First results of the R2D2 project

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on behalf of
the R2D2 collaboration

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Introduction

- To demonstrate the Majorana nature of neutrino the most sensitive experimental way is an observation of the so called **0νββ decay**.
- The three **main requirements** to search for such a rare phenomenon are:

Excellent energy resolution

Low background

Large masses of isotopes

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

goal of R2D2 (Rare Decays with Radial Detector)

- 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.

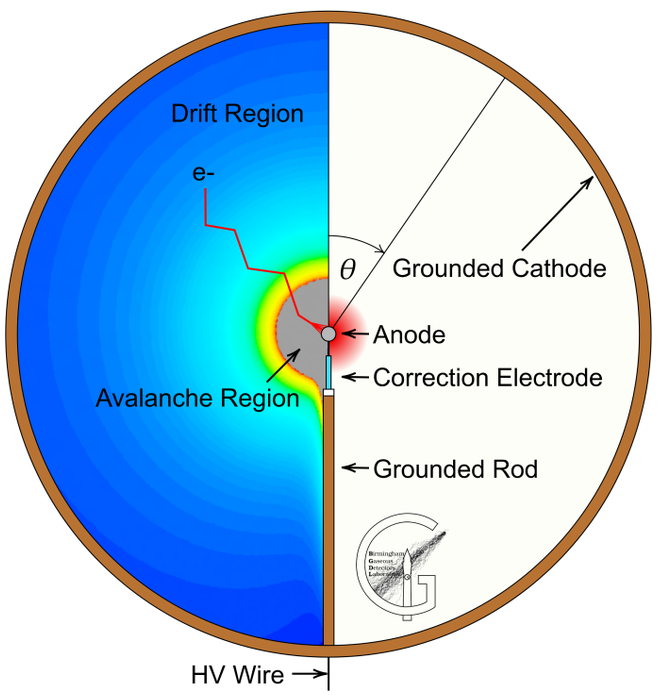
→ **How?** →

Using a spherical high pressure xenon TPC

The detector

- The detector is a spherical Xenon gas TPC as proposed by Giomataris et al. and used today in the NEWS-G collaboration for the search of dark matter.
- The design has to be optimised for the background reduction in the $\beta\beta0\nu$ search with ^{136}Xe ($Q_{\beta\beta}$ of 2.458 MeV).

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 (zero?) background due to the very low material budget.
- Scalability to large isotope masses (1 ton = 1 m radius at 40 bars)
- Low detection threshold at the level of 30 eV i.e. single electron signal.
- High detection efficiency (~ 65% after selection cuts).
- Simplicity of the detector readout with only one (or few in the upgraded version) readout channels.

R2D2 collaboration

- A proto-collaboration has been formed.
- 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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The R2D2 Roadmap

