R2D2 project

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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**:

requirements

Excellent energy resolution

Low background

Large masses of isotopes

→ **Can we meet all these features at the same time?** →

goal of R2D2 (Rare Decays with Radial Detector)

two electrons identification

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.

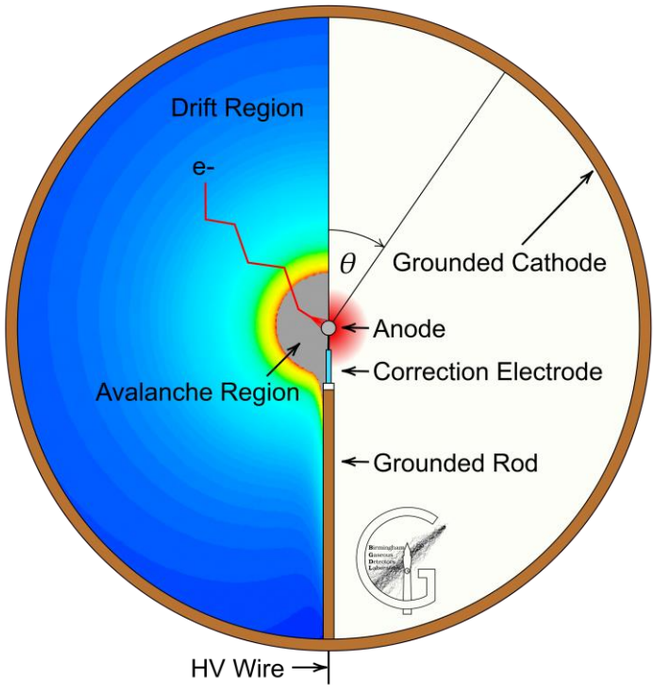
→ **How?** →

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

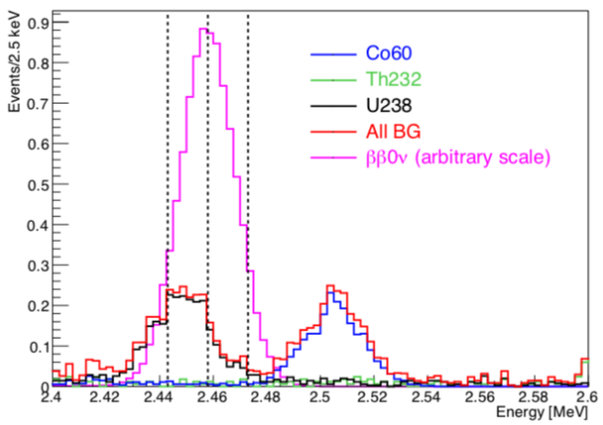
If prototype 1 successful

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



JINST 13 (2018) no.01, P01009

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

Depending on the results

and fundings

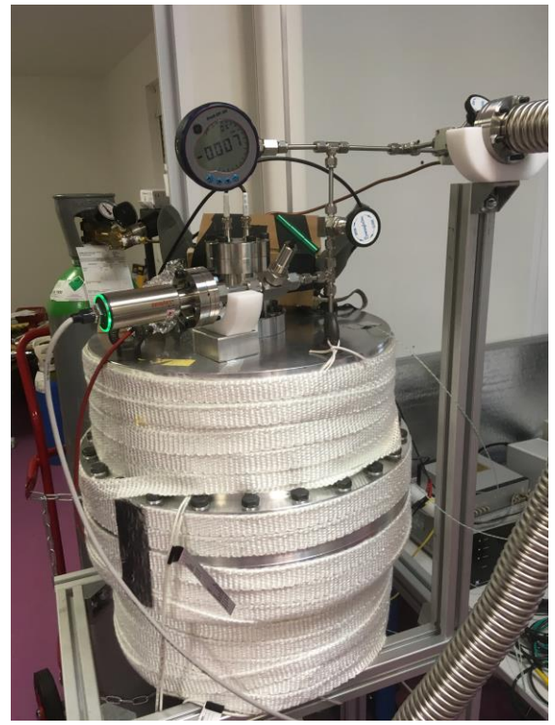
Experiment

Going towards a 1 ton background free detector

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

Experimental setup

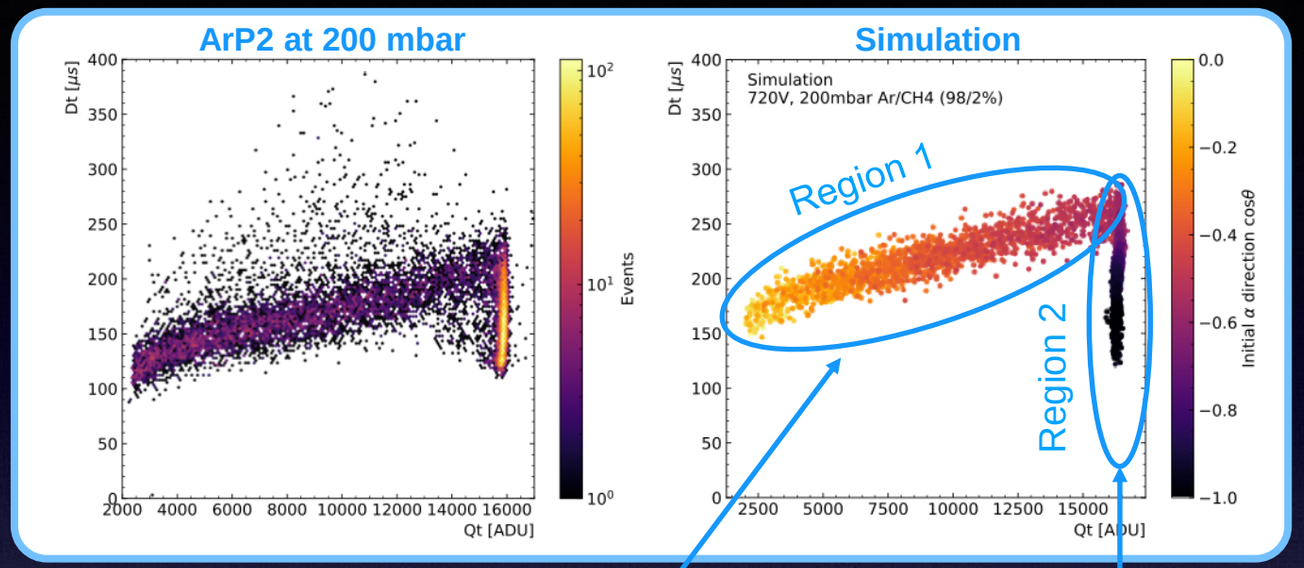
- In 2018 the R2D2 was funded as R&D by the IN2P3: the main goal is the **demonstration that the desired energy resolution is achievable**.
- A 20 cm radius sphere made of Aluminium (i.e. no low background but much cheaper) was built at CENBG.
- Efforts were made to reduce the noise via:
  - Isolated 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)

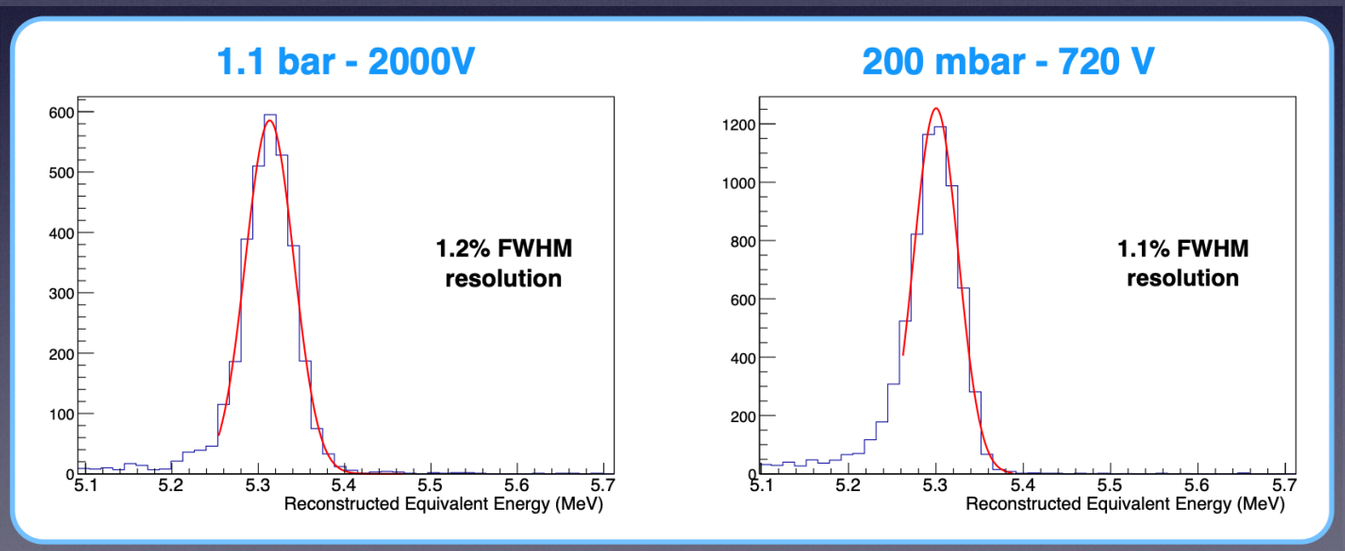


Certified sphere to go up to 40 bars and Xenon recuperation system delivered in spring 2021 under commissioning

