The BiPo-3 detector

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Outline

1. Neutrinoless double beta decay and the SuperNemo experiment
2. BiPo-3 measurement principle
3. Description of the BiPo-3 detector
4. Background measurement
5. Measurement of the SuperNemo double-β source foils
6. Sensitivity of the BiPo-3 detector

Neutrinoless double beta decay

$2\beta0\nu$ decay:
(Z,A) $\rightarrow$ (Z+2,A) + $2e^-$

$\hookrightarrow \Delta$ **L = 2**

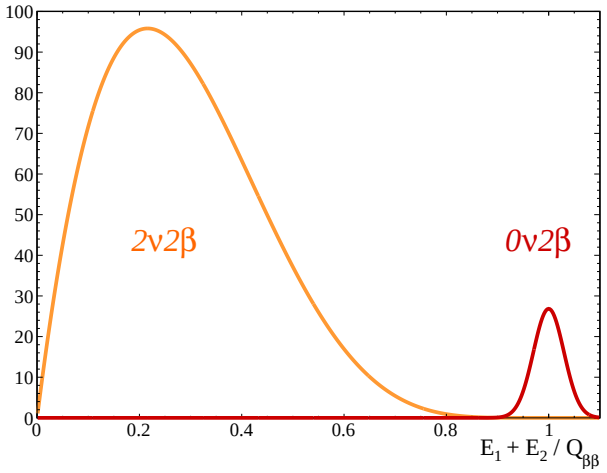
$\rightarrow$ physics beyond the Standard Model

- What's the absolute ν mass scale?
- Are ν's Dirac ($\nu \neq \bar{\nu}$) or Majorana ($\nu = \bar{\nu}$)?

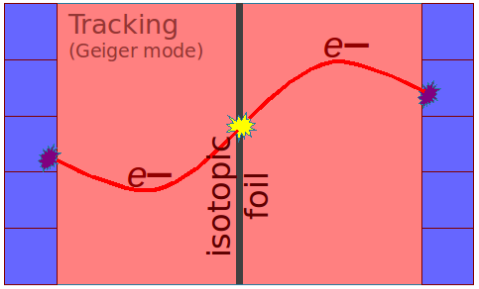
If $2\beta0\nu$ is observed $\Longrightarrow$ ν's are Majorana particles

- $T_{1/2}^{2\beta0\nu} > 10^{25}$ ys

Experimental signature:



SuperNemo



Combines tracker and calorimetric measurements

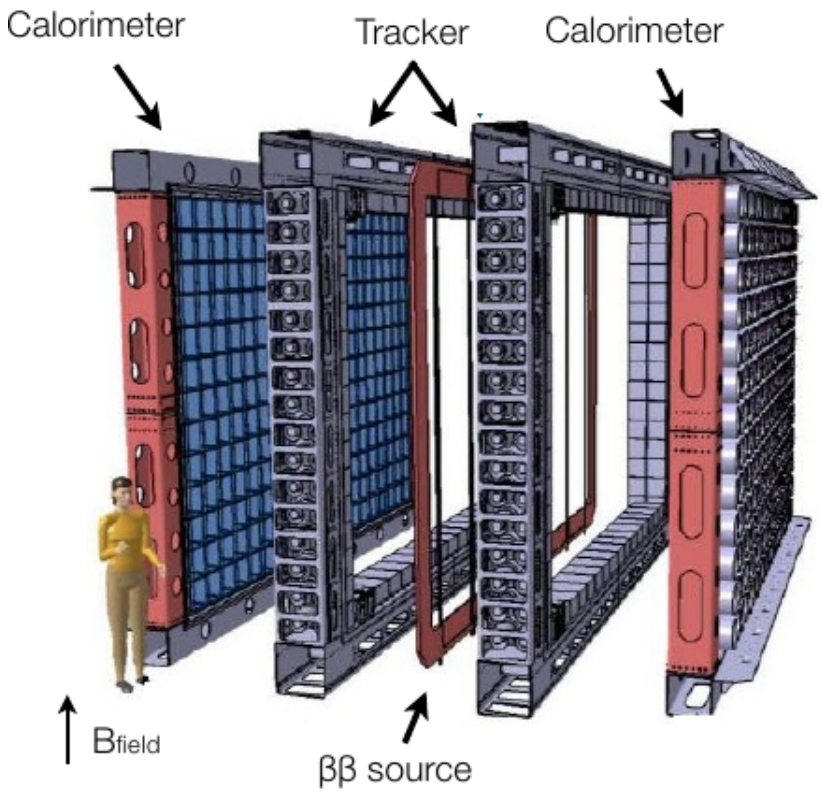
- Baseline isotope: ^{82}Se ($Q_{\beta\beta}$=3 MeV). 20 modules, 100 kg of ^{82}Se
- Targetted sensitivity $T_{1/2}(2\beta0\nu) > 10^{26}$ y

First module (demonstrator):

- ^{82}Se mass= 7 kg
- Construction finished by end 2016

Backgrounds:

- **Main background from $\beta\beta$ source foils : ^{208}Tl (Q_β = 4.99 MeV) and ^{214}Bi (Q_β = 3.27 MeV)**
- Required contamination in ^{82}Se foils :
  - A(^{208}Tl) $< 2\ \mu$Bq/kg
  - A(^{214}Bi) $< 10\ \mu$Bq/kg



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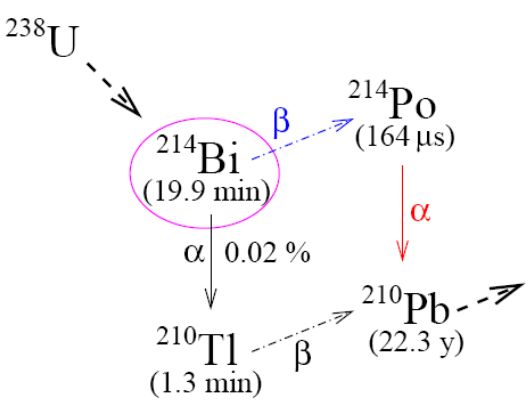
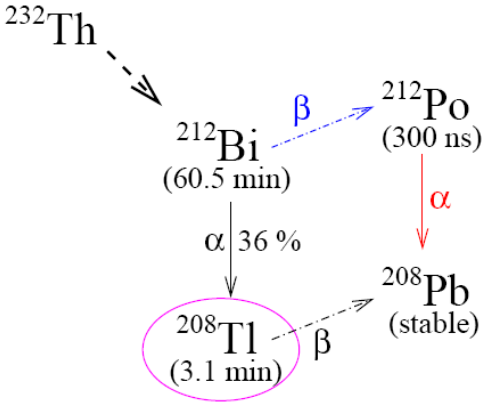
The BiPo-3 detector: detection principle

