SuperNEMO
Neutrinoless Double Beta Decay Experiment

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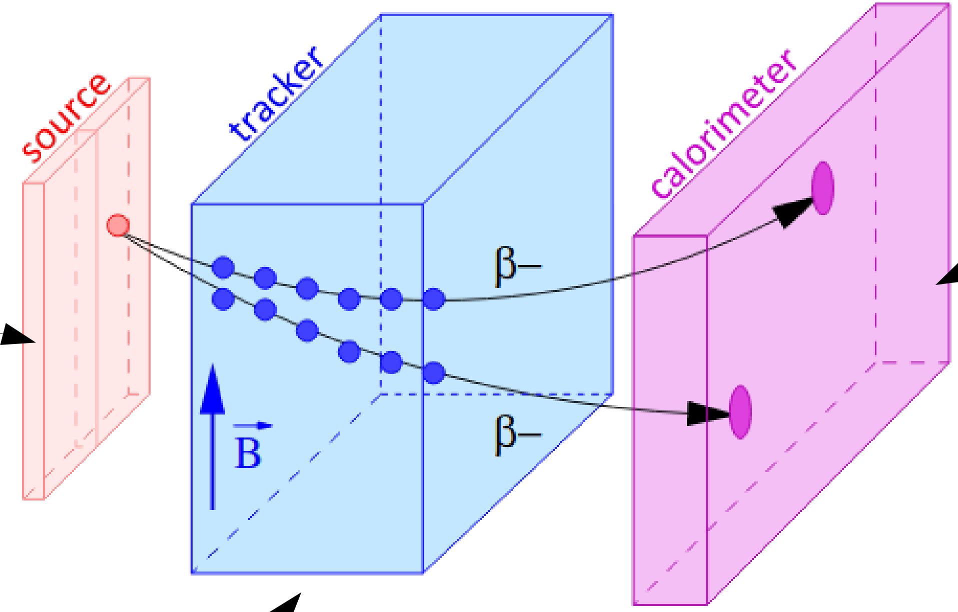
supernemo collaboration

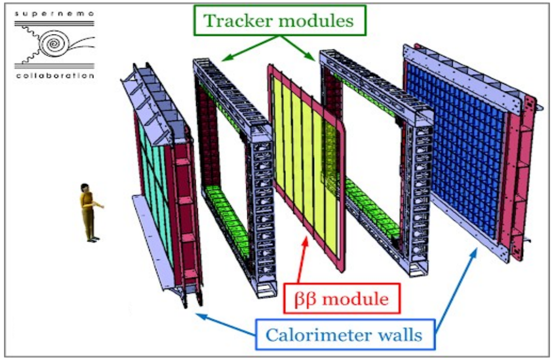
SuperNEMO: Tracker-Calorimeter Detector

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)



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)

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

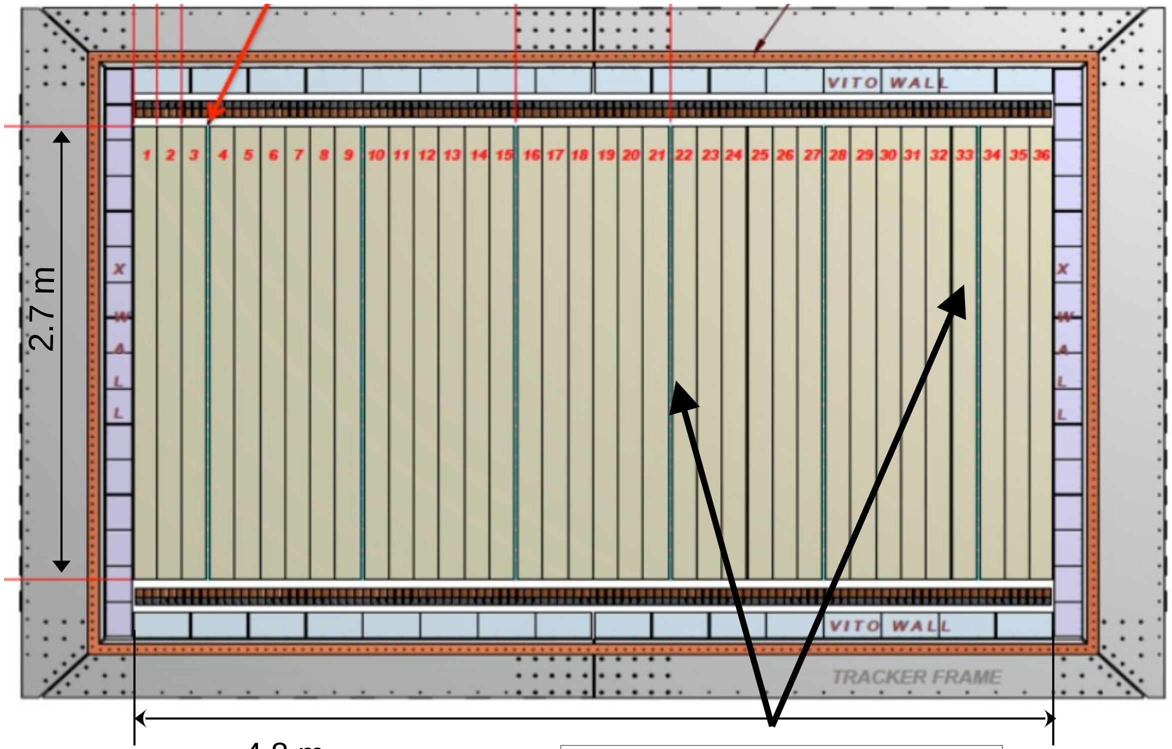
(NEMO-3)

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

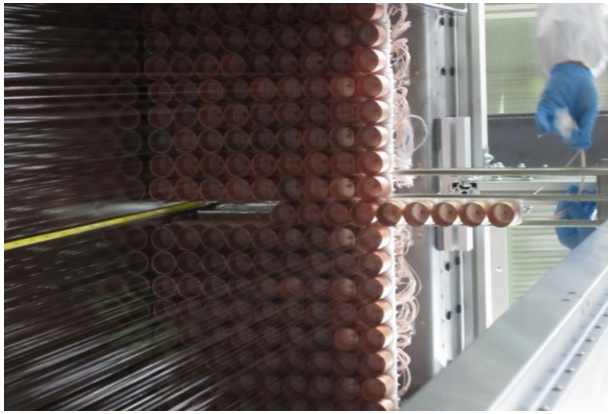
Selenium Source Foils Geometry



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

SuperNEMO: Hardware Status

Current Status:

- The tracker frame was deformed and successfully lifted to reduce short cut tracker cells to < 2%

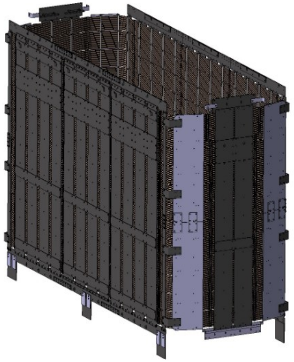
- The gas tightness inside the tracker chamber is in a good progress and over pressure inside is achieved

