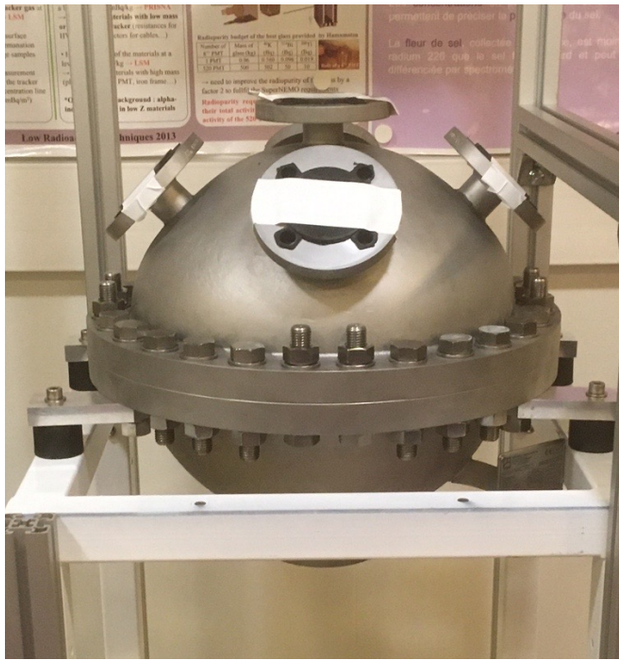
# Technical developments

## Mechanics

- The main issue on the mechanics are:
  - Need of vacuum at the level of $10^{-8}$ mbar.
  - Certification to operate at 40 bars.
- "vacuum" and "high pressure" are expertises quite different and our mechanic pool struggled to have these two domains talking to each other.
- **Certification is extremely expensive** for relatively easy task. Any additional piece added to the detector (flange, tube, etc.) has to be certified and no in-house welding is allowed which makes the evolution of the setup slower and more expensive. **Is there a solution at IN2P3?** Just a few examples:
  - The S2.0 Prototype costed 15keuro.
  - A quotation for a cylinder certified was 25keuro.
  - A welding of a tube on a bottle costed 2keuro.




CONCEPTION APPROUVEE
Suivant DESP 2014/68/UE
N° E-F-20-09-RAVANAT-10545
Les remarques indiquées sur le courrier d'accompagnement sont à prendre en compte.
Metz, le 17 SEPTEMBRE 2020
TÜV SÜD Industrie Service GmbH
Organisme Notifié n°0036

