Simulations: DANAE setup at Sapienza

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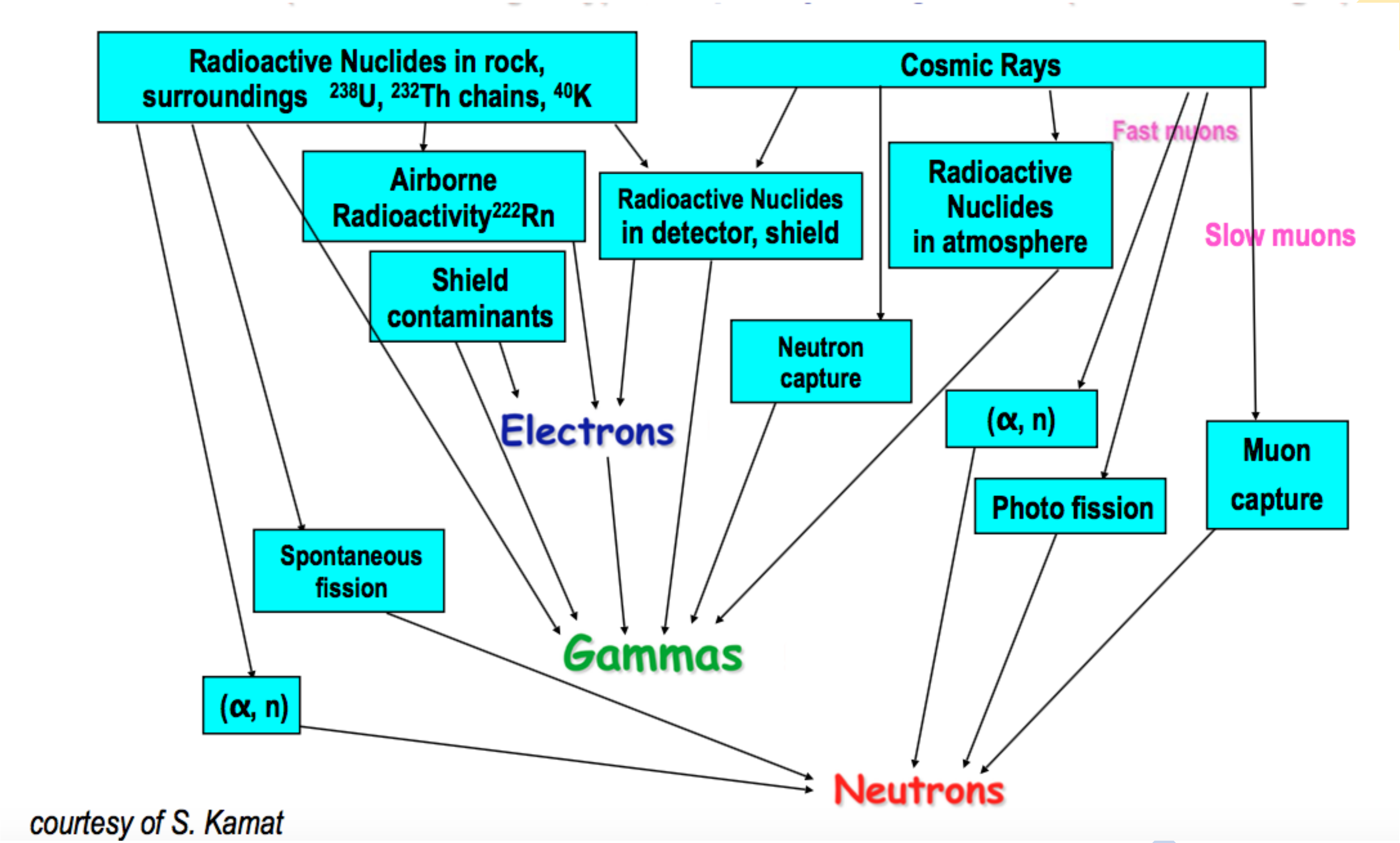
March 19, 2024

The three main things to consider when doing direct detection dark matter experiments

Backgrounds, backgrounds, and backgrounds

Cosmic rays and natural radioactivity



DANAE setup at Sapienza

Wafer details and cryostat

- Single Si crystal

3” in diameter and 5 mm thick

- Dice mass: 0.34 g

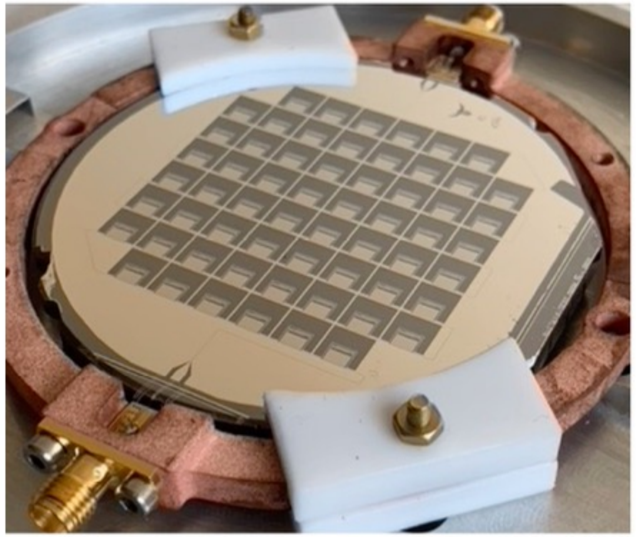
- Sapienza cryostat with geometry built from measurements and drawings

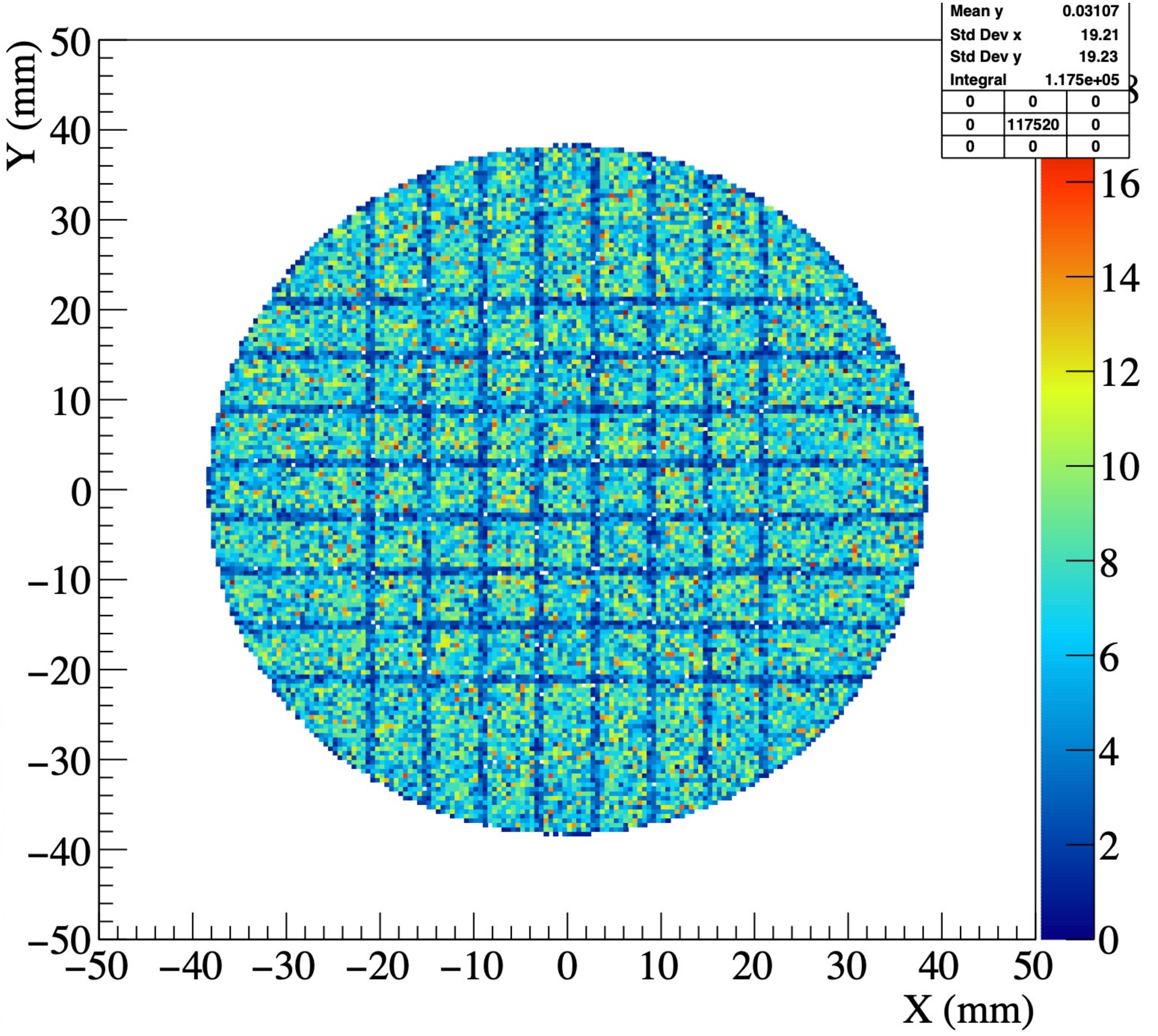
- Grooves included: 0.5 mm

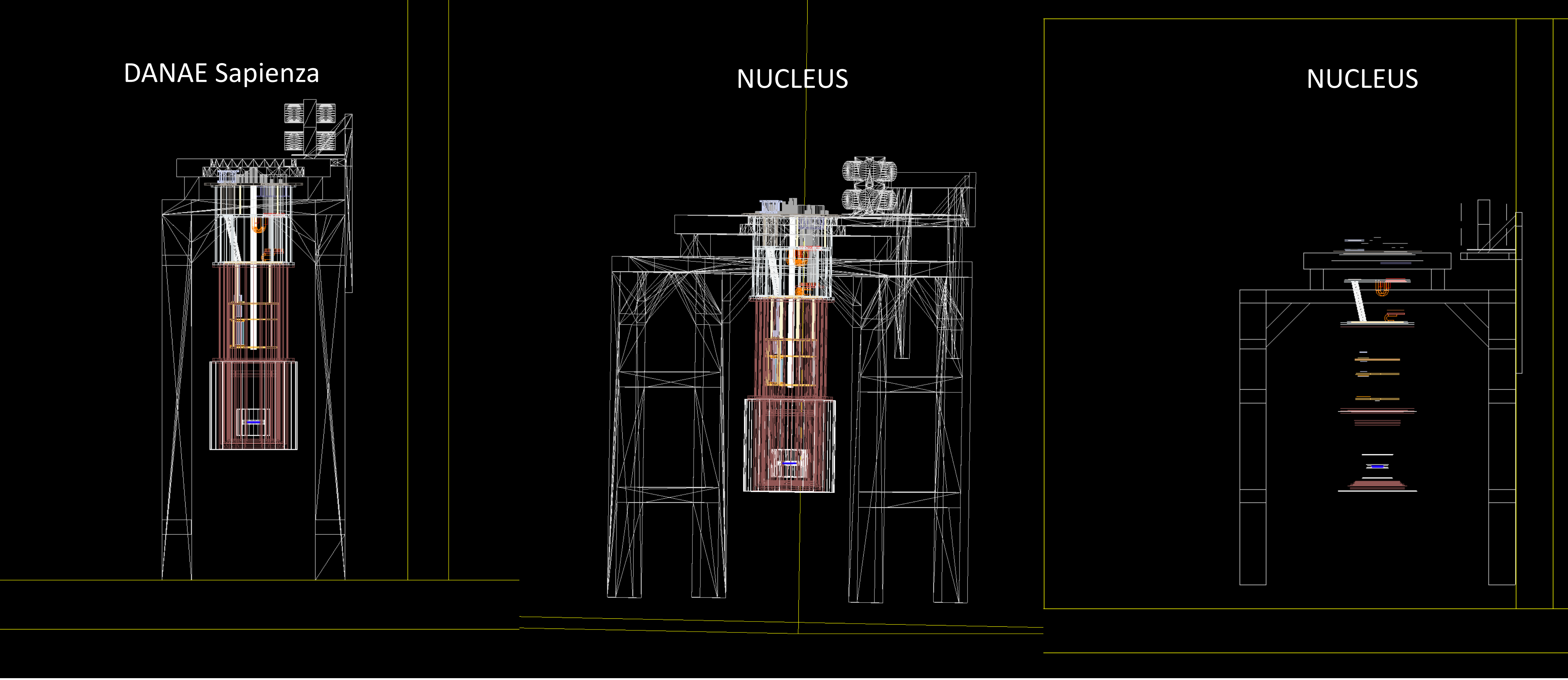
- Dice dimensions:
  5.4 x 5.4 x 5 mm^3

- Bottom disk: 0.5 mm
  (included in the 5 mm dice)

- Copper ring included







MC model in GEANT4 implementing the Sapienza cryostat

Monte Carlo simulations of backgrounds using GEANT4

What we have now

Two GitHub repositories:

Experiment at Sapienza:

https://github.com/ericvj/BULLKID_Sapienza

Experiment at Gran Sasso:

https://github.com/ericvj/BULLKID_GranSasso ericvj / BULLKID_Sapienza

Type / to search

Code | Issues | Pull requests | Actions | Projects | Security | Insights | Settings

BULLKID_Sapienza Private

Unwatch 1 | Fork 0 | Star 0

main | 1 Branch | 0 Tags | Go to file t | Add file | Code

ericvj Update README.md a778cc5 · last week 4 Commits

Sapienza	Update to two wafer geometry at Sapienza	last week
Makefile	Uploading code and GEANT4	4 months ago
README.md	Update README.md	last week
geant4-v11.1.3.tar.gz	Uploading code and GEANT4	4 months ago

README

BULLKID at Sapienza with GEANT4.11.1.p03

About

Code for Monte Carlo simulations using GEANT4.11.3 for the BULLKID experiment

Readme
Activity
0 stars
1 watching
0 forks

Releases

No releases published
Create a new release

Packages

No packages published
Publish your first package

Languages

C++ 98.7% Other 1.3%

What we have now

- How to use in one-two-three:

1. clone: gh repo clone ericvj/BULLKID_Sapienza or
   git clone git@github.com:ericvj/BULLKID_Sapienza.git
2. cd BULLKID_Sapienza
3. make

provides compilation of GEANT4 and DANAE experiment

- You need a github account, request access to GEANT4 code

Ready and working!

(compilation in 6 minutes and 8 sec with Apple M1 Pro)

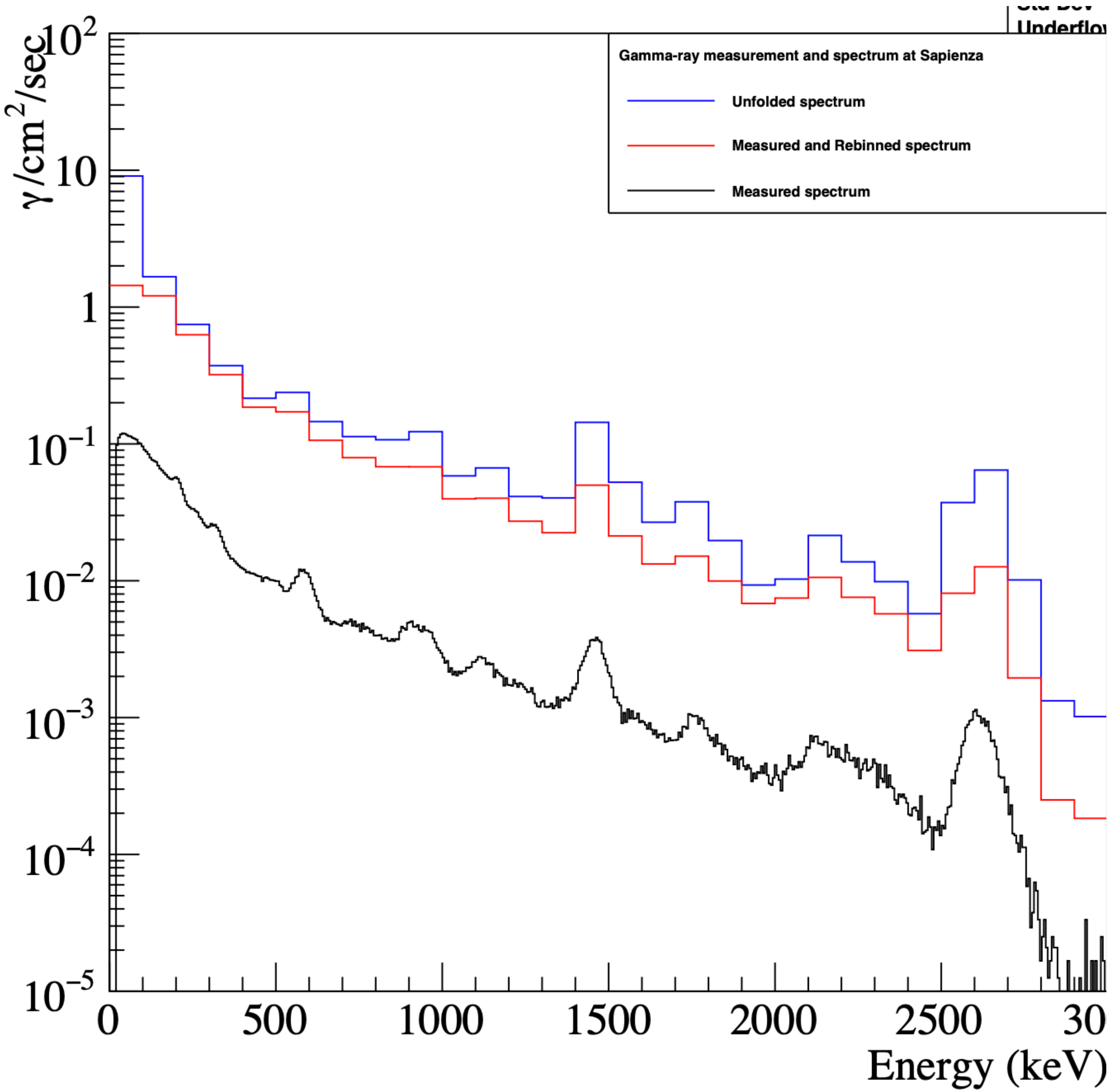
Gamma-rays from the room at Sapienza

Validation of MC simulation

- Obtain gamma spectrum in Sapienza laboratory using spectrum from NaI
  (from Laura Cardani)

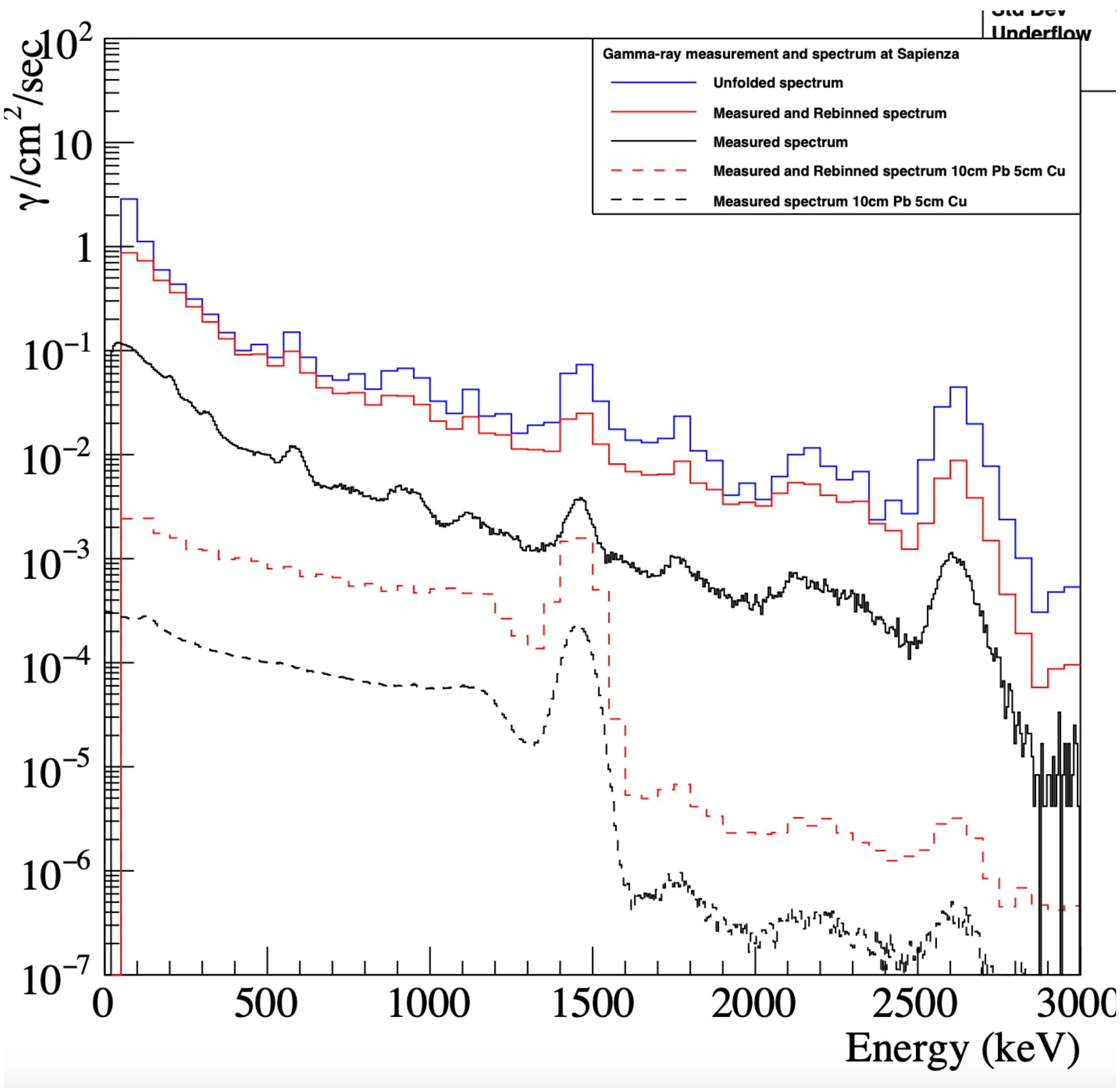
- Unfolding performed with 100 keV energy bins

