Background Simulation Study for Deep Underground Cavities

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Outline

- **Introduction on Low Background experiments**
- **The main background sources for deep underground labs**
- **Shower development in rock: the analysis procedure**
- **Summary & Outlook**

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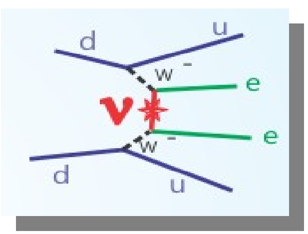
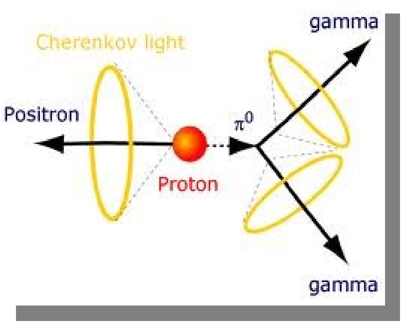
Low Background Experiments

Particularly rare physics processes like:





- **Direct Dark Matter interaction**
- **Neutrinoless Double Beta Decay**
- **Low Energy Neutrinos' interaction (solar, sterile neutrinos etc)**
- **Proton decay**

Experiments have very small expected event rates!!
(e.g. $0\nu2\beta$ decay < 0.1 events/(kg y))

They ALL need a very low background!!

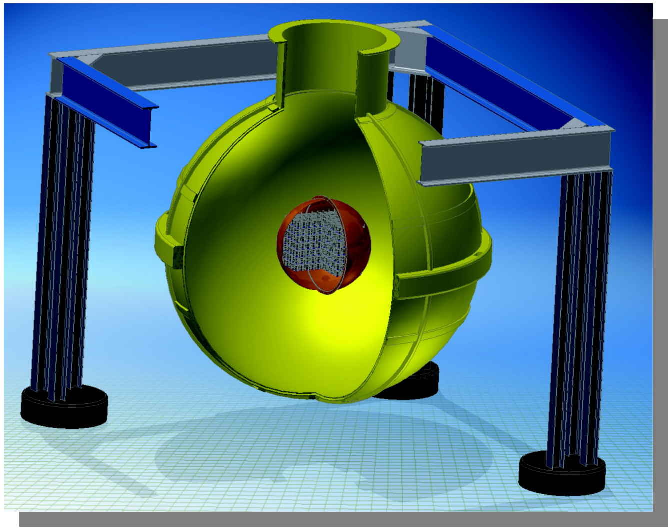
Expected Event Rate

What we can do to enhance the expected event rate?

- **Increase the exposure:**

  → **increase the data taking period**

Expected Event Rate



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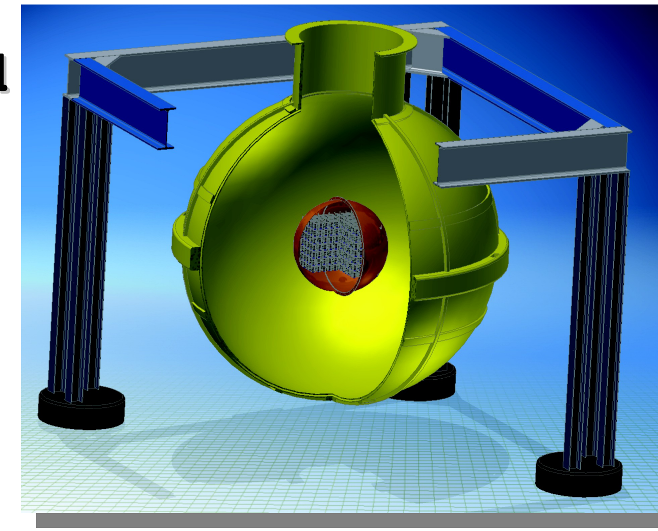
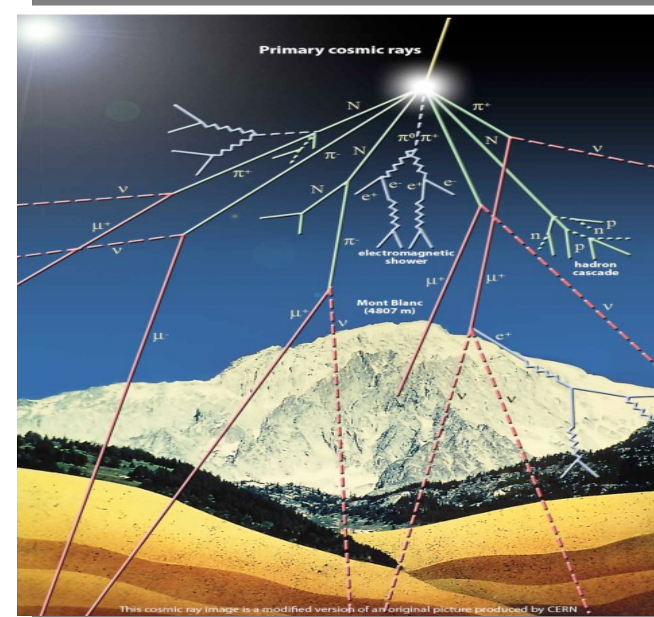
  → 1 Ton experiments

Expected Event Rate

What we can do to enhance the expected event rate?

- **Increase the exposure:**
  - → increase the data taking period
  - → increase the mass
    → **1 Ton experiments**
- **Increase the S/B ratio:**
  - → reduce the background
    → ***Move deeper Underground***
    → **Effective Shielding**





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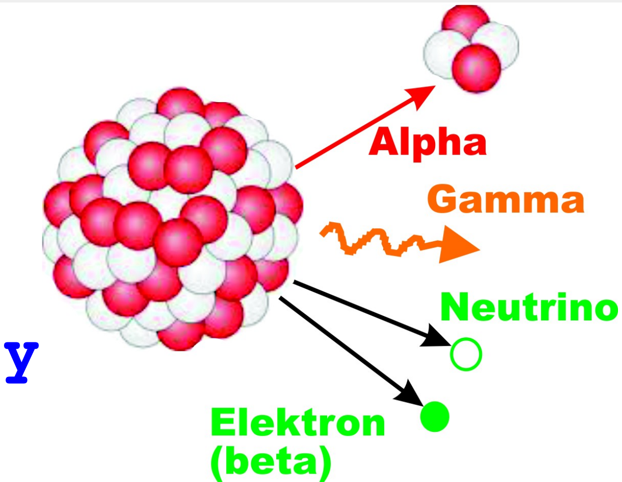
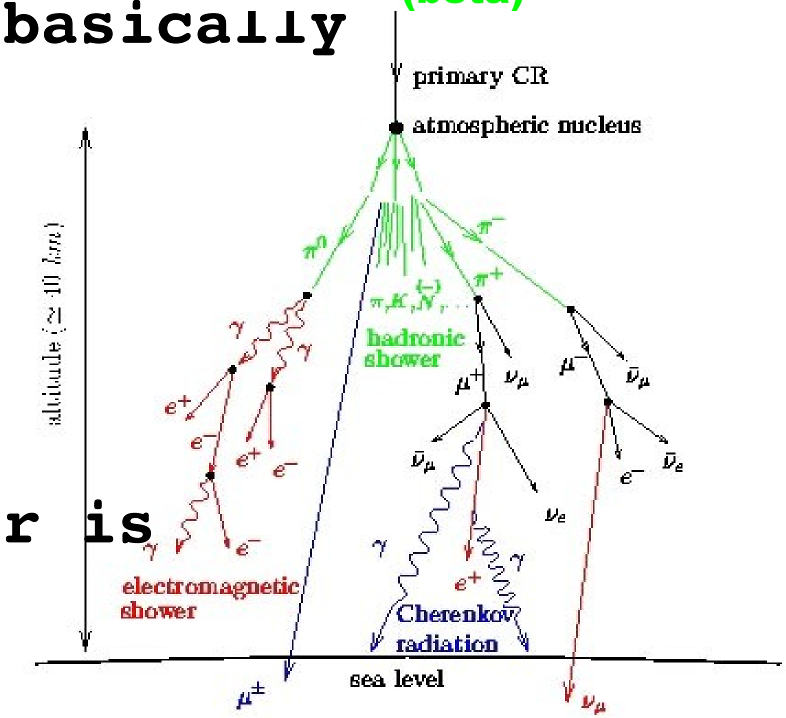
Background Sources

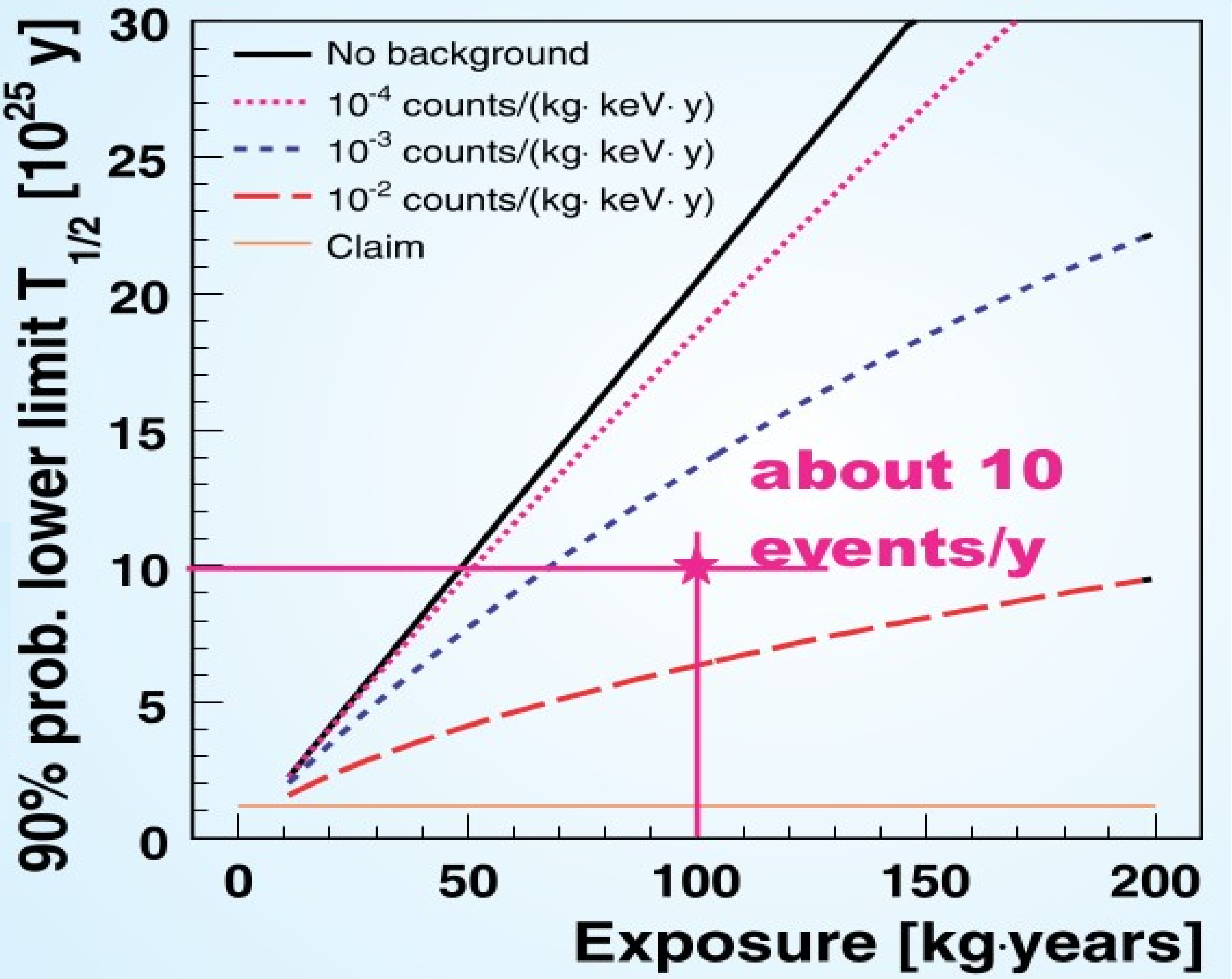
- **Three different sources:**
  - **Intrinsic detector radioactivity**
  - **Environmental Natural radioactivity**
  - **Cosmic Rays-induced showers** (basically muon and neutrino-induced)



