Shielding design for BULLKID-DM

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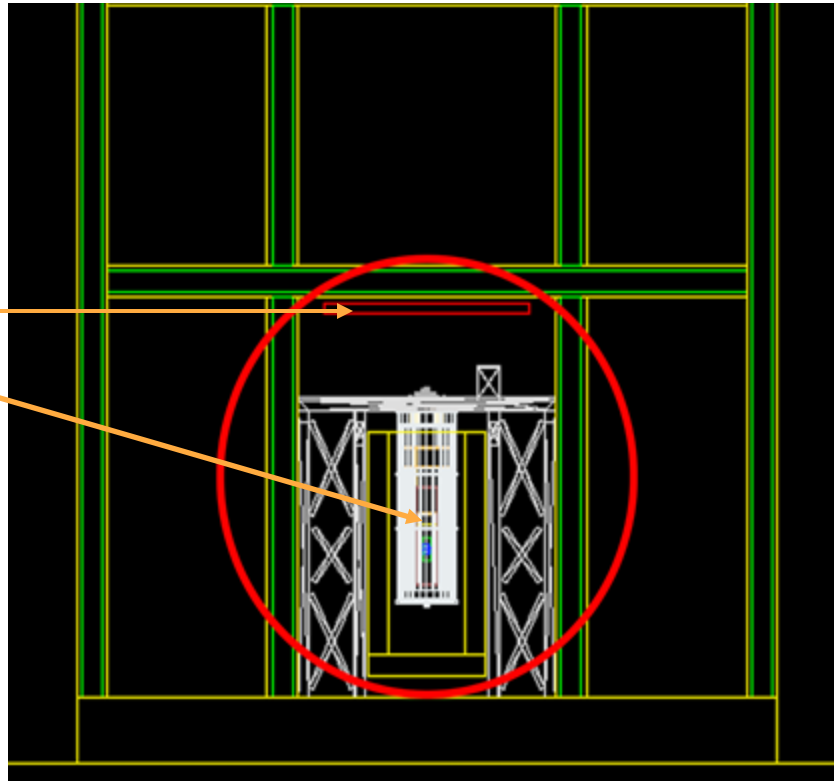
Simulations for external shielding

- Gamma activity measure at LNGS

(C. Bucci et al., *Eur. Phys. J. A* **41**, 155–168 (2009))

- Sphere with 2 m radius around the cryostat
- All simulations include
  - 10 cm thick Lead top shield
  - 10 cm thick Copper cryo top shield
- Assume the activity of Pb OPERA
- Cu purity not considered in the simulations

- Simulations performed with GEANT4.11.1 using Shielding Physics List
- Facility geometry according to the drawings has been implemented



Main gamma-ray lines at Gran Sasso and limits from OPERA Pb

Isotope	Energy [keV]	Intensity [γ/m^2/day]
^{208}Tl	2614	7.8×10^6
^{214}Bi	2204	3.1×10^6
^{214}Bi	1764	8.2×10^6
^{40}K	1460	2.9×10^7
^{214}Bi	1238	2.8×10^6
^{214}Bi	1120	6.3×10^6

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sample:          39 lead sheets OPERA
weight:          5.4149 kg
live time:               1424949 s
detector:                GeCris

radionuclide concentrations:

Th-232:
Ra-228:          < 0.18 mBq/kg          <==>    < 4.4 E-11 g/g
Th-228:          < 0.46 mBq/kg          <==>    < 1.1 E-10 g/g

U-238:
Ra-226           < 0.12 mBq/kg          <==>    < 9.6 E-12 g/g
Th-234           < 2.5 mBq/kg           <==>    < 2.0 E-10 g/g
Pa-234m          < 8.0 mBq/kg           <==>    < 6.5 E-10 g/g

U-235:
U-235:           < 6.7 mBq/kg           <==>    < 1.2 E-8 g/g

K-40:            < 1.8 mBq/kg           <==>    < 5.9 E-8 g/g

Cs-137:          < 0.26 mBq/kg

Co-60:           < 10 microBq/kg        @ start of measurement @ 26-

Pb-210:          (58 +- 9) Bq/kg        @ start of measurement @ 26-

upper limits with k=1.645,
uncertainties are given with k=1 (approx. 68% CL);
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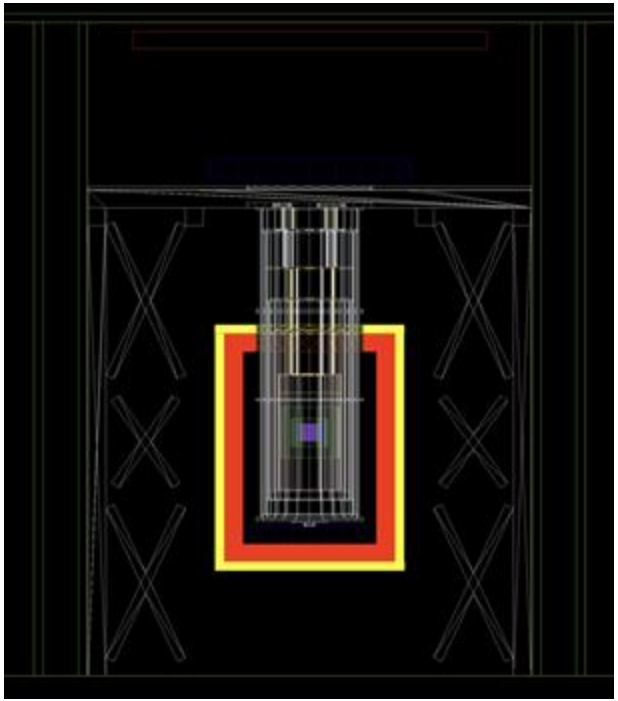
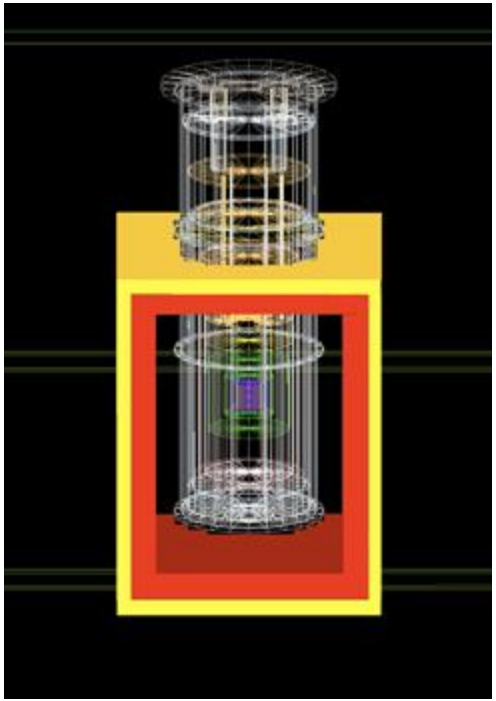
Underground facility implemented in GEANT4

