New Enclosure background contribution Monte Carlo study

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Geant4 version: 4.10.02

Geometry

General setup: one single cylindrical crystal (diameter 3.7", length 8"), surrounded by the new copper enclosure, immersed in the bath of liquid scintillator (no insertion system). Crystal PMTs are also represented. Steel vessel geometry imported from the CAD design. The air box (2.2x1.8x1.6 m^3) is surrounded by a layer of 40 cm of Polyethylene, in turn surrounded by a layer of 90 cm of water.

Copper Enclosure:
The new copper enclosure geometry **(by D. Orlandi e M. Paris)** has been implemented in Geant4 **(by S. Cerioli)** using a copper G4Polycone reproducing both the lateral cylindrical surface and the end-caps. In *Figure 1*, the red line shows the profile of the G4Polycone. This geometrical object was used as radioactive source in the simulation. Further geometrical details of the new enclosure were also implemented (PTFE and copper frames for the crystal positioning; the 3 copper bars, PTFE crystal wrap) but for the moment they act just as passive component of the setup.

Copper Radioactivity:

The intrinsic enclosure copper radioactivity has been evaluated considering contributions from ^{40}K ($7 \pm 2 \cdot 10-4$ Bq/kg)[1], ^{238}U and progeny (5 ppt - secular equilibrium assumed), ^{232}Th and progeny (0.5 ppt - secular equilibrium assumed). Activities were assumed to be at the levels already achieved (or limits) by the CUORE Collaboration[2]. Values are summarized in *Table 1*. It is worth mentioning that the DAMA Collaboration reported[3] much higher limits of radioactivity for the copper box that houses the NaI(Tl) detectors: [^{238}U] < 0.5 ppb, [^{232}Th] < 1 ppb, [^{nat}K] < 0.6

[1] Paper in preparation by the CUORE collaboration.
[2] M. Clemenza et al. "Ultra Sensitive Neutron Activation Measurements of ^{232}Th in Copper", AIP Conf. Proc. **1338**, 37 (2011)
F. Alessandria et al., "Validation of techniques to mitigate copper surface contamination in CUORE", Astroparticle Physics 45 (2013) 13–22
[3] R. Bernabei et al., "The DAMA/LIBRA apparatus", NIM A 592 (2008) 297– 315.

ppm. Regarding a possible bulk contamination by an additional component of ^{210}Pb (not in equilibrium with the ^{238}U chain) the CUORE collaboration, in its "Measurement of the Two-Neutrino Double Beta Decay Half-life of 130Te with the CUORE-0 Experiment"[4] was not able to decouple such a contribution, identifying ^{210}Pb as a purely superficial contamination source. Based on this result, the analysis presented in this report does not take into account an additional ^{210}Pb bulk contamination, while an evaluation of the background from a possible surface contribution will be performed in the future.

Table 1: List of long-lived copper radioactive contaminants included in the Monte Carlo evaluation of the new enclosure background contribution.

Isotope	Activity / Concentration
^{40}K	0.7 mBq/kg
^{238}U	5 ppt
^{232}Th	0.5 ppt

Copper Cosmogenic Activation:

In the background simulation it has been also taken into account the copper cosmogenic radio-activation. L. Baudis et al.[5] reported a study on the cosmogenic activation of xenon and OFHC copper (*10.35 kg* sample) after 345 days of exposure to cosmic rays at *3470 m* above see level. The high-altitude activation measurements were then converted into specific saturation activities at sea level.

In this study radioisotopes were considered of interest based on their half-life ($T_{1/2} > 5$ days) and on their γ spectrum (at least one line above 60 keV with BR > 10% is requested). The full list, reported in *Table 2* along with their specific activities, has been considered for the evaluation of the contribution to the SABRE background due to the new copper enclosure.

[4] C. Alduino et al., "Measurement of the Two-Neutrino Double Beta Decay Half-life of 130Te with the CUORE-0 Experiment", e-Print: arXiv:1609.01666v1. Submitted to Eur. Phys. J. C.

