Status and sensitivity of the SuperNEMO demonstrator

Steven Calvez, GdR Neutrino May 2017

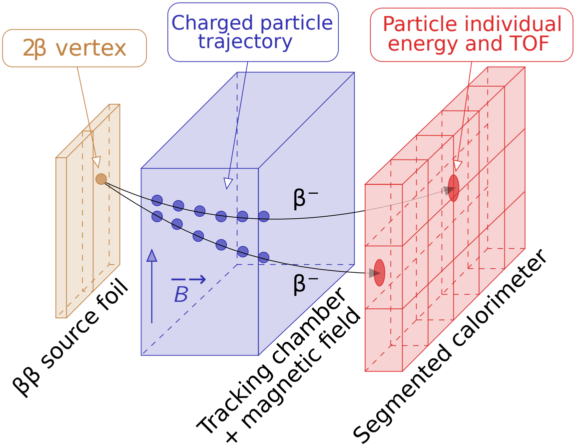
Steven Calvez ✎ calvez@lal.in2p3.fr

Outline

- The SuperNEMO experiment
- Status of the demonstrator integration
- Particle reconstruction and identification
- Sensitivity of the demonstrator

The SuperNEMO experiment

- SuperNEMO is a $0\nu\beta\beta$ experiment combining tracking and calorimetry techniques.



The demonstrator design

Tracker :

Wire chamber (2034 wires)

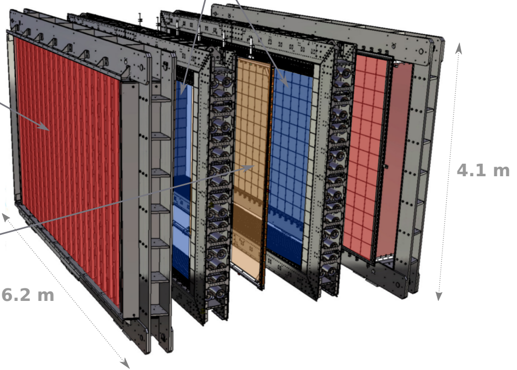
3D track reconstruction

Calorimeter :

440 x 8’’ PM + 272 x 5’’ PM coupled to polystyrene scintillators

Energy resolution :
4 % FWHM @ $Q_{\beta\beta}$

Time resolution :
σ = 400 ps @ 1 MeV



Source :

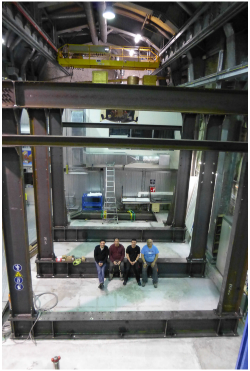
7 kg of ^{82}Se

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

Integration of the demonstrator in LSM

Mechanical structure and clean tent : LAL

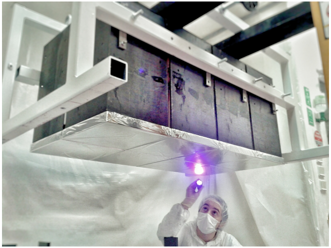
- Assembly of the support frame and the temporary clean tent.



Integration of the demonstrator in LSM

Calorimeter : CENBG and LAL

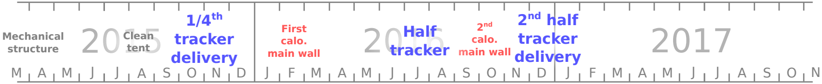
- Assembly of the calorimeter frame and populating it with calorimeter blocks



Integration of the demonstrator in LSM

Tracker : UK

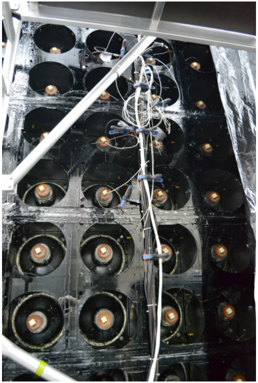
- Delivery and assembly of the 4 tracker sections.

