LIME background simulation summary

CYGNO Collaboration Meeting – 19-20 December 2022

F. Di Giambattista

LIME data taking plan

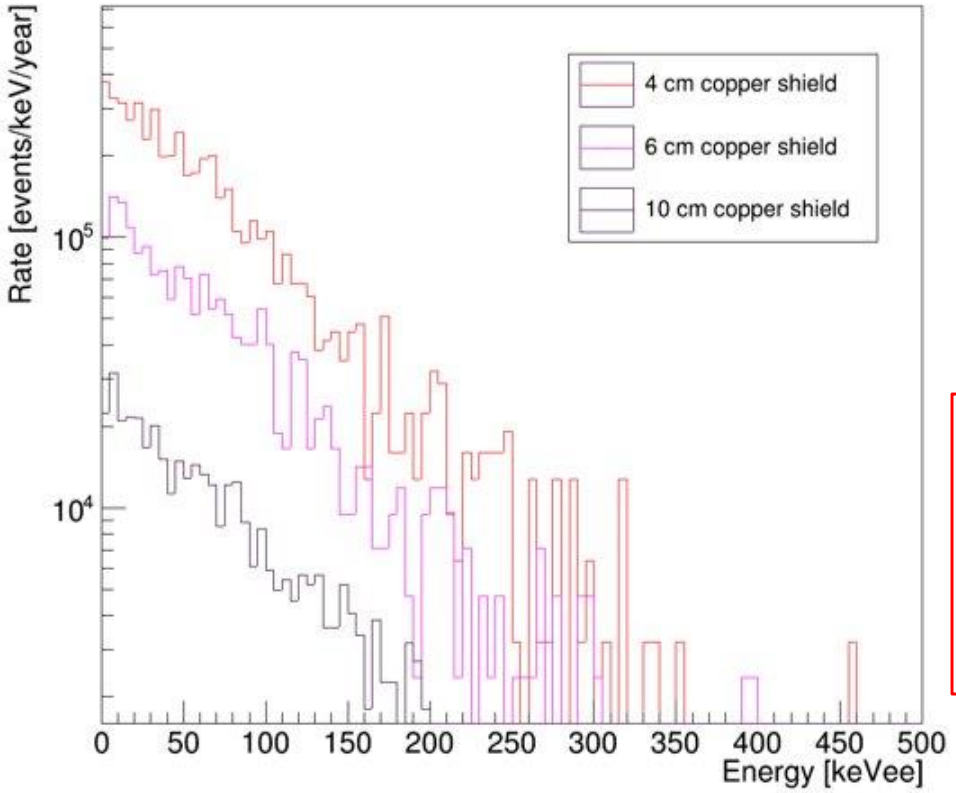
LIME data taking underground just started. We plan to install increasingly thick shieldings to perform different measurements, in view of the final low background setup with full shielding.
I simulated the expected background in the different shielding configurations

- **No shield**:
  - Periodic calibration with ^{55}Fe X-ray source, background measurement
- **6 cm of copper**:
  - Background measurement, AmBe neutron source measurement, and periodic calibration
- **10 cm of copper**:
  - Background measurement and periodic calibration
  - Measurement of the *fast neutron flux* underground
- **10 cm of copper + 40 cm of water**:
  - Final test of LIME operation in the conditions of the future Dark Matter experiment

Background sources underground

- **External background**:
  - Gammas and neutrons from the lab environment
    - Input spectra as measured in Hall C at LNGS:
      - Gamma flux measured by Sabre collaboration
      - Neutron flux from P. Belli et al., Il Nuovo Cimento A vol. 101, p. 959-966 (1989)
- **Internal background**:
  - Radioactivity of detector's materials
    - Input activity as measured by M.Laubenstein from our samples
  - Radioactivity of the copper shielding (main contributor ^{210}Bi)
    - Input activity as measured from OPERA dismissed copper
- **Radiogenic neutrons** (SOURCES4C + GEANT4)
  - (α,n) and spontaneous fission induced neutron spectra calculated from SOURCES4C used as input in GEANT4
- **Cosmogenic neutrons**: neutrons produced by muons interacting in the detector, *to be assessed with MUSUN+GEANT4*;

External gammas



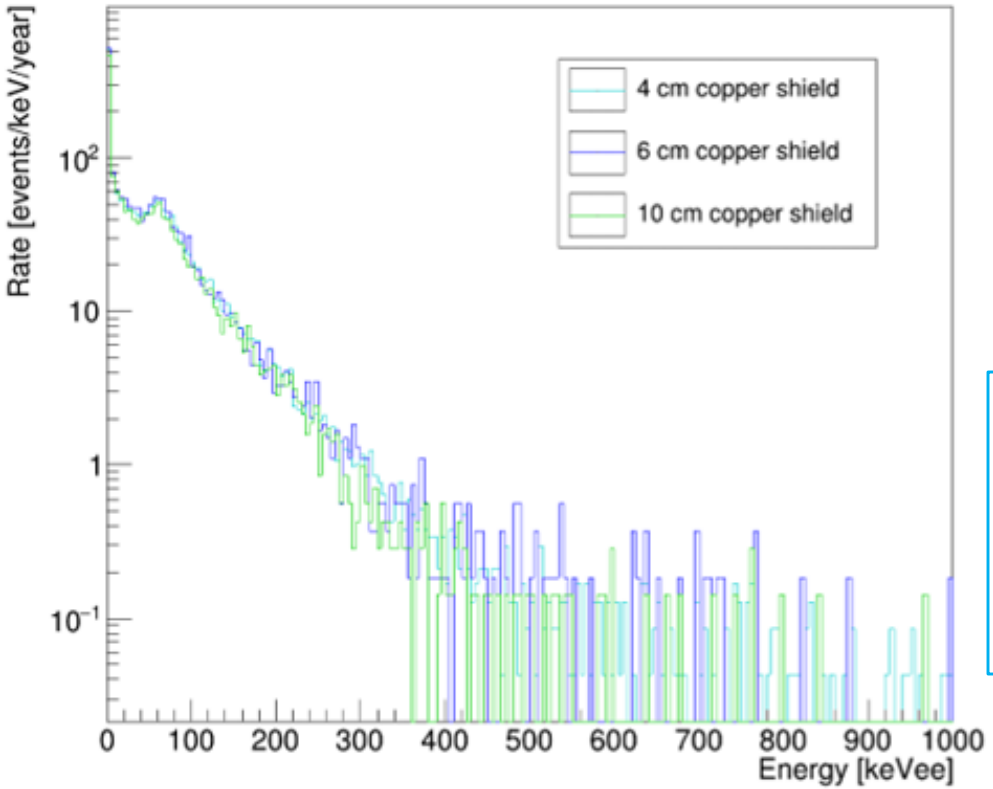
No shield:
$1.15(4)\times10^9$ ER/yr in 0-3000 keV
$1.13(4)\times10^9$ ER/yr in 1-3000 keV
$4.1(2)\times10^8$ ER/yr in 1-20 keV

6cm copper:
$9.5(3)\times10^6$ ER/yr in 0-3000 keV
$9.4(7)\times10^6$ ER/yr in 1-3000 keV
$2.3(2)\times10^6$ ER/yr in 1-20 keV

4cm copper:
$2.68(6)\times10^7$ ER/yr in 0-3000 keV
$2.6(1)\times10^7$ ER/yr in 1-3000 keV
$6.2(3)\times10^6$ ER/yr in 1-20 keV

10cm copper:
$1.97(5)\times10^6$ ER/yr in 0-3000 keV
$1.95(9)\times10^6$ ER/yr in 1-3000 keV
$4.7(2)\times10^5$ ER/yr in 1-20 keV

