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Test of the NEMO 3 background model using Cu foil data

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Abstract
Cu foil data was carefully analised in this note in order to test background model used for $\beta\beta$ analysis.

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1 Introduction

Cu foil (620.8 g) was installed in the sector 0 of the NEMO 3 detector to perform background study. It was measured on Ge detector before [1] and proved to be a very pure material.

2 Background model

2.1 External background model

There are two approaches for external background model building.

First approach [2, 3] is based on the statement that if one can reproduce spectrum of external γ quants reaching source foil that will be enough to predict background in $\beta\beta$ channel. In order to measure external γ spectrum, $e\gamma$-external channel was analised. The results of the fit and activities found are summarized in [2].

Another approach is try to reconstruct real activities of detector components, using Ge measurements, $e\gamma$-external channel, OCE (one crossing electron) channel etc. Most recent update on the status of this analysis can be found at [4].

First model is used throught the note if overwise is not stated.

2.2 Rn in the wire chamber background model

In this note results of $e\gamma$-internal events analysis are used. The method itself was described in details [5]. Most recent update and results can be found at [6].

Also for Phase II standard runlist it was decided to select only runs with low Rn activity (< 400 mBq) [7]. Consequently effective ^{214}Bi activity was remeasured for this run list:

$$A_{^{214}\mathrm{Bi}} = 83.9 \pm 2.4(\mathrm{stat})\ \mathrm{mBq}$$

3 Cu foil internal background

3.1 $e\gamma$-int channel

$e\gamma$-int channel channel is used also to estimate surface contamination of ^{214}Bi. The method and selection cuts are described in [5]. For Cu foil follwoing updated results were obtained:

$$\mathrm{A}_{\mathrm{Cusurf}}(^{214}\mathrm{Bi}) = 19.5 \pm 3.5(\mathrm{stat})\ \mathrm{PhaseI}$$

$$\mathrm{A}_{\mathrm{Cusurf}}(^{214}\mathrm{Bi}) = 8.5 \pm 1.9(\mathrm{stat})\ \mathrm{PhaseII\ (standart\ runlist)}$$

At Fig. 1 and Fig. 2 all $e\gamma$-int events in Cu shown. Only events where electron track strats at GG layers 0 or 1 were selected. This cut is similar to the one used in $\beta\beta$ analysis.

Also this channel allows to analise α particle detection efficiency(see Table 1). Two effects are contributing here in different directions: a) there are more single delayed hit αs in the data then in MC; b) a part of surface contamination is actually inside the foil, so produce less α tracks in the data then in MC.

In order to do precise $\beta\beta$ analysis, one need to match number of tagged α particles in the data and MC. Simplest way: introduce correction factor. For Phase I part of Bi MC events "without α" should be marked as "with α" (Pcorr_{α} factor), because first effect is more important. For Phase II opposite, $\mathrm{Pcorr}_{no\alpha}$ part of MC events marked as "with α" should be treated as "without α" (second effect is dominating).

3.2 1e channel

Single electron channel is important to measure internal contamination of such isotopes as ^{40}K, ^{234m}Pa, ^{210}Bi, ^{211}Pb and ^{207}Tl.

Vertex distribution of 1e events from Cu shows that edges of the foil are contaminated (counting rate factor $\sim$2 larger in comparison with the rest of the foil). So for further analysis cut $|Z| < 110$ cm on the event vertex applied.

1e events energy is shown at Fig. 3 and Fig. 4. Background activities found summurised in the Table 2.