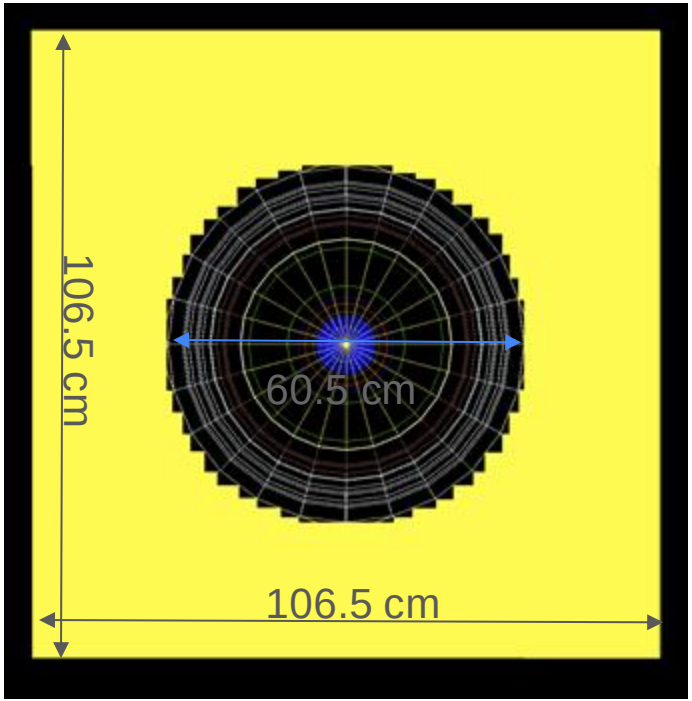
Output from the simulations presented as:

- Record energy for tracks entering the experimental volume inside the cryostat from 0 to 3 MeV in counts/MeV/day/liter
- Record energy hits in BULLKID-DM in two energy ranges (in d.r.u.):
  - 0 to 1 keV
  - 0 to 50 keV

