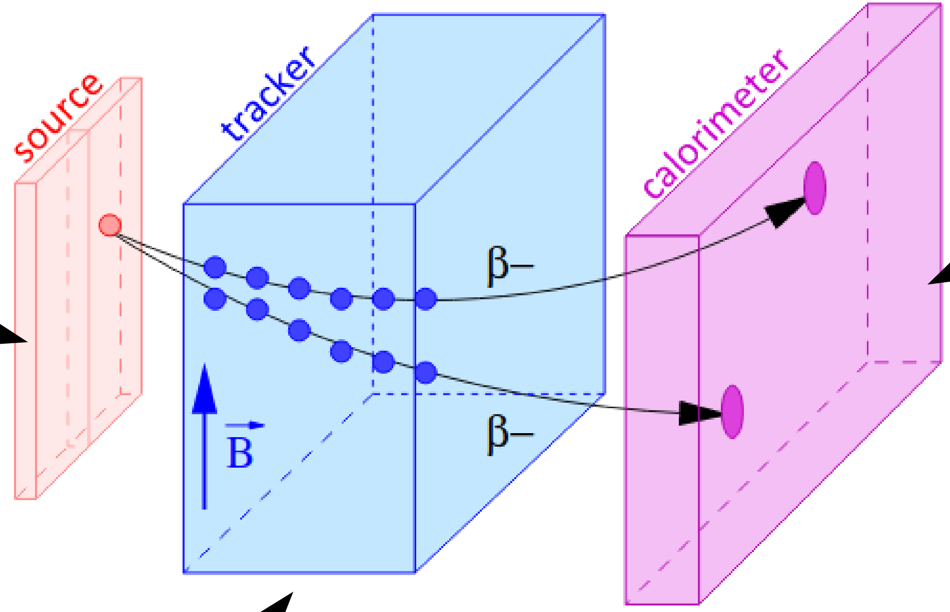
SuperNEMO

Double-Beta Research in France Workshop II

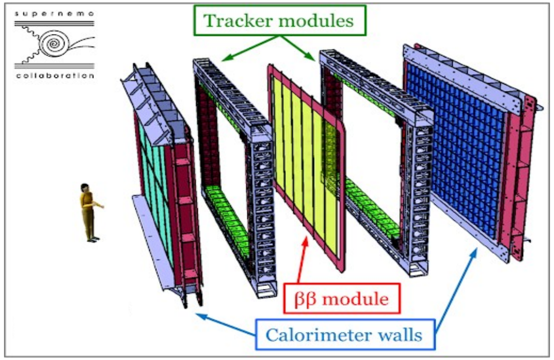
Malak HOBALLAH on behalf of the SuperNEMO Collaboration
Oct 16, 2020

SuperNEMO: Tracker-Calorimeter Detector

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



Measure **individual particle energies** giving access to decay mechanism
Measure particles **time-of-flight** to reject backgrounds



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

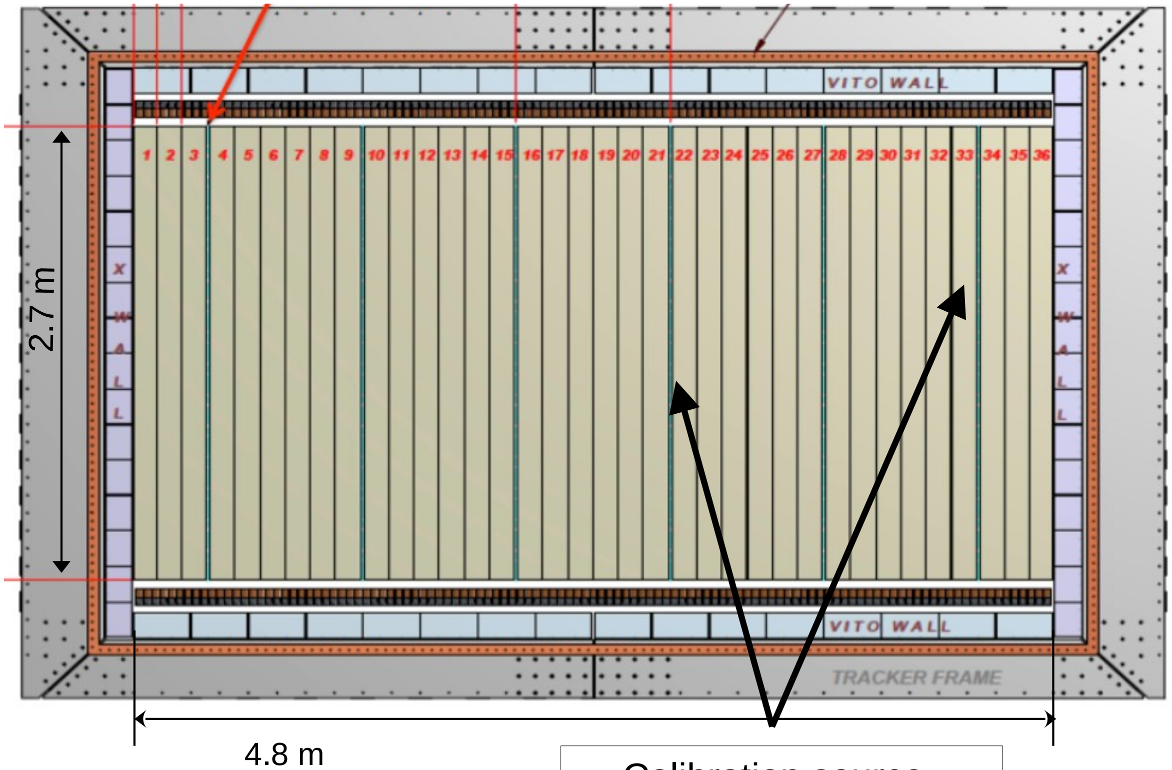
(NEMO-3)

