Update of MC Simulations

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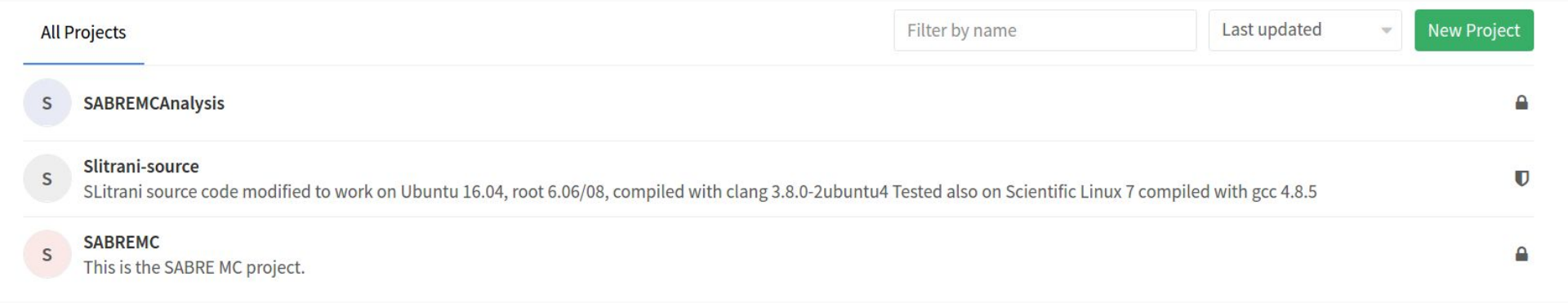
Simulation code

- The code for Monte Carlo simulation is on a private gitlab group hosted by INFN servers https://baltig.infn.it/SABRE
- Access is granted to INFN members and external collaborators with INFN AAI credentials (an INFN member have to ask credentials for externals)
- Code is structured in:
  - **SABREMC:** Simulation code, GEANT4 based: Geometry, physics interaction, propagation, detectors
  - **SABREMCAnalysis:** Analysis code, and scripts to create histograms, plots and tables, C++ and python based
- Roma and Melbourne are also working on light collection simulation with SLitrani, a ROOT-based tool to simulate optical photons https://crystalclear.web.cern.ch/crystalclear/SLitraniX/SLitrani/index.html
  - **SLitrani-source** repository contains SLitrani source code tested to work on modern linux distributions and ROOT6



Status of the Monte Carlo simulations

Link to the spreadsheet with contaminations and background rates in DMM and KMM:
https://docs.google.com/spreadsheets/d/1j-zV_J_Qijx5RKv6jD9fb4xSRTMqARNcoqU7qkc3jXw/edit?usp=sharing

Complete simulations with the "old" geometry (no CIS, simplified vessel, old shield design):

- Crystal PMTs (kovar body + quartz window + ceramic plate)
- Enclosure copper body

Complete simulations with latest geometry for PoP:

- Enclosure copper belts and bars
- Enclosure teflon belts
- CIS Copper
- CIS Steel
- Steel Vessel (see Francesco)

NEW !

Ongoing simulations:

- Crystal (Maddalena)
- Crystal wrapping (Claudia)
- Liquid scintillator (Francis)
- Vessel PMTs (Giulia)

To do

- Decide wether old complete simulations have to be repeated
- Shielding (PE)
- External backgrounds
  - Need simulation optimization
  - to discuss if will go in another paper

Radioactive contamination in crystal PMTs

Crystal PMTs Hamamatsu R11410 3”