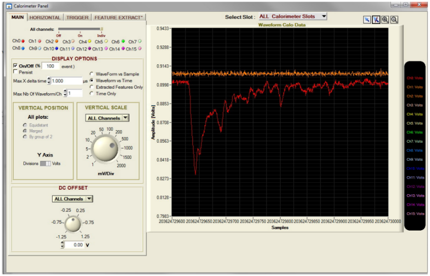


Integration of the demonstrator in LSM

Commissioning

- Commissioning of one half of the demonstrator is underway.





Mechanical structure · 2015 · Clean tent · 1/4th tracker delivery · First calo. main wall · 2016 · Half tracker · 2nd calo. main wall · 2nd half tracker delivery · Half detector commissioning · 2017

M A M J J A S O N D | J F M A M J J A S O N D | J F M A M J J A S O N

Integration of the demonstrator in LSM

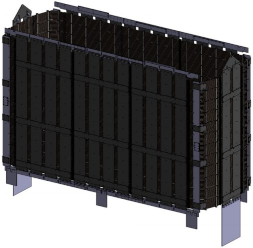
Source : LAPP

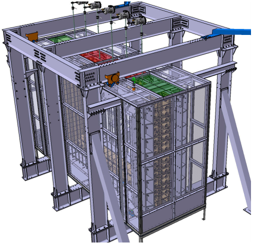
- Installation of the source strips.

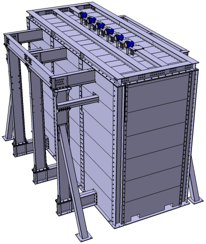
Integration of the demonstrator in LSM

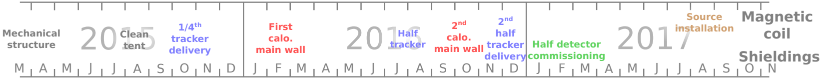
Magnetic coil and shieldings : LPC and LAL

- Assembly of the magnetic coil, the anti-radon tent and the shieldings (pure iron and water).









Goals of the demonstrator

- Run for 2.5 years with 7 kg of ^{82}Se (and maybe ^{150}Nd in a second phase if the enrichment is mastered)
- Prove SuperNEMO can be a background-free experiment in the Region of Interest

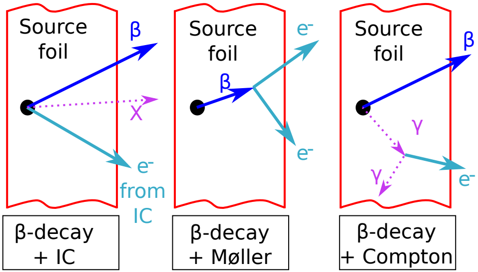
$$T_{1/2}^{0\nu,\mathrm{lim}} \propto \begin{cases} m \cdot t & \text{without background} \\ \sqrt{\frac{m \cdot t}{b \cdot \Delta E}} & \text{with background} \end{cases}$$

with m the mass of $\beta\beta$-isotope, t the acquisition time, b the background rate in counts.keV^{-1}.kg^{-1}.y^{-1} and ΔE the energy resolution.

Background origins

- Main backgrounds :

→ A contamination of the source in β/γ emitters : mainly **^{208}Tl** and **^{214}Bi** because of their high transition energy.
→ **Radon** in the tracker gas : daugther nuclei depositing close to the source and decaying to ^{214}Bi.

