MC simulations for CUPID-Mo background model

Pia Loaiza

Towards a background model

For the construction of the background model it is crucial to select a relevant list of sources to fit the experimental data.

The contribution of each source is simulated with a Monte Carlo.

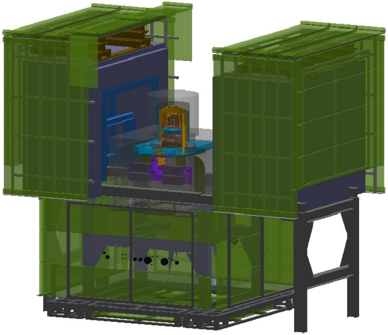
The Monte Carlo program

- Based on EDELWEISSIII Monte Carlo simulation
- At present running on GEANT4.10.03

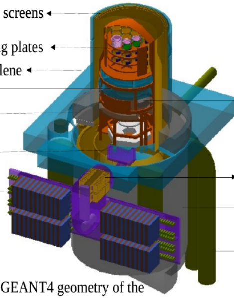
Changes for CUPID-Mo simulations w.r.t EDW3 code:

- Particle generator: Add DECAY0 as particle generator, used as default. DECAY0 is an event generator for simulation of double beta processes and radioactive decays developped and maintained by V. Tretyak
- Physics List: Shielding Physics List replaced by Livermore for ElectroMagnetic processes. Physics List from geant4/examples/advanced/underground_physics (binning, energy ranges for EM, Hadronic, Ion processes)
- Range cuts explicitely declared in Physcis List→ cuts can be chosen for a right balance of accuracy and CPU time
- CUPID-Mo bolometer geometry implemented (slide 4)

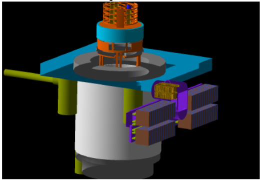
GEANT4 geometry



Shielding geometry



GEANT4 geometry of the EDELWEISS set-up

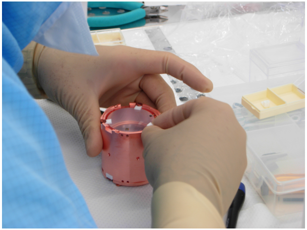


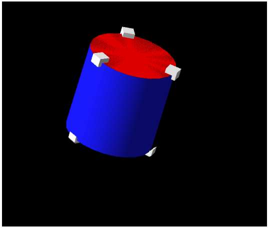
GEANT4 implementation of LiMo bolometer geome

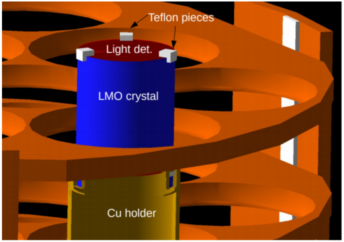
LMO crystals, PTFE holders, Light detector, Copper holder and springs implemented

Data from Anastasiia

	size (mm)	Total mass (g)
Enr.LMO crystal	44x45	211
Ge Light Detector	44x0.17	1.37
Copper Holder	50.5x54.5	287.5
Teflon LMO Top	10x10	1.5 x 3
Teflon LMO bottom	3x2	0.3 x 3
Teflon LD	5x1x1	1.8 x 3
Kapton	5x5	- x 3
M3 screws	12 mm	3x3
M3 screws	6 mm	1.5x3
Top Cap	50.5x2	55
Bottom Cap	50.5x2	40
Copper bars	180x20X2	105x3
M3 screws	6 mm	9x18
Spring		0.43 x 15



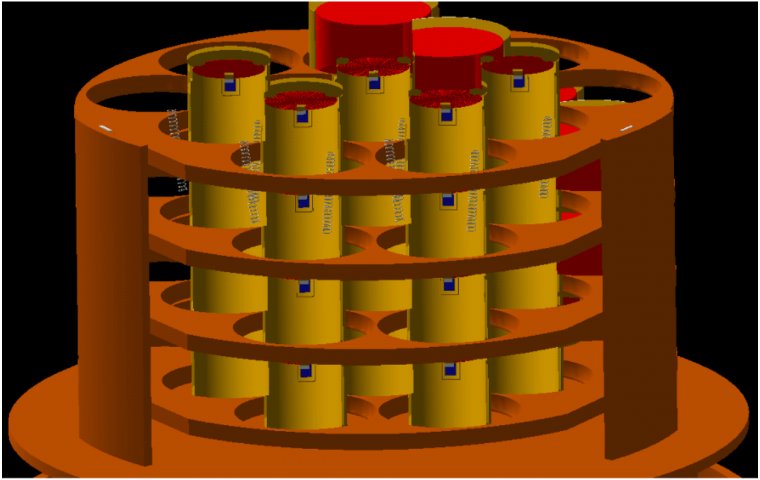




GEANT4 geometry for LiMo bolometers

CUPID-Mo detectors

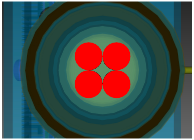
GEANT4 geometry for CUPID-Mo towers:

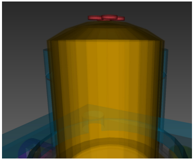


- Detectors configuration as Input file and loaded with line command in macrofile /EDWIII/boloConfigFile boloConfigRun314.txt

V. Kobyshev, D. Poda, A. Zolotarova

- Four plastic containers with KCl positioned on top of 300K screen





	N_{decays}	N_{peak}	Efficiency in peak	$N_{cont.}$ (1.1-1.2 MeV)	Efficiency (1.1-1.2 MeV)	Peak/Cont.
ZMO sim	$1.00\cdot10^{8}$	465(22)	$4.65(22)\cdot10^{-6}$	371(19)	$3.71(19)\cdot10^{-6}$	1.25(12)
LMO sim	$1.00\cdot10^{8}$	45(7)	$0.45(7)\cdot10^{-6}$	68(8)	$0.68(8)\cdot10^{-6}$	0.66(18)
ZMO exp	$1.74(2)\cdot10^{9}$	6177(79)	$3.56(9)\cdot10^{-6}$	5674(75)	$3.26(4)\cdot10^{-6}$	1.09(4)
LMO exp	$1.74(2)\cdot10^{9}$	663(26)	$0.38(2)\cdot10^{-6}$	1194(35)	$0.69(2)\cdot10^{-6}$	0.55(4)
ZMO sim/exp			**1.31(9)**		**1.14(7)**	**1.15(15)**
LMO sim/exp			**1.18(17)**		**0.99(15)**	**1.2(4)**

Agreement simulation and experimental data for LMO $\sim$ 20%

Background sources

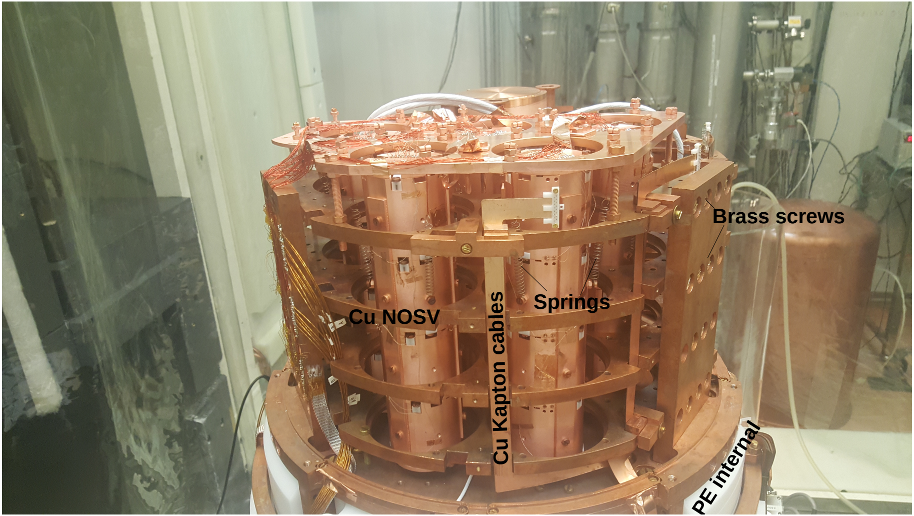
The strategy to choose the list of relevant sources:

- List of known sources from construction and their radiopurity measurements
- Gamma lines identified in experimental spectrum

Sources can be distinguished as:

- Internal = crystal
- Next to bolometers (slide 4)
- Near sources = roughly all inside 10 mK
- External = Everything Not at 10 mK, below the bolometers plates or at the level of 300K screen