## Volume_name	Isotope	Activity[mBq/PMT]
#CrystalPMTBody	40K	<0.99
#CrystalPMTBody	60Co	7e-02
#CrystalPMTBody	238UUpperChain	<0.095
#CrystalPMTBody	238ULowerChain	<0.26
#CrystalPMTBody	232ThChain	<0.36
#CrystalPMTBody	208Tl	<0.1296(BR 36%)
#CrystalPMTBody	212Po	<0.2304(BR 64%)
#CrystalPMTWindow	40K	<8.1e-02
#CrystalPMTWindow	60Co	<4.5e-03
#CrystalPMTWindow	238UUpperChain	<0.33
#CrystalPMTWindow	238ULowerChain	0.036
#CrystalPMTWindow	232ThChain	<1.2e-02
#CrystalPMTWindow	208Tl	<0.432e-02(BR 36%)
#CrystalPMTWindow	212Po	<0.768e-02(BR 64%)
#CrystalPMTFeedthrough	40K	<1.1
#CrystalPMTFeedthrough	60Co	<0.016
#CrystalPMTFeedthrough	238UUpperChain	2.4
#CrystalPMTFeedthrough	238ULowerChain	0.26
#CrystalPMTFeedthrough	232ThChain	<0.21
#CrystalPMTFeedthrough	208Tl	<0.0756(BR 36%)
#CrystalPMTFeedthrough	212Po	<0.1536(BR 64%)

lasses of PMTs components (to convert the numbers in the table in mBq/kg):
- Kovar Body: 0.091 kg
- Quartz window: 0.030 kg
- Ceramic Feedthrough plate: 0.015 kg

Activities in mBq/kg from reference https://arxiv.org/pdf/1503.07698.pdf (Tab. 3 e 4).

Masses of PMT parts (from GEANT):

