R2D2 project

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on behalf of
the R2D2 collaboration

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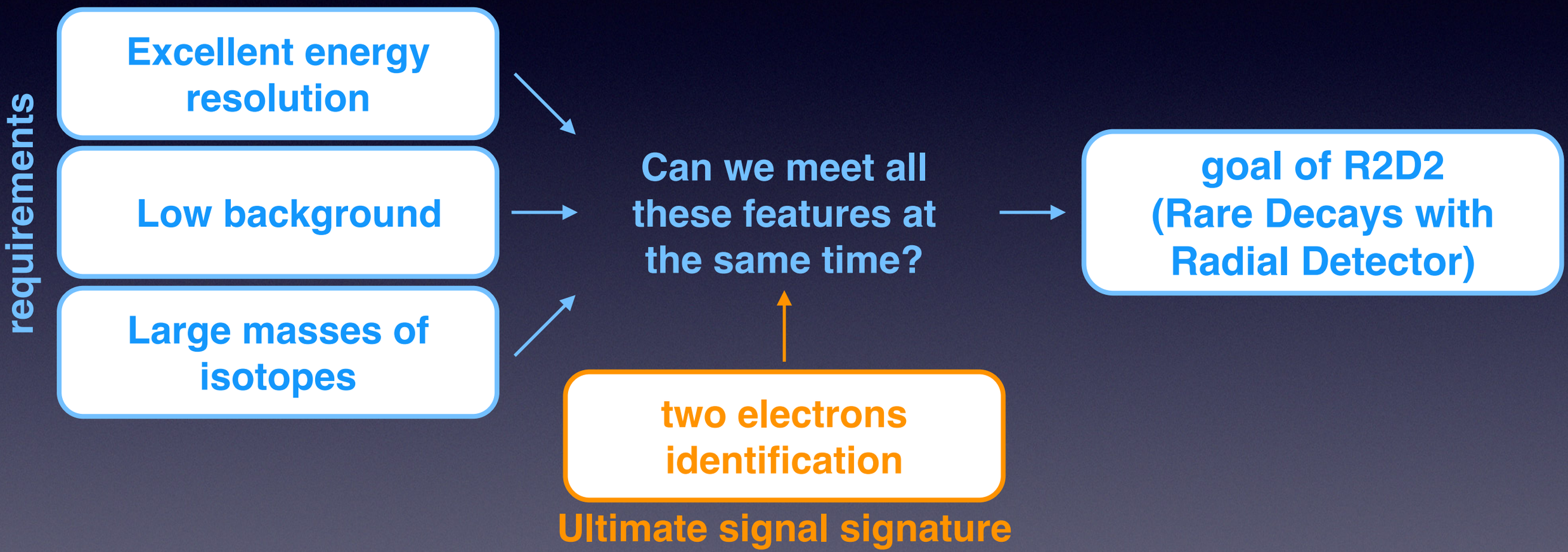
Scientific context

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



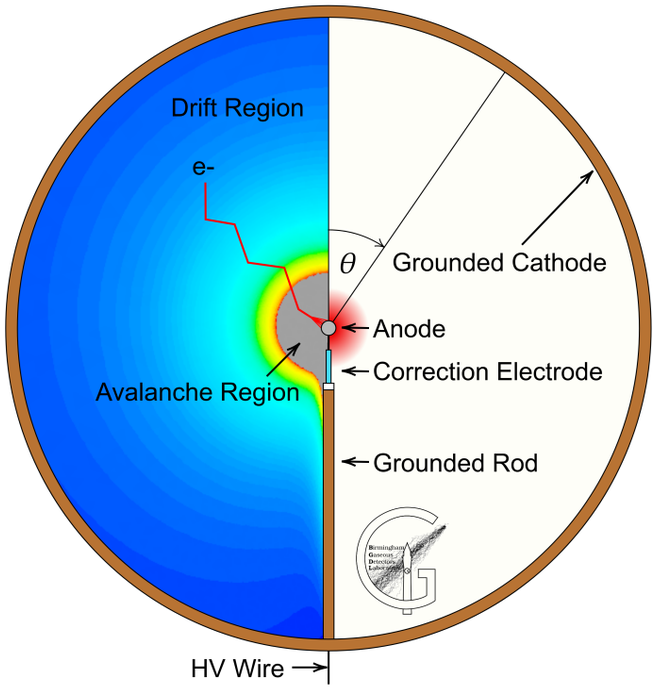
- R2D2 is an **R&D program** aiming at the development of a **low background large scale detector** to search for the neutrinoless double beta decay.

→ 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.

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 (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.

For a ton scale detector, 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).

