SuperNEMO

Demonstrator Commissioning Status Update

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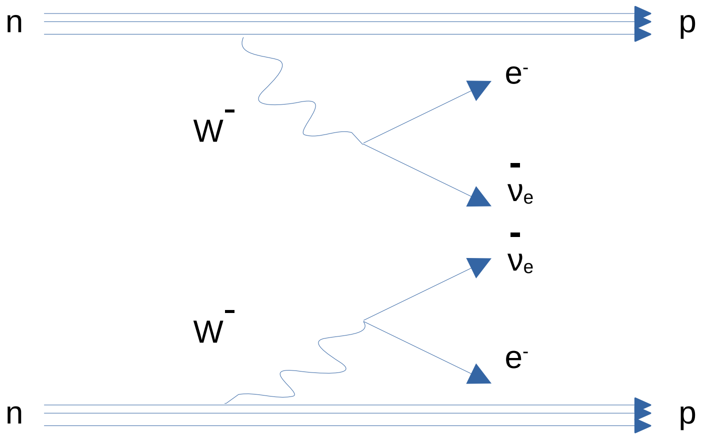
On Behalf of the SuperNEMO Collaboration

July 15, 2022

Neutrinoless Double Beta Decay: A Hypothetical Radioactive Process

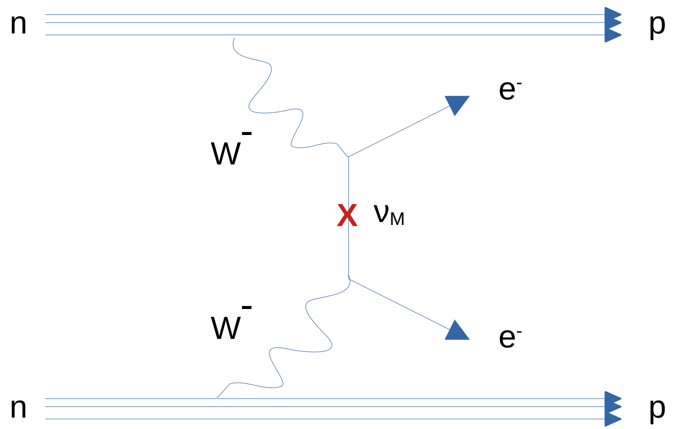
Two neutrino double beta decay



Observed for 12 isotopes

$\nu \overset{?}{\equiv} \overline{\nu}$ → **0νββ**

Zero neutrino double beta decay



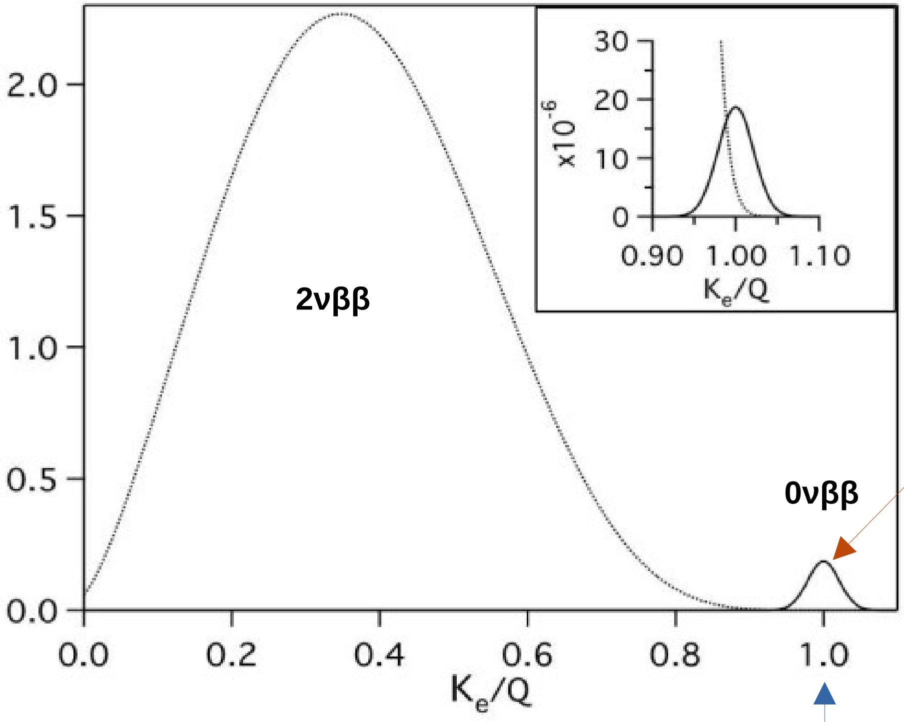
Forbidden by the Standard Model
Not observed

0νββ —$T^{0\nu}_{1/2} > 10^{24} - 10^{26}$→ Proves Majorana nature of **ν**s → + CP violation → leptogenesis

MATTER CREATION

0νββ Signal Detection: Requisites (Other than Actually Existing…)

We need a double beta isotope



$Q_{\beta\beta}$

0νββ signal

Need Ultra-low Background experiments

+

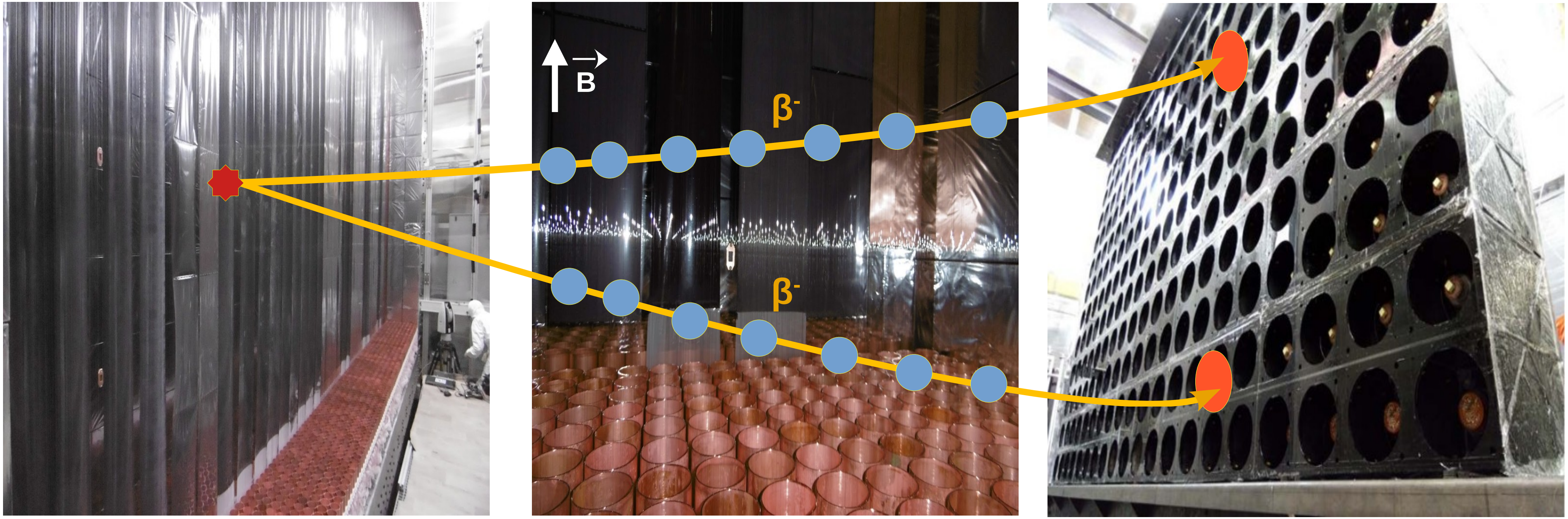
Good energy resolution

SuperNEMO: Tracker-Calorimeter Detection Principle

6.23 kg ^{82}**Se**
$Q_{\beta\beta}$ = 2.998 MeV
NEMO-3 : $T_{1/2}^{2\nu}$ = 9.4 x 10^{19} y

3D reconstruction of charged particle tracks

Measure individual particle energies



Exposure 17.5 kg.y

Ultra low Background
< 10^{-4} events/keV/kg.yr

$T^{0\nu}_{1/2}$ > 4 * 10^{24} y
$\langle m_\nu \rangle$ < (260 – 500) meV (90% CL)

Where is SuperNEMO?