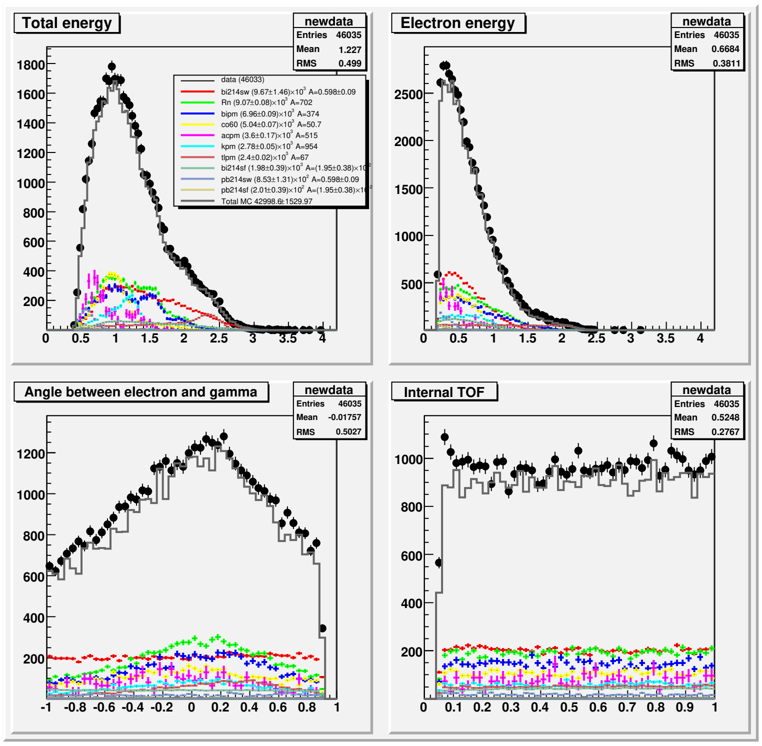

Figure 1: All $e\gamma$-events at Cu. Electron track from layer 0-1. Phase I data.

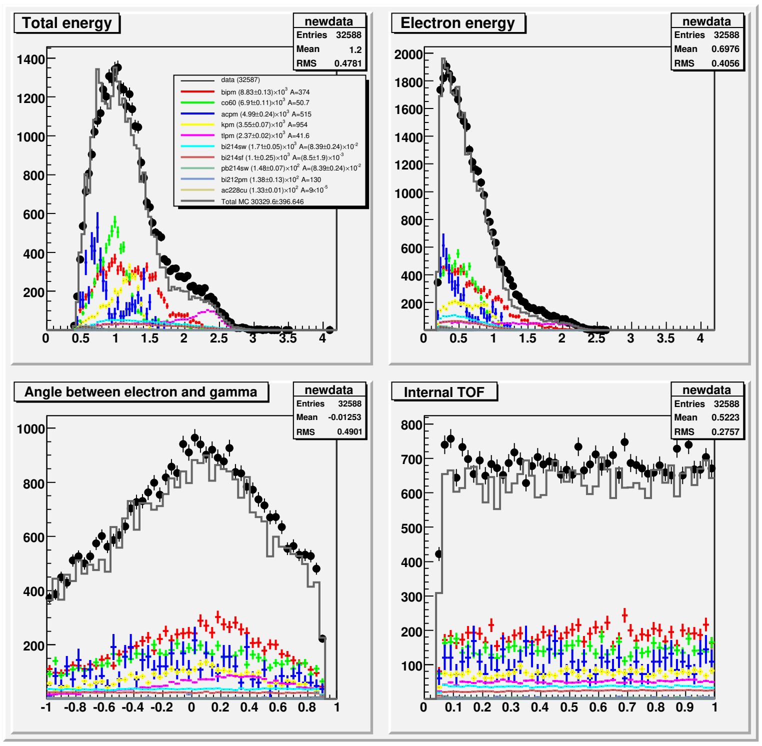

Figure 2: All $e\gamma$-events at Cu. Electron track from layer 0-1. Phase II data.

