First results of the R2D2 Project

A Spherical Gaseous TPC R&D

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on behalf of the R2D2 collaboration

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GDR Neutrino - 24/11/2020

Motivations

- A full simulation (*JINST 13 (2018) no.01, P01009*) shows that by using an extremely low background Spherical High-Pressure Gaseous TPC, we could reach a competitive sensitivity.
- Experimentally, founding evidence of $\beta\beta0\nu$ requires at least **three main features**:
  1. Excellent energy resolution;
  2. Extremely low radioactive background;
  3. High masses of $\beta\beta$ emitter medium.

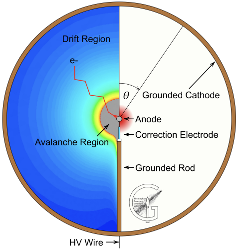
  2-tracks recognition can be an important additional asset.
- **R2D2** - *Rare Decays with Radial Detector* : R&D project to evaluate the feasibility of a ton scale detector with **ultimate low background**.

Detector's principles

Main advantages

- Simplicity of readout: one channel (or few with sensor upgrade) + light readout.
- Simplicity of mechanical structure ⇒ Low material budget ⇒ Low background.
- Scalable to large isotope masses (1 ton = 1m radius at 40bars).
- Low detection threshold (single electron).
- Two tracks recognition.
- High energy resolution (1% FWHM expected at ^{136}Xe $Q_{\beta\beta} = 2.458 MeV$).

Spherical, High pressure, Xenon TPC (also used in NEWS-G).



$\beta\beta$ emitter gas served as detector medium.

R2D2 Roadmap

Prototype 1 Demonstrate the detector capabilities[1] with a focus on **energy resolution**, no radio-purity → Up to 10 kg (40 bars) Xenon prototype.

- *Funded by IN2P3 and Bordeaux University Idex (elctronics Grant OWEN)and Running*

Prototype 2 **Demonstrate the almost zero background** → 50kg of Xenon in radio-pure detector using Liquid Scintillator as veto; possibly first measurements with limits on $m_{\beta\beta} < 160 - 330 meV$:

- *Sensitivity studies[2] carried out*

Experiment **Cover the Inverse Hierarchy** $m_{\beta\beta} < 10 meV$:

⟶ Go to 1 ton of Xenon with background free detector.

⟶ Investigate other gases (background cross-check; higher $Q_{\beta\beta}$; explore the tracking abilities).

[1] *ArXiv:2007.02570*

[2] *JINST 13 (2018) no.01, P01009*

The collaboration

R2D2 is **approved as IN2P3 R&D** since 2018 to assess the possibility to reach the required energy resolution.

A Proto Collaboration

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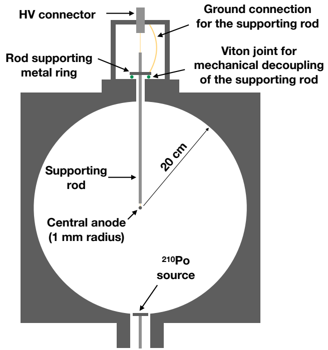
There are close synergies with the NEWS-G experiment.

Design

- It aims to **demonstrate that the desired energy resolution is achievable**.
- Prototype built in aluminum (radio-purity not required at this stage).
- Improvement of noise:
  - Vibration reduction
  - Controlled temperature and environment
  - Low noise custom electronics (OWEN project[3])

[3] https://r2d2.in2p3.fr/owen.html

Operation



- ^{210}Po source of 5.3 MeV α allows to study gas and signal behaviours.
- **Argon P2** (98% Ar, 2%CH_4) used in the early stage of the experiment (like Xe, Ar is an inert gas, it emits scintillation light, it has a similar ionization threshold).
- **Different pressures tested (various track length)**: mainly 200 and 1100 mbars.
- In sealed mode: **short runs** (30min) to avoid contamination effects. Purification technology mature[4,5] for longer runs.

