Latest 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

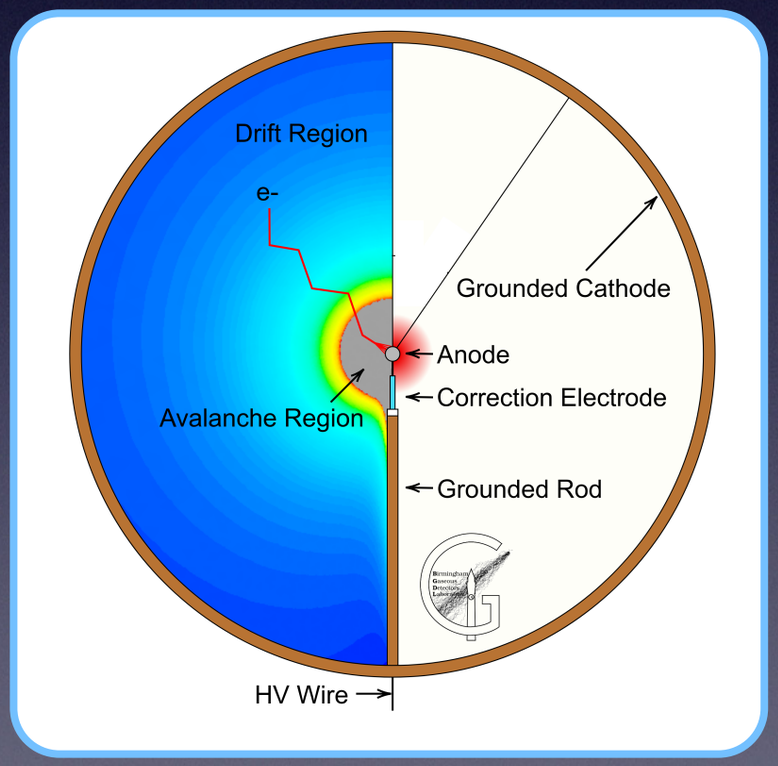
→ **Can we meet all the requirements at the same time?** → **goal of R2D2 (Rare Decays with Radial Detector)**