Layout of the shielding with the addition of a hat shield

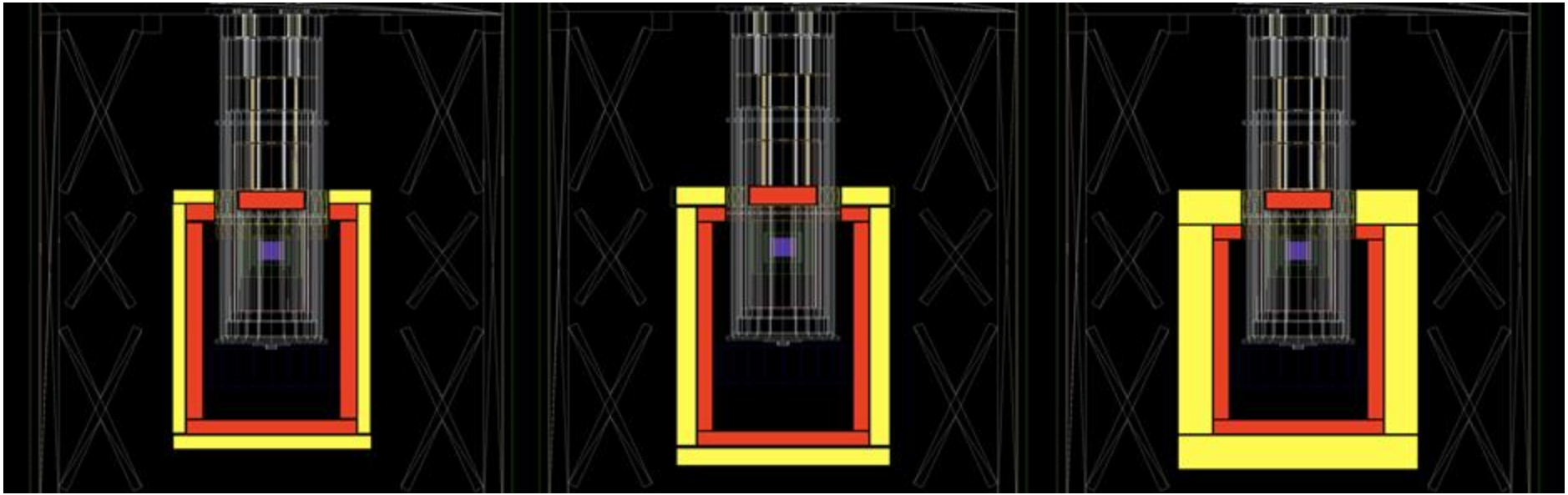






Addition of hat shield from initial proposal

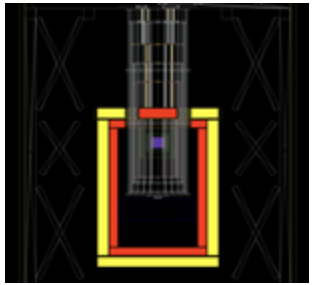
6 cm Pb | 10 cm Pb | 18 cm Pb

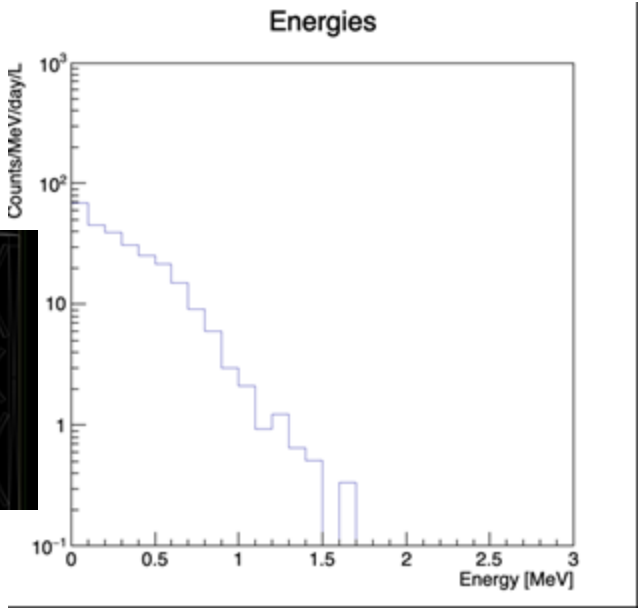


Consider, in all cases, 8 cm of Cu (in red). Thickness obtained from previous simulations, required to reduce OPERA Pb background contribution in BULLKID-DM.

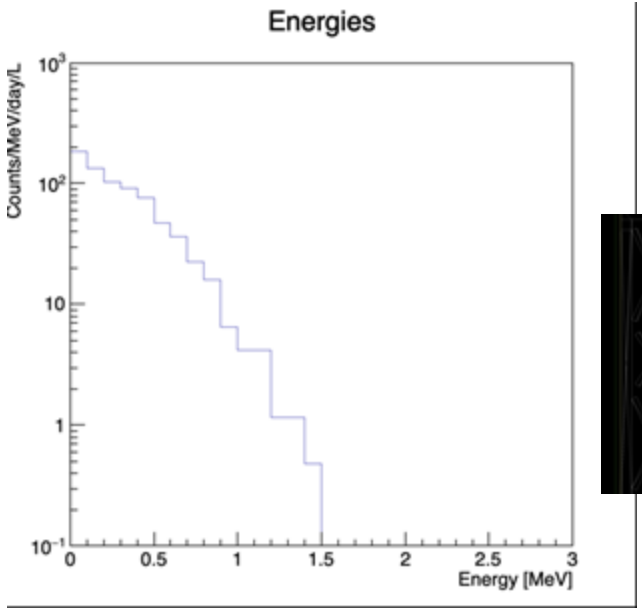
Difference between new (with hat shield) and previous proposed design

- There is a noteworthy change between using or not the hat shield
  - Histograms for the case of 10 cm of Pb and 8 cm of Cu

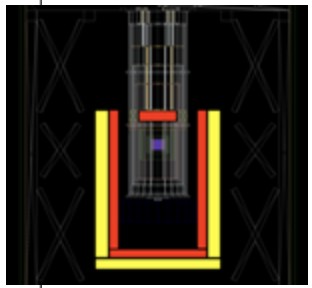




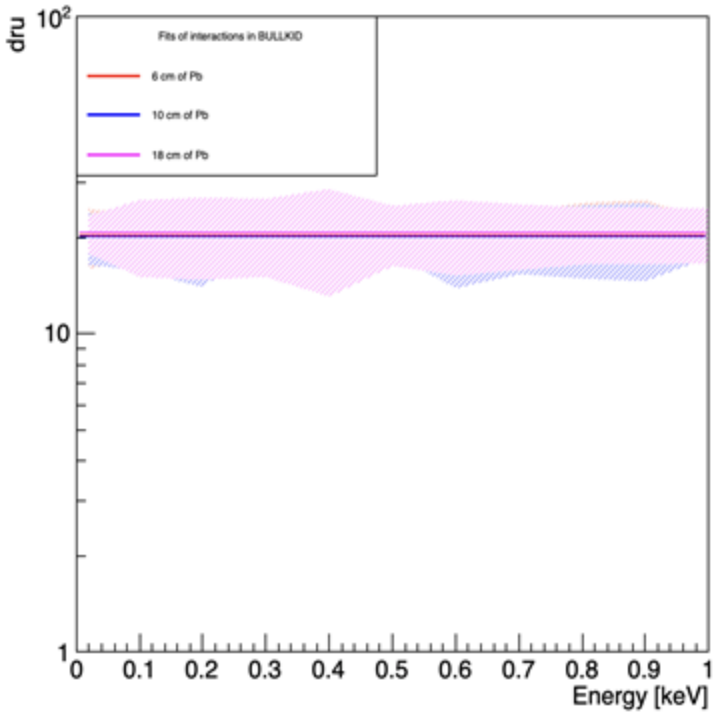
Histogram integral:
270.774 counts/day/liter

