SuperNEMO
Neutrinoless Double Beta Decay Experiment

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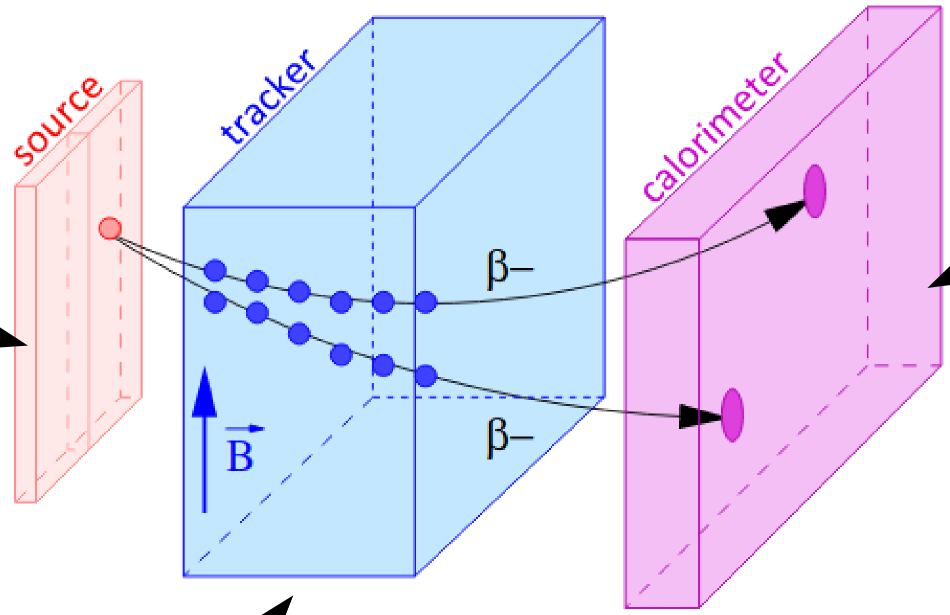
Jun 1, 2021

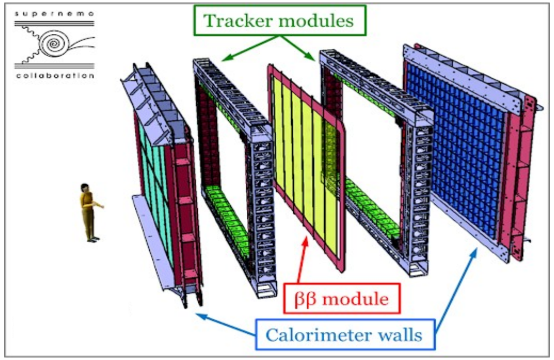
SuperNEMO: Tracker-Calorimeter Detector

Source is separate from detector
→ ability to **study several isotopes**

Measure **individual particle energies** giving access to decay mechanism



Full topological reconstruction → **High background rejection**
(expected $<10^{-4}$ events/keV/kg.yr)



The SuperNEMO Demonstrator Source

6.23 kg of ^{82}Se as ββ source

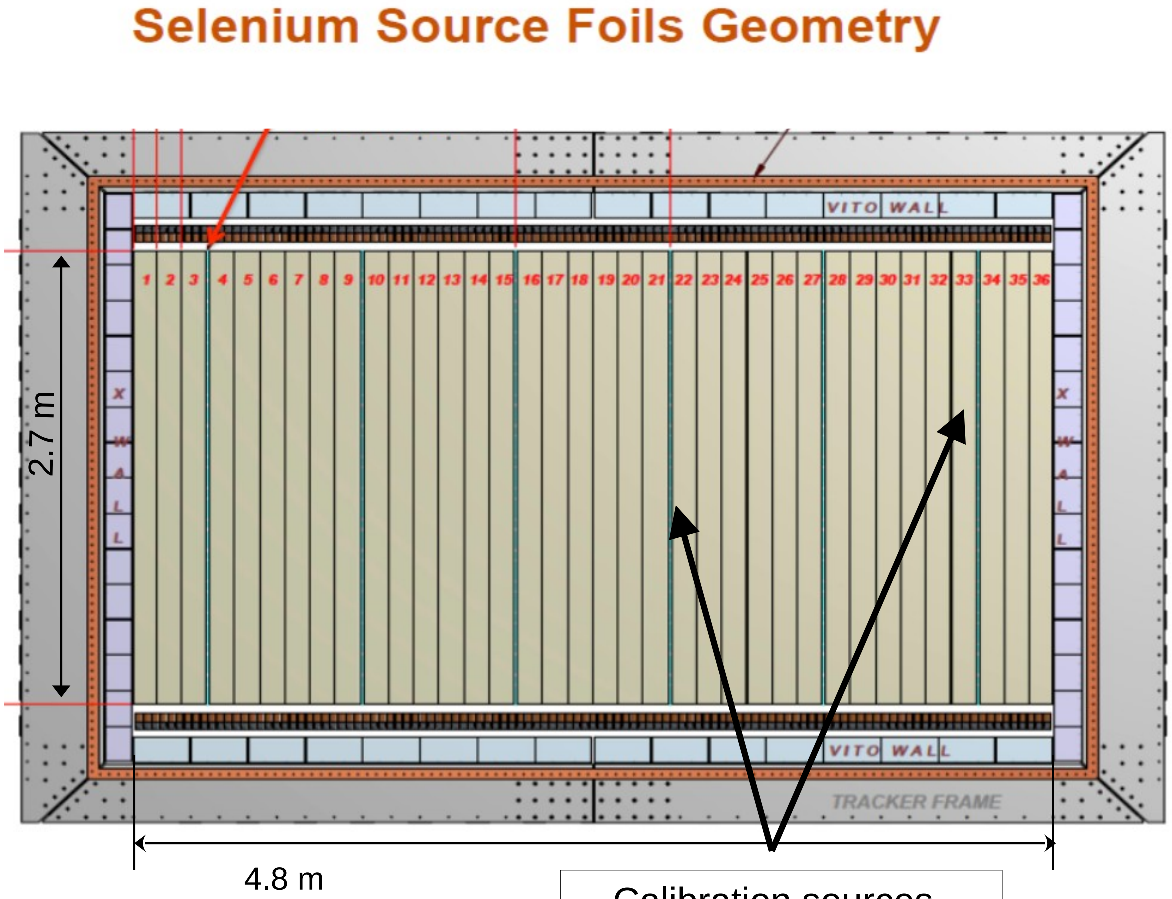
$Q_{\beta\beta}$ = 2.998 MeV $T_{1/2}^{2\nu}$ = 9.4 x 10^{19} y

(NEMO-3)

Radio-Purity of ^{82}Se foils	Specifications (µBq/kg)	Measured values for best source using BiPo-3 detector (µBq/kg)
^{208}Tl	< 2	~ 20 ± 10
^{214}Bi	< 10	< 290 at 90% CL

500 kg.y exposure (100 kg, 5 years)