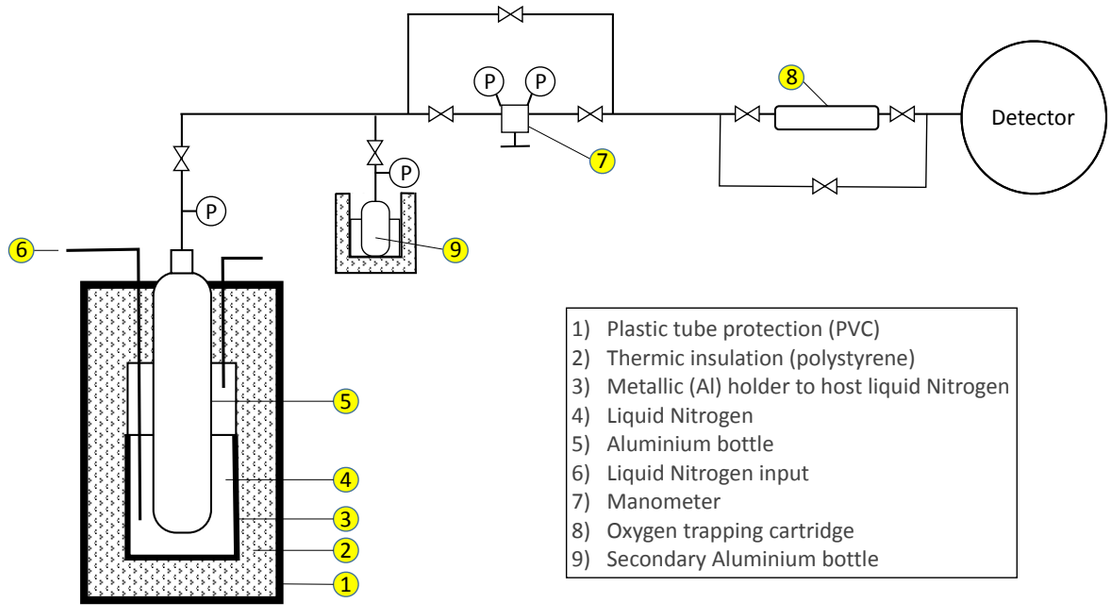


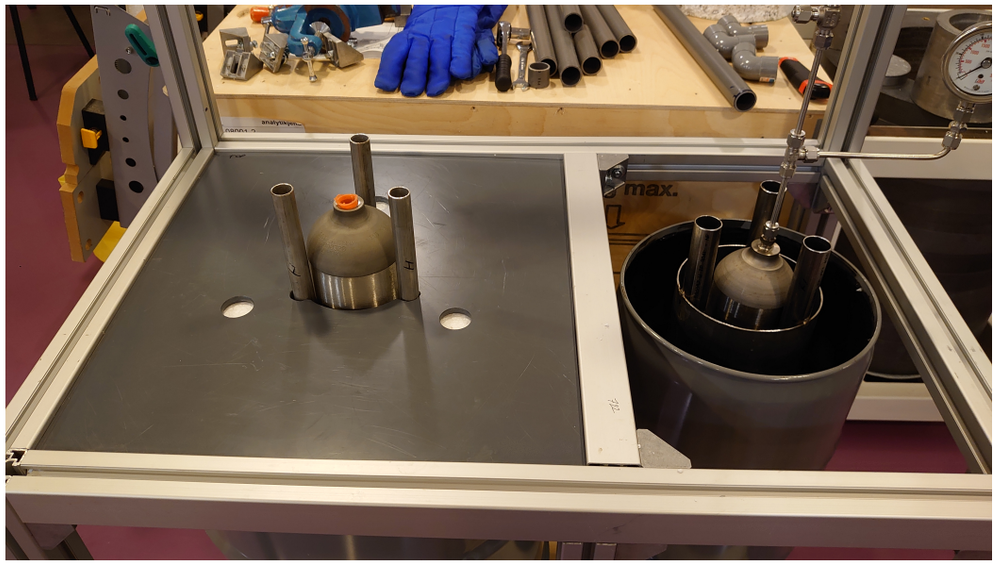
# Technical developments

## Gas system (1)

- Operating the detector with xenon need a **very high gas purity** (sub-ppm?) and an **efficient recuperation and recirculation system**.
- The recuperation system is based on cryogenic pumping and the know how is well established (in particular we rely on CPPM).
- The purification relies on commercial cartridge (such as cold getter oxysorb) and the use of hot getter (not present today in our setup) should improve the purification.
- **The issue is the recirculation of the gas at high pressure**. The actual pump works up to a few bars and cartridges can be operated up to 17 bars.
- Expertise exist in the international community (XENON, PANDA-X, etc.) and we hope to profit from the SUBATECH expertise of the XENON group.

### Recuperation system from CPPM

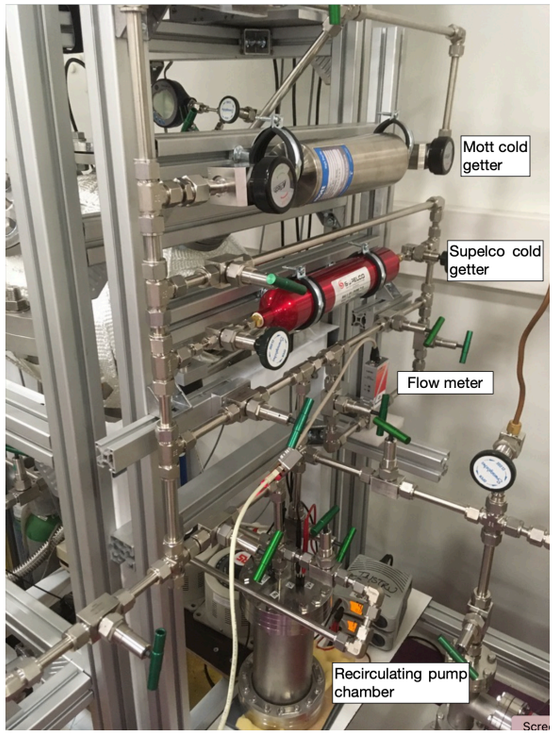


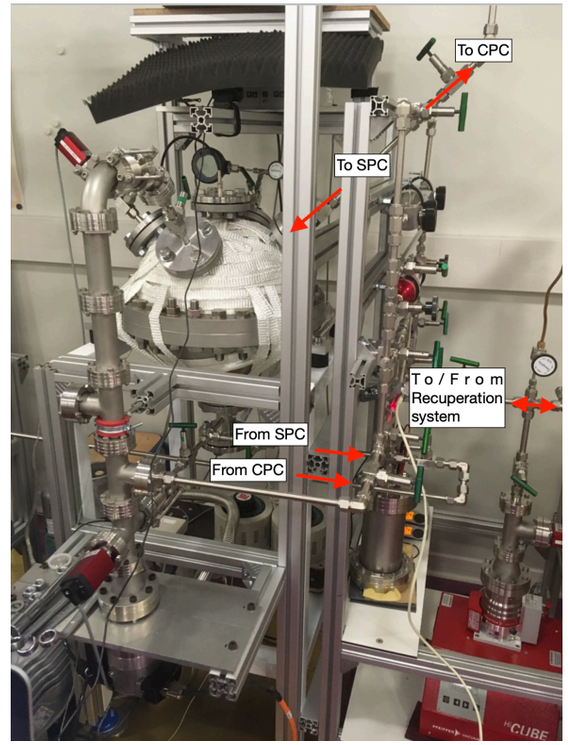



# Technical developments

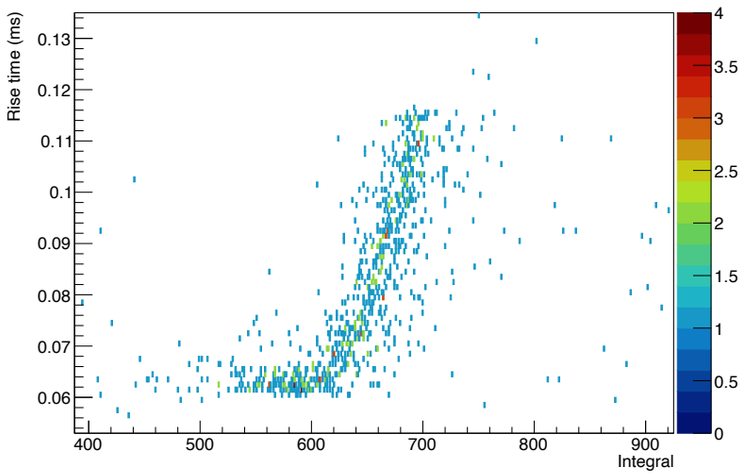
## Gas system (2)