External neutrons



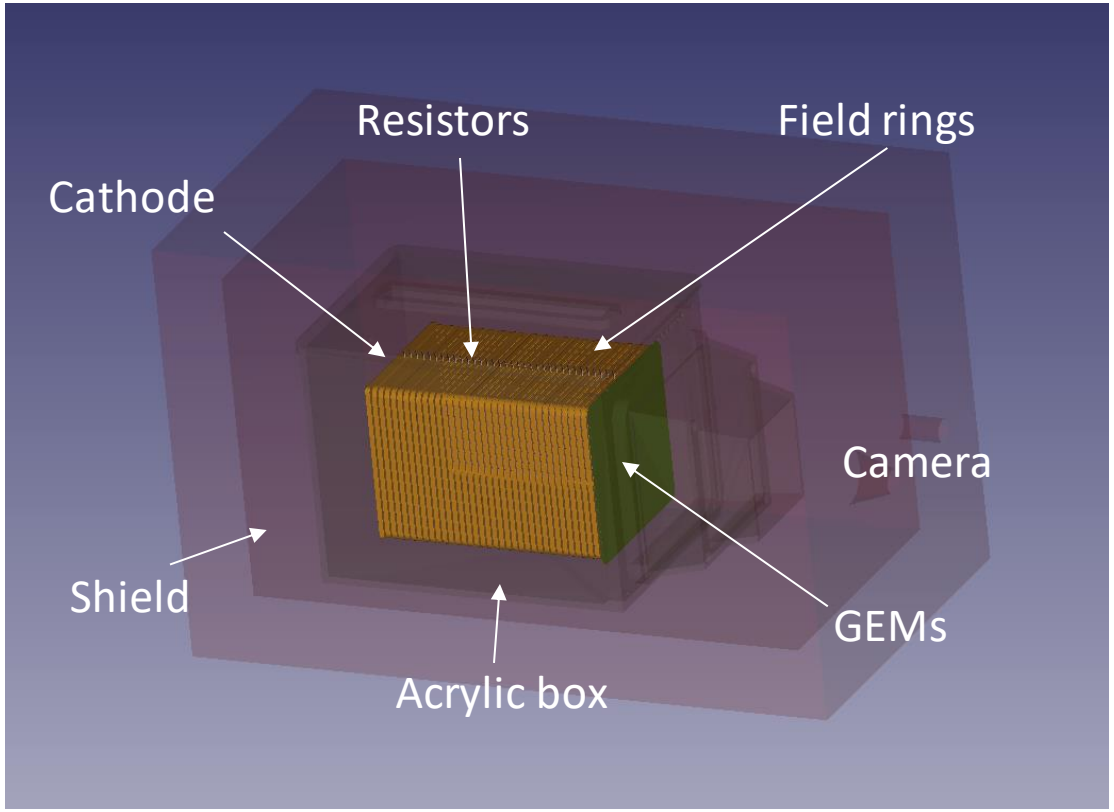
No shield:
1810(96) NR/yr in 0-3000 keV
1450(140) NR/yr in 1-3000 keV
350(40) NR/yr in 1-20 keV

4cm copper:
1020(15) NR/yr in 0-3000 keV
850(35) NR/yr in 1-3000 keV
410(9) NR/yr in 1-20 keV

6cm copper:
1190(30) NR/yr in 0-3000 keV
1000(80) NR/yr in 1-3000 keV
495(20) NR/yr in 1-20 keV

10cm copper:
1130 (30) NR/yr in 0-3000 keV
930(70) NR/yr in 1-3000 keV
550(20) NR/yr in 1-20 keV

Internal background



- Materials used to build LIME are **radioactive** and induce events in the gas
- The parts that were simulated are the **cathode**, the **GEMs**, the field cage **rings**, the **resistors** on top of the field cage, the **acrylic box** and the **camera** (body and lens separated)
- The **copper shielding** of different thicknesses was imported from the CAD design produced by C.Capoccia

Internal background

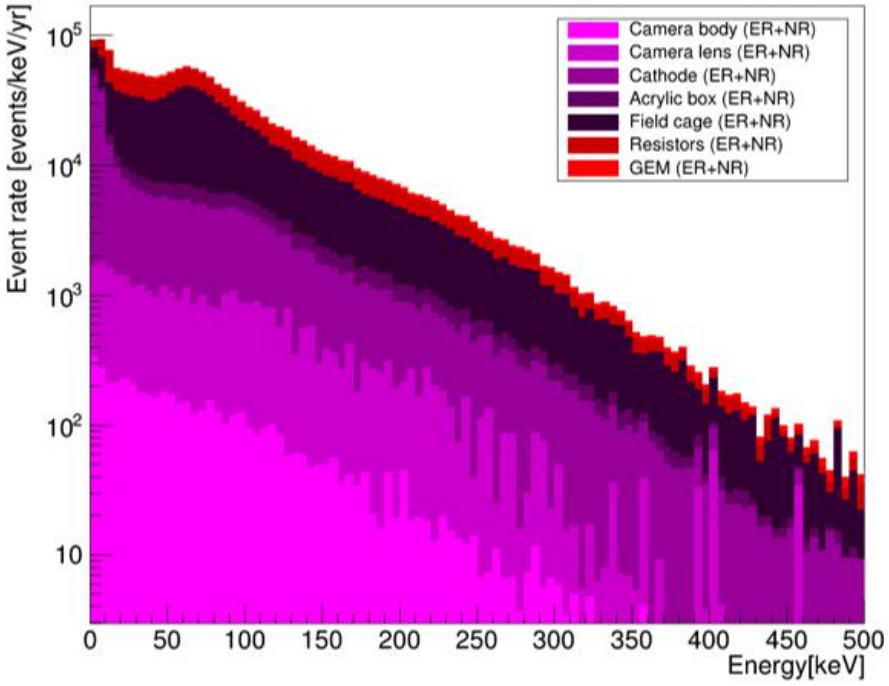
For each measured isotope and each isotope belonging to a detected natural chain I simulated the induced background in the detector

	Radionuclide	FieldRings	Cathode	Resistors	GEM	Acrylic	Camera body	Camera lens
^{238}U chain	234Th	<2,10E-01	<2,10E-01	1,99E+01	1,63E-01	-	3,16E+00	4,22E+00
	234mPa	<7,70E-02	<7,70E-02	2,19E+01	-	-	-	-
	226Ra	<1,30E-03	<1,30E-03	2,16E+00	3,25E-02	<3,50E-03	8,13E-01	1,92E+00
	210Pb	-	-	5,94E+02	-	-	-	-
^{232}Th chain	228Ra	<1,10E-03	<1,10E-03	3,50E+00	<3,09E-02	<5,00E-03	9,49E-01	3,61E-01
	228Th	<1,30E-03	<1,30E-03	3,36E+00	<1,56E-02	<4,50E-03	9,49E-01	3,65E-01
^{235}U chain	235U	<1,60E-03	<1,60E-03	3,37E-01	<1,58E-02	-	1,81E-01	1,45E-01
Other	40K	<6,00E-03	<6,00E-03	<1,78E+00	<3,58E-01	<3,50E-02	8,59E-01	5,15E+01
	137Cs	<4,70E-04	<4,70E-04	<7,35E-02	<8,13E-03	-	4,07E-02	<2,67E-02
	60Co	<5,70E-04	<5,70E-04	<7,73E-03	<7,48E-03	-	<5,42E-03	<4,64E-02
	58Co	9,00E-04	9,00E-04	<3,10E-03	-	-	-	-
	Mn54	<4,30E-04	<4,30E-04	<3,27E-03	-	-	-	-
	La138	-	-	-	-	-	-	2,44E+00

