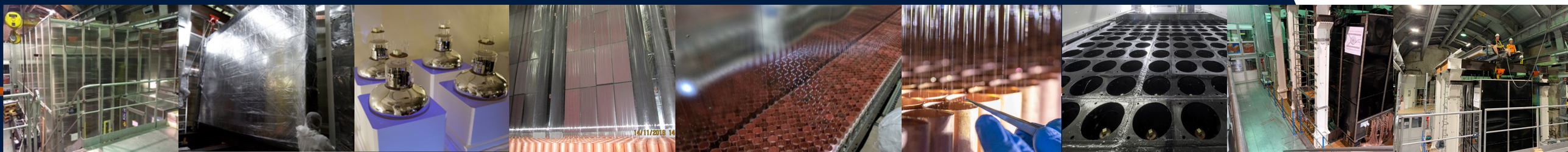
Calibration systems of the SuperNEMO demonstrator experiment

IRN Neutrino, 06/13/2025

Granjon Mathis



Summary

- SuperNEMO experiment demonstrator
- Absolute calibration: ^{207}Bi radioactive sources
- Relative calibration: LED injection

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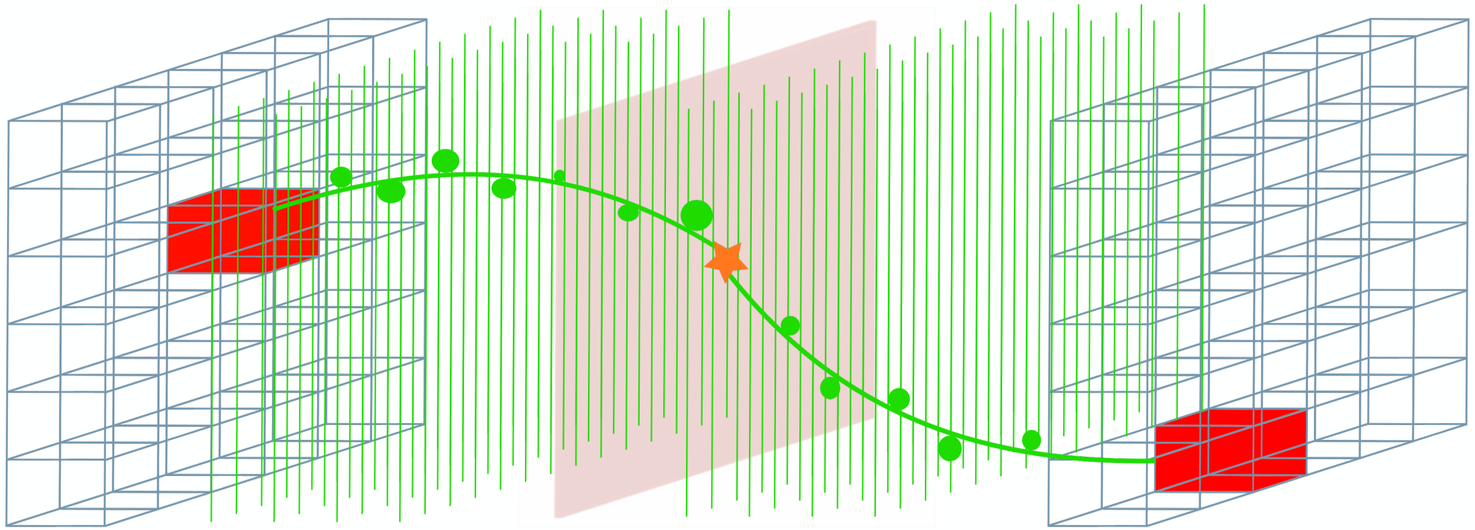
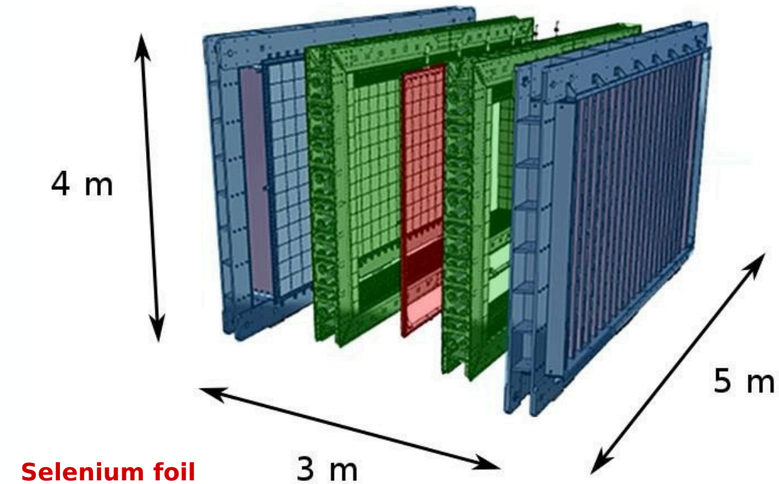
The SuperNEMO demonstrator

Unique detector in the world looking for neutrinoless double beta decay **with** particle tracks



SuperNEMO demonstrator

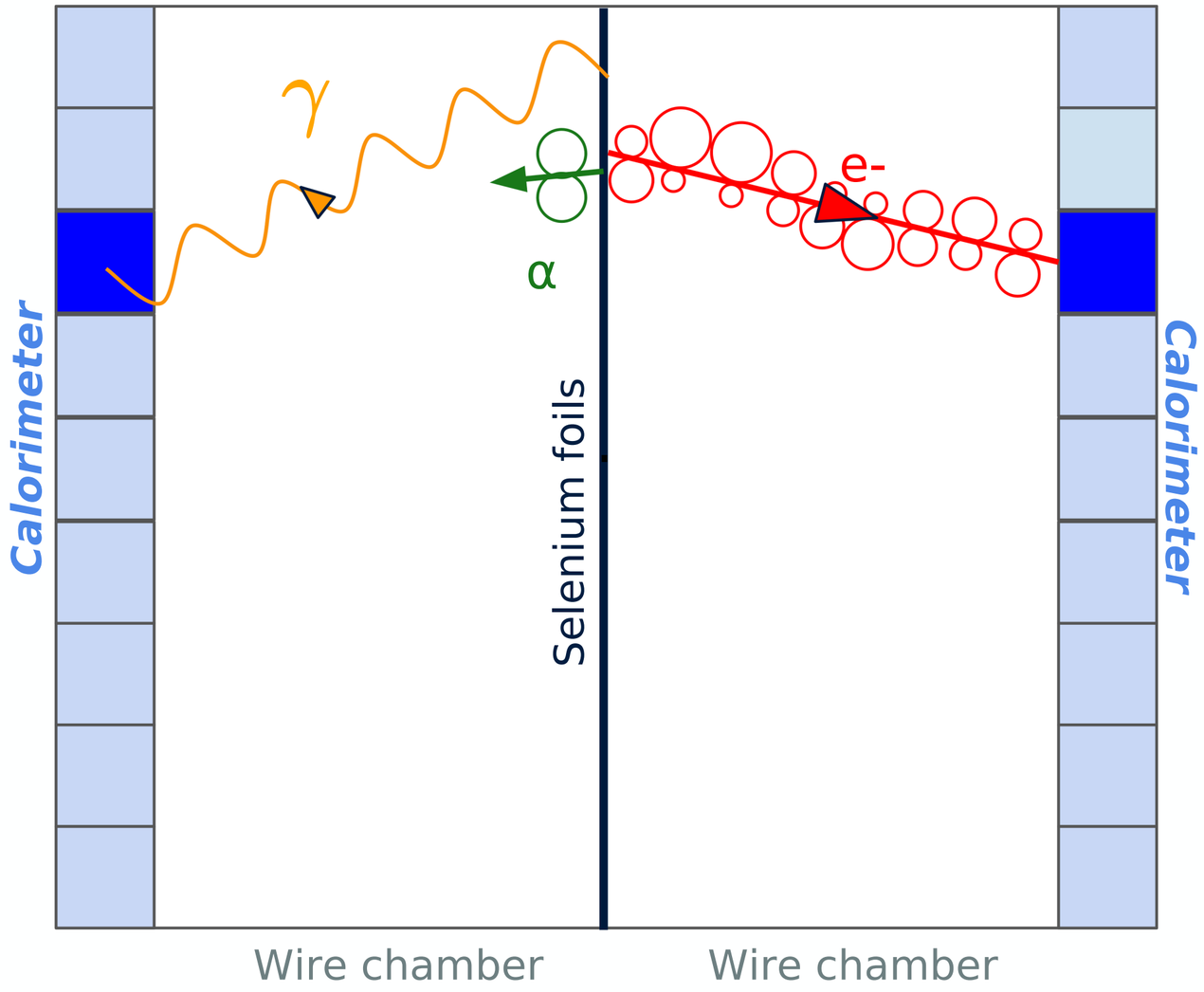


Selenium foil
300 um thick
6.11 kg of 82Se
(Qββ= 2.99 MeV)

TRACKER
2034 drift cells
in Geiger mode

CALORIMETER
712 Optical Modules (OMs)
1 OM = PS + 8" or 5" PMT

Particle identification in SuperNEMO



γ : **no track**, only calo hit

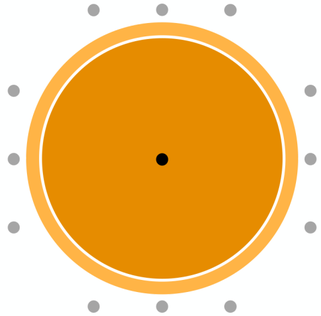
α : **short track**, no calo hit

e- : **track and calo hit**

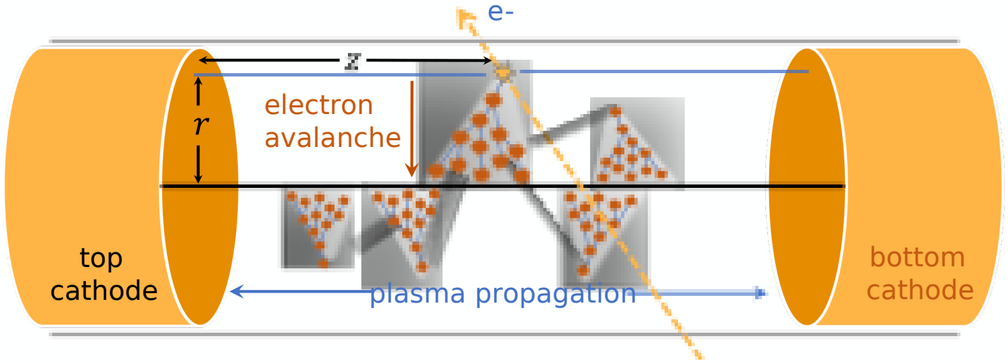
Track reconstruction in SuperNEMO

3D Track reconstruction :

- Using drift cells in Geiger mode
- Track reconstruction is necessary for **electrons**
- Assumption: **Straight** e- tracks

