Status Report of the BiPo-3 detector

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The BiPo-3 detector, running since 2013, is a low radioactive detector dedicated to measuring ultra-low natural contaminations of ^{208}Tl and ^{214}Bi in thin materials and initially developed to measure the radiopurity of the neutrinoless double β decay source foils of the SuperNEMO experiment.

We have reported in previous SC the results of the ^{208}Tl and ^{214}Bi contamination in the first eight SuperNEMO source foils: $\mathcal{A}(^{208}\text{Tl}) = (21 \pm 11)$ μBq/kg and $\mathcal{A}(^{214}\text{Bi}) <$ 290 μBq/kg, of the ^{82}Se mixture. We report here preliminary results for other source foils in the SuperNemo demonstrator.

1 Introduction

The goal of the SuperNEMO experiment is to search for the neutrinoless double β decay, $\beta\beta0\nu$. One of the main sources of background for SuperNEMO is a possible contamination of ^{208}Tl (Q_β = 4.99 MeV) and ^{214}Bi (Q_β = 3.27 MeV) produced inside the $\beta\beta0\nu$ source foils. To measure the required low levels in the $\beta\beta0\nu$ foils the collaboration has developed the BiPo-3 detector.

The principle of detection of the BiPo-3 detector and the analysis method have been reported in previous reports.

2 The enriched ^{82}Se foils in the SuperNemo demonstrator

The demonstrator will contain 7 kg of $\beta\beta0\nu$ isotope in the form of thin foils (13.5 x 270) cm, about 250 μm thick. Two types of purification process and two procedures have been used to produce the foils. The first foils, containing 1.95 kg of ^{82}Se purified by double distillation, have been produced by our russian colleagues from ITEP using the same method as the SuperNemo predecesor, NEMO3. To produce these enriched ^{82}Se foils, thin and chemically purified ^{82}Se powder is mixed with 10% Polyvinyl alcohol (PVA) glue and then deposited between two mylar foils. The mylar foil is 12 μm thick and it has been irradiated at JINR Dubna with an ion beam producing a large number of microscopic holes in order to ensure a good bond with the PVA glue and to allow the water evaporation during the drying of the glue.

BiPo-3 measurements showed that the irradiated mylar is contaminated at the level of ~100 μBq/kg, while the raw mylar is radiopure (< 50 μBq/kg). Therefore the collaboration decided to develop a new source production method in charge of the LAPP laboratory in Annecy, France using raw mylar instead of irradiated mylar. In parallel, a new Se purification technique has also been developed at JINR, Dubna, Russia based on the inverse chromatography method. A second group of foils containing 1.5 kg of ^{82}Se, have been produced by LAPP using enriched ^{82}Se purified by inverse chromatography, so called 'Dubna' foils. A third group of foils, called French foils, with a total of $\sim$ 1 kg of ^{82}Se have been also produced at LAPP using Se enriched by inverse chromatography. The Dubna and the French foils are thus, in principle equivalent since they have the same purification and production method, their difference being the place where the Se has been enriched. Another group of foils, so-called 'Tomsk' foils have been produced by LAPP with Se purified by double distillation. Table 1. summarizes the groups of source foils for the demonstrator that have been measured with the BiPo detector. A last group of foils with Se from another purification method have been made, which are not listed on Table 1 since they have not been measured with BiPo.

Name	**Mass** ^{82}**Se** (kg)	**Purification**	**Production**
ITEP	1.95	double distillation	ITEP (as NEMO3) Irradiated Mylar
Dubna	1.5	inverse chromatography	LAPP Raw Mylar
French	0.97	inverse chromatography	LAPP Raw Mylar
Tomsk	1.4	double distillation	LAPP Raw Mylar

Table 1: Purification methods and production for the SuperNemo demonstrator foils which have been measured with the BiPo detector.

2.1 Analysis method

We search for an excess of BiPo events in data above the background expectation in the delayed alpha energy spectrum. The backgrounds are the intrinsic detector contamination on the surface of the scintillators and the random coincidences from Compton electrons falling inside the coincidence time window. For the measurement of the ^{82}Se foils, the contamination inside the Mylar is added as an extra component of background. The delayed energy spectra of the background components are simultaneously fitted to the observed data. The energy spectra of each component are calculated by Monte Carlo and the number of events are constrained by the values from the dedicated previous measurements within the uncertainty interval. The delayed energy spectrum of the contamination of the ^{82}Se+ PVA mixture is added and the number of events is left free in the fit. All contributions are simultaneously fitted to the observed data. The result of the fit gives the estimated number of disintegrations generated on the Se+ PVA mixture and provides a cross-check for the expected background.