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

Développements Techniques

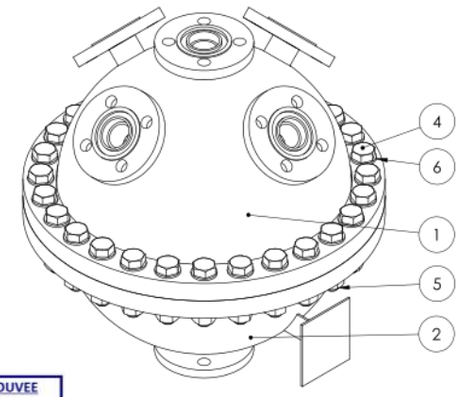
Mécanique

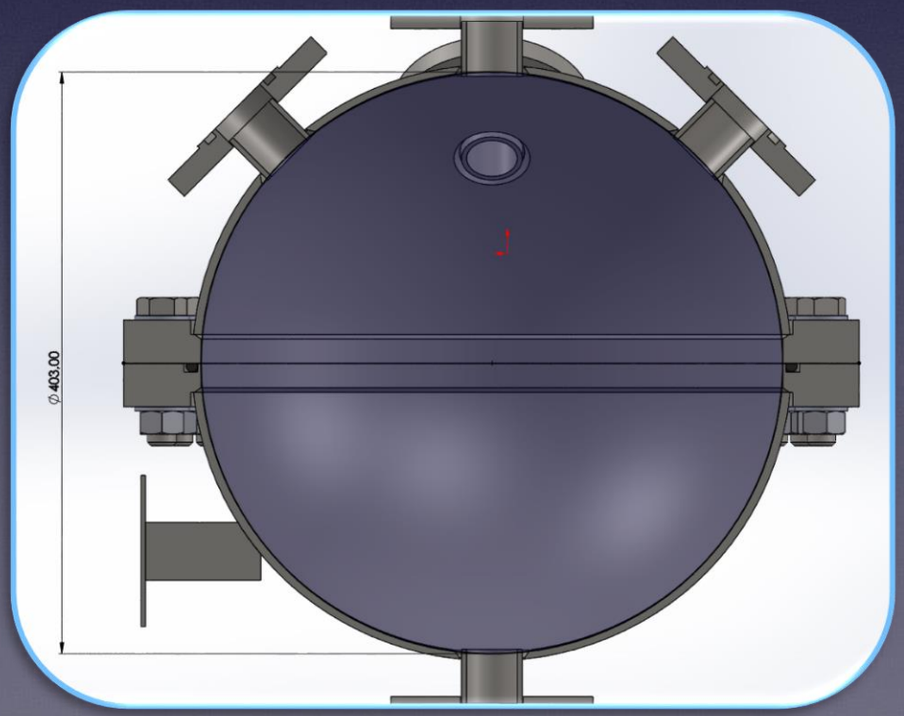
Spécifications de l'enceinte :

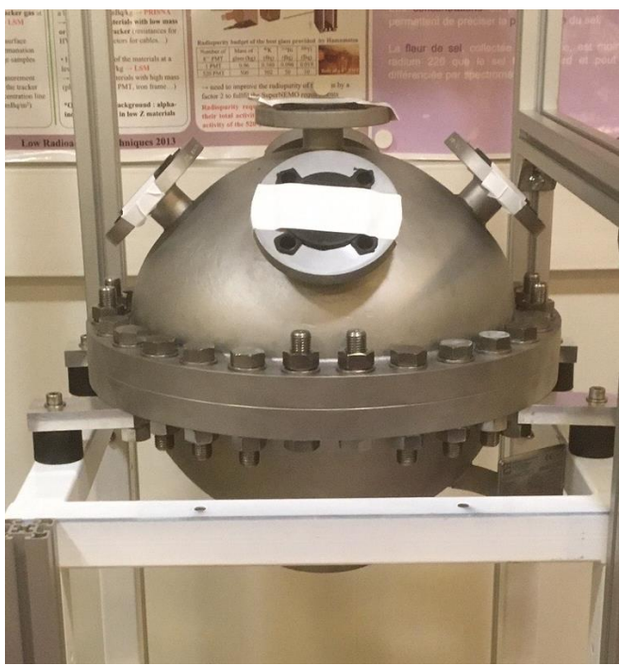
- Besoin de faire le vide de l'ordre de 10^{-8} mbar.
- Certification jusqu'à 40 bars.

⇨ Etude et plan CENBG

⇨ Fabrication/Certification RAVANAT







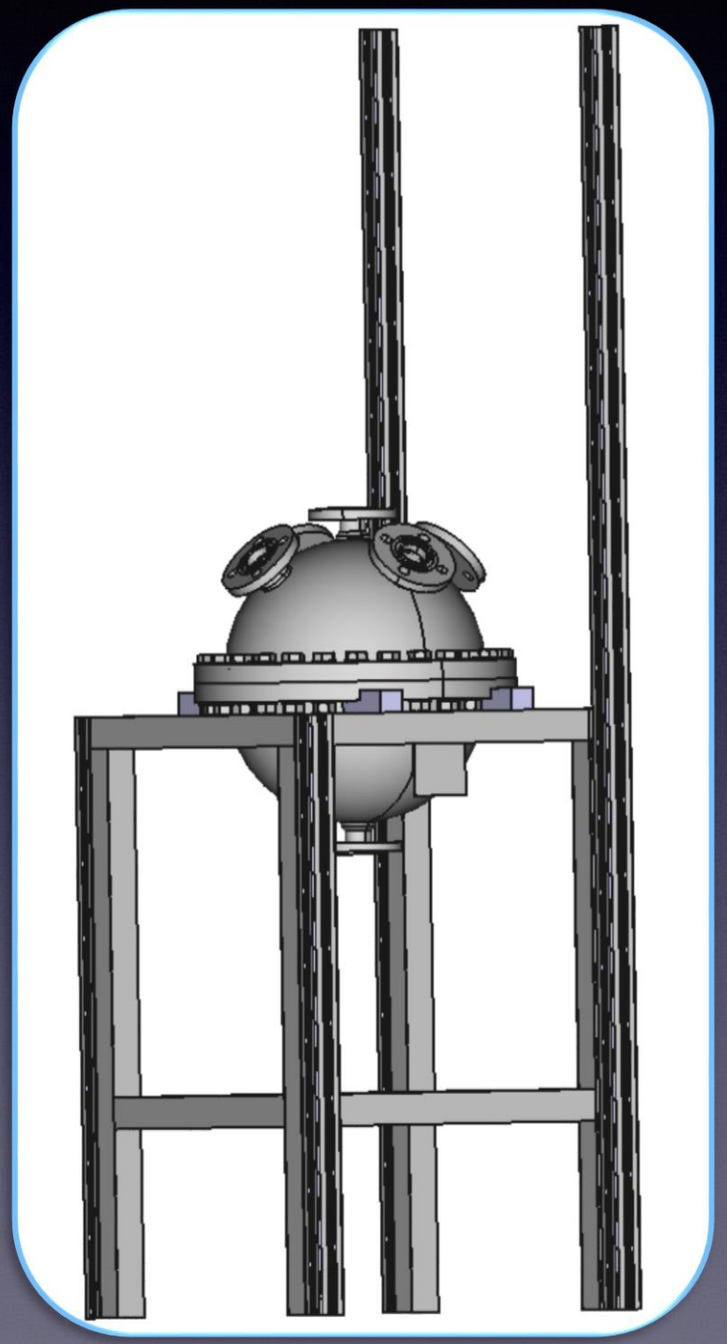
Développements Techniques

Mécanique

Châssis support de la sphère :