Known sources: the set-up



Known sources

	Element	Mass	Activity (mBq/kg) ^{226}Ra	Activity (mBq/kg) ^{228}Th	Total activity (mBq) ^{226}Ra	Total activity (mBq) ^{228}Th
Next to bolo	Ge-LD[a]	1.37 g	^{238}U: $<$ 0.019	^{232}Th: $<6\ 10^{-3}$	$<2.6\ 10^{-5}$	$<8.2\ 10^{-6}$
	NTD[a]	60 g	^{238}U: $<$ 12	^{232}Th: $<$4.1	$<$ 0.7	$<$ 0.2
	PTFE clamps[a]	10.8 g	^{238}U: $<$0.022	^{232}Th: $<6.1\ 10^{-3}$	$<2.4\ 10^{-4}$	$<6.6\ 10^{-5}$
	Cu screws	176 g				
	Springs	8.1 g	(11 $\pm$ 3)	(21 $\pm$ 5)	**0.09 $\pm$0.02**	**0.20 $\pm$0.05**
Near (10 mK)	**Kapton connect.**	31 g	14 $\pm$7	67 $\pm$31	0.4$\pm$0.2	**2 $\pm$1**
	Cu Kapton cables	0.51 kg	8 $\pm$6	15 $\pm$10	**4$\pm$3**	**8 $\pm$ 5**
	NOMEX cables	4 g	21	19	0.08	0.08
	CuBe press-fit	0.5 g	102 $\pm$59	153 $\pm$31	0.05 $\pm$0.03	0.08 $\pm$0.02
	Brass screws	2 kg	-	3.5 $\pm$0.9	-	**7 $\pm$ 1.8**
	Cu NOSV[b]	295 kg	$<$0.016	$<$0.012	$<$4.7	$<$3.5
Ext	Cu CuC2[c]	328 kg	(0.025 $\pm$ 0.015)	(0.033 $\pm$ 0.016)	8 $\pm$ 5	11 $\pm$ 6
1K	**PE internal**	151 kg	(0.65 $\pm$ 0.08)	(0.30 $\pm$ 0.07)	**98 $\pm$ 12**	**45 $\pm$ 11**
further	**Conn. 1K to 100K**	430 g	(2600 $\pm$ 400)	(450 $\pm$ 44)	**1118 $\pm$ 170**	**194 $\pm$ 20**

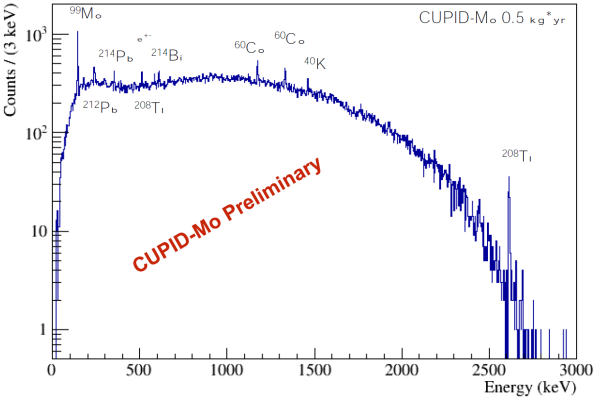
Others:

- Springs: ^{228}Ra:(26$\pm$ 9) mBq/kg; ^{40}K:(3.6$\pm$ 0.4) Bq/kg
- CuBe press-fit: ^{238}U:(12$\pm$ 2) Bq/kg; ^{232}Th:(980$\pm$ 196) mBq/kg
- Brass-screws: ^{210}Pb:(620 $\pm$ 254) mBq/kg; ^{137}Cs:(2.6 $\pm$ 1.5) mBq/kg

[a] CUORE-0, Measurement of the two neutrino double-beta decay half-life of 130Te with COURE-0 experiment, Alduino et al, EPJC 77, 13 (2017)

[b] From M. Laubensten, Appl. Rad. and Isot. 61 (2004) 167

[c] M. Laubensten, private comm.



Energy (keV)	Isotope
140	^{99}Mo
238	^{212}Pb
352	^{214}Pb
583	^{208}Tl
609	^{214}Bi
1173	^{60}Co
1332	^{60}Co
1460	^{40}K
2615	^{208}Tl

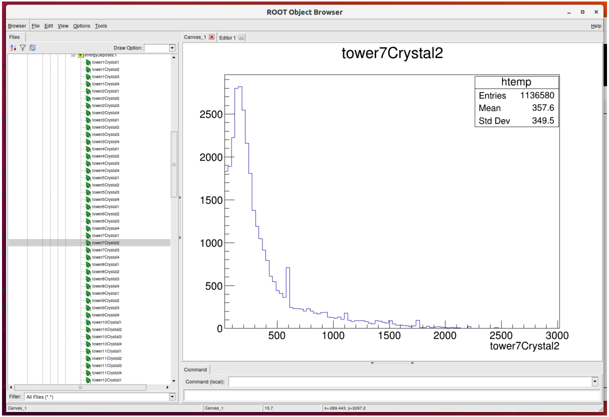
Besides the 'known sources':

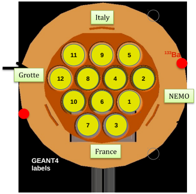
- ^{99}Mo, $T_{1/2} = 2.75$ d, from neutron activation due to AmBe source
- ^{60}Co unexpected contamination