- **Full system commissioned in 2022**.
- Flowmeters showed a recirculation at the level of 1.5 liter per minute depending on the gas pressure.
- **Impact of the recirculation clearly seen in data.**

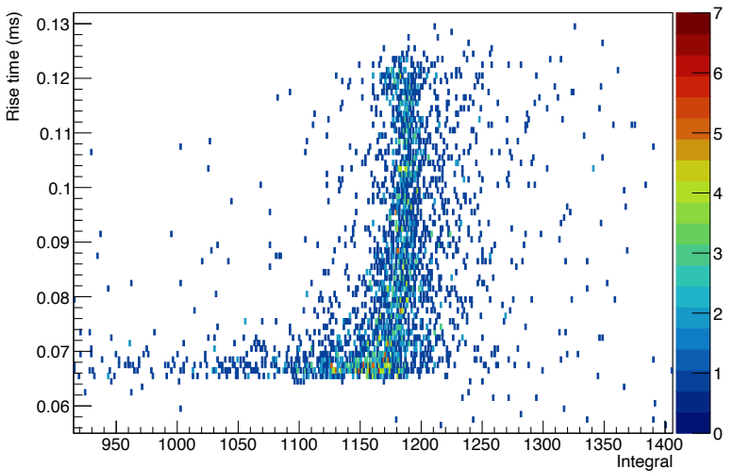



**24h**



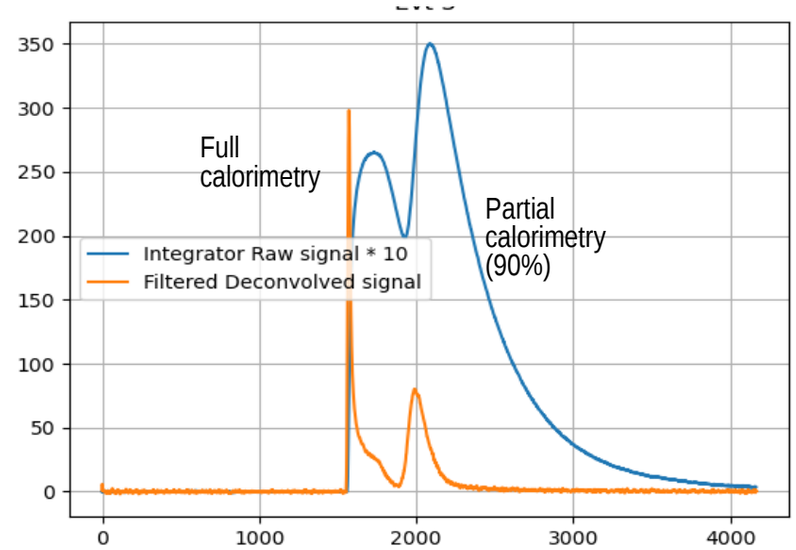

**48h**



# Technical developments

## Electronics and DAQ

- The electronics is a hot point of the project since a dedicated low noise electronics chain is foreseen to obtain an excellent energy resolution.
- In particular 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.
- A specific work related to **Artificial Intelligence** is also ongoing in synergy with the **THINK** project of IN2P3 both for the final onboard technology and for the offline waveform processing in order to analyse signal and possibly reconstruct two-electrons tracks signature in the signal.
- Indeed a **signal treatment** is a hot point of the project to achieve ultimate energy resolution and have multit-tracks recognition for 2β event selection.

