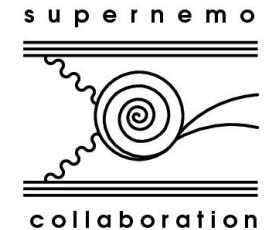


SuperNEMO demonstrator status

Xalbat Aguerre

Emmanuel Chauveau, Christine Marquet
IRN Neutrino 17/11/2022



Summary

Neutrinoless double beta decay

SuperNEMO status

Calorimeter studies (my work):

- Absolute energy calibration
- Relative energy calibration
- Background studies

Summary

Neutrinoless double beta decay

SuperNEMO status

Calorimeter studies (my work):

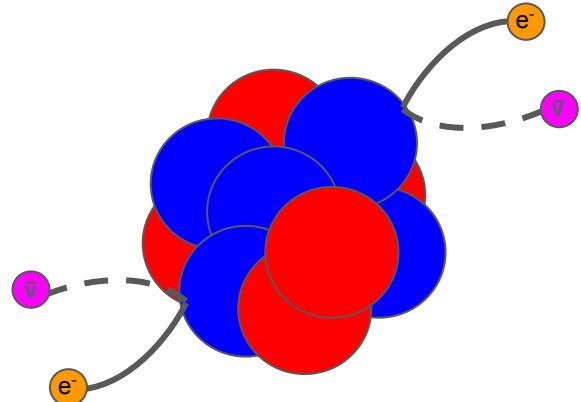
- Absolute energy calibration
- Relative energy calibration
- Background studies

Neutrinoless double beta decay

Forbidden by the Standard Model (Leptonic number violation)

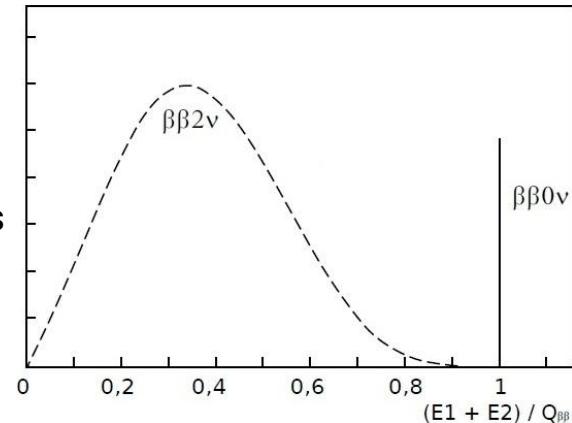
If observed \Rightarrow proof of the **Majorana nature** of neutrinos ($\nu = \bar{\nu}$):

- Could be responsible for **leptogenesis with CP violation**
- Could bring information about the **neutrino absolute masses**
- Could answer the **mass hierarchy**

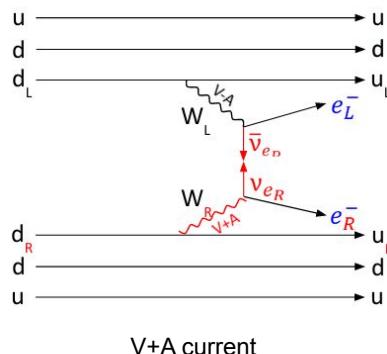
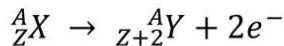
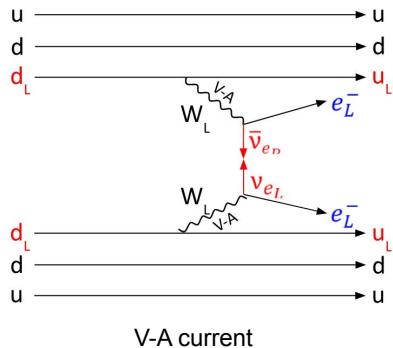
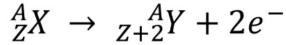


Very high half life ($> 10^{24}$ y) \rightarrow **Need of very small background**

Discrimination between $0\nu\beta\beta$ and $2\nu\beta\beta$ with the sum of e^- energies
 \rightarrow **Need a very good energy resolution!!!**



Neutrinoless double beta mechanisms



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](#)

Summary

Neutrinoless Double beta decay

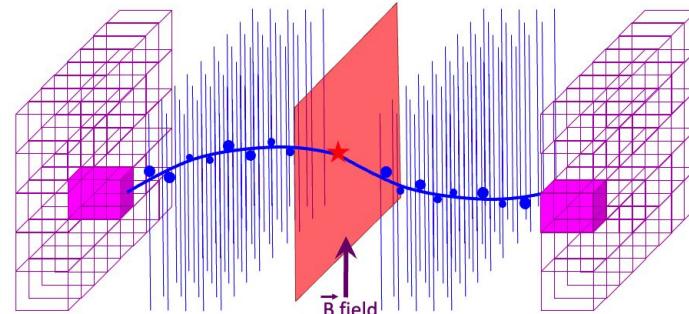
SuperNEMO status

Calorimeter studies (my work):

- Absolute energy calibration
- Relative energy calibration
- Background studies

SuperNEMO technique

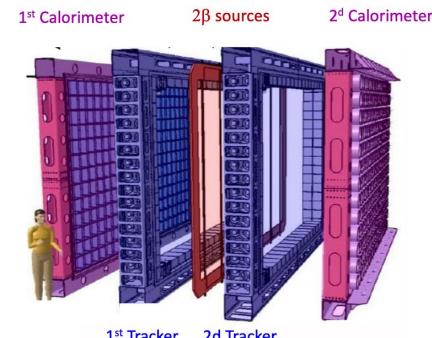
1. **$\beta\beta$ source foil:** free choice of most **isotopes**
2. **Tracker:** charged particle **trajectory**
3. **Calorimeter:** **energy** of **each** particle



Advantages:

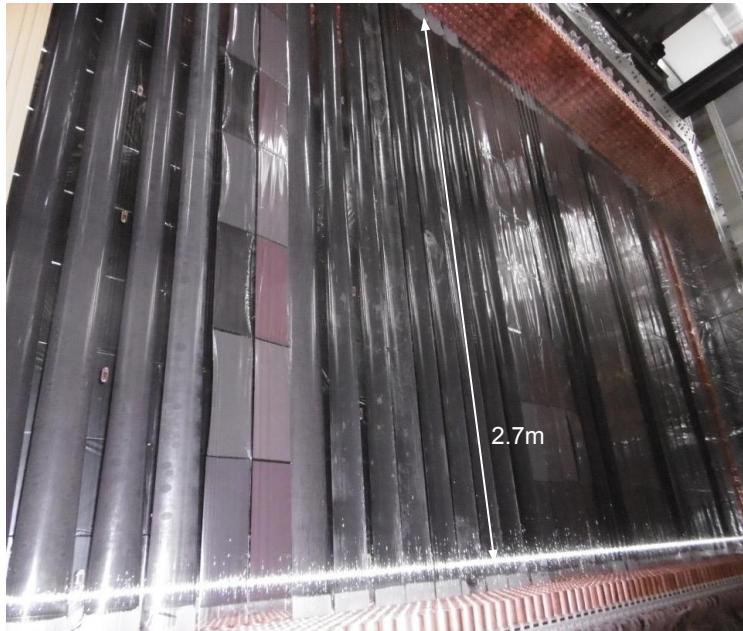
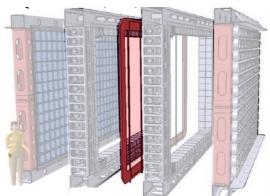
Access to the **full kinematics** of the decay:

- Golden $0\nu\beta\beta$ events
- Background modelling (dedicated channels)
- Differentiate the $0\nu\beta\beta$ mechanisms
- High precision nuclear studies with $2\nu\beta\beta$ 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 ($\beta\beta$ isotope)

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

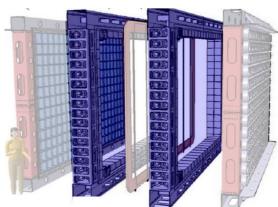
High $T_{1/2}^{2\nu} = 9.4 \cdot 10^{19} \text{ y}$

Thickness: $\sim 280 \mu\text{m}$

Radiopurity (measured by BiPo detector):

- $^{208}\text{Tl} < 25 \mu\text{Bq/kg}$
- $^{214}\text{Bi} < 290 \mu\text{Bq/kg}$