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

For full detector of 500 kg.y exposure (5 years)

For demonstrator of 17.5 kg.y exposure (2.5 years)

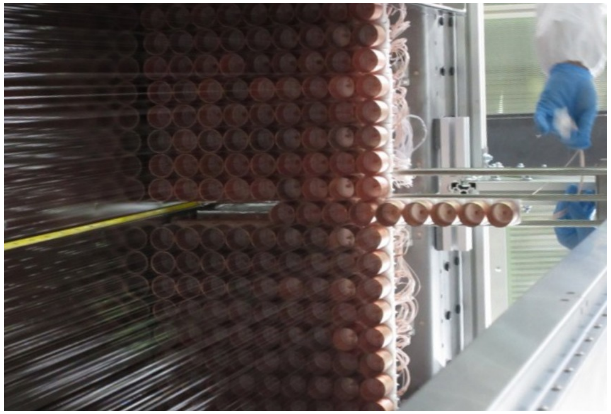
Selenium Source Foils Geometry



Calibration source deployment system

Absolute energy calibration ^{207}Bi

The SuperNEMO Tracker



2034 drift cells operating in Geiger mode

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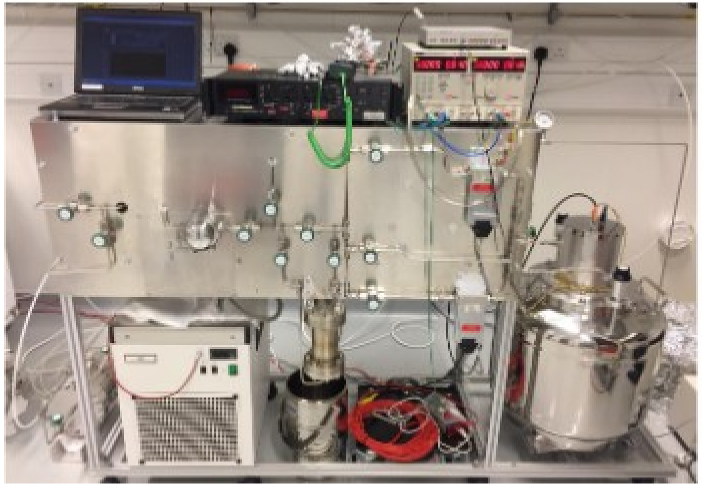
3D reconstruction of charged particle tracks
($\mu^{\pm}$, $e^{\pm}$, α)

¼ tracker under construction



Rn concentration line (RnCL), measures activities as low as 0.1 μBq/m^3 for large volumes

	Specifications (mBq/m^3)	First Measurements (mBq/m^3)
^{222}Rn emanation	0.15	0.16 ± 0.05

Measured with RnCL, We can reach the specifications with a Helium flow rate of 2 m^3/h

Tracker Deformation & Lifting: September 2020

The tracker frame was deformed → short circuit in 270 cells (10% of the tracker).

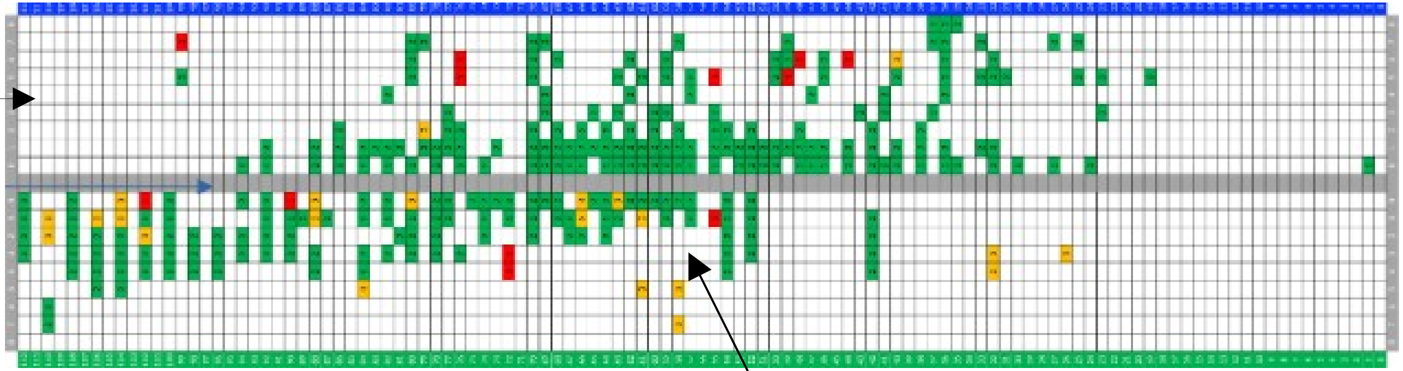
The Frame was raised ~ 4mm successfully with careful monitoring

- The structure is mechanically stable and is being monitored with laser gauges.