Remaining Tasks:

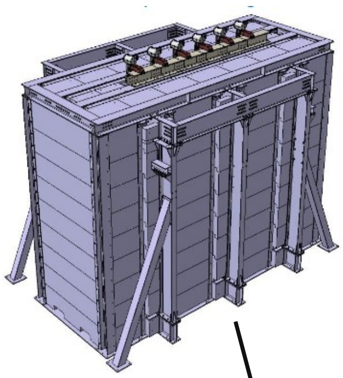
- Tracker Commissioning

- Magnetic field

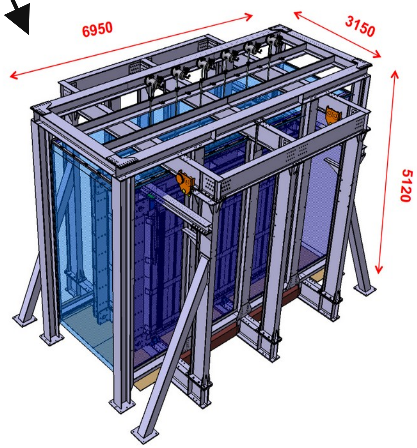
- Shielding



Magnetic field coils
25G

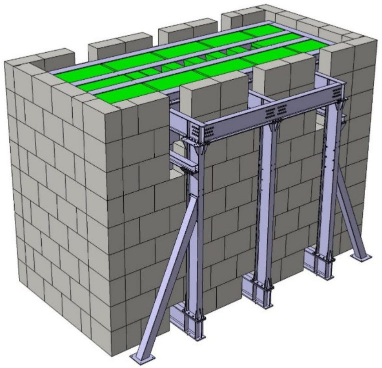


Iron shielding
20 cm



Anti-Radon tent

polyethylene water tanks and boron polyethylene plates



The SuperNEMO Calorimeter

712 Optical Modules

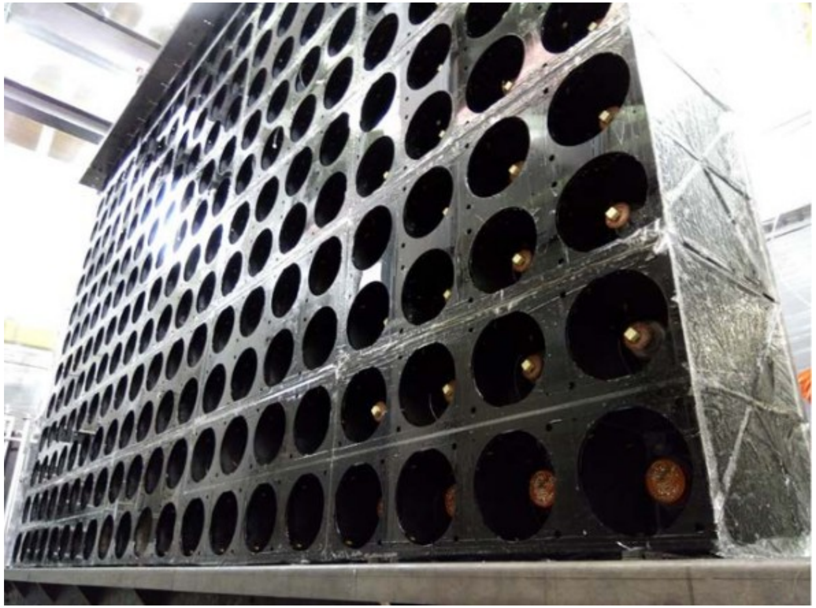
8” PMTs
↓
Energy resolution 8% FWHM at 1 MeV

(14% - 17% for NEMO-3)

Time resolution < 400 ps for electrons @ 1 MeV

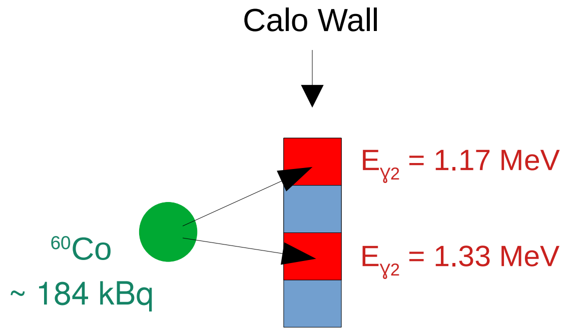
Experiment	^{40}K (Bq)	^{226}Ra (Bq)	^{232}Th (Bq)
SuperNEMO Demonstrator	540	197	124
NEMO-3	832	302	49.4
Relative activity (A(SN)-A(NEMO-3))/A(NEMO-3)	**-35%**	**-35%**	**+151%**

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

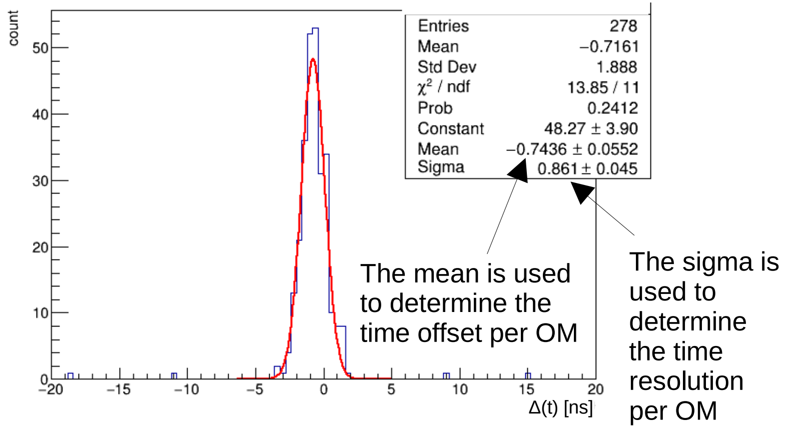


Operational and taking data since 2018!