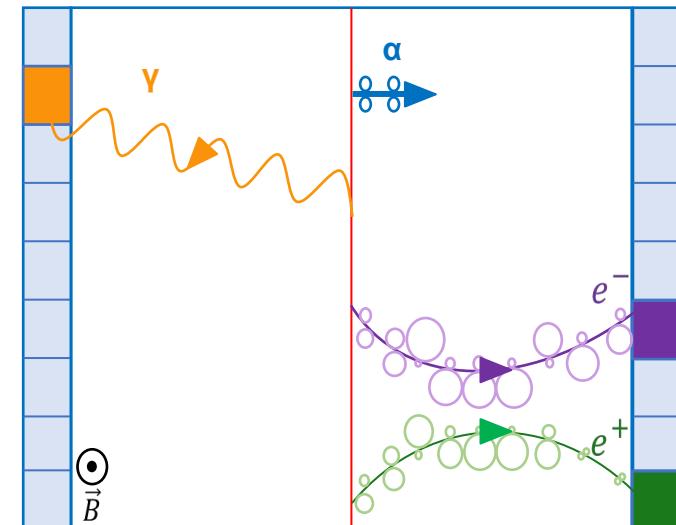
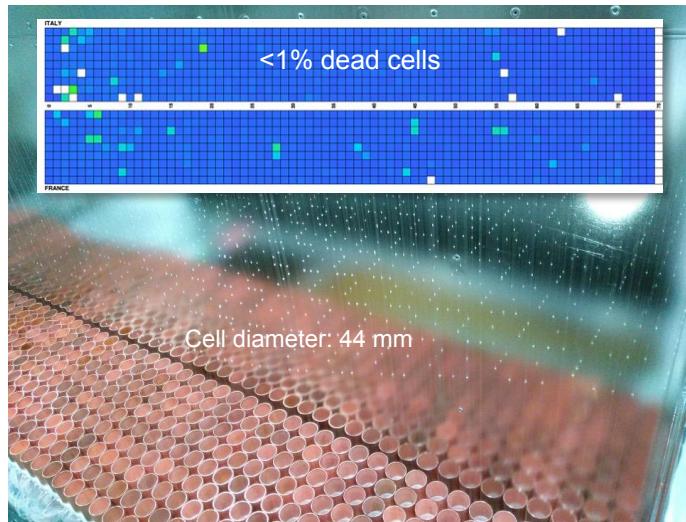
Tracker



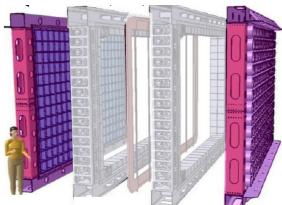
2034 drift cells (14970 wires of 40-50 μm) in Geiger mode

3D track reconstruction

Fully installed and commissioned



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

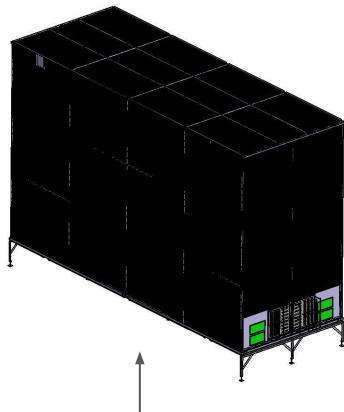
Time resolution < 400 ps for e^- at 1 MeV

Status of the demonstrator

Today: Source foil, Tracker and Calorimeter ready

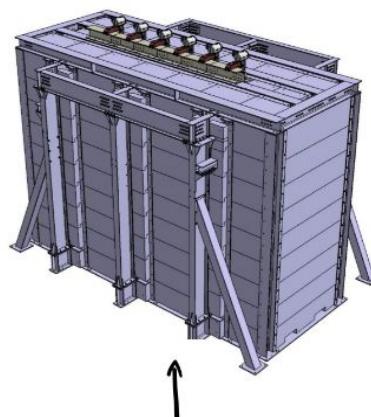
Still need to install part of the shielding:

Anti Rn tent - Done



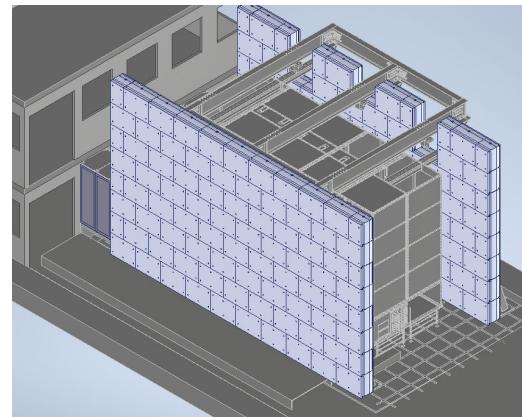
Gas tight PE plate

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

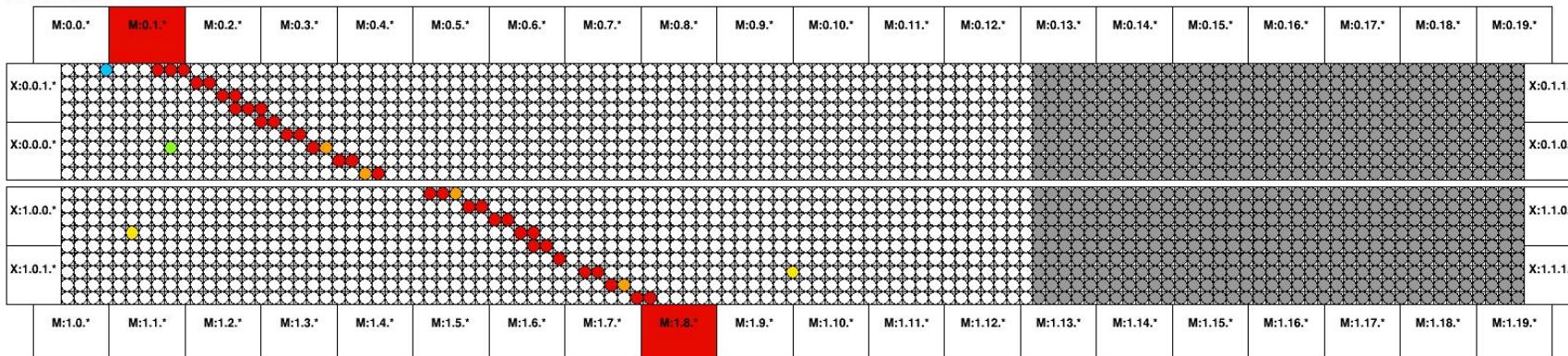
Today: Source foil, Tracker and Calorimeter ready

Still n

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

ing - Mid-2023.
(5 m³) and
(15 m³)

RUN 812 // TRIGGER 577



Summary

Neutrinoless Double beta decay

SuperNEMO status

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

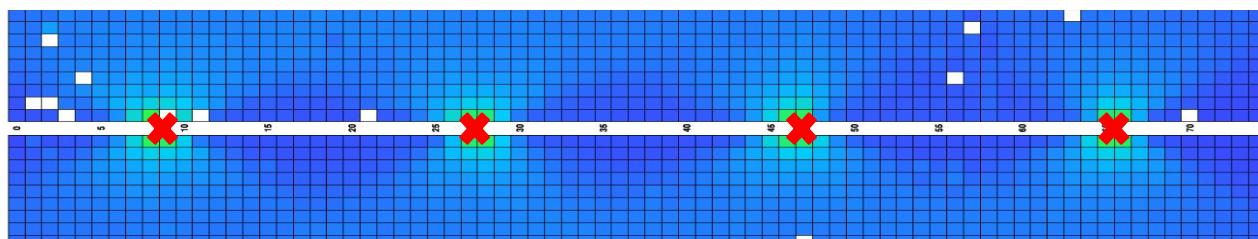
Relative calibration using LED light (Light Injection system)

Nominal absolute calibration: ^{207}Bi Sources



^{207}Bi source

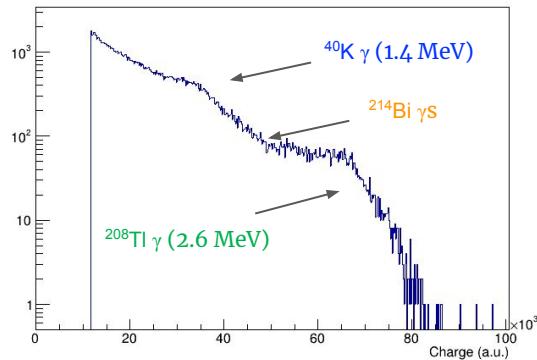
42 movable ^{207}Bi sources (automatic system) (IC e^- at 482, 976 and 1682 keV)
Need the tracker to **tag the e^- of the ^{207}Bi .** Started this method recently.
More to come next time!



