R2D2 Status

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NEWS-G Collaboration Meeting

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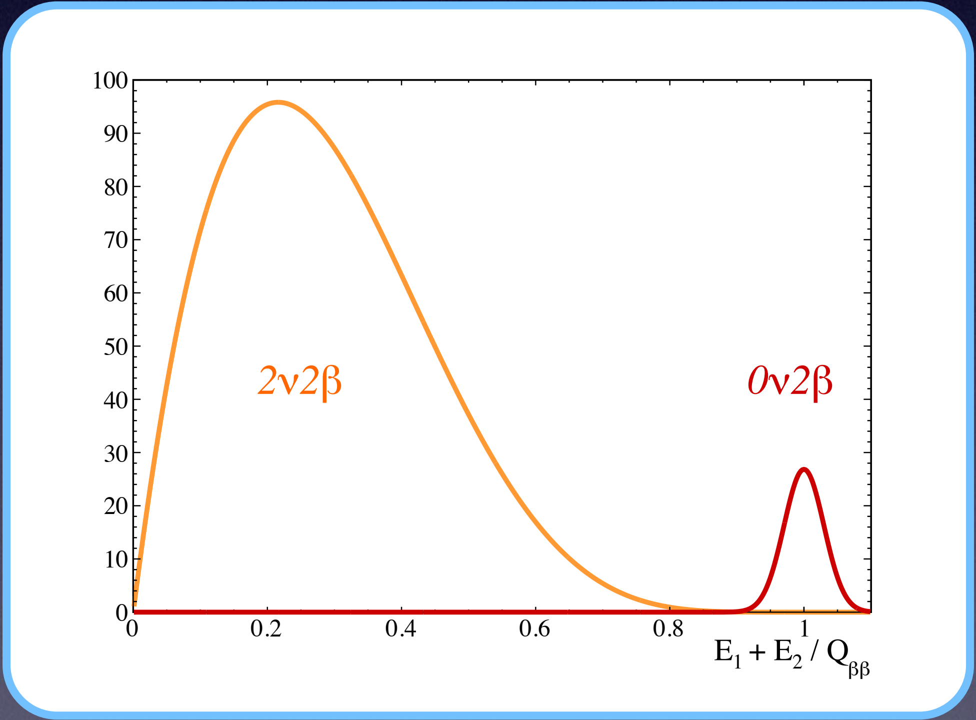
Introduction (1)

- To demonstrate the Majorana nature of neutrino the most sensitive experimental way is an observation of the so called **$0\nu\beta\beta$ decay**.
- The measurement relies on the observation of a peak in the distribution of the energy of the two electrons corresponding to the $Q_{\beta\beta}$ of the reaction.



Requirements

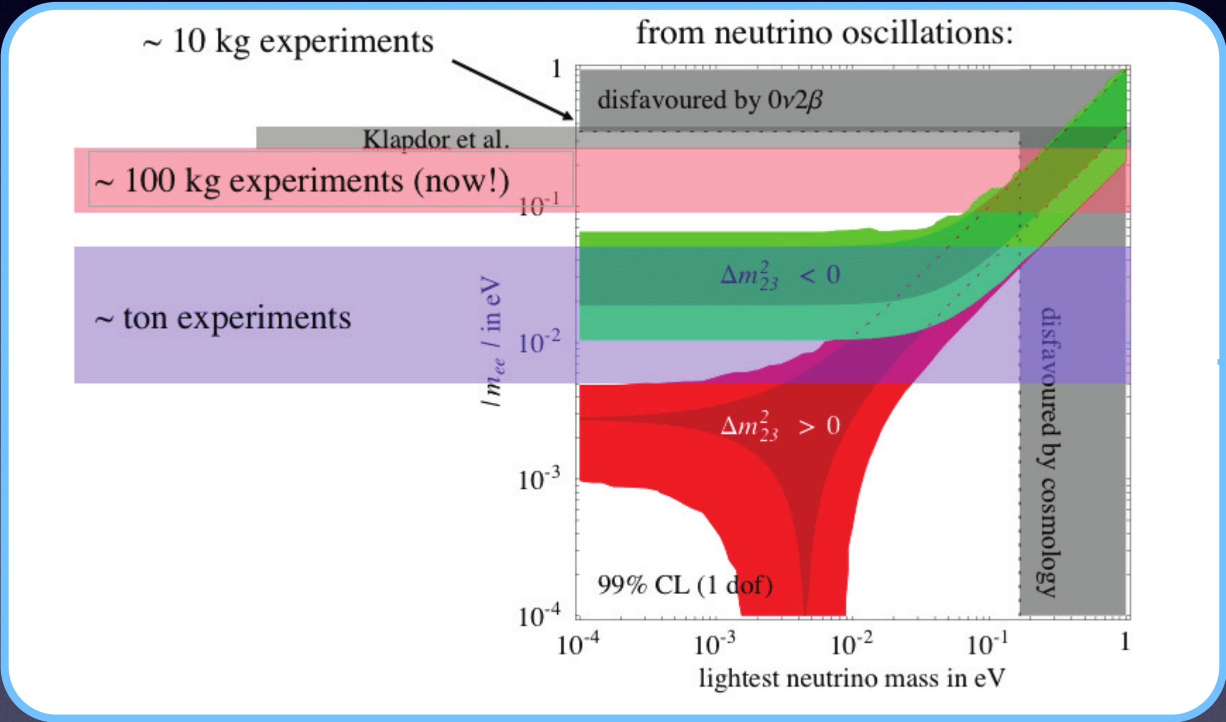
Excellent energy resolution

Low background

The most natural way to achieve low background is to have a low material budget detector

Introduction (2)

- Experiments so far are just hitting the inverted mass hierarchy region and to fully cover it we need a ton scale experiment.



Requirements

Large masses of isotopes

Gaseous isotopes have the advantage of reaching large masses easily and at relatively low cost, with an extremely low radioactive contamination with respect to solid isotopes

Status

- Presently used technologies do not meet all the requirements at the same time.

	Energy resolution	Low background	Large isotope masses
Solid state detectors	**Extremely good (0.1% at Q value)**	**Extremely low (zero background)**	**Large number of crystals/ electronics channels Difficult scalability to large masses**
Liquid Xenon experiments	**Order of 4% at Q value**	**Far from zero background**	**Ton scale easily achievable**
Gaseous Xenon experiments	**Order of 1% at Q value**	**Far from zero background**	**Complex detector Feasible at ton scale?**

Can we meet all the requirements at the same time? → **goal of R2D2**

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.

The R2D2 project (1)

- R2D2 stands for Rare Decays with Radial Detector.
- The idea is to use a **high pressure Xenon gas TPC spherical detector** to search for the $\beta\beta0\nu$ decay, profiting from the following features:
  - High energy resolution (goal of 1% FWHM at ^{136}Xe $Q_{\beta\beta}$ of 2.458 MeV)
  - Low detection threshold at the level of 30 eV i.e. single electron signal.
  - High detection efficiency (about 65% after selection cuts).
  - Simplicity of the detector readout with only one (or few in the upgraded version) readout channels.
  - Extremely low (zero?) background due to the very low material budget.
  - Scalability to large isotope masses.

R2D2 is an R&D program aiming at validating all these detector features paving the way for a future ton scale detector

The R2D2 project (2)

- A proto-collaboration has been recently 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

Under commissioning - Funded by IN2P3 R&D

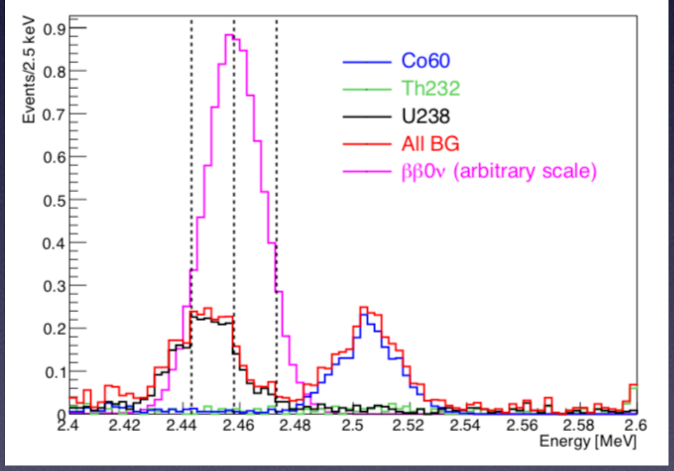
Up to 7.9 kg (40 bars) Xenon prototype (no low radioactivity) to demonstrate the detector capability in particular on the energy resolution

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



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Depending on the results and fundings