Time Calibration and Time Resolution of OMs using ^{60}Co Runs



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

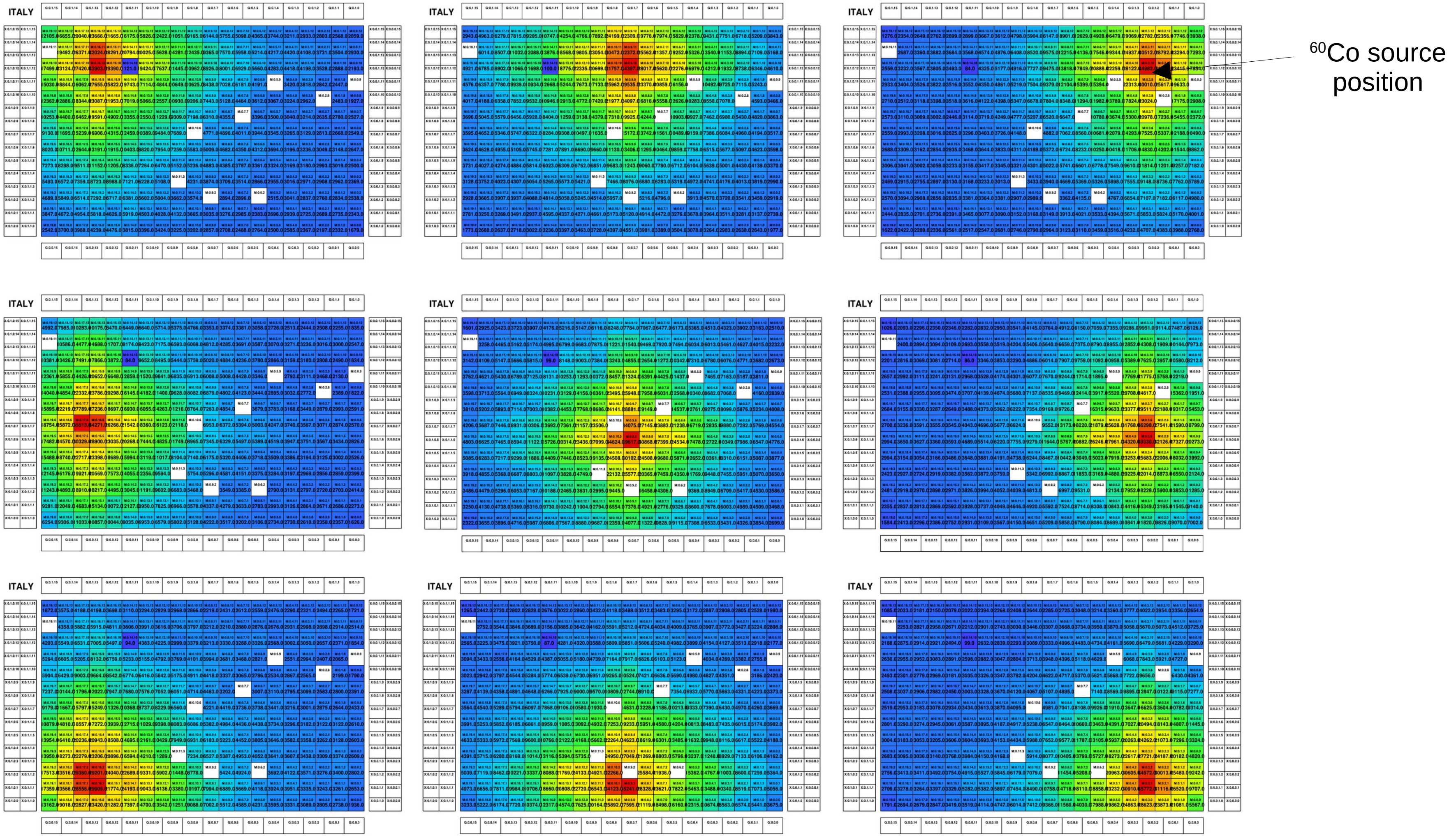


^{60}Co runs should offer a good calculation of the:

- Time offset (from 0 ns) in each OM, this offset is unique per OM, it takes into account: cable length + total delays inside (electronics, scintillation time, …)

- Time resolution of Calorimeter for ɣs @ 1 MeV

The SuperNemo Calorimeter & ^{60}Co Runs



Total 26 ^{60}Co runs on different positions across the Calorimeter walls

Time Offset Per OM

As the two ɣs are emitted simultaneously from the source, the time difference between the two registered hit = 0, if using the following time equation per hit:

$$t_i = t_{\gamma_i}(ns) - ToF_i - \epsilon_i$$

Corrected time of detection

time measurement [ns]

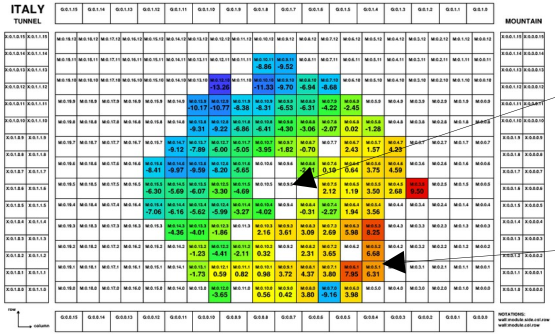
Time of Flight of ɣ from source to scintillator block (known)

Time offset of OM:
unique per OM, fixed, unknown

We can measure the offsets relatively to the offset of a chosen reference OM using $t_i - t_j = 0$

Method to Determine the Time Offset Per OM

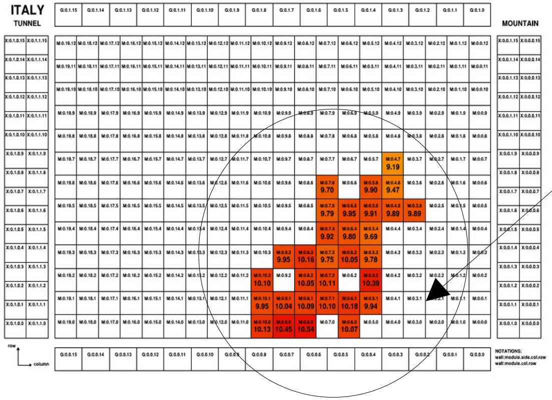
Step 1: Determine the offset of OMs “j” in coincidences with the reference OM (offset = mean of Δt distribution between OM “ref” & “j”).



Reference offset OM

OMs “j”

Step 2: For OMs “k” that are not characterized in step 1, determine the time offset using the coincidences between OM “k” and OMs already characterized in step1 (OMs “j”).

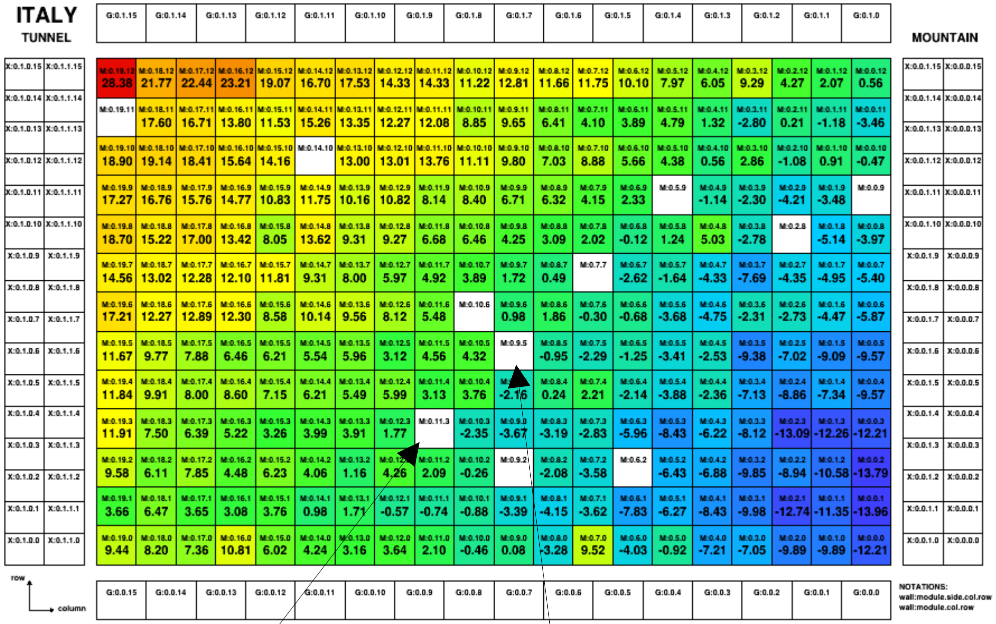


OM “k” not determined in step 1

OMs (red squares) calibrated from step 1 (OMs “j”)

Steps 3, 4: If OMs were not characterized in the previous steps, determine their time offset w.r.t OMs “k”.