- **Two different components:**
  - **Charged** → easy to veto
  - **Neutral** → high shielding power is required (neutron, gammas)



Importance of Background



Allen Caldwell, Kevin Kröninger, Phys.Rev.D 74 (2006) 092003

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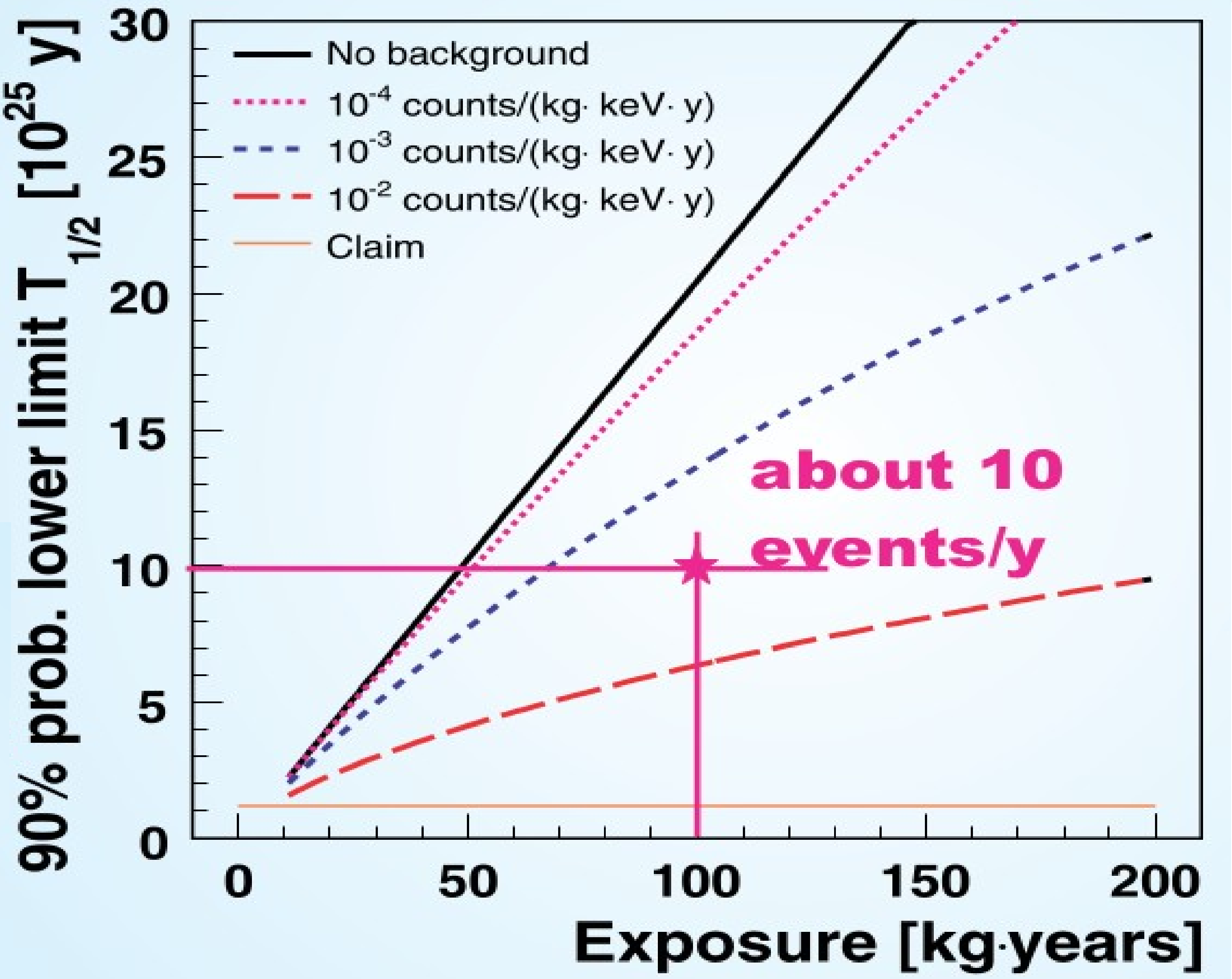

To build an experiment is crucial to know which level of background you can allow and which you can not!

Allen Caldwell, Kevin Kröninger, Phys.Rev.D 74 (2006) 092003

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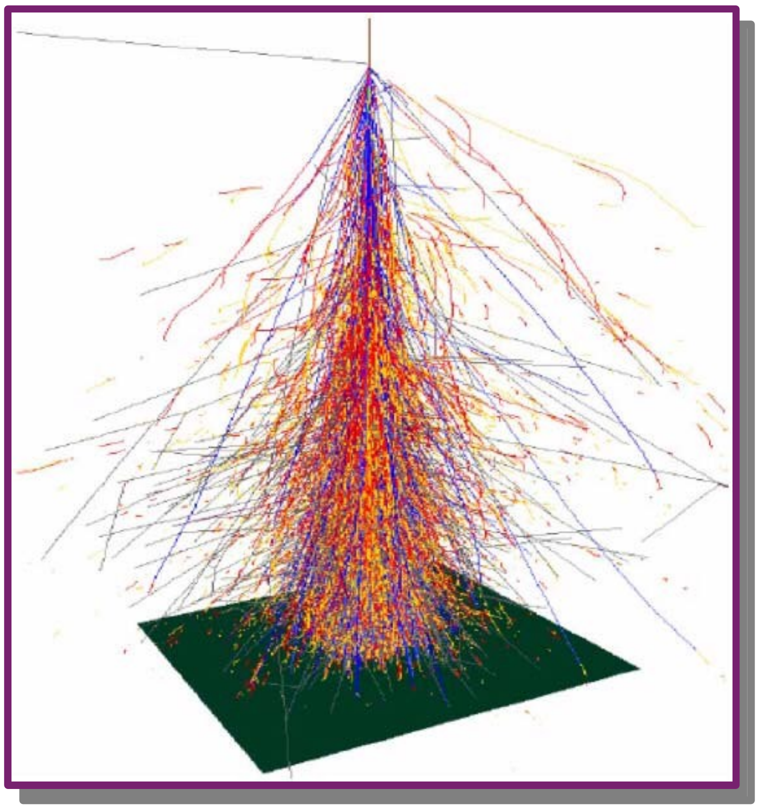
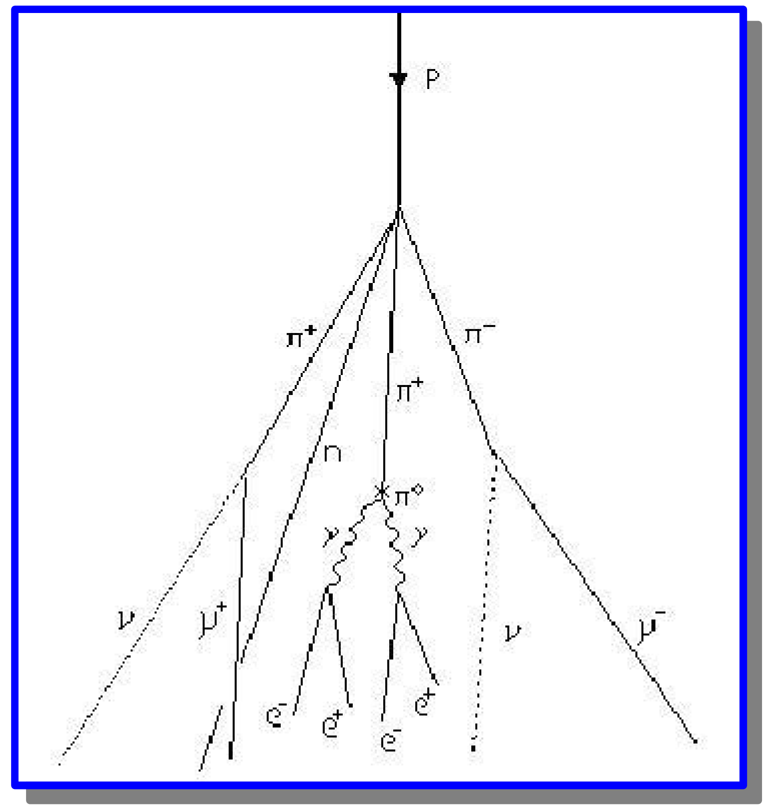
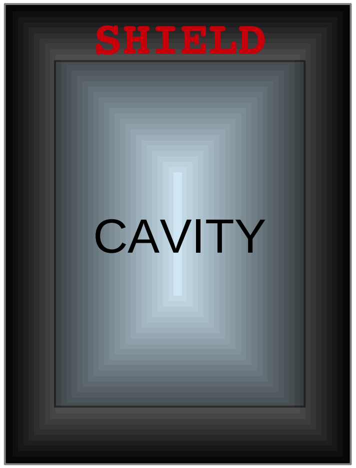
What we want to do?