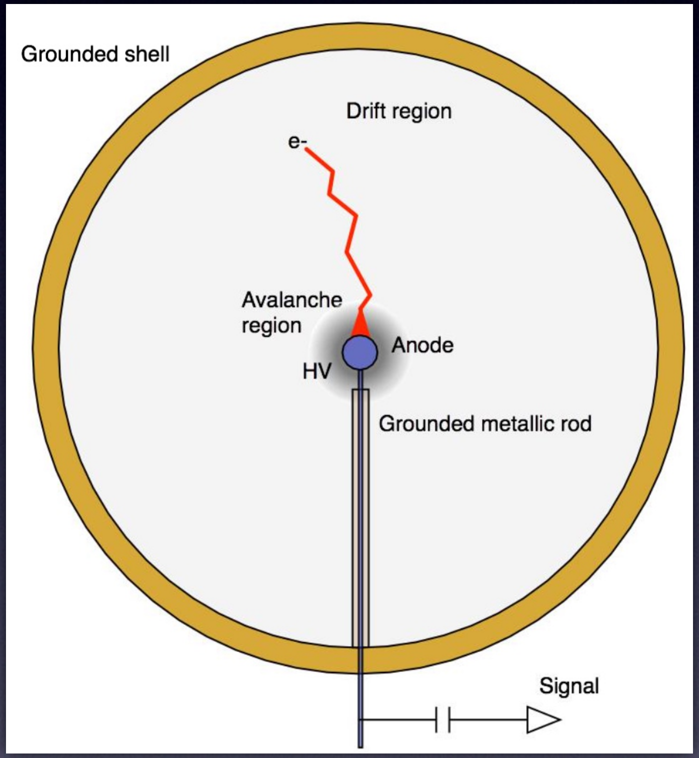
Experiment

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 $Q_{\beta\beta}$, as well as the possibility to do tracking

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).



3 key requirements for $0\nu\beta\beta$

- **Energy resolution** → To be validated
- **Low background** → Low material budget
- **Large masses of isotopes** → Easily scalable (1ton = 1m radius) or multiple spheres

Prototype 2

Sensitivity studies

- A **full Monte Carlo simulation** was developed to assess our capability to reject background and to evaluate the possible sensitivity on the searched signal.
- We considered a geometry including active and passive veto and a small mass of 50 kg of Xenon corresponding to the foreseen prototype (37 cm radius at 40 bars).
- We studied the intrinsic background coming from the vessel material and all the additional **external background** which we **reduced at a level of less than 0.1 events per year**.
- We could set in one year a **limit on the $\beta\beta0\nu$ half life of 2.5 $\times$ 10^{25} years** ($<m_{\beta\beta}>$ < (160 - 330) meV) with a **signal efficiency of 64%** and a **background at the level of 2 events per year** in 50 kg **under the following assumptions**:

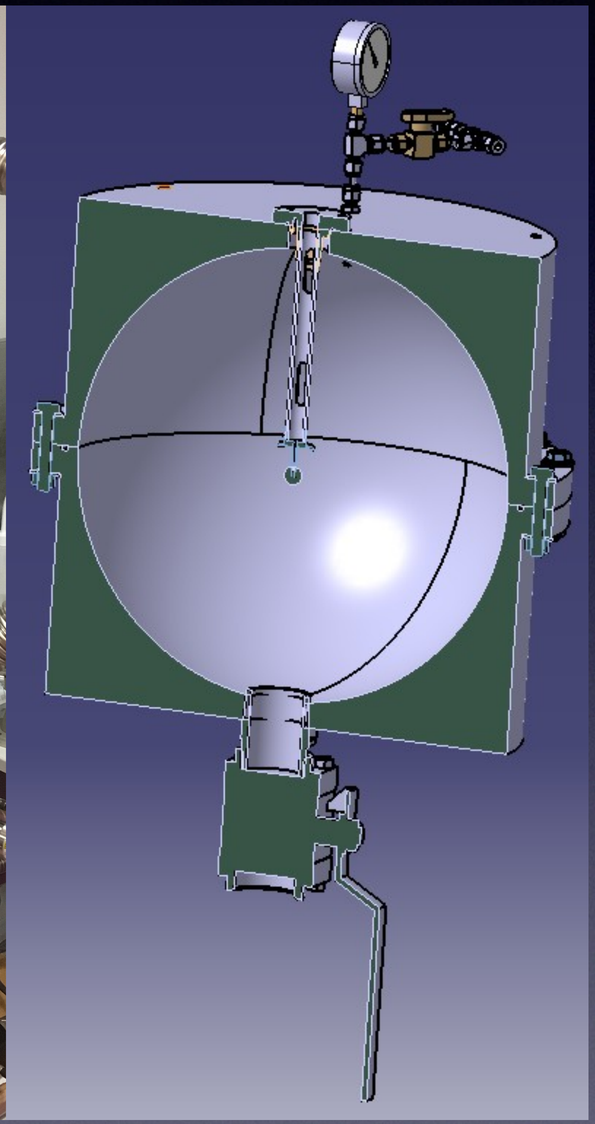
  - Energy resolution of 1% FWHM at the $Q_{\beta\beta}$ of 2.458 MeV.
  - Optimized ROI of $Q_{\beta\beta} \pm 0.6\%$.
  - Possibility of performing a radial energy deposition reconstruction.
  - A threshold as low as 200 keV for the liquid scintillator.
  - Copper activity of 10 μBq/kg.

Goal of the R2D2 R&D

Prototype 1

R2D2 R&D

- In 2018 the R2D2 was funded as R&D by the IN2P3.
- The **main goal** of the R&D is the **demonstration that the desired energy resolution can be achieved**.
- To do that the idea is to use a smaller detector (20 cm radius) made of Aluminium i.e. no low background but much cheaper.
- The setup is under commissioning at CENBG.



Energy resolution

- The energy resolution is the **most critical point to be validated**.

A. Bolotnikov, B. Ramsey / Nucl. Instr. and Meth. in Phys. Res. A 396 (1997) 360–370

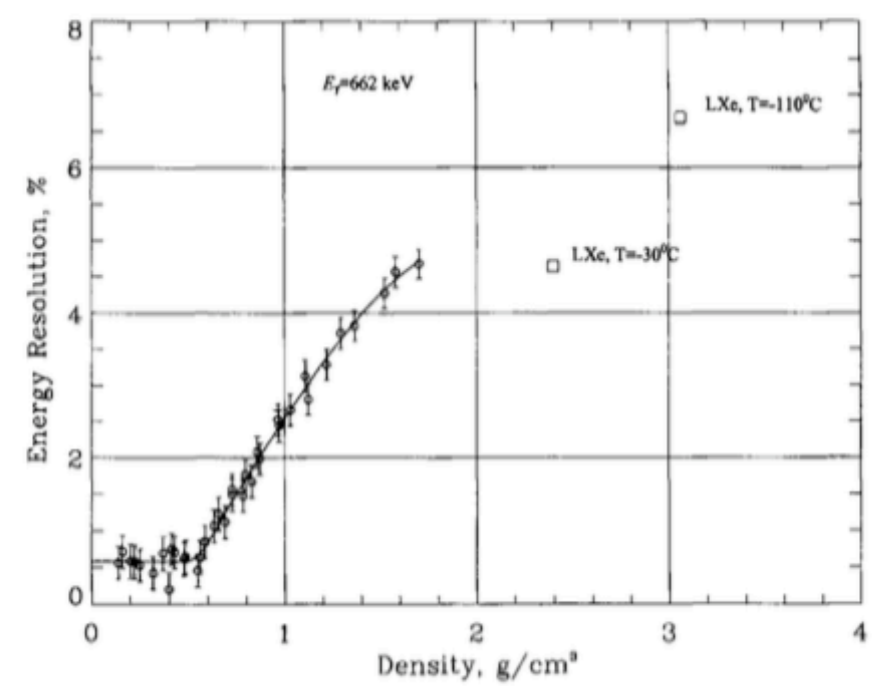


Fig. 5. Density dependencies of the intrinsic energy resolution (%FWHM) measured for 662 keV gamma-rays.

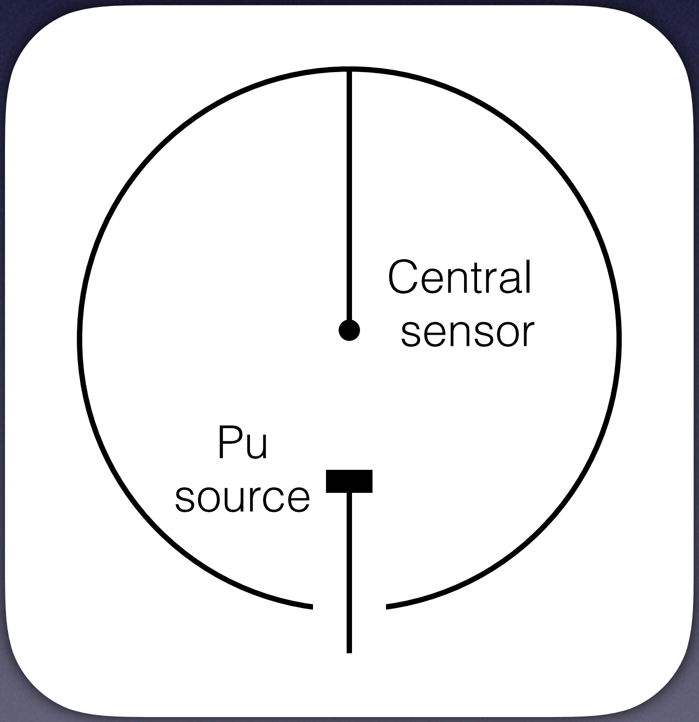
- A resolution of 0.6% FWHM at 662 keV in proportional counter has already been demonstrated (this could be rescaled to 0.3% at the Xenon Q value of 2.458 MeV).
- Current liquid Xenon based experiments reached energy resolution at the level of 3-4%.
- NEXT, combining charge and light readout reached 1% FWHM.
- R&D on multi ball sensor at Saclay demonstrated a resolution of 27% FWHM at 5.9 keV (this could be rescaled to 1.3% at the Xenon Q value of 2.458 MeV).