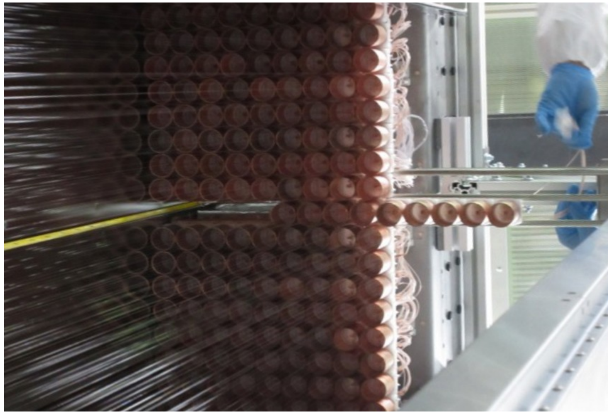
For source of demonstrator of 17.5 kg.y exposure



Calibration sources

Absolute energy calibration ^{207}Bi

The SuperNEMO Tracker



2034 drift cells operating in Geiger mode

↓

3D reconstruction of charged particle tracks
($\mu^{\pm}$, $e^{\pm}$, α)

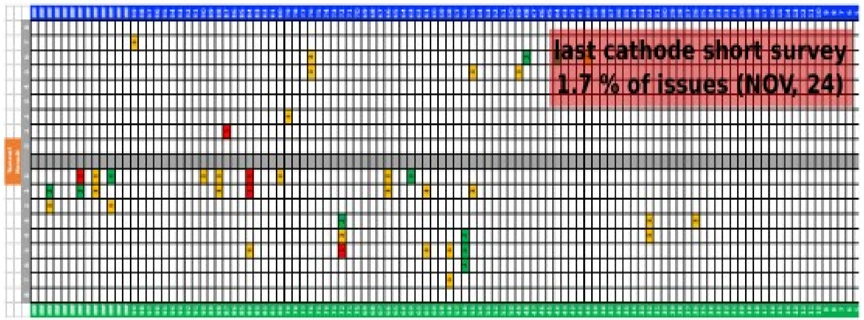
	Specifications (mBq/m^3)	Measurements extrapolated to a tracker gas flux of 2 m^3/h (mBq/m^3)
^{222}Rn emanation	0.15	0.16 ± 0.05

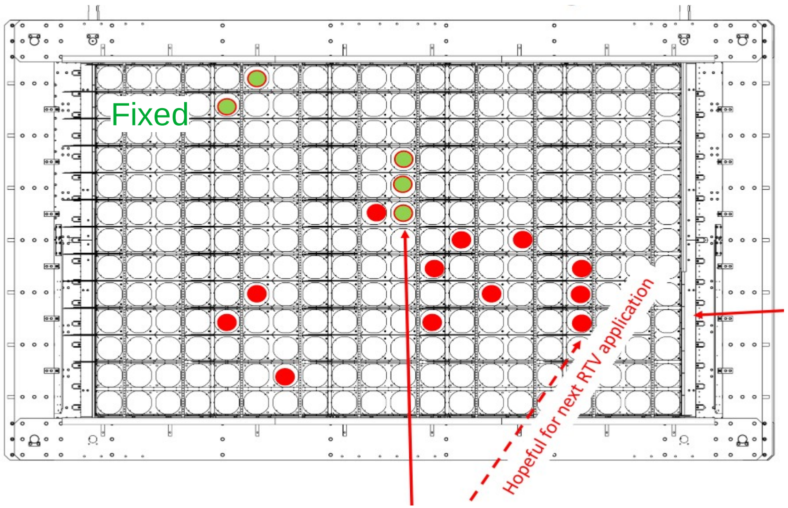
Tracker Deformation & Lifting: September 2020

The tracker frame was deformed → short circuit in 270 cells.

The Frame was raised ~ 4mm successfully with careful monitoring:

- Short circuit cells were reduced from approximately 20% to < 2%
- The structure is mechanically stable and is being monitored with laser gauges
- The source foils were not damaged in the process





Leaks identified in the demonstrator frame and the on site team is in a very good progress of fixing them

Tests for over pressure are planned (current measurements ~ 7 mbar with Argon → to be done with Helium)

The SuperNEMO Calorimeter

712 Optical Modules

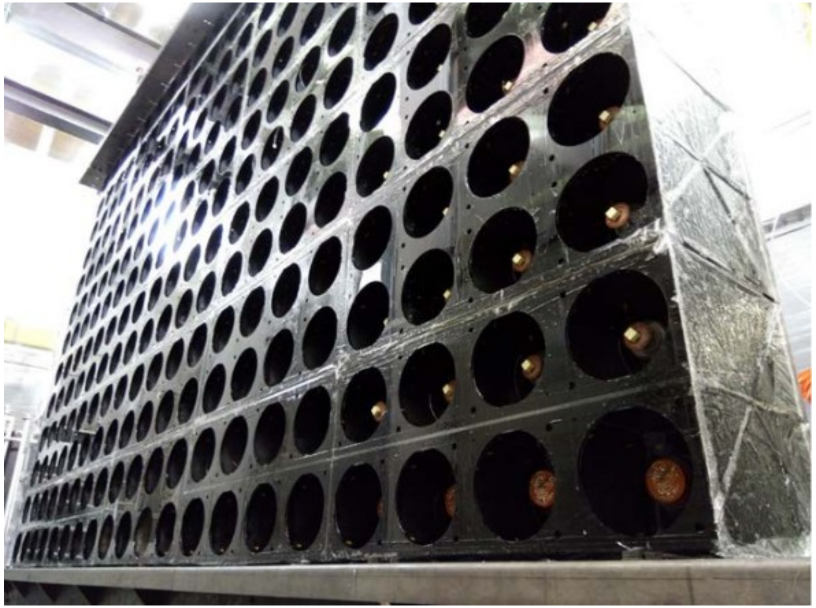
8” PMTs

↓

Energy resolution 8% FWHM at 1 MeV

(14% - 17% for NEMO-3)

Time resolution < 400 ps for electrons @ 1 MeV



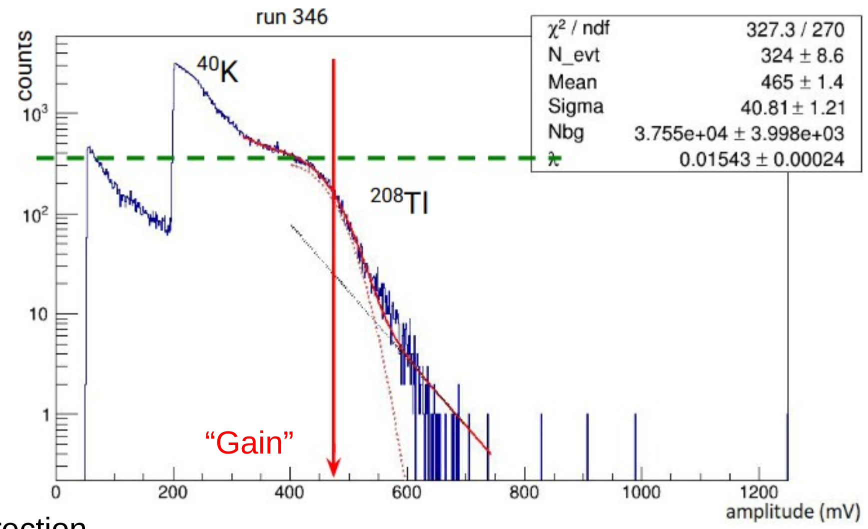
Experiment	**^{40}K (Bq)**	**^{226}Ra (Bq)**	**^{232}Th (Bq)**
SuperNEMO Demonstrator	540	197	124
NEMO-3	832	302	49.4
Relative activity (A(SN)-A(NEMO-3))/A(NEMO-3)	**-35%**	**-35%**	**+151%**