- To get rid of the Background →
  Study the **Hadronic** and **Electromagnetic** Showers behavior





Vertical & Horizontal Safety Distances



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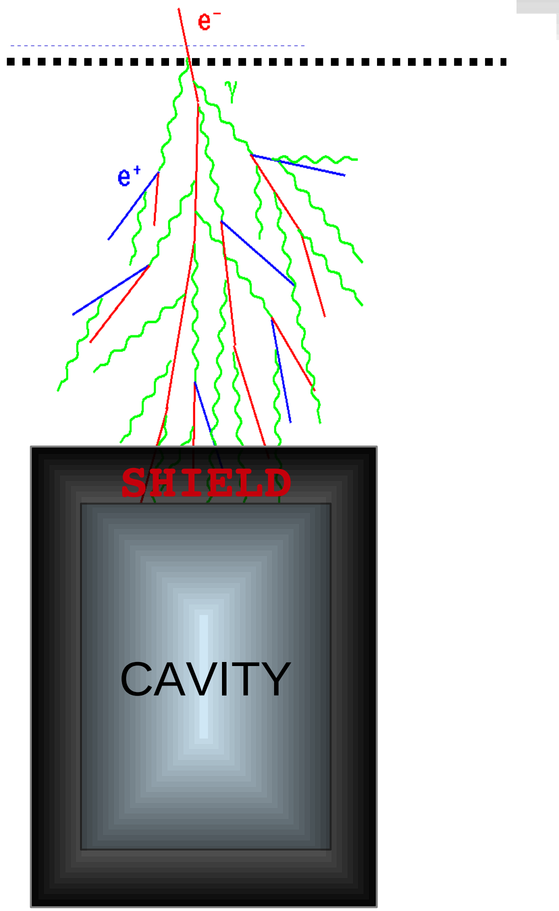

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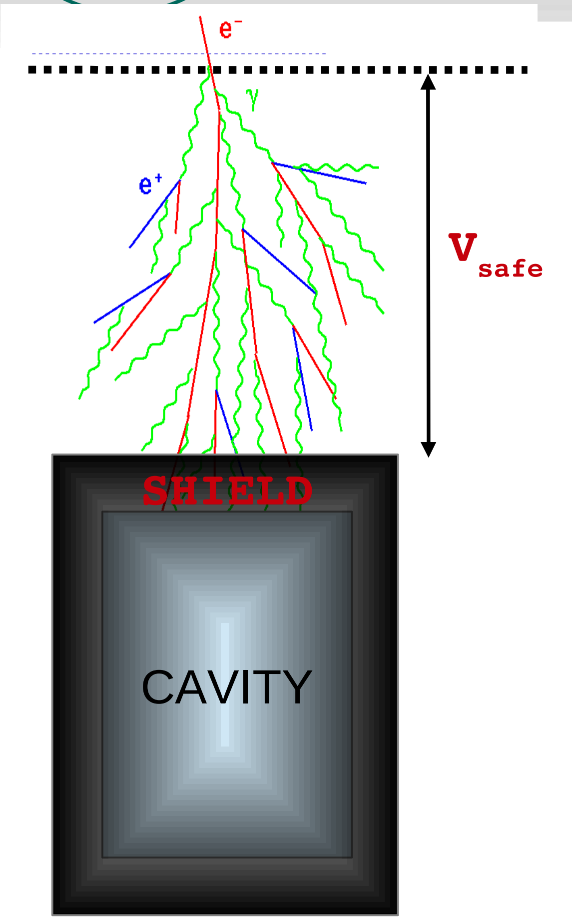
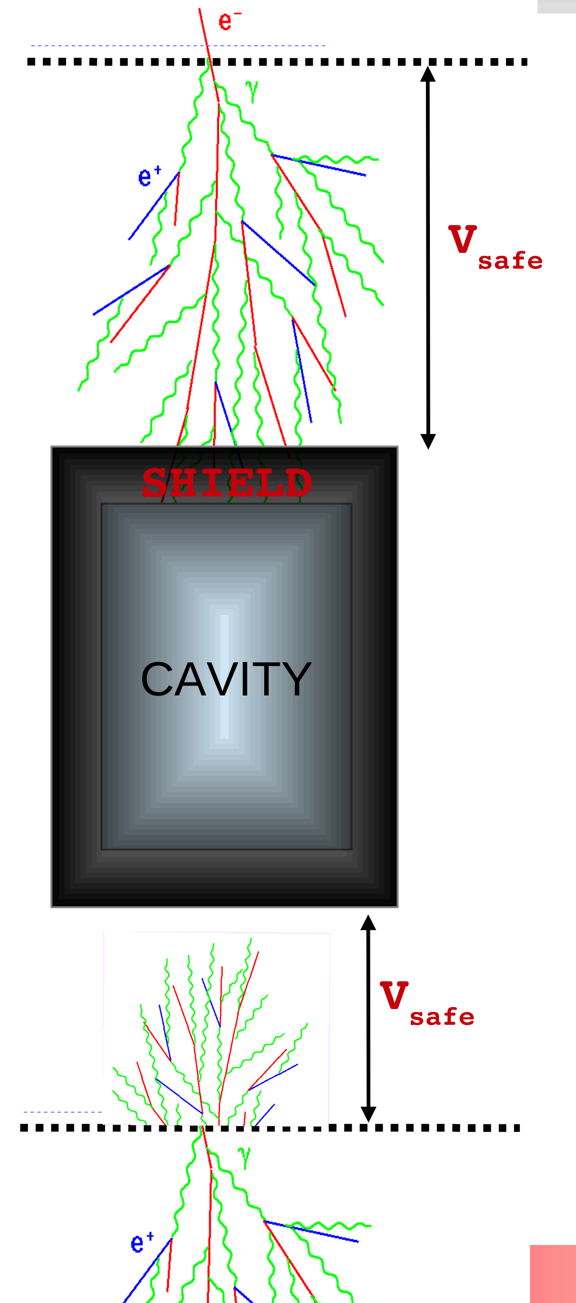


- **V_{safe} :** vertical distance (from the interaction point) after which the shower has 10 MeV left