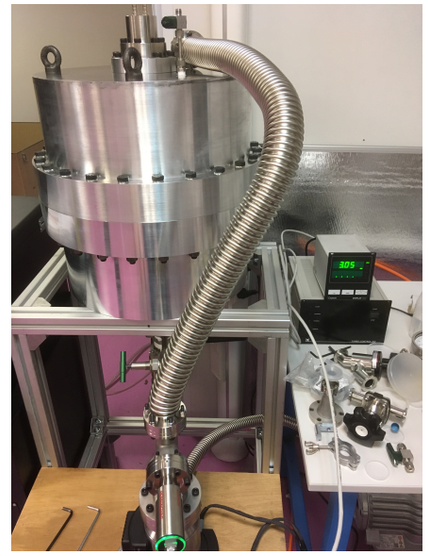
Prototype 1

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

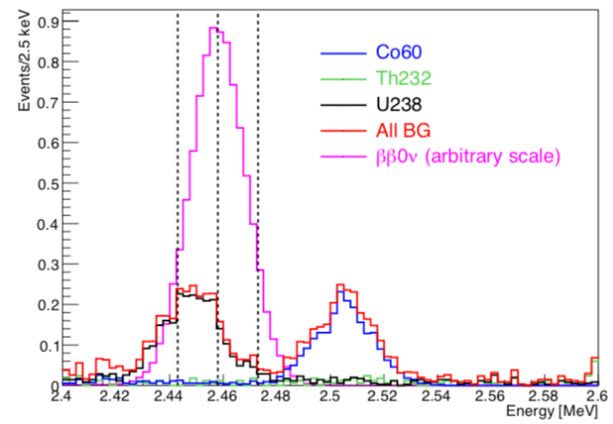


Prototype 2

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



JINST 13 (2018) no.01, P01009

Depending on the results and fundings

Experiment

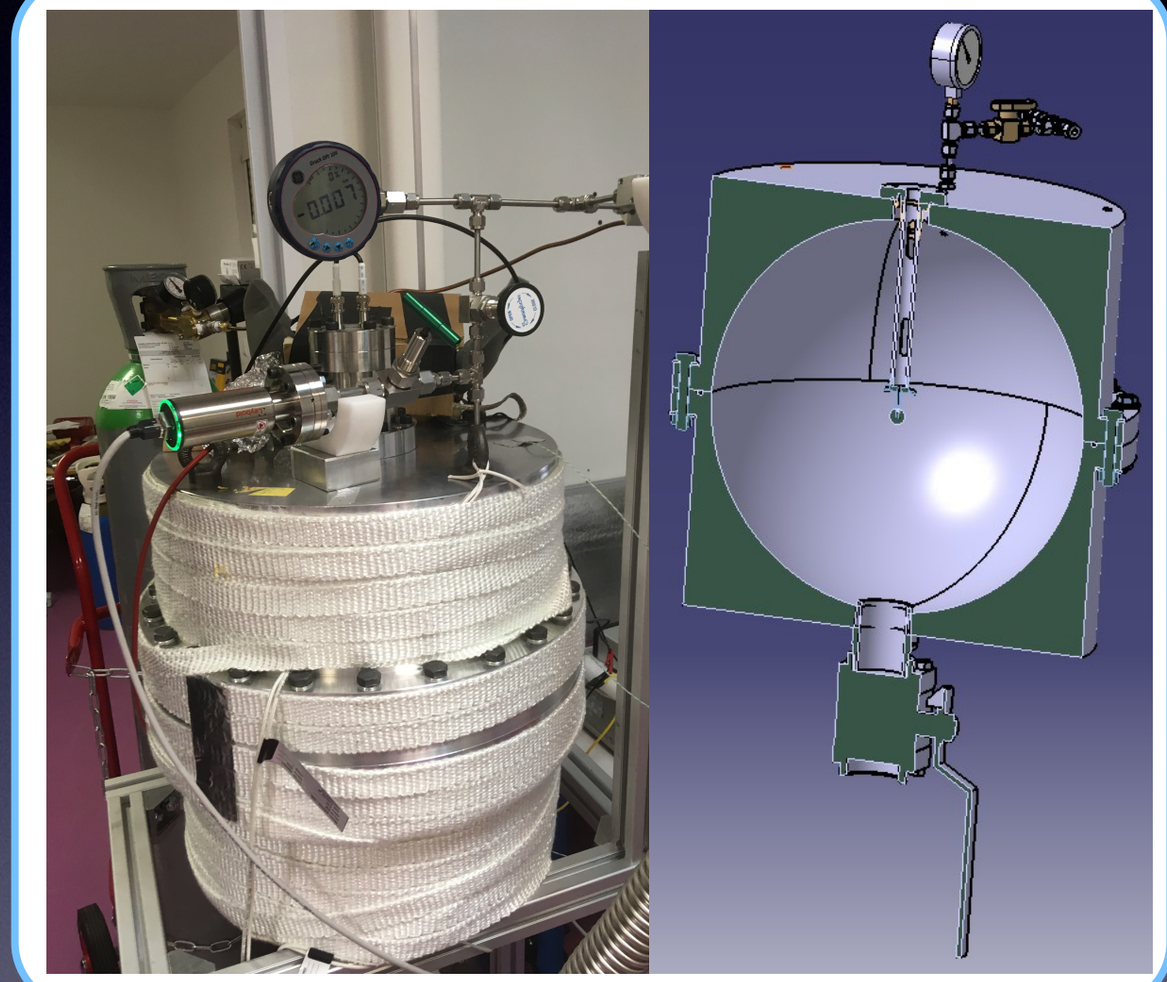
Going towards a 1 ton background free detector