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**

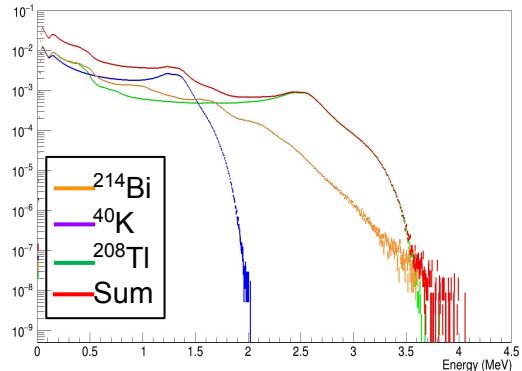
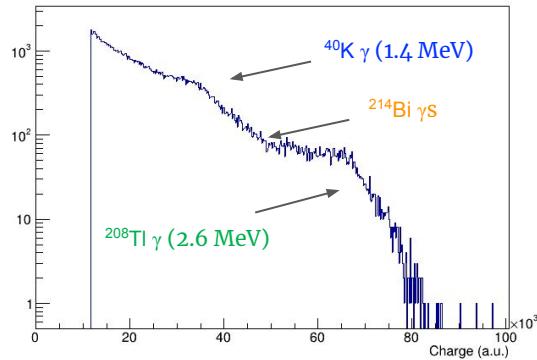


Main components of ambient background visible above 1 MeV:

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

Absolute energy calibration

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



Main components of ambient background visible above 1 MeV:

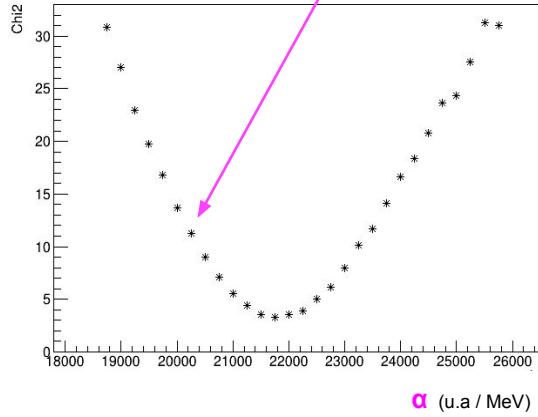
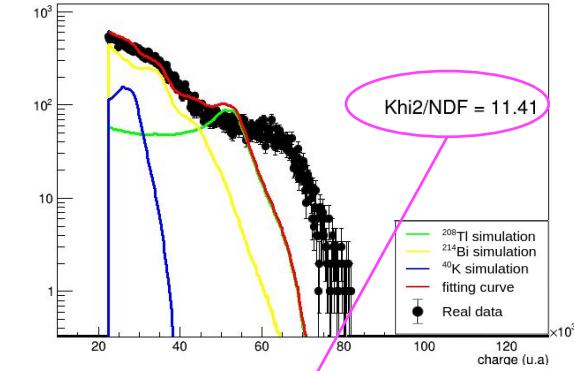
- ^{40}K (γ 1.4 MeV)
- ^{214}Bi (many γ between 1-2.4 MeV)
- ^{208}TI (γ 2.6 MeV)

MC simulation of these 3 components (from the LSM walls)

3 reference PDF (probability density function) used for calibration

Absolute energy calibration

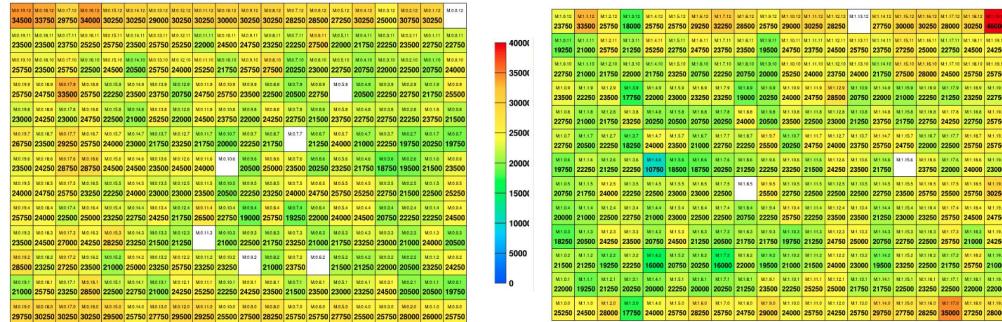
Calibration performed while waiting for the nominal method using LSM ambient background



Fitting with: $\alpha \times (A_{\text{K}} \text{PDF}_{\text{K}} + A_{\text{Bi}} \text{PDF}_{\text{Bi}} + A_{\text{Tl}} \text{PDF}_{\text{Tl}})$
 (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 (1 α = 1 optical module)

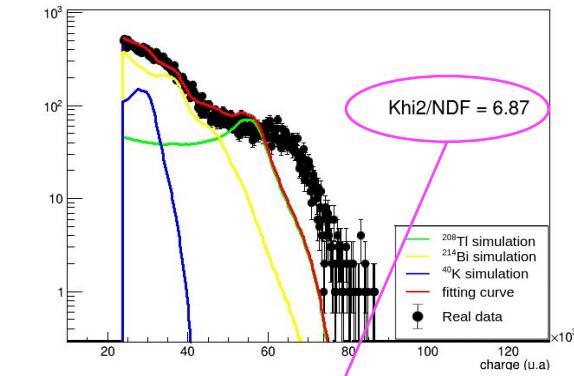
Repeat for each optical modules



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

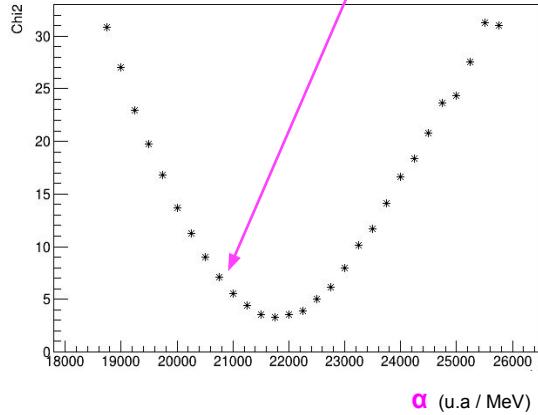
Absolute energy calibration

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

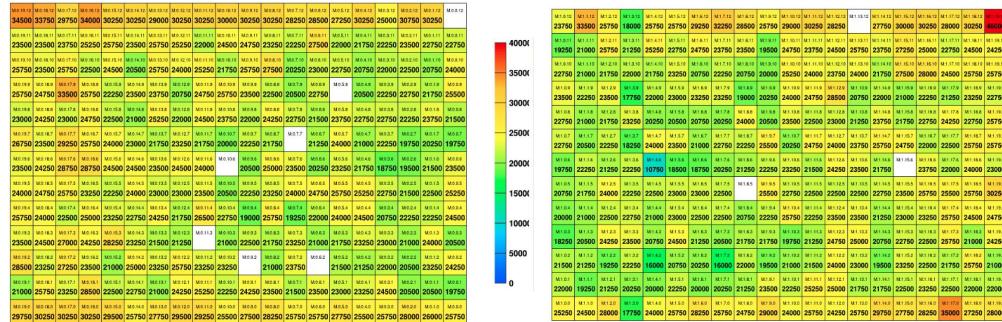


Fitting with: $\alpha \times (A_K PDF_K + A_{Bi} PDF_{Bi} + A_{Ti} PDF_{Ti})$
 (3 degrees of freedom : 1 normalization per MC components)

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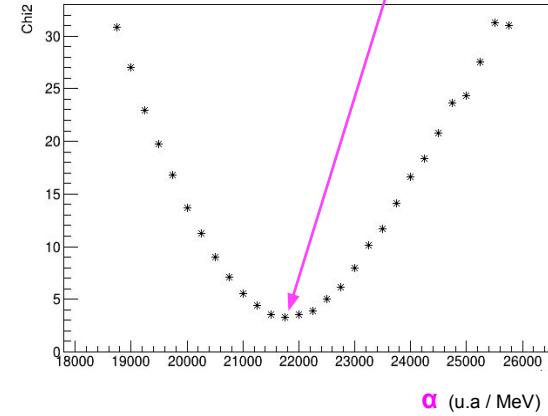
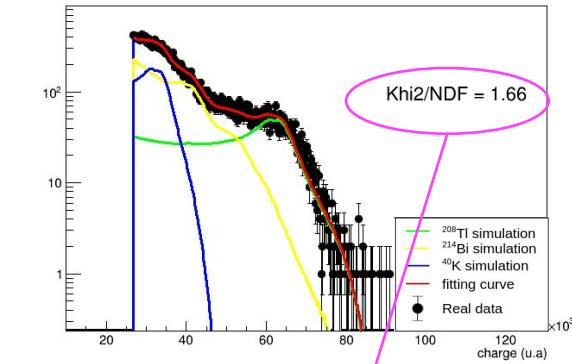
Repeat for each optical modules



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

Absolute energy calibration

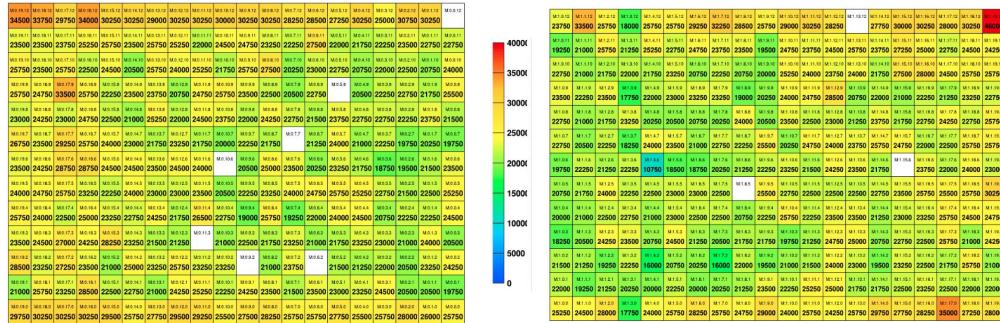
Calibration performed while waiting for the nominal method using LSM ambient background