Table 1: Number of events with α particle in $e\gamma$-int channel in Cu

	N_α	N_α^{MC}	$N_{^{214}Bi}^{MC}$	$Pcorr_\alpha$	$Pcorr_{no\alpha}$
Phase I	4973	4687	11650	0.041	
Phase II	1041	1201	2810		0.13

Table 2: Activities of β-emiters found in Cu

Background	A, mBq	Ge measurement, mBq [1]
^{210}Bi wires	5050 (whole wire chamber)	–
^{210}Bi surface	17.4 (per 40 m^2)	–
^{234m}Pa	1.22	< 3.1
^{40}K	0	< 5
^{211}Pb	0	< 0.12 (^{235}U)
^{207}Tl	0	< 0.12 (^{235}U)

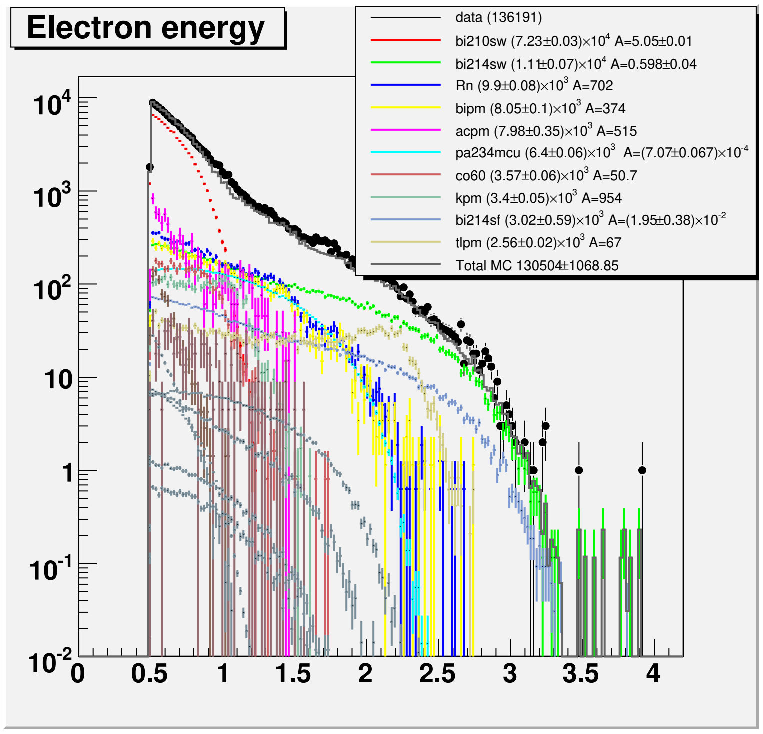

Figure 3: 1e events at Cu. Electron track from layer 0. Phase I data.

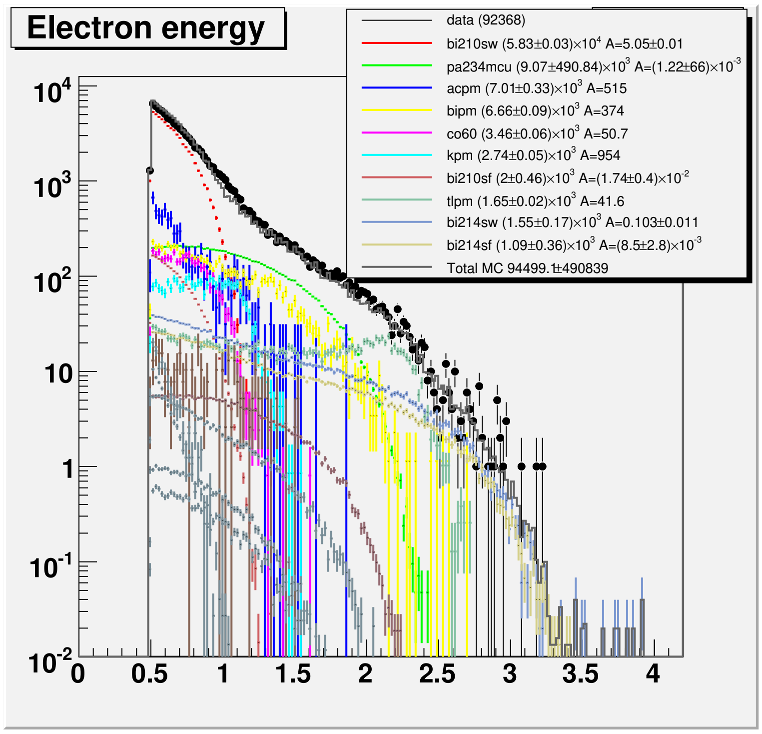

Figure 4: 1e events at Cu. Electron track from layer 0. Phase II data.

