

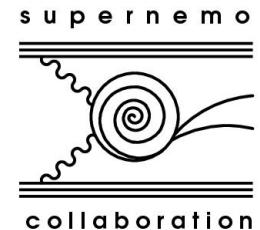
Energy calibration of the SuperNEMO calorimeter

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université
de
BORDEAUX





SuperNEMO demonstrator

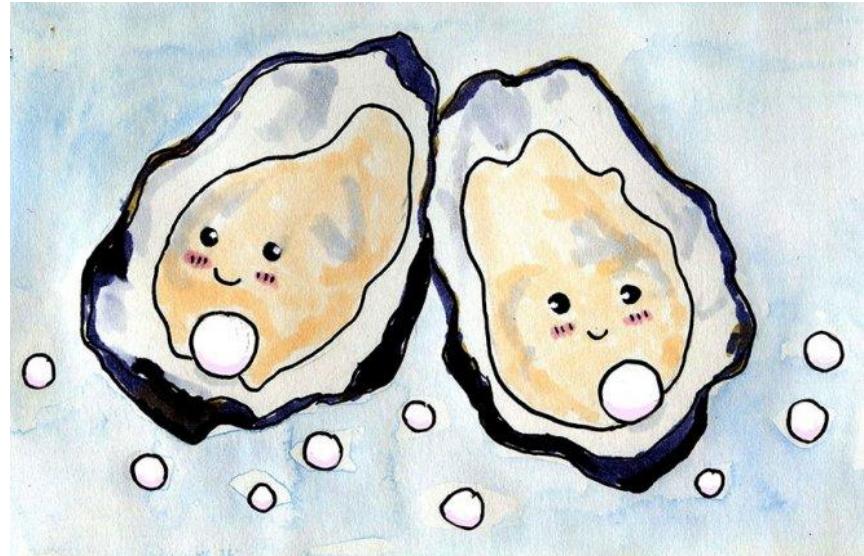
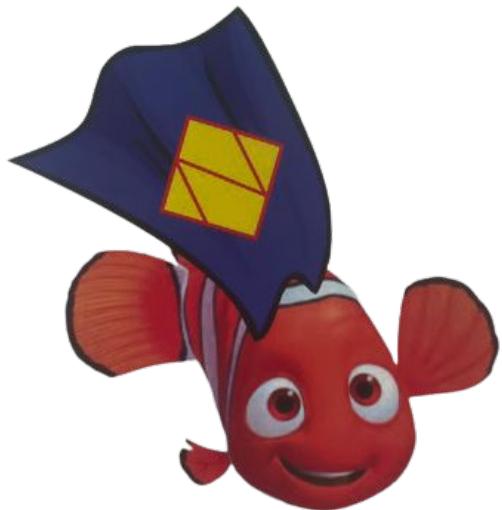


Absolute energy calibration: γ background



Relative energy calibration: Light Injection System

SuperNEMO:



SuperNEMO demonstrator

SuperNEMO's goal -> Detect **neutrinoless double beta decay**
Unique technology to **reconstruct particle's kinematic**

Source foil

36 thin foils of ^{82}Se
($M_{\text{tot}} = 6.11\text{kg}$, $Q_{\beta\beta} = 2.99\text{MeV}$)

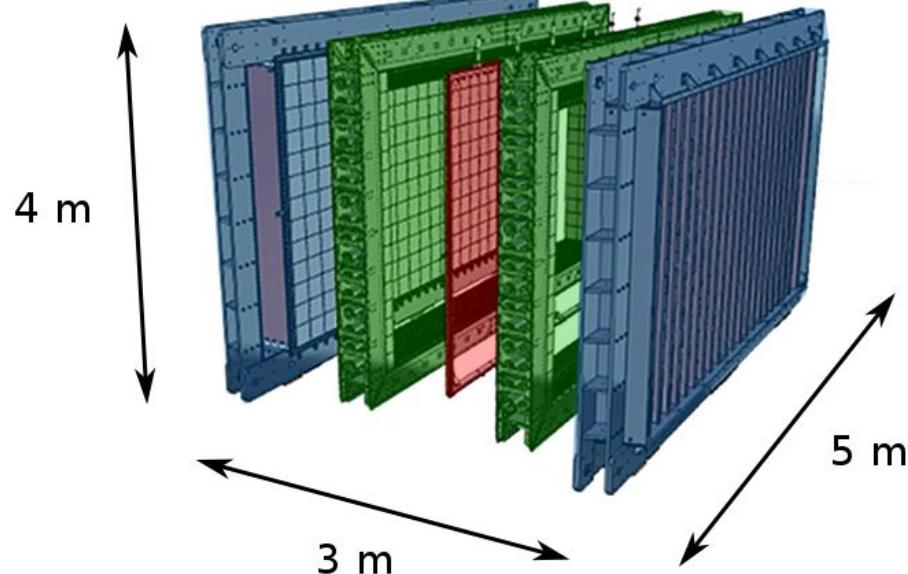
Tracker

2034 **Geiger cells** (14970 wires)
→ trajectory reconstruction
→ particle identification

Calorimeter

712 **Optical modules**
→ energy measurement
→ time flight measurement

➡ See Malak's talk



Good energy resolution and calibration requirements

$T_{1/2}^{0\nu} > 10^{25}$ y -> very few events

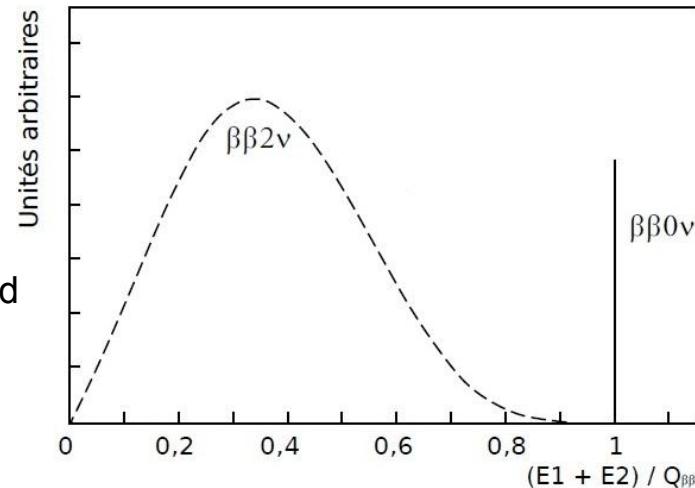
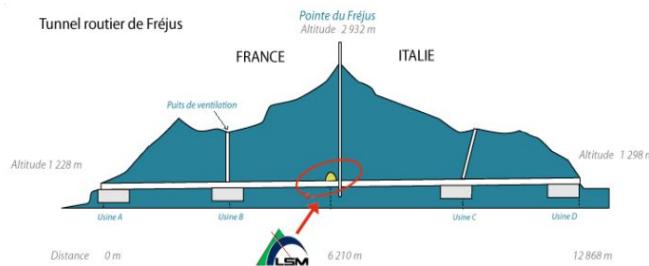
Background noise due to the $\beta\beta 2\nu$

Require as less background noises as possible

The experiment is under 4800m water equivalent



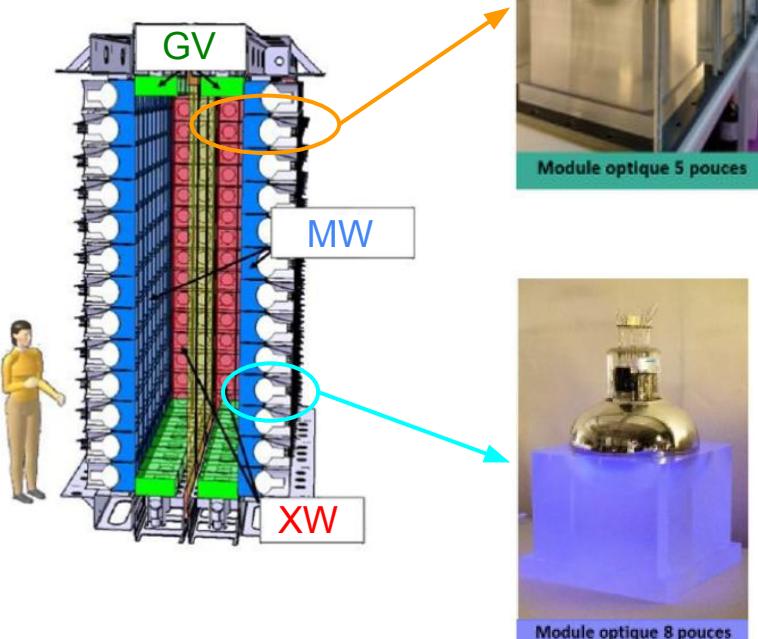
Good energy resolution and calibration is needed