- Short circuit cells were reduced from approximately 20% to 2%

- The source foils were not damaged in the process

Expert team from UK & Fr



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 1 MeV electrons

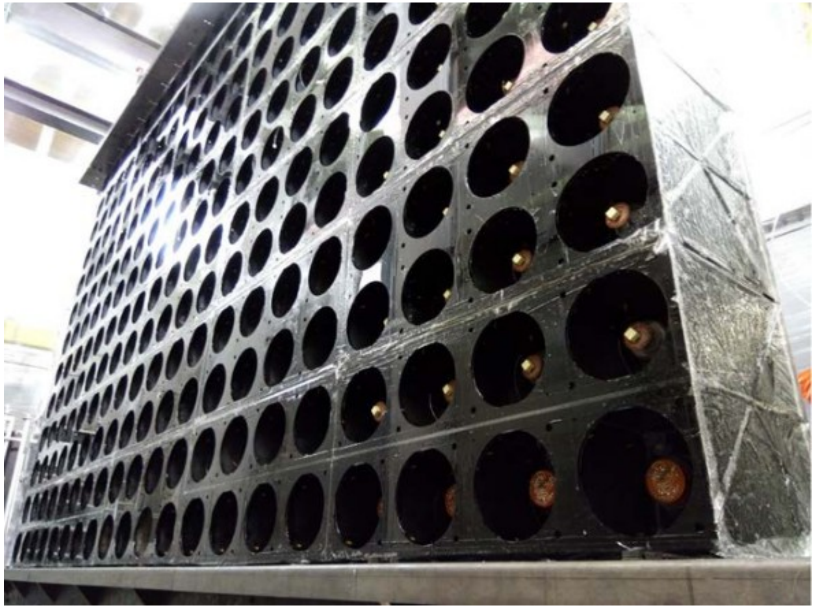
Radio-purity of PMTs, Activity of all OMs:

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%**

↑

No significant contribution to the 2ν and 0ν search

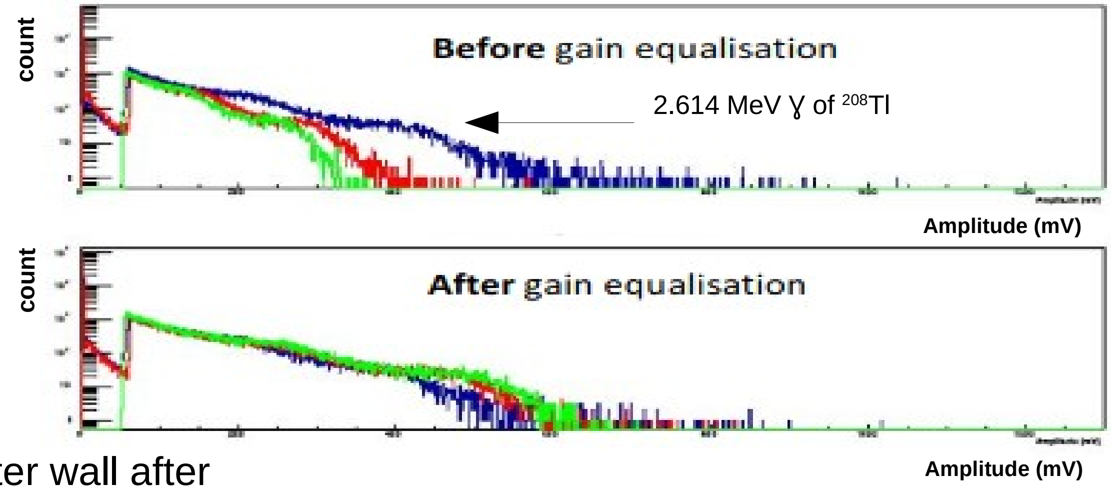
Operational and taking data since 2018!



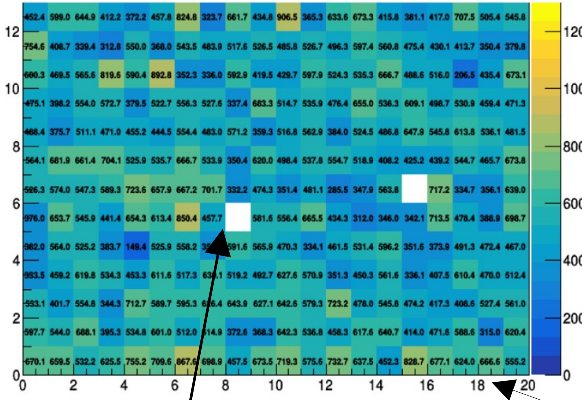
Calorimeter Commissioning: Energy Calibration and PMTs HV gain equalization