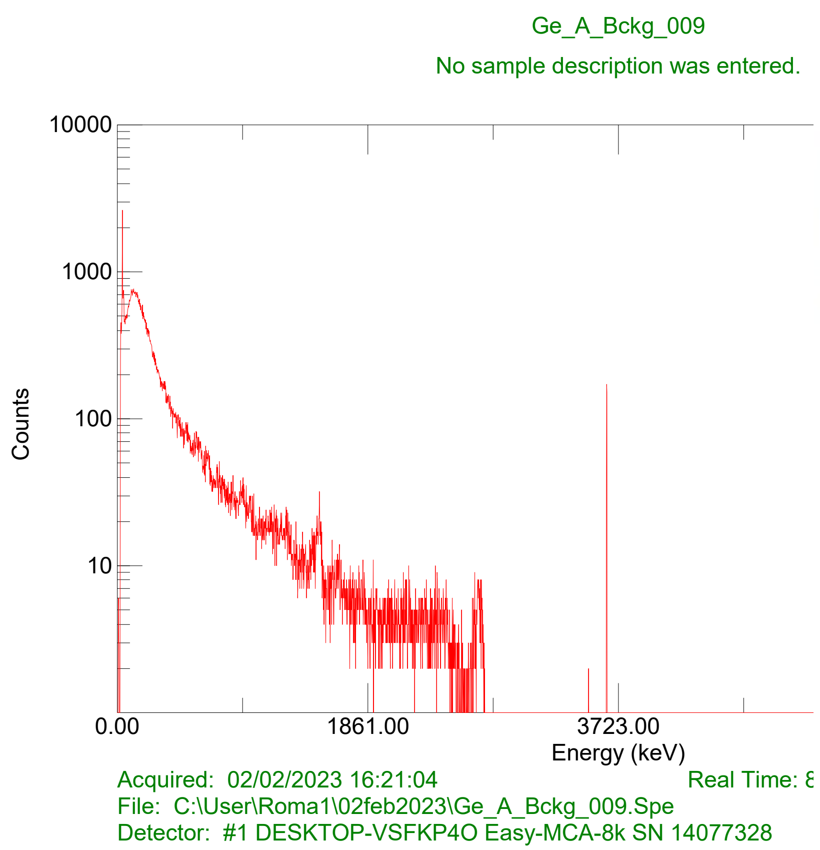
- Flux = 13.47 $\gamma/\mathrm{cm}^2/\mathrm{sec}$



Validation of MC simulation

- NaI internal backgrounds from crystal are negligible
- 1% approximately





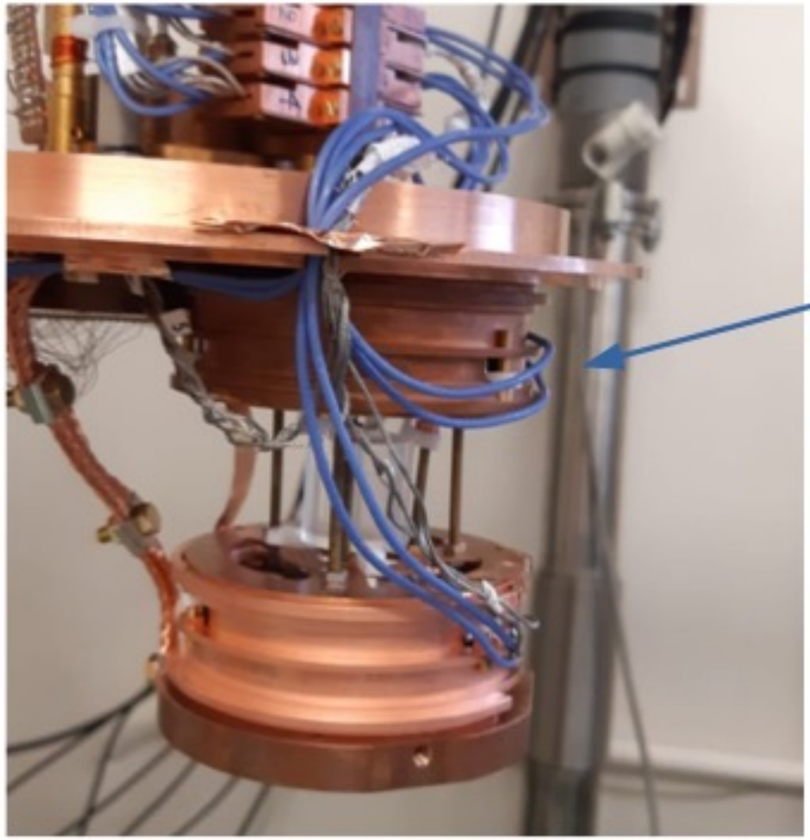
Slide from:

Beatrice Mauri

Data from:

Riccardo Cerulli

Detector assembly (1)



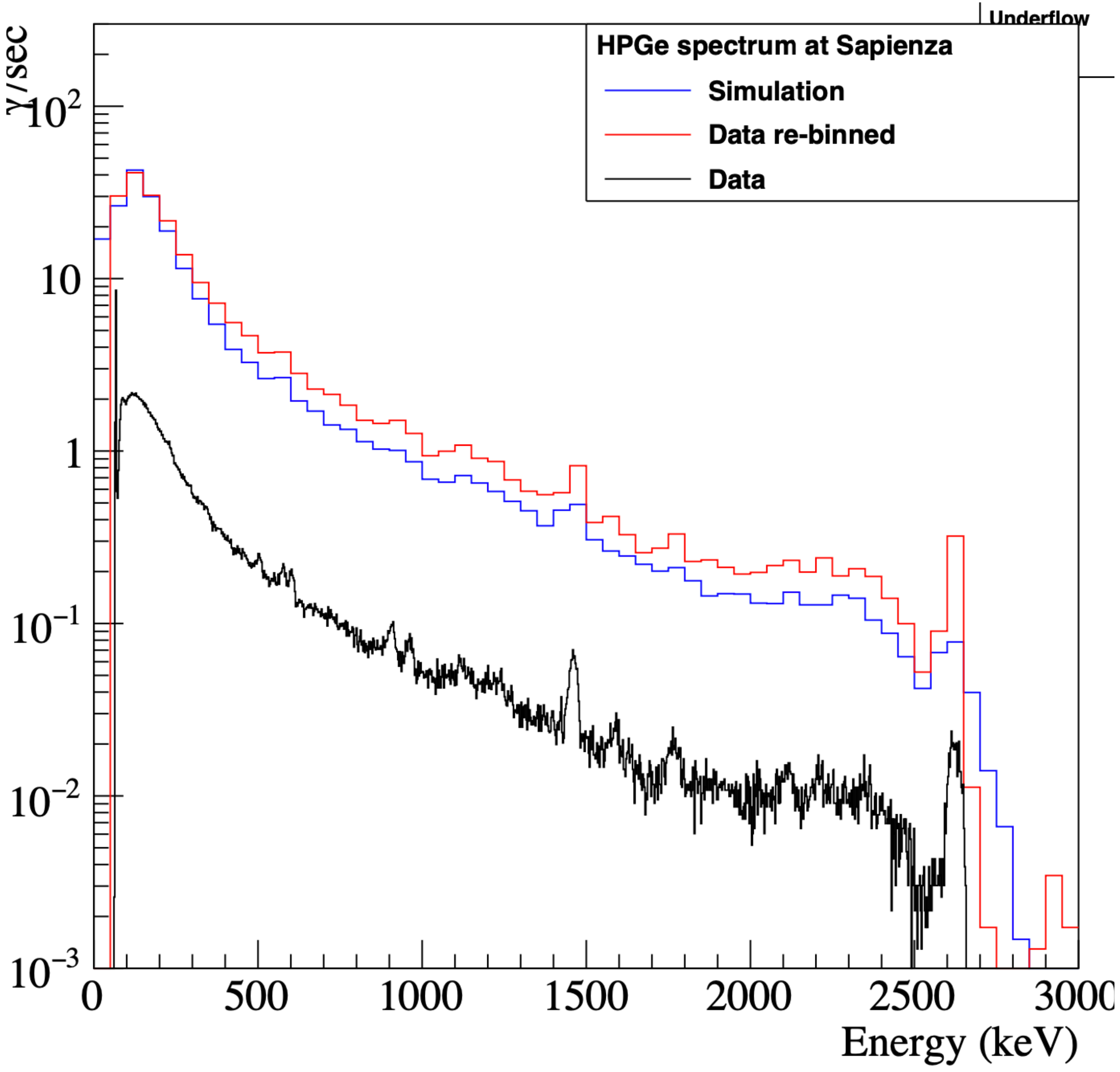
Top HPGe crystal:

- ϕ= 70 mm, h = 20 mm, m=400 g
- impurity density < 10^{10} cm^{-3}
- Electrodes: Al co-planar grid geometry (Interdigit detector)
- Bias: 10 V on one side, 0V on the other
- Gain: 1000
- Sampling frequency: 100 kHz

These electrodes are used like the planar electrodes.

Validation of MC simulation

- Simulated unfolded gamma spectrum of HPGe setup inside the cryostat
- Agreement with HPGe setup is ~15% from 100 keV to 3 MeV

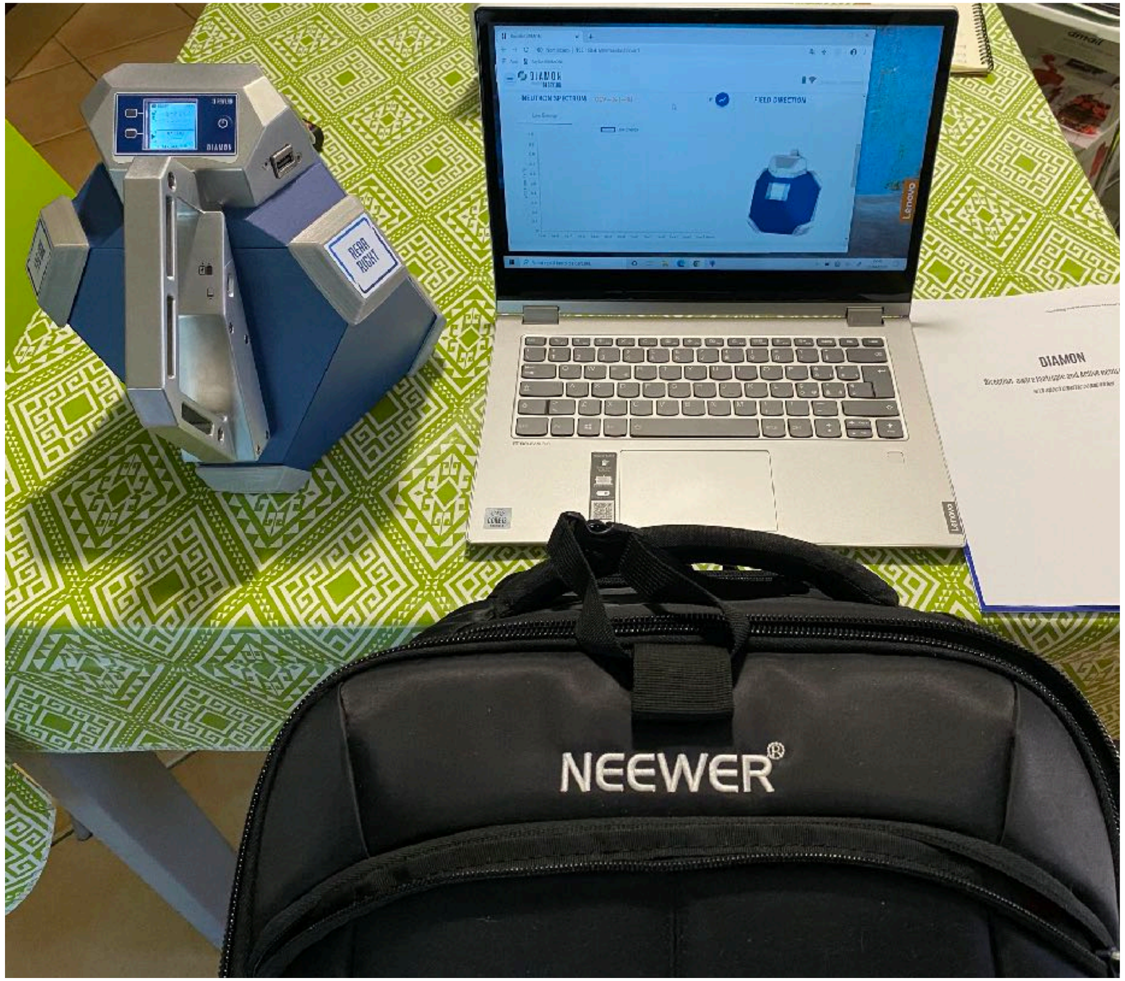


Neutrons from the room at Sapienza

From Claudia Tomei

SETUP

- **DIAMON was designed to enhance the isotropy of the angular response over the whole energy range and improve the overall mechanical design (higher versatility and portability)**
  - **Overall dimensions: 25x25x30 cm^3**
  - **Weight: 6 kg (ergonomic handle to carry it around)**
- **Control laptop (Lenovo IdeaPad C340-14IML, with touch screen)**
- **Trolley bag for easy transport**



From Claudia Tomei

MEASUREMENTS AT SAPIENZA

Measurement in the laboratory of cryogenic detectors (floor 1)

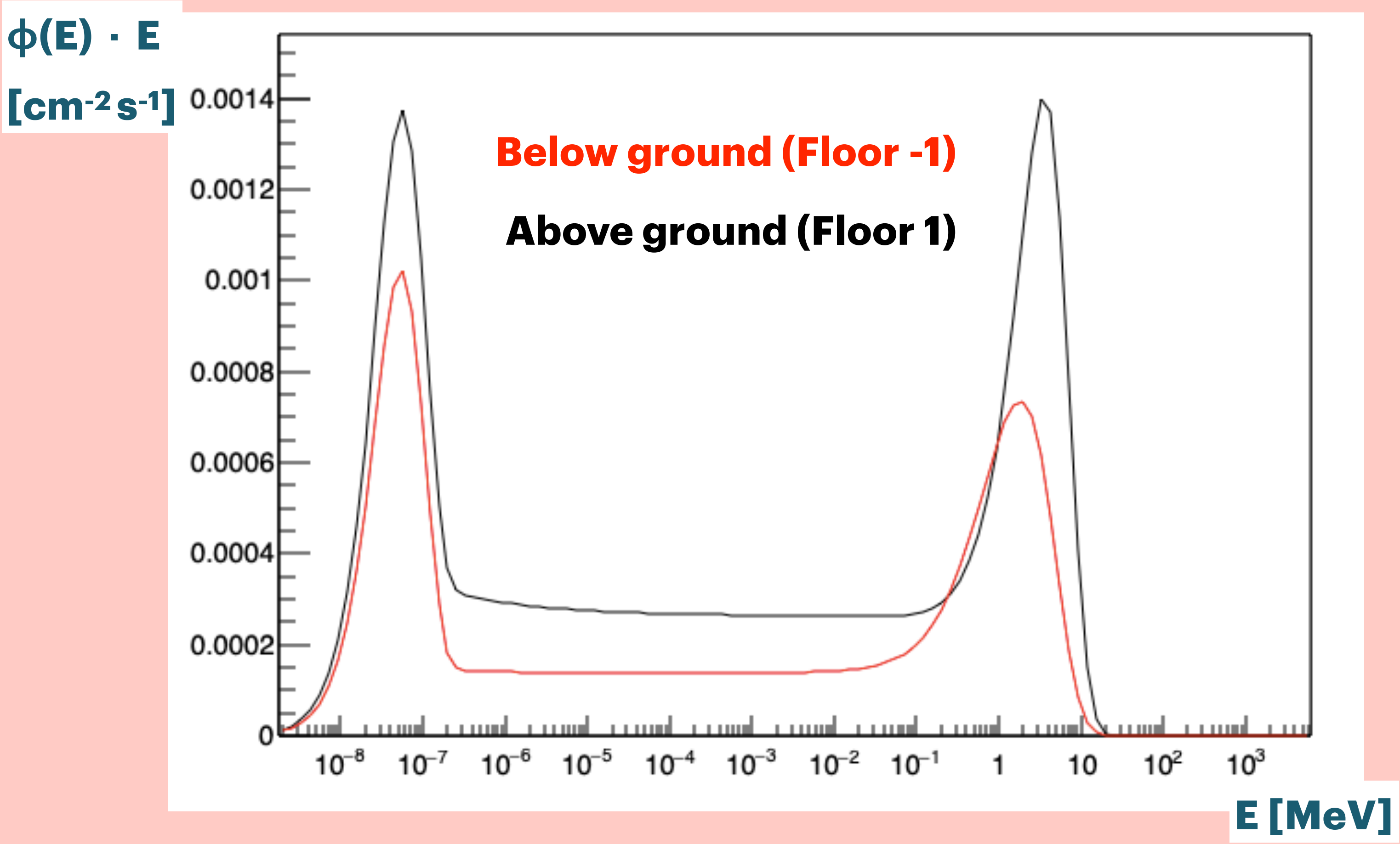
Tue May 19, Measurement Time: 2.1 d

- **Average number of counts: 135**
- **Flux : 0.010 cm^{-2} s^{-1}**
  - **thermal: 31%**
  - **epithermal: 35%**
  - **fast: 34%**

Average experimental data uncertainty: 8.7%

Avg - MAX deviation UNFOLDING/EXP cps: 12.6% | 43.8%

From Claudia Tomei



Subleading backgrounds on surface

Cosmogenic backgrounds at Sapienza: muons and neutrons

CRY generator

C. Hagmann, D. Lange and D. Wright, "Cosmic-ray shower generator (CRY) for Monte Carlo transport codes," *2007 IEEE Nuclear Science Symposium Conference Record*, Honolulu, HI, USA, 2007, pp. 1143-1146, doi: 10.1109/NSSMIC.2007.4437209.

Monte Carlo model of the Earth's atmosphere

Primary protons in the energy range of 1 GeV - 100 TeV are injected at the top of the atmosphere.

The codes follow the tracks of all relevant secondary particles (neutrons, muons, gammas, electrons, and pions) and tally their fluxes at selectable altitudes.

Comparisons with cosmic ray data at sea level show good agreement.