3.3 Discussion about model precision

It can be seen that in general MC slightly deviates from the data. The worst case is for $e/gamma$-int channel, with ∼7.5% deviation. It is difficult to say where the difference comes from. It can origoinate in the model itself: some important components of background are missing. Or it can come from GEANT3.21 limitation. External background contribution crucially depends on Compton crosssection. Since GEANT promises not better then 10% accuracy for tabled cross-sections, this level of data-MC agreement for $e\gamma$ and 1e channels can be considered as a very good one.

Another argument in the favour of GEANT to be a source of discrepancy: analysis of small isotopes. In that isotopes due to small surface, external background contribution is not dominant any more. Also the agreement with MC is much better [8].

4 $\beta\beta$ channel in Cu foil

For $\beta\beta$ events selection the standard cuts, as defined in [7], were used with additional condition for event vertex $|Z| < 110$ cm. Runs analised are from the common runlist to be used for comparisons (see Victor's e-mail from 15/03/07).

4.1 Phase I data

Number of events found in the data is 275, while MC prediction is 212.5 ± 10.6 events. Error is statistical error due to limited MC statistics and statistical uncertainties in measured Rn activities. Detailed break down to all background contributions is shown in the Table 3.

The difference observed is about 3.2σ. Event spectra are shown at the Fig. 5. One can see that excess in the data corresponds to low energy ($E_{sum} < 1$ MeV) and large angle ($Cos(\alpha_{12} < 0.)$). If this additional cuts are applied, the number of data events is 64, predicted MC is 37.1 ± 4.6. This corresponds to 2.9σ difference.

Note, that even 30% increase in Rn activity could explain only half of the observed deficit.

Table 3: $\beta\beta$ events in Cu foil during Phase I.

		My bgr model		Victor bgr model [4]	
Component	Efficiency	A, Bq	N expected	A, Bq	N expected
DATA		time 404.079 d	275		
Ac228 pmt	1.40e-10	515	2.51 ± 1.45	133	0.65 ± 0.37
Tl208 pmt	3.85e-09	67	8.99 ± 1.42	47	6.31 ± 1.00
Bi214 pmt	9.48e-10	374	12.38 ± 3.73	520	17.22 ± 5.19
Rn	6.37e-10	702	15.62 ± 3.12	580	12.90 ± 2.58
K40 pmt	7.51e-11	954	2.50 ± 1.44	831	2.18 ± 1.26
Co60 petal	1.79e-09	50.7	3.17 ± 1.58	25	1.56 ± 0.78
Eu152 SS	2.92e-09			33	3.37 ± 3.36
Bi214sw	2.60e-06	$(598 \pm 6)e-03$	54.30 ± 2.56	"	"
Pb214sw	1.59e-06	$(598 \pm 6)e-03$	33.33 ± 5.57	"	"
Tl208sw	2.21e-06	2.8e-03	0.22 ± 0.02	"	"
Bi210sw	9.00e-08	5.05 ± 0.01	15.88 ± 3.97	"	"
Bi214sf	3.26e-05	$(19.5 \pm 3.5)e-03$	22.24 ± 4.08	"	"
Pb214sf	2.25e-05	$(19.5 \pm 3.5)e-03$	15.37 ± 2.84	"	"
Bi210sf	6.71e-07	$(17.4 \pm 5)e-03$	0.41 ± 0.14	"	"
Ac228cu	2.83e-04	9e-05	0.89 ± 0.08	"	"
Bi212cu	2.53e-04	6e-05	0.53 ± 0.05	"	"
Pa234mcu	5.48e-04	$(1.22 \pm 0.07)e-03$	23.36 ± 1.47	"	"
Tl208cu	6.98e-04	3e-05	0.73 ± 0.04	"	"
Total MC			212.45 ± 10.61		211.46 ± 11.33

In order to compare different models of external background, Victor's model [4] was investigated as well (Table. 3, Fig. 6). In order to simplify analysis following external background components were skipped: PMT Pb214, SS Bi210, SS Bi214, SS Pb214, SS Pa234m, Tour Cs 137, mmet Pa234m. Their total contribution to $e\gamma$-ext channel is only 2.4%.

