SuperNEMO demonstrator status

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Summary

Neutrinoless double beta decay

SuperNEMO status

Calorimeter studies (my work):

- Absolute energy calibration
- Relative energy calibration
- Background studies

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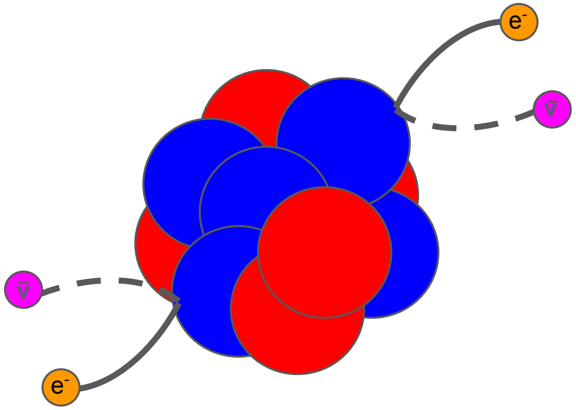
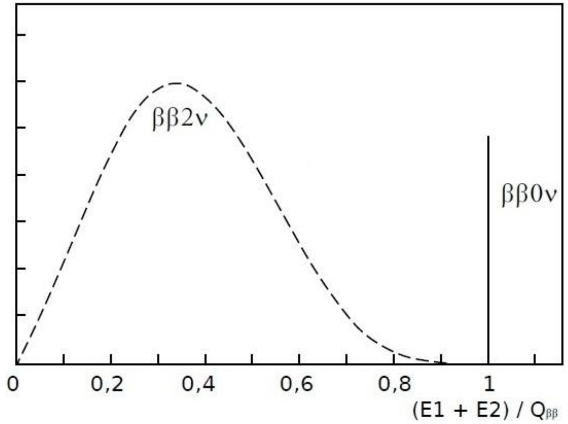
Neutrinoless double beta decay



Forbidden by the Standard Model (Leptonic number violation)

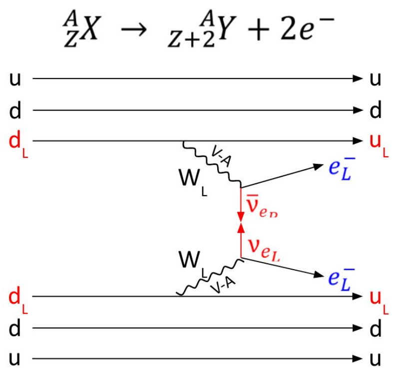
If observed ⇒ proof of the **Majorana nature** of neutrinos (**ν = ν̄**):
- Could be responsible for **leptogenesis with CP violation**
- Could bring information about the **neutrino absolute masses**
- Could answer the **mass hierarchy**



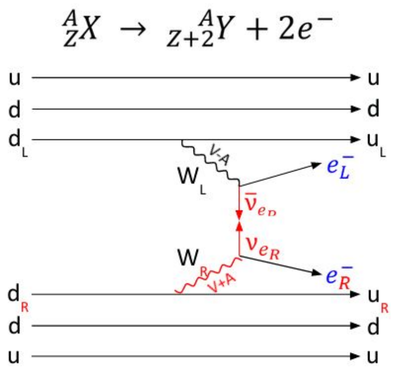
Very high half life (> 10^{24} y) → **Need of very small background**

Discrimination between 0νββ and 2νββ with the sum of e^- energies
→**Need a very good energy resolution!!!**

Neutrinoless double beta mechanisms



V-A current



V+A current

Different neutrinoless double beta mechanisms:

- V-A current (all experiments half-life calculation are based on these mechanisms)
- V+A current
- Majoron emission
- R-parity violation

Mechanisms could be distinguished thanks to:

- Individual energy of each e^-
- Angular distribution

SuperNEMO technique is able to differentiate them

R. Arnold, et al., Probing new physics models of neutrinoless double beta decay with SuperNEMO, Eur. Phys. J. C 70 (2010) 927

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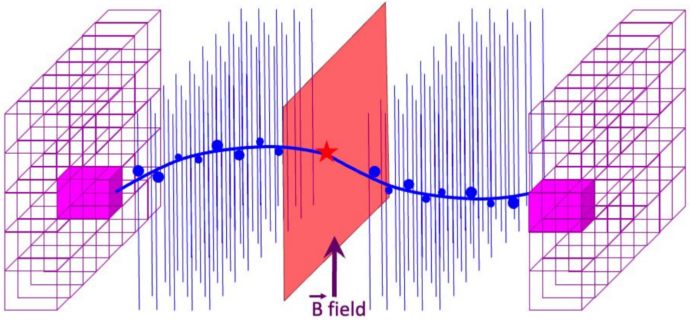
SuperNEMO technique

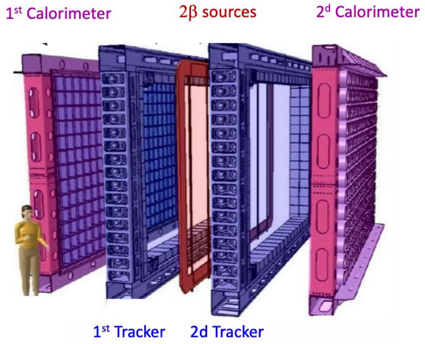
1. **ββ source foil:** free choice of most **isotopes**
2. **Tracker**: charged particle **trajectory**
3. **Calorimeter**: **energy** of **each** particle



Advantages:

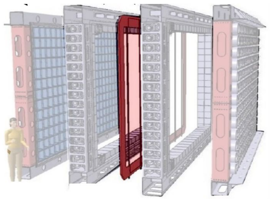
Access to the **full kinematics** of the decay:

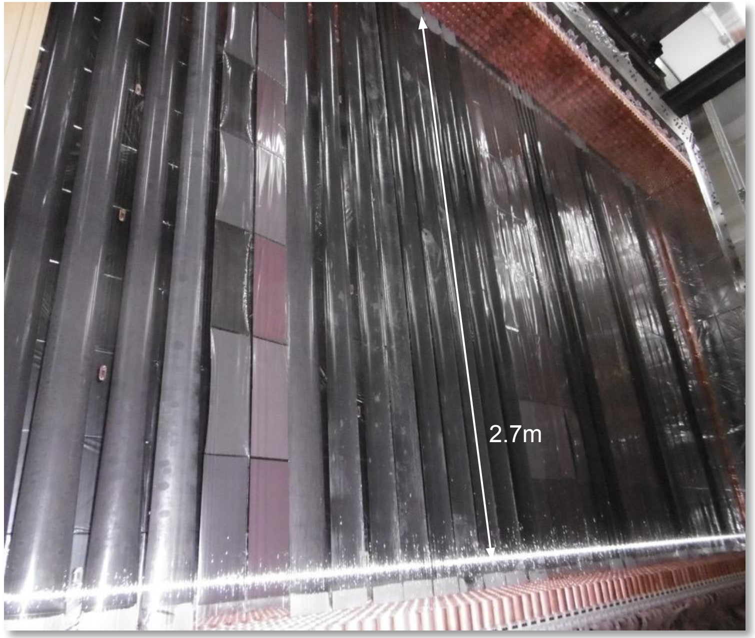
- Golden 0νββ events
- Background modelling (dedicated channels)
- Differentiate the 0νββ mechanisms
- High precision nuclear studies with 2νββ events



@Laboratoire Souterrain de Modane (under 4800 m.w.e)

Source foil





Source foil in the middle of the detector

6.23 kg of ^{82}Se (ββ isotope)

High $Q_{\beta\beta}$ = 2.998 MeV

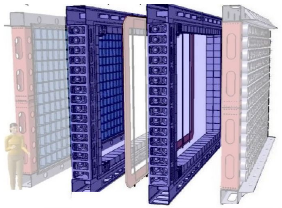
High $T_{1/2}^{2\nu} = 9.4 \cdot 10^{19}$ y

Thickness: ~280 µm

Radiopurity (measured by BiPo detector):