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

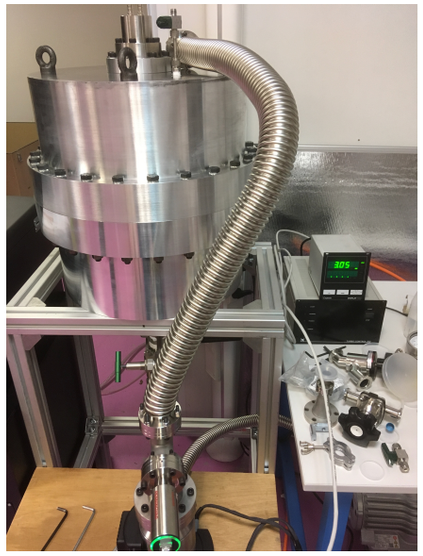
Prototype 1

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

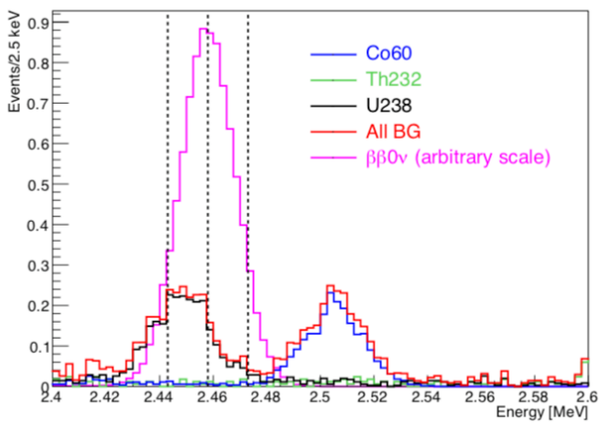
$m_{\beta\beta}$ < 160 - 330 meV

Depending on the results and fundings

Experiment

Going towards a 1 ton background free detector

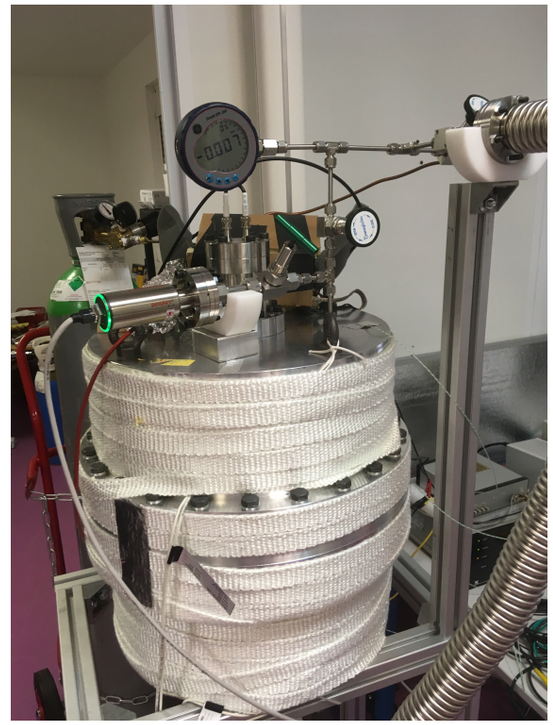
$m_{\beta\beta}$ < 10 meV (I.H. covered)



JINST 13 (2018) no.01, P01009

Experimental setup

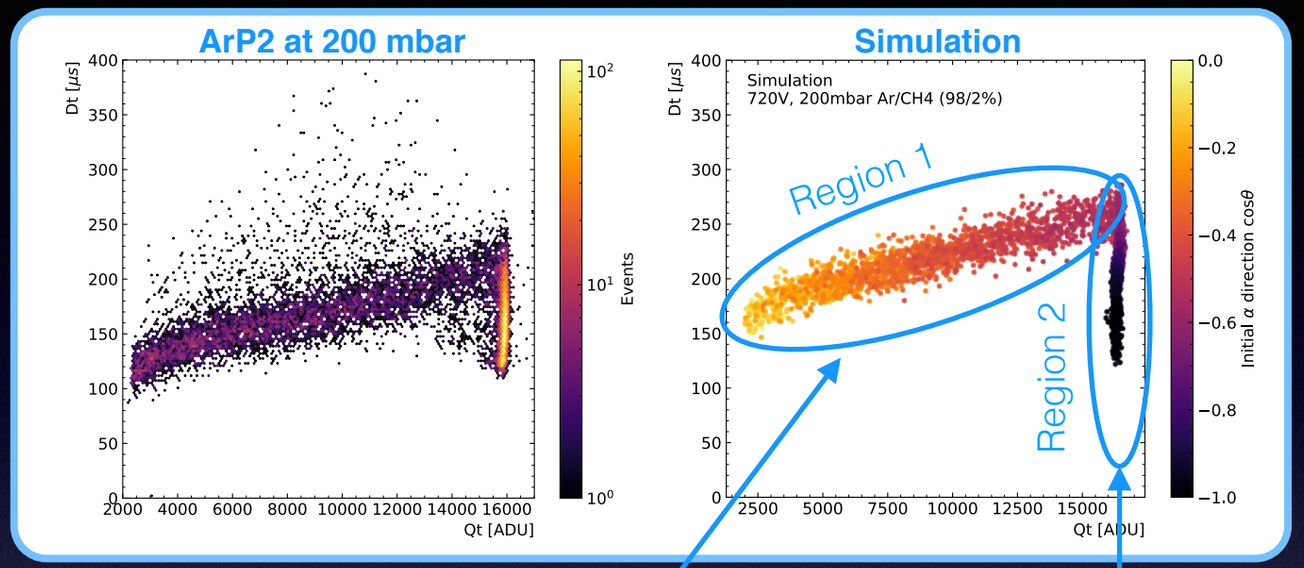
- In 2018 the R2D2 was funded as R&D by the IN2P3: the main goal is the **demonstration that the desired energy resolution is achievable**.
- A 20 cm radius sphere made of Aluminium (i.e. no low background but much cheaper) was built at CENBG.
- Efforts were made to reduce the noise via:
  - Isolated 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 was **operated with Ar (98%) + CH_4 (2%)** at CENBG at **pressures up to 1.1 bar**. First resolution results were published (*JINST* 16 (2021) 03, P03012)