Fitting with: $\alpha \times (A_K PDF_K + A_{Bi} PDF_{Bi} + A_{Ti} PDF_{Ti})$
 (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 (1 α = 1 optical module)

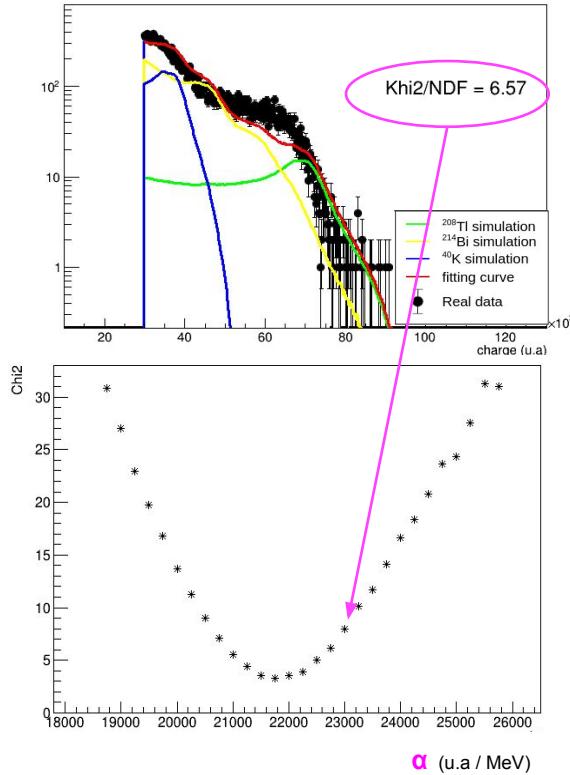
Repeat for each optical modules



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

Absolute energy calibration

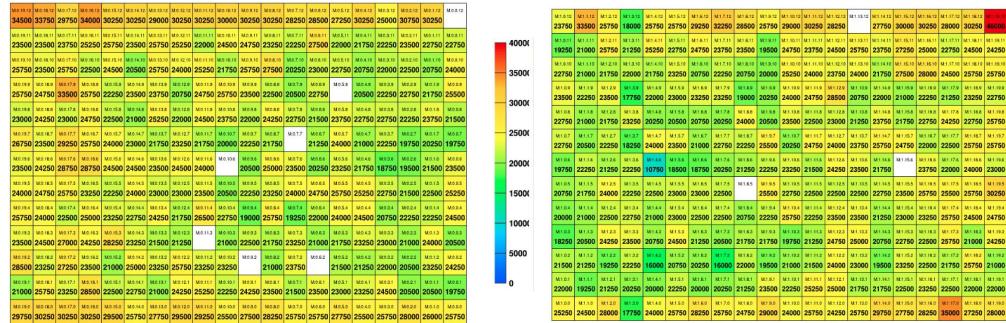
Calibration performed while waiting for the nominal method using LSM ambient background



Fitting with: $\alpha \times (A_K PDF_K + A_{Bi} PDF_{Bi} + A_{Tl} PDF_{Tl})$
 (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 (1 α = 1 optical module)

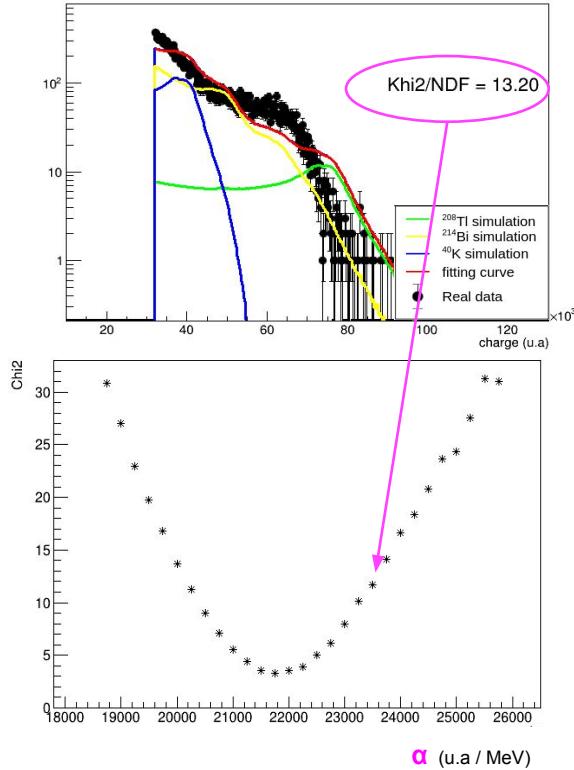
Repeat for each optical modules



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

Absolute energy calibration

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

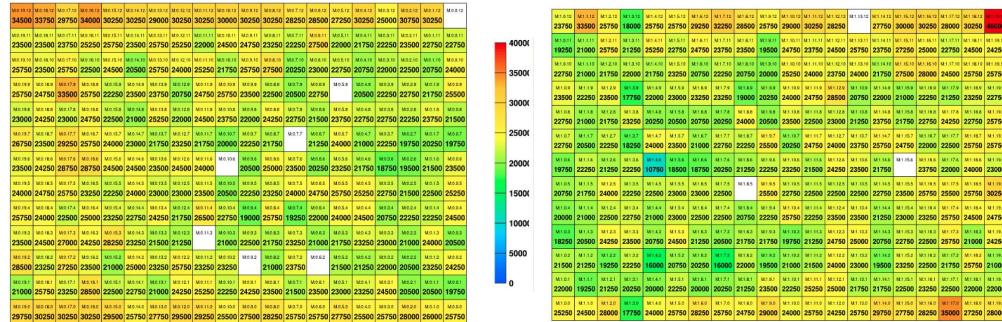


Fitting with: $\alpha \times (A_K PDF_K + A_{Bi} PDF_{Bi} + A_{Ti} PDF_{Ti})$
 (3 degrees of freedom : 1 normalization per MC components)

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

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

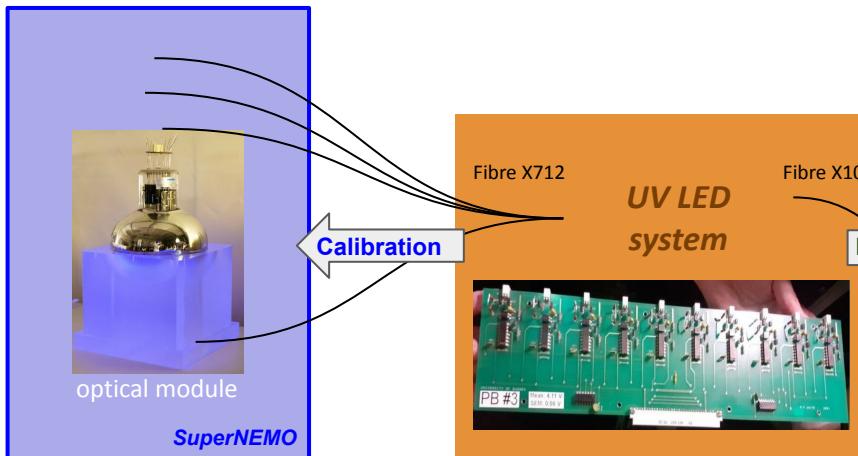
Repeat for each optical modules



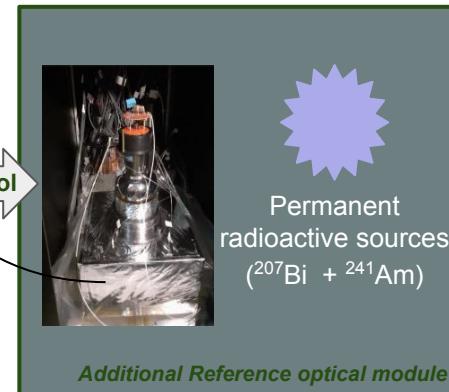
View of α for the 2 main calorimeter optical modules (square = optical module)

Relative energy calibration

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



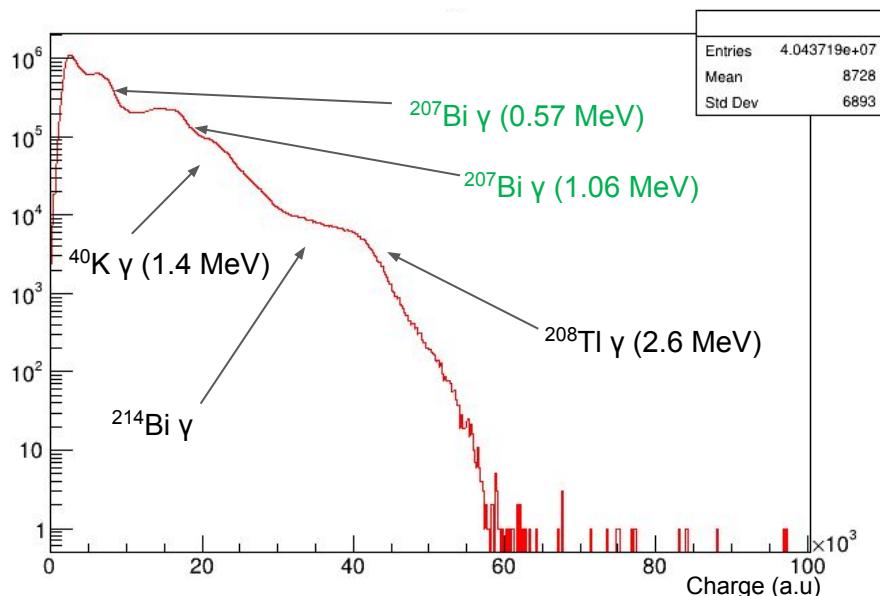
LED light calibrated with **5 Reference Optical Modules** external to the detector