- Système anti vibration

⇨ Etude, plan et fabrication CENBG



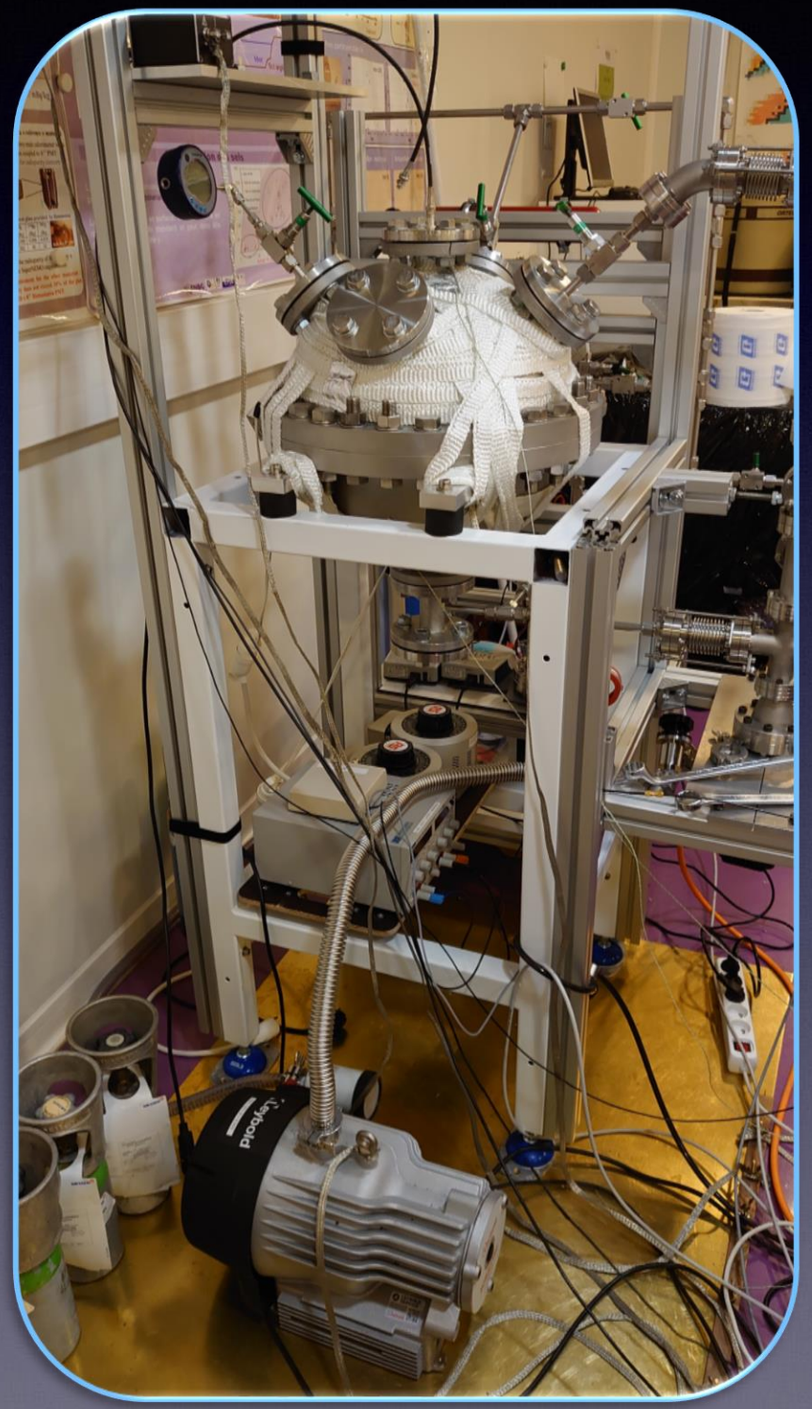
Développements Techniques

Instrumentation

Mise en pression de l’enceinte :

- Pompage primaire + Turbo (vide « nettoyage »)
- Injection de gaz (Ar ou ArCH4)

