

BiPo: A dedicated radiopurity detector for the SuperNEMO experiment

Héctor Gómez Maluenda on behalf of SuperNEMO Collaboration

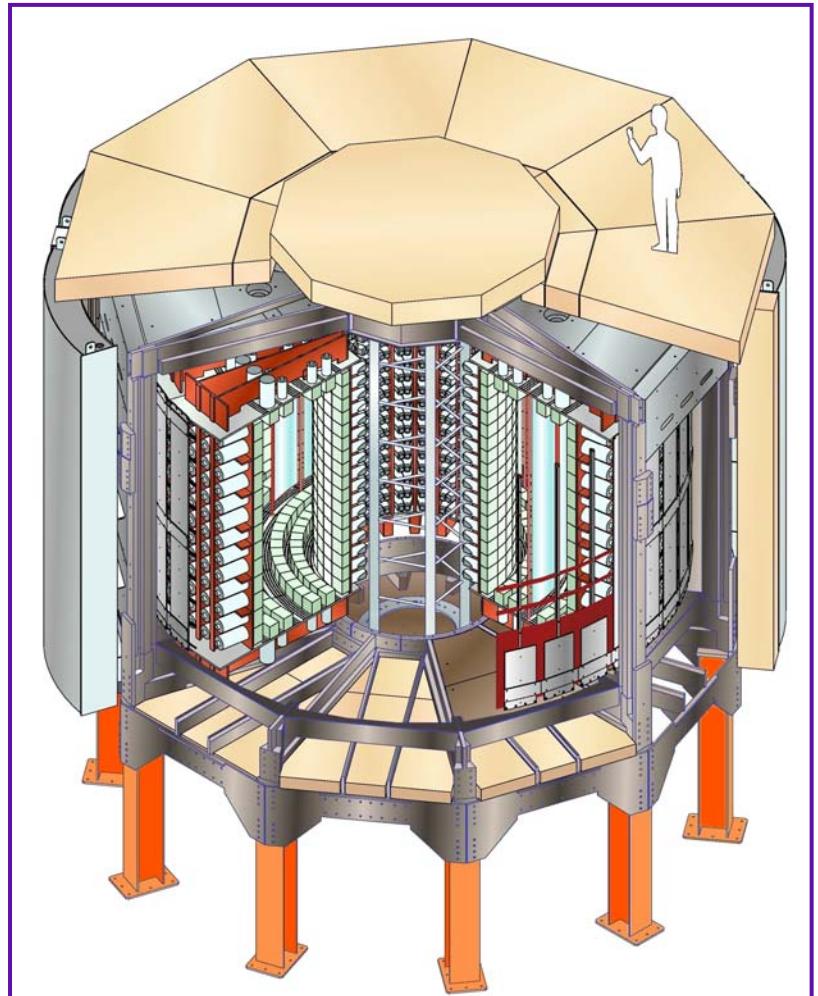
Laboratoire de l'Accélérateur Linéaire

gomez@lal.in2p3.fr

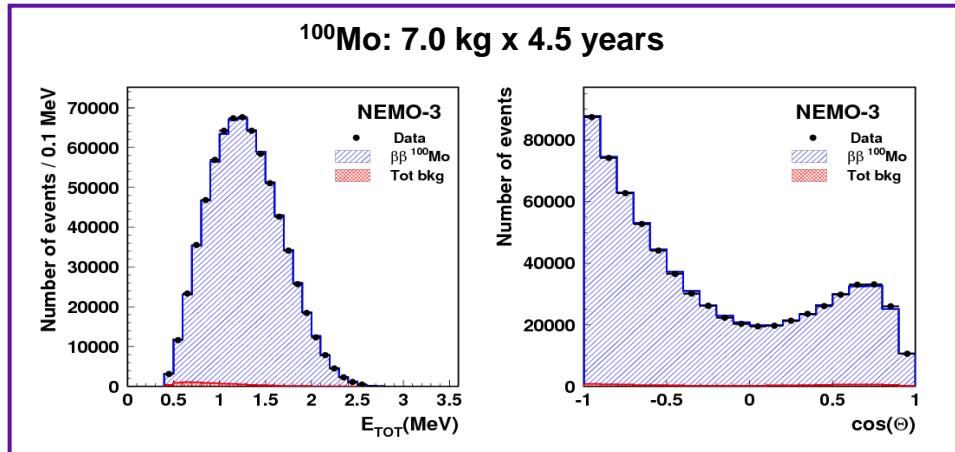
- NEMO 3 and SuperNEMO experiments.
 - Motivation: SuperNEMO $\beta\beta$ source foils radiopurity.
- The BiPo detector.
- First results.
- Outlook and Prospects.
- Summary and Conclusions.

NEMO 3

- **10 kg** of $\beta\beta$ isotopes:
 - 6.9 kg of ^{100}Mo , 0.9 kg of ^{82}Se
 - Also ^{130}Te , ^{116}Cd , ^{150}Nd , ^{96}Zr and ^{48}Ca
- “Tracko – calo” detection:
 - Tracking → Geiger cells
 - Calorimetry → Polystyrene + 3" & 5" PMTs
- Located at Modane Underground Laboratory:
 - Depth ~4800 mwe
- Running from February 2003 until January 2011.
- Results on $T_{1/2}^{2\nu\beta\beta}$ and $T_{1/2}^{0\nu\beta\beta}$ for different isotopes.
- Complete background characterization.



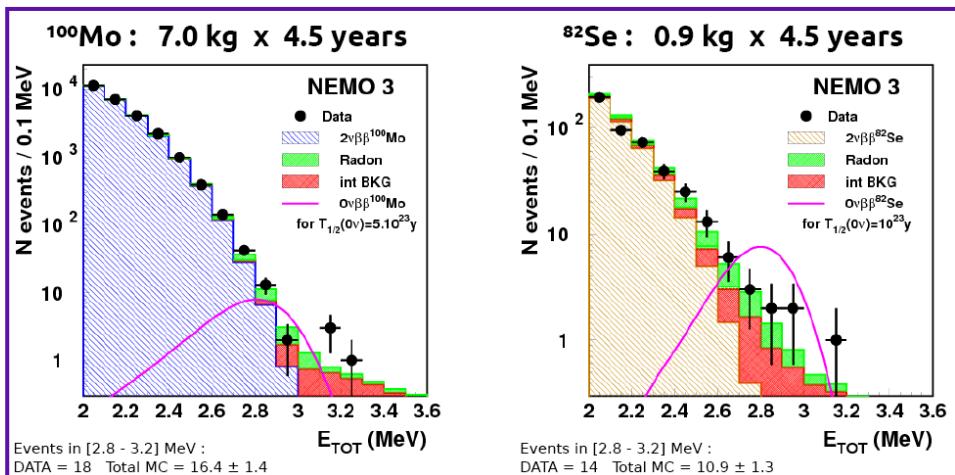
NEMO 3 - Preliminary Results



$2\nu\beta\beta$

$$T_{1/2}^{2\nu\beta\beta}(^{100}\text{Mo}) = (7.16 \pm 0.01 \text{ (stat.)} \pm 0.54 \text{ (sys.)}) 10^{18} \text{ y.}$$

$$T_{1/2}^{2\nu\beta\beta}(^{82}\text{Se}) = (9.6 \pm 0.1 \text{ (stat.)} \pm 1.0 \text{ (sys.)}) 10^{19} \text{ y.}$$



$0\nu\beta\beta$

$$T_{1/2}^{0\nu\beta\beta}(^{100}\text{Mo}, \langle m_\nu \rangle) > 1.0 10^{24} \text{ y (90\% C.L.)}.$$

$\langle m_\nu \rangle < 310 - 960 \text{ meV}$

$$T_{1/2}^{0\nu\beta\beta}(^{82}\text{Se}, \langle m_\nu \rangle) > 3.2 10^{23} \text{ y (90\% C.L.)}.$$

$\langle m_\nu \rangle < 940 - 2600 \text{ meV}$



NEMO 3

^{100}Mo , ^{82}Se and others

7 kg

18 %

15 % FWHM @ 1 MeV

$\sim 100 \mu\text{Bq/kg}$

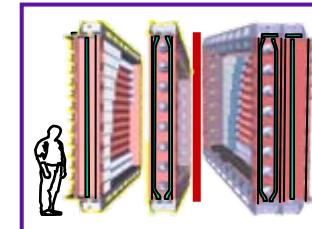
$< 300 \mu\text{Bq/kg}$

$\sim 5 \text{ mBq/m}^3$

10^{24} y

$\langle m_\nu \rangle < 0.3 - 0.9 \text{ eV}$

From NEMO 3 to SuperNEMO



SuperNEMO

^{82}Se (^{150}Nd or ^{48}Ca ?)