Exploit the detector with other gases to cross check the background and possibly obtain interesting results selecting higher Qββ, as well as the possibility to do tracking

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

Experimental setup

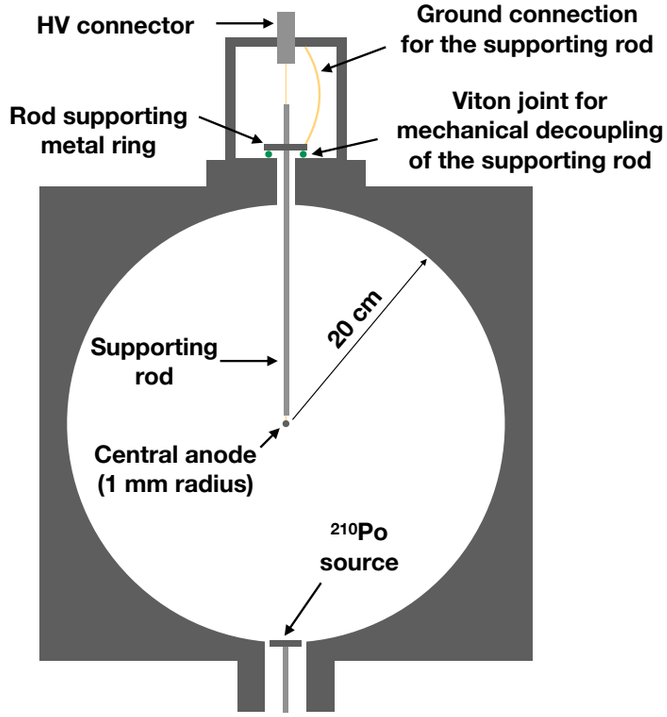
- In 2018 the R2D2 was funded as R&D by the IN2P3: the main goal is the **demonstration that the desired energy resolution is achievable**.
- A 20 cm radius sphere made of Aluminium (i.e. no low background but much cheaper) was built at CENBG.
- Efforts were made to reduce the noise as much as possible:
  - Isolated and temperature controlled environment.
  - Vibrational insulation of the supporting structure and of the central anode.
  - Custom made low noise electronics (OWEN project).
- The setup was commissioned and is currently being **operated with Ar (98%) + CH_4 (2%)** at CENBG at **pressures up to 1.1 bar**.

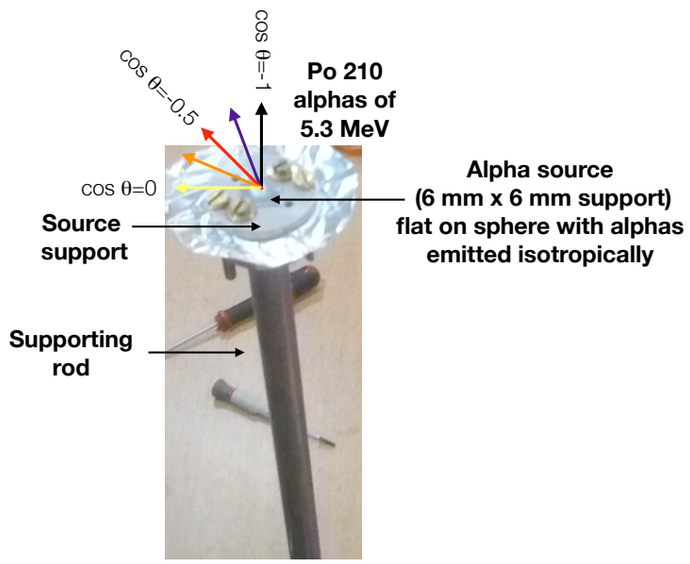


→ **Certified sphere to go up to 40 bars and Xenon recuperation system expected in October 2020**