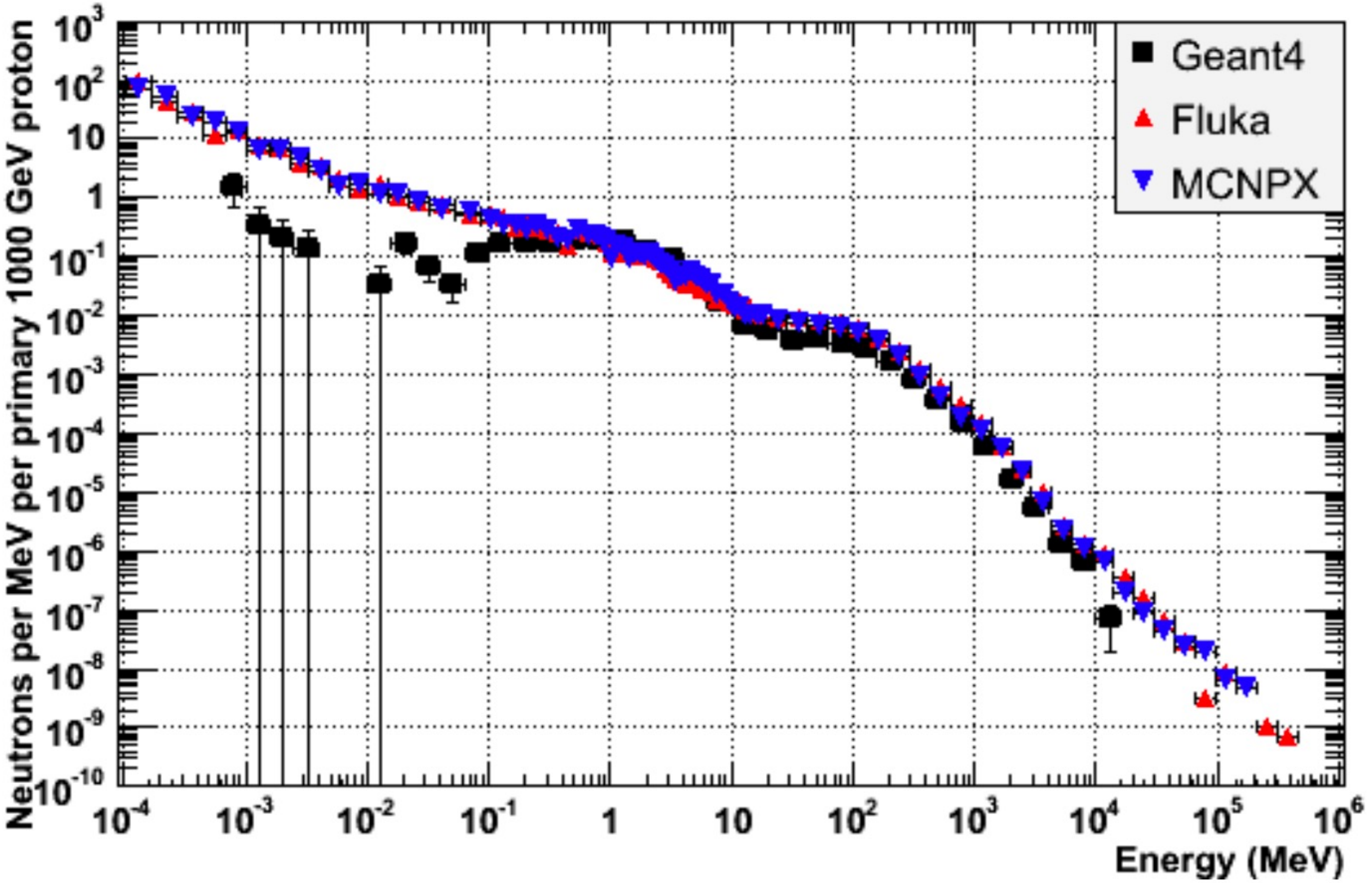
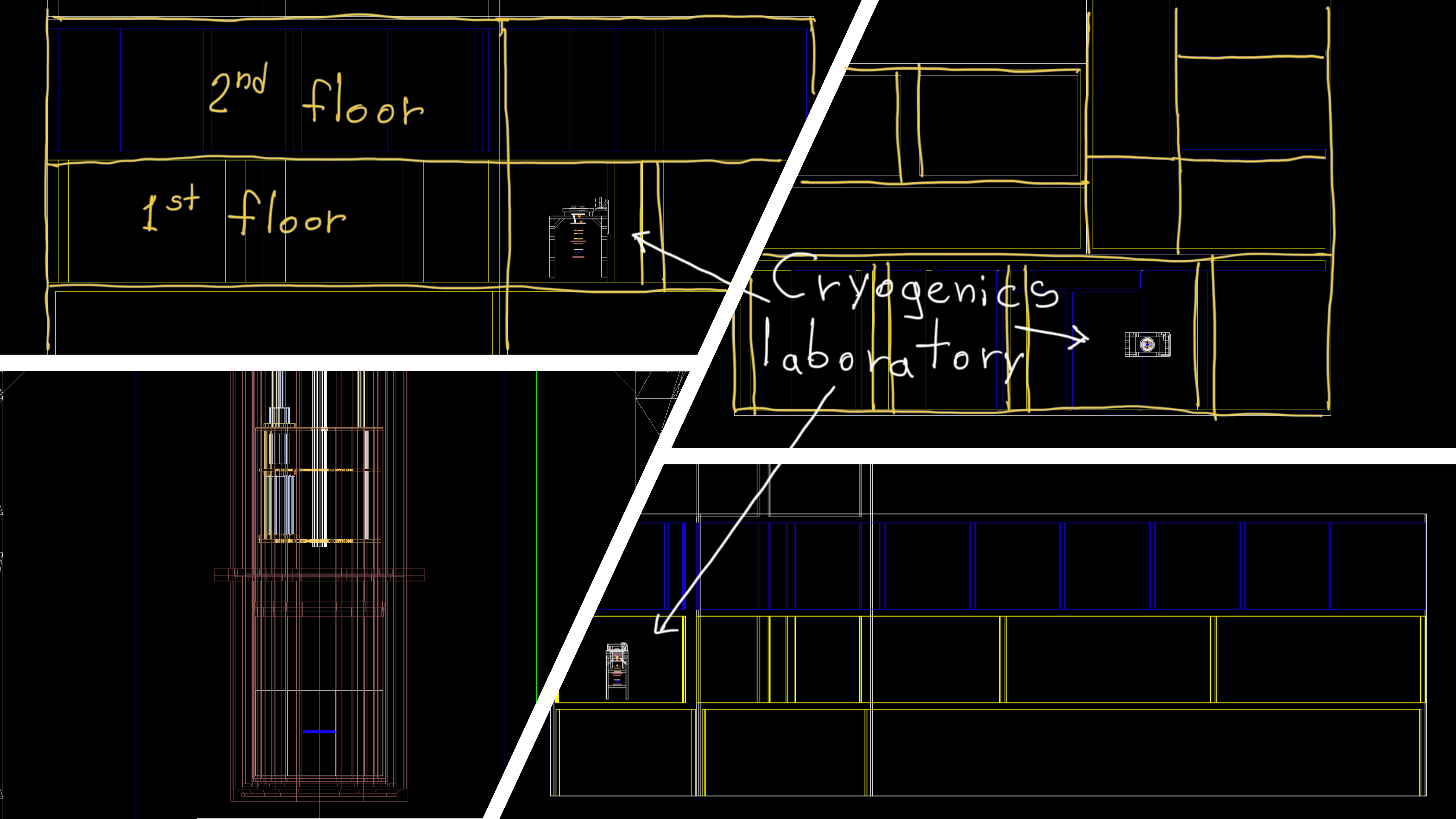
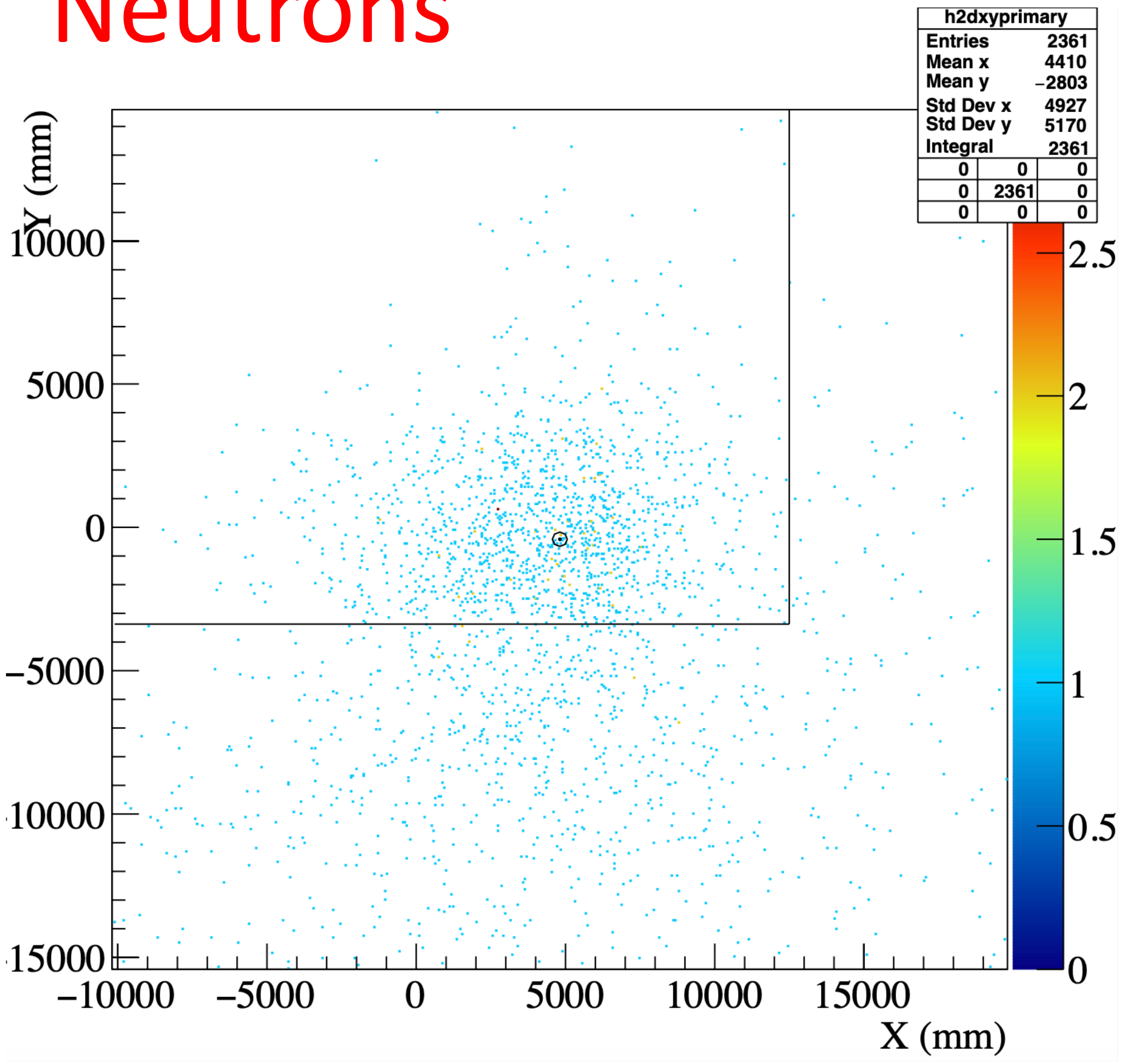


Figure 2: MC-generated neutron spectra at sea level. The incident proton energy is 1TeV.

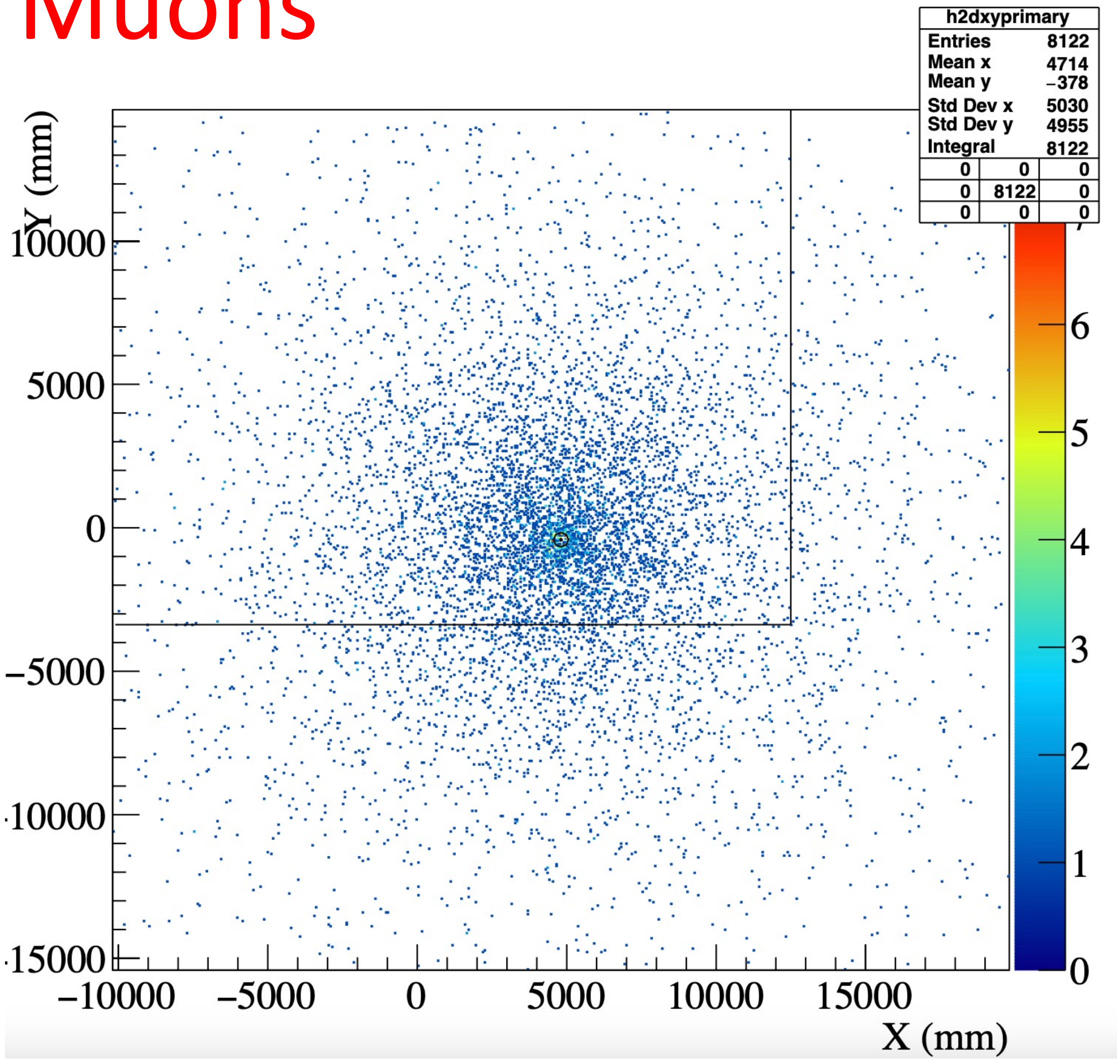


2nd floor
1st floor
Cryogenics laboratory

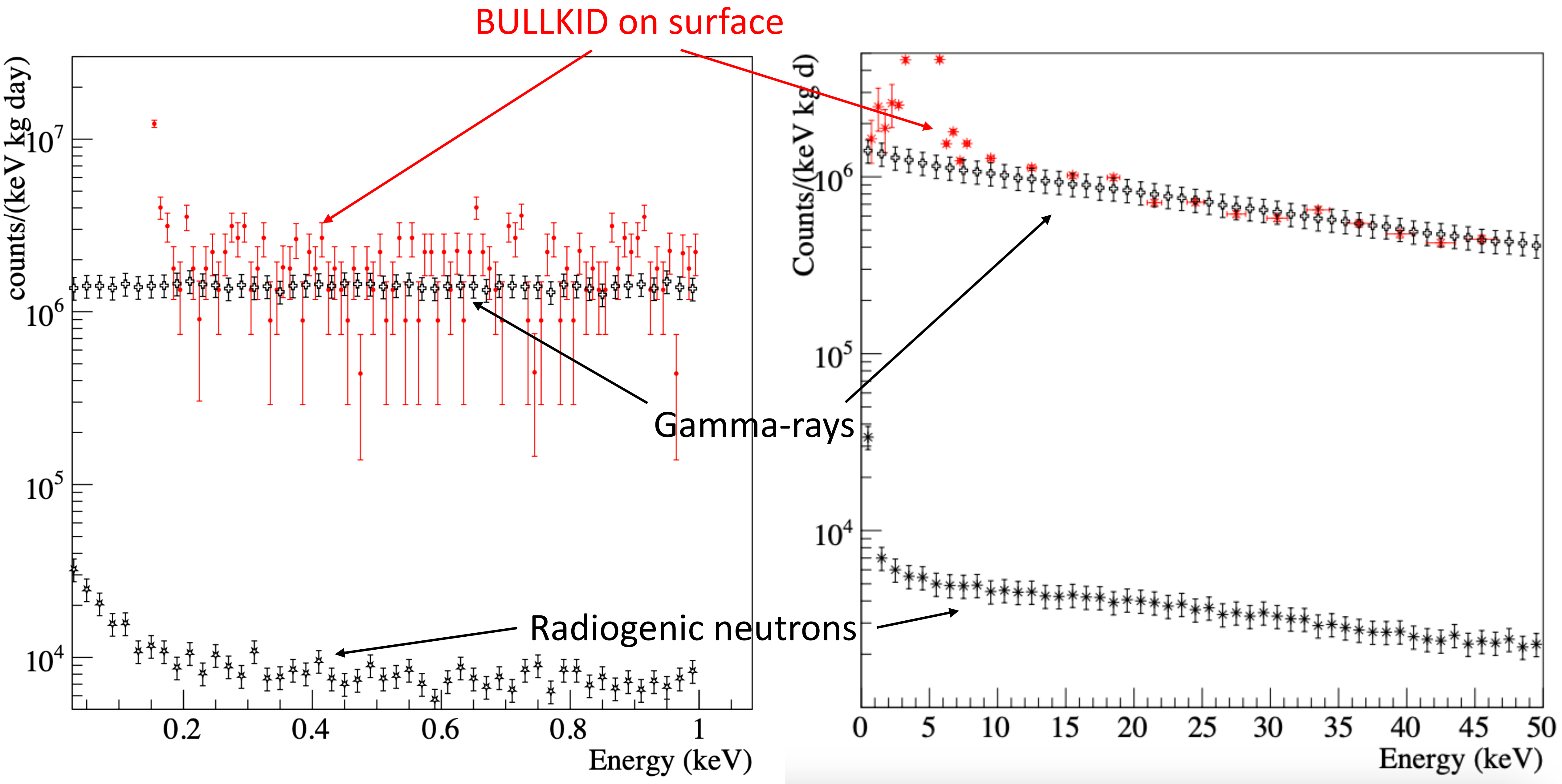
Neutrons



Muons



Results for gammas and neutrons

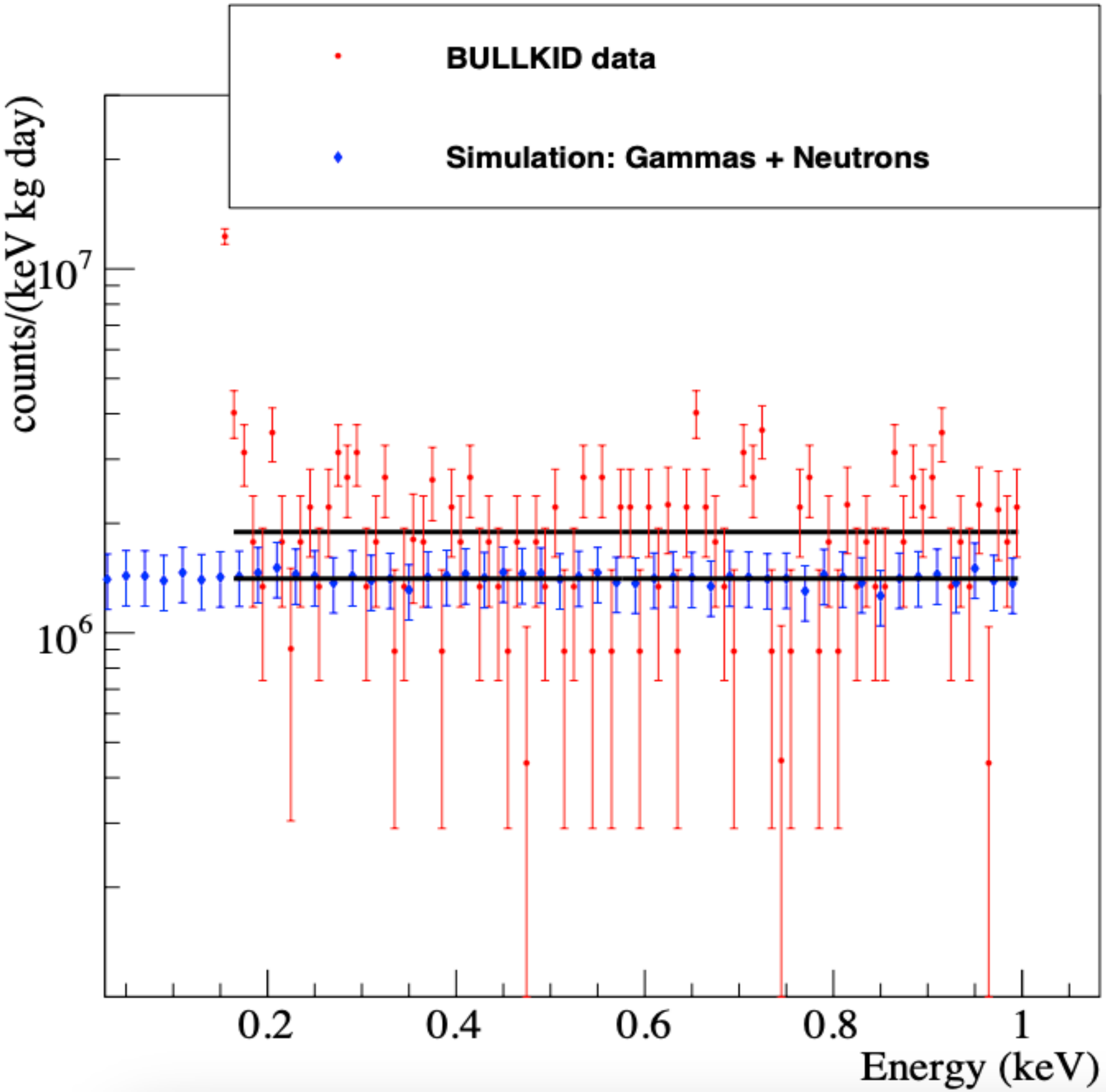

BULLKID on surface
Gamma-rays
Radiogenic neutrons
counts/(keV kg day)
Energy (keV)
Counts/(keV kg d)
Energy (keV)

Comparison to the experiment

All events in one dice, tagging events in the first ring of dices surrounding it

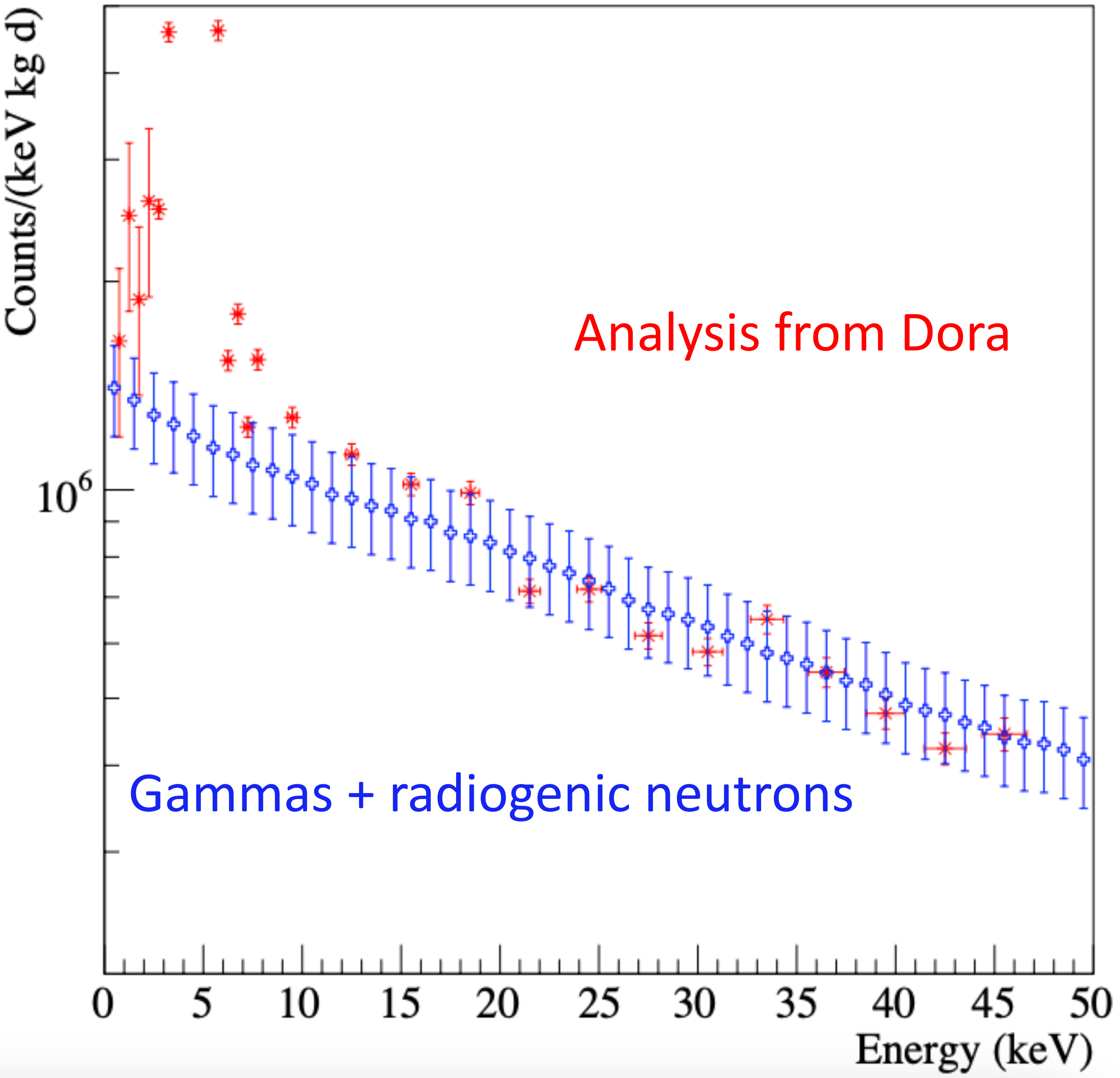
Data: 1.8927×10^6 d.r.u.

Sim: 1.4094×10^6 d.r.u.



