Status of the R2D2 cylindrical TPC R&T

F. Piquemal (CNRS/IN2P3)

R&D R2D2 collaboration

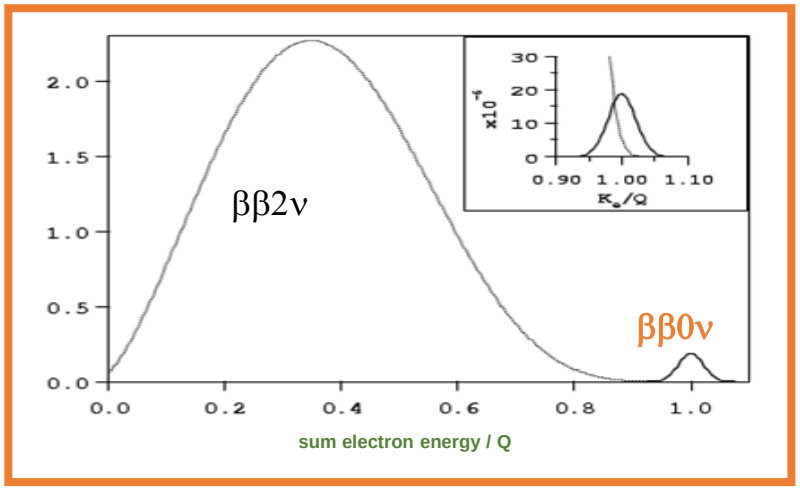
PAUL Symposium – Paarl (South Africa) – January 2024

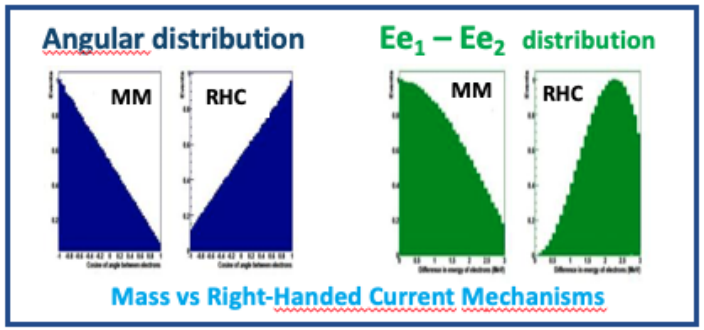
ββ(0ν) : Physics case

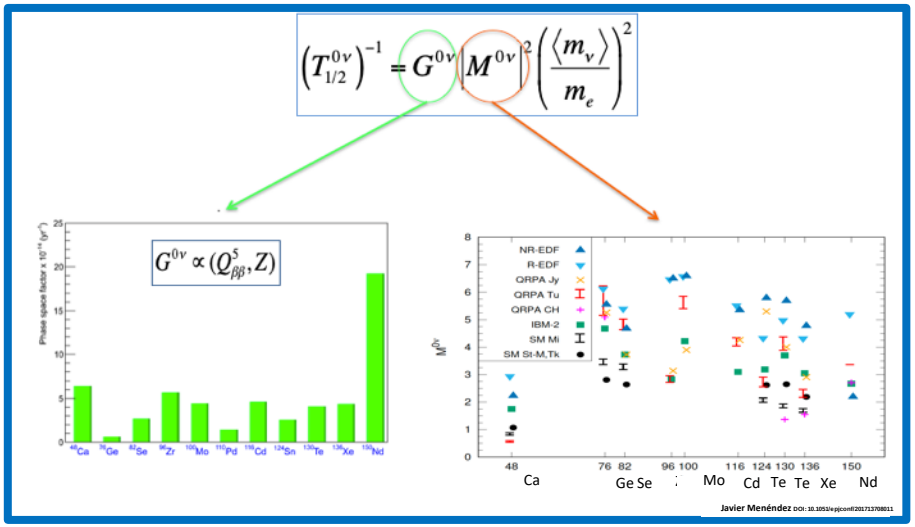
- Nature of neutrino: Dirac or Majorana
- Neutrino mass hierarchy
- Absolute neutrino mass
- Right-handed current interaction
- CP violation in leptonic sector
- Search of Supersymetry

Neutrinoless Double beta decay observables

$(A,Z) \rightarrow (A,Z+2) + 2\,e^-$







Decay to Excited States : $(A,Z) \rightarrow (A, Z+2) + 2\,e^- + 1 \text{ or } 2\,\gamma$

Identification of daugther nucleus : $Xe \rightarrow Ba^{++} + 2\,e^-$

Double beta decay sensitivities

Light neutrino exchange

Background

$$T^{0n}_{1/2}(y) \propto \frac{\varepsilon}{A}\sqrt{\frac{M \cdot t}{N_{Bckg} \cdot \Delta E}}$$

