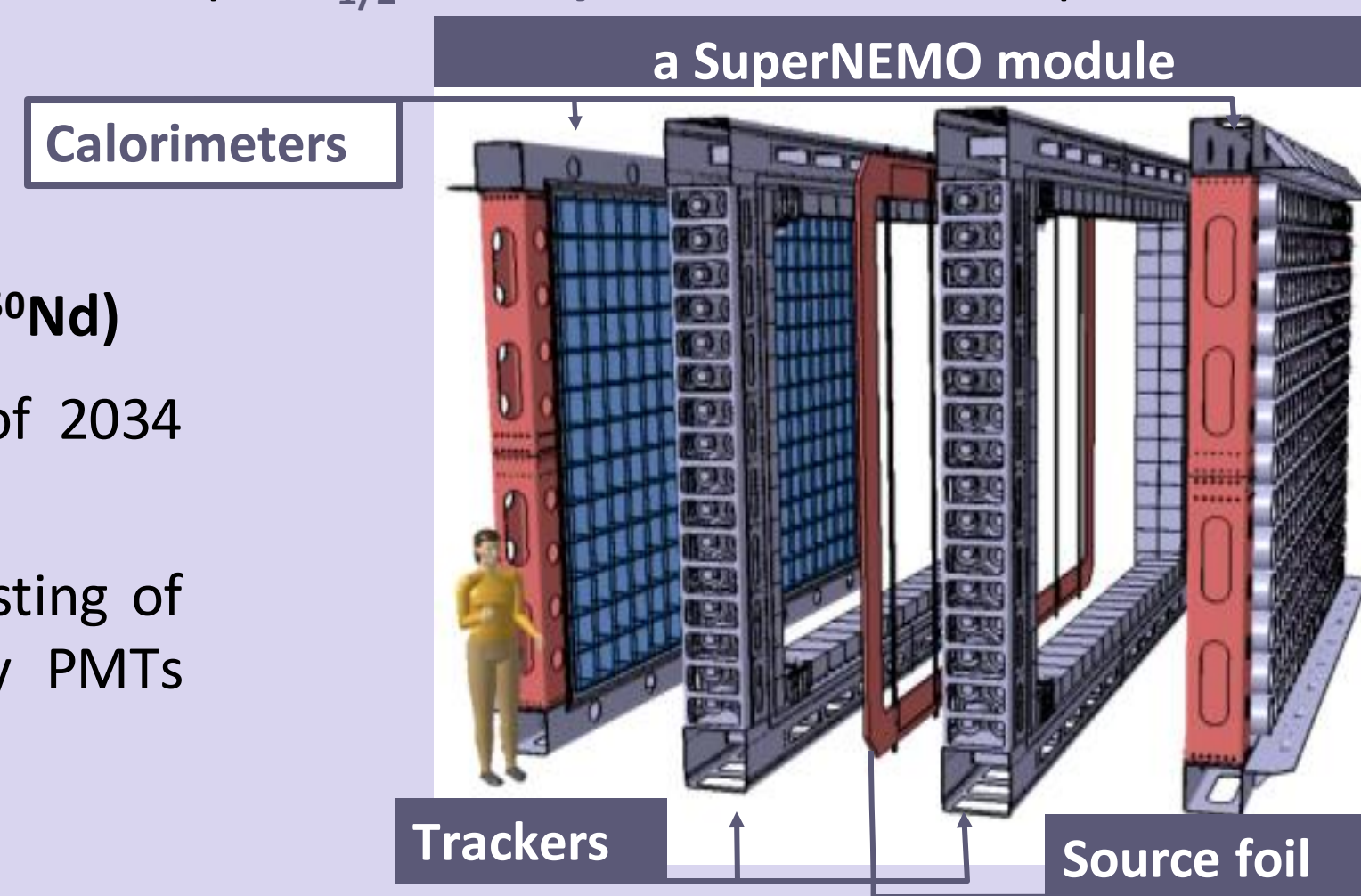


The SuperNEMO detector

SuperNEMO is a **$0\nu\beta\beta$ experiment** based on the NEMO-3 technique of tracking and calorimetry. It will search for neutrinoless double beta decay with **unique kinematics** access testing different New Physics mechanisms (V+A, Majoron, SUSY...) and probing the 2 electron signature (golden events). The modular design has been optimised to reach a half-life sensitivity of $T_{1/2} \approx 10^{26}$ years, which corresponds to a neutrino mass sensitivity of ~ 50 meV.

A SuperNEMO module contains :

- a central thin **source** of ~ 5 kg ^{82}Se (or ^{96}Zr , ^{150}Nd)
- surrounded by a **tracking chamber** made of 2034 drift cells in Geiger mode
- enveloped in an **electron calorimeter** consisting of 712 plastic scintillators and low-radioactivity PMTs acting also as a gamma tagger