SuperNEMO calorimeter

712 Optical Modules (OM) : plastic scintillator + photomultiplier to detect incident particles

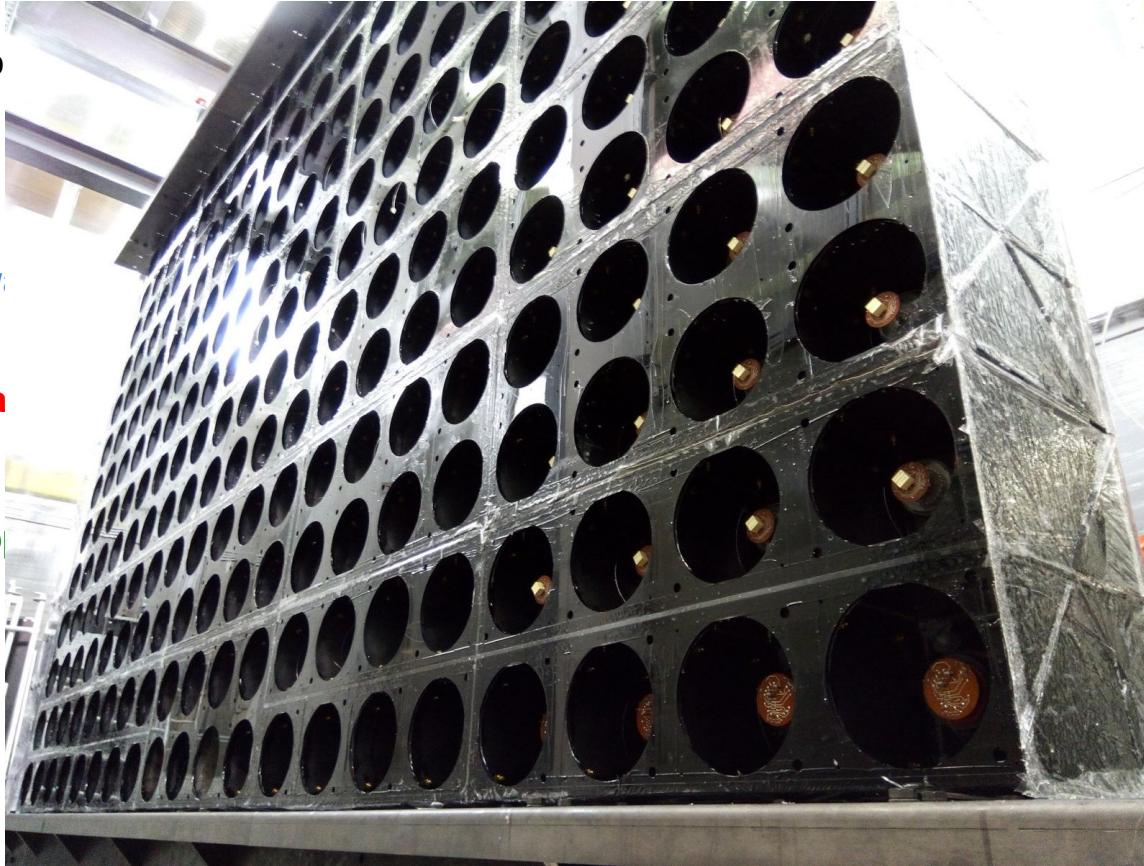
- **2 main wall (MW)** : 2X 260 OM. FWHM ~8% at 1MeV
- **2 side walls (XW)** : 2X64 OM with lower performances
- **2 Veto top and bottom (GV)**: 2X32 OM acting as a veto for the γ



SuperNEMO's calorimeter

712 Optical Mo
photomultiplier

- **2 main wa**
- **2 side wa**
- **2 Veto to**
as a veto



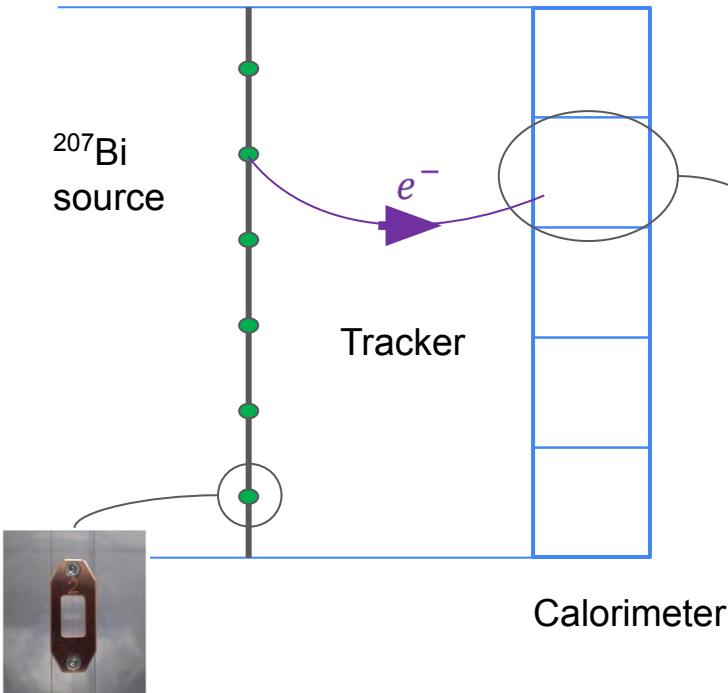
Module optique 5 pouces



Module optique 8 pouces

Calorimeter calibrations in SuperNEMO :

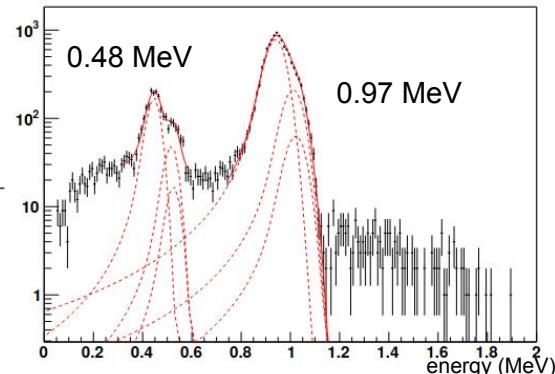
- Absolute calibration: - ^{207}Bi source (nominal method)



Emits monoenergetic internal conversion electrons

Maximum energy of 1.77 MeV

42x ^{207}Bi source evenly distributed in the detector
with an automatic deployment system



Calorimeter calibrations in SuperNEMO :

- **Absolute** calibration: - ^{207}Bi source (nominal method)
 - γ background (as long as the shielding is not in place)
- **Relative** calibration: - Light Injection System



SuperNEMO demonstrator



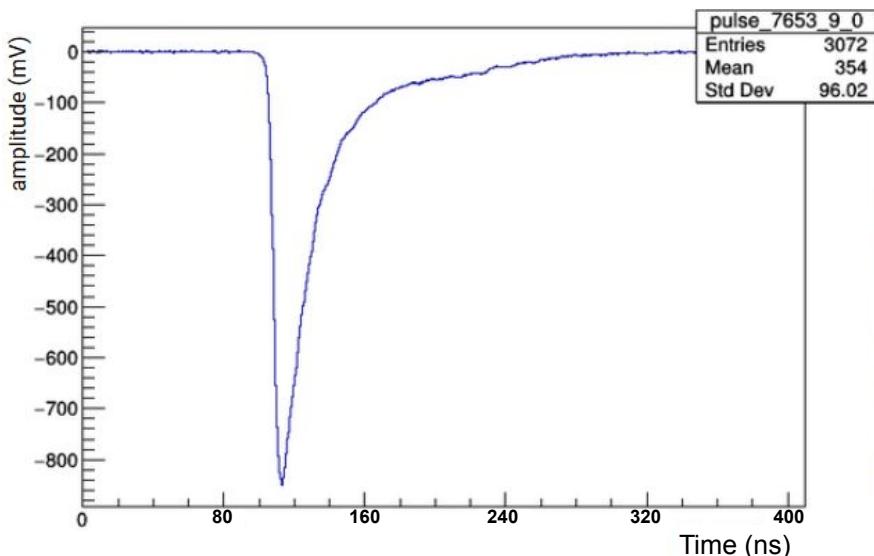
Absolute energy calibration: γ background



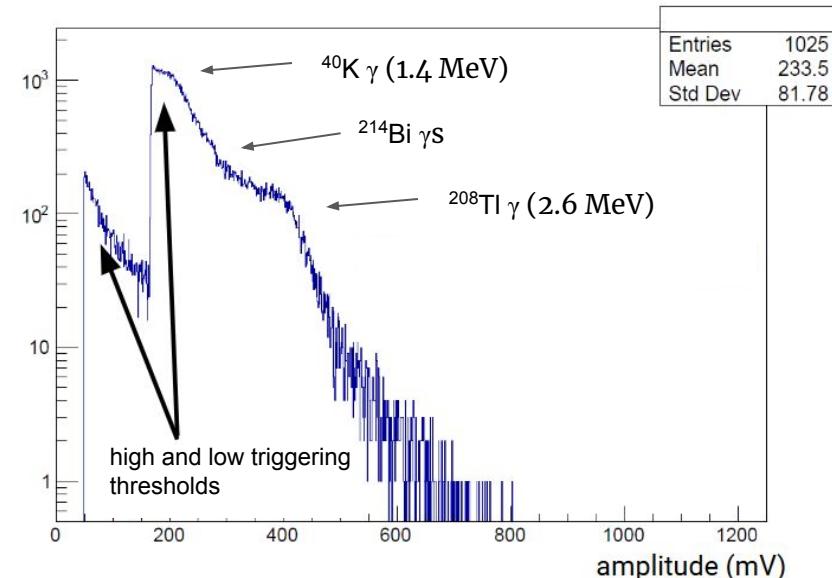
Relative energy calibration: Light Injection System

Signal and spectrum of an Optical Module (OM)

