SuperNEMO

Neutrinoless Double Beta Decay Experiment

Time Characterization of the Calorimeter

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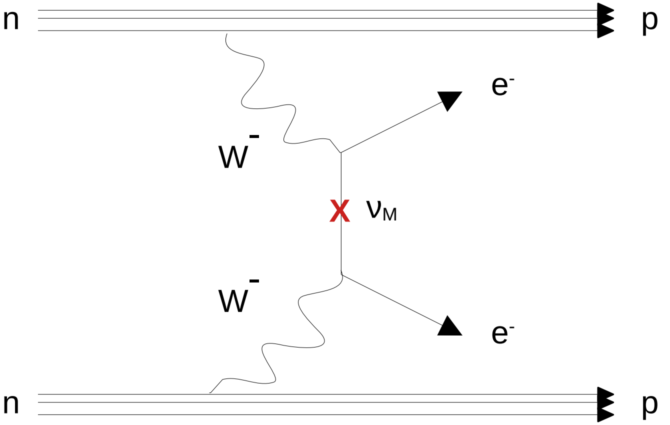
Oct 20, 2021

Neutrinoless Double Beta Decay: A Hypothetical Radioactive Process



Forbidden by the Standard Model : Violates the Leptonic number

If observed

Proves the Majorana nature of neutrinos : particles are their own anti particles

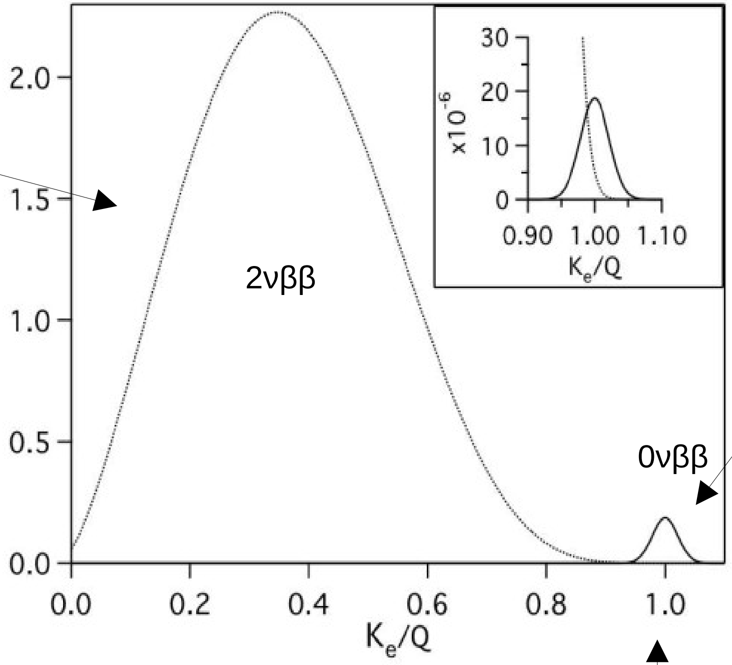
Together with CP violation, could be responsible for leptogenesis: Matter and anti-matter assymetry

Clues on whether they have normal or inverted hierarchy

Together with other observables (sum of neutrino masses constrained from cosmology or ν_e mass constrained from single-beta decay experiments), could bring information about the neutrinos absolute masses.

Neutrinoless Double Beta Decay: A Hypothetical Radioactive Process Signal

Normal double beta signal

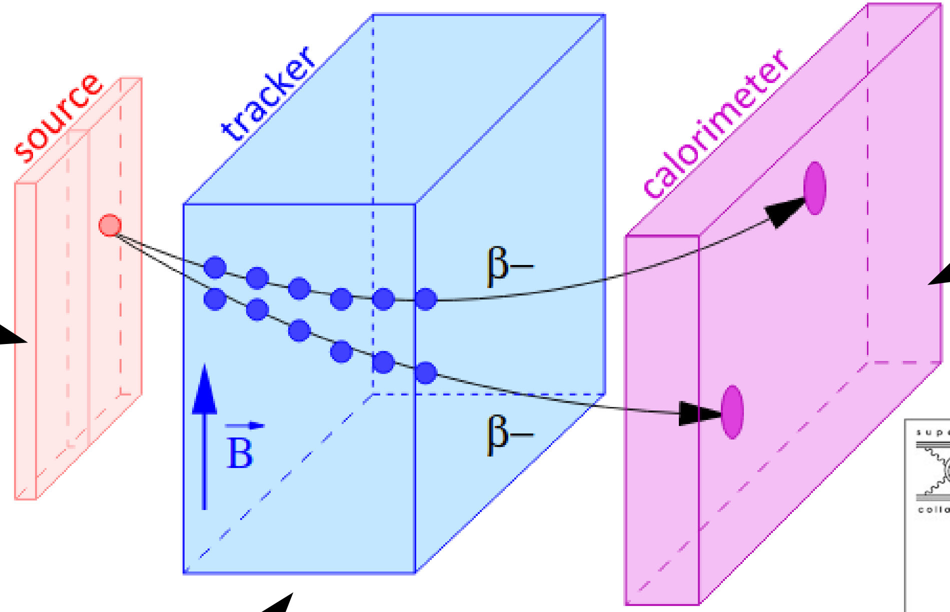


0νββ signal → Need Ultra-low Background experiments

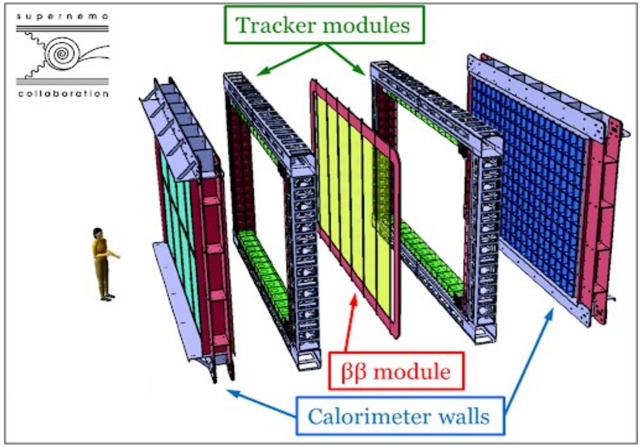
$Q_{\beta\beta}$

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 :

0νββ Search :