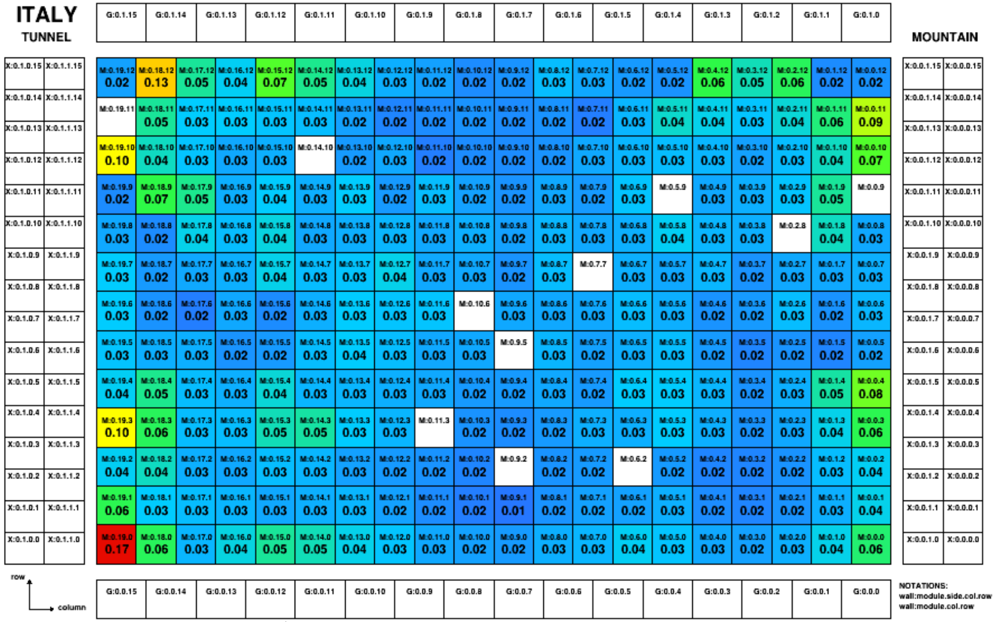
Final Offset Values per OM for Italian Main Wall, Combining all Runs



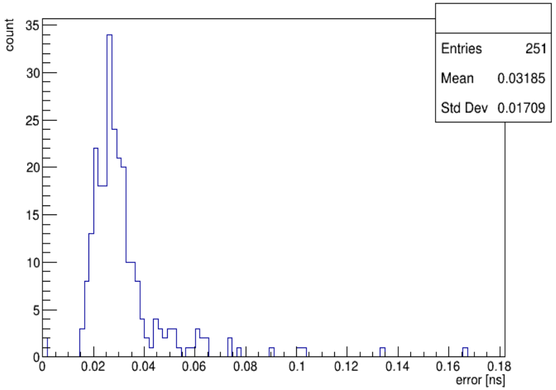
Color scale: Final offset values / OM [ns]

Dead OMs

Reference OM



Error on final offset values



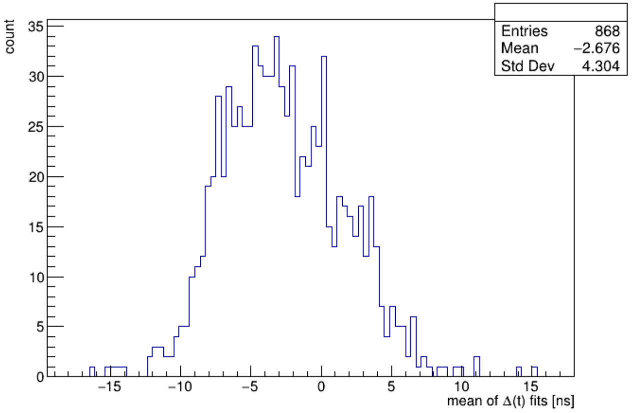
Color scale: Error on final offset values / OM [ns]

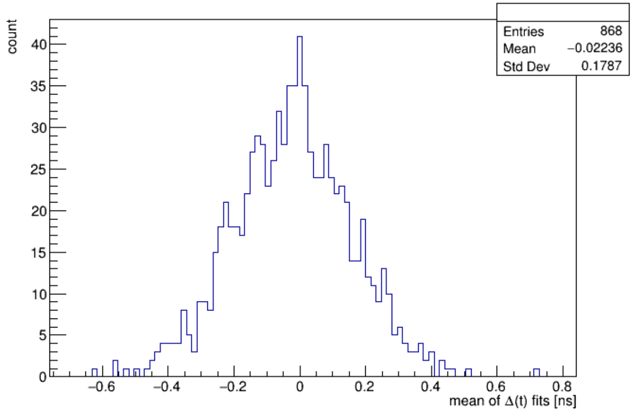
These maps are produced for all of the calorimeter walls (4 walls in total)

Δ(t) Distributions Mean and their Errors Before & After Correction: Main French Wall

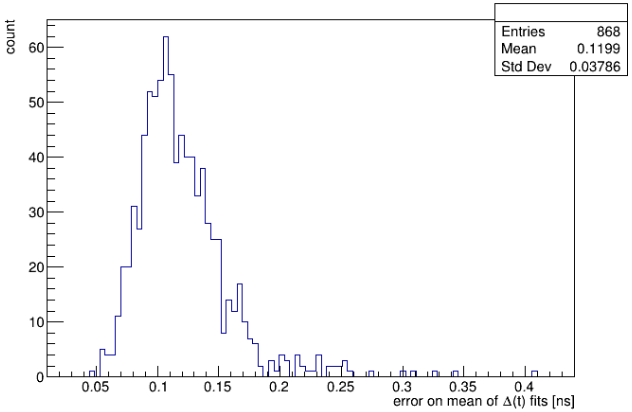
Before correction of offset → After correction of offset