Detector operation

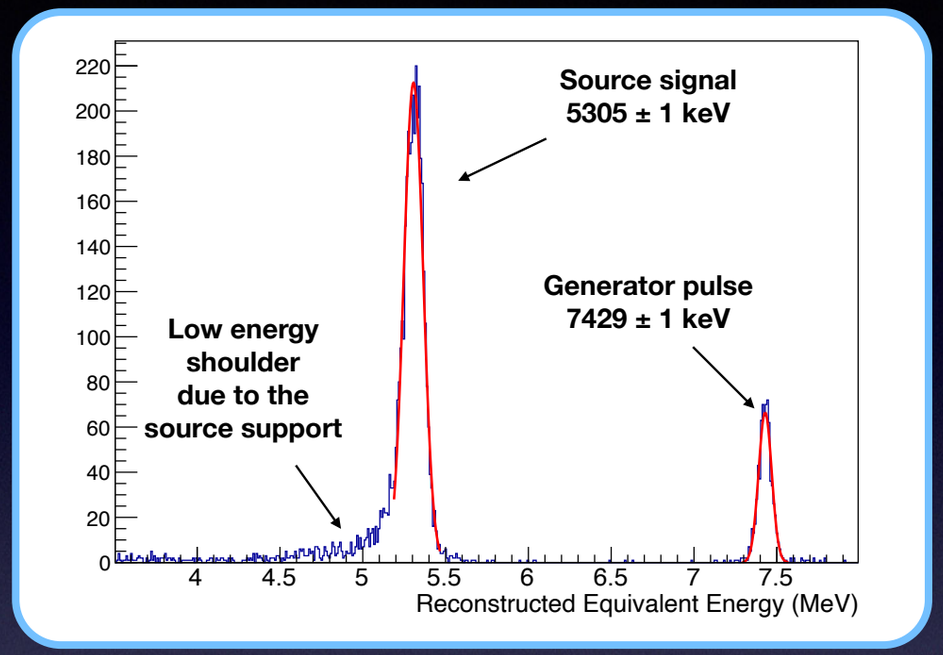
- To assess the energy resolution a 4Bq ^{210}Po alpha source of 5.3 MeV was used.
- The source deposited on a silver film is located on a support and inserted from the bottom of the detector.
- Runs were taken as different pressures.
- A pulse generator was used as input in the electronic chain to monitor and correct for possible electronics response variations.
- Runs were typically short (30 minutes) to avoid to apply corrections due to gas degradation and new gas was used each time after pumping the detector at a vacuum of 10^{-6} mbar.
- A dedicated simulation (*JINST 15 (2020) C06013*) based on Geant4 and Garfield++ was used to cross check the obtained results and confirm our understanding of the detector response.