[5] L.Baudis et al., "Cosmogenic activation of xenon and copper", Eur. Phys. J. C (2015) 75: 485

Table 2: List of cosmogenic isotopes included in the intrinsic background MC simulation. Specific saturation activities are reported along with half-lives.

Isotope	$T_{1/2}$ (days)	Activity (uBq/kg)
^{60}Co	1925	340
^{58}Co	71	798
^{57}Co	272	519
^{56}Co	77	108
^{54}Mn	312	154
^{46}Sc	84	27
^{59}Fe	44	47
^{48}V	16	39

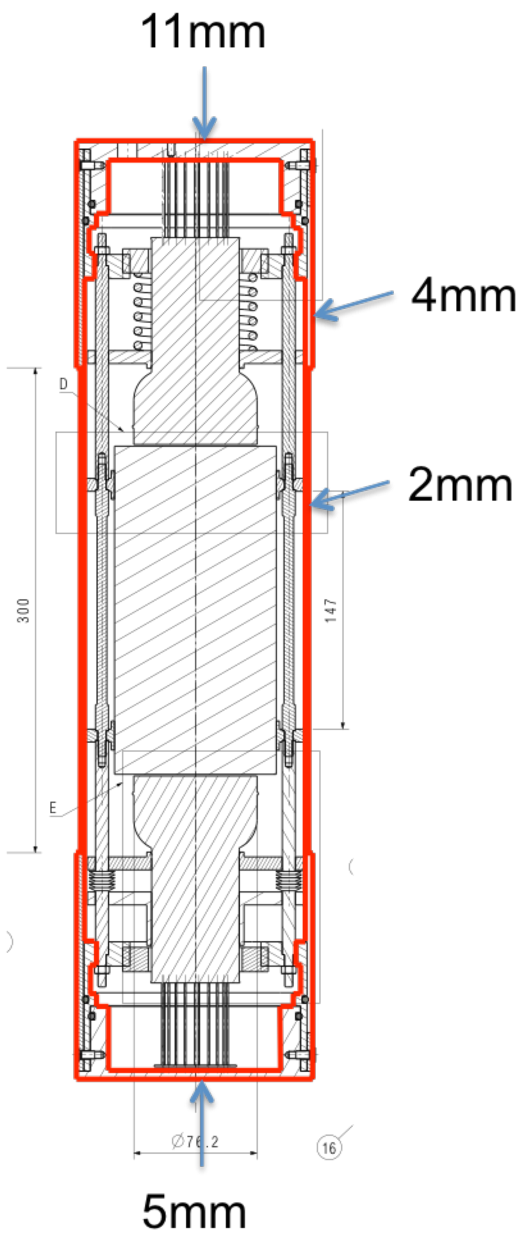

Figure 1: Profile of the copper G4Polycone used as active source of background.

Data treatment:

A gaussian smearing has been applied to the data to account for a 2% √E [MeV] energy resolution in the NaI(Tl) crystal. An energy resolution of 6% √E [MeV] has been applied to the veto signal. Veto is considered to have 100% efficiency above a 100 keV threshold.

RESULTS

Dark Matter Mode (DMM)

The new enclosure contribution to the background in DMM has been evaluated selecting MC events with energy deposition between 2 to 6 keV in the crystal and less than 100 keV in the Liquid Scintillator. *Figure 2* shows the background decomposition in two different moments: as soon as the copper enclosure gets underground (Top) and after 6 months (Bottom). The dominant contribution comes from cosmogenic isotopes, followed by ^{40}K. After 6 months, the cosmogenics contribution lowers to the constant level of the ^{40}K contribution, getting to ~1/10 of the total BG due to the enclosure in two years.