- ^{208}Tl < 25 µBq/kg
- ^{214}Bi < 290 µBq/kg

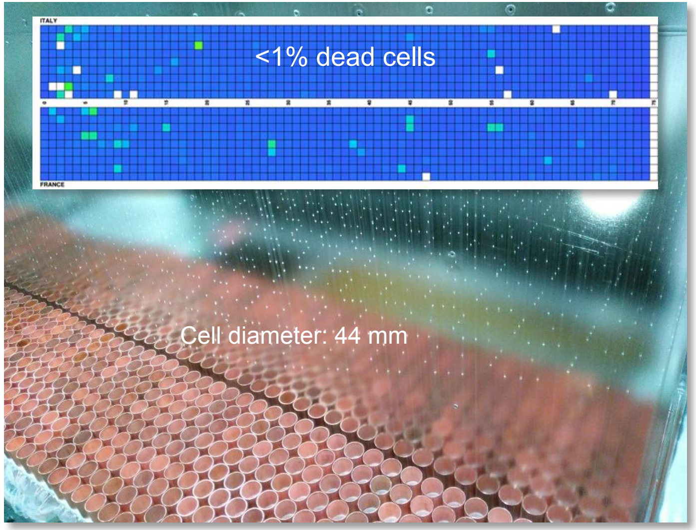
Tracker

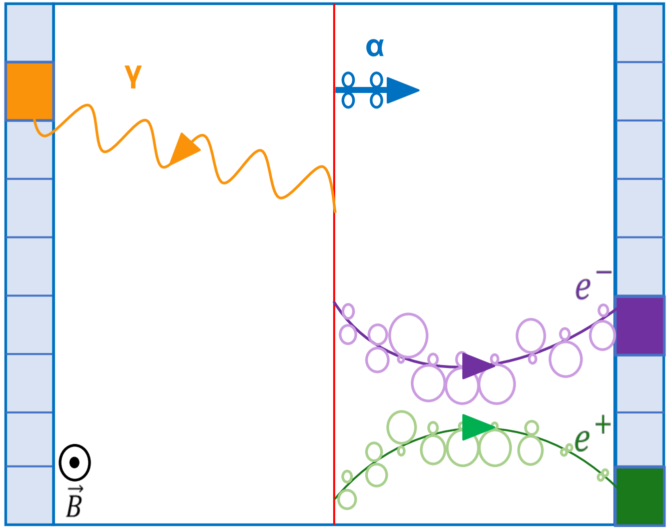


2034 drift cells (14970 wires of 40-50 µm) in Geiger mode

3D track reconstruction

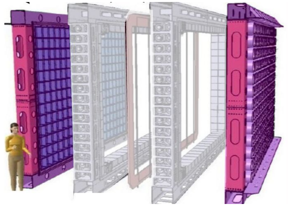
Fully **installed and commissioned**





Top view of the tracker with different particle tracks

Calorimeter



One of the calorimeter wall prior detector's closure

712 Optical Modules (scintillator + photomultiplier)

8" optical module

- Main walls:
  440 optical modules with **8" PMT**
  8% FWHM @1 MeV

- Sides / top / bottom (veto):
  272 optical modules with **5" PMT**
  12-15% FWHM @ 1 MeV

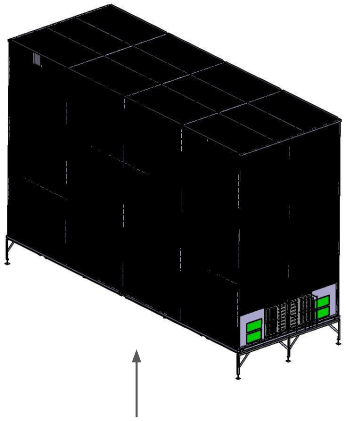
Time resolution < 400 ps for e^- at 1 MeV

Status of the demonstrator

Today: Source foil, Tracker and Calorimeter ready

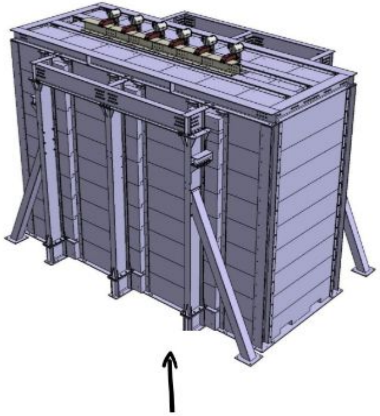
Still need to install part of the shielding:

Anti Rn tent - Done



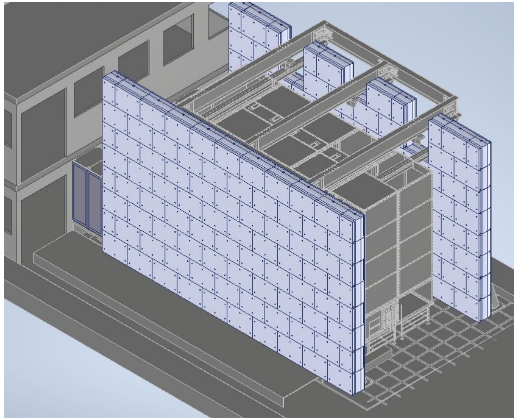
Gas tight PE plate

Gamma shielding - Early 2023
Iron plates (261 t)



18 cm iron shield

Neutron shielding - Mid-2023.
Mix of water (57.6 m^3) and
Polyethylene (15 m^3)



Status of the demonstrator

Today: Source foil, Tracker and Calorimeter ready

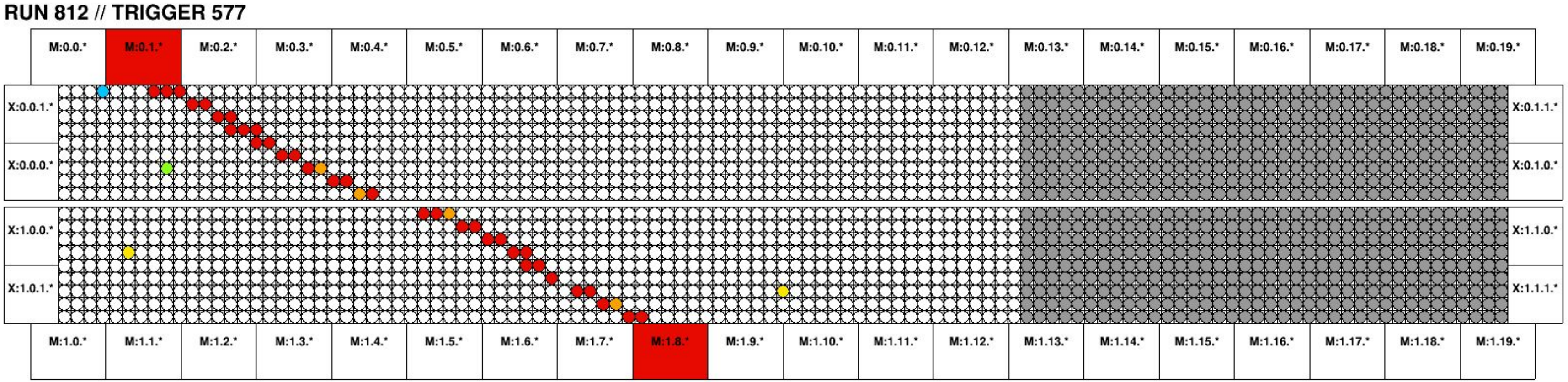
Still r

Ant g - Mid-2023.

5 m^3) and

(15 m^3)

Data taking has started (background studies)
Double beta data planned mid 2023



Summary

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Calorimeter studies (my work):

- Absolute energy calibration
- Relative energy calibration
- Background studies

Energy calibration of the calorimeter

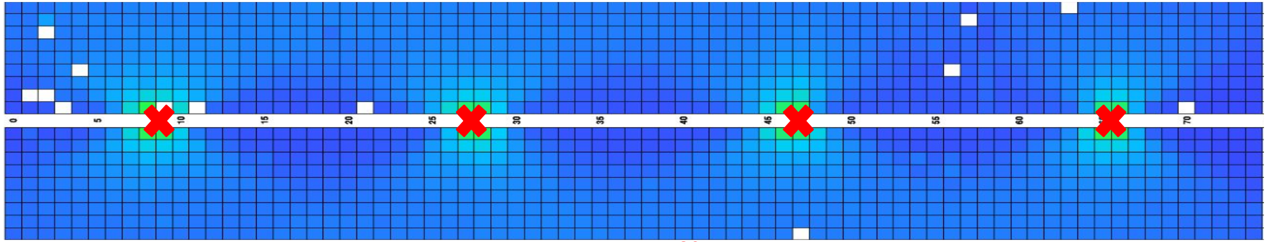
3 Methods of calibration:

Absolute calibration with **^{207}Bi sources** (Nominal method)
Absolute calibration with LSM **ambient background** run
Relative calibration using **LED light** (Light Injection system)

Nominal absolute calibration: ^{207}Bi Sources

^{207}Bi source

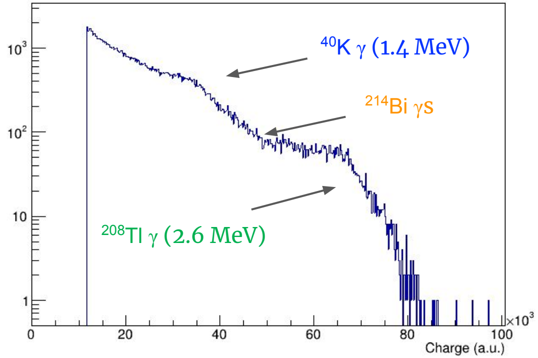
42 movable ^{207}Bi sources (automatic system) (IC e^- at 482, 976 and 1682 keV)
Need the tracker to **tag the e^- of the ^{207}Bi.** Started this method recently.
More to come next time!