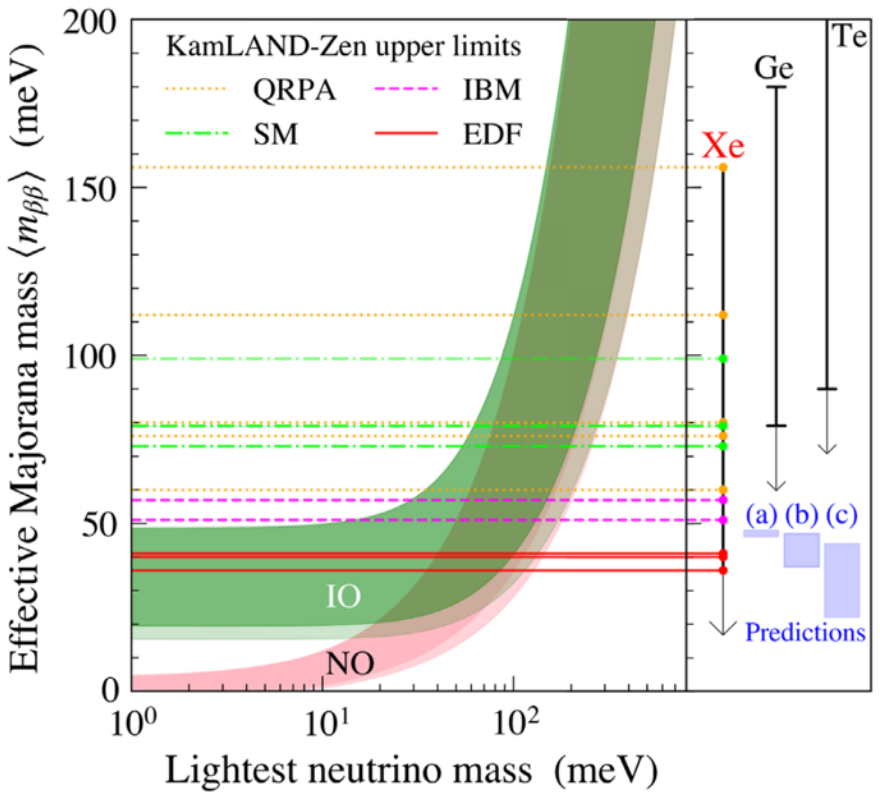
$$< m_\nu > \propto \sqrt[4]{M}$$

NO Background

$$T^{0n}_{1/2}(y) \propto \frac{\varepsilon}{A} M \cdot t$$

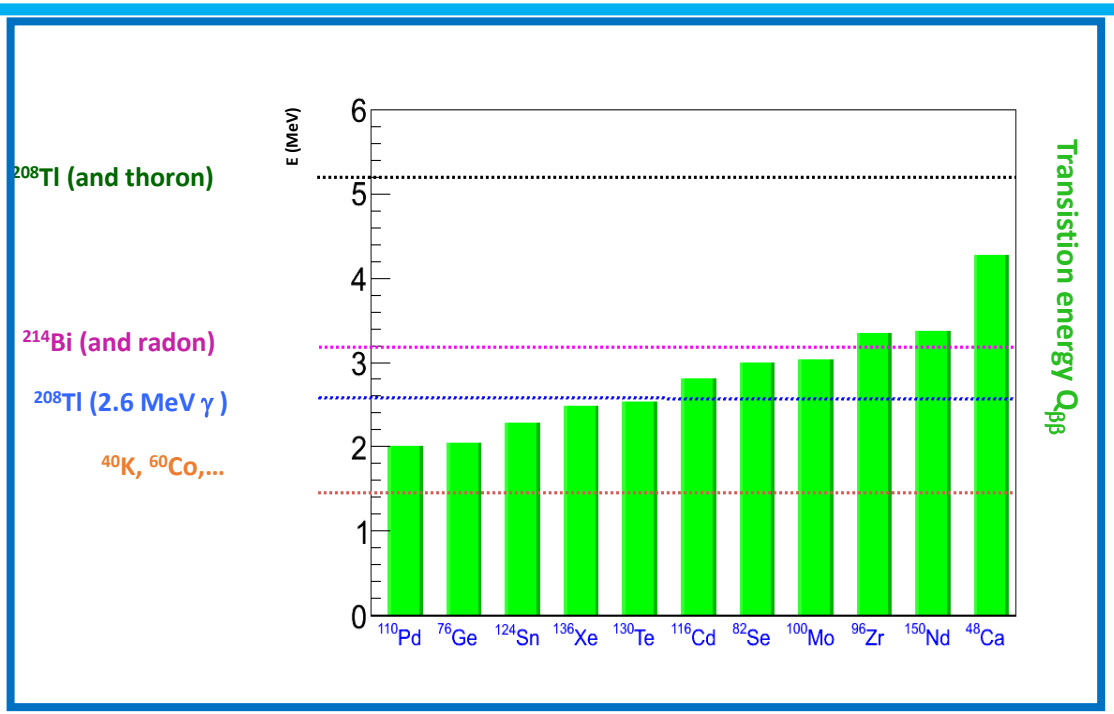
$$< m_\nu > \propto \sqrt{M}$$

ε :efficiency, M: Mass, t: time, N_{bckg}: Background events, ΔE: energie resolution, A: isotope mass



•*Phys.Rev.Lett.* 130 (2023) 5, 051801

The main issue : the background from natural radioactivity



List of other sources of background (non exhautive):

- Muons (underground labs)
- **γ from (n,γ) reactions**
- **γ from μ** bremstrahlung
- Muon spallation products
- α emitters from bulk or surface contaminations for calorimeters
- ββ(2ν) if modest energy resolution

The issue is to select materials

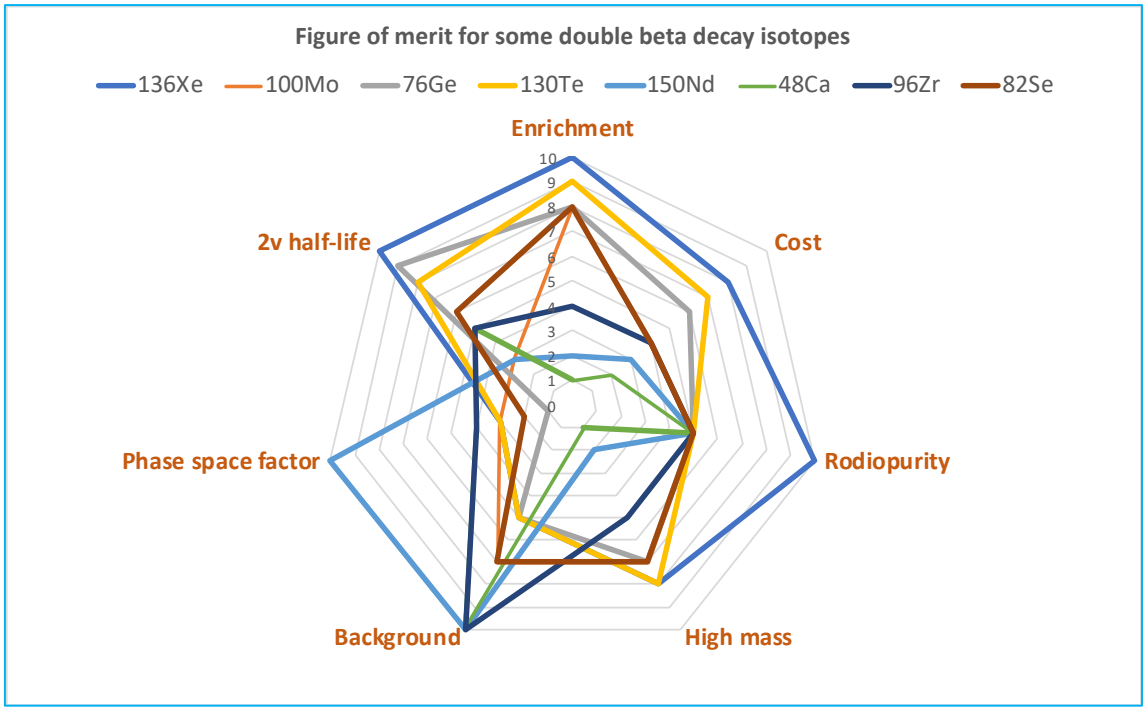
2 μBq/Kg in ^{208}Tl correspond to about 20 decays/year

Large number of measurements

Each component and each batch has to be screened

Large number of samples, long time of measurement

Figure of Merit of DBD isotopes



Enrichment : possibility of enrichment

Cost : cost of production

Radiopurity: radiopurity after production

High mass : possibility to obtain tons

Background : $Q_{\beta\beta}$ < 2.6 MeV (^{208}Tl)
$Q_{\beta\beta}$ < 3.2 MeV (^{214}Bi)
$Q_{\beta\beta}$ > 3.2 MeV

Phase space factor (Nuclear Matrix Element not taken into account)

2ν half-life : higher half life lesser background

R2D2 strategy toward a ton scale experiment free of background

Objective : to design an experiment able to cover IO hierarchy ($m_{\beta\beta}$ < 10 meV)

Excellent energy resolution

Gazeous Xenon detector
$\Delta E/E < 1\%$ at $Q_{\beta\beta}$

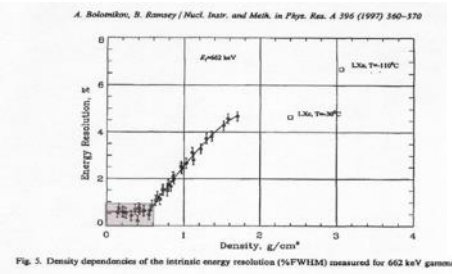


Fig. 5. Density dependencies of the intrinsic energy resolution (%FWHM) measured for 662 keV gamma-rays.