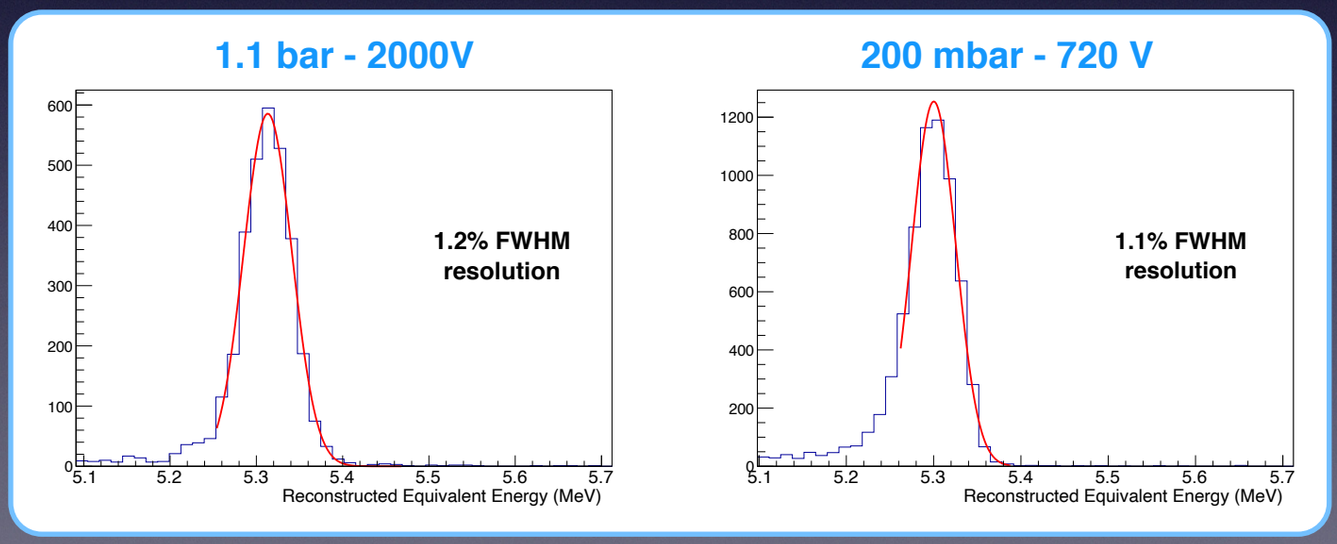


Certified sphere to go up to 40 bars and Xenon recuperation system delivered in spring 2021 under commissioning

First results

- To assess the energy resolution a 4Bq ^{210}Po alpha source of 5.3 MeV was used: the source was deposited on a silver film is located on a support and inserted from the bottom of the detector.
- 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.
- **Waveform processing** is applied to filter noise and exploit the most the detector signal.
- 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).