Tracker hit rate (top view) with **^{207}Bi sources** deployed

Absolute energy calibration

Calibration performed while waiting for the nominal method **using LSM ambient background**



Main components of ambient background visible above 1 MeV:

- **^{40}K** (γ 1.4 MeV)
- **^{214}Bi** (many γ between 1-2.4 MeV)
- **^{208}Tl** (γ 2.6 MeV)

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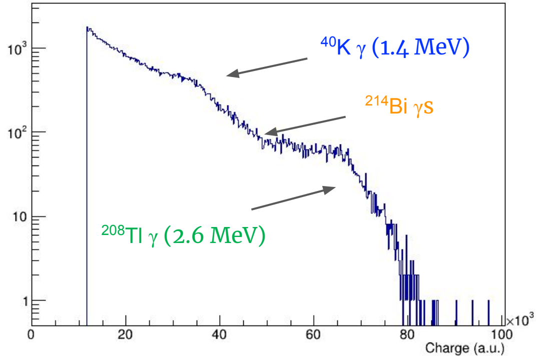

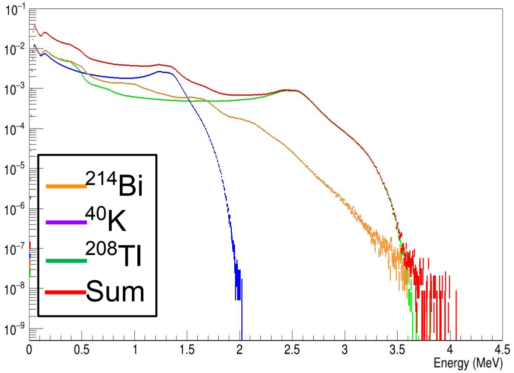

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- **^{40}K** (γ 1.4 MeV)
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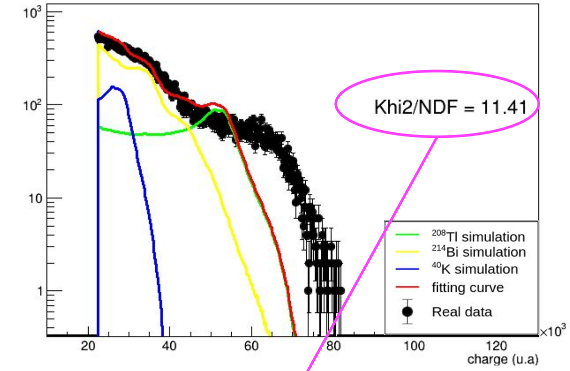
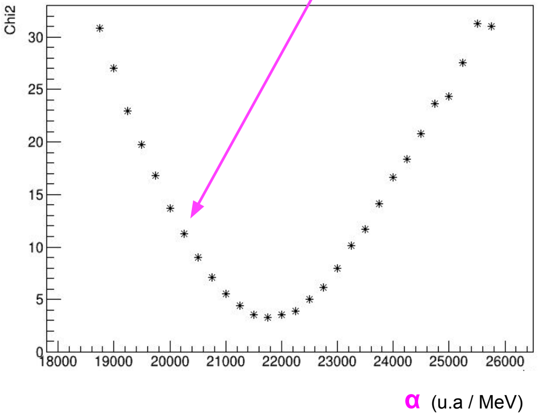
MC simulation of these 3 components (from the LSM walls)

3 reference PDF (probability density function) used for calibration

Absolute energy calibration

Calibration performed while waiting for the nominal method using LSM ambient background





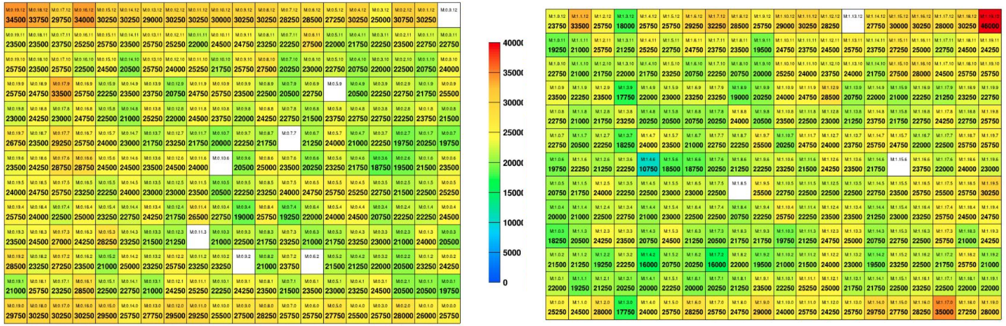
Fitting with: α x ($A_K PDF_K$ + $A_{Bi} PDF_{Bi}$ + $A_{Tl} PDF_{Tl}$)

(3 degrees of freedom : 1 normalization per MC components)

Iterate for different calibration parameter α (**α = energy scale)**

Best α deduced with the **minimal Chi2** (1α = 1 optical module)

Repeat for each optical modules



View of α for the 2 main calorimeter optical modules (square = optical module)

Absolute energy calibration

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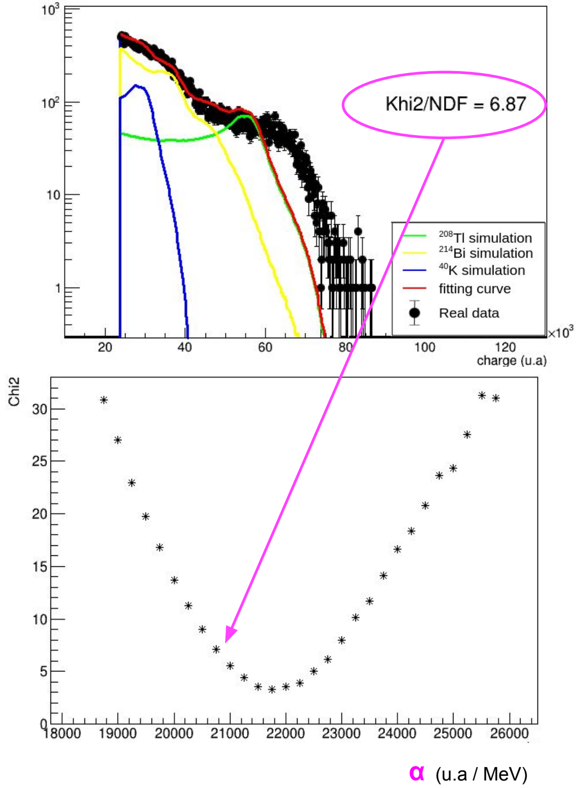

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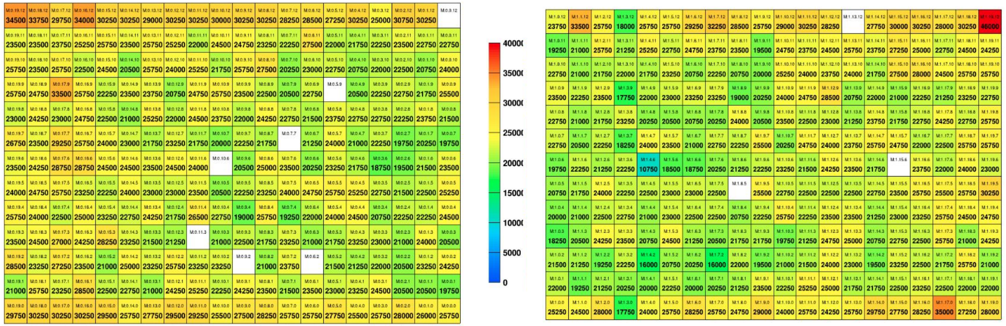