- Errors in the simulation are dominated by systematics from the gamma-ray (~15%) and neutron (~8.7%) spectra measurements

Error = 17.3%



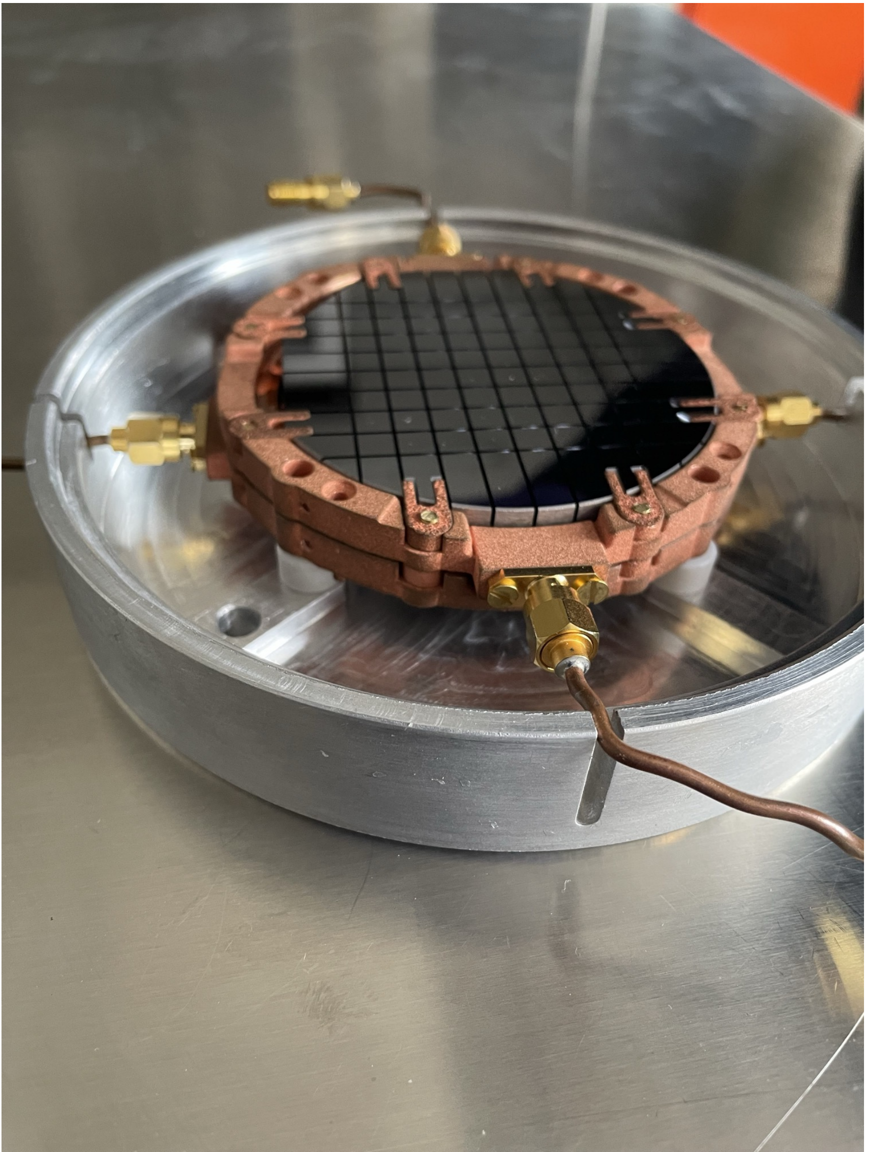
Is it possible to shield on surface and considerably reduce the background?

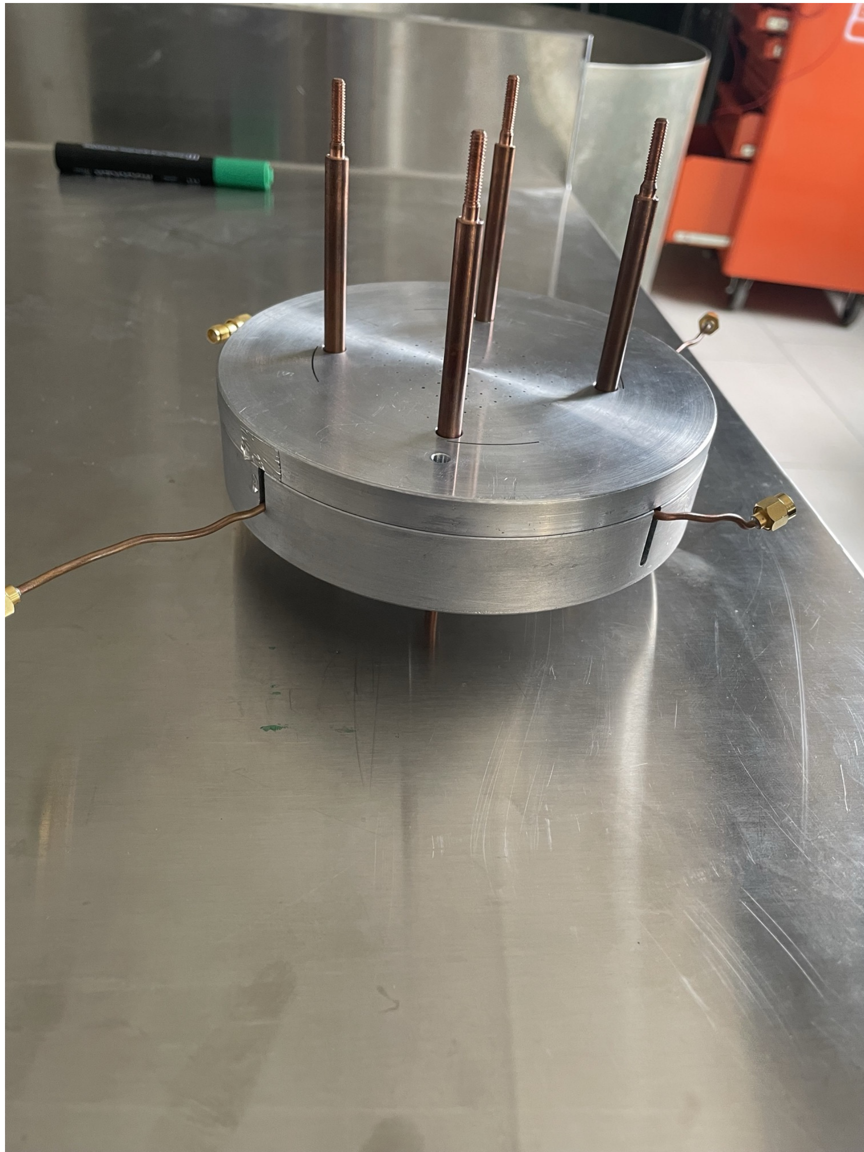
Simulation of shielding configurations at Sapienza:

holder material

Change of holder material:

Al, Cu, Pb





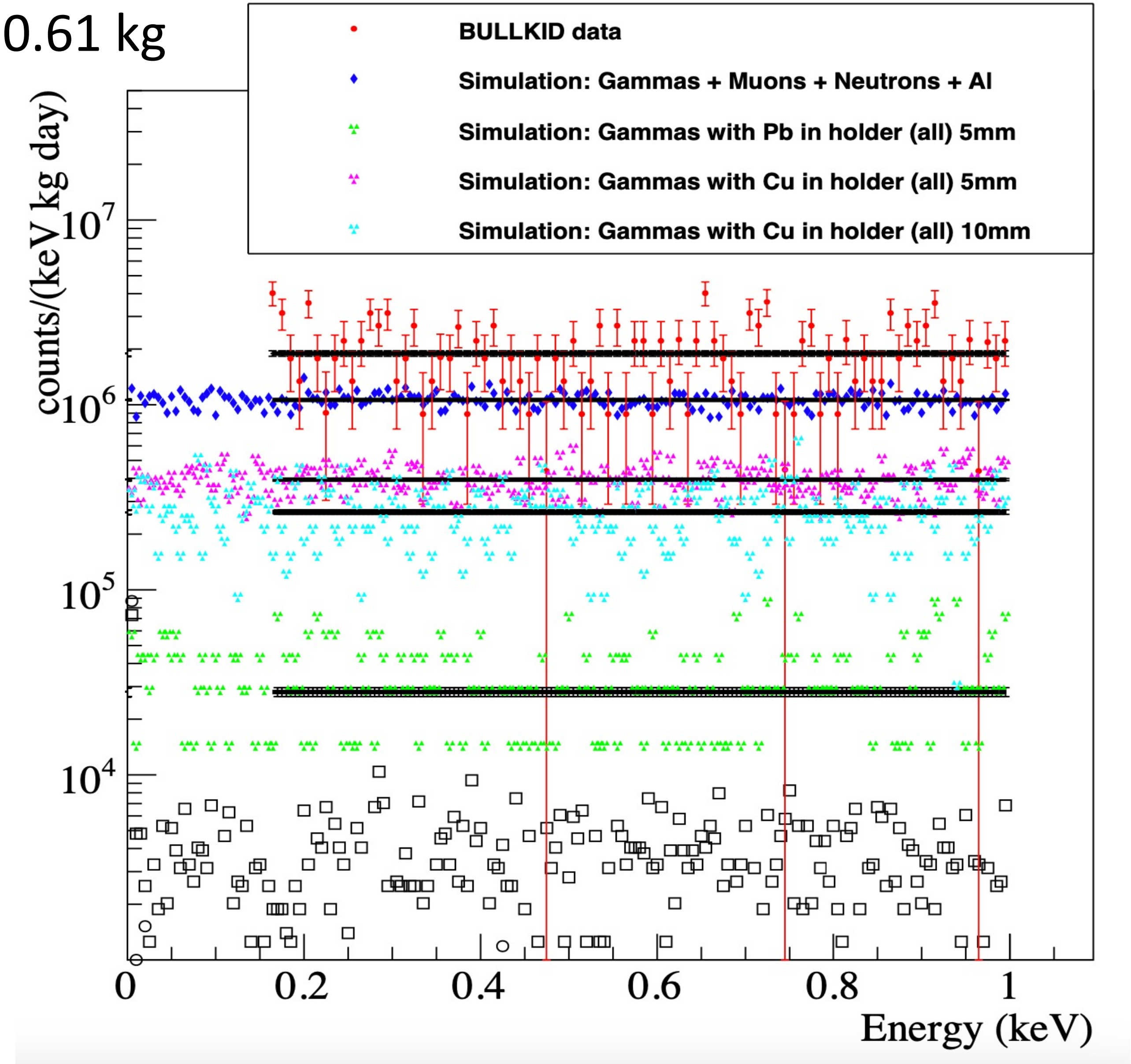
Al in holder: 0.61 kg

Data = 1.89×10^{6}

Cu in holder 5mm= 3.94×10^{5}

Cu in holder 10 mm= 2.63×10^{5}

Pb in holder 5mm= 2.80×10^{4}



Pb in all holder (5mm): 2.56 kg

Cu in all holder, 5 and 10 mm: 2.02 and 4.54 kg

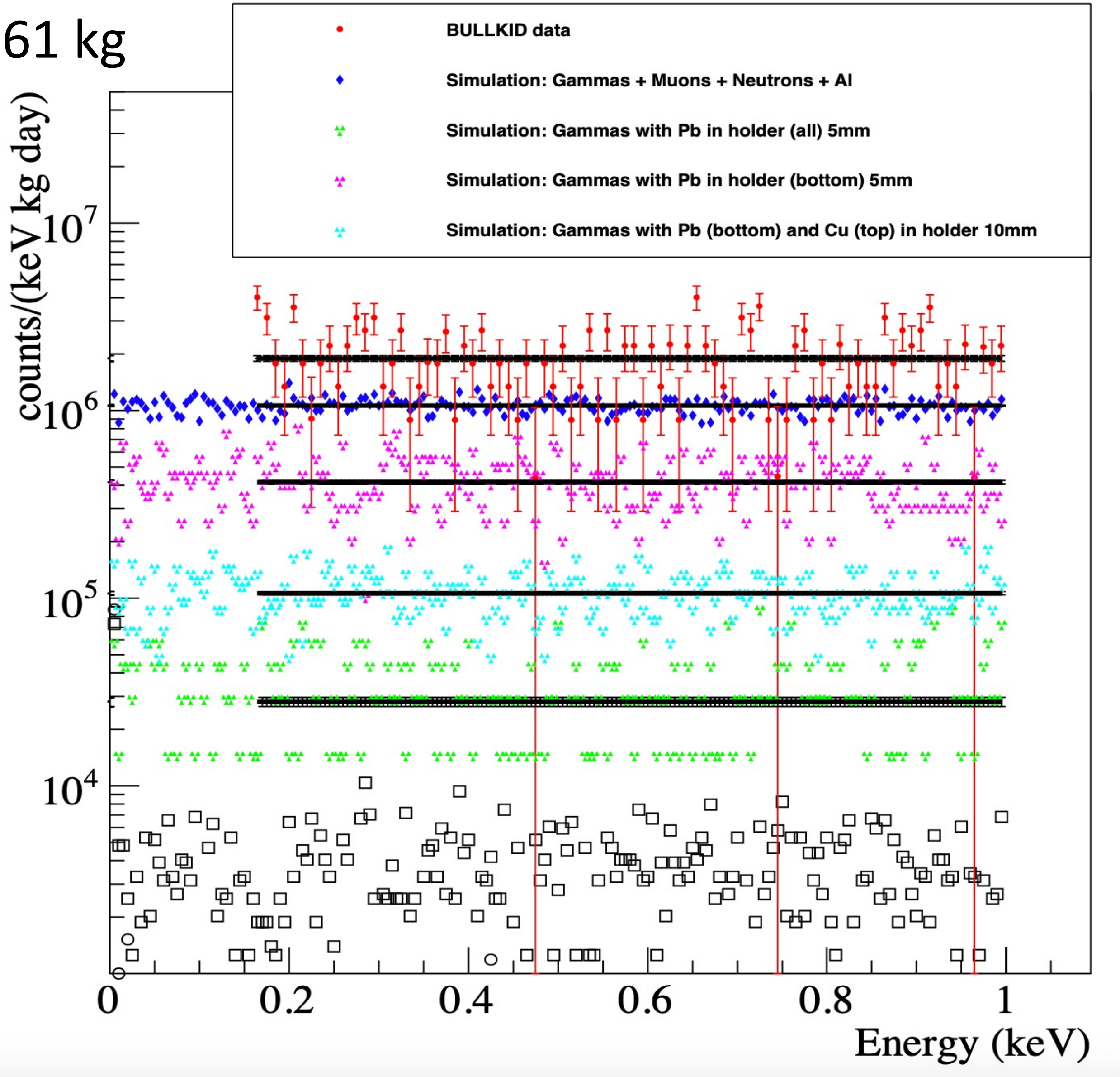
Data = 1.89×10^{6}

Al in holder: 0.61 kg

Pb in holder (bottom)= 4.15×10^{5}

Pb in holder (bottom) and Cu in holder (10 mm)= 1.06×10^{5}

Pb in holder 5mm= 2.80×10^{4}



Pb in all holder (5 mm): 2.56 kg

Pb in all holder (3 mm): 1.34 kg

Pb in all holder (3 mm) and Cu in all holder (5 mm): 3.55 kg

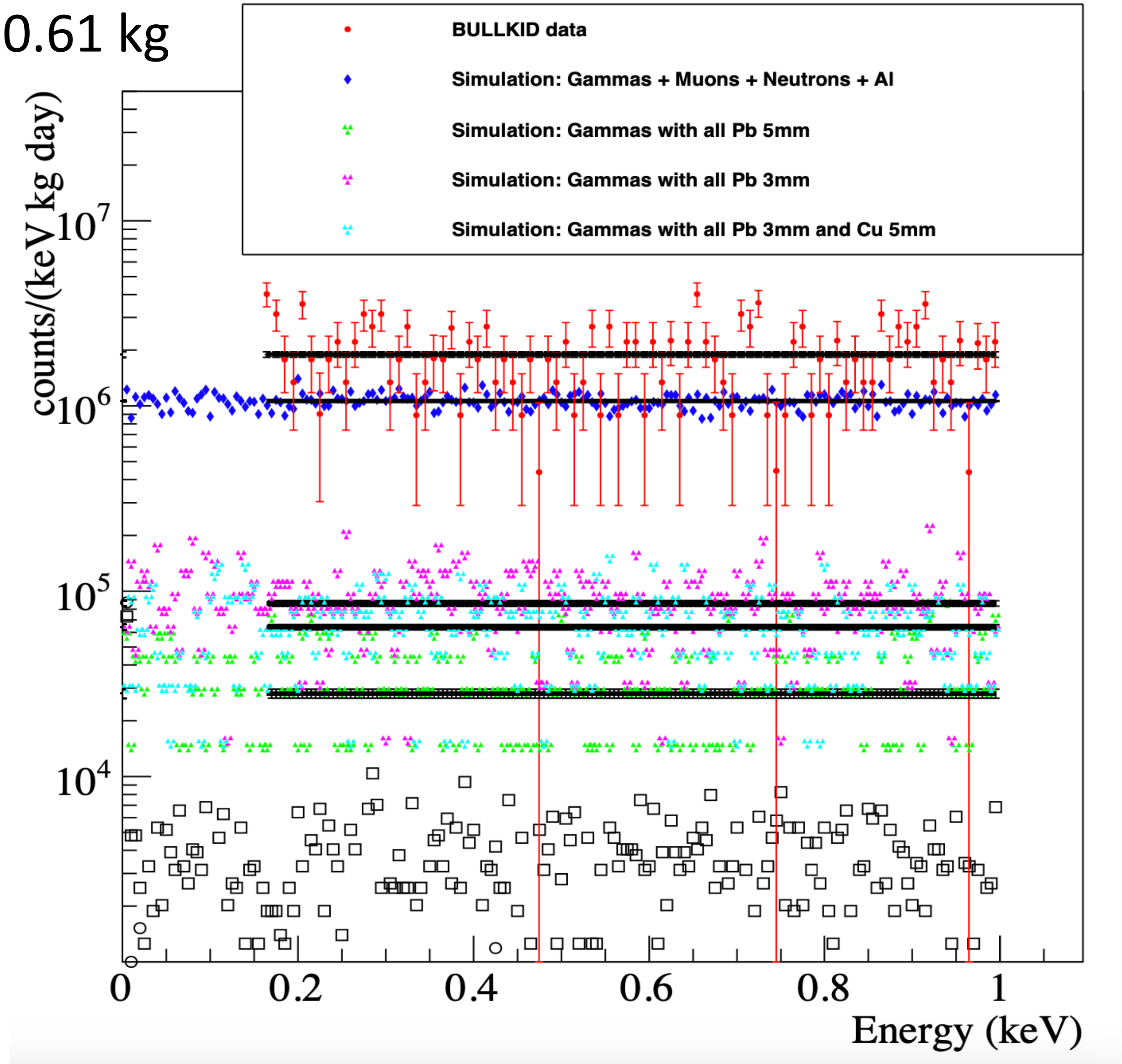
Al in holder: 0.61 kg

Data = 1.89×10^6

Pb in holder 3mm= 8.60×10^4

Pb in holder 3mm and Cu in holder 5mm= 6.40×10^4

Pb in holder 5mm= 2.80×10^4



Pb in all holder (5 mm): 2.56 kg

Pb in all holder (3 mm): 1.34 kg

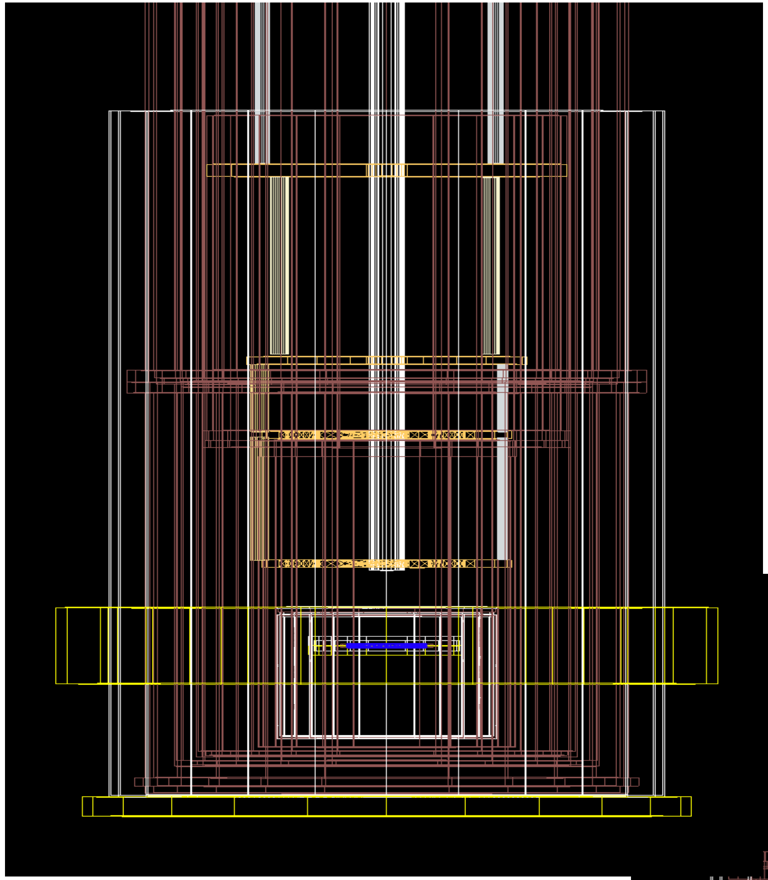
Pb in all holder (3 mm) and Cu in all holder (5 mm): 3.55 kg

External shielding configurations:

several setups simulated with lead and water

Example of shielding configurations simulated

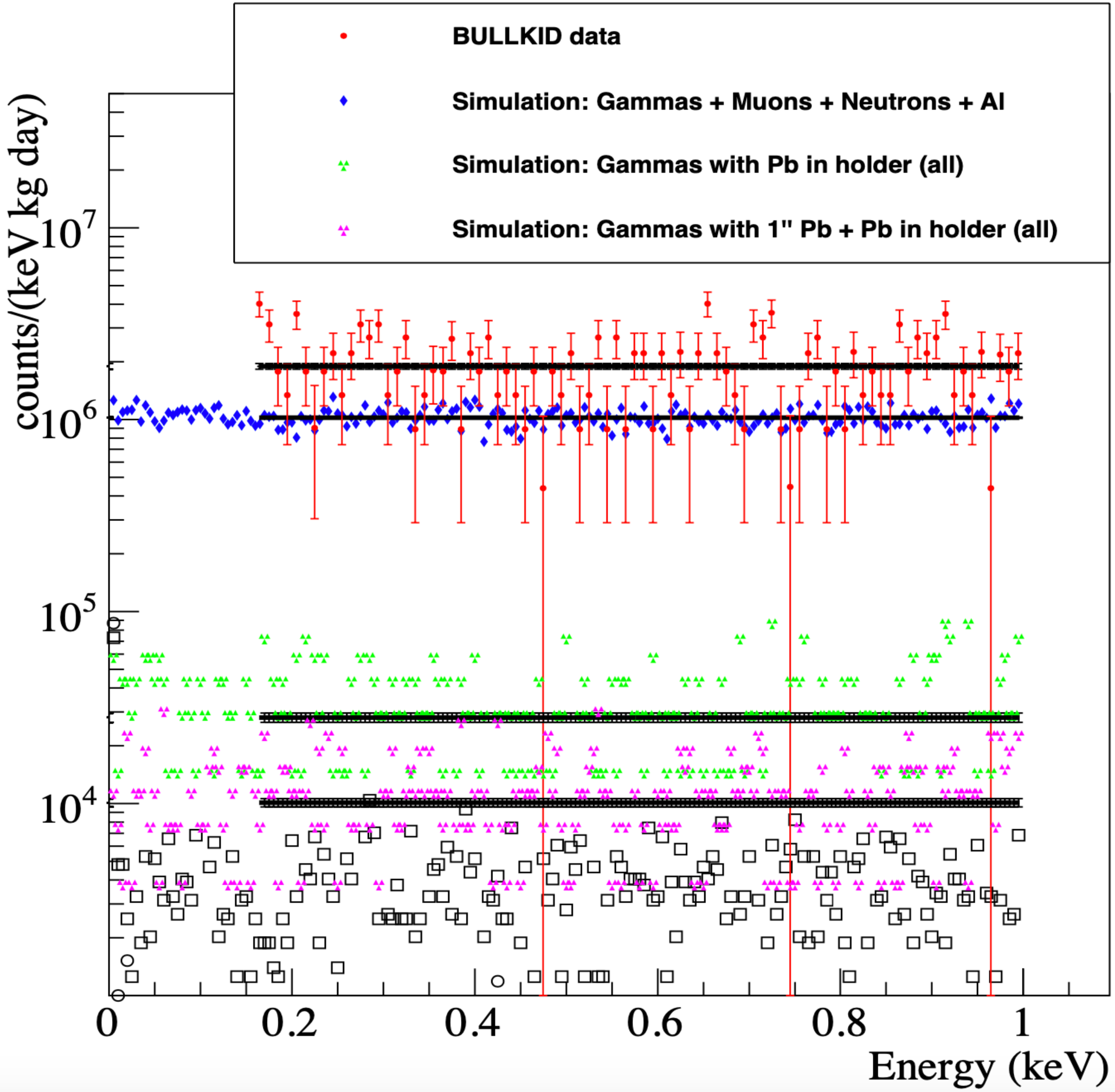
- Pb in holder (all and bottom half only): 1.9 kg
- 1” Pb castle + Pb in holder (all): (230 + 1.9) kg
- 1” Pb base + 1” belt + Pb in holder (all): (130 + 1.9) kg