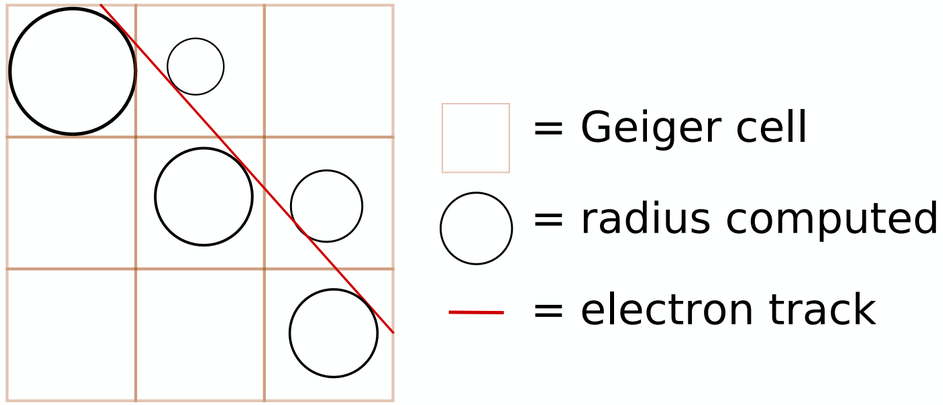


Top view of a Geiger cell (x,y) plane



Side view of a Geiger cell (y,z) plane

Purpose of the algorithm: link circles to find **the e- trajectory**

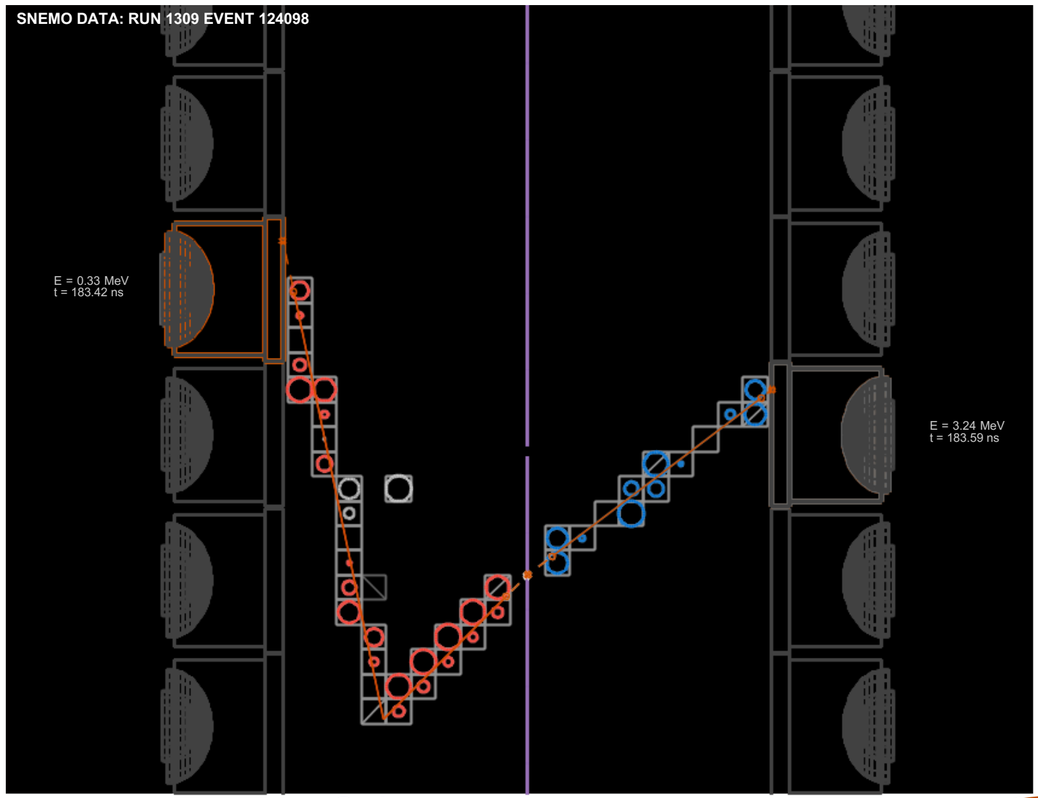


Exemple of events in SuperNEMO

Double beta event in SuperNEMO data

OMs Geiger cells ^{82}Se foil

Algorithm **improvement**: detecting tracks with scattering

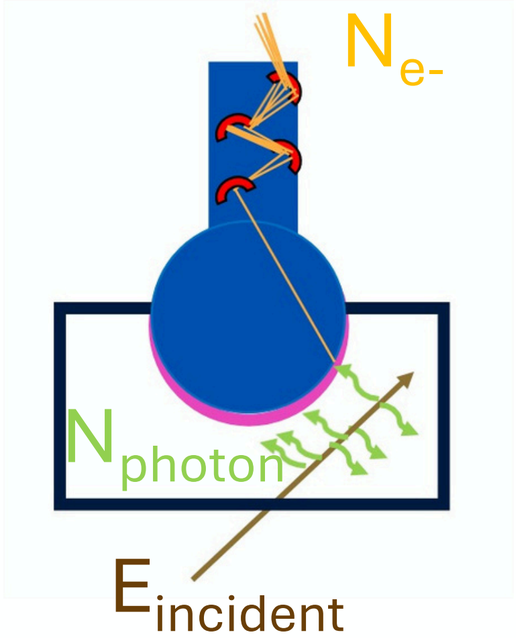


OMs Geiger cells ^{82}Se foil

Two methods to follow gain variation

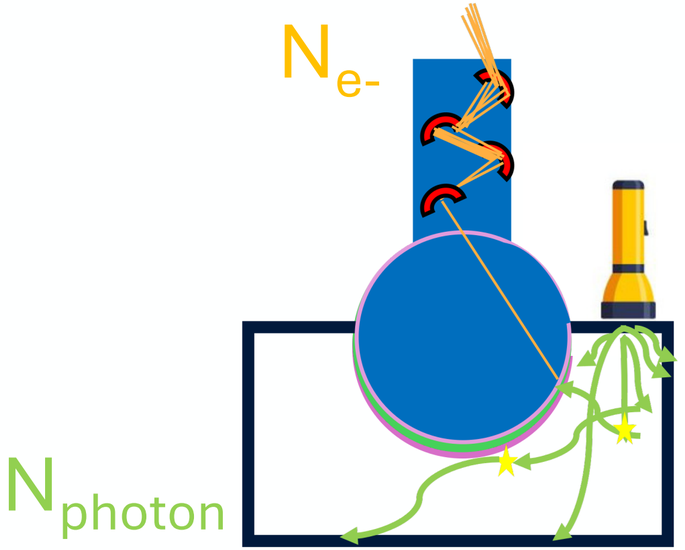
Absolute calibration:

radioactive source ^{207}**Bi**



Relative calibration:

LED injection



Two methods to follow gain variation

Absolute calibration:

radioactive source ^{207}**Bi**

Method characteristics:

- Precise
- Absolute
- Long (6 hours)

Relative calibration:

LED injection

Method characteristics:

- Short (2 min)
- Daily
- Relative

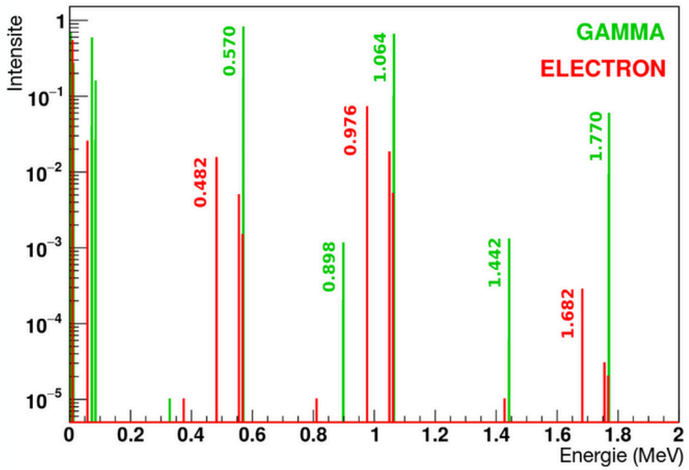
My work: verify that the **relative** and the **absolute** calibration methods are comparable within a **percent**!

Summary

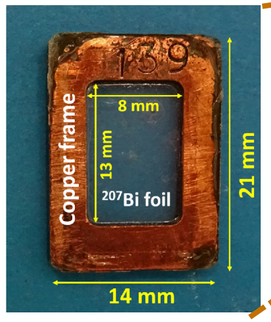
- SuperNEMO experiment demonstrator
- Absolute calibration: ^{207}Bi radioactive sources
- Relative calibration: LED injection