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

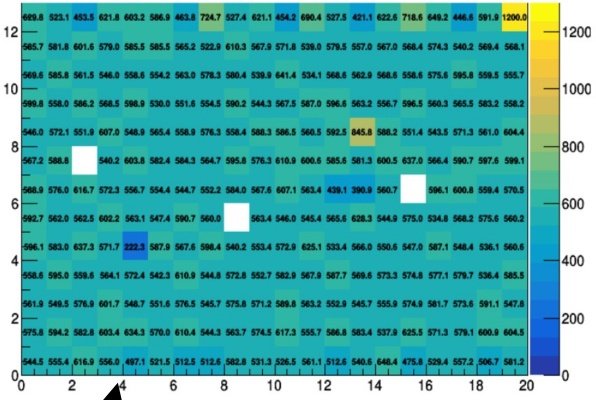
PMTs signals amplitudes



Calorimeter wall before



Calorimeter wall after



Dead Oms

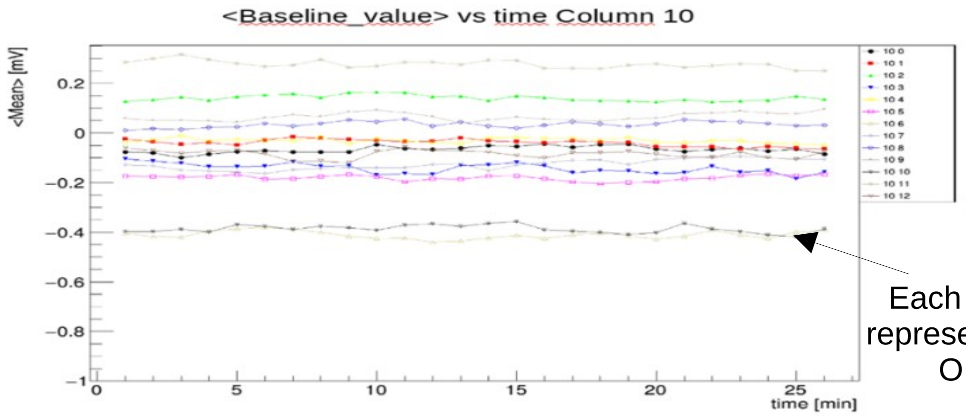
Each square represents an OM

After equalization → **Spread in PMTs HV gain < 10%**

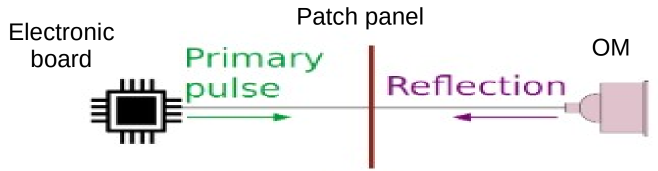
Better results expected with electron source (^{207}Bi) and tracker commissioned

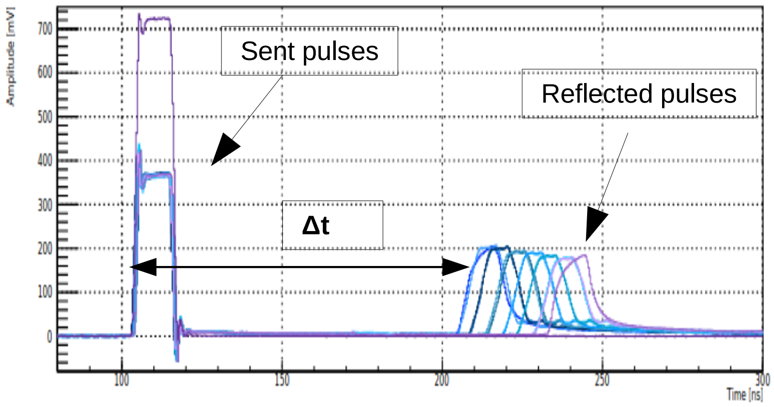
Calorimeter Commissioning: Baseline & Reflectometry Tests

Baseline calculations → very low noise and stable electronics



Each color represents an OM

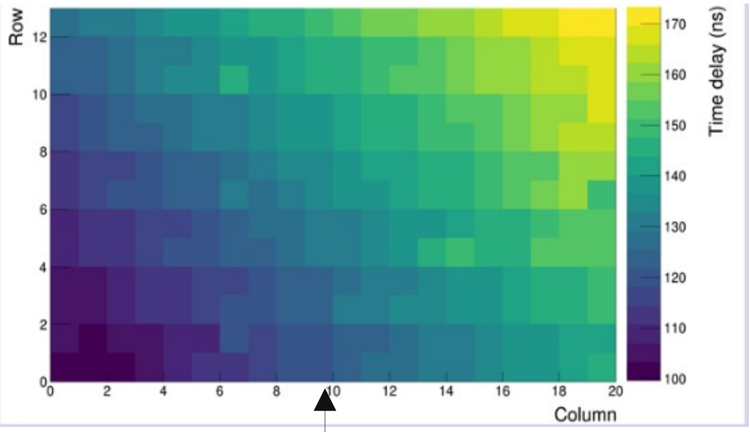




Reflectometry tests to test signal attenuation and time delays between PMT channels using electronics generated pulses

