SuperNEMO

Neutrinoless Double Beta Decay Experiment

Demonstrator Commissioning Status Update

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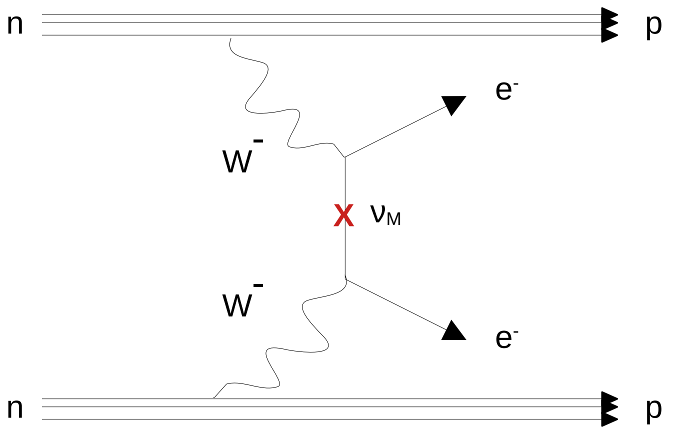
On behalf of the SuperNEMO Collaboration

Dec 2, 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

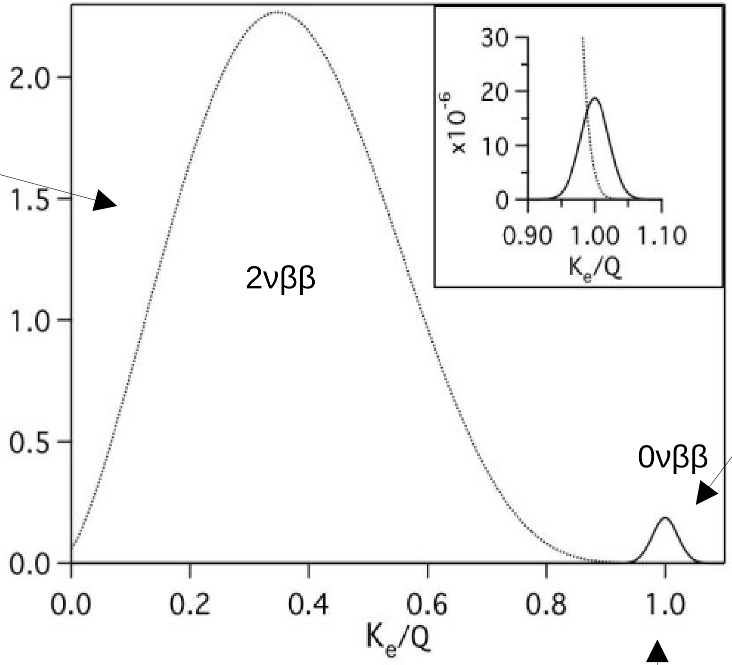
Together with CP violation, could be responsible for leptogenesis: Matter and anti-matter assymetry