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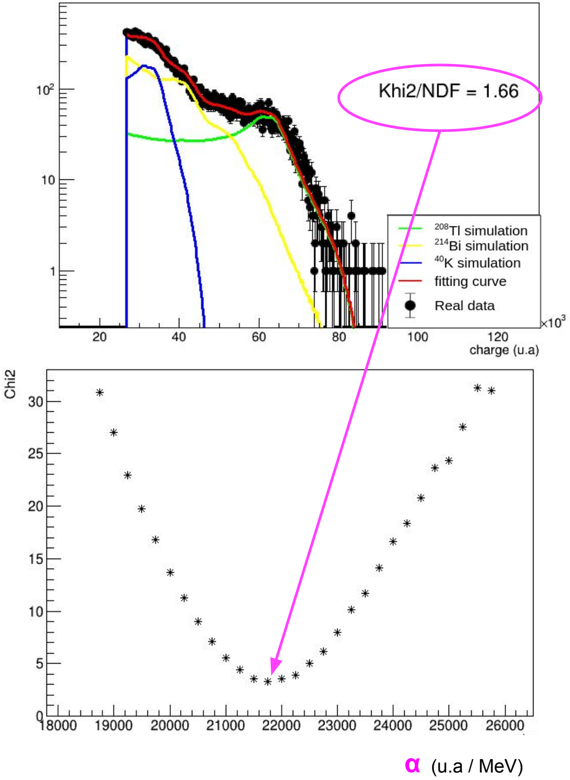

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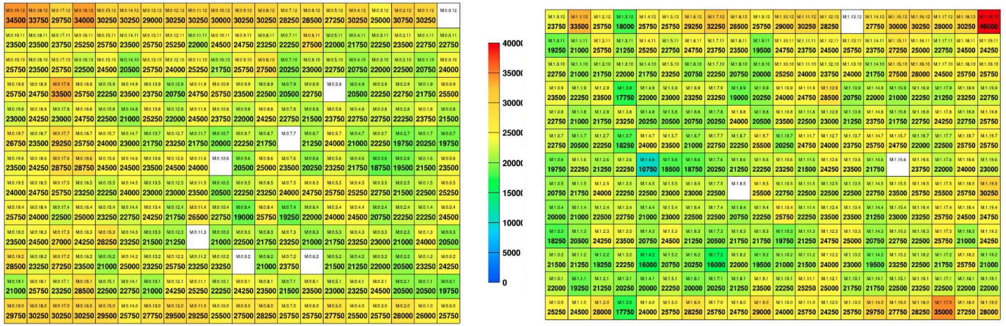

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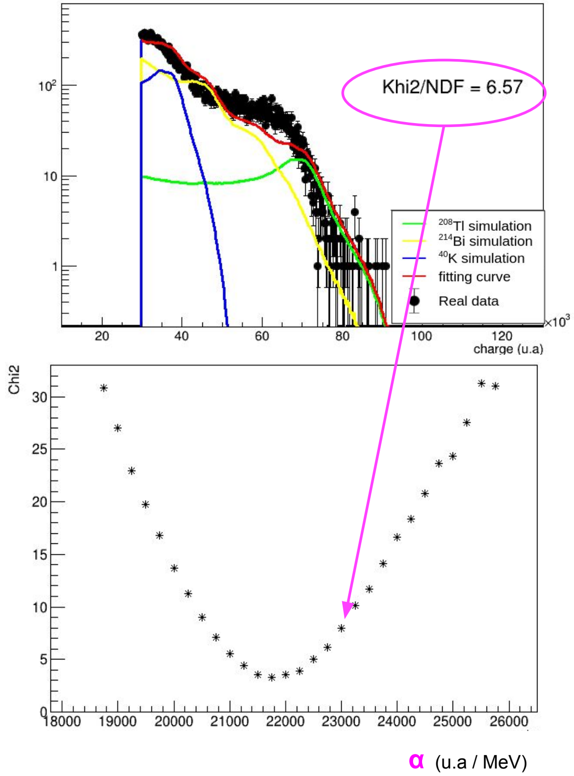

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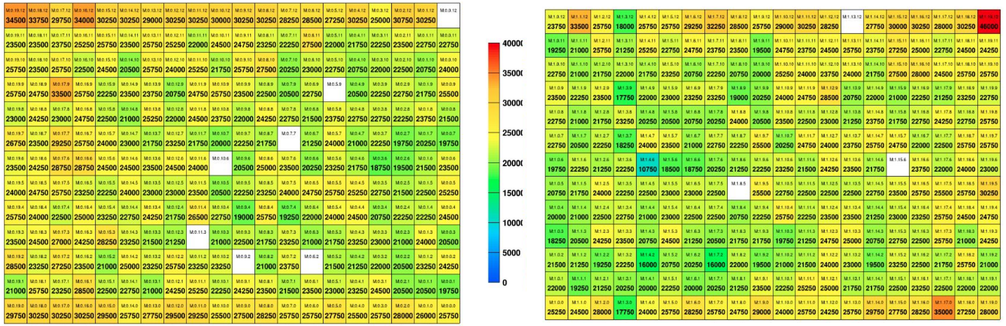

View of α for the 2 main calorimeter optical modules (square = optical module)

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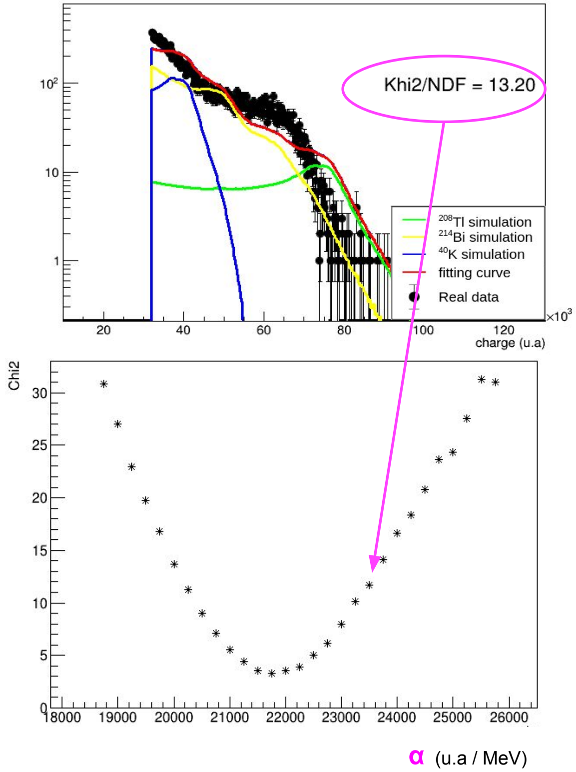