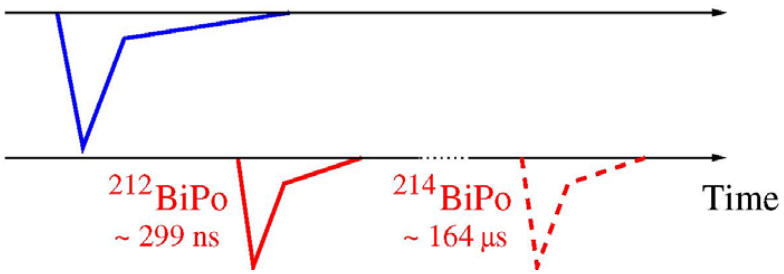
- BiPo-3 has been developed to measure ultra low levels of ^{208}Tl and ^{214}Bi in the SuperNemo source foils.
- Detection principle: β - α delayed coincidence detection

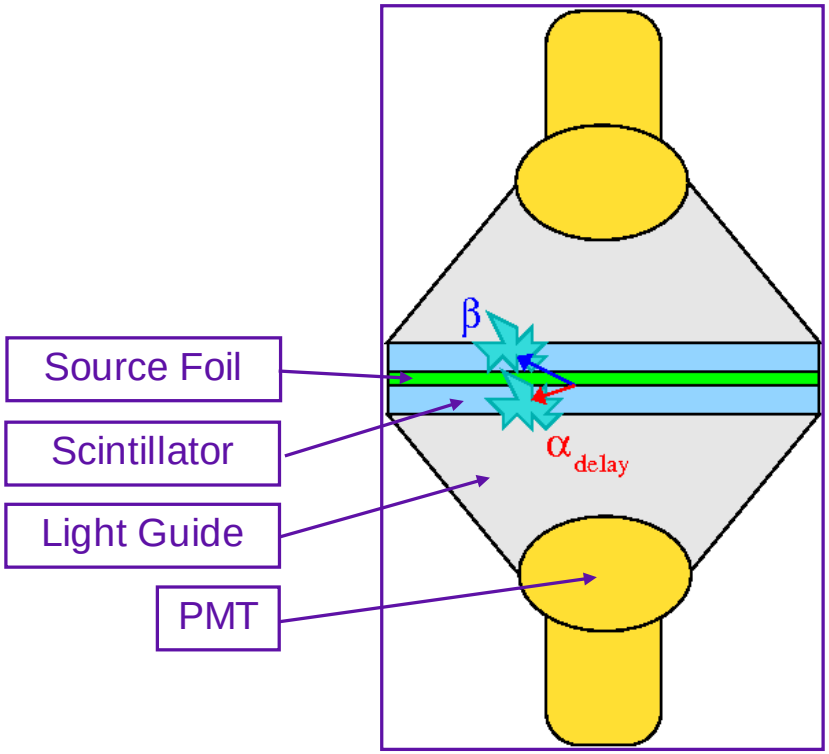




Detection principle

The foil of interest is installed between two thin low radioactive organic scintillators





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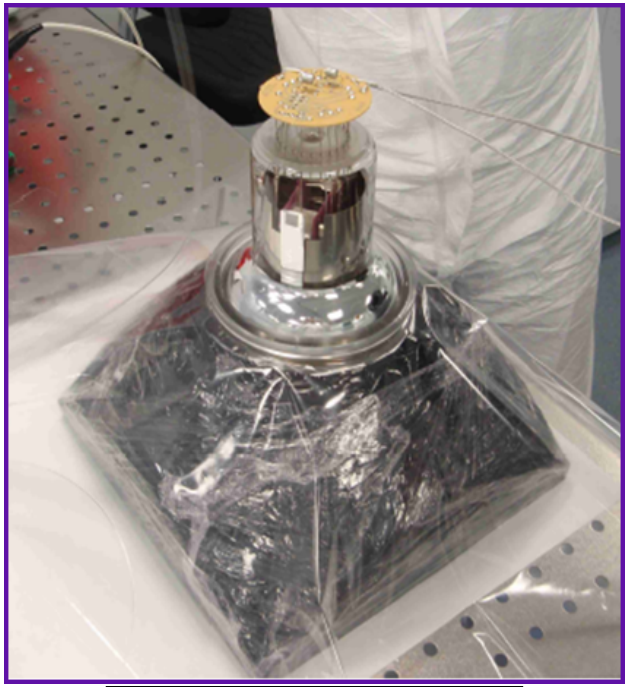
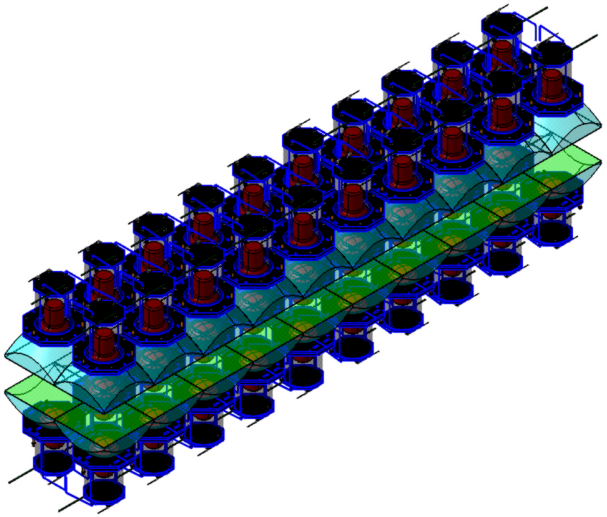
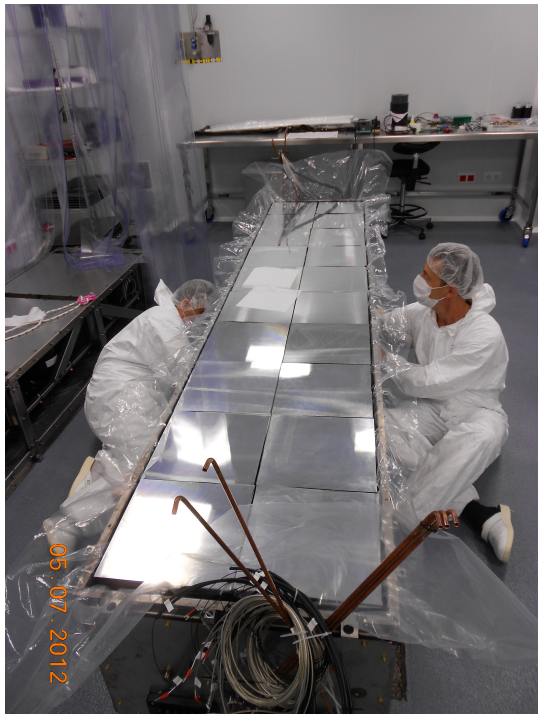
The set-up