→ **In principle the ultimate showstopper could be given by inhomogeneities of the central sensor but a resolution at the level of 1% could be reached. R&D ongoing**

Preliminary results

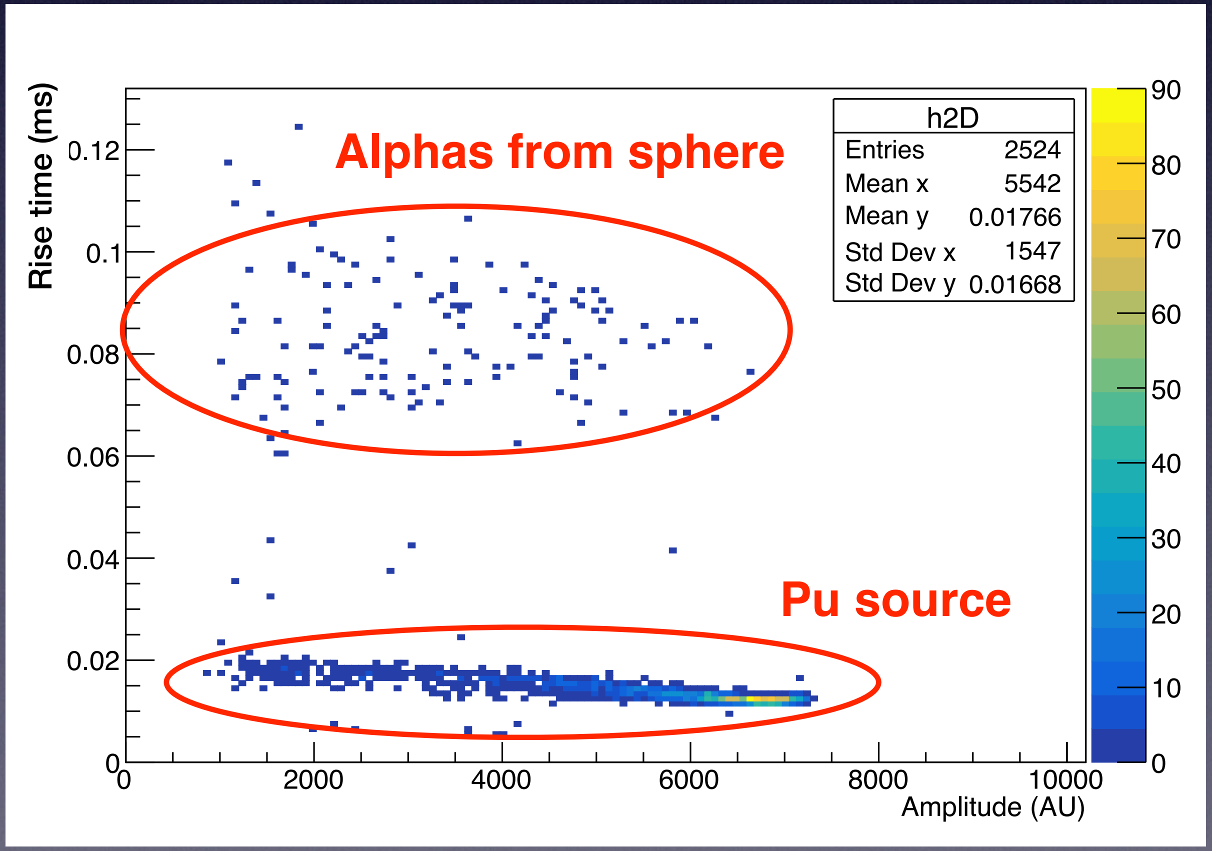
- We used a 3.7 kBq Pu239 source (alpha of 5.15 MeV emitted) in a plastic holder with a 2 mm hole in order to reduce the activity at the level of 3 Bq.
- For now we use Ar 98% and CH4 2% before moving to Xenon.

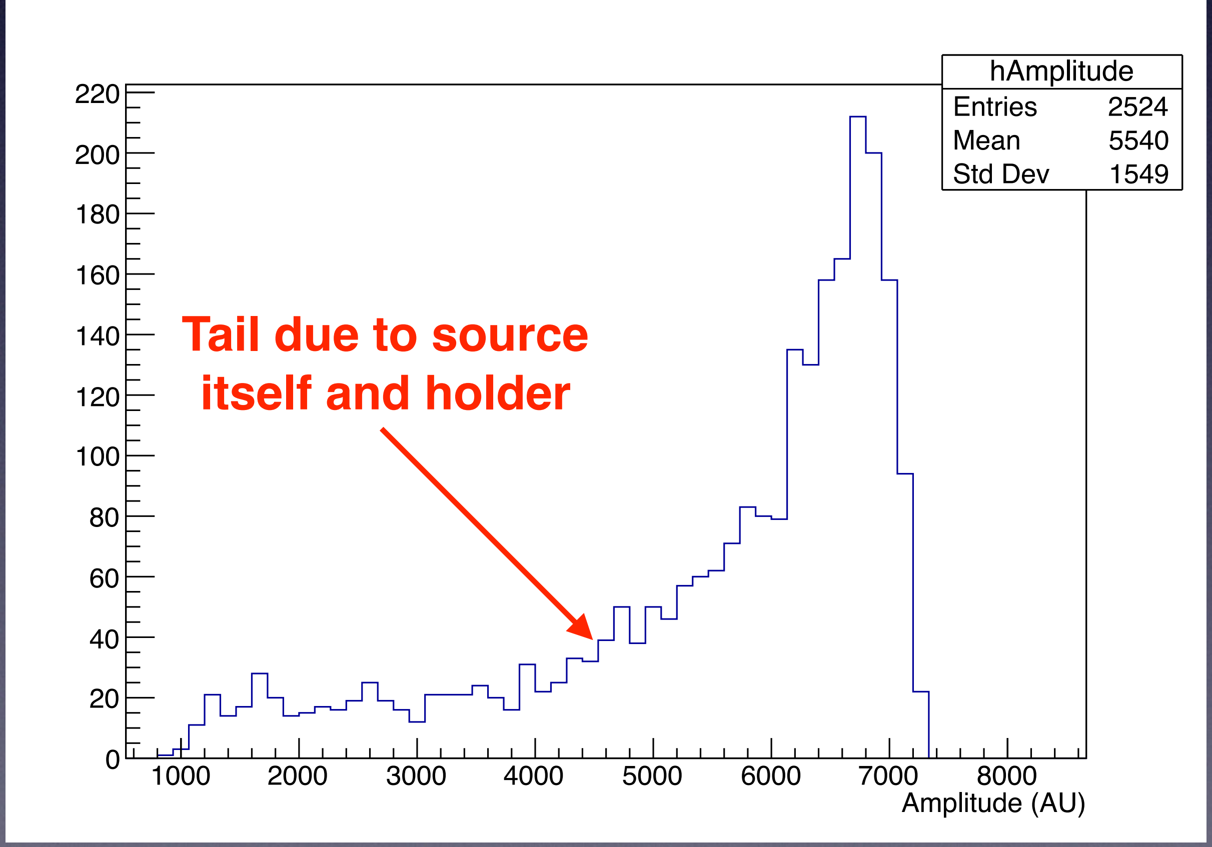
- In the future we aim at a sliding rod to change the radial position of the source. For now we placed it at 10 cm from the central sensor.
- Data were taken at 1.3 bar and 2000V.