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

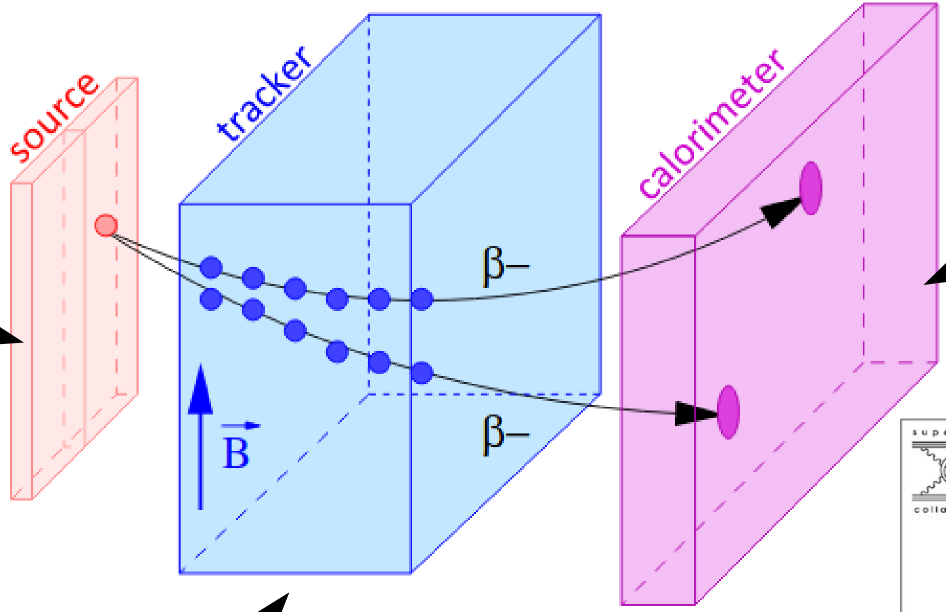


0νββ signal → Need Ultra-low Background experiments

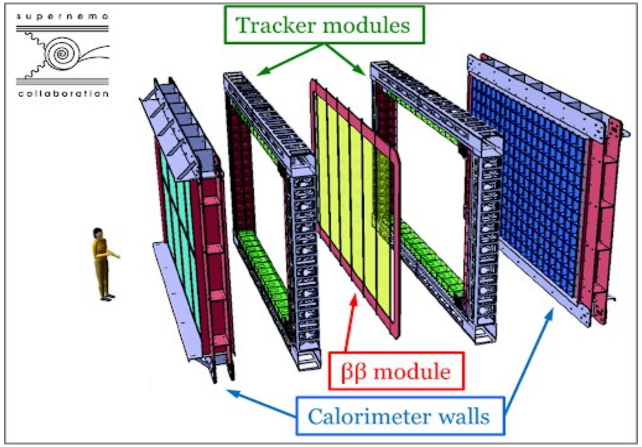
$Q_{\beta\beta}$

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

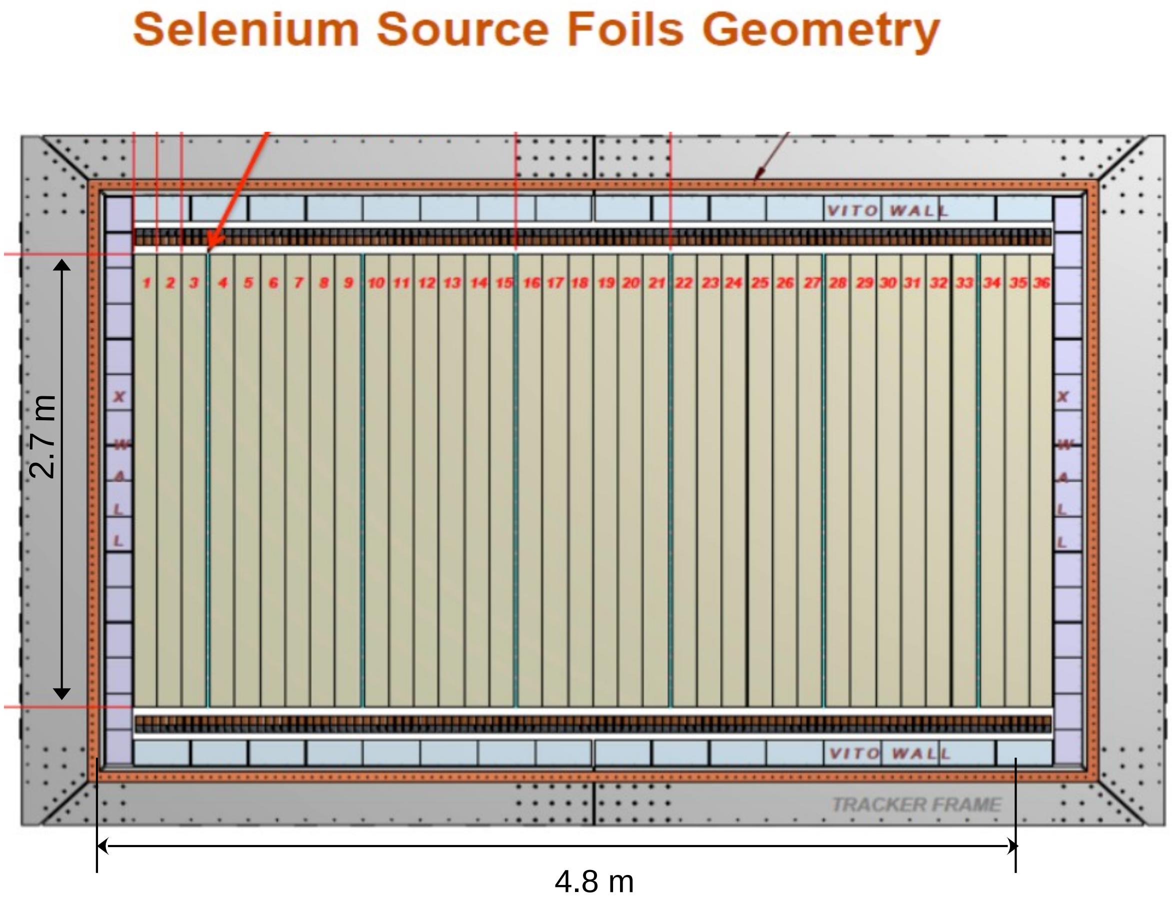
$Q_{\beta\beta}$ = 2.998 MeV $T_{1/2}^{2\nu}$ = 9.4 x 10^{19} y

(NEMO-3)

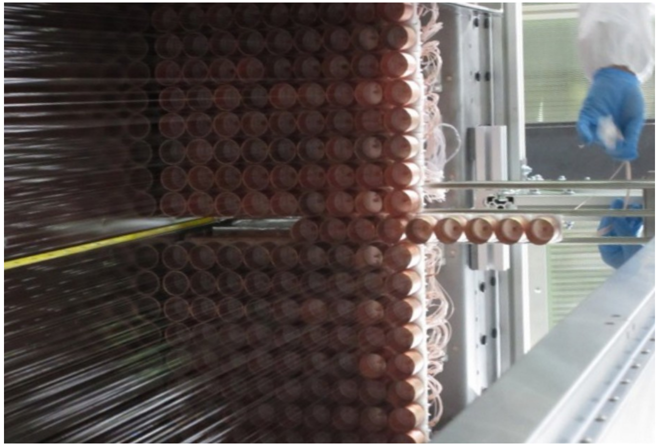
Radio-Purity of ^{82}Se foils	Specifications (µBq/kg)	Measured values for best source using BiPo-3 detector (µBq/kg)
^{208}Tl	< 2	~ 20 ± 10
^{214}Bi	< 10	< 290 at 90% CL

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

For source of demonstrator of 17.5 kg.y exposure



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

Already commissioned
and
data to be analyzed

The SuperNEMO Calorimeter

712 Optical Modules

8” PMTs

↓

Energy resolution 8% FWHM at 1 MeV

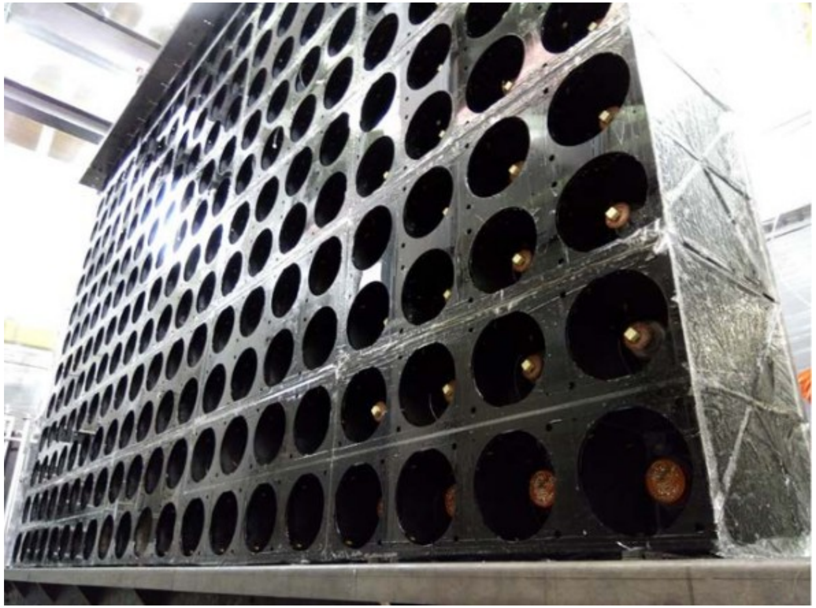
(14% - 17% for NEMO-3)