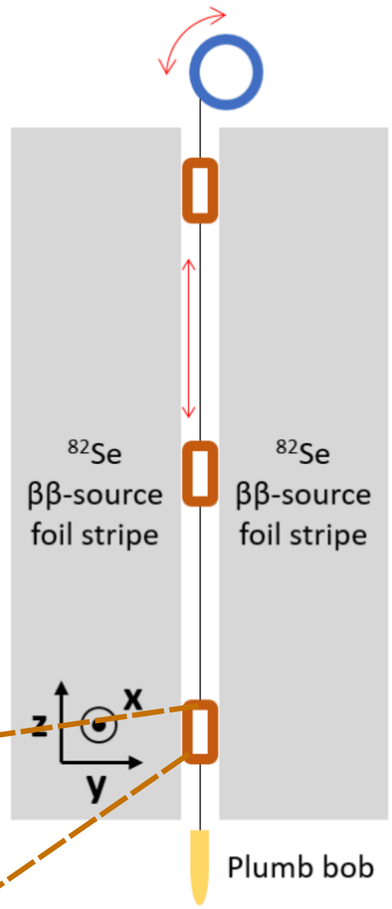
^{207}Bi absolute calibration system

Theoretical spectra of ^{207}Bi sources

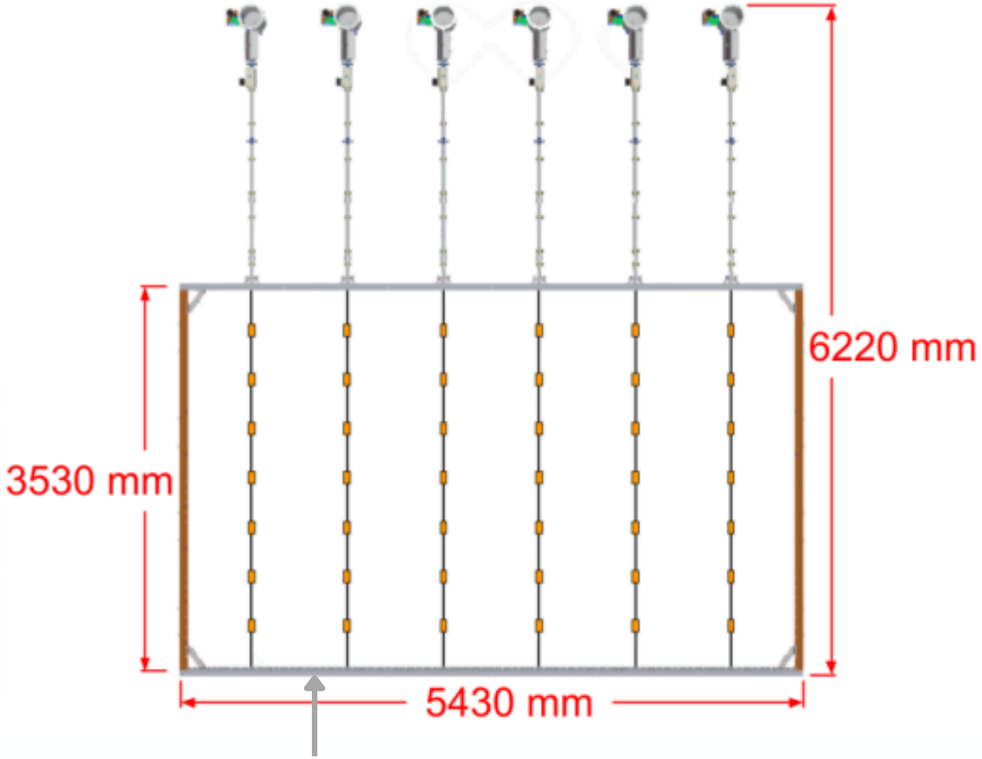


Automatic deployment of 42 ^{207}Bi sources





Bismuth deployment system



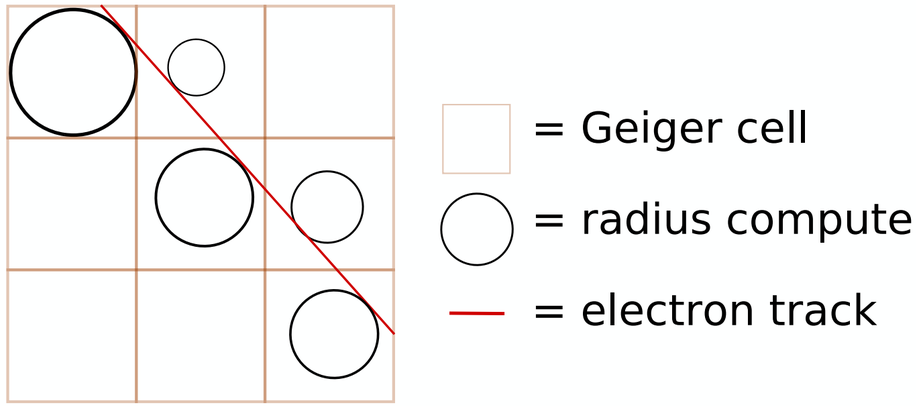
Side view of the ^{82}Se foil

^{207}Bi absolute calibration system

My work:

- Reconstruct e- data with the new track algorithm
- Create an e- selection
- Automate the fit based on theoretical branching ratio of ^{207}Bi e-
- Sort behaviour of Optical Modules for the SuperNEMO collaboration

^{207}Bi absolute calibration system



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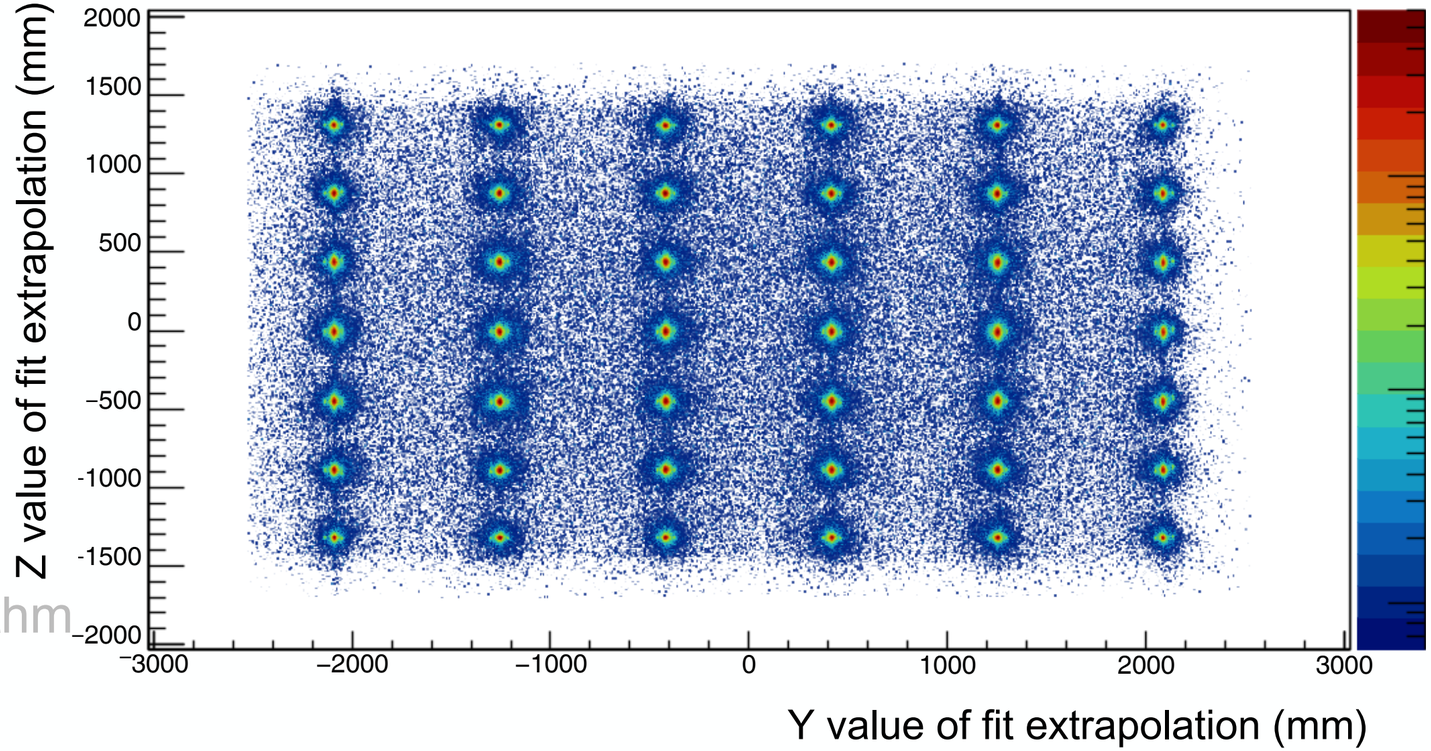
^{207}Bi absolute calibration system

Extrapolated vertices of e- tracks on the ^{82}Se source plane



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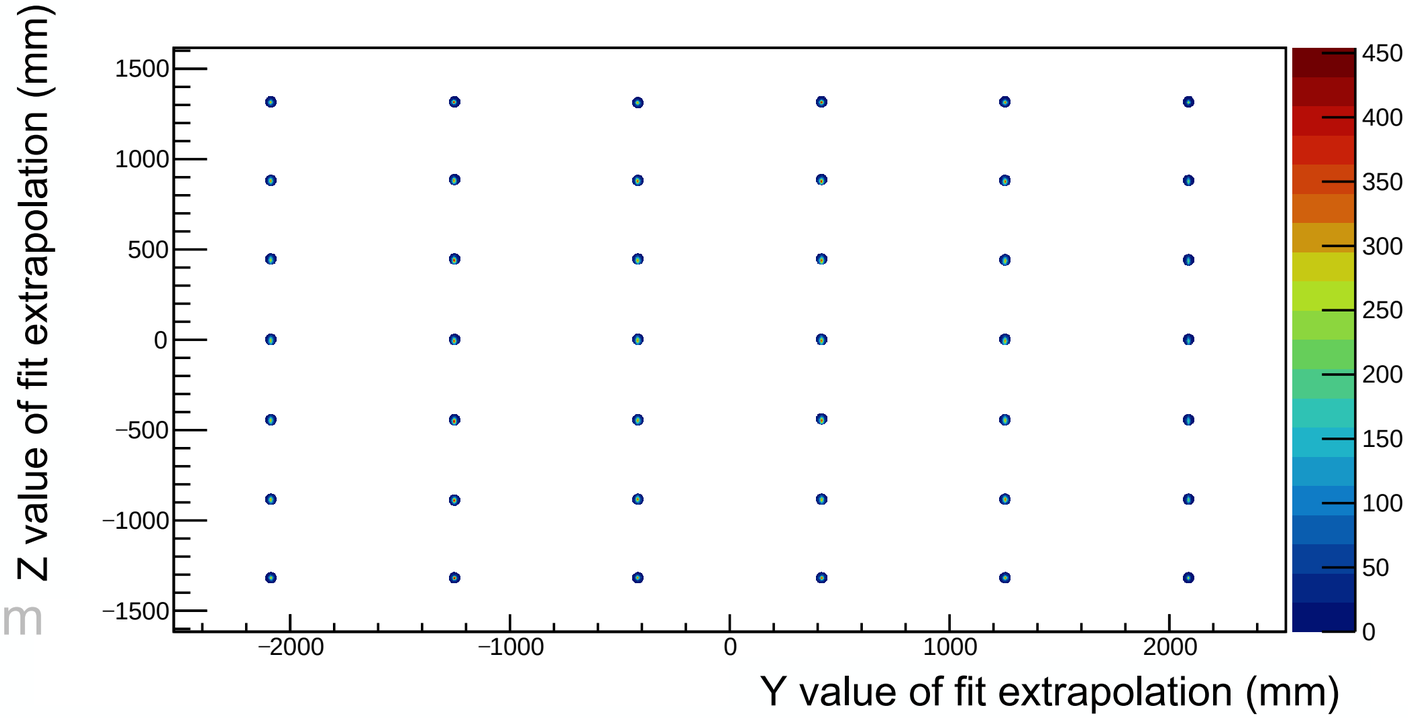

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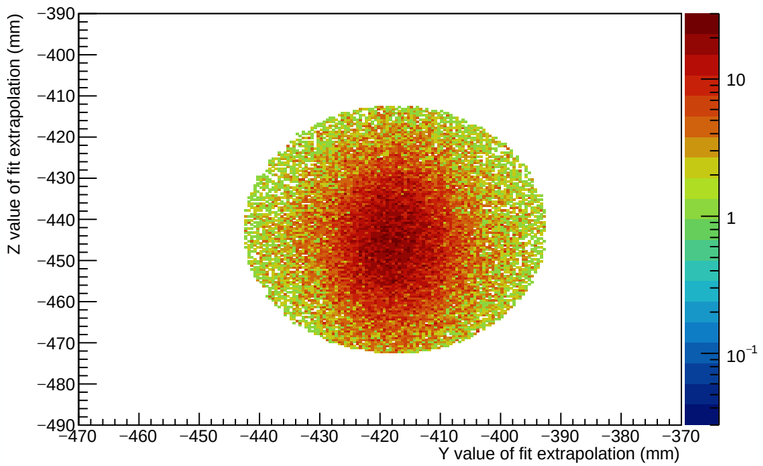
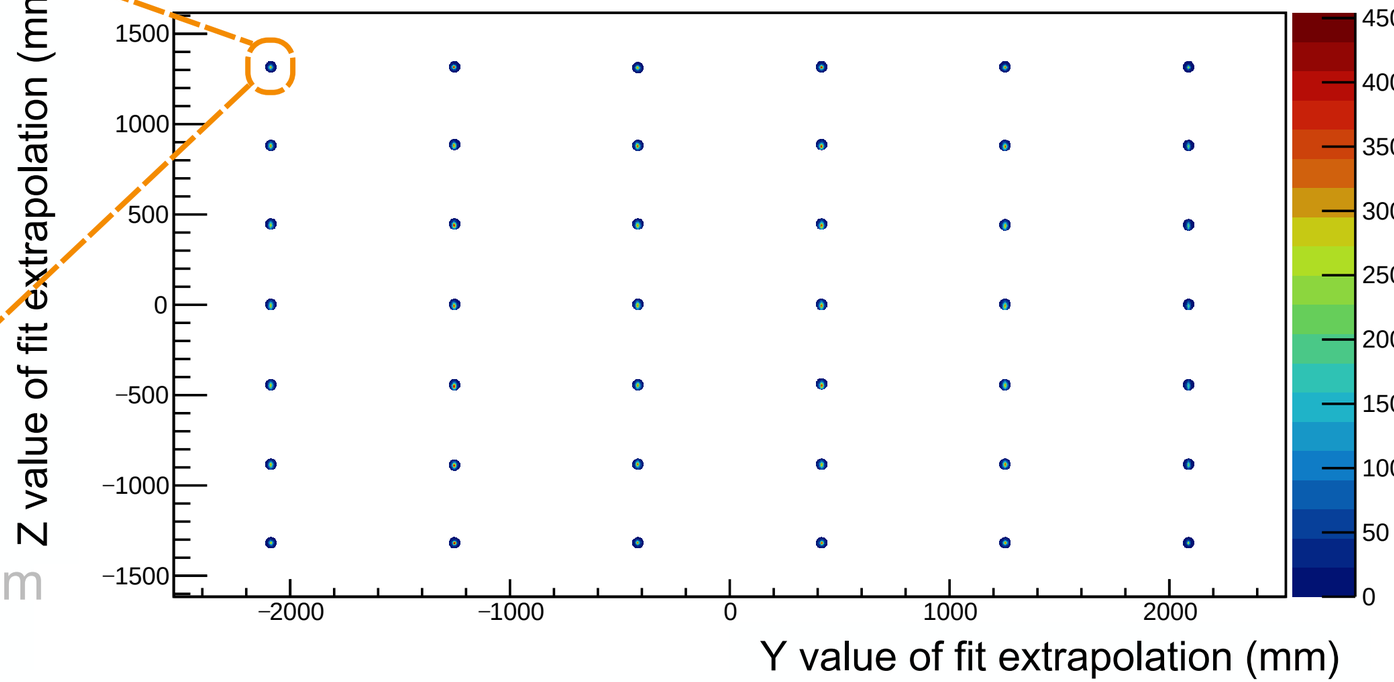