- 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**

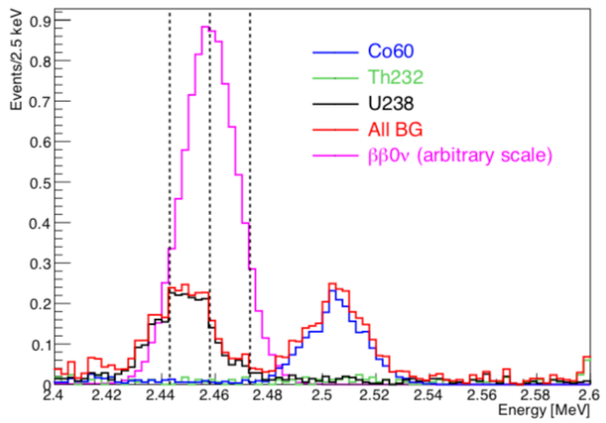
Prototype 2

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

↓ **Depending on the results and fundings**



JINST 13 (2018) no.01, P01009

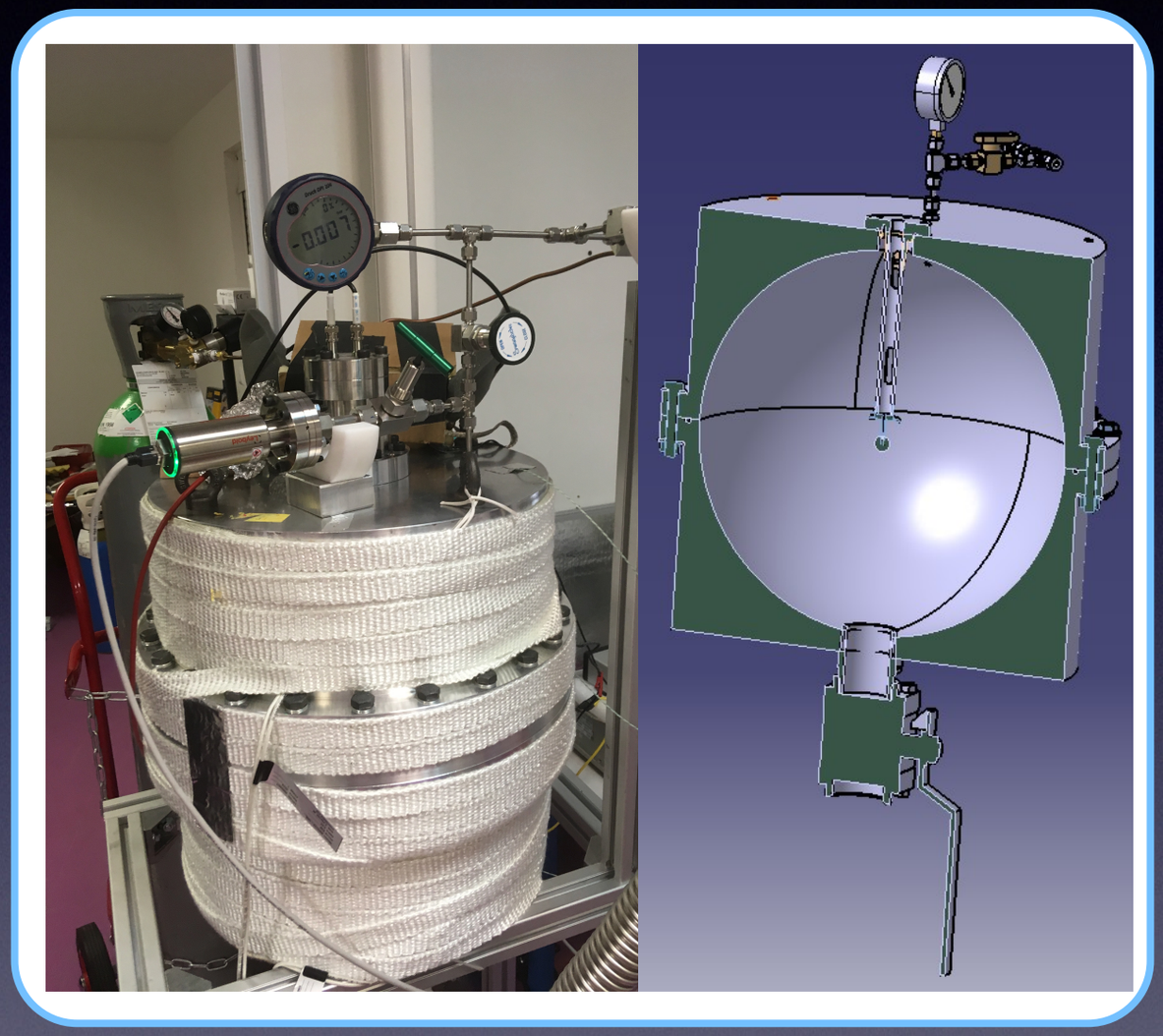
Experiment

Going towards a 1 ton background free detector

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

Experimental setup

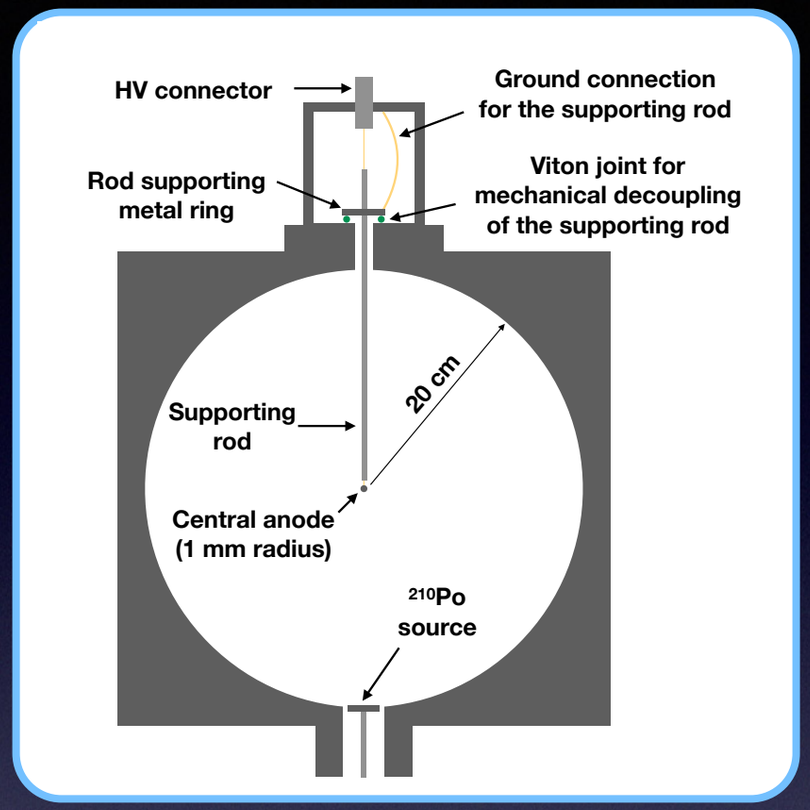
- In 2018 the R2D2 was funded as R&D by the IN2P3: the main goal is the **demonstration that the desired energy resolution is achievable**.
- A 20 cm radius sphere made of Aluminium (i.e. not low background but much cheaper) was built at CENBG.
- Efforts were made to reduce the noise as much as possible:
  - 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**.