$\sim 100 \text{ kg}$

30 %

7 % FWHM @ 1 MeV

$< 2 \mu\text{Bq/kg}$

$< 10 \mu\text{Bq/kg}$

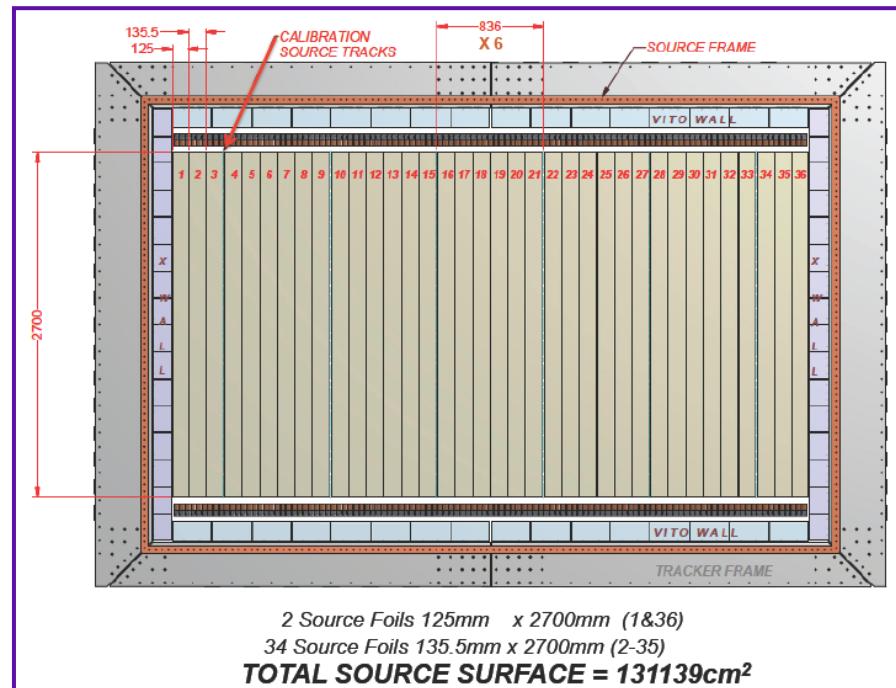
$< 0.15 \text{ mBq/m}^3$

10^{26} y

$\langle m_\nu \rangle < 0.04 - 0.1 \text{ eV}$

SuperNEMO $\beta\beta$ source foils radiopurity

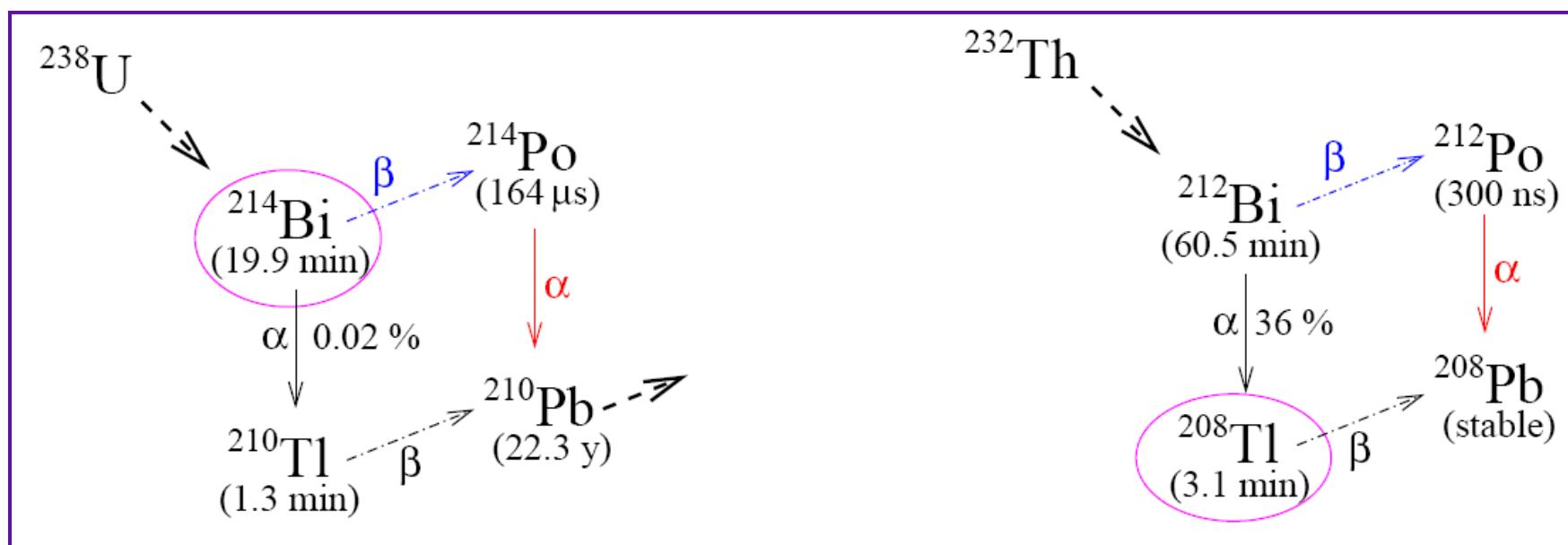
- SuperNEMO experiment will have ~100 kg of $\beta\beta$ emitter distributed in the so-called source foils.
- Sensitivity requirements limits the source foil contamination to:
 - $< 2 \mu\text{Bq/kg}$ ($0.5 \mu\text{Bq/m}^2$) *in ^{208}Tl*
 - $< 10 \mu\text{Bq/kg}$ ($2.5 \mu\text{Bq/m}^2$) *in ^{214}Bi*
- HPGe detectors only gave limits for NEMO-3:
 - $< 100 \mu\text{Bq/kg} \ ^{208}\text{Tl}$ for the source foil
 - $< 60 \mu\text{Bq/kg} \ ^{208}\text{Tl}$ for the Se powder
- In addition:
 - Better to measure the source itself (particular geometry)
 - Non destructive measurement procedure



**NECESSITY OF A DEDICATED
DETECTOR**

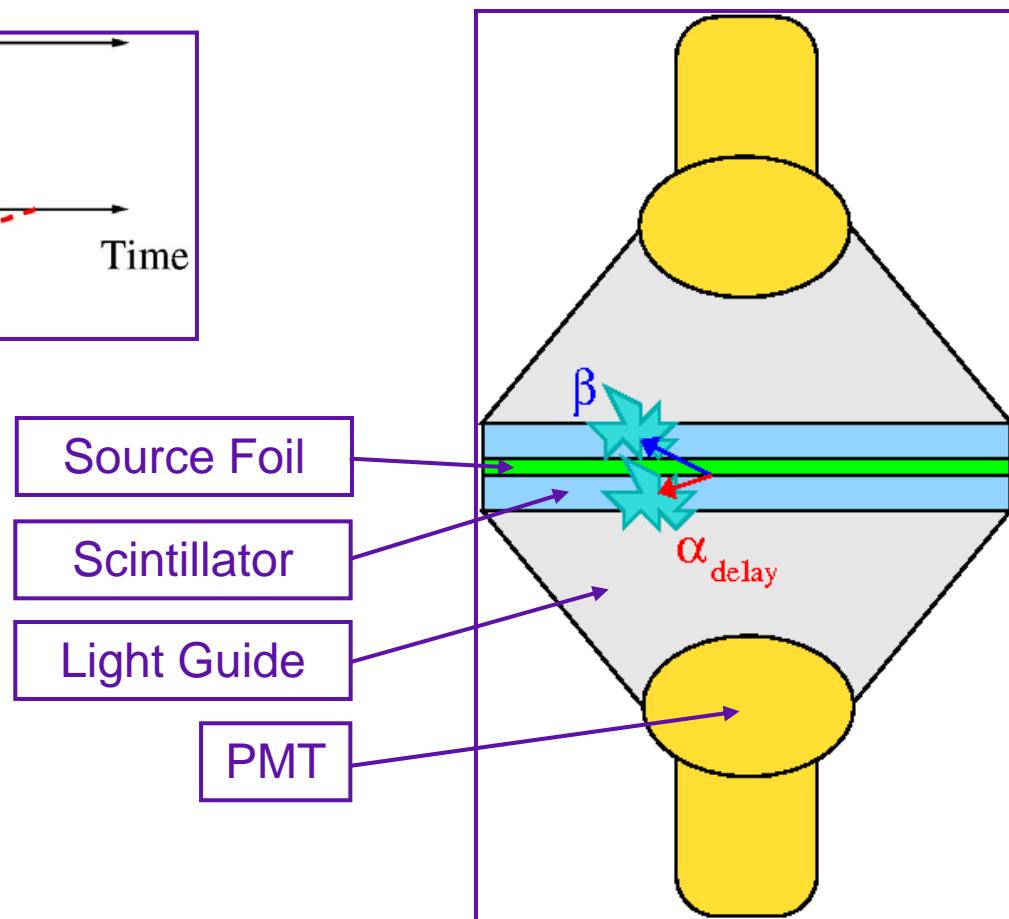
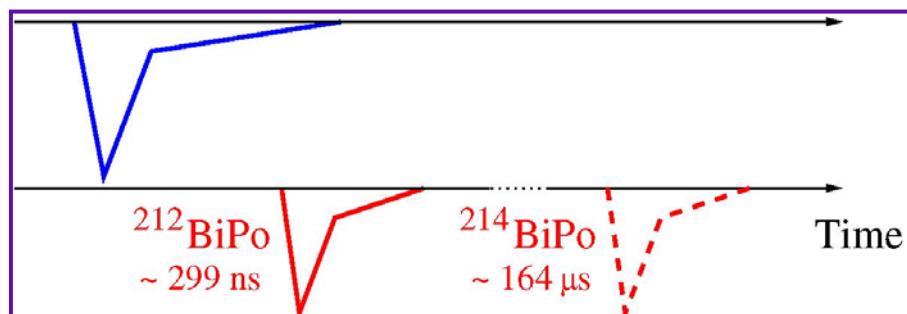
The BiPo detector: Detection Principle

- BiPo is a dedicated detector for the measurements of ultra-low levels of contamination in ^{208}Tl and ^{214}Bi present in the SuperNEMO source foils.
 - Detection principle → BiPo $\beta - \alpha$ delayed coincidence detection.

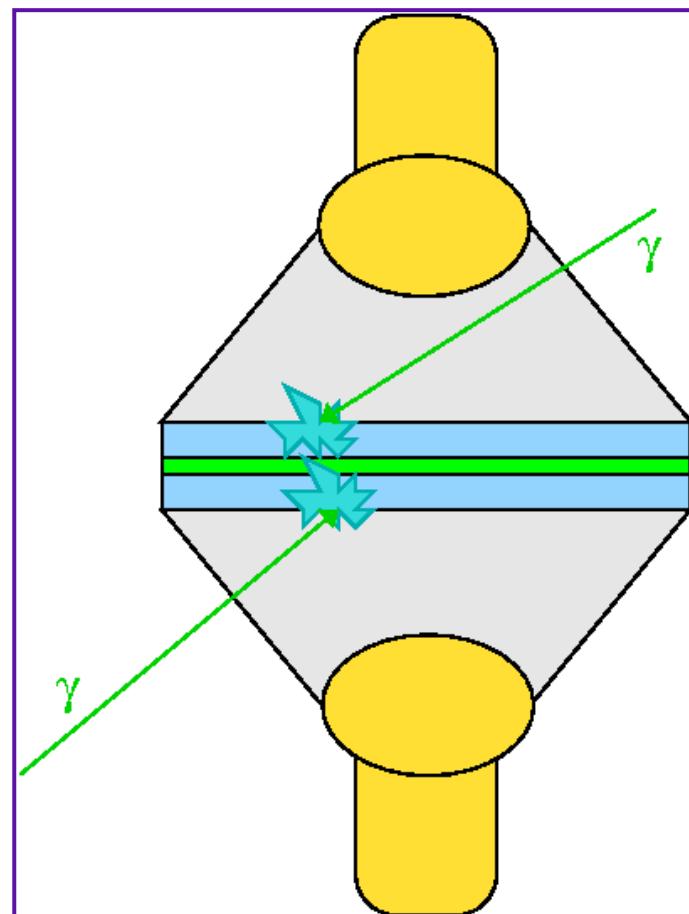
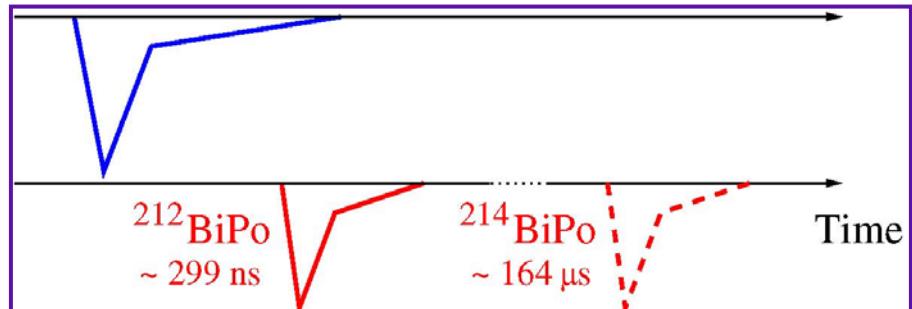


The BiPo detector: Signal and Backgrounds

- BiPo is a dedicated detector for the measurements of ultra-low levels of contamination in ^{208}TI and ^{214}Bi present in the SuperNEMO source foils.
- Detection principle → BiPo $\beta - \alpha$ delayed coincidence detection.