Calorimeter wall

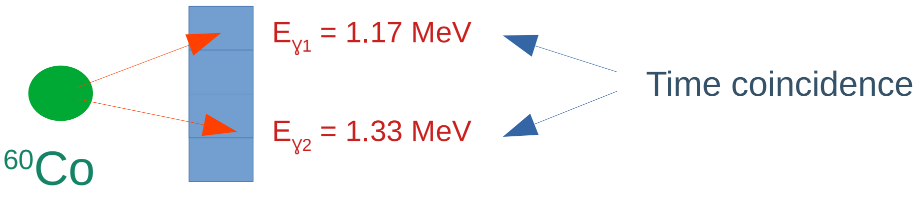
Long cable



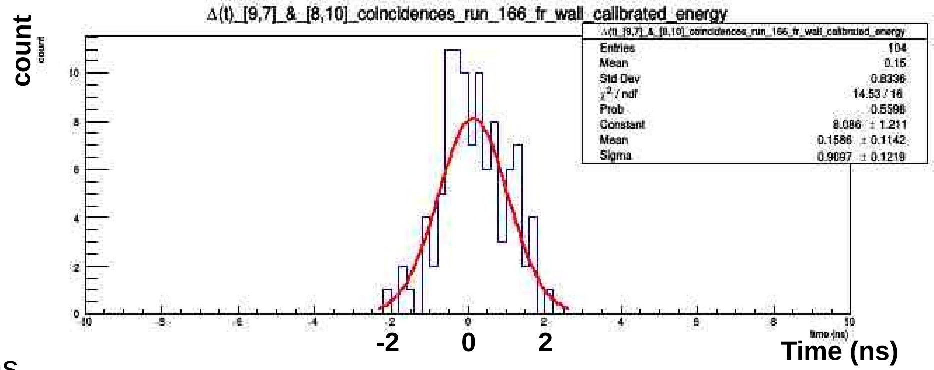
Short cable

Each square represents an OM

Calorimeter Commissioning: Time Resolution



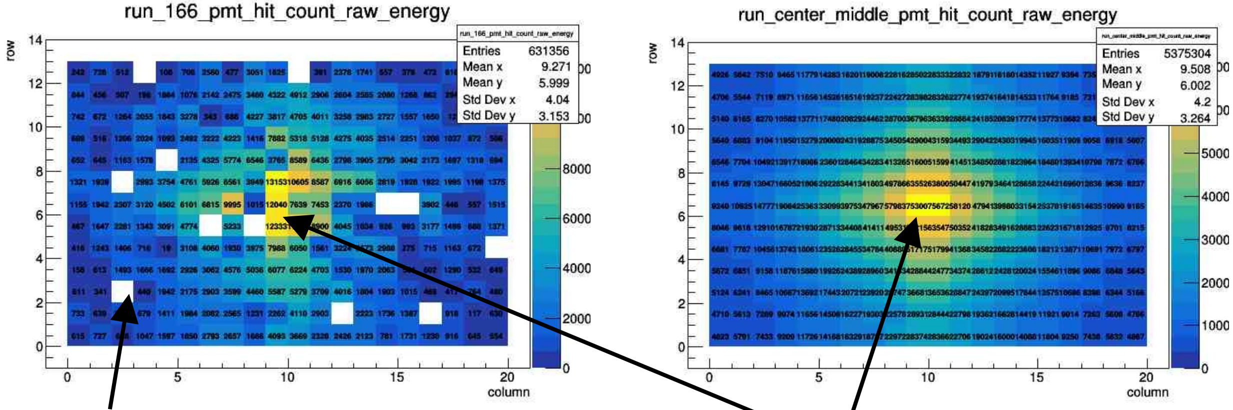
Time difference between 2 Oms hits in coincidence



Counting rate of the Oms:

Calorimeter wall, real data run

Calorimeter wall, simulations



Dead Oms, most are recovered

^{60}Co source position

Time resolution *primarily results* using ^{60}Co give a **< 600 ps** for γs @ 1 MeV

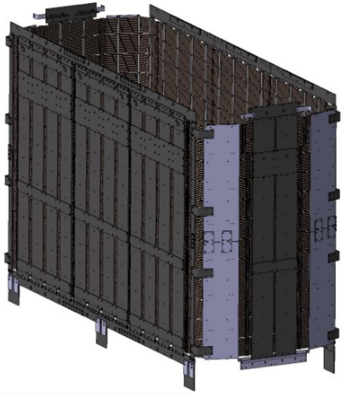
Better results expected with an electron source (^{207}Bi) and tracker commissioned

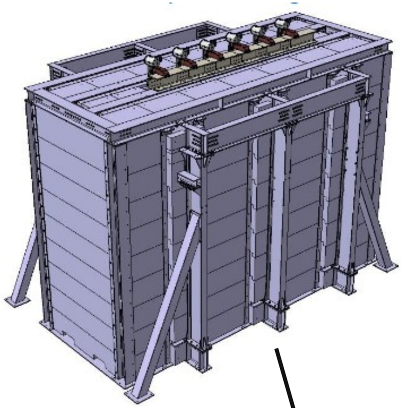
SuperNEMO: Hardware Status

Remaining Tasks:

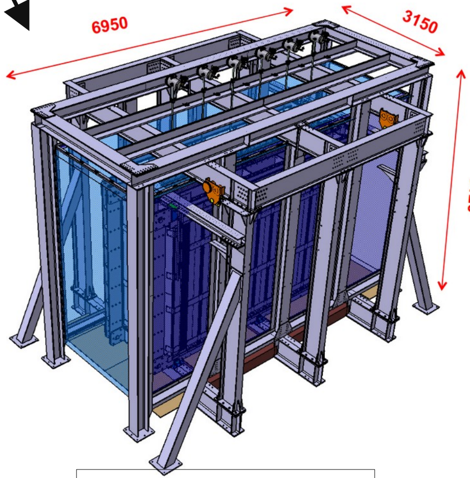
- Gas Tightness (after lifting)
- Tracker Commissioning
- Magnetic field
- Shielding