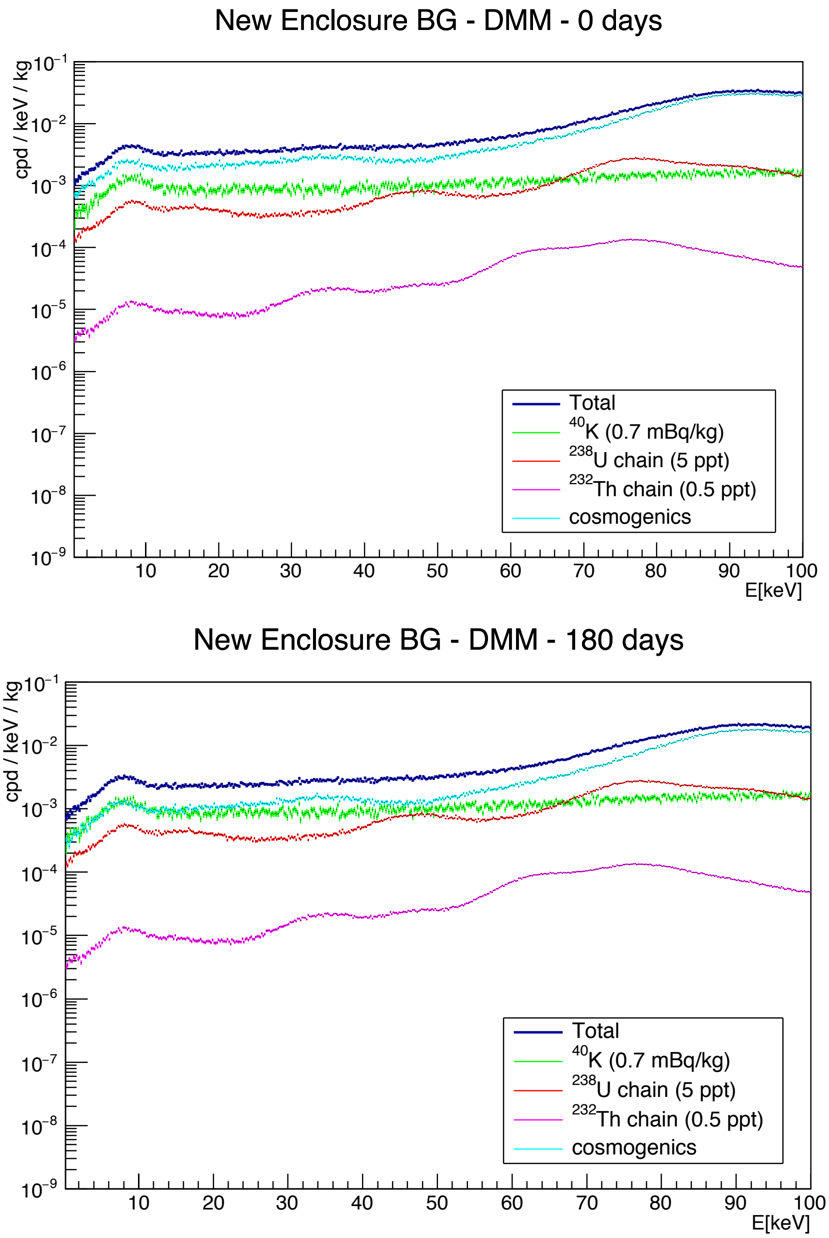

Figure 2: DMM background contribution due to the new copper enclosure @ 0 days [Top] and after 6 months in underground [Bottom], showing the reduction of the cosmogenic contribution.

Figure 3 shows the total background from enclosure with and without veto and the ratio of the two. In the 2-6 keV range the veto suppression factor is about 4.