-PMT body (kovar): 91.7 g

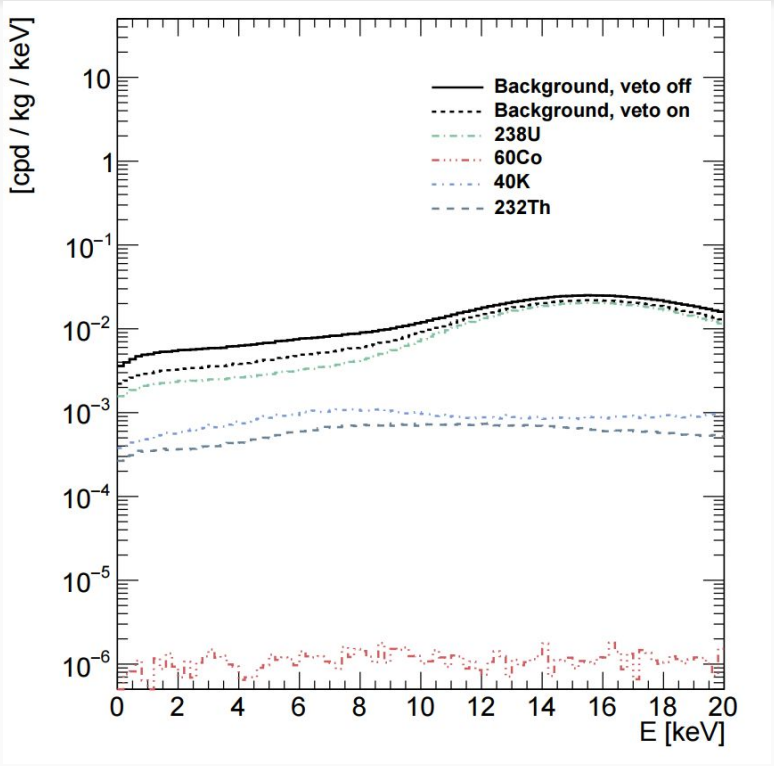
-PMT window (quartz): 30 g

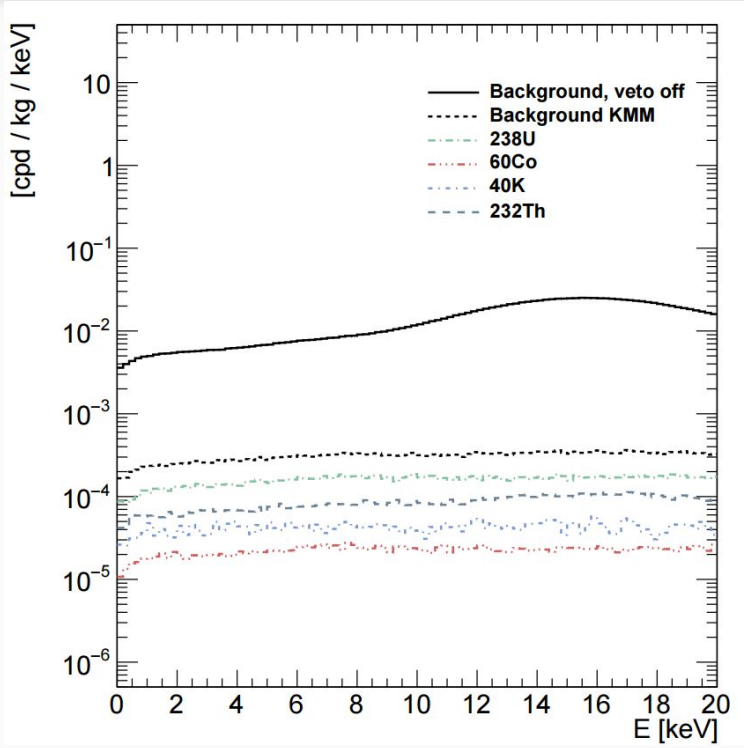
-PMT feedthrough plate (ceramic): 15.3 g

consistent with what reported in the XENON reference.

We have followed the approach of Emily Shields in her PhD thesis: use the best limit on U238 for the upper part of the chain and the best limit on Ra226 for the lower part.

Background from 1 PMT crystal





#Isotope	Bkg [cpd/kg]	BkgDMM [cpd/kg]	BkgKMM [cpd/kg]
40K	0.003759 +/- 2.2e-05	0.003282 -/+ 2e-05	9.231e-05 +/- 3.8e-06
238U chain	0.01599 +/- 3.2e-05	0.01139 -/+ 2.8e-05	0.0003001 +/- 3.3e-06
60Co	0.0004206 +/- 2e-06	4.331e-06 -/+ 2.1e-07	4.308e-05 +/- 6.5e-07
232Th chain	0.006772 +/- 1.7e-05	0.001923 -/+ 9.6e-06	0.0001464 +/- 2.5e-06
Total	**0.02694 +/- 4.2e-05**	**0.0166 -/+ 3.6e-05**	**0.0005819 +/- 5.7e-06**
K40 Crystal	0.8879 +/- 0.0046	0.1437 +/- 0.0019	0.3794 +/- 0.0030

Background from enclosure teflon

## Volume_name	Isotope	Activity[Bq/kg]
#TeflonBelts	40K	<2.25e-3
#TeflonBelts	238U_UpperChain	<6.2e-3
#TeflonBelts	238U_LowerChain	<0.31e-3
#TeflonBelts	232Th_UpperChain	<0.39e-3
#TeflonBelts	232Th_LowerChain	<0.16e-3
#TeflonBelts	208Tl	<5.76e-5 (BR 36%)
#TeflonBelts	212Po	<1.24e-4 (BR 64%)
#TeflonBelts	60Co	<0.11e-3
#TeflonBelts	137Cs	<0.13e-3