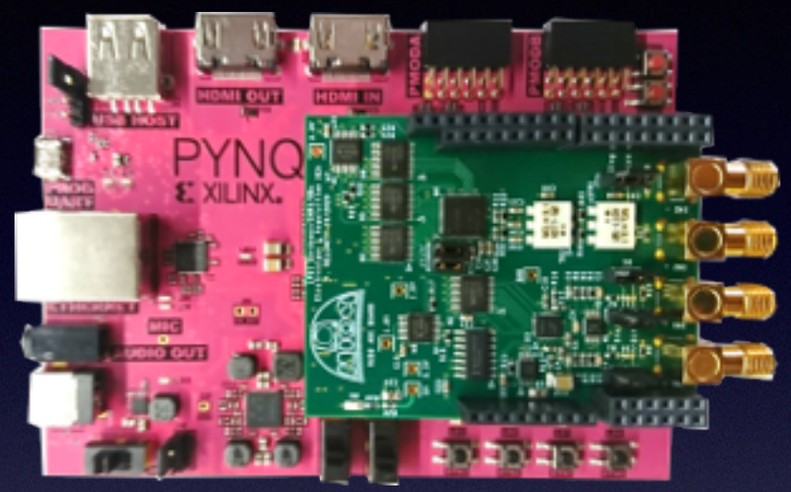



**2 alphas reconstruction**

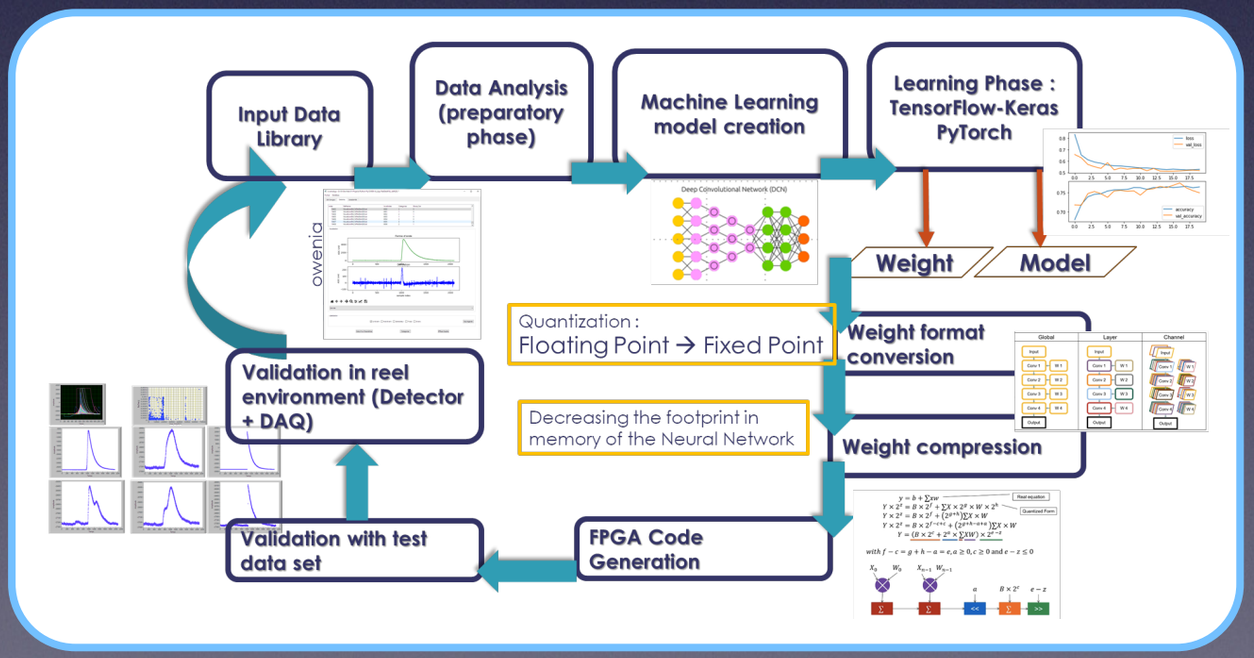
# OWEN

## 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)

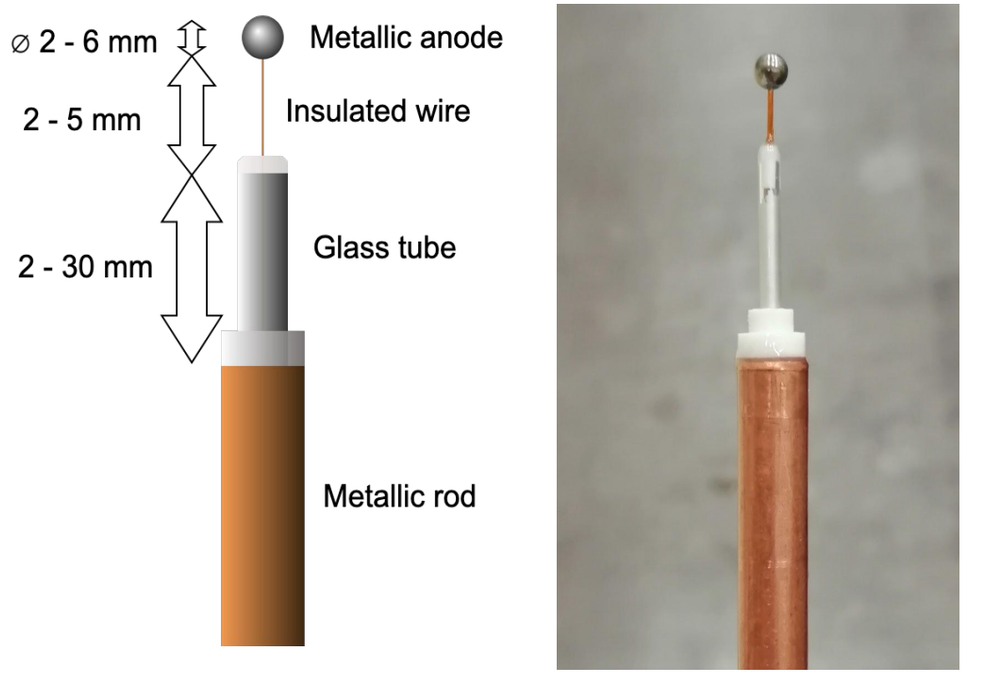


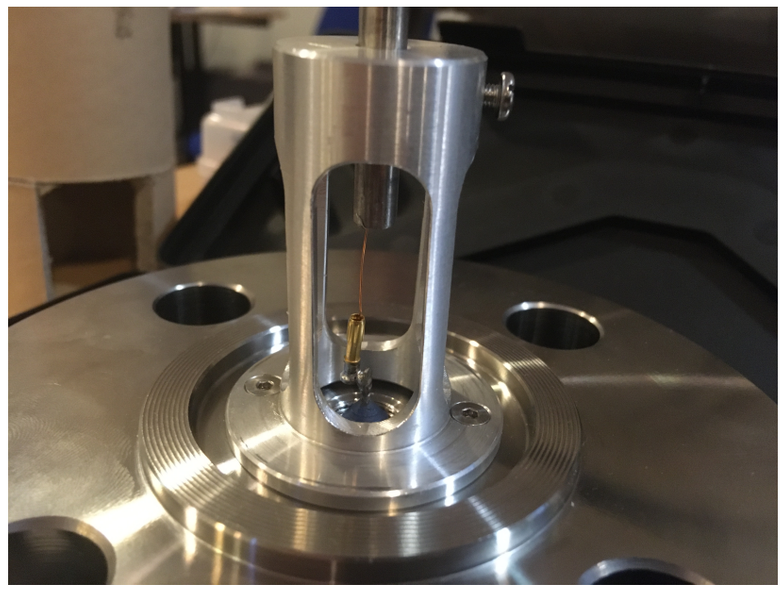

**Full system expected to be ready for experiments in 2023**

# Technical developments

## Sensor

- 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**. We are in discussion with AXON to perform micro soldering without drilling the anode and compromise its sphericity.
- Multi channel sensor was also tested but channel equalisation is currently an issue for resolution.



# 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

Leakage current

Not shielded (noise)

Not certified for HP

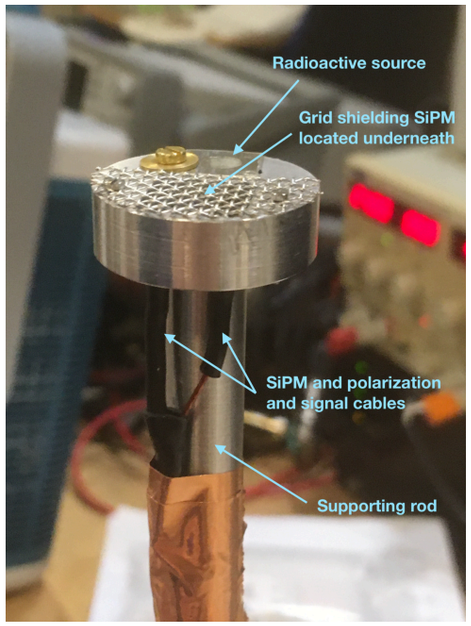
- We tested several commercial options but **each feed through has to be welded by a certified company and the behavior in terms of noise is not guarantee to be the same after and before**.
- Discussion ongoing with AXON company (already collaborating in JUNO) and prototype expected in 2023.