At LSM

→

Under Frejus Mountain

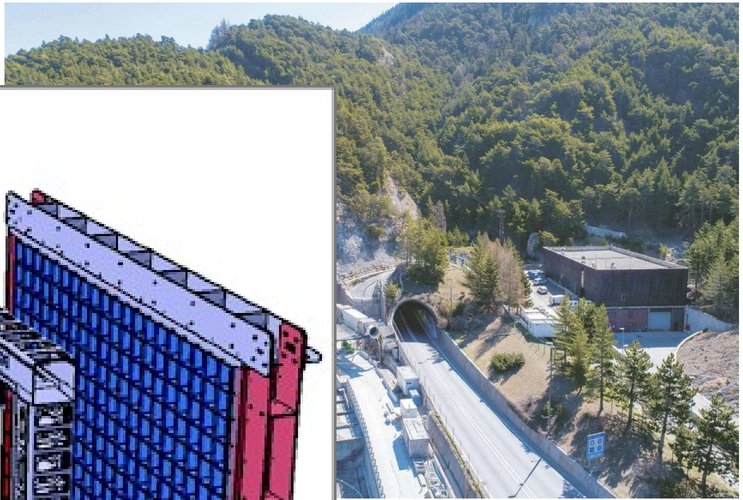
Inside the tunnel

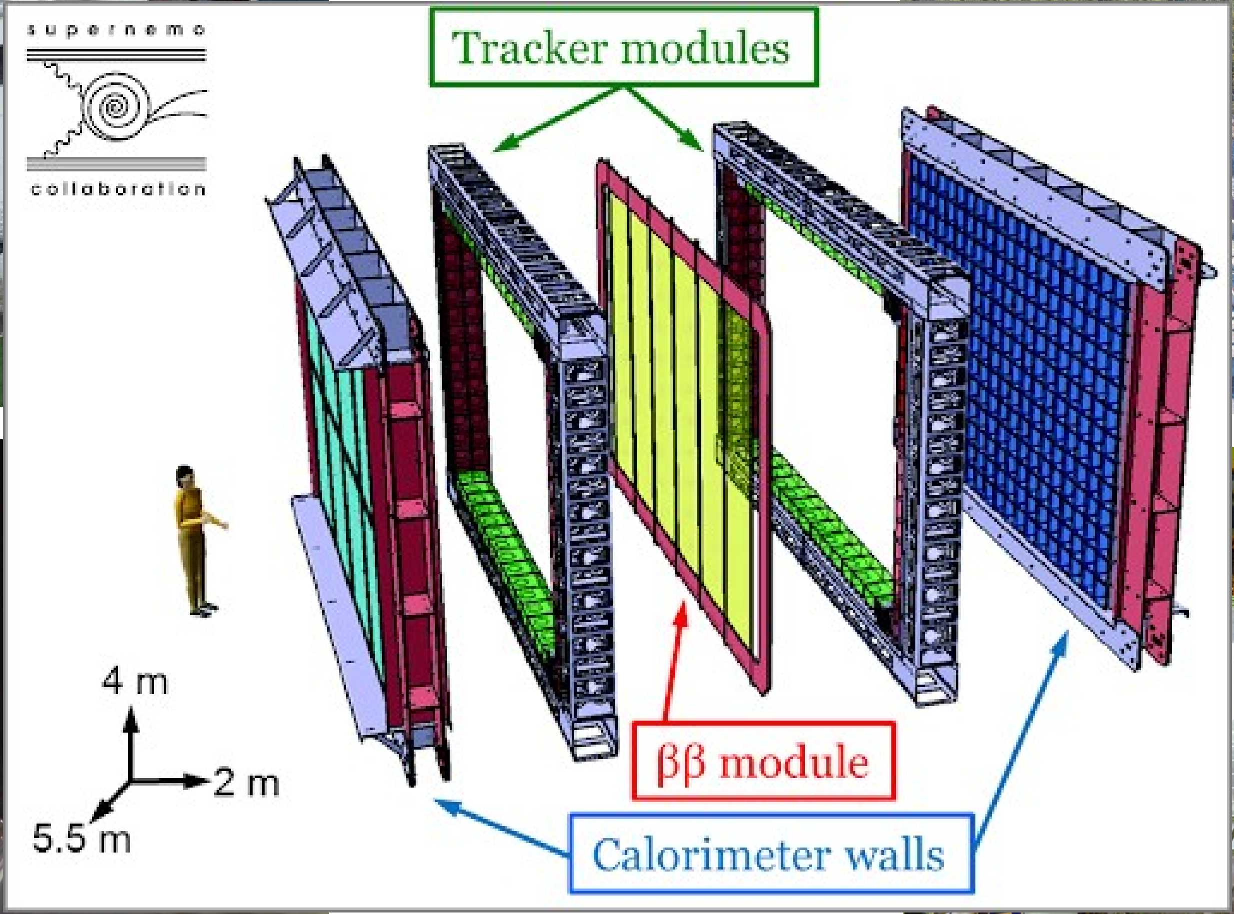
Inside a clean tent

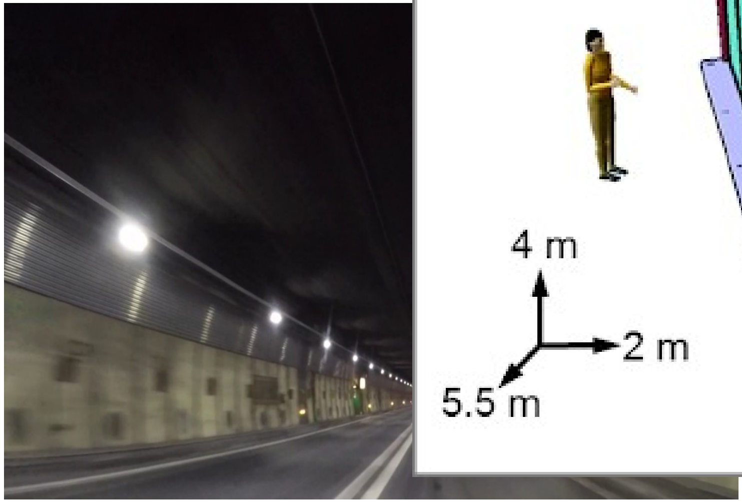
→

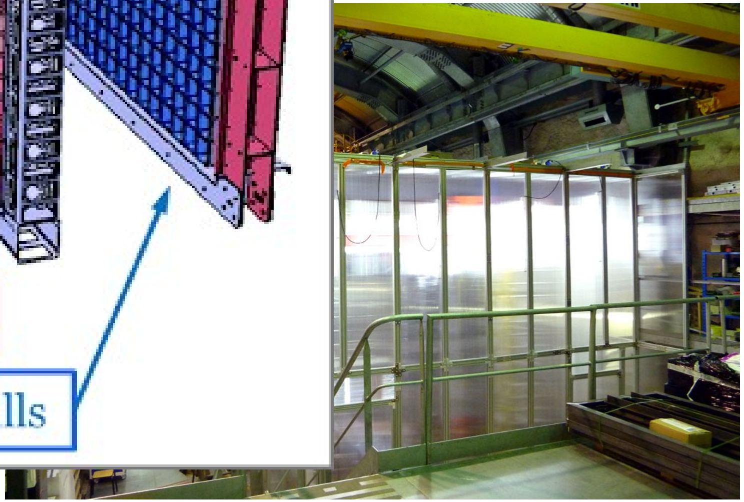
~ 4800 m.w.e

SuperNEMO: The Missing Picture









SuperNEMO: Searching and Setting Constraints

Single energy spectrum
+
Angular distribution

0νββ Search → Double beta decay mechanisms (Light Majorana neutrino, right handed currents, ...)

2νββ Study → Quenching of axial-vector coupling constant (g_A)

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

→ Higher State Dominance & Single State Dominance

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

Gives information

The Calorimeter

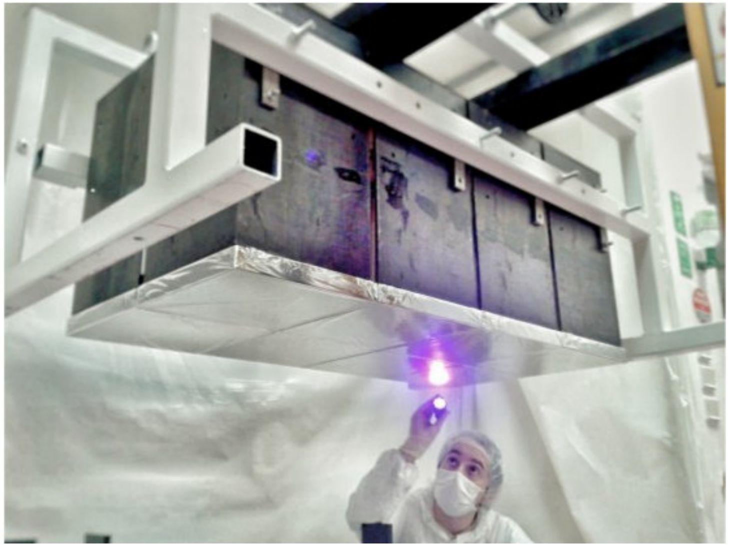
712 Optical Modules

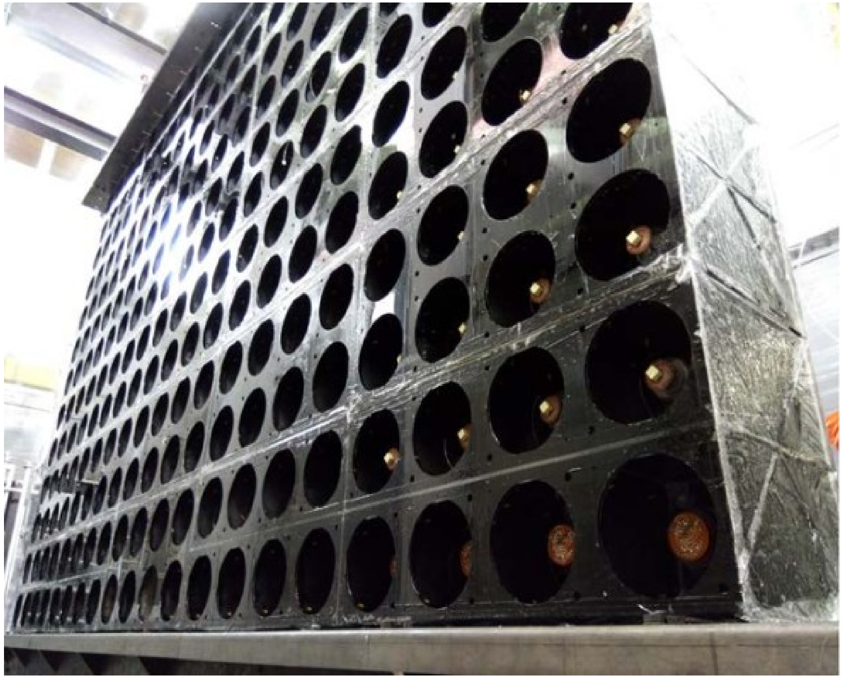
272 → 5” PMTs

440 → 8” PMTs

8” PMTs → 8% FWHM at 1 MeV

8” PMTs → < 400 ps for electrons @ 1 MeV





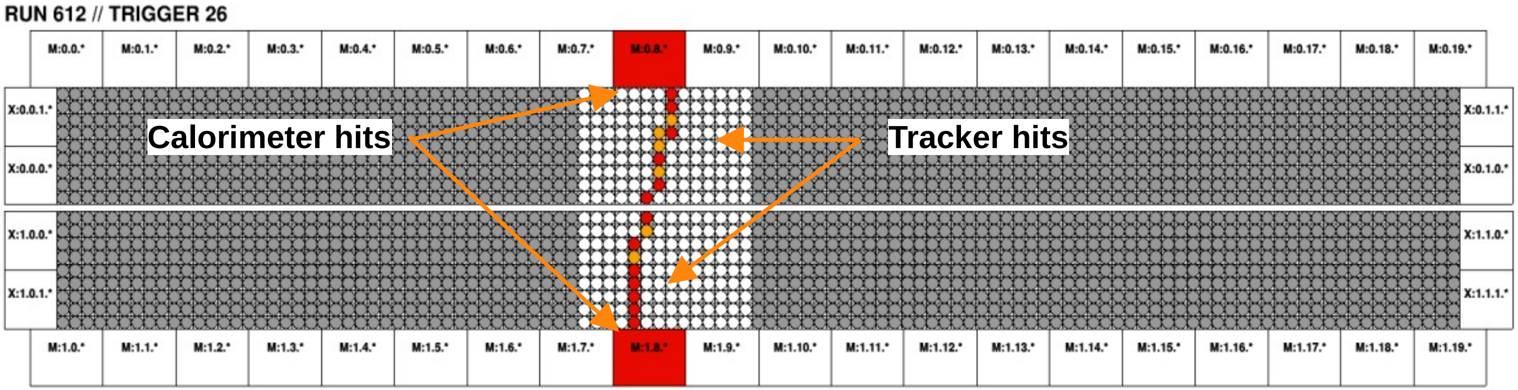
Commissioned in 2018

The Tracker

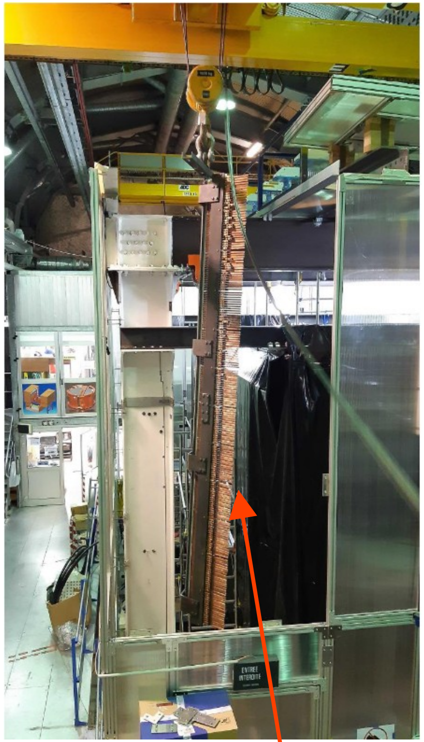
2034 drift cells operating in Geiger mode