Output signal of an OM of the calorimeter



Amplitude spectrum of an OM



Different spectra for different types of OM

Main Wall om spectra



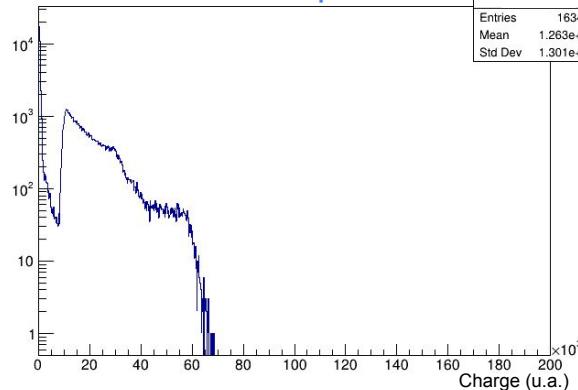
Mwall 8''



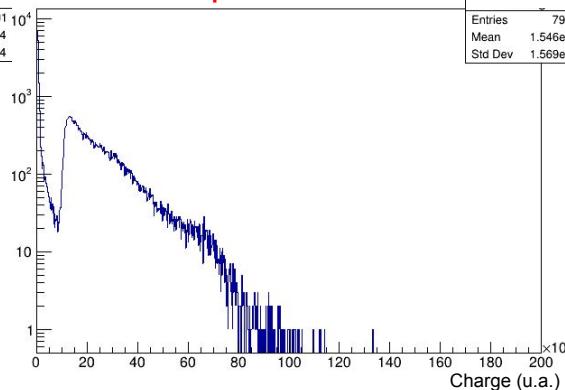
Mwall 5''

Different spectra for different types of OM

Main Wall om spectra



XW om spectra



Mwall 8''



Mwall 5''

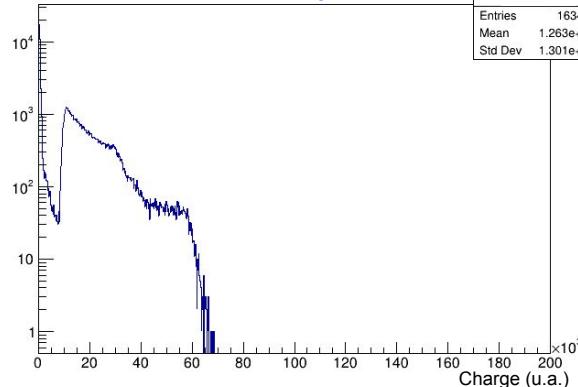


Xwall

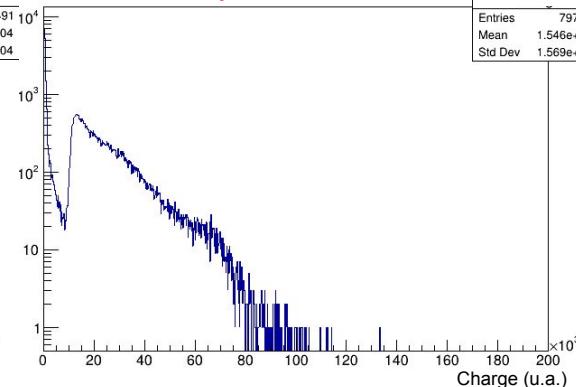


Different spectra for different types of OM

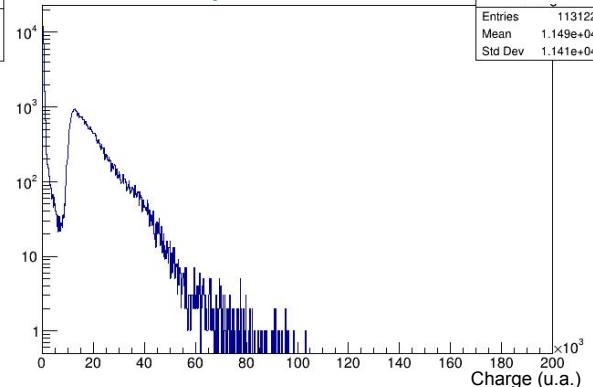
Main Wall om spectra



XW om spectra



GV om spectra



Mwall 8''



Mwall 5''



Xwall



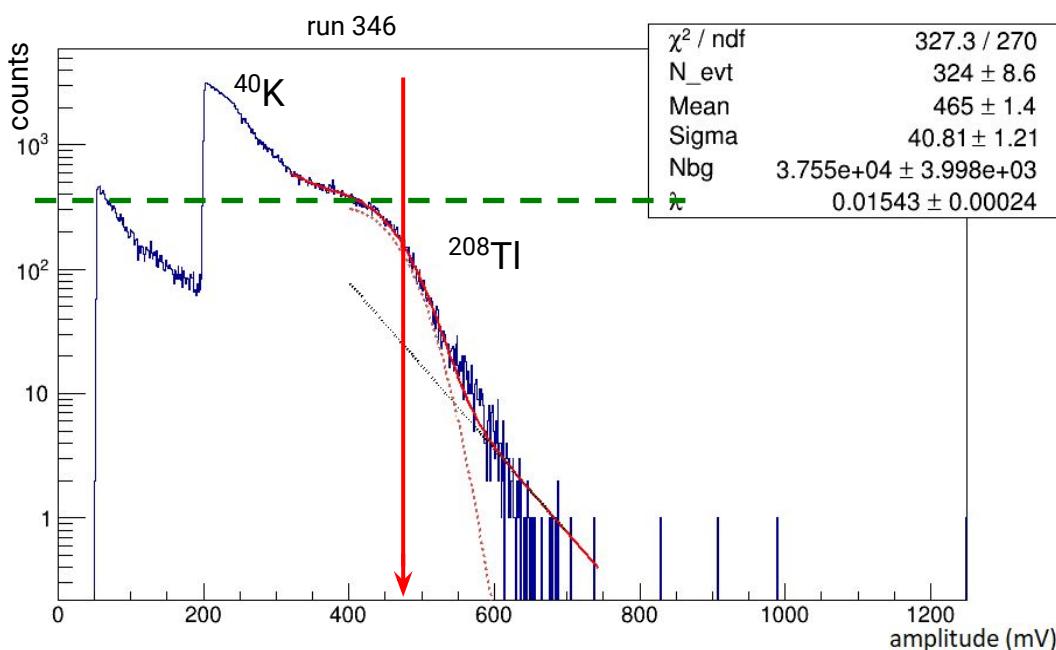
Gveto



Calorimeter calibration : 1st fit method with background run

$$\frac{N_{\text{evt}}}{2} \left(1 + \operatorname{erf} \left(\frac{(\text{Mean} - x)}{\sigma \sqrt{2}} \right) \right) + N_{\text{bg}}$$

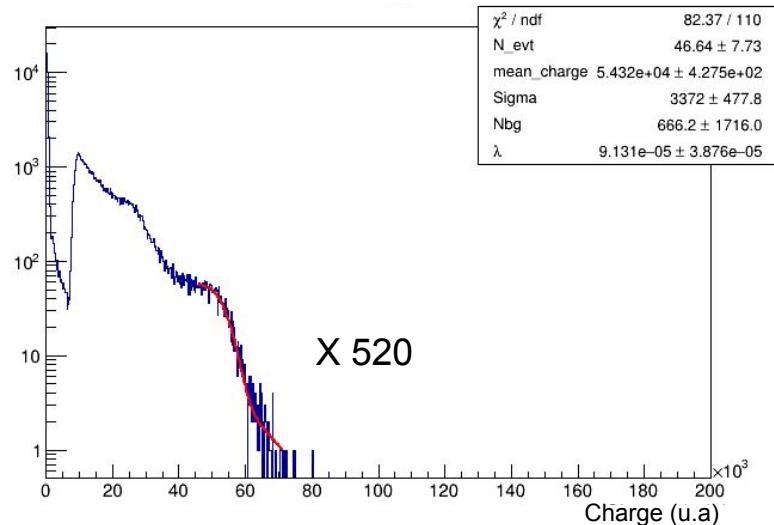
- N_{evt} = nb of evt at the beginning of the Compton edge
- Mean = fitted “gain” : Position where the fall is the strongest
- σ = thickness of the fall of the Compton edge
- N_{bg}, λ = exponential’s parameters



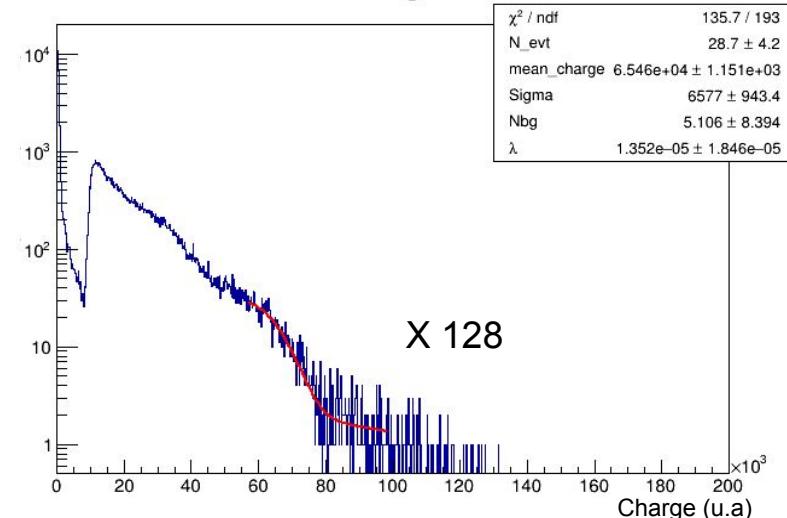
Calorimeter calibration : 1st fit method with background run