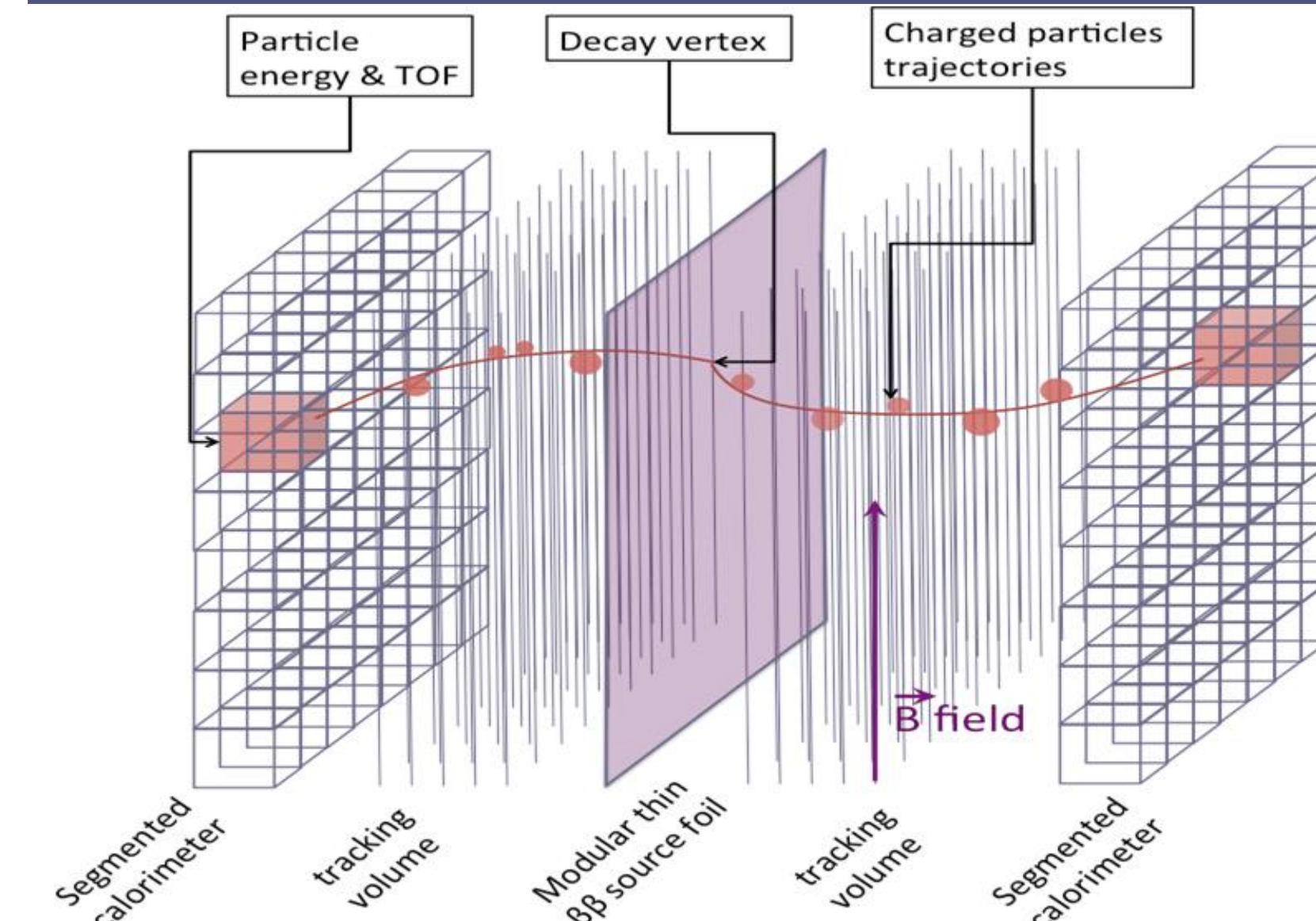
The demonstrator :

First module to test the technical feasibility of the experiment and measure the background levels with :

- 6.3 kg x 2.5 years of ^{82}Se
- $T_{1/2}(0\nu\beta\beta) > 6.6 \times 10^{24}$ years
- $\langle m_\nu \rangle < (0.15 - 0.4)$ eV

Commissioning of the calorimeter started in 2019
@ Laboratoire Souterrain de Modane (LSM) France