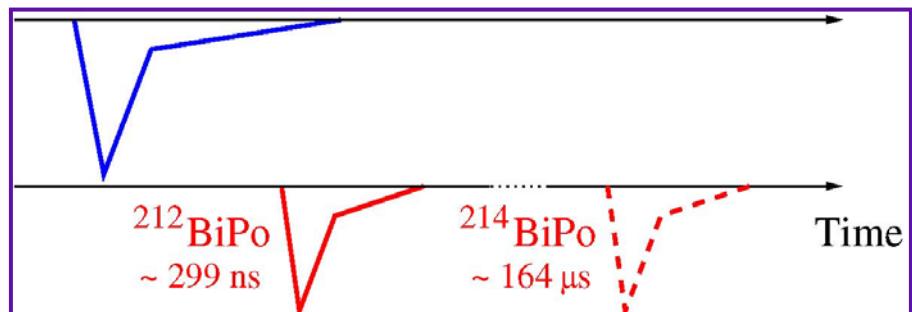


- BiPo is a dedicated detector for the measurements of ultra-low levels of contamination in ^{208}TI and ^{214}Bi present in the SuperNEMO source foils.
 - Detection principle → BiPo $\beta - \alpha$ delayed coincidence detection.

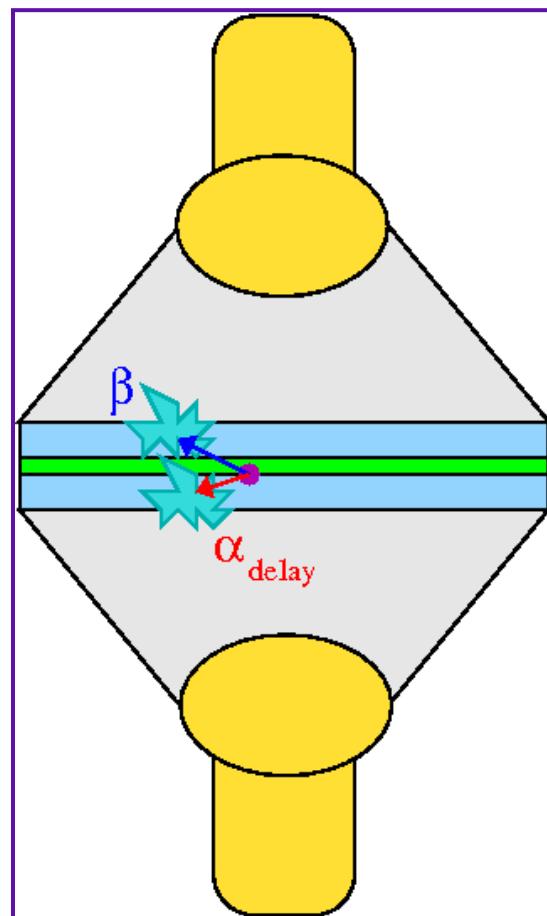


- **Background sources:**
 - γ -induced random coincidences

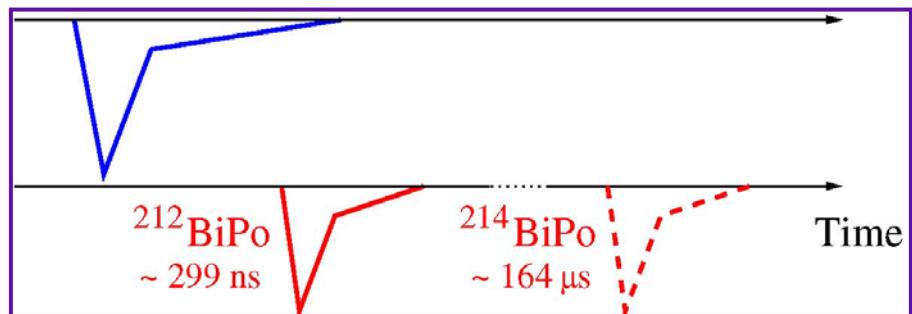
- BiPo is a dedicated detector for the measurements of ultra-low levels of contamination in ^{208}TI and ^{214}Bi present in the SuperNEMO source foils.
- Detection principle → BiPo $\beta - \alpha$ delayed coincidence detection.



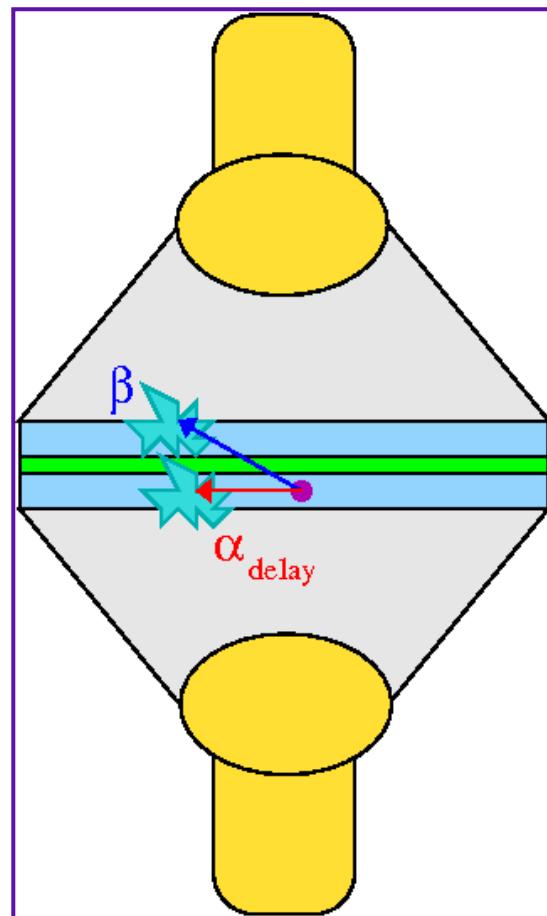
- **Background sources:**
 - γ -induced random coincidences
 - Scintillator surface contamination
 - Radon contamination in the sensitive volume



- BiPo is a dedicated detector for the measurements of ultra-low levels of contamination in ^{208}TI and ^{214}Bi present in the SuperNEMO source foils.
- Detection principle → BiPo $\beta - \alpha$ delayed coincidence detection.

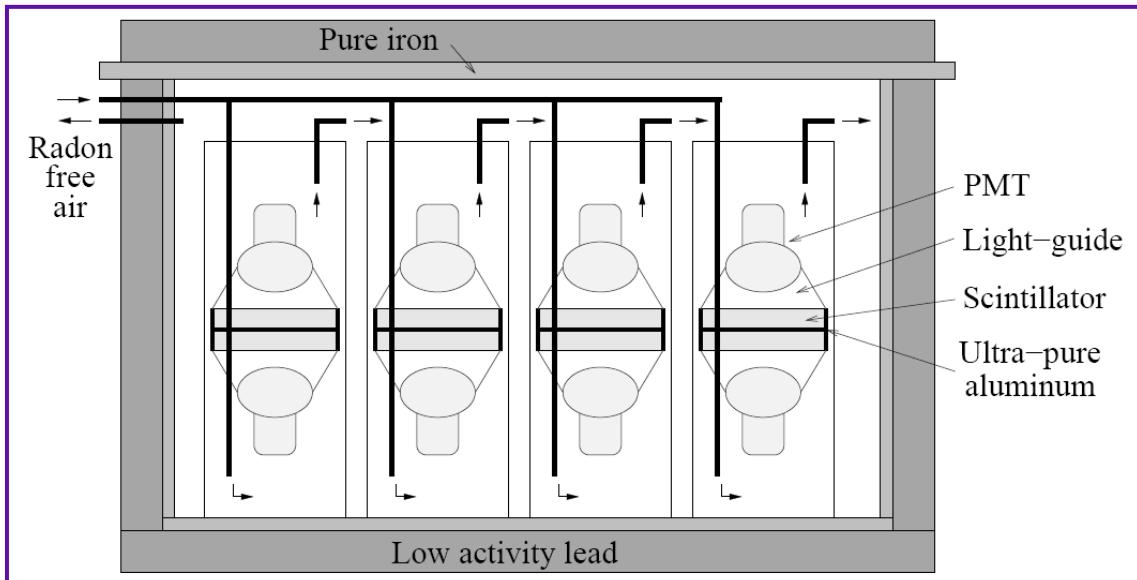


- **Background sources:**
 - γ -induced random coincidences
 - Scintillator surface contamination
 - Radon contamination in the sensitive volume
 - Scintillator bulk contamination



The BiPo detector: Previous R & D

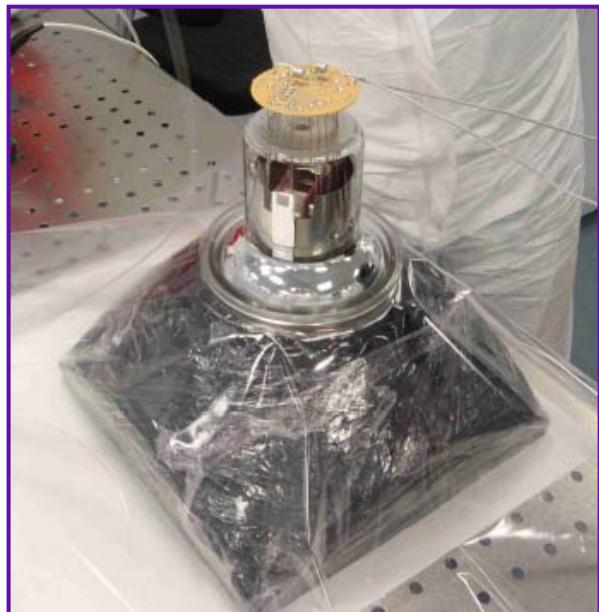
- BiPo prototypes have validated the detection principle and have shown that experimental requirements can be reached.
- **BiPo 1:**
 - Detection principle tested with a calibrated **Al foil** between the scintillators
 - **^{208}TI** contamination level of **$1.5 \mu\text{Bq}/\text{m}^2$ of scintillator** measured (NIM A 622 (2010) 120-128)



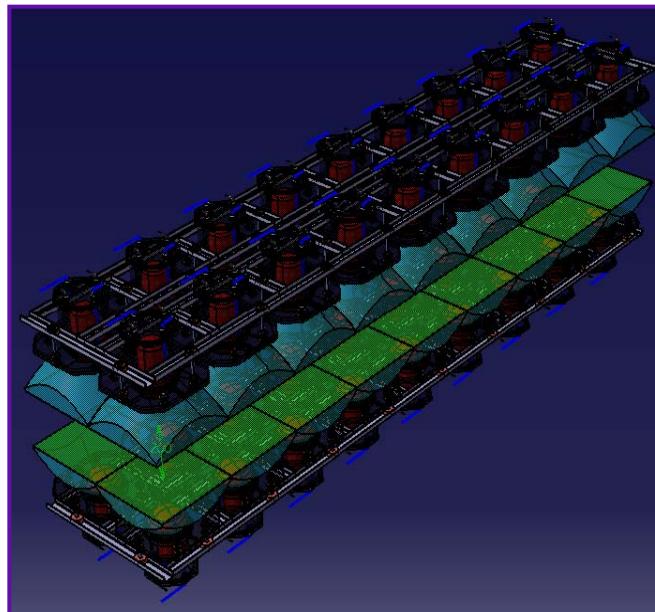
The BiPo detector: Final setup

- Main features:

- 2 modules detector → Possibility to measure 8 SuperNEMO source foils simultaneously
- 20 30x30 cm² optical sub-modules in each module → 3.6 m² of sensitive surface
- 2 mm thick polystyrene scintillator plates (with 200 nm aluminization) developed at JINR
- Light guide geometry optimized
- Detector volume separation and nitrogen flushing for Rn suppression and external shielding



Optical Module



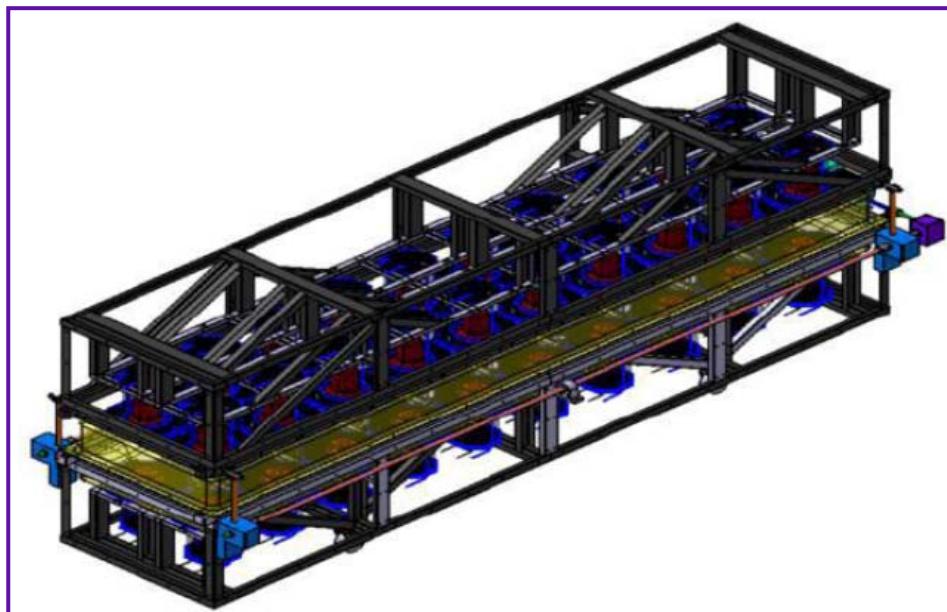
Assembling of BiPo OMs in the structure



The BiPo detector: Final setup

- Main features:

- 2 modules detector → Possibility to measure 8 SuperNEMO source foils simultaneously
- 20 30x30 cm² optical sub-modules in each module → 3.6 m² of sensitive surface
- 2 mm thick polystyrene scintillator plates (with 200 nm aluminization) developed at JINR
- Light guide geometry optimized
- Detector volume separation and nitrogen flushing for Rn suppression and external shielding

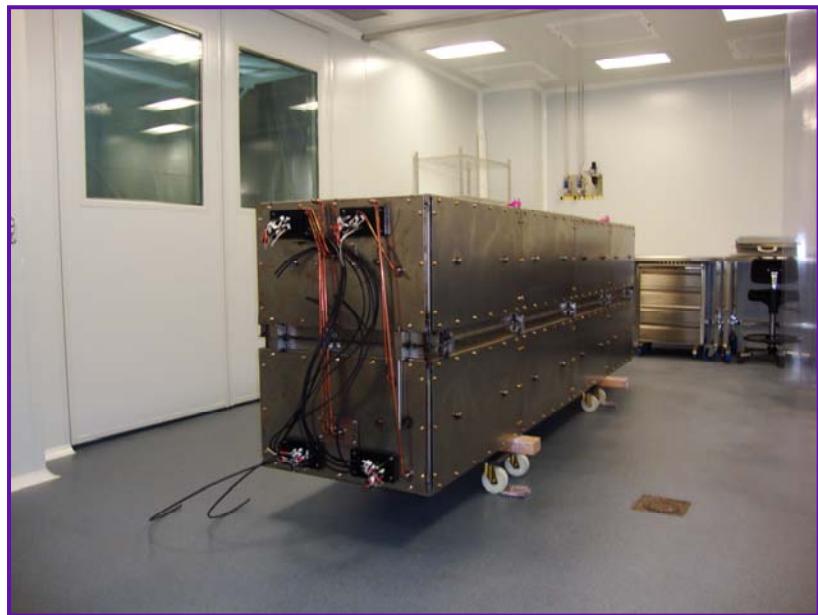


Assembling of BiPo OMs in the structure

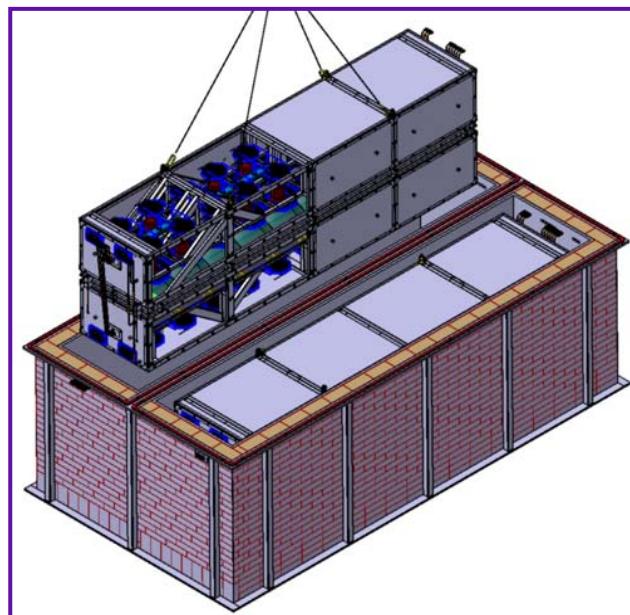
The BiPo detector: Final setup

- Main features:

- 2 modules detector → Possibility to measure 8 SuperNEMO source foils simultaneously
- 20 30x30 cm² optical sub-modules in each module → 3.6 m² of sensitive surface
- 2 mm thick polystyrene scintillator plates (with 200 nm aluminization) developed at JINR
- Light guide geometry optimized
- Detector volume separation and nitrogen flushing for Rn suppression and external shielding



Closed BiPo module



Placement inside the tank and shielding



The BiPo detector: Final setup

- Main features:

- 2 modules detector → Possibility to measure 8 SuperNEMO source foils simultaneously
- 20 30x30 cm² optical sub-modules in each module → 3.6 m² of sensitive surface
- 2 mm thick polystyrene scintillator plates (with 200 nm aluminization) developed at JINR
- Light guide geometry optimized
- Detector volume separation and nitrogen flushing for Rn suppression and external shielding

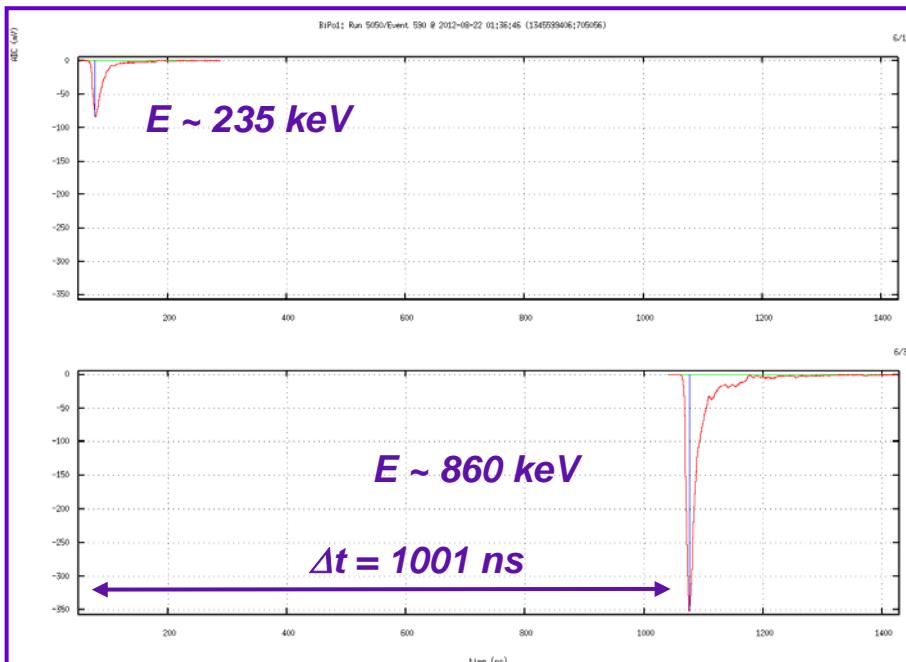


- **Start** of the installation at LSC in **July 2012**
- After several updates the **final setup** was completed in **January 2013**
- At **present** both modules are **taking data** in their final configuration

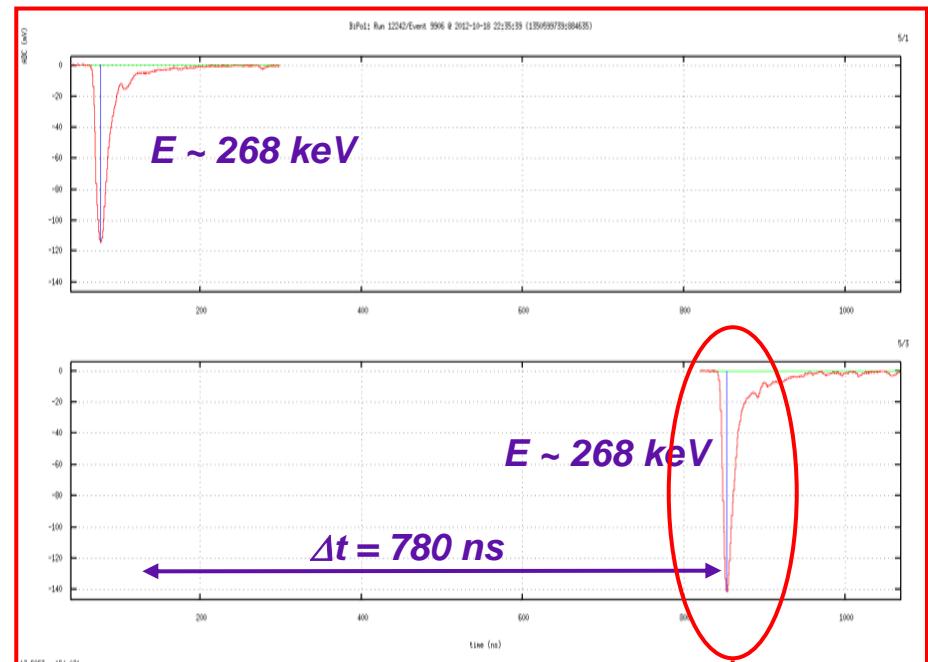
First results: Background measurement

- Background measurement: Test the radiopurity of the scintillators
Have a first estimation of the reachable sensitivity
 - Module 1: **$231 \text{ m}^2 \times d$** exposure (85 days of measurement)