Activities shown are in units of Bq/kg

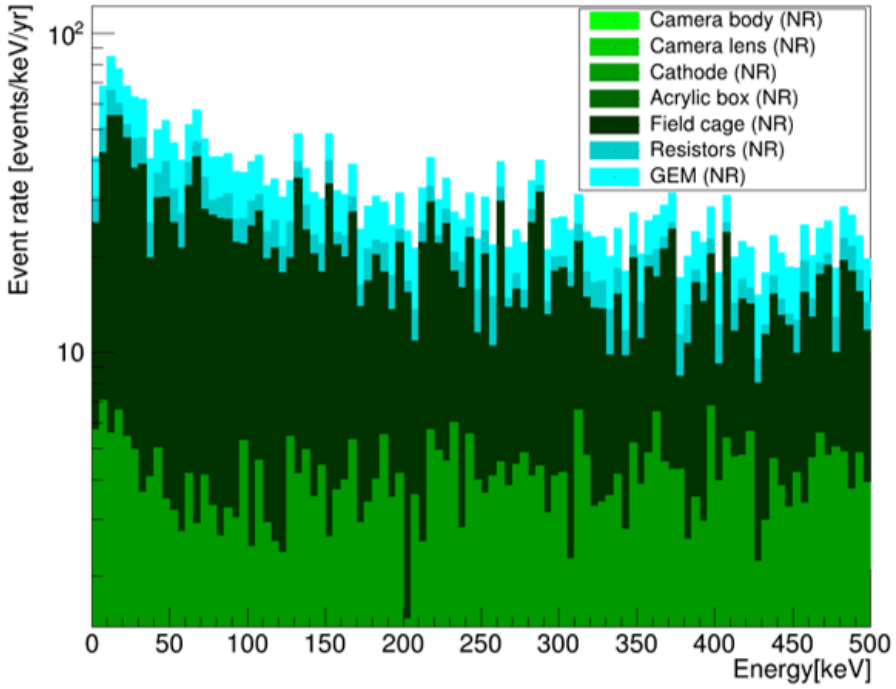
Internal background

Main contributions from copper rings and cathode and resistors



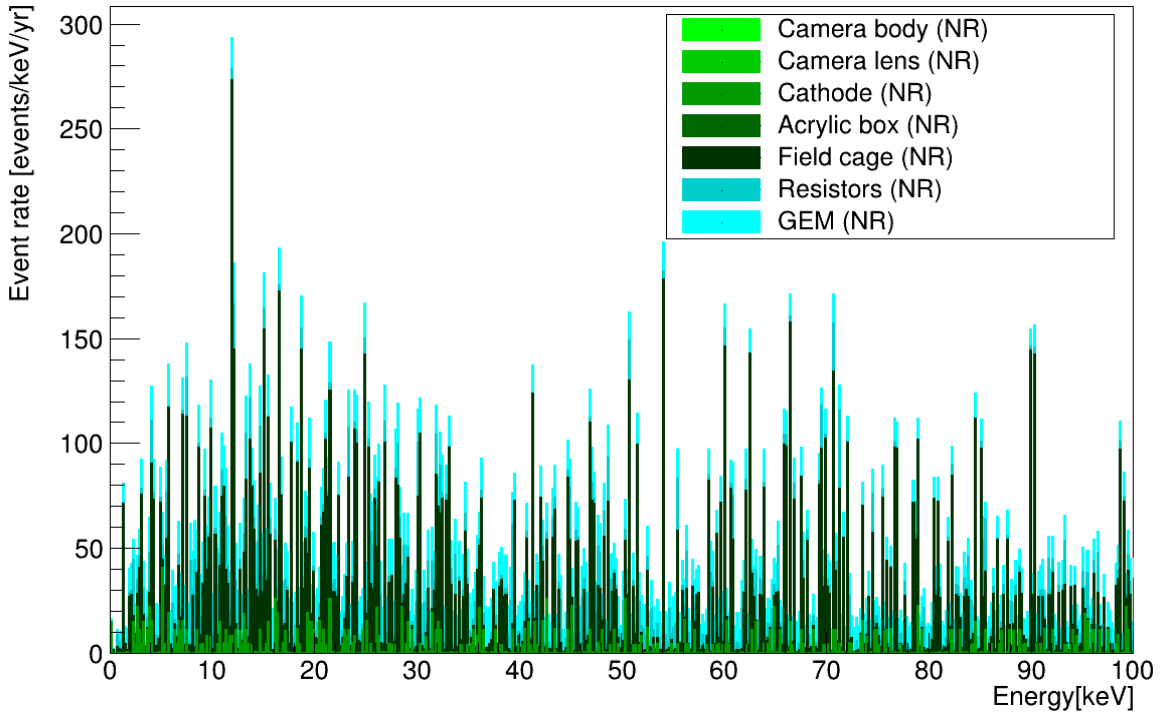
7.403(6)×10^6 (ER+NR)/yr in 0-3000 keV
7.317(6)×10^6 (ER+NR)/yr in 1-3000 keV
1.534(1)×10^6 (ER+NR)/yr in 1-20 keV

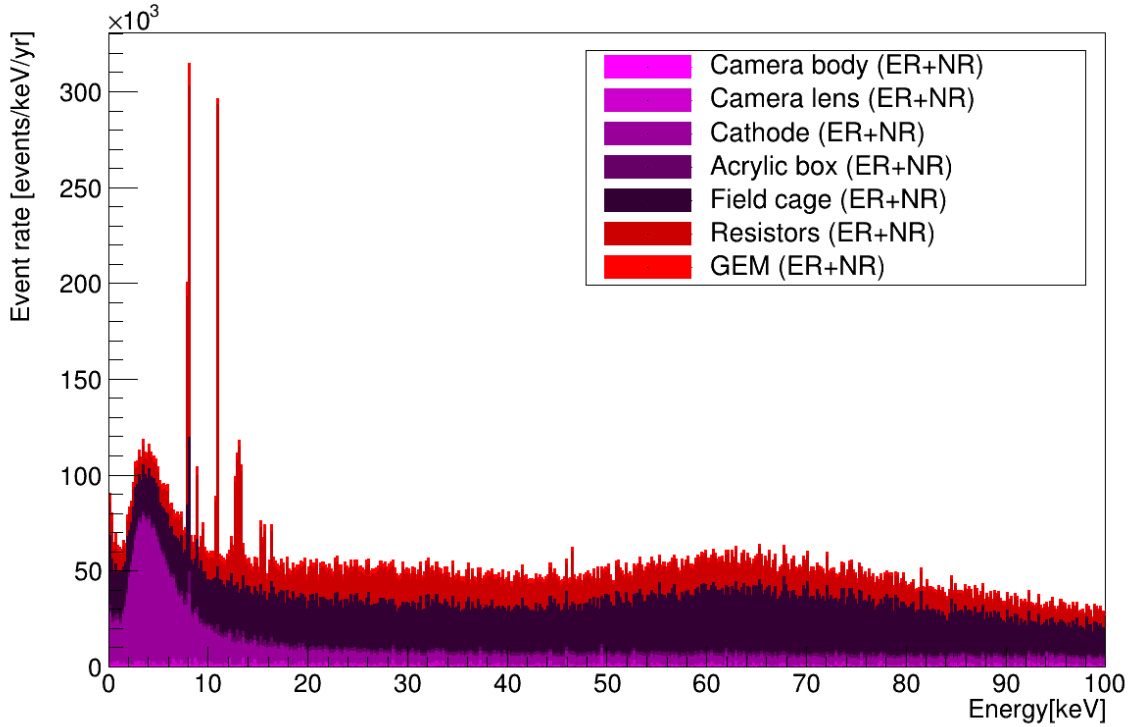
Main contributions from rings, cathode, resistors and GEMs