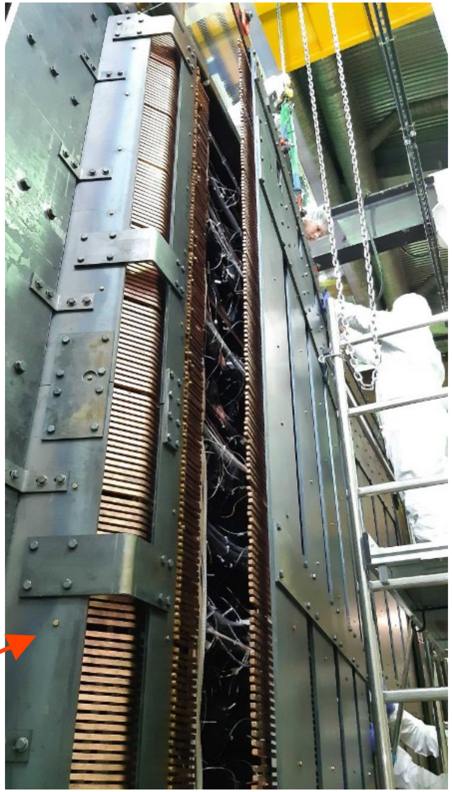
3D reconstruction of charged particle tracks ($\mu^{\pm}$, $e^{\pm}$, α)

First tracks observed in summer 2021



Hardware Status



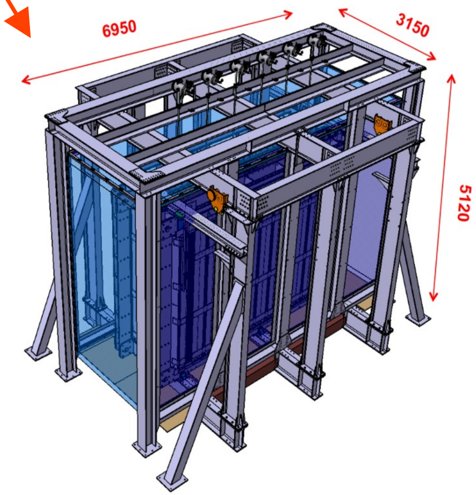


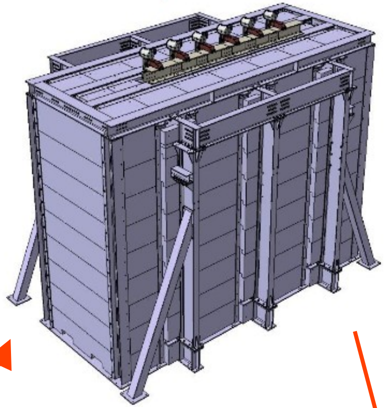
Magnetic field coil
25G

(Summer 2021)

Anti-Radon tent

(End 2022)

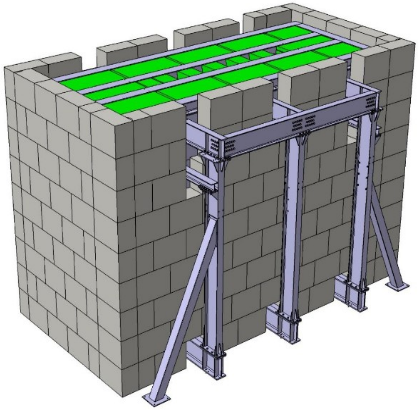


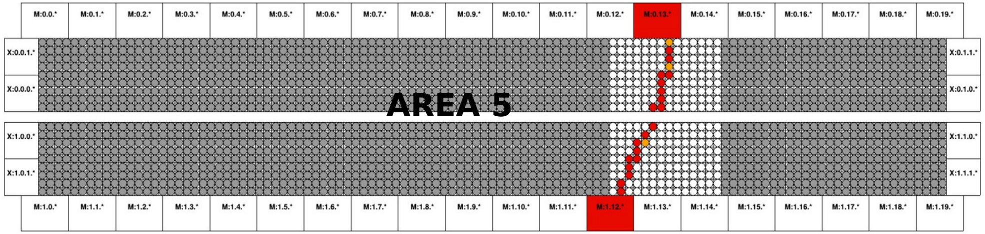


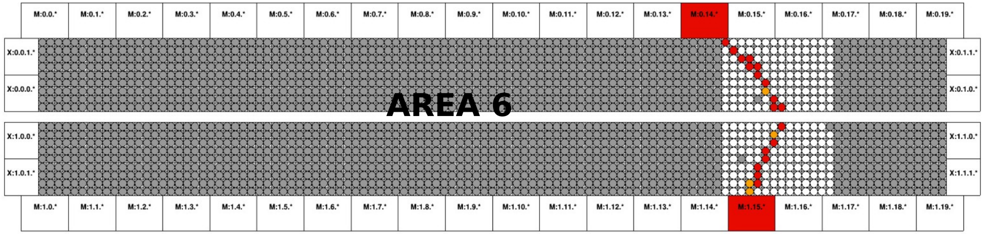
Iron shielding
20 cm

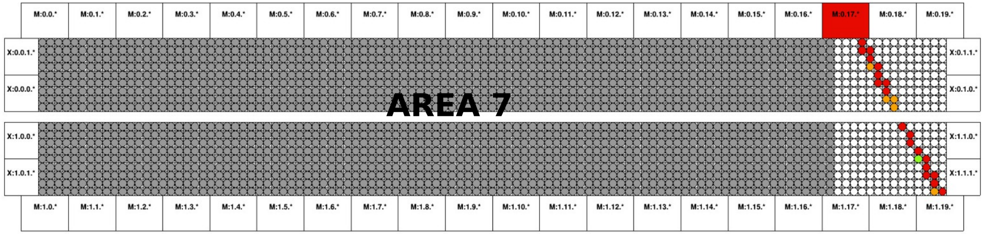
(~ Mid 2023)

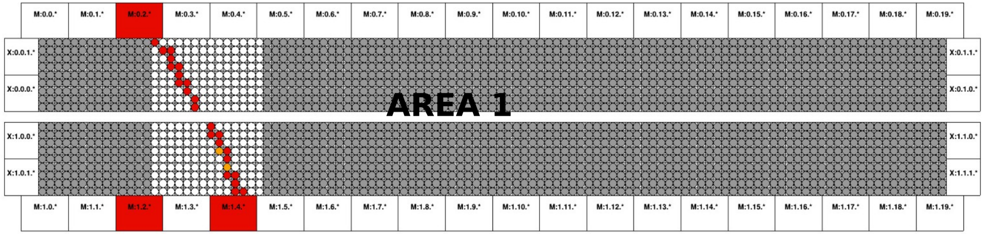
Polyethylene water tanks and boron polyethylene plates





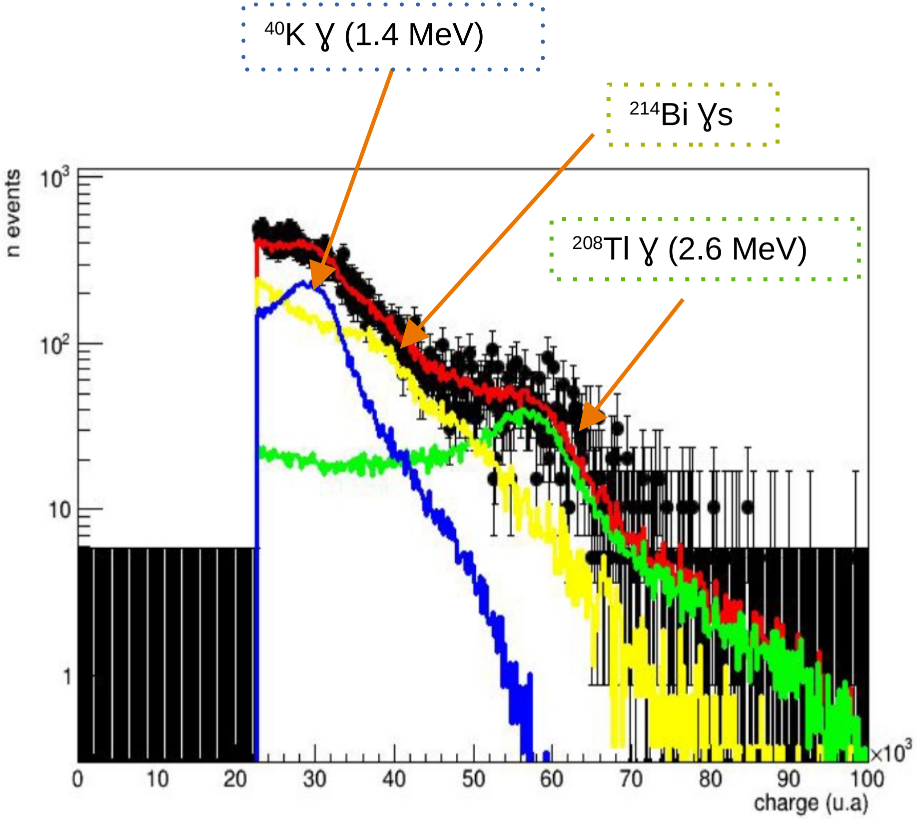






Detector Commissioning and Calibration

Energy Calibration: **First Approach** Method – Background Fitting



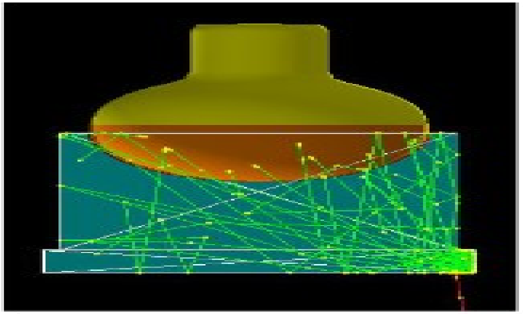
Optical corrections were taken into account:

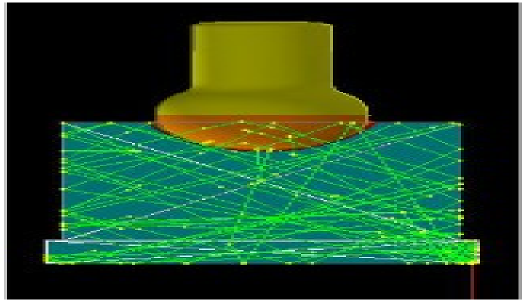
Non-Linear Effects with Energy:

- Birks Effect
- Cherenkov Effect

Geometrical Corrections:

- Interaction point

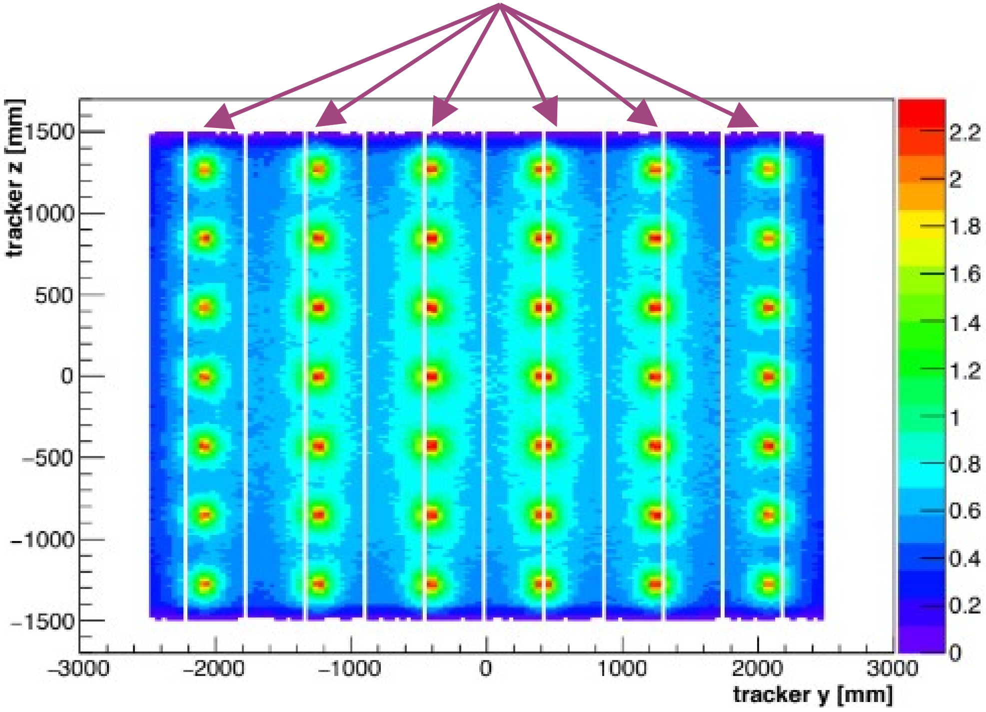




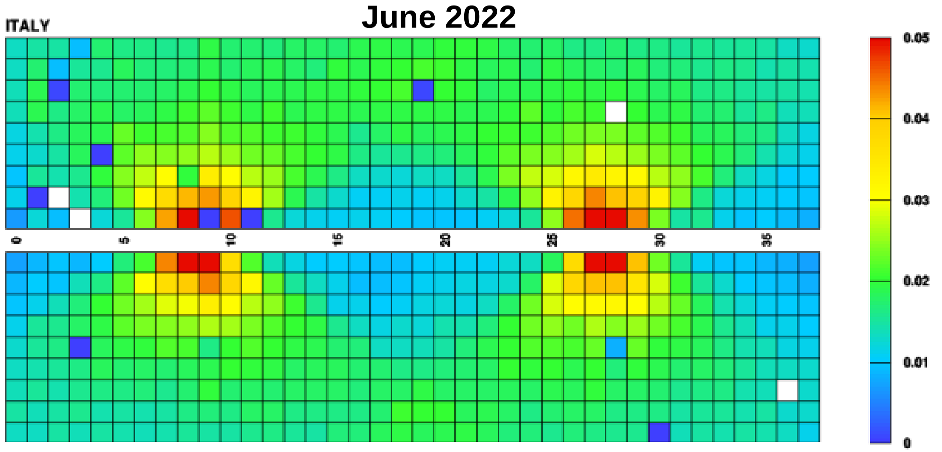
→ Obtain amplitude gain that will be used to adjust HV for each PM

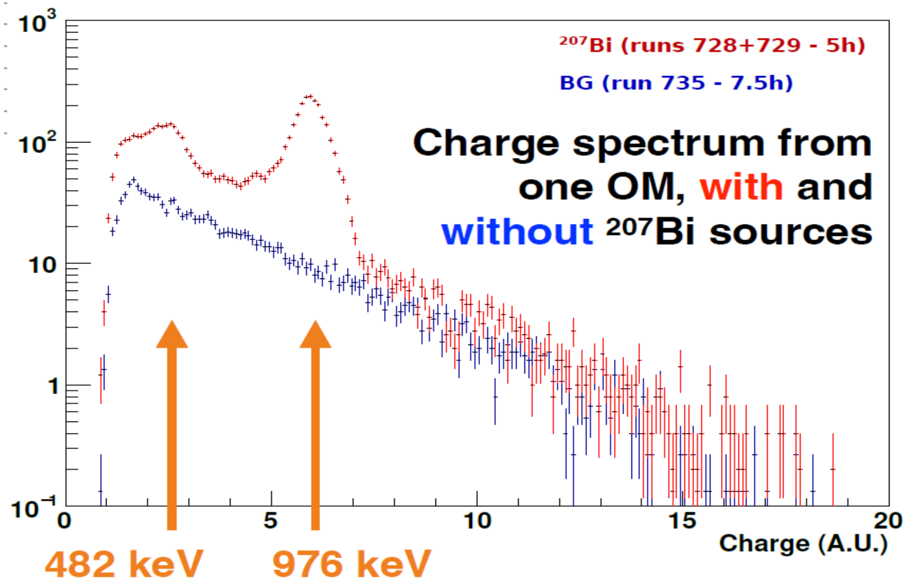
Energy Calibration: Intended Method → **To be Done**

^{207}Bi sources that can be automatically deployed



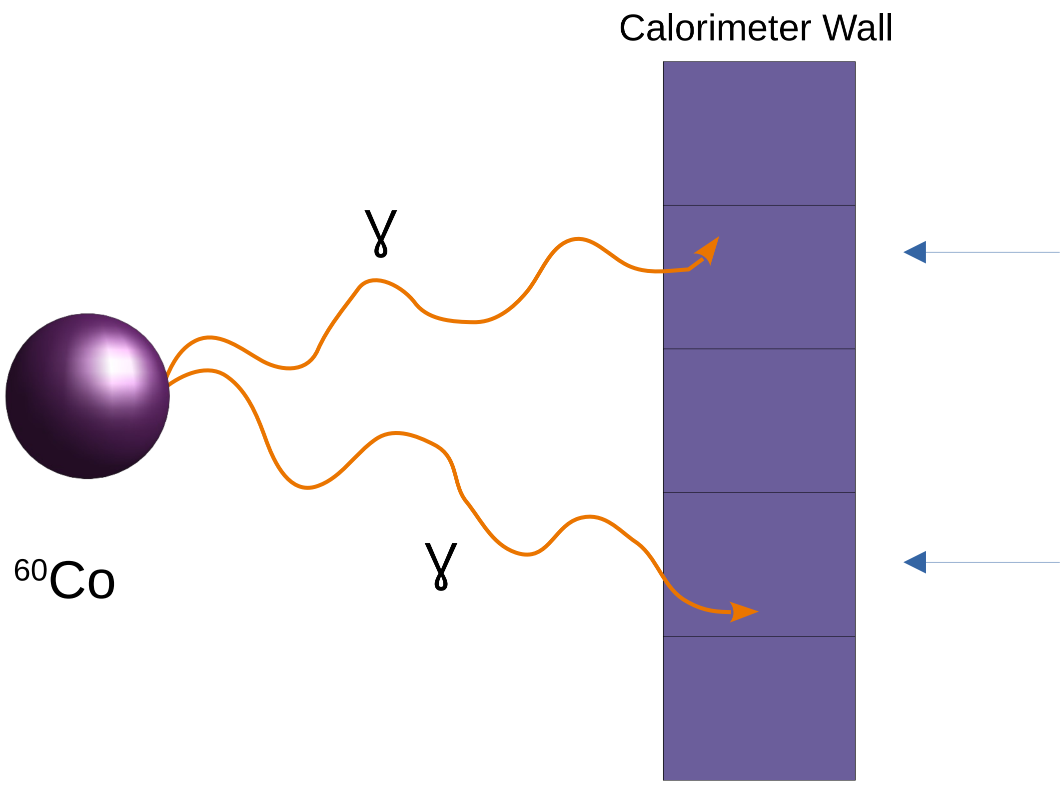
Upper view of the tracker hits with the sources deployed

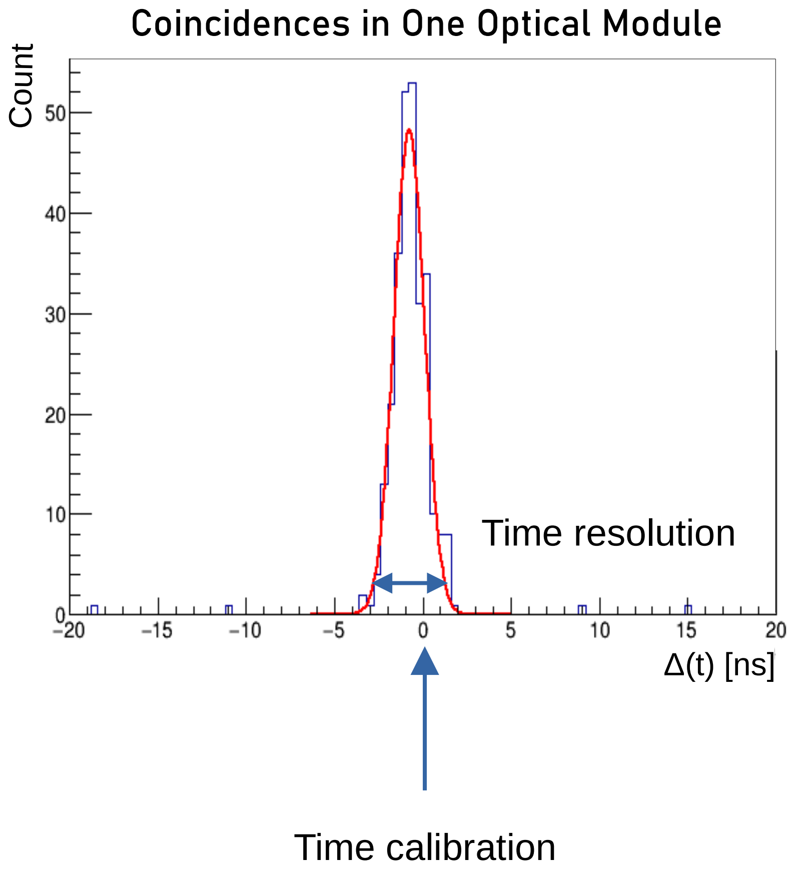




Perform calibration with the two internal conversion electrons of ^{207}Bi

Time Characterization of Optical Modules Using γs





No shielding installed yet ; Tracker was not commissioned

Time Resolution of Optical Modules Using ɣs

σ_t (ɣ @ 1 MeV)= 0.614 ± 0.002 (stat) + 0.064 (sys) [ns]