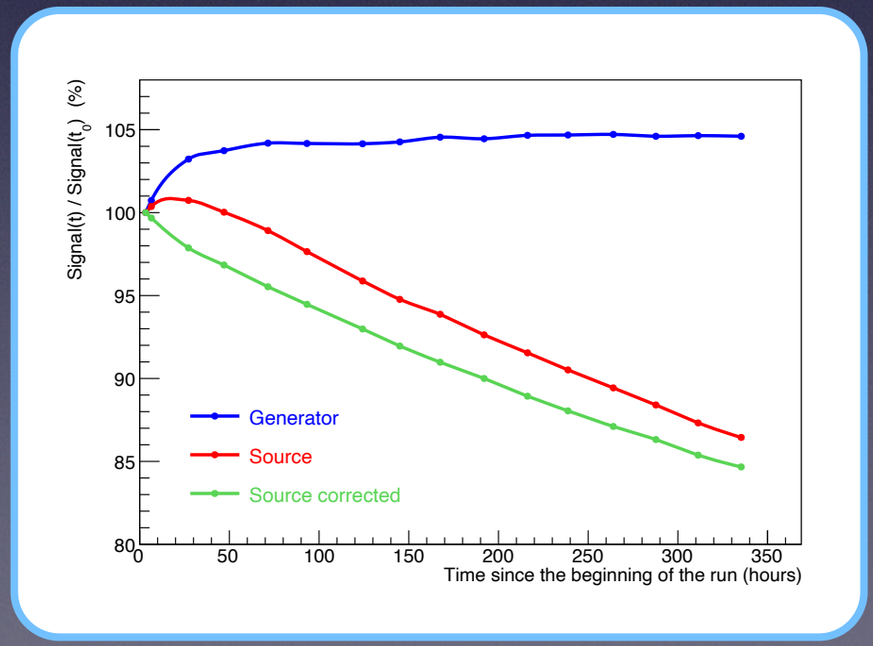




Detector stability

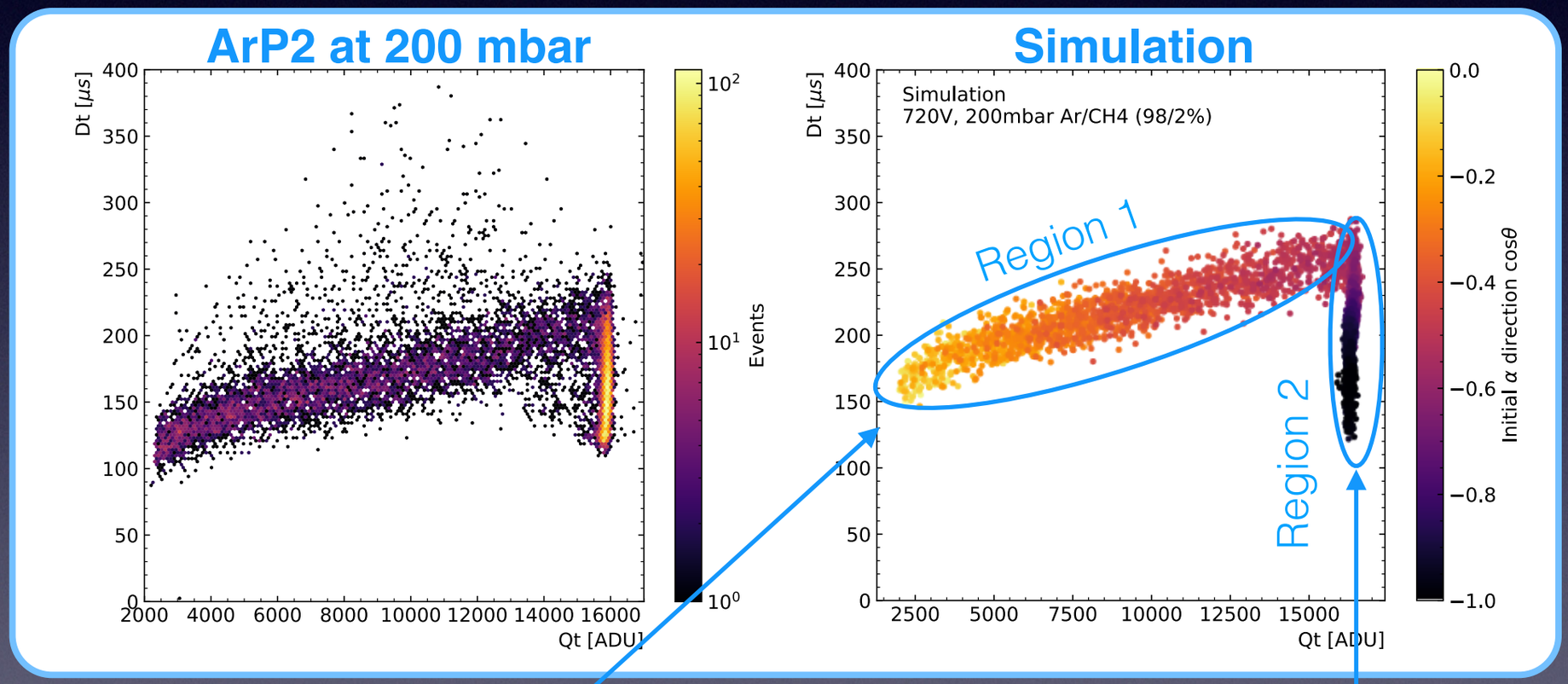
- Short runs over a period of 14 days without changing the gas were taken to assess detector stability.
- Electronegative impurities concentration, due to material outgassing and leakages, increases in time resulting into a smaller number of electrons reaching the anode.
- The mean value of the reconstructed energy for alphas and for the generator was used to estimate the signal loss variation in time.
- A loss of 0.05% per hour was measured.
- Such a loss can be corrected offline, and reduced in future upgrades of the detector reducing the leakage (today at 5×10^{-9} mbar/s).