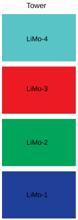
Identified background sources

- Internal = crystal : $2\beta2\nu$, ^{40}K, ^{210}Pb
- Next to bolometers = springs, ^{60}Co in LD5?
- Near sources = brass-screws, kapton connectors, Cu kapton cables, ^{60}Co from source?
- External = PE internal, connectors, Others

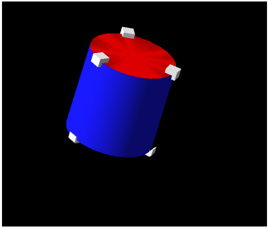
A simulation takes typically 12hs - 24 hs at the In2p3 Computing Center.
One simulation is splitted in 10 parallel jobs.
The files and the code are in the git repository:
https://gitlab.in2p3.fr/loaiza/cupid-mo-sims/



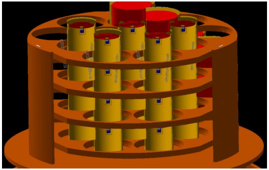


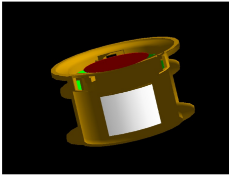


Internal sources == crystal



- $2\beta2\nu$ SSD 2b2nu of ^{100}Mo (gs), 10^7 evts generated ✓
- ^{40}K, 10^7 evts generated ✓
- ^{210}Bi, 10^7 evts generated ✓
- ^{210}Pb, 10^7 evts generated ✓

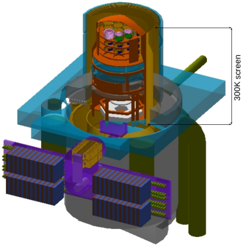




- Springs
  - ^{208}Tl, 10^7 evts generated ✓
  - ^{212}Pb
  - ^{214}Bi 10^7 evts generated ✓
  - ^{214}Pb
  - ^{40}K 10^7 evts generated ✓
- Kapton connectors in Edelweiss detectors:
  - ^{208}Tl, 10^6 evts generated ✓
  - ^{212}Pb, 10^6 evts generated ✓
  - ^{214}Bi, 10^6 evts generated ✓
  - ^{214}Pb, 10^6 evts generated ✓
- Brass screws
  - ^{208}Tl, 10^6 evts generated ✓
  - ^{212}Pb, 10^6 evts generated ✓
  - ^{210}Pb

External sources

Everything not at 10 mK, below the bolometers plates, at the level of 300K screen or external lead. Contaminations simulated on 300K screen.



- ^{208}Tl, 10^8 evts generated ✓
- ^{212}Pb, 10^8 evts generated ✓
- ^{214}Bi, 10^8 evts generated ✓
- ^{214}Pb, 10^8 evts generated ✓
- ^{40}K, 10^8 evts generated ✓

- Main background sources identified
- 18 background sources simulated for background model

To do:

- ^{60}Co plus some radionuclides
- Calibration and simulation as benchmarking for the MC
- MC code: add time and type of particle in output

CUPID-Mo
^{56}Co source simulation results

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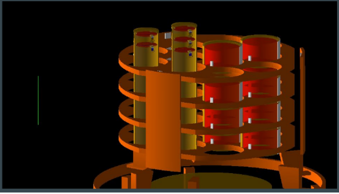
Mykola Zarytsky

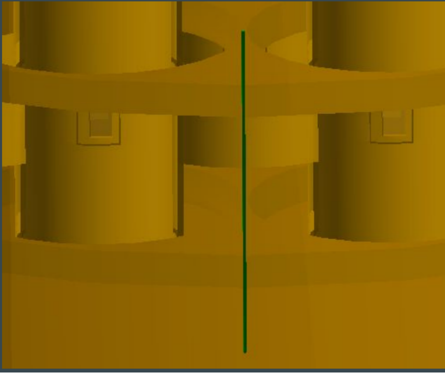
^{56}Co source geometry in GEANT4

Source position: on 300K screen, facing CUPID-Mo towers

The source geometry

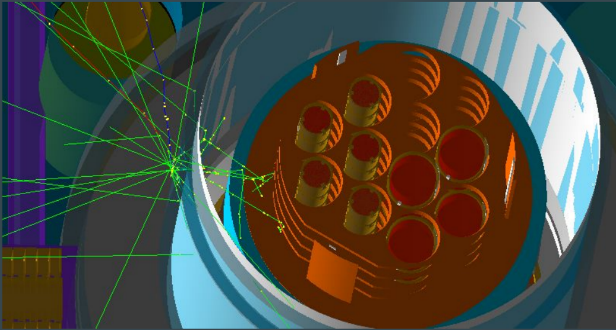
- Shape - cylinder
- Height - 10 cm
- Diameter - 1 mm
- Mass - 0.62 g
- Material - Fe wire