Extrapolated vertices of e- tracks on the ^{82}Se source plane



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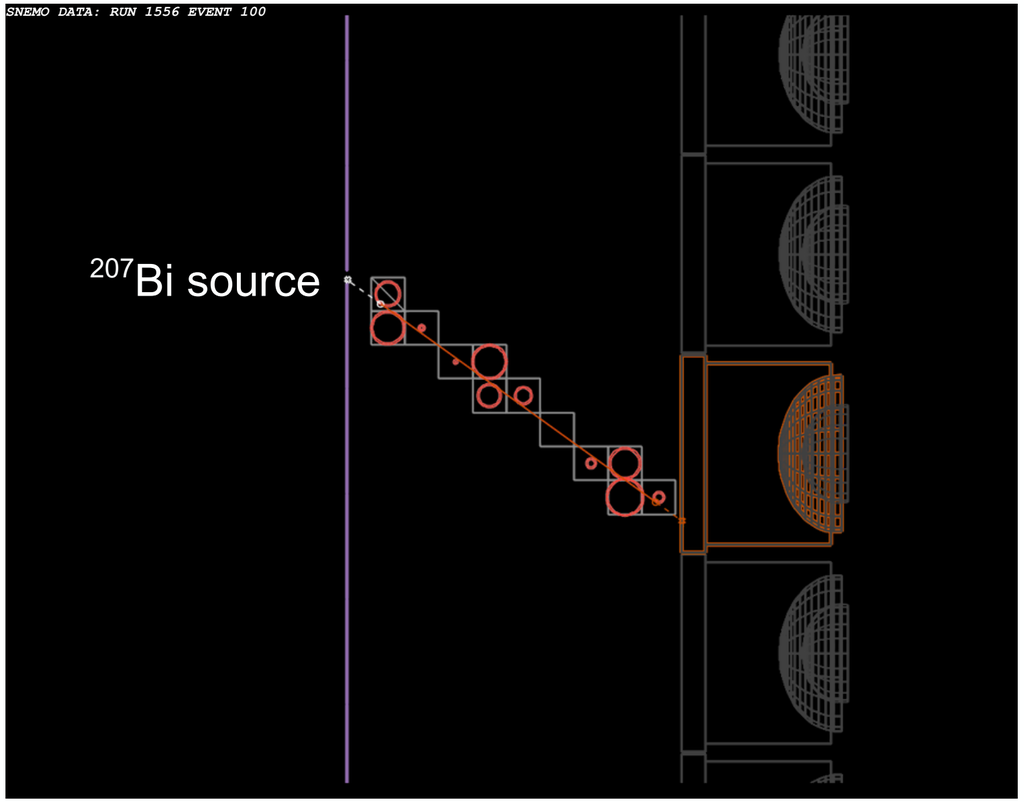
^{207}Bi absolute calibration system

Example of selected event



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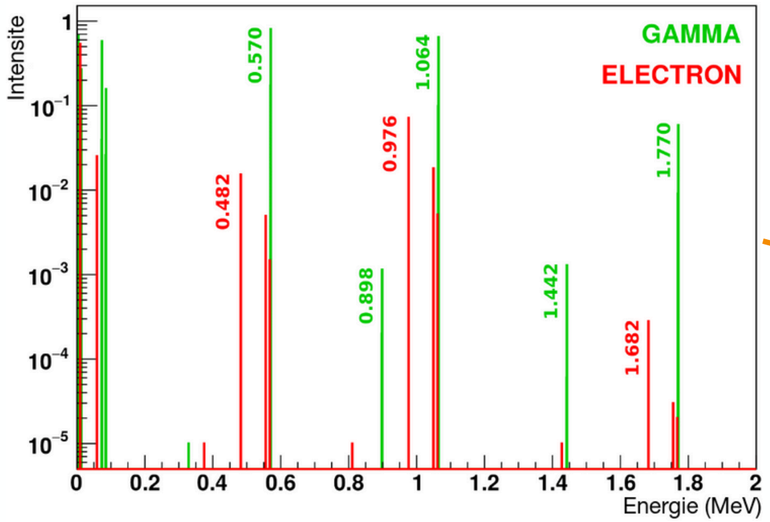
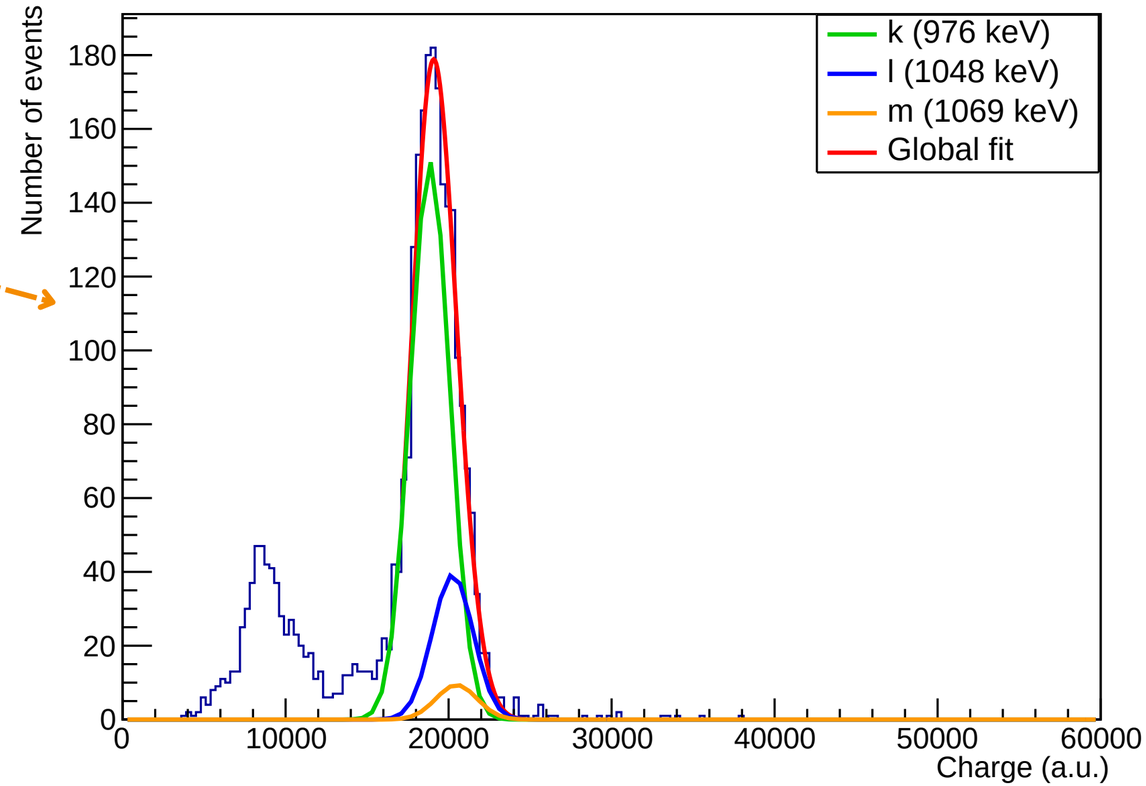
Theoretical spectra of ^{207}Bi sources



Charge e- spectra with ^{207}Bi deployment



My work:

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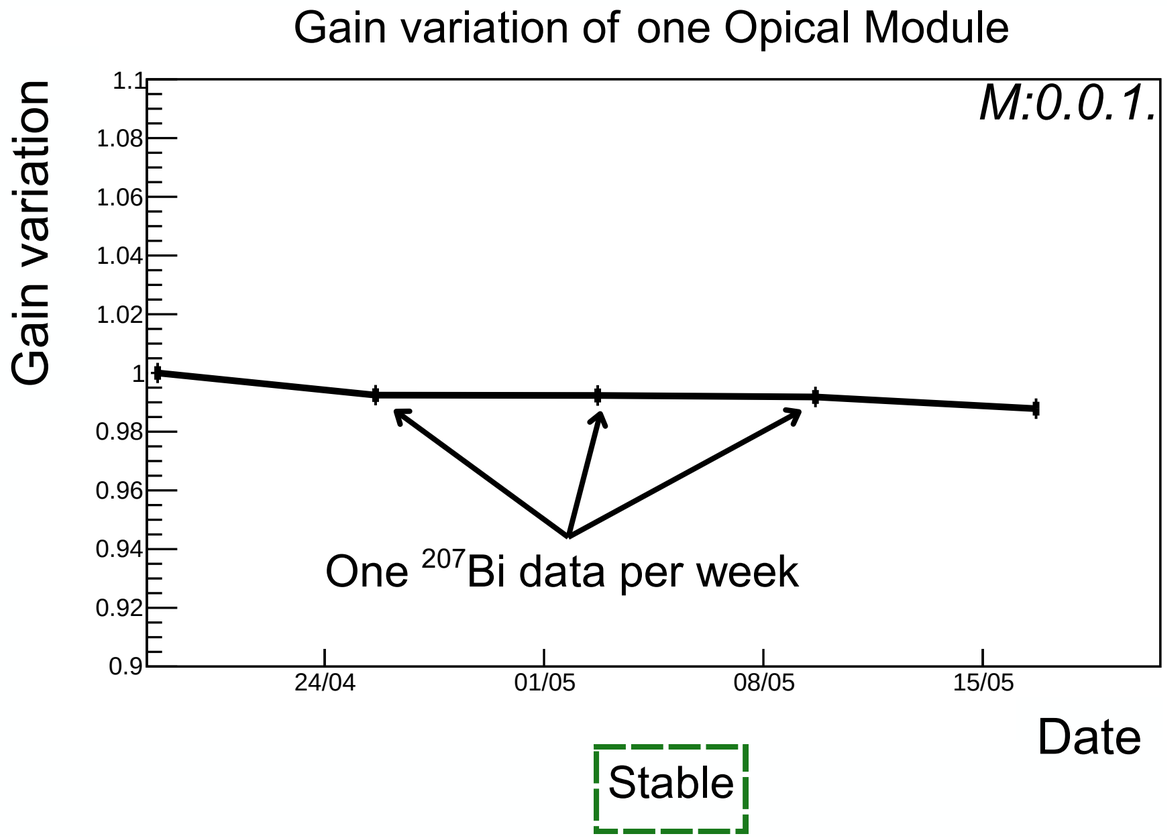
- Automate the fit based on theoretical branching ratio of ^{207}Bi e-