[4] *V Álvarez et al, JINST 7 (2012) T06001*

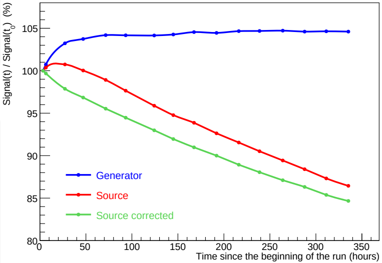
[5] *Chen et al, Science China Physics, Mechanics & Astronomy 60 (2017) no.6, P061011*

Stability

In gaseous detectors, energy **response could vary** according to:

- Temperature (→ pressure, electronics)
- Gas electronegative impurities

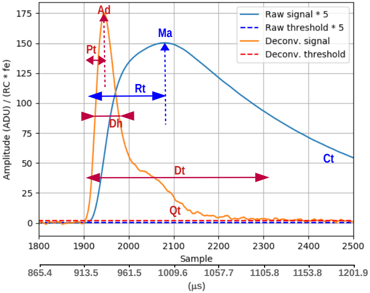
1. **Control the electronics response**: use a **generator signal** in input to test the electronic.
   → *Correct the source signal.*
2. **Evaluate signal variations due to gas**: -0.05%/h.
   → *Allow offline corrections for several weeks data taking .*



Signal variation (%) over 14 days.

Waveform analyses

For very high precision measurements, we compute **variables from integrator and deconvoluted** signals.



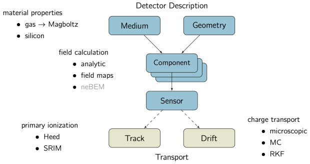
The **shape of the deconvoluted signal contain the event history**.

- Charge observables (linked to energy): Qt compares to Ct $\rightarrow$ accuracy of deconvolution
- Temporal observables linked to anode distance and track length: Dt (signal width neglecting ion tail) and Dh $\rightarrow$ α angular direction
- Pt: direction of the track (toward anode $\Rightarrow$ small Pt)

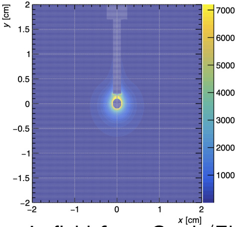
Simulation Tools

Based on

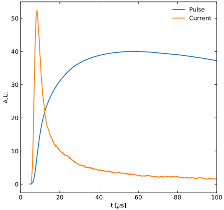
- Finite Elements Software: Ansys[1] or Gmsh[2]+Elmer[3]
- Geant4[4]: simulation of primary interaction
- Garfield++[5]: simulation of gas, electrons transport and charge collection.



Main Garfield++ classes.



Electric field from Gmsh/Elmer (V=720V).



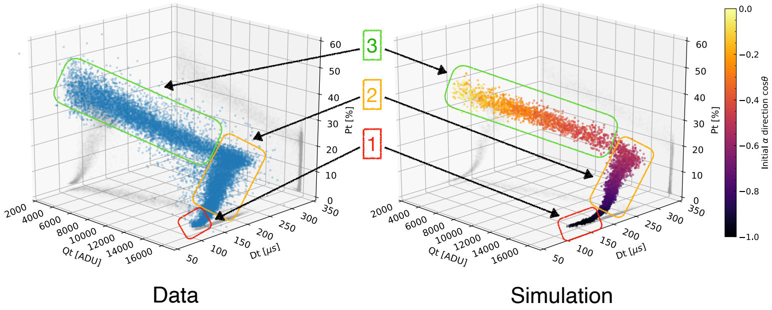
Signal produce by α track (orange) and its integration (blue).

[1] ansys.com [2] gmsh.info [3] csc.fi/web/elmer [4] geant4.web.cern.ch [5] garfieldpp.web.cern.ch

Simulation outcomes

The observables combination are closely linked to the **event topology, resulting in specific patterns**, *e.g.* 3 regions in the following plots:

1. Tracks toward the anode.
2. Tracks at larger angles but contained in gas.
3. Tracks hitting the cathode (loosing energy in it).



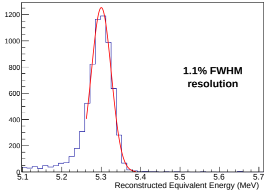
→ Allow a good understanding of the data (*e.g.* the α track direction).