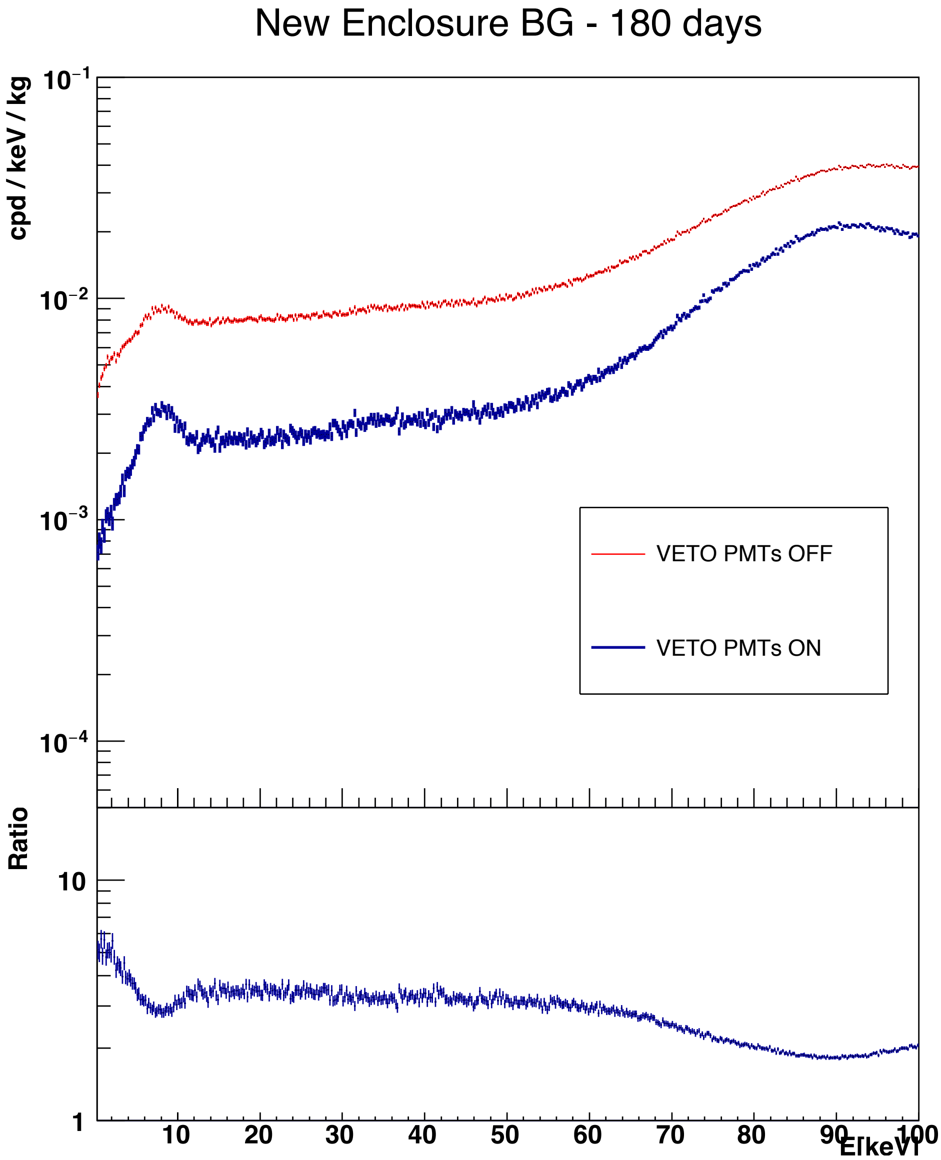

Figure 3: [Top] Total background contribution in DMM due to copper enclosure with and without veto after 6 months underground. [Bottom]: Veto suppression factor.

In DMM the background contribution due to the copper enclosure can then be preliminarely quantified as:

- 0.98 10^{-2} cpd/kg @ 0 days in underground
- 0.68 10^{-2} cpd/kg after 6 months in underground

This second value can be compared to the contribution from the crystal intrinsic contamination (0.47 cpd/kg). For completeness, in *Table 3* all the background contributions simulated so far are reported (**values refer to after 6 months in**

underground). Including the copper enclosure contribution, the total DMM background estimated so far amounts to **0.135 cpd / keV / kg**.

Table 3: Dark Matter Mode background summary after 6 months in underground.