Extract values after an e^- selection based on theoretical branching ratio

- Sort behaviour of Optical Modules for the SuperNEMO collaboration

^{207}Bi absolute calibration system



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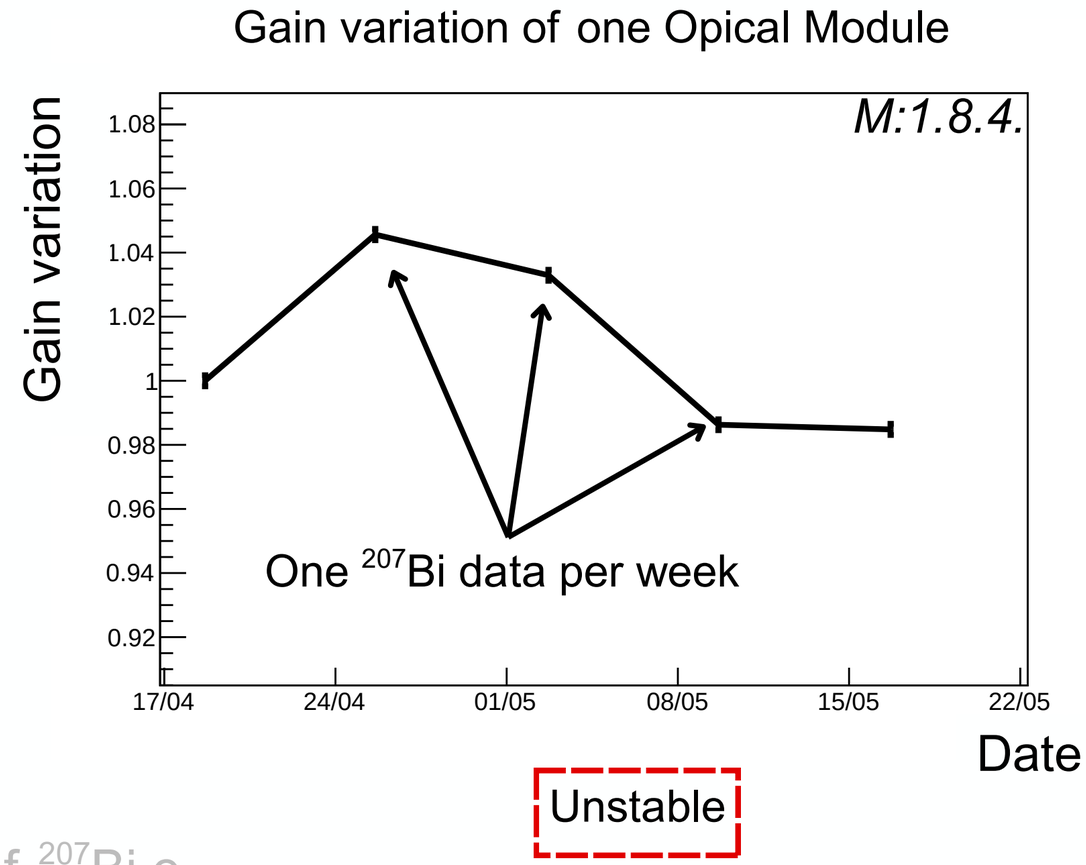

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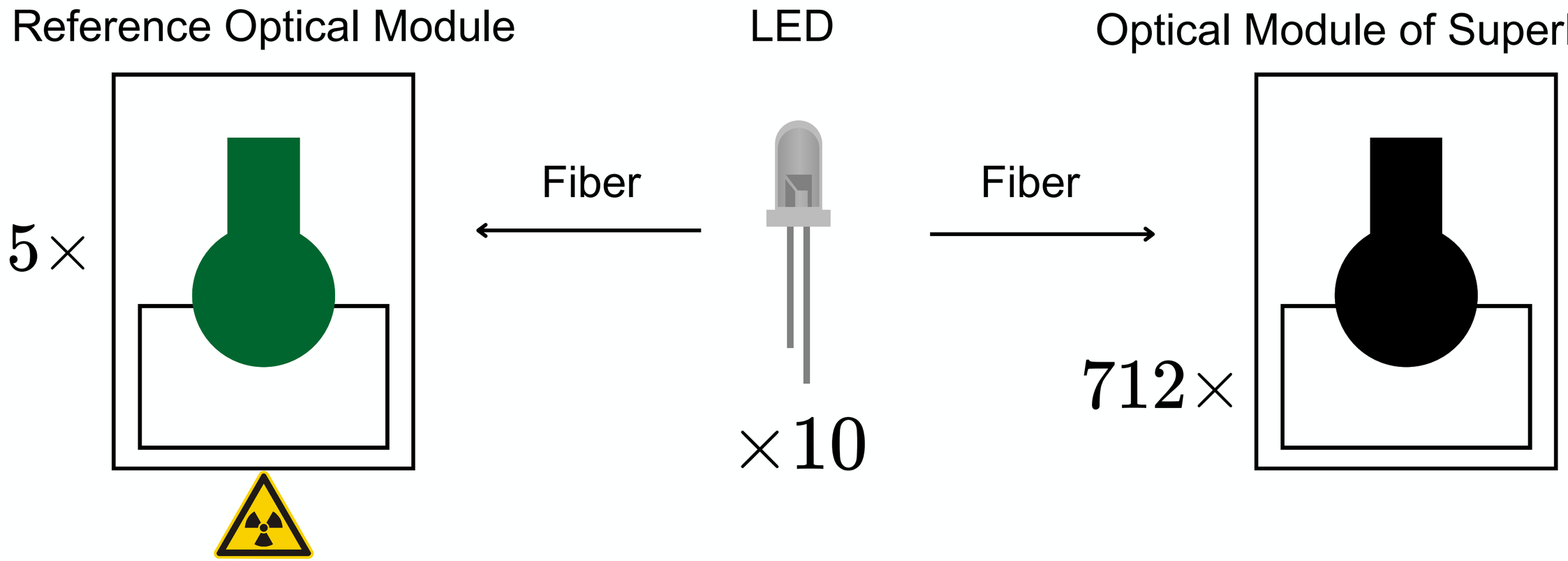
Relative calibration using Light Injection system

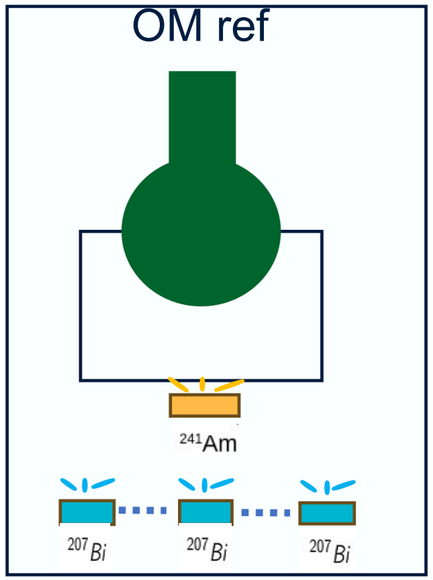


Relative calibration: reference OMs

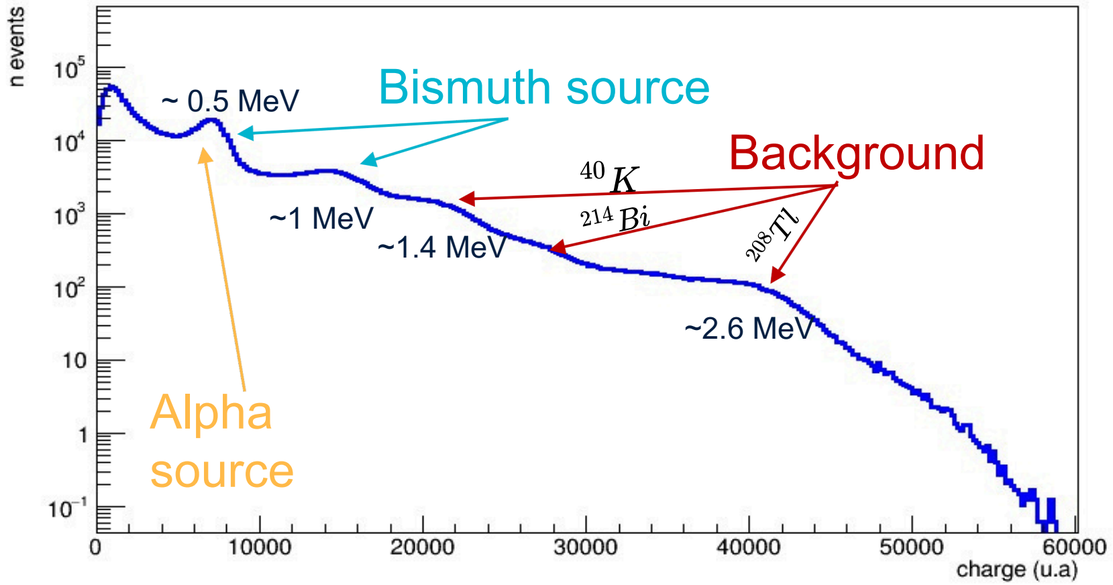
Reference OMs are outside SuperNEMO

Signals recorded by reference OMs come from 3 different origins

- Environmental gamma background (^{208}Tl, ^{214}Bi, ^{40}K, ...)
- Alpha source (^{241}Am)
- Gamma + electron source (^{207}Bi)



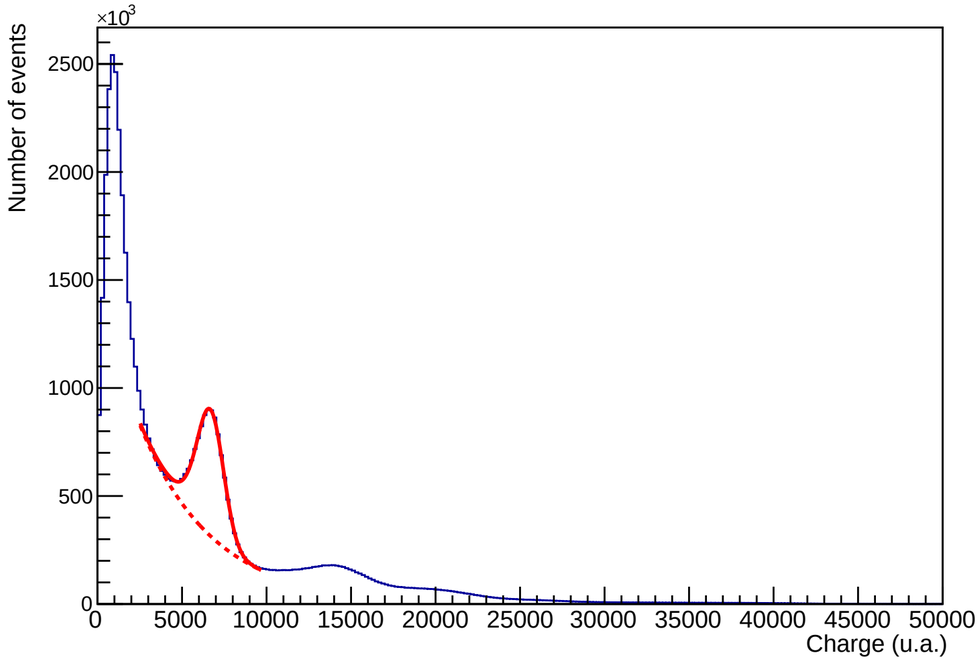
Example of charge spectrum for 1 reference OM