Preliminary results

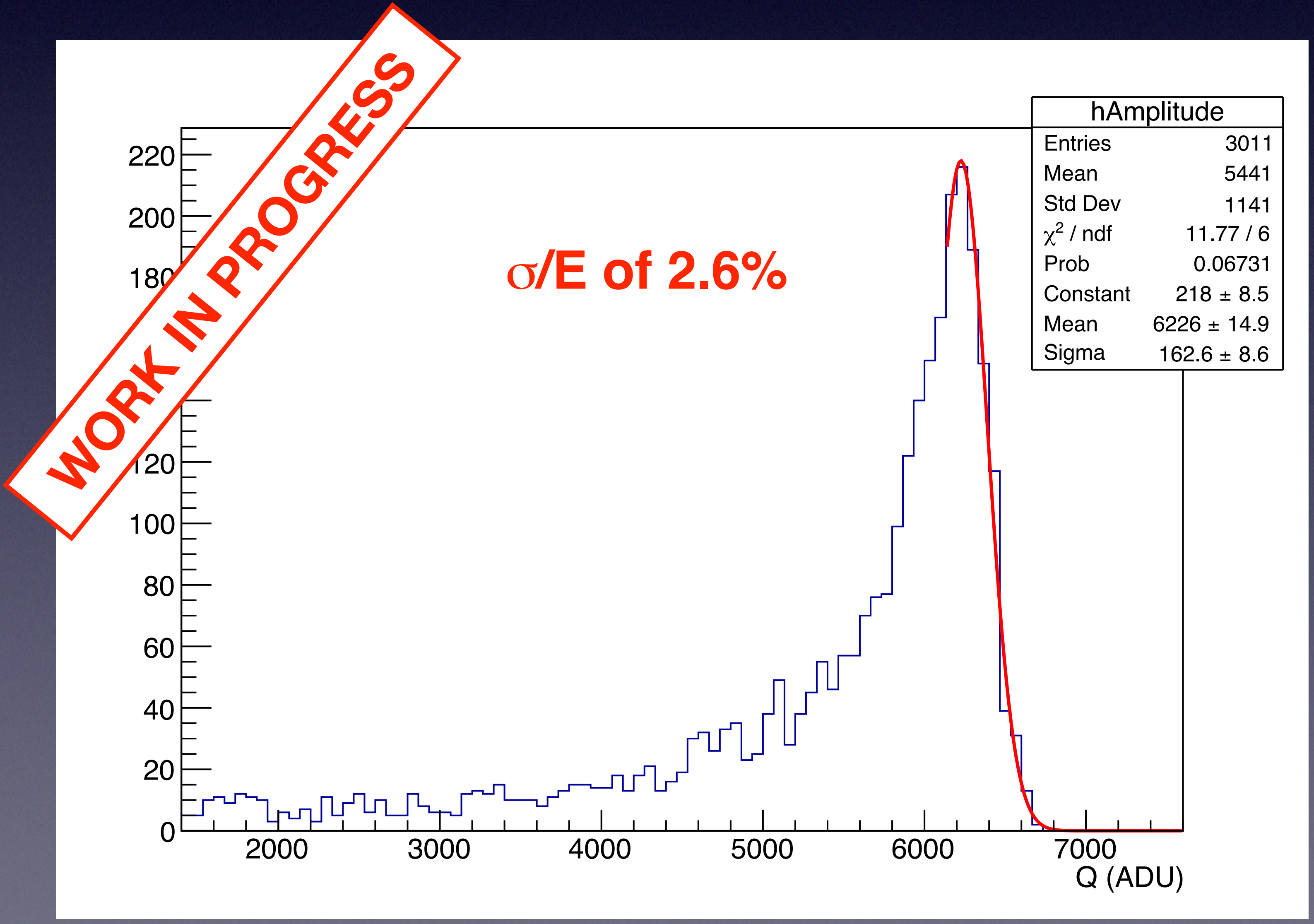
- The signal is well identified, however due to the long low energy tail it is not possible to well fit the peak and extract the energy resolution. To have a **rough estimate** we can try to **fit the high energy side of the peak**.





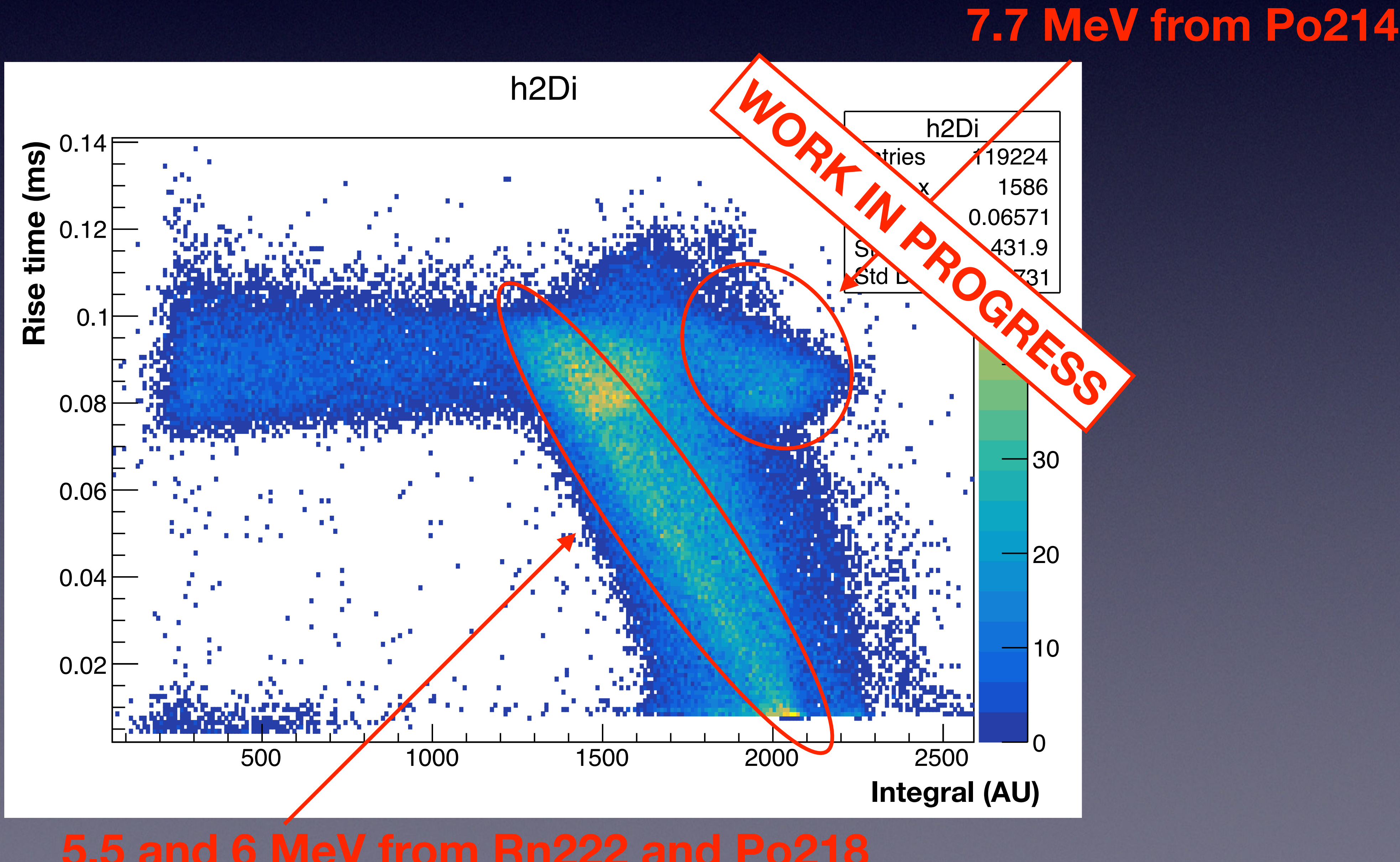
Noise filter

- Before fitting the signal we applied a waveform analysis to remove the noise due to electronics and room noise (detector not in a clean environment).
- In addition a deconvolution of the waveform is applied to recover the signal charge and correct for the ballistic deficit.



Pitchblende

- To get rid of the issue related to the source itself we used Rn222 from pitchblende.
- We observed alphas as expected however we have a strong dependence on the radial position which means we still have some electronegative impurities in the detector (mostly likely oxygen). Probably coming from the pitchblende.