Data = 1.89×10^6

Pb in all holder= 2.80×10^4

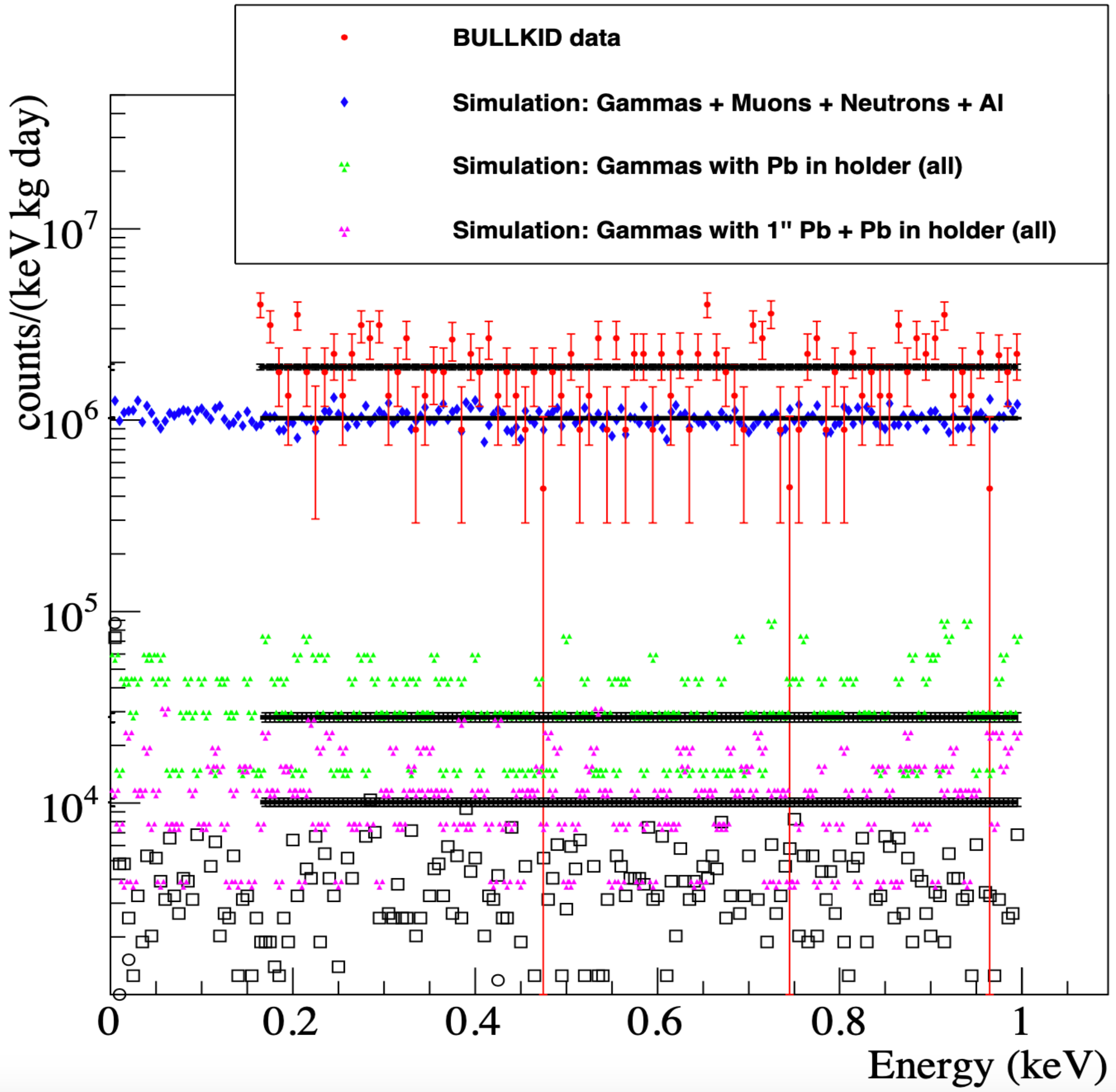
Pb in all holder + 1” Pb castle= 1.01×10^4

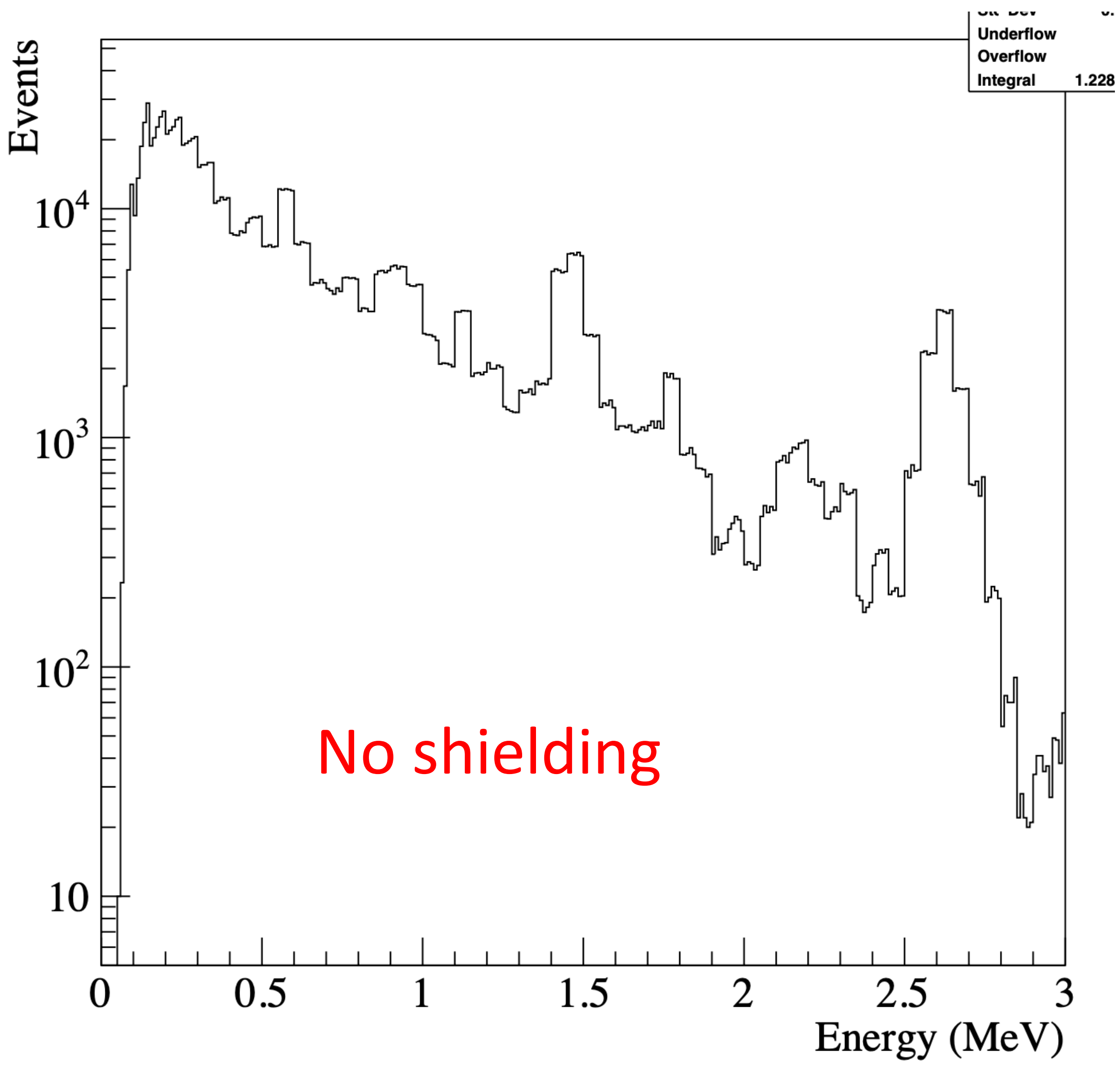


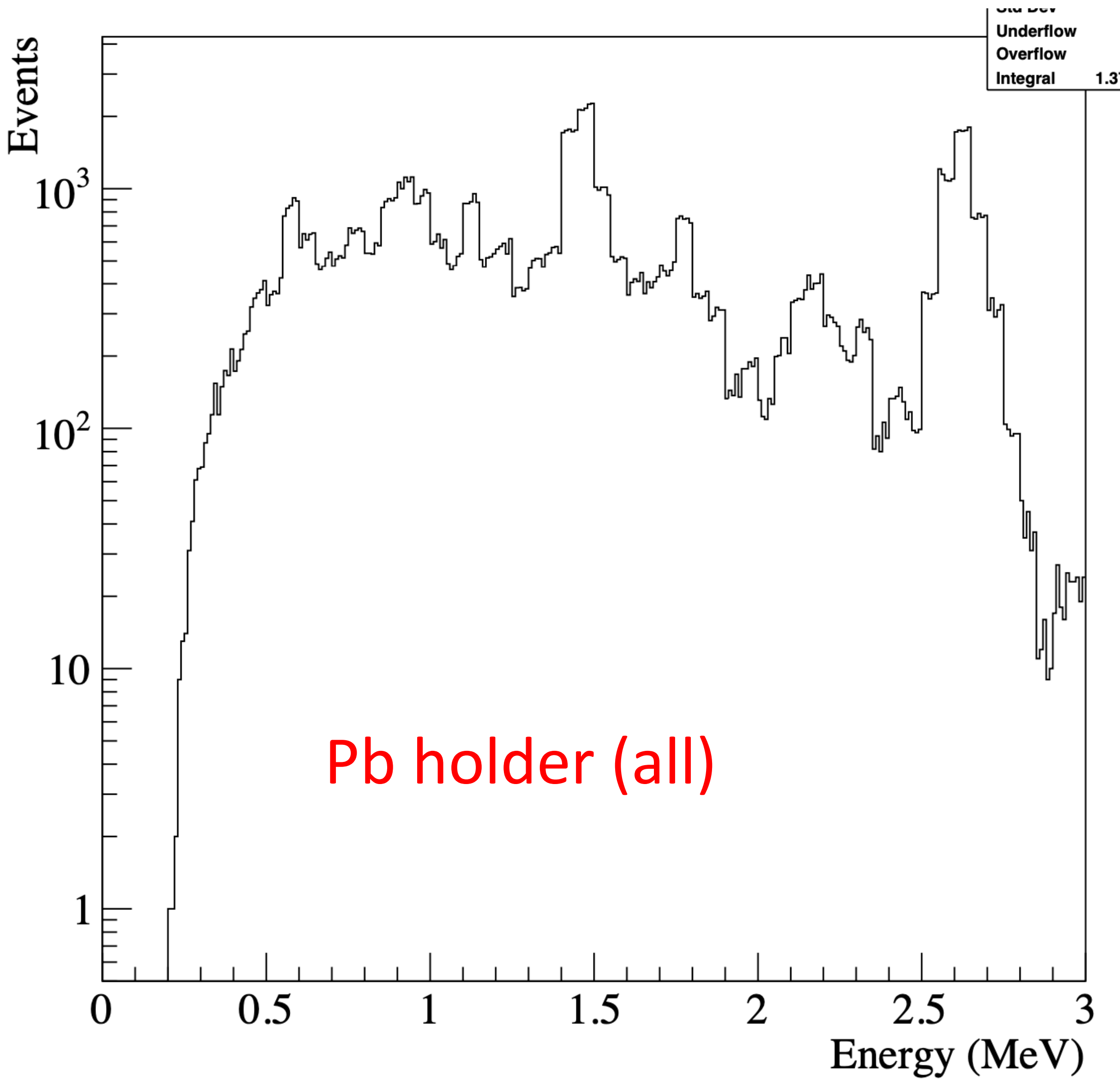
MC = 1.02×10^6
Pb in all holder + 1” castle= 1.01×10^4

Pb mass= 182.5 kg (if mu-metal cover is removed)
Thickness: 1 inch
Height: ~32.5 cm

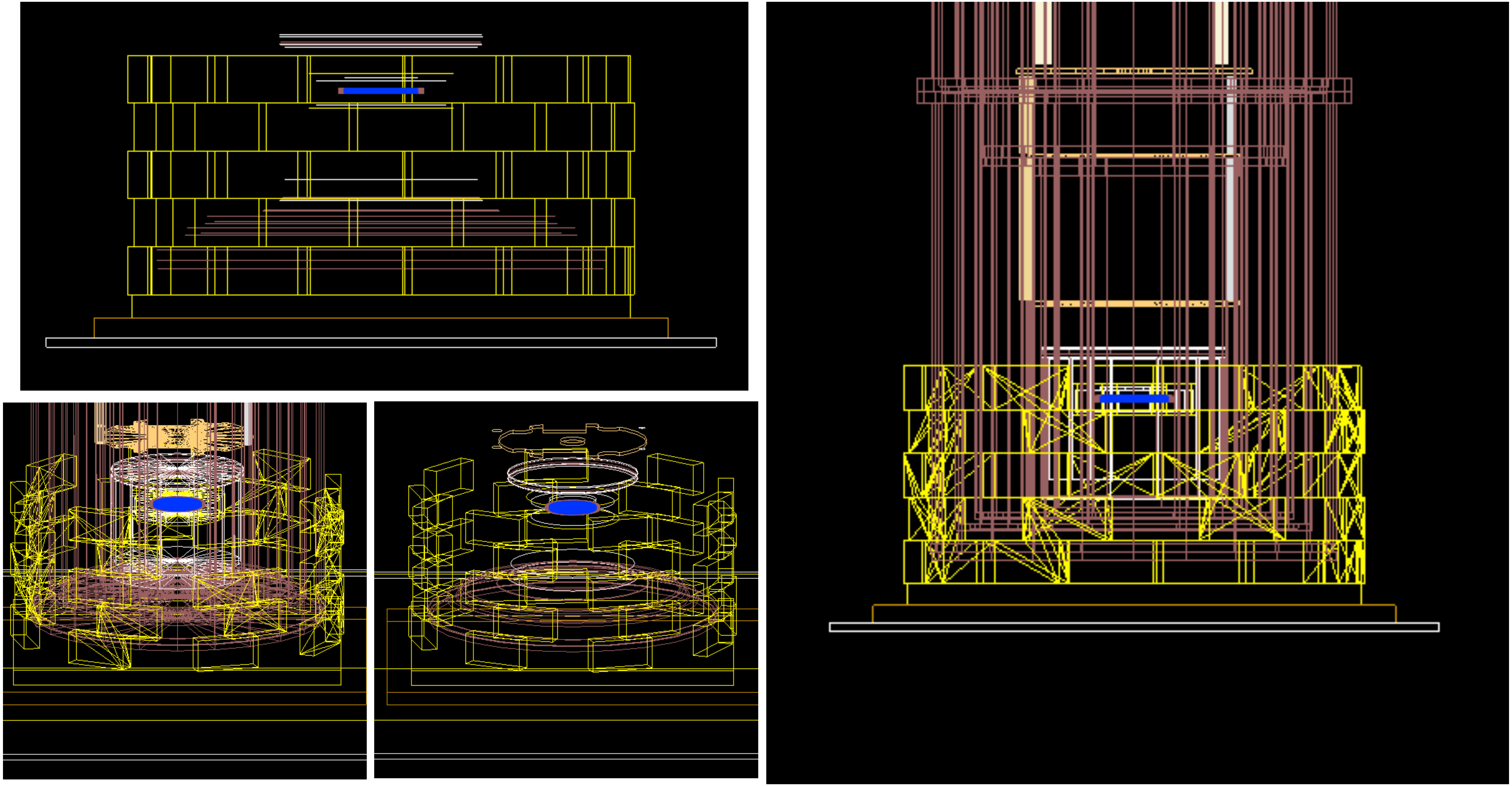
~ 2 orders of magnitude!!

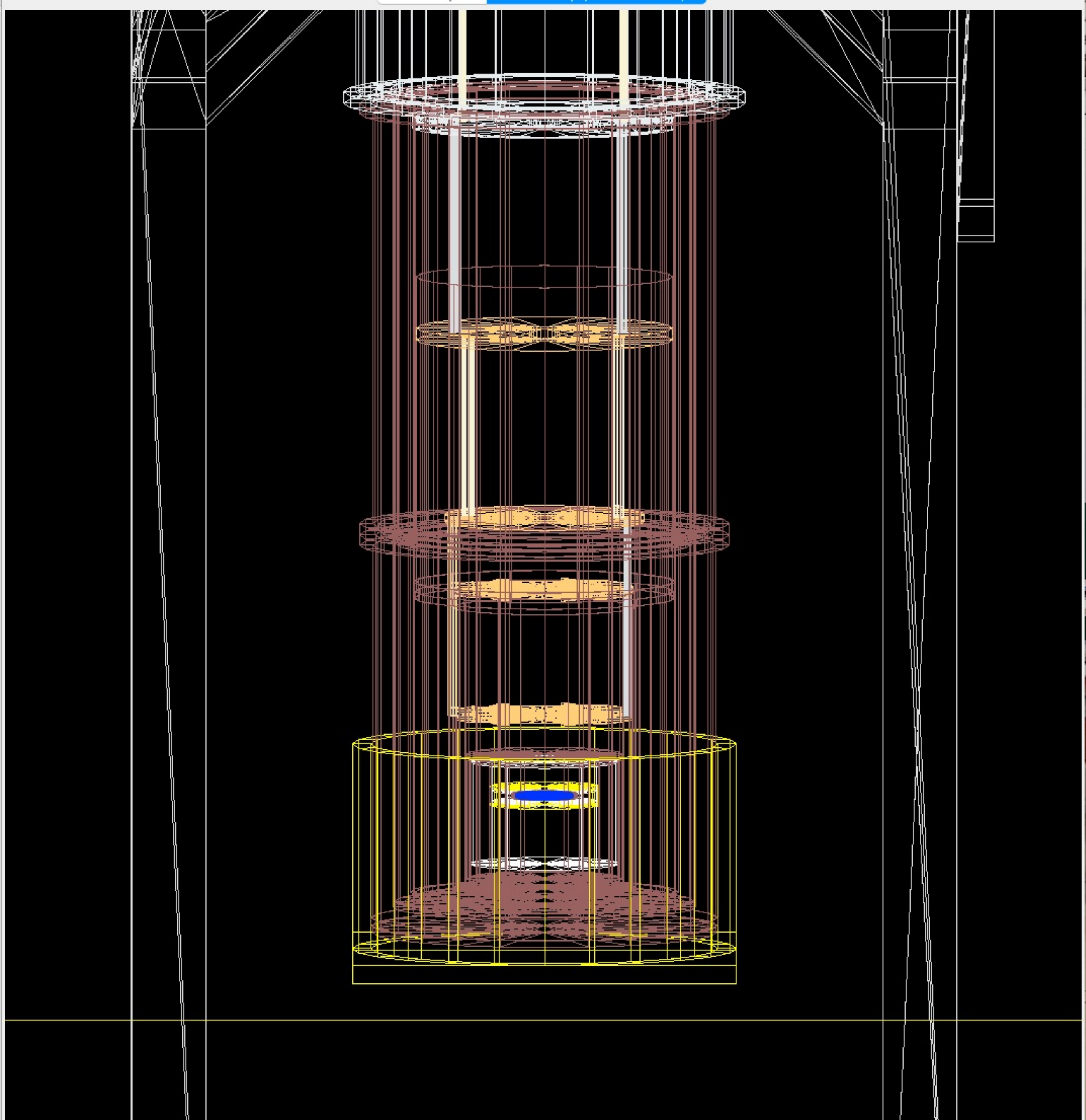


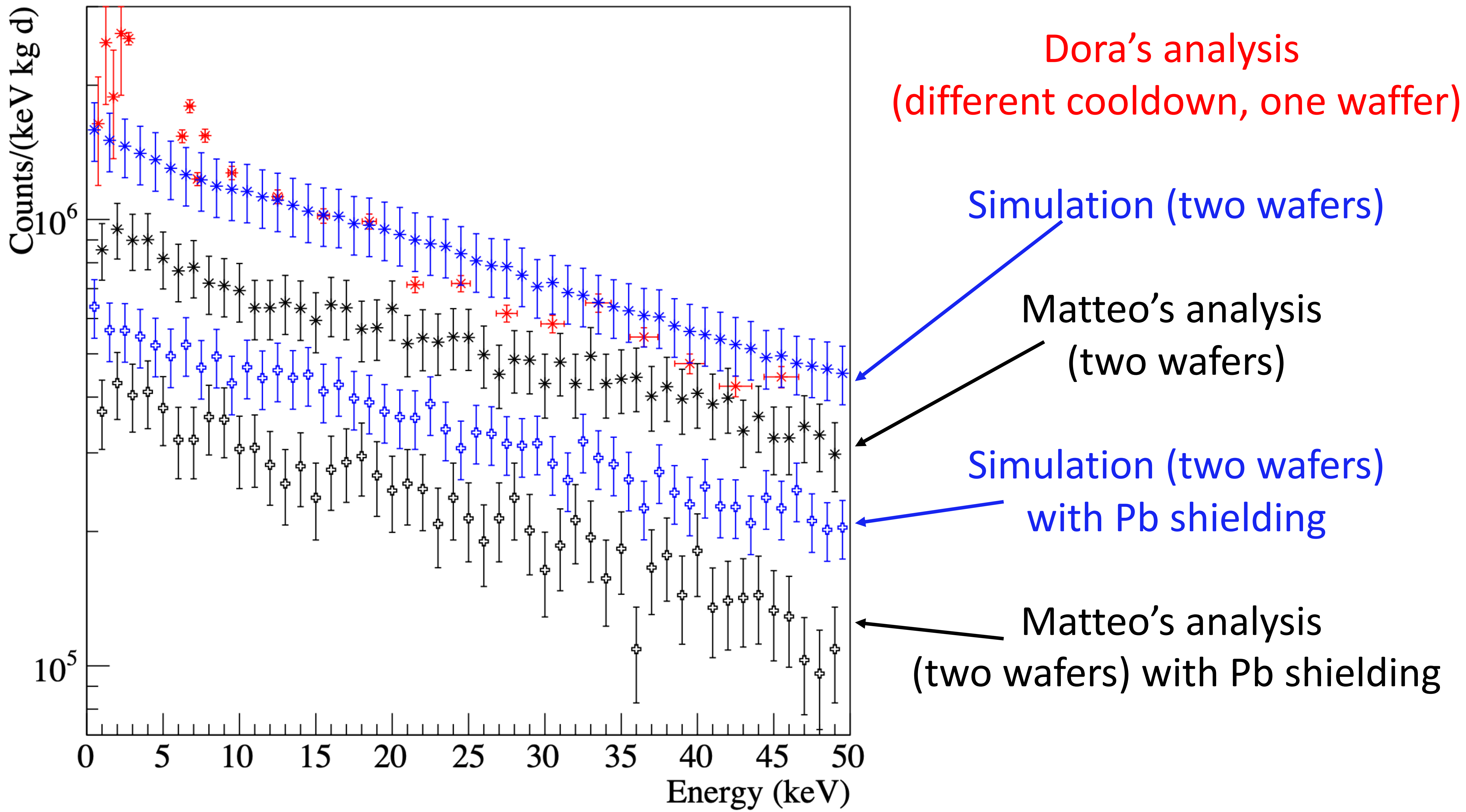

Std Dev
Underflow
Overflow
Integral 1.228
Events
10^4
10^3
10^2
10
0
0.5
1
1.5
2
2.5
3
Energy (MeV)
No shielding