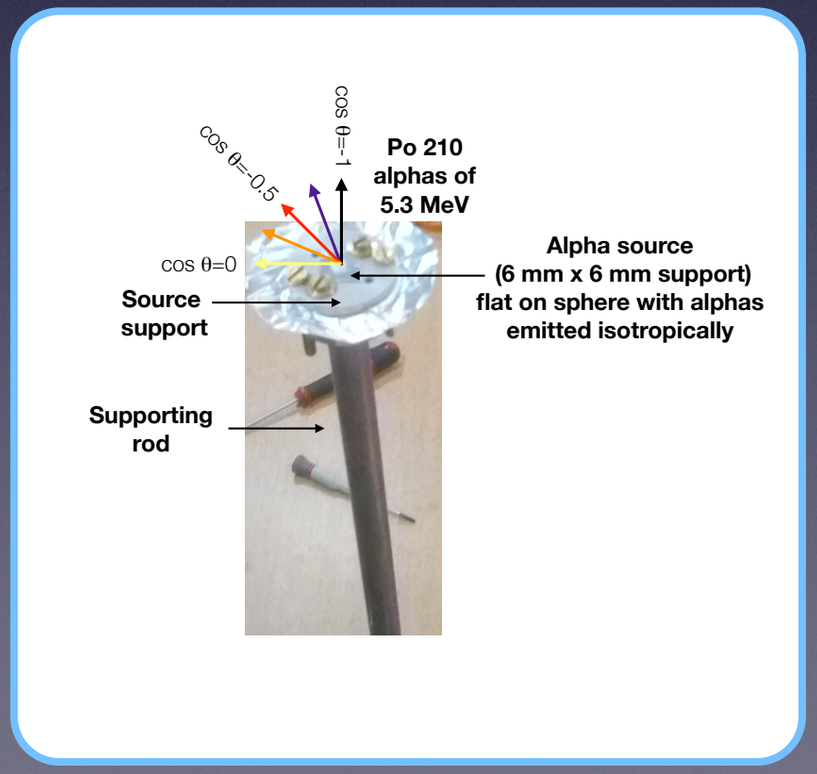


→ **Certified sphere to go up to 40 bars and Xenon recuperation system under commissioning**

Detector operation

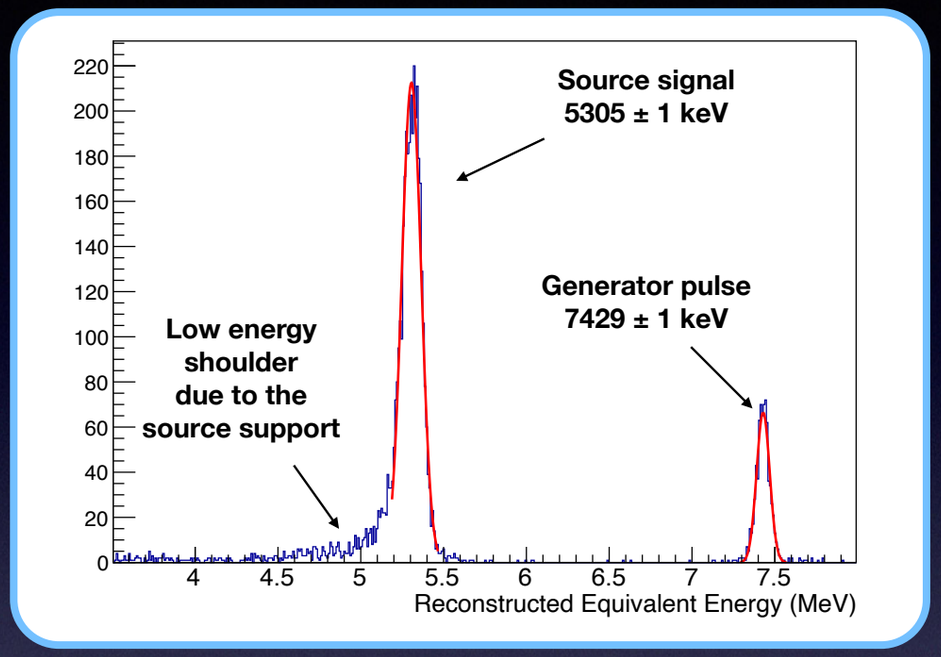
- To assess the energy resolution a 4Bq ^{210}Po alpha source of 5.3 MeV was used.
- The source deposited on a silver film is located on a support and inserted from the bottom of the detector.
- Runs were taken at different pressures.
- A pulse generator was used as input in the electronic chain to monitor 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.