↑ Not the dominant background for 2ν and 0ν search

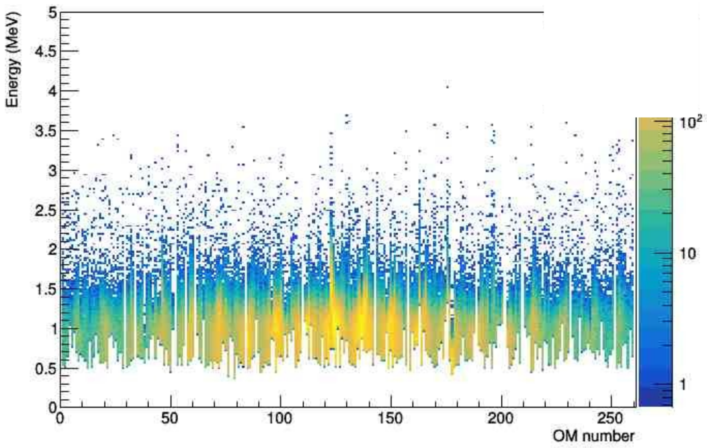
Operational and taking data since 2018!

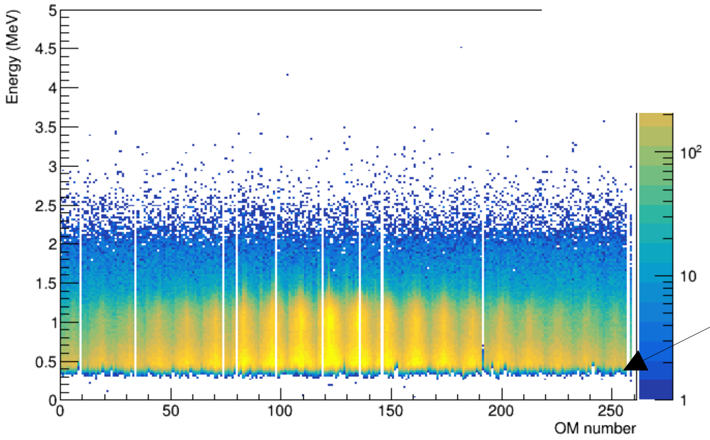
Energy Calibration of the Calorimeter

PMT Gain equalization done with a dedicated method using ^{208}Tl Compton edge



Before correction → After correction

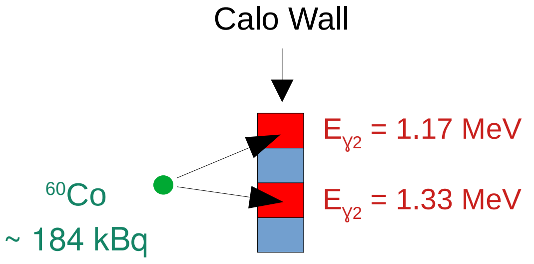




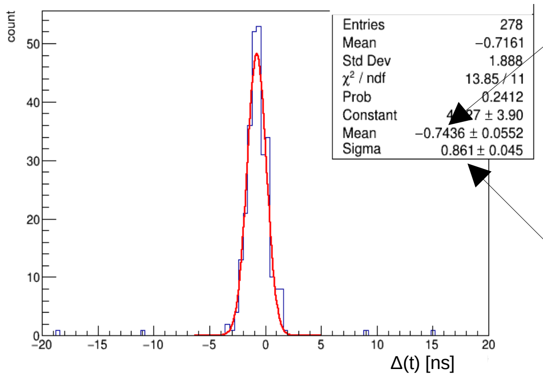
Gain equalization is very good in order to perform energy cuts to reject backgrounds

Work of : Xalbat AGUERRE, Ph.D (CENBG)

Time Calibration and Time Resolution of Calorimeter Walls: ^{60}Co Source Runs



$$\Delta(t)(ns) = t_{\gamma_1} - t_{\gamma_2}$$



Mean: Used to determine the time offset per OM (time calibration)

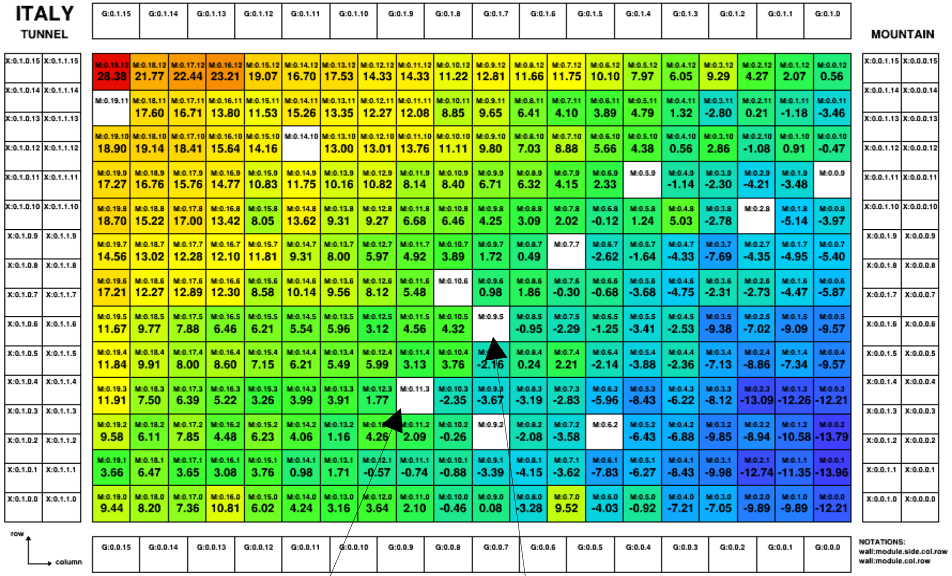
Sigma: Used to determine the time resolution per OM

Offer a good calculation of the:

- Time offset per OM, it takes into account: cable length + total delays inside (electronics, scintillation time, …)

- Time resolution of Calorimeter for ɣs @ 1 MeV

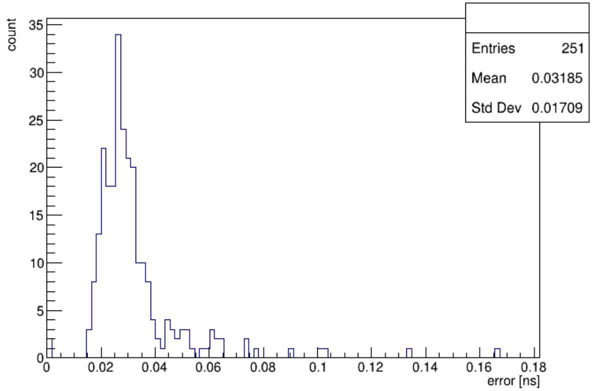
Time Calibration: Final Offset Values per OM for a Calorimeter Wall Combining all Runs