  ⇨ Objectif Xénon

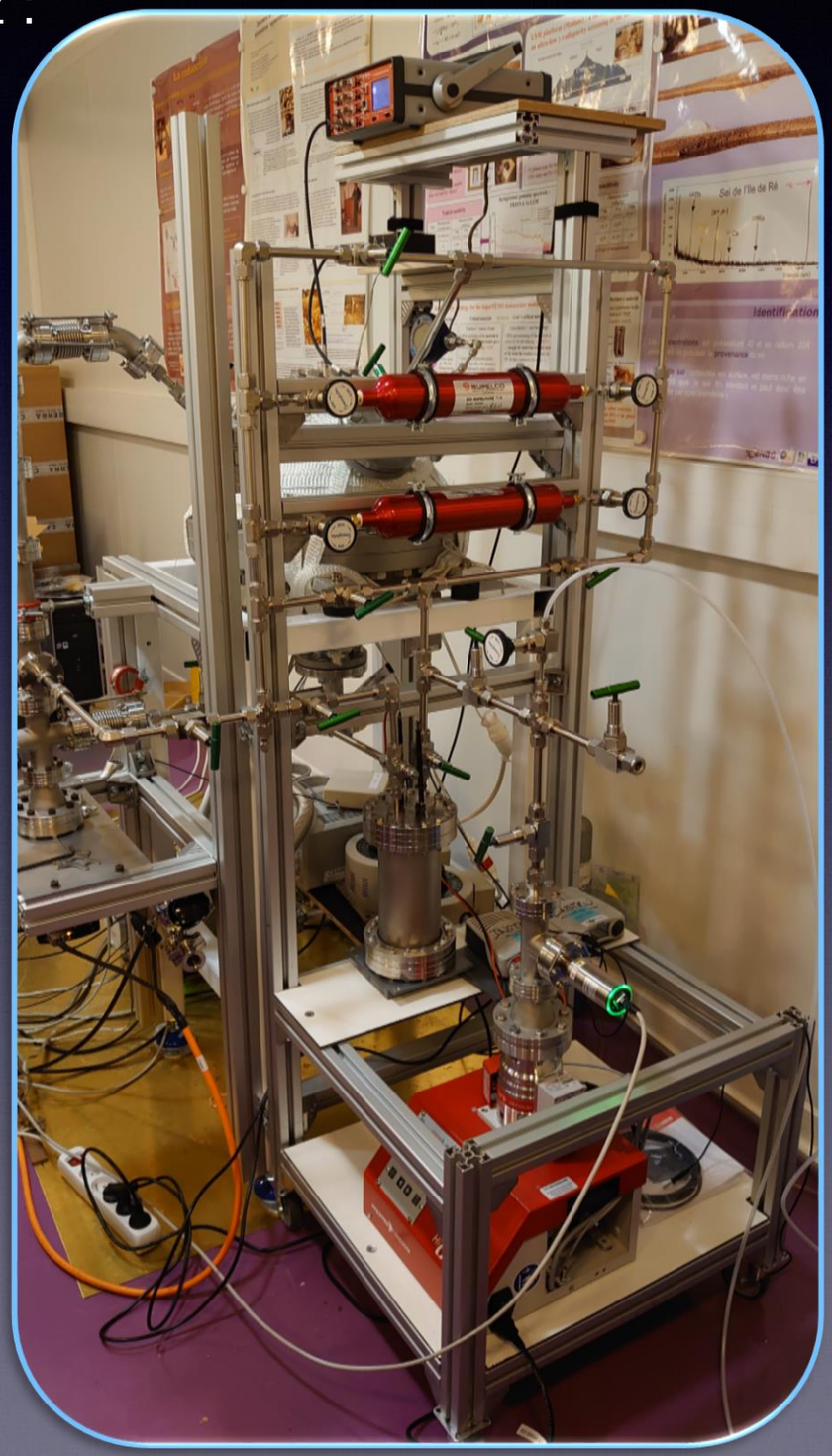


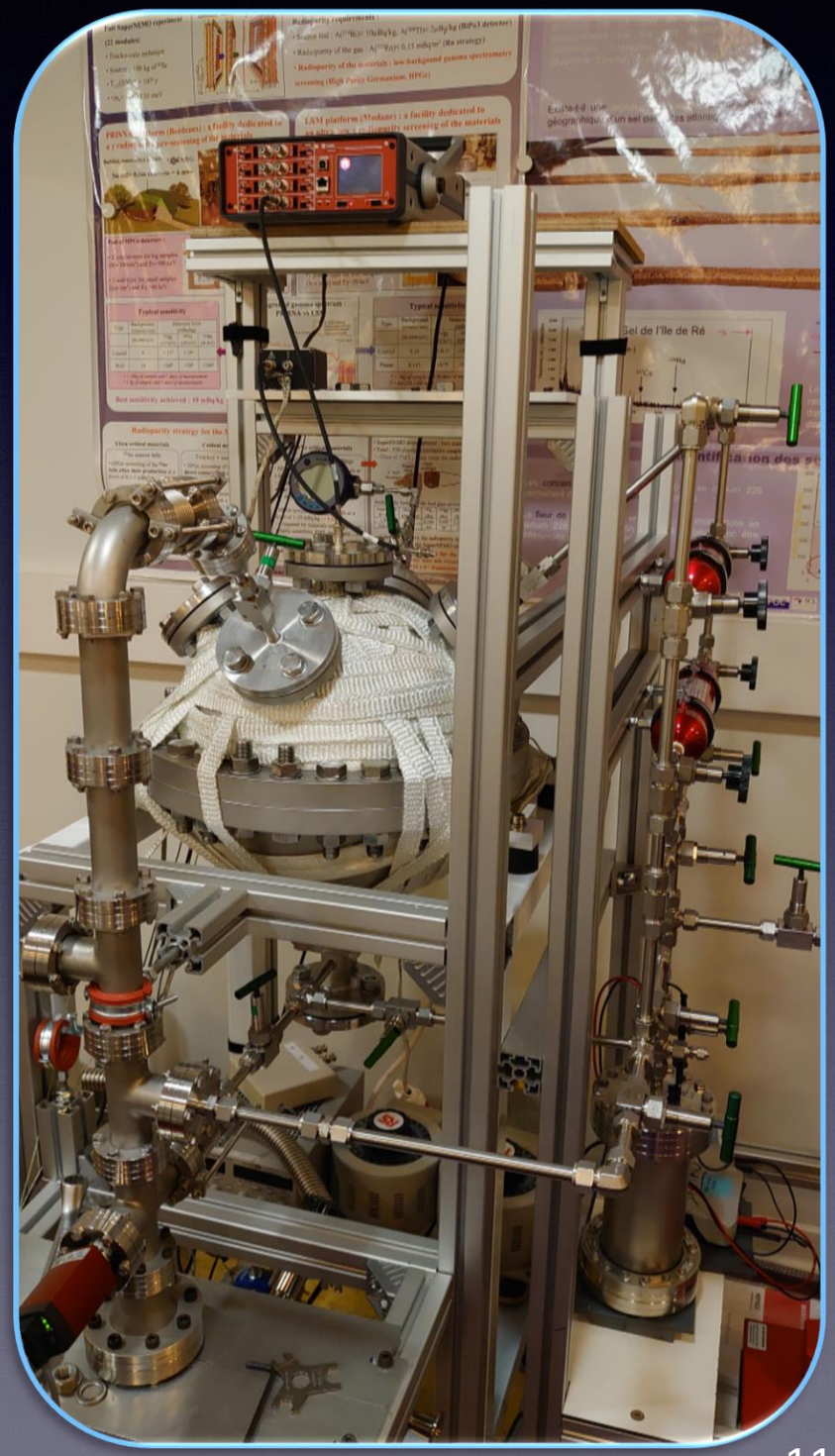
Développements Techniques

Instrumentation

Système de recirculation du gaz :

