Preliminary Studies of Cryogenic Veto Using Simulation

BULLKID Collaboration Meeting Pisa 15/01/2025

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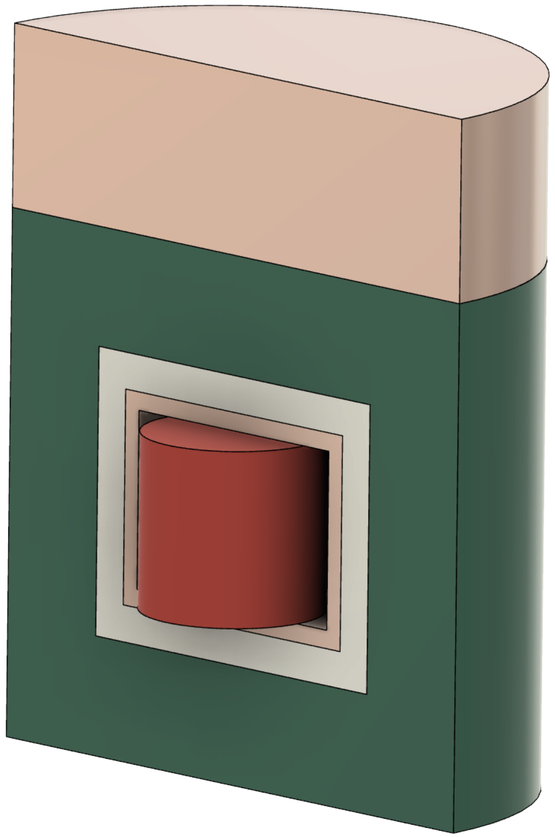
Introduction:

- **Cryogenic veto:**
  - **Baseline** Solution: BULLKID main detector is enclosed in a **copper shield** placed at mk temperature to reduce backgrounds
  - **Veto**: we are investigating the possibility to substitute Cu with a **scintillator crystal** for a more effective background reduction.

- **Veto studies through simulations:**
  - **Eric Vazquez Jauregui** provided a very accurate **geant4** simulation of the BULLKID experiment.
  - This simulation can be employed to aid veto development:
    - **Validate** performances **compared to Cu shield**
    - Evaluate the best veto **material**
    - Develop the veto **geometry**
    - Simulate a **realistic veto model**

- **This presentation:**
  - Preliminary simulation of γ, n external **backgrounds**
  - **Comparison** of different scintillating crystal (**BGO, GSO, GAGG**) with the **Cu shield**.



BULLKID main detector

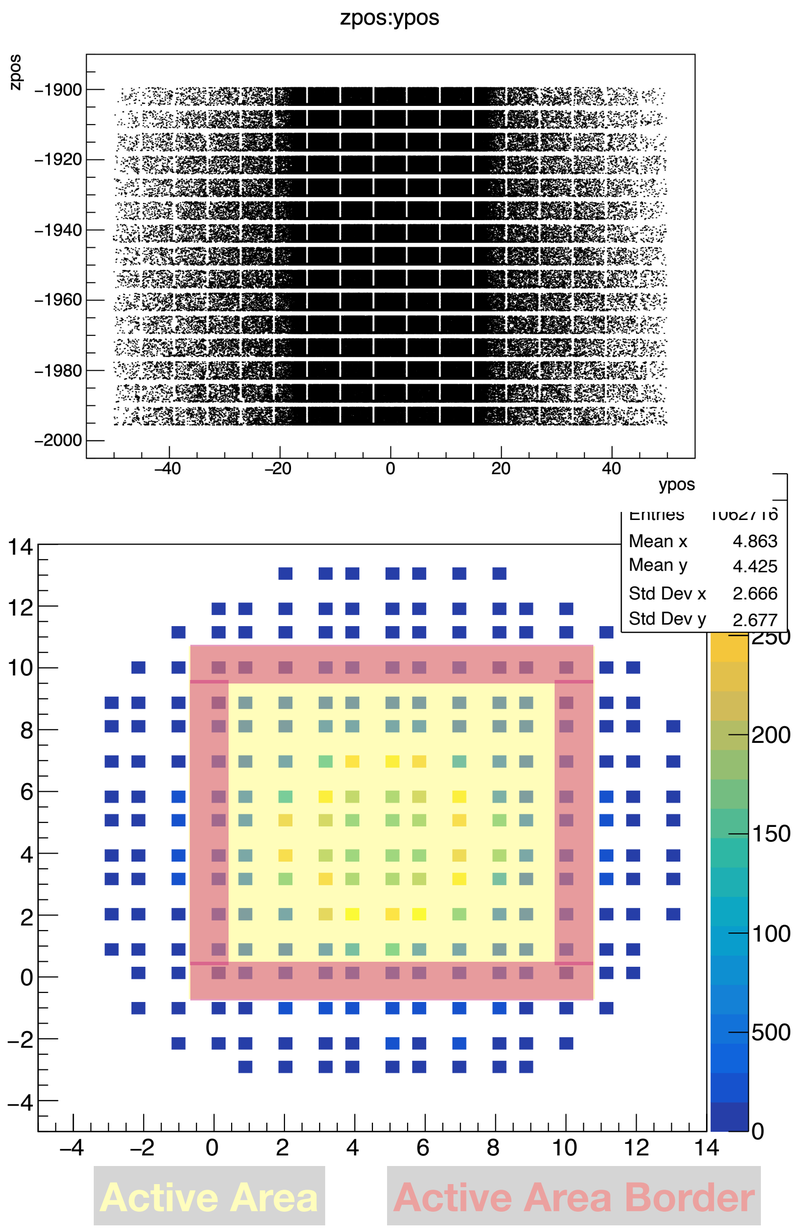
Cu Shield / Veto

Reconstructing events in BULLKID:

- **BULLKID detector:**
  - BULLKID detector is composed of multiple **Si wafers** divided in **dice**.
  - Inside the wafer an **active area** is instrumented with **KIDs**.
  - The **boundary** of the active area is **used as anti-coincidence**

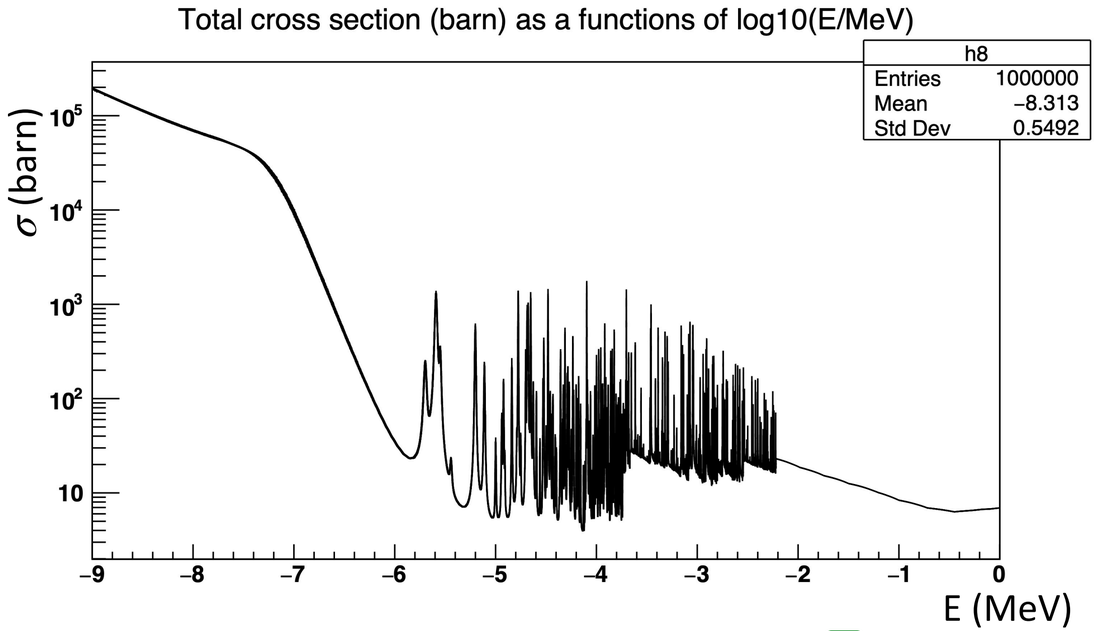
- **Simulation output:**
  - For every primary particle (event) the simulation provide **all** the energy deposits (**Hits**) in the BULLKID main detector

- **Processing simulation output:**
  1. **Sum all the hits** from the same silicon die.
  2. **Phonon leakage** (PL):
     - Due to PL ∼ 50% of the energy is spread in in the adjacent cells (to be implemented)
  3. **Select** dice with total energy **eCell > 200 eV**.
  4. **Event selection**:
     1. Ecell>200eV.
     2. Inside active area.
     3. No cell above threshold in the active area boundary.
     4. Only 1 cell above threshold.