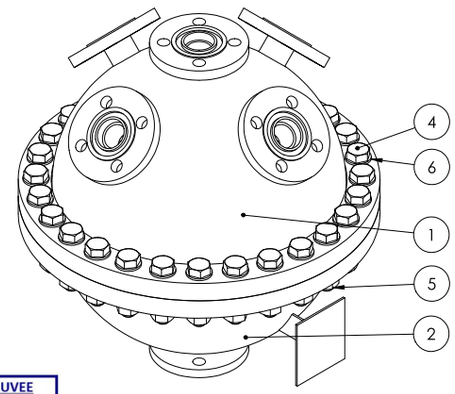


JINST 16 (2021) 03, P03012

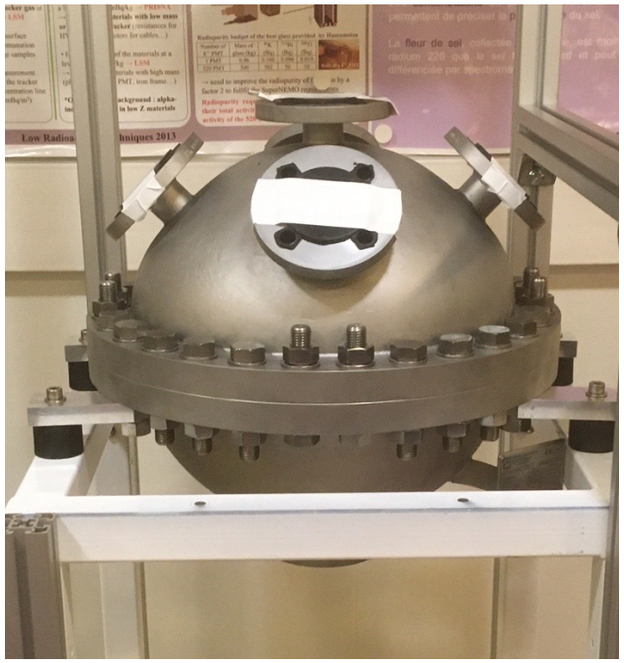
Technical developments

Mechanics

- The main issue on the mechanics are:
  - Need of vacuum at the level of 10^{-8} mbar.
  - Certification to operate at 40 bars.
  - Vibrational and external noise insulation.
- With the first prototype built at CENBG we obtained a vacuum of 10^{-7} mbar limited probably by material outgassing, and we are not certified to operate at high pressure.
- A new detector made by the Ravanat company certified up to 40 bars has been delivered in spring 2021. So far we obtained a vacuum at the level of 10^{-6} mbar limited by outgassing (heating foreseen when final sensor will be installed).
- 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.
- “vacuum” and “high pressure” are expertises quite different and our mechanic pool struggled to have this two domains talking to each other. **Does it exist or would it be helpful to have such expertise at IN2P3?**



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

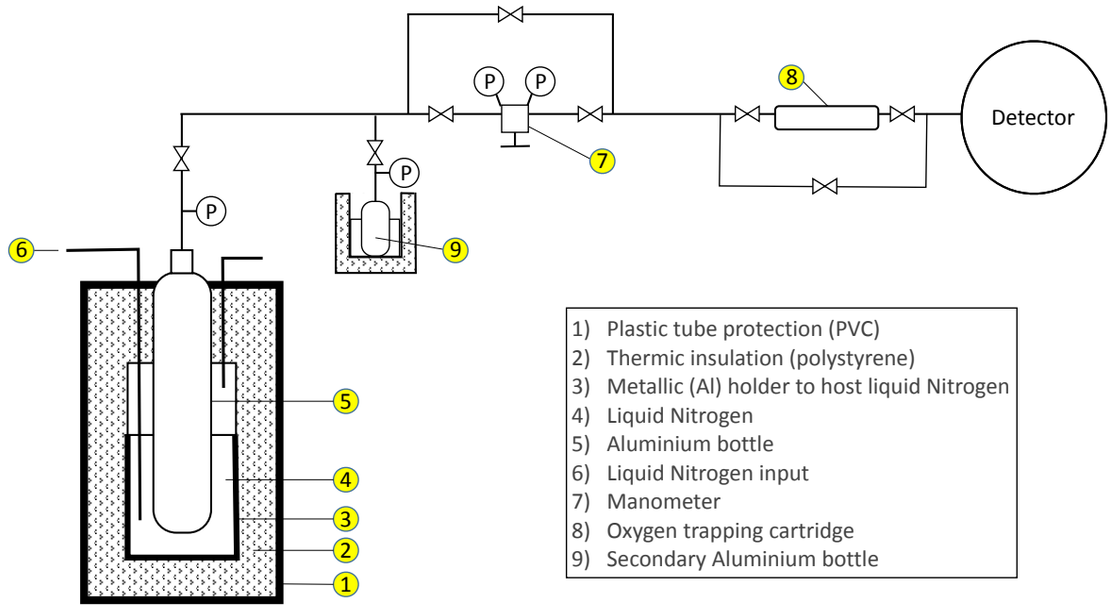


Technical developments

Gas system

- 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 oxysorb) but **the issue is the recirculation of the gas at high pressure**. The actual pump works up to a few bars.
- Expertise exist in the international community (XENON, PANDA-X, etc.) and we hope to profit from the SUBATECH expertise of the XENON group.