Results

- At 200 mbar alpha tracks have a length of about 15 to 20 cm.
- Several variables were computed on the waveform to study the signals, two of which are the total reconstructed charge (Qt) and the signal length (Dt).
- The **agreement between data and simulation is very good** and the detector behaviour is well understood.



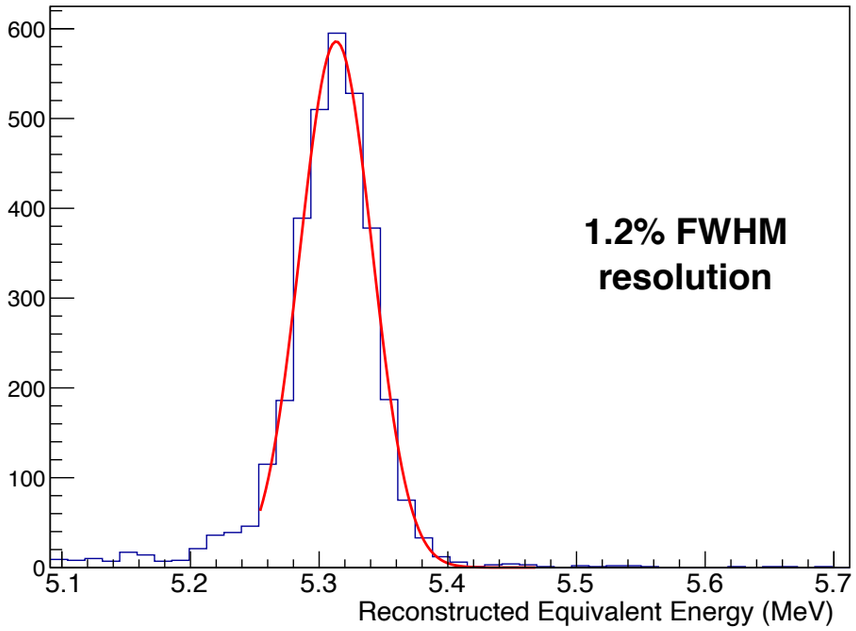
Tracks hitting the cathode (large angle, cosθ<-0.4) have a decreasing Qt and the decrease in Dt is driven by threshold effect (smaller signals go under threshold in a smaller time).

Tracks not hitting the cathode at large angle (cosθ = -0.6) should have a smaller Dt with respect to tracks going towards the anode (cosθ = -1) since electron drift is similar. It is not the case since diffusion effects dominate as demonstrated by the simulation.