As it was suggested in the begining, since both model describes correctly $e\gamma$-external channel, there is no difference for predicted $\beta\beta$ contribution.

4.2 Phase II data

Number of events found in the data is 127, while MC prediction is 144 ± 11 events.

Detailed break down to all background contributions is shown in the Table 4. Like in the Phase I, two external background models were compared. Experimental spectra shown at Fig. 7.

As one can see the DATA-MC agreement is much better for Phase II data.

4.3 $\beta\beta$ events with α in Cu foil

In the Table 5 shown number of $\beta\beta$ events selected as containing α. Also MC prediction, and MC prediction after correction (see Table 1) applied. Statistically data and MC are in agreement.

5 Conclusion

Comparison of two external background models shows that they are identical from the point of view of $\beta\beta$ background predicted. Though first approach is more simple on practice (less MC simulations involved). Also, in order to use second approach additional MC simulations needed. E.g. there is only 1 $\beta\beta$ event found in the whole Eu152 SS simulations! Same applies to all smaller components skipped here.

There is statistically significant excess of data events for Phase I. Excess is not observed for Phase II data. Prelimiary conclusion: it can be related to Rn. If so, then it should be proportional to foils surface

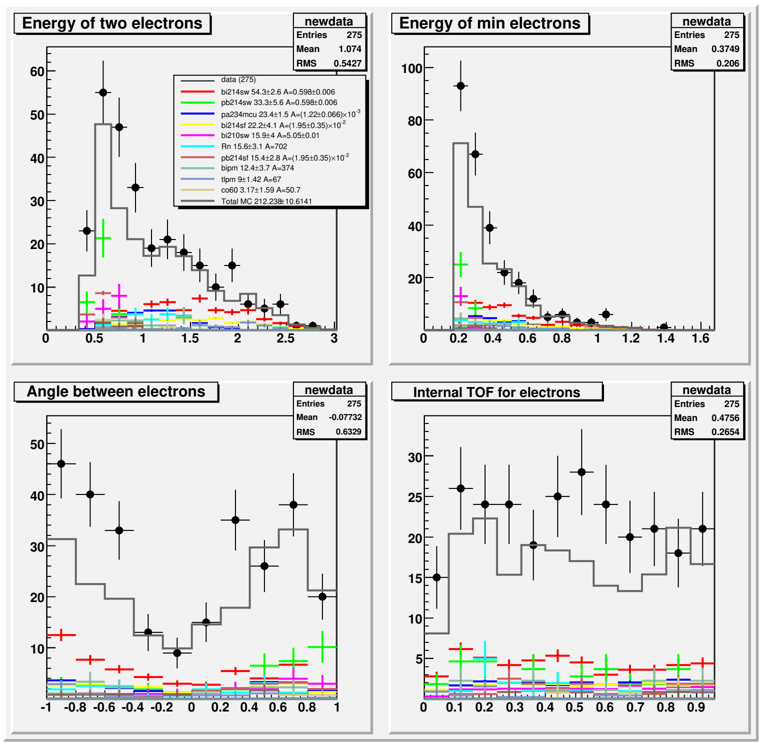

Figure 5: $\beta\beta$ events at Cu. Phase-I data.