2 212-BiPo candidates



~ 0.3 random coincidences are expected

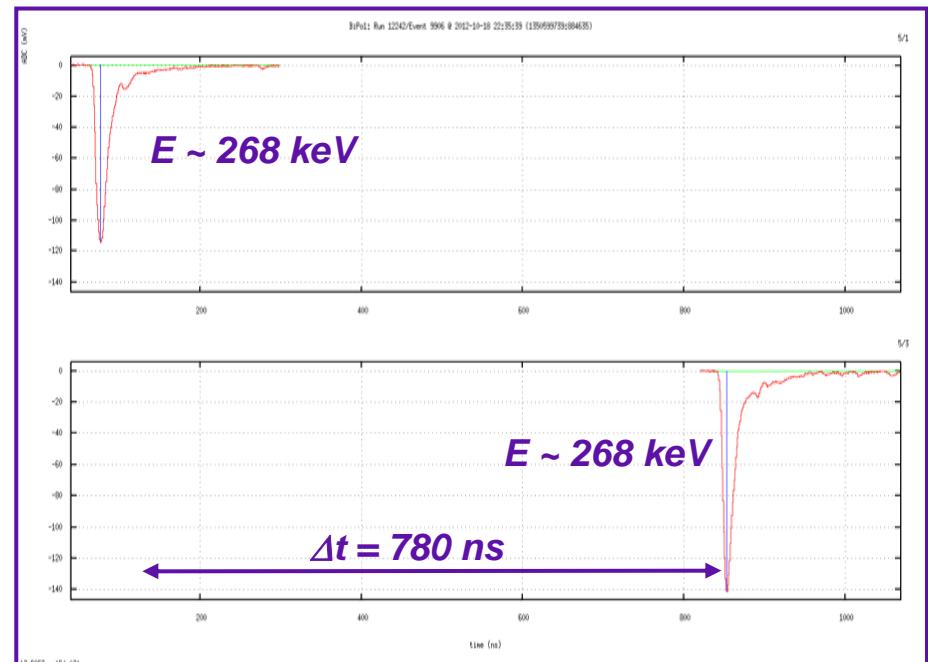
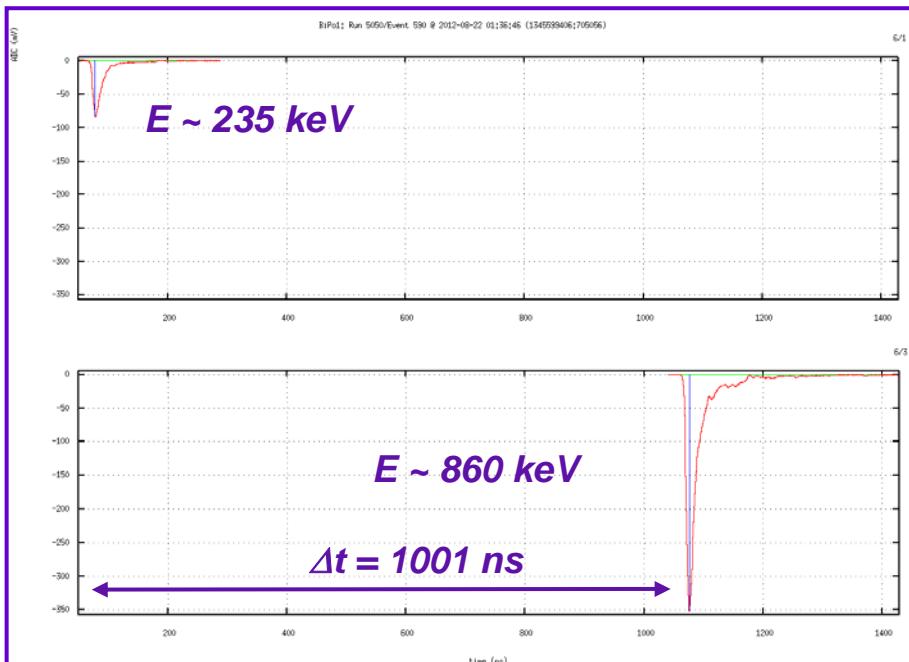


β/α discrimination for the delayed signal to be implemented

First results: Background measurement

- Background measurement: Test the radiopurity of the scintillators
Have a first estimation of the reachable sensitivity
 - Module 1: **$231 \text{ m}^2 \times d$** exposure (85 days of measurement)

2 212-BiPo candidates



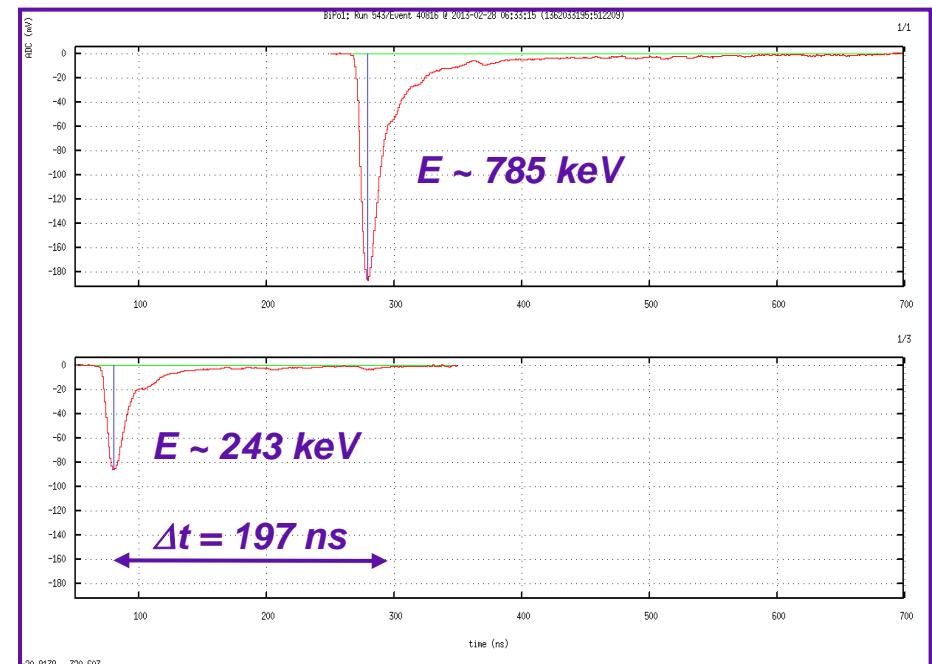
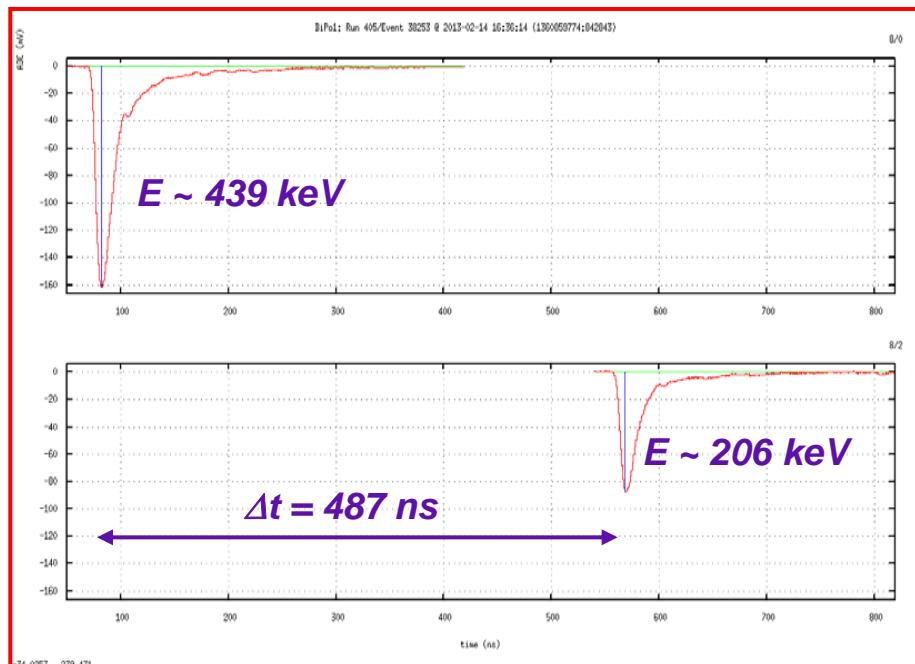
If both candidates are considered as valid events (conservative assumption)

$$A(^{208}\text{TI}) = 0.09 \mu\text{Bq}/\text{m}^2 \text{ scintillator}, [0.02 - 0.40] \mu\text{Bq}/\text{m}^2 @ 90\% \text{ C.L.}$$

First results: Background measurement

- Background measurement: Test the radiopurity of the scintillators
Have a first estimation of the reachable sensitivity
 - Module 2: **$187 \text{ m}^2 \times d$** exposure (55 days of measurement, still ongoing)

2 212-BiPo candidates



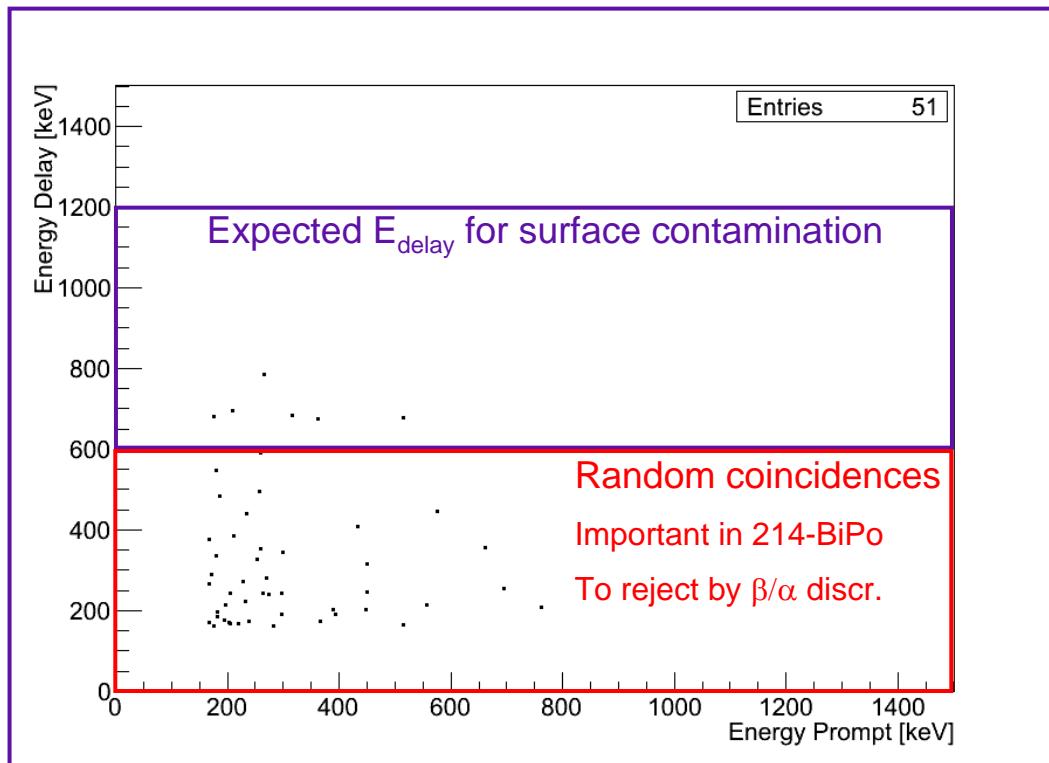
Again one of the candidates is not clear but it is considered.