Source	Concentration	Rate w VETO (cpd/kg)	Rate w/o VETO (cpd/kg)
^{40}K	9 ppb	$1.5\ 10^{-1}$	$8.0\ 10^{-1}$
^{87}Rb	0.1 ppb	$2.4\ 10^{-1}$	$2.4\ 10^{-1}$
^{210}Pb	0.01 mBq/kg (DAMA) - 0.6 mBq/kg (ANAIS)	**$3.0\ 10^{-2}$** (1.60)	**$3.0\ 10^{-2}$** (1.60)
^{238}U	0.6 ppt	$5.0\ 10^{-2}$	$5.0\ 10^{-2}$
^{232}Th	0.5 ppt	$4.0\ 10^{-3}$	$4.0\ 10^{-3}$
^{22}Na	0.8 mBq/kg	$8.0\ 10^{-3}$	$7.0\ 10^{-2}$
^{125}I	7.3 mBq/kg	$4.0\ 10^{-2}$	$4.0\ 10^{-2}$
^{126}I	4.3 mBq/kg	$6.0\ 10^{-4}$	$8.0\ 10^{-4}$
^{129}I	0.96 mBq/kg	$1.0\ 10^{-2}$	$1.0\ 10^{-2}$
External Gammas	0.25 γ /cm^2 /s	~ 10^{-3}	~ 10^{-2}
PE 40 cm	1.4 mBq/kg ^{40}K, 0.32 mBq/kq ^{214}Bi, 0.4 mBq/kg, ^{208}Tl (*0.36BR)	$3.3\ 10^{-4}$	$1.2\ 10^{-2}$
Copper enclosure	0.7 mBq/kg ^{40}K, 5ppt ^{238}U, 0.5 ppt ^{232}Th, Copper cosmogenics	$6.8\ 10^{-3}$	$2.6\ 10^{-2}$
Total NaI Intrinsics		$4.7\ 10^{-1}$ (2.04)	1.12 (2.69)
Total NaI Cosmogenics		$5.9\ 10^{-2}$	$1.2\ 10^{-1}$
Total Background		$5.4\ 10^{-1}$ (2.11)	1.29 (2.86)

The decomposition of the DMM background due to cosmogenic isotopes in copper is reported in *Figure 4*. Normalization is done using copper activity values as soon as the copper gets underground.