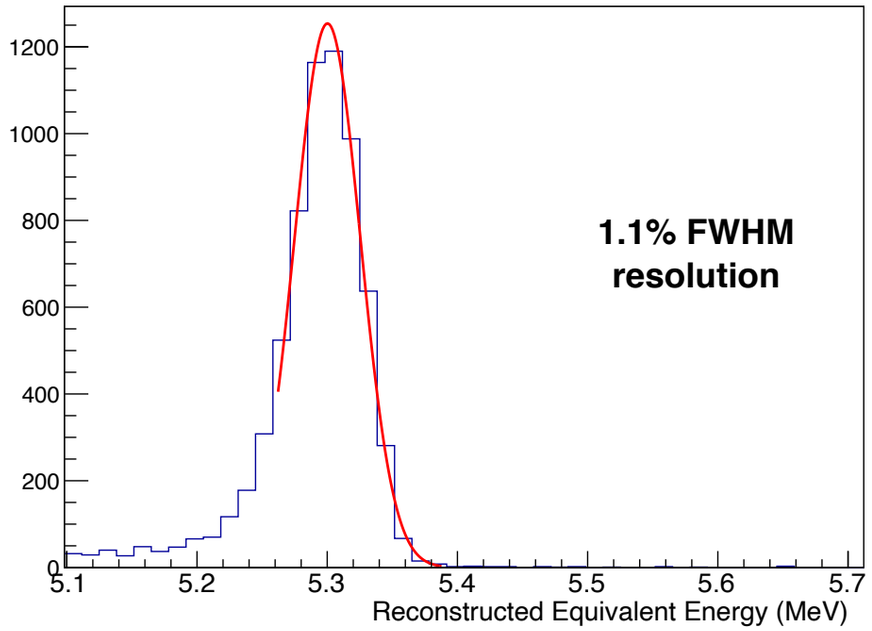
Resolution

- 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).
- We estimate to 0.6% the contribution of the source itself and of the electronics giving an intrinsic resolution due to the detector at 0.97%.