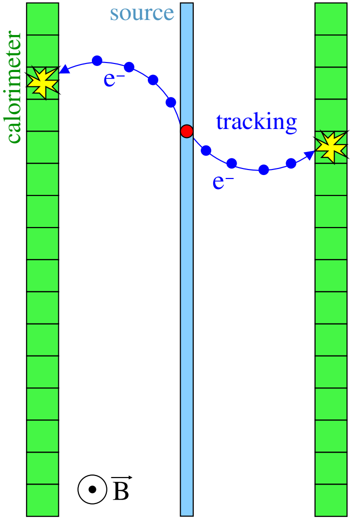


● = radioisotope; β = electron from β-decay; IC = internal conversion

Comparison between NEMO-3 and SuperNEMO

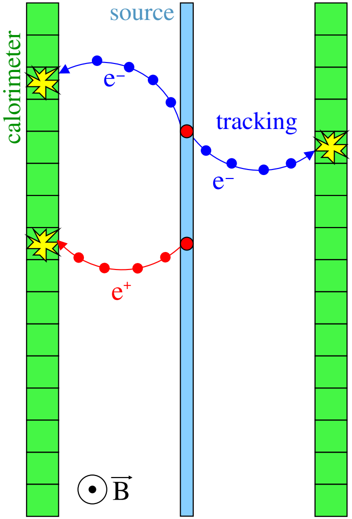
	NEMO3	SuperNEMO
Mass	7 kg	7 kg | 100 kg
Isotopes	^{100}Mo	^{82}Se
	among 7 isotopes	(^{150}Nd, Copper,...)
Calo. energy res. @ $Q_{\beta\beta}$		
FWHM - σ	8 % - 3.4 %	4 % - 1.7 %
Backgrounds :		
A(^{208}Tl)	$\sim$ 100 μBq/kg	$\leq$ 2 μBq/kg
A(^{214}Bi)	$\sim$ 300 μBq/kg	$\leq$ 10 μBq/kg
A(Radon) in tracker	$\sim$ 5 mBq/m^3	$\leq$ 0.15 mBq/m^3
0ν efficiency	18 %	30 %
Exposure	35 kg·y	17.5 kg·y | 500 kg·y
Sensitivity		
$T_{1/2}^{0\nu2\beta}$ (90% C.L.)	$> 1.1\ 10^{24}$	$> 6\ 10^{24}$ y | $> 10^{26}$ y
$\langle m_{\beta\beta}\rangle$	$<$ 0.33 - 0.87 eV	$<$ 0.2 - 0.55 eV | $<$ 0.04 - 0.1 eV

Particle identification



- **Electron** : a negatively curved track with an associated calorimeter hit.
- **Positron** : a positively curved track with an associated calorimeter hit.
- **Alpha** : a (delayed) short straight track.
- **Gamma** : One or more unassociated calorimeter hits.

Particle identification



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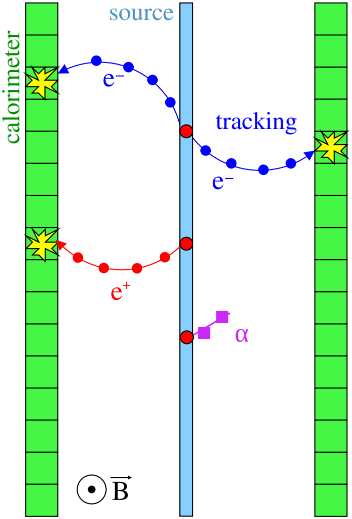

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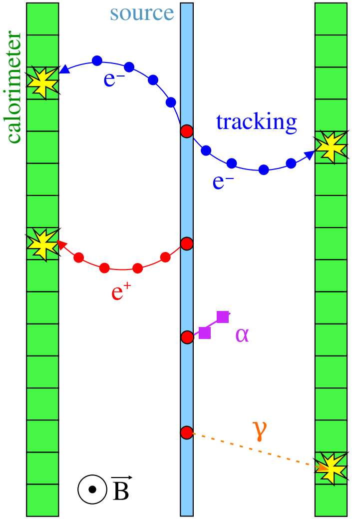

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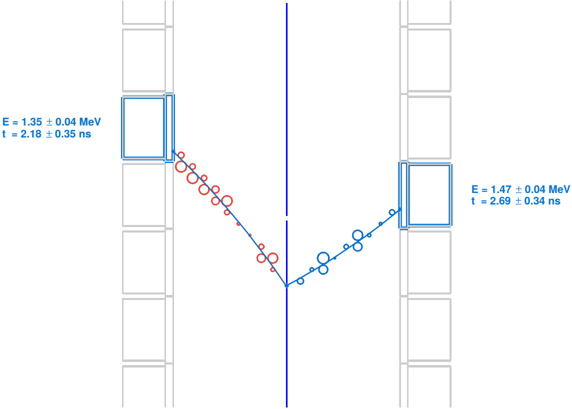
Event reconstruction