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

Relative energy calibration

External Reference optical module calibration



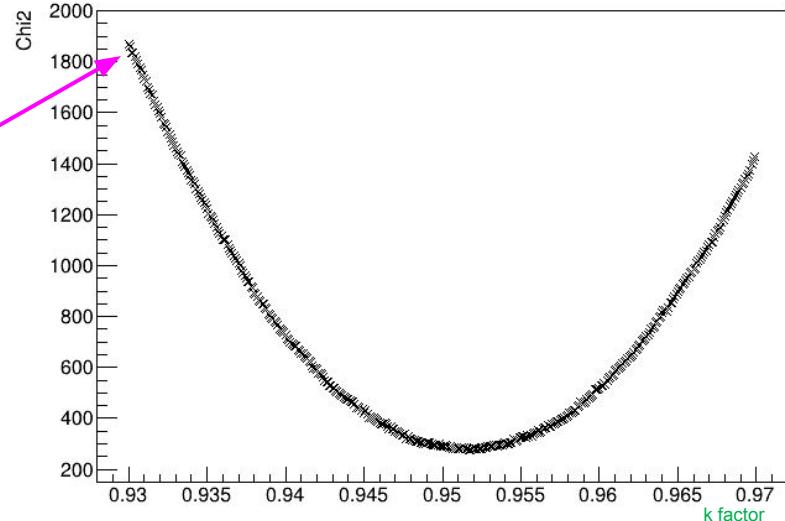
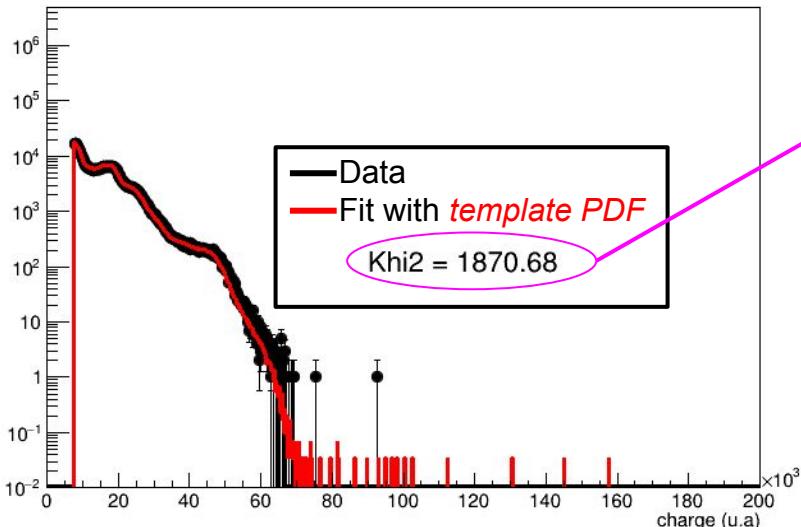
Using LSM ambient background + ^{207}Bi sources
(to constraint the spectrum shape)

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



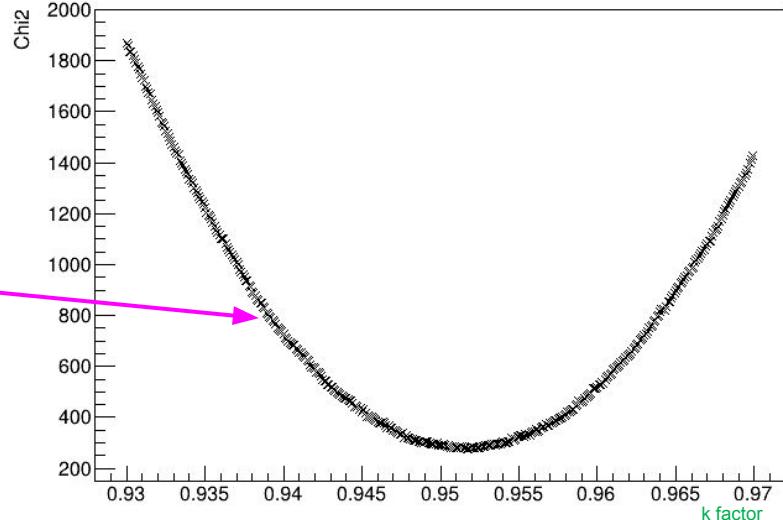
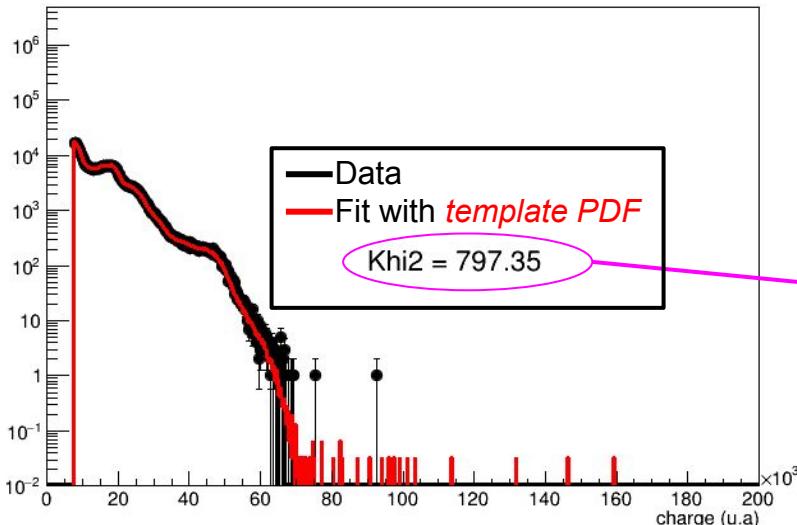
Scale **template PDF($k \times \text{charge}$)** for various k by steps of 0.01 % (k = gain variation scale factor)

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

Best k deduced with the **minimal χ^2**

Relative energy calibration

External Reference optical module calibration



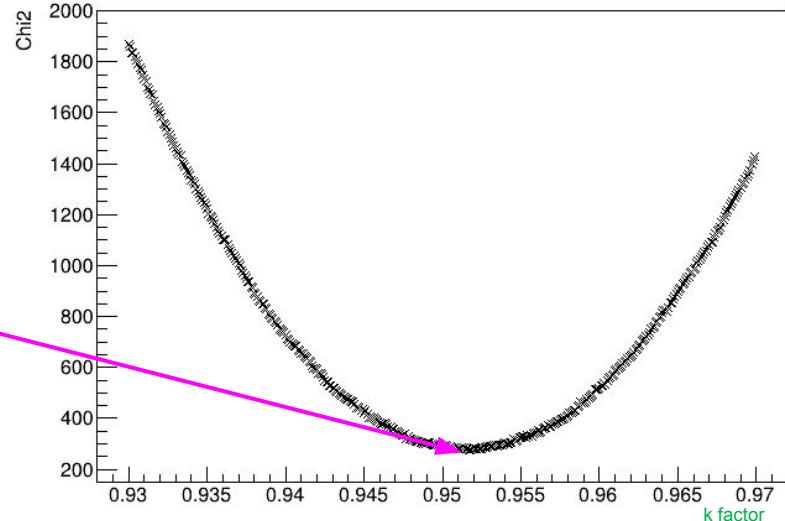
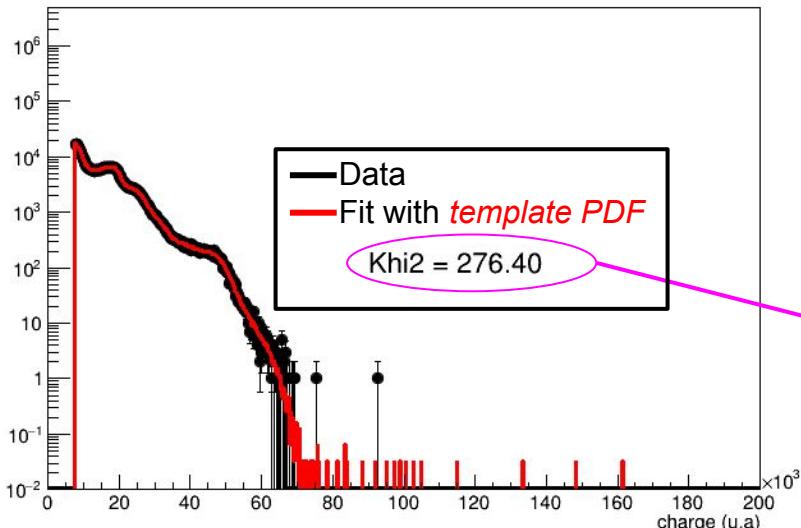
Scale template PDF($k \times \text{charge}$) for various k by steps of 0.01 % (k = gain variation scale factor)