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%**

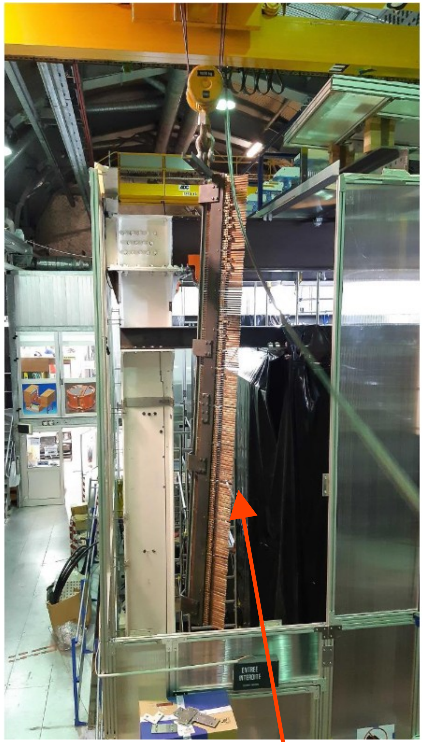
↑

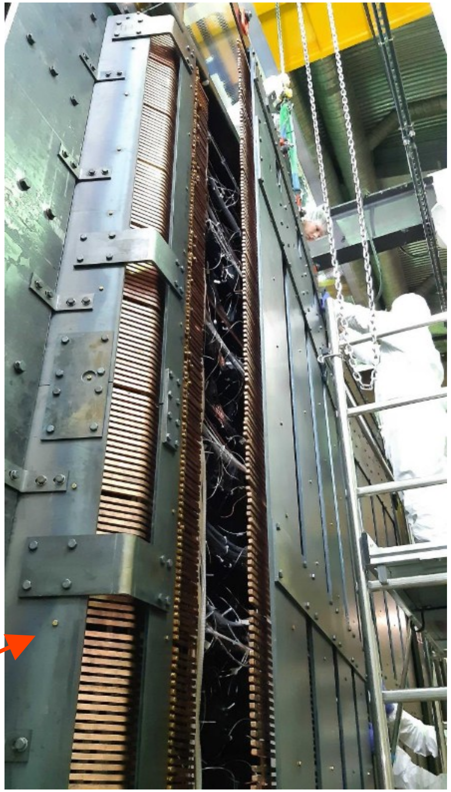
Not the dominant background for 2ν and 0ν search



Operational and taking data since 2018!

SuperNEMO: Hardware Status



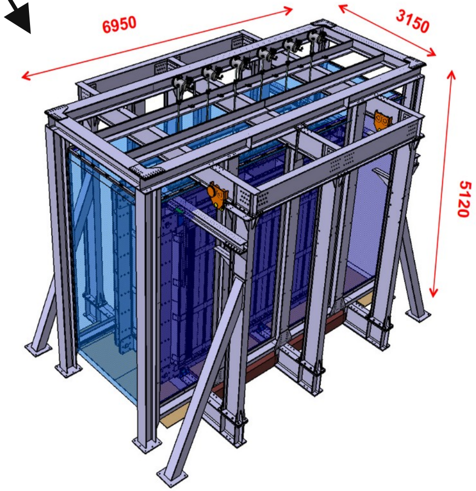


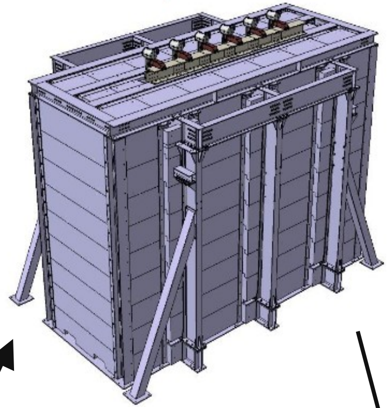
Magnetic field coils
25G

(Summer 2021)

Anti-Radon tent

(~ Beginning 2022)