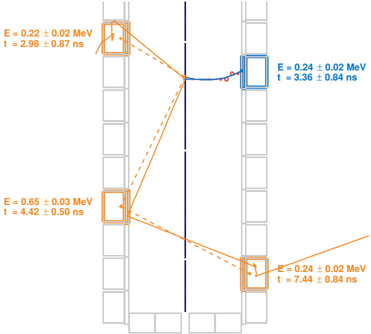
- Display of a $0\nu\beta\beta$ event from Monte-Carlo simulations (top view).



Gamma reconstruction

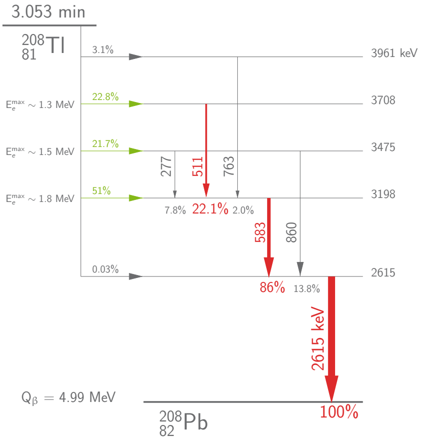
- γ's can bounce around in the detector and hit several calorimeter blocks.
- Need a dedicated algorithm based on the Time-Of-Flight to reconstruct the γ particles : the γ-tracko-clustering
- Trade off between pure tracking (TOF only) and simple clustering (neighbouring hits only).

- Number of γ's and energy reconstructed more accurate.

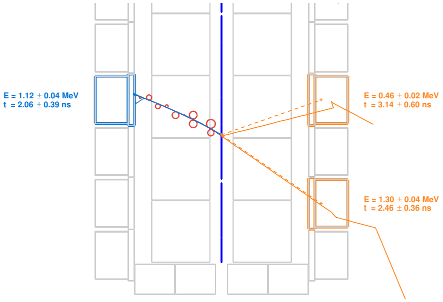


Dedicated background channels

- ^{208}Tl mostly emits a β and 2 γ's :

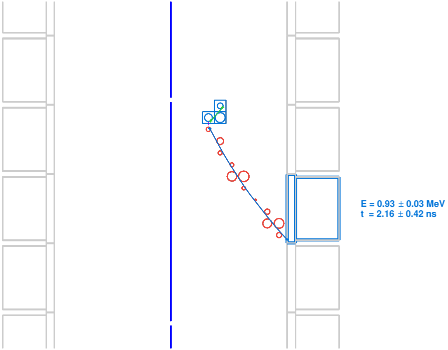


- Measure ^{208}Tl in the 1e2γ channel :



Dedicated background channels

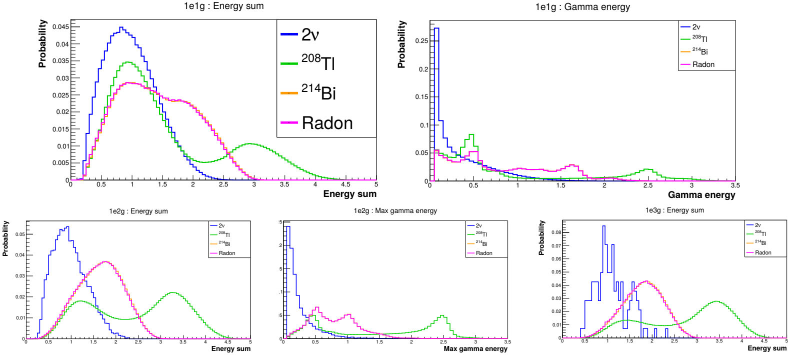
- Measure Radon with the $1e1\alpha(N\gamma)$ events from the tracker:



- A(Radon) = 150 $\mu Bq/m^3$ can be measured with a **10 % stat. uncertainty in less than a week**

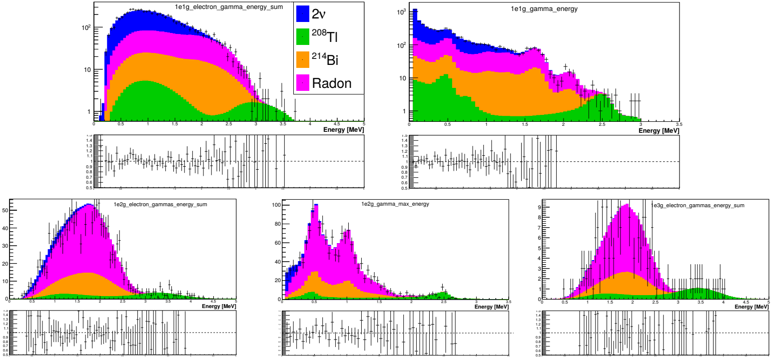
Background measurement : ^{208}Tl and ^{214}Bi

- Use discriminating variables in the 1e1γ, 1e2γ and 1e3γ channels to measure the ^{208}Tl and ^{214}Bi source contaminations:



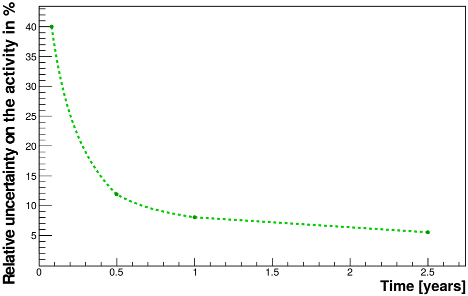
Background measurement : ^{208}Tl and ^{214}Bi

- Global fit on several distributions across different channels for a pseudo-experiment :



Background measurement : ^{208}Tl and ^{214}Bi

- The uncertainty on the measurement is obtained from the distribution of the activities measured in a large number of pseudo-experiments.



- 10 % stat. uncertainty in **8 months** on A(^{208}**Tl**) = 2 µBq/kg
- 10 % stat. uncertainty in **3 months** on A(^{214}**Bi**) = 10 µBq/kg

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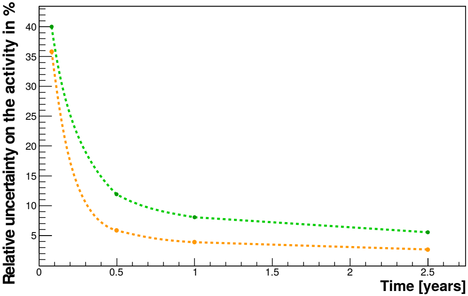
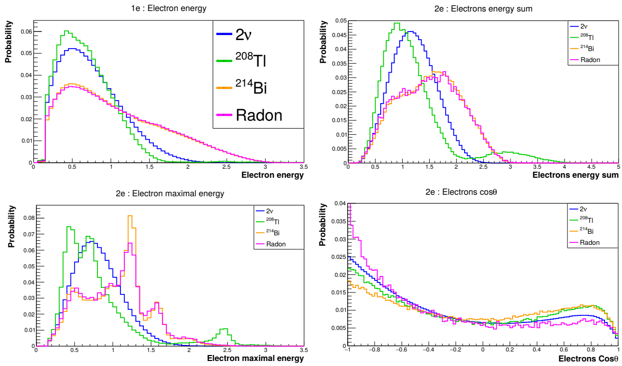


- 10 % stat. uncertainty in **8 months** on A(^{208}**Tl**) = 2 µBq/kg
- 10 % stat. uncertainty in **3 months** on A(^{214}**Bi**) = 10 µBq/kg