Zero background

Simplifying the design

Single readout channel (Reduction of matter)

Identification of the 2 electrons

Ton-scale experiment

^{136}**Xe**
Easy to enrich
Free from natural radioactivity

High pressure to optimise detector mass vs isotope mass

High pressure xenon TPC → **R2D2 R&D program**

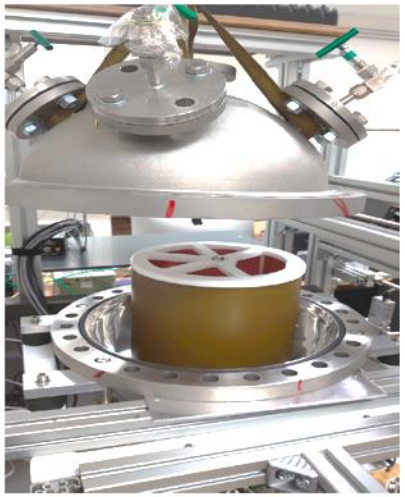
R2D2 strategy

Test Facility at LP2i Bordeaux (no radiopurity consideration)

SPC-1 (2018)
D = 0.4 m
r_{ball} = 1 mm
(1 bar)

SPC-2 (2021)
D = 0.4 m
r_{ball} = 1 mm or 3 mm
(40 bar)

CPC-20 (2022)
L x D = 1 x 0.37 (m)
r_{wire} = 20 µm
(1 bar)

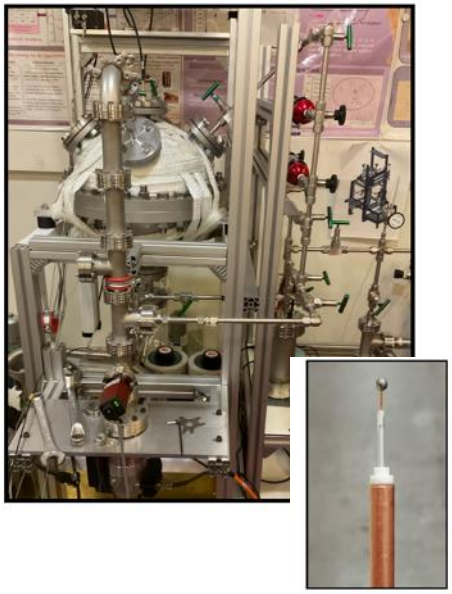


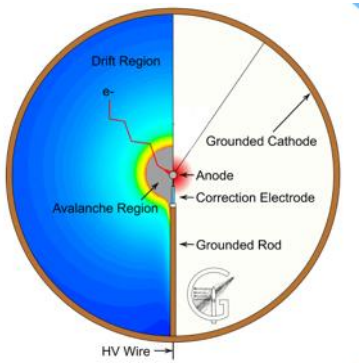
CPC-50 (2023)
L x D = 0.27 x 0.27 (m)
r_{wire} = 50 µm
(40 bar)

Amplifier positioned outside the tank (cables)