Vertical & Horizontal Safety Distances



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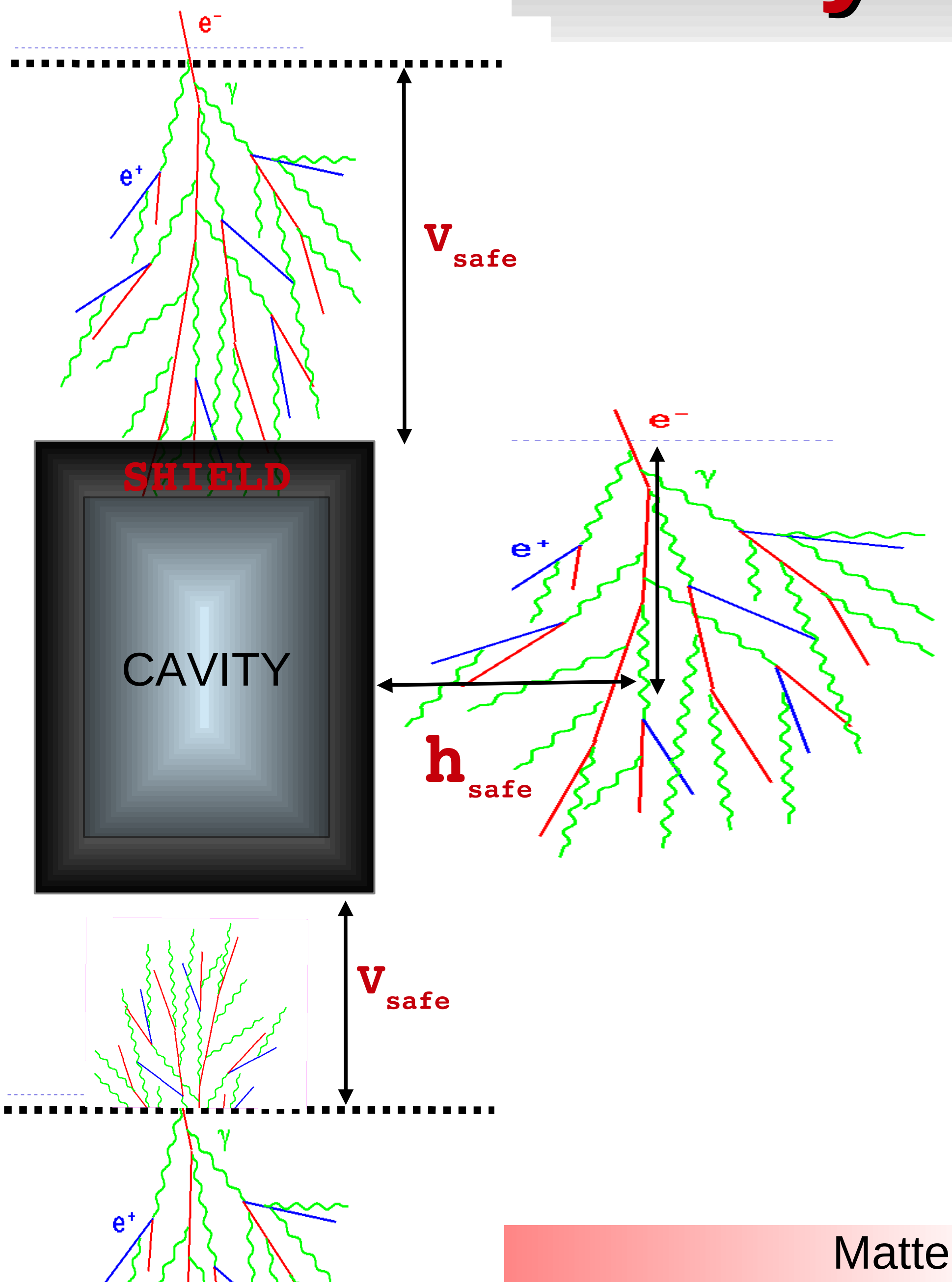
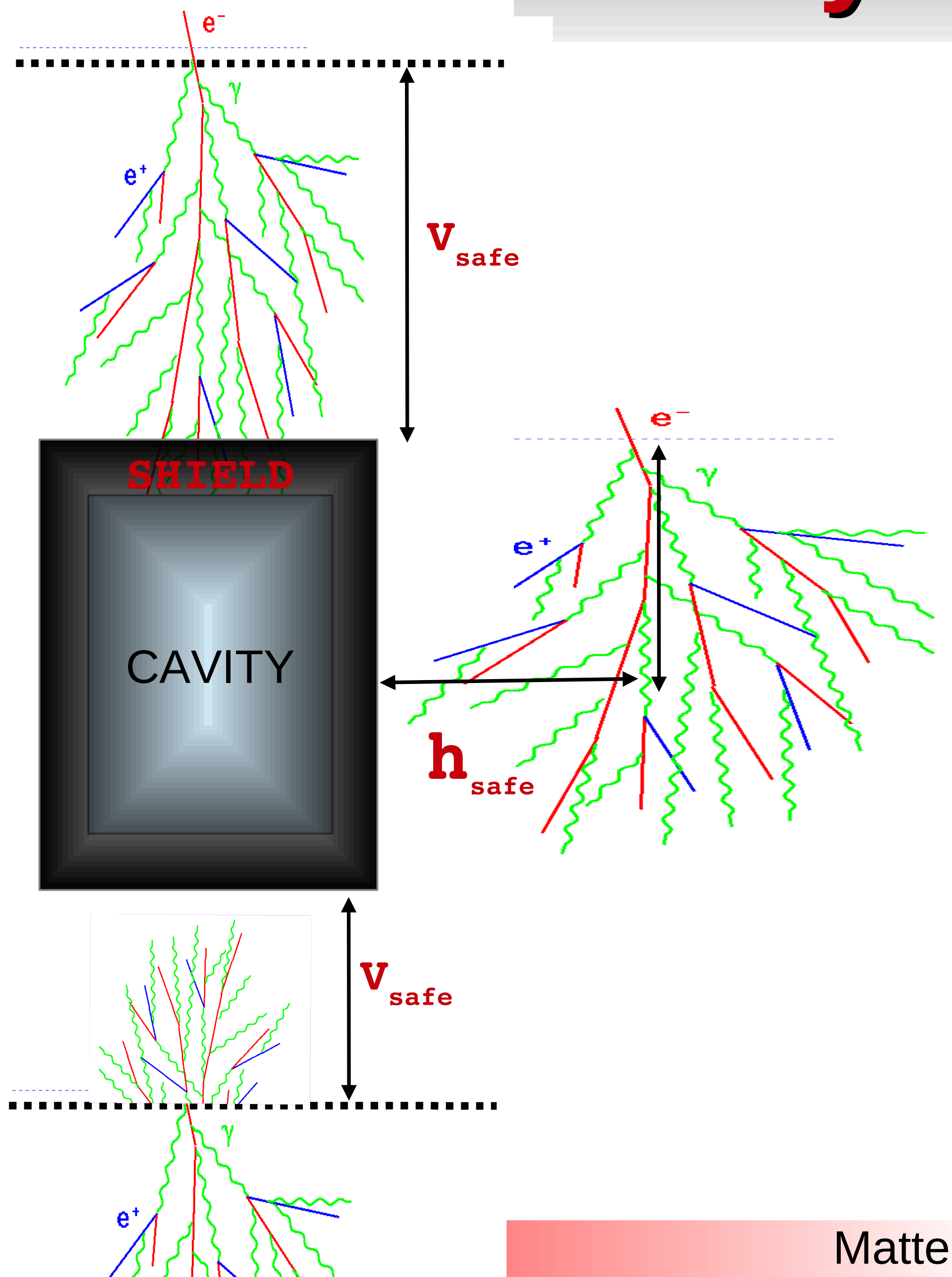
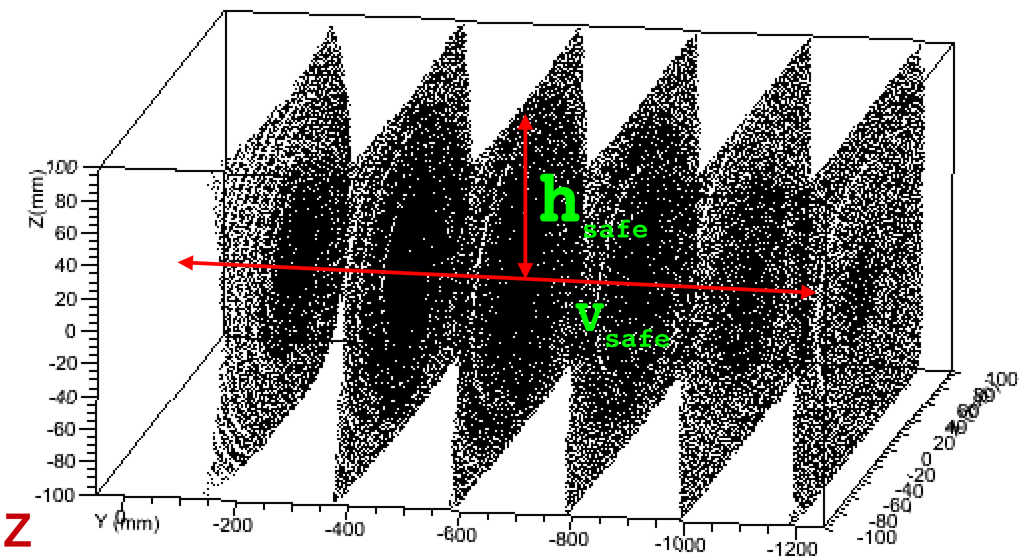


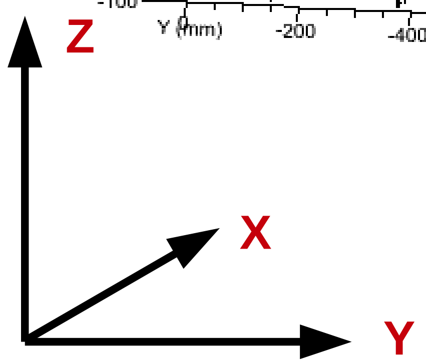
- $\mathbf{V_{safe}}$ **:** vertical distance (from the interaction point) after which the shower has 10 MeV left

- $\mathbf{h_{safe}}$ **:** horizontal distance (from the mean energy position) after which only 10 MeV can reach the shield

Vertical & Horizontal Safety Distances

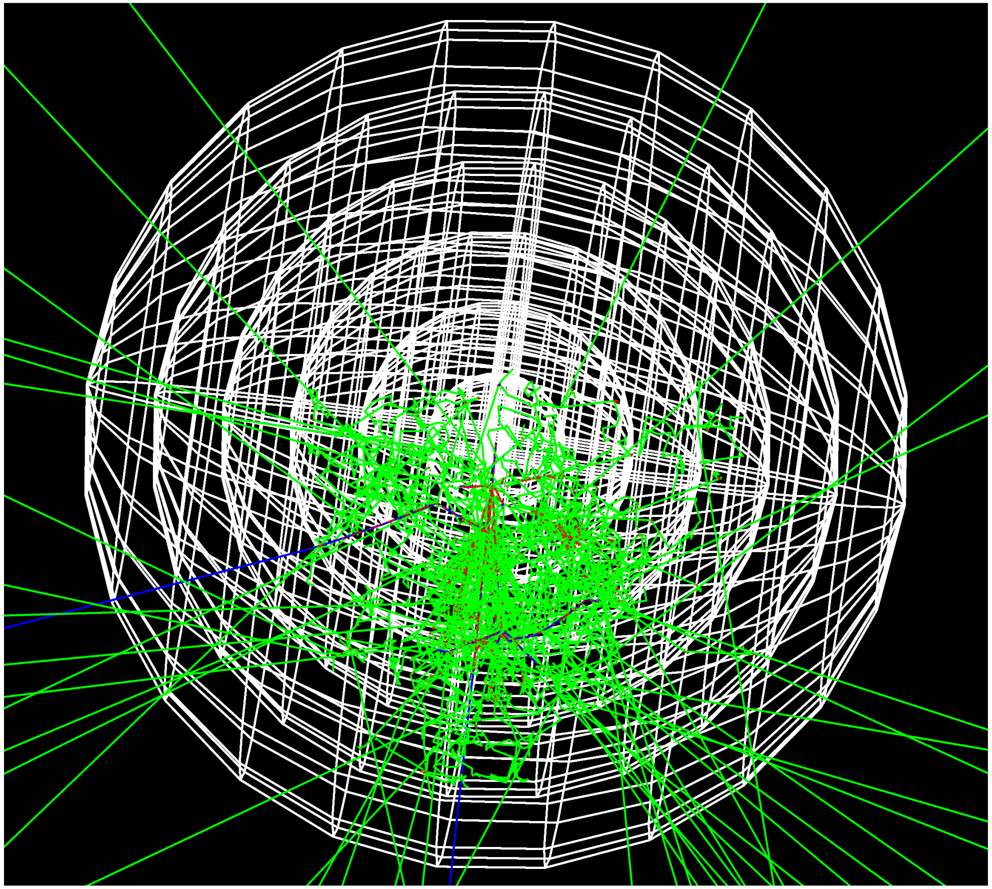


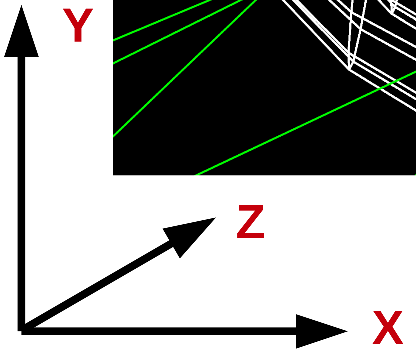




How do we do that?