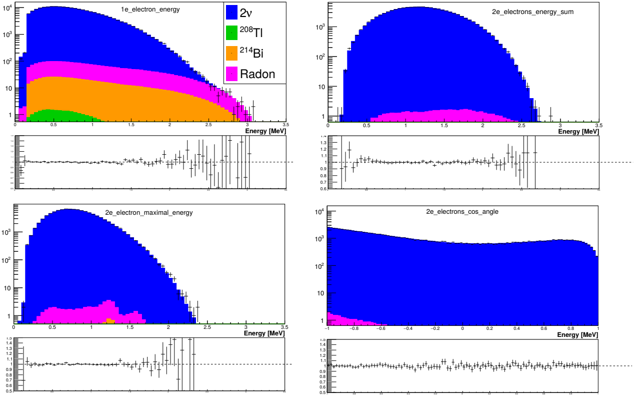
Background measurement : $2\nu\beta\beta$

- Global fit on discriminating variables in the 1e and 2e channels to measure the $2\nu\beta\beta$ half-life:



Background measurement : $2\nu\beta\beta$

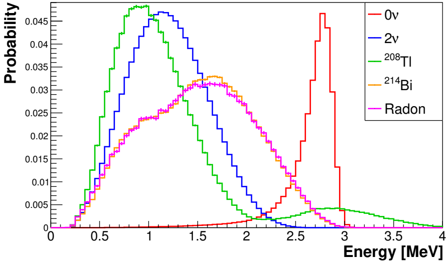
- Measure the $2\nu\beta\beta$ half-life on several pseudo-experiments : **0.4 % stat. uncertainty** with the demonstrator (17.5 kg·y)



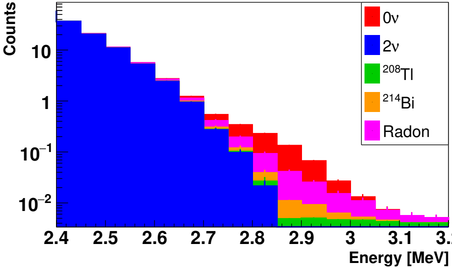
$0\nu\beta\beta$ sensitivity

- For the mass mechanism, considering the demonstrator expected conditions, namely $A(^{208}Tl) = 2\mu Bq/kg$, $A(^{214}Bi) = 10\mu Bq/kg$, $A(Radon) = 150\mu Bq/m^3$ with a 17.5 kg·y exposure
- Select $\beta\beta$-like events and look at the energy sum spectrum :

Arbitrary normalization



Normalized to activities



	$2\nu\beta\beta$	^{208}Tl	^{214}Bi	Radon
Events in [2.8;3]	$1.8\ 10^{-2}$	$2.0\ 10^{-2}$	$2.5\ 10^{-2}$	$1.1\ 10^{-1}$

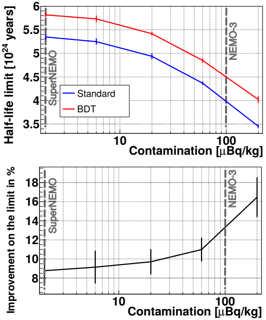
$0\nu\beta\beta$ sensitivity using multivariate analysis

- Train **BDTs** from ROOT's TMVA to discriminate signal events from background events using **topological information from the 2e channel**.
- **Energy variables** are correlated but the **vertices separation** and the **internal probability** are helpful discriminating variables.
- Compare the **sensitivity** obtained using the two electrons energy sum spectrum or the BDT score and using the **CLs technique**.

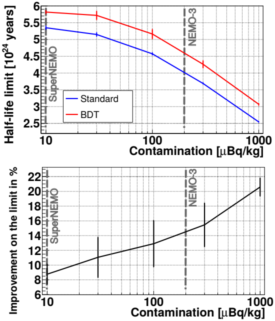
Impact of the background levels

- Sensitivity depending on the different background levels

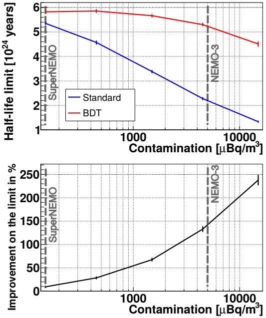
^{208}Tl



^{214}Bi



Radon



Conclusion

- Thanks to its **tracking capabilities**, SuperNEMO can use **dedicated channels** to accurately **characterize the background** (even ultra-low level contaminations).
- The **multivariate analysis** improves the sensitivity by at least **10 %** considering the stringent background levels are reached, and more otherwise (90 % sensitivity increase assuming the NEMO3 background levels).
- The demonstrator is being **commissioned** and the **data taking** should start in the **Autumn 2017**
- The demonstrator should reach a sensitivity of