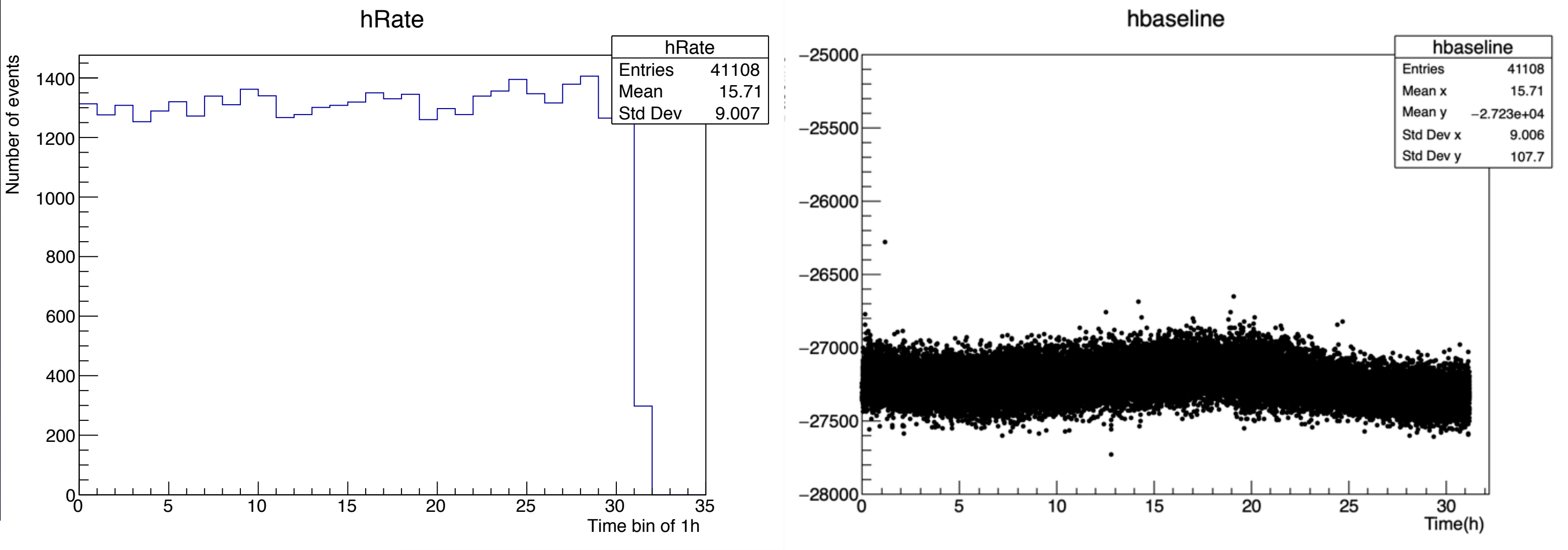


Thorite rods

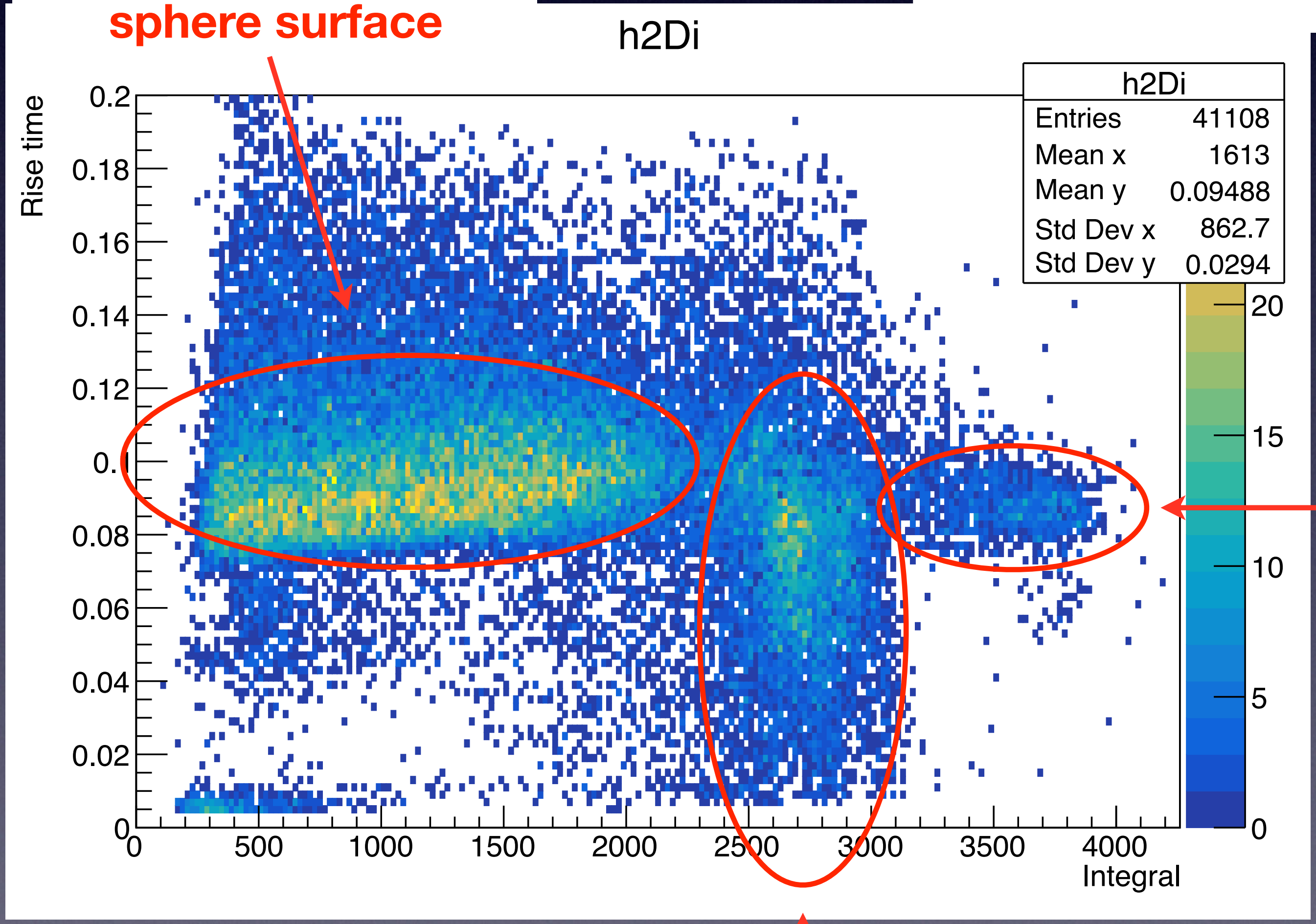
- We used the thorite welding rods at the level of the hole at the bottom of the sphere in a dedicated holder to avoid betas (the holes in the two layers are not in face of each other)

Thorite rods

- We see the Rn220 inside the sphere!
- Integral independent from the rise time… no oxygen!