1.1 bar - 2000V



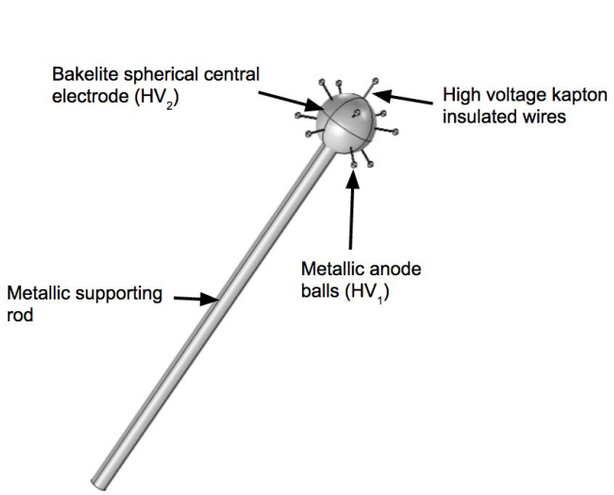
200 mbar - 720 V

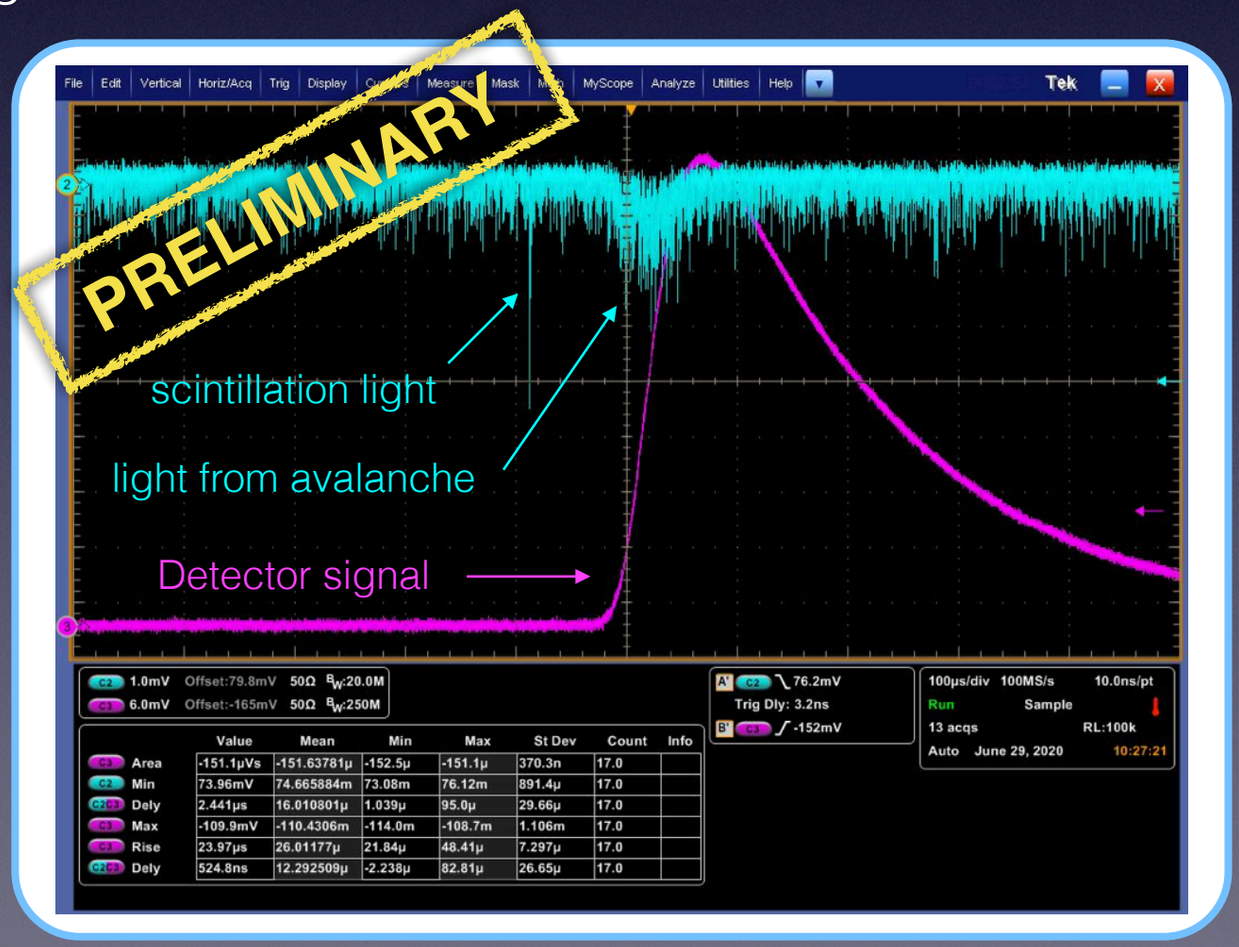


ArXiv:2007.02570

Next steps

- The results should be confirmed in different conditions:
  - Higher pressure → New detector certified at 40 bars in October
  - With electrons → ^{207}Bi source available but more than 10 bars needed to contain electron tracks
  - In xenon → Recuperation and recirculation systems ready in October
  - With a diffuse source → Clean radon source yet to be found (problem with electronegative impurities)
- Further developments of the electronics ongoing.
- Tests to read the scintillation light for a precise time stamp ongoing (excellent preliminary results).
- Possibility to use multi-sensor anode (ACHINOS).





Conclusions

- The R2D2 collaboration has been formed and the R&D has been approved by IN2P3.
- Preliminary studies showed that we could have competitive sensitivity with small masses and **potentially zero background detectors with large masses**.
- A good detector understanding demonstrated and a **resolution at the level of 1.1% was achieved** with alphas at 5.3 MeV.
- We also demonstrated that the **energy resolution is not degraded going from point-like energy deposits to long particle tracks**.
- Results to be confirmed in xenon at higher pressure.
- Depending on the success of the R&D we hope to move on in order to build a prototype allowing for real physics results.