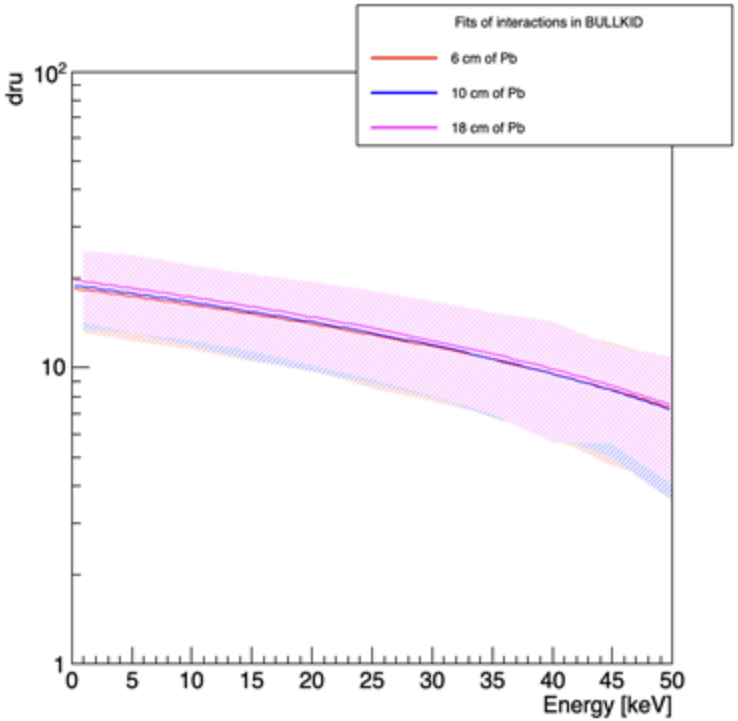


Histogram integral:
728.803 counts/day/liter

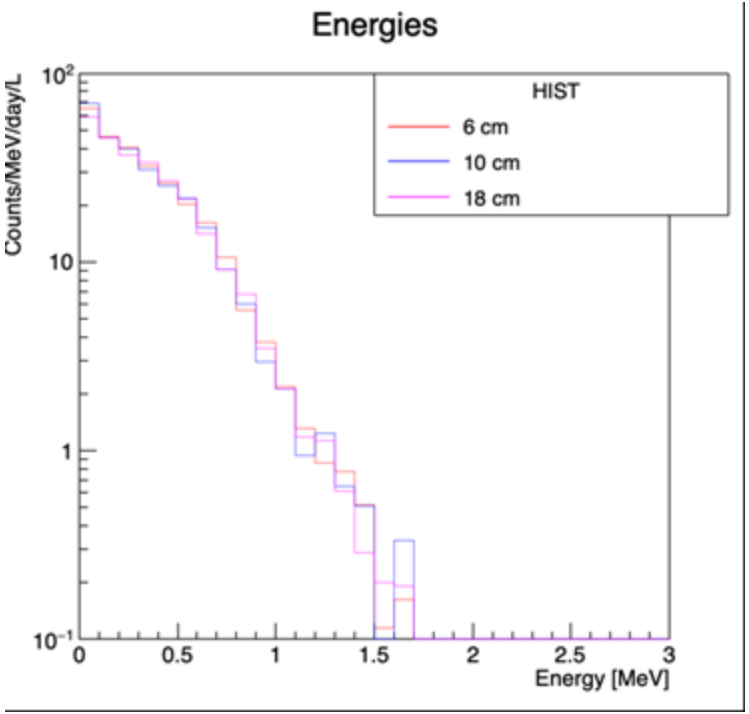


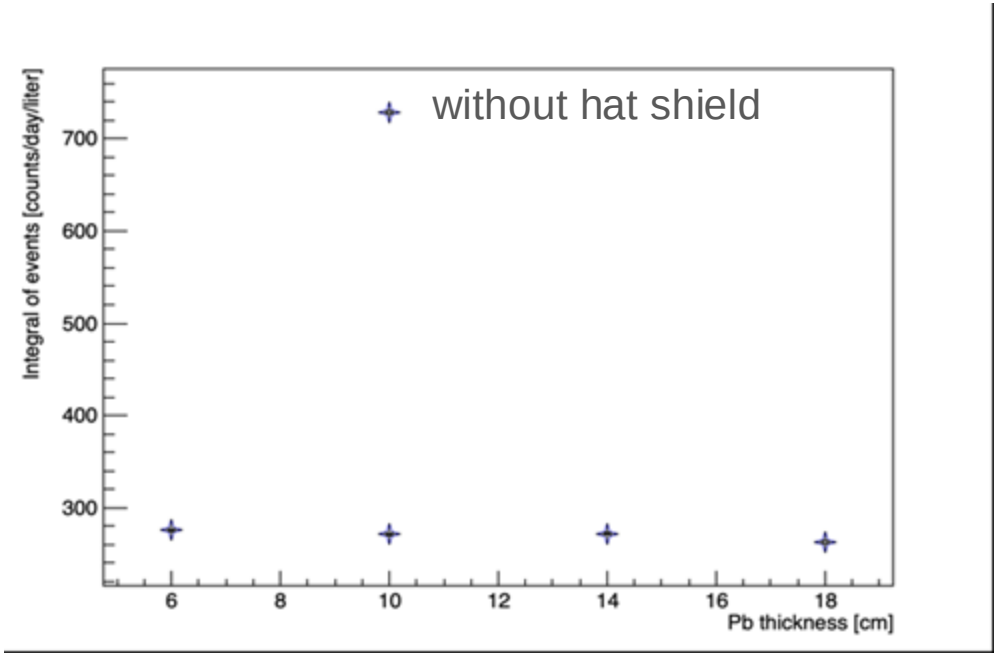
- For BULLKID-DM, there is not a considerable difference between cases of 6, 10, or 18 cm of Pb with 8 cm of Cu and adding the hat shield (errors are a few d.r.u)