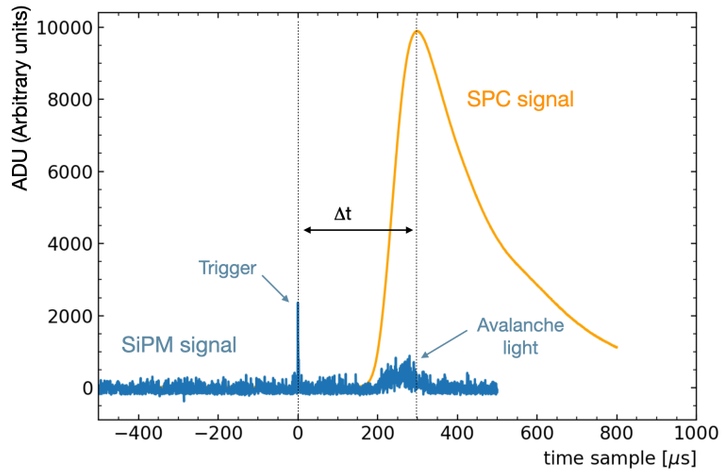
**Note: This is an issue only for SPC**

# 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.

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# Next steps

- Huge improvements were carried out since last year namely measurements in argon up to 3 bars and first measurements in xenon. We need now  to confirm the results:

  - Higher pressure → Small cylinder could be operated within the sphere (10 cm drift) up to 40 bars. Larger cylinder certified would be needed in the future but expensive…

  - With electrons → $^{207}$Bi source available but more than 10 bars needed to contain electron tracks

  - With a diffuse source → Clean radon source yet to be found (problem with electronegative impurities)

- Further gas quality  is needed in order to increase pressure and hot getter should be used (recently funded and ordered but delivery time of 9 months…received in May 2023).
- We need to demonstrate the two tracks reconstruction in the cylindrical geometry (ongoing).
- Further developments are ongoing on the DAQ to have a faster readout.