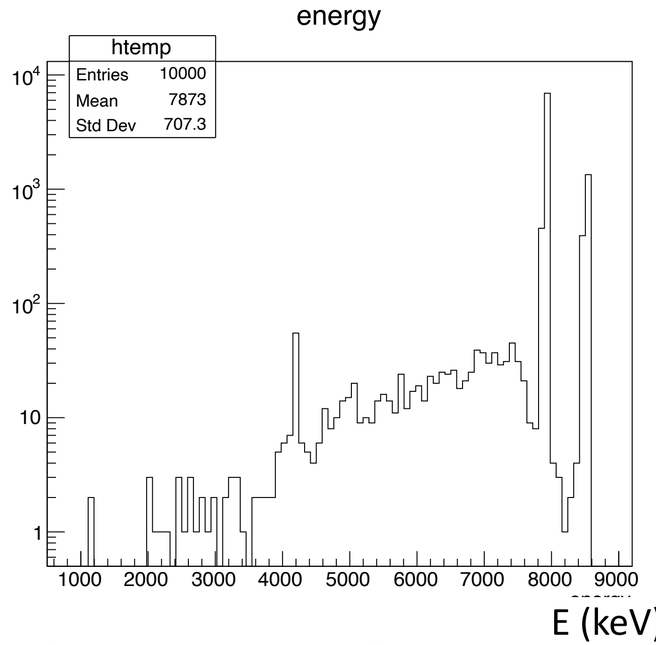


Gadolinium:

- **Neutron cross section:**
  - GAGG and GSO scintillator crystals contains Gadolinium
  - Gd has the highest thermal **neutron capture cross section** (∼273 kbarn), excellent material for enhancing neutron shielding.
- **Verifying Gd properties in geant 4:**



Gd Neutron capture **cross section** ✅



Gamma Energy Spectrum due to Gd neutron capture in GSO. ✅

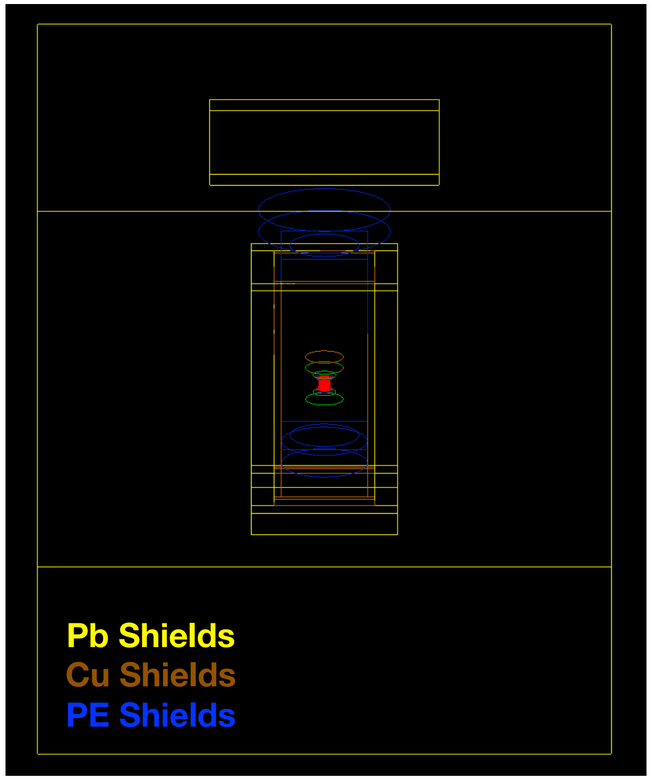
- **Hadronic Physics parameters:**
  - To obtain the correct gamma emission must set the following parameters:

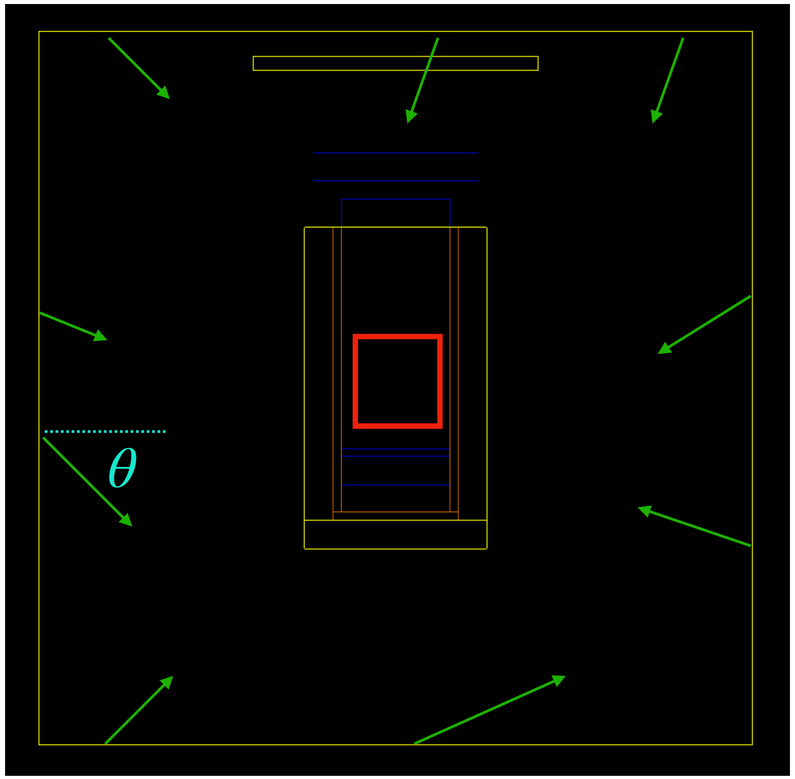
```
UseOnlyPhotoEvaporation ? 1
DoNotAdjustFinalState ?  1
```

Simulation simplifications:

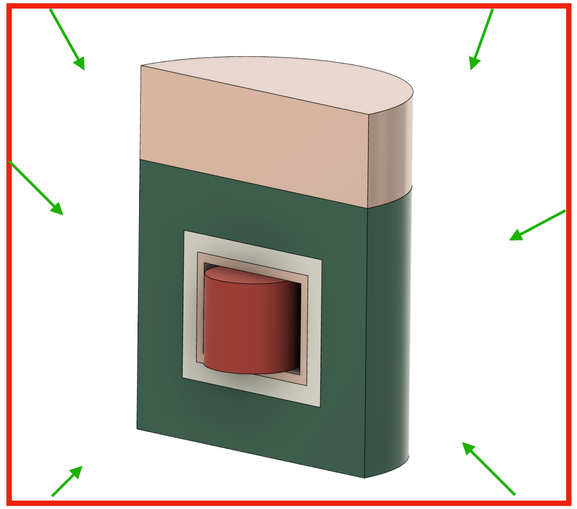
- Currently, the simulations are running on my laptop. Simulating external backgrounds with the full setup is not feasible because too few events are collected:
  - Include **only external shields.**
  - Divide the simulation into **two steps** to increase the number of events in the BULLKID detector**.**