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

2νββ 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

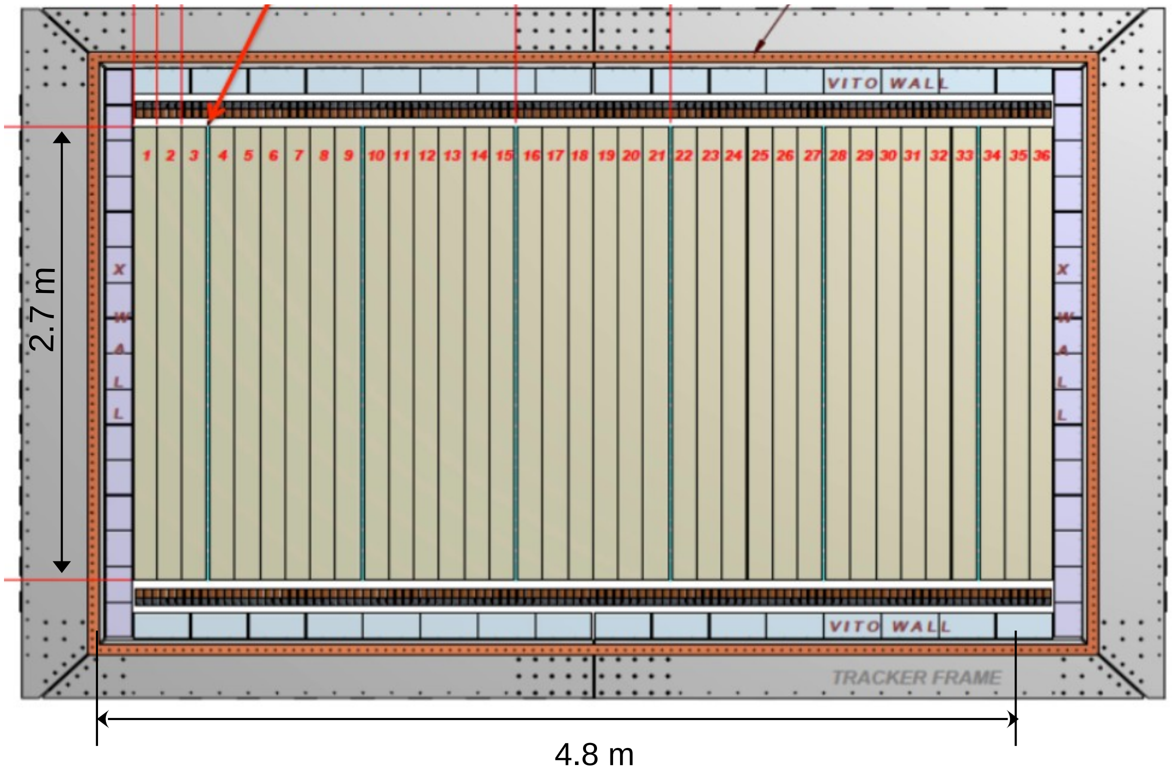
(NEMO-3)

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

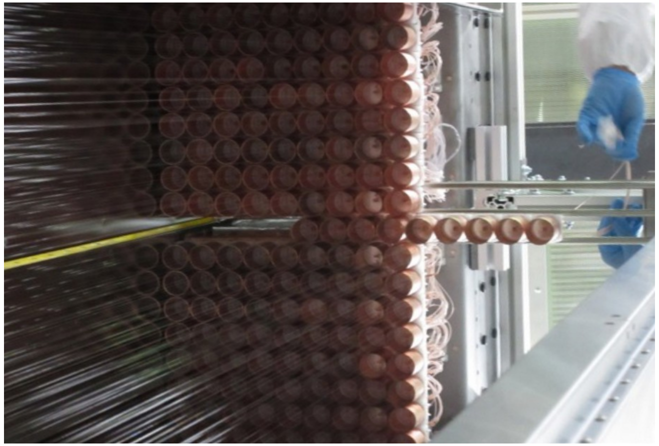
Required for 500 kg.y exposure (100 kg, 5 years)

For source of demonstrator of 17.5 kg.y exposure

Selenium Source Foils Geometry



The SuperNEMO Tracker



2034 drift cells operating in Geiger mode

↓

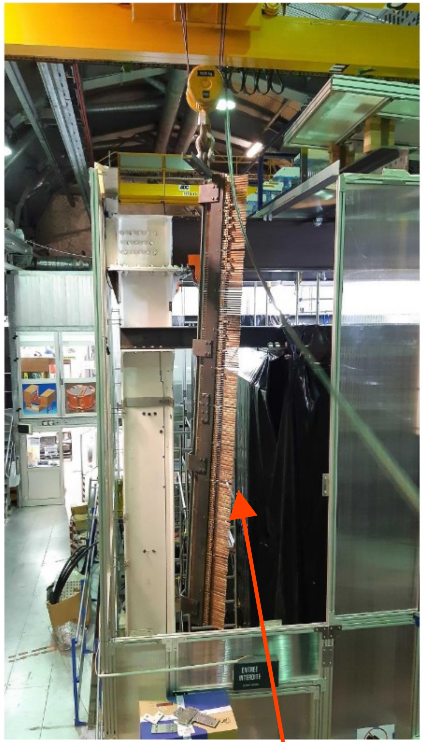
3D reconstruction of charged particle tracks
($\mu^{\pm}$, $e^{\pm}$, α)

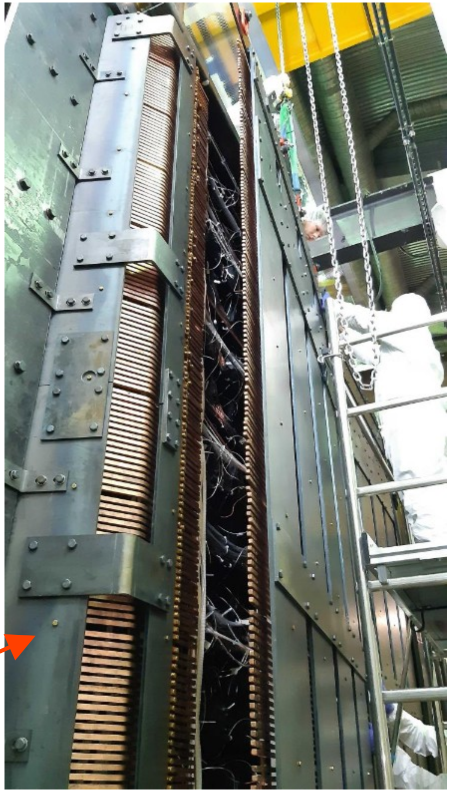
Over pressure of 10 mbar is achieved inside tracker chamber

	Specifications (mBq/m^3)	Measurements can be xtrapolated to a tracker gas flux of 2 m^3/h (mBq/m^3)
Radon emanation	0.15	0.16 ± 0.05

Already commissioned and data to be analyzed

SuperNEMO: Hardware Status

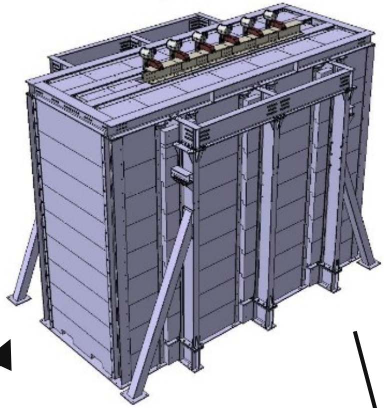




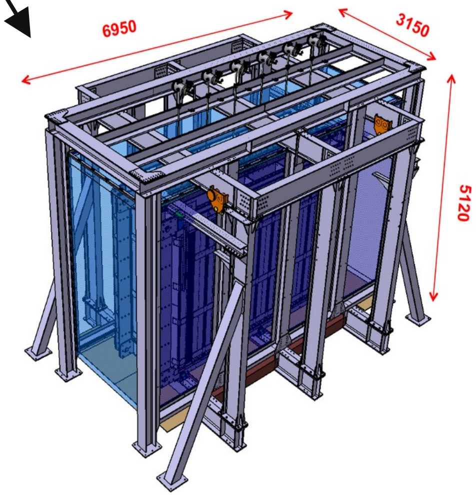
Magnetic field coils
25G

Remaining Tasks:

- Anti-Radon tent
- Shielding

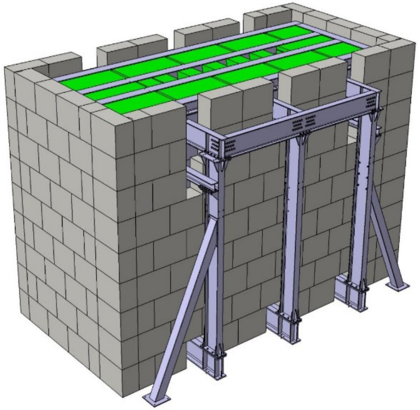


Iron shielding
20 cm



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

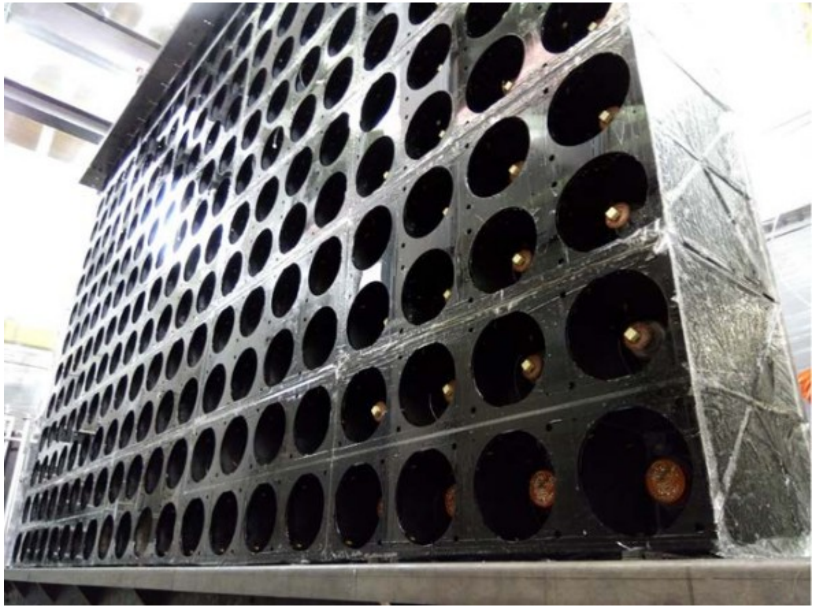
(14% - 17% for NEMO-3)

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%**

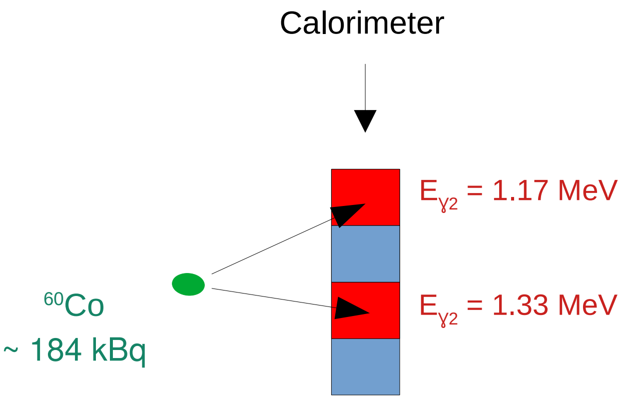
↑

Not the dominant background for 2ν and 0ν search

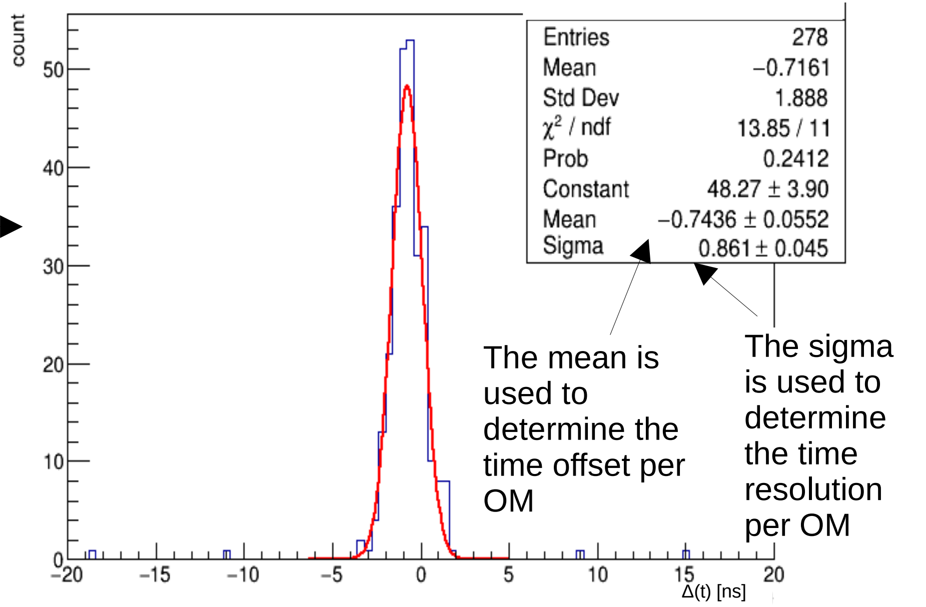


Operational and taking data since 2018!

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



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



Good calculation of the:

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

- Time resolution of Calorimeter for ɣs @ 1 MeV

Time Offset Per OM

As the two ɣs are emitted simultaneously from the source, the time difference between the two registered hit is ‘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]

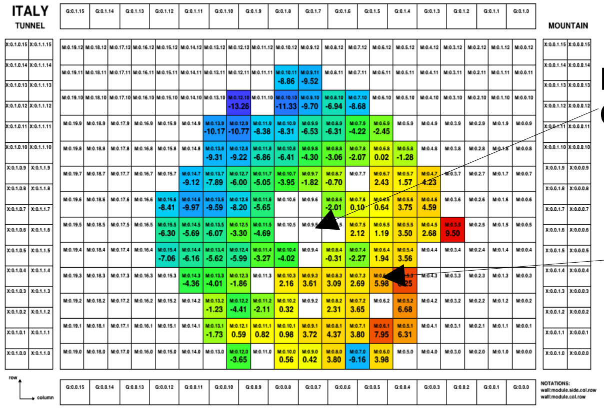
Time of Flight of ɣ from source to scintillator block (known)

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

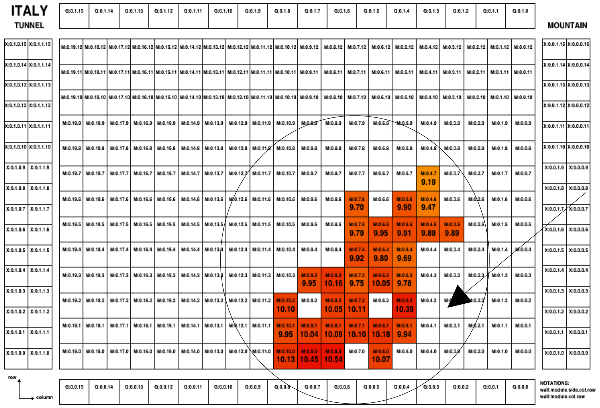
Step 1: Determine the offset of OMs “j” in coincidences with the reference OM (offset = mean of Δt distribution between OM “ref” & “j”).



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 “j”.