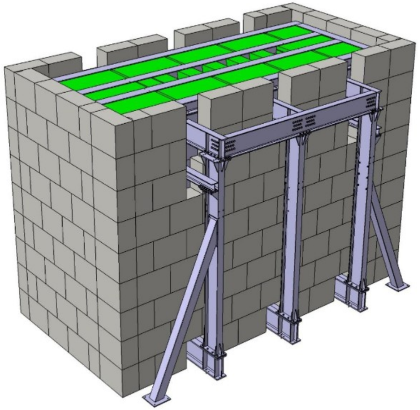




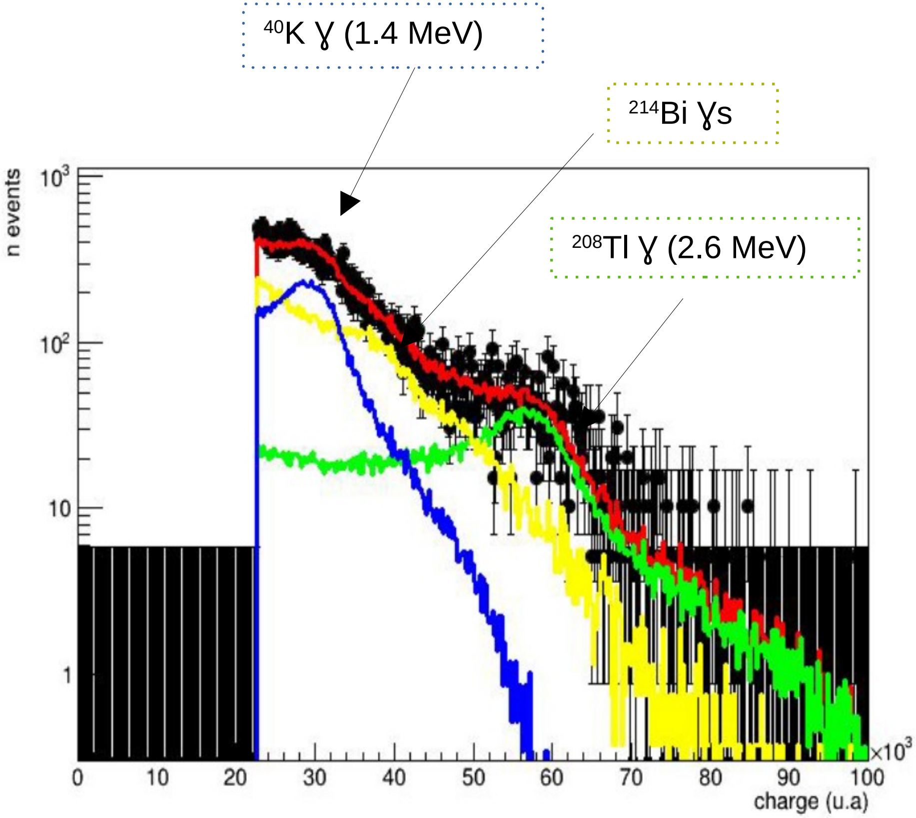
Iron shielding
20 cm

(~ Mid 2022)

Polyethylene water tanks and boron polyethylene plates



Energy Calibration



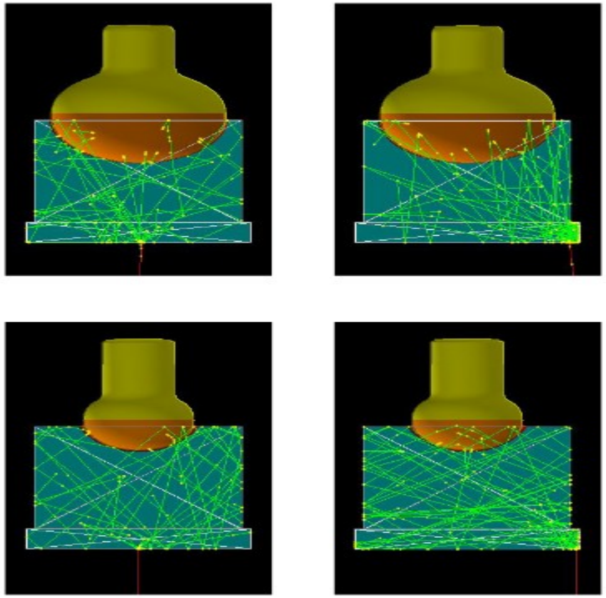
Optical corrections were taken into account:

Non-Linear Effects with Energy:

- Birks Effect
- Cherenkov Effect

Geometrical Corrections:

- Interaction point

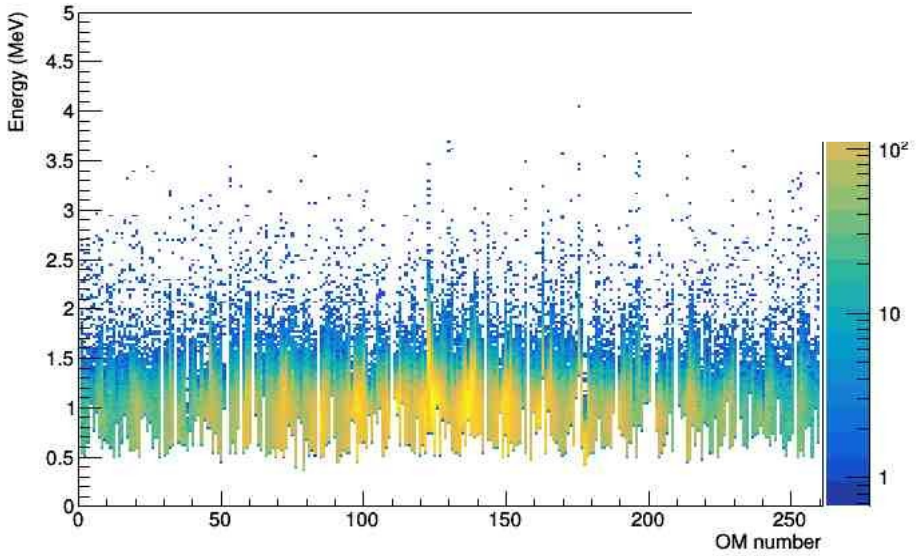


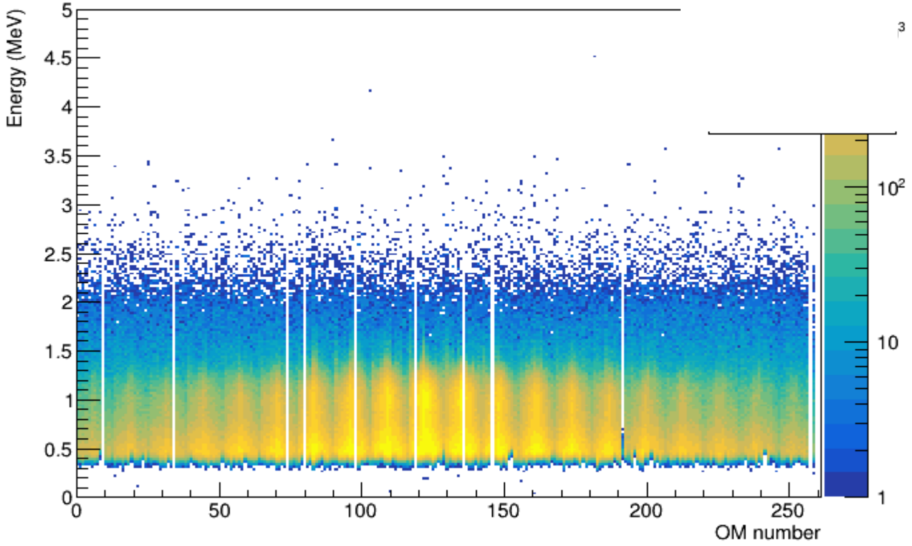
→ Obtain amplitude gain that will be used to adjust HV for each PM