A tracker-calorimeter detector

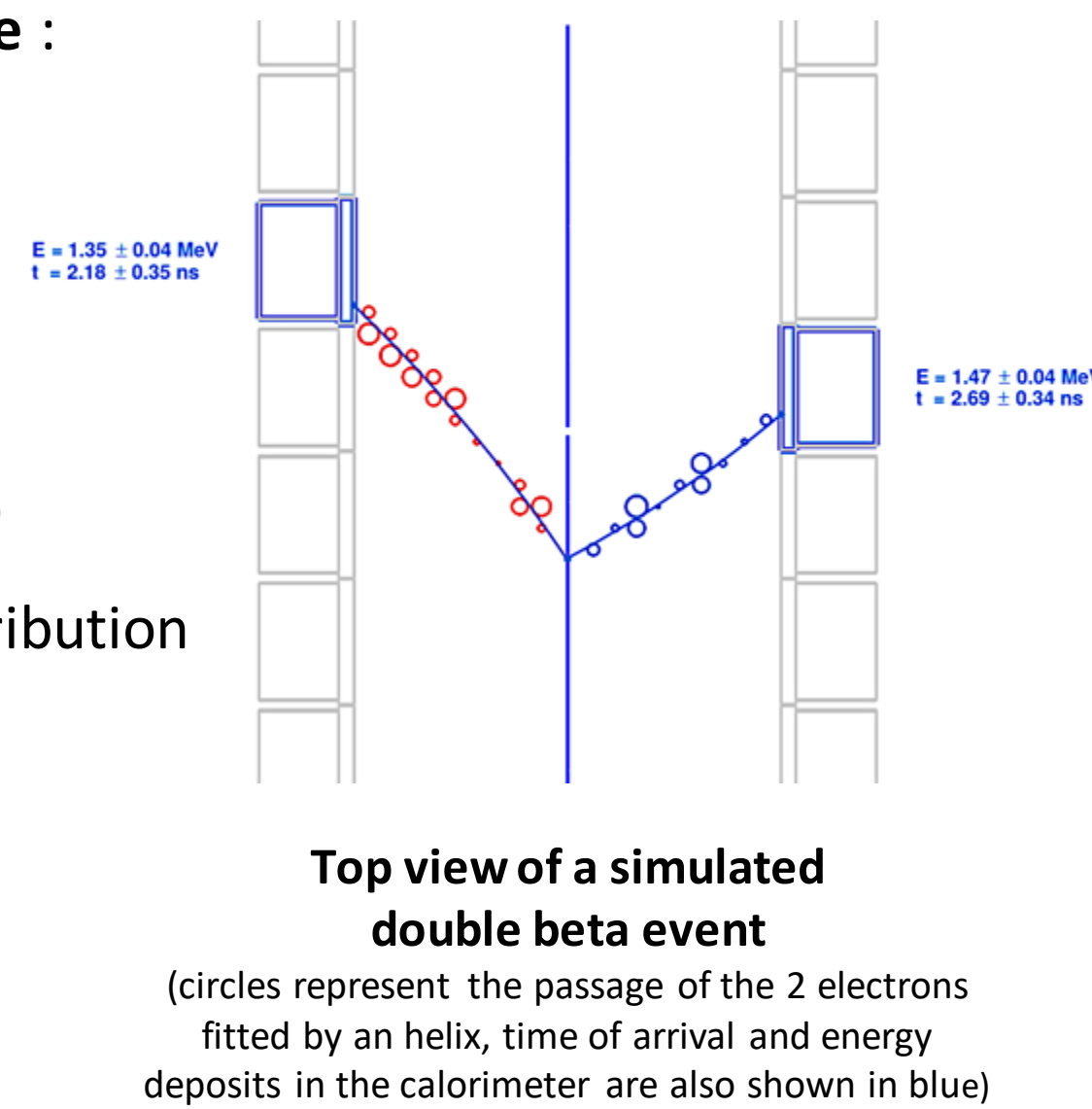


A segmented calorimeter to measure :

- Individual deposited energy
- Time of flight

A tracking detector to :

- Identify the particles (e^+ , e^- , α , γ)
- Measure 2 electrons angular distribution



The main wall calorimeter design

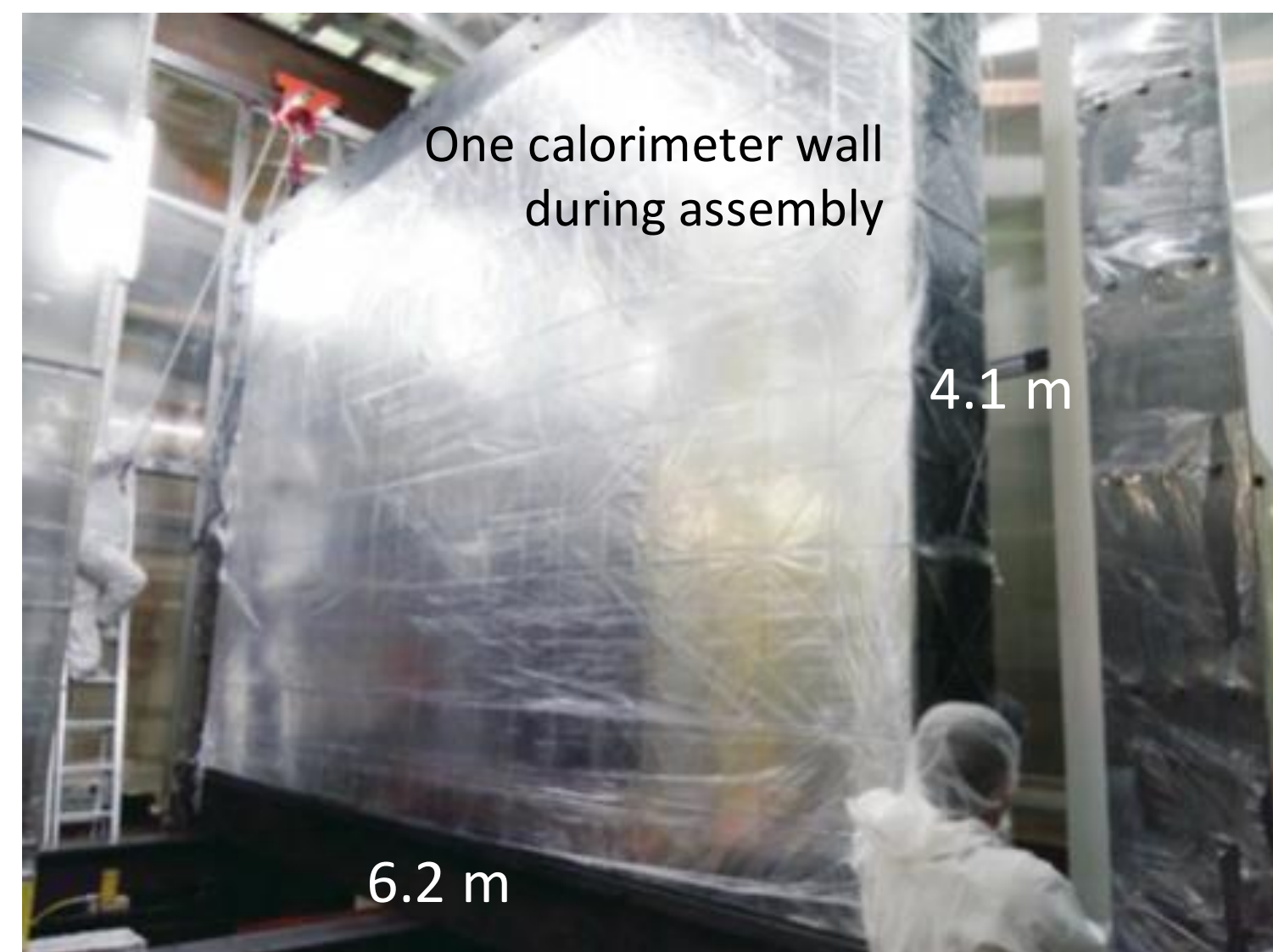
Two main walls form the highest resolution parts of the calorimeter. Other parts have poorer energy resolution but ensure 4π γ tagging and maintain efficiency for double beta decays near the edge of the detector