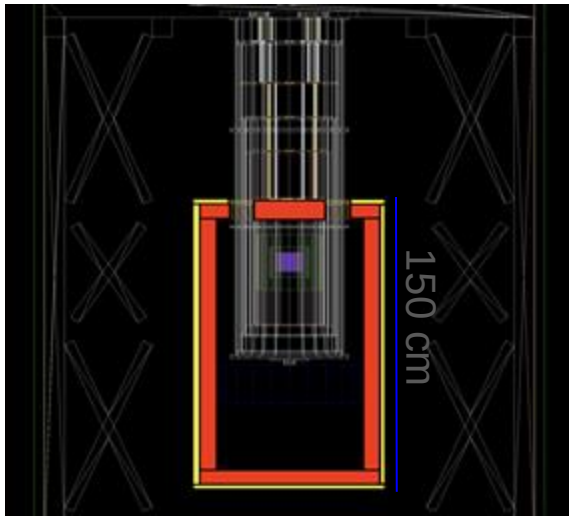
Event rate in the experimental volume:
similar as in BULLKID-DM, no considerable difference





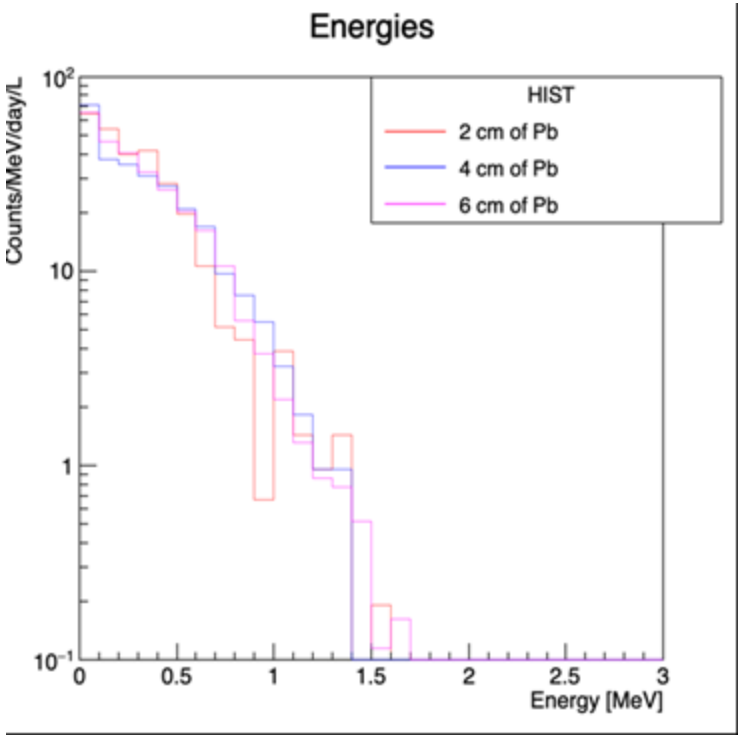
What is the minimum Pb thickness?

- Explore in steps of 2 cm
- Compare cases of 2 and 4 cm of Pb thickness with 6 cm
- It seems there is not a considerable difference between these cases inside the experimental volume

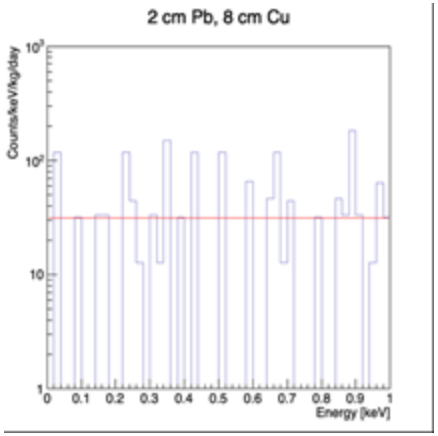


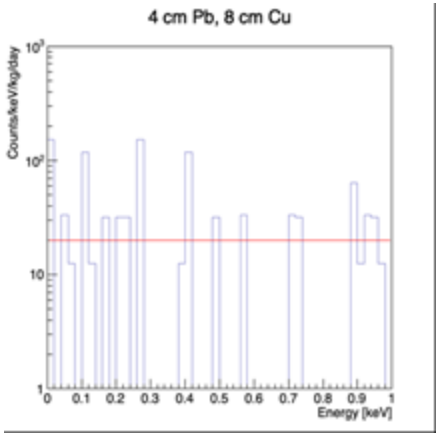
2 cm Pb thickness (yellow)

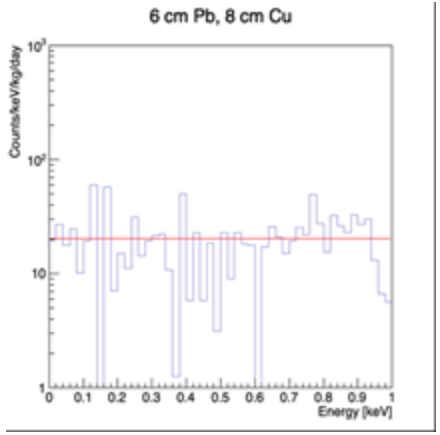
8 cm Cu thickness (red)