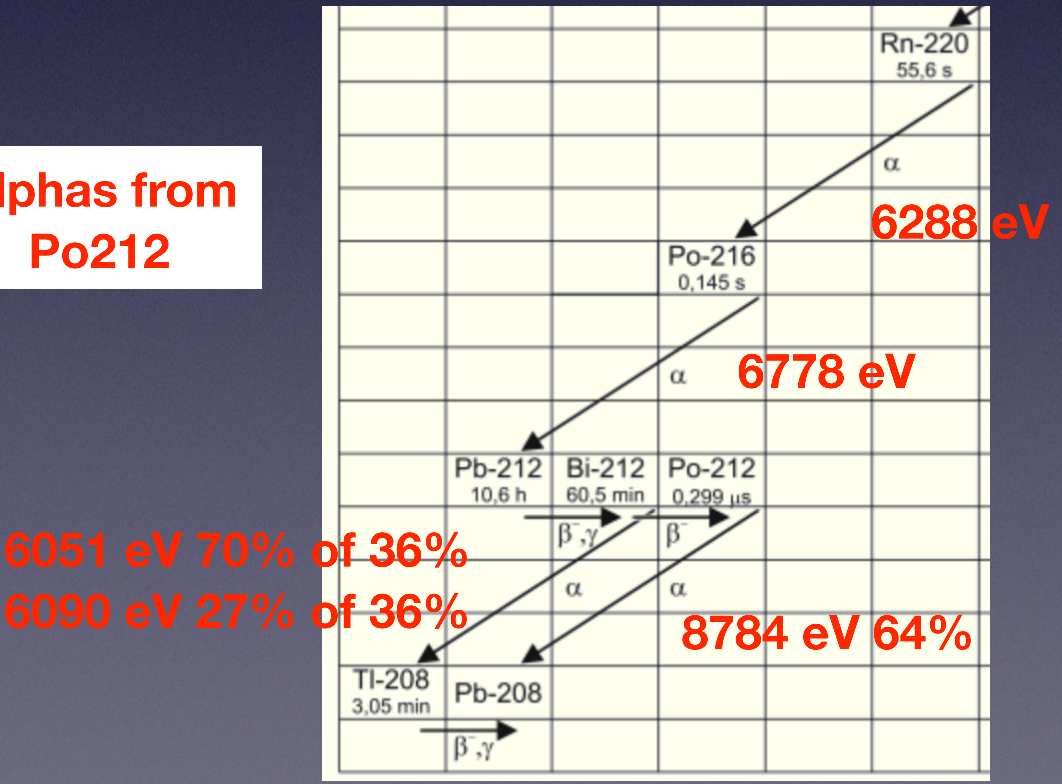


Background from the sphere surface



Alphas from Po212

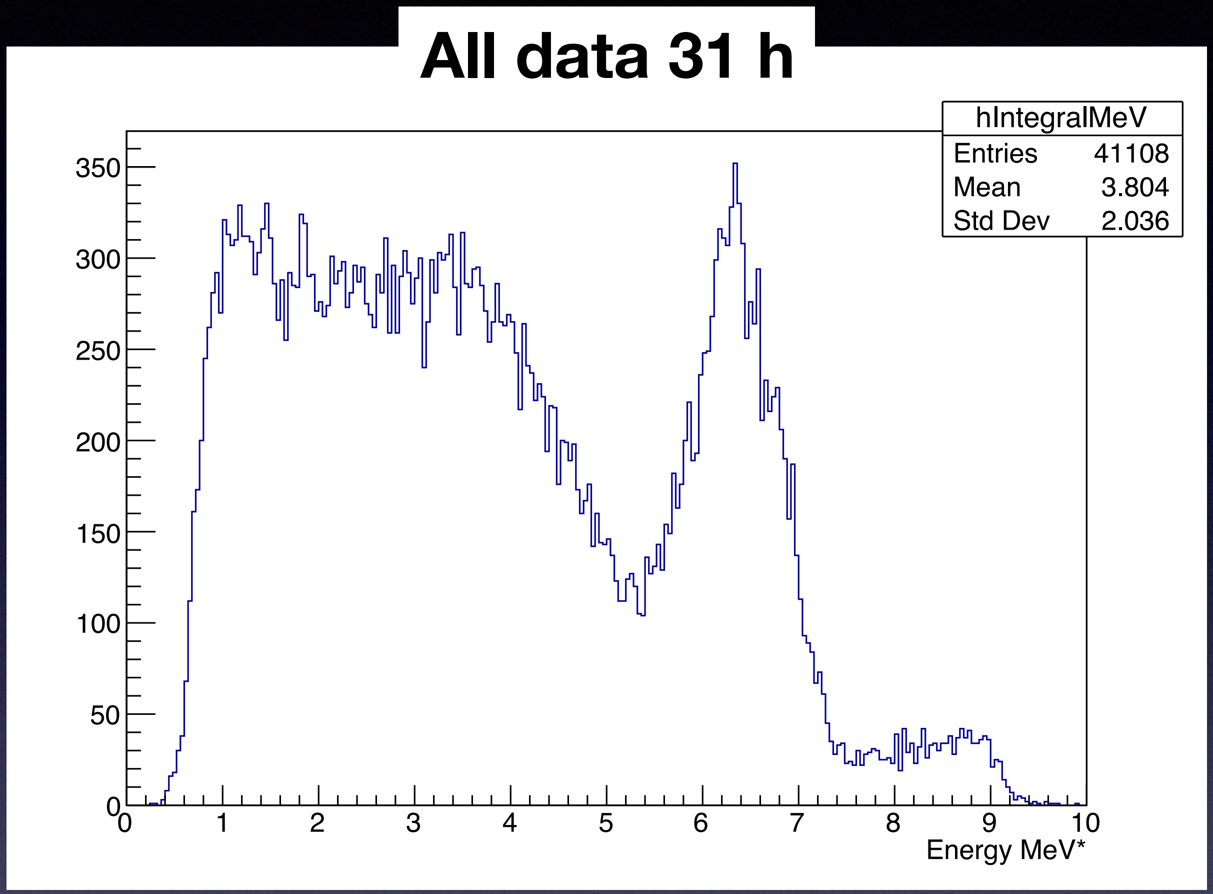
Alphas from Rn220, Po216 and Bi212

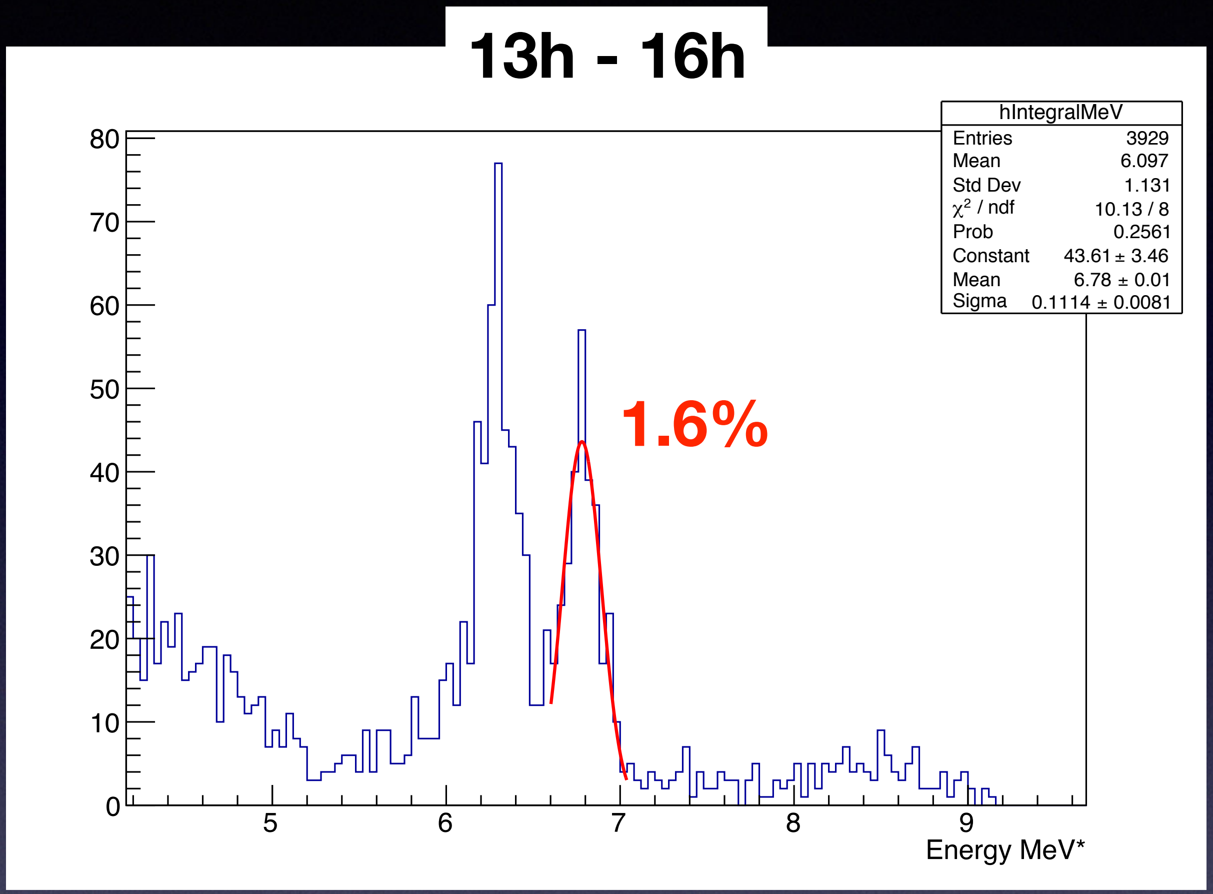


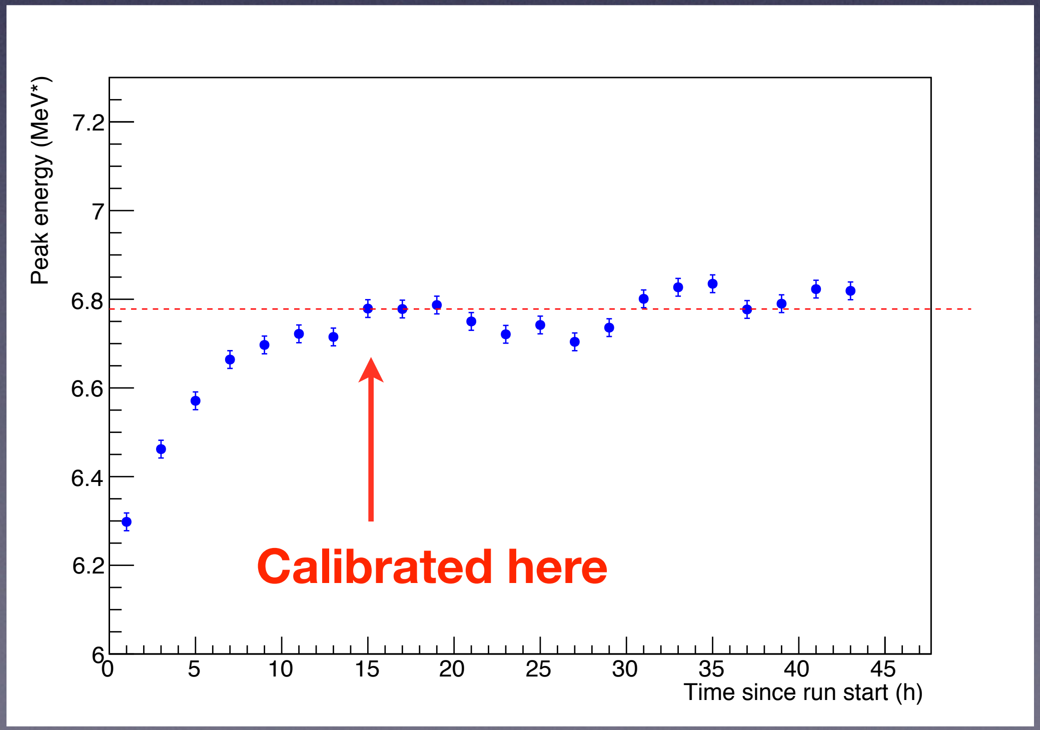
A.Meregaglia

Thorite rods

- The peak is not well defined. It is well defined on shorter periods. Does it move in time?