520 Optical Modules

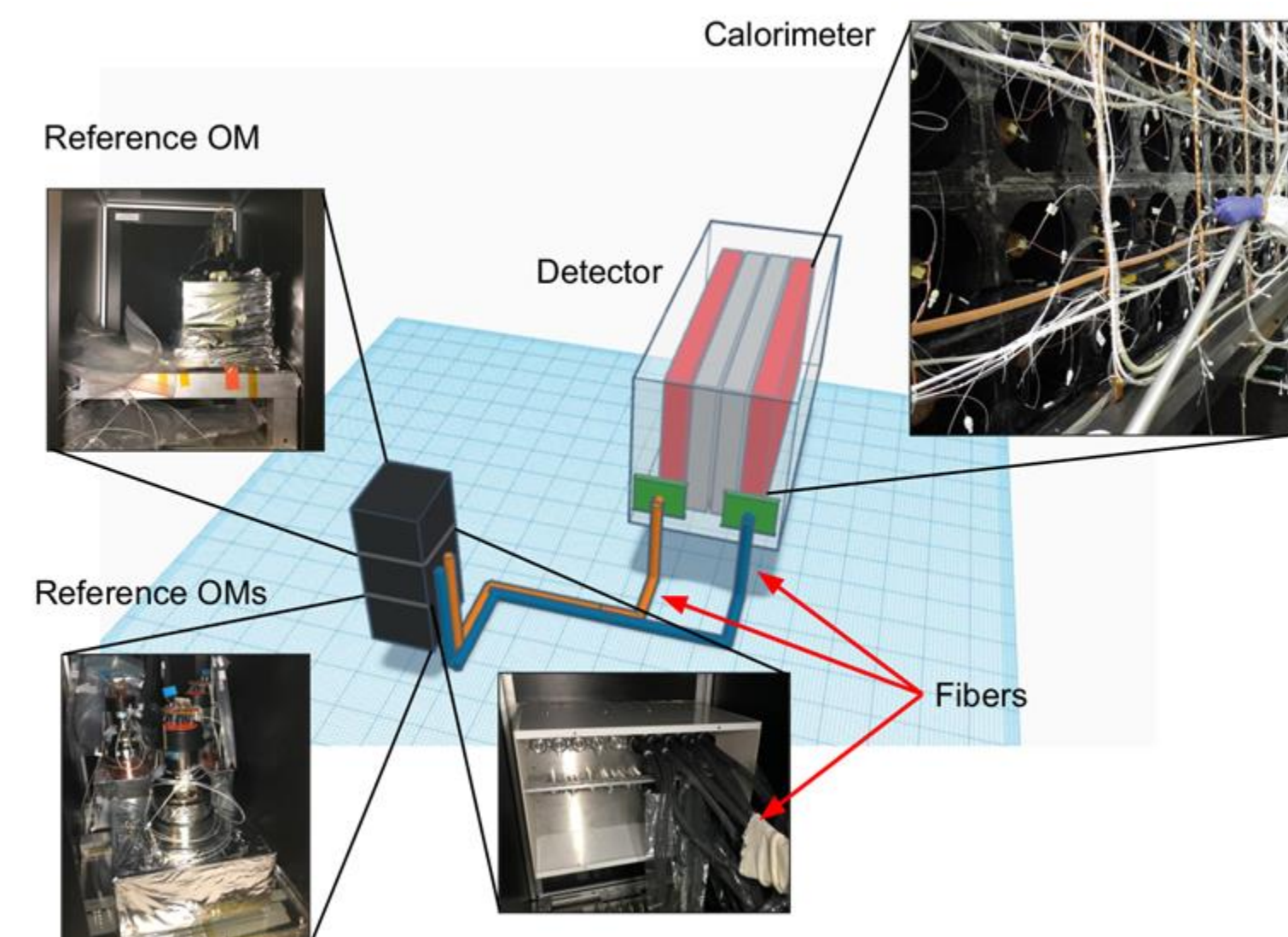
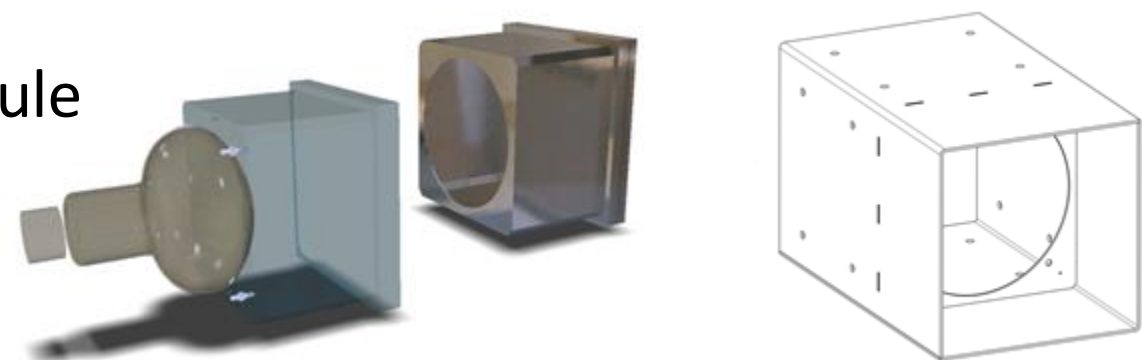
- each made of
- 10 L Envinet polystyrene scintillator
- R5912-03mod Hamamatsu Photonics 8" PMT
- Teflon and aluminised mylar wrapping
- Pure iron magnetic shield (25 G in tracker)

Requirements

- Energy resolution **8 % (FWHM) @ 1 MeV**
- Time resolution **400 ps (σ) @ 1 MeV**
- Gain survey with an accuracy < 1 %
- Low background PMT (300 mBq/kg for ^{40}K ; 120 mBq/kg for ^{214}Bi ; 22 mBq/kg for ^{208}Tl)
- Low backscattering