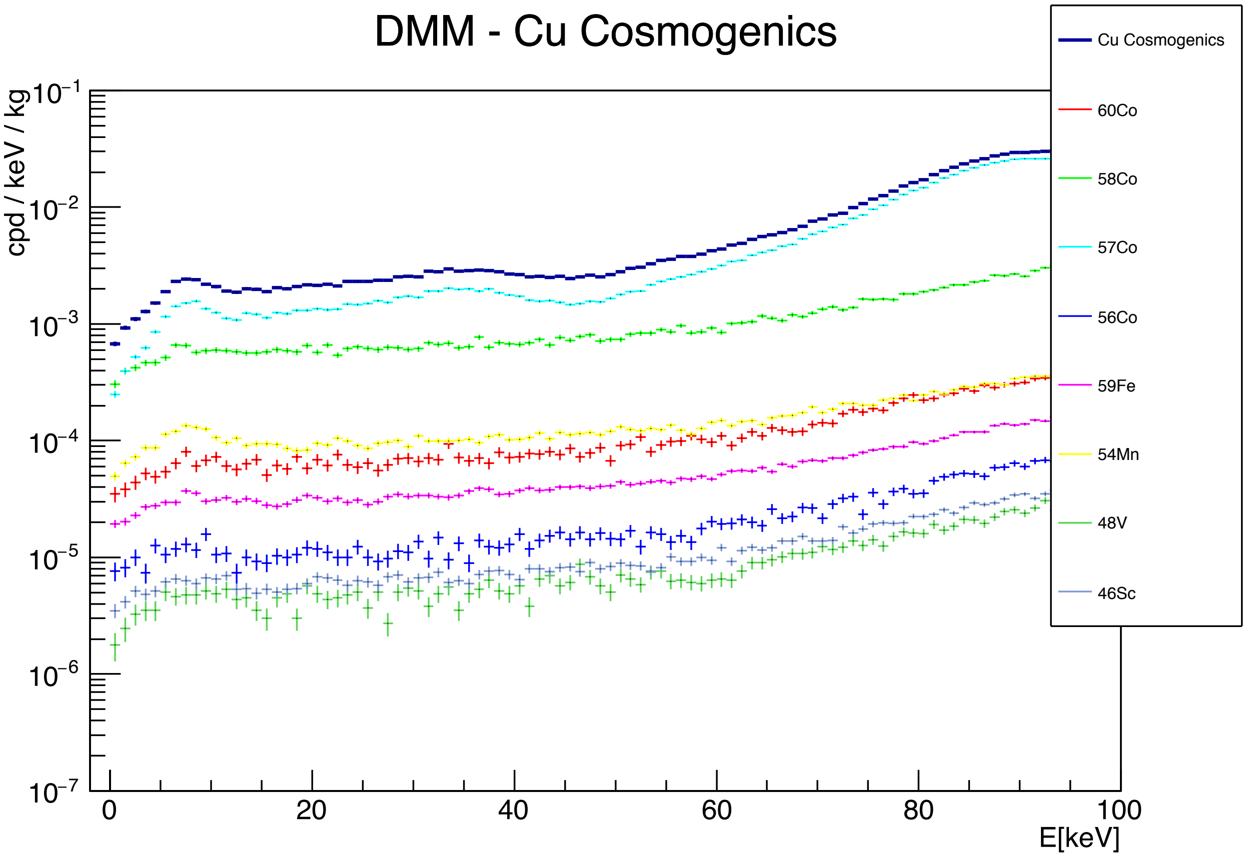

Figure 4: DMM background due to cosmogenic isotopes in copper enclosure (0 days in underground).

40K Measurement Mode (KMM)

The new enclosure contribution to the background in KMM has been evaluated selecting MC events with energy deposition between 2 to 4 keV (±1σ) in the crystal and 1.28 MeV to 1.64 MeV (±2.5σ) in the liquid scintillator.

Figure 5 shows the background decomposition in two different moments: as soon as the copper enclosure gets underground (Top) and after 2 years (Bottom).

In KMM the new copper enclosure generates a continuum background with the cosmogenic component being the dominant one (about a factor 10 higher then Uranium chain and ^{40}K contributions). The cosmogenic contribution results to be quite persistent, still being dominant after 2 years of data taking.