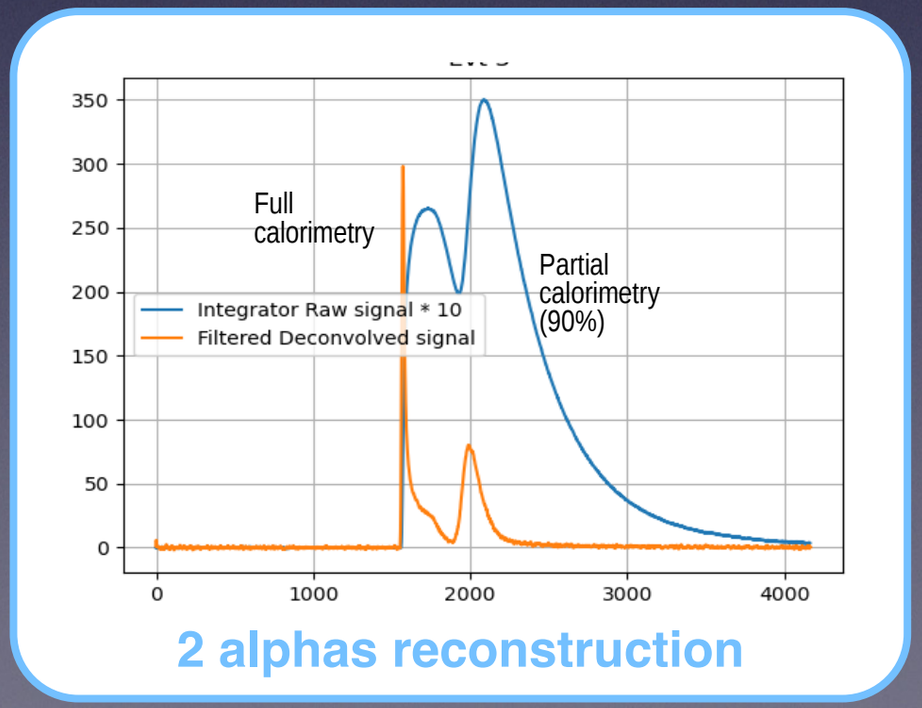
Recuperation system from CPPM



Technical developments

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-2021) 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.



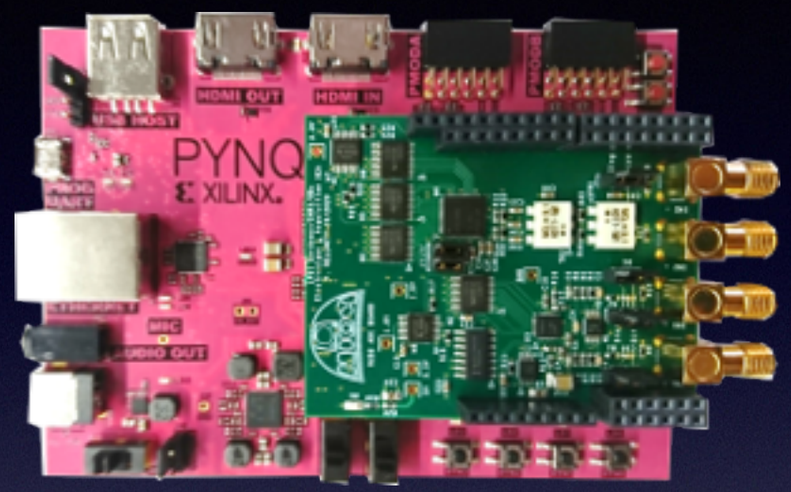
2 alphas reconstruction

OWEN

Optimal Waveform recognition Electronic Node

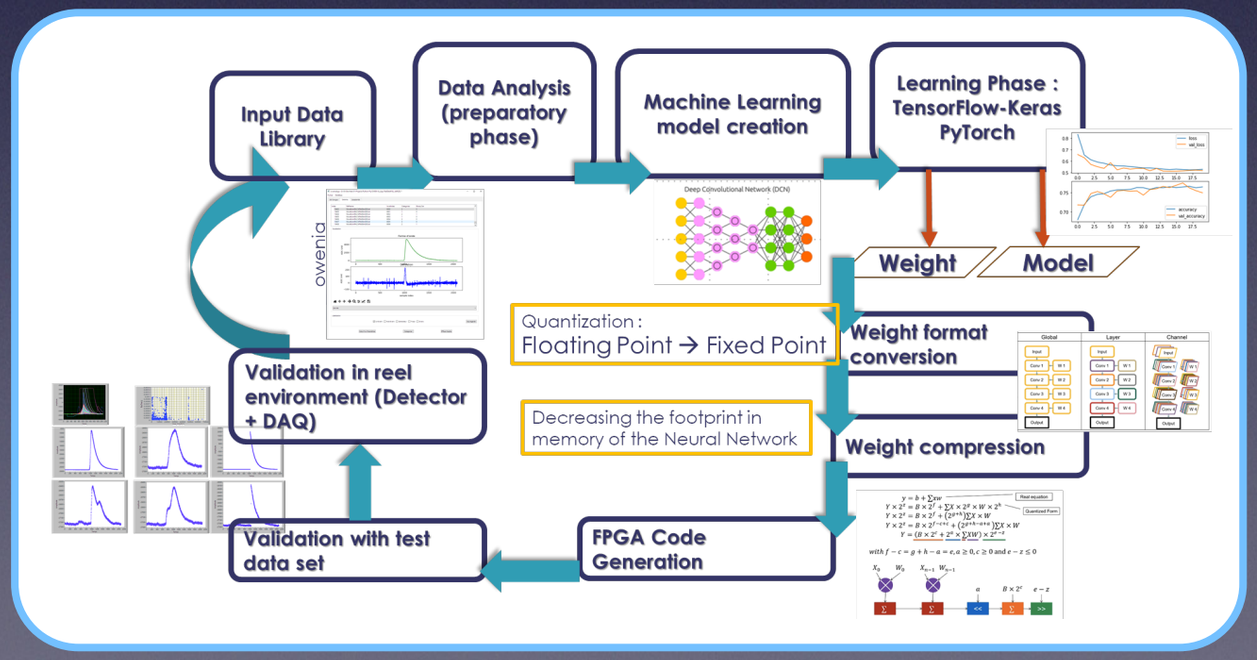
- **Hardware developments**:
  - Very low noise front end
  - Optimized waveform digitization with High resolution (18 bits)
  - Embedded processor in integrated shape @ 1Gb/s