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



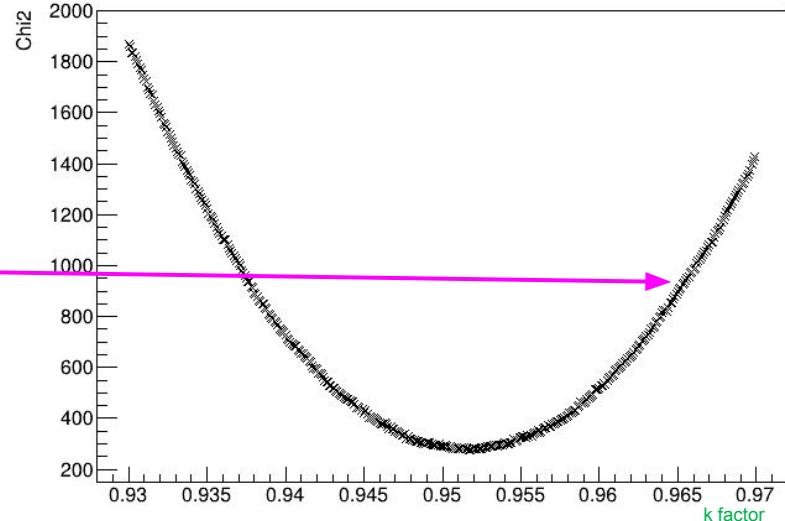
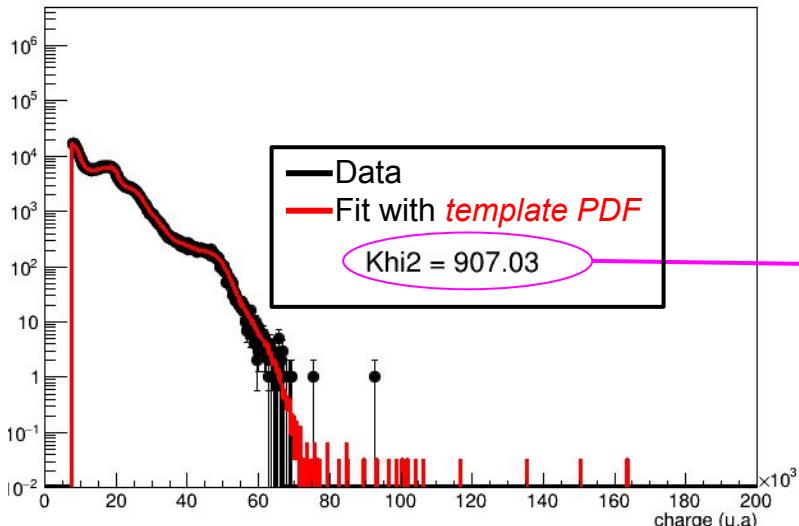
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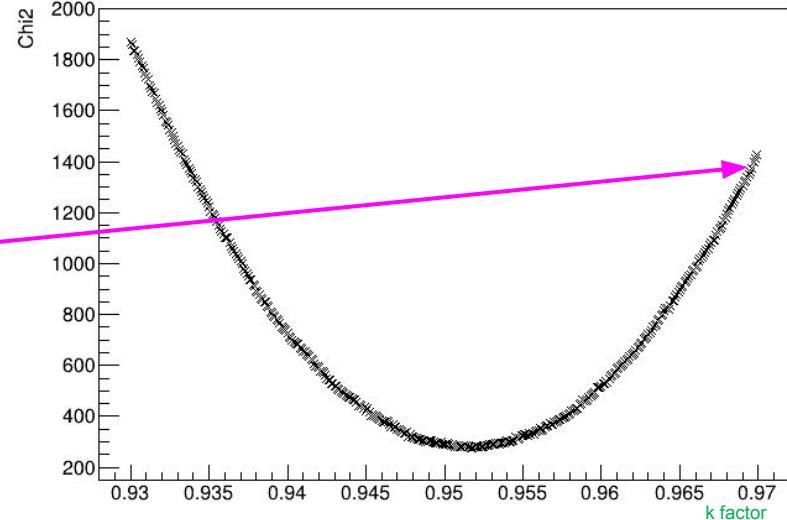
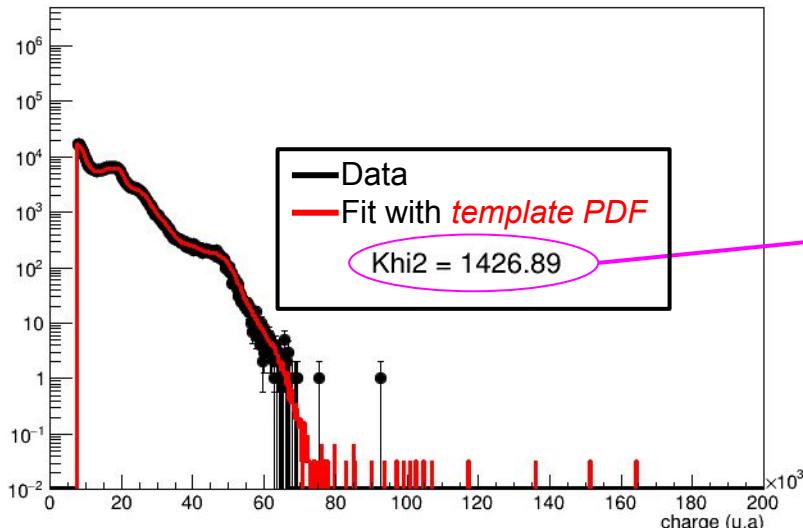
Scale **template PDF($k \times \text{charge}$)** for various k by steps of 0.01 % (k = gain variation scale factor)

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



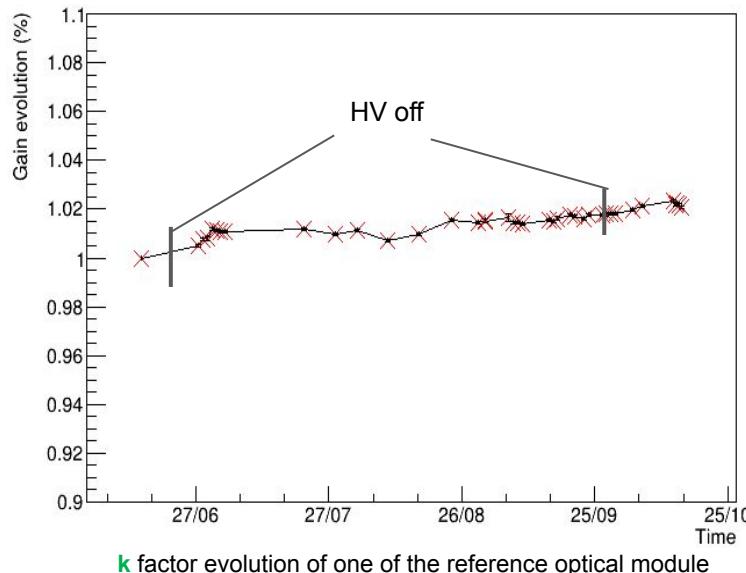
Scale **template PDF($k \times \text{charge}$)** for various k by steps of 0.01 % (k = gain variation scale factor)

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

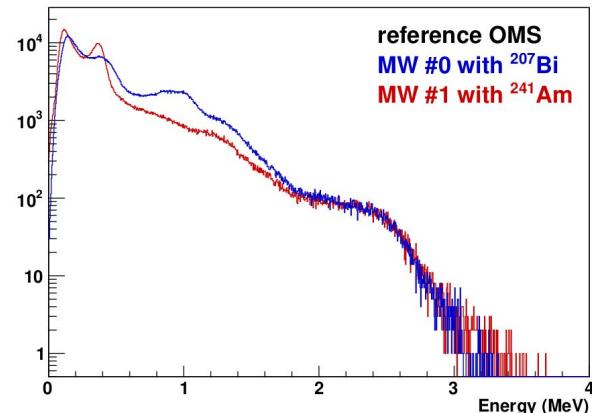
Best k deduced with the **minimal Chi 2**