**Move on to a real project and international collaboration**

# Funding and manpower

- We obtained an IdEX Emergence grant from Bordeaux University of 30k euro for two years for the electronics development.
- We are funded as IN2P3 R&D. So far so good but no guarantee for the following year.

| Group | Funding 2018 (k€) | Funding 2019 (k€) | Funding 2020 (k€) | Funding 2021 (k€) | Funding 2022 (k€) | Funding 2023 (k€) |
|---|---|---|---|---|---|---|
| LP2I Bordeaux | 25 | 22 | 10 | 23 | 20 | 17 |
| LSM | 5 | 2 | 5 | - | - | - |
| CPPM | 3.5 | 2 | 5 | - | - | - |
| SUBATECH | 1.5 | 2 | 5 | 5 | 8 | 8 |
| CEA | - | - | - | - | - | - |
| Total | 35 | 28 | 25 | 28 | 28 | 25 |

Table 4: Summary table of the IN2P3 funding since 2018.

- We were granted (1/2 bourse IN2P3) a Ph.D. (V.Cecchini) in co-tutelle with SUBATECH (2019-2022), and a Ph.D. funded by ANR-Bordeaux University (P.Charpentier) on a specific call related to A.I. (2021-2024).
- We have a strong technical support from LP2I Bordeaux.

| Service | Tasks | Number of people involved | FTP 2023 |
|---|---|---|---|
| Electronics | low noise electronics and DAQ development | 3 | 1.3 |
| Mechanics | Detector development and high pressure certification | 1 | 0.2 |
| Instrumentation | Vacuum and gas related detector development | 1 | 0.1 |

Table 5: Summary table of the LP2I Bordeaux technical participation to the project.

| Group | Physicists 2018 (FTE) | Physicists 2019 (FTE) | Physicists 2020 (FTE) | Physicists 2021 (FTE) | Physicists 2022 (FTE) | Physicists 2023 (FTE) |
|---|---|---|---|---|---|---|
| LP2I Bordeaux | 3 (0.7) | 3 (0.7) | 3.5 (1.3) | 3.5 (1.3) | 4.5 (2.3) | 3.5 (1.8) |
| LSM | 2 (0.3) | 2 (0.3) | 2 (0.3) | 2 (0.3) | 1 (0.3) | 1 (0.3) |
| CPPM | 1 (0.2) | 1 (0.2) | 1 (0.2) | 1 (0.2) | 1 (0.2) | 1 (0.2) |
| SUBATECH | 1(0.6) | 1(0.6) | 1.5(1.1) | 1.5(1.1) | 1.5(1.1) | 1(0.6) |
| CEA | 3 (0.2) | 3 (0.2) | 2 (0.1) | 2 (0.1) | 2 (0.1) | 2 (0.1) |
| Total | 10 (2) | 10 (2) | 10 (3) | 10 (3) | 10 (4) | 9 (3) |

Table 3: Summary table of the groups manpower since 2018.

# 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 0νββ 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

https://r2d2.in2p3.fr/

# RH support asked to LP2I

- The R&D phase of the project is almost over and the next phase would be a low background detector to be located underground.
- Fundings are needed for the next phase which could come from the ANR and/or from the establishment of an official international collaboration and the approval as project at IN2P3.
- RH support from LP2I Bordeaux will be needed to carry out the proposed project. The needed resources are summarised here below.
  - **Mechanics**: Conception of the detector and of the supporting infrastructure. The construction will be probably done by external companies.
  - **Instrumentation**: Conception of the system concerning vacuum, and xenon recovery-purification system based on the existing one.
  - **Electronique**: Development-improvement of the electronics-DAQ to reach 1% resolution.

# Conclusions

- We have a good knowledge of the detector and we validated his functioning in Argon up to 15 bar and in xenon up to 3 bar.
- The most critical issue is gas purity which is something in principle well established worldwide.
- A dedicated low noise electronics has to be developed in particular to work in ionization mode and to read the sensor at both ends to reconstruct longitudinal position.

**To successfully continue the project we need to secure fundings and strengthen the international collaboration**

# QUESTIONS

# Questions Corinne (1)

- Q: à propos de cette figure 3, on est d'accord que c'est la simu SPC avec 50 kg.an de 136Xe, à 40 bars, une résolution FWHM de 1% à , une ROI de 0,6% autour de Qbb, avec une structure de la SPC en cuivre avec une activité de moins de 10 microBq/kg ? C'est la simu avec les performances ultimes d'un SPC R2D2 ?

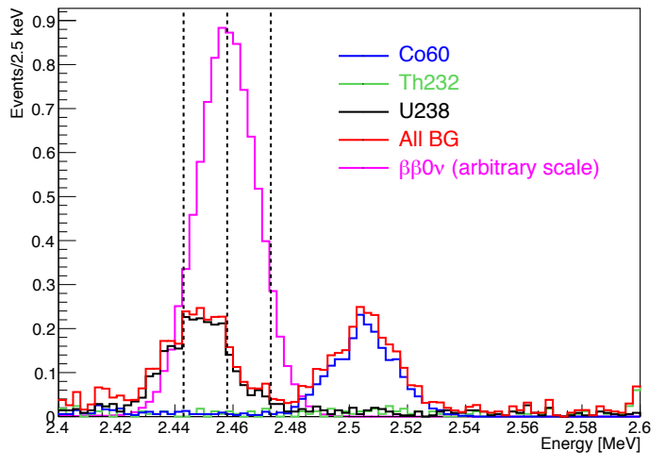


Figure 3: *Figure taken from Ref. [16]. Background events after the selection cuts in the 50 kg setup considering 1 year of data taking. The vertical lines represent the $Q_{\beta\beta}$ and the ROI at 0.6% of the $Q_{\beta\beta}$.*

- A: It is indeed the first sensitivity study of the SPC published in 2018.