Std Dev
Underflow
Overflow
Integral 1.3
Events
10^3
10^2
10
1
0
0.5
1
1.5
2
2.5
3
Energy (MeV)
Pb holder (all)

Going back to the experiment: comparison to data with shielding

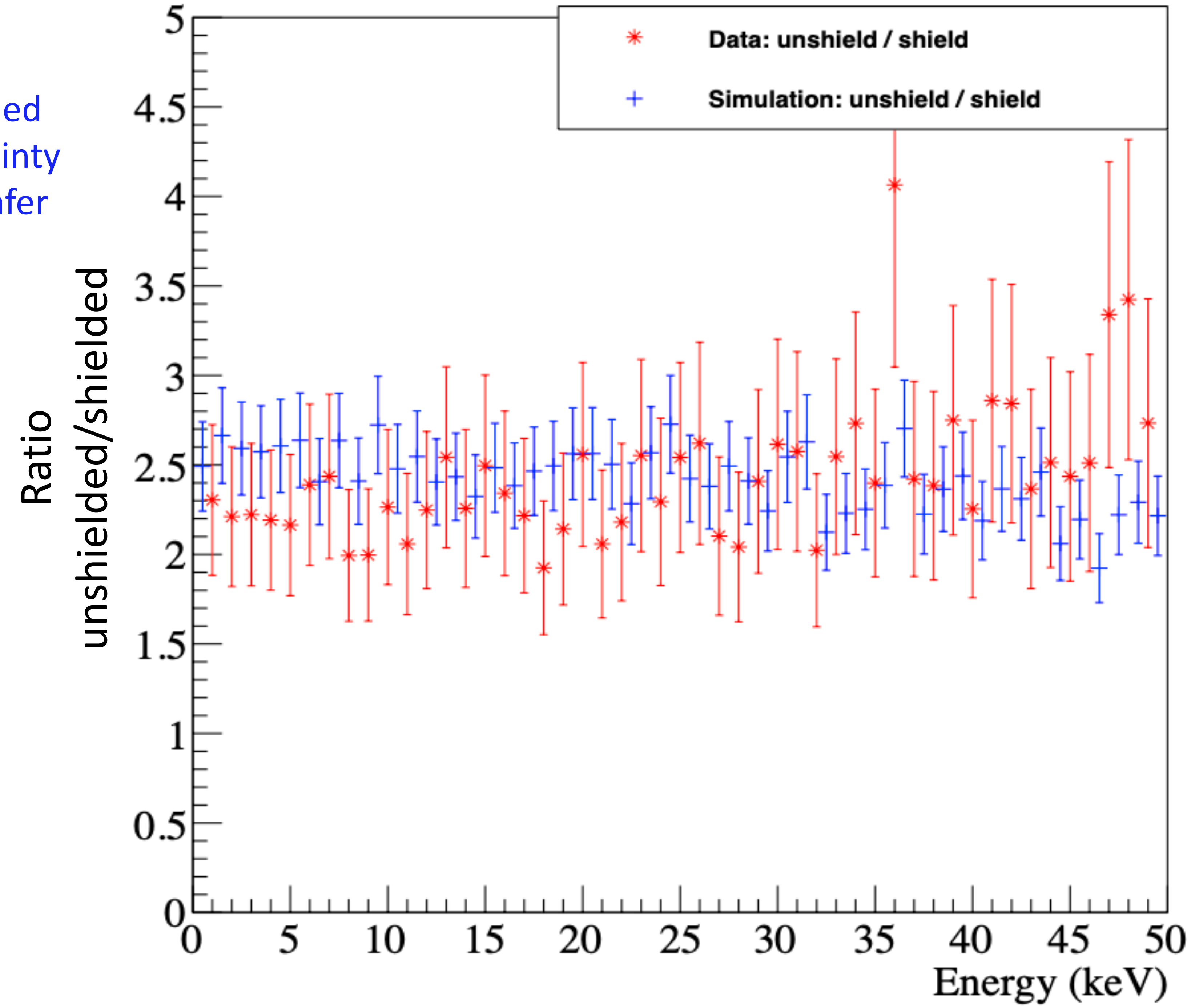




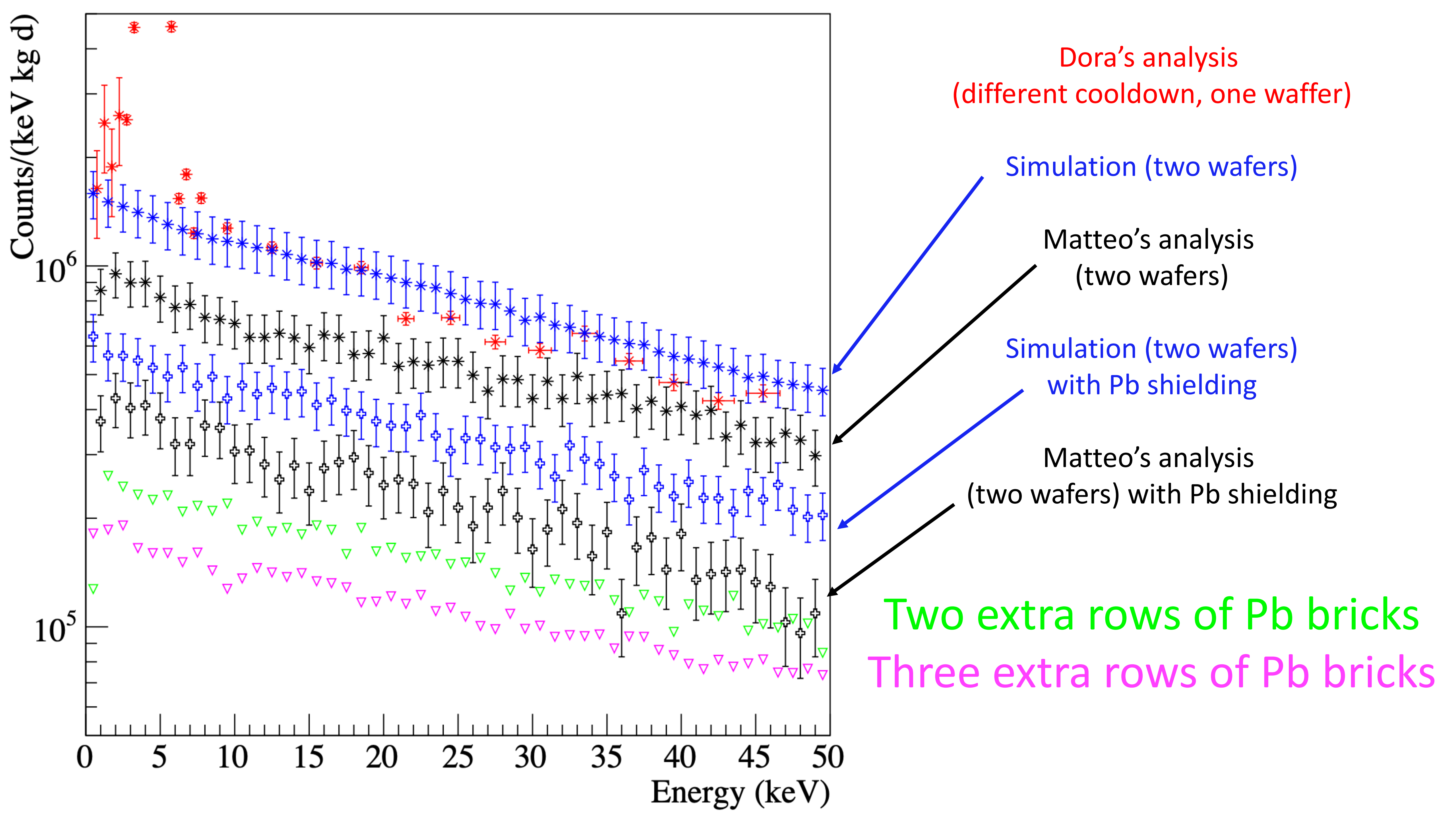



Counts/(keV kg d)
10^6
10^5
0
5
10
15
20
25
30
35
40
45
50
Energy (keV)
Dora's analysis
(different cooldown, one waffer)
Simulation (two wafers)
Matteo's analysis
(two wafers)
Simulation (two wafers)
with Pb shielding
Matteo's analysis
(two wafers) with Pb shielding

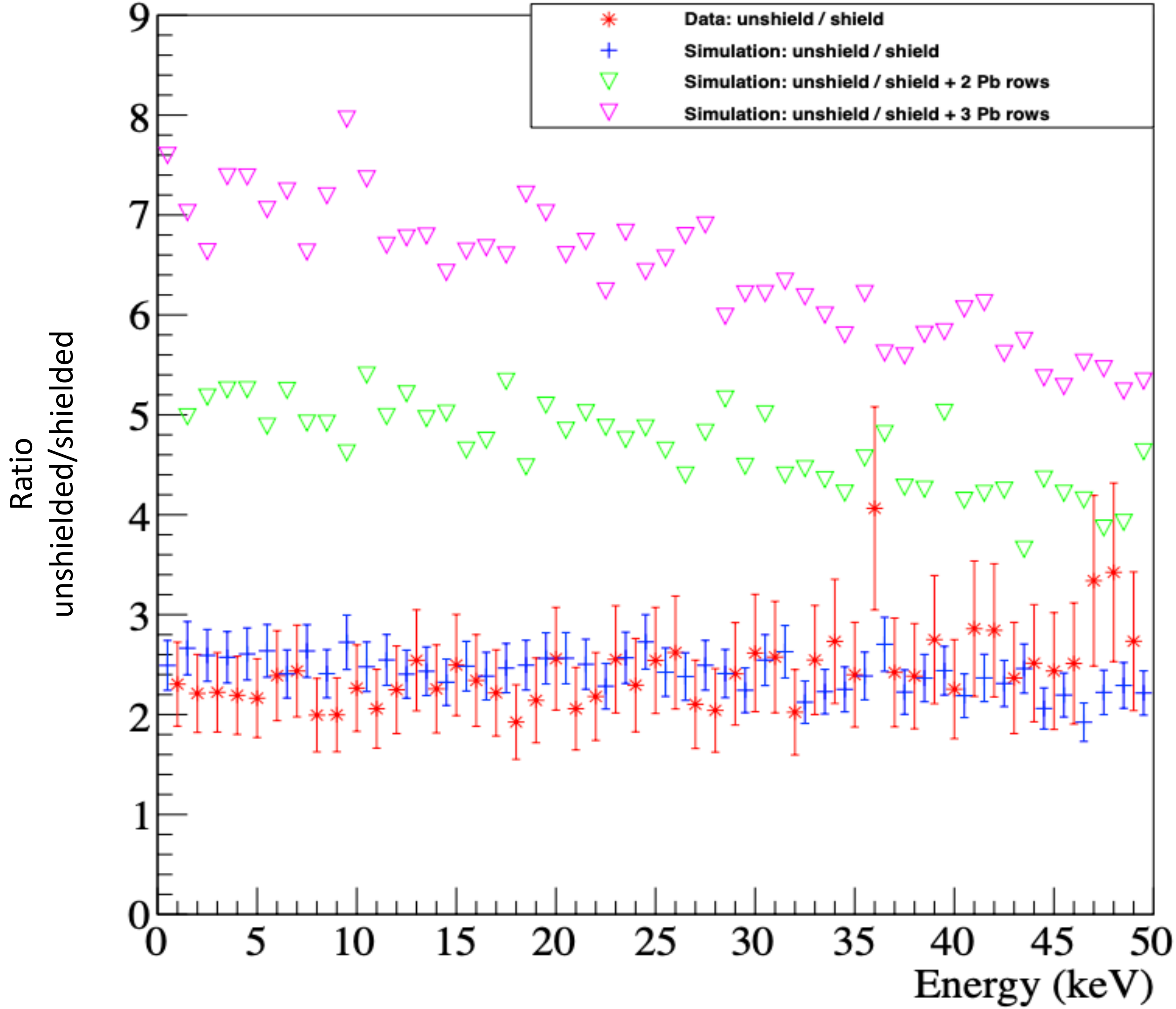
10% difference in shielded Setup for a 4mm uncertainty in the position of the wafer



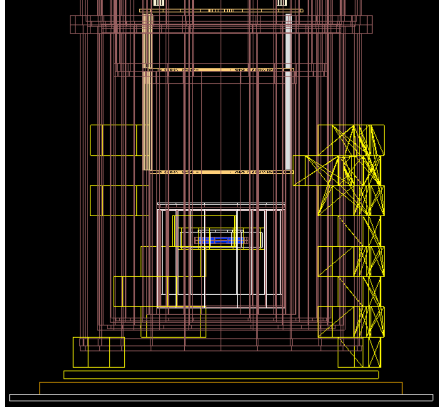
Optimization of the shielding



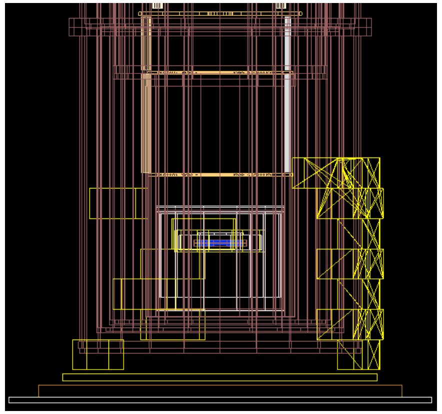
Counts/(keV kg d)
10^6
10^5
0
5
10
15
20
25
30
35
40
45
50
Energy (keV)
Dora's analysis
(different cooldown, one waffer)
Simulation (two wafers)
Matteo's analysis
(two wafers)
Simulation (two wafers)
with Pb shielding
Matteo's analysis
(two wafers) with Pb shielding
Two extra rows of Pb bricks
Three extra rows of Pb bricks



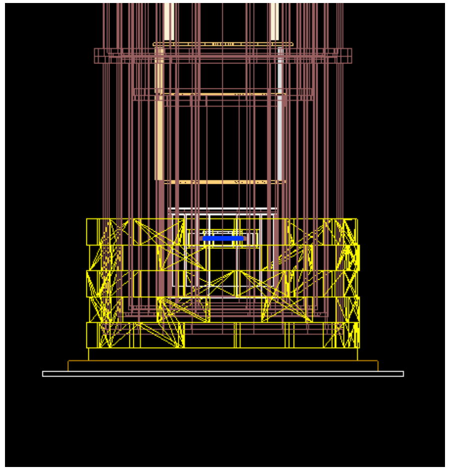
240 kg Pb

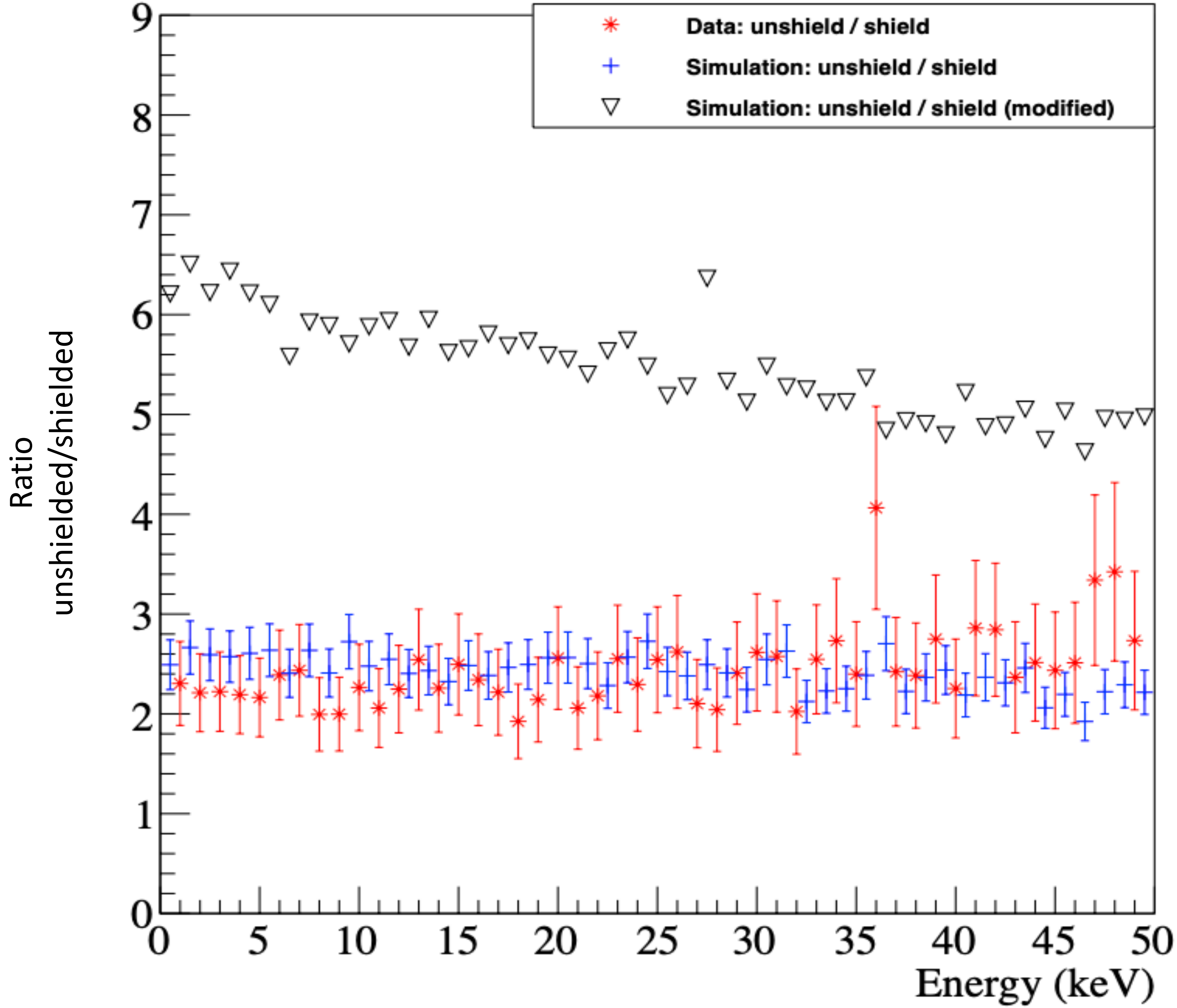


220 kg Pb



180 kg Pb





173 kg Pb

2 cm bricks (8)