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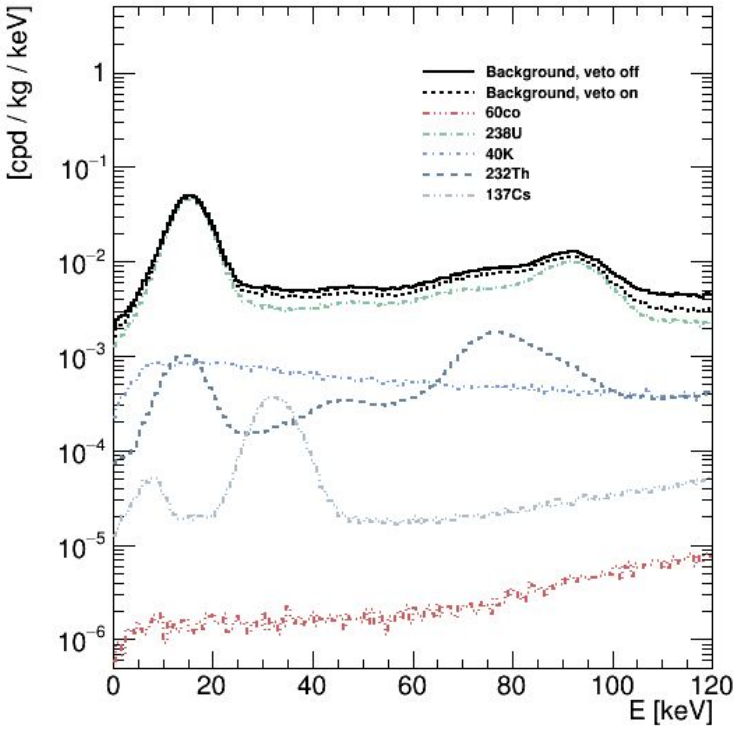
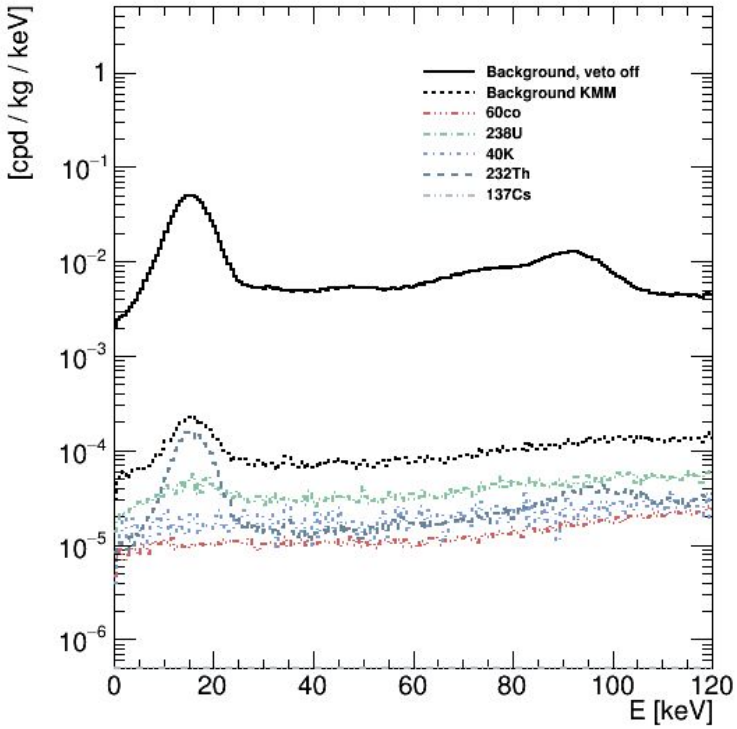
Material screening and selection for XENON100

Background from enclosure teflon





#Filename	Bkg [cpd/kg]	BkgDMM [cpd/kg]	BkgKMM [cpd/kg]
#			
40K	0.00246 +/- 3.8e-05	0.002289 -/+ 3.7e-05	3.273e-05 +/- 4.4e-06
238U	0.01221 +/- 0.00013	0.01118 -/+ 0.00013	5.313e-05 +/- 3.1e-06
60co	0.0001699 +/- 2.2e-06	5.062e-06 -/+ 3.8e-07	1.789e-05 +/- 7.2e-07
232Th	0.001417 +/- 1e-05	0.0004855 -/+ 5.5e-06	2.268e-05 +/- 1.4e-06
137Cs	0.0002802 +/- 3.3e-06	0.000127 -/+ 2.2e-06	0 +/- 0
#			
Total	**0.01654 +/- 0.00014**	**0.01408 -/+ 0.00014**	**0.0001264 +/- 5.6e-06**