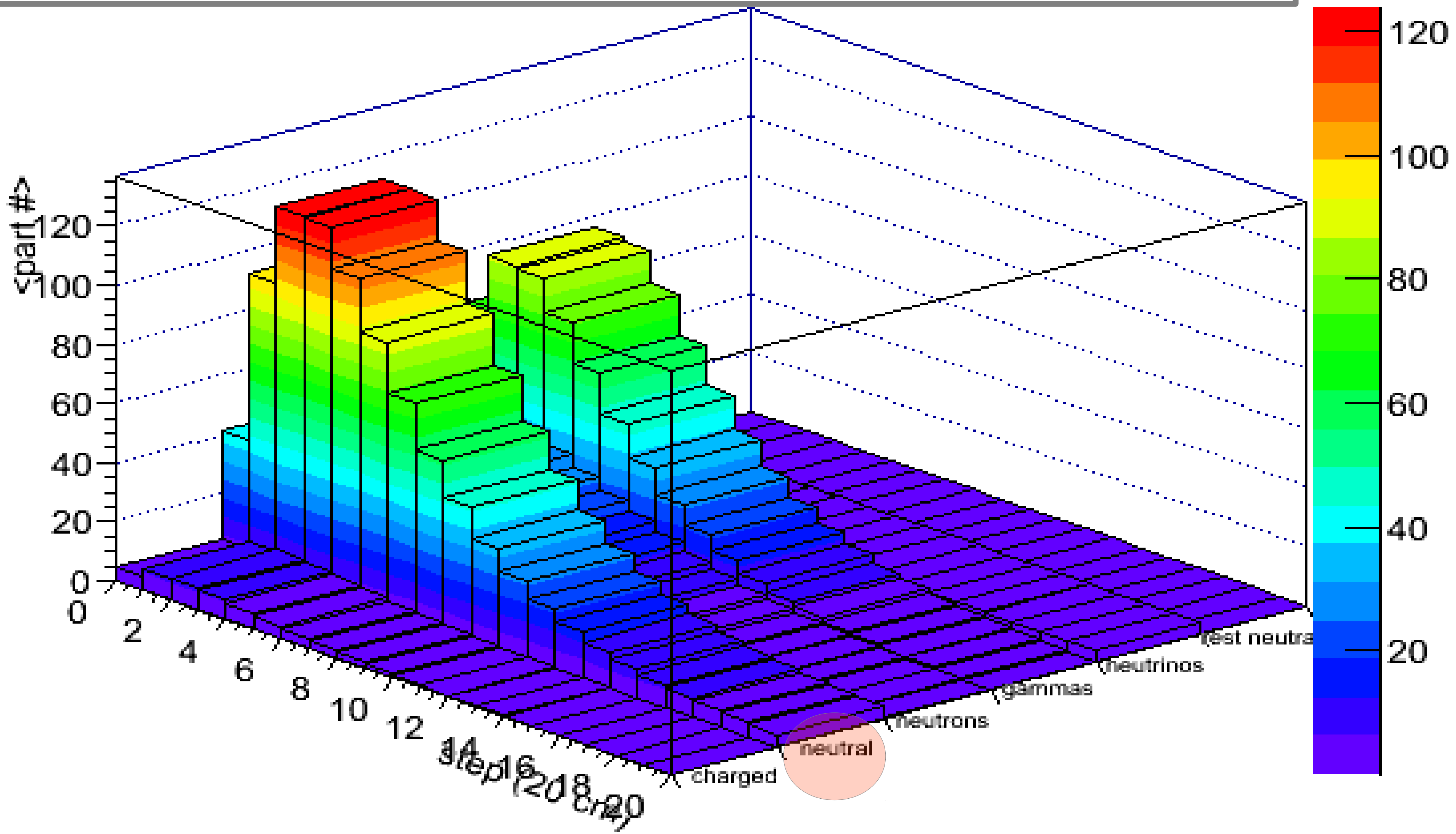
- Shot a particle of certain energy along **-Y** direction
- Let it creates a shower in the center of a rock-made sphere (**divided into sub-spheres**)
- Record all the particles with their properties (e.g. **position, kinetic energy, charge**, etc.) that arrive at each single sub-sphere surface





Global Results (1)

proton @ 10 GeV : particles # distribution vs step



Global Results (2)

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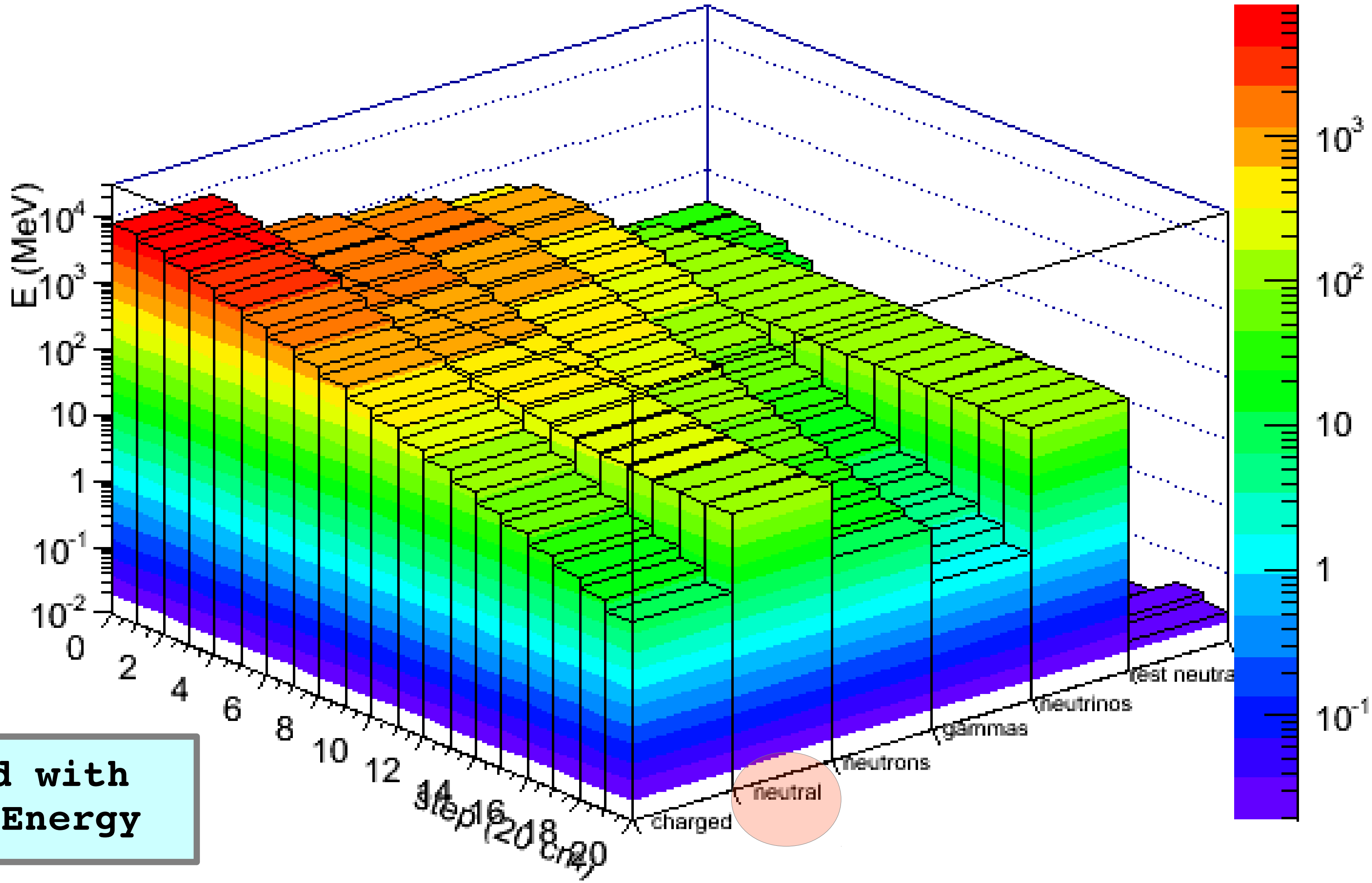
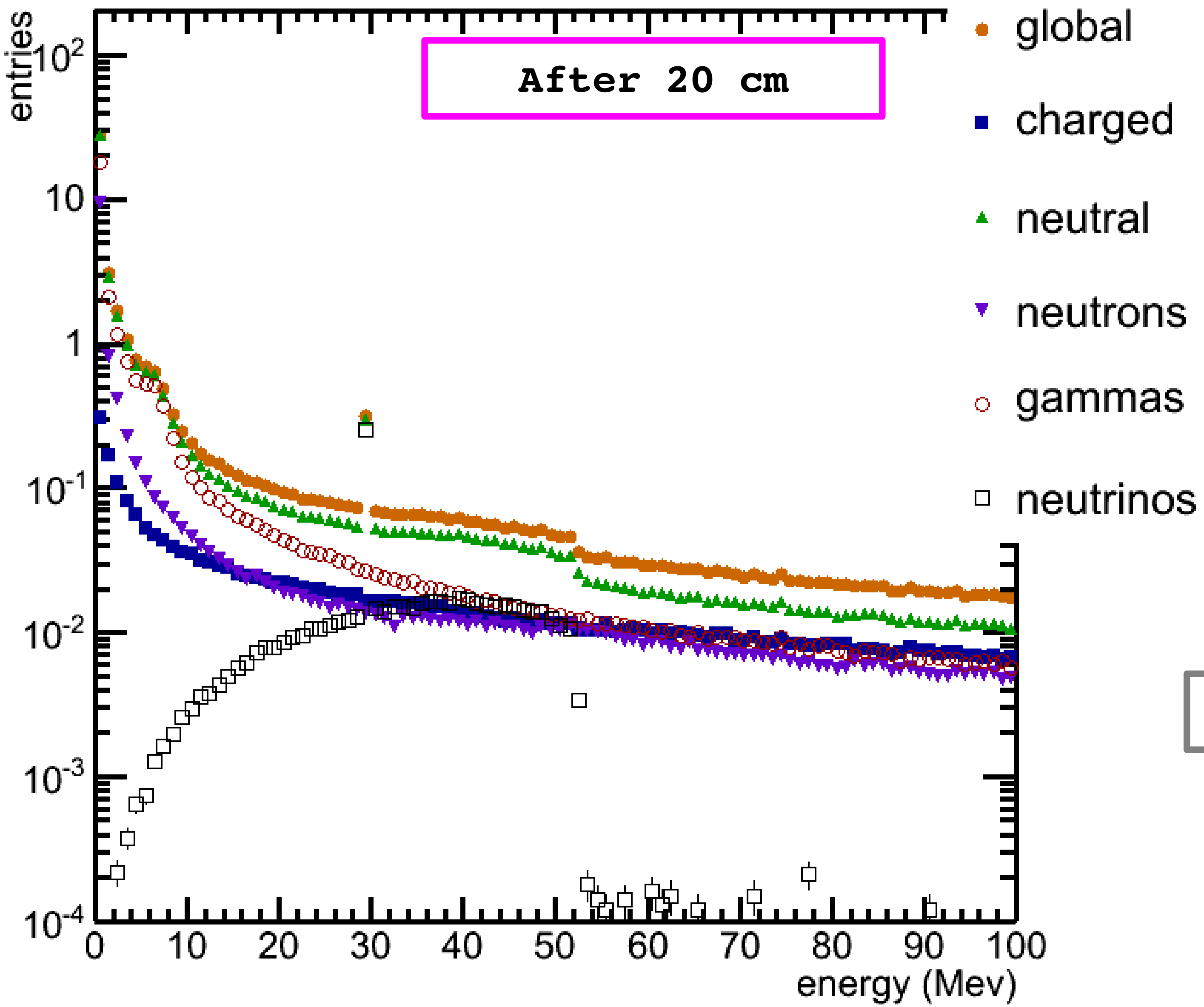