1.25 cm base

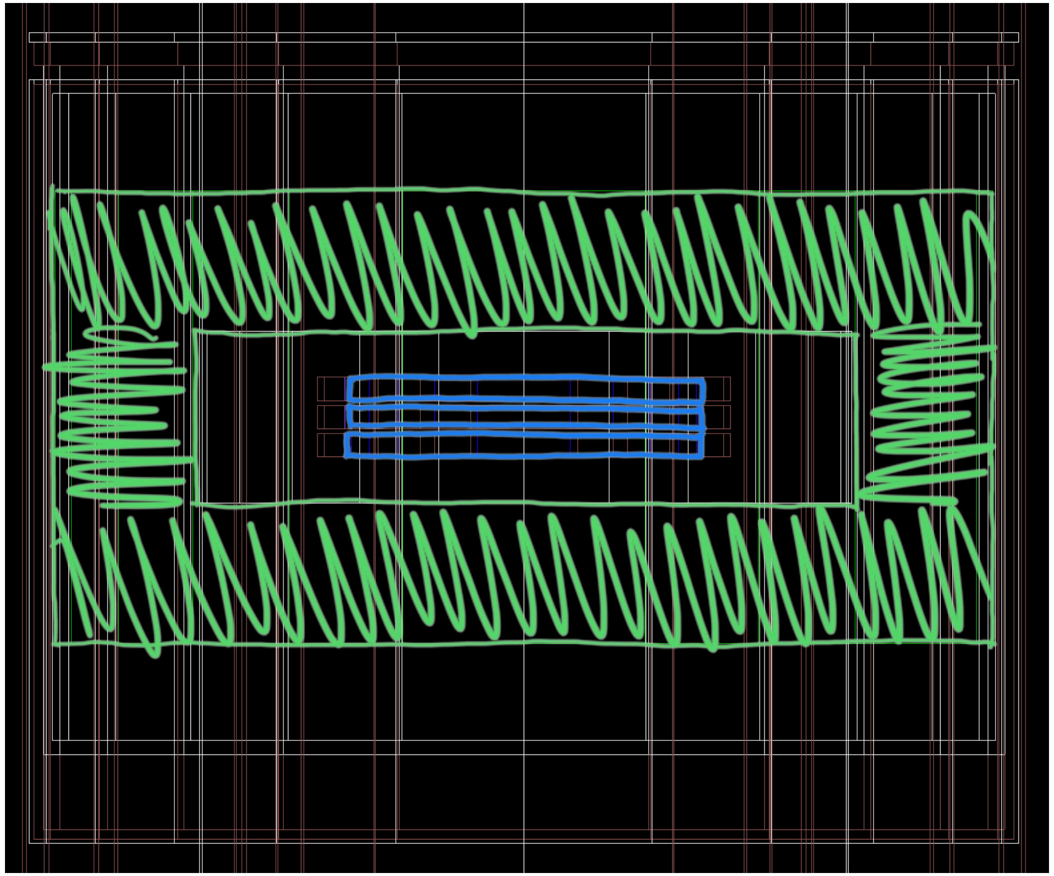
180 kg Pb

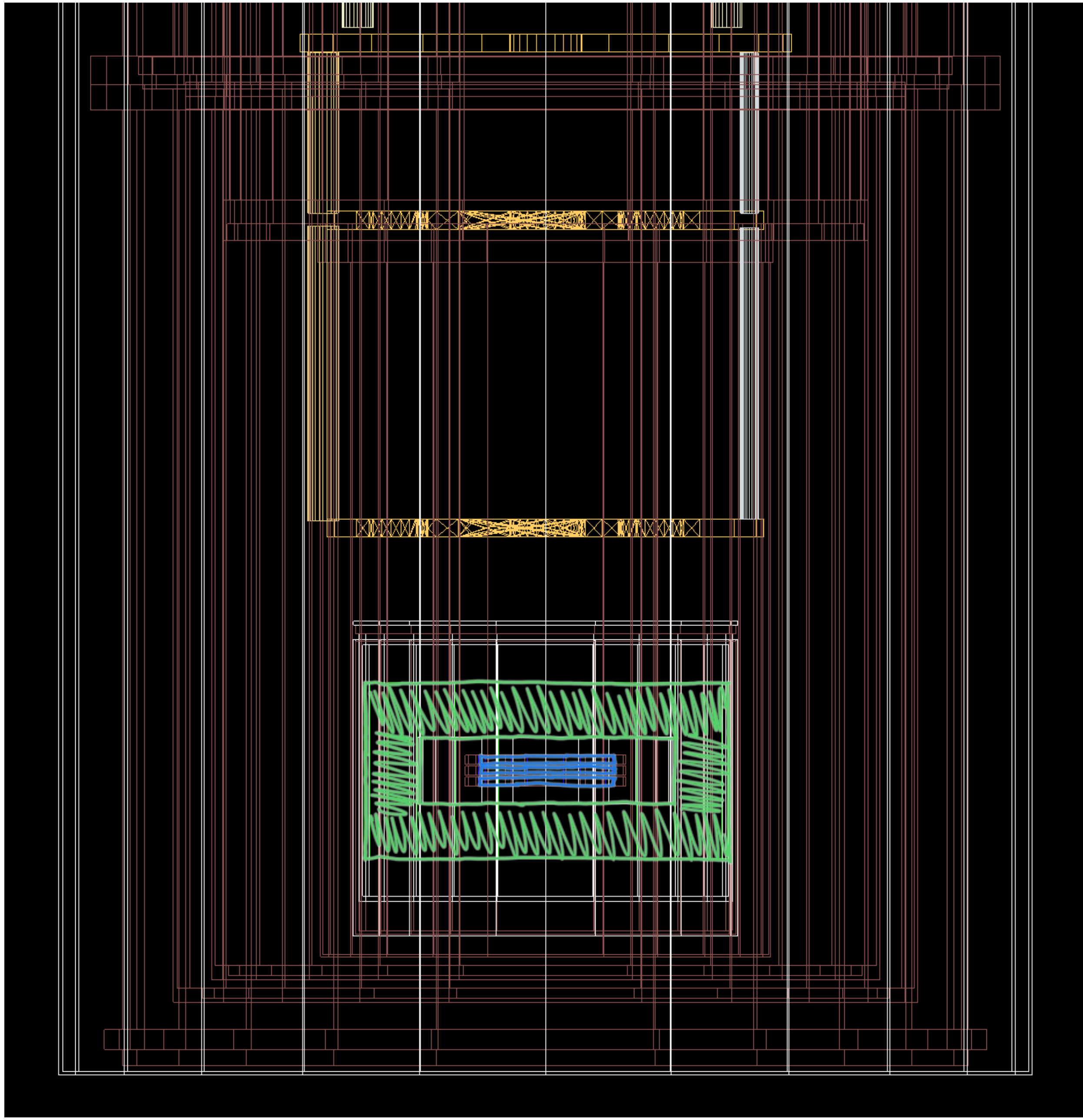
2.5 cm bricks (5)

2.5 cm base

Simulations of a cryogenic active veto made of PWO

- 3 cm PWO crystal
- 3 Si waffers



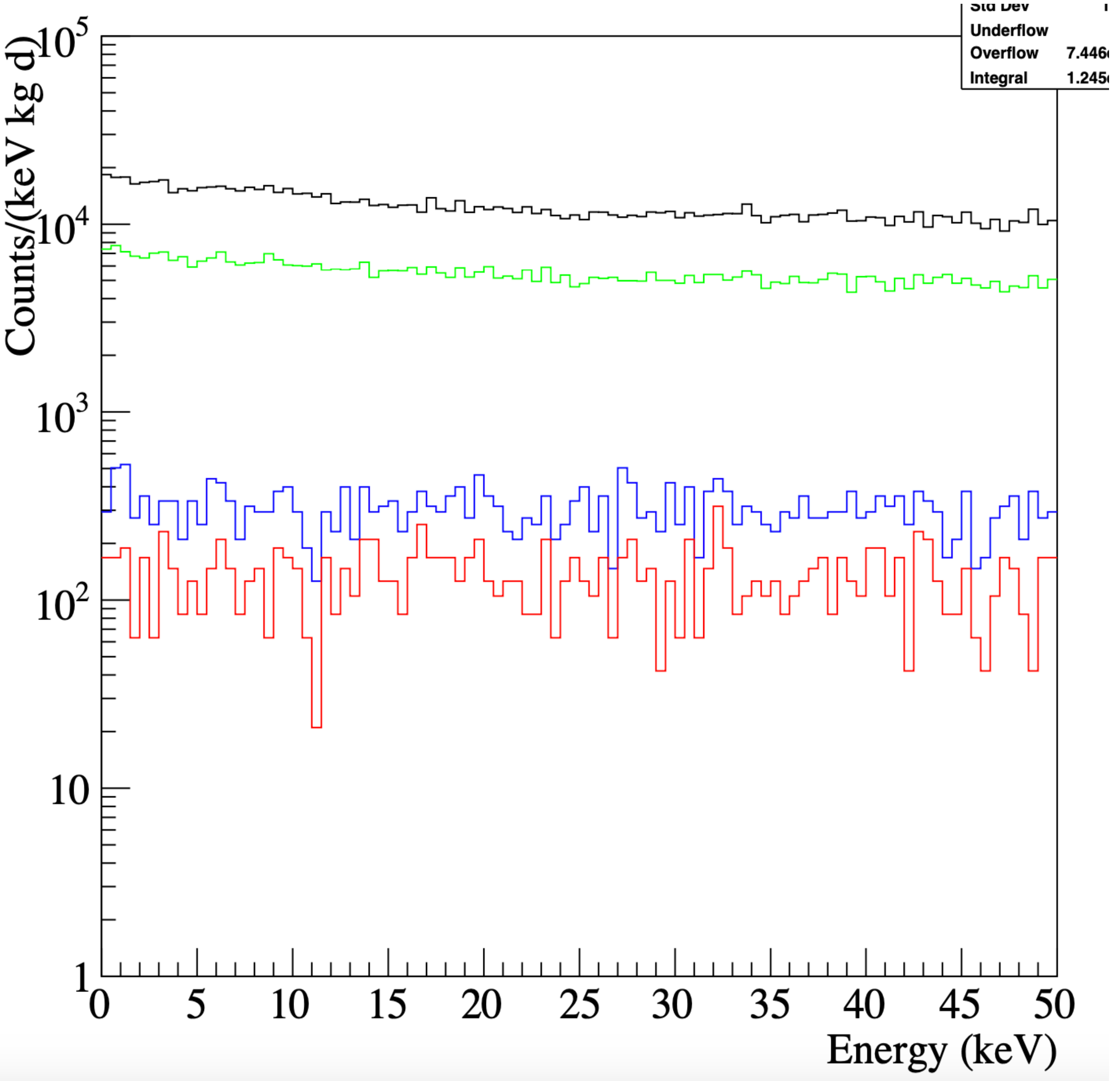


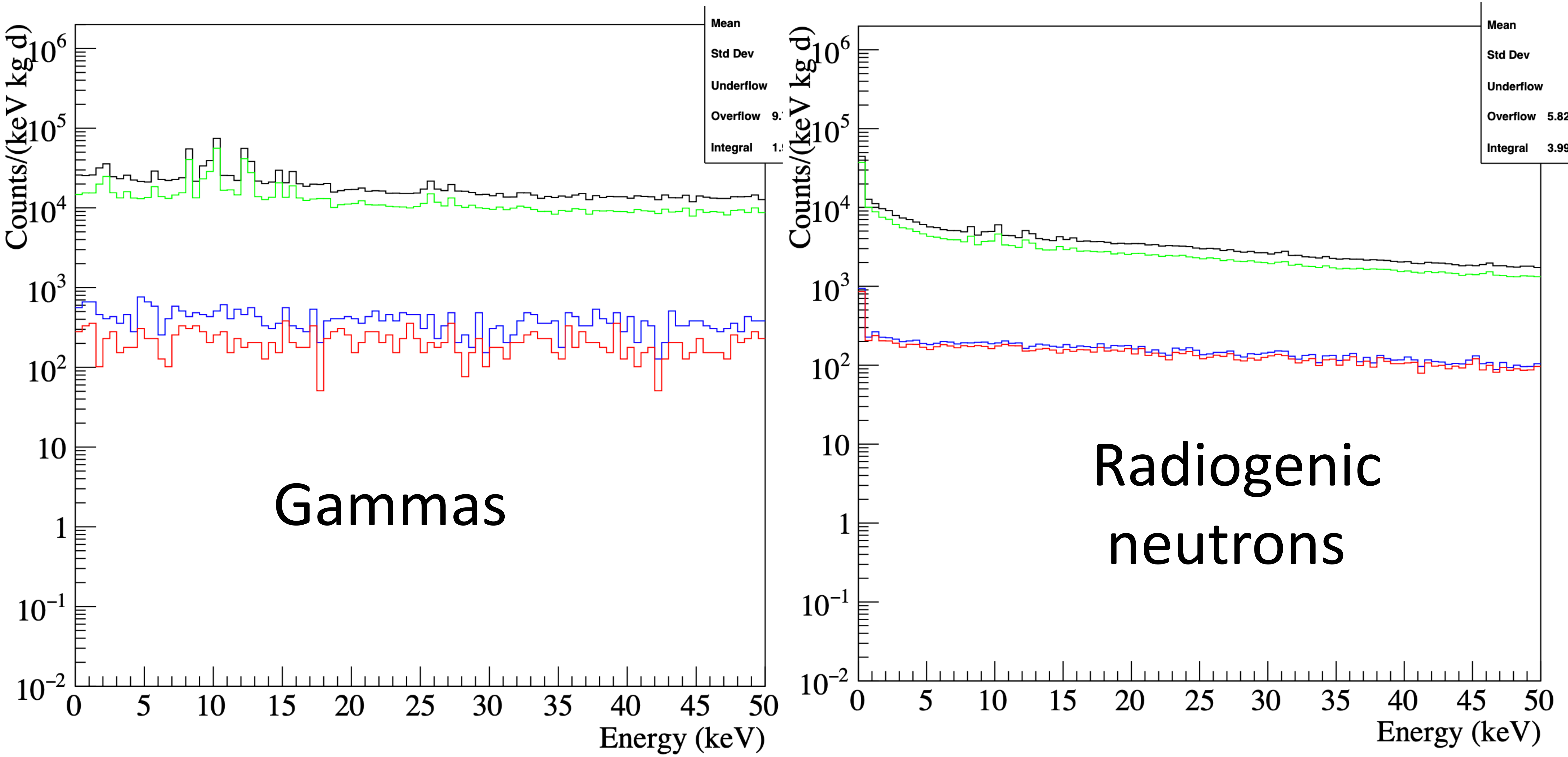
All events in central wafer

vetoing in other 2 wafers

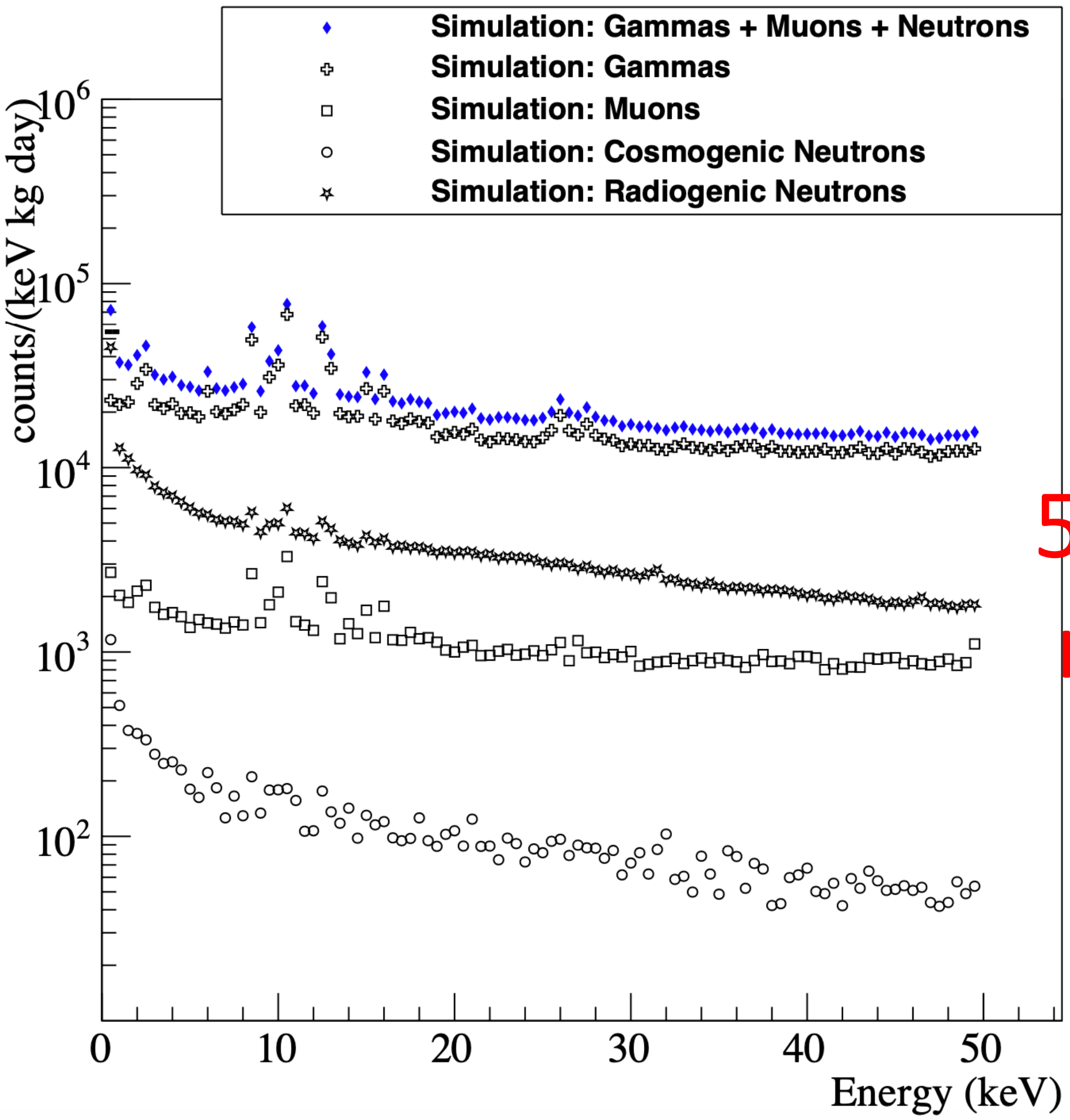
vetoing in PWO crystal

vetoing in PWO and 2 waffers

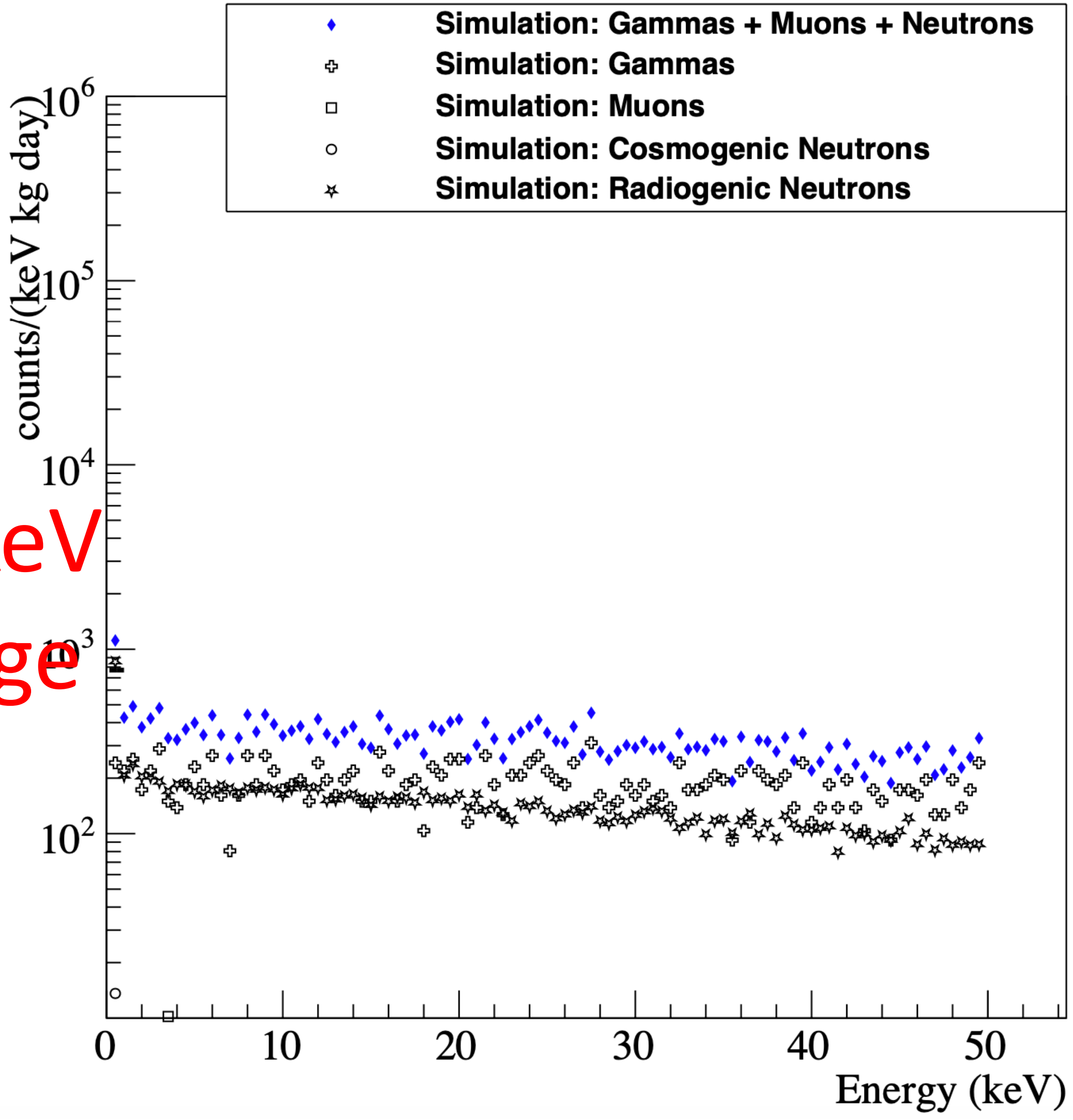



Mean
Std Dev
Underflow
Overflow 9.
Integral 1.
Counts/(keV kg d)
Energy (keV)
Gammas
Mean
Std Dev
Underflow
Overflow 5.82
Integral 3.99
Counts/(keV kg d)
Energy (keV)
Radiogenic neutrons