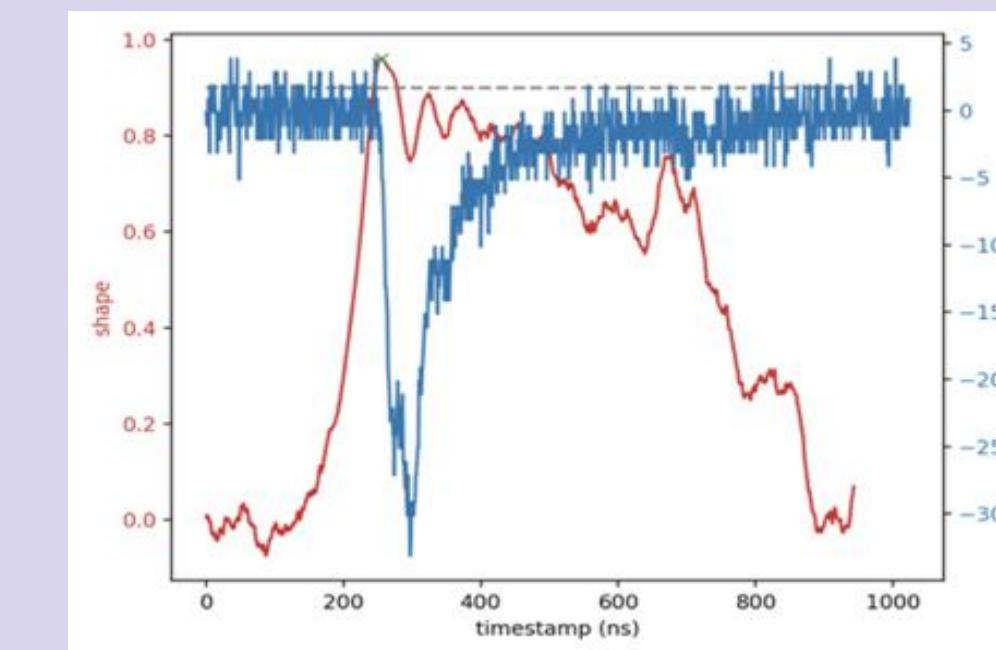
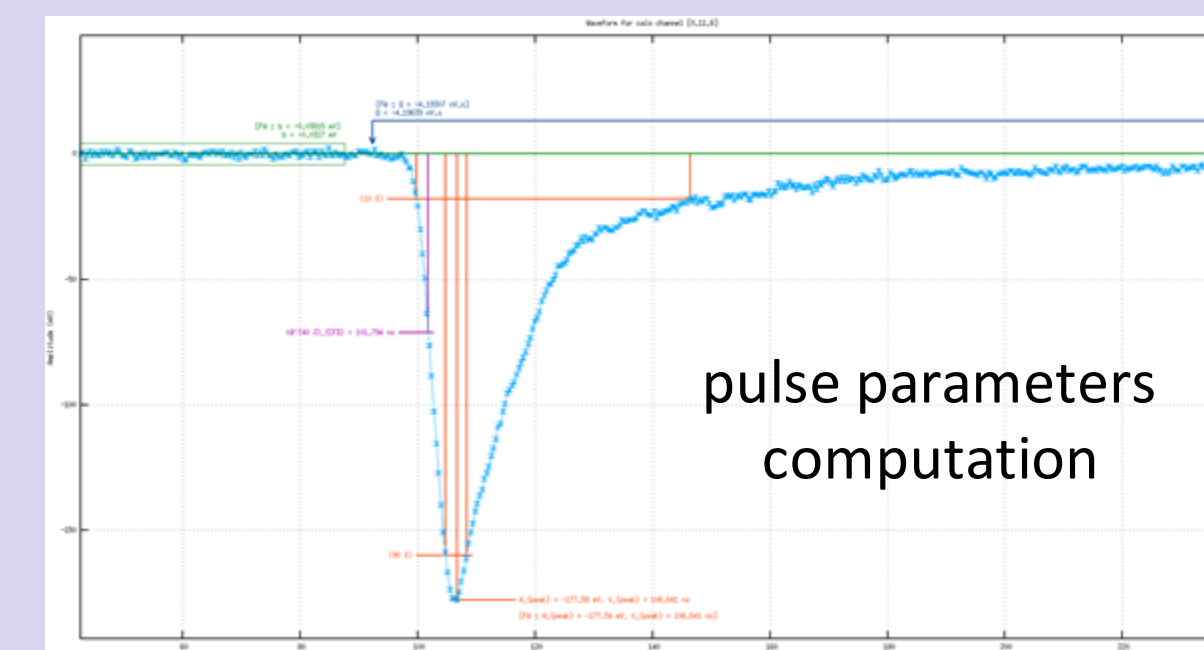
Individual optical module and the pure iron magnetic shield



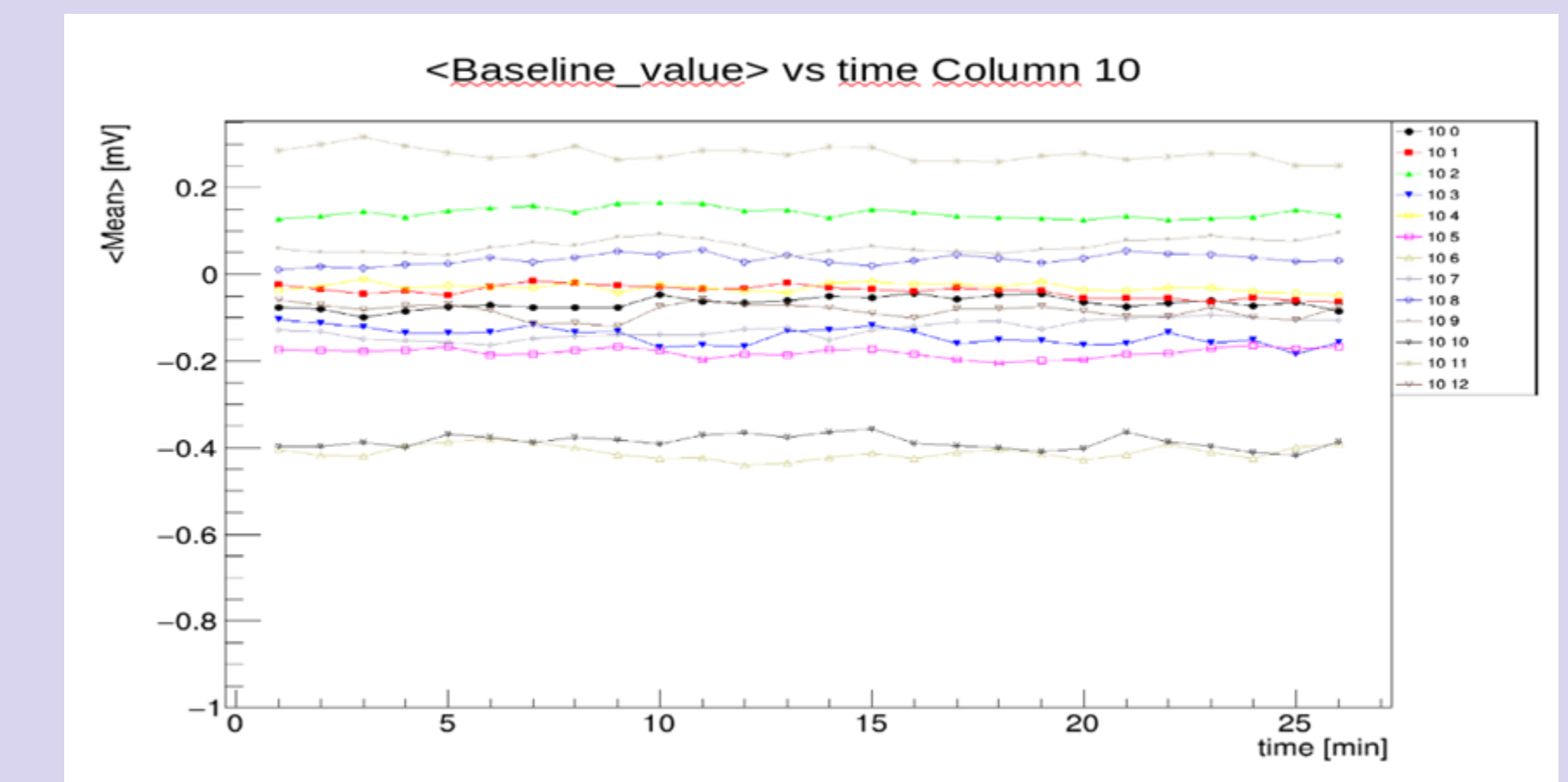
Relative time/energy calibration with LED + fibers
+ Absolute energy calibration with ^{207}Bi sources