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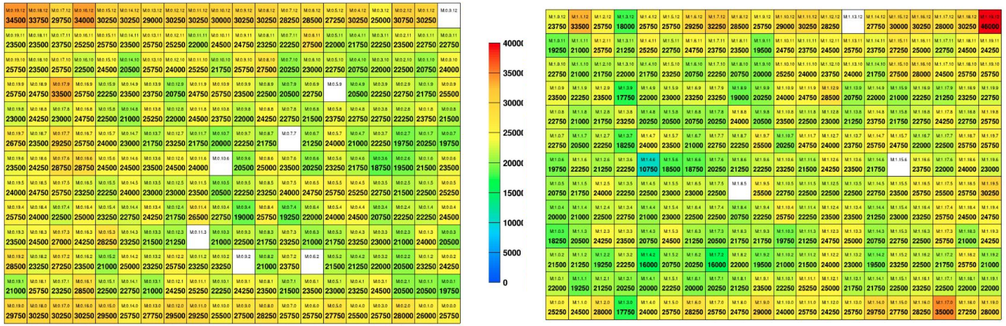
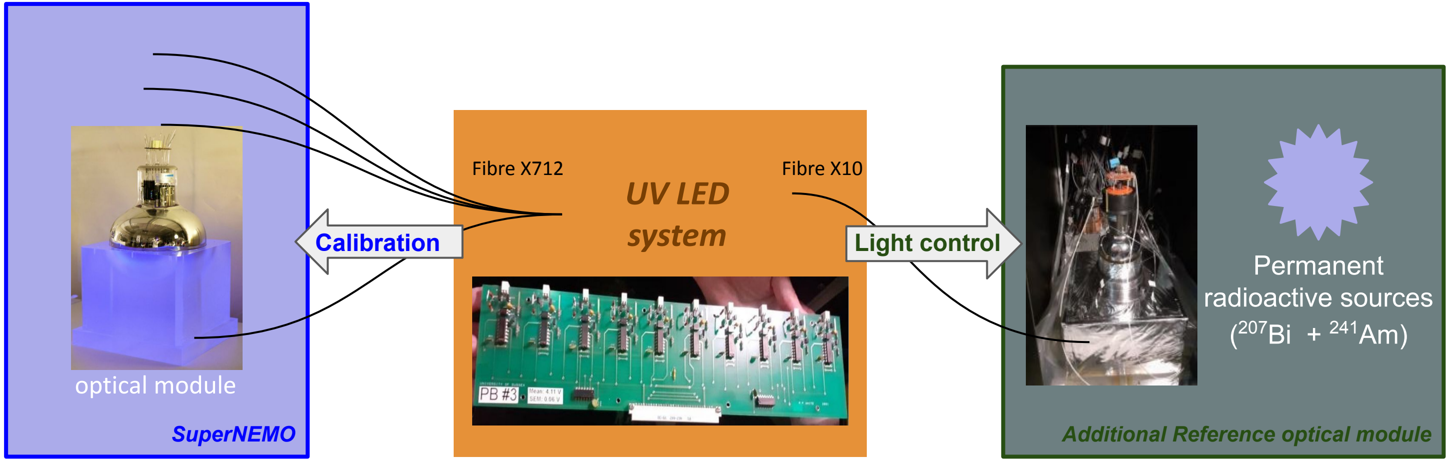


View of α for the 2 main calorimeter optical modules (square = optical module)

Relative energy calibration

LED light sent to each of the calorimeter's 712 Optical Modules to **monitor their gain evolution**

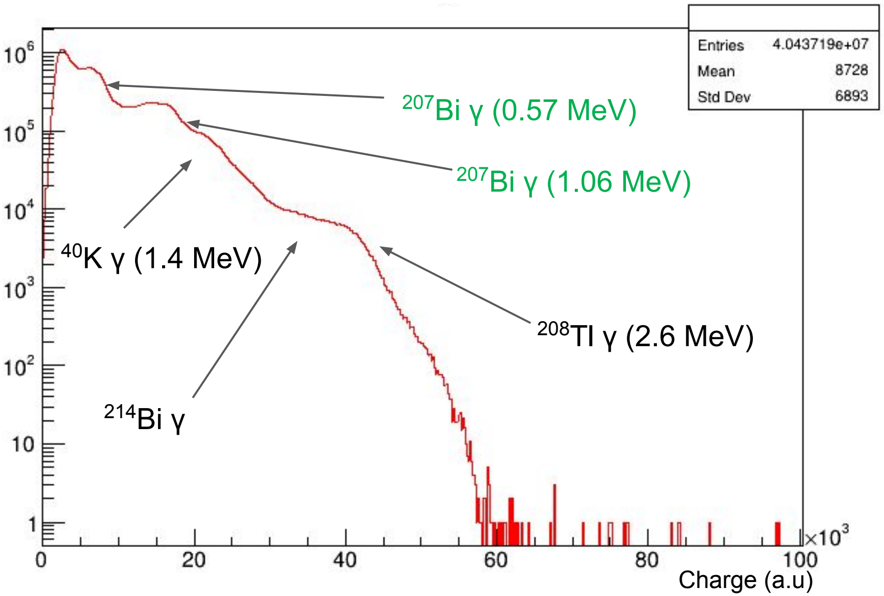
LED light calibrated with **5 Reference Optical Modules external to the detector**



Very fast way to calibrate the calorimeter (few minutes) doable on **daily basis**, but ***relative* calibration**

Relative energy calibration

External Reference optical module calibration



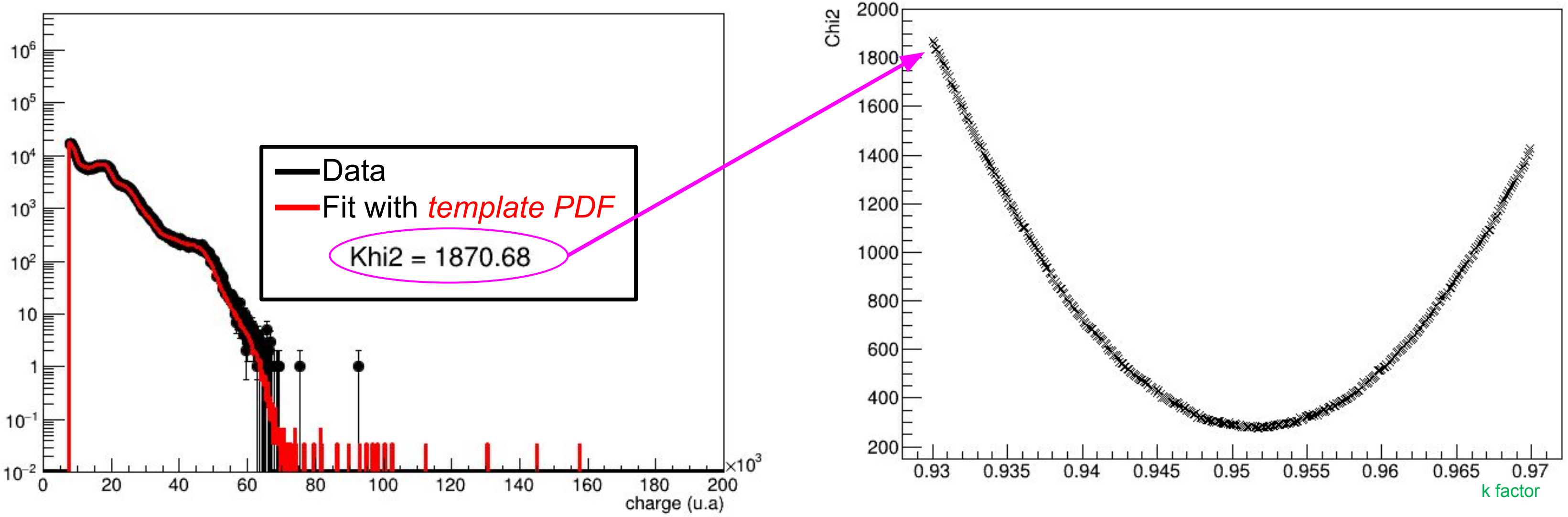
Using LSM ambient background + ^{207}Bi sources
(to constraint the spectrum shape)

Long data run (15.6h) used as ***template* PDF**
(1 PDF for each of 5 reference optical modules)

Use each template PDF to follow the gain variation of each reference optical module

Relative energy calibration

External Reference optical module calibration



Scale **template PDF(k x charge)** for various k by steps of 0.01 % (k = gain variation scale factor)

↓

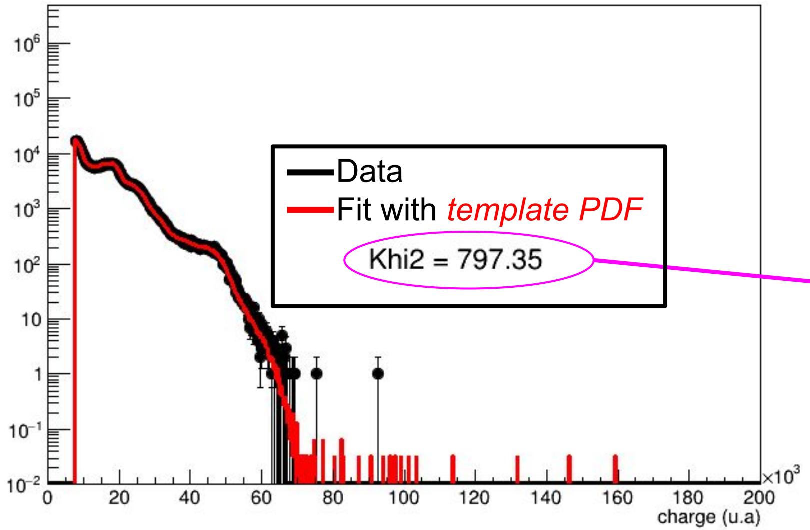
Fit dataset for each scaled template PDF (1 D.O.F = normalization)