Gain fitting with an “erf” function over the Compton edge of the ^{208}TI (2.6MeV):

1 MW 8" OM (#267)



1 XW OM (#570)

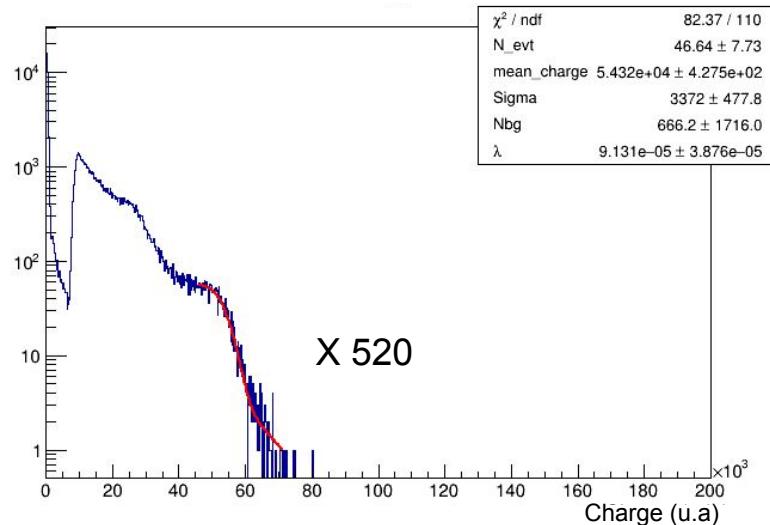


All MW and XW OM gains have been equalized

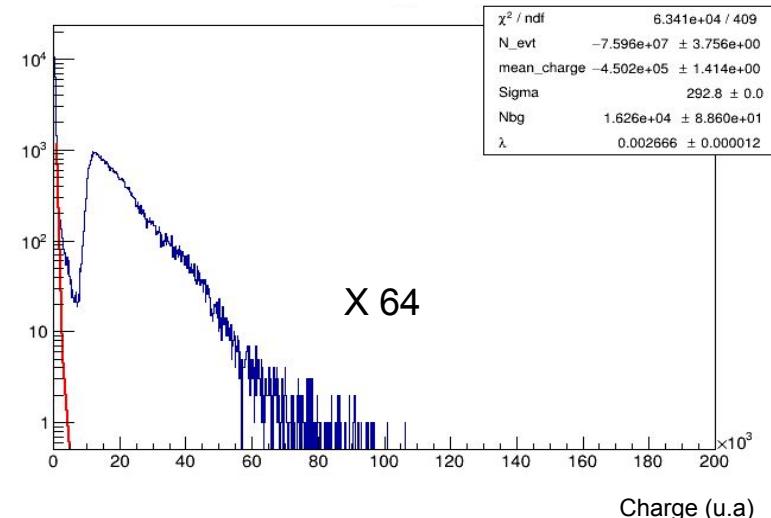
Calorimeter calibration : 1st fit method with background run

Gain fitting with an “erf” function over the Compton edge of the ^{208}TI (2.6MeV):

1 MW 8" OM (#267)



1 GV OM (#698)



All MW and XW OM gains have been equalized

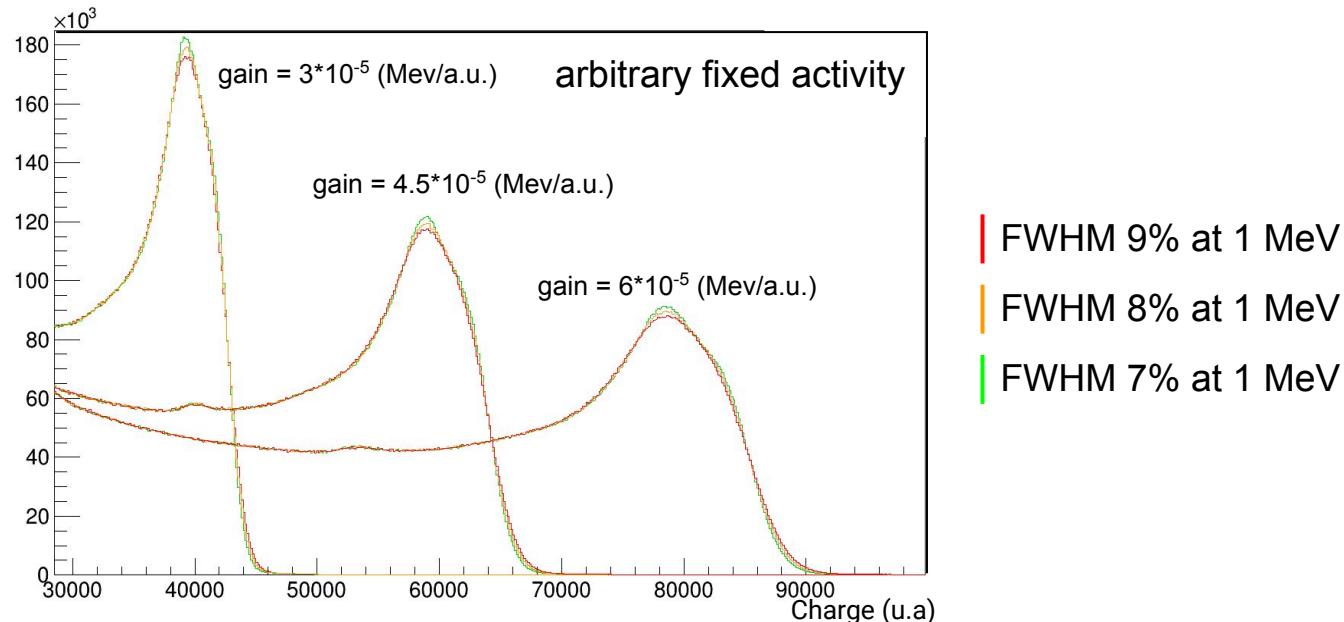
Impossible to fit GV spectra with this method : new method is needed !

2nd Method : fit of the full spectra with simulated spectra

Simulation of ^{208}TI + ^{214}Bi + ^{40}K from the LSM walls - 10^7 generated events

Each spectrum is then adjusted depending on the **gain**, **energy resolution** and **detected activity** for each OM

Example: ^{208}TI detected spectra with 3 different gains and energy resolutions (FWHM at 1MeV),



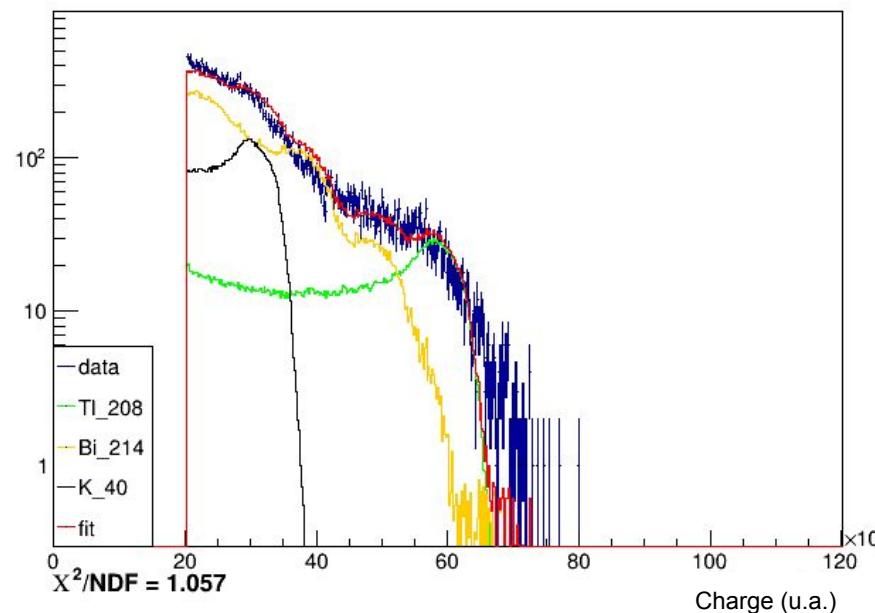
2nd Method : fit of the full spectra with simulated spectra

Simulation of ^{208}TI + ^{214}Bi + ^{40}K from the walls of the lab - 10^8 generated events

Each spectrum is then adjusted depending on the **gain**, **energy resolution** and **detected activity** for each OM

Example of ^{208}TI , ^{214}Bi and ^{40}K **simulated spectrum** adjustment to real data of one OM (MW 8")