- **Step 1**: Particles emitted from a surface **outside the external shields** and collected on a surface just outside the veto/copper shield**.**
  - **External shield: Pb, Cu, PE**



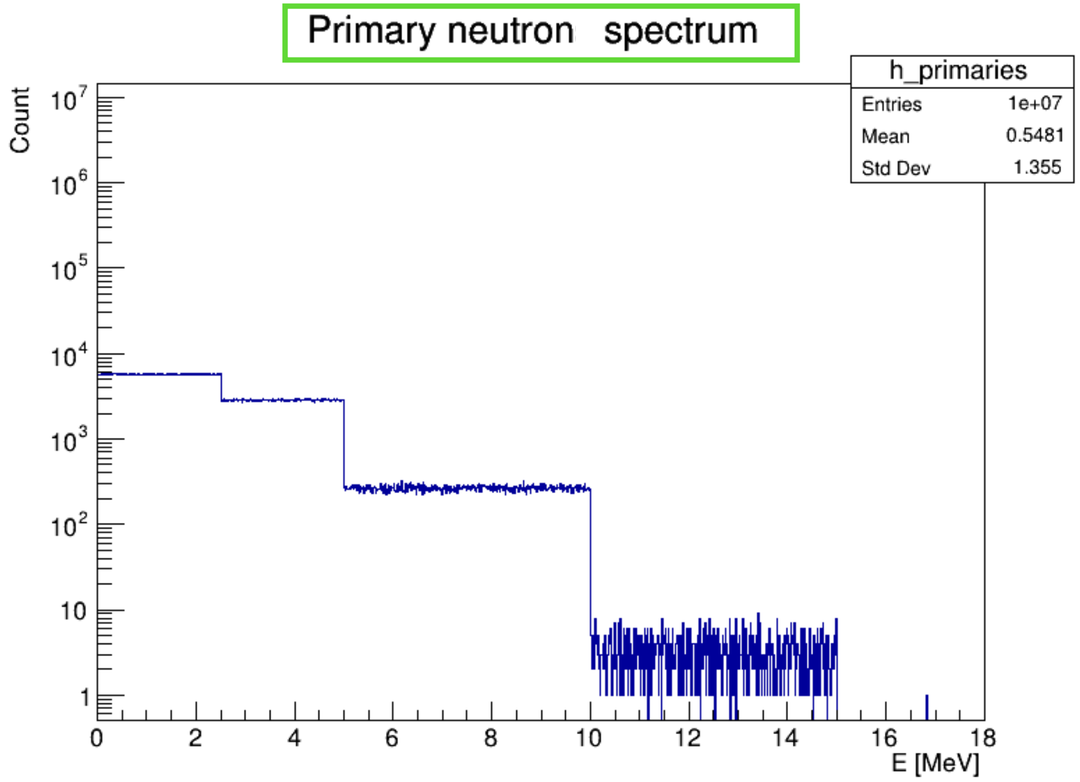


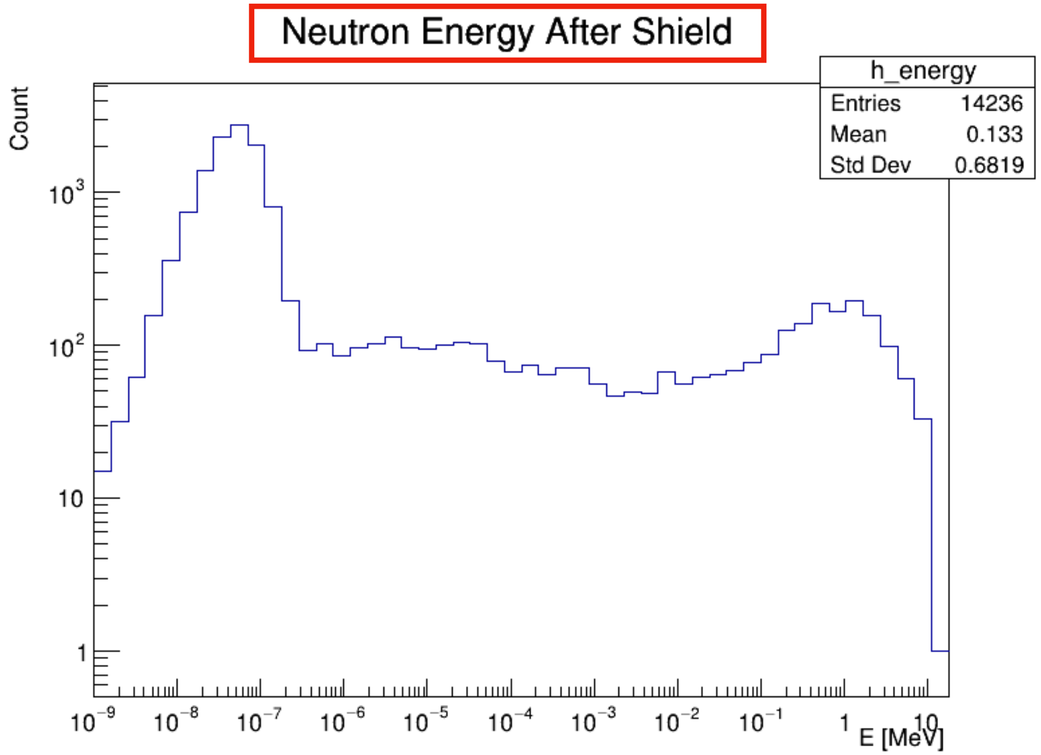
- **Step 2**: Particles emitted from the **inner surface** enclosing the veto/Cu shield using **energy spectrum obtained in step 1**.



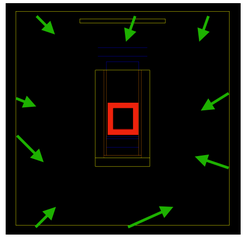
- In step 1 and step 2, particles are emitted with an angular distribution $dp \sim \cos(\theta) d\cos(\theta)$ to reproduce an **isotropic uniform flux**, regardless of the surface geometry.

Step 1 neutron backgrounds:

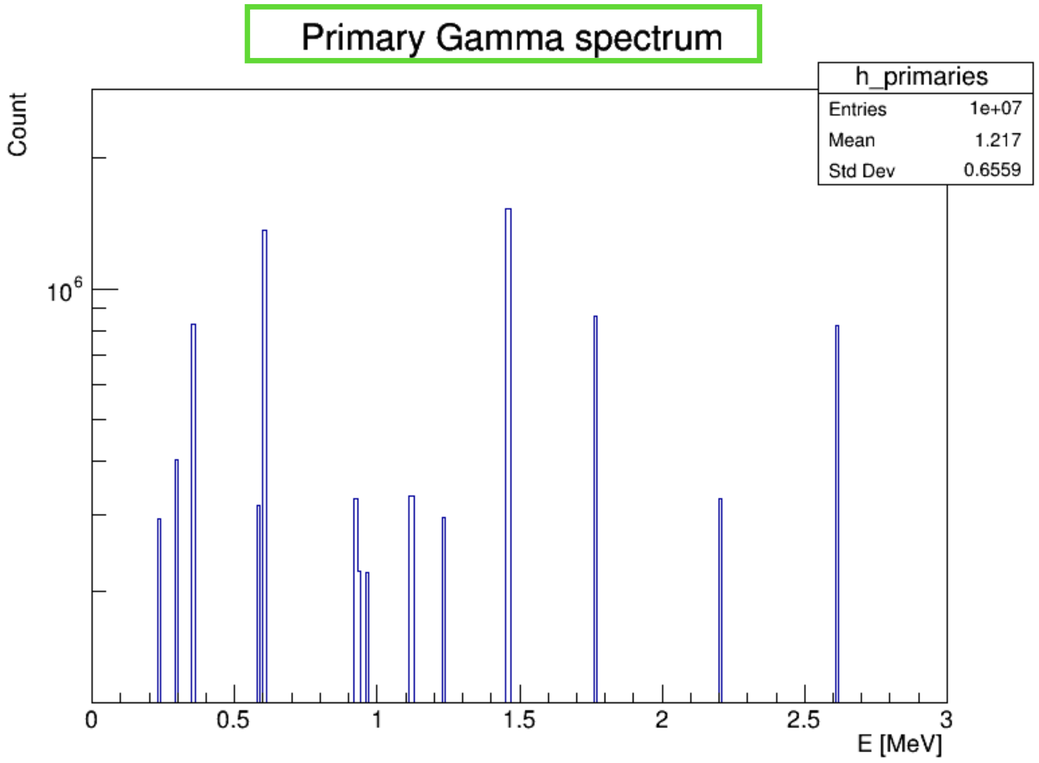


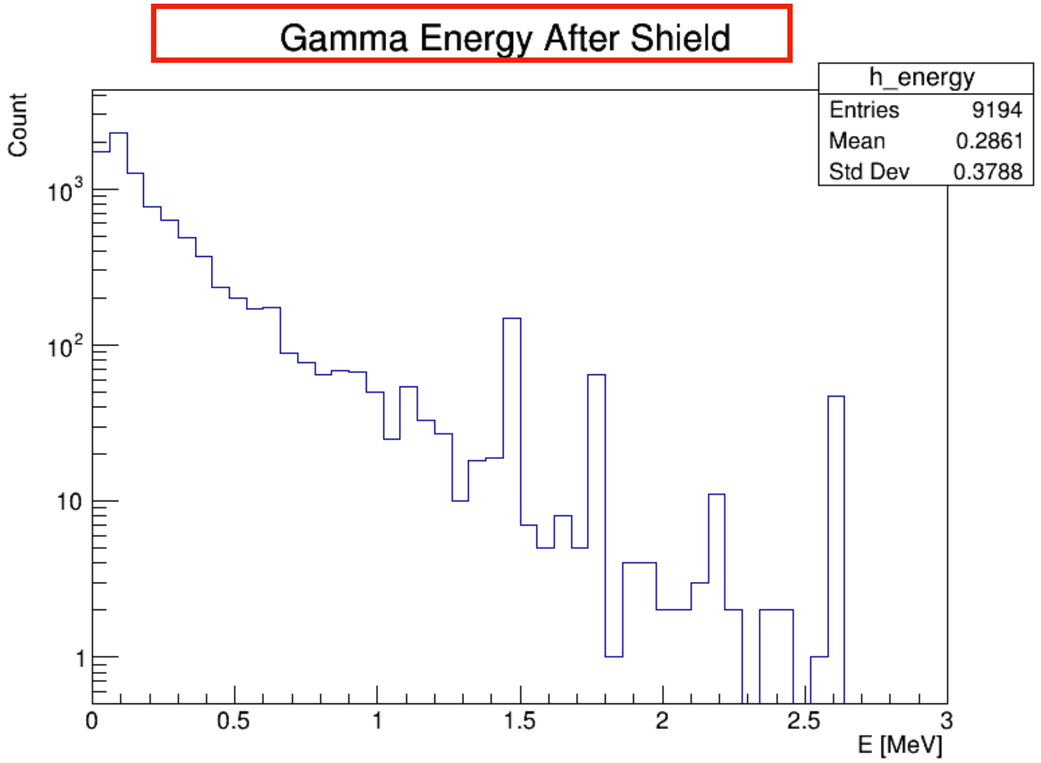


- Primary Spectrum: **neutron** spectrum in LNGS [Ref. 1].
- **External shied** suppress background of a **factor** ~ 700.
- Secondary spectrum collected in a **log-binned histogram** to accurately model low-energy neutrons

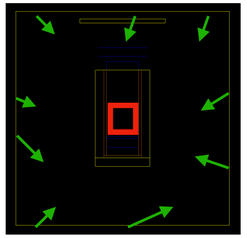


Step 1 gamma backgrounds:



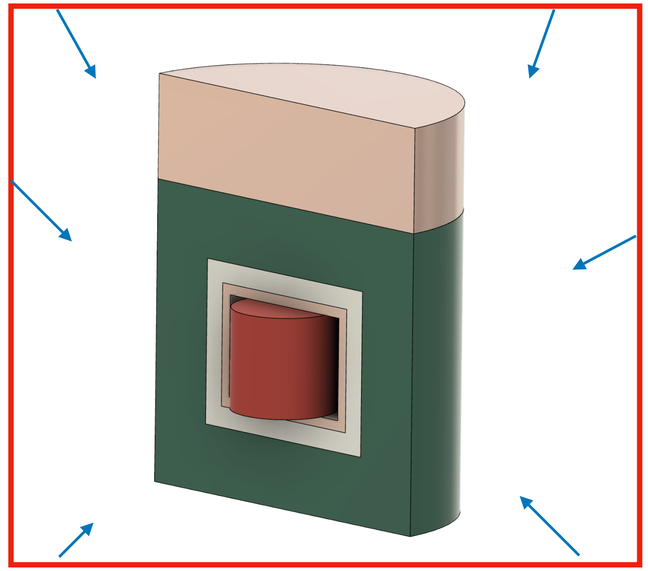


- Primary Spectrum: **natural radioactivity** gamma lines in LNGS [Ref. 2].
- **External shied** suppress background of a **factor** ~ 1100.
- Secondary spectrum is shifted toward low energies



Step 2 veto study:

- Particles emitted from the **inner surface** enclosing the veto/Cu shield using **energy spectrum** obtained **in step 1**
- Simulation is repeated using different **material of the Shield:**
  - **Copper**
  - **BGO**
  - **GSO**
  - **GAGG**
- With scintillators, the veto is **active**: **rejects events** if **(Veto Energy) > (Veto threshold)**