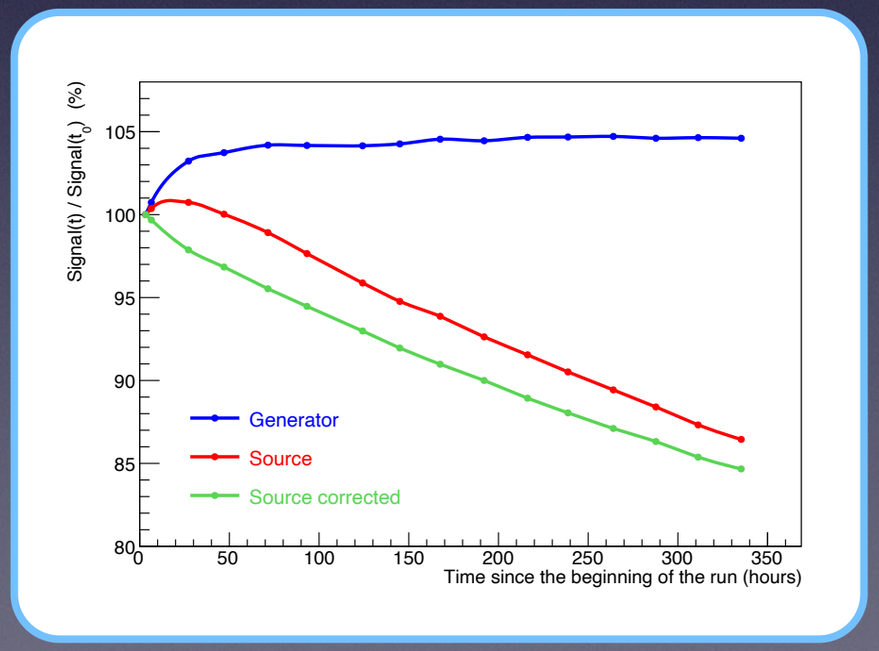




Detector stability

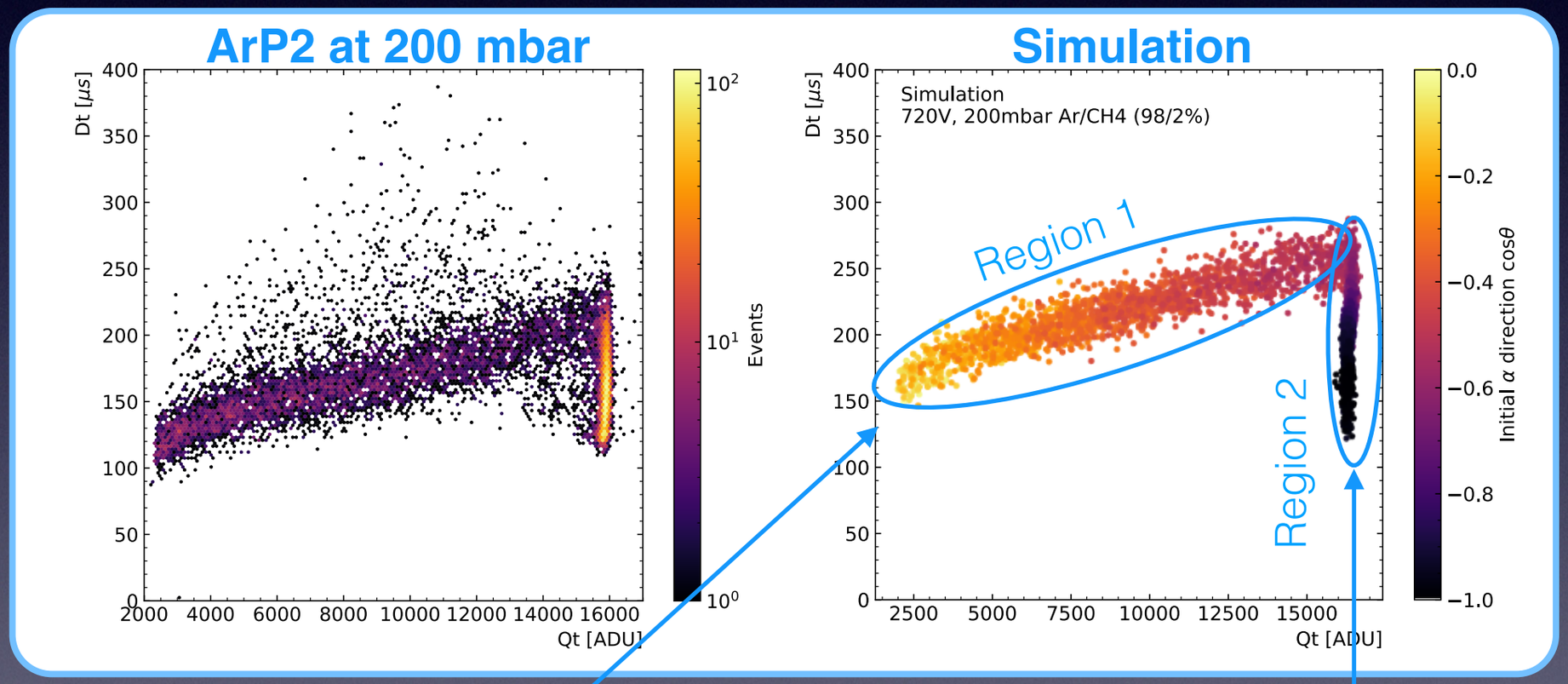
- Short runs over a period of 14 days without changing the gas were taken to assess detector stability.
- Electronegative impurities concentration, due to material outgassing and leakages, increases in time resulting into a smaller number of electrons reaching the anode.
- The mean value of the reconstructed 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