- Detection "unit"= optical sub-module : polystryrene scintillator plates (300x300x2) mm^3 coupled to 5" PMTs through a PMMA optical guide
- Scintillator surface covered with 200 nm radiopure aluminium
- The optical sub-modules are assembled in one Module with 20 pairs of optical sub-modules
- BiPo-3 = 2 Modules $\rightarrow$ Total detector surface= 3.6 m^2



Optical sub-module

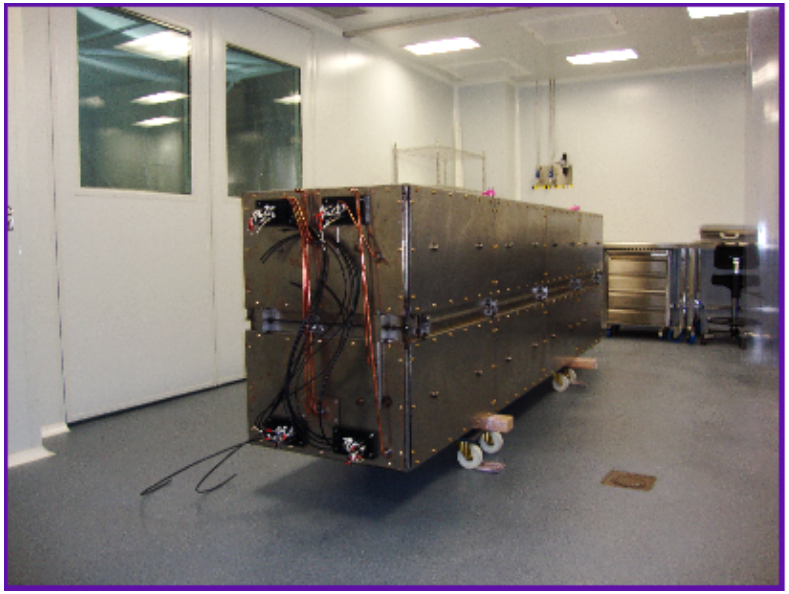


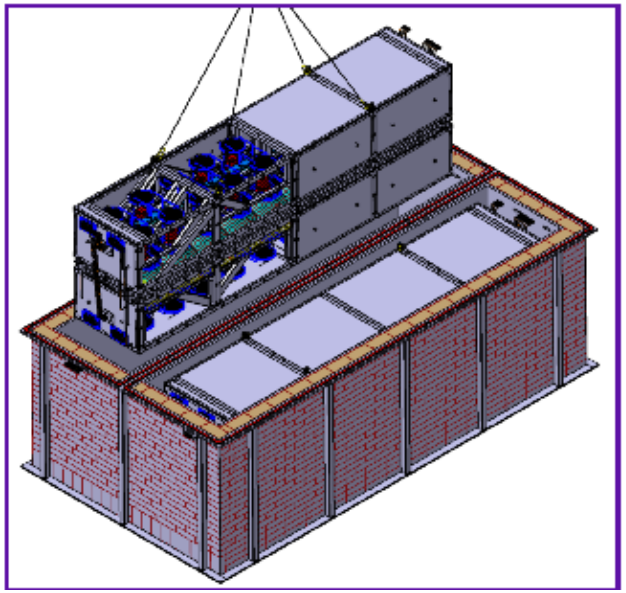


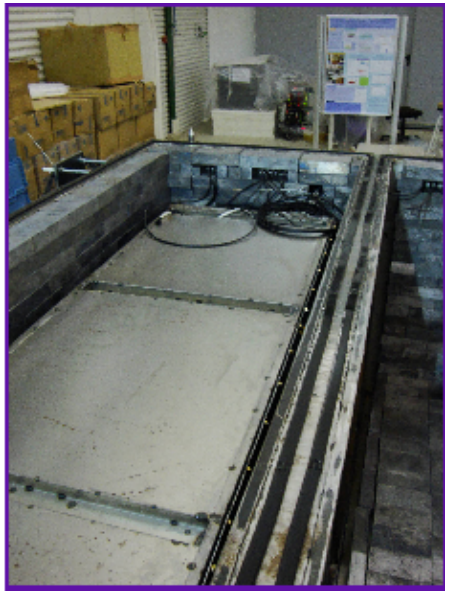
BiPo-3 Module with 20 pairs of optical sub-modules

The Shielding

- Installed in the Canfranc Underground Laboratory (2500 m.w.e)
- Radiopure iron structure to hold the sub-optical modules
- External shielding 10 cm lead
- Stainless steel tank. Nitrogen flushing for Rn mitigation







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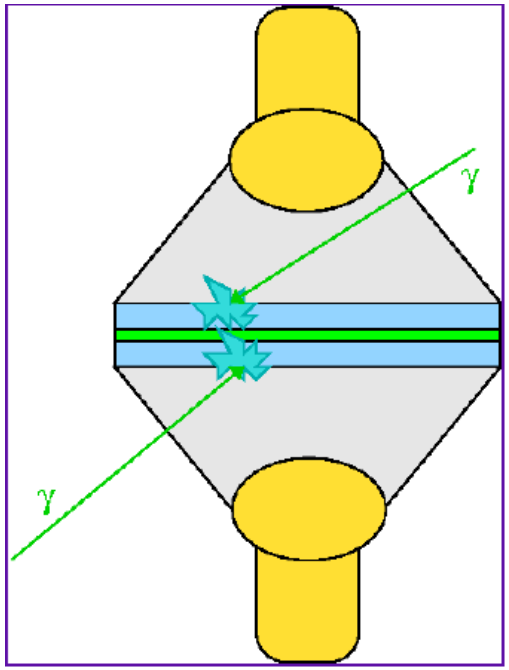
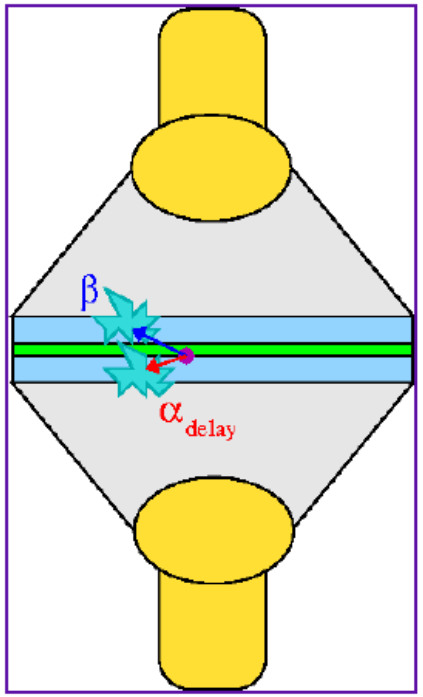
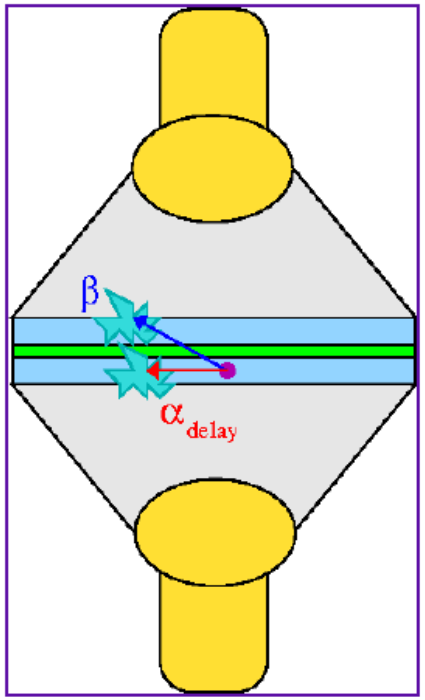
The backgrounds