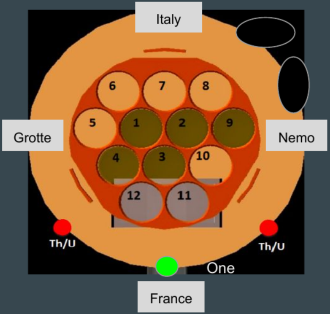
Particles generation

- ^{56}Co source
- No such nuclear in Decay0
- G4Source Ion used
  - A = 56
  - Z = 27



10 events tracks

Overall gamma rate in a single crystal



Events generated for one and two - 2.8 * 10^7
Crystal 1 is the bottom one.

Values are in 10^{-3} counts per decay.

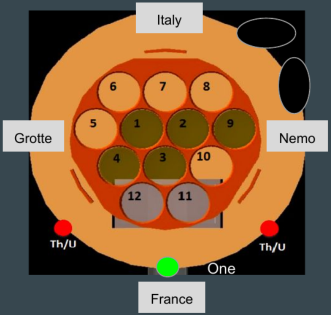
One:

Tower / Crystal	Tower 10	Tower 11	Tower 12	Tower 3	Tower 4
Crystal 1	1.598(8)	3.94(1)	3.91(1)	2.085(9)	1.585(8)
Crystal 2	1.571(7)	3.98(1)	3.94(1)	2.086(9)	1.535(7)
Crystal 3	1.448(7)	3.63(1)	3.62(1)	1.869(8)	1.43(7)
Crystal 4	1.288(7)	2.94(1)	2.92(1)	1.636(8)	1.27(7)

Two:

Tower / Crystal	Tower 10	Tower 11	Tower 12	Tower 3	Tower 4
Crystal 1	3.56(1)	5.17(1)	5.18(1)	3.40(1)	3.54(1)
Crystal 2	3.60(1)	5.17(1)	5.15(1)	3.42(1)	3.54(1)
Crystal 3	3.23(1)	4.69(1)	4.68(1)	3.06(1)	3.18(1)
Crystal 4	2.75(1)	3.94(1)	3.94(1)	2.71(1)	2.73(1)

Overall peak rate in a single crystal



Events generated for one and two - 2.8 * 10^7
Crystal 1 is the bottom one.
Values are in 10^{-6} counts per decay.

One:

Tower / Crystal	Tower 10	Tower 11	Tower 12	Tower 3	Tower 4
Crystal 1	0.6(1)	1.7(2)	1.2(2)	0.9(2)	0.4(1)
Crystal 2	0.5(1)	1.9(3)	1.8(3)	0.6(2)	0.5(1)
Crystal 3	0.6(1)	1.2(2)	1.4(2)	0.5(1)	0.5(1)
Crystal 4	0.5(1)	0.9(2)	1.2(2)	0.6(1)	0.4(1)

Two:

Tower / Crystal	Tower 10	Tower 11	Tower 12	Tower 3	Tower 4
Crystal 1	1.6(2)	1.9(3)	2.0(3)	1.1(2)	1.3(2)
Crystal 2	1.5(2)	2.0(3)	2.3(3)	1.3(2)	1.4(2)
Crystal 3	0.7(2)	1.5(2)	1.8(3)	1.3(2)	0.9(2)
Crystal 4	0.9(2)	1.1(2)	1.3(2)	1.2(2)	1.1(2)

Some remarks

Which activity?
Constraints:

- Max 100 Bq required for the transport
- Single detector event rate needs to be below 1/6 Hz (from Ben)

(Following calculations from Ben):
One source:

- Largest single detector overall gamma rate: $3.98\ 10^{-3}$ cts/decay, max 1/6 Hz $\rightarrow$ Max source activity = 42 Bq
- Peak event rate : $4.1\ 10^{-7}$ - $1.9\ 10^{-6}$ cts/decay $\rightarrow$ 10 - 50 counts at 3.25 MeV per week

Two sources:

- Largest single detector overall gamma rate: $5.18\ 10^{-3}$ cts/decay, max 1/6 Hz $\rightarrow$ Max source activity = 32 Bq
- Peak event rate : $7\ 10^{-7}$ - $2.3\ 10^{-6}$ cts/decay $\rightarrow$ 14 - 56 counts at 3.25 MeV per week

Largest dispersion between crystals for one source case $\rightarrow$ two sources might be preferable