Best Fit



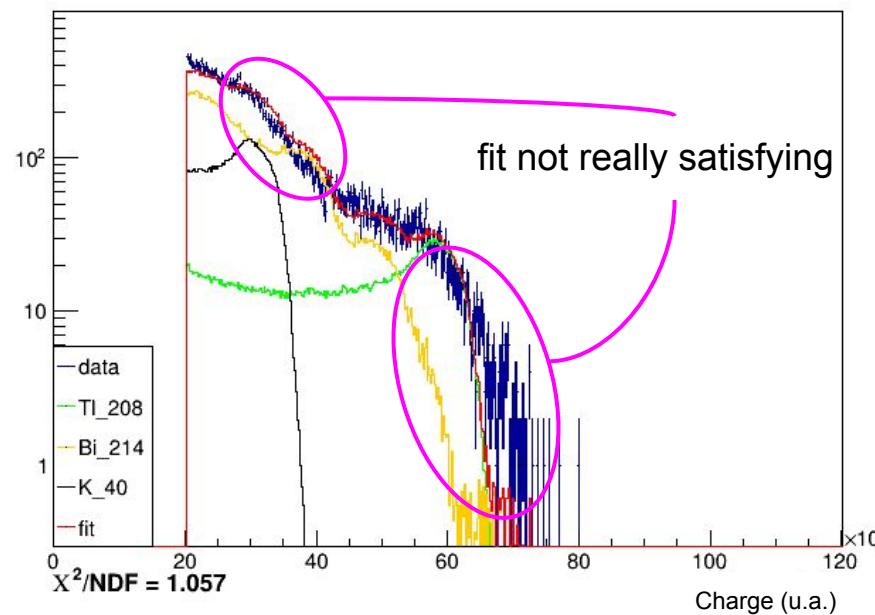
2nd Method : fit of the full spectra with simulated spectra

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Example of ^{208}TI , ^{214}Bi and ^{40}K simulated spectrum adjustment to real data of one OM (MW 8")

Best Fit

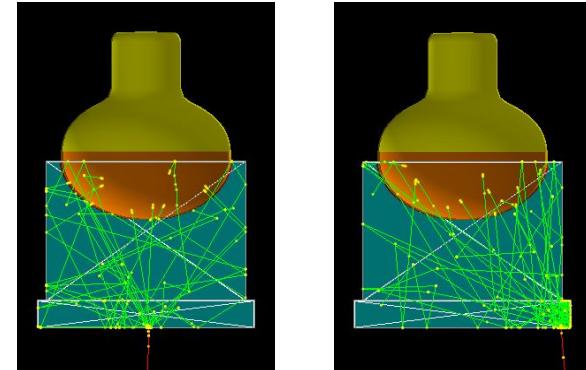


Application of Optical Corrections

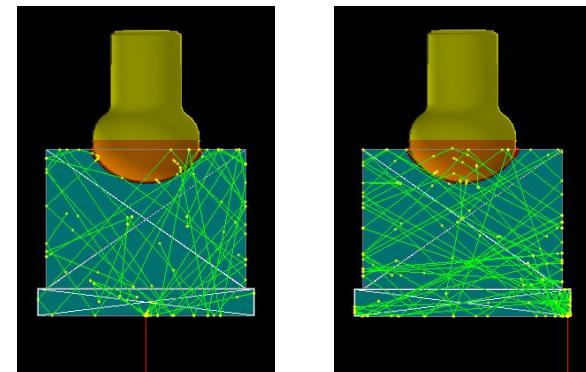
3 corrections applied on simulated spectra based on optical simulations:

- Birks effect correction
- Cerenkov effect correction
- Geometrical correction (difference due to the geometry of the optical modules and the location where the incident particle deposits energy)

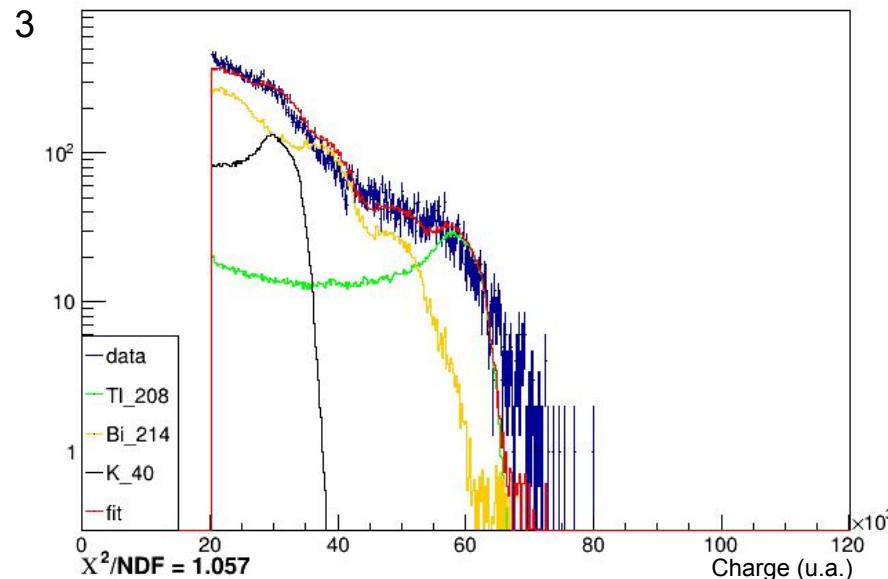
Non linear effects with energy



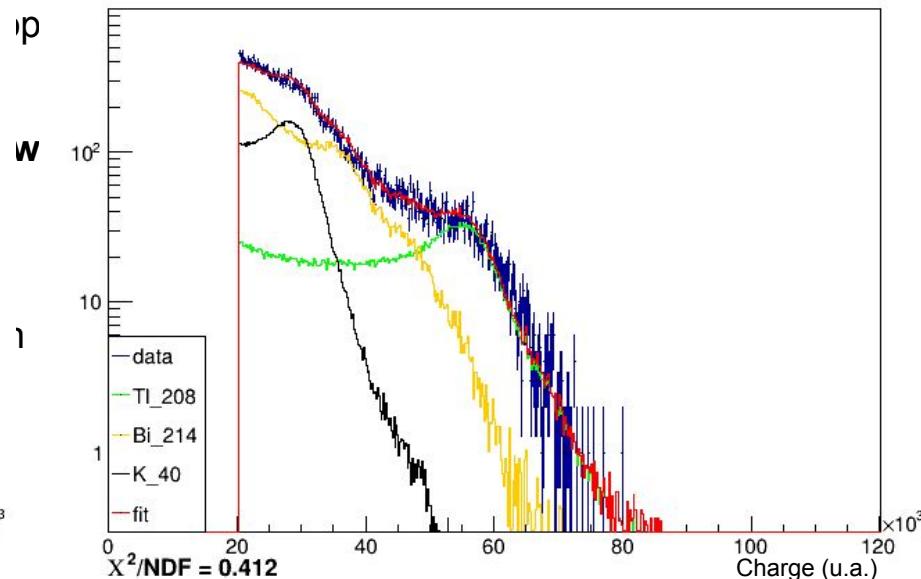
Non linear effects with interaction position



Application of Optical Corrections



Without optical correction



With optical correction



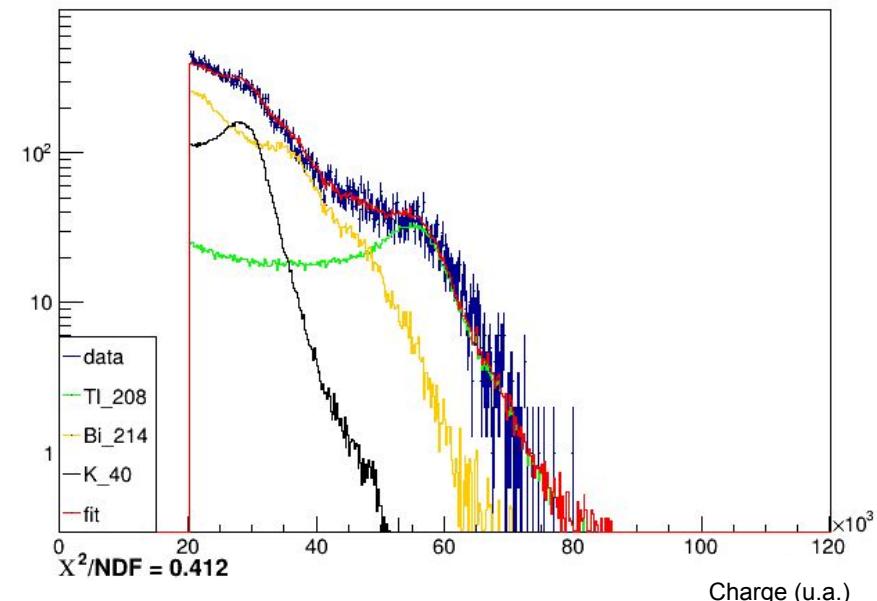
Estimation of the γ background of the lab

The method seem to **work to measure the gain** of the OMs

However, we **can't measure energy resolution** with it

We can estimate the **γ background** for the component we simulate ^{208}Tl , ^{214}Bi and ^{40}K

-> Estimation of the **γ flux for each OM**



Estimation of the γ background of the lab

Expected γ background for ^{208}TI (2.6 MeV): $10^{-2} \sim 10^{-4} \text{ } \gamma \text{ cm}^{-2} \text{ s}^{-1}$ / **measured** $10^{-2} \text{ } \gamma \text{ cm}^{-2} \text{ s}^{-1}$