Color scale: Final offset values / OM [ns]

Dead OMs

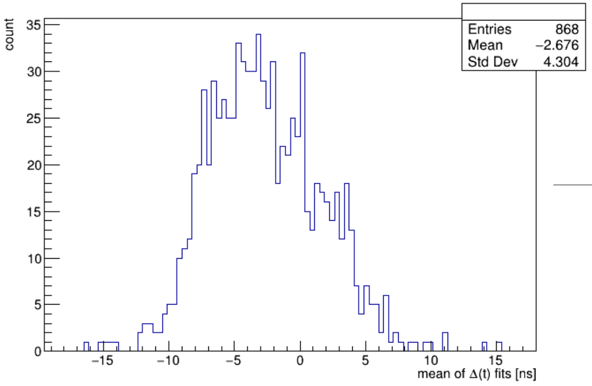
Reference OM



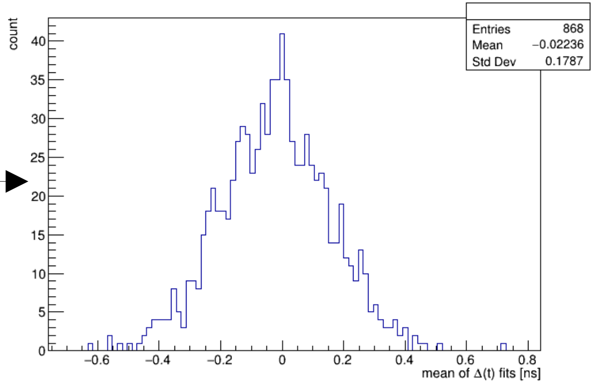
These maps are produced for the full calorimeter walls

The time calibration performed **achieved 1 [ns] precision on timing** after applying the calibration. Perfect for rejecting background using time of flight measurements.

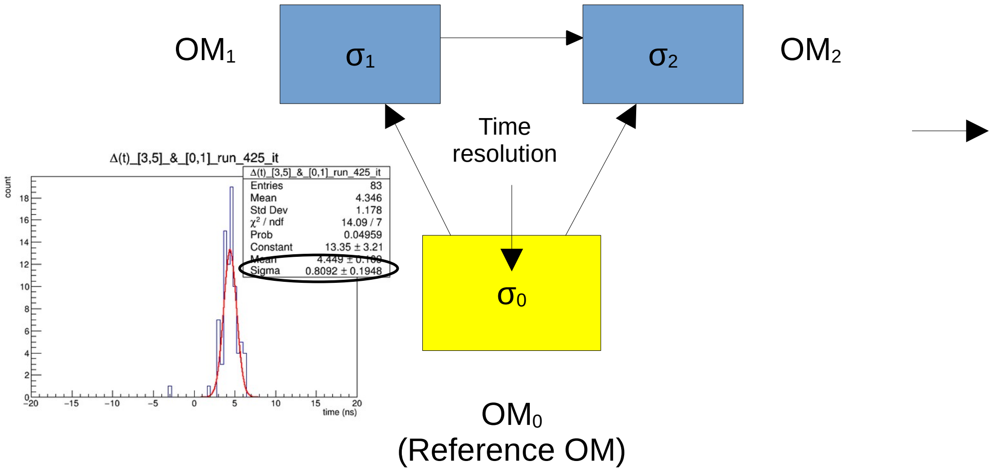
Δ(t) distribution before correction



Δ(t) distribution after correction



Time Resolution: Method to Determine the Time Resolution Per OM



Using parameters from the 3 coincidences we can retrieve the time resolutions σ_0 , σ_1 and σ_2

For a given OM, several independent measurements of time resolutions (σ_0) for ɣs @ 1 MeV are combined.

Use weighted average to get final resolution/OM

& **full wall resolution**

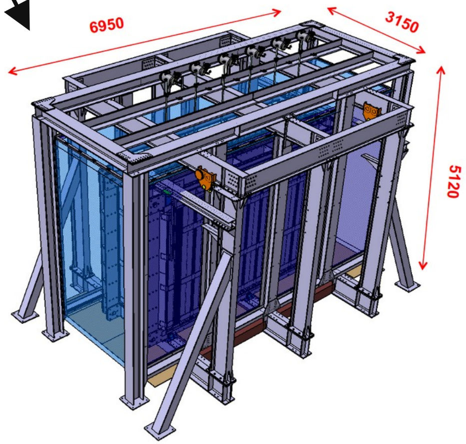
Time resolution for ɣs @ 1MeV (for 8” OMs) : 0.614 ± 0.002 (stat) + 0.064(sys) – 0.000(sys) [ns]
Time resolution for ɣs @ 1MeV (for 5” OMs) : 0.814 ± 0.006 (stat) + 0.073 (sys) – 0.000 (sys) [ns]

SuperNEMO: Hardware Status

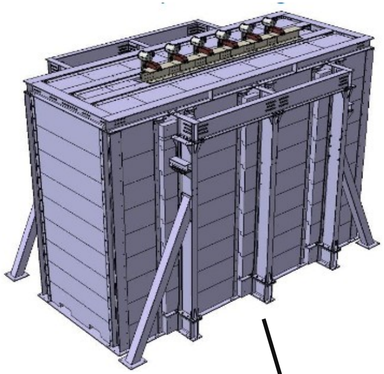
Remaining Tasks:

- Tracker Commissioning
- Magnetic field
- Shielding

Magnetic field coils
25G

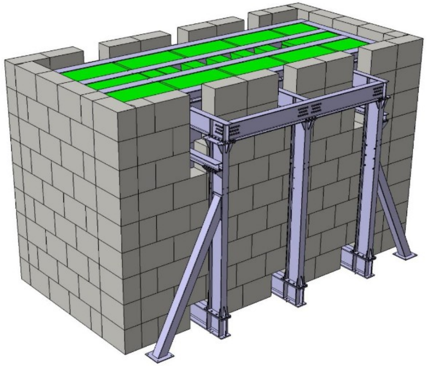


Anti-Radon tent



Iron shielding
20 cm

polyethylene water tanks and boron polyethylene plates



SuperNEMO: The Physics

Demonstrator :

- Expected sensitivity: *17.5 kg.y* exposure of ^{82}Se → $T^{0\nu}_{1/2} > 4 * 10^{24}$ y
  $\langle m_\nu \rangle$ < (260 – 500) meV (90% CL)

- Measure background contamination

More physics :

$0\nu\beta\beta$ Search :

- Different double beta decay mechanisms (Light Majorana neutrino, right handed currents, …) using the full kinematics (single electron energy and angular distribution)

$2\nu\beta\beta$ Study:

- Quenching of axial-vector coupling constant (g_A)

- Higher State Dominance (HSD) and Single State Dominance (SSD)

- Exotic Decays (Majoron (n = 2, 3, 7), Lorentz violation and Bosonic neutrino)

Recap

- The calorimeter is commissioned, working and taking data since 2018.