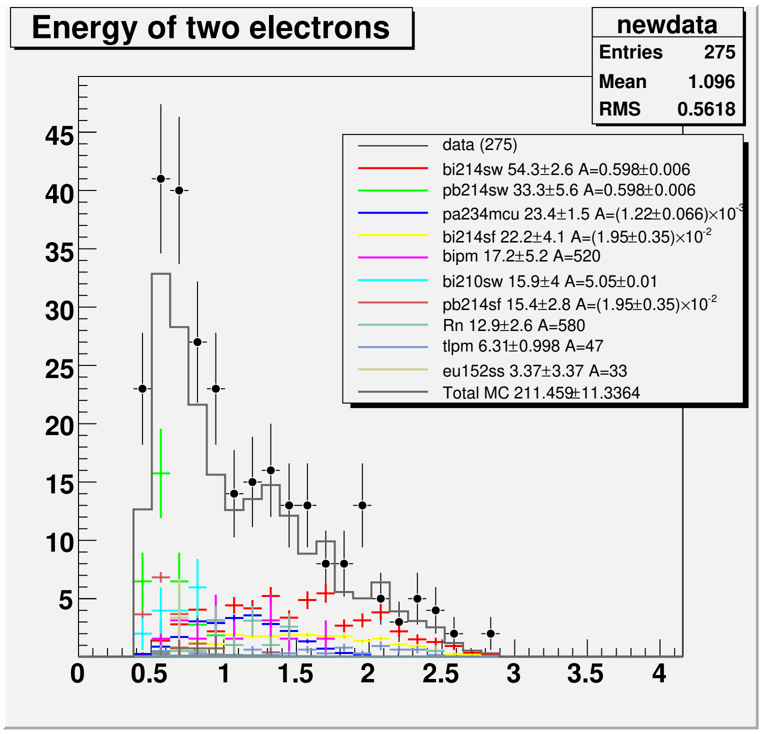

Figure 6: $\beta\beta$ events at Cu, Victor's external bgr model [4]. Phase-I data.

Table 4: $\beta\beta$ events in Cu foil during Phase II.

		My bgr model		Victor bgr model [4]	
Component	Efficiency	A, Bq	N expected	A, Bq	N expected
DATA		time 534.829 d	127		
Ac228 pmt	2.40e-10	515	5.94 ± 2.24	120	1.38 ± 0.52
Tl208 pmt	3.68e-09	41.6	7.08 ± 1.21	43	7.32 ± 1.25
Bi214 pmt	1.26e-09	374	25.17 ± 6.50	520	34.99 ± 9.03
K40 pmt	1.13e-10	954	4.98 ± 2.49	831	4.34 ± 2.17
Co60 petal	2.52e-09	50.7	5.90 ± 2.64	20	2.33 ± 1.04
Eu152 SS	0, noMC events			33	0
Bi214sw	2.52e-06	$(84 \pm 6)e-03$	9.78 ± 1.37	"	"
Pb214sw	1.59e-06	$(84 \pm 6)e-03$	4.06 ± 1.03	"	"
Tl208sw	2.44e-06	2.8e-03	0.32 ± 0.03	"	"
Bi210sw	1.14e-07	5.05 ± 0.01	26.62 ± 6.27	"	"
Bi214sf	3.21e-05	$(8.5 \pm 1.9)e-03$	12.61 ± 2.86	"	"
Pb214sf	2.23e-05	$(8.5 \pm 1.9)e-03$	8.78 ± 2.00	"	"
Bi210sf	3.53e-07	$(17.4 \pm 5)e-03$	0.28 ± 0.11	"	"
Ac228cu	2.86e-04	9e-05	1.19 ± 0.11	"	"
Bi212cu	2.62e-05	6e-05	0.73 ± 0.07	"	"
Pa234mcu	5.25e-04	(1.22 ± 0.07)e-03	29.65 ± 1.90	"	"
Tl208cu	6.31e-04	3e-05	0.87 ± 0.06	"	"
Total MC			143.98 ± 10.89		145.84 ± 12.09