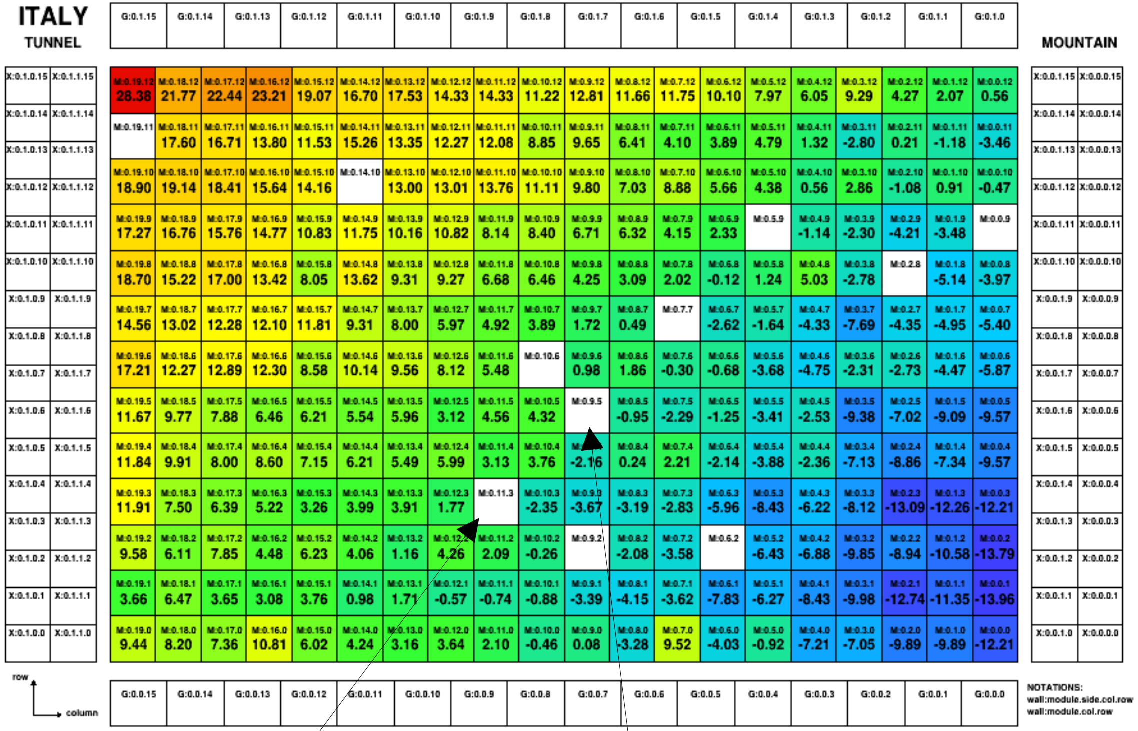


OM “k” not determined in step 1

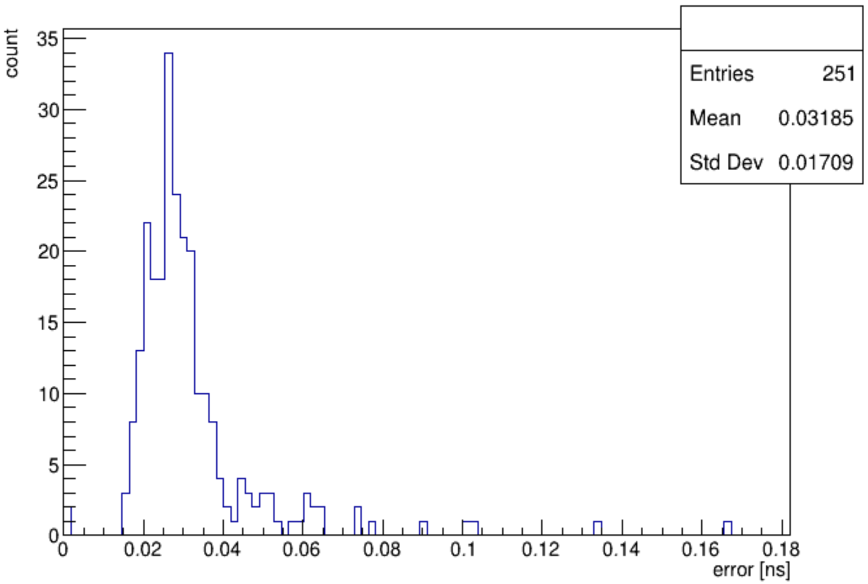
OMs calibrated (red squares) from step 1 (OMs “j”)

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 a Main Wall, Combining all Runs



Error on final offset values



Color scale: Final offset values / OM [ns]

Dead OMs

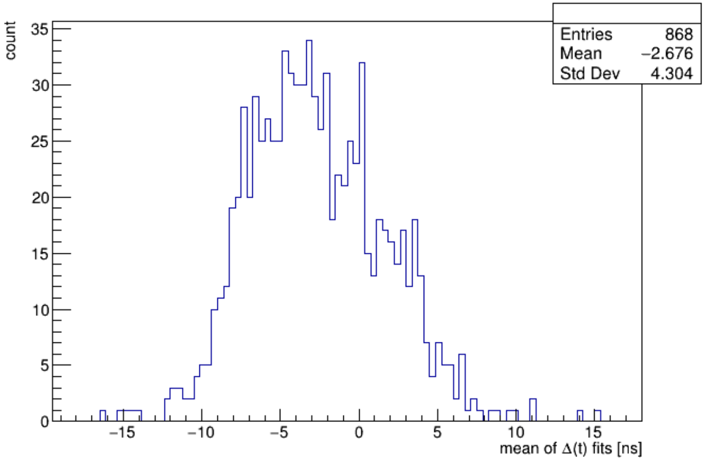
Reference OM

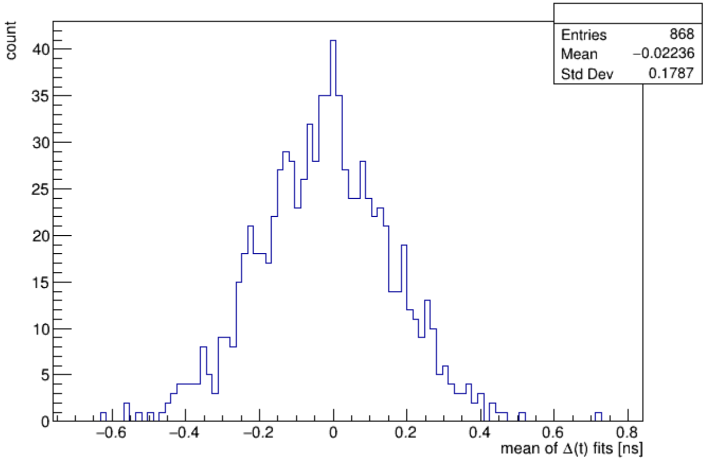
These maps are produced for all of the calorimeter walls

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

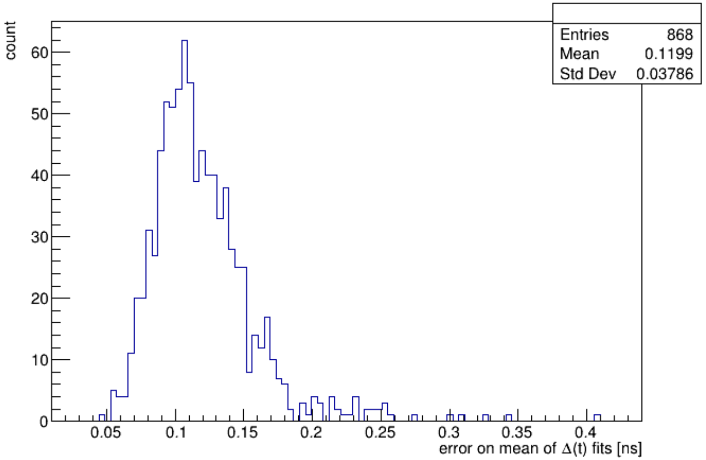
Before correction of offset → After correction of offset