- A time and energy calibration of the calorimeter walls is done.

- Preliminary time resolution is extracted for ɣs @ 1 MeV.

- The tracker has been lifted and the shorts in the tracker cells have been reduced to < 2%.

- The tracker chamber tightness is in a very good progress, over pressure achieved.

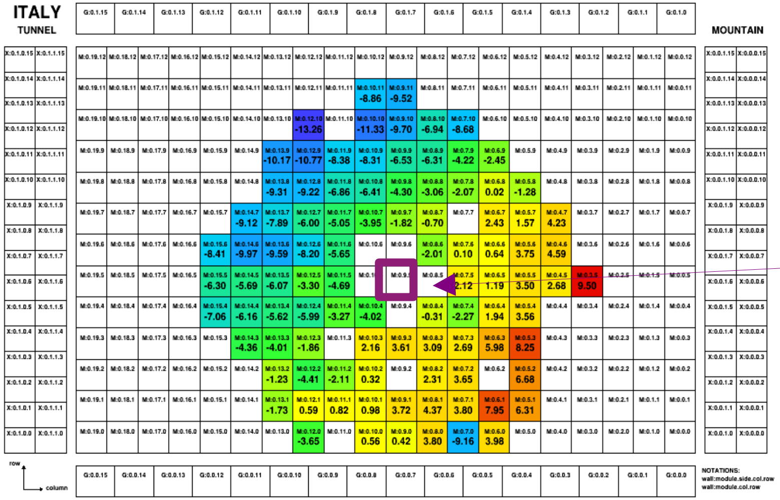
- Final checks are being made for the very soon commissioning of the tracker.

END

Backup

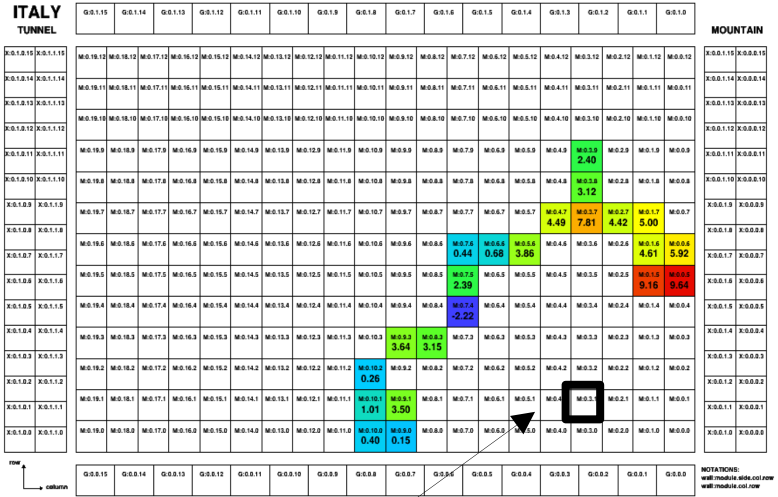
Time Calibration: Steps to Calculate the Time Offset per OM One Run Example

Step 1

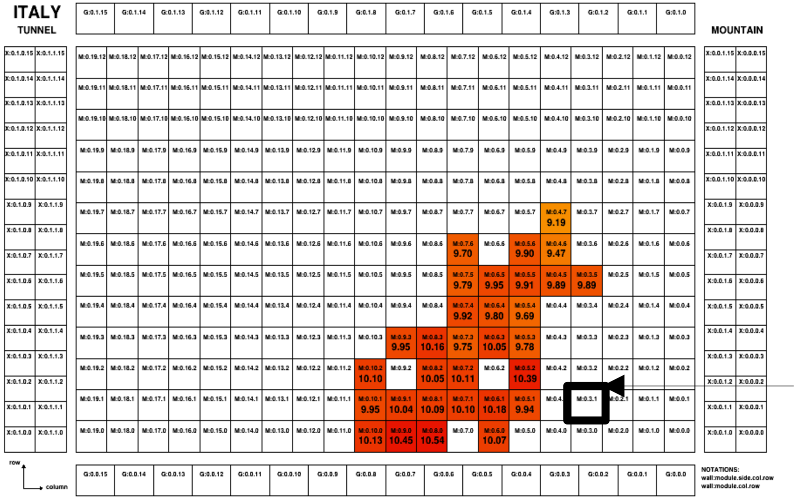


Reference OM

Step 3

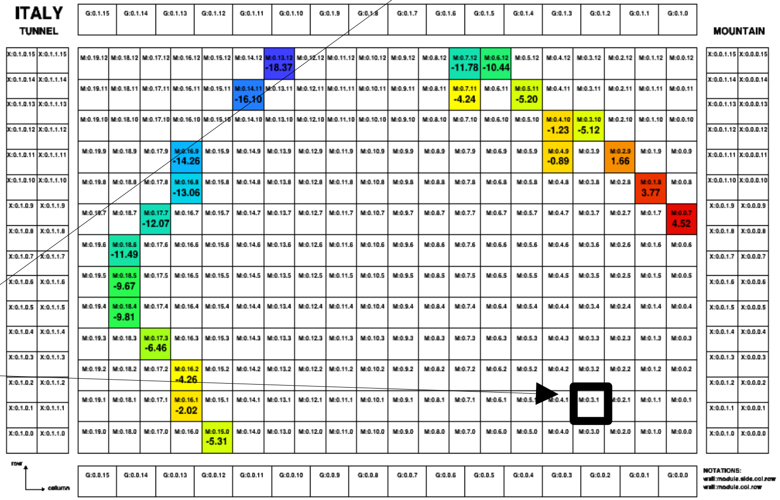


Step 2



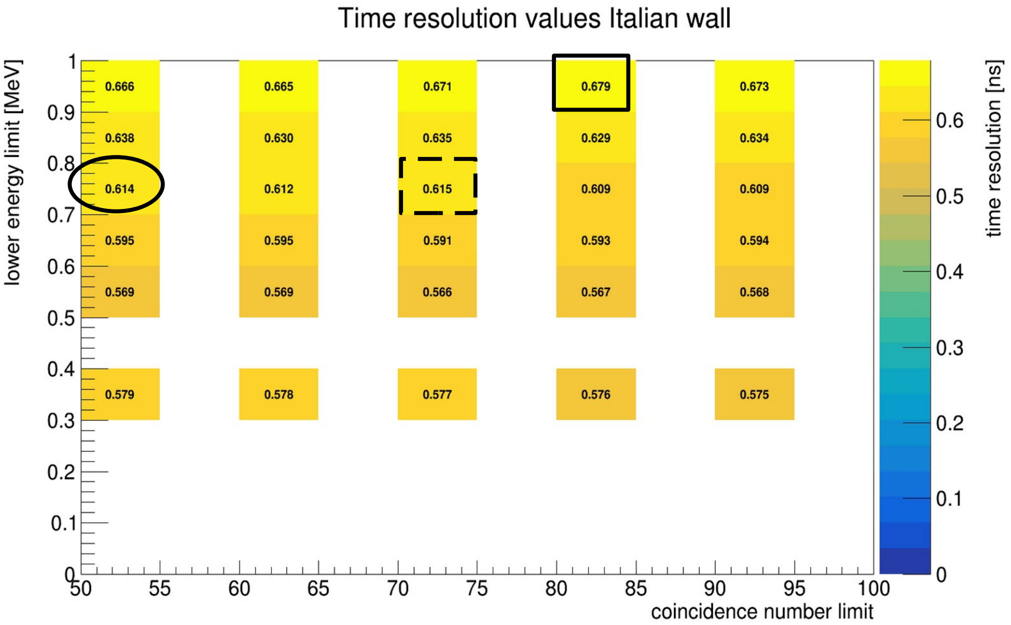
Source position

Step 4
Extra extrapolation



Color scale: Offset values / OM [ns]