M:0.19.11	M:0.18.11 0.42	M:0.17.11 0.51	M:0.16.11 0.69	M:0.15.11 0.60	M:0.14.11 0.60	M:0.13.11 0.67	M:0.12.11 0.61	M:0.11.11 0.63	M:0.10.11 0.55	M:0.9.11 0.53	M:0.8.11 0.56	M:0.7.11 0.61	M:0.6.11 0.56	M:0.5.11 0.70	M:0.4.11 0.63	M:0.3.11 0.66	M:0.2.11 0.45	M:0.1.11 0.58	M:0.0.11 0.66
M:0.19.10 0.70	M:0.18.10 0.60	M:0.17.10 0.52	M:0.16.10 0.69	M:0.15.10 0.62	M:0.14.10	M:0.13.10 0.72	M:0.12.10 0.62	M:0.11.10 0.56	M:0.10.10 0.67	M:0.9.10 0.60	M:0.8.10 0.68	M:0.7.10 0.55	M:0.6.10 0.73	M:0.5.10 0.58	M:0.4.10 0.64	M:0.3.10 0.64	M:0.2.10 0.59	M:0.1.10 0.53	M:0.0.10 0.54
M:0.19.9 0.61	M:0.18.9 0.63	M:0.17.9 0.57	M:0.16.9 0.69	M:0.15.9 0.70	M:0.14.9 0.60	M:0.13.9 0.71	M:0.12.9 0.46	M:0.11.9 0.55	M:0.10.9 0.53	M:0.9.9 0.46	M:0.8.9 0.66	M:0.7.9 0.64	M:0.6.9 0.65	M:0.5.9	M:0.4.9 0.68	M:0.3.9 0.55	M:0.2.9 0.49	M:0.1.9 0.49	M:0.0.9
M:0.19.8 0.62	M:0.18.8 0.86	M:0.17.8 0.61	M:0.16.8 0.69	M:0.15.8 0.66	M:0.14.8 0.56	M:0.13.8 0.51	M:0.12.8 0.65	M:0.11.8 0.58	M:0.10.8 0.51	M:0.9.8 0.63	M:0.8.8 0.61	M:0.7.8 0.57	M:0.6.8 0.66	M:0.5.8 0.66	M:0.4.8 0.63	M:0.3.8 0.68	M:0.2.8	M:0.1.8 0.40	M:0.0.8 0.52
M:0.19.7 0.52	M:0.18.7 0.56	M:0.17.7 0.50	M:0.16.7 0.50	M:0.15.7 0.59	M:0.14.7 0.50	M:0.13.7 0.73	M:0.12.7 0.63	M:0.11.7 0.54	M:0.10.7 0.58	M:0.9.7 0.60	M:0.8.7 0.51	M:0.7.7	M:0.6.7 0.51	M:0.5.7 0.63	M:0.4.7 0.64	M:0.3.7 0.62	M:0.2.7 0.69	M:0.1.7 0.57	M:0.0.7 0.56
M:0.19.6 0.51	M:0.18.6 0.54	M:0.17.6 0.57	M:0.16.6 0.64	M:0.15.6 0.53	M:0.14.6 0.62	M:0.13.6 0.66	M:0.12.6 0.65	M:0.11.6 0.56	M:0.10.6	M:0.9.6 0.55	M:0.8.6 0.66	M:0.7.6 0.62	M:0.6.6 0.57	M:0.5.6 0.64	M:0.4.6 0.63	M:0.3.6 0.65	M:0.2.6 0.66	M:0.1.6 0.60	M:0.0.6 0.59
M:0.19.5 0.63	M:0.18.5 0.57	M:0.17.5 0.72	M:0.16.5 0.62	M:0.15.5 0.66	M:0.14.5 0.60	M:0.13.5 0.55	M:0.12.5 0.62	M:0.11.5 0.53	M:0.10.5 0.47	M:0.9.5 0.55	M:0.8.5 0.51	M:0.7.5 0.63	M:0.6.5 0.62	M:0.5.5 0.53	M:0.4.5 0.67	M:0.3.5 0.61	M:0.2.5 0.51	M:0.1.5 0.55	M:0.0.5 0.44
M:0.19.4 0.75	M:0.18.4 0.67	M:0.17.4 0.61	M:0.16.4 0.56	M:0.15.4 0.60	M:0.14.4 0.61	M:0.13.4 0.64	M:0.12.4 0.58	M:0.11.4 0.67	M:0.10.4 0.68	M:0.9.4 0.66	M:0.8.4 0.67	M:0.7.4 0.58	M:0.6.4 0.55	M:0.5.4 0.60	M:0.4.4 0.79	M:0.3.4 0.58	M:0.2.4 0.58	M:0.1.4 0.39	M:0.0.4 0.60
M:0.19.3 0.74	M:0.18.3 0.72	M:0.17.3 0.37	M:0.16.3 0.43	M:0.15.3 0.57	M:0.14.3 0.52	M:0.13.3 0.64	M:0.12.3 0.68	M:0.11.3	M:0.10.3 0.64	M:0.9.3 0.54	M:0.8.3 0.59	M:0.7.3 0.63	M:0.6.3 0.64	M:0.5.3 0.48	M:0.4.3 0.59	M:0.3.3 0.67	M:0.2.3 0.43	M:0.1.3 0.48	M:0.0.3 0.64
M:0.19.2 0.55	M:0.18.2 0.67	M:0.17.2 0.54	M:0.16.2 0.74	M:0.15.2 0.58	M:0.14.2 0.62	M:0.13.2 0.51	M:0.12.2 0.56	M:0.11.2 0.64	M:0.10.2 0.64	M:0.9.2	M:0.8.2 0.67	M:0.7.2 0.64	M:0.6.2	M:0.5.2 0.53	M:0.4.2 0.65	M:0.3.2 0.64	M:0.2.2 0.56	M:0.1.2 0.60	M:0.0.2 0.58
M:0.19.1 0.52	M:0.18.1 0.66	M:0.17.1 0.50	M:0.16.1 0.67	M:0.15.1 0.68	M:0.14.1 0.56	M:0.13.1 0.46	M:0.12.1 0.62	M:0.11.1 0.62	M:0.10.1 0.55	M:0.9.1 0.58	M:0.8.1 0.62	M:0.7.1 0.61	M:0.6.1 0.69	M:0.5.1 0.66	M:0.4.1 0.65	M:0.3.1 0.55	M:0.2.1 0.62	M:0.1.1 0.73	M:0.0.1 0.69

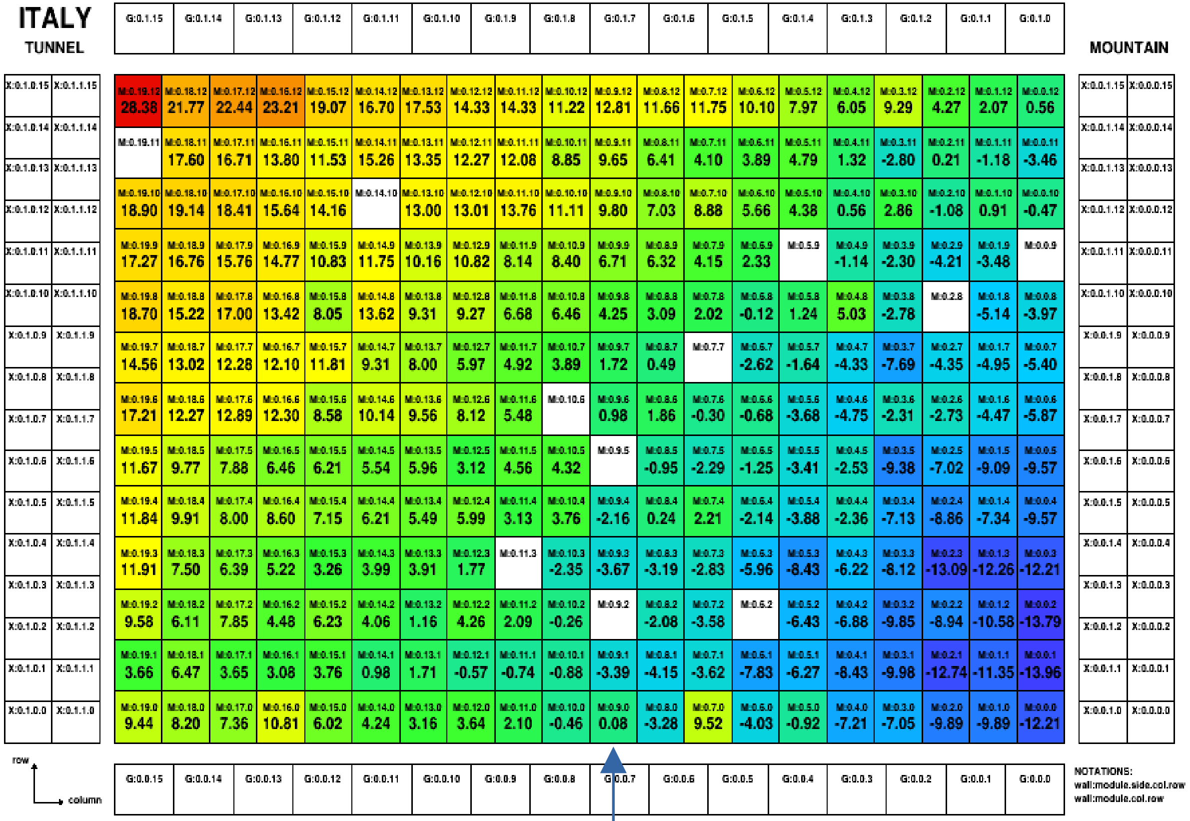
Color: Time resolution [ns]

Using e^- s from ^{207}Bi calibration sources

$\sigma_t^{Expected}$ (e^- @ 1 MeV) < 400 ps

No shielding installed yet ; Tracker was not commissioned

Time Calibration of Optical Modules Using ɣs



Color: Time delay [ns]

Scintillator blocks

The time calibration performed using ɣs **achieved < 0.2 [ns] precision on timing** after applying the calibration.

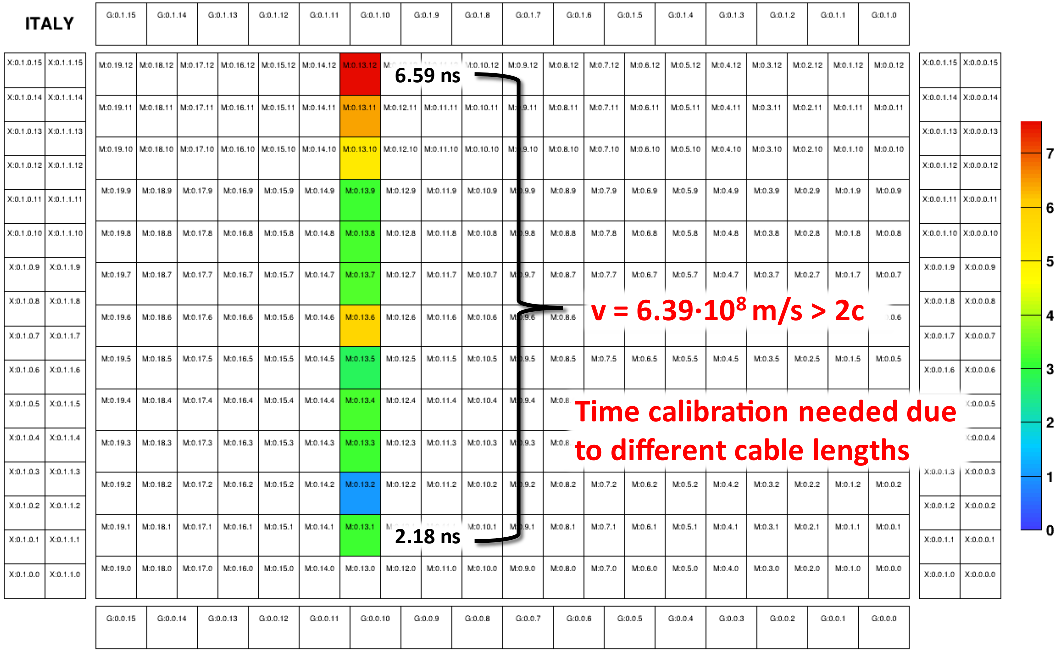
Enough to reject background using time of flight measurements.