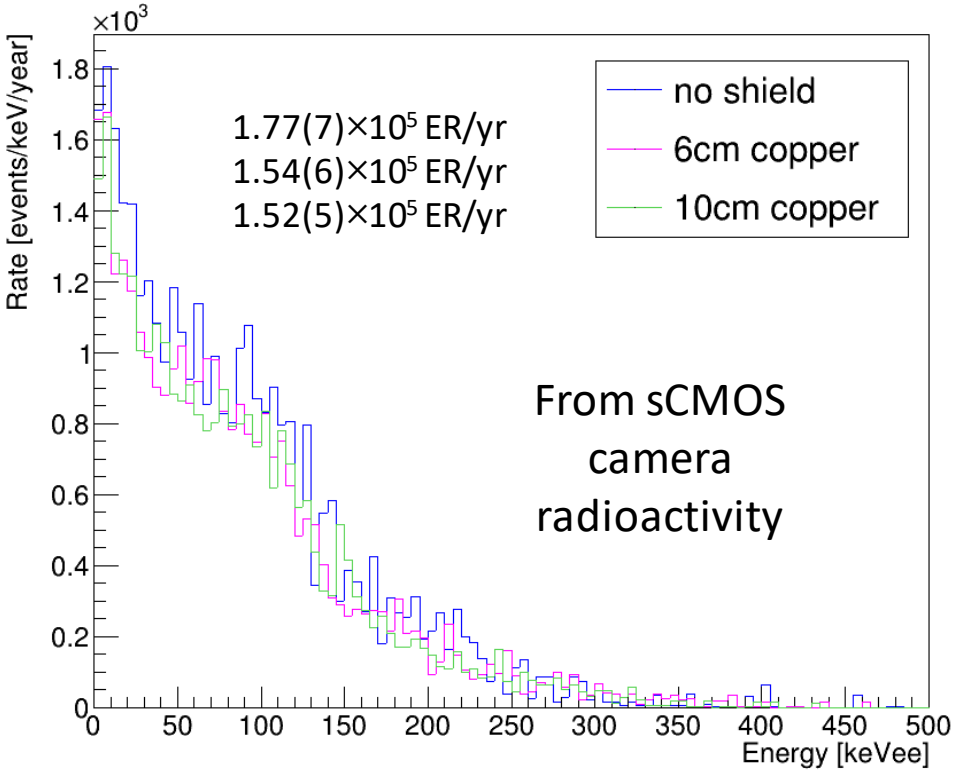
6.11(5)×10^4 NR/yr in 0-3000 keV
6.11(5)×10^4 NR/yr in 1-3000 keV
1.36(2)×10^3 NR/yr in 1-20 keV

Internal background

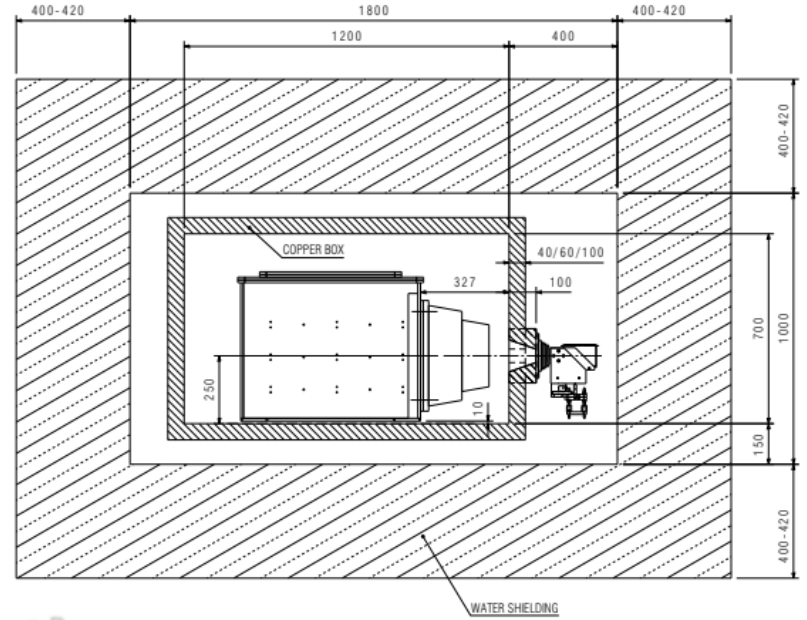




Camera background with shielding

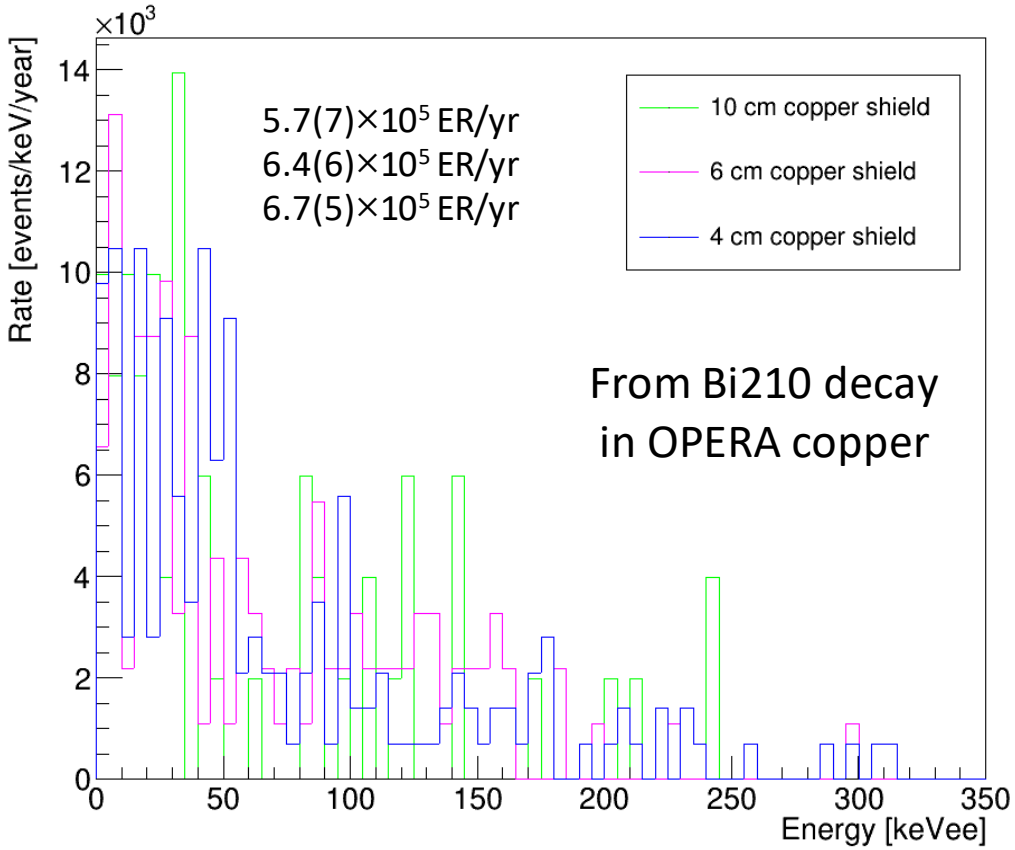


No significant difference between different shielding configurations, we can not passively reduce the induced background