- **Random coincidences**
  Compton e^- from external γs

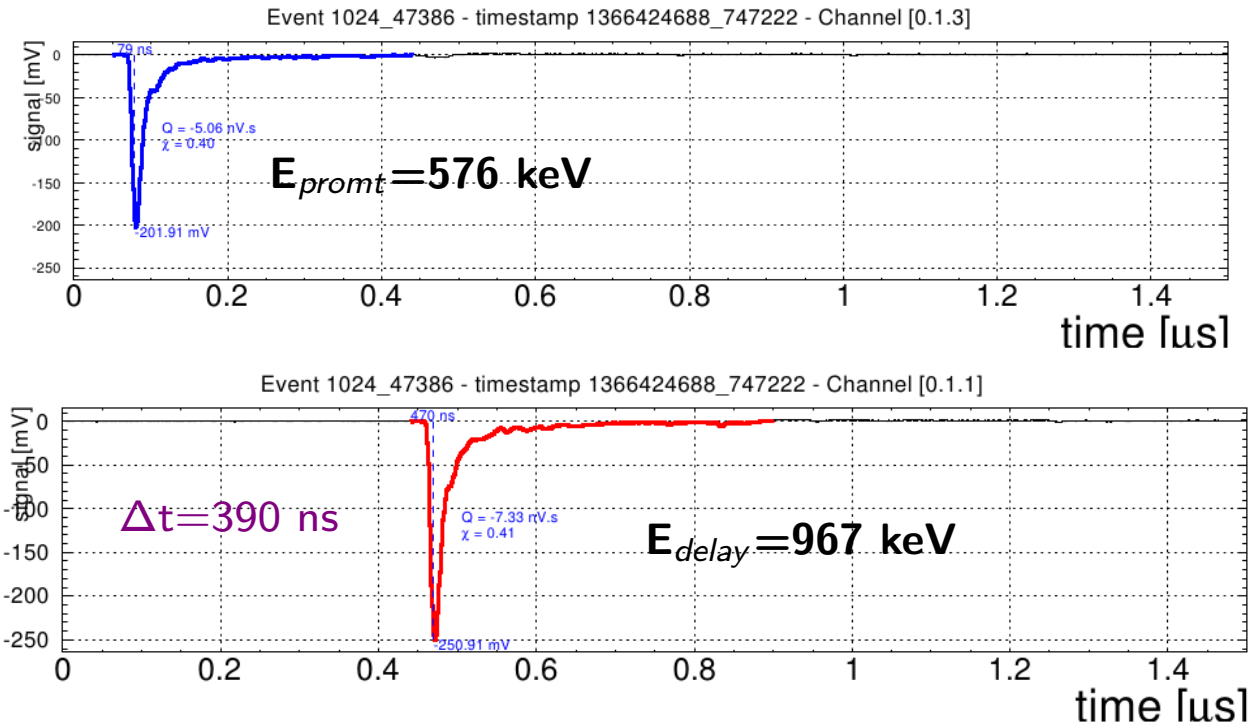


- **Scintillator surface contamination**
- **Radon in the sensitive volume**



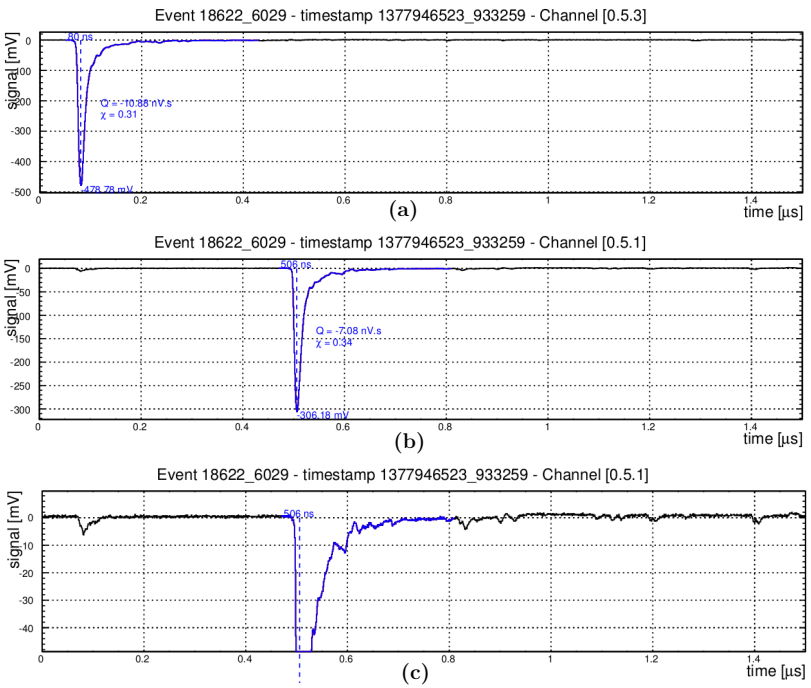
- **Scintillator bulk contamination**
  rejected

Event selection for ^{212}BiPo



- *Back-to-back* event
- The delay time between the prompt and the delayed signal is : 20 ns$<\Delta t<$1500 ns (^{212}Po $T_{1/2}$=300 ns)
- E_{prompt} >200 keV and E_{delay} > 150 keV
- The PMT noise pulses are rejected by pulse shape analysis.
- Rejection of 3 first days to reduce ^{220}Rn, $T_{1/2}$=56 s (+ ^{212}Pb, $T_{1/2}$=11 h)