Ohsumi & all, 2002 - D. Malczewski & all 2012





SuperNEMO demonstrator

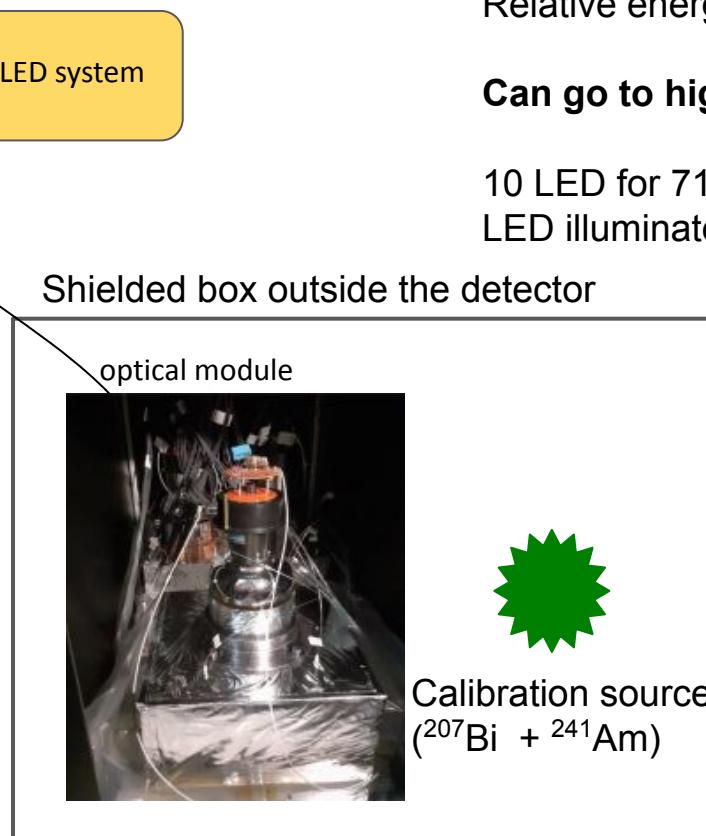
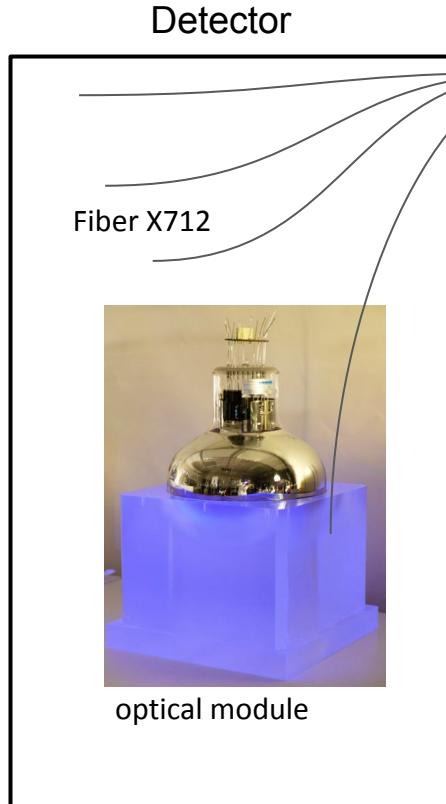


Absolute energy calibration: γ background



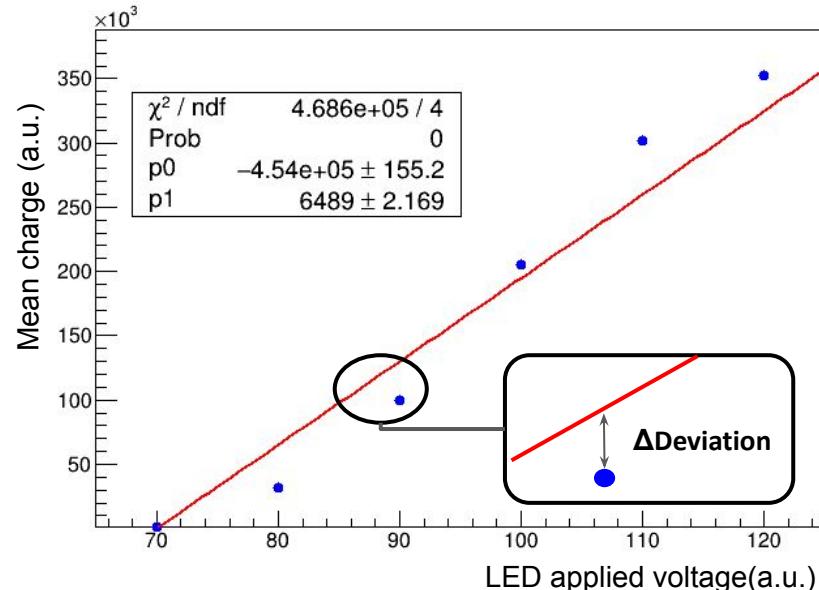
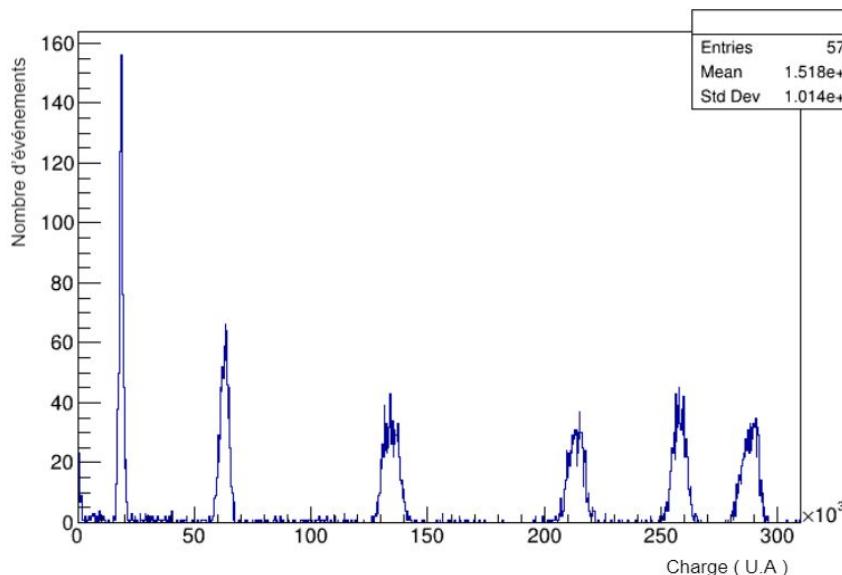
Relative energy calibration: Light Injection System

Light Injection system : relative energy calibration system



Light Injection System: Highlighting of a non-linearity

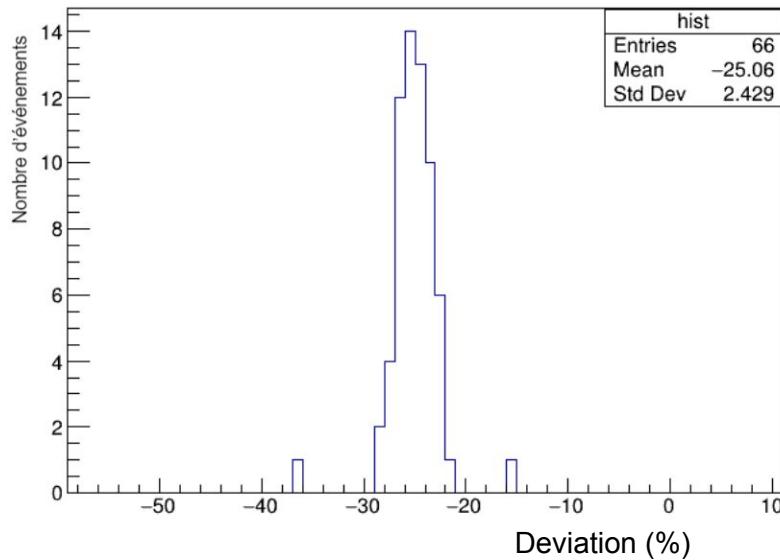
Tests with 6 different intensities of the LED's \rightarrow 6 charge peaks for each OM \rightarrow linearity measurement



Error bar are on the plot but there are too little to be seen

Calculation of the deviation between the fit and the measured data for an OM linked to 1 LED

Non linearity explanation : variation of the difference for 1 LED



For 1 LED, the **gaussian distribution** of the deviation shows that the non-linearity is **due to the LED**

There are big uncertainties on the value of the voltage applied to the LED

If we quantify these uncertainties, we may be able to make the necessary corrections to really study the linearity of OM

Conclusion

- **SuperNEMO** : -detect **neutrinoless double beta decay**
-Unique technology to **reconstruct particle's kinematic**
- **γ background calibration** : -1st method: fit of the **^{208}TI Compton front**
-2nd method: fit of the full spectra with **simulated spectra**
-Estimation of the γ background of the lab
- **Light Injection System** : -**Relative energy** calibration using LED
-**Study of the linearity** of the Optical Module
-Observation of **non-linearity** due to the LED

Backup

Estimation of the γ background of the lab

Expected γ background for ^{214}Bi (2.2 MeV): $\sim 10^{-4} \gamma \text{ cm}^{-2} \text{ s}^{-1}$