Magnetic field coils
25G



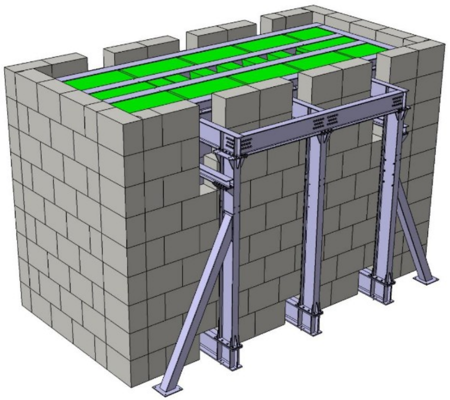


Iron shielding
20 cm



Anti-Radon tent

polyethylene water tanks and
boron polyethylene plates



SuperNEMO: The Physics

Demonstrator :

- Expected sensitivity: *17.5 kg.y* exposure of ^{82}Se

- Measure Background contamination

$T^{0\nu}_{1/2} > 4 * 10^{24}$ y

$<m_\nu>$ < (260 – 500) meV (90% CL)

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 Stat Dominance (HSD) and Single State Dominance (SSD)

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

Fini

Backup

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)

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

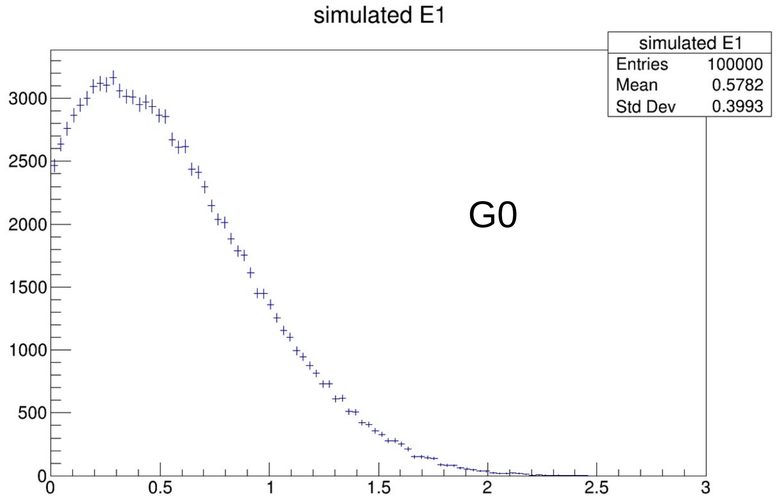
where $$\xi_{31}^{2\nu} = \frac{M_{GT-3}^{2\nu}}{M_{GT-1}^{2\nu}},$$

The “g_A” processes

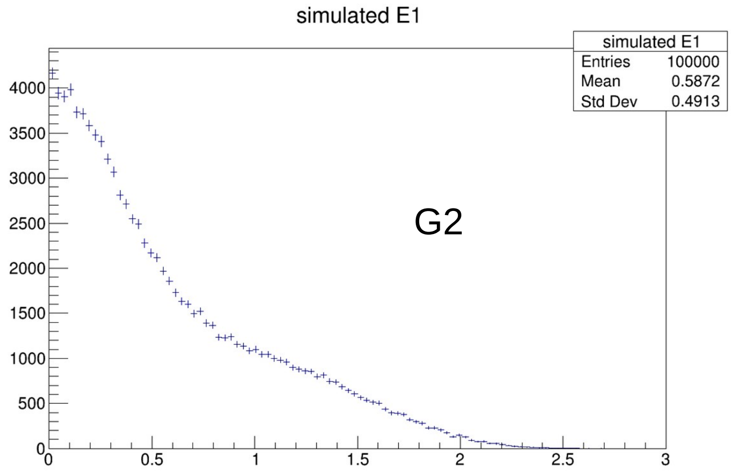
Fit single and total energy spectra to get a value for ξ_{31}

Gamow–Teller matrix element from Shell Mode calculation

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



plots for Se82



Axial-Vector Coupling Constant (g_A) Studies

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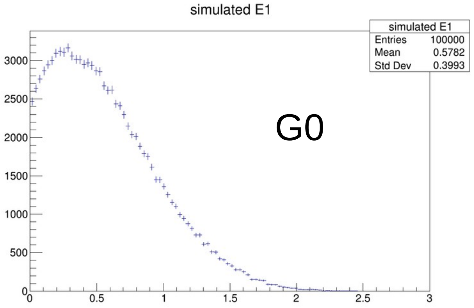
$$\left[T_{1/2}^{2\nu\beta\beta}\right]^{-1} = \left(g_A^{\mathrm{eff}}\right)^4 \left|M_{GT-1}^{2\nu}\right|^2 \left(G_0^{2\nu} + \xi_{31}^{2\nu} G_2^{2\nu} + \frac{1}{3}\left(\xi_{31}^{2\nu}\right)^2 G_{22}^{2\nu} + \left(\frac{1}{3}\left(\xi_{31}^{2\nu}\right)^2 + \xi_{51}^{2\nu}\right) G_4^{2\nu}\right)$$