$$A(^{208}\text{TI}) = 0.23 \mu\text{Bq}/\text{m}^2 \text{ scintillator}, [0.06 - 0.67] \mu\text{Bq}/\text{m}^2 @ 90\% \text{ C.L.}$$

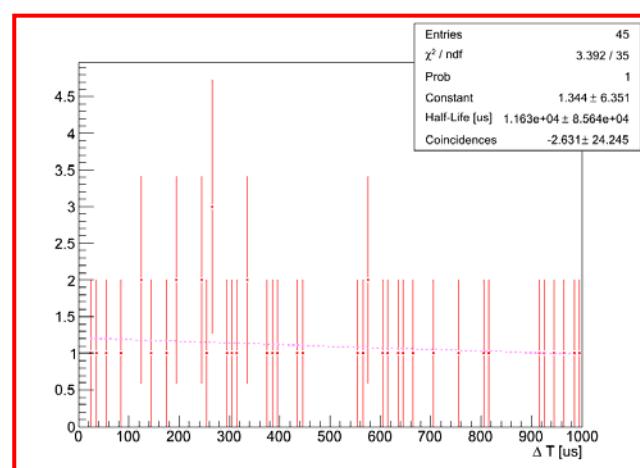
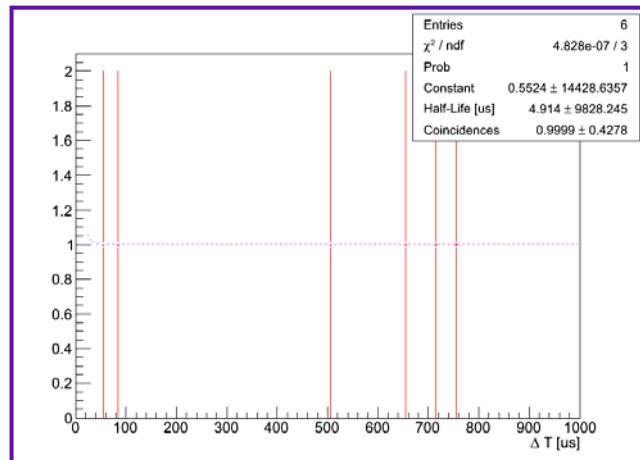
First results: Background measurement

- Background measurement: Test the radiopurity of the scintillators
Have a first estimation of the reachable sensitivity
 - Module 1: **$231 \text{ m}^2 \times d$** exposure (85 days of measurement)

6 surface contamination 214-BiPo candidates



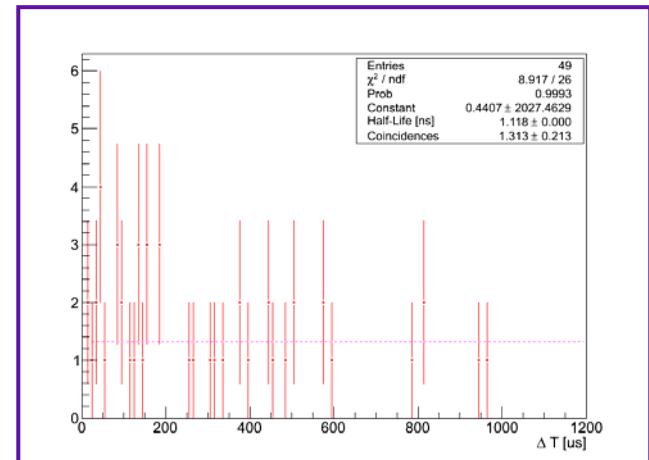
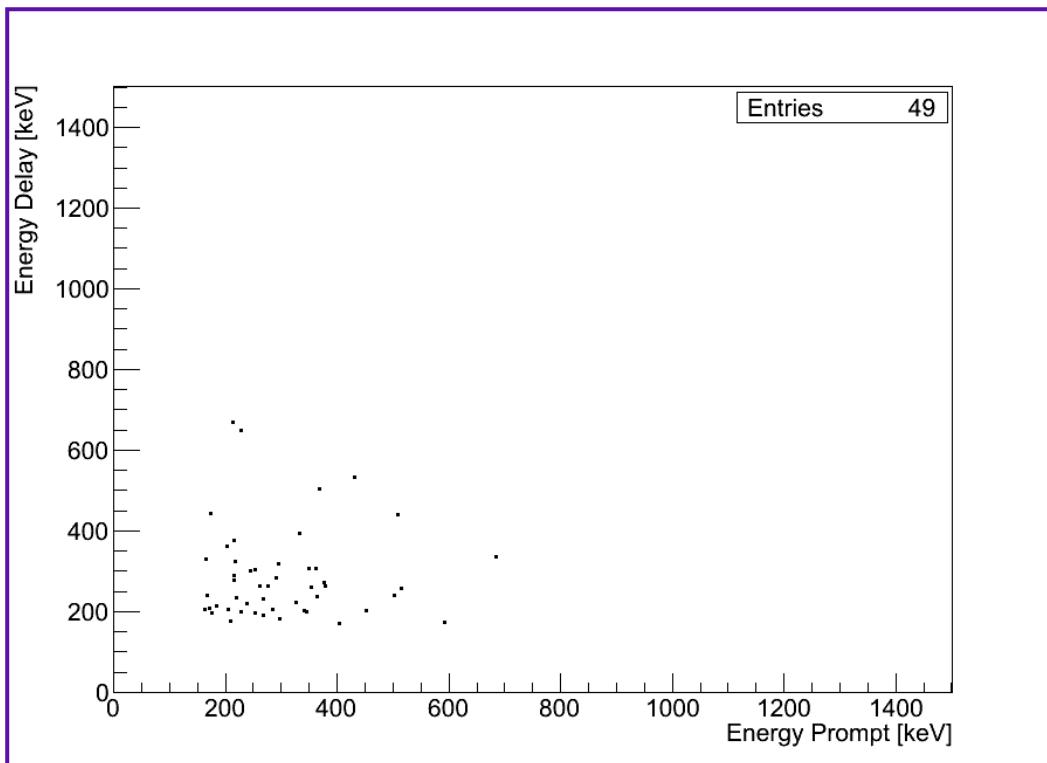
$A(^{214}\text{Bi}) = 1.50 \mu\text{Bq}/\text{m}^2$ scintillator,
 $[0.70 - 2.73] \mu\text{Bq}/\text{m}^2$ @ 90% C.L.



First results: Background measurement

- Background measurement: Test the radiopurity of the scintillators
Have a first estimation of the reachable sensitivity
 - Module 2: ***187 m² x d*** exposure (55 days of measurement, still ongoing)

49 *214-BiPo* candidates



Working for more accurate energy calibration to obtain a value

First results: Background measurement

- Background measurement: Test the radiopurity of the scintillators
Have a first estimation of the reachable sensitivity

- Module 1: **$231 \text{ m}^2 \times \text{d}$** exposure (85 days)

2^{212}BiPo events detected and 7^{214}BiPo events detected

- Module 2: **$187 \text{ m}^2 \times \text{d}$** exposure → (55 days, still ongoing)

Activity ($\mu\text{Bq}/\text{m}^2$ scintillator) @ 90 % C.L.		
	^{208}TI	^{214}Bi
Module 1	$0.09 [0.02 - 0.40]$	$1.50 [0.70 - 2.73]$
Module 2	0.23 [0.06 – 0.67]	-
BiPo-1	1.50 [0.55 – 1.75]	< 80

First results: Background measurement

- Background measurement: Test the radiopurity of the scintillators
Have a first estimation of the reachable sensitivity

- Module 1: **$231 \text{ m}^2 \times d$** exposure (85 days)

2^{212}BiPo events detected and 7^{214}BiPo events detected

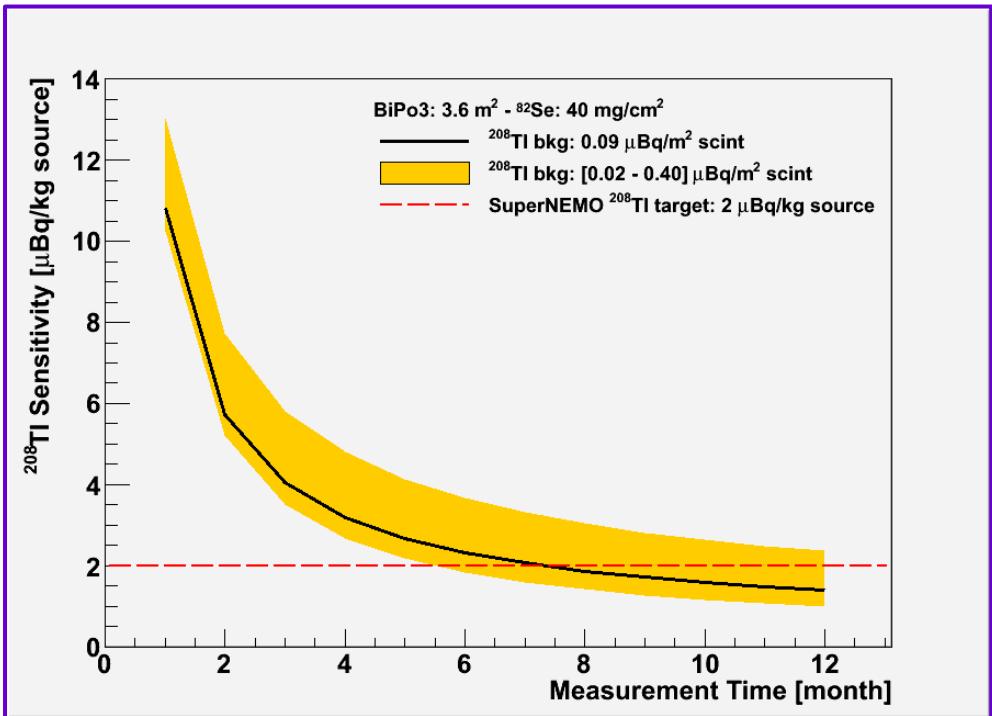
- Module 2: **$187 \text{ m}^2 \times d$** exposure → (55 days, still ongoing)

Activity ($\mu\text{Bq}/\text{m}^2$ scintillator) @ 90 % C.L.		
	^{208}TI	^{214}Bi
Module 1	$0.09 [0.02 - 0.40]$	$1.50 [0.70 - 2.73]$
Module 2	0.23 [0.06 – 0.67]	-
BiPo-1	1.50 [0.55 – 1.75]	< 80