$$\mathbf{T^{0\nu}_{1/2} > 5.9\ 10^{24}\ y\ 90\ \%\ C.L.}$$
$$\mathbf{\langle m_{\beta\beta} \rangle < 200\ -\ 550\ meV}$$

BACKUP

Choice of isotope

- Table of the double beta emitters with their transition energy $Q_{\beta\beta}$, their natural isotopic abundance, the $2\nu\beta\beta$ half-life and the $0\nu\beta\beta$ phase space factor $G_{0\nu}$.

Isotope	$Q_{\beta\beta}$ (keV)	η (%)	$T_{1/2}^{2\nu}$ (10^{21} y)	$G_{0\nu}$ (10^{-25} y^{-1})
^{48}Ca	4272	0.187	0.064	2.439
^{76}Ge	2040	7.61	1.926	0.244
^{82}Se	2995	8.73	0.096	1.079
^{100}Mo	3034	9.63	0.007	1.754
^{116}Cd	2805	7.49	0.028	1.894
^{130}Te	2529	33.8	0.82	1.698
^{136}Xe	2479	8.9	2.165	1.812
^{150}Nd	3368	5.6	0.009	8.000

The γ tracko-clustering

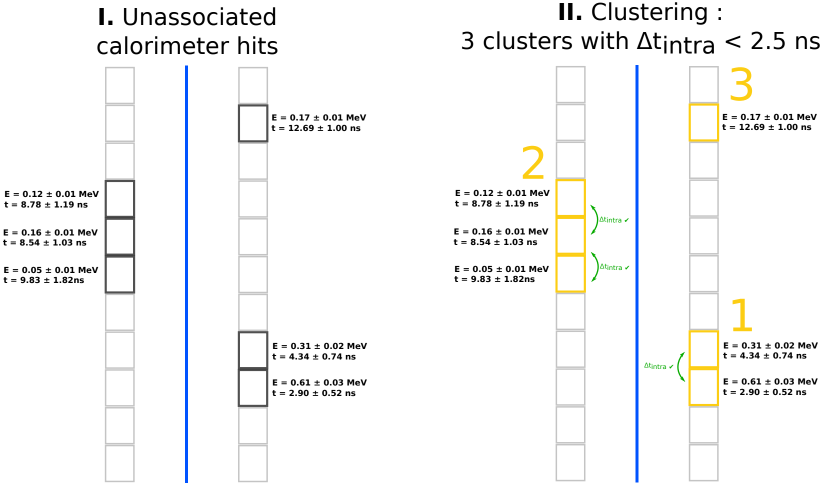
- The γ-clustering, *a la* NEMO3, relies mainly on geometry. It gathers the neighbouring unassociated calorimeter hits into clusters to which is associated a new γ.
- The γ-tracking is based on Time-Of-Flight (TOF) calculations.

$$\chi^2_{int} = \frac{\left((t_2^{exp} - t_1^{exp}) - \frac{\ell_{1\to 2}}{c}\right)^2}{\sigma^2_{t_1} + \sigma^2_{t_2} + \sigma^2_{\ell}}$$

$$P(\chi^2_{int}) = 1 - \frac{1}{\sqrt{2\pi}} \int_0^{\chi^2_{int}} x^{-\frac{1}{2}} e^{-\frac{x}{2}} dx$$