➔ delivery to experimental use in fall 2021



- **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)

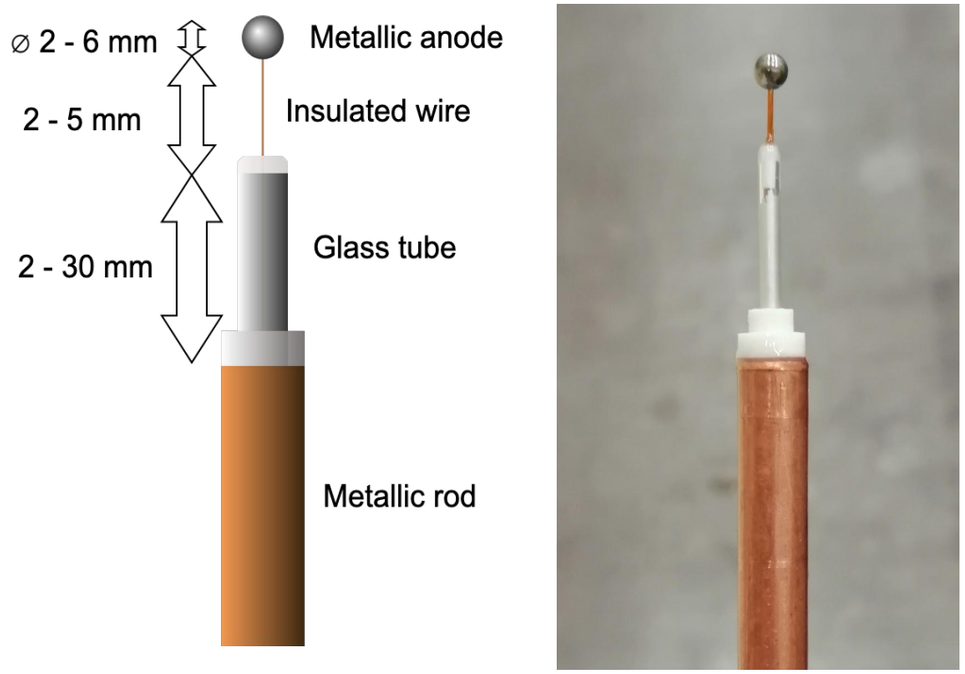
➔ delivery to experimental use in fall 2021

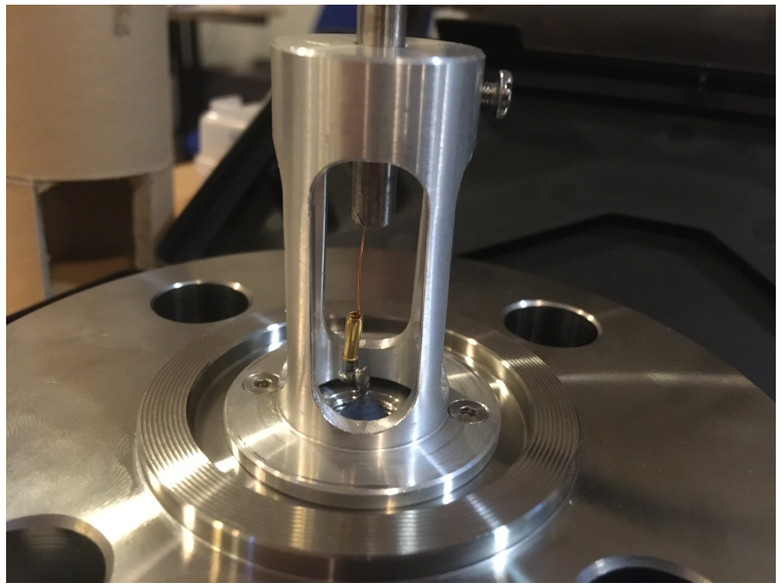


Technical developments

Sensor

- The sensor is the key point of the 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.