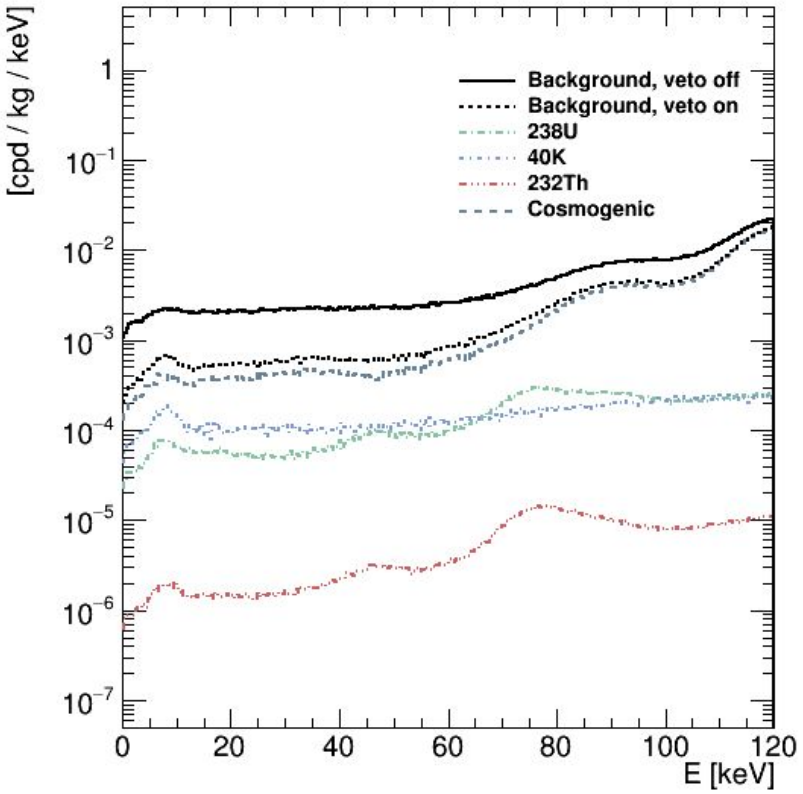
Background from Enclosure copper (belts & bars)

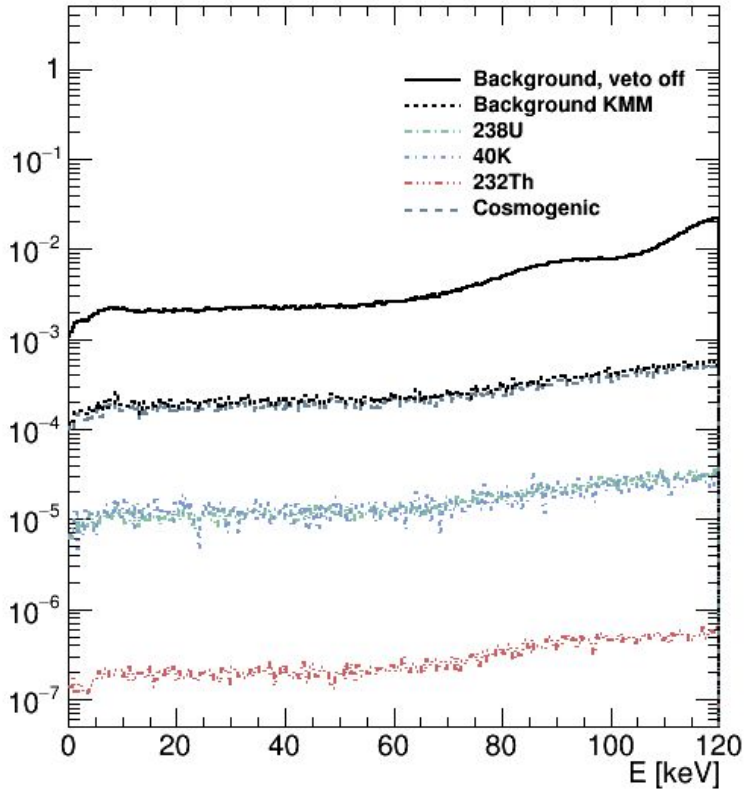
## Volume_name	Isotope	Activity[Bq/kg]
#CisCopperTube	40K	0.7e-3
#CisCopperTube	56Co	108e-6
#CisCopperTube	57Co	519e-6
#CisCopperTube	58Co	798e-6
#CisCopperTube	60Co	340e-6
#CisCopperTube	54Mn	154e-6
#CisCopperTube	238UChain	6.22e-5
#CisCopperTube	232ThChain	2.04e-6
#CisCopperTube	208Tl	7.344e-7 (BR 36%)
#CisCopperTube	212Po	1.3056e-6 (BR 64%)

Contamination and activities taken from CUORE:
http://www.sciencedirect.com/science/article/pii/S0927650513000443