Relative calibration: reference OMs

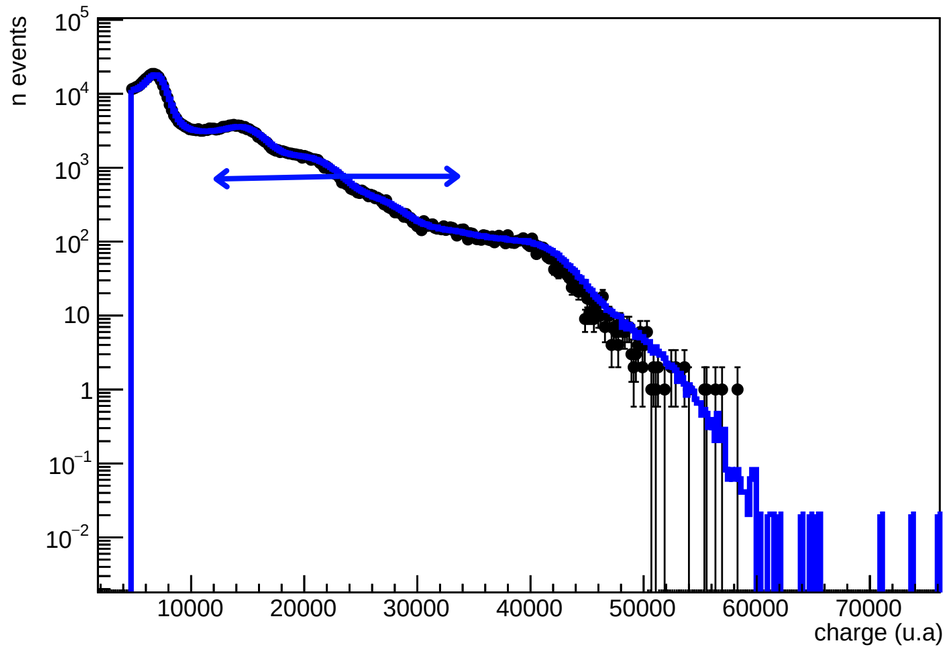
Two methods to compare gain variation of reference OMs

Alpha peak



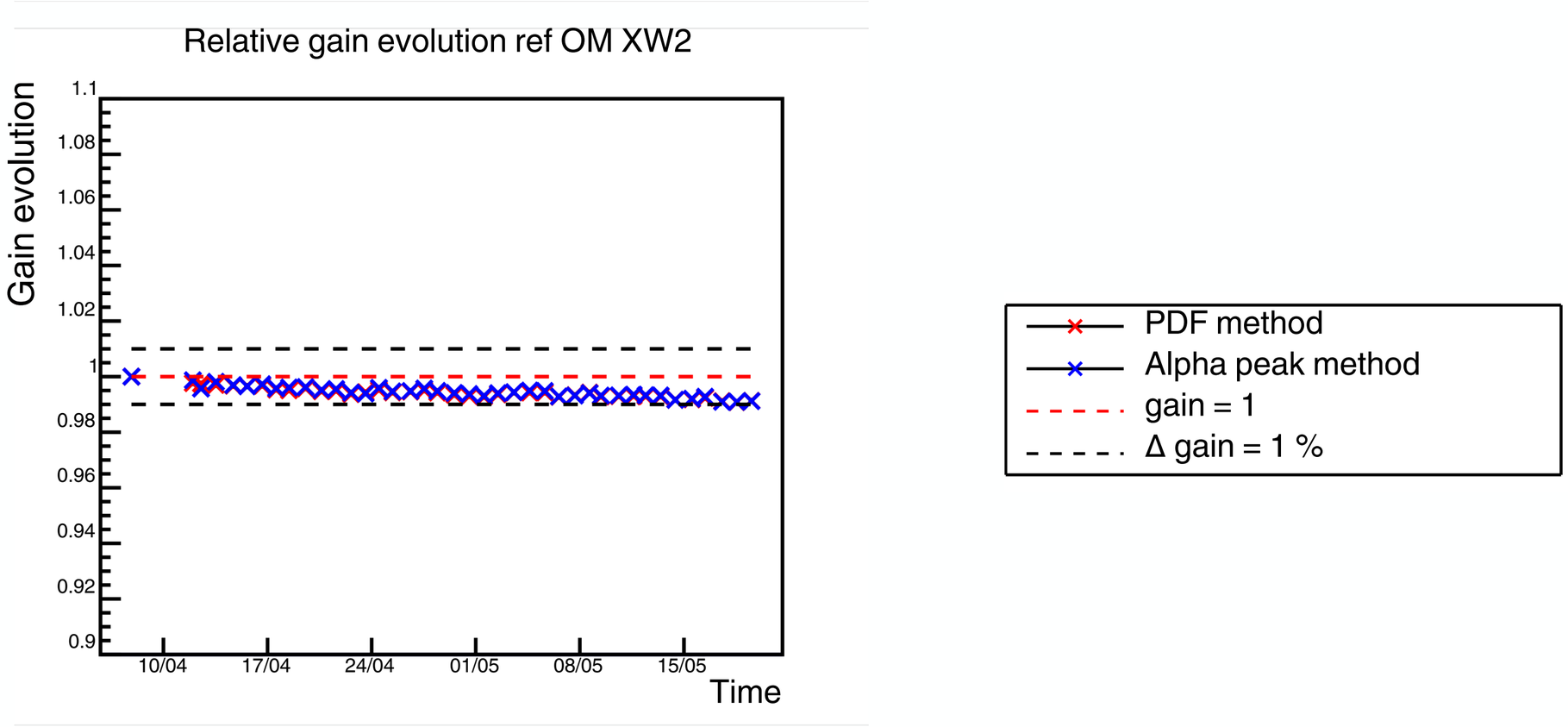
Using the known alpha peak at low energy

Pdf



Using a PDF and Chi2 computation

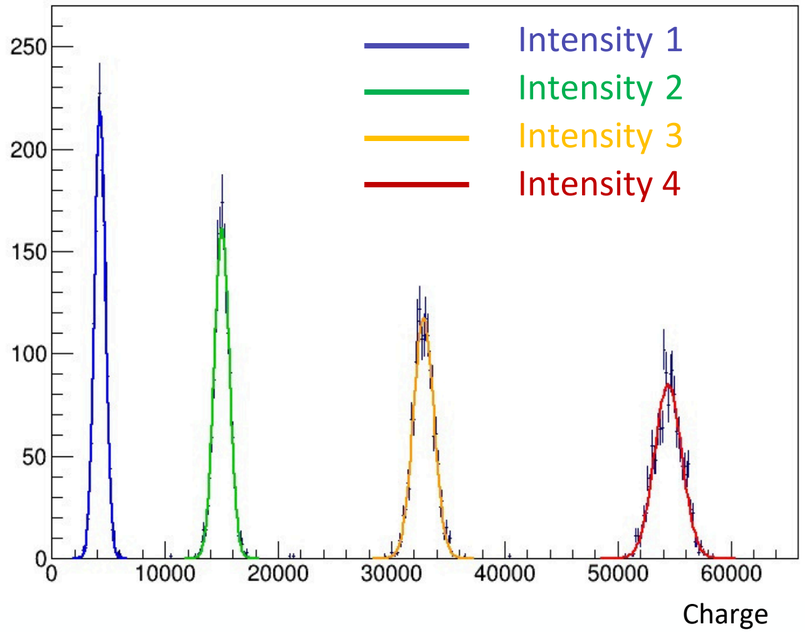
Relative calibration: reference OMs



- Stability of reference OMs gain variation (<1% on ~ 1 month !)
- Good agreement between the alpha and PDF methods (~ < 0.2 %)

Relative calibration: LED injection

Charge spectra for 1 OM during LED sequence

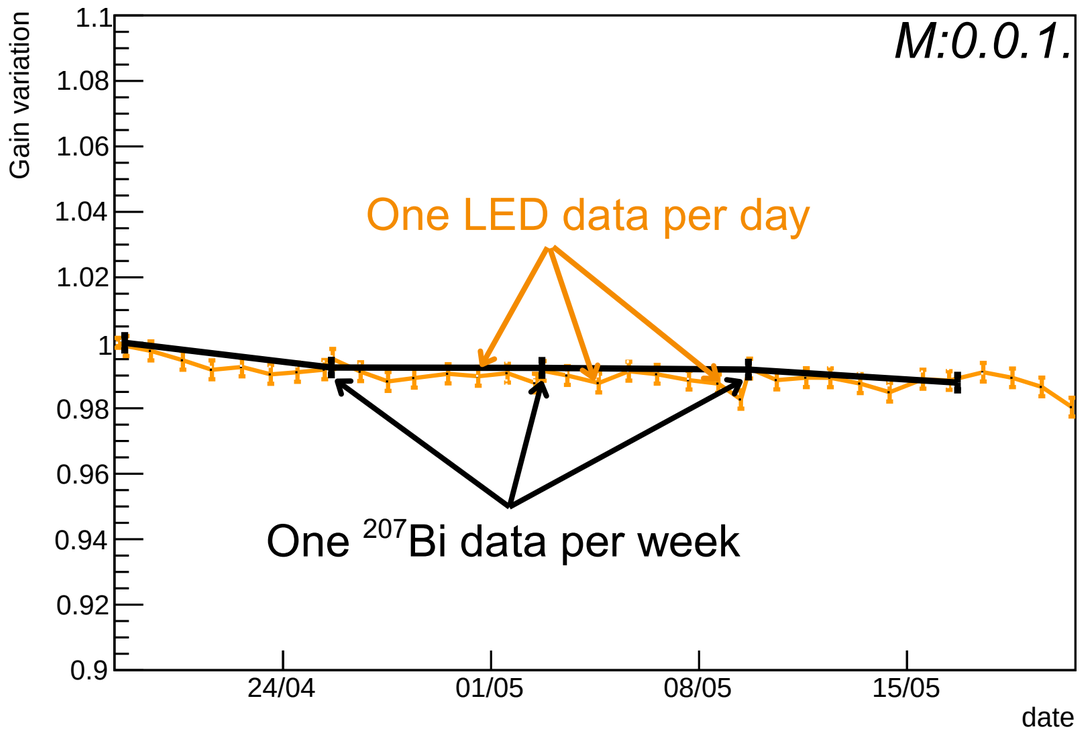


- Covers a wide energy range using four different LED intensity levels
- Each intensity distribution is fitted with a Gaussian to extract the mean
- LED stability is evaluated by analyzing variations in the mean values