Used with cathodic HV bias

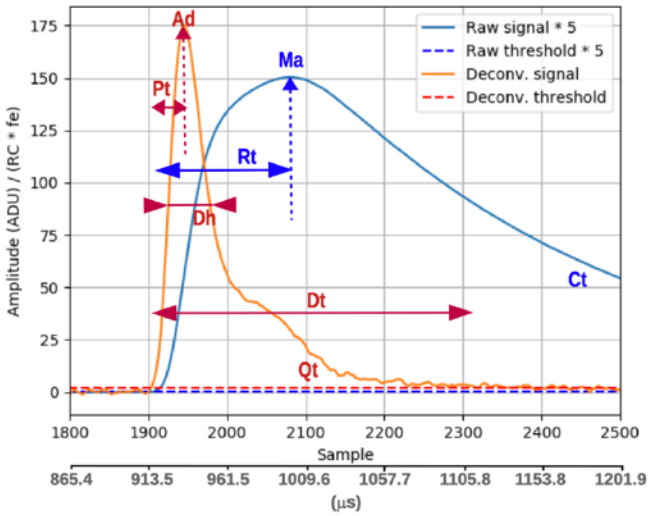
Spherical TPC strategy



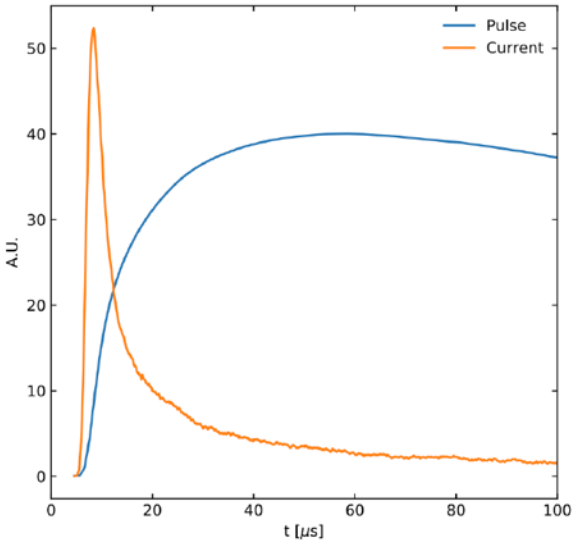


Proposed by I. Giomataris et used in NEWS dark matter search experiment

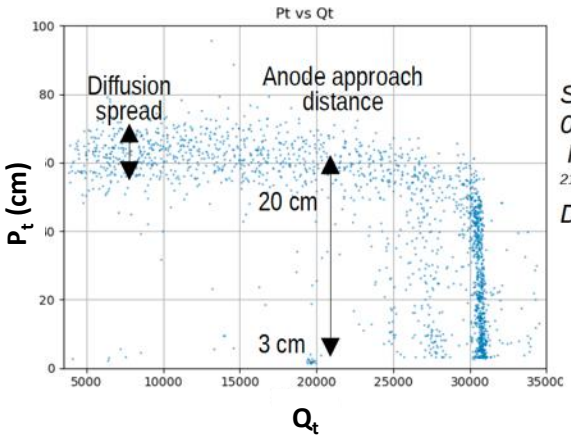
Signal



Simulation



Spherical TPC Results

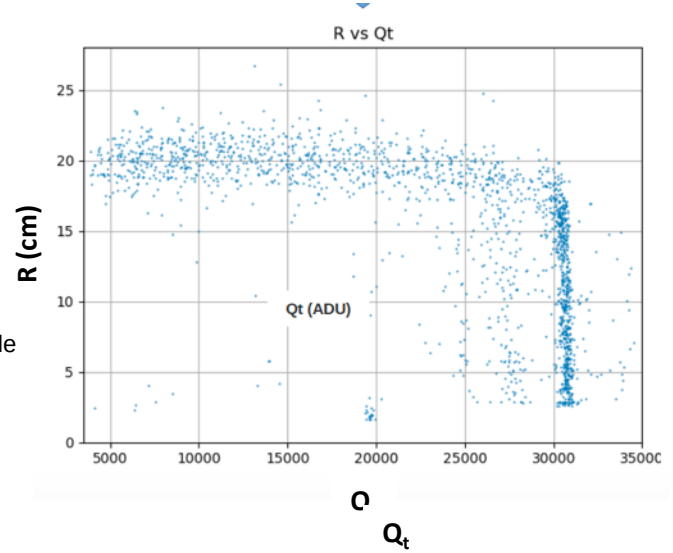


SPC – ArP2 - 0.2 bar - 800 V - Prop. Mode - ^{210}Po source - Deconv. signal

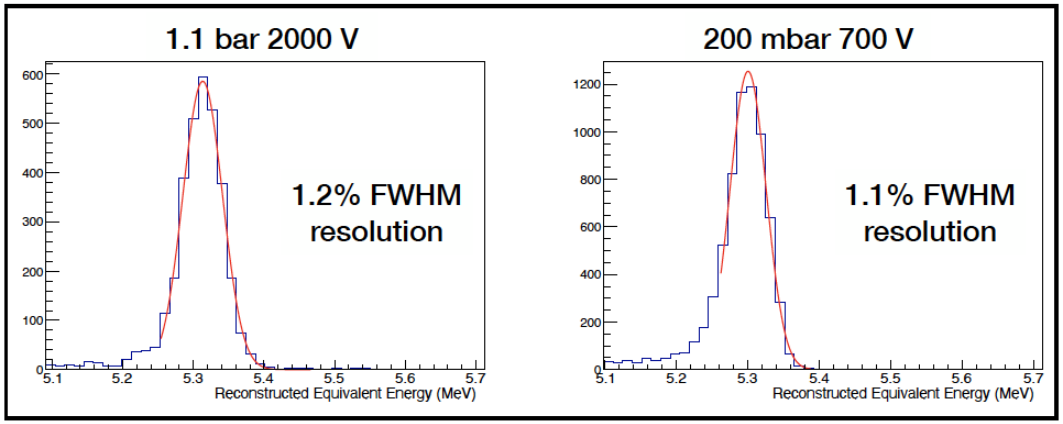
$Pt = Ptmax * (R/Rmax)^{\alpha}$

R : radial distance

Inversion of this functional then made it possible to recover the distance of the track



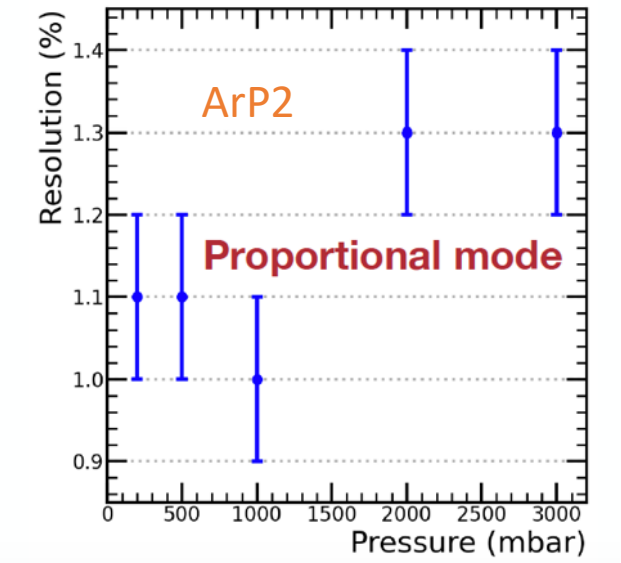
No impact of track length on the resolution
Use of α source
3-4 cm at 1.1 bar
15 – 20 cm at 200 mbar