Sampling of the PMT waveforms

All PMT signals are sampled @ 2.56 GS/s by the FEB electronics (wavecatcher technology). The PMT pulses' parameters are reconstructed offline : baseline, time, amplitude & charge. Matched filtering analysis is used for waveform analysis (times, shapes, pile-up) and detection of pre- and afterpulses, or pathological PMTs.



The matched filtering analysis (score in red) allows identification of main, pre- and after- pulses

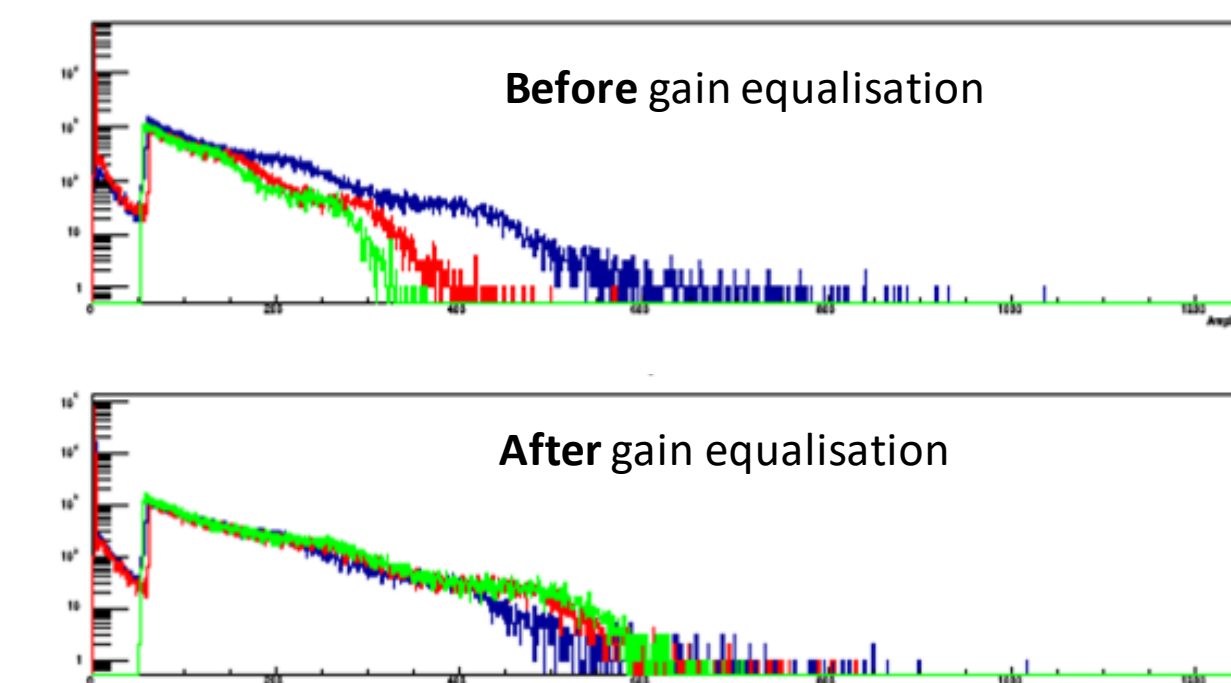


Very low noise and stable electronics, as shown by the baseline calculations over time