Event selection for ^{212}BiPo



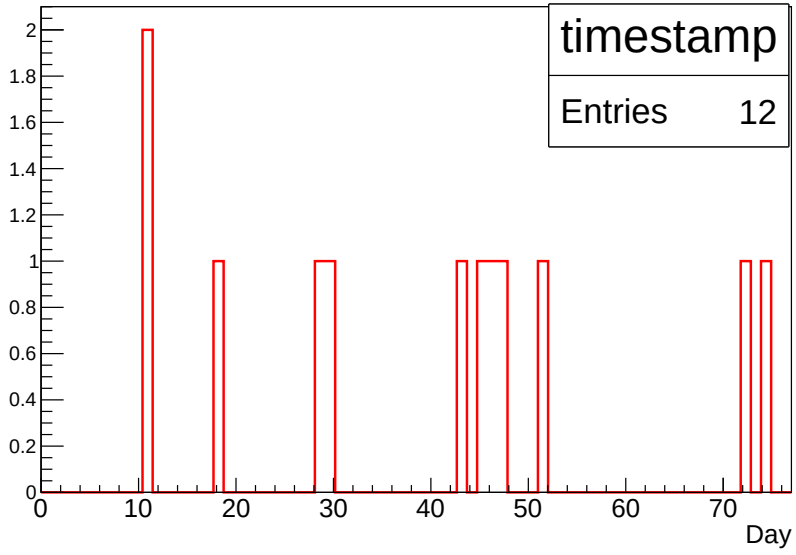
- *Back-to-back* event
- The delay time between the prompt and the delayed signal is : 20 ns$<\Delta t<$1500 ns (^{212}Po $T_{1/2}$=300 ns)
- E_{prompt} >200 keV and E_{delay} > 150 keV
- The PMT noise pulses are rejected by pulse shape analysis.

- Rejection of 3 first days to reduce ^{220}Rn, $T_{1/2}$=56 s (+ ^{212}Pb, $T_{1/2}$=11 h)
- If a signal greater than 3 mV ($\sim$ 10 keV) is detected in coincidence with the prompt signal in the opposite scintillator, the BiPo event is recognized as a bulk contamination background event and is rejected.

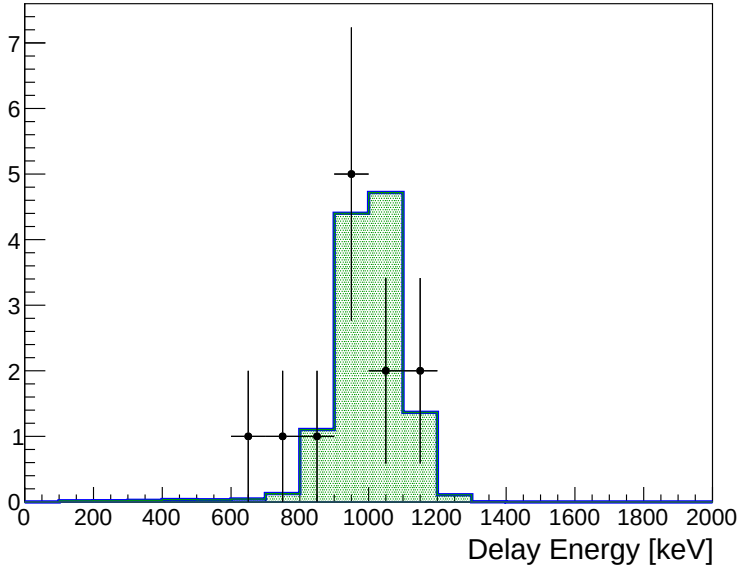
Background measurements: ^{212}BiPo

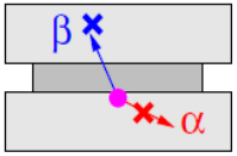
Module 2: 75 days of measurement x 3.42 m^2 scintillator surface

12 ^{212}BiPo candidates



Fit of spectra from MC simulations of Scint. Surface contamination:





Scintillator surface contamination

- All events from surface background: α's deposit all its energy inside the scintillator $\rightarrow$peak at about 1000 keV
- For events with $E_\alpha < 700$ keV $\rightarrow$ background free measurement

Result of the background measurement for ^{212}BiPo

	Module 2 Final shield
Duration (days)	75.7
Scint. surface (m^2)	3.42
Data events	12
Surf. Bkg (fit)	12.0±3.5
$\mathcal{A}(^{208}\mathrm{Tl})$ μBq/m^2	1.0 ± 0.3

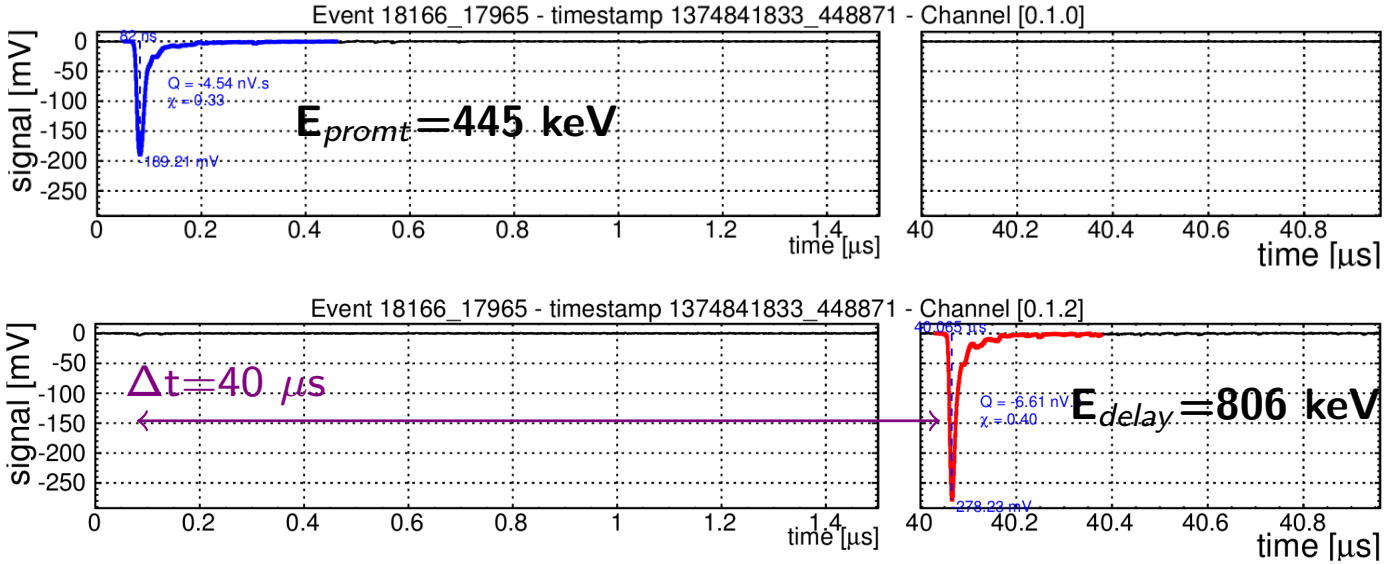
Result of the background measurement for ^{212}BiPo

- Three dedicated background measurements (200.4 days of measurement)
- 29 events observed