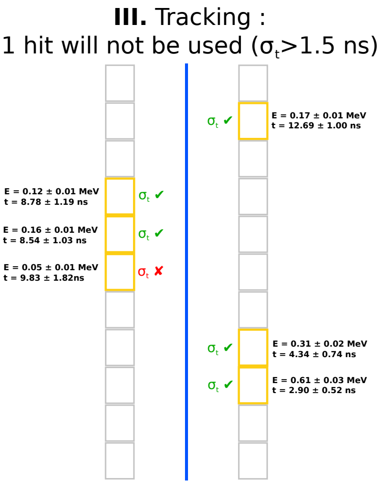
The γ-tracko-clustering

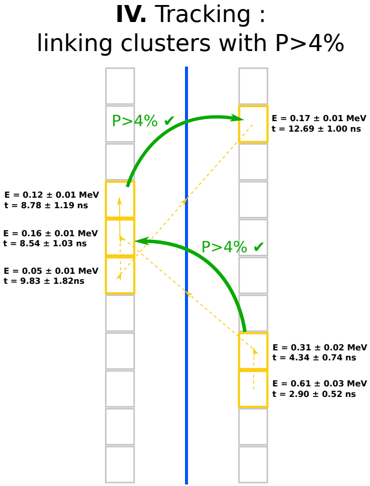
The algorithm first performs a standard clustering...



The γ-tracko-clustering

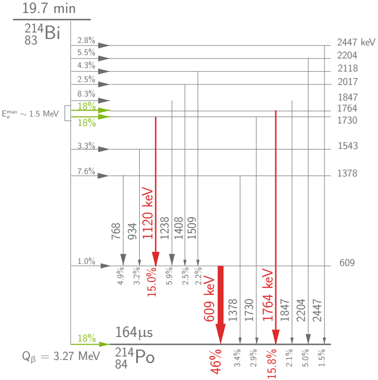
...then links the clusters based on TOF probability



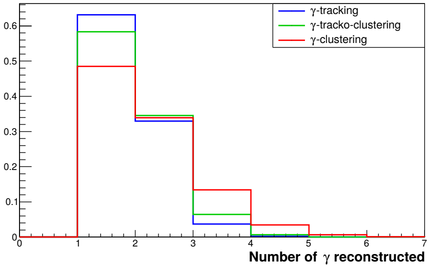


Number of γ's reconstructed in ^{214}Bi

- Between 0 and 2 γ's emitted : γ-clustering overestimates the number of γ's

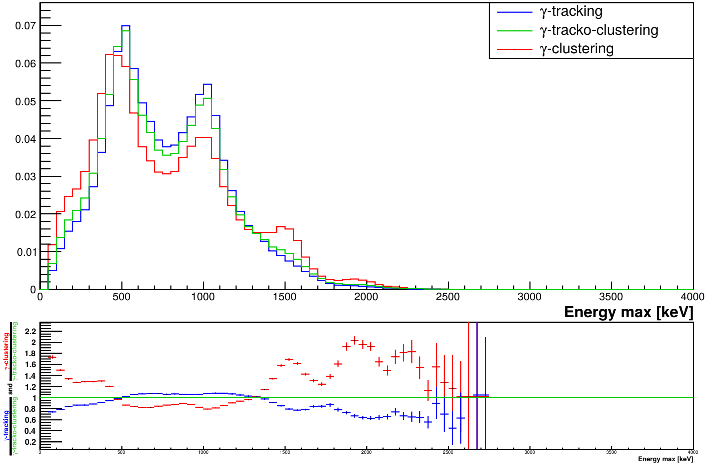


Number of γ's reconstructed



Example of ^{214}Bi : spectra comparison

- **Highest enery γ spectrum in the ^{214}Bi 1e2γ channel** : the γ-clustering splits γ's



BDT configuration

- Split the samples in 4 (A,B,C,D), train on A+B, test on B and C, and conversely.
- Configuration "slow training":
  - AdaBoost : $\beta = 0.2$
  - 1200 trees
  - Minimal node size : 50 events
  - Maximal tree depth : 3
  - Separation index : Gini index