- In ArP2 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.

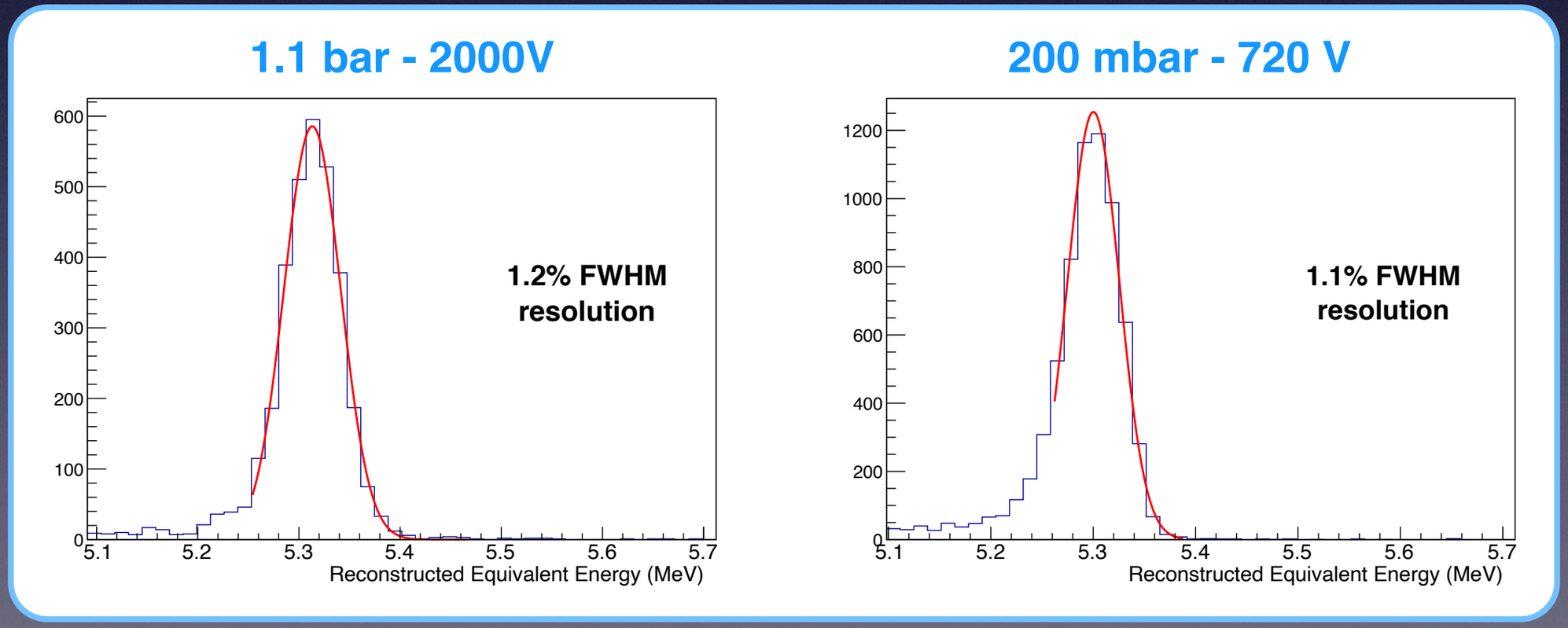


Tracks hitting the cathode (large angle, cosθ<-0.4) have a decreasing Qt and the decrease in Dt is driven by threshold effect (smaller signals go under threshold in a smaller time).