Weighted with Kinetic Energy

Global Results: Energy Spectra



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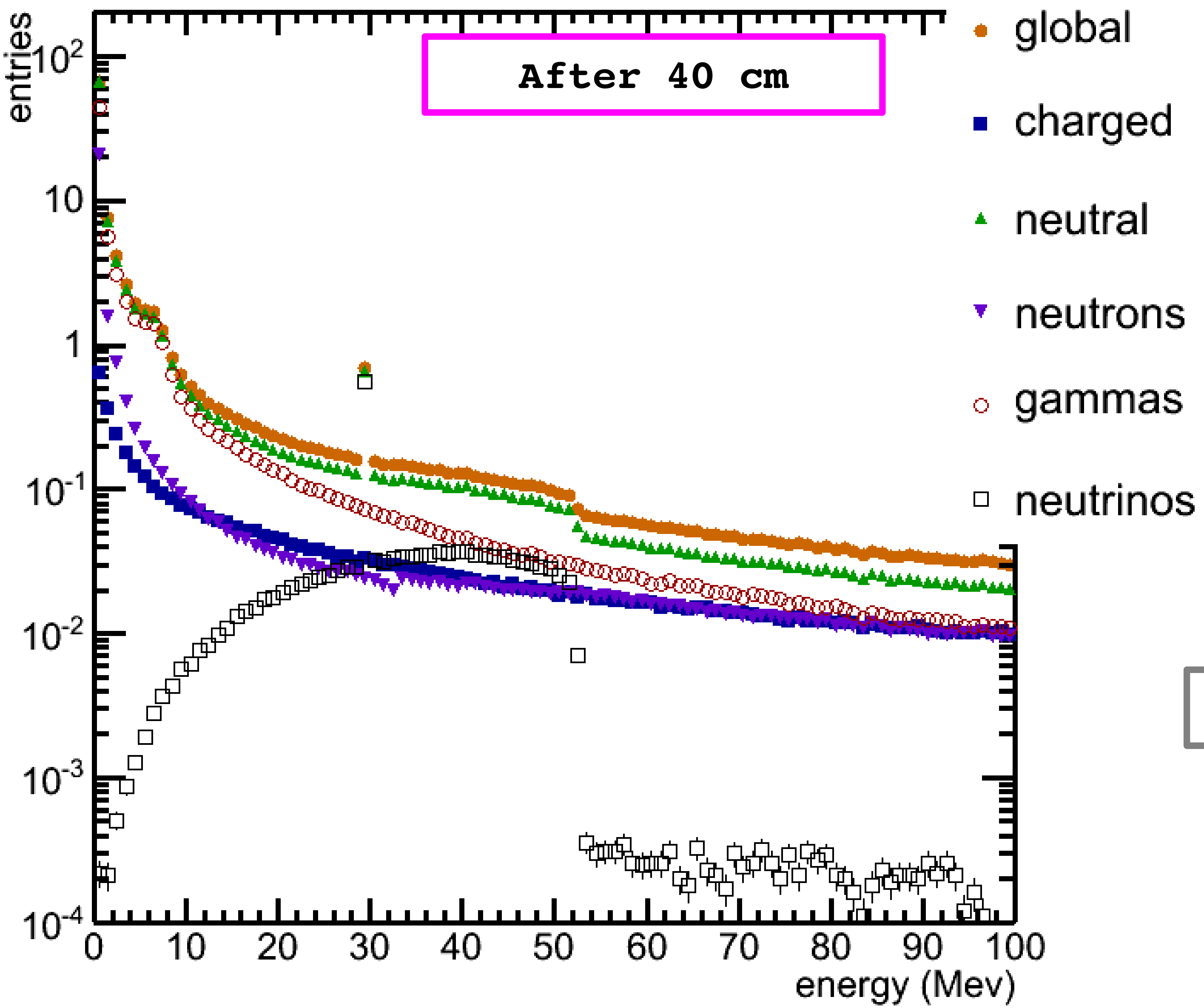

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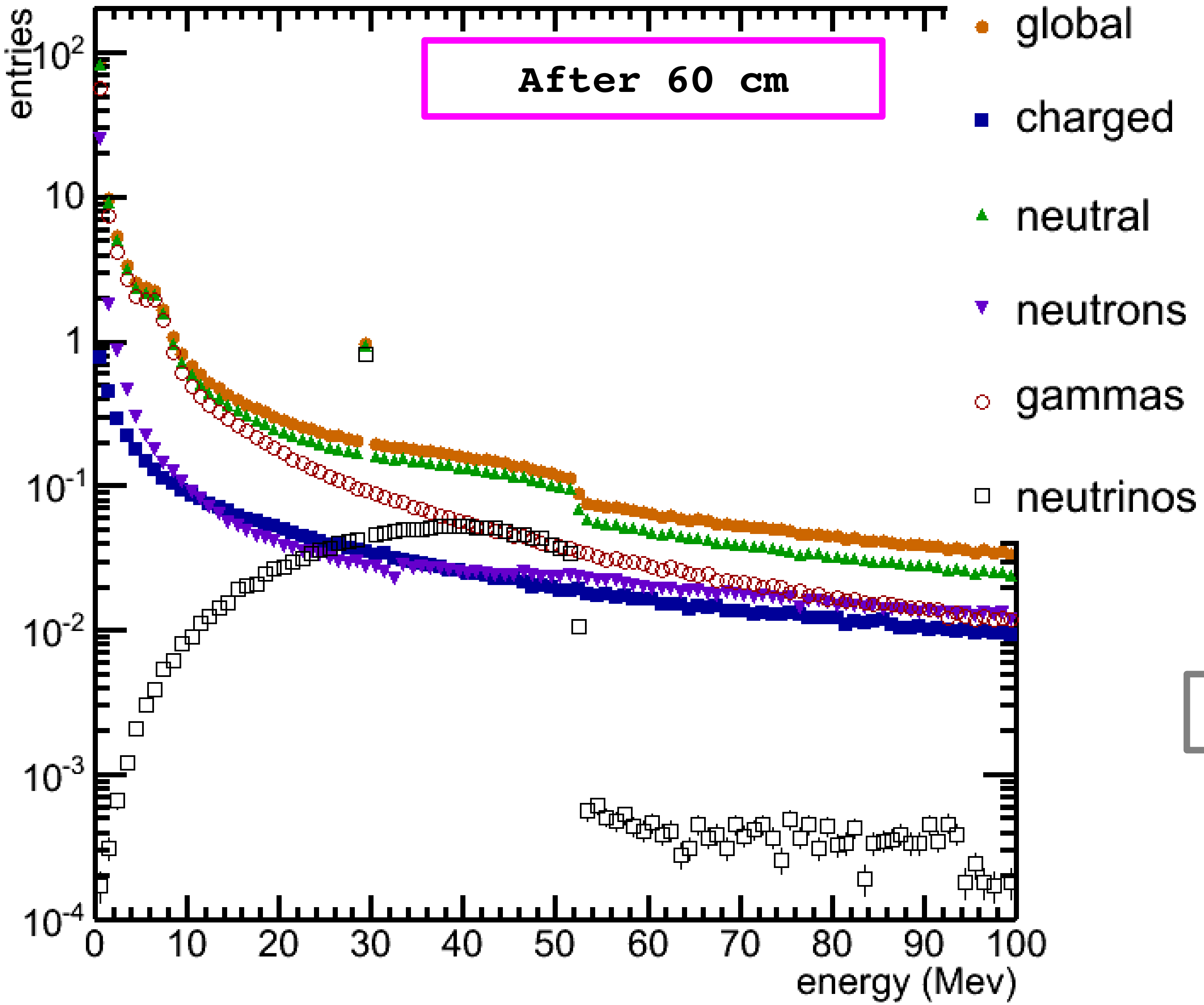

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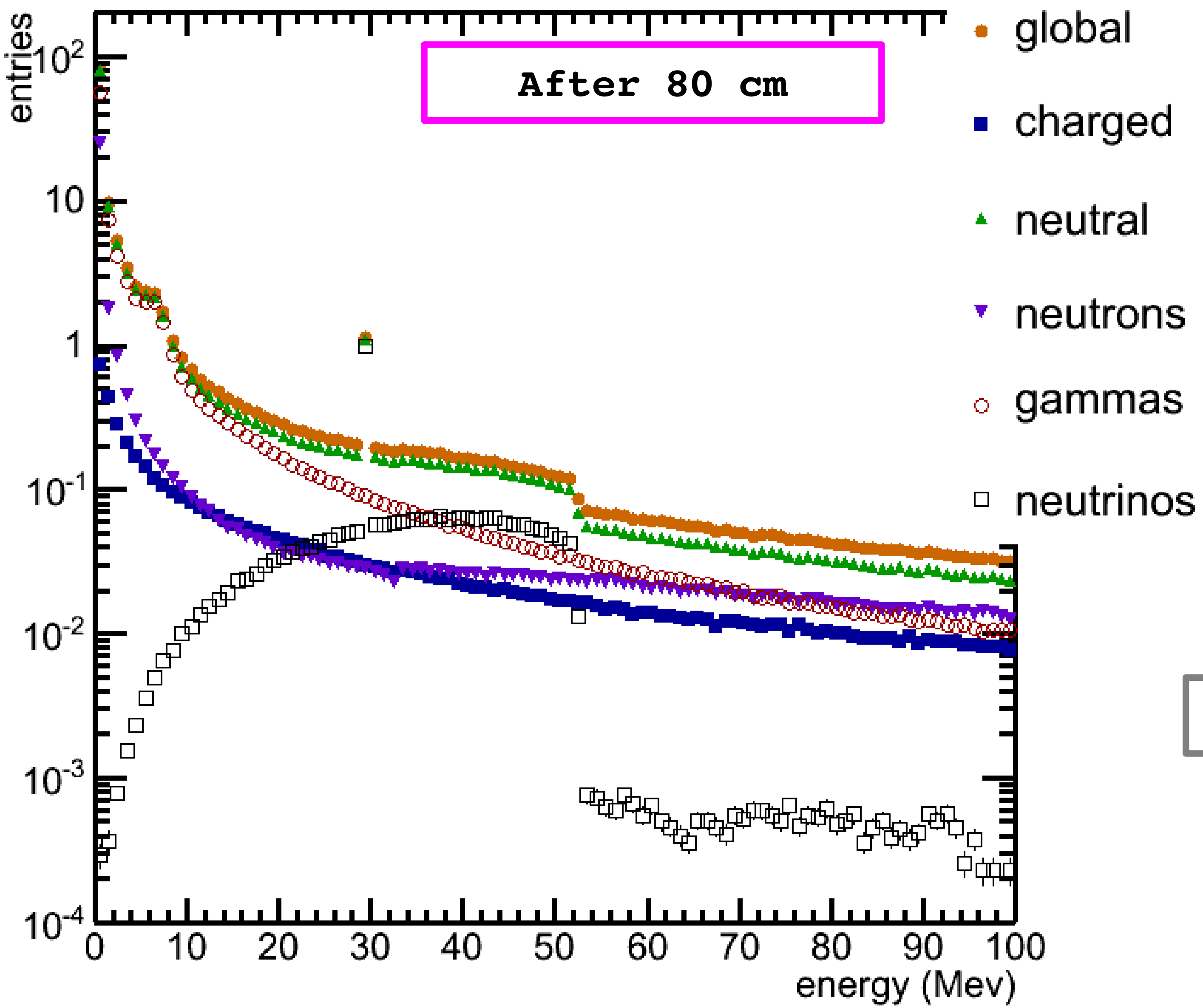