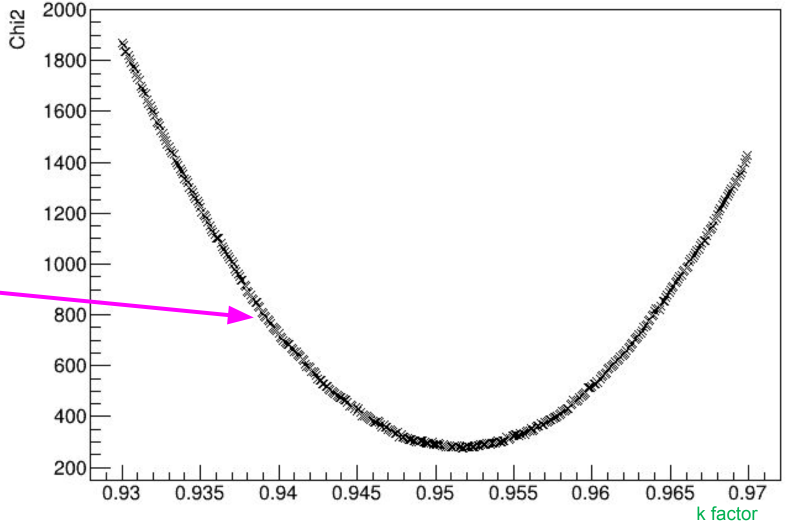
↓

Best k deduced with the **minimal Chi2**

Relative energy calibration

External Reference optical module calibration





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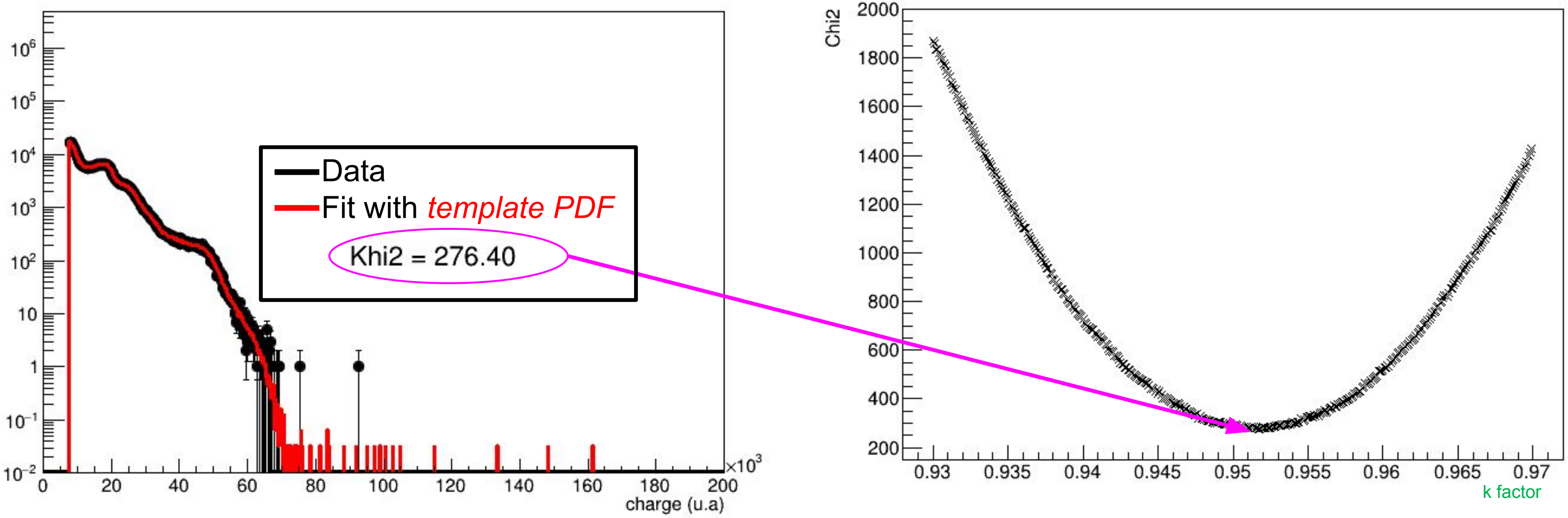

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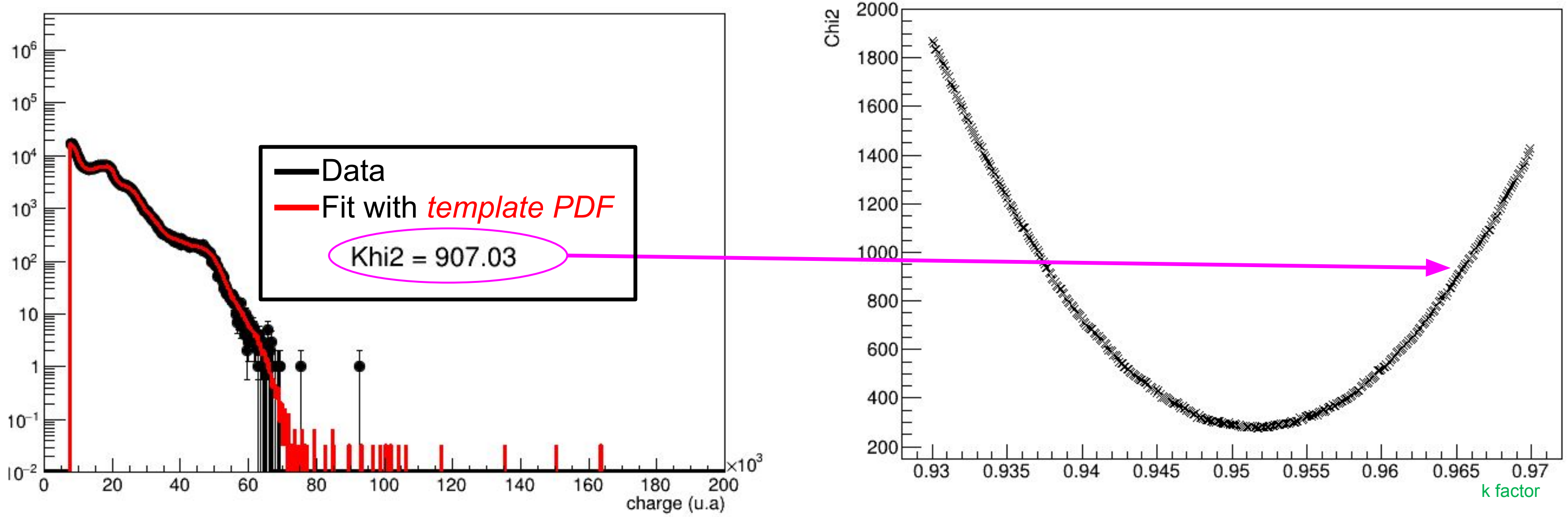

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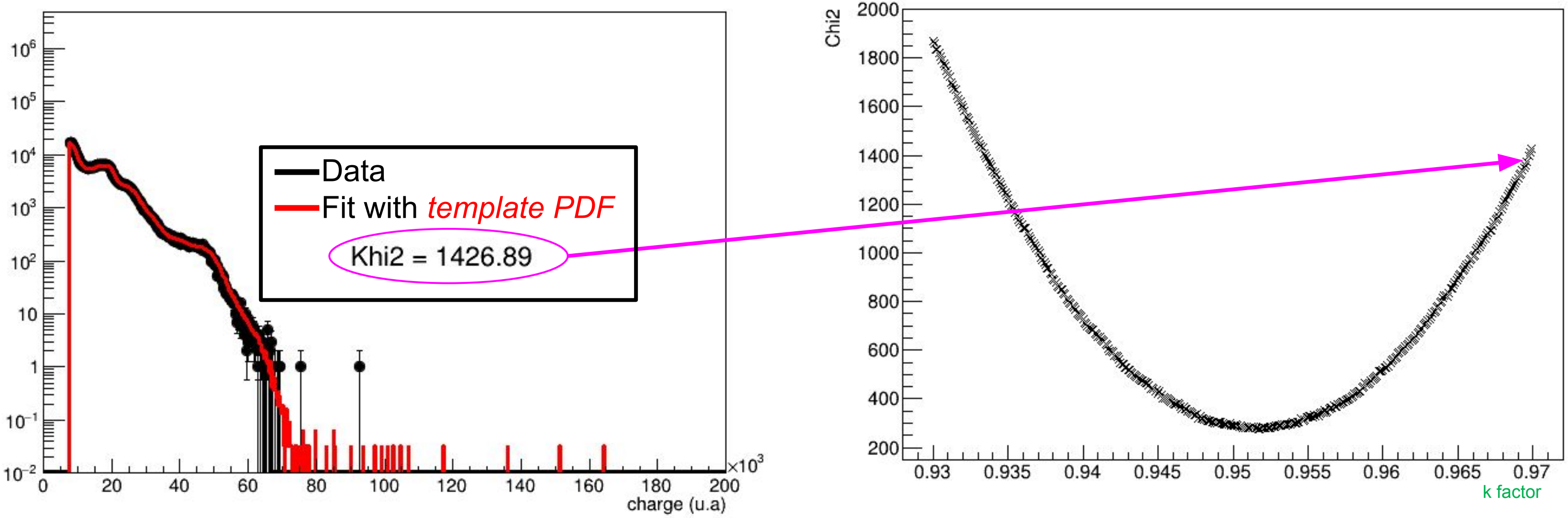