- Purification





Développements Techniques

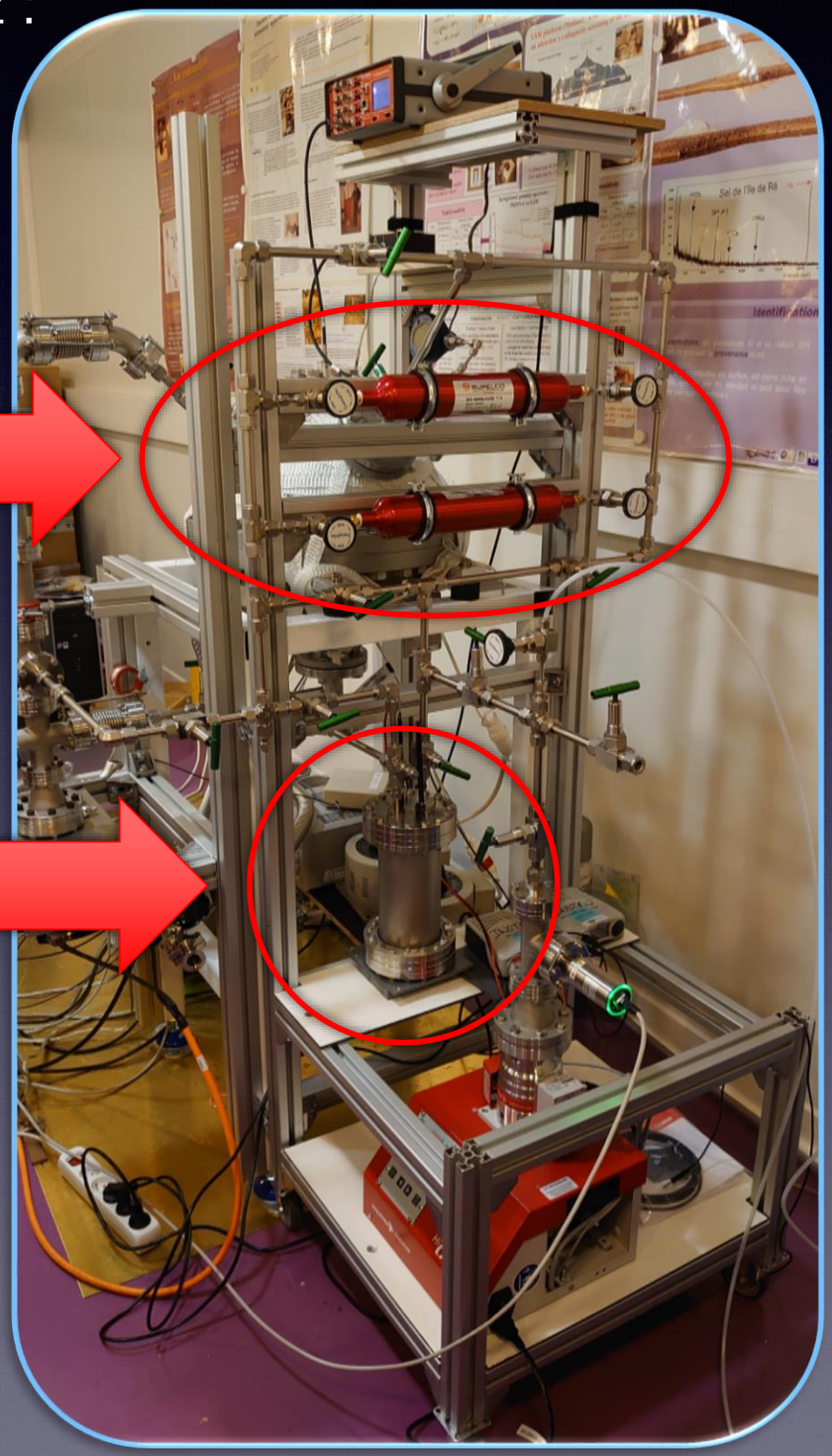
Instrumentation

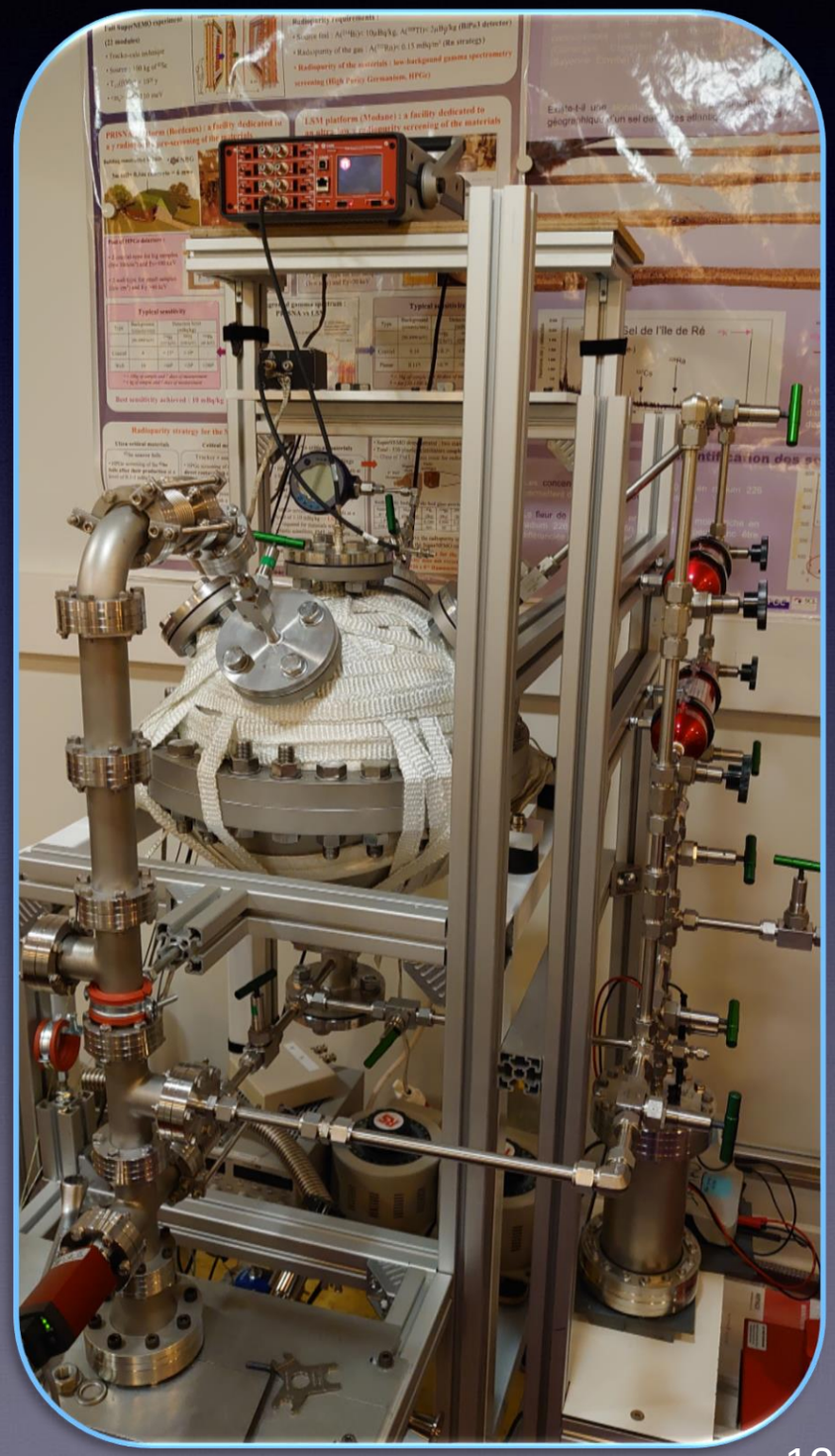
Système de recirculation du gaz :

- Purification

Cartouche

Pompe





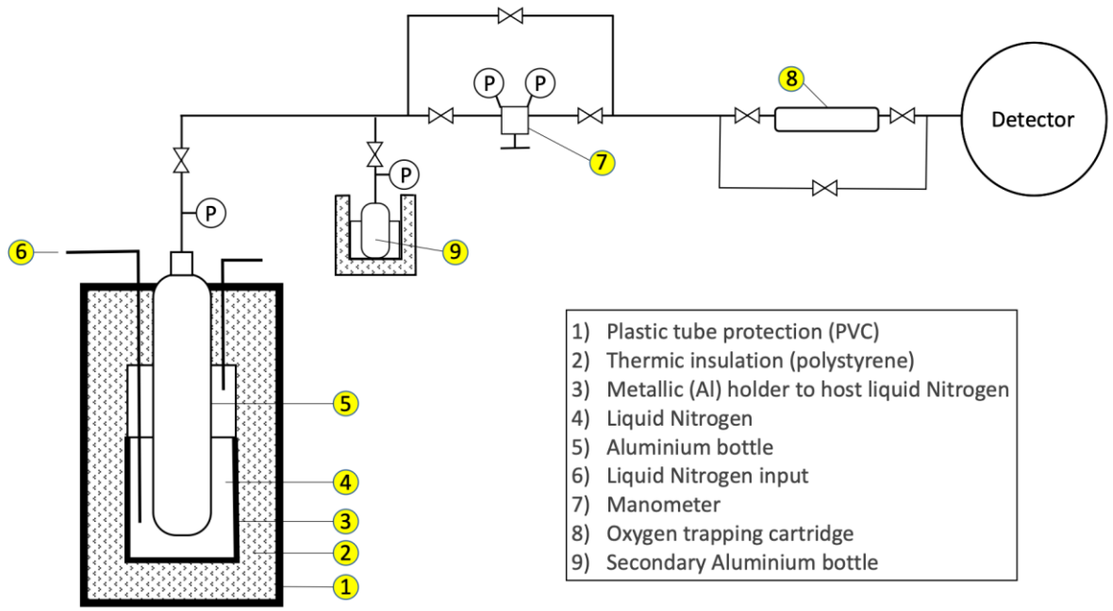
Développements Techniques

Instrumentation

Système de récupération du gaz :

- ⇨ Inspiré du système du CPPM
- ⇨ En cours de développement

Recuperation system from CPPM



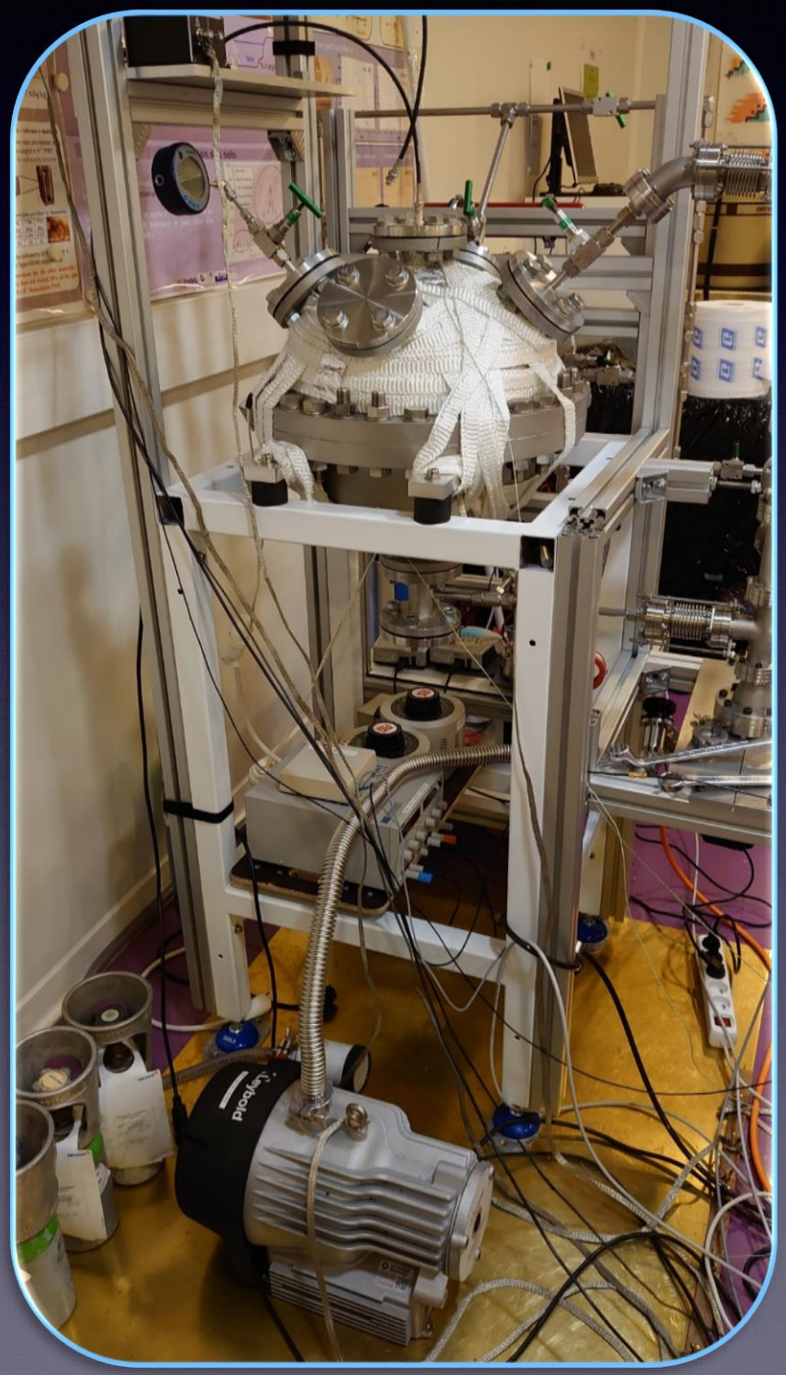
1) Plastic tube protection (PVC)
2) Thermic insulation (polystyrene)
3) Metallic (Al) holder to host liquid Nitrogen
4) Liquid Nitrogen
5) Aluminium bottle
6) Liquid Nitrogen input
7) Manometer
8) Oxygen trapping cartridge
9) Secondary Aluminium bottle