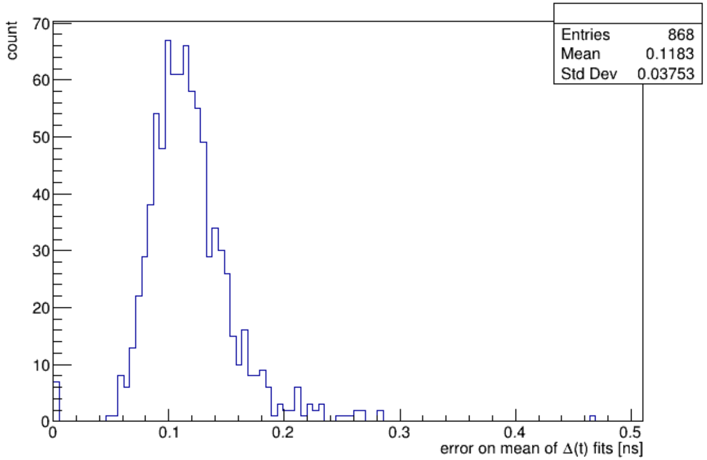
Mean value of Δt distributions





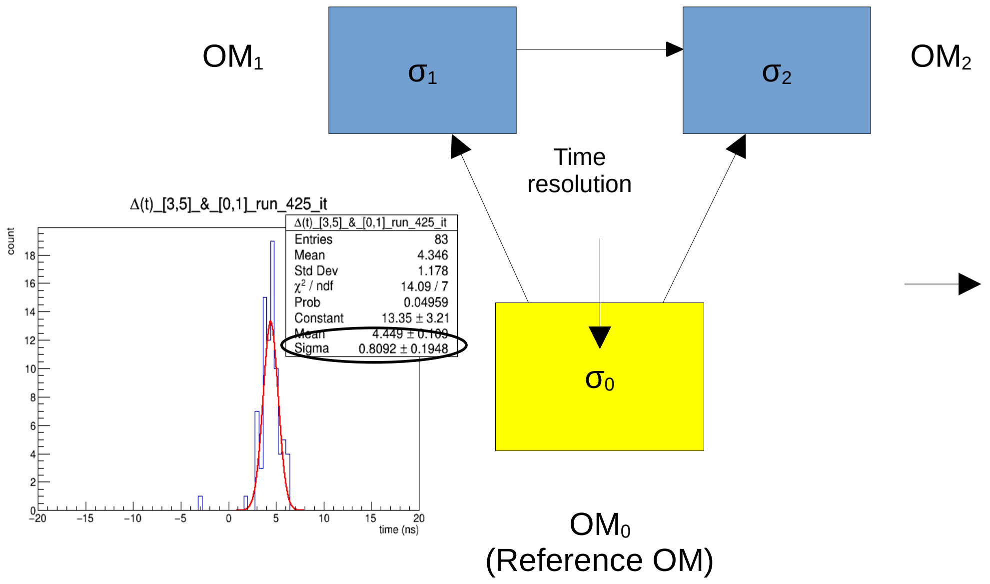
Error on mean value of Δt distributions





The time calibration performed **achieved <~ 0.2 [ns] precision on timing** after applying the calibration. Enough to reject background using time of flight measurements.

Time Resolution: Method to Determine the Time Resolution Per OM



Using parameters from the 3 coincidences we can retrieve the time resolutions $\sigma_0 \pm \delta\sigma_0$, $\sigma_1 \pm \delta\sigma_1$ and $\sigma_2 \pm \delta\sigma_2$

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]
for 5” OMs : 0.814 ± 0.006 (stat) + 0.073 (sys) – 0.000 (sys) [ns]

Sensitivity of SuperNemo to the Quenching of the Axial-Vector Coupling Constant (g_A)

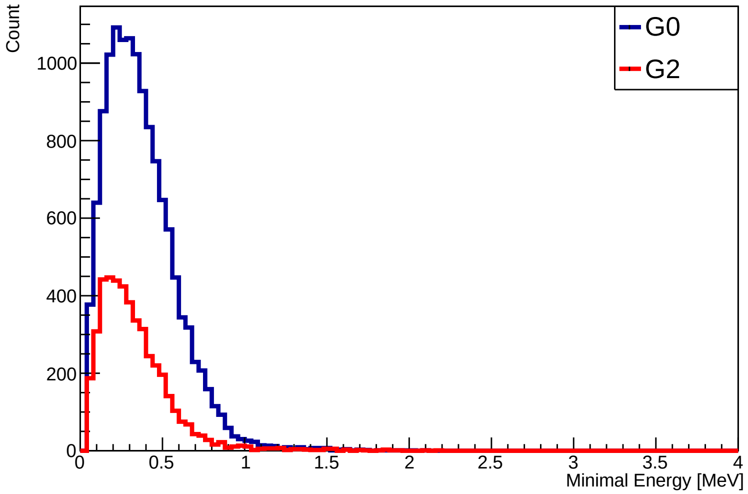
F.Šimkovic et al. Phys. Rev. C 97, 034315 (2018)

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

2νββ processes with different kinematics

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

Determines the contribution of G0 and G2



Calculating the Sensitivity:

- Generate many pseudo-data samples with different ξ_{31} value in the SuperNemo environment with background
- Fit energy spectra of each sample → retrieve ξ_{31} → estimate the bias and the dispersion between different samples

Conclusion

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

- The tracker is commissioned and taking data -> Data to be analyzed

- A time calibration of the calorimeter walls is done.

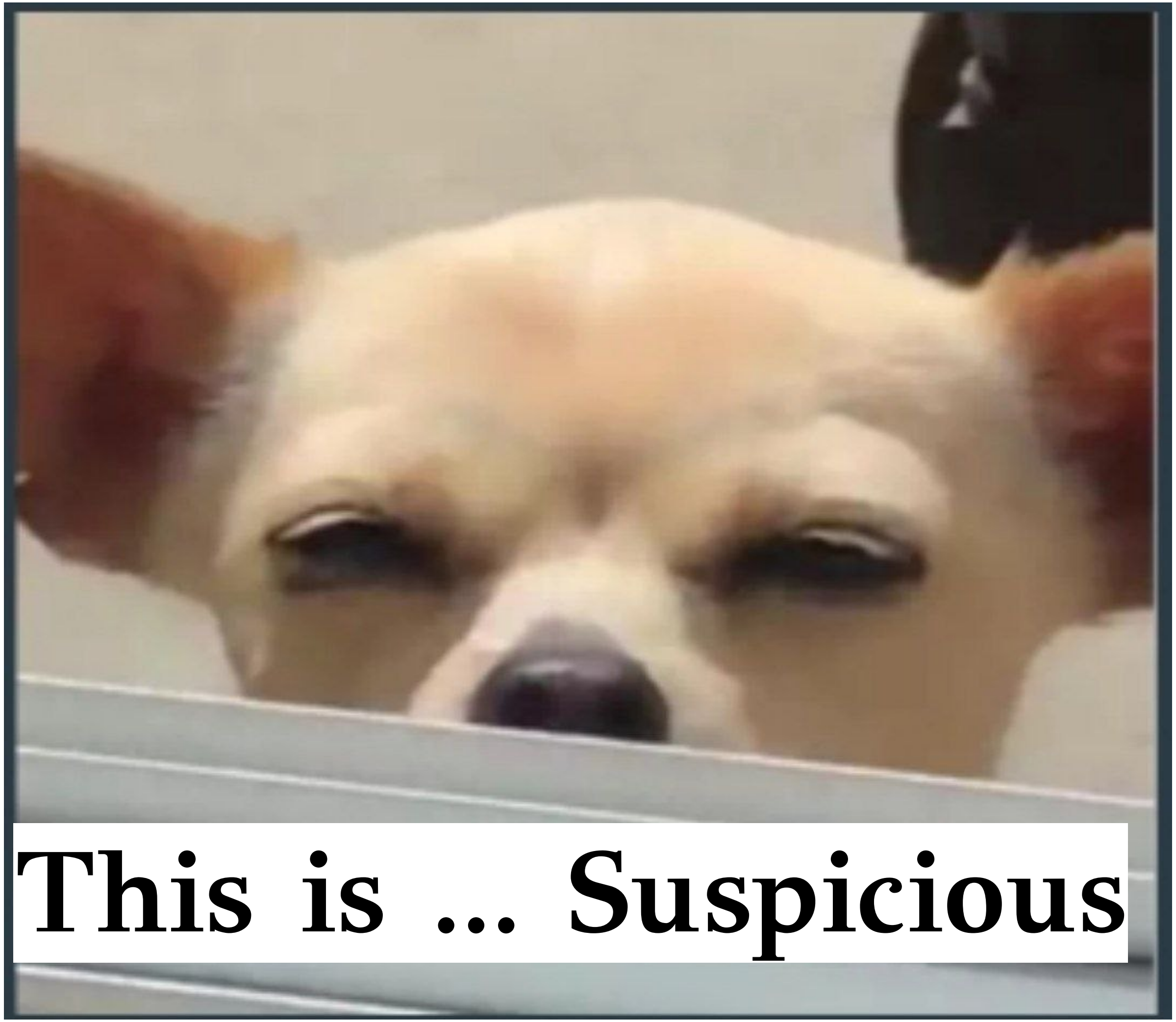
- Preliminary time resolution is extracted for γs @ 1 MeV → To be done with e^-s.