- Q: Si oui : c'est une simu bien prometteuse en termes de bdf, mais je n'arrive pas à me rendre compte car le signal  correspond à une échelle arbitraire : ça permet d'atteindre une limite sur la période de combien ? La comparaison dans le texte est faite avec EXO-200, mais quid de nEXO par exemple ?

- A: The limit on the lifetime in the study is 2.5 x $10^{25}$ years. The comparison was done in terms of background events with respect to running experiments. We have no values for nEXO on the background and no certainty that they can reach the desired background level. Anyway the goal of the ton scale detector is to rule out the inverted hierarchy region as nEXO would like to do.

# Questions Corinne (2)

- Q: J'aurais bien aimé voir à quoi ressemblent les différents types d'événements qu'on est capable de distinguer (gammas, électrons, alphas, neutrons, reculs nucléaires) : possible de les montrer dans la présentation ?
- A: We have no display of the events. The study carried out in 2018 was based on the different reconstructed variables.

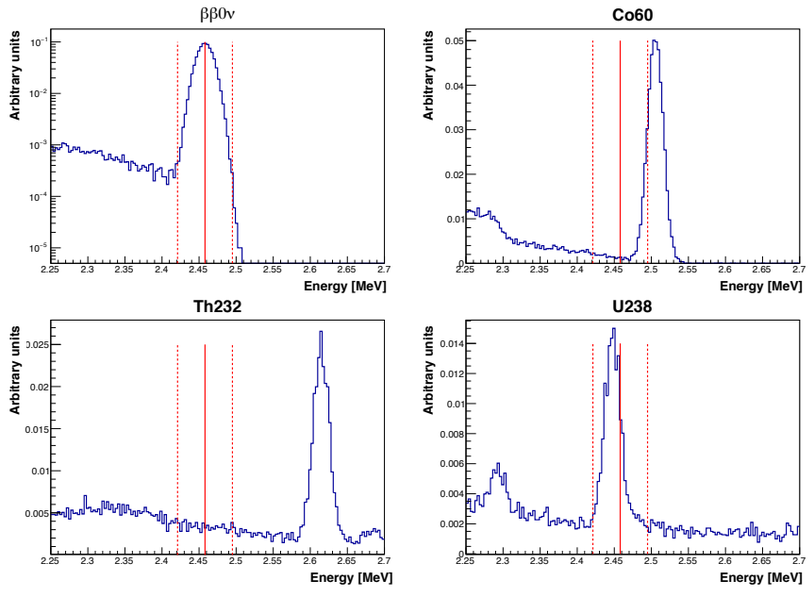


**Figure 3**: *Energy spectrum in arbitrary units (normalized to 1) of expected ββ0ν signal (top left), $^{60}$Co background (top right), $^{232}$Th chain background (bottom left) and $^{238}$U chain background (bottom right). The $Q_{\beta\beta}$ is shown by the solid red line whereas the limits of ROI of ±1.5% with respect to the $Q_{\beta\beta}$ are shown by the dashed red lines.*

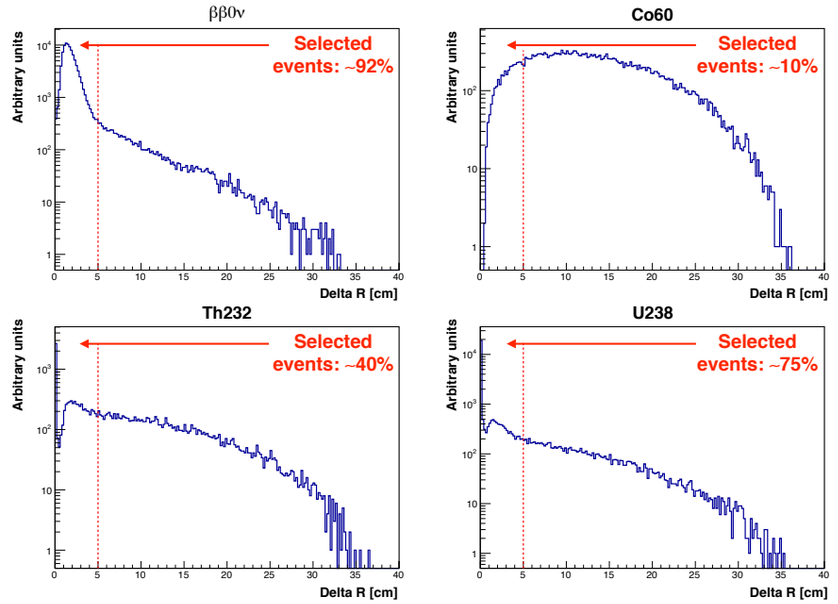


**Figure 5**: *ΔR distribution for ββ0ν signal (top left), $^{60}$Co background (top right), $^{232}$Th chain background (bottom left) and $^{238}$U chain background (bottom right) before ROI and LS based selection. The selected region with ΔR < 5 cm is shown by the dashed red line.*