Développements Techniques

Electronique

Minimisation du bruit :

- Blindage au sol
- Mise en commun masse mécanique/Electronique
- Choix des alimentations

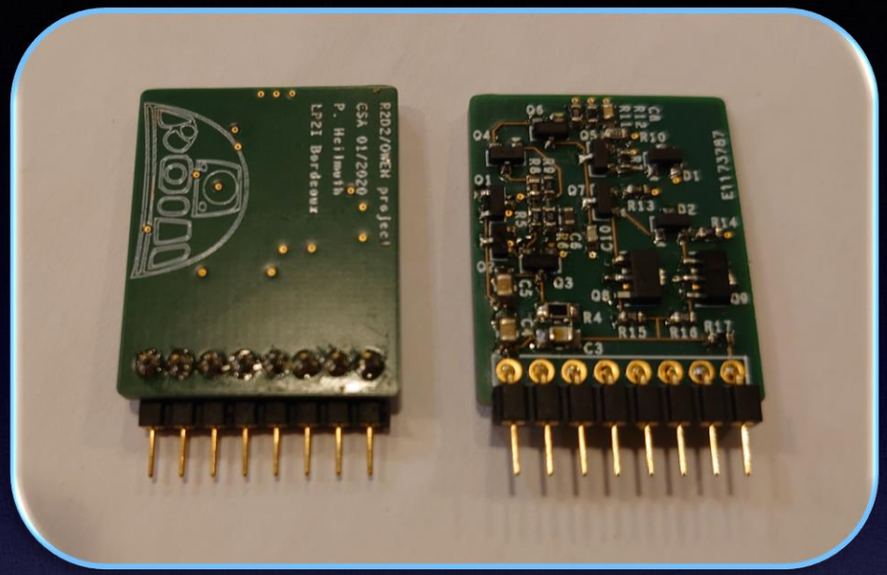


Développements Techniques

Electronique

Préampli de charge :

- 0,75V/pC
- 1fC -> 2pC



Carte Mère 1 voie :

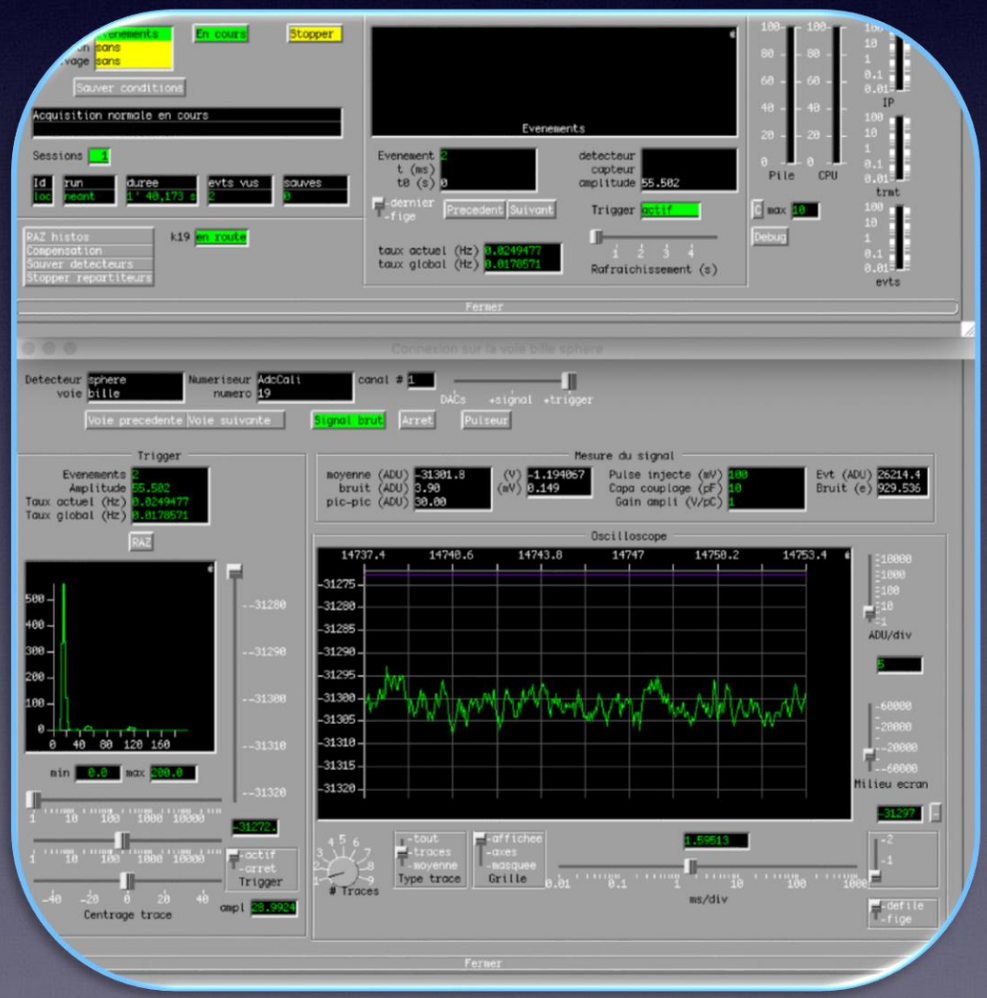
- Support 1 préampli
- Boitier blindé

Développements Techniques

Electronique

Carte acquisition CALI

- Développé par le CEA
- 16 bits
- Echantillonnage 2MSPS



Développements Techniques

Electronique

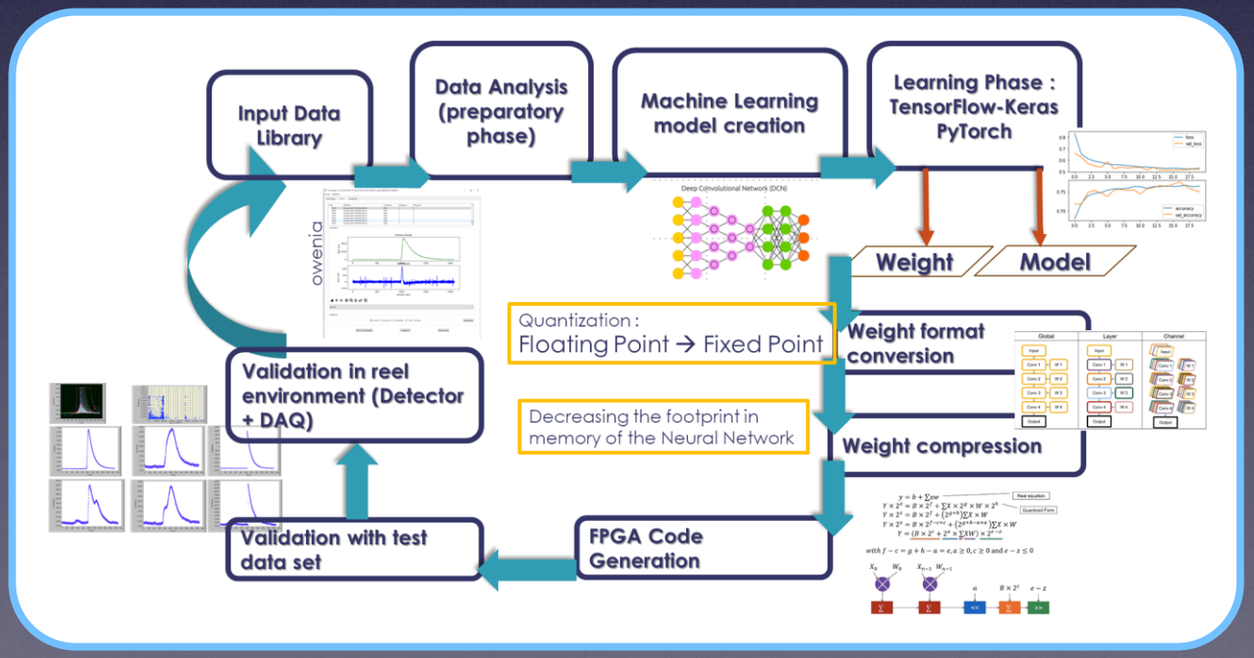
Carte acquisition « CENBG » en cours de développement