Cosmogenic activities taken from xenon:
https://arxiv.org/pdf/1507.03792v2.pdf

Background from Enclosure Copper belts and bars





Isotope	Bkg [cpd/kg]	BkgDMM [cpd/kg]	BkgKMM [cpd/kg]
40K	0.0005698 +/- 1.2e-05	0.0004243 -/+ 1e-05	2.078e-05 +/- 2.2e-06
238U	0.0005072 +/- 5.7e-06	0.0001932 -/+ 3.5e-06	2.058e-05 +/- 1.1e-06
232Th	1.874e-05 +/- 1.8e-07	5.085e-06 -/+ 1e-07	2.898e-07 +/- 2.1e-08
Cosmogenic	0.00636 +/- 6e-05	0.001168 -/+ 2.7e-05	0.0003046 +/- 1.2e-05
Total	**0.007455 +/- 6.1e-05**	**0.00179 -/+ 2.9e-05**	**0.0003462 +/- 1.2e-05**

Background from CIS (Copper + Steel)

Contamination and activities taken from CUORE:
http://www.sciencedirect.com/science/article/pii/S0927650513000443

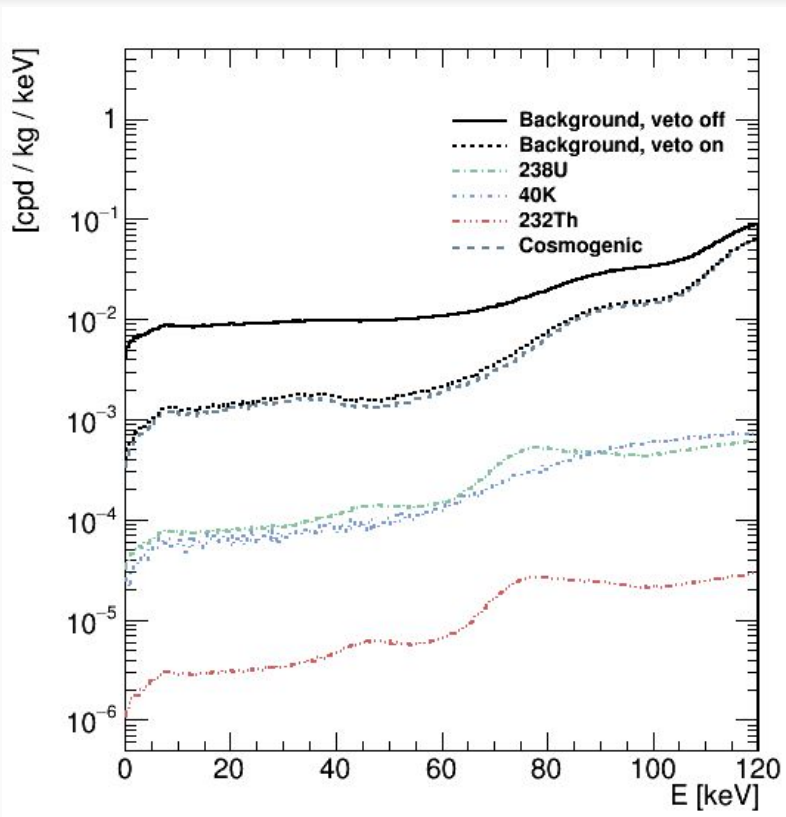
Cosmogenic activities taken from xenon:
https://arxiv.org/pdf/1507.03792v2.pdf