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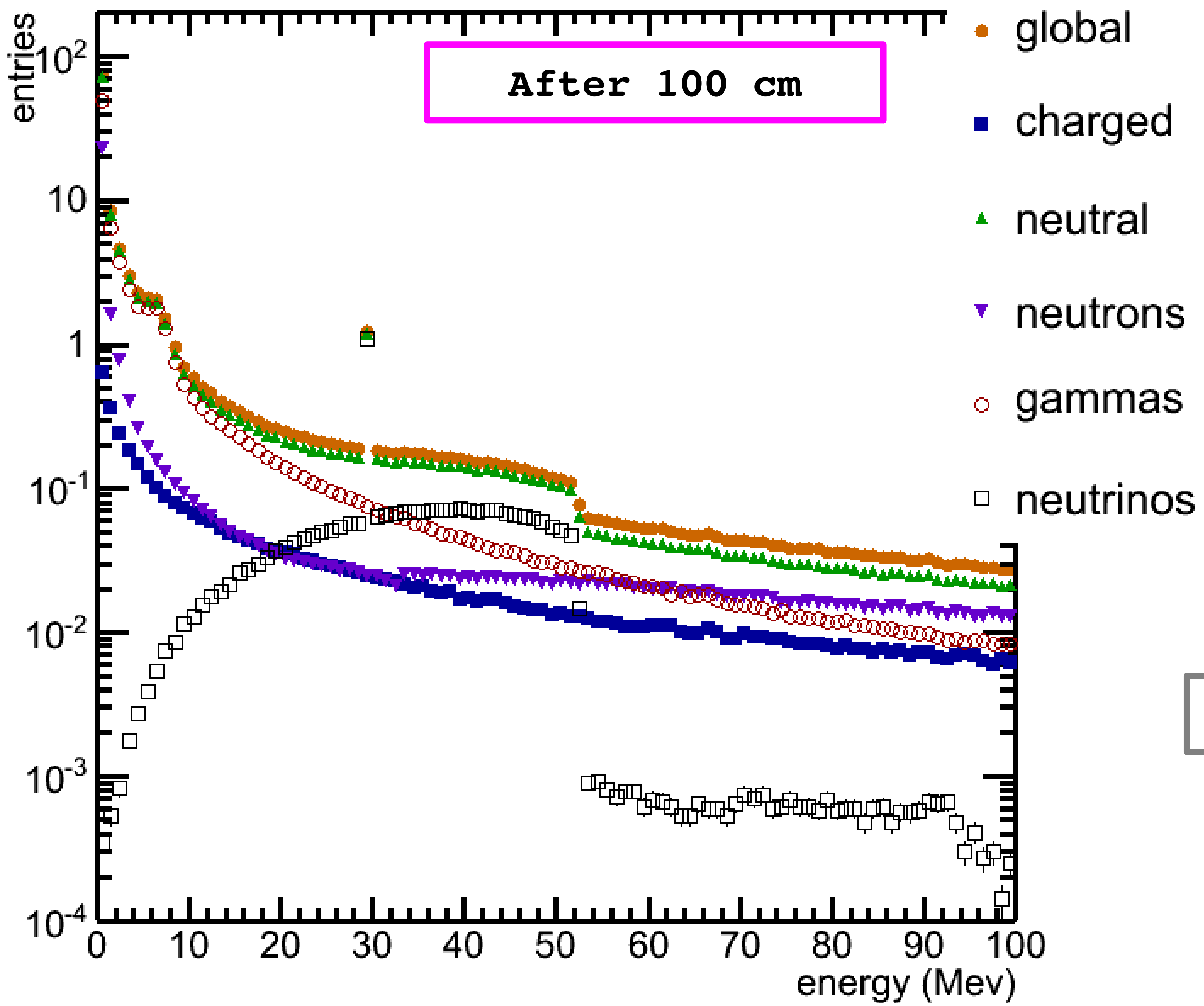

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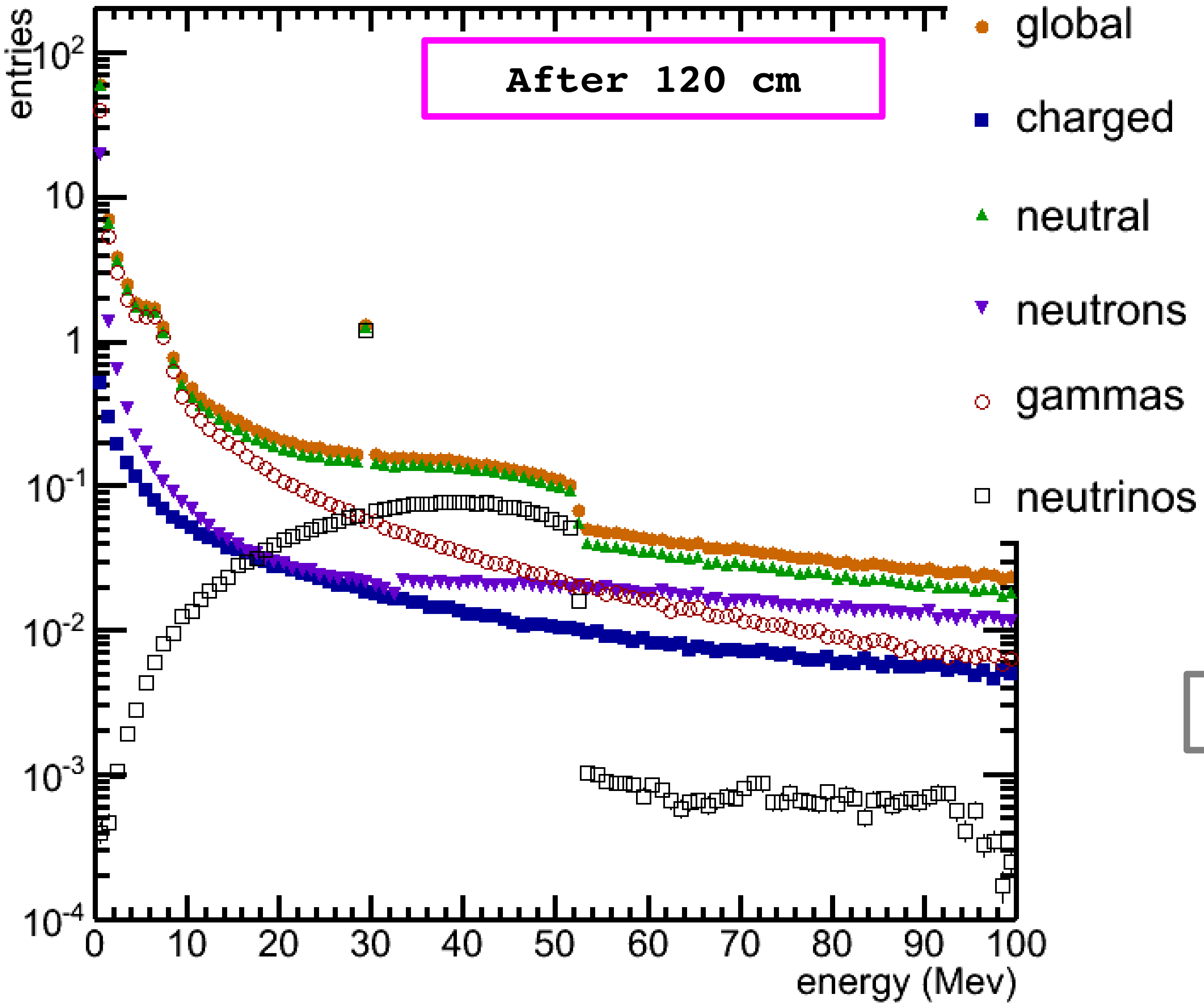