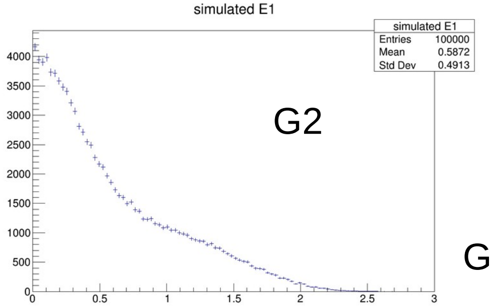
The 4 "g_A" processes

where $$\xi_{31}^{2\nu} = \frac{M_{GT-3}^{2\nu}}{M_{GT-1}^{2\nu}}, \quad \xi_{51}^{2\nu} = \frac{M_{GT-5}^{2\nu}}{M_{GT-1}^{2\nu}}$$

Neglecting next order terms it may be truncated to:

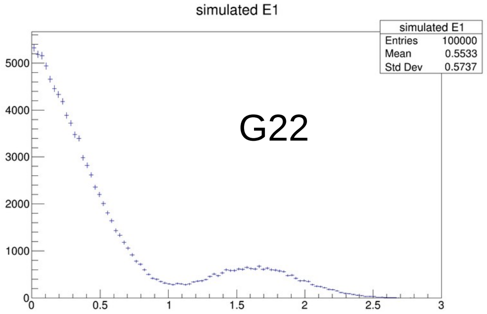
$$\left[T_{1/2}^{2\nu\beta\beta}\right]^{-1} \simeq \left(g_A^{\mathrm{eff}}\right)^4 \left|M_{GT-3}^{2\nu}\right|^2 \frac{1}{\left|\xi_{31}^{2\nu}\right|^2} \left(G_0^{2\nu} + \xi_{31}^{2\nu} G_2^{2\nu}\right)$$