dans le cadre du projet OWEN

- 18 bits voie lente, 2 MSPS
- 14 bits voie rapide, 250 MSPS
- Plateforme Zynq

Intelligence Artificielle embarqué

- Classification des waveforms
- Intégration dans le FPGA

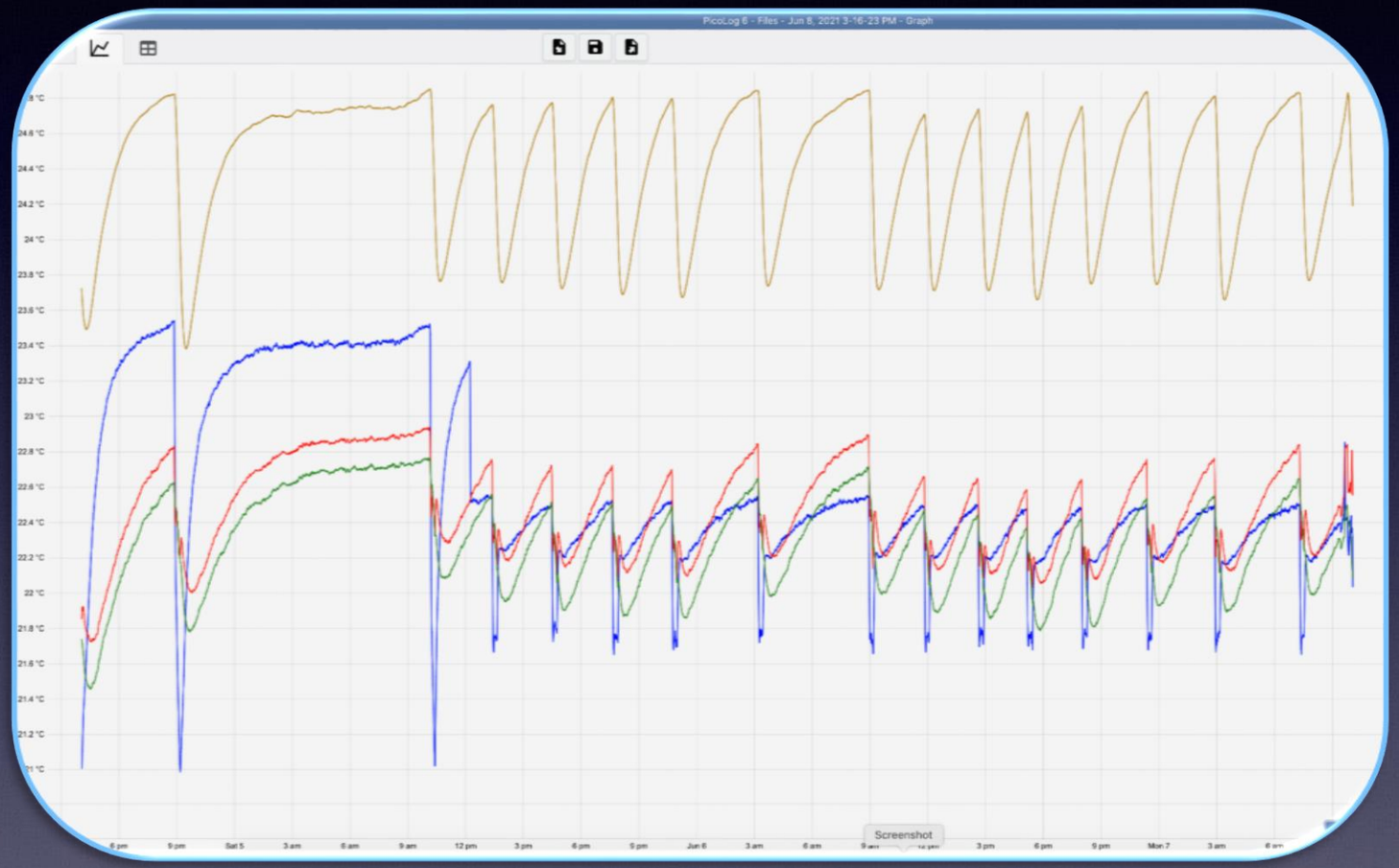


Développements Techniques

Electronique

Monitorage de la température

- Plusieurs capteurs

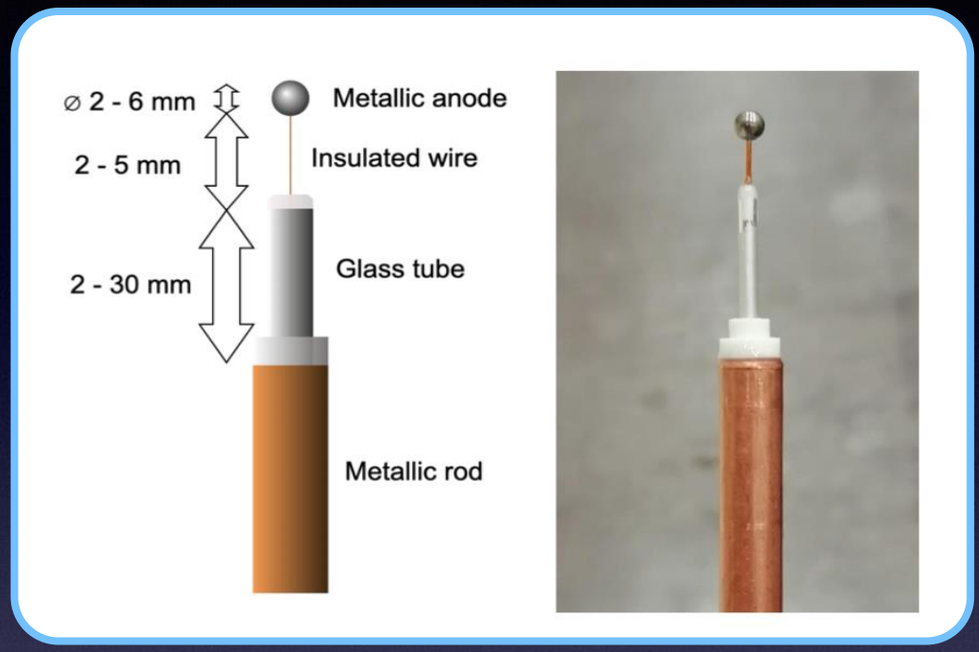


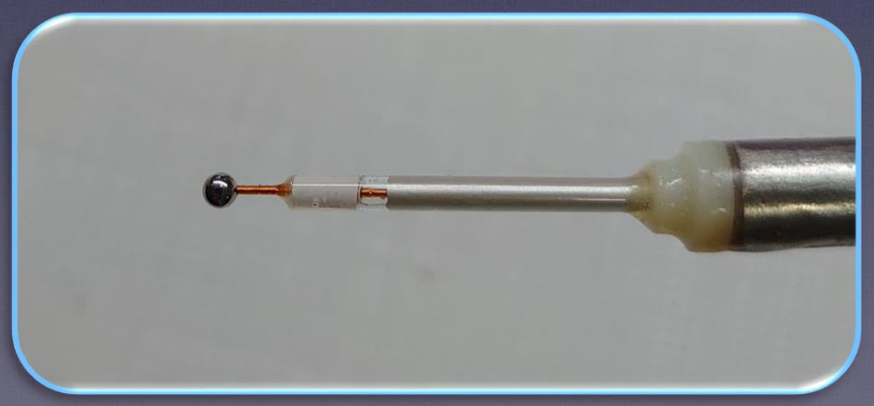
Développements Techniques

Détecteur 1

Composition du détecteur

- Bille en acier/inox de petit diamètre
- Polarisation de la bille (max 20kV)
  - ⇨ Câble HT
  - ⇨ Perçage + soudure sur bille
  - ⇨ Minimiser le bruit!