Time Resolution & Systematic Errors, Italian Wall 8” OMs



Reference value at 0.7 MeV and > 50 coincidences

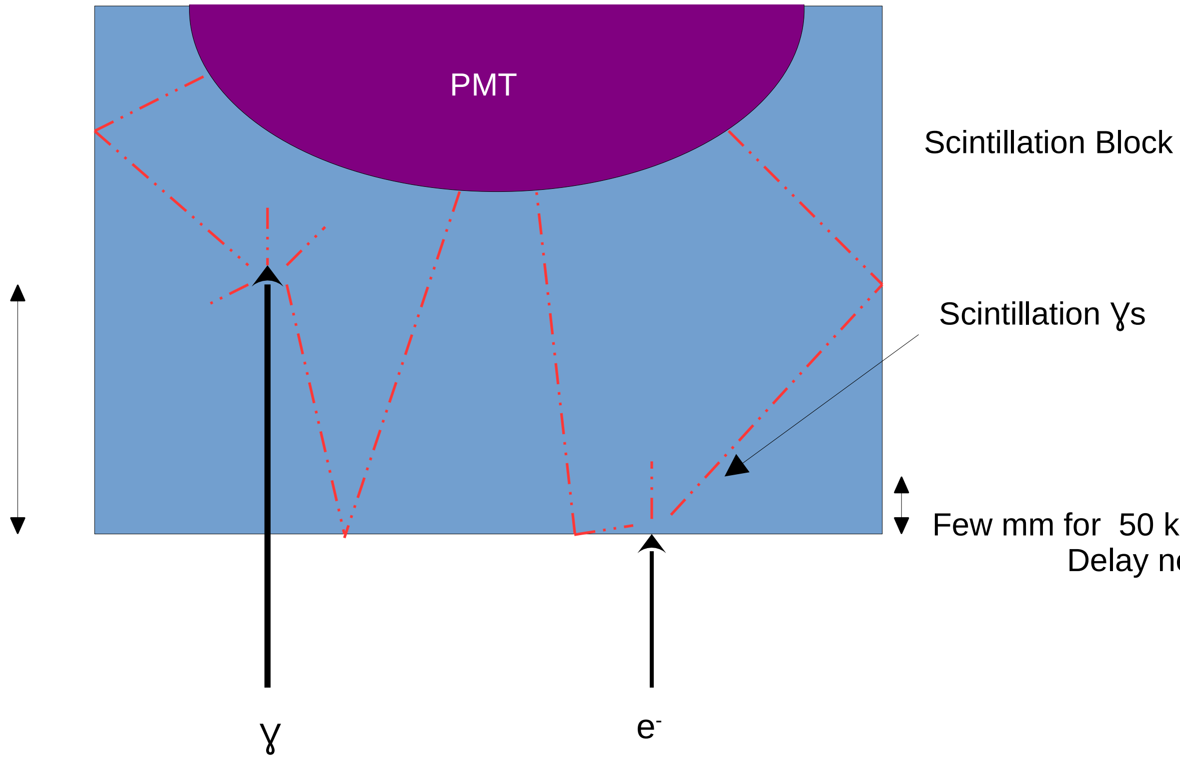
Maximum difference from reference value

Minimal difference from reference value

Time resolution 8” = 0.614 ± 0.002 (stat) + 0.064(sys) – 0.000(sys) ns

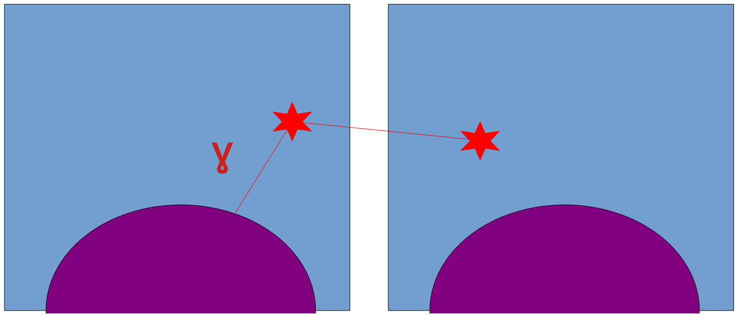
Interaction of ɣs and e^-s Inside the Scintillation Block

Around 10 cm
$E_ɣ$ ~ 1 MeV
Delay > 1.25 ns

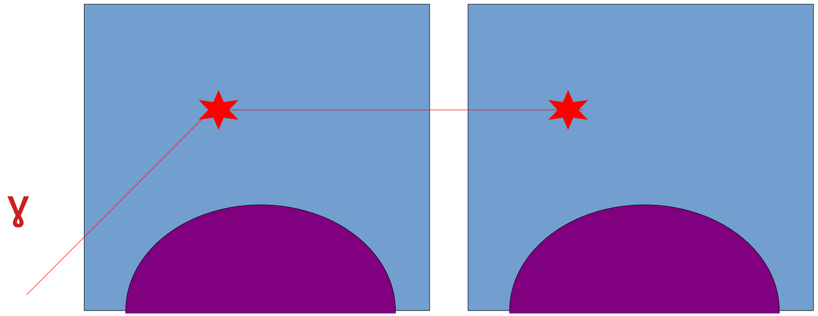


Few mm for 50 keV < e^- < 10 MeV
Delay negligible

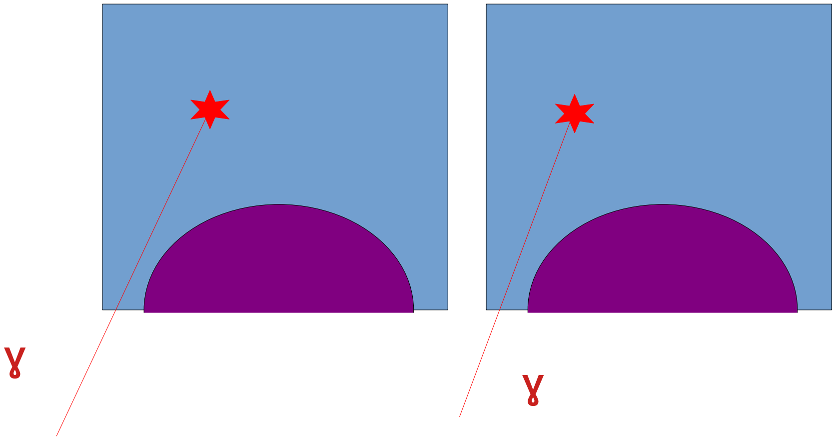
Cobalt Source Background



PMT glass contamination



Gamma from source or lab undergoing double Compton



Random coincidences

Axial-Vector Coupling Constant (g_A) Studies

Following the paper *F.Šimkovic et al. Phys. Rev. C 97, 034315 (2018)*
the $2\nu\beta\beta$ decay rate may be expressed as:

(ignoring higher order terms)

$$\left[T_{1/2}^{2\nu\beta\beta}\right]^{-1} \simeq \left(g_A^{\text{eff}}\right)^4 \left|M_{GT-3}^{2\nu}\right|^2 \frac{1}{\left|\xi_{31}^{2\nu}\right|^2} \left(G_0^{2\nu} + \xi_{31}^{2\nu} G_2^{2\nu}\right)$$

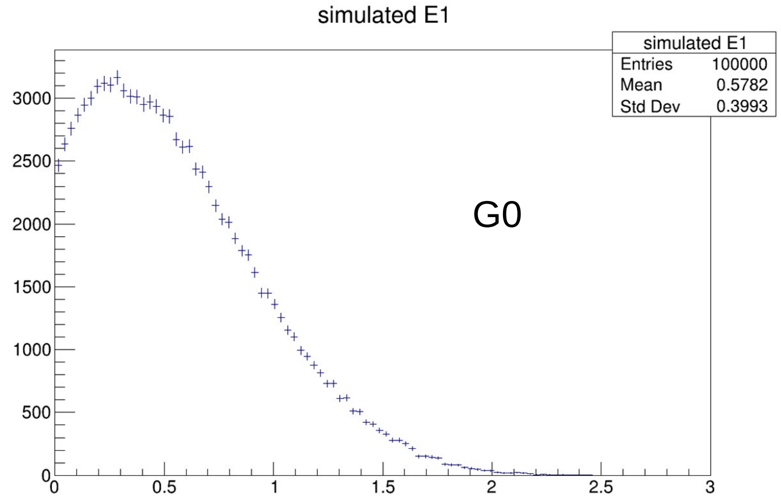
where $$\xi_{31}^{2\nu} = \frac{M_{GT-3}^{2\nu}}{M_{GT-1}^{2\nu}},$$

The “g_A” processes

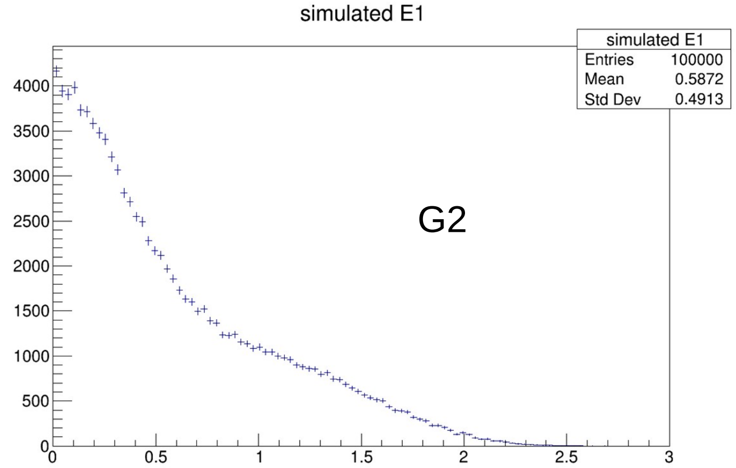
Fit single and total energy spectra to get a value for ξ_{31}

Gamow–Teller matrix element from Shell Model calculation

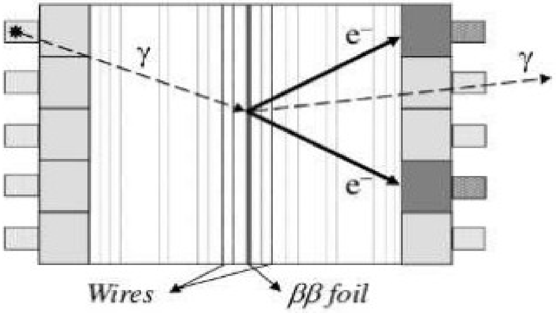
Finally obtain g_A value for $2\nu\beta\beta$

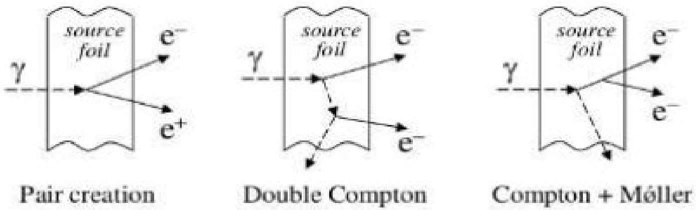


plots for Se82



SuperNEMO: Background Identification

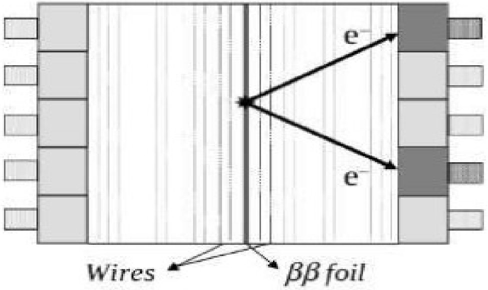


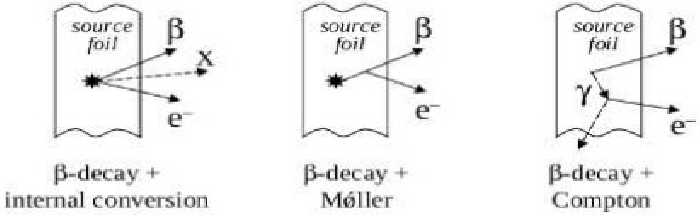


2 e⁻ produced by an external ɣ,

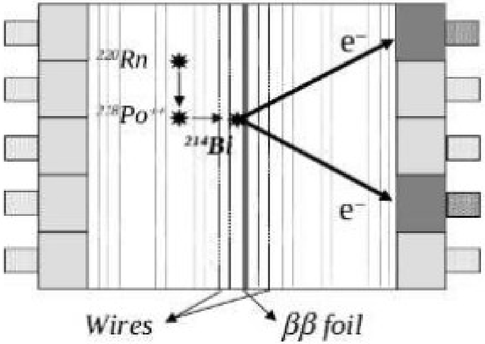
Detected through (ɣ,e) external channel

2 e⁻ produced by ^{214}Bi and ^{208}Tl contamination inside the ββ foils





Detection Channels:
(1e,2ɣ) for ^{208}Tl
(1e,1α) for ^{214}Bi
(ɣ,e) for external backgrounds