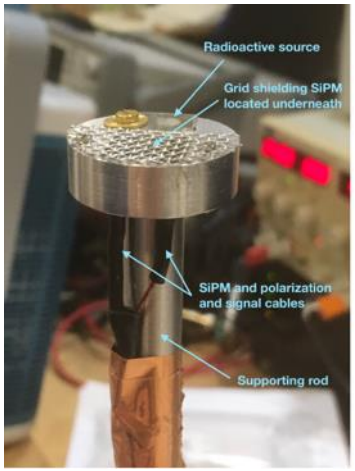
Proportional mode

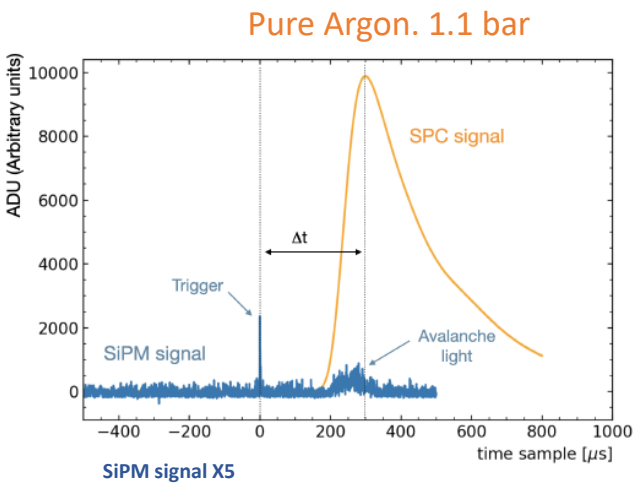
Spherical TPC Results

Resolution with ArP2



Detection of light with pure Argon

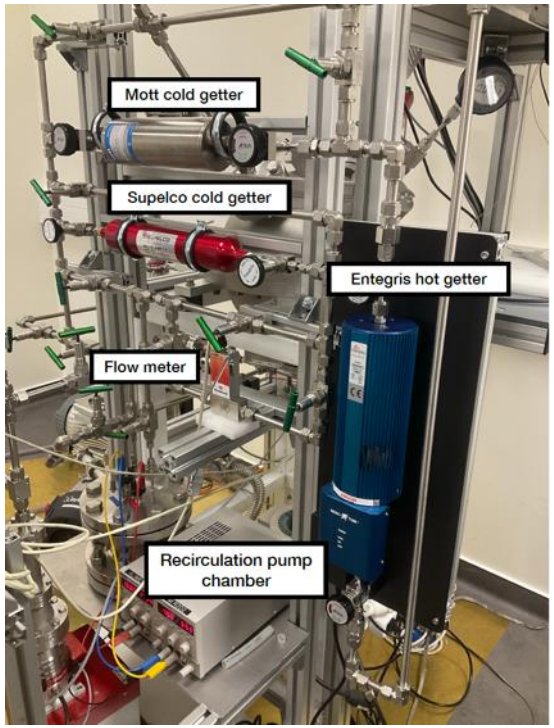


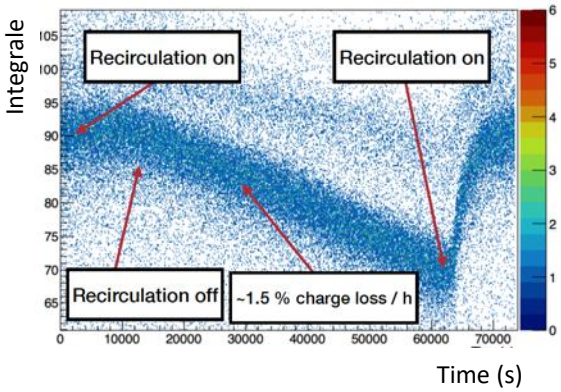


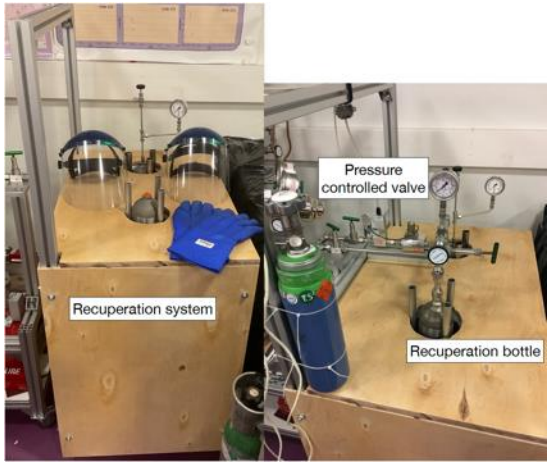
SiPM signal X5

NIM A Volume 1028, 1 April 2022, 166382

Gas sytem







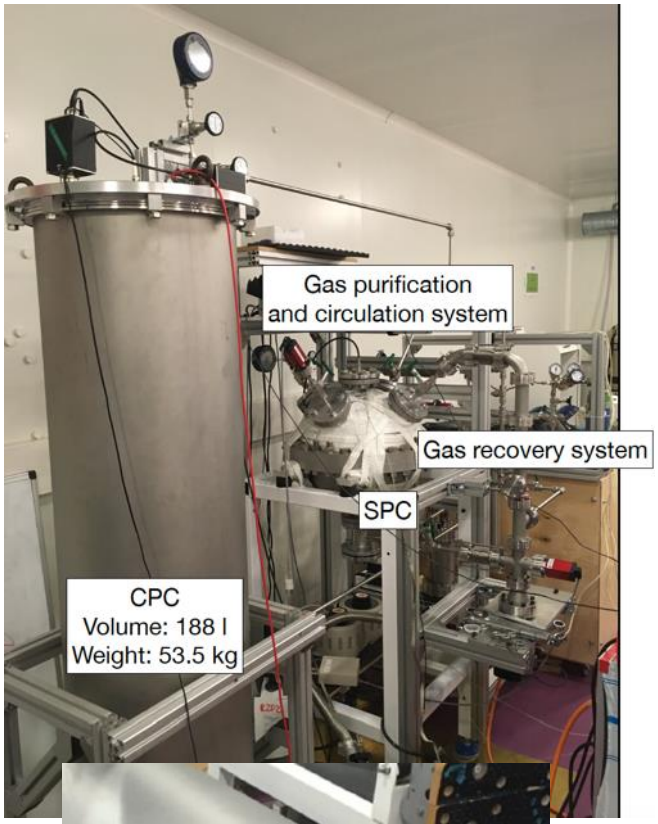
Pressure limit 10 bars for hot getter
Xenon : pressure limit 6 bars from recovery system

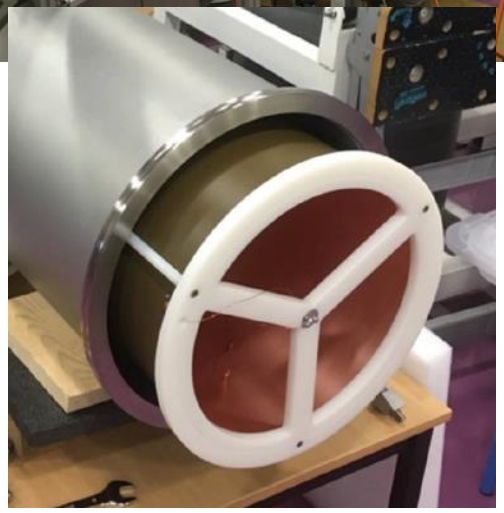
Outcome of SPC R&D

- Recirculation gas system
- Xenon recovery system
- Simulation validation
- Signal treatment

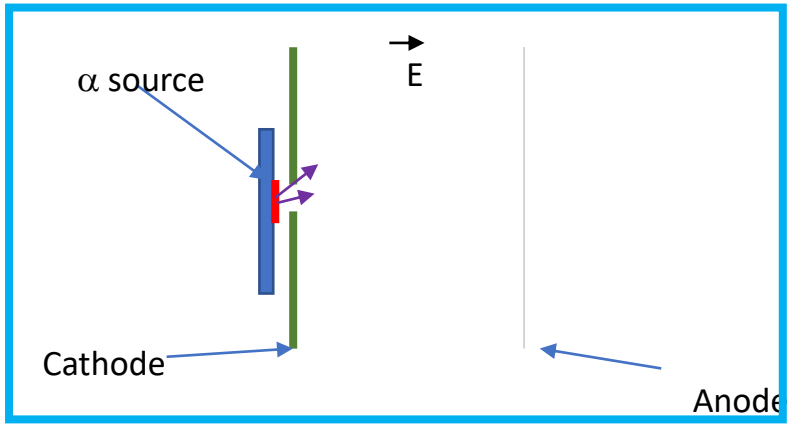
Limitation from noise on the anode when HV increased