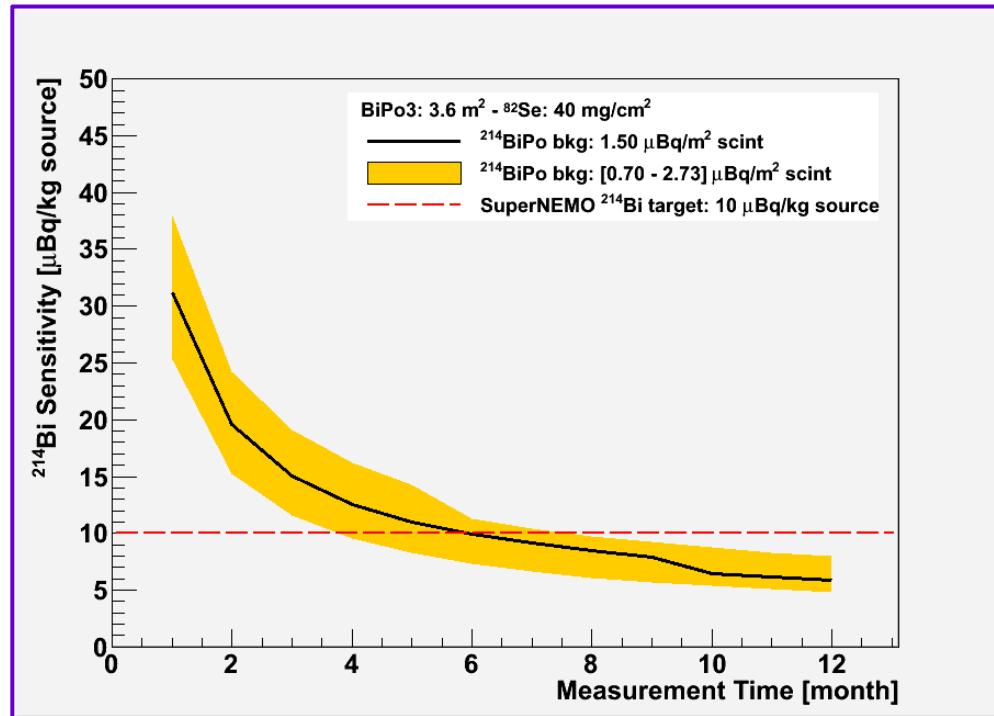
Wait the β/α discrimination for final values, specially for the ^{214}Bi

First results: Expected sensitivity

- Considering the background levels measured with first module, the expected sensitivity for the measurement of the ***SuperNEMO source foils*** could be estimated
 - Covering all the surface of both detectors (***3.6 m²***)
 - ⁸²Se-based foil of ***40 mg/cm²*** thickness



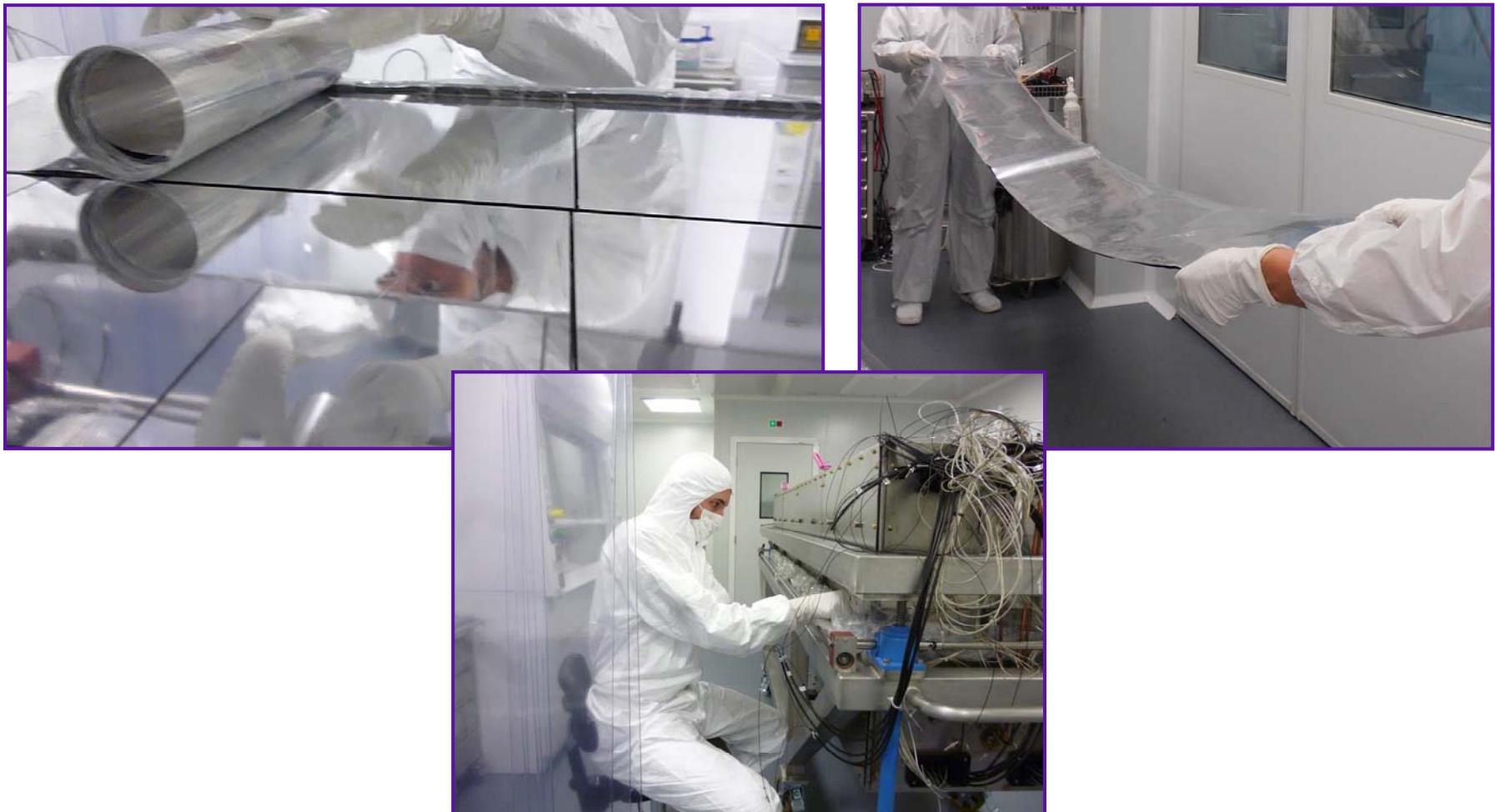
~ 0.13 bkg events expected per month



~ 1.5 bkg events expected per month

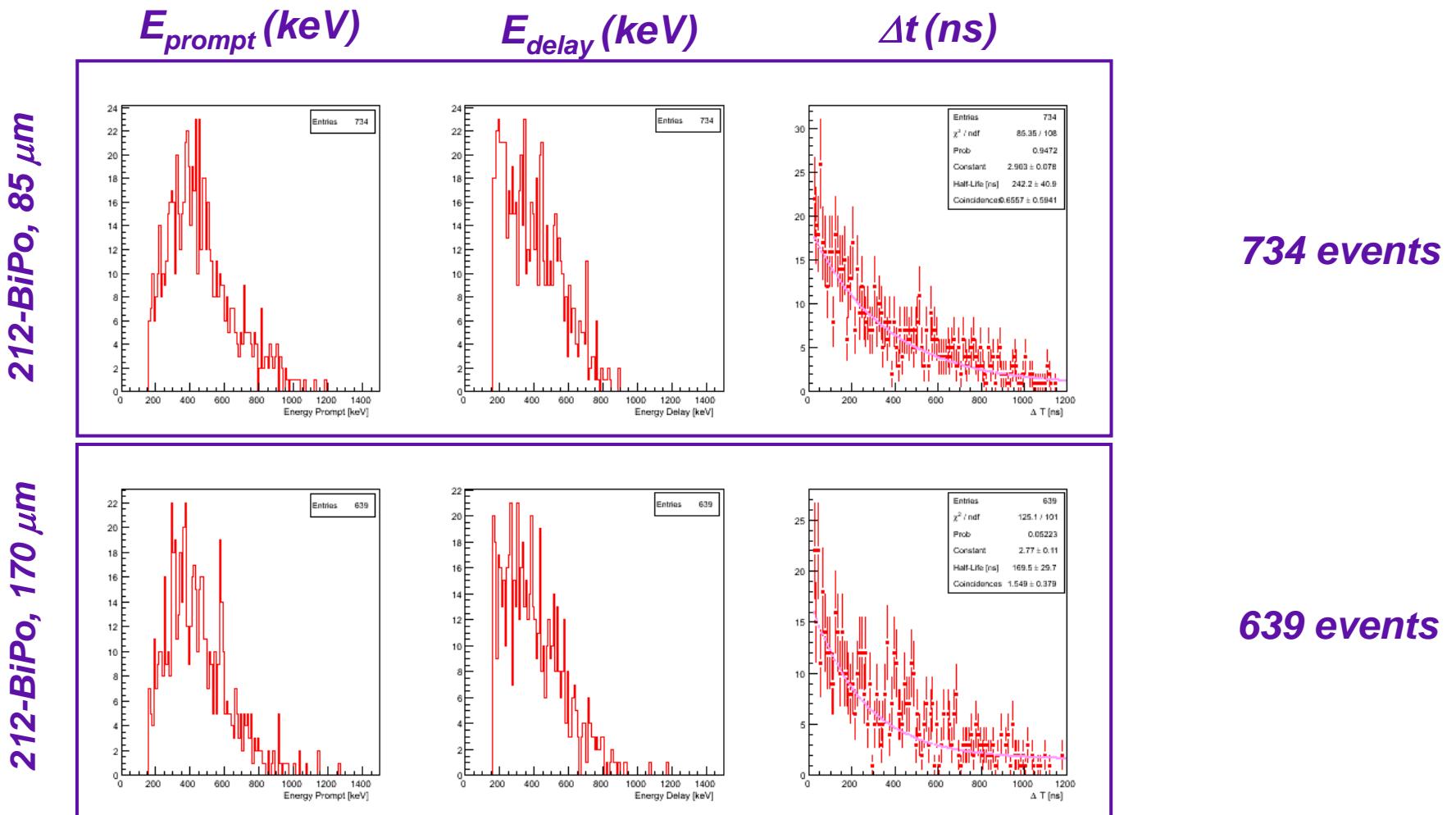
First results: Aluminum calibration

- **Al foil calibration:** Calibration with a source with the same geometry that the future samples that will allow to test the detection principle and the efficiency estimations.
- Two different sample thicknesses (85 and 170 µm) in order to obtain more information (for the moment only in Module 1)