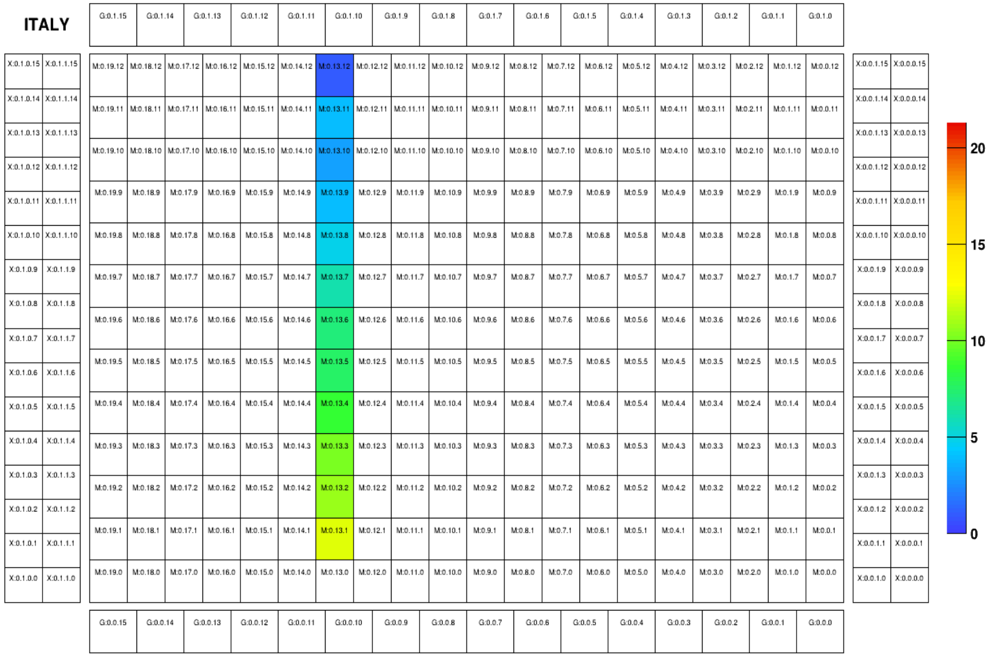
No shielding installed yet ; Tracker was not commissioned

No time calibration applied → **Time calibration applied**

time scheme of a passing muon

run 553 – time scheme of a passing muon



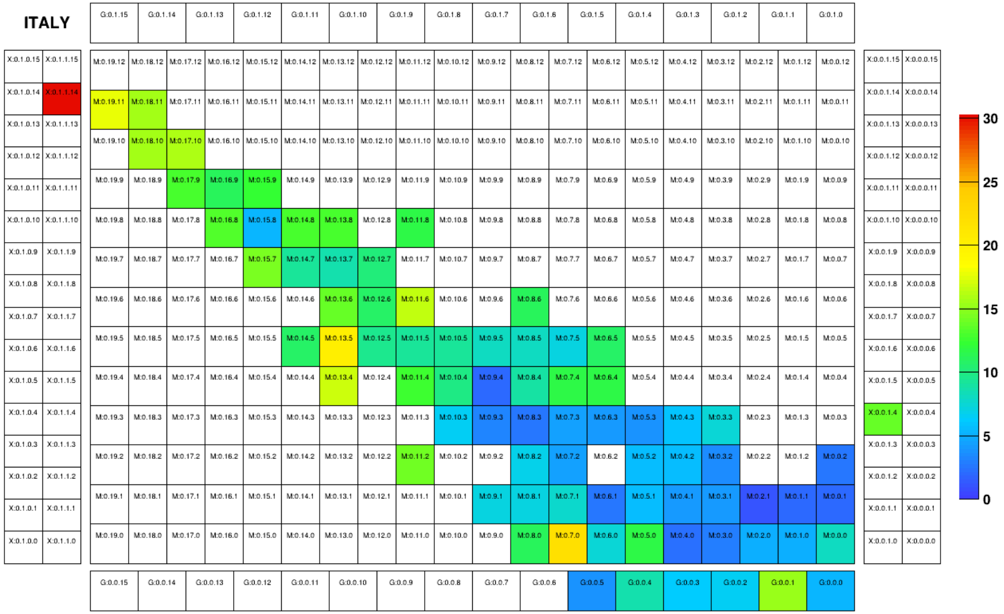


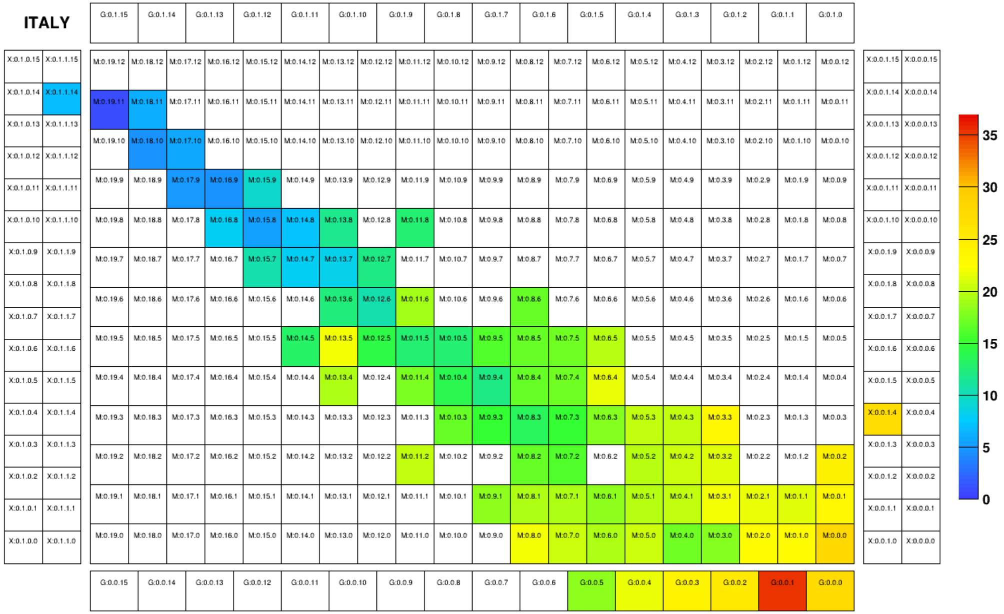
Color: Time [ns]

Time Calibration of Optical Modules: Confirmation of Results

No time calibration applied → **Time calibration applied**

time scheme of a passing muon



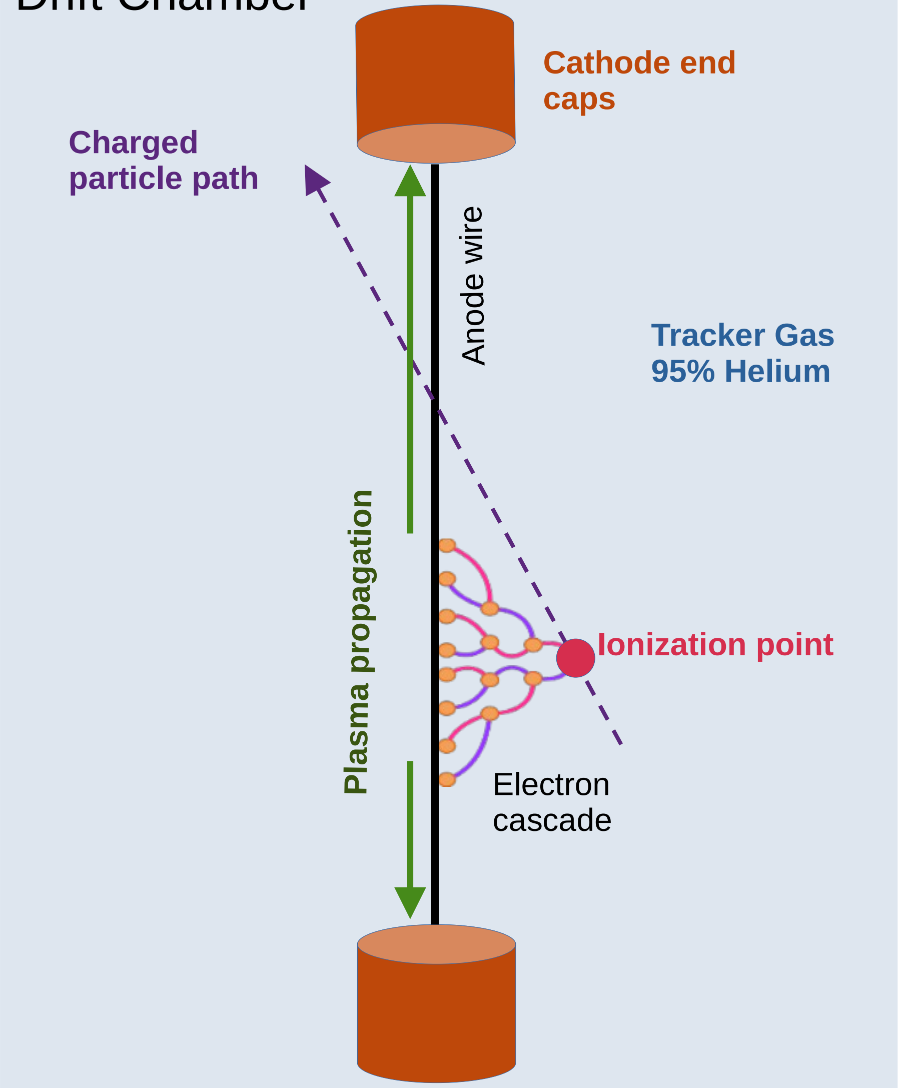


Color: Time [ns]

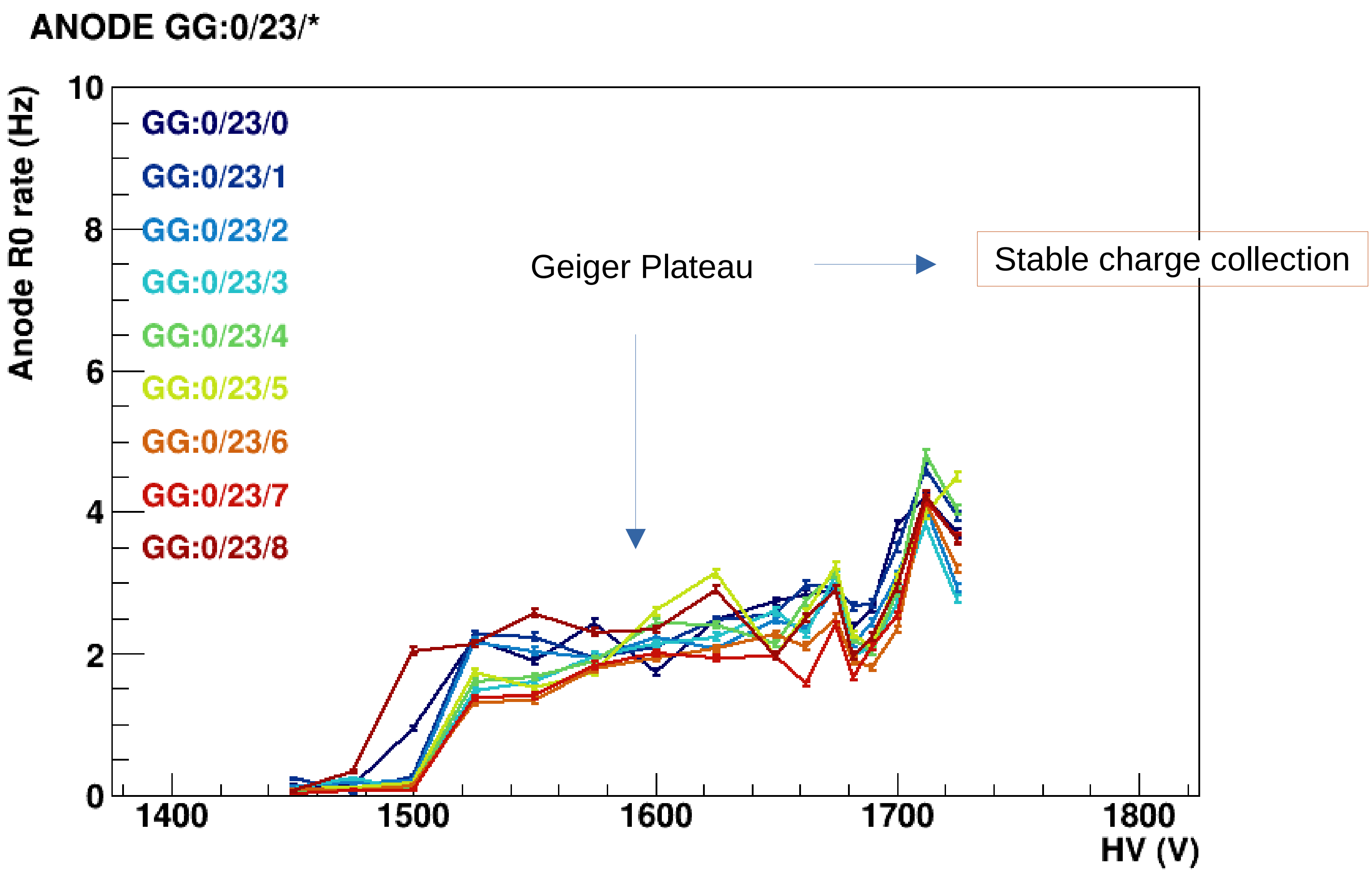
The Tracker: A High Granularity Wire Drift Chamber