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

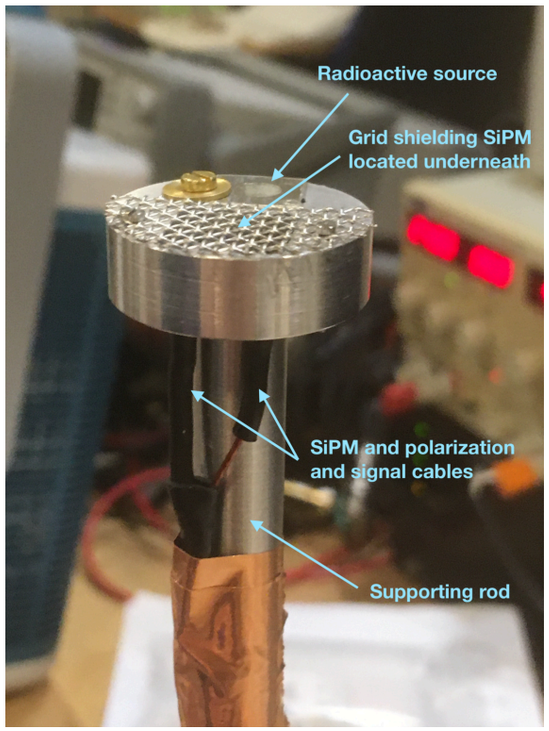
- The resolution was computed at 200 mbar and 1.1 bar.
- We obtained a similar resolution showing **no impact due to the length of the tracks** (from 3-4 cm at 1.1 bar to 15-20 cm at 200 mbar).
- We estimate to 0.6% the contribution of the source itself and of the electronics giving an intrinsic resolution due to the detector at 0.97%.