Energy Calibration, First Results

Old results that do not take into account optical corrections

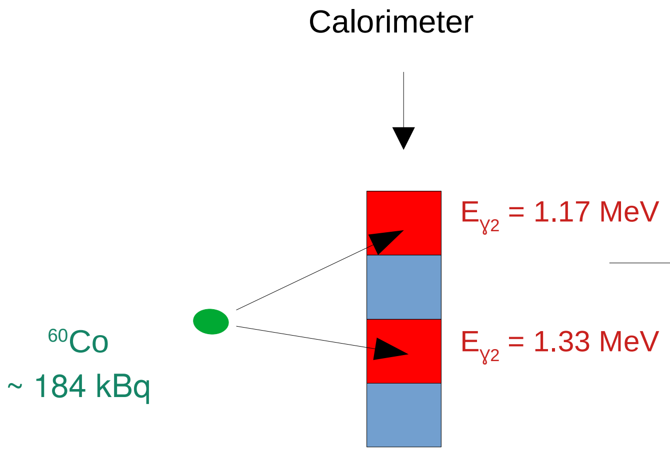
Before correction → After correction



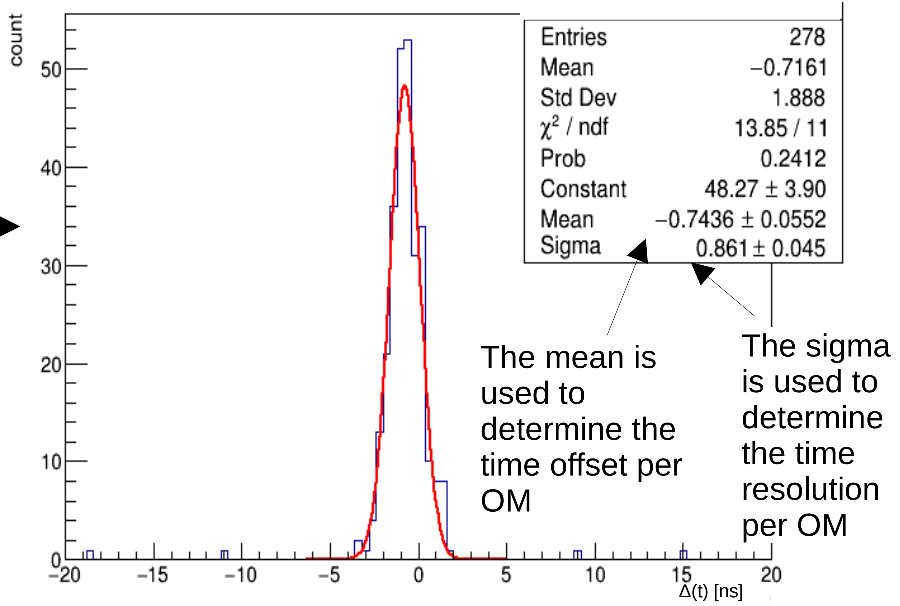


New corrections are expected very soon

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



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



1- **Time resolution:** Using parameters from time coincidences of several OMs, we can retrieve the time resolution per OM

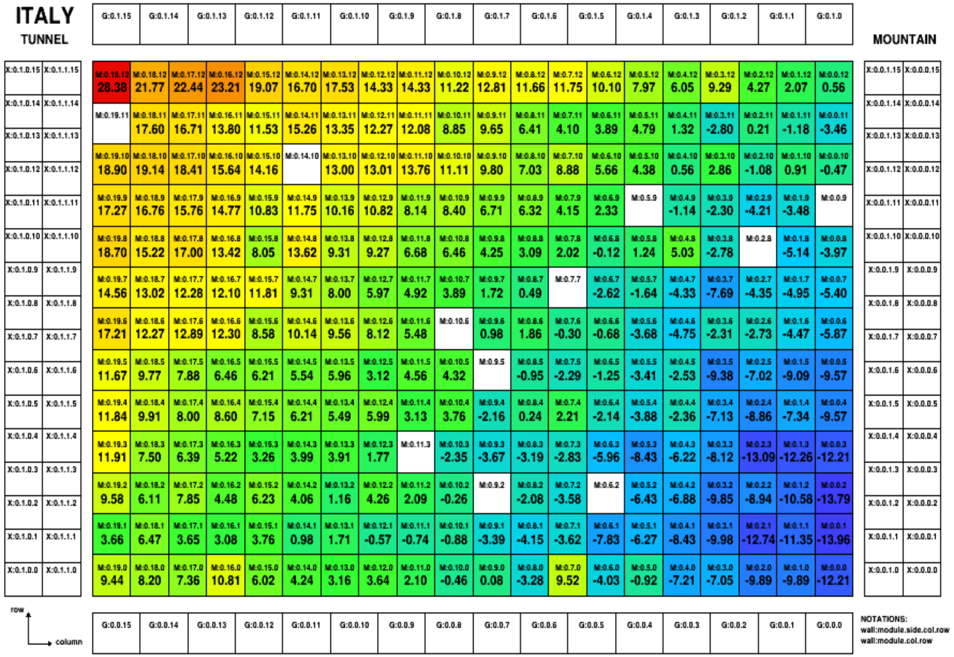
Time resolution for ɣs @ 1MeV for all OMs

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]

→ To be done with e^-s

Time Calibration of OMs Using ^{60}Co Runs

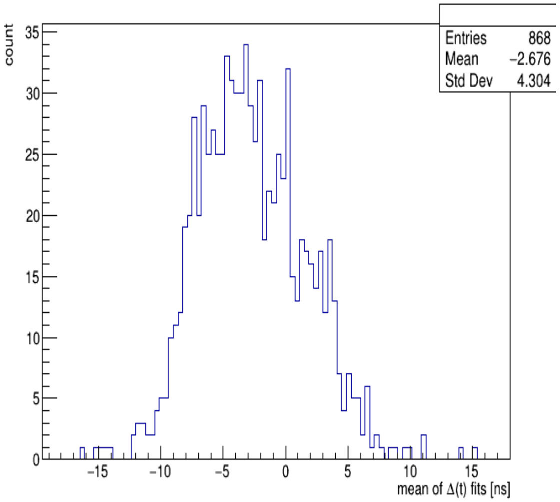
2- Time offset in each OM is unique per OM, it takes into account: cable length + total delays inside (electronics, scintillation time, …)