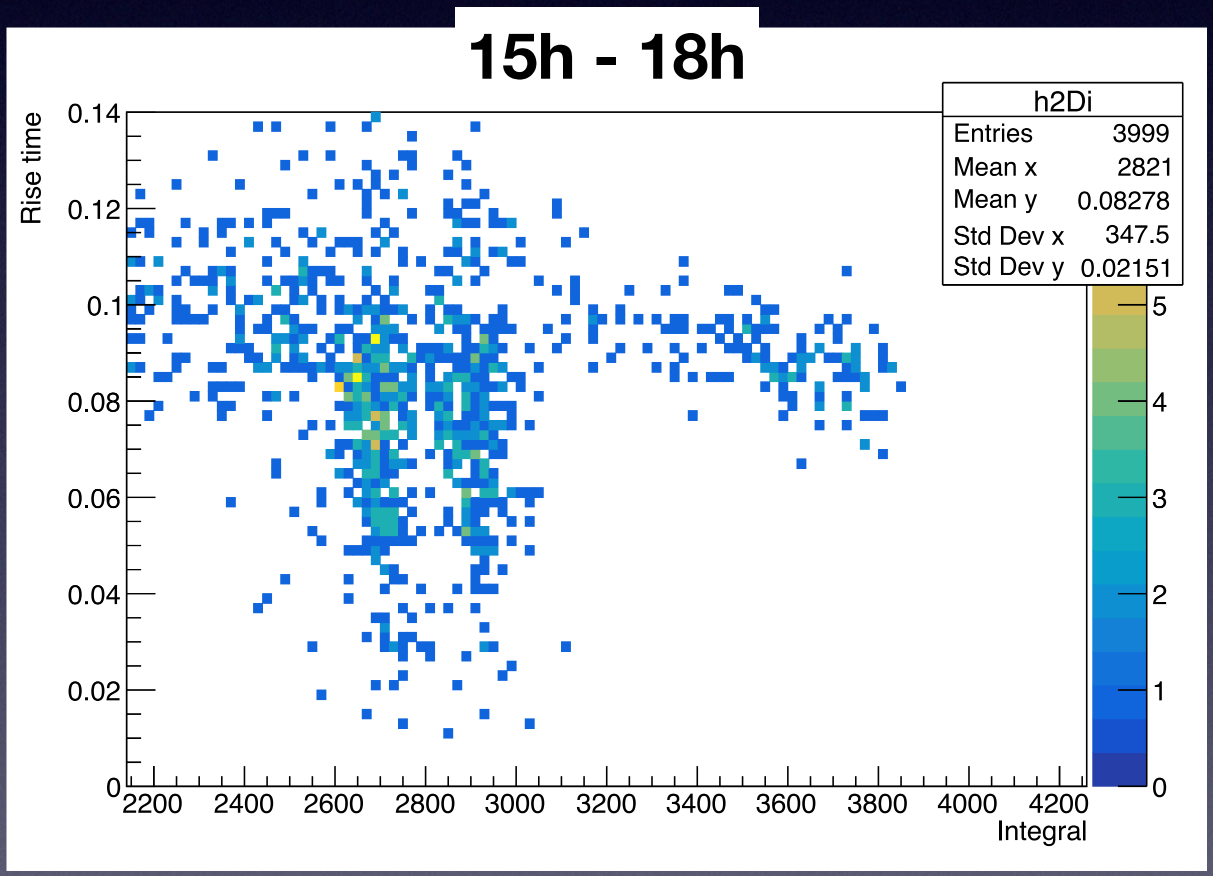


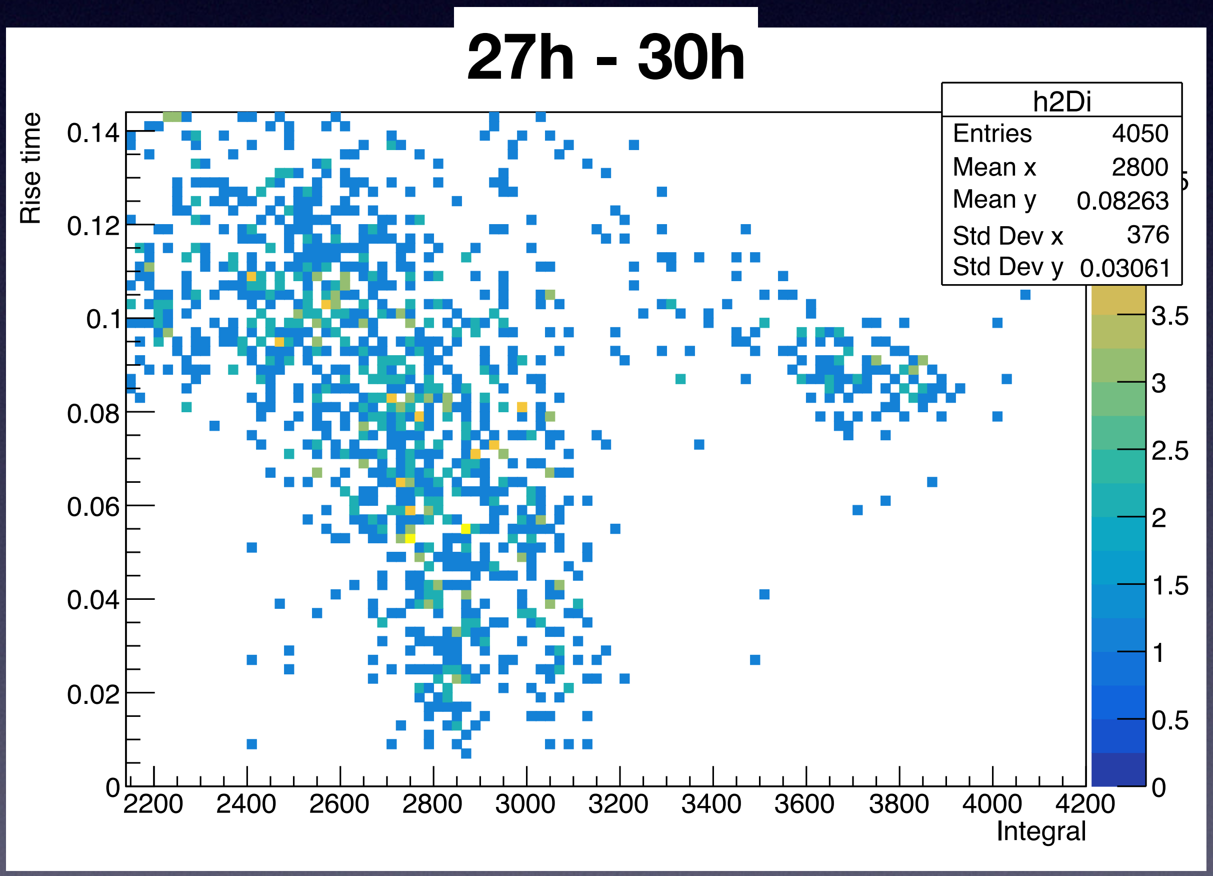




Thorite rods - time evolution

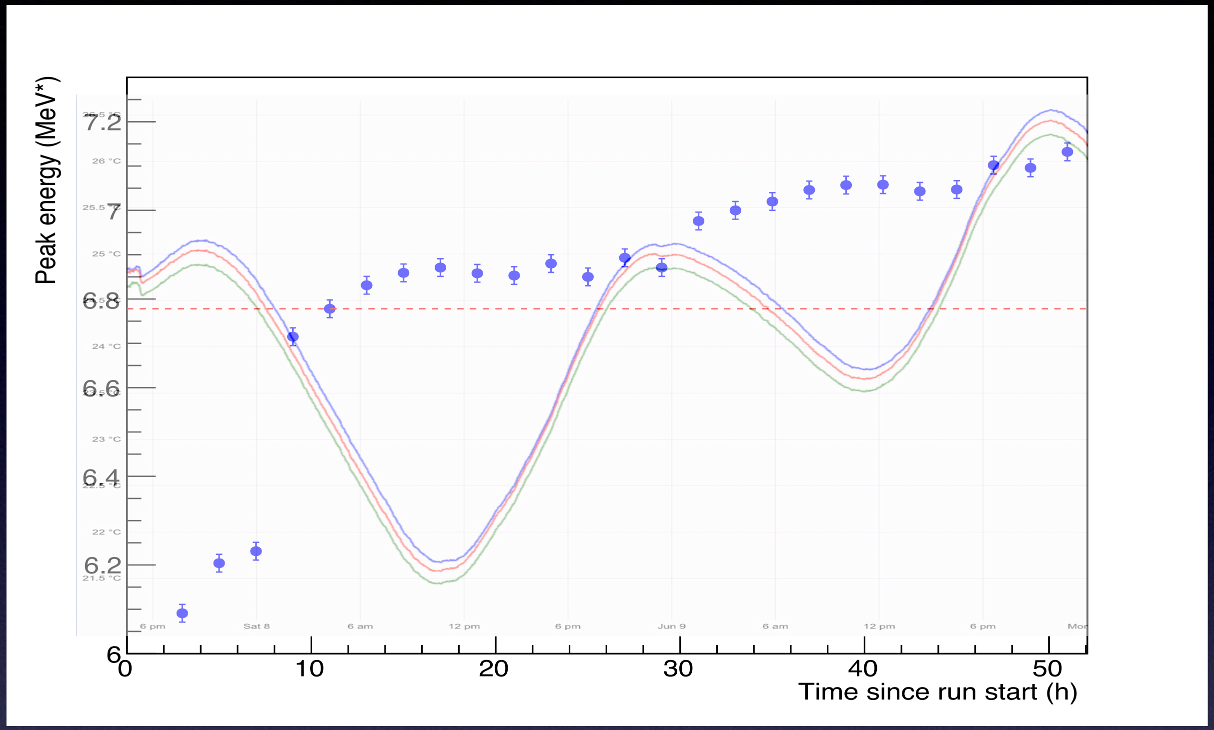
- Less radial position independent?
- Oxygen coming in should reduce the integral whereas the peak value increases.
- What happens?