BULLKID main detector

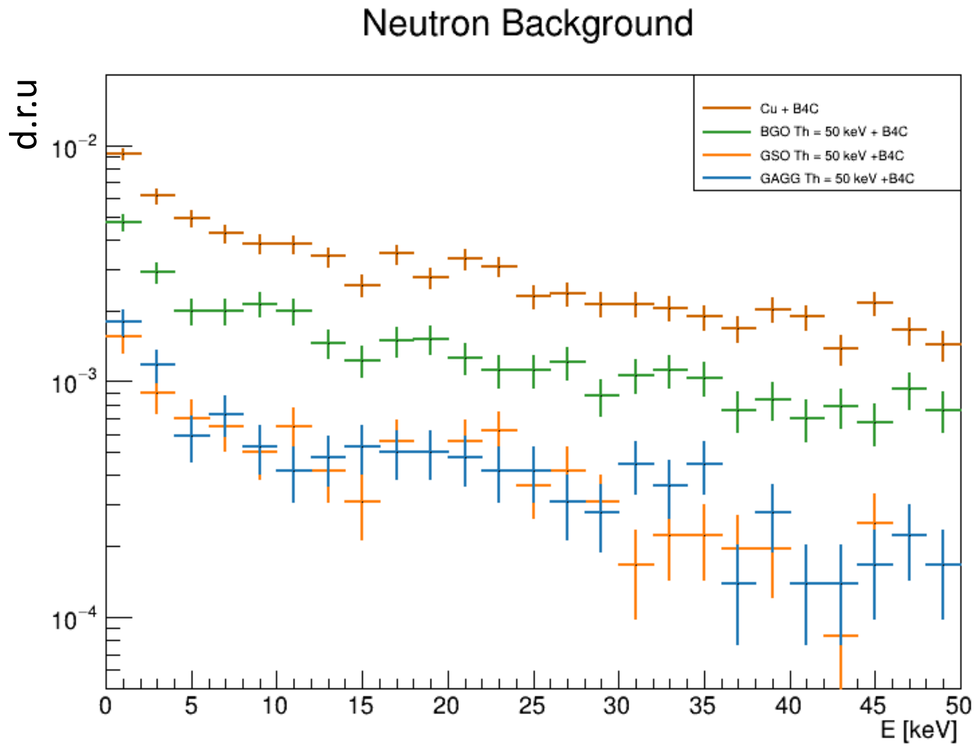
Cu Shield / Veto

Top Cu Shield

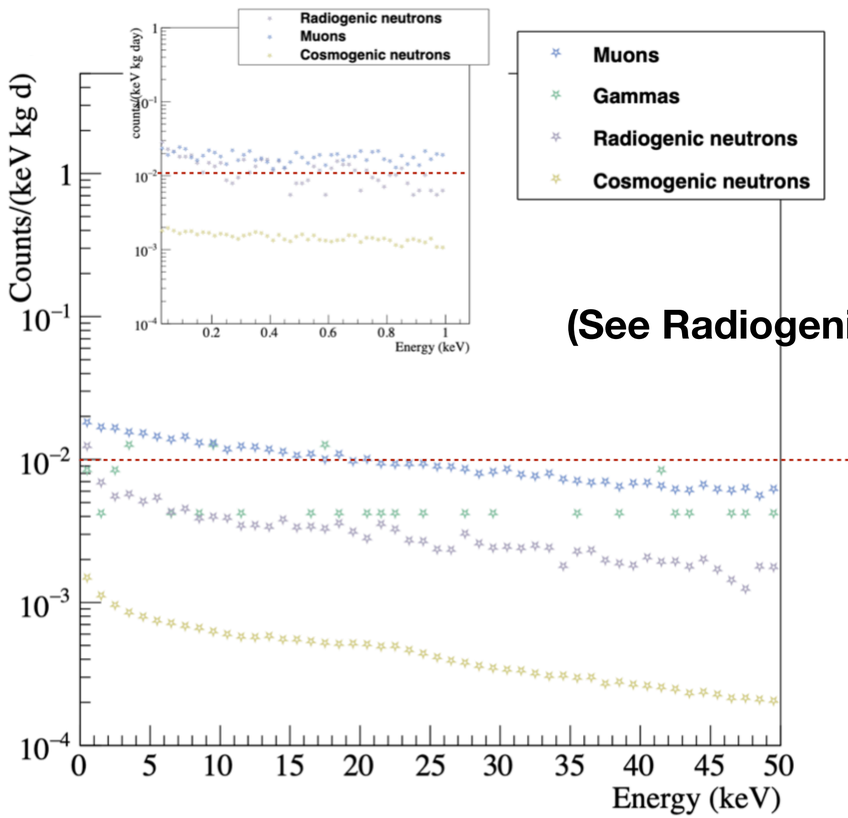
Inner Cu Shield

B4C inner shield

Step 2 neutron backgrounds:

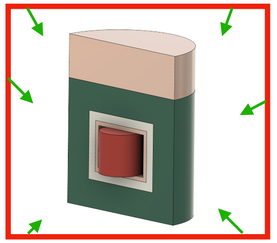


Eric Vazquez Results

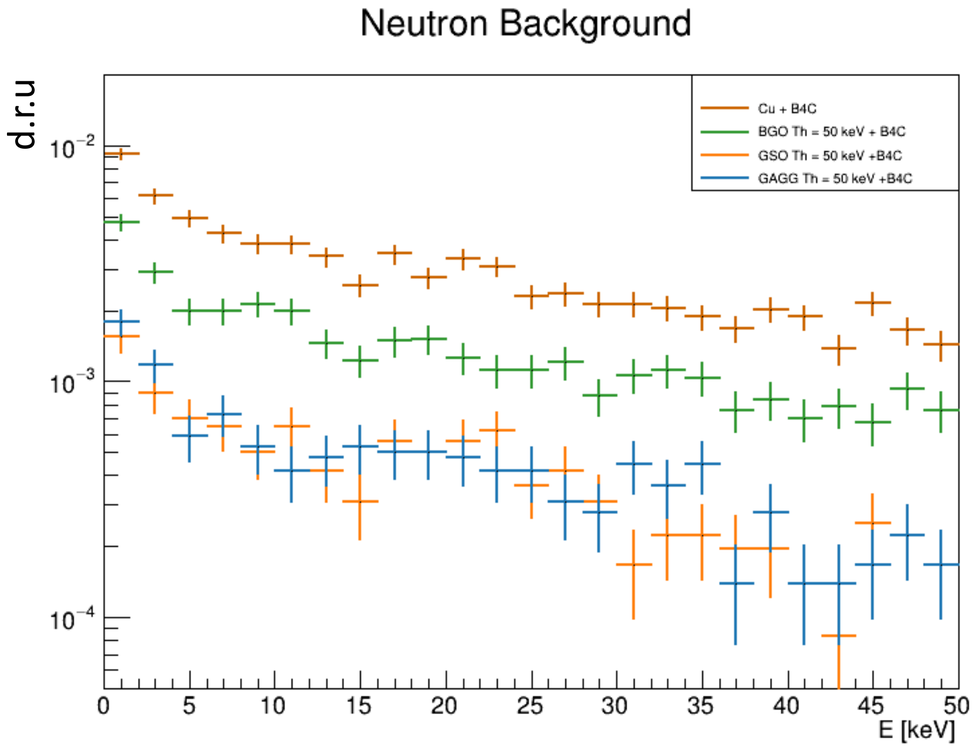


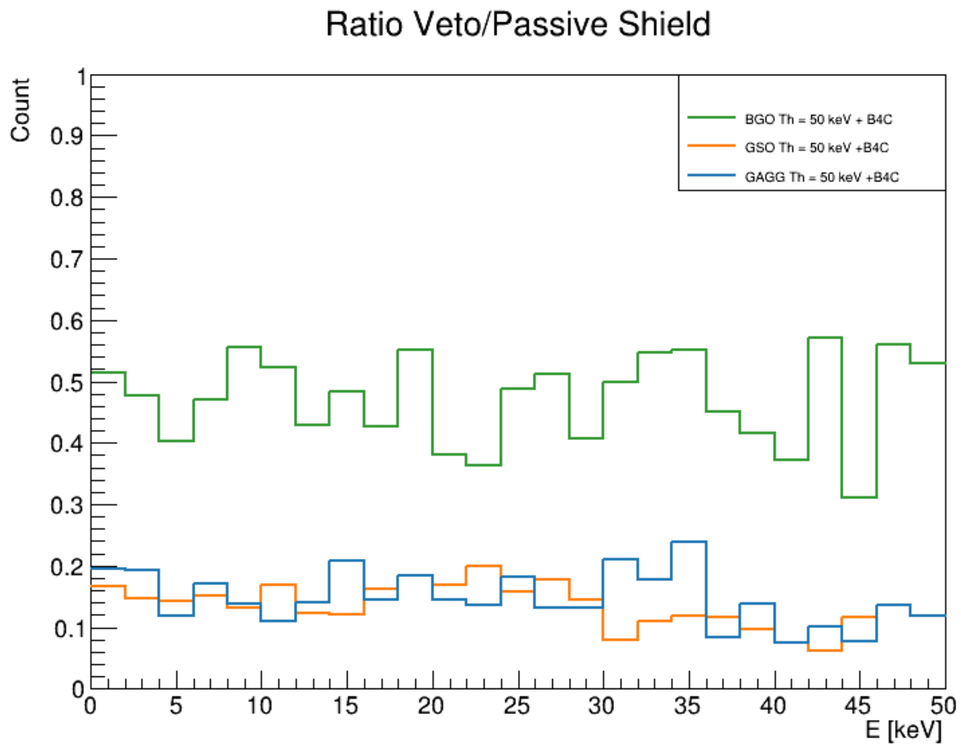
(See Radiogenic neutrons)