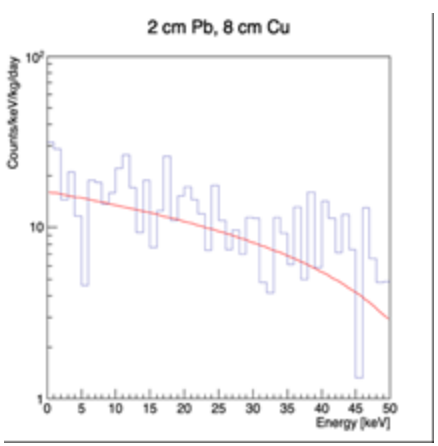


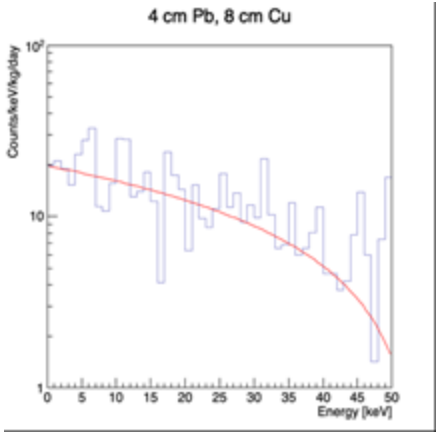
- Histograms showing the hits in BULLKID-DM for the cases with steps of 2 cm

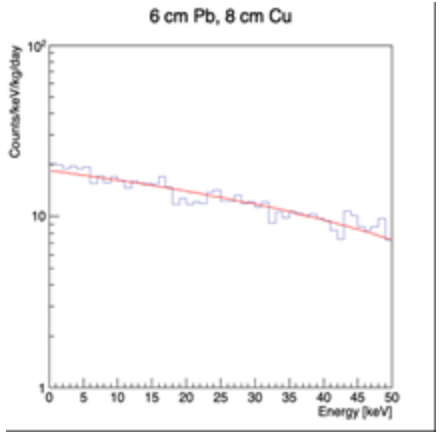










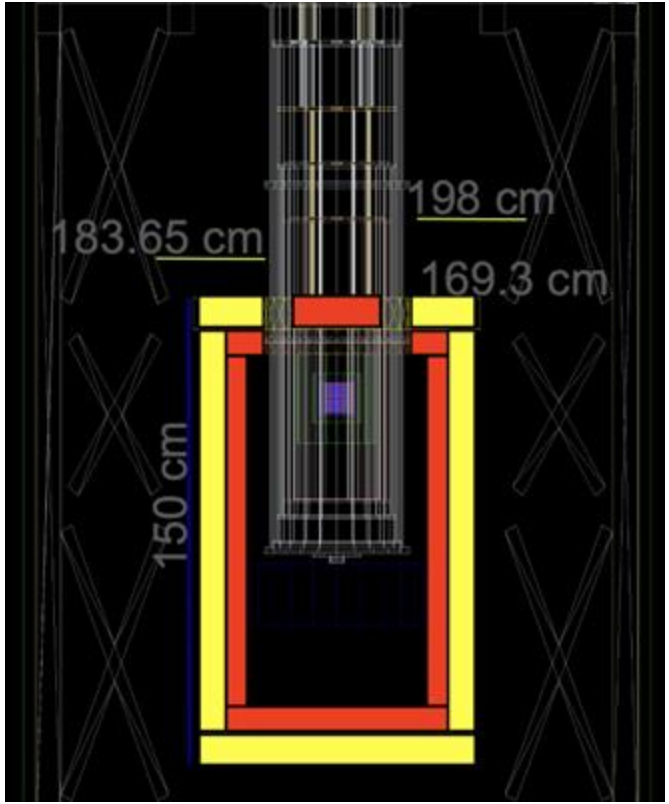


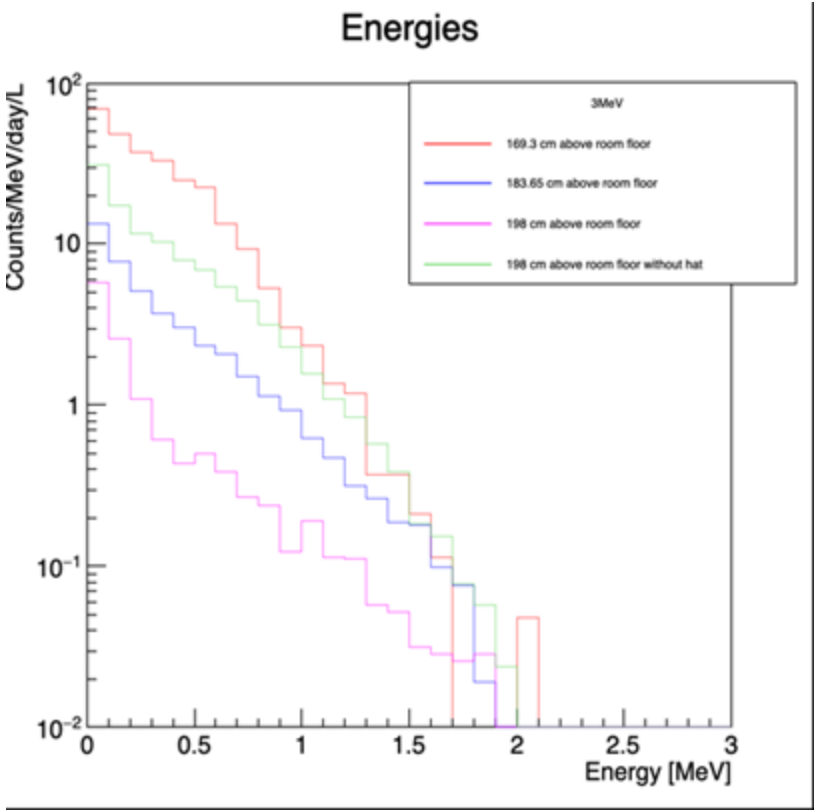
Assuming that the bricks would be 5 cm thick, consider:

- 15 cm for shielding
  - 10 cm of Cu thickness
  - 5 cm of Pb thickness
- Shielding height 150 cm

Now, tune shield height and position

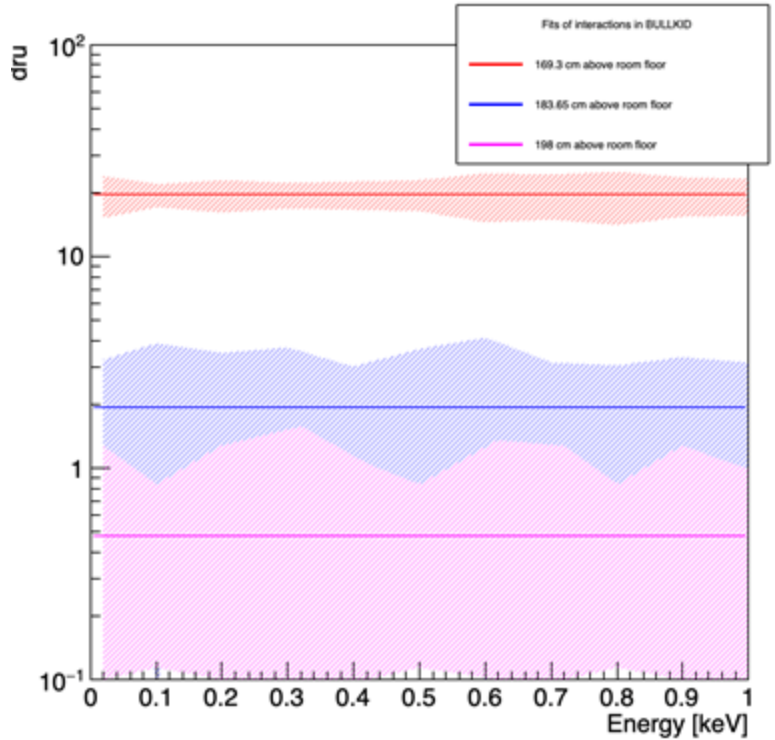
- Move shield position over Z
  - highest point above the floor at:
    - 198 cm
    - 183.65 cm
    - 169.3 cm

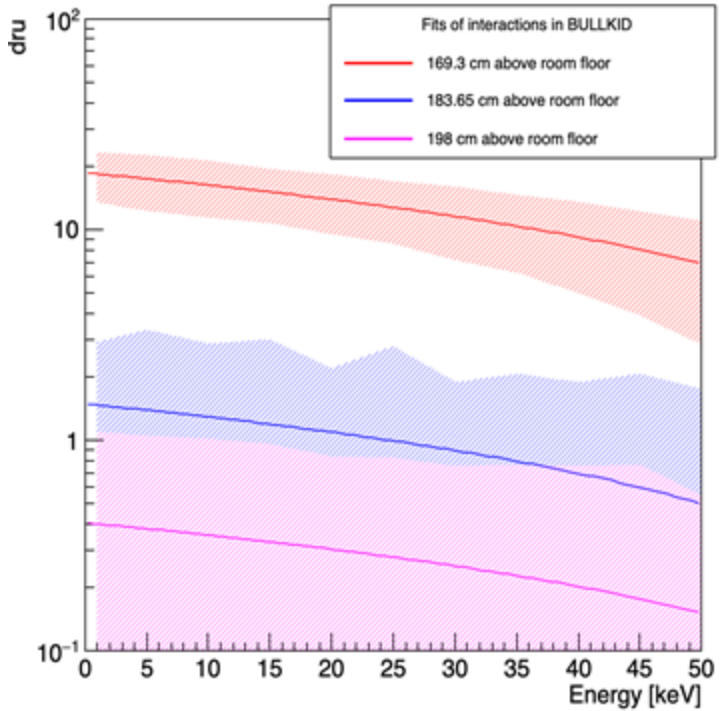




Centimeters above the room floor	Histogram integral [events per day per liter]
169.3	272.6
183.6	43.2
198.0	12.7
198.0 (no-hat)	105.3