Cylindrical TPC : First test





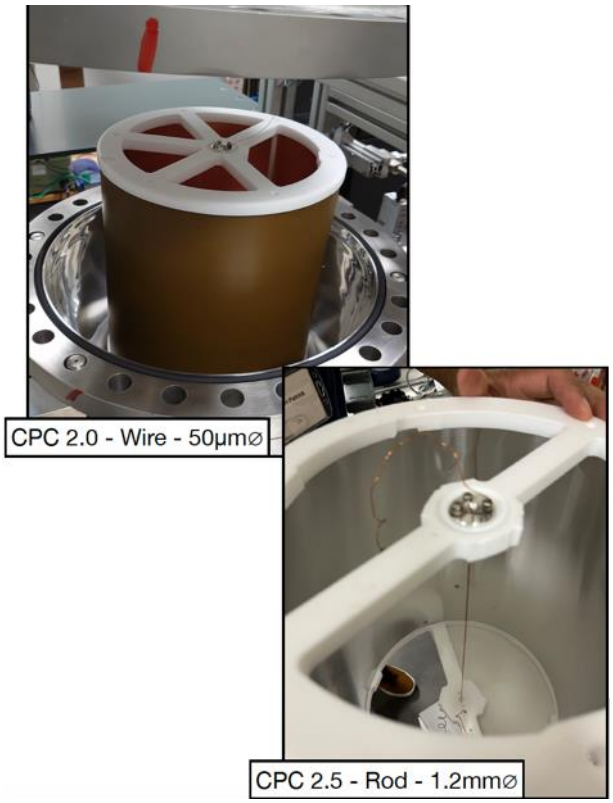
- Inox Tube: 1m50 x 40cm ø.
- Copper cathode: 1m x 35 cm ø.
- Tungsten anode: 50 µm ø.
- ^{210}Po source.



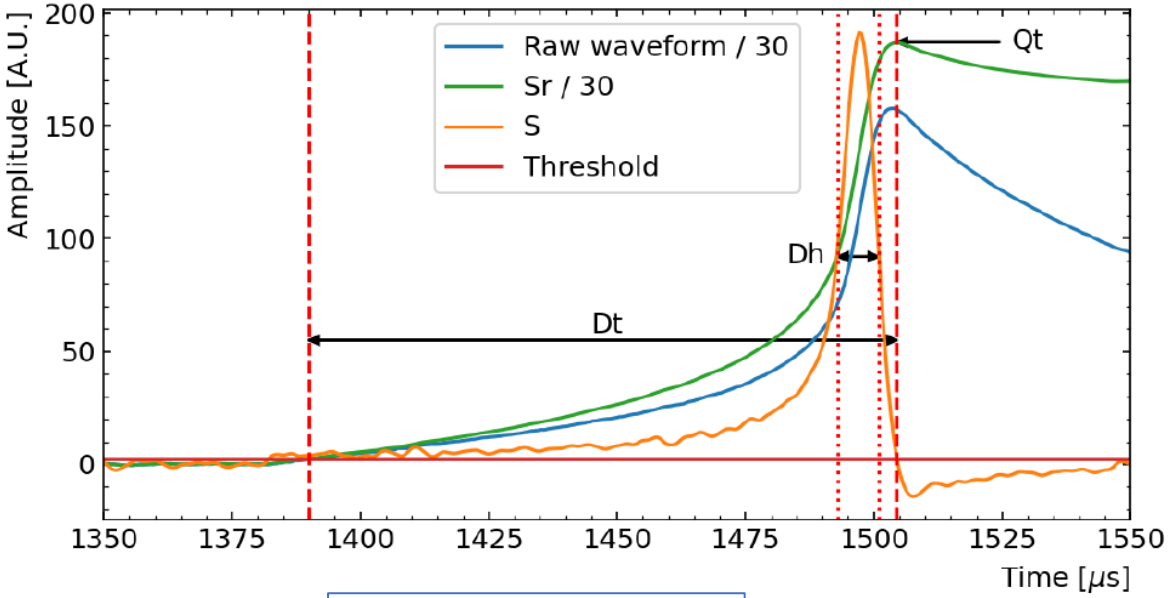
α energy altered by distorsion of electric field near hole and possible interaction at the edge of the hole

Resolution : ~ 1.5 % (FWHM) in Ar at 1.1 bar and Eα = 5.4 MeV

Cylindrical TPC : ionization mode



Signal treatment



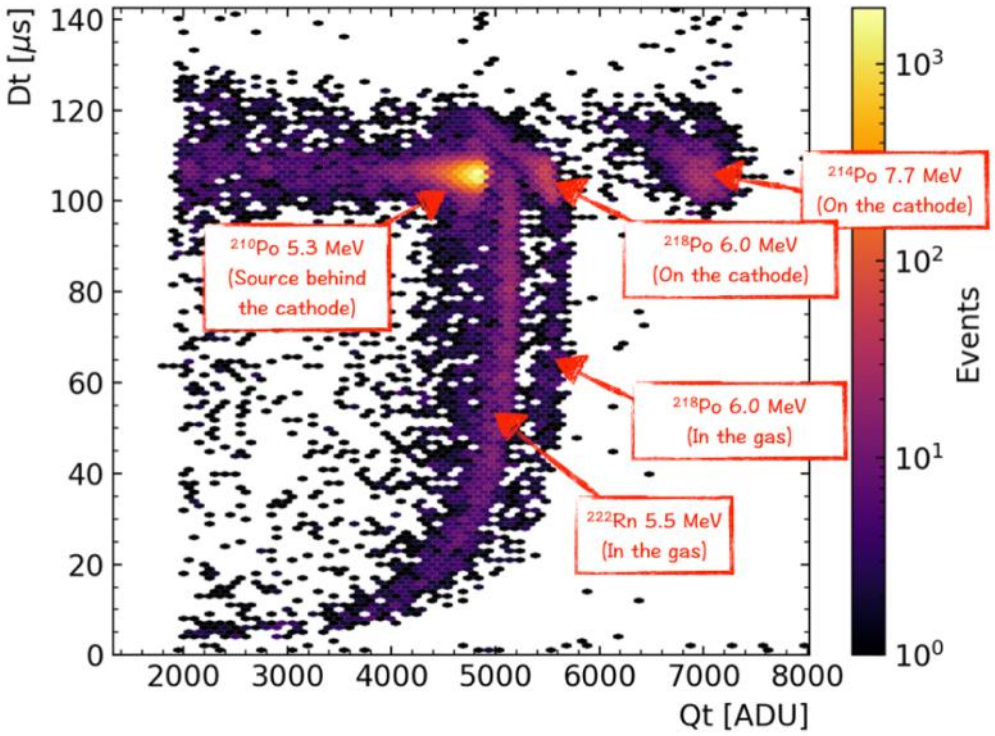
S deconvoluted signal
Sr reintegrated signal