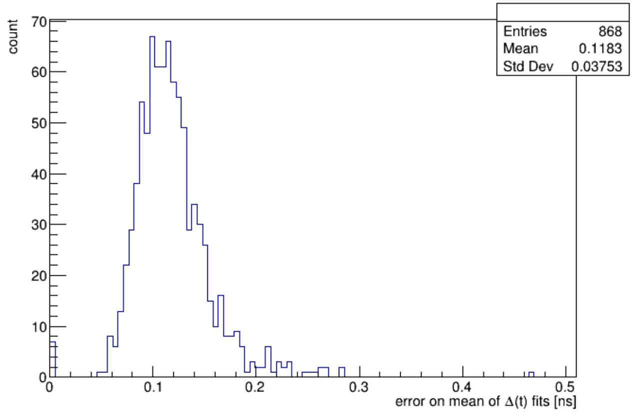
Mean value of Δt distributions



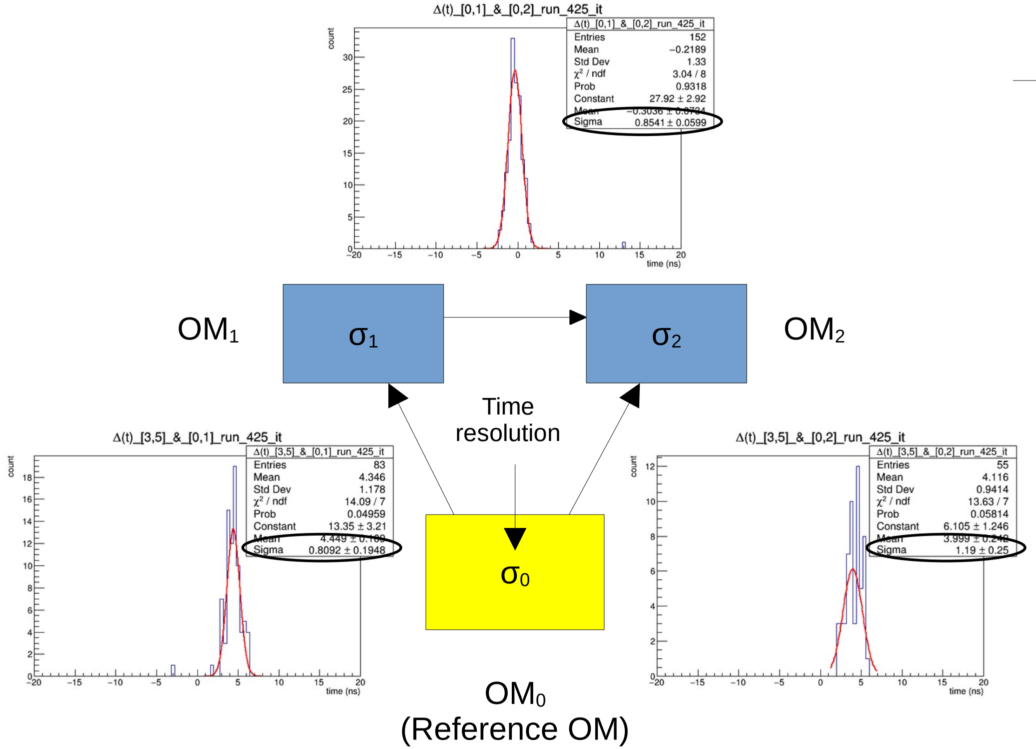


Error on mean value of Δt distributions





Method to Determine the Time Resolution Per OM Using ^{60}Co Runs



Combination of (OM_0, OM_1, OM_2)

↓

3 equations with 3 unknowns time resolutions σ_0, σ_1 and σ_2

↓ Solving

$\sigma_0 \pm \delta\sigma_0$
$\sigma_1 \pm \delta\sigma_1$
$\sigma_2 \pm \delta\sigma_2$

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**

Recap

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

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

- Primary time resolution is extracted for γs @ 1 MeV.

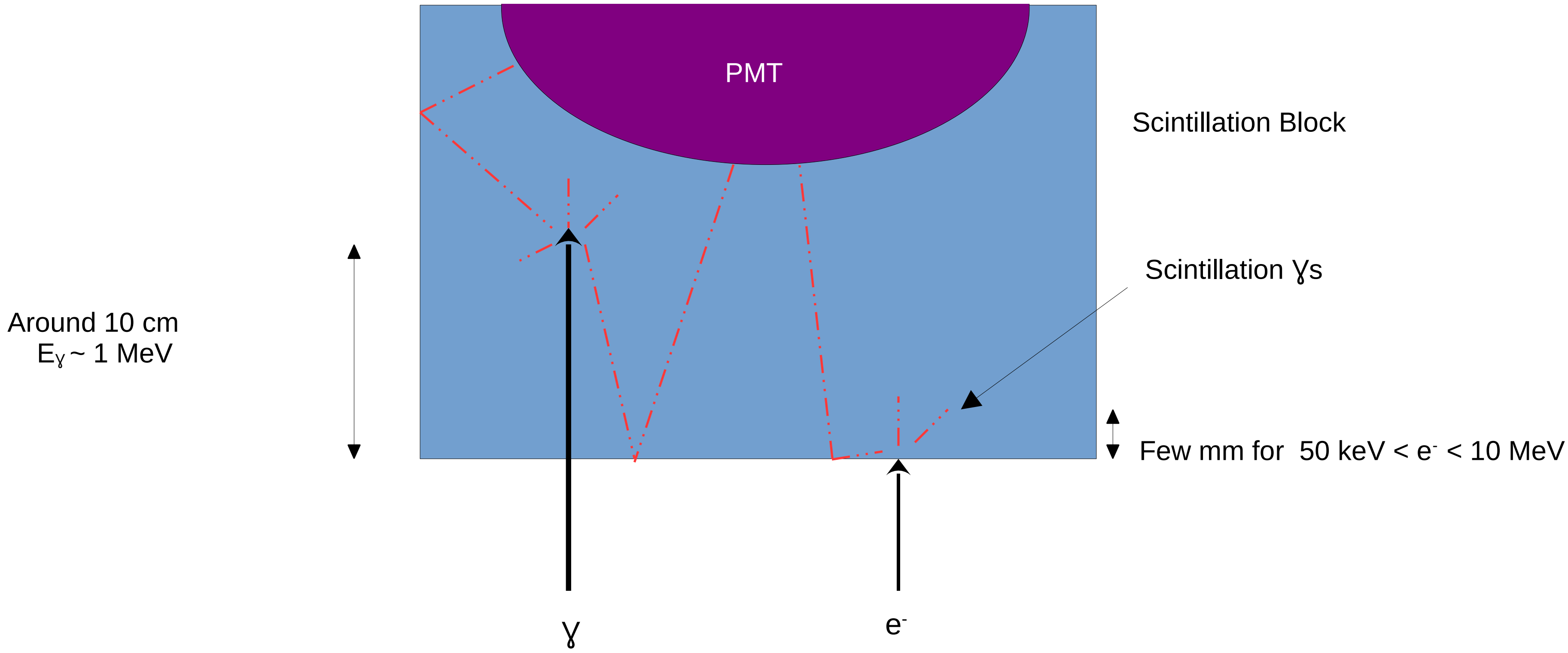
- The tracker has been lifted and the shorts in the tracker cells have been reduced to < 2%.

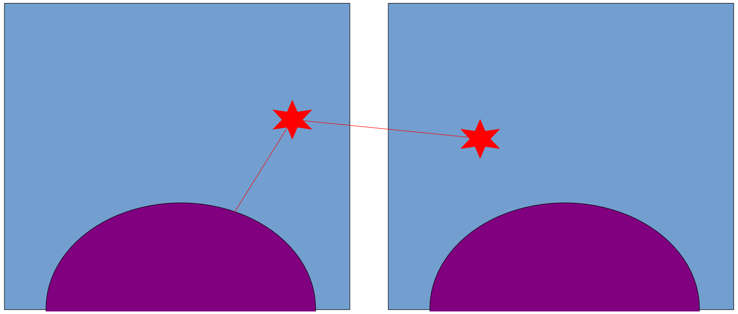
- The tracker chamber tightness is in a very good progress and final checks are being made.

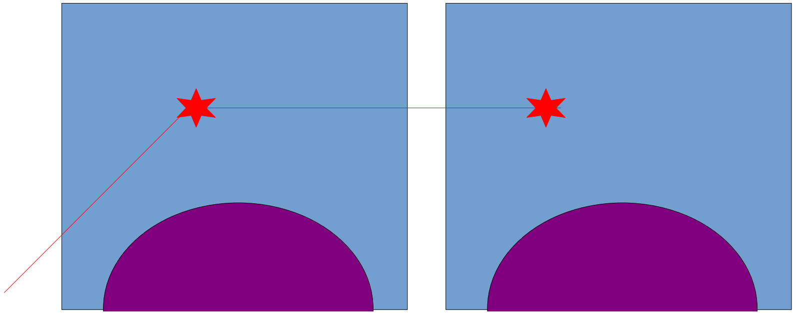
END

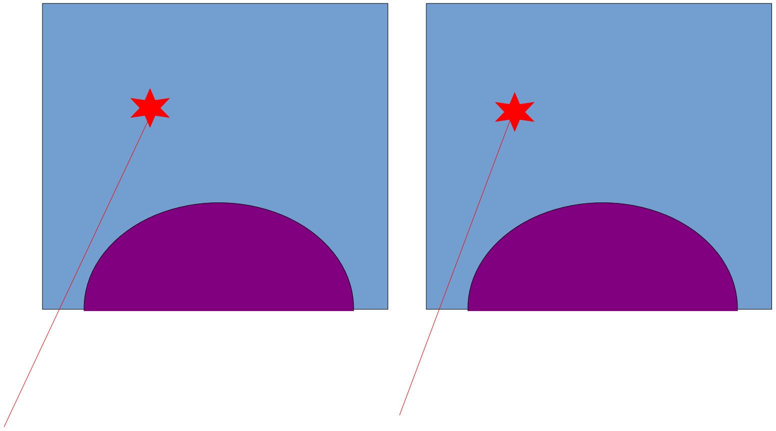
Backup

Interaction of ɣs and e⁻s Inside the Scintillation Block



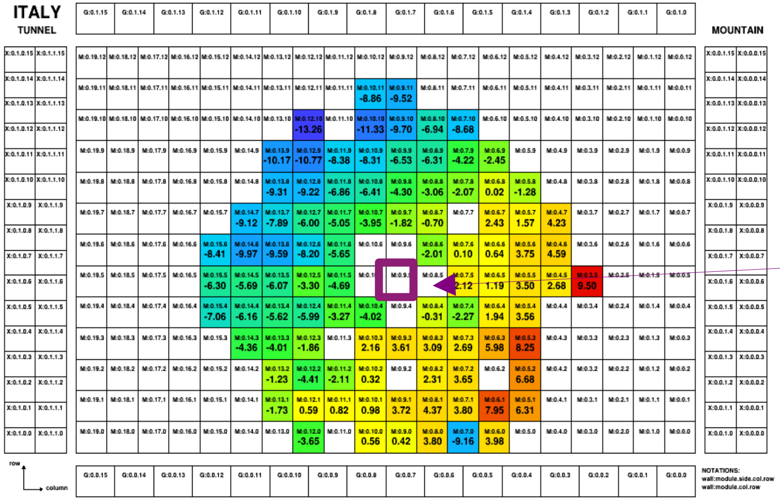




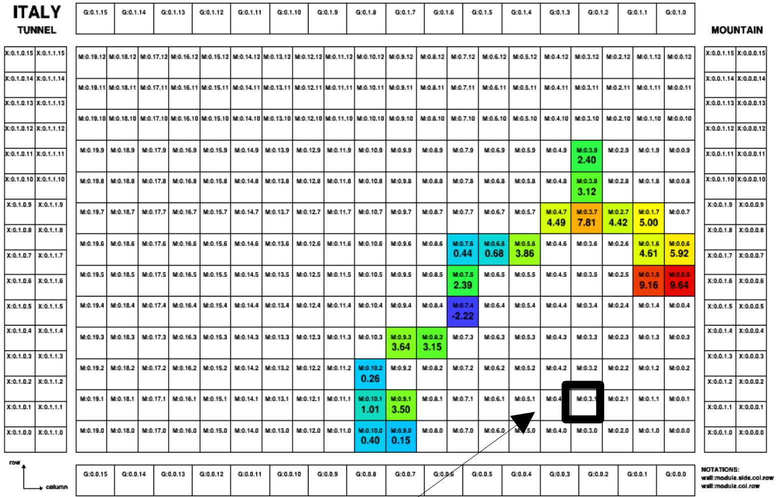


Visualization of Each Extrapolation Step one run example

Step 1

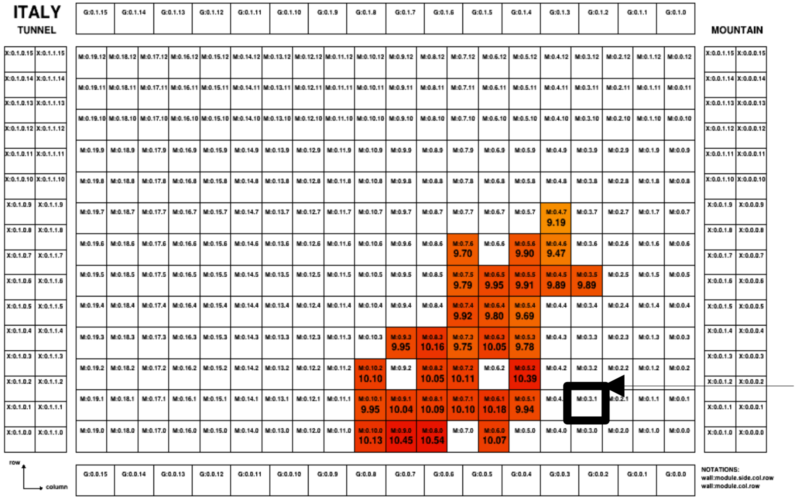


Step 3



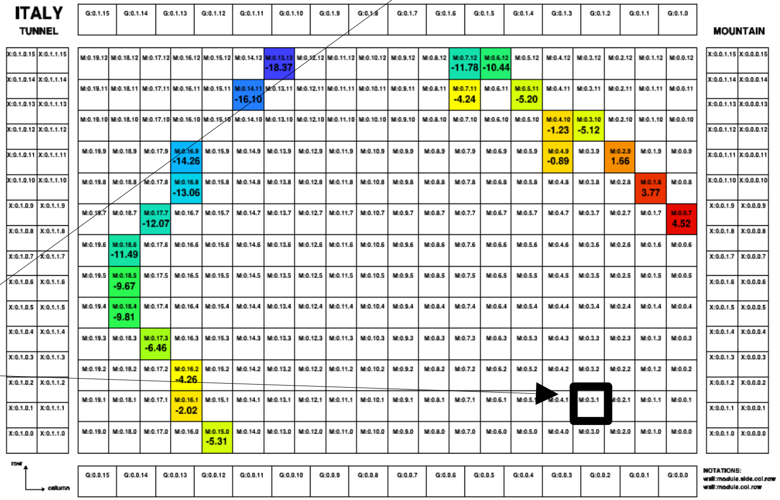
Reference OM

Step 2



Source position

Step 4 Extra extrapolation



Color scale: Offset values / OM [ns]

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)

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

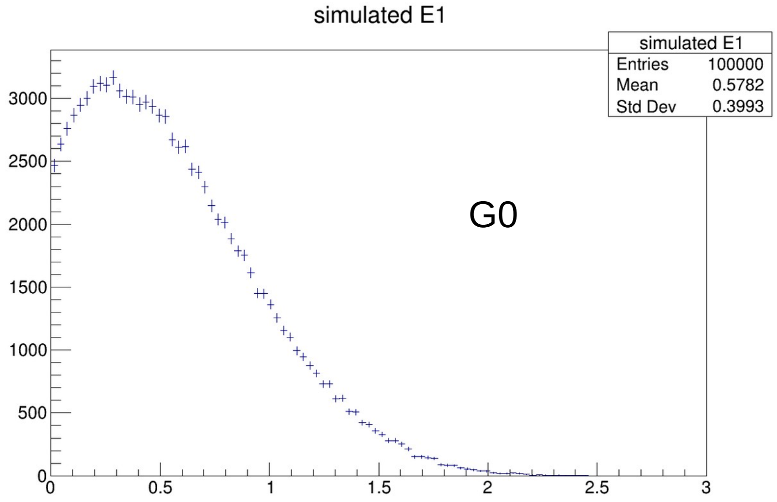
where $$\xi_{31}^{2\nu} = \frac{M_{GT-3}^{2\nu}}{M_{GT-1}^{2\nu}},$$

The "g_A" processes

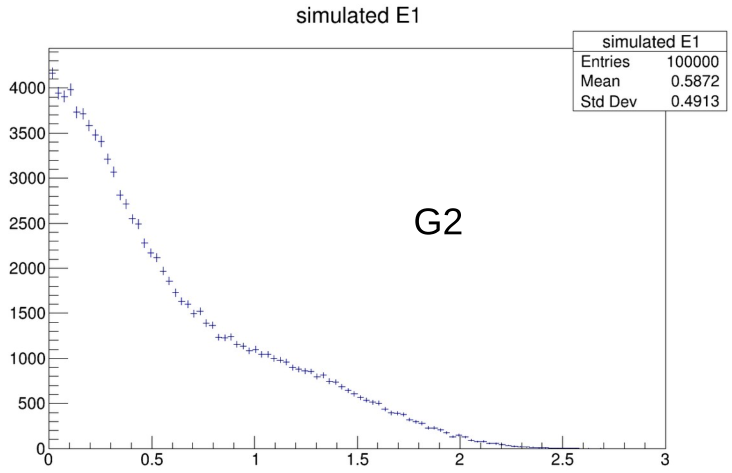
Fit single and total energy spectra to get a value for ξ_{31}

Gamow–Teller matrix element from Shell Model calculation

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



plots for Se82



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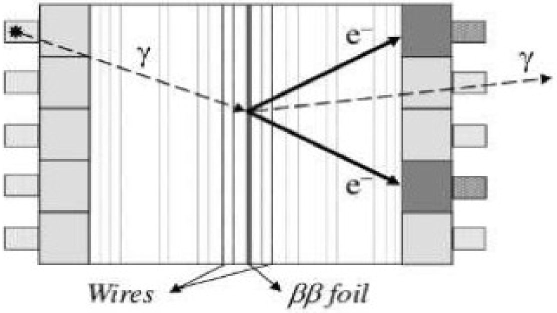
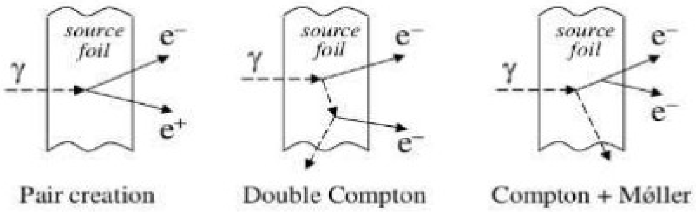
SuperNEMO: Background Identification

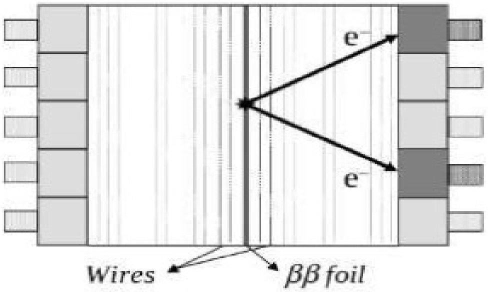


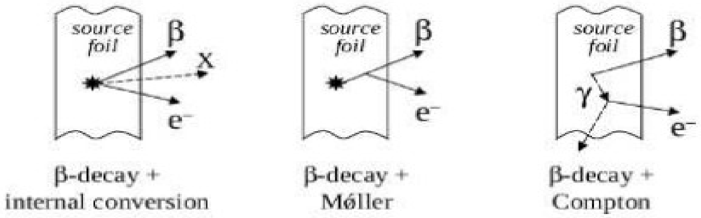


2 e^- produced by an external γ,

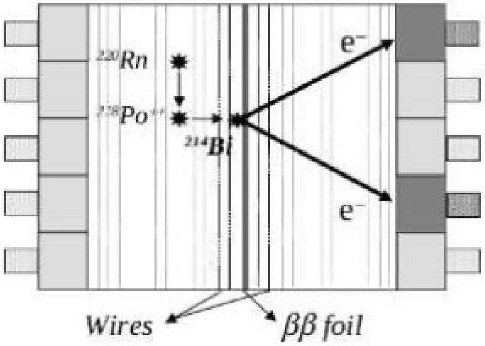
Detected through (γ,e) external channel

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





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



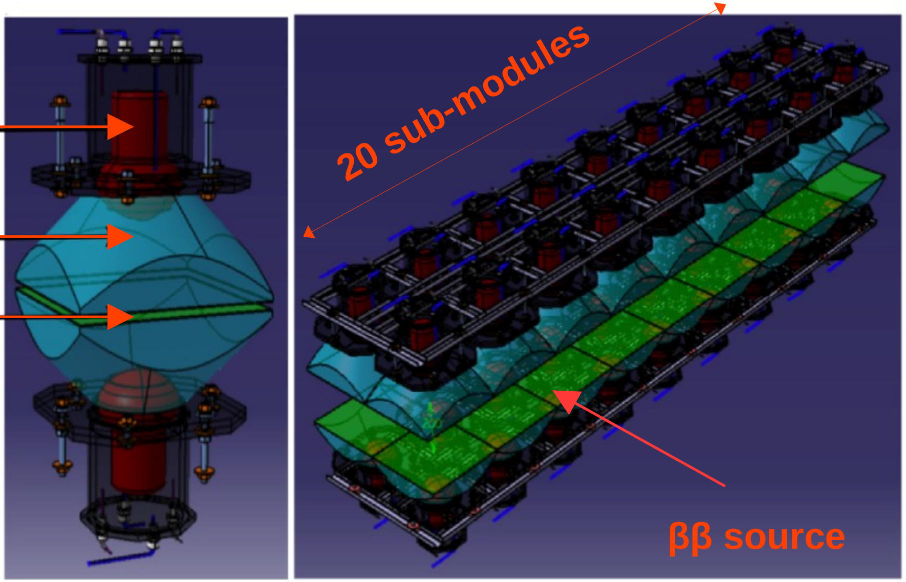
Radon background, ^{222}Rn can emanate from the detector materials, or the rocks of the laboratory then diffuse towards the tracker.
Also, the entrance gas of the tracker can be contaminated

BiPo-3 Detector: Successfully running since 2012

5” photomultiplier

Light guide

Scintillator

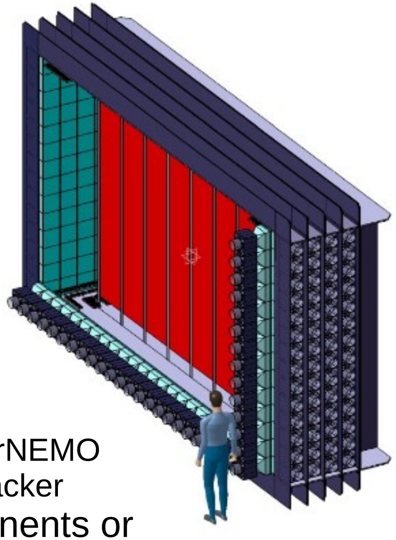


Scheme of two optical sub-modules (on the left) and of the whole detector (on the right)

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

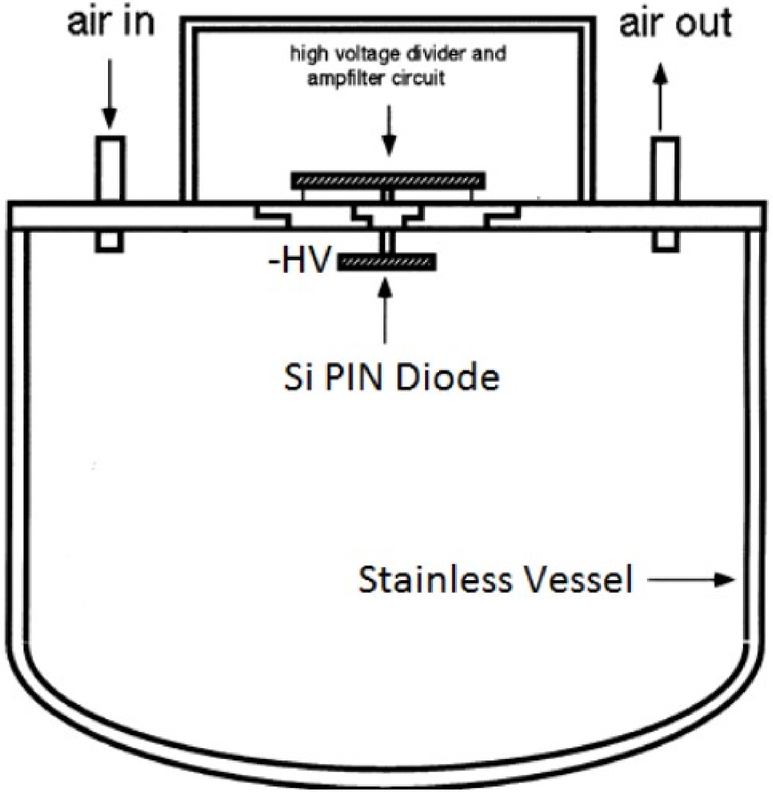
→ RnCL

→ 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

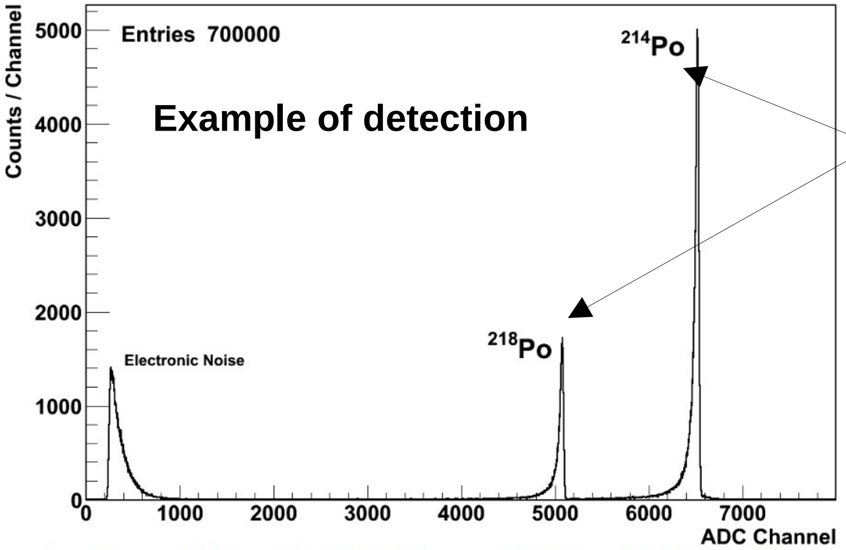
- The concentrated sample is then heated and transferred to an electrostatic detector via helium purge.



- ^{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