Ohsumi & all, 2002 - D. Malczewski & all 2012

M:0.19.12 0.006	M:0.18.12 0.006	M:0.17.12 0.007	M:0.16.12 0.007	M:0.15.12 0.006	M:0.14.12 0.008	M:0.13.12 0.005	M:0.12.12 0.008	M:0.11.12 0.008	M:0.10.12 0.008	M:0.9.12 0.008	M:0.8.12 0.006	M:0.7.12 0.005	M:0.6.12 0.006	M:0.5.12 0.006	M:0.4.12 0.006	M:0.3.12 0.006	M:0.2.12 0.006	M:0.1.12 0.006	M:0.0.12 0.005
M:0.19.11 0.005	M:0.18.11 0.005	M:0.17.11 0.006	M:0.16.11 0.006	M:0.15.11 0.006	M:0.14.11 0.006	M:0.13.11 0.006	M:0.12.11 0.008	M:0.11.11 0.008	M:0.10.11 0.007	M:0.9.11 0.005	M:0.8.11 0.006	M:0.7.11 0.005	M:0.6.11 0.005	M:0.5.11 0.007	M:0.4.11 0.005	M:0.3.11 0.005	M:0.2.11 0.006	M:0.1.11 0.005	M:0.0.11 0.005
M:0.19.10 0.007	M:0.18.10 0.005	M:0.17.10 0.005	M:0.16.10 0.006	M:0.15.10 0.006	M:0.14.10 0.000	M:0.13.10 0.006	M:0.12.10 0.007	M:0.11.10 0.006	M:0.10.10 0.006	M:0.9.10 0.005	M:0.8.10 0.007	M:0.7.10 0.007	M:0.6.10 0.007	M:0.5.10 0.006	M:0.4.10 0.005	M:0.3.10 0.005	M:0.2.10 0.004	M:0.1.10 0.005	M:0.0.10 0.006
M:0.19.9 0.007	M:0.18.9 0.006	M:0.17.9 0.006	M:0.16.9 0.010	M:0.15.9 0.006	M:0.14.9 0.007	M:0.13.9 0.006	M:0.12.9 0.006	M:0.11.9 0.008	M:0.10.9 0.008	M:0.9.9 0.005	M:0.8.9 0.006	M:0.7.9 0.006	M:0.6.9 0.006	M:0.5.9 0.005	M:0.4.9 0.005	M:0.3.9 0.005	M:0.2.9 0.007	M:0.1.9 0.005	M:0.0.9
M:0.19.8 0.006	M:0.18.8 0.005	M:0.17.8 0.006	M:0.16.8 0.007	M:0.15.8 0.008	M:0.14.8 0.007	M:0.13.8 0.007	M:0.12.8 0.006	M:0.11.8 0.005	M:0.10.8 0.007	M:0.9.8 0.005	M:0.8.8 0.004	M:0.7.8 0.005	M:0.6.8 0.008	M:0.5.8 0.006	M:0.4.8 0.006	M:0.3.8 0.005	M:0.2.8 0.007	M:0.1.8 0.007	M:0.0.8 0.006
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M:0.19.5 0.007	M:0.18.5 0.006	M:0.17.5 0.007	M:0.16.5 0.005	M:0.15.5 0.007	M:0.14.5 0.009	M:0.13.5 0.007	M:0.12.5 0.009	M:0.11.5 0.008	M:0.10.5 0.006	M:0.9.5 0.009	M:0.8.5 0.007	M:0.7.5 0.007	M:0.6.5 0.007	M:0.5.5 0.005	M:0.4.5 0.006	M:0.3.5 0.006	M:0.2.5 0.005	M:0.1.5 0.005	M:0.0.5 0.005
M:0.19.4 0.007	M:0.18.4 0.008	M:0.17.4 0.005	M:0.16.4 0.006	M:0.15.4 0.006	M:0.14.4 0.008	M:0.13.4 0.006	M:0.12.4 0.007	M:0.11.4 0.007	M:0.10.4 0.007	M:0.9.4 0.007	M:0.8.4 0.006	M:0.7.4 0.007	M:0.6.4 0.007	M:0.5.4 0.006	M:0.4.4 0.006	M:0.3.4 0.006	M:0.2.4 0.006	M:0.1.4 0.005	M:0.0.4 0.005
M:0.19.3 0.007	M:0.18.3 0.006	M:0.17.3 0.007	M:0.16.3 0.005	M:0.15.3 0.009	M:0.14.3 0.010	M:0.13.3 0.007	M:0.12.3 	M:0.11.3 	M:0.10.3 0.010	M:0.9.3 0.007	M:0.8.3 0.008	M:0.7.3 0.007	M:0.6.3 0.007	M:0.5.3 0.005	M:0.4.3 0.007	M:0.3.3 0.006	M:0.2.3 0.005	M:0.1.3 0.007	M:0.0.3 0.006
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M:0.19.1 0.006	M:0.18.1 0.005	M:0.17.1 0.007	M:0.16.1 0.006	M:0.15.1 0.008	M:0.14.1 0.007	M:0.13.1 0.009	M:0.12.1 0.008	M:0.11.1 0.010	M:0.10.1 0.009	M:0.9.1 0.012	M:0.8.1 0.007	M:0.7.1 0.011	M:0.6.1 0.009	M:0.5.1 0.008	M:0.4.1 0.010	M:0.3.1 0.010	M:0.2.1 0.007	M:0.1.1 0.007	M:0.0.1 0.006
M:0.19.0 0.009	M:0.18.0 0.010	M:0.17.0 0.012	M:0.16.0 0.013	M:0.15.0 0.013	M:0.14.0 0.016	M:0.13.0 0.014	M:0.12.0 0.014	M:0.11.0 0.016	M:0.10.0 0.014	M:0.9.0 0.014	M:0.8.0 0.013	M:0.7.0 0.017	M:0.6.0 0.017	M:0.5.0 0.012	M:0.4.0 0.012	M:0.3.0 0.011	M:0.2.0 0.011	M:0.1.0 0.009	M:0.0.0

Estimation of the γ background of the lab

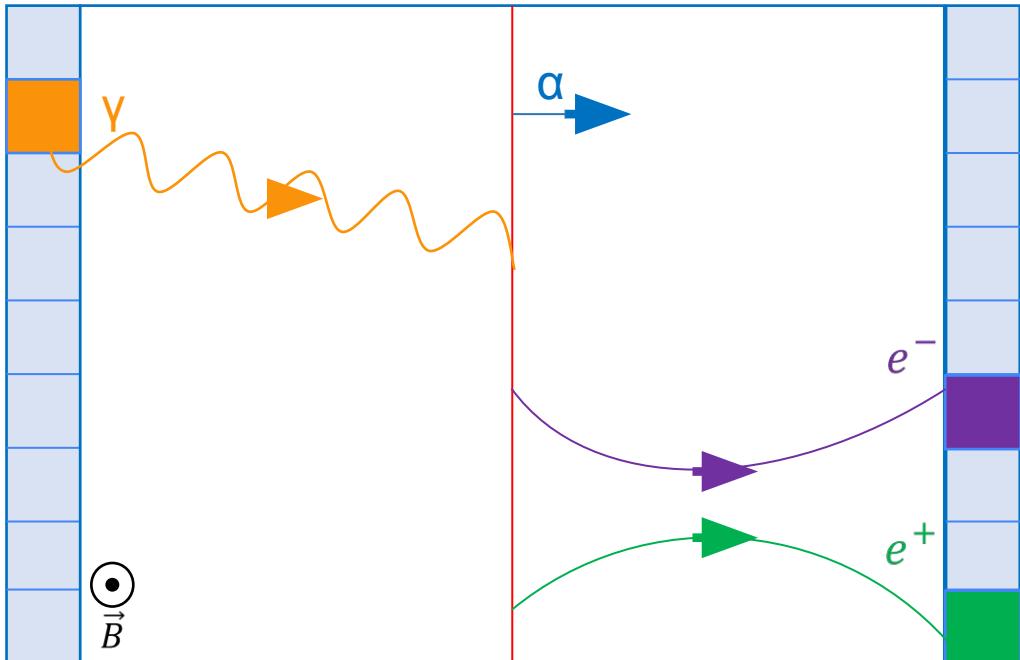
Expected γ background for ^{40}K (1.4 MeV) : $10^{-1} \sim 10^{-3} \text{ g cm}^{-2} \text{ s}^{-1}$