	Module 1 Temporary shield	Module 1 Final shield	Module 2 Final shield	**Combined**
Duration (days)	73.5	51.2	75.7	200.4
Scint. surface (m^2)	2.7	3.06	3.42	3.10
Data events	9	8	12	29
Surf. Bkg (fit)	7.4±2.9	8.0±3.4	12.0±3.5	27.7±5.4
$\mathcal{A}(^{208}\mathrm{Tl})$ μBq/m^2	0.8 ± 0.3	1.0 ± 0.4	1.0 ± 0.3	0.9 ± 0.2

- **Surface background:** $\mathcal{A}(^{208}\mathrm{Tl}) = 0.9 \pm 0.2$ μ**Bq/m**^{2}

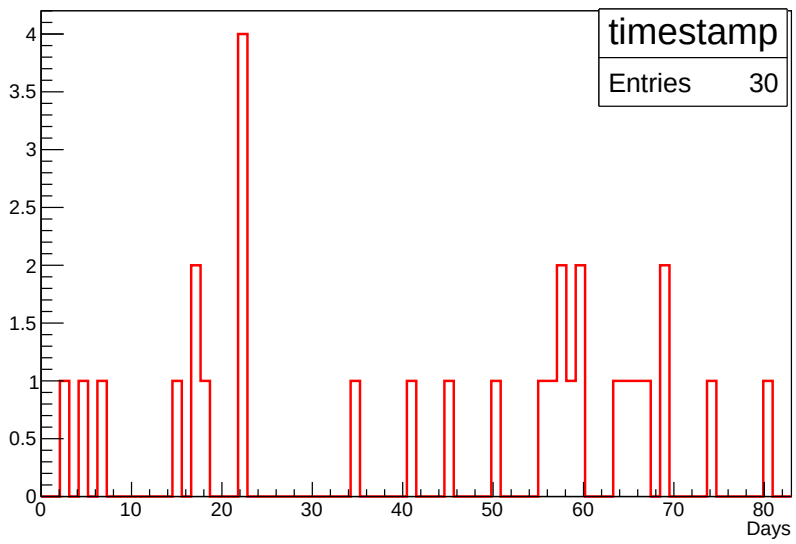
Event selection for ^{214}BiPo



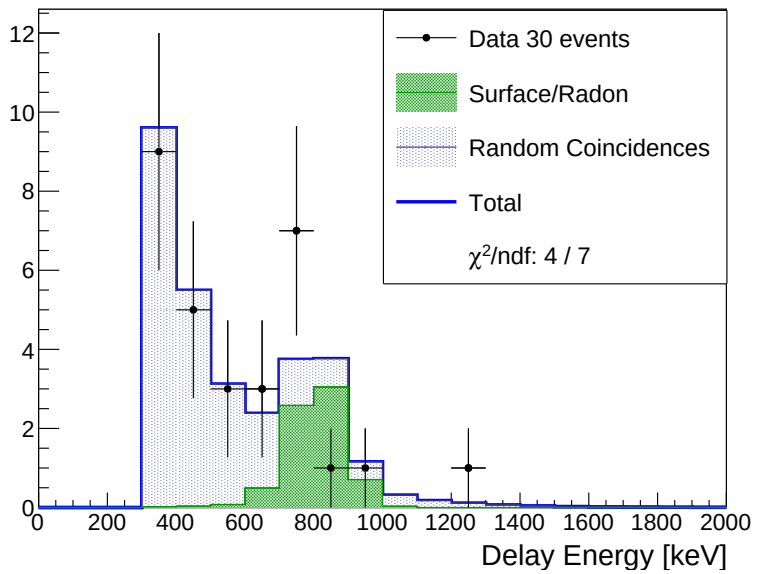
- *Back-to-back* event
- The delay time between the prompt and the delayed signal is: 10 μs$<\Delta$t$<$1000 μs (^{214}Po $T_{1/2}$=164 μs)
- E_{prompt} >200 keV and E_{delay} > 300 keV
- The PMT noise pulses are rejected by pulse shape analysis.
- If a signal greater than 3 mV ($\sim$ 10 keV) is detected in coincidence with the prompt signal in the opposite scintillator, the BiPo event is recognized as a bulk contamination background event and is rejected.
- Rejection of 15 first days to reduce ^{222}Rn, $T_{1/2}$=3.8 d

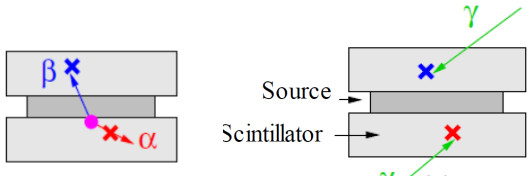
Background measurements: ^{214}BiPo

Module 2: 75 days of measurement x 3.42 m^2 scintillator surface
30 ^{214}BiPo candidates



Fit of spectra from MC simulations (Surf.) and singles from data (R.C):





- Events from surface background: α's depositing all its energy inside the scintillator $\rightarrow$ peak at about 850 keV
- Randon coincidences at low energies $\rightarrow$ dominant background

Result of the background measurement for ^{214}BiPo

	Module 2 Final shield
Duration (days)	75.7
Scint. surf. area (m^2)	3.42
Data events	30
Surf. Bkg. (fit)	6.9±3.4
Coinc. (fit)	23.1±5.3
Coinc. (single rate)	25.0
$\mathcal{A}(^{214}\mathrm{Bi})$ μBq/m^2	1.0 ± 0.5

Coincidences rate using singles:

$$N_{RC}(single\ rate) = 2 \times r_p \times r_d \times \Delta T \times T_{obs}$$

Result of the background measurement for ^{214}BiPo

- Two dedicated background measurements with final shield

	Module 1 Final shield	Module 2 Final shield	**Combined Final shield**
Duration (days)	36.2	75.7	111.9
Scint. surf. area (m^2)	3.06	3.42	3.24
Data events	18	30	48
Surf. Bkg. (fit)	2.5±2.3	6.9±3.4	9.4±4.1
Coinc. (fit)	15.5±4.2	23.1±5.3	38.5±7.6
Coinc. (single rate)	14.3	25.0	39.3
$\mathcal{A}(^{214}\mathrm{Bi})$ μBq/m^2	1.0 ± 0.9	1.0 ± 0.5	1.0 ± 0.4

- **Surface background:** $\mathcal{A}(^{214}\mathrm{Bi}) = 1.0 \pm 0.4$ μ**Bq/m**^{2}
- Random coincidences average: 0.12 counts/day/m^2