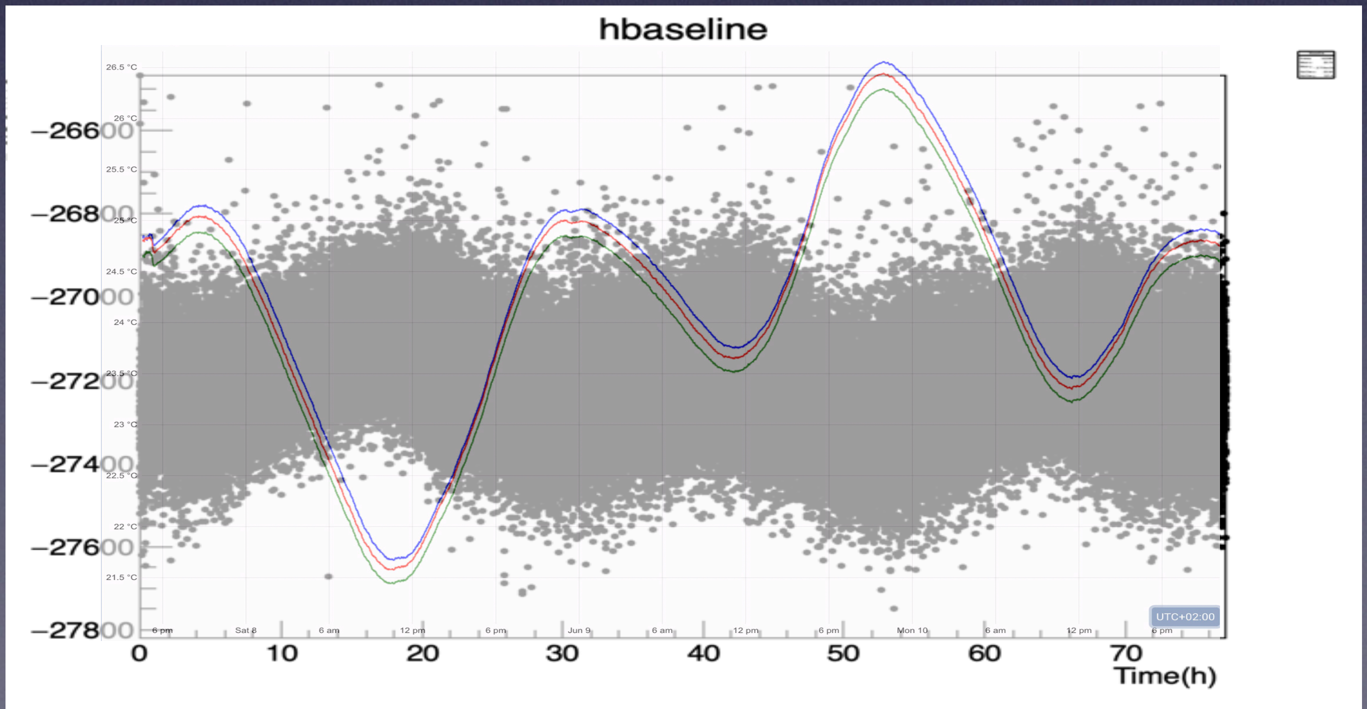




Temperature effects

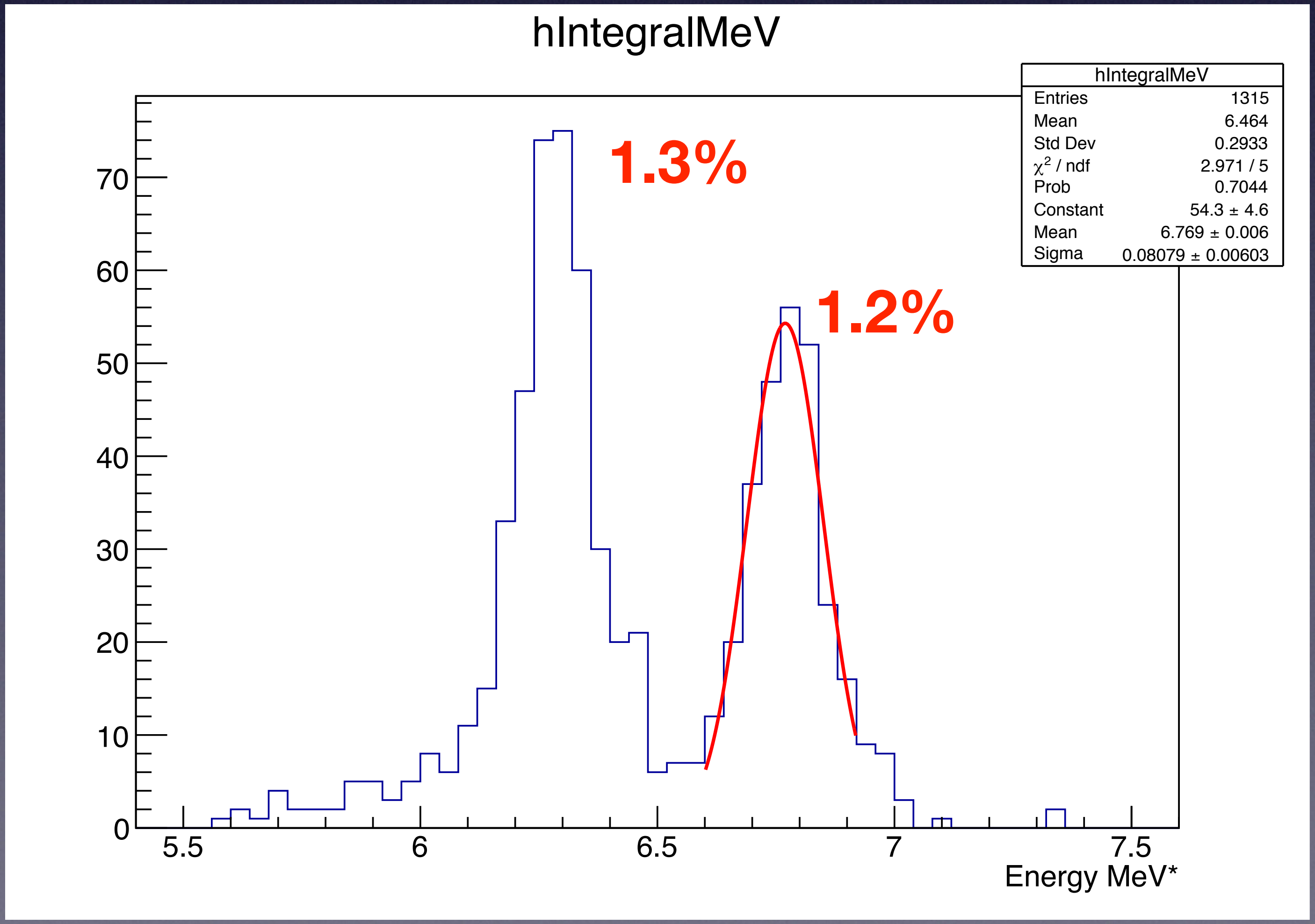
- We took a run monitoring the temperature to see if we had correlations.
- The baseline is affected by the temperature. Not so clear for the gain (after 52 hours the peak can not be fitted anymore)





To do

- We need to understand the gain changes and to stabilise the detector.
- We need to understand why the gas is degraded so rapidly (after 2 days).
- The best results we obtained so far is about 1.2% sigma resolution… we still need to gain a factor of 4… how?



Status and outlook

- The R2D2 proto-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**.
- One additional of the advantages of such a detector would be the possibility to use different gases in the same detector. If the technology will be proven successful the use of Xenon will be only a first phase of a more complete project.
- An R&D program has started with the main goal of assessing the achievable energy resolution, which is the first possible showstopper.
- **Results are promising** although we still have to solve small technical issues before moving to Xenon.
- Depending on the success of the R&D we hope to move on in order to build a prototype allowing for real physics results.