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

- 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). Other expertise at IN2P3?

Leakage current

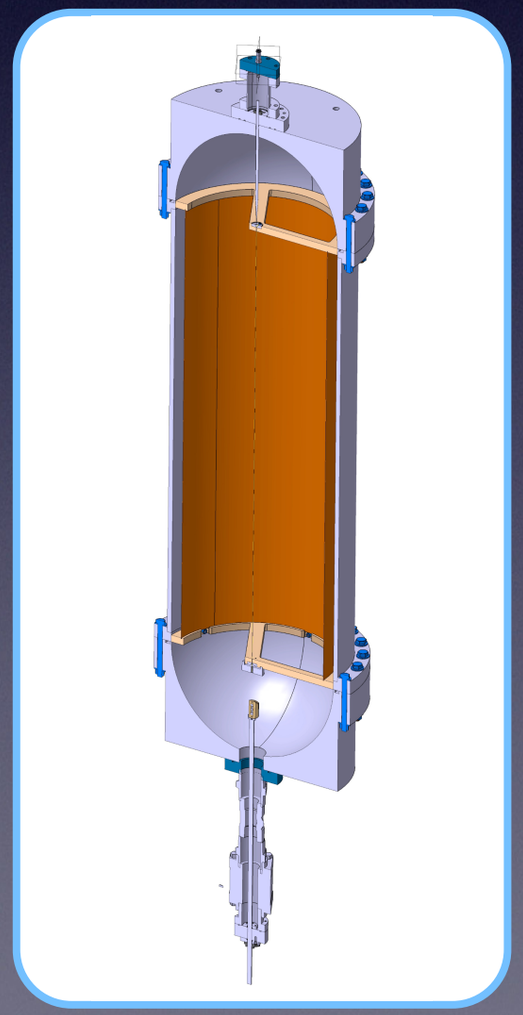
Not shielded (noise)

Not certified for HP

Technical developments

Geometry

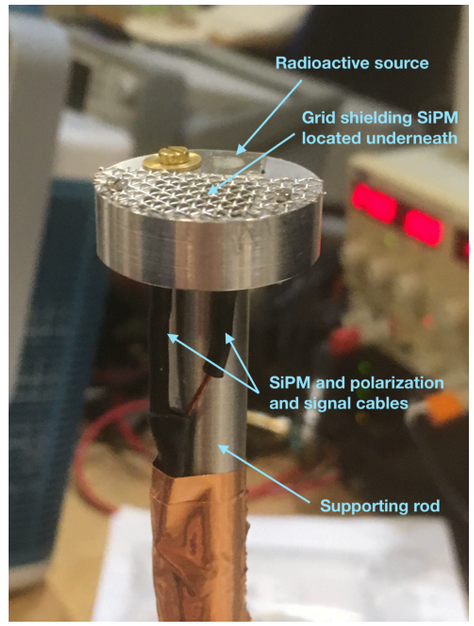
- One of the question we ask ourselves since the beginning (and many people ask us) is: **sphere or cylinder**?
- The sphere has the advantage of a larger gain (field $\propto 1/R^2$) and no edges effects, whereas the cylinder has the advantage of using a wire which is simpler than the sensor and it has no supporting rod distorting the field.
- Tests in single Wire Proportional Chambers ongoing at SUBATECH (reconditioning the very first SPC prototype):
  - Check of resolution.
  - Validation of observables interpretation.
  - Test of non-polarized anode.
  - Test of internal shielding (PTFE).

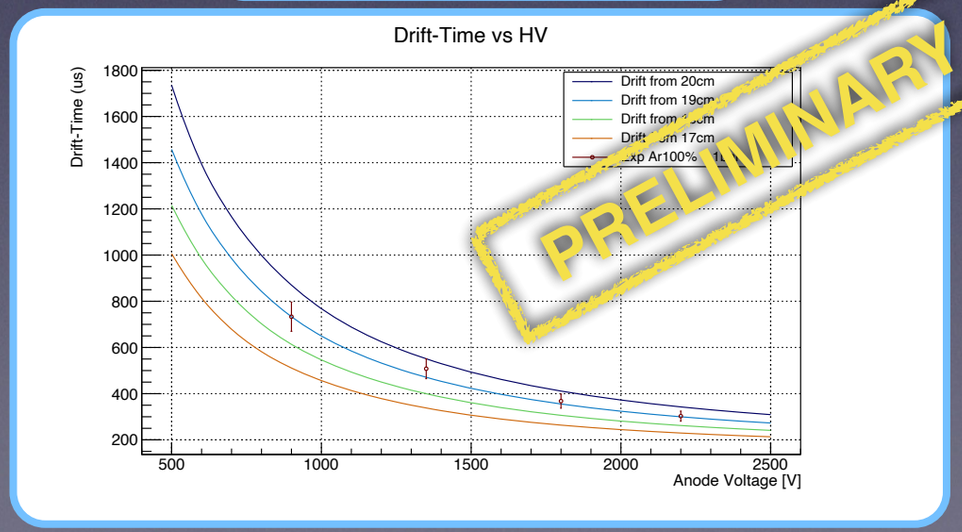


Technical developments

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.