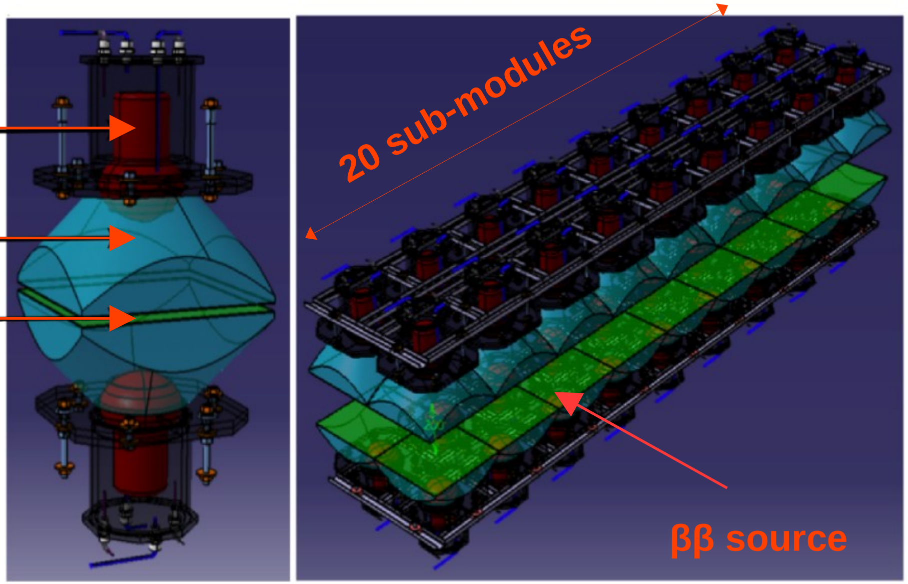
Radon background, ^{222}Rn can emanate from the detector materials, or the rocks of the laboratory then diffuse towards the tracker.
Also, the entrance gas of the tracker can be contaminated

BiPo-3 Detector: Successfully running since 2012

5” photomultiplier

Light guide

Scintillator

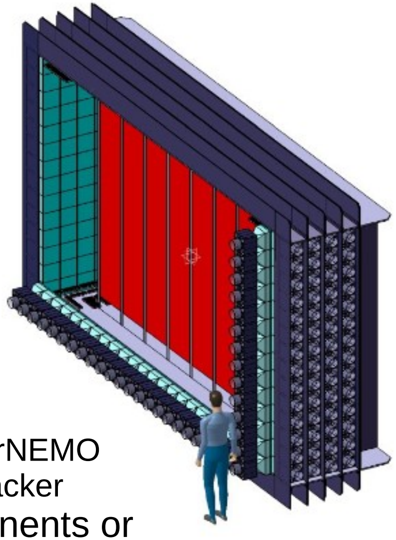


Scheme of two optical sub-modules (on the left) and of the whole detector (on the right)

The ^{212}Bi (^{208}Tl) and ^{214}Bi contaminants inside the foil are identified by the detection of a β decay followed by delayed α particles emitted in the opposite direction.

Surface covered with 200 nm of evaporated ultrapure aluminium in order to optically isolate each scintillator and
to improve the light collection efficiency

Can also identify random coincidences, radiopurity of the scintillators and Radon and Thoron presence in the gas between the foil and the scintillators.



SuperNEMO Tracker components or c-sections

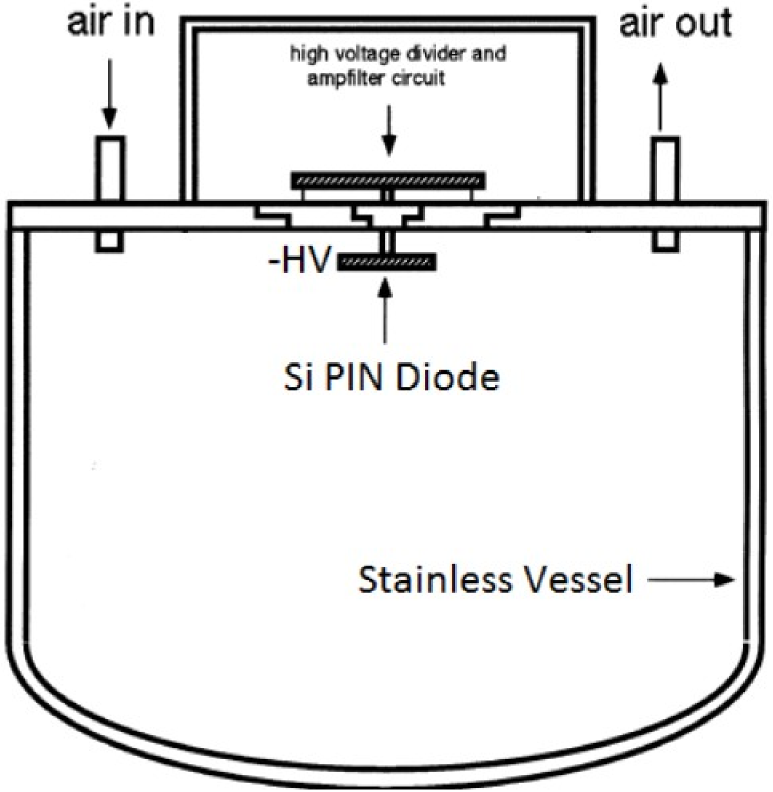
RnCL

Electrostatic Detector

measures activities as low as 0.1 µBq/m^3 for large volumes

- Gas from the tracker components inside emanation chambers is pumped through a cooled ultra-pure carbon trap and the ^{222}Rn in the gas is adsorbed

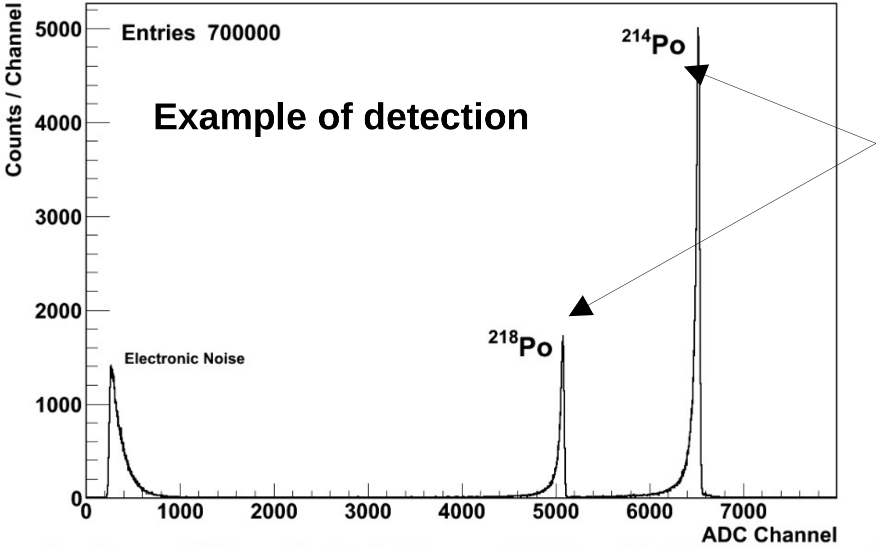
- The concentrated sample is then heated and transferred to an electrostatic detector via helium purge.



- ^{222}Rn is pumped into the vessel where it decays.

- Daughters of ^{222}Rn decay are mostly positive ions → these ions are collected on the PIN diode due to the applied negative HV.

- Once on the photodiode, they decay and their α particles can be identified by the energy deposited.



Daughters of ^{222}Rn