Relative energy calibration

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



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



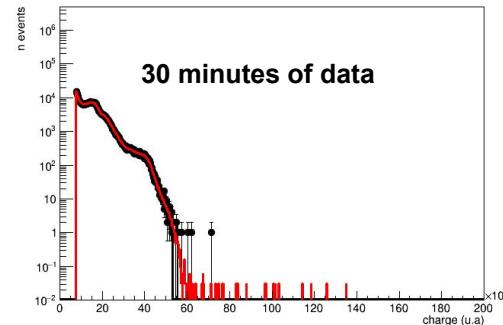
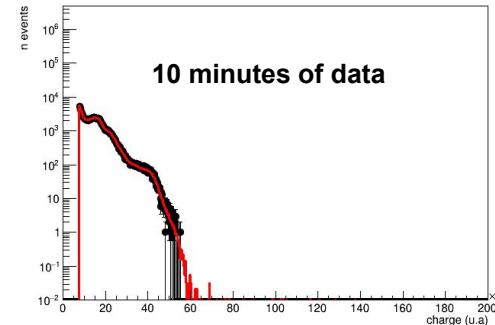
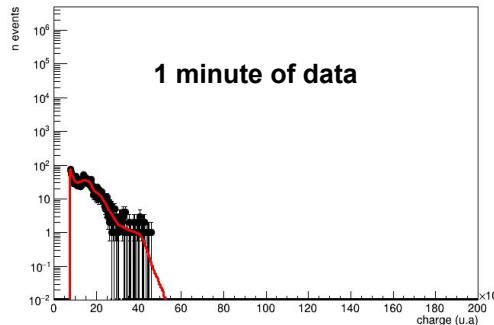
Relative energy calibration

Optimization of calibration run duration

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

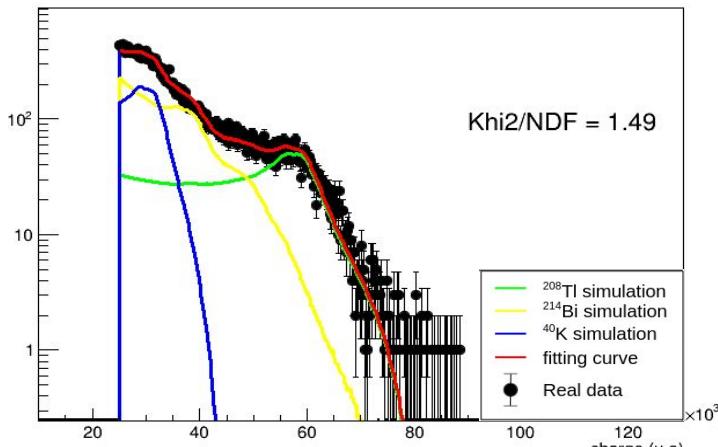
Run duration	1 min	5 min	10 min	30 min	60 min
Error on k	0.34 %	0.15 %	0.10 %	0.06 %	0.04 %

< 1% from 1 minute!!



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

Background studies



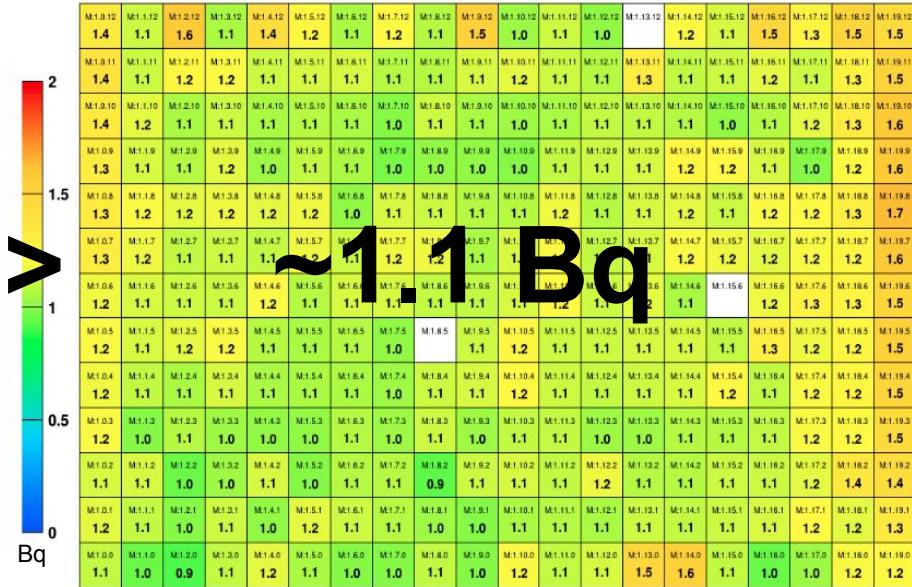
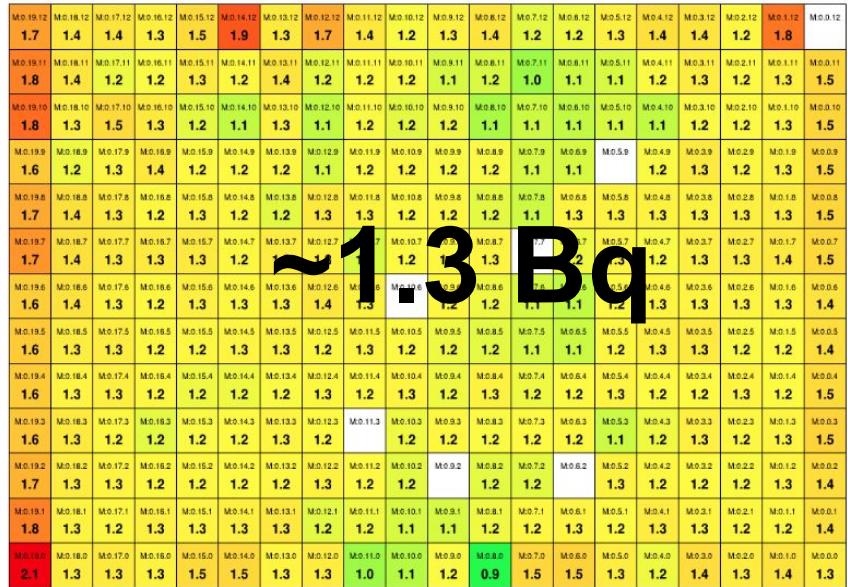
Outcome of the absolute calibration with LSM background:

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

From: $\alpha \times (A_{\text{K}} \text{PDF}_{\text{K}} + A_{\text{Bi}} \text{PDF}_{\text{Bi}} + A_{\text{Tl}} \text{PDF}_{\text{Tl}})$

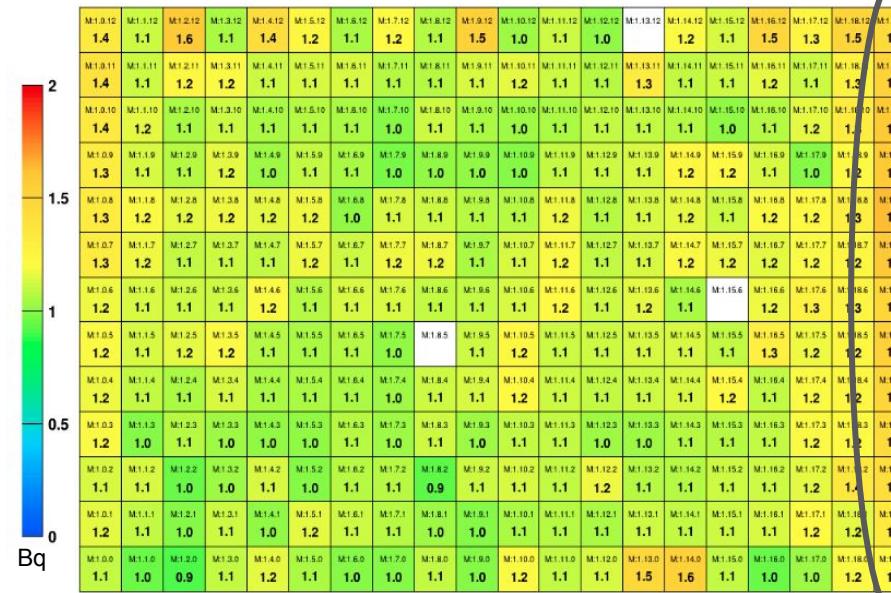
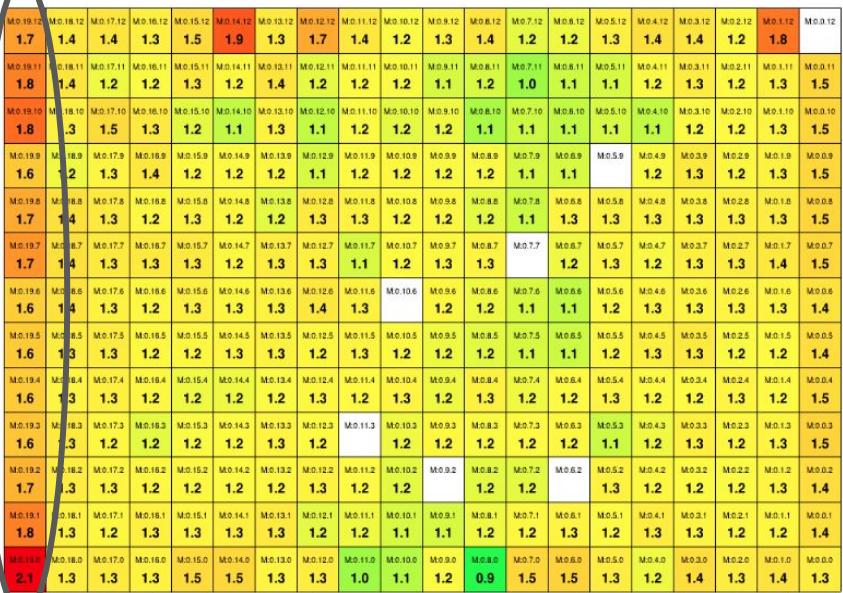
Background studies