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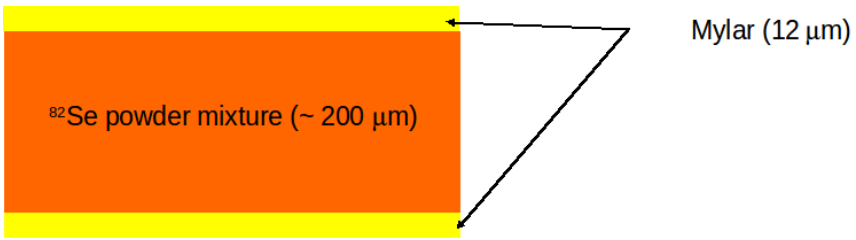
The SuperNemo double-β source foils

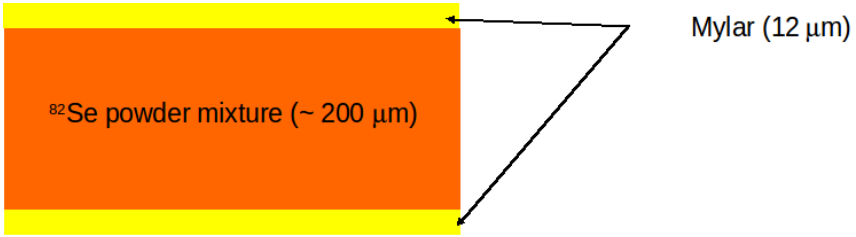


270 cm long and 13.5 cm wide

Foils in the BiPo detector

All raw materials have been measured with BiPo

The SuperNemo double-β source foils



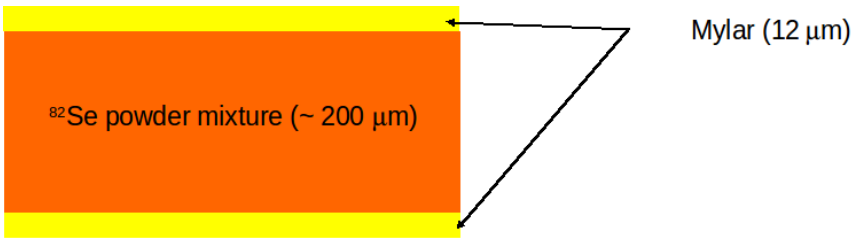
270 cm long and 13.5 cm wide

Foils in the BiPo detector

All raw materials have been measured with BiPo

Sample	$\mathcal{A}(^{208}\mathrm{Tl})$ (μBq/kg) 90% C.L.	$\mathcal{A}(^{214}\mathrm{Bi})$ (μBq/kg) 90% C.L.
Raw Mylar	< 49	< 195

The SuperNemo double-β source foils



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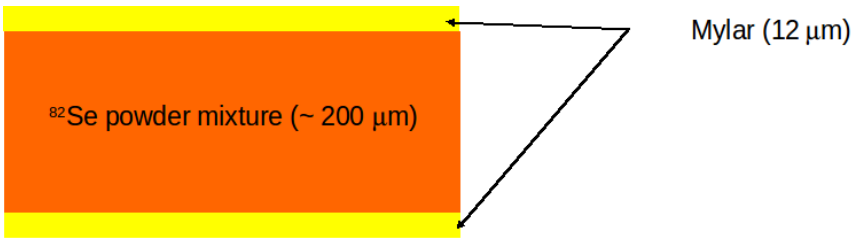
Sample	$\mathcal{A}(^{208}\mathrm{Tl})$ (μBq/kg) 90% C.L.	$\mathcal{A}(^{214}\mathrm{Bi})$ (μBq/kg) 90% C.L.
Raw Mylar	< 49	< 195
Irradiated Mylar	$48 - 153$	< 688

The SuperNemo double-β source foils



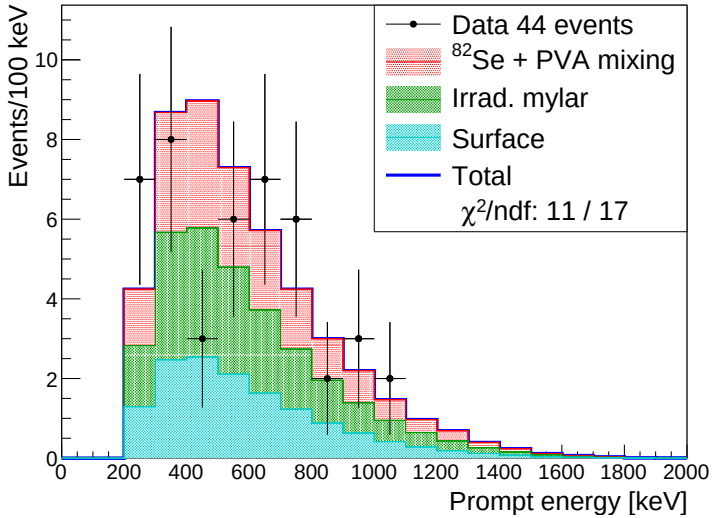
270 cm long and 13.5 cm wide

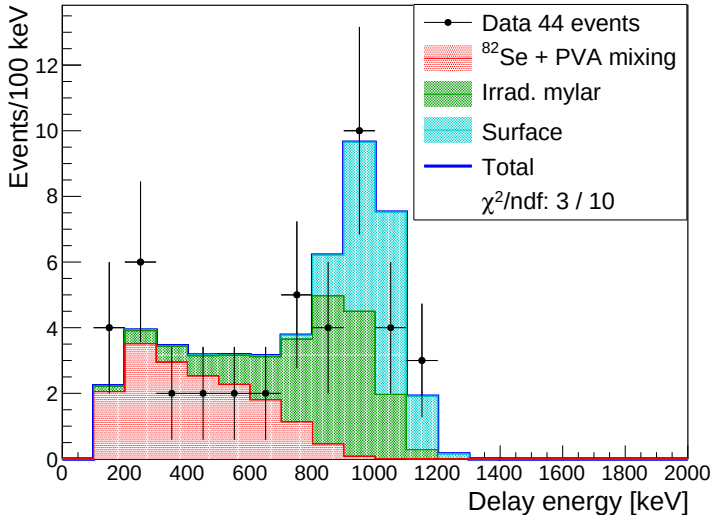
Foils in the BiPo detector

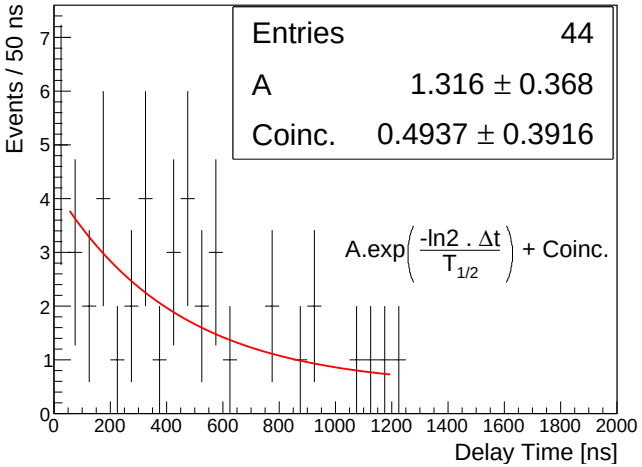
All raw materials have been measured with BiPo