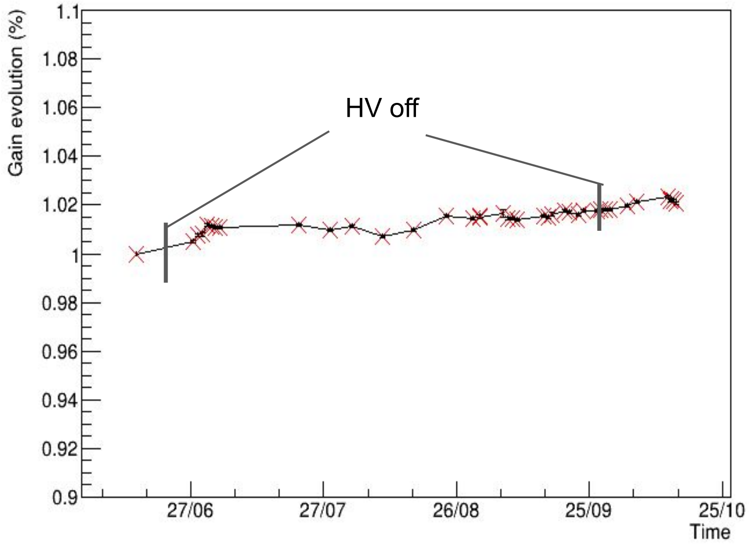
Scale **template PDF(k x charge)** for various k by steps of 0.01 % (k = gain variation scale factor)

Fit dataset for each scaled template PDF (1 D.O.F = normalization)

Best k deduced with the **minimal Chi2**

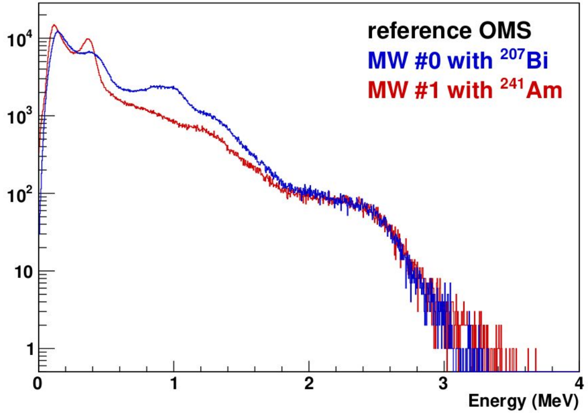
Relative energy calibration

Calibration of the external reference optical module over the last 5 months



k factor evolution of one of the reference optical module

Cross-check with alpha sources (^{241}Am) ongoing



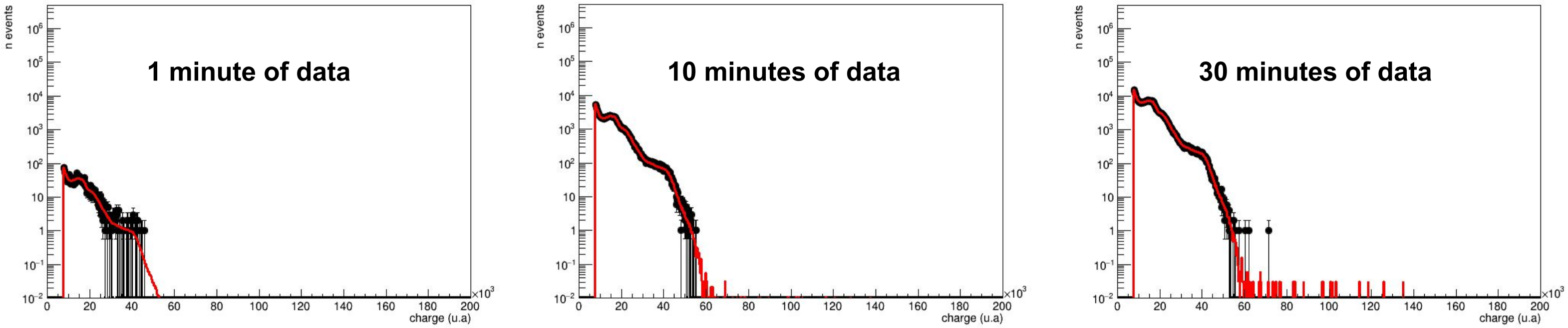
Relative energy calibration

Optimization of calibration run duration

Error on k calibration factor (calculated at 1σ) **for different run durations**

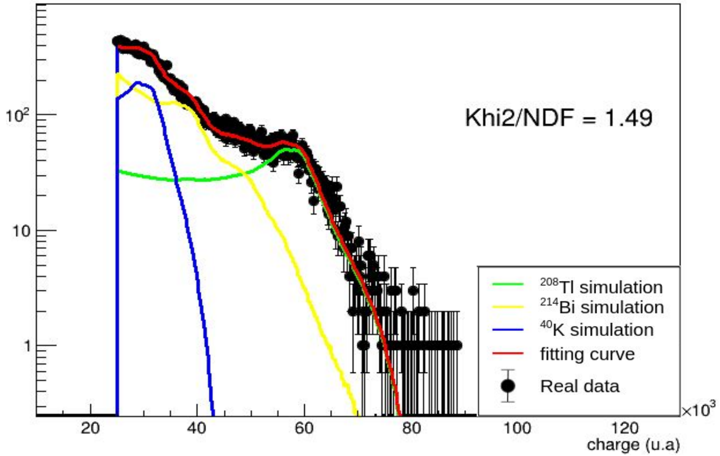
Run duration	1 min	5 min	10 min	30 min	60 min
Error on **k**	0.34 %	0.15 %	0.10 %	0.06 %	0.04 %

< 1% from 1 minute!!



New calibration method with data template PDF of reference optical modules:
Precise and fast (10 minutes) gain measurement

Background studies



Fit of LSM ambient background with MC simulations

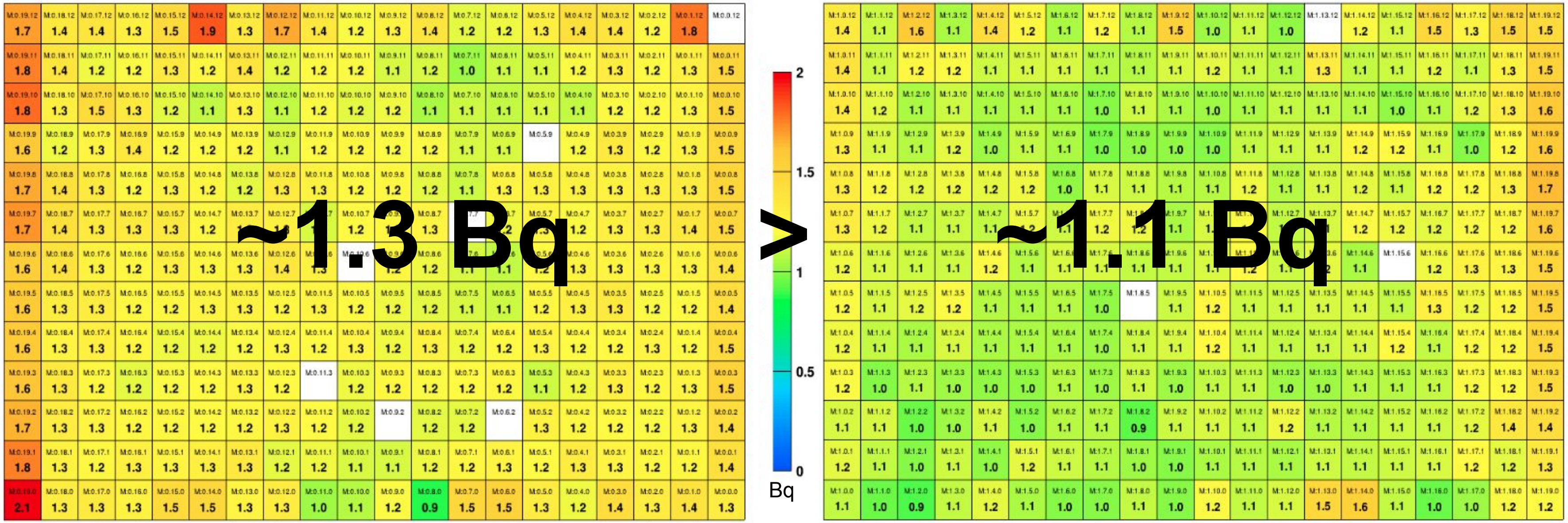
Outcome of the absolute calibration with LSM background:

Measurement of the **activity** of the ambient γ sources (^{40}K, ^{208}Tl and ^{214}Bi)

From: $\alpha \times (A_K PDF_K + A_{Bi} PDF_{Bi} + A_{Tl} PDF_{Tl})$

Background studies

Estimated ^{208}Tl activity (Bq) > 2 MeV of the main calorimeter (each square represent an optical module)



- Higher rate on the side closer to the rock of the lab wall (left plot)

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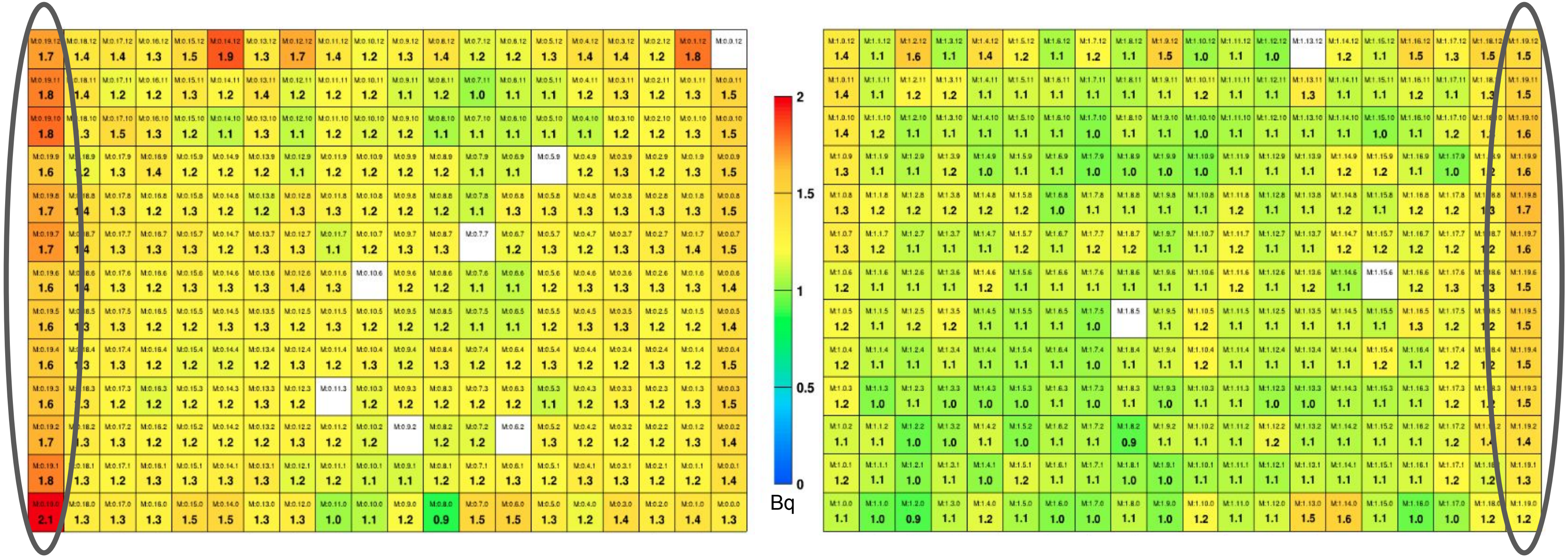
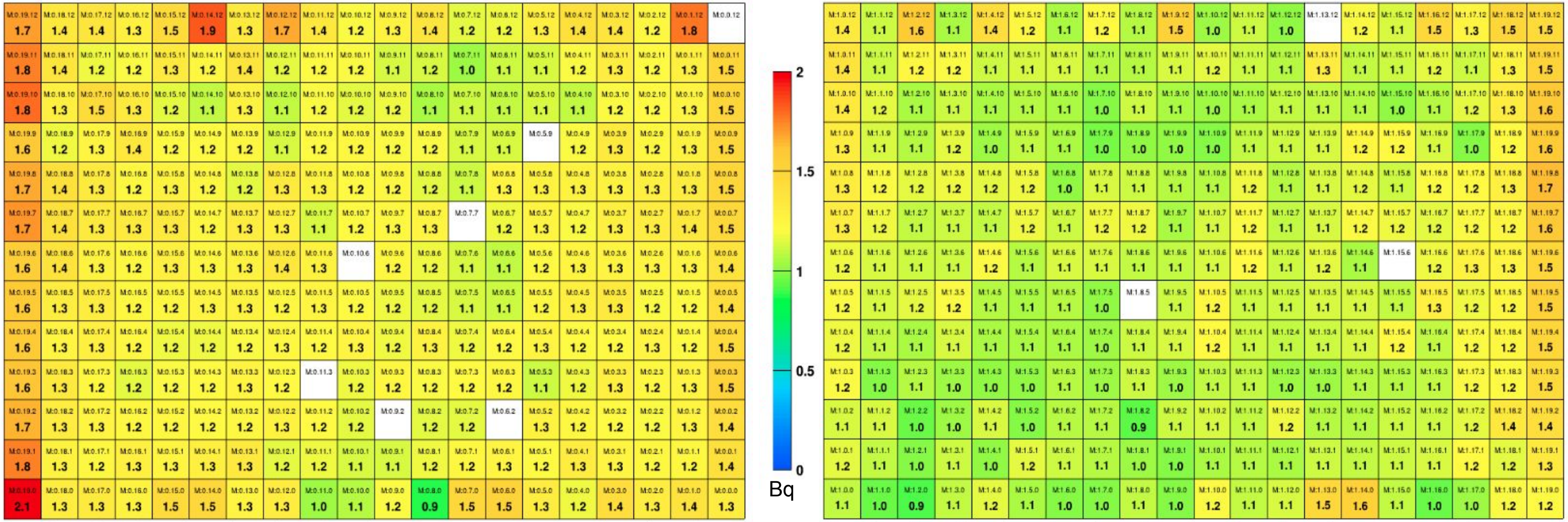


- Higher rate on the side closer to the rock of the lab wall (left plot)
- Higher rate at border/side due to missing self-shielding by other optical modules

Background studies

Estimated ^{208}Tl activity (Bq) > 2 MeV of the main calorimeter (each square represent an optical module)



Average main wall: **1.2 ± 0.2 Bq** (data) **VS ~2.3 Bq** (expected using Ohsumi & all, 2002 - D. Malczewski & all 2012)

No extra activity is seen, and we provide a new ^{208}Tl activity measurement around SuperNEMO

Conclusion

The demonstrator **has started taking data**:
- **Calorimeter and tracker ready**
- **Background studies** in progress
- **Gamma shield** early 2023 and **neutron shield** mid 2023
- **Double beta runs mid 2023**

3 **Methods of energy calibration** of the calorimeter:
- Absolute calibration with ^{207}**Bi sources** (Nominal method) starting now.
- Absolute calibration with LSM **ambient background**:
  - New technique using MC simulations was developed, allowing both energy calibration and gamma flux measurement for all 712 optical modules
- Relative calibration with **LED light**:
  - Another technique developed to calibrate external reference optical modules based on high stat reference spectrum:
    Reaching statistical error of 0.1% with 10 minutes

9 countries, 21 Laboratories

Thank you !