Développements Techniques

Détecteur 1

Extraction des signaux

- Polarisation de la bille (HT)
- Connecteur sur bride
  - ⇨ HT + HP
  - ⇨ Pas de courant de fuite
  - ⇨ Minimiser le bruit

Courant de fuite

Pas de blindage (bruit)

Non certifié HP

Développements Techniques

Détecteur 1

Support Détecteur

- ⇨ Maintien de la canne
- ⇨ Eviter les claquages
- ⇨ Minimiser le bruit

Toutes ces contraintes : bruit + HT + HP + Soudure câble ⇔ Bille de 2mm

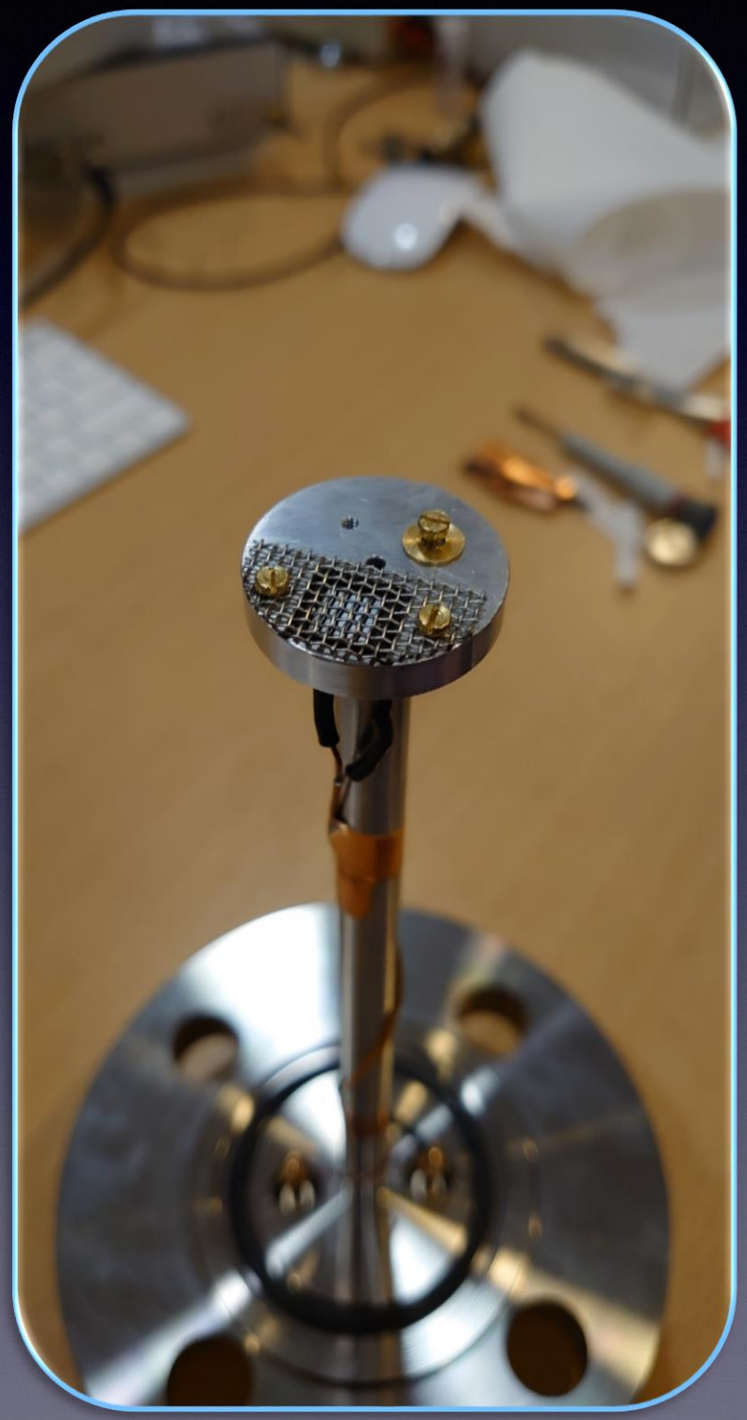
⇨ Etude R&D avec AXON

Développements Techniques

Détecteur 2

Détection de la lumière

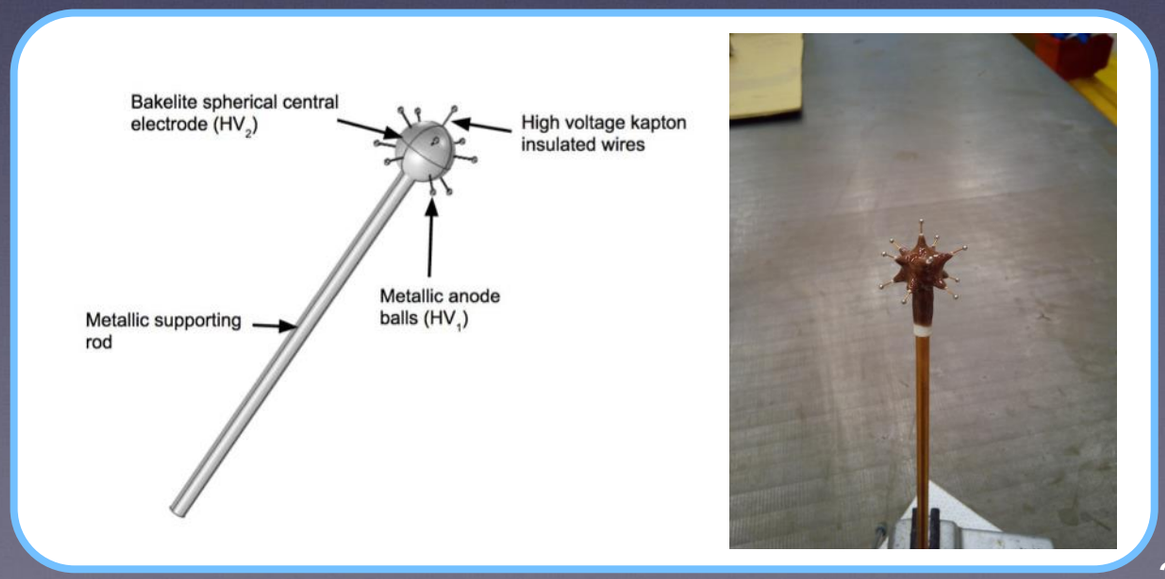
- SiPM VUV Hamamatsu
- Préampli/HT Hamamatsu



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.

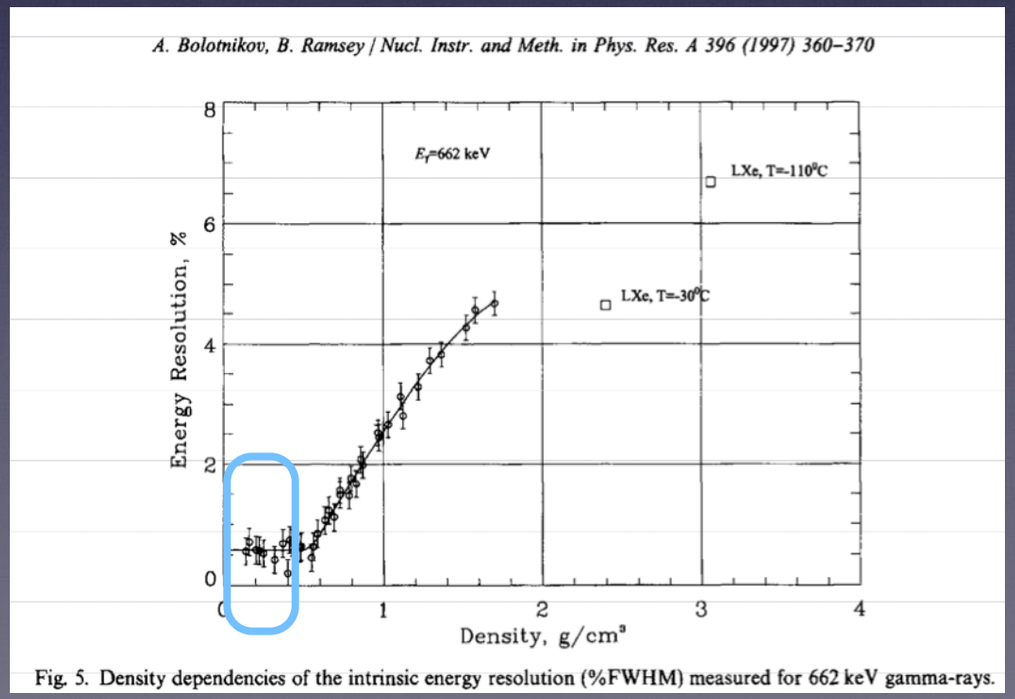


Fig. 5. Density dependencies of the intrinsic energy resolution (%FWHM) measured for 662 keV gamma-rays.