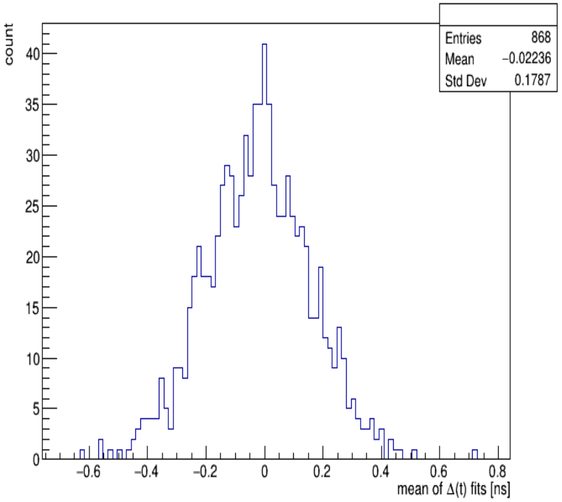


Color scale: Final offset values / OM [ns]

Mean value of Δt distributions

Before correction of offset → After correction of offset

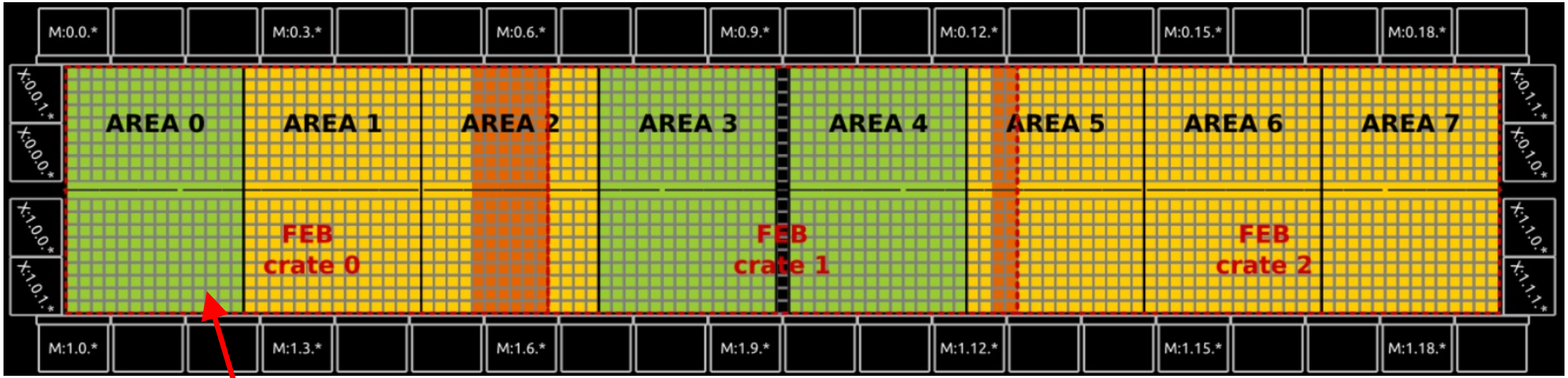




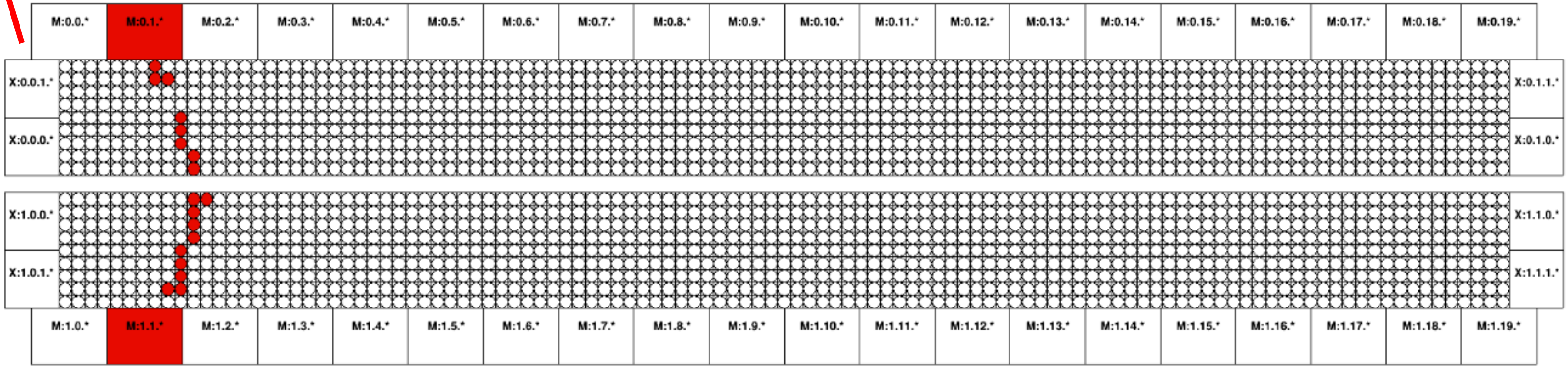
The time calibration performed **achieved <~ 0.2 [ns] precision on timing** after applying the calibration. Enough to reject background using time of flight measurements.