→ Cross-check with data: **good agreement**.

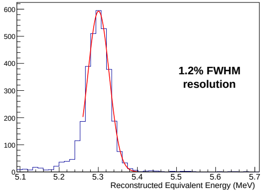
Resolution - Track length effects

Explore response at **200mbar (720V) and 1100mbar (2000V)** at the same gain level, with a main difference:

→ The α **track length** (∼20cm vs ∼4cm respectively)



200mbar



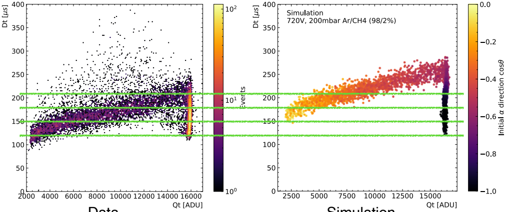
1100mbar

⇒ **Track length and pressure do not (strongly) affect the energy resolution**

N.B.: The contribution of the source and the electronic are estimated to account for ∼0.6%

Resolution - Direction effects

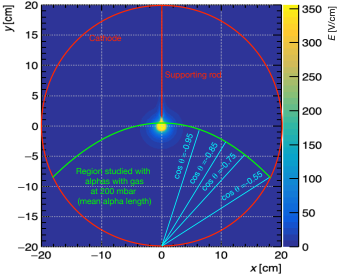
Cuts for angle selection from simulation.

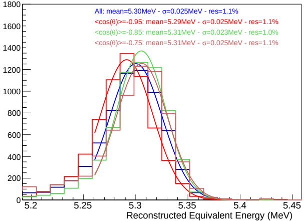


Data Simulation

Dt cuts corresponding to angular direction selection.

⇒ **Track direction doesn't affect energy resolution.**

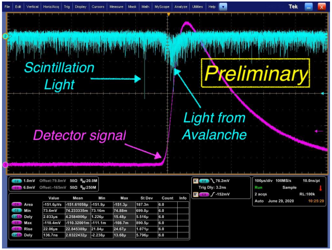




200mbar - 720V data.

Next steps

1. Confirm the result in different conditions:
   - Using **Xenon** → Recuperation system under construction
   - Ionization by **electrons** → Need at least 10bars to contain electrons track
   - At **higher pressure** → Detector certified for high pressure is being installed
   - Using a **diffuse source** → Need to find a Radon source clean from electronegative impurities.
2. Read the **scintillation light** to get precise timestamp (promising test are ongoing).
3. **Electronics developments** are ongoing.
4. Upgrade sensor from single anode one to a multi-anode one (ACHINOS[6] project).



First result of light readout.

[6] *JINST 12 (2017) no.12, P12031*

Conclusions

- A good understanding of detector was achieved, demonstrated by a **simulation in agreement with data**.
- **1.1% energy resolution** have been reached in Argon with 5.3MeV α.
- **Neither track length nor direction affect the energy resolution**.

Improved performances still expected:

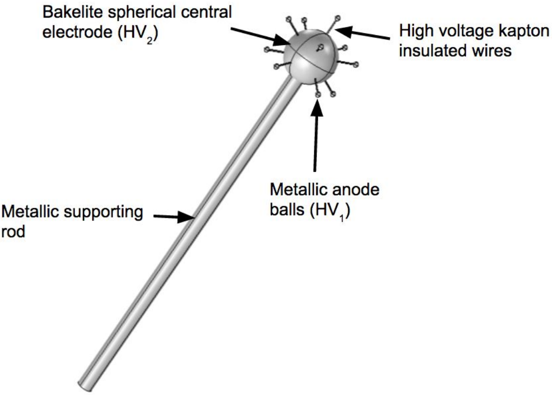
$\rightarrow$ Sensor updates and light readout could improve performances.

$\rightarrow$ Results have to be confirmed in Xenon.

$\Rightarrow$ Expect to build prototype with features adapted to physics measurements (depending on results).

BACKUP

ACHINOS



Multi-anode sensor "ACHINOS" design