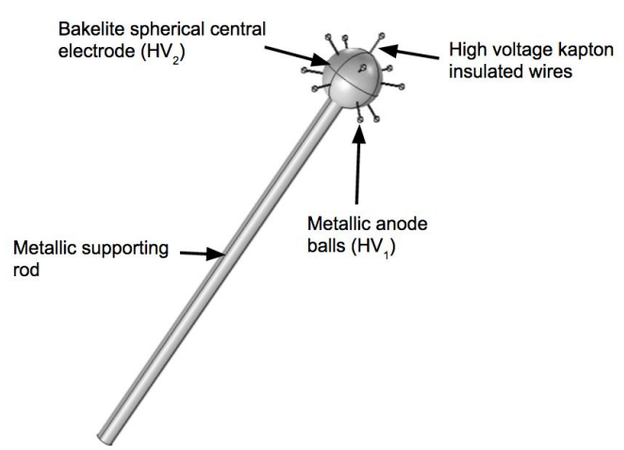




Next steps

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

- Further developments of the electronics ongoing and the OWEN full electronic chains will be ready soon.
- Waveform analysis developments on going for better noise reduction and two tracks recognition.
- Test with Cylindrical detector.
- Possibility to use multi-sensor anode (ACHINOS).



Conclusions

- The R2D2 collaboration has been formed and the R&D has been funded by IN2P3.
- A lot of work is ongoing especially concerning the electronics development and waveform analysis exploiting and enriching the available IN2P3 know how.
- 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 but **no show stopper identified so far**.
- At present from the detection performance point of view, going to high pressure and ionisation mode is not seen as a problem.
- Depending on the success of the R&D we hope to move on in order to build a prototype allowing for real physics results.

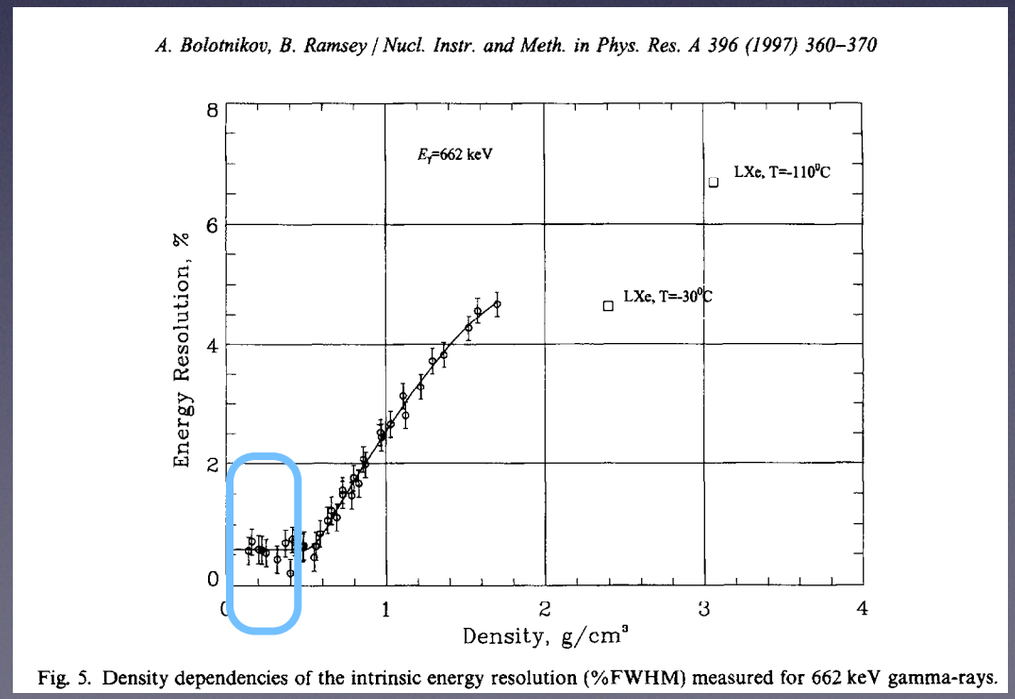


Fig. 5. Density dependencies of the intrinsic energy resolution (%FWHM) measured for 662 keV gamma-rays.