- **Cu shield consistent** with Eric Vazquez previous results.
- Veto **threshold = 50 keV**.
- With **GAGG** and **GSO** neutron background reduced of a **factor** ~ 10
- Whit **BGO** neutron background reduced of a **factor** ~ 2



Step 2 neutron backgrounds:





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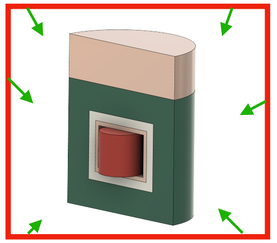
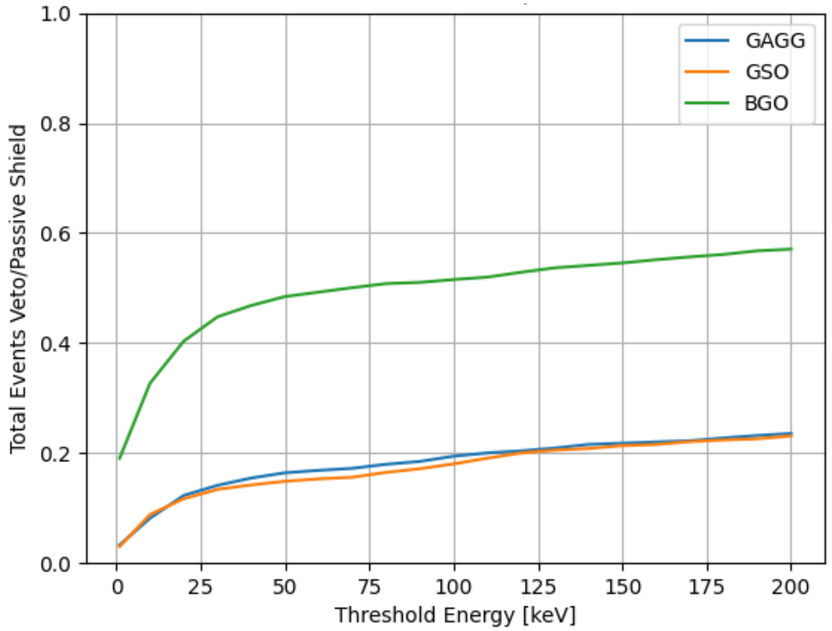


Step 2 neutron backgrounds:

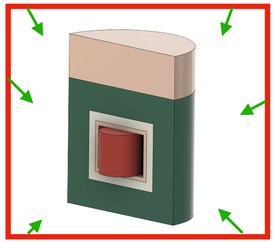
- **Effect of the veto threshold:** a guideline for **optimizing** the **detector parameters.**

Ratio of total Events (in [0,16] keV) Veto/Passive Shiela as a function of veto threshold

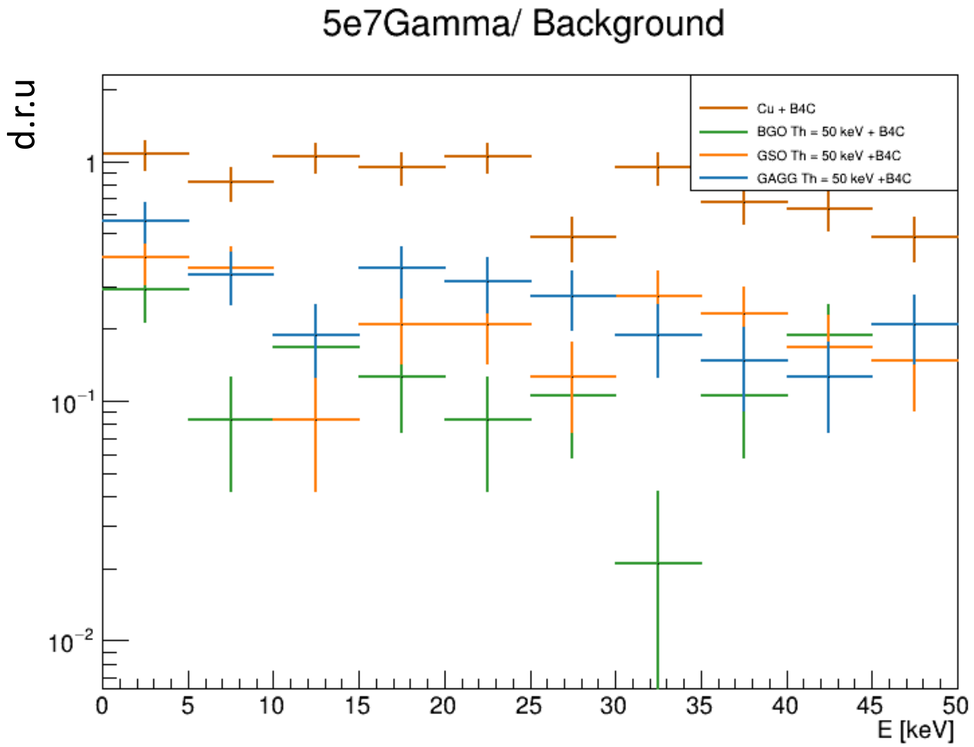


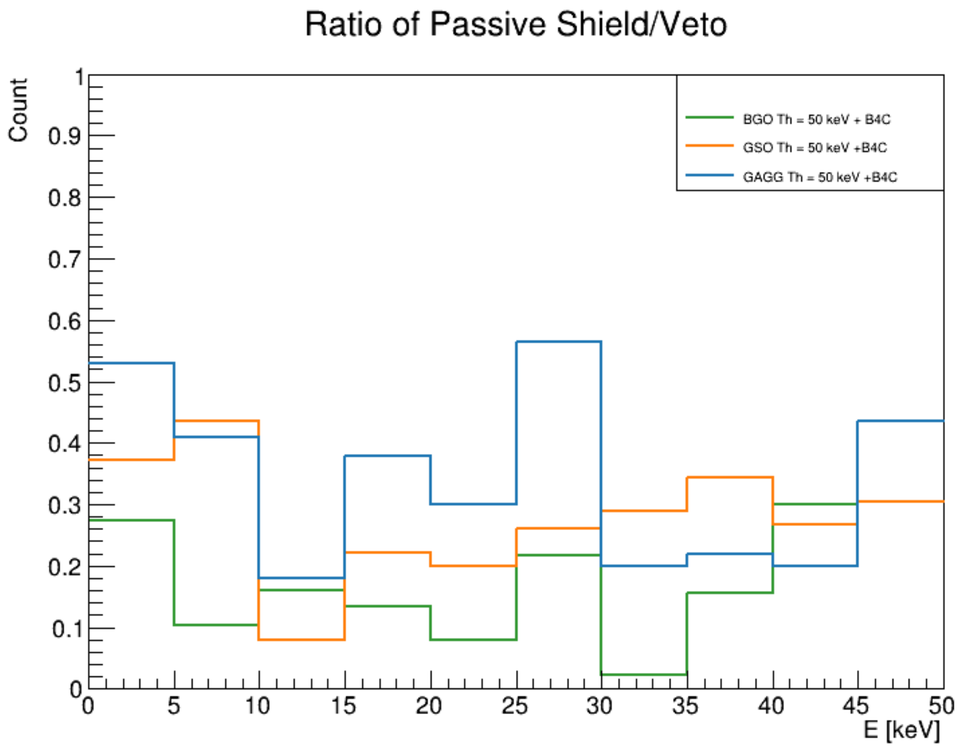
$$\frac{\sum \text{Events in [0,16] keV(Veto)}}{\sum \text{Events in [0,16] keV(Passive Cu Shield)}}$$