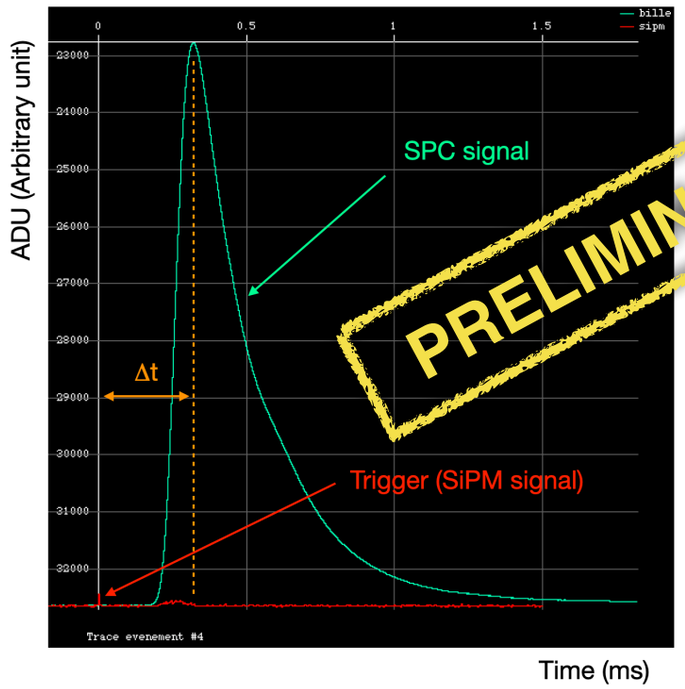


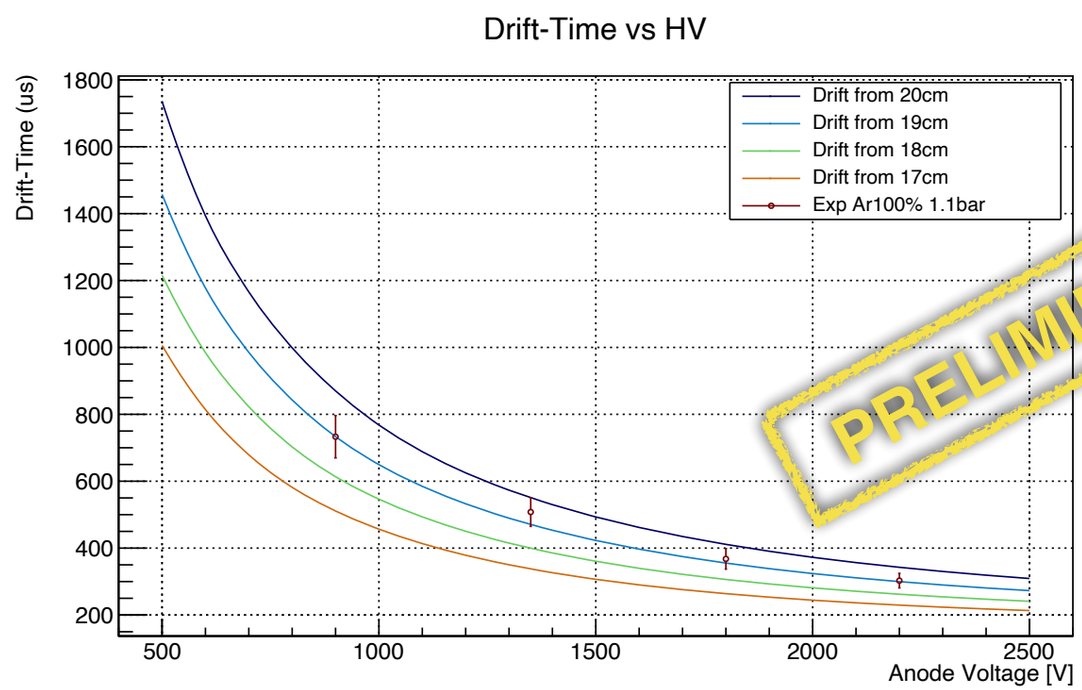
JINST 16 (2021) 03, P03012

Scintillation light detection

- 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 and a second signal on time with the SPC signal due to the light emitted in the avalanche.
- The time between the trigger and the SPC signal 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.