2.2 Measurement of the 'Dubna' foils

Two foils so-called 'Dubna' (see section 2 for details) have been measured from 15 December 2016 to 19 March 2017 and from 28 April 2017 to 7 August 2017. The analyzed data corresponds to 111.94 days for the ^{212}BiPo measurement and 130.1 days for the ^{214}BiPo measurement, the total effective mass of the ^{82}Se+PVA mixture is 401 g (374 g), and the effective scintillators surface area is 1.62 m^2 (1.44 m^2) for the ^{212}BiPo (^{214}BiPo) measurement.

For ^{212}BiPo, 3 events are observed and 0 events are expected. Taking into account the detection efficiency of 1.96%, we obtain

$$\mathcal{A}(^{208}\text{Tl}) : 22[8-54]\ \mu\text{Bq/kg (90\% C.L.)}$$

For ^{214}BiPo, the energy spectra of the prompt electron and delayed alpha signals are presented in Figure 1. The data are compared to the result of the fit as described in section 2.1. To reject the surface background and to reduce the background contribution from the bismuth contamination inside the irradiated mylar, an upper limit on the delayed energy is added at 600 keV allowing to increase the signal over background ratio.

With a delayed energy lower than 600 keV, ^{214}BiPo 14 events are observed and 11.5 background events are expected from the fit. Considering the slight excess as a background fluctuation, and taking into account the detection efficiency of 0.4% an upper limit at 90% C.L. is set to the ^{214}Bi contamination of the ^{82}Se+PVA mixture:

$$\mathcal{A}(^{214}\text{Bi}) < 595\ \mu\text{Bq/kg (90\% C.L.)}$$

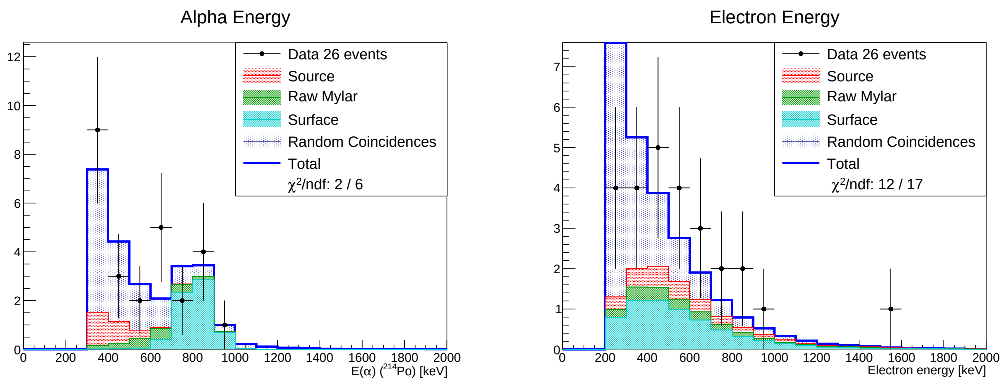

Figure 1: Distributions of the alpha and electon energy for the ^{214}BiPo measurement of the 'Dubna' enriched ^{82}Se SuperNEMO foils, with 130.1 days of data collection. The data is compared to the expected background from the contamination on the surface of the scintillators (light blue histogram), the Mylar (green histogram) and random coincidences (dark blue histogram). Shown in red the expected contribution from the ^{82}Se+PVA mixture.

2.3 Measurement of the 'Tomsk' foils

The so-called 'Tomsk' foils use Se purified by double distillation and have been produced at LAPP, France. Two of such foils have been measured from 15 December 2016 to 19 March 2017.

The analyzed data corresponds to 70.64 days for the ^{212}BiPo measurement and 64.1 days for the ^{214}BiPo measurement, the total effective mass of the ^{82}Se+PVA mixture is 327 g, and the effective scintillators surface area is 1.26 m^2.

After the selection of the BiPo212 events below 700 keV, 8 events are observed and 0.7 are expected from background. The energy spectra of the prompt electron and delayed alpha signals are presented in Figure 2. Taking into account the detection efficiency of 1.5% (calculated by simulating ^{212}BiPo events distributed uniformly inside the ^{82}Se+PVA mixture), this corresponds to a 90% C.L. interval for the ^{208}Tl activity of the ^{82}Se+PVA mixture of:

$$\mathcal{A}(^{208}\text{Tl}) : 137[66 - 254]\ \mu\text{Bq/kg (90\% C.L.)}$$

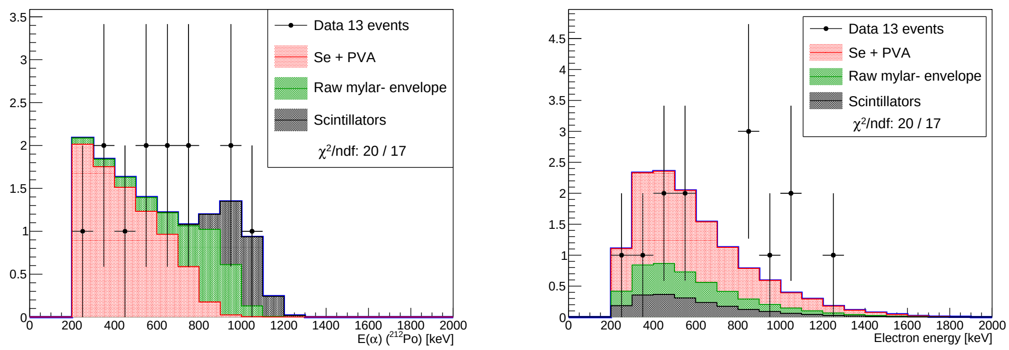

Figure 2: Distributions of the alpha and electron energy for the ^{212}BiPo measurement of the 'Tomsk' (see text for details) enriched ^{82}Se SuperNEMO foils. The data is compared to the expected background from the contamination on the surface of the scintillators (black histogram) and the Mylar (green histogram). Shown in red the contribution from the ^{82}Se+PVA mixture.

The selection of BiPo214 events with a delayed energy lower than 600 keV, resulted in 7 events observed and 9 background events expected. The energy spectra of the prompt electron and delayed alpha signals are presented in Figure 3. Taking into account the detection efficiency of 0.4%, this corresponds to a 90% C.L. upper limit for the ^{214}Bi activity of the ^{82}Se+PVA mixture of:

$$\mathcal{A}(^{214}\text{Bi}) < 525\ \mu\text{Bq/kg (90\% C.L.)}$$

3 Summary

BiPo-3 is measuring the radiopurity of the neutrinoless double β decay source foils of the SuperNEMO demonstrator which will contain 7 kg of ^{82}Se as baseline isotope.

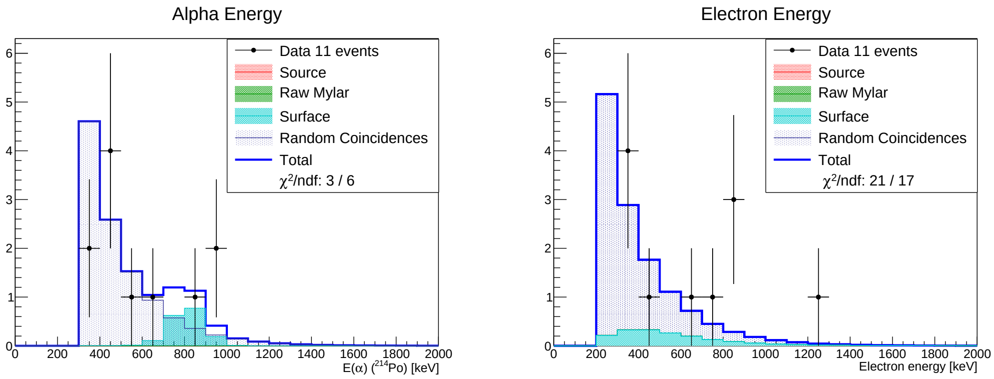

Figure 3: Distributions of the alpha and electron energy for the ^{214}BiPo measurement of the 'Tomsk' (see text for details) enriched ^{82}Se SuperNEMO foils. The data is compared to the expected background from the contamination on the surface of the scintillators (light blue histogram), the Mylar (green histogram) and random coincidences (dark blue).

In this report, we presented the results of the ^{208}Tl and ^{214}Bi activities of two groups of foils, so called 'Dubna' and 'Tomsk' foils (see text for details). The activities of the ^{82}Se+PVA mixture in the foils, at 90% C.L, are summarized in Table 2.

Name	**Mass** ^{82}**Se** (kg)	**Purification**	**Production**	$\mathcal{A}(^{208}$Tl) (μBq/kg)	$\mathcal{A}(^{214}$Bi) (μBq/kg)
ITEP	1.95	double distillation	ITEP Irradiated Mylar	20[11 -32]	<290 290 ± 290
Dubna	1.5	inverse chromatography	LAPP Raw Mylar	22[8 - 54]	< 595
French	0.97	inverse chromatography	LAPP Raw Mylar	< 106	< 1374
Tomsk	1.4	double distillation	LAPP Raw Mylar	137[66 - 254]	<525

Table 2: ^{208}Tl and^{214}Bi activities for the SuperNemo demonstrator foils as measured with the BiPo detector. All results are given at 90% C.L.

The BiPo-3 detector has become a generic detector for the measurement of ^{208}Tl and^{214}Bi in thin materials at extremely low levels. Starting by the end of 2017 the DarkSide experiment will measure samples with the detector on a regular basis.