CESIDIO.CAPOCCIA@LNF.INFN.IT

Shield radioactivity

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rame OPERA: ICP-MS
Th [ppt] <15
U [ppt] <5

rame OPERA: HPGE
sample:        copper, magnet, OPERA
weight:        10658.4 g
live time:    2122026 s
detector:    GeMPI

radionuclide concentrations:

Th-232:
Ra-228:        < 73 microBq/kg        <==>    < 1.8 E-11 g/g
Th-228        < 64 microBq/kg        <==>    < 1.6 E-11 g/g

U-238:
Ra-226        < 0.10 mBq/kg        <==>    < 8.4 E-12 g/g
Pa-234m        < 1.9 mBq/kg        <==>    < 5.7 E-10 g/g

U-235        < 0.51 mBq/kg        <==>    < 9.0 E-10 g/g

K-40:        (0.4 +- 0.2) mBq/kg    <==>    (1.4 +- 0.7) E-8 g/g

Cs-137        < 28 microBq/kg

Co-60:        (31 +- 13) microBq/kg

Ag-108m:    (0.25 +- 0.03) mBq/kg

Bi-207:        (0.61 +- 0.06) mBq/kg

Pb-210:        (7 +- 2) Bq/kg

upper limits with k=1.645,
uncertainties are given with k=1 (approx. 68% CL);

Ra-228 from Ac-228;
Th-228 from Pb-212 & Bi-212 & Tl-208;
Ra-226 from Pb-214 & Bi-214;
U-235 from U-235 & Ra-226/Pb-214/Bi-214
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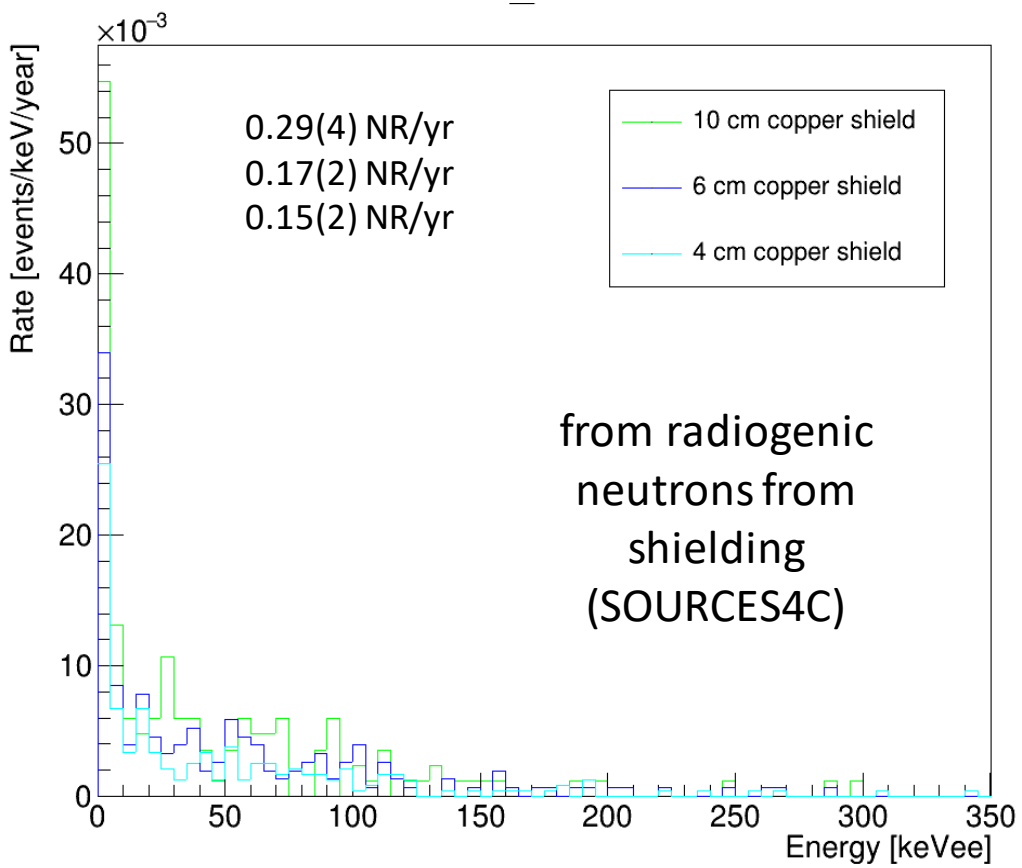
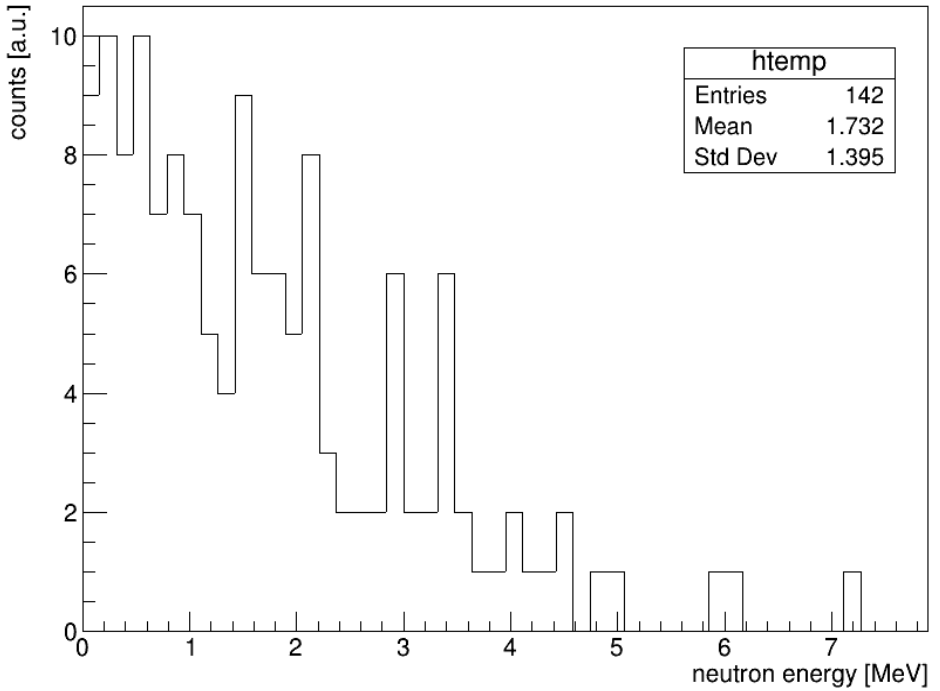
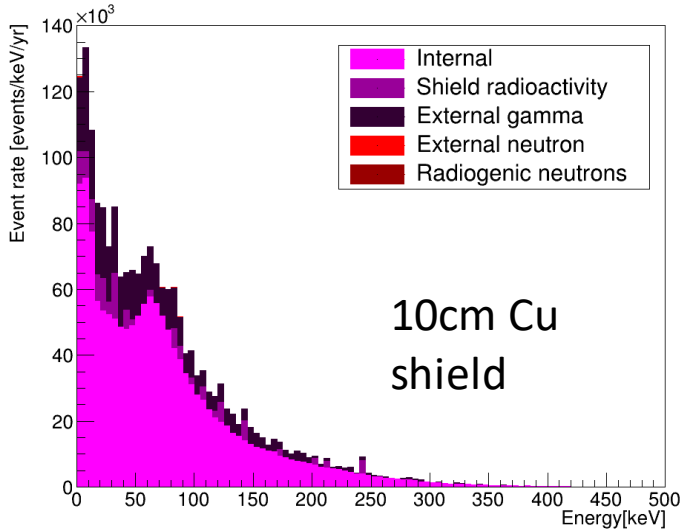
Radiogenic neutrons