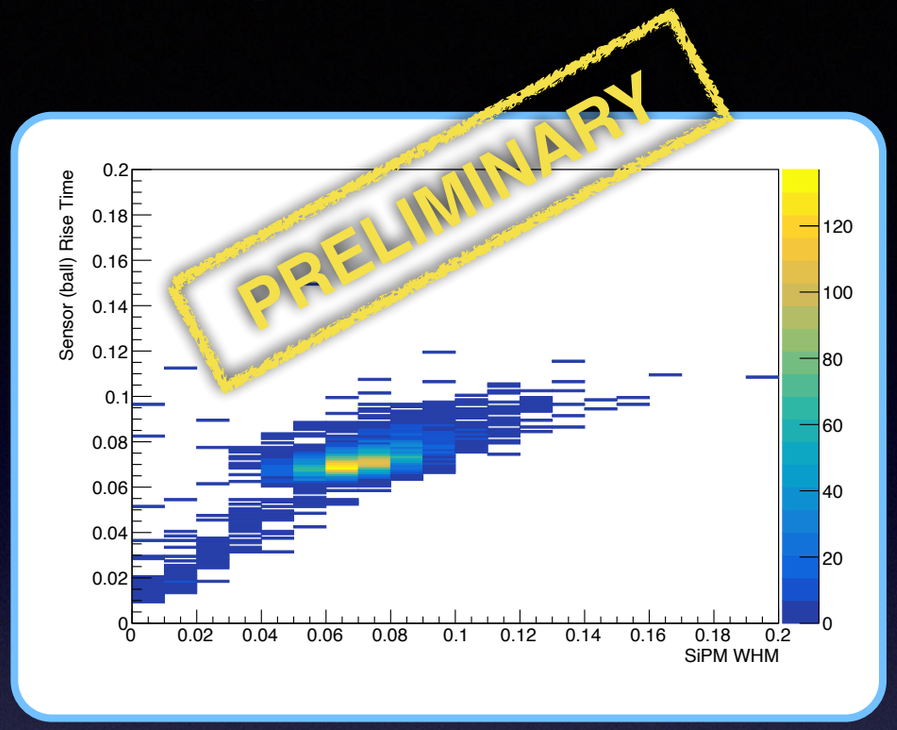


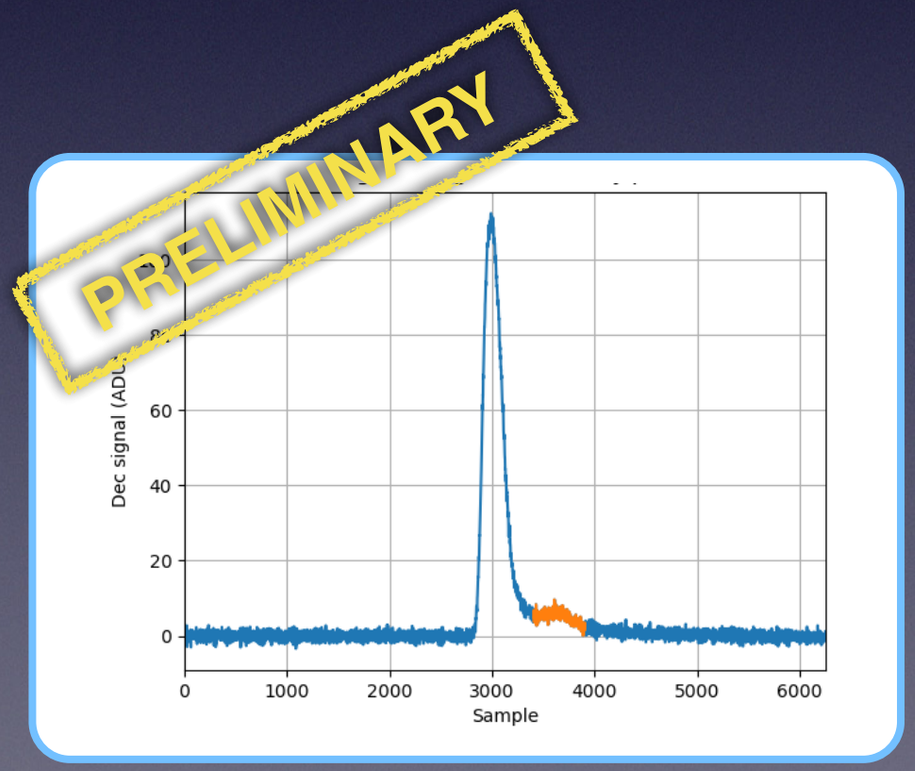




Avalanche light analysis

- We studied the light emitted in the avalanche to see if we could extract some information on the event topology.
- **Work is in progress** but the **SiPM signal width is proportional to the SPC signal rise-time** typically used for **radial position reconstruction**.
- A delayed signal is also observed on the anode corresponding to electrons ripped off the cathode by the avalanche photons (confirmed by the time difference which corresponds to a 20 cm drift).
- **Preliminary studies** showed that the **energy resolution is not degraded** when such a component is present in the waveform, which indicates that it could be possible to operate the detector without a quencher.

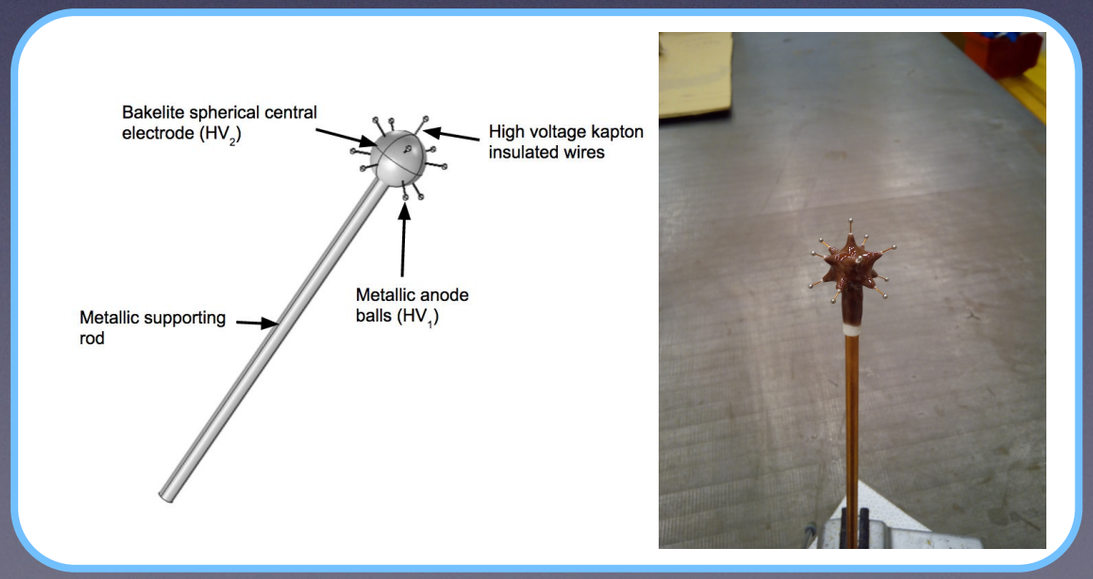




Next steps

- The results should be confirmed in different conditions:
  - Higher pressure → New detector certified at 40 bars under commissioning
  - With electrons → ^{207}Bi source available but more than 10 bars needed to contain electron tracks
  - In xenon → Recuperation and recirculation systems ready in summer
  - With a diffuse source → Clean radon source yet to be found (problem with electronegative impurities)

- Fundings requested for low background prototype
- Possibility to use multi-sensor anode (ACHINOS).



Conclusions

- The R2D2 collaboration has been formed and the R&D has been approved by IN2P3.
- Preliminary sensitivity 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.
- **Scintillation light in argon** used as trigger for the first time.
- Results in xenon and at higher pressure expected by the end of the year.