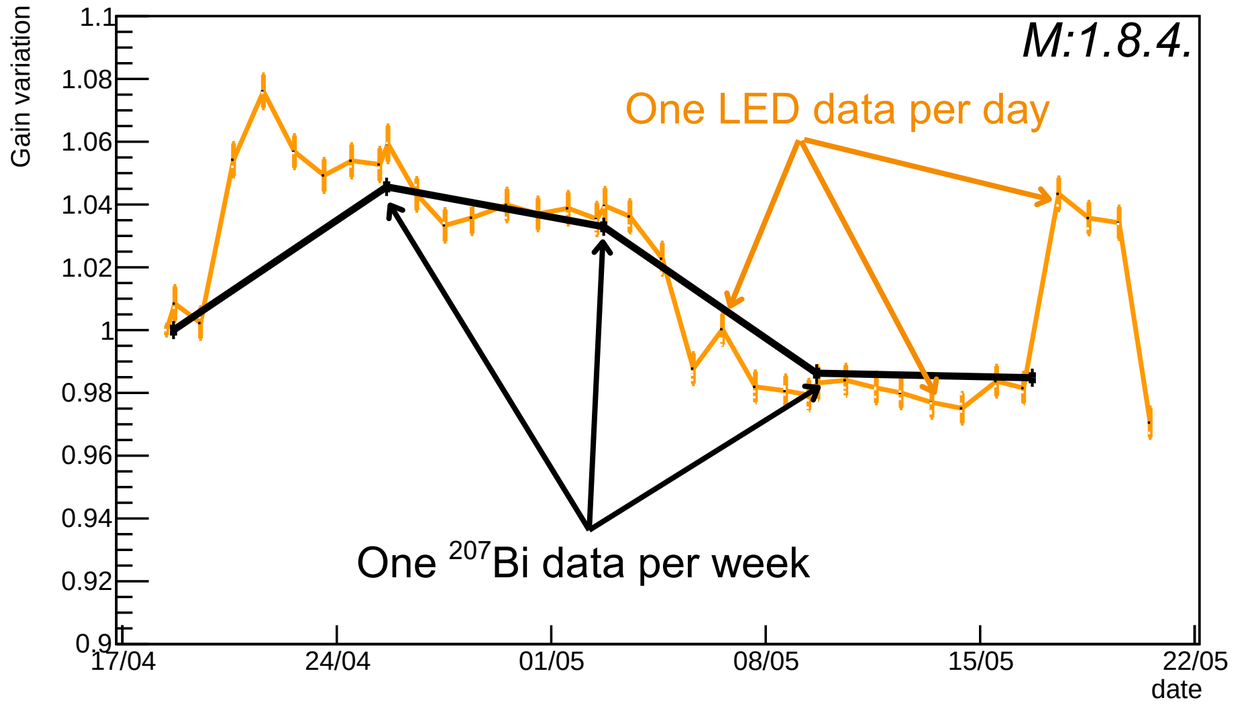
Compare closest LED intensity with ^{207}Bi energy peak

Comparison of the two calibrations methods

Gain variation of a “short terme” stable Optical Module



Gain variation of a unstable “short term” Optical Module



- OMs gain following for ~ 1 month
- Good agreement between LED and ^{207}Bi calibrations (<1% deviation)

Comparison of the two calibrations methods

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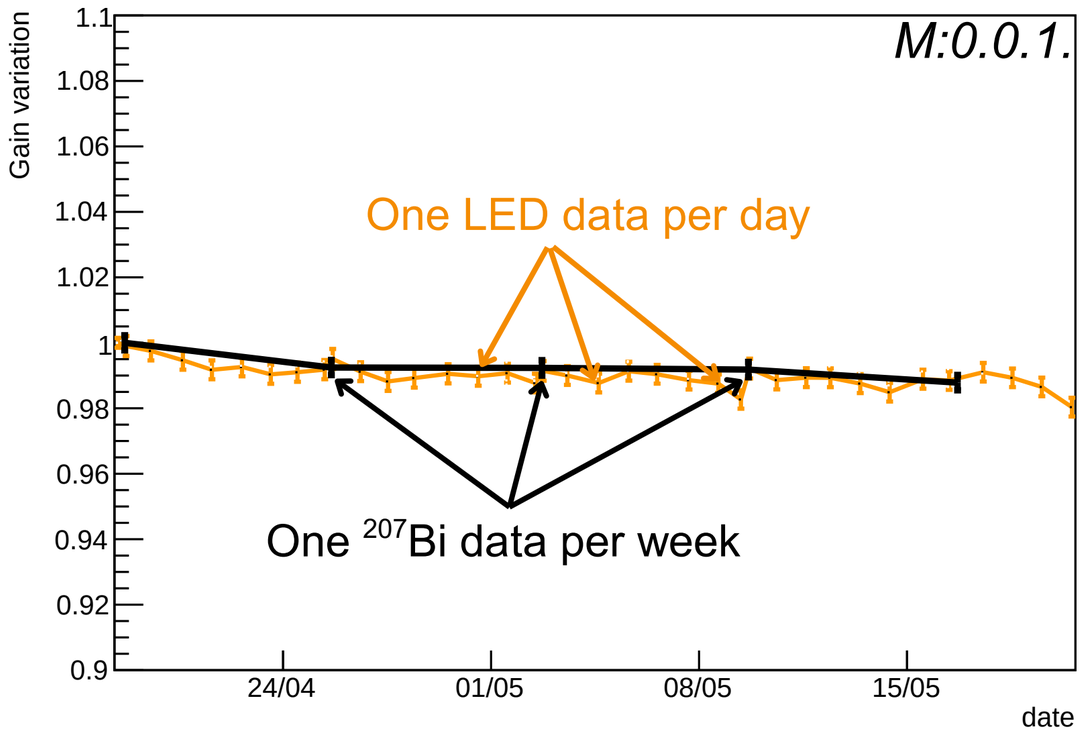


On ~ 1 month of data

characteristics	% OMs
Short-term stability	96.8 %

supernemo

preliminary

- OMs gain following for ~ 1 month
- Good agreement between LED and ^{207}Bi calibrations (<1% deviation)

Conclusion

- Algorithm developed for LED and ^{207}Bi data analysis
- First results on main calorimeters show:
  - Good agreement between LED calibration and ^{207}Bi data
  - Most OMs have a short term stability ~ 97 %
- Next step:
  - Extend the analysis to a longer data-taking period
  - Calculate the daily gain variation of OMs
  - Identify OMs to reject in the SuperNEMO $\beta\beta$ analysis
  - Determine the energy resolution of each OMs

Thanks for listening

1st year

2nd year

to be continued ...

Backup slides

LED instead of Laser

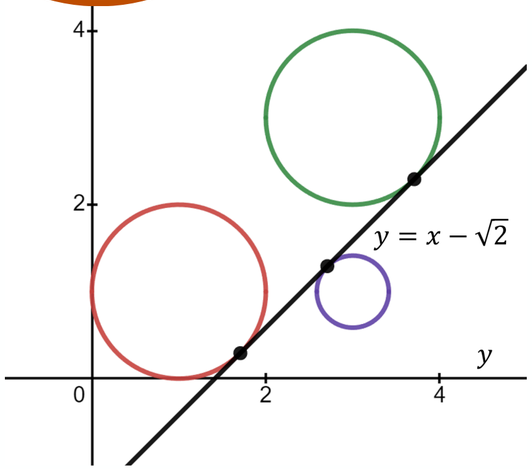
LED

- More stable
- Easier to change intensity
- Higher repetition rates possible
- Cheaper

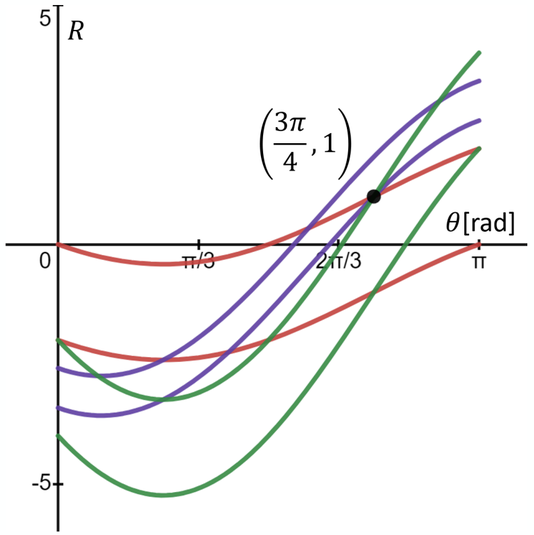
Laser

- Higher intensity
- Faster pulse
- Instable in NEMO-3

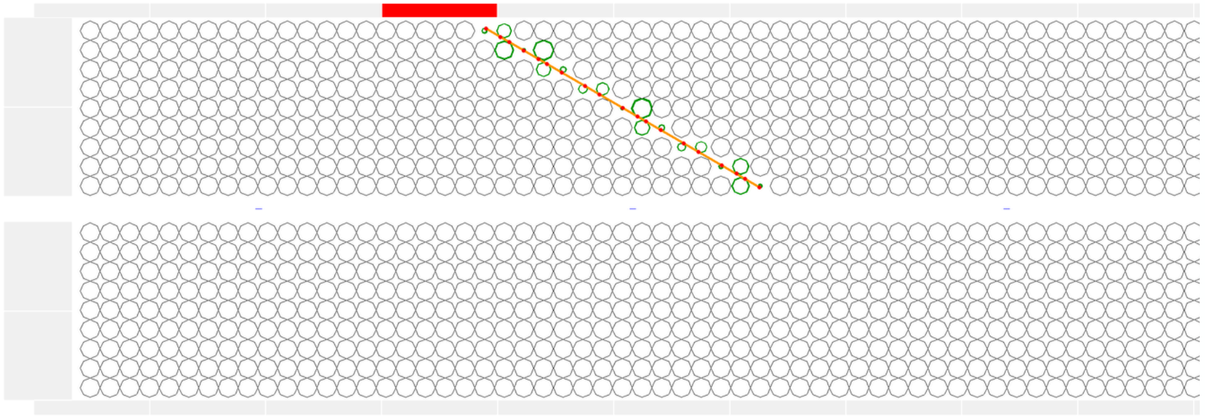
Track reconstruction



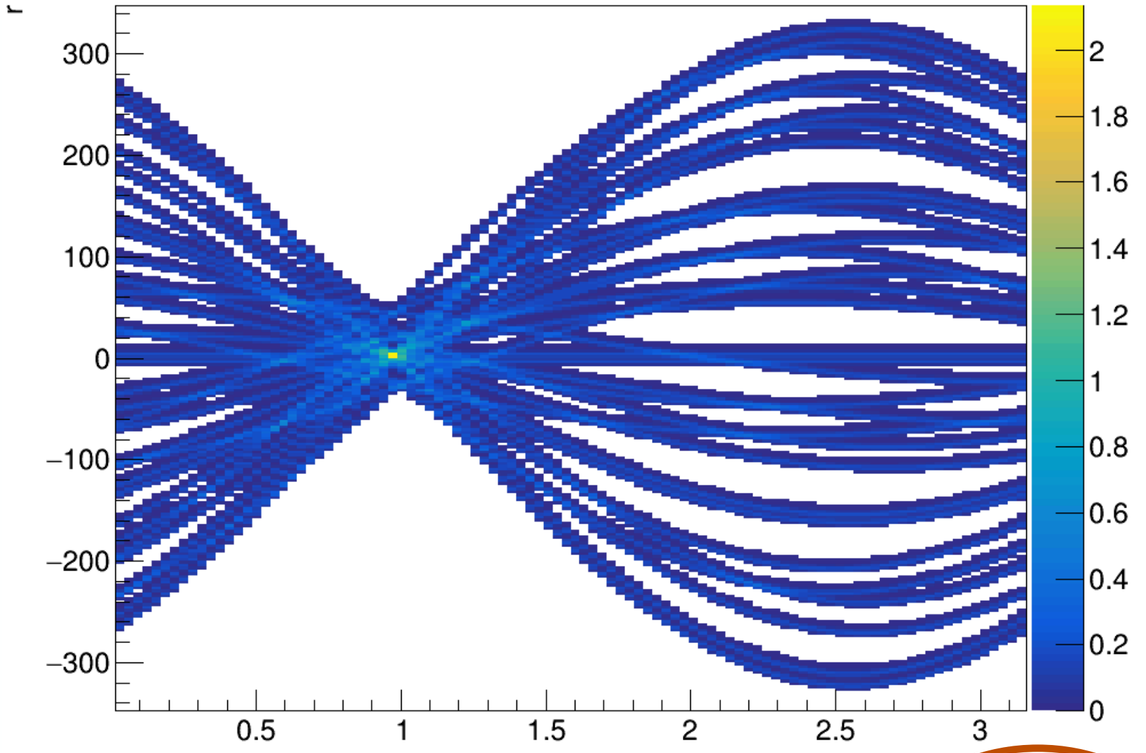
(a) Three circles and their tangent



(b) Legendre image



Using Legendre transformation



^{207}Bi decay process

Internal conversion : the nucleus of ^{207}Bi captures an orbital electron ($n \rightarrow p$)