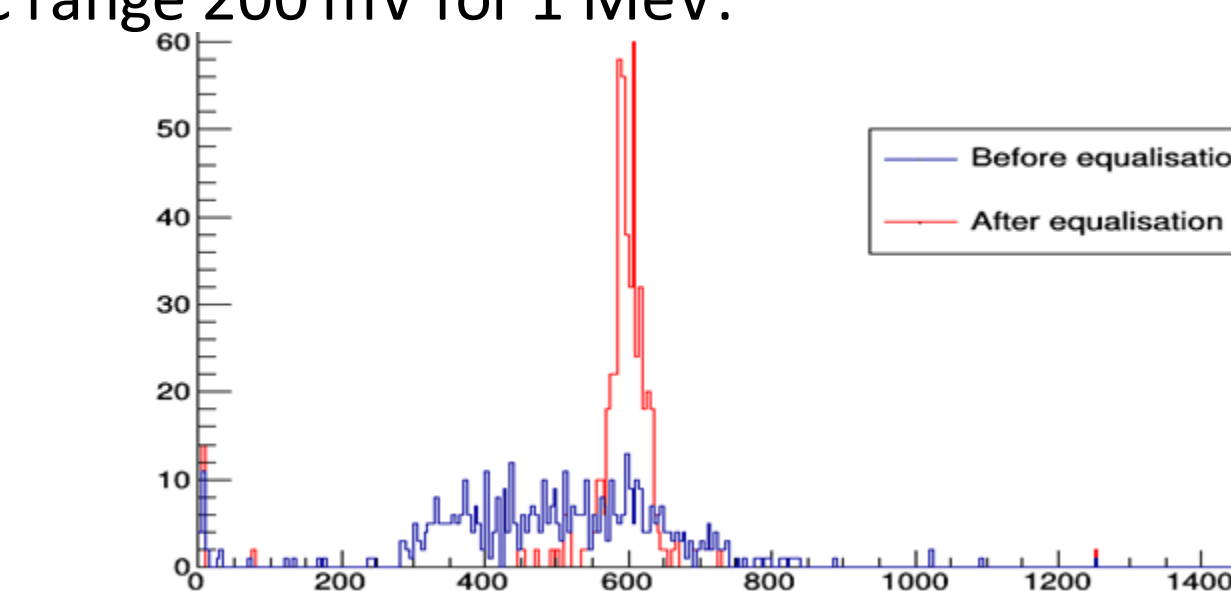
Energy response and gain equalisation

A gain alignment of the optical modules was performed after their integration in the calorimeter, taking into account the cable lengths, detector and electronics effects...

Development of a dedicated method using the laboratory natural radioactivity (^{208}Tl 2.6 MeV γ Compton edge) to align the spectra:

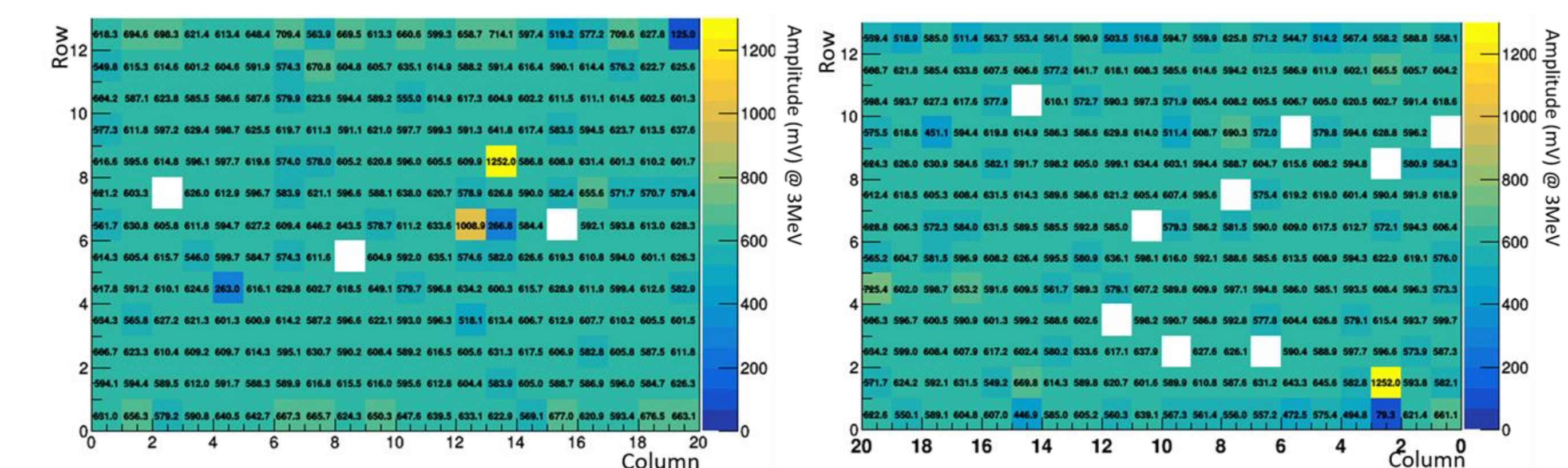


Amplitude spectra of optical modules adjusted to the electronics dynamic range 200 mV for 1 MeV:



The 520 main wall optical modules are equalised with gain spread $< 10\%$

First gain measurement for the optical modules of the 2 main walls:

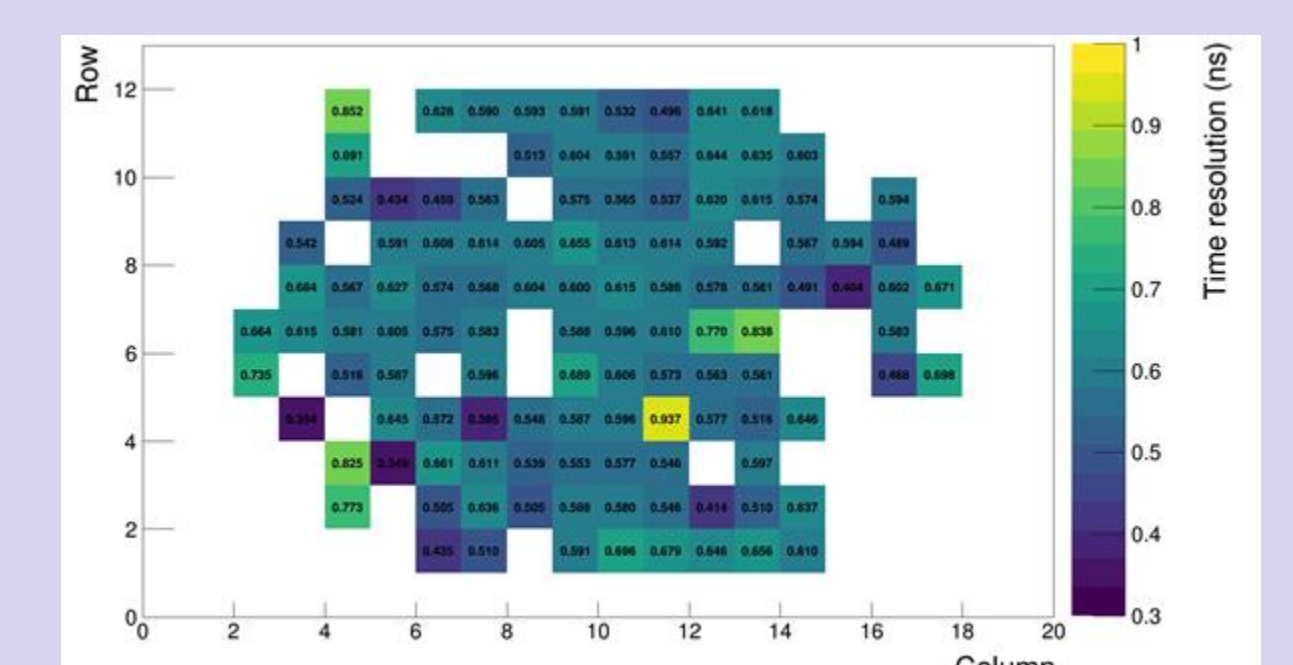


Timing resolution of the calorimeter

- The **Cobalt-60** isotope decays through two short life-times energy levels of 1.17 MeV & 1.33 MeV
- The Cobalt-60 source ($A = 232$ kBq) has been placed at different positions in front of the calorimeter wall to align in time the whole main walls
- The two corresponding γ particles are detected in coincidence, allowing characterisation of the timing and its resolution.

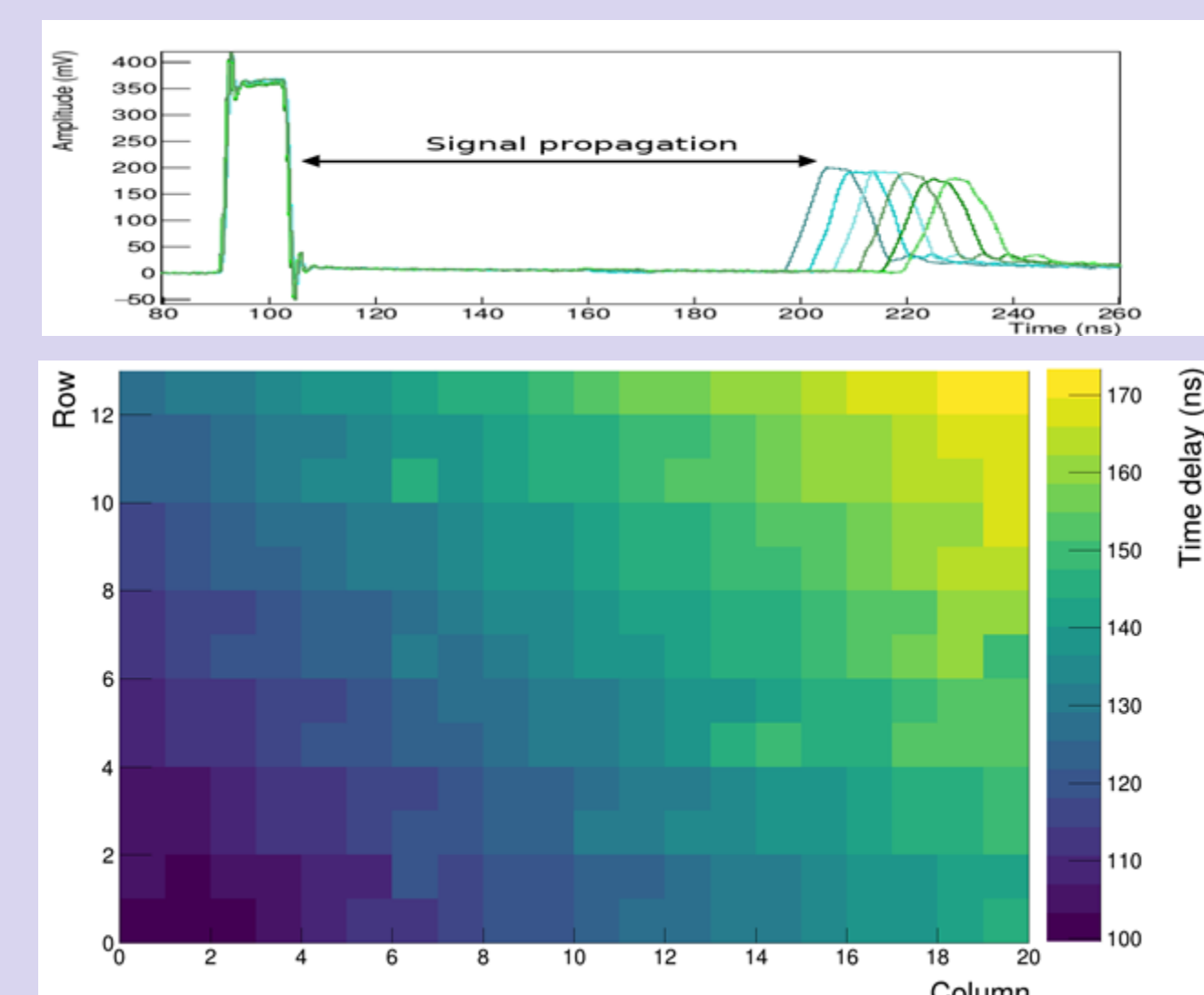


Encouraging result with these first short runs (low stat) and γ particles
 $\sigma < 600$ ps @ 1 MeV
(better results expected with electrons and tracker precision)



Time characterisation of the calorimeter

- Electrical impulses** sent from the electronic boards through each electronic channel to test detector cabling and PMT connection
- After travelling inside coaxial cables the signal is **reflected** on the PMT divider, and comes back to the electronic to be sampled and stored with the primary pulse (see top right figure)
- useful tool to **test the detector performances and the cabling quality**
 - To calibrate the **time delay between channels** (bottom right picture) by measuring the propagation time of the signal
 - To measure the **timing and signal attenuation** from the shape analysis of the returned pulses



More data coming : longer ^{60}Co runs, AmBe neutrons, internal ^{207}Bi sources, muons...