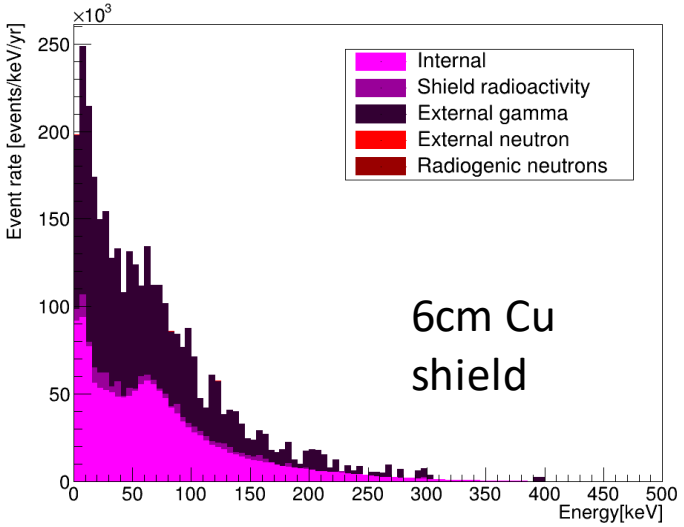


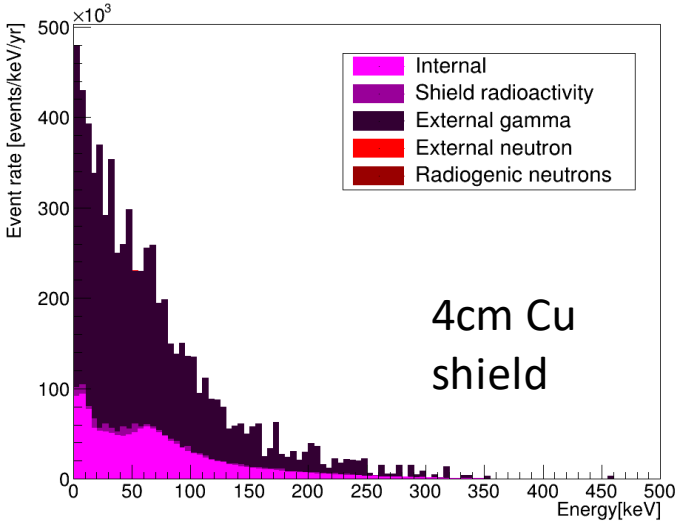


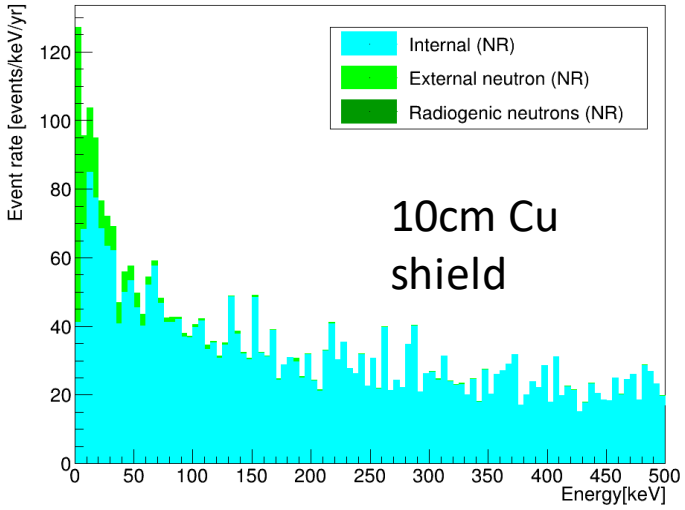
Neutron spectrum calculated with SOURCES4C, includes (α,n) reactions and spontaneous fission neutrons