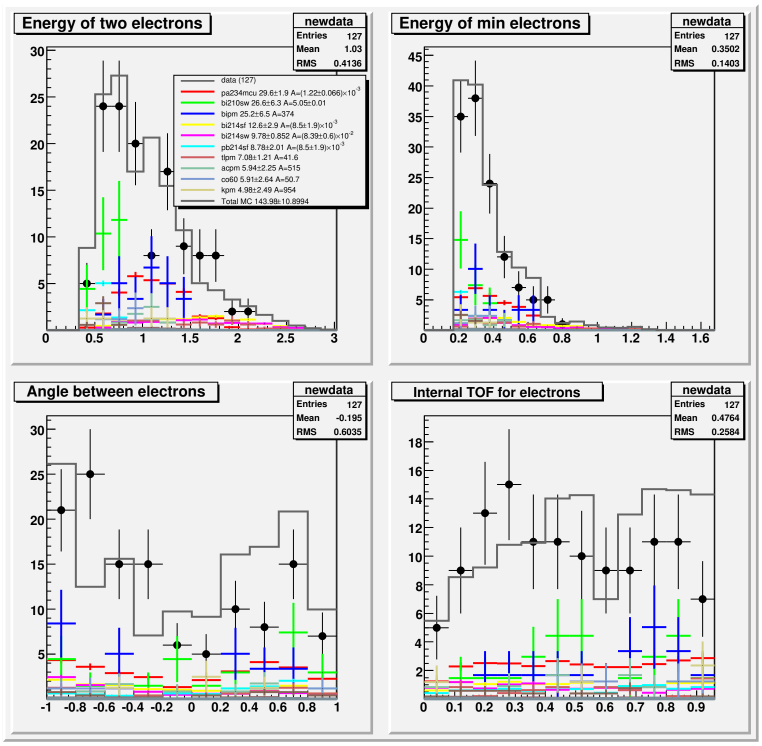

Figure 7: $\beta\beta$ events at Cu. Phase II data.

Table 5: Number of $\beta\beta$ events with α particle in Cu.

	N_α	N_α^{MC}	N_α^{MC} corrected
Phase I	30	28.26 ± 2.22	30.24 ± 2.22
Phase II	3	8.74 ± 1.31	7.60 ± 1.31

Table 6: Estimated $\beta\beta$ background systematics for NEMO 3 sources during Phase I. It is compared with the expected number of $\beta\beta 2\nu$ events.

Source	Surface, sectors	Background systematics, events	$T_{1/2}^{\beta\beta 2\nu}$,y	$N_{2\nu}^{\beta\beta}$ in Phase I, 5% efficiency
Cu	1	64		
Te-nat	1+5/7	109		
^{130}Te	2	127	$2.7 \cdot 10^{21}$	43
^{116}Cd	1	64	$3.8 \cdot 10^{19}$	2145
^{150}Nd	1/7	9.1	$6.8 \cdot 10^{18}$	825
^{96}Zr	1/14	4.5	$2.1 \cdot 10^{19}$	110
^{48}Ca	1/14	4.5	$4.3 \cdot 10^{19}$	77
^{100}Mo	11+5/7	743	$9.5 \cdot 10^{18}$	165000
^{82}Se	2+2/7	145	$8.3 \cdot 10^{19}$	3135

and one can estimate possible systematics for other isotopes (Table 6). This problem is important only for future ^{130}Te analysis.

References

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`http://www.hep.ucl.ac.uk/~vv/extbgr/`
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[3] V. Vasiliev, Logic for external background problem, talk at Orsay Febraury 2007 meeting.

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`http://www.hep.ucl.ac.uk/~vv/radon/radon.ps`

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[8] N. Fatemi-Ghomi, Measurement of the half-life of ^{150}Nd to $2\nu\beta\beta$ with the NEMO 3 detector.

APPENDIX 1
$\beta\beta$ *events* > 2.75 *MeV in Cu.*

```
Run 2295 Event 199113 Esum = 2.79496 copper
Sc 0 1 2 9 E=1.41196 L=67.7792
Sc 0 3 1 1 E=1.383 L=29.5884
DXY = 0.0371262 DZ = 0.421455 COS12=-0.902552 TOFI = 0.628395 TOFE=1.34527e-06 Alpha = 0 0 0 Esub = 0
Delayed hits
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```