Ohsumi & all, 2002 - D. Malczewski & all 2012

M:0.19.12 0.127	M:0.18.12 0.180	M:0.17.12 0.151	M:0.16.12 0.182	M:0.15.12 0.172	M:0.14.12 0.163	M:0.13.12 0.223	M:0.12.12 0.177	M:0.11.12 0.267	M:0.10.12 0.169	M:0.9.12 0.126	M:0.8.12 0.129	M:0.7.12 0.139	M:0.6.12 0.147	M:0.5.12 0.187	M:0.4.12 0.134	M:0.3.12 0.118	M:0.2.12 0.137	M:0.1.12 0.121	M:0.0.12 0.153
M:0.19.11 0.115	M:0.18.11 0.084	M:0.17.11 0.126	M:0.16.11 0.141	M:0.15.11 0.155	M:0.14.11 0.191	M:0.13.11 0.152	M:0.12.11 0.155	M:0.11.11 0.149	M:0.10.11 0.146	M:0.9.11 0.140	M:0.8.11 0.136	M:0.7.11 0.182	M:0.6.11 0.115	M:0.5.11 0.146	M:0.4.11 0.114	M:0.3.11 0.094	M:0.2.11 0.094	M:0.1.11 0.083	M:0.0.11 0.157
M:0.19.10 0.150	M:0.18.10 0.088	M:0.17.10 0.116	M:0.16.10 0.138	M:0.15.10 0.139	M:0.14.10 0.000	M:0.13.10 0.148	M:0.12.10 0.173	M:0.11.10 0.140	M:0.10.10 0.168	M:0.9.10 0.142	M:0.8.10 0.178	M:0.7.10 0.191	M:0.6.10 0.152	M:0.5.10 0.145	M:0.4.10 0.122	M:0.3.10 0.111	M:0.2.10 0.134	M:0.1.10 0.091	M:0.0.10 0.118
M:0.19.9 0.109	M:0.18.9 0.104	M:0.17.9 0.082	M:0.16.9 0.155	M:0.15.9 0.092	M:0.14.9 0.125	M:0.13.9 0.160	M:0.12.9 0.104	M:0.11.9 0.131	M:0.10.9 0.112	M:0.9.9 0.124	M:0.8.9 0.104	M:0.7.9 0.142	M:0.6.9 0.116	M:0.5.9 0.116	M:0.4.9 0.124	M:0.3.9 0.108	M:0.2.9 0.111	M:0.1.9 0.102	M:0.0.9
M:0.19.8 0.142	M:0.18.8 0.091	M:0.17.8 0.118	M:0.16.8 0.138	M:0.15.8 0.141	M:0.14.8 0.135	M:0.13.8 0.082	M:0.12.8 0.109	M:0.11.8 0.145	M:0.10.8 0.117	M:0.9.8 0.110	M:0.8.8 0.135	M:0.7.8 0.112	M:0.6.8 0.118	M:0.5.8 0.115	M:0.4.8 0.100	M:0.3.8 0.125	M:0.2.8 0.111	M:0.1.8 0.140	M:0.0.8
M:0.19.7 0.113	M:0.18.7 0.112	M:0.17.7 0.103	M:0.16.7 0.102	M:0.15.7 0.145	M:0.14.7 0.142	M:0.13.7 0.124	M:0.12.7 0.195	M:0.11.7 0.126	M:0.10.7 0.163	M:0.9.7 0.173	M:0.8.7 0.114	M:0.7.7 0.159	M:0.6.7 0.091	M:0.4.7 0.105	M:0.3.7 0.114	M:0.2.7 0.112	M:0.1.7 0.200	M:0.0.7 0.116	
M:0.19.6 0.158	M:0.18.6 0.119	M:0.17.6 0.140	M:0.16.6 0.093	M:0.15.6 0.123	M:0.14.6 0.098	M:0.13.6 0.105	M:0.12.6 0.130	M:0.11.6 0.173	M:0.10.6 0.130	M:0.9.6 0.146	M:0.7.6 0.125	M:0.6.6 0.108	M:0.5.6 0.087	M:0.4.6 0.134	M:0.3.6 0.107	M:0.2.6 0.135	M:0.1.6 0.145	M:0.0.6 0.116	
M:0.19.5 0.151	M:0.18.5 0.148	M:0.17.5 0.124	M:0.16.5 0.138	M:0.15.5 0.151	M:0.14.5 0.154	M:0.13.5 0.153	M:0.12.5 0.132	M:0.11.5 0.175	M:0.10.5 0.116	M:0.9.5 0.151	M:0.8.5 0.156	M:0.7.5 0.136	M:0.6.5 0.152	M:0.5.5 0.161	M:0.4.5 0.134	M:0.3.5 0.136	M:0.2.5 0.108	M:0.1.5 0.099	M:0.0.5 0.176
M:0.19.4 0.135	M:0.18.4 0.100	M:0.17.4 0.118	M:0.16.4 0.243	M:0.15.4 0.161	M:0.14.4 0.137	M:0.13.4 0.135	M:0.12.4 0.125	M:0.11.4 0.123	M:0.10.4 0.154	M:0.9.4 0.180	M:0.8.4 0.160	M:0.7.4 0.127	M:0.6.4 0.164	M:0.5.4 0.120	M:0.4.4 0.147	M:0.3.4 0.210	M:0.2.4 0.120	M:0.1.4 0.122	M:0.0.4 0.146
M:0.19.3 0.155	M:0.18.3 0.140	M:0.17.3 0.127	M:0.16.3 0.168	M:0.15.3 0.205	M:0.14.3 0.149	M:0.13.3 0.155	M:0.12.3 0.156	M:0.11.3 0.254	M:0.10.3 0.125	M:0.9.3 0.145	M:0.8.3 0.131	M:0.7.3 0.136	M:0.6.3 0.207	M:0.4.3 0.120	M:0.3.3 0.146	M:0.2.3 0.202	M:0.1.3 0.111	M:0.0.3 0.163	
M:0.19.2 0.156	M:0.18.2 0.185	M:0.17.2 0.104	M:0.16.2 0.144	M:0.15.2 0.170	M:0.14.2 0.173	M:0.13.2 0.220	M:0.12.2 0.150	M:0.11.2 0.317	M:0.10.2 0.149	M:0.9.2 0.231	M:0.8.2 0.154	M:0.7.2 0.148	M:0.6.2 0.230	M:0.4.2 0.137	M:0.3.2 0.195	M:0.2.2 0.151	M:0.1.2 0.098	M:0.0.2 0.106	
M:0.19.1 0.245	M:0.18.1 0.171	M:0.17.1 0.169	M:0.16.1 0.138	M:0.15.1 0.277	M:0.14.1 0.152	M:0.13.1 0.170	M:0.12.1 0.219	M:0.11.1 0.308	M:0.10.1 0.231	M:0.9.1 0.174	M:0.8.1 0.200	M:0.7.1 0.132	M:0.6.1 0.222	M:0.5.1 0.145	M:0.4.1 0.310	M:0.3.1 0.185	M:0.2.1 0.152	M:0.1.1 0.096	M:0.0.1 0.124
M:0.19.0 0.208	M:0.18.0 0.216	M:0.17.0 0.242	M:0.16.0 0.318	M:0.15.0 0.283	M:0.14.0 0.463	M:0.13.0 0.293	M:0.12.0 0.313	M:0.11.0 0.282	M:0.10.0 0.372	M:0.9.0 0.278	M:0.8.0 0.406	M:0.7.0 0.220	M:0.6.0 0.331	M:0.5.0 0.309	M:0.4.0 0.498	M:0.3.0 0.517	M:0.2.0 0.417	M:0.1.0 0.328	M:0.0.0

Particles identification

Vue de dessus



Identification des particules

Alphas, gammas, électrons,
positrons

Corrections optiques : effet Birks

Saturation de la scintillation ⇒ Non-linéarité dans la production de lumière

$$R(E_0) = S \int_0^{E_0} \frac{1}{1 + k_B \frac{dE}{dx}} dE$$

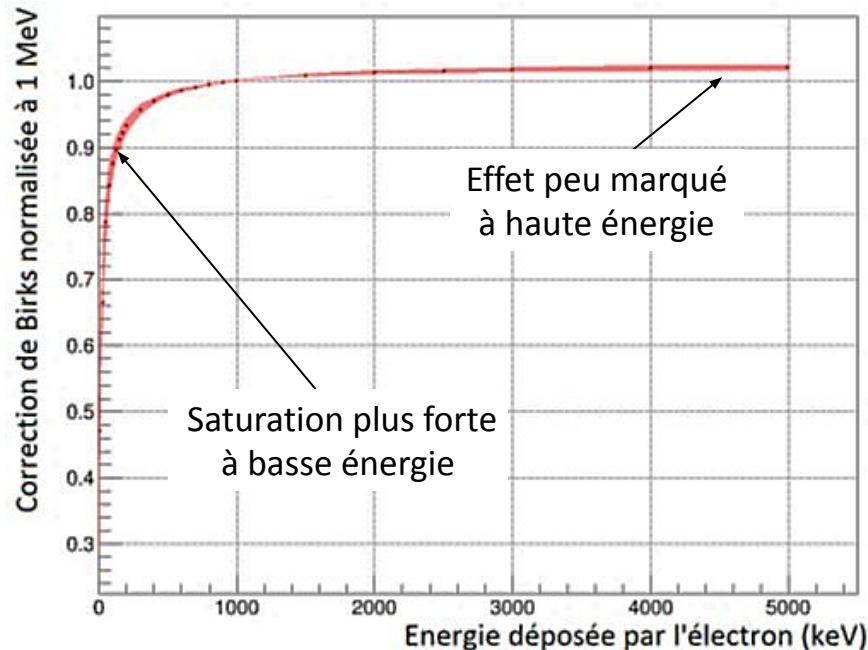
$R(E_0)$: rendement lumineux pour $E_{déposée} = E_0$

S : facteur de normalisation

k_B : constante de Birks qui traduit la saturation

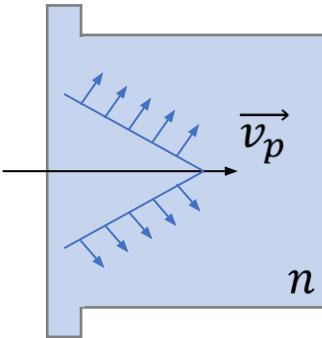
$\frac{dE}{dx}$: pouvoir d'arrêt

$$C_{Birks} = \frac{N_{ph}^{Sc+Birks}(E)}{N_{ph}^{Sc}(1\text{ MeV}) \times E}$$



Corrections optiques : effet Cerenkov

Production de photon quand $\|\vec{v}_p\| > \frac{c}{n}$ \Rightarrow Non-linéarité dans la production de lumière



\vec{v}_p : vitesse de la particule
 n : indice de réfraction

$n = 1,61$ (scintillateur de SuperNEMO)

- $E_{seuil} = 146 \text{ keV}$
- $N_{ph}^{Cerenkov}(1 \text{ MeV}) \approx 217$

$$C_{Cerenkov} = \frac{N_{ph}^{Sc+Cerenkov}(E)}{N_{ph}^{Sc+Cerenkov}(1 \text{ MeV}) \times E}$$