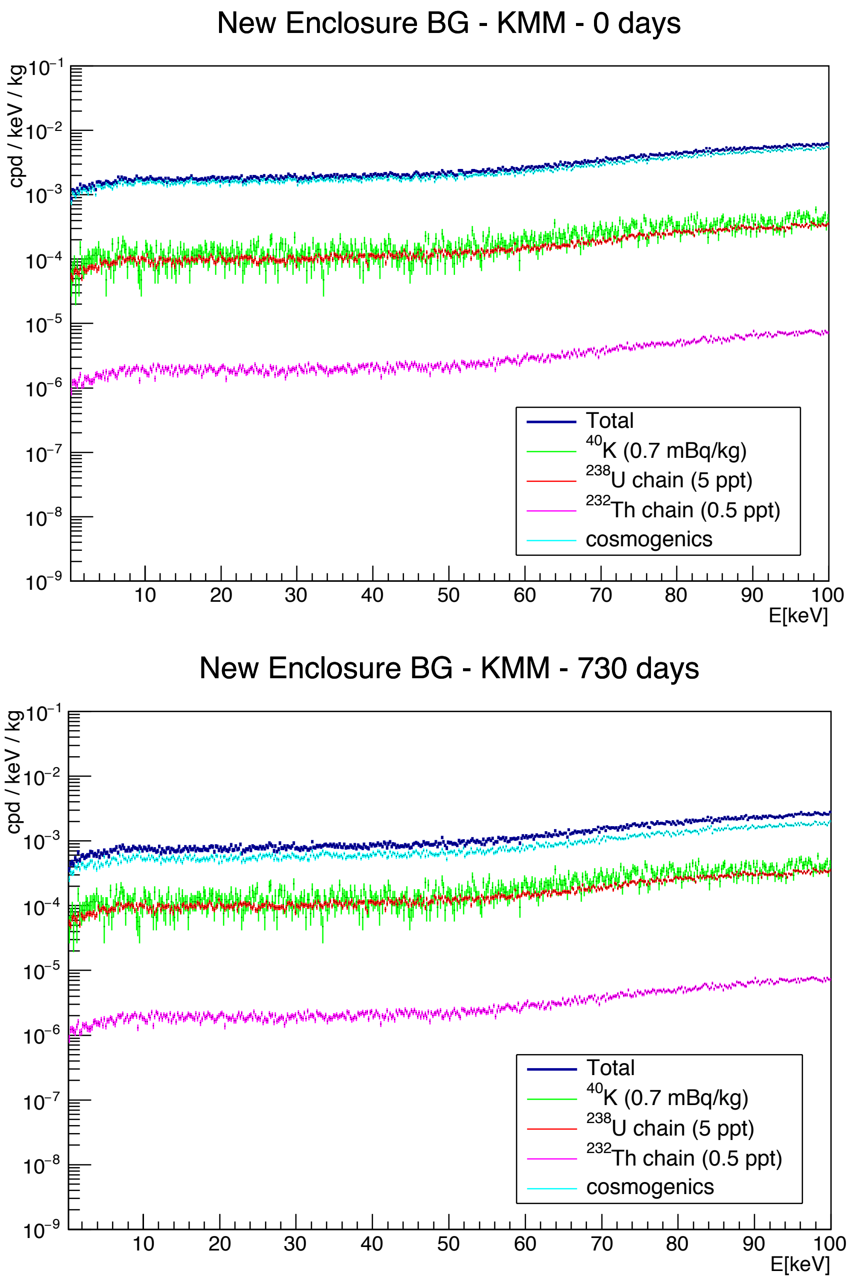

Figure 5: Background contribution in KMM due to the new copper enclosure @ 0 days [Top] and after 2 years in underground [Bottom], showing the reduction of the cosmogenic contribution.

The copper enclosure background contribution is slowly decreasing in time because of the decay of cosmogenic isotopes and can be preliminarely quantified as:

- 0.28 10^{-2} @ 0 days in underground
- 0.21 10^{-2} after 60 days

For completeness, in *Table 4* all the background contributions to the KMM simulated so far are reported. The signal to noise ratio is about 30.

Table 4: ^{40}K Measurement Mode background summary.

Source	Concentration or total flux	Rate (cpd/kg)
^{40}K	9 ppb	3.7 10^{-1}
^{87}Rb	0.1ppb	0
^{210}Pb	0.6 mBq/kg (ANAIS 37)	0
^{238}U	0.6 ppt	6.5 10^{-6}
^{232}Th	0.5 ppt	4.7 10^{-5}
^{126}I	4.3 mBq/kg	1.3 10^{-3} (5.3 10^{-5} after 60 days)
^{22}Na	0.8 mBq/kg	4.2 10^{-4} (4.0 10^{-4} after 60 days)
External gammas	0.25 gamma/cm^2/s	7.0 10^{-3}
PE 40 cm	1.4 mBq/kg ^{40}K, 0.32 mBq/kq ^{214}Bi, 0.4 mBq/kg, ^{208}Tl (*0.36 BR)	~9.1 10^{-4}
Copper Enclosure	0.7 mBq/kg ^{40}K, 5ppt ^{238}U, 0.5 ppt ^{232}Th, Copper cosmogenics	2.8 10^{-3} (2.1 10^{-3} after 60 days)
Random Coincidences		4.4 10^{-5}
Total background		1.2 10^{-2} (1.0 10^{-2} after 60 days)
S/N		~ 30

The decomposition of the cosmogenic component is reported in *Figure 6*. Normalization is done using copper activity as soon as the copper gets underground. Contributions from ^{54}Mn and ^{57}Co are completely absent.