- Th=50 keV:
  - BGO background reduced of a factor ~ 2
  - GAGG GSO background reduced of a factor ~ 10
- **Moderate dependance** on the **threshold in [50,200] keV**



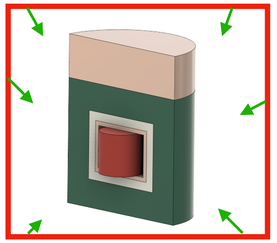
Step 2 gamma backgrounds:





- **Cu shield NOT consistent** with Eric Vazquez previous results
- Veto **threshold = 50 keV**.
- With **GAGG** and **GSO** neutron background reduced of a **factor** ~ 3, whit **BGO** ~ 6
- **Veto performance could improve for internal gamma backgrounds**

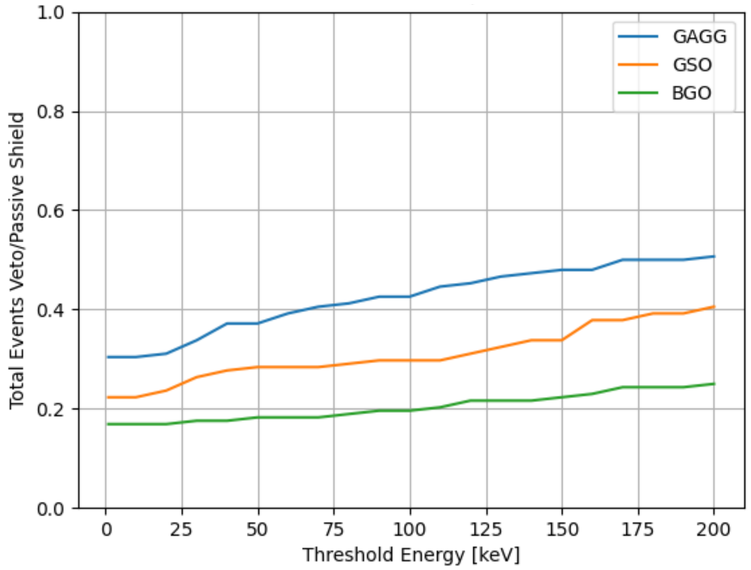
Need to run full simulation for more conclusive results



Step 2 gamma backgrounds:

- **Effect of the veto threshold:** a guideline for **optimizing** the **detector parameters.**

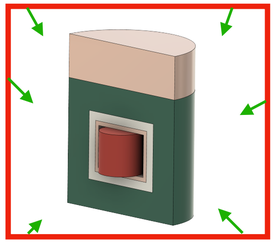
Ratio of total Events (in [0,16] keV) Veto/Passive Shiela as a function of veto threshold



$$\frac{\sum \text{Events in [0,16] keV(Veto)}}{\sum \text{Events in [0,16] keV(Passive Cu Shield)}}$$

- Th=50 keV:
  - BGO background reduced of a factor ~ 6
  - GAGG GSO background reduced of a factor ~ 3
- **Veto performance could improve for internal gamma backgrounds**
- **More dependance on the threshold in [50,200] keV compared to neutrons**

Need to run full simulation for more conclusive results



Conclusions:

- Started studying the veto through simulation.
- Despite a simplified simulation setup, some preliminary results on the veto have been obtained
- Using an active veto reduces gamma and neutrons by up to a factor of 10
    - Large room for optimization
- The secondary spectra obtained are useful for fast simulations in optimizing veto geometry

- Next Steps:
    - Brainstorming on veto geometry to improve performance.
    - Running full simulations, including internal backgrounds, muons and a more realistic veto geometry.

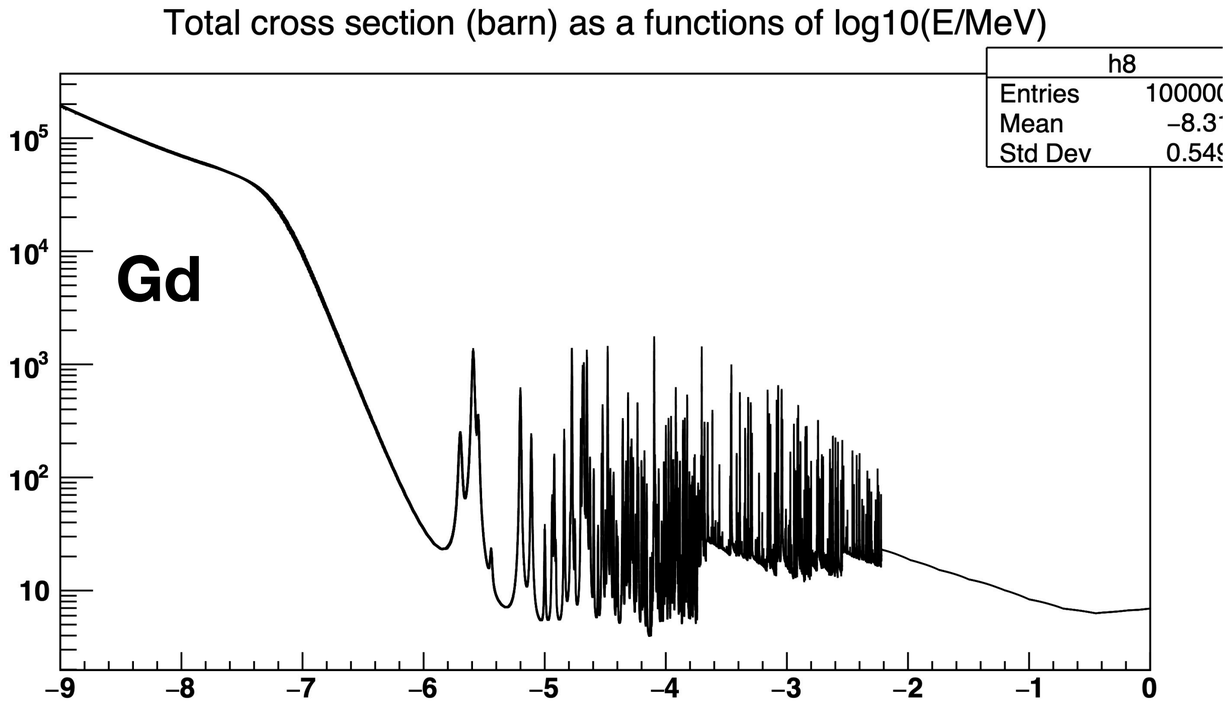
References:

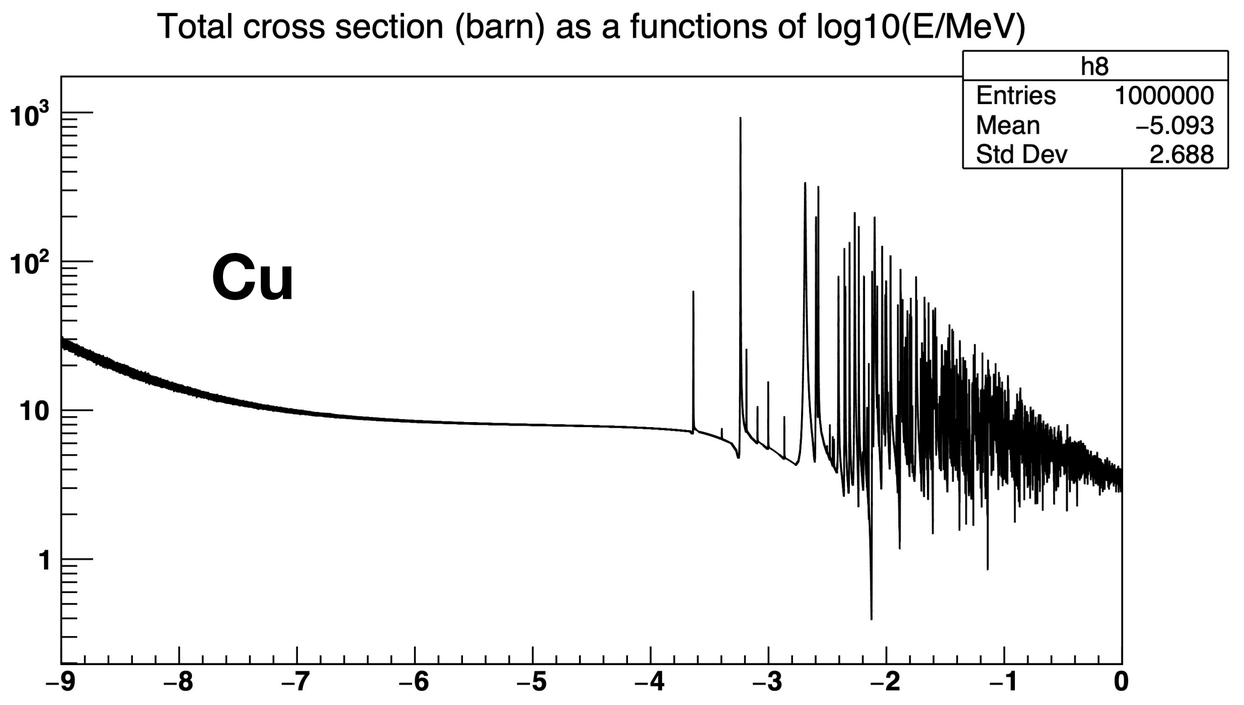
Ref [1]:
Belli, P., et al. "Deep underground neutron flux measurement with large BF 3 counters." *Il Nuovo Cimento A (1971-1996)* 101.6 (1989): 959-966.

Ref [2]
Bucci, C., et al. "Background study and Monte Carlo simulations for large-mass bolometers." The European Physical Journal A 41 (2009): 155-168.

Gd vs Cu neutron total cross section:

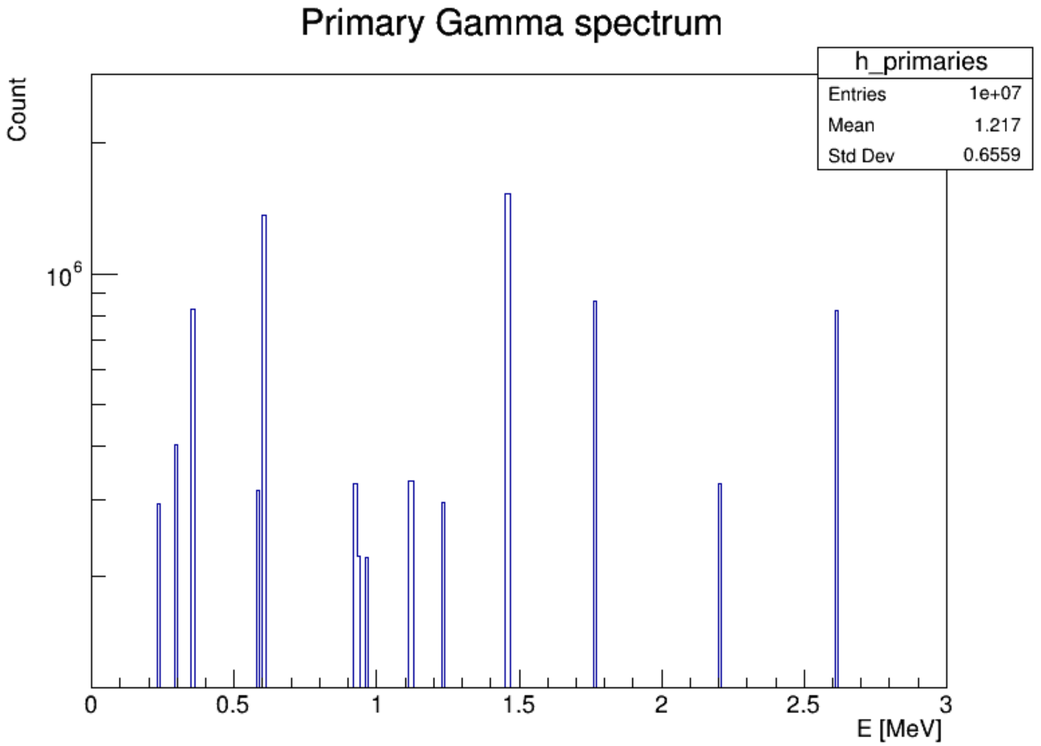
Back-up



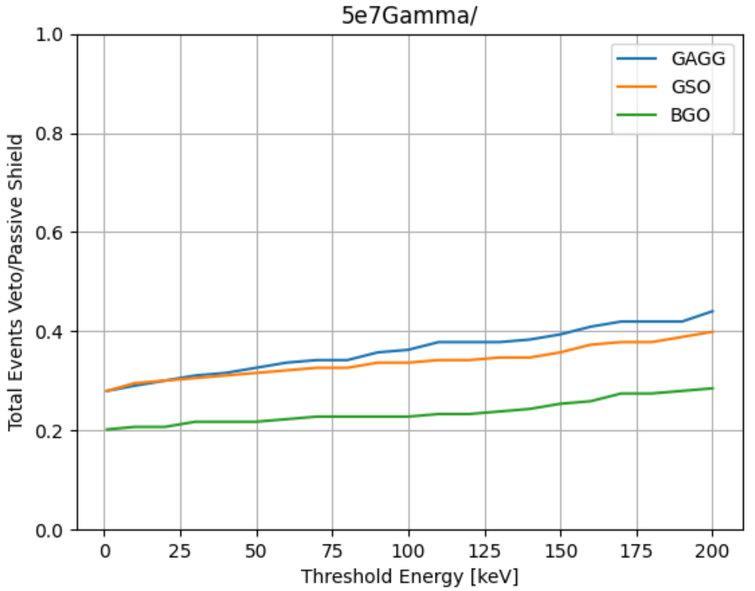


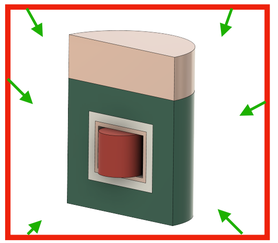
Step 2 gamma backgrounds no external shields: Back-up

- **Effect of the veto threshold:** a guideline for **optimizing** the **detector parameters.**



Ratio of total Events (in [0,16] keV) Veto/Passive Shiela as a function of veto threshold





From counts to d.r.u. :

Total Experimental Flux

$$\text{d.r.u}\left[\frac{\text{count}}{\text{kg day keV}}\right] = \Phi\left[\frac{\text{\# Particles}}{\text{m}^2\text{day}}\right] \frac{\text{\# Sim. Bck Events} \times \text{ Gun Surface } [\text{m}^2]}{\text{\# Sim. Primaries} \times \text{Bullkid Mass [kg]} \times \text{Bin width [keV]}}$$

$$\left(\frac{\text{Events in intermediate surface}}{\text{Primaries Sim. step 2.}}\right)$$

In 2 steps simulation