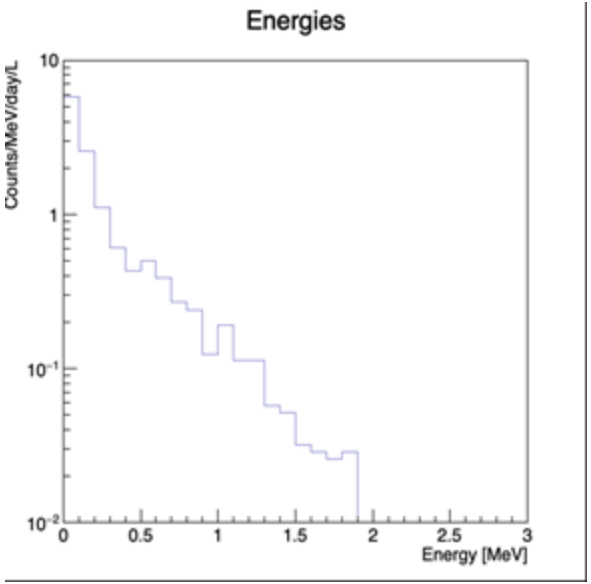
BULLKID-DM, 5 cm of Pb + 10 cm of Cu

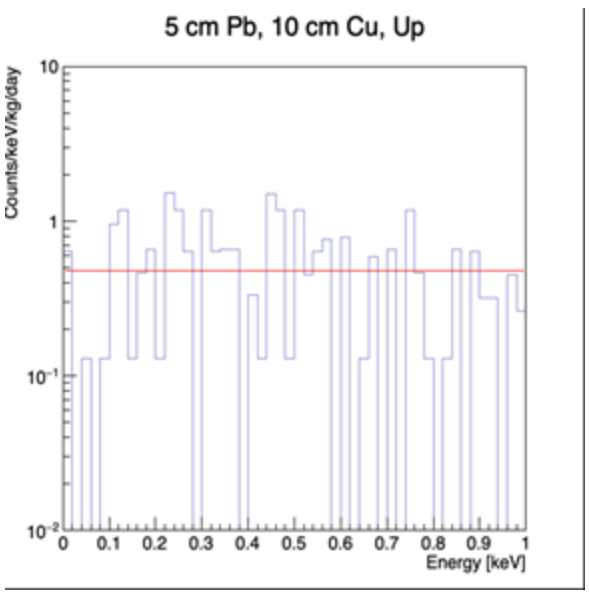


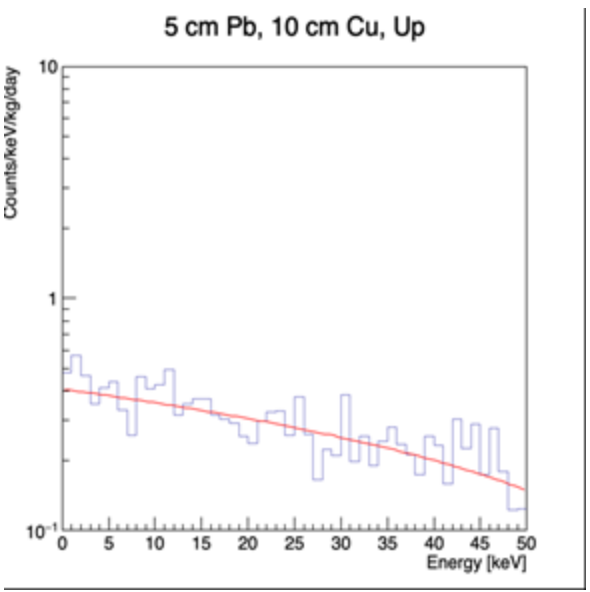


5 cm Pb, 10 cm Cu: 198 cm above the room floor

Best case!







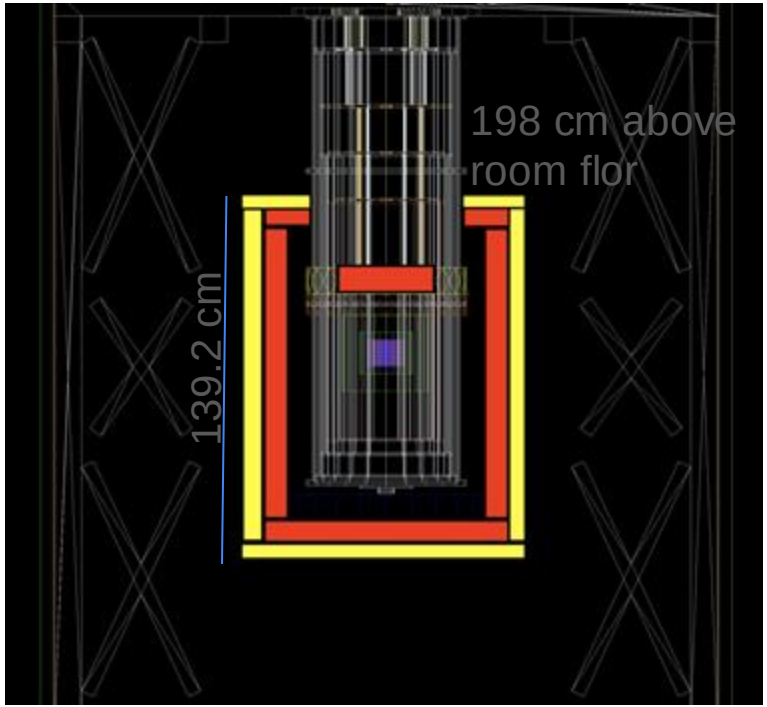
Copper mass: 5.06 T
Lead mass: 4.32 T

New shield design proposed:

- 10 cm Cu and 5 cm Pb
  - Cu mass: 4.72 T
  - Pb mass: 4.07 T

  Additionally, considered this option:
- 5 cm Cu and 10 cm Pb
  - Cu mass: 2.11 T
  - Pb mass: 7.41 T

- Perform simulations to estimate radiopurity of Cu and Pb



Conclusions

- Adding a hat shielding does considerably reduce the background
- Most of the background comes from the empty spaces above BULLKID (inside the cryostat) that cannot be shielded
- The best case now is 10 cm of Cu and 5 cm of Pb at 198 cm above the room floor (Cu mass of 4.7 T)
- Considering 10 cm of Pb and 5 cm of Cu (Cu mass of 2.1 T) is better but depends on the assay of Pb from OPERA
- Simulations for Cu purity are pending
- Next: external neutron shielding and then move to internal (cold) shielding