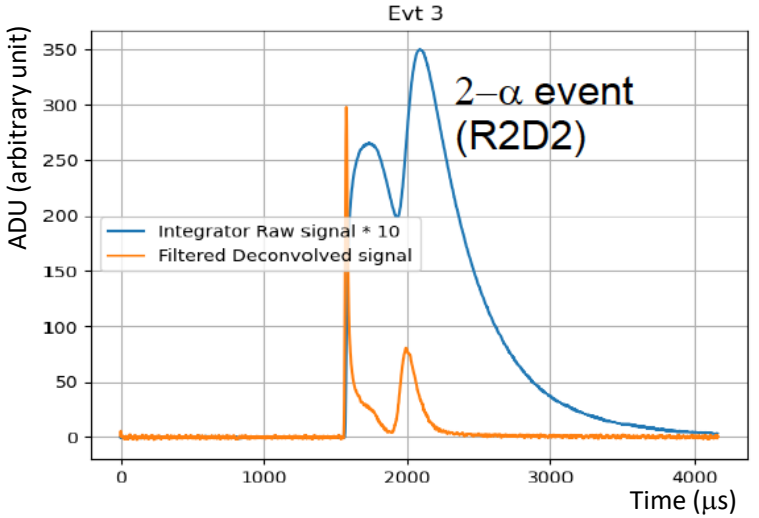
Dt : total duration of signal → direct measurement of the maximum radial distance from the track to the anode

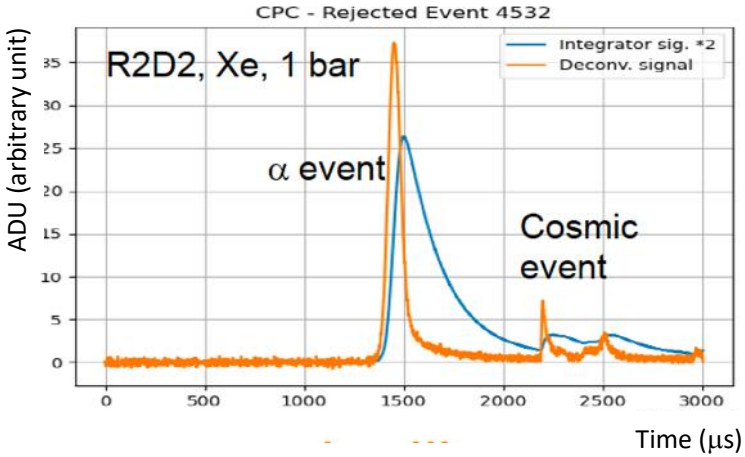
Dh: width of the signal S at half height → linked to to the radial extent of the track

Publication in preparation

Cylindrical TPC : ionization mode

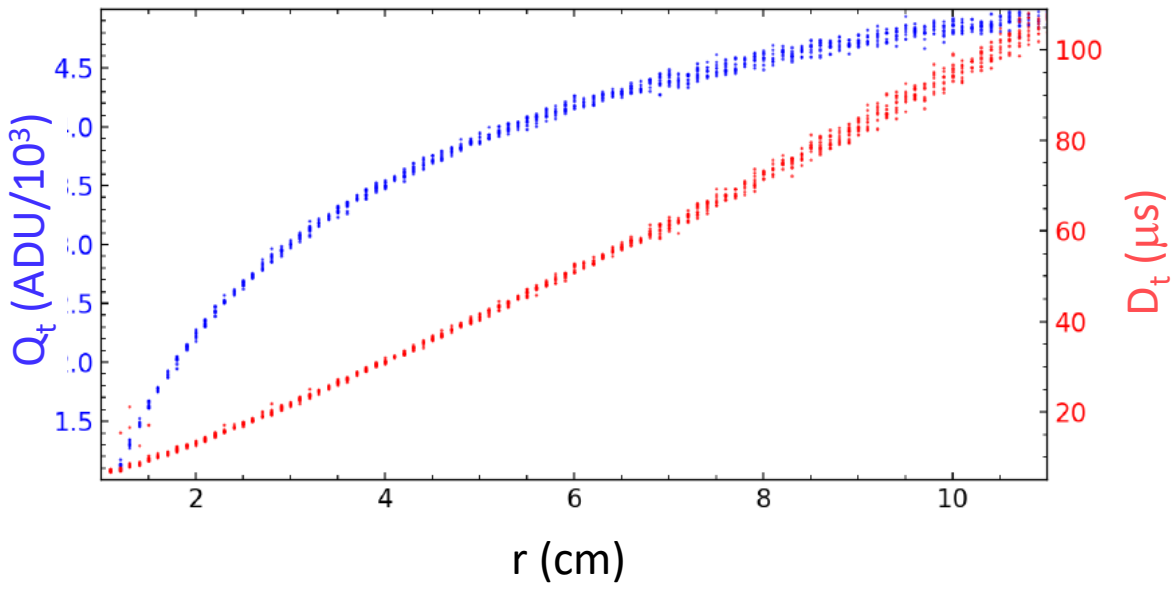






Cylindrical TPC : ionization mode

Measurement of the radial position of the event (remove background from the sides)