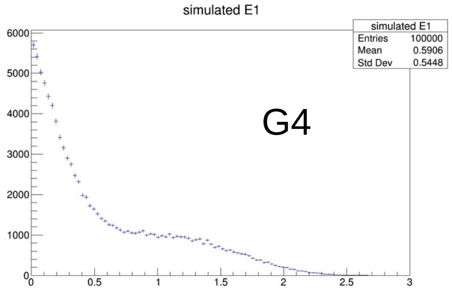




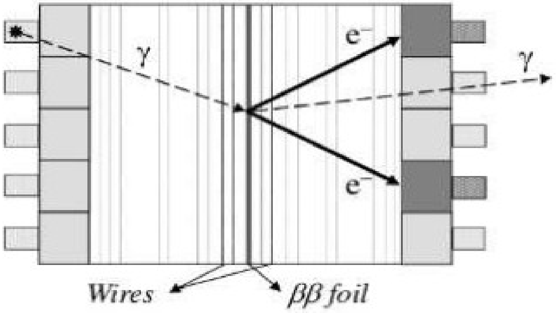
G2

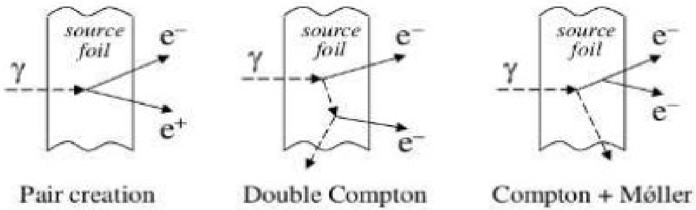
plots for Se82





SuperNEMO: Background Identification

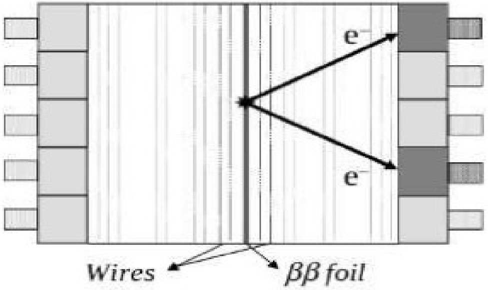


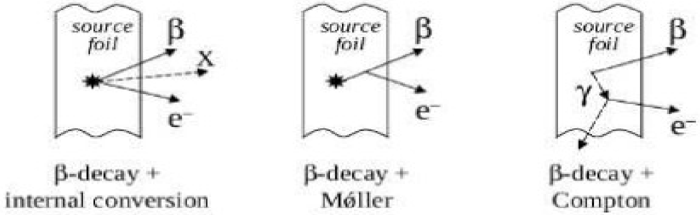


2 e^- produced by an external ɣ,

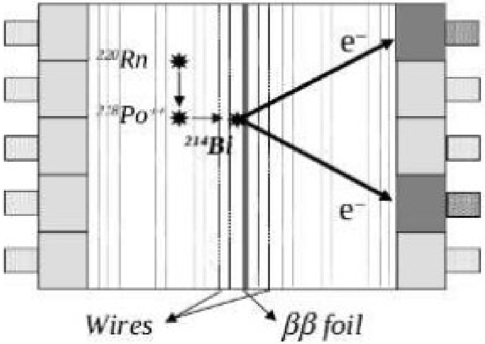
Detected through (ɣ,e) external channel

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



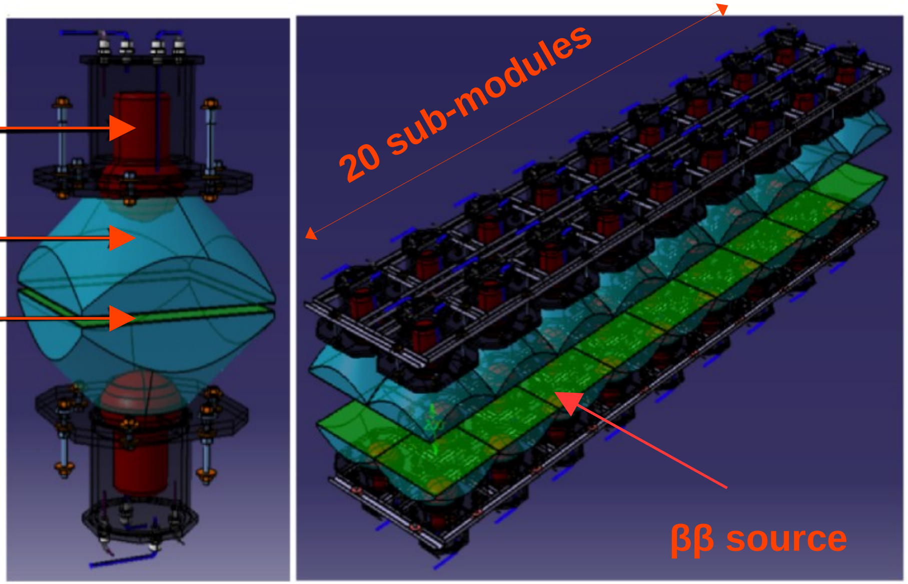
Radon background, ^{222}Rn can emanate from the detector materials, or the rocks of the laboratory then diffuse towards the tracker.
Also, the entrance gas of the tracker can be contaminated

BiPo-3 Detector: Successfully running since 2012

5” photomultiplier

Light guide

Scintillator



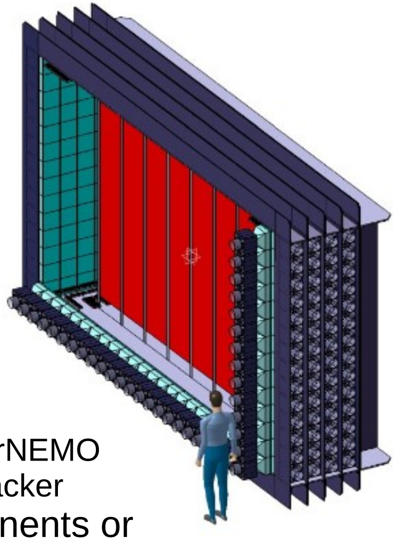
Scheme of two optical sub-modules (on the left) and of the whole detector (on the right)

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.

Radon Concentration Line (RnCL)



SuperNEMO Tracker components or c-sections

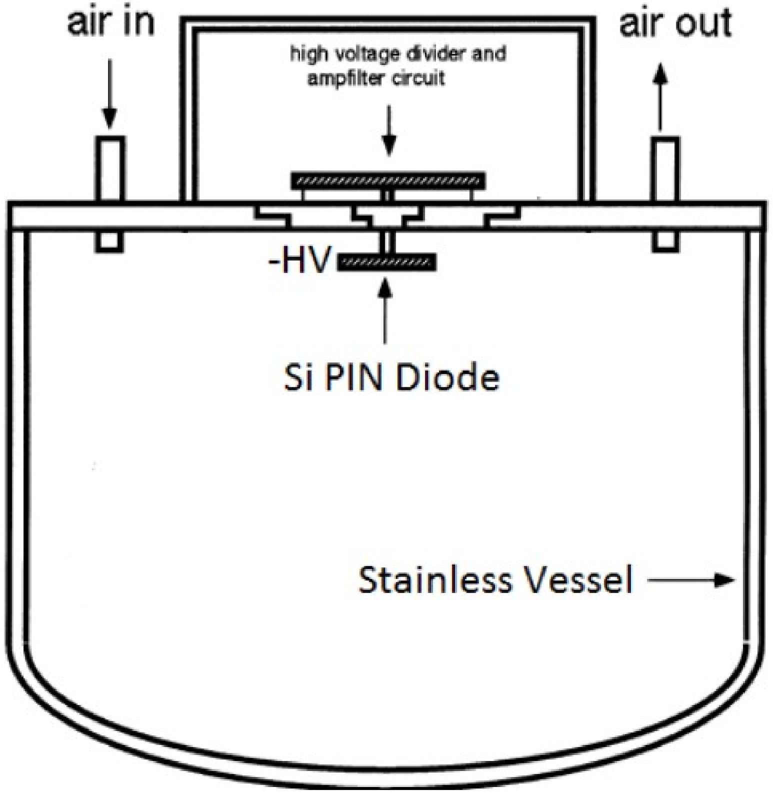
RnCL

Electrostatic Detector

- Gas from the tracker components or c-sections 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.

Radon Concentration Line (RnCL)



- ^{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.