Anode signal
+
Cathode plasma signals

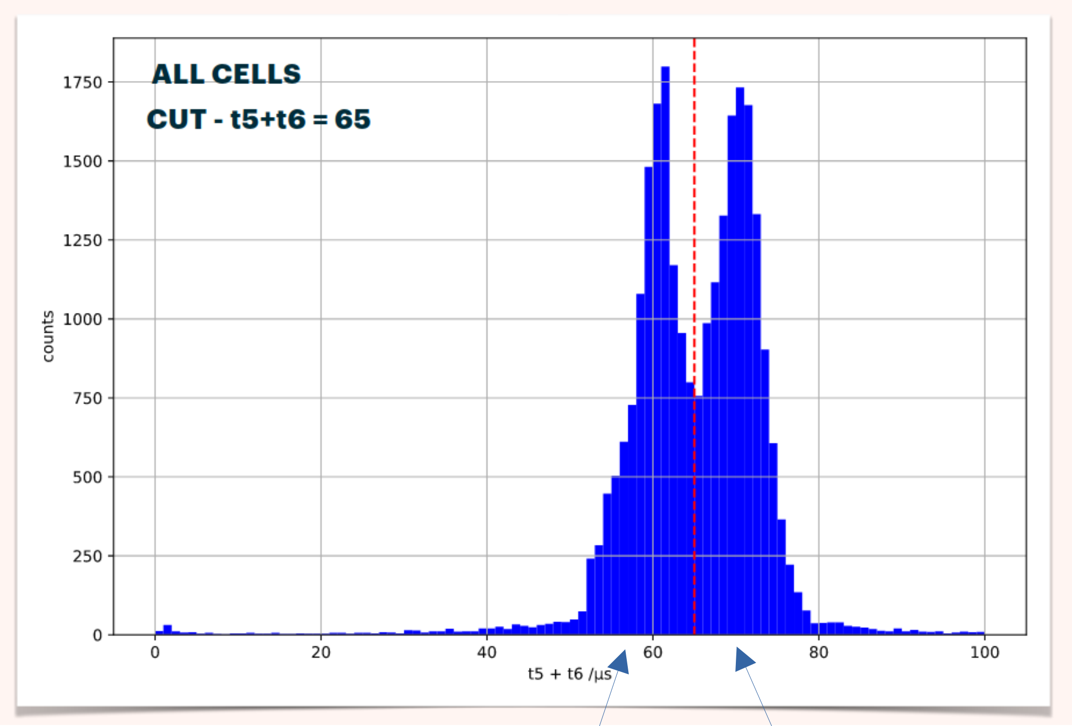
Reconstruct the position of particle interaction



Tracker Cells Gain Optimization

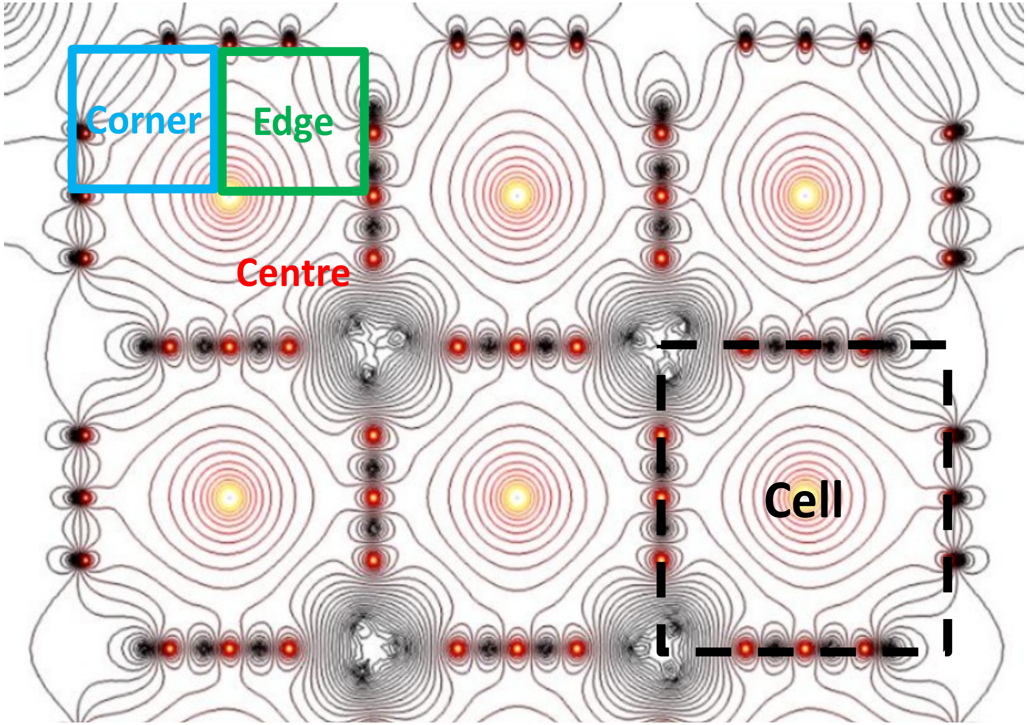


Tracker Cells Plasma Drift Time



Cells at corners

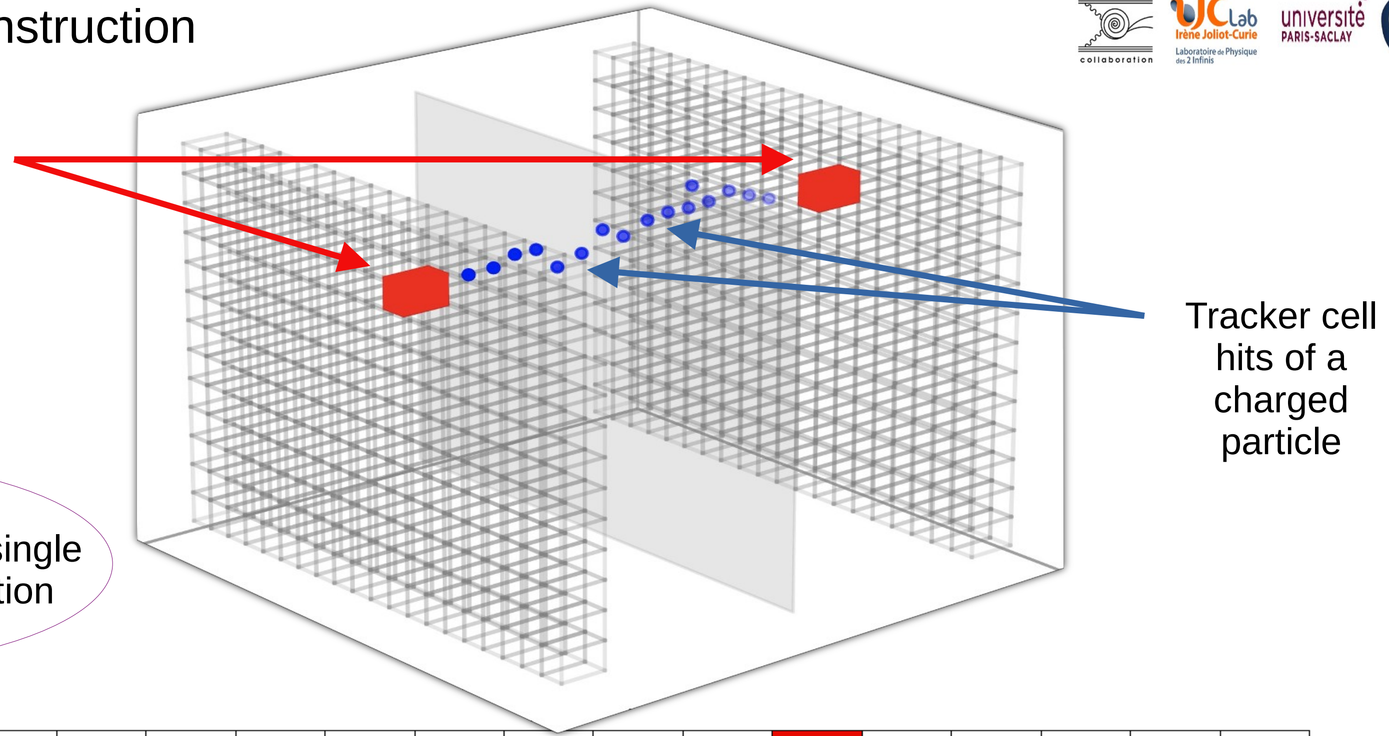
Cells at center

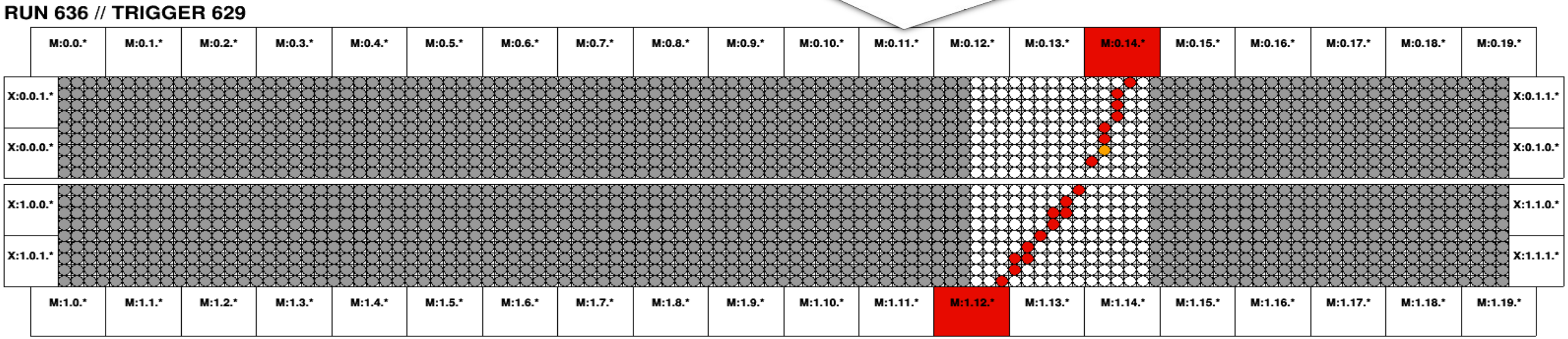


Charged Particle Track Reconstruction

Tracker: Full reconstruction of particle tracks

Calorimeter: Measuring of single energy and time of interaction





SuperNEMO: Constraining the Quenching Value of g_A

Phys. Rev. C 97, 034315

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

2νββ processes: Describes energy & momentum of initial and final nucleus

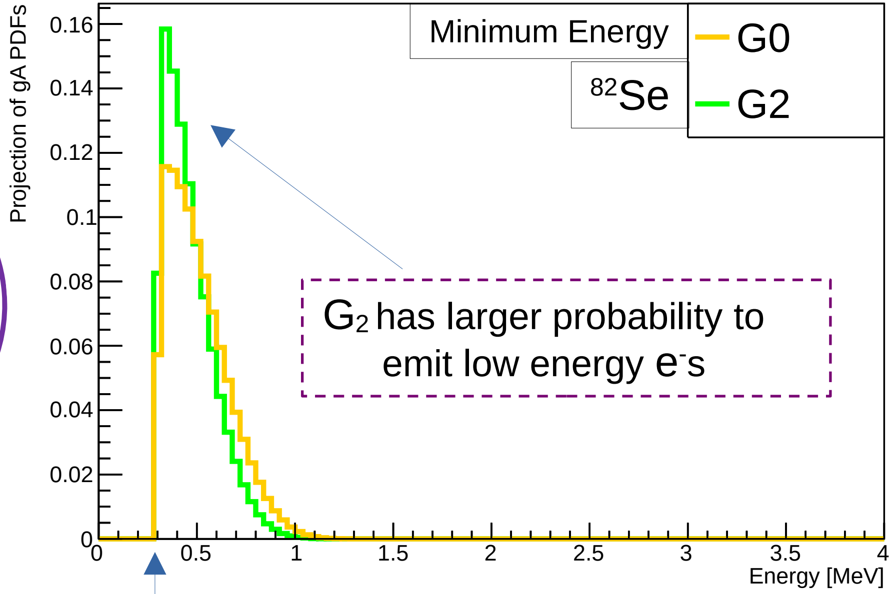
Strength of particle interaction inside the nucleus