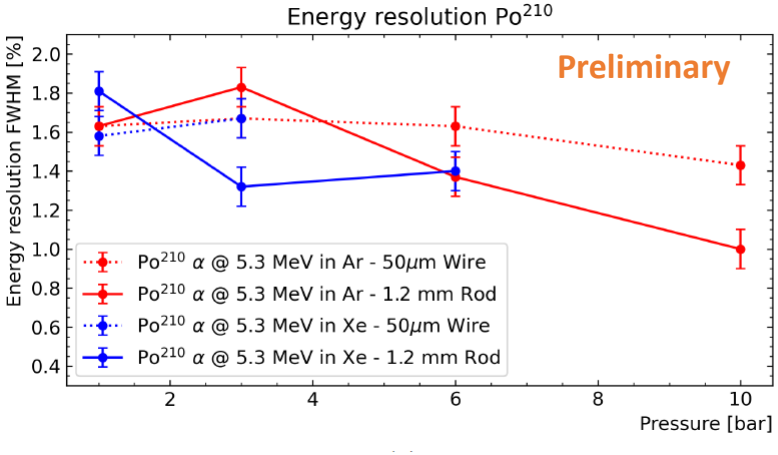


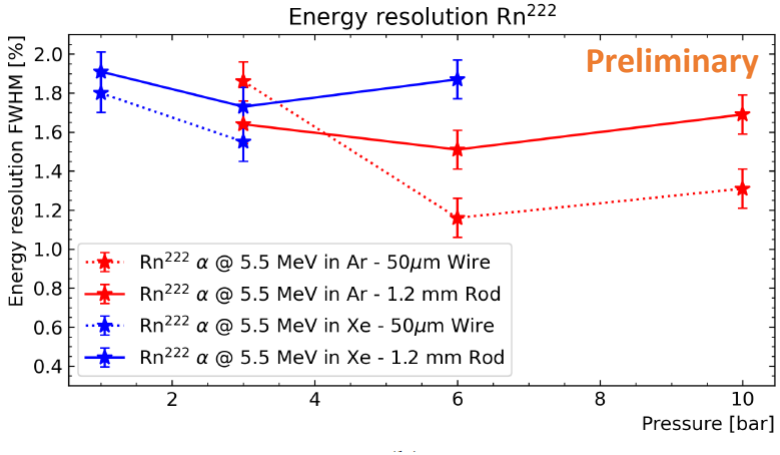
Qt : total charge of the event

Dt : Total duration of the signal

Position along the wire can be obtained reading signal of both sides of the wire

Cylindrical TPC : ionization mode





- Similar resolution for Ar et Xe
- Similar results for α source on the cathode or on the volume (radon)
- Limited by purity of the gas (outgasing of the device)
- Limitation from electronics noise (not optimised for ionisation mode)

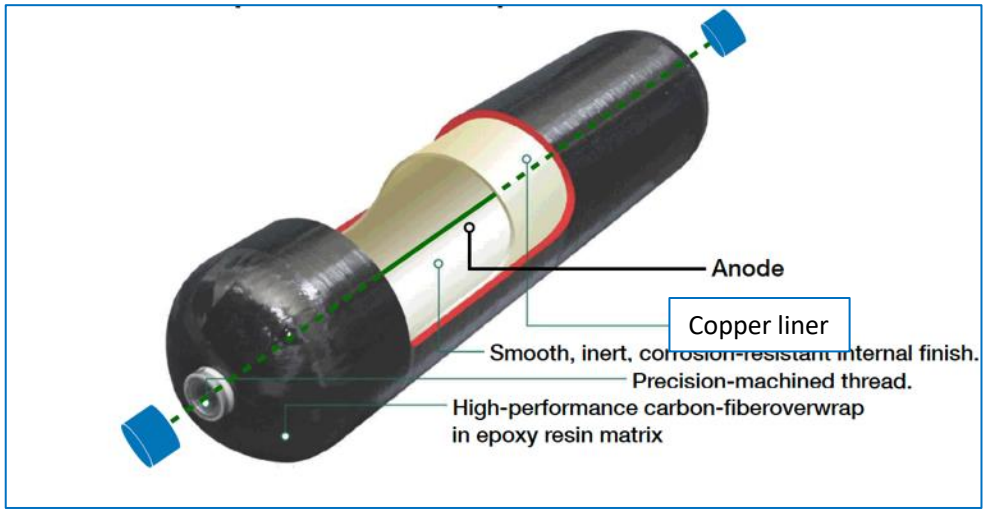
Cylindrical TPC : Low background

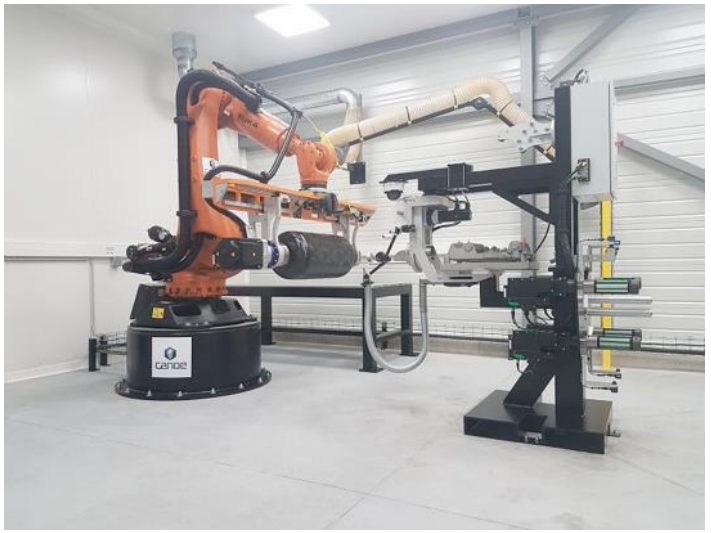
Study of the possibility to use a vessel based on the principle of H tanks : High pressure device (700 bars)

Thin (few mm) → limited amount of matter

The issue is the background : contact with some companies and we started to measure radiopurity of some materials

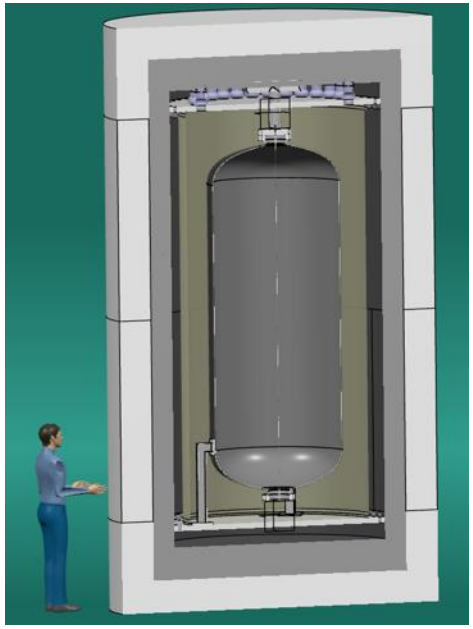
(Natural radioactivity : ~ Bq/kg in U and Th → 10^{-6} – 10^{-8} Bq/kg in U and Th to reach zero background)

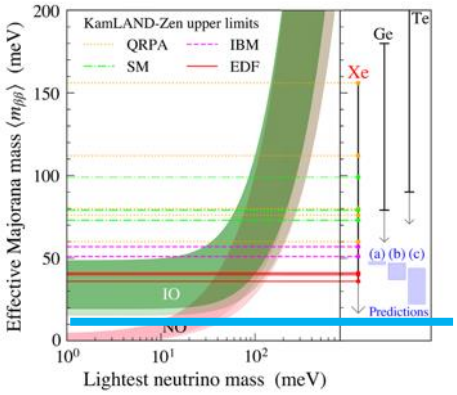




Status of the R2D2 R&D

- ❑ **The objective is to develop a ton-scale experiment to cover IO hierarchy.**
- ❑ **Results on the energy resolution are very promising**
- ❑ **Capability to localise the place of the decay**
- ❑ **Use of Ar gas to check radiopurity of the full detector**
- ❑ **A challenge : the identification of 2 e^- at high pressure (> 20 bars)**
- ❑ **Development to try to produce low radioactivity composite vessel**
- ❑ Development of a dedicated low noise electronics including embedded AI on FPGA to work in ionisation mode
- ❑ Improvement of the prototype to reach 40 bars
- ❑ **Possibility to duplicate the detector in several deep underground laboratories**





R2D2 goal