Without vetoing

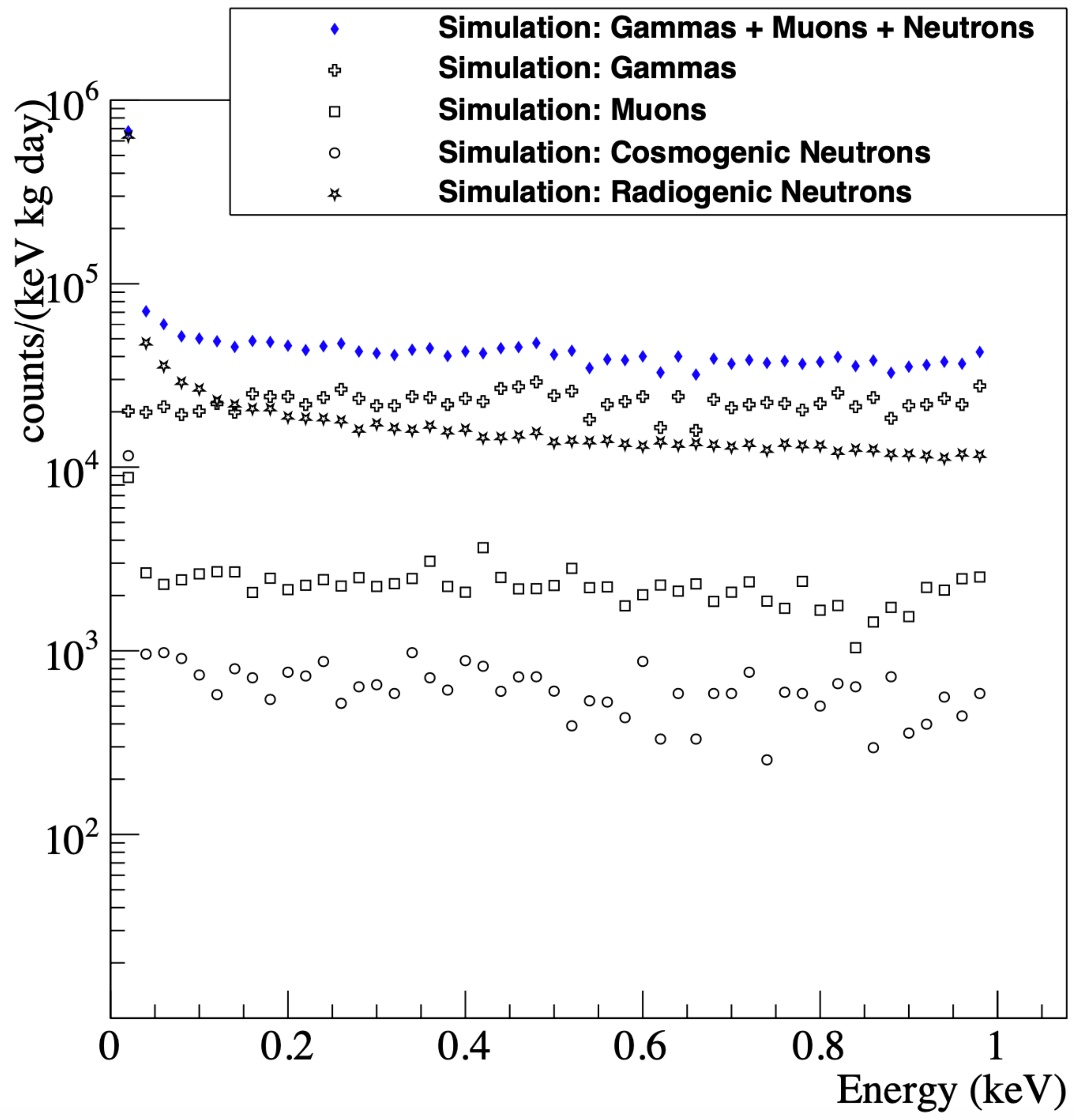


Vetoing all PWO events



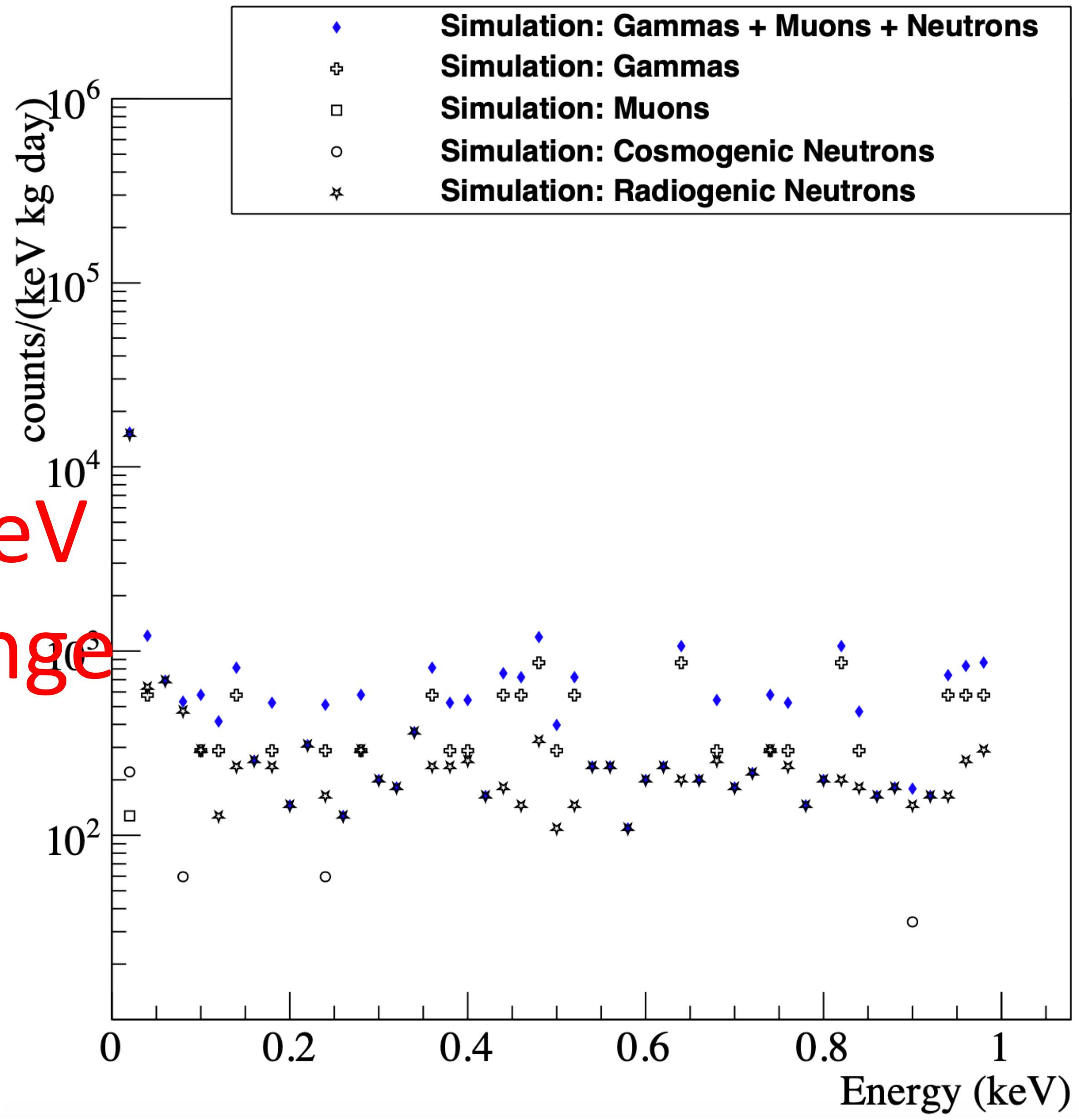
50 keV range

Without vetoing



Vetoing all PWO events

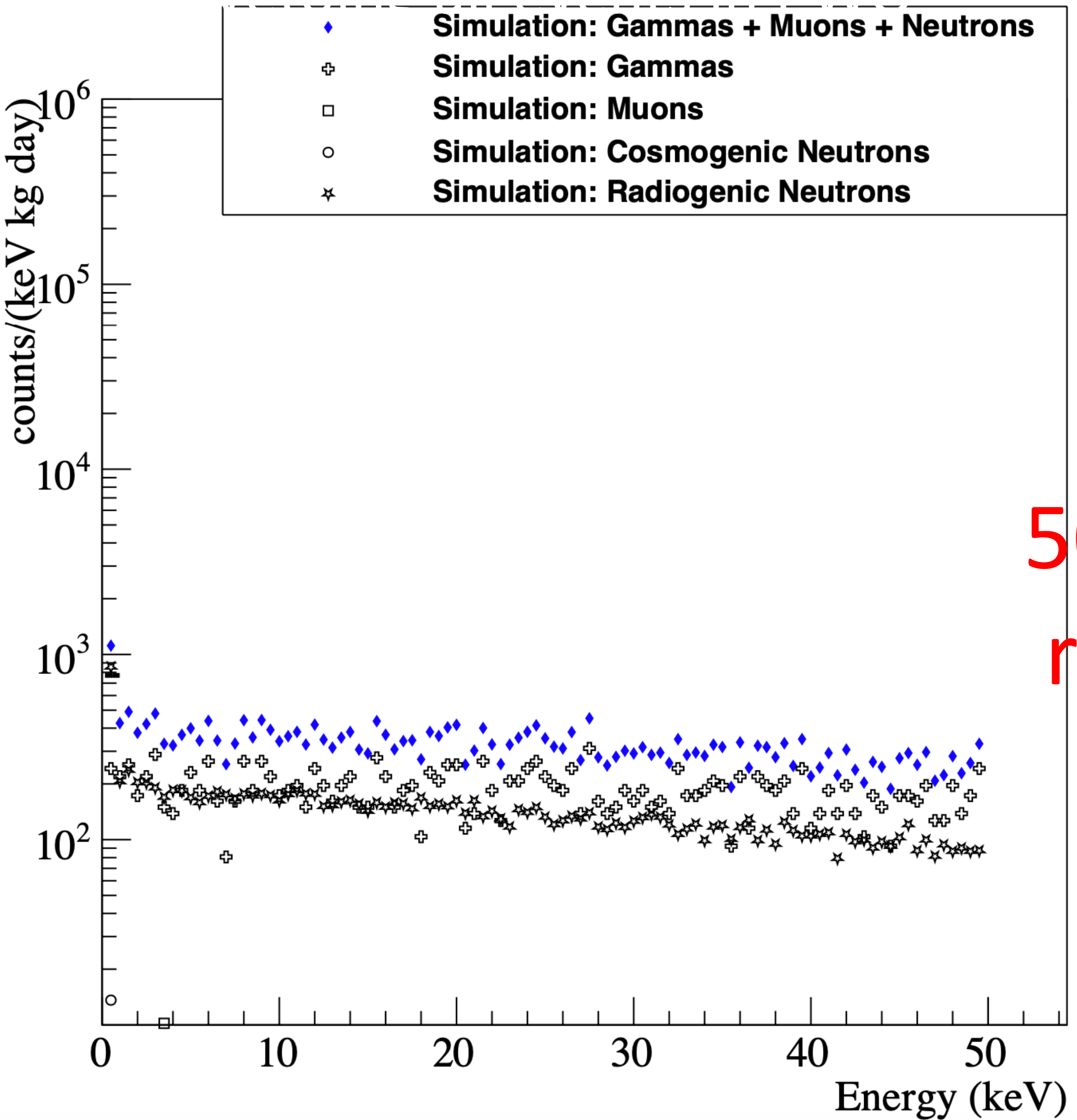
1 keV range



Simulations of a cryogenic active veto made of PWO

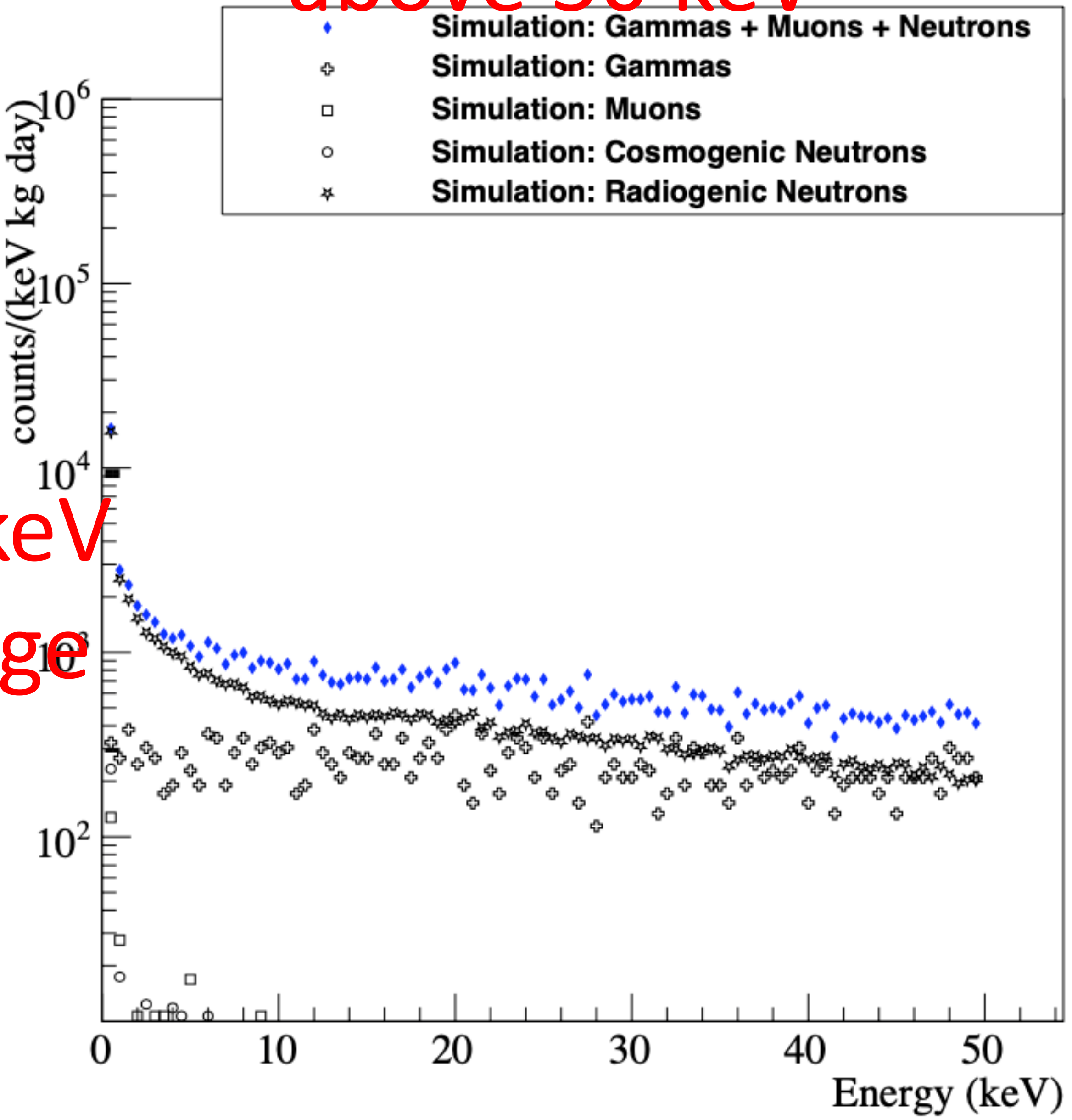
50 keV energy cut

Vetoing all PWO events

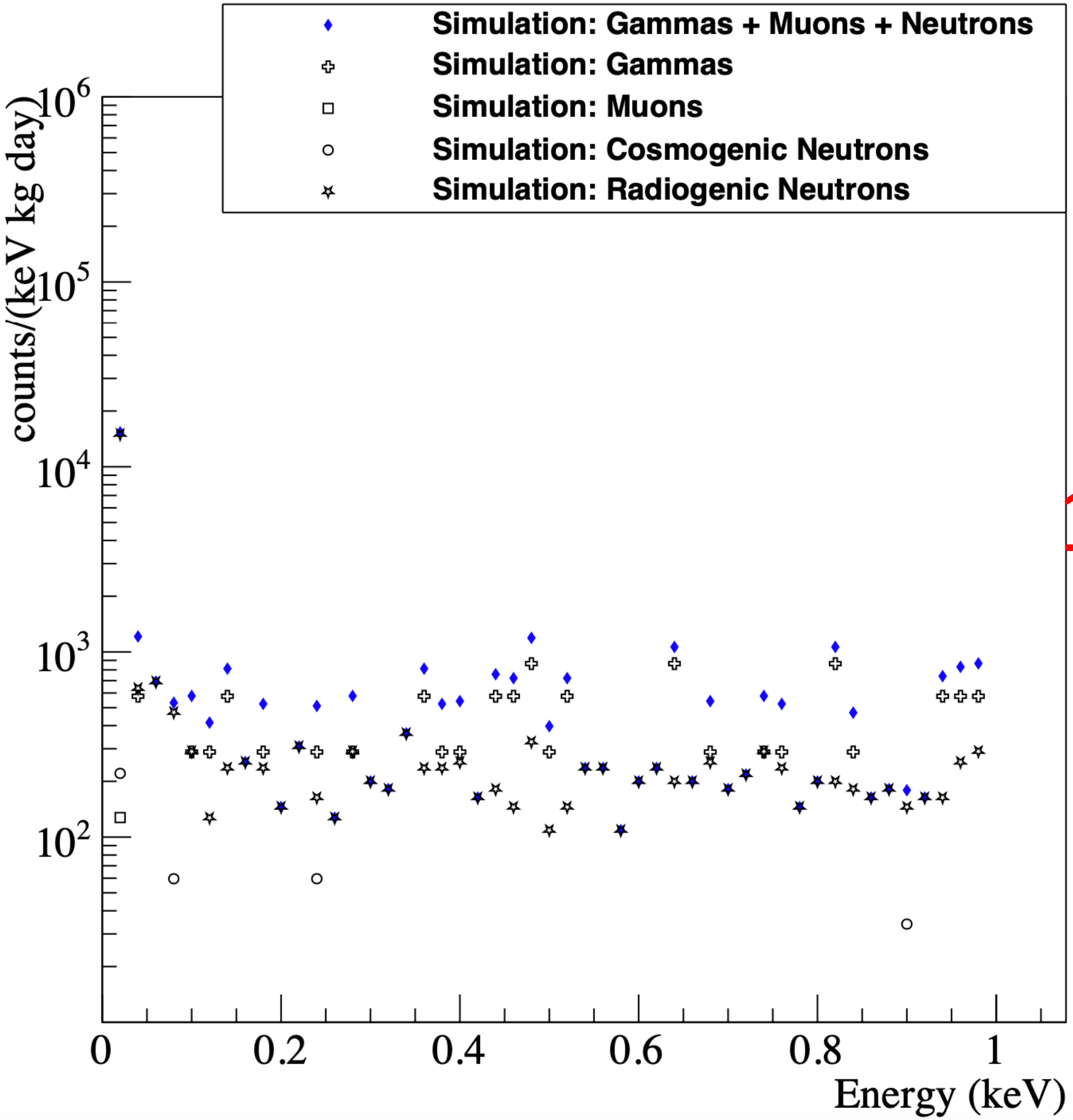


50 keV range

Vetoing PWO events above 50 keV

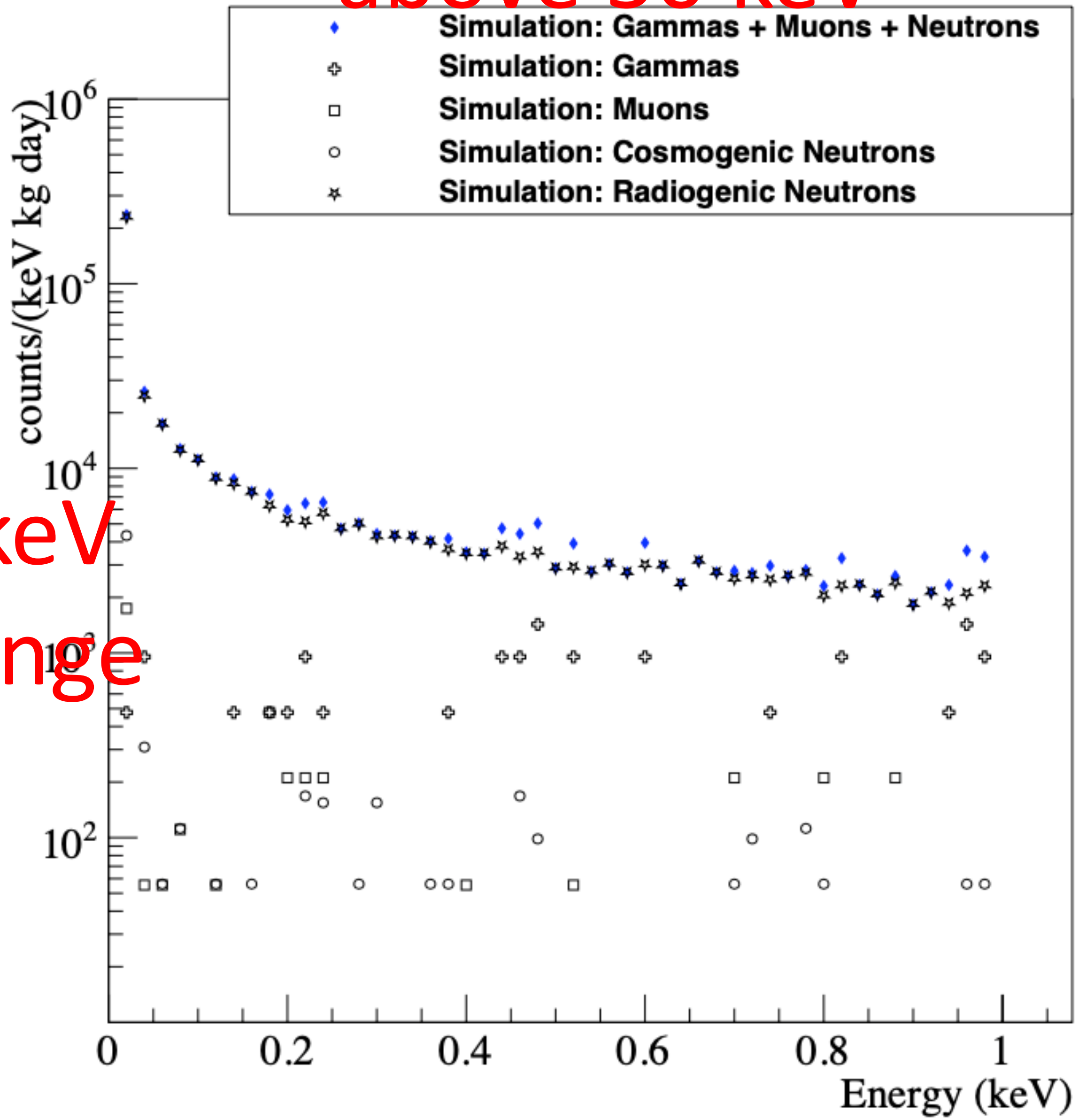


Vetoing all PWO events



1 keV range

Vetoing PWO events above 50 keV

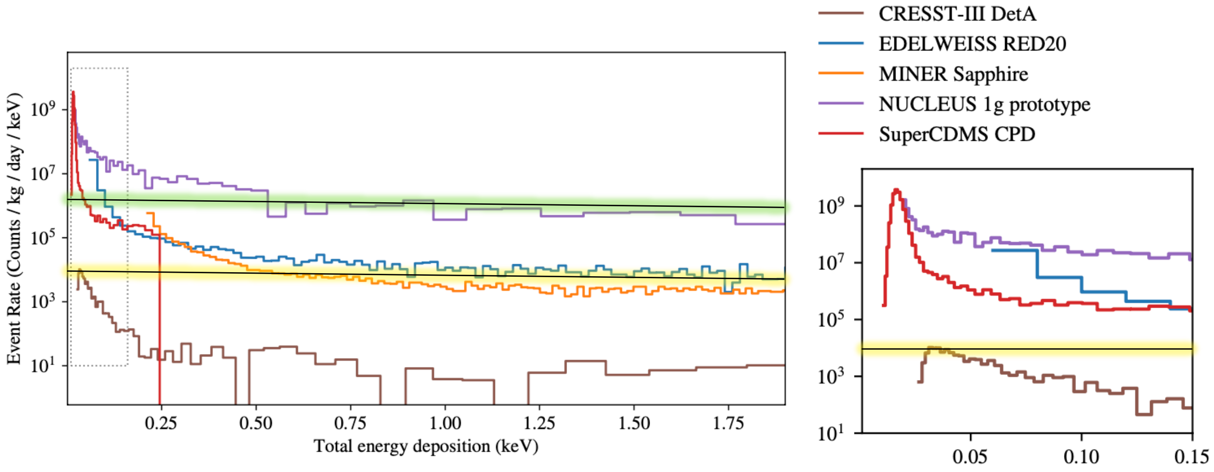


Summary and Conclusions

✓Very good agreement between data and simulations

✓Possible to reduce two orders of magnitude on surface (with relatively little effort)

Background issue in phonon experiments



P. Adari, et al.: EXCESS workshop: Descriptions of rising low-energy spectra SciPost Phys. Proc. 9 (2022) 001

✓An internal veto on surface is valuable to learn its feasibility and assess capacity, possible issues

What's next?

- Keep optimizing shielding
- add scintillation and quenching to crystal
- explore other crystals (BGO, CGO)