- Studies for the sensitivity to the quenching is under progress

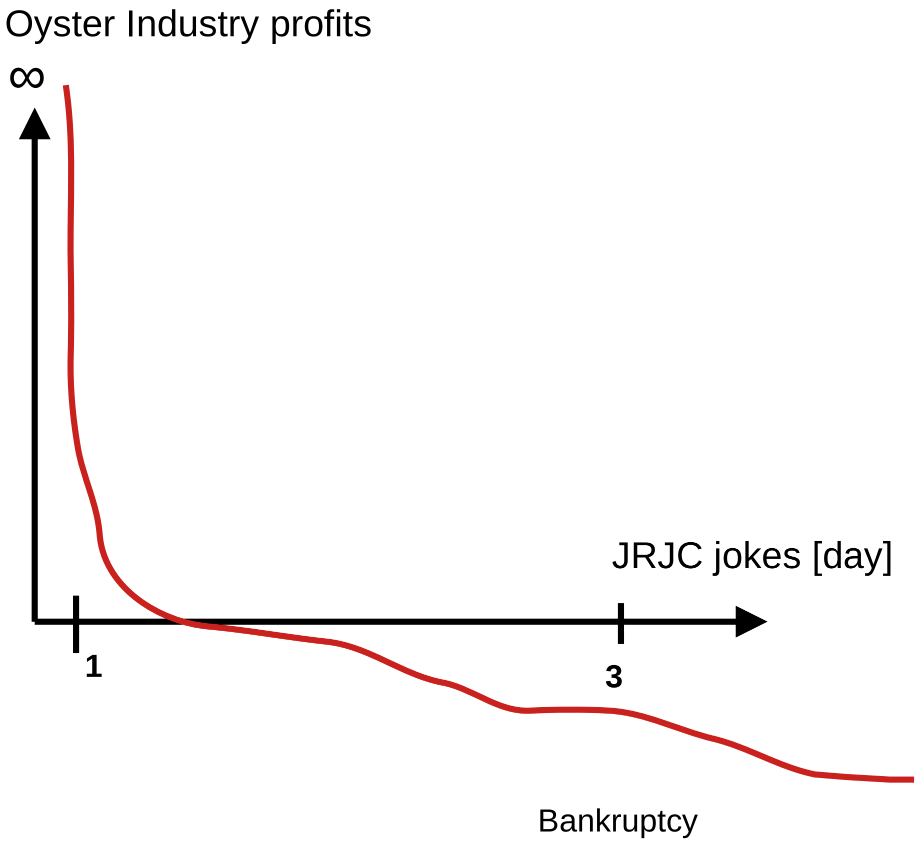
- Study the Rn222 contamination inside the tracker is under progress

END

Why Should I post an Oyster joke?




I'VE FINALLY FOUND IT... AFTER few presentations
THE Oyster OF TRUTH!
JRJC
Oyster jokes are already DEAD
NYEHHH
JRJC
Robotatertotcomics


Oyster Industry profits
∞
JRJC jokes [day]
1
3
Bankruptcy

Backup

Time Resolution 5” vs. 8”

de-excitation time of scintillator

Dispersion time, linked to PE creation on photocathode

$$\sigma_t = \sqrt{\tau_{sc}^2 + \frac{\left(FWHM_{transit\ time}/2\sqrt{2\ln(2)}\right)^2}{N_{PE}}}$$

Uncertainty on measured time

Number of photoelectrons

$$N_{PE} = E * \left(2\sqrt{2\ln(2)}/FWHM_E\right)^2$$

Energy resolution

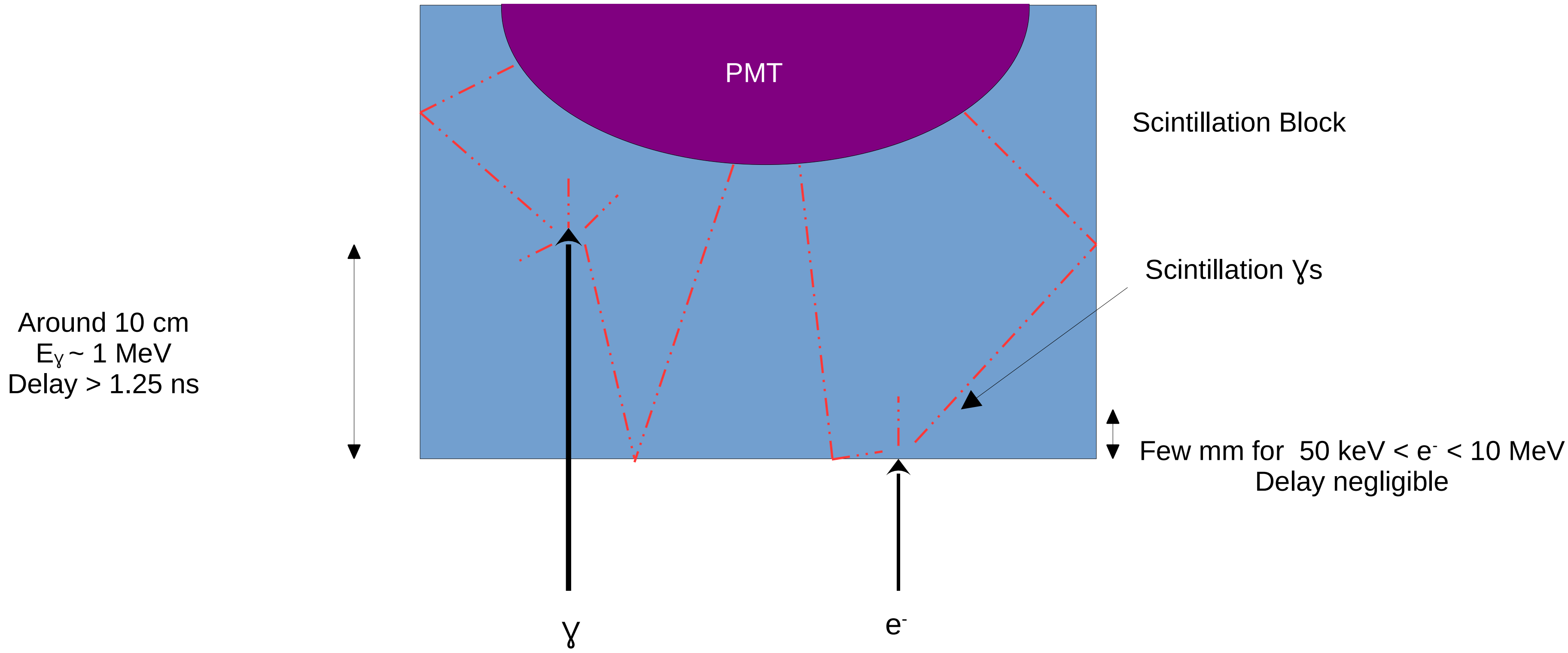
Energy deposited

Energy resolution : 5” ~ 11 %
8” ~ 8%

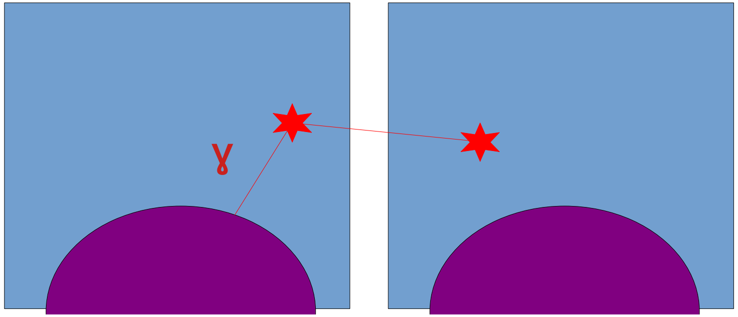
Time resolution: 5” ~ 800 ps
8” ~ 600 ps