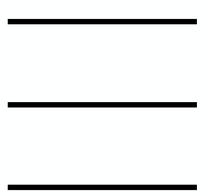
$$^{207}Bi + e^{-} \rightarrow ^{207} Pb^{*} + \nu_{e-}$$

Two ways of decay for the Pb*

internal conversion

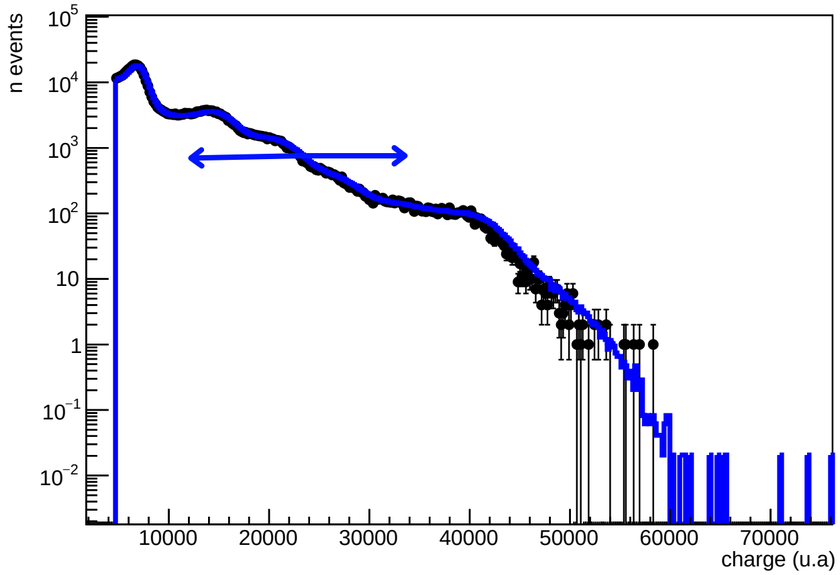
gamma emission

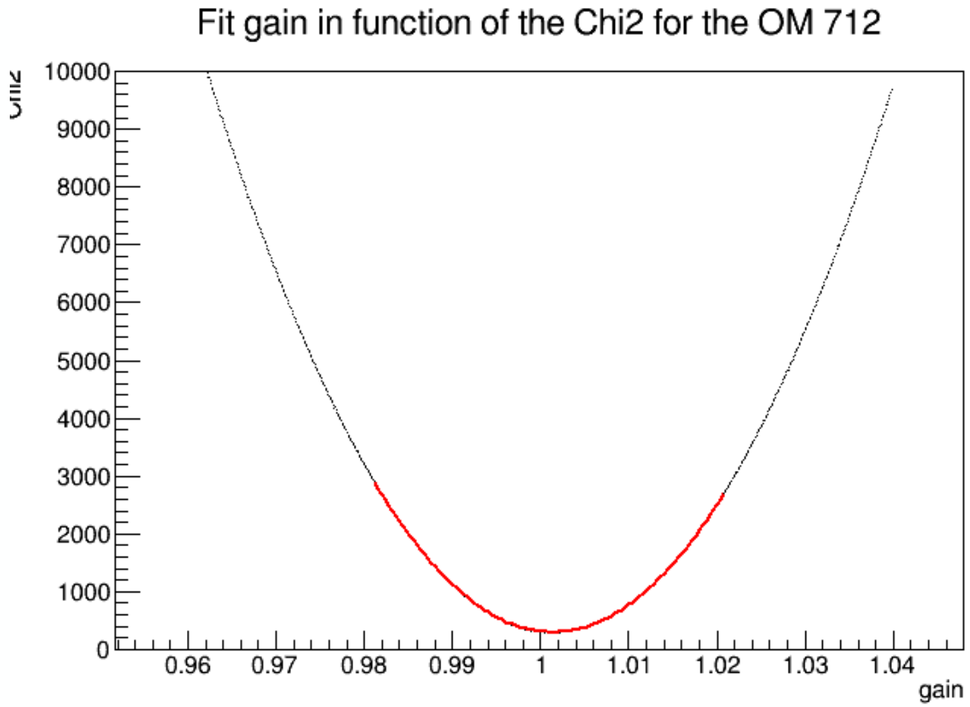
	Énergie (keV)	Intensité (%)
e1 (K)	481,7	1,53
e1 (L)	553,8	0,44
e1 (M)	565,8	0,11
e2 (K)	975,7	7,08
e2 (L)	1047,8	1,84
e2 (M)	1059,8	0,44
e3 (K)	1682,2	0,023
e3 (L)	1754,4	0,003
γ1	569,7	97,7
γ2	1063,7	74,5
γ3	1770,2	6,87



3 excited states

PDF method explanation

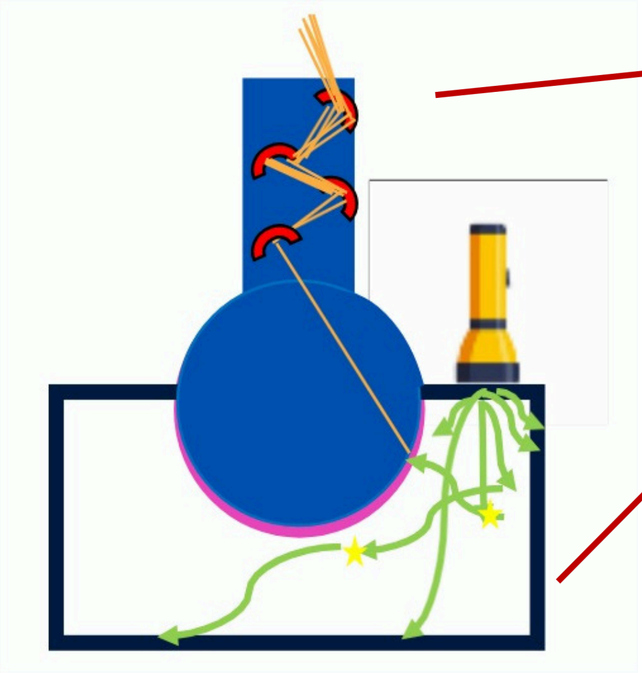




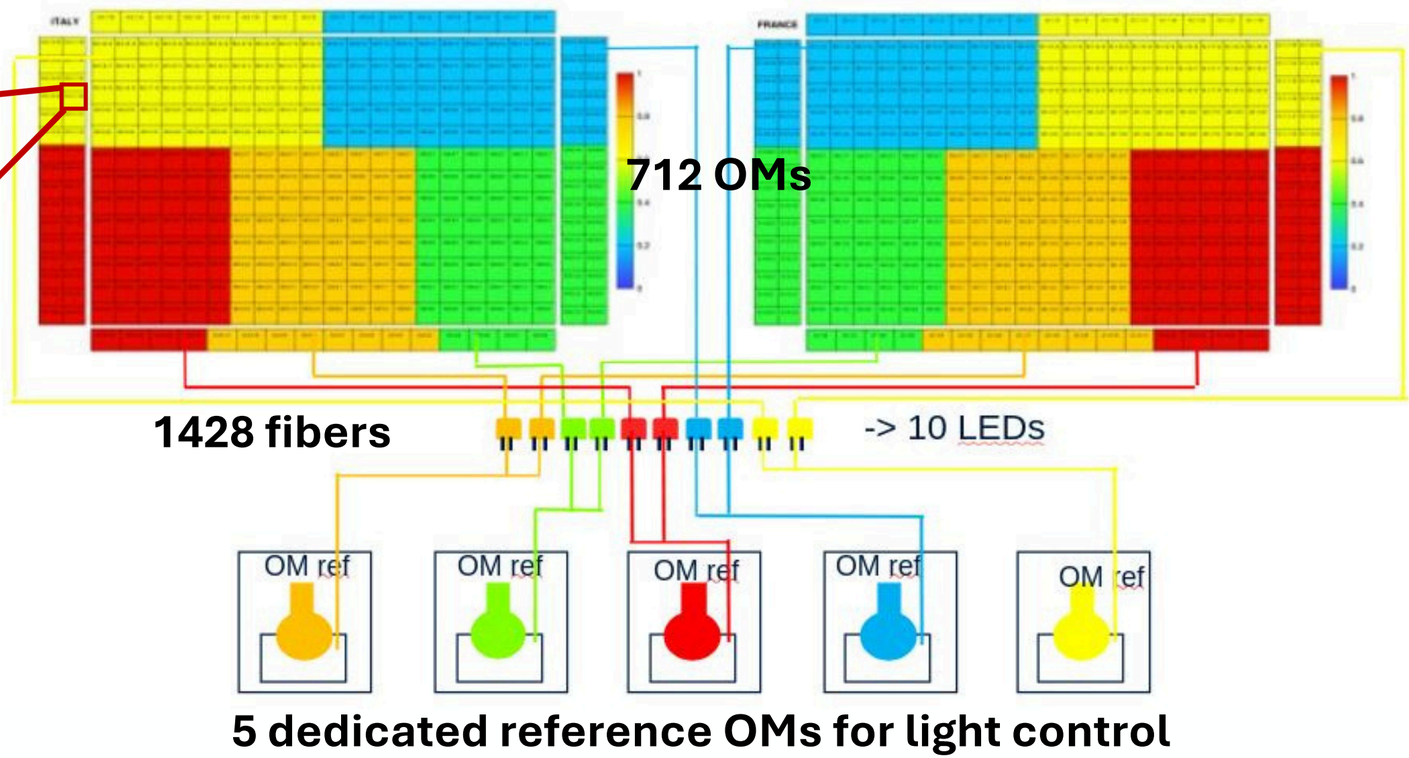
Each bin multiplied by $gain \in [0.5, 1.5]$

Relative calibration using Light Injection system

Light injection principle in 1 OM



Exploded view of the SuperNEMO calorimeter (OMs)



5 dedicated reference OMs for light control

Material presentation

- ^{82}Se foil:
-
- Plastic scintillator
  - Excellent radiopurity
  - High light yield
  - Fast time response
  - low back-scattering probability