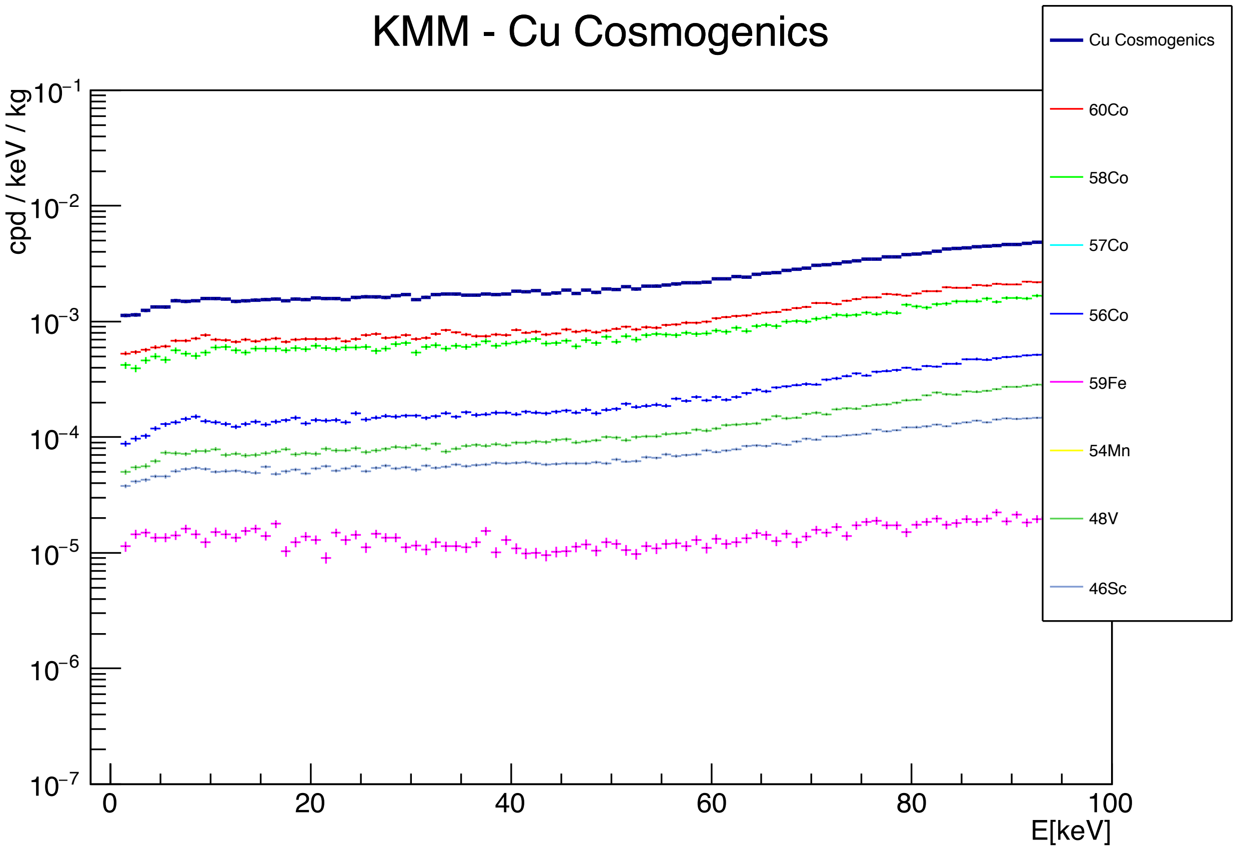

Figure 6: KMM background due to cosmogenic isotopes in copper enclosure (0 days in underground).