Tracker Commissioning, September 2021

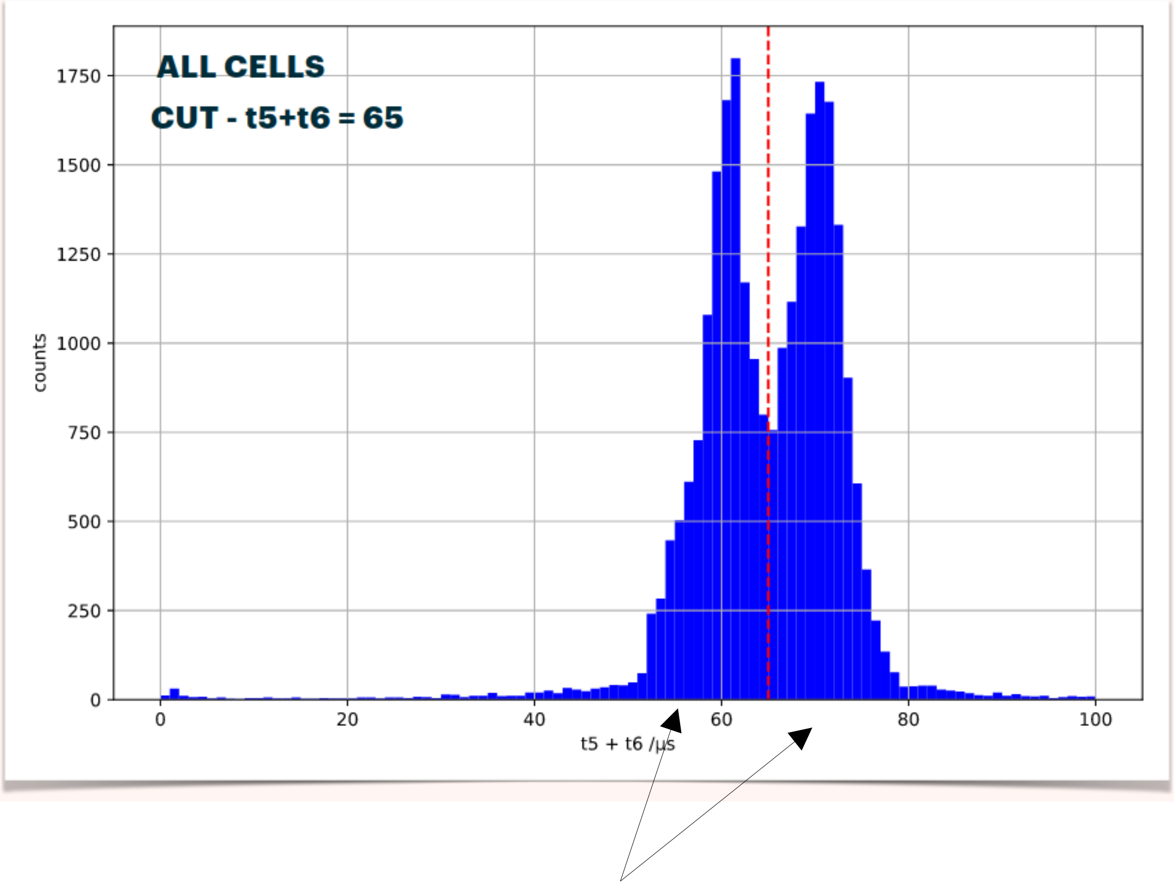
Tracker commissioned in stages due to the arrival of the tracker HV crates → 7 areas commissioned separately



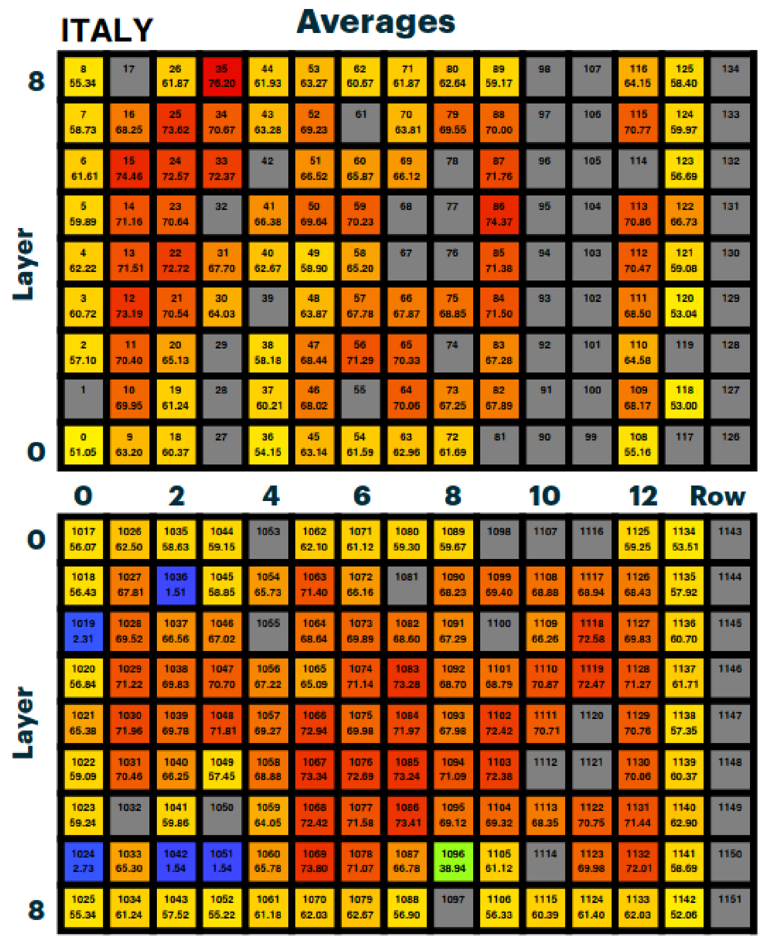
Example tracker + calorimeter signal visualization



Tracker Commissioning, Cathode Drift Time



Effect of neighbouring cell electric field



Color scale: Cathode drift time

Conclusion

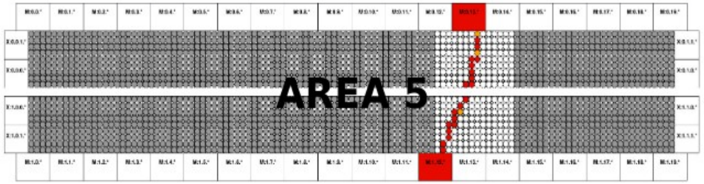
- The calorimeter is commissioned, working and taking data since 2018.