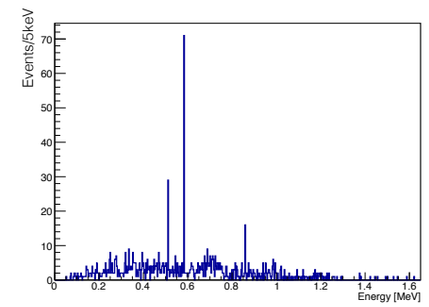


**Figure 4**: *Energy deposited in the liquid scintillator for events of the $^{232}$Th decay chain selected in the ROI according to their energy deposition in the Xenon active volume.*

| Source | Events in ROI ($Q_{\beta\beta}$ ± 1.5%) | + LS cut (Energy in LS< 200 keV) | + Rmin cut (Rmin< 36 cm) | + ΔR cut (ΔR< 5 cm) |
|---|---|---|---|---|
| $^{60}$Co | 6.9 ± 0.1 | 6.9 ± 0.1 | 6.9 ± 0.1 | 0.8 ± 0.1 |
| $^{232}$Th chain | 28.0 ± 0.8 | 4.6 ± 0.3 | 3.7 ± 0.3 | 0.8 ± 0.1 |
| $^{238}$U chain | 9.3 ± 0.2 | 8.8 ± 0.2 | 7.5 ± 0.2 | 3.0 ± 0.1 |
| $\beta\beta0\nu$ | 82.1% ± 0.3% | 82.1% ± 0.3% | 81.9% ± 0.3% | 76.2% ± 0.3% |

**Table 1**: *Number of background events per year for different background sources as a function of the cuts which are applied on top of each other from left to right. The ββ0ν signal efficiency is also reported.*

# Questions Corinne (3)

- Q: Est-ce que vous avez déjà une simulation identique pour le CPC (il me semble que non) ? Si non, qui a ça en charge, et quand pouvez-vous espérer ? Et en attendant, est-il possible d'extrapoler la simu SPC ? Qu'est-ce que ça change vraiment pour la figure 3 ?
- A: We did not perform the same study for the CPC but that is foreseen thanks to the help of the Czech colleagues who recently joined R2D2. Most of our manpower was dedicated to the hardware development. However we do not expect any major difference in terms of sensitivity as long as the background stays the same. A lot of work is ongoing indeed in order to develop a CPC with a thin structure holding the pressure and guaranteeing a low background.
- Q: je compte 9 physiciens IN2P2-CEA actuellement dans la table 3, il est indiqué 17 membres en page 1 (13 IN2P3 et 4 CEA). Ce dernier chiffre inclut les personnels des services techniques, on est d'accord ?
- A: That is correct. The list of signatures of the latest publication is:


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*


10 Physicist IN2P3
5 IT IN2P3
3 CEA
5 UK

# Questions Corinne (4)

- Q: quid des collaborateurs étrangers ? il est fait mention de Birmingham avec le financement E-ACHINOS.
- A: We do not have a formal collaboration, however we collaborated with Birmingham through the E-ACHINOS founding. Furthermore the group from Prague University has recently joined the R2D2 effort (4 permanents with FTE to be defined).
- Q: pourquoi le LSM et le CCPM n'ont plus de ressources In2P3 depuis 2020 ?
- A: This is a choice of IN2P3. We ask for money for the two groups but since the amount of money is small IN2P3 prefers to give all the money to LP2I and we pay for their travellings.
- Q: on a les FTE CEA physiciens, mais pas le nombre total de personnes impliquées, ni leurs financements
- A: There are 3 persons however two of them are now retired. Most of their fundings were coming through the NEWS-G experiment and R&D on the actions development.
- Q: qu'est-ce que E-ACHINOS ? que fait Birmingham dans la collaboration ? Sont-ils membres officiellement ?
- A: Birmingham has the know how of the GARFIELD simulation and of the sensor development (with CEA). The are members of R2D2 (they signed the paper and presented it at conferences)

# Questions Corinne (5)

- Q: le financement IN2P3 est associé à une R&D ? une R&T ? A priori va rester récurrent ?
- A: The founding is an R&D IN2P3 and it is not sure that it will continue since it has been going on for 6 years. The R&D phase is however almost over and we hope to move to a project scale soon.
- Q: d'autres demandes sont-elles prévues (ANR, ERC ?)
- A: We asked for ANR fundings and we are waiting the results of the phase 2.
- Q: valeurs des résolutions pour ces derniers tests (même préliminaires, c'est pour voir l'amélioration) ?
- A: At high pressure we are now dominated by gas purity. We are testing the detector in ionization mode and found an almost stable resolution at the level of 2% between 1 and 10 bars in ArP2. Signal treatment is fundamental in particular in ionization mode and we believe that we can soon improve the resolution to the level of 1% with a better tretment, reducing the external noise and with a dedicated electronics.
- Q: en quoi est le cylindre (aluminium aussi ? cuivre ?)
- A: We are working to see if the composite materials are ok in terms of radioactivity. Such materials would grant a pressurized detector with a thickness of few mm.

# Questions Corinne (6)

- Q: timeline pour la suite ?
- A: We are already trying to establish a stronger international collaboration and if we manage to demonstrate the stability of energy resolution up to high pressure in xenon we would like to ask IN2P3 to move to the project phase. That would be possibly in Autumn or next year.

# Questions JeanPierre (1)

- Q: avez-vous des demandes en cours pour des financements non récurrents ? En particulier, pour une seconde phase venant de l'IdEx (OWEN) ?
- A: We are waiting for the ANR results. Concerning OWEN we applied for the phase 2 but the project was not funded further.