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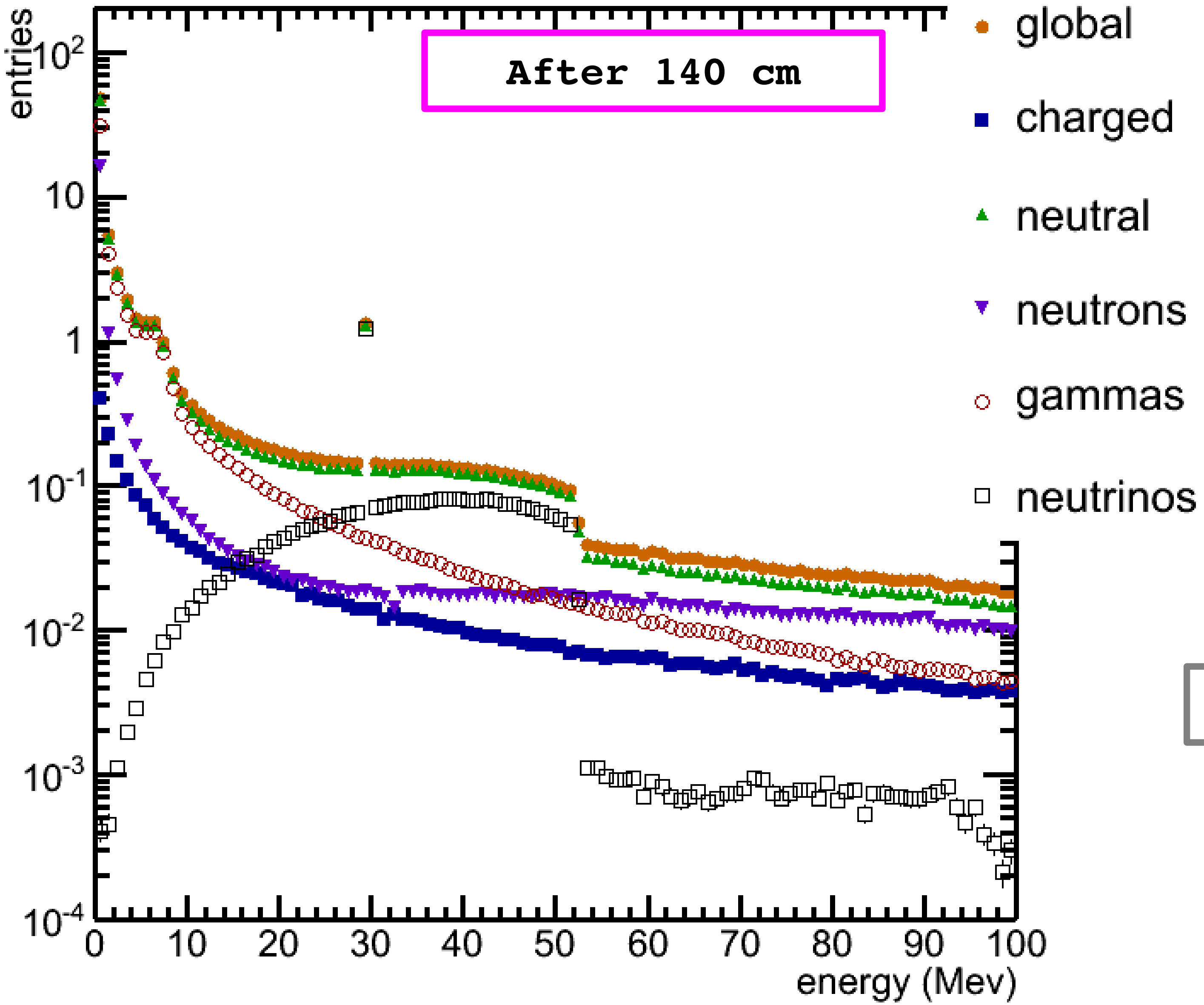

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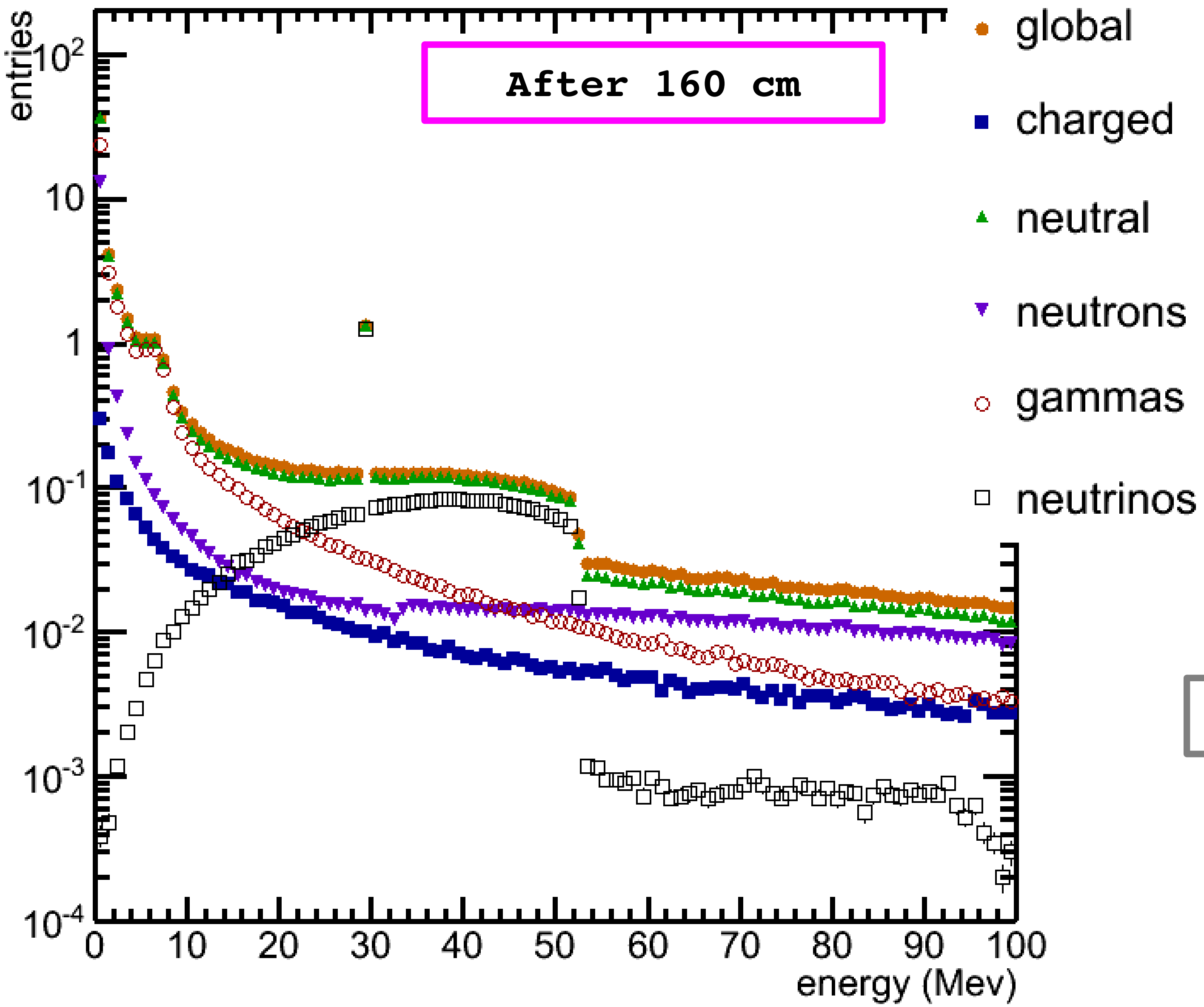

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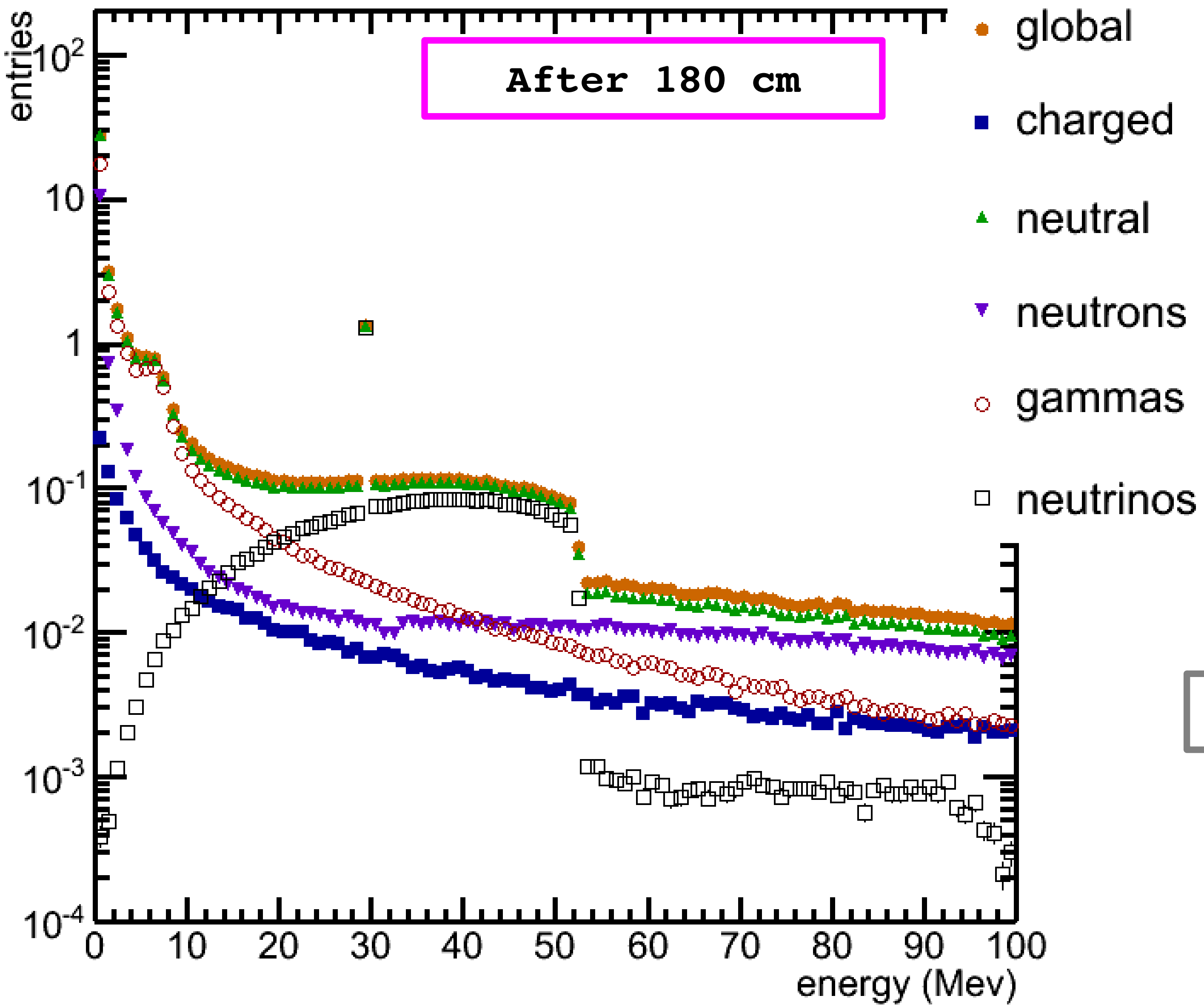

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