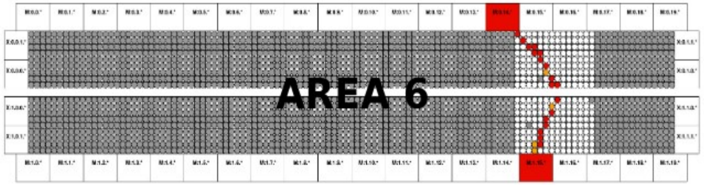
- The tracker is commissioned and taking data since September 2021 -> Data to be analyzed

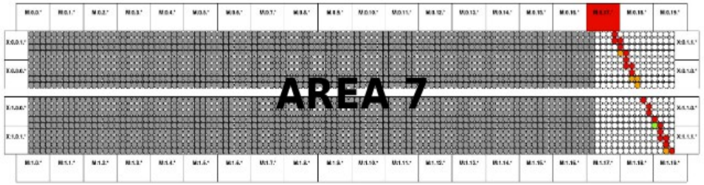
- A time calibration of the calorimeter walls is done.

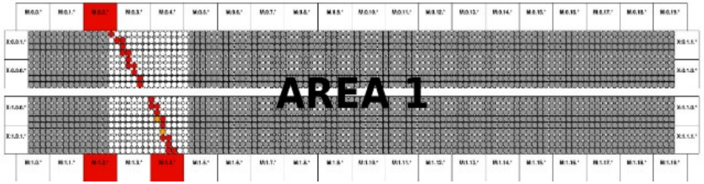
- Preliminary time resolution is extracted for γs @ 1 MeV → To be done with e^-s using ^{207}Bi calibration source .

- Energy Calibration of the Calorimeter walls is done, improvements are being worked on.









END

Backup

Quenching of g_A

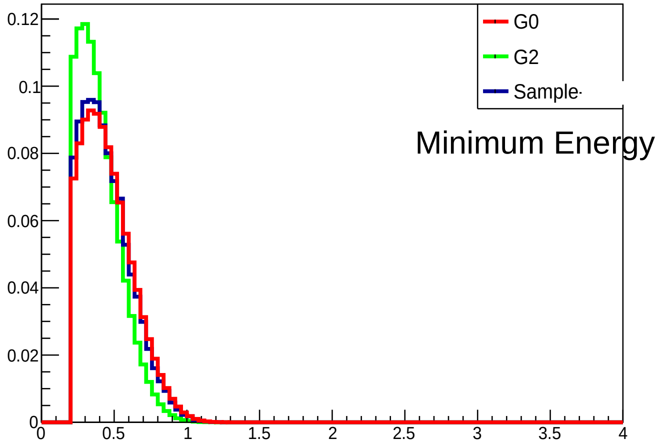
F.Šimkovic et al. Phys. Rev. C 97, 034315 (2018)

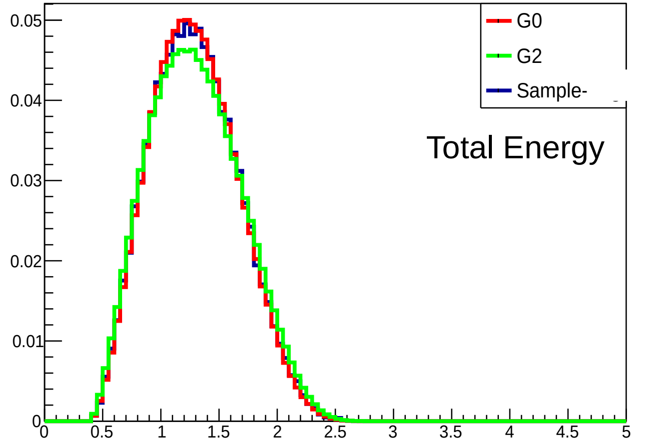
$$\left[T_{1/2}^{2\nu\beta\beta}\right]^{-1} \simeq \left(g_A^{eff}\right)^4 \left[M_{GT-3}^{2\nu}\right]^2 \frac{1}{\left[\xi_{31}^{2\nu}\right]^2}\left(G_0^{2\nu} + \xi_{31}^{2\nu} G_2^{2\nu}\right)$$

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





G_A Analysis and the ξ_{31} Factor

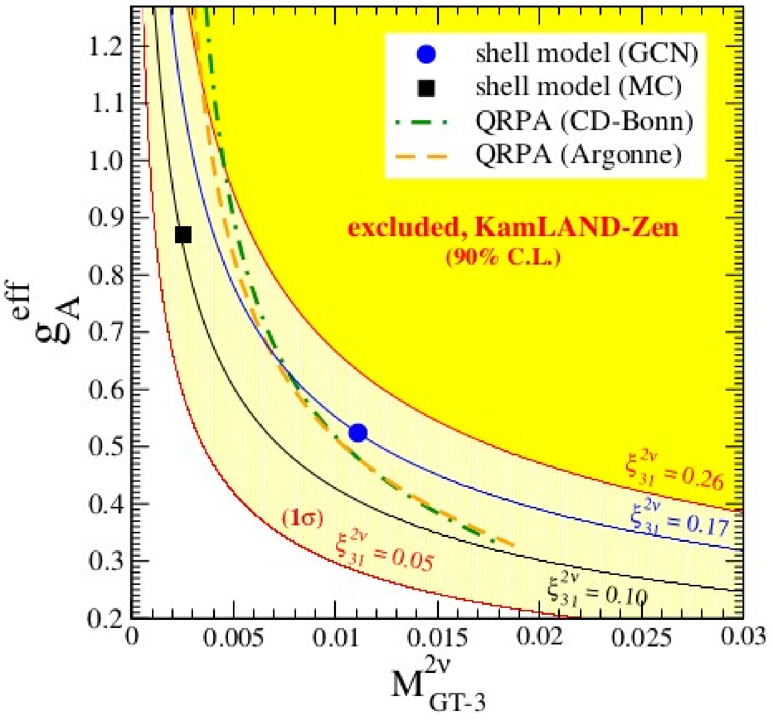


FIG. 3: Effective axial-vector coupling g_A^{eff} as a function of the matrix element $M^{2\nu}_{GT-3}$ for ^{136}Xe $2\nu\beta\beta$ decay. The yellow (light yellow) region $\xi^{2\nu}_{31} < 0.26$ (0.05) is excluded by the present KamLAND-Zen measurement at 90% (1σ) C.L. Nuclear shell model results 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