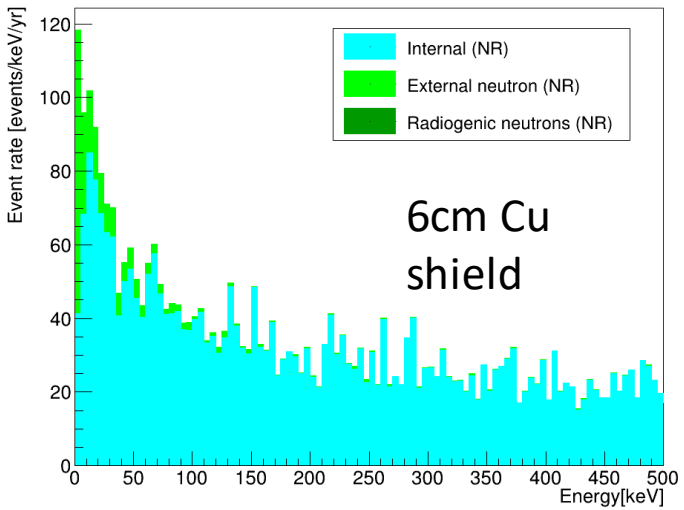
Shielding comparison

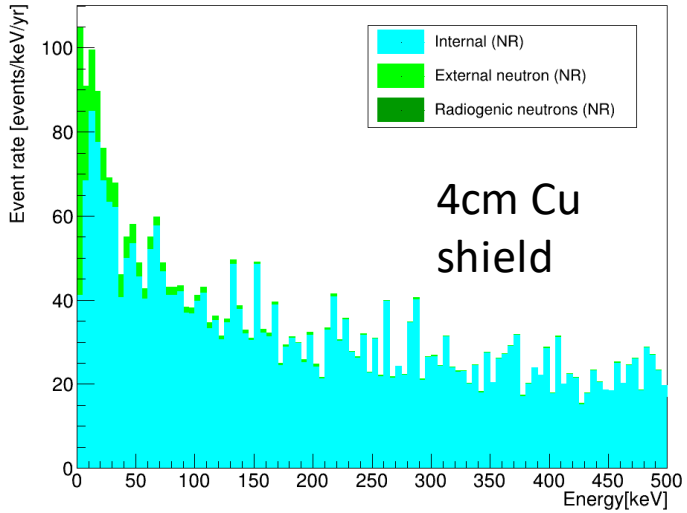




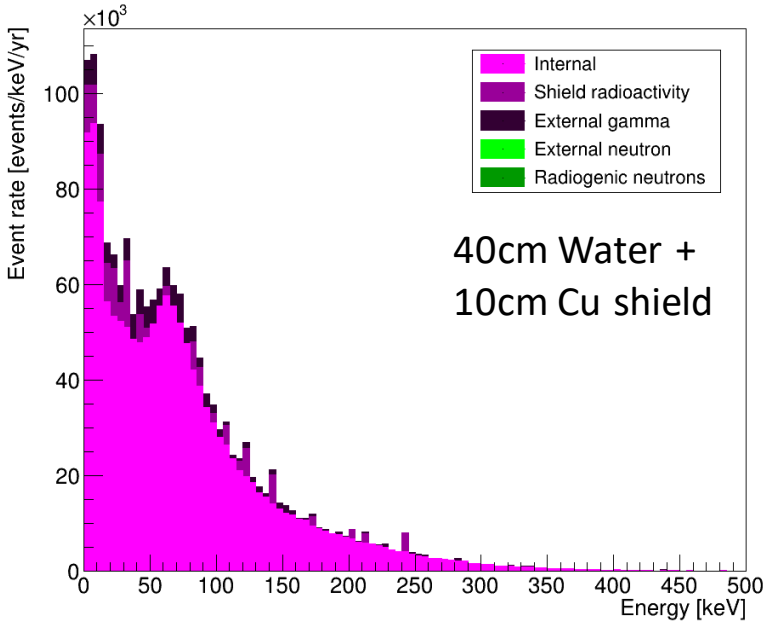


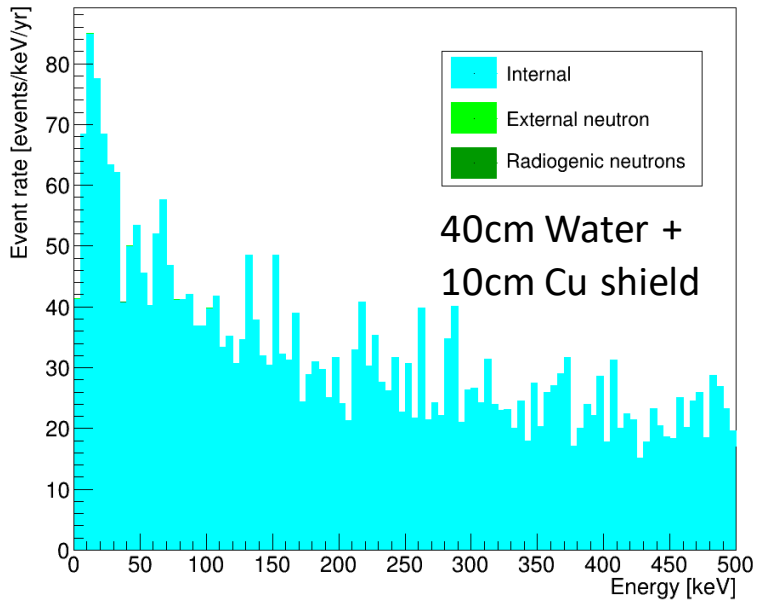






Background with water shielding



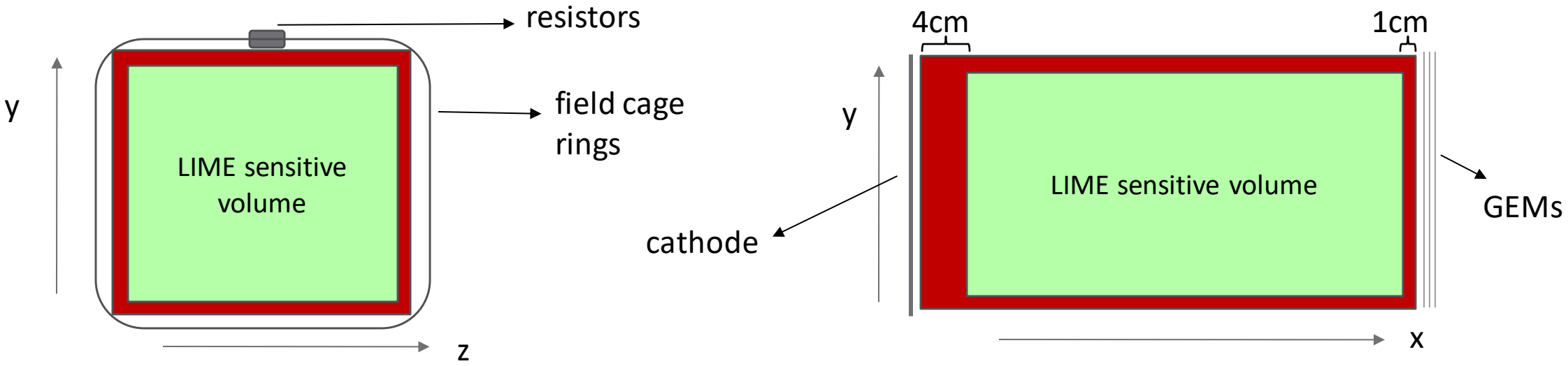


From gammas:
$5.13(30)\times10^5$ ER/yr in 0-3000 keV
$5.09(30)\times10^5$ ER/yr in 1-3000 keV
$1.1(1)\times10^5$ ER/yr in 1-20 keV

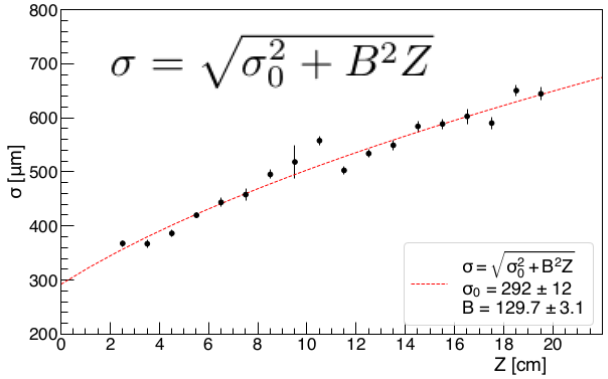
From neutrons:
2.3(2) NR/yr in 0-3000 keV
2.0(3) NR/yr in 1-3000 keV
1.0(1) NR/yr in 1-20 keV

External neutron background reduces to 2 NR/yr. The main source of background left is the internal one

Detector fiducialization

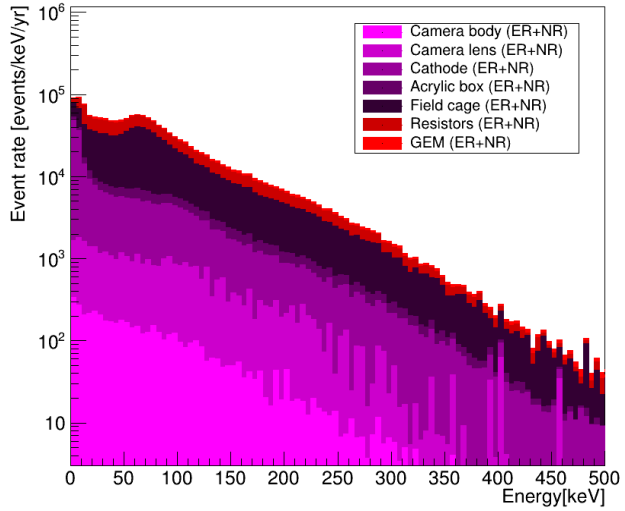


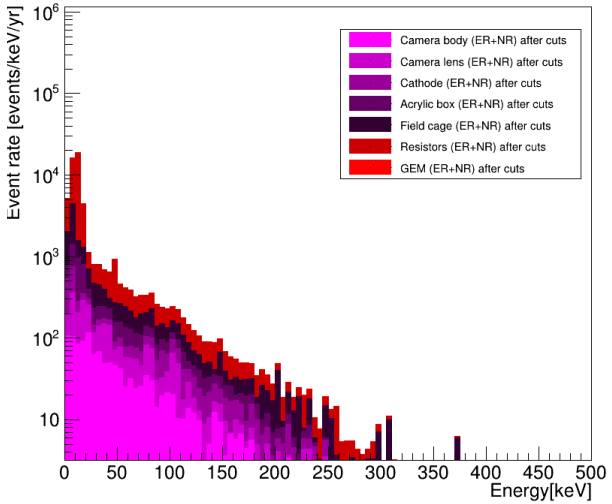
- Tracks close to the borders of the sensitive region can be excluded from image analysis
- From track shape we can retrieve the distance from the GEMs (diffusion dependent on z)