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



Background studies

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

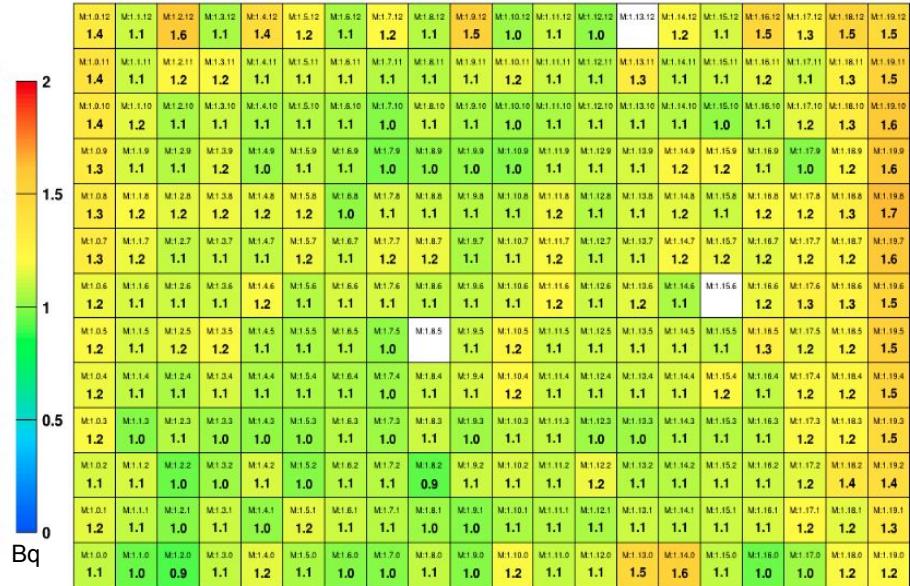


- Higher rate on the side closer to the rock of the lab wall (left plot)
 - Higher rate at border/side due to missing self-shielding by other optical modules

Background studies

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

M0.19.12	M0.18.12	M0.17.12	M0.16.12	M0.15.12	M0.14.12	M0.13.12	M0.12.12	M0.11.12	M0.10.12	M0.9.12	M0.8.12	M0.7.12	M0.6.12	M0.5.12	M0.4.12	M0.3.12	M0.2.12	M0.1.12	M0.0.12	
1.7	1.4	1.4	1.3	1.5	1.9	1.3	1.7	1.4	1.2	1.3	1.4	1.2	1.2	1.3	1.4	1.4	1.2	1.8		
M0.19.17	M0.18.17	M0.17.17	M0.16.17	M0.15.17	M0.14.17	M0.13.17	M0.12.17	M0.11.17	M0.10.17	M0.9.17	M0.8.17	M0.7.17	M0.6.17	M0.5.17	M0.4.17	M0.3.17	M0.2.17	M0.1.17	M0.0.17	
1.8	1.4	1.2	1.2	1.3	1.2	1.4	1.2	1.2	1.2	1.1	1.2	1.0	1.1	1.1	1.2	1.3	1.2	1.3	1.5	
M0.19.20	M0.18.20	M0.17.20	M0.16.20	M0.15.20	M0.14.20	M0.13.20	M0.12.20	M0.11.20	M0.10.20	M0.9.20	M0.8.20	M0.7.20	M0.6.20	M0.5.20	M0.4.20	M0.3.20	M0.2.20	M0.1.20	M0.0.20	
1.8	1.3	1.5	1.3	1.2	1.1	1.3	1.1	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.2	1.2	1.3	1.5		
M0.19.9	M0.18.9	M0.17.9	M0.16.9	M0.15.9	M0.14.9	M0.13.9	M0.12.9	M0.11.9	M0.10.9	M0.9.9	M0.8.9	M0.7.9	M0.6.9	M0.5.9	M0.4.9	M0.3.9	M0.2.9	M0.1.9	M0.0.9	
1.6	1.2	1.3	1.4	1.2	1.2	1.1	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.2	1.3	1.2	1.3	1.5		
M0.19.8	M0.18.8	M0.17.8	M0.16.8	M0.15.8	M0.14.8	M0.13.8	M0.12.8	M0.11.8	M0.10.8	M0.9.8	M0.8.8	M0.7.8	M0.6.8	M0.5.8	M0.4.8	M0.3.8	M0.2.8	M0.1.8	M0.0.8	
1.7	1.4	1.3	1.2	1.3	1.2	1.2	1.3	1.3	1.2	1.2	1.1	1.3	1.3	1.3	1.3	1.3	1.3	1.5		
M0.19.7	M0.18.7	M0.17.7	M0.16.7	M0.15.7	M0.14.7	M0.13.7	M0.12.7	M0.11.7	M0.10.7	M0.9.7	M0.8.7	M0.7.7	M0.6.7	M0.5.7	M0.4.7	M0.3.7	M0.2.7	M0.1.7	M0.0.7	
1.7	1.4	1.3	1.3	1.2	1.3	1.3	1.1	1.2	1.3	1.3	1.2	1.2	1.3	1.2	1.3	1.3	1.4	1.5		
M0.19.6	M0.18.6	M0.17.6	M0.16.6	M0.15.6	M0.14.6	M0.13.6	M0.12.6	M0.11.6	M0.10.6	M0.9.6	M0.8.6	M0.7.6	M0.6.6	M0.5.6	M0.4.6	M0.3.6	M0.2.6	M0.1.6	M0.0.6	
1.6	1.3	1.4	1.2	1.3	1.3	1.4	1.3	1.2	1.1	1.1	1.1	1.2	1.3	1.3	1.3	1.4				
M0.19.5	M0.18.5	M0.17.5	M0.16.5	M0.15.5	M0.14.5	M0.13.5	M0.12.5	M0.11.5	M0.10.5	M0.9.5	M0.8.5	M0.7.5	M0.6.5	M0.5.5	M0.4.5	M0.3.5	M0.2.5	M0.1.5	M0.0.5	
1.6	1.3	1.3	1.2	1.2	1.3	1.3	1.2	1.3	1.2	1.2	1.1	1.1	1.2	1.3	1.3	1.2	1.2	1.4		
M0.19.4	M0.18.4	M0.17.4	M0.16.4	M0.15.4	M0.14.4	M0.13.4	M0.12.4	M0.11.4	M0.10.4	M0.9.4	M0.8.4	M0.7.4	M0.6.4	M0.5.4	M0.4.4	M0.3.4	M0.2.4	M0.1.4	M0.0.4	
1.6	1.3	1.3	1.2	1.2	1.2	1.3	1.2	1.3	1.2	1.3	1.2	1.2	1.3	1.2	1.2	1.3	1.2	1.5		
M0.19.3	M0.18.3	M0.17.3	M0.16.3	M0.15.3	M0.14.3	M0.13.3	M0.12.3	M0.11.3	M0.10.3	M0.9.3	M0.8.3	M0.7.3	M0.6.3	M0.5.3	M0.4.3	M0.3.3	M0.2.3	M0.1.3	M0.0.3	
1.6	1.3	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.1	1.2	1.2	1.1	1.2	1.3	1.2	1.5		
M0.19.2	M0.18.2	M0.17.2	M0.16.2	M0.15.2	M0.14.2	M0.13.2	M0.12.2	M0.11.2	M0.10.2	M0.9.2	M0.8.2	M0.7.2	M0.6.2	M0.5.2	M0.4.2	M0.3.2	M0.2.2	M0.1.2	M0.0.2	
1.7	1.3	1.3	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.3	1.4			
M0.19.1	M0.18.1	M0.17.1	M0.16.1	M0.15.1	M0.14.1	M0.13.1	M0.12.1	M0.11.1	M0.10.1	M0.9.1	M0.8.1	M0.7.1	M0.6.1	M0.5.1	M0.4.1	M0.3.1	M0.2.1	M0.1.1	M0.0.1	
1.8	1.3	1.2	1.3	1.3	1.2	1.2	1.1	1.1	1.2	1.2	1.3	1.2	1.3	1.2	1.2	1.3	1.2	1.4		
M0.19.0	M0.18.0	M0.17.0	M0.16.0	M0.15.0	M0.14.0	M0.13.0	M0.12.0	M0.11.0	M0.10.0	M0.9.0	M0.8.0	M0.7.0	M0.6.0	M0.5.0	M0.4.0	M0.3.0	M0.2.0	M0.1.0	M0.0.0	
2.1	1.3	1.3	1.3	1.5	1.5	1.3	1.3	1.0	1.1	1.2	0.9	1.5	1.5	1.3	1.2	1.4	1.3	1.4	1.3	



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 !