Describes the nuclear decay and nuclear effects

Can be quenched due to the multi-nucleon interactions not taken into account

Due to many approximations used in NMEs

Different kinematics

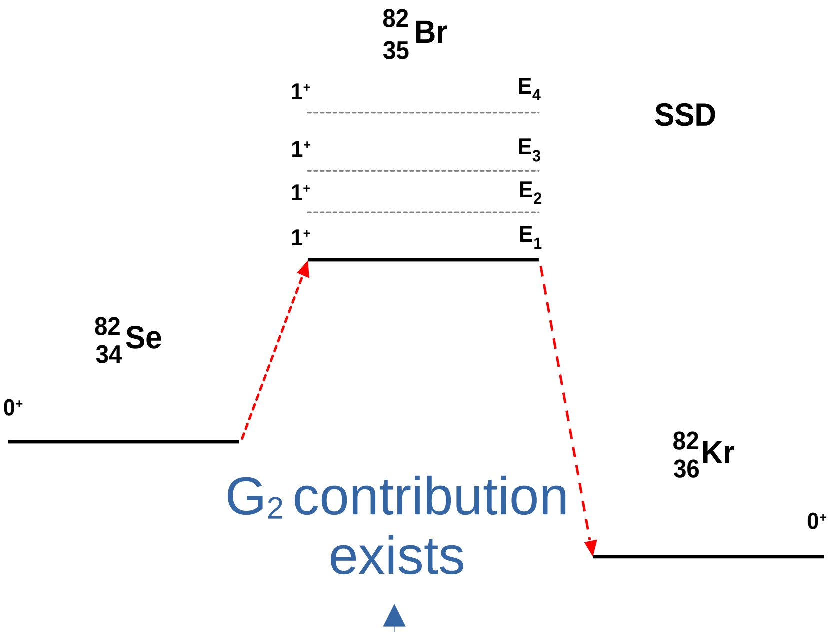


G_2 has larger probability to emit low energy e^-s

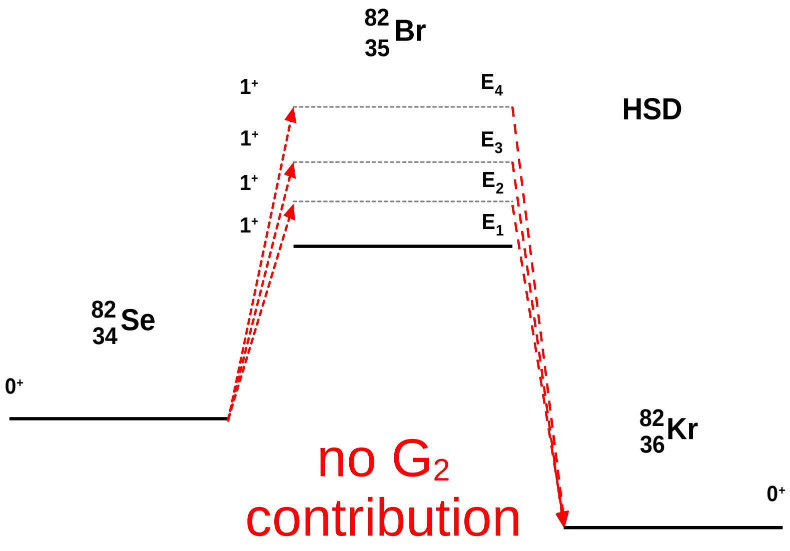
E > 300 keV

g_A Quenching : SSD and HSD – Two Nuclear Models

Single State Dominance



Higher State Dominance



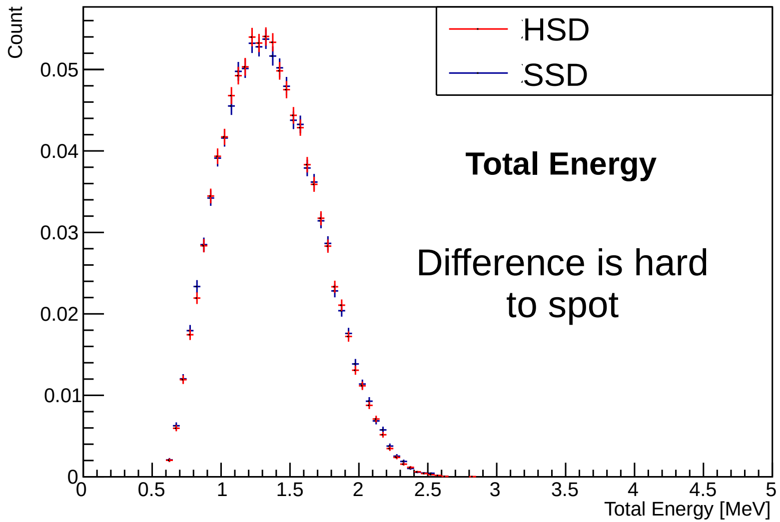
Larger probability to emit low energy electrons → Affects the efficiency of detection

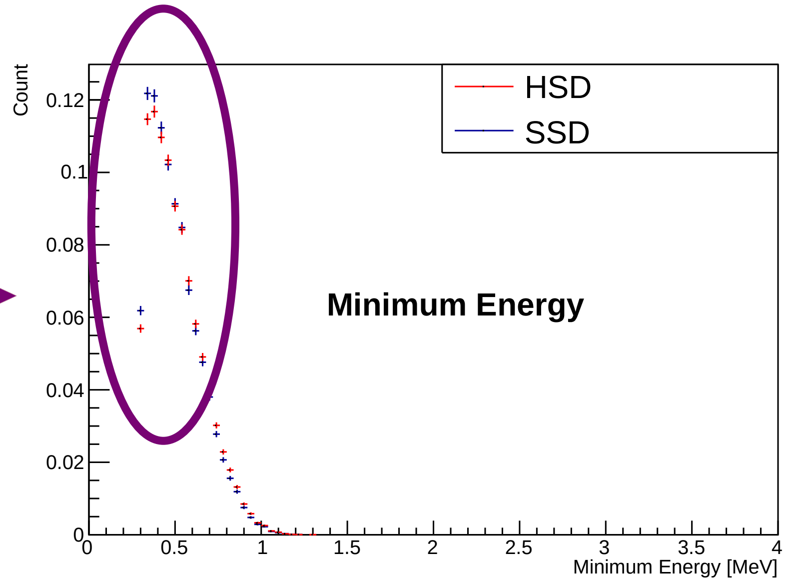
HSD and SSD; ^{82}Se : Difference in Energy Distributions

Single State Dominance $G_0 + G_2$ contribution

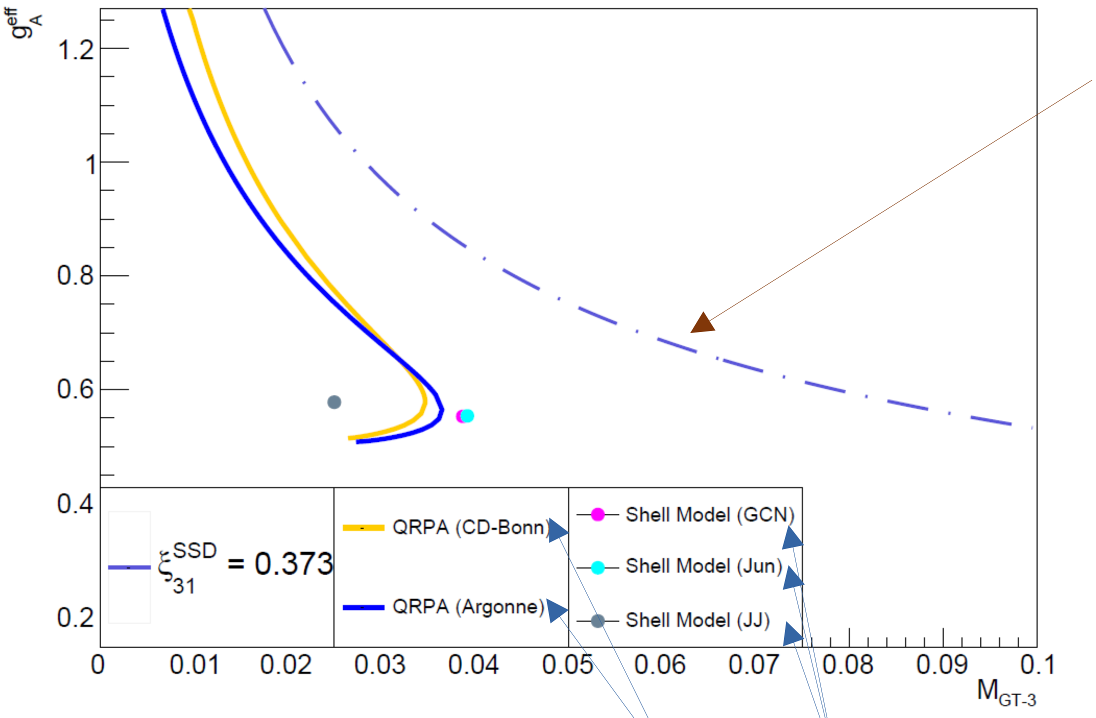
Higher State Dominance G_0 contribution

Need large stats and precise measurements





SuperNEMO to Constrain g_A



Different interactions between nucleons

Previous NEMO-3 results favor the SSD case
Eur. Phys. J. C (2018) 78:821

Cupid-0 disfavored HSD at 5.5 σ
DOI: 10.1103/PhysRevLett.123.262501

SuperNEMO has the technology and ability to set constraints on the quenching value of g_A and exclude nuclear models **!**

QRPA and SSD calculations by Fedor Simkovic

Shell Model calculations by Javier Menendez

In Summary ...

SuperNEMO

- Is a unique tracker-calorimeter detector for 2ν and 0ν double beta studies; using ^{82}Se
- Demonstrator is in the commissioning phase:
  - Calorimeter fully calibrated and studied
  - Tracker commissioned and data are being analyzed
- Can constrain the quenched axial-vector coupling constant value
- Can exclude nuclear models describing the decay process

Complete demonstrator in spring 2023 !