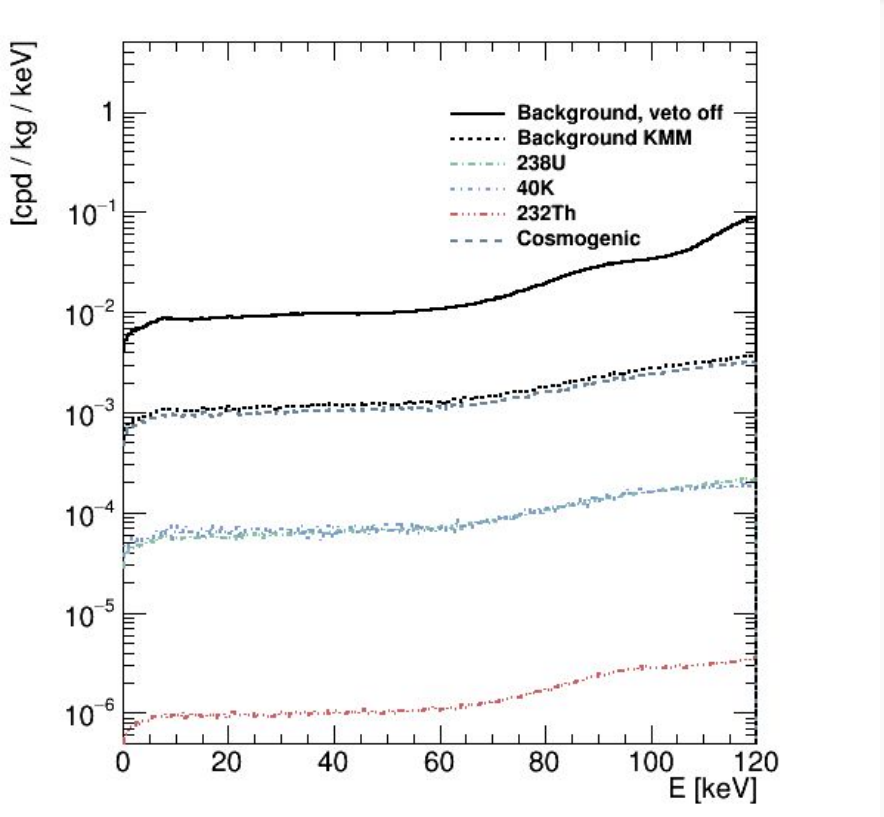
## Volume_name	Isotope	Activity[Bq/kg]
#CisCopperTube	40K	0.7e-3
#CisCopperTube	56Co	108e-6
#CisCopperTube	57Co	519e-6
#CisCopperTube	58Co	798e-6
#CisCopperTube	60Co	340e-6
#CisCopperTube	54Mn	154e-6
#CisCopperTube	238UChain	6.22e-5
#CisCopperTube	232ThChain	2.04e-6
#CisCopperTube	208Tl	7.344e-7 (BR 36%)
#CisCopperTube	212Po	1.3056e-6 (BR 64%)

CIS STEEL
https://phy-sabreweb.princeton.edu/sabrewiki/index.php/Veto_North_-_Information_on_Raw_Materials

## Volume_name	Isotope	Activity[Bq/kg]
#CISSteelBar	40K	1,24E-04
#CISSteelBar	238UChain	3.732e-3
#CISSteelBar	232ThChain	4.07e-4
#CISSteelBar	208Tl	1.4652e-4 (BR 36%)