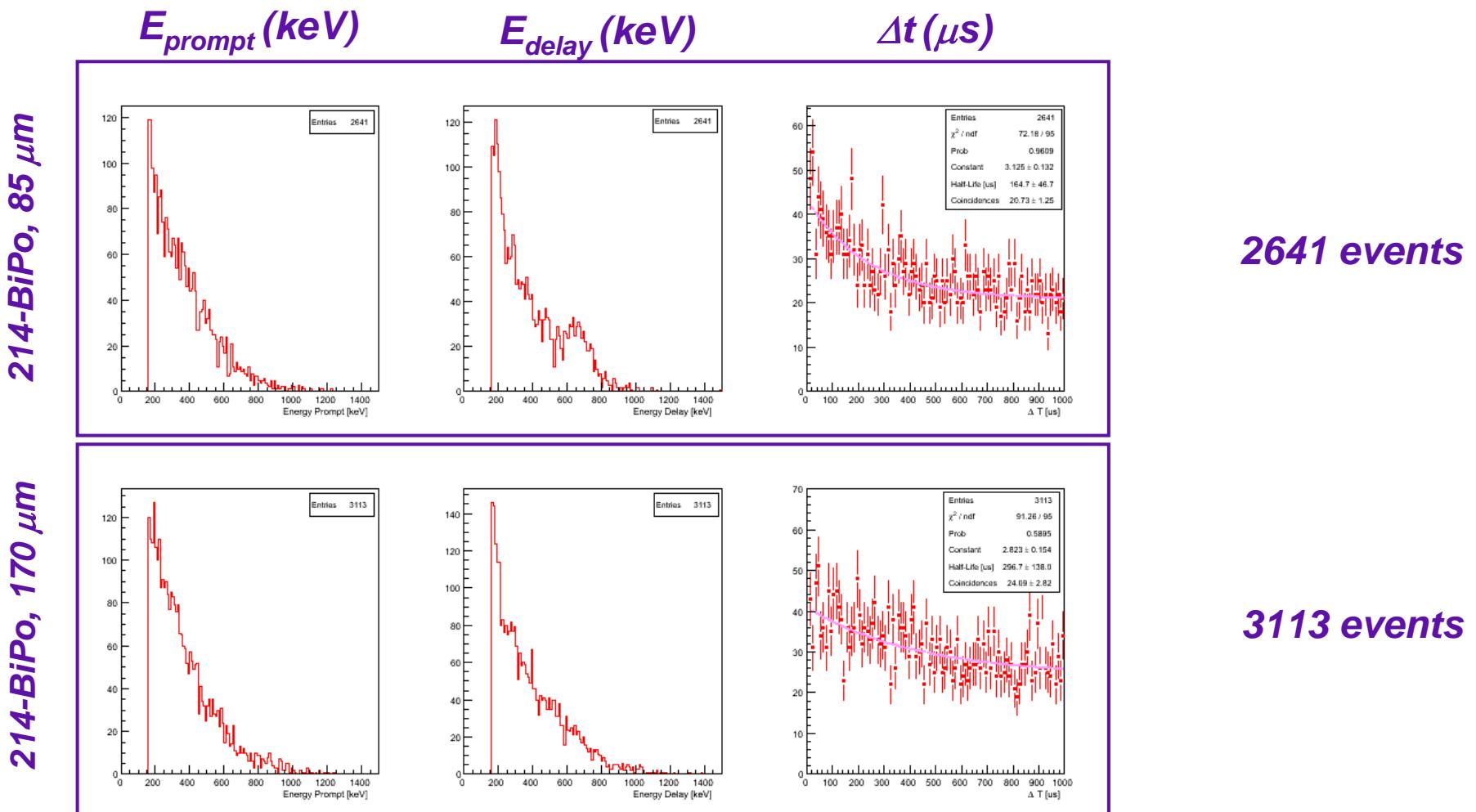
First results: Aluminum calibration

- **Al foil calibration:** Calibration with a source with the same geometry that the future samples that will allow to test the detection principle and the efficiency estimations.
- After **23 days** of measurement



First results: Aluminum calibration

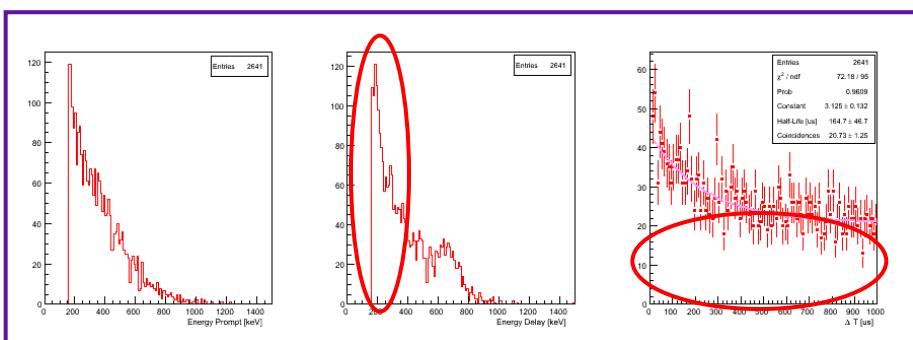
- **Al foil calibration:** Calibration with a source with the same geometry that the future samples that will allow to test the detection principle and the efficiency estimations.
- After **23 days** of measurement



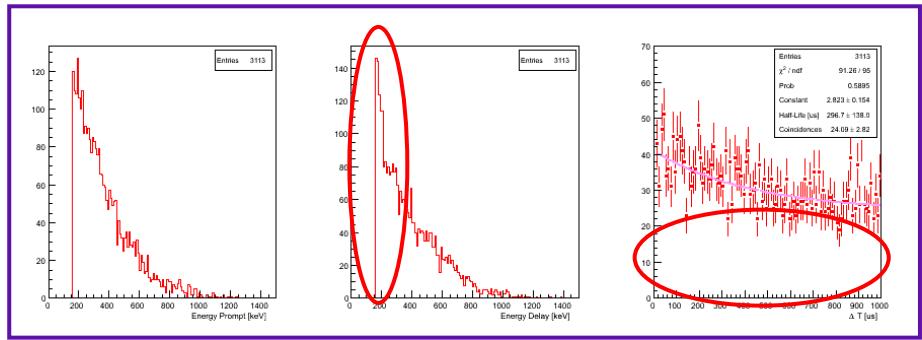
First results: Aluminum calibration

- **Al foil calibration:** Calibration with a source with the same geometry that the future samples that will allow to test the detection principle and the efficiency estimations.
- After **23 days** of measurement

214-BiPo data 85 μm



214-BiPo data 170 μm



A lot of random coincidences that makes more difficult the data analysis and the comparison data-simulation

Further β/α discrimination should “clean” these data (around 80% of efficiency)

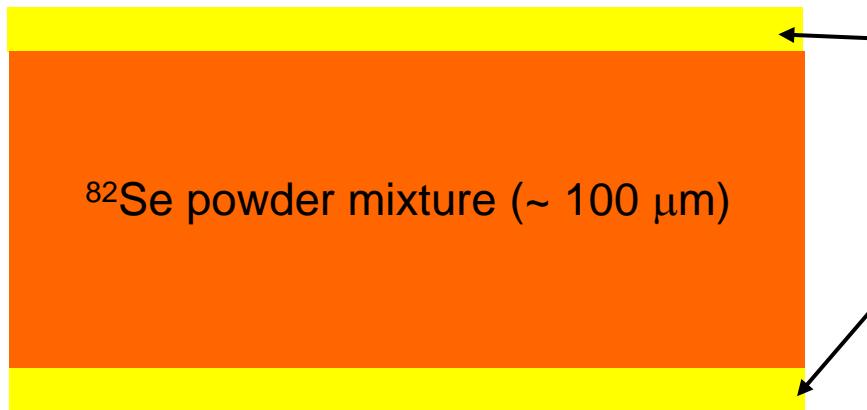
- **Al foil calibration:** Calibration with a source with the same geometry that the future samples that will allow to test the detection principle and the efficiency estimations.
- After **23 days** of measurement

Activity (mBq/kg)		
	$^{212}\text{BiPo}$	$^{214}\text{BiPo}$
BiPo-3 Module 1	$131 \pm 2 \text{ (stat)} \pm 28 \text{ (sys)}$	$40 \pm 3 \text{ (stat)} \pm 9 \text{ (sys)}$
BiPo-1	$160 \pm 5 \text{ (stat)} \pm 30 \text{ (sys)}$	-
BiPo-3 prototype	$138 \pm 2 \text{ (stat)}$	$40 \pm 12 \text{ (stat)}$
Preliminary HPGe meas.*	$186 \pm 30 \text{ (stat)}$	< 50

*A more precise HPGe measurement is currently ongoing at LSM

- **Module 1**

- Ongoing the **Backing Film** measurement (component of the SuperNEMO $\beta\beta$ source foils)



Backing Film ($\sim 10 \mu\text{m}$)

^{82}Se powder mixture ($\sim 100 \mu\text{m}$)

2 samples prepared to measure in **BiPo**

8 layers of $300 \times 30 \text{ mm}^2$ each ($96 \mu\text{m}$)



Outlook and prospects

- **Module 1**

- Ongoing the **Backing Film** measurement (component of the SuperNEMO $\beta\beta$ source foils)
- Measure the 4 μm **Polyethylene film** (in principle clean but it is necessary to assure at BiPo level)
- Measure any other **available sample**

- **Module 2**

- Finalize the **Background** measurement
- Make the **Calibration Run** with the Aluminum foil
- Start to measure **available samples** (not before next summer)

- **Data analysis**

- Complete the analysis tools (β/α discrimination)
- Re-analyze the available data with these new tools
- Carry out systematic data analysis

Summary and Conclusions

- **NEMO 3** experiment has provided the most accurate measurements to date of $T_{1/2}^{2\nu\beta\beta}$ for 7 isotopes and competitive limits on $T_{1/2}^{0\nu\beta\beta}$ for ^{82}Se and ^{100}Mo .
- **SuperNEMO** experiment will use an improved version of the same technique with **100 kg** of $\beta\beta$ emitter trying to reach the $\langle m_\nu \rangle \sim 50 \text{ meV}$ level.
- One requirement for SuperNEMO is to have really good **radiopurity** levels for the **source foils**: $< 2 \mu\text{Bq/kg}$ in ^{208}Tl and $< 10 \mu\text{Bq/kg}$ in ^{214}Bi .
- **BiPo** is a **dedicated** detector designed to measure these foils with the required sensitivity.
- A set of **prototypes** have shown the **viability** to construct the detector proving the **detection principle**.
- The **final setup** has started to be constructed in July'12 and has been completed last January.
- First **background measurements** showed that the **required sensitivity** could be reached in the expected time.
- Preliminary **calibrations** assure the validity of the analysis and the detection efficiency estimation.
- First **components** of the SuperNEMO **$\beta\beta$ source foils** started to be **measured**.

BiPo: A dedicated radiopurity detector for the SuperNEMO experiment

Héctor Gómez Maluenda on behalf of SuperNEMO Collaboration

Laboratoire de l'Accélérateur Linéaire

gomez@lal.in2p3.fr

- NEMO 3 and SuperNEMO experiments.
 - Motivation: SuperNEMO $\beta\beta$ source foils radiopurity.
- The BiPo detector.
- First results.
- Outlook and Prospects.
- Summary and Conclusions.