Ratio between 5” and 8”: Energy 11/8 = 1.375
Time 800/600 = 1.333

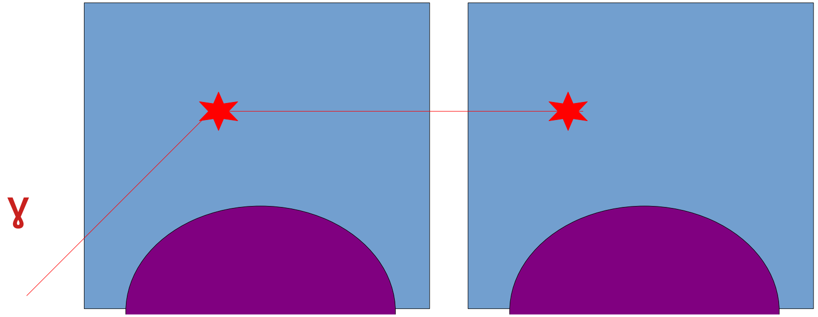
Interaction of ɣs and e⁻s Inside the Scintillation Block



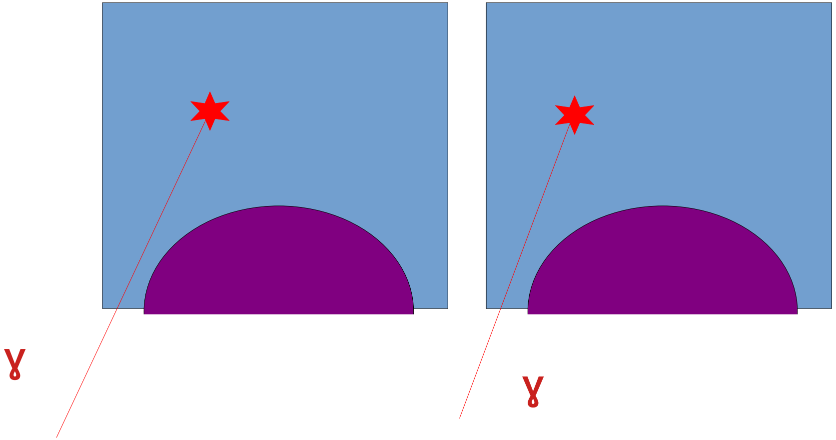
Cobalt Source Background



PMT glass contamination

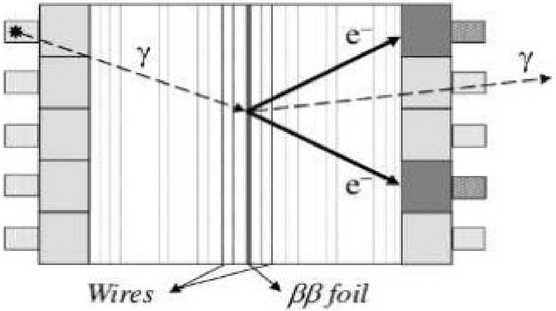


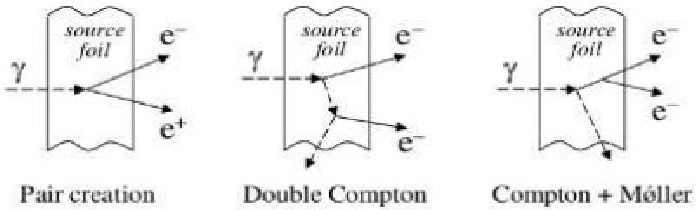
Gamma from source or lab undergoing double Compton



Random coincidences

SuperNEMO: Background Identification

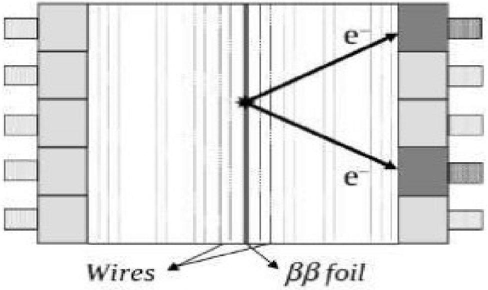


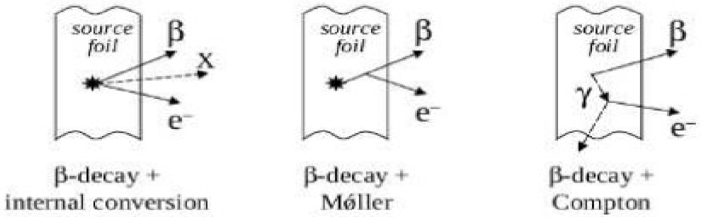


2 e⁻ produced by an external ɣ,

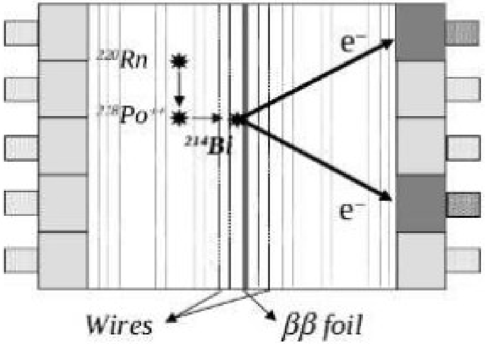
Detected through (ɣ,e) external channel

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



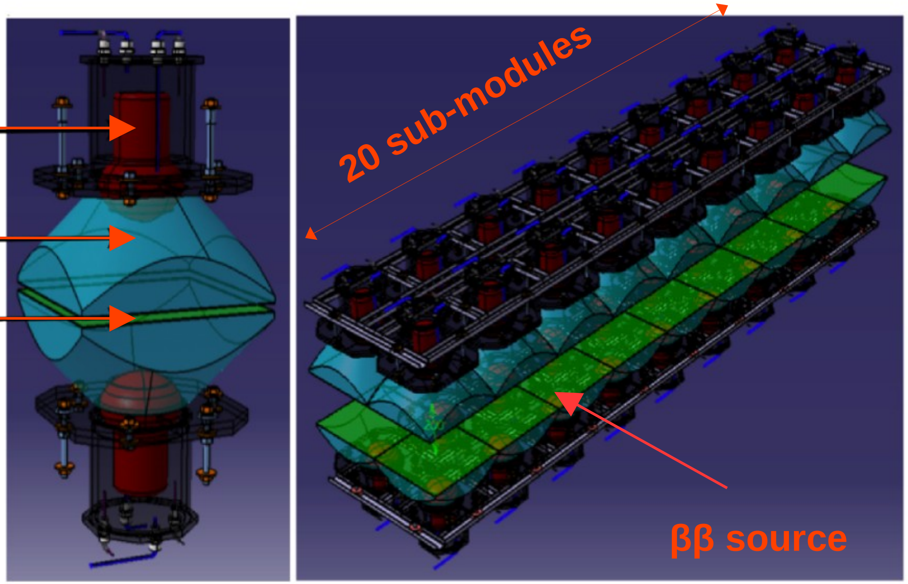
Radon background, ^{222}Rn can emanate from the detector materials, or the rocks of the laboratory then diffuse towards the tracker.
Also, the entrance gas of the tracker can be contaminated