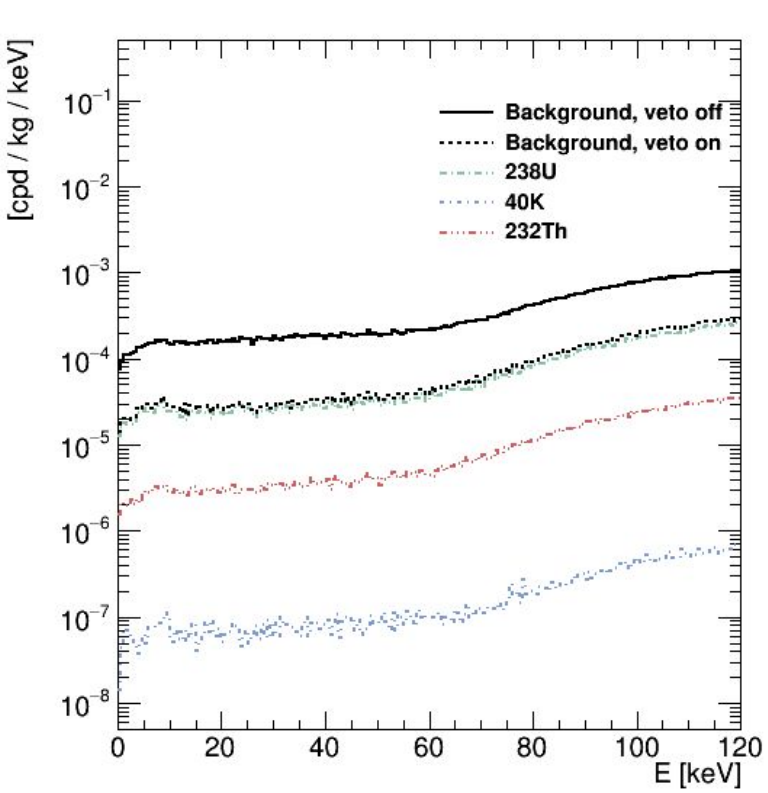
Background from CIS Copper

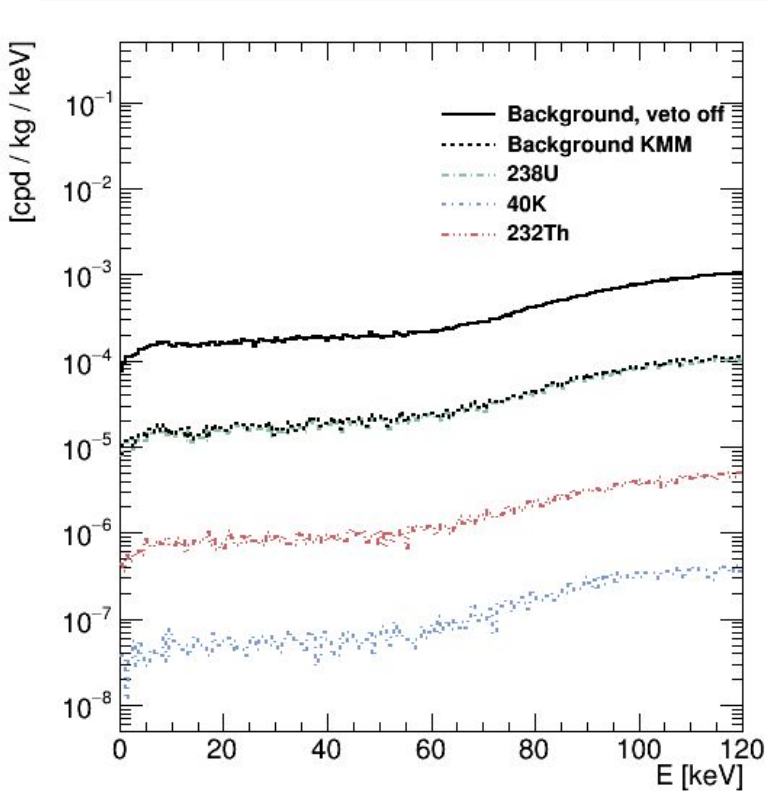




#Isotope	Bkg [cpd/kg]	BkgDMM [cpd/kg]	BkgKMM [cpd/kg]
40K	0.0009237 +/- 1.2e-05	0.0001874 -/+ 5.2e-06	0.0001159 +/- 4.1e-06
238U	0.00154 +/- 4.5e-06	0.000243 -/+ 1.8e-06	0.0001014 +/- 1.1e-06
232Th	6.358e-05 +/- 1.5e-07	9.019e-06 -/+ 6.1e-08	1.718e-06 +/- 2.4e-08
Cosmogenic	0.02778 +/- 8e-05	0.003342 -/+ 3e-05	0.001696 +/- 1.9e-05
Total	**0.0303 +/- 8.1e-05**	**0.003782 -/+ 3e-05**	**0.001915 +/- 1.9e-05**

Background from CIS steel





#Isotope	Bkg [cpd/kg]	BkgDMM [cpd/kg]	BkgKMM [cpd/kg]
40K	1.136e-06 +/- 4.4e-08	2.201e-07 -/+ 1.9e-08	1.014e-07 +/- 1.3e-08
238U	0.0004809 +/- 7.1e-06	9.128e-05 -/+ 3.1e-06	2.494e-05 +/- 1.6e-06
232Th	6.275e-05 +/- 7.3e-07	9.956e-06 -/+ 3.2e-07	1.221e-06 +/- 9.2e-08
Total	**0.0005448 +/- 7.1e-06**	**0.0001015 -/+ 3.1e-06**	**2.626e-05 +/- 1.6e-06**