Sample	$\mathcal{A}(^{208}\mathrm{Tl})$ (μBq/kg) 90% C.L.	$\mathcal{A}(^{214}\mathrm{Bi})$ (μBq/kg) 90% C.L.
Raw Mylar	< 49	< 195
Irradiated Mylar	$48 - 153$	< 688
PVA	< 12	< 505

The SuperNemo double-β source foils: ^{212}BiPo







- Combined 2 measurements: 262 d (1st measur.), 161.3 d (2nd measur.)
- Mass(Se + PVA)=359 g (1st measur.), 777 g (2nd measur.)
- Efficiency= 2.65% (1st measur.), 1.55% (2nd measur.)
- E_{delay}>150 keV: 44 events
- 150 keV<E_{delay}<700 keV: N_{data}= 18 events, N_{backg}= 4.3 events

^{82}Se powder mixture: $\mathcal{A}(^{208}\mathrm{Tl}) = (21 \pm 11)\ \mu\mathrm{Bq/kg}\ (90\%\ \mathrm{C.L.})$

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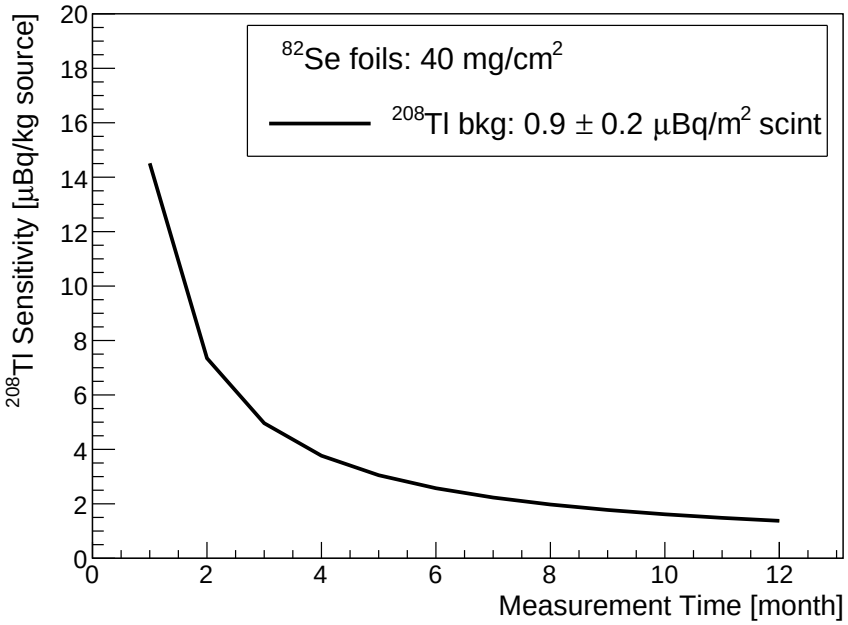
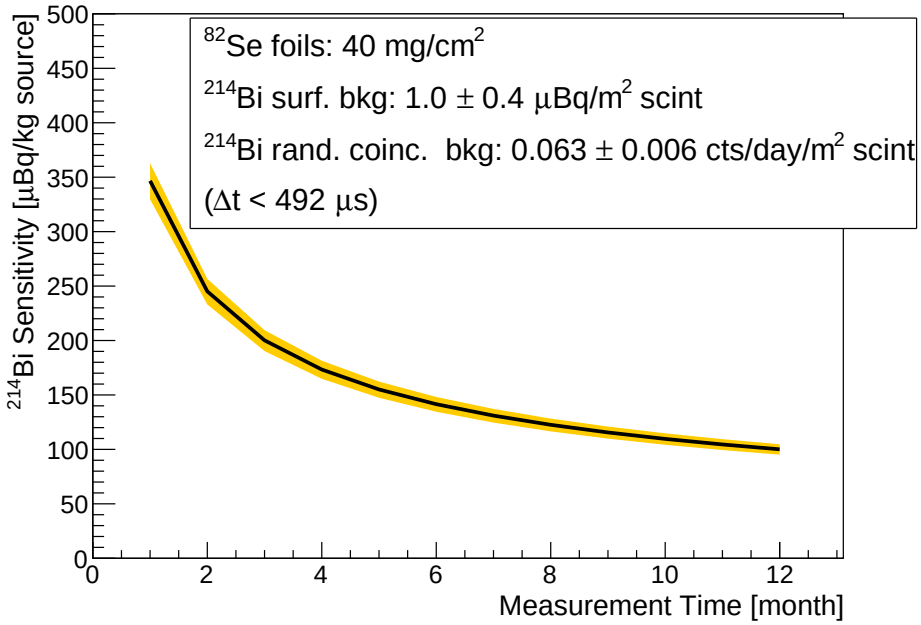
Sensitivity of the BiPo-3 detector

Using total BiPo-3 area= 3.6 m^2





- Mylar ideally radiopure
- Backgrounds: Surface background and random coincidences from dedicated bkg measurements

^{82}Se powder mixture: $\mathcal{A}(^{208}\mathrm{Tl}) < 2\ \mu\mathrm{Bq/kg}$ (90% C.L.) in 6 months

^{82}Se powder mixture: $\mathcal{A}(^{214}\mathrm{Bi}) < 140\ \mu\mathrm{Bq/kg}$ (90% C.L.) in 6 months

Conclusions

- BiPo-3 is dedicated to the measurement of ultra-low levels of ^{208}Tl and ^{214}Bi in thin materials
- Background sources: scintillator surface contamination and random coincidences
- Surface background from scintillators have been measured: $\mathcal{A}(^{208}\mathrm{Tl}) = 0.9 \pm 0.2\ \mu\mathrm{Bq/m^2}$ and $\mathcal{A}(^{214}\mathrm{Bi}) = 1.0 \pm 0.4\ \mu\mathrm{Bq/m^2}$
- Random coincidences: negligible for ^{208}Tl, dominant background for ^{214}Bi with 0.12 counts/day/m^2
- e^-/α discrimination by pulse shape analysis under development
- First SuperNemo source foils measured: $\mathcal{A}(^{208}\mathrm{Tl}) = (21 \pm 11)\ \mu\mathrm{Bq/kg}$ and $\mathcal{A}(^{214}\mathrm{Bi}) < 290\ \mu\mathrm{Bq/kg}$ (90% C.L.)
- Sensitivity $\mathcal{A}(^{208}\mathrm{Tl}) < 2\ \mu\mathrm{Bq/kg}$ and $\mathcal{A}(^{214}\mathrm{Bi}) < 140\ \mu\mathrm{Bq/kg}$ (90% C.L.) in 6 months.