V.C. Antochi et al, NIMA 999 (2021) 165209

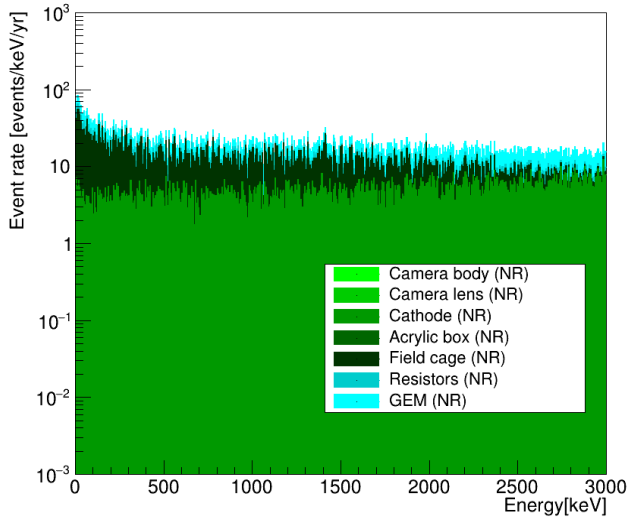
Detector fiducialization

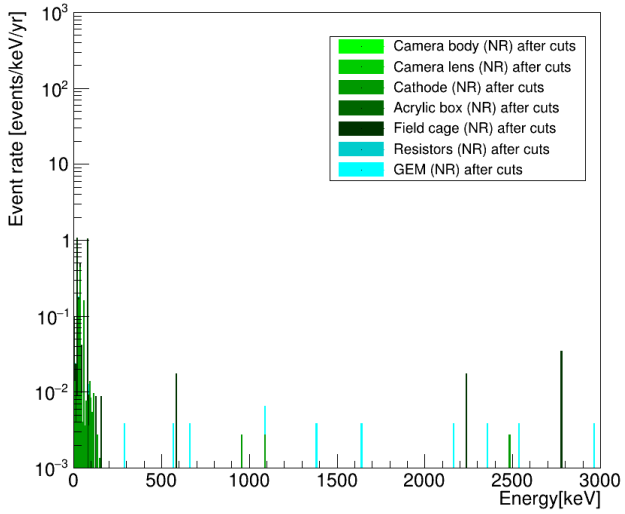




No cuts: **7.34(3)×10⁶** ER/yr
After cuts: **2.8(4)×10⁵** ER/yr

96% of events are excluded

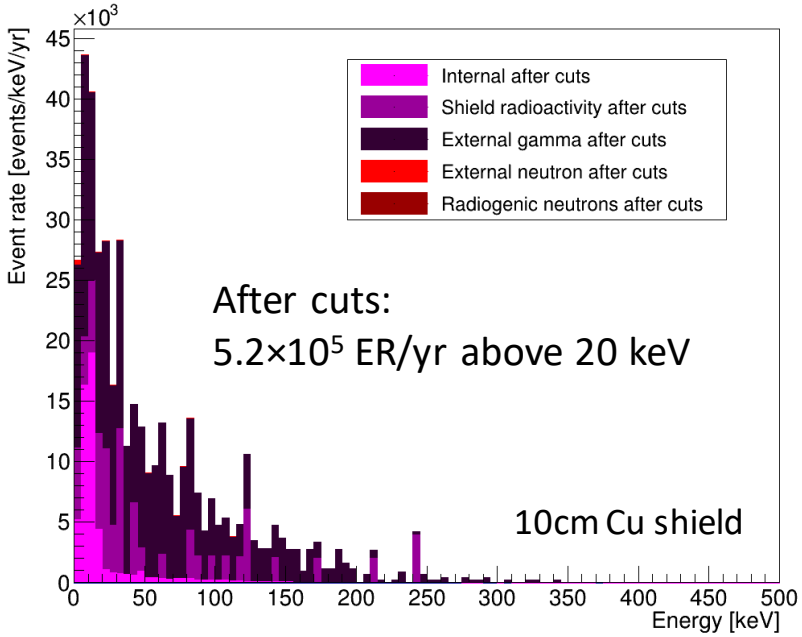


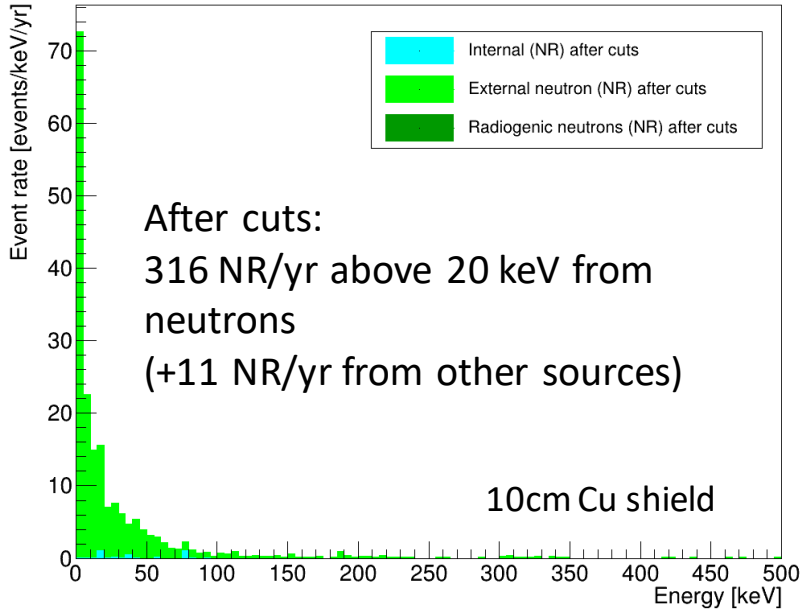


No cuts: **6.1(1)×10⁴** NR/yr
After cuts: **17(1)** NR/yr left

99.97% of events are excluded

Neutron background after cuts





Neutron flux measurement underground:

- Before cuts: **930** NR/yr above 1 keV (+**61000** background NR/yr)
- After cuts: **772** NR/yr above 1 keV (+**16** NR/yr from other sources)

- After the fiducial cuts, we expect **~105 NR** induced by external neutrons above 20 keV in 4 months of data taking (with **5 NR** of background)

Summary table

Shielding	External		Internal		Shielding radioactivity		Total	
	ER/yr	NR/yr	ER/yr	NR/yr	ER/yr	NR/yr	ER/yr	NR/yr
No shield	1.13e9	1450	7.26e6	6.11e4	-	-	1.14e9	6.25e4
4cm copper	2.64e7	850	7.26e6	6.11e4	6.7e5	0	3.43e7	6.19e4
6cm copper	9.40e6	980	7.26e6	6.11e4	6.4e5	0	1.73e7	6.21e4
10cm copper	1.95e6	915	7.26e6	6.11e4	5.7e5	0	9.78e6	6.20e4
40cm water + 10cm copper	5.09e5	2.0	7.26e6	6.11e4	5.7e5	0	8.34e6	6.11e4

Rates refer to events >1 keV

Conclusions

- A full simulation of the **expected background** sources at underground LNGS was done for the LIME detector
- First results from data taking are **consistent** with the predicted simulated rate (~30 Hz)
- The internal background is an issue for LIME, we need **radiopure materials** for the next phases of CYGNO
  - We can reduce its impact by **fiducializing** the sensitive volume
- The background induced by the camera **cannot be reduced** with a passive shielding, different lens and sensors are necessary
- Cosmogenic neutrons produced by muons interacting in the shielding might not be negligible in view of the next phases of CYGNO, we need to include it in the future simulations

Thank you for your attention!