BiPo-3 Detector: Successfully running since 2012

5” photomultiplier

Light guide

Scintillator

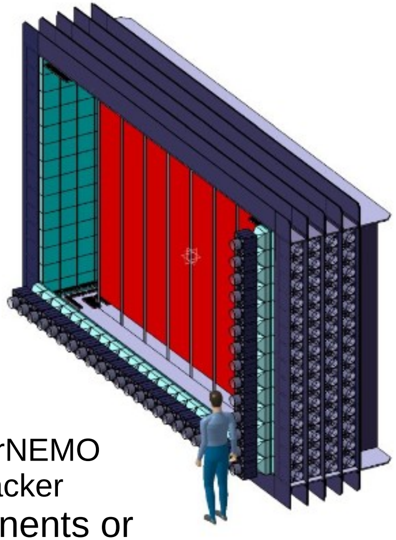


Scheme of two optical sub-modules (on the left) and of the whole detector (on the right)

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

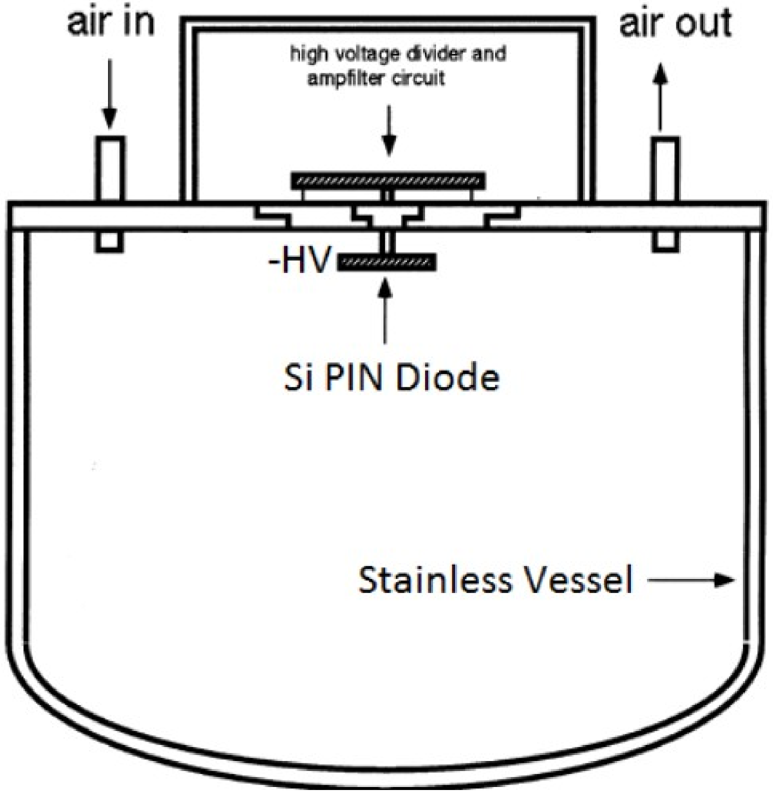
→

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

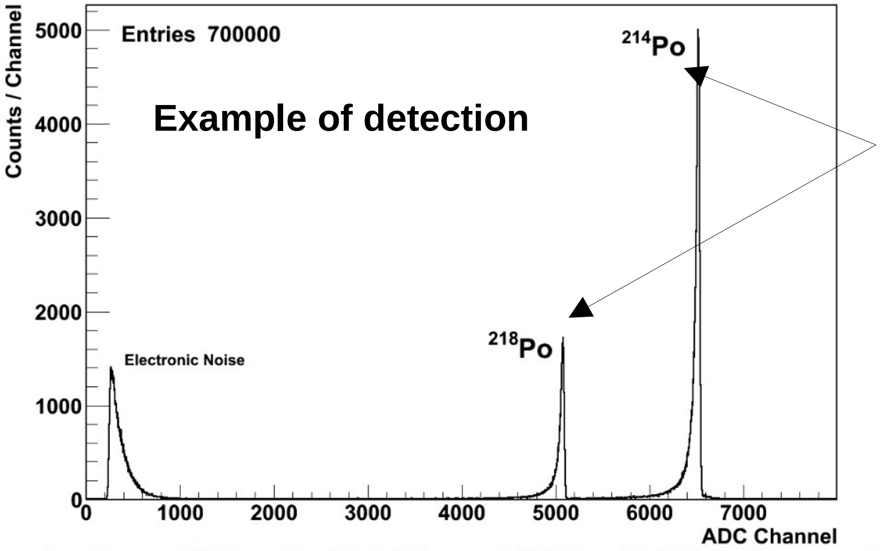
- The concentrated sample is then heated and transferred to an electrostatic detector via helium purge.



- ^{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

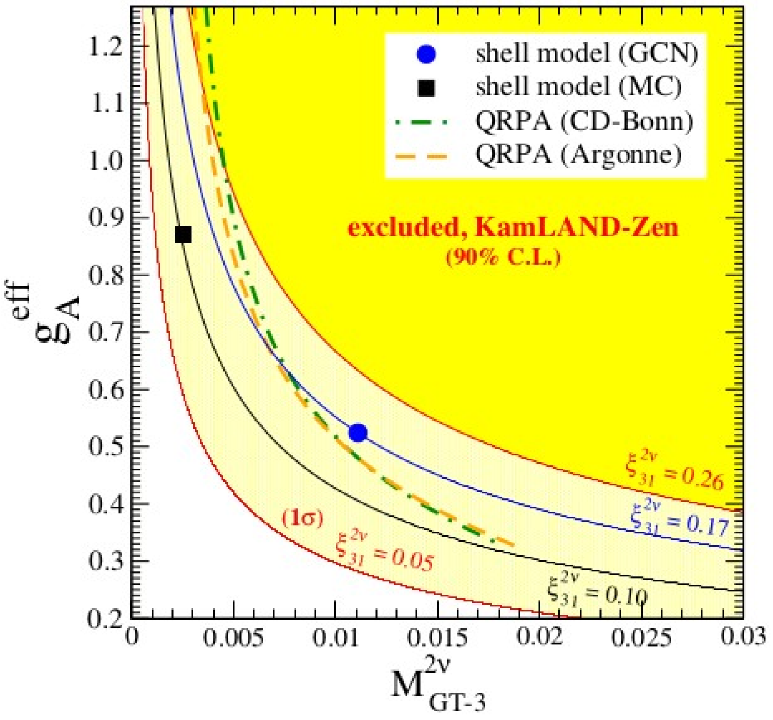


FIG. 3: Effective axial-vector coupling $g_A^{\rm eff}$ as a function of the matrix element $M_{GT-3}^{2\nu}$ for ^{136}Xe $2\nu\beta\beta$ decay. The yellow (light yellow) region $\xi_{31}^{2\nu} < 0.26$ (0.05) is excluded by the present KamLAND-Zen measurement at 90% (1σ) C.L. Nuclear shell model results are displayed by the blue circle (GCN interaction) and black square (MC). QRPA results are shown by the dashed orange (Argonne interaction) and dashed-dotted green (CD-Bonn) curves.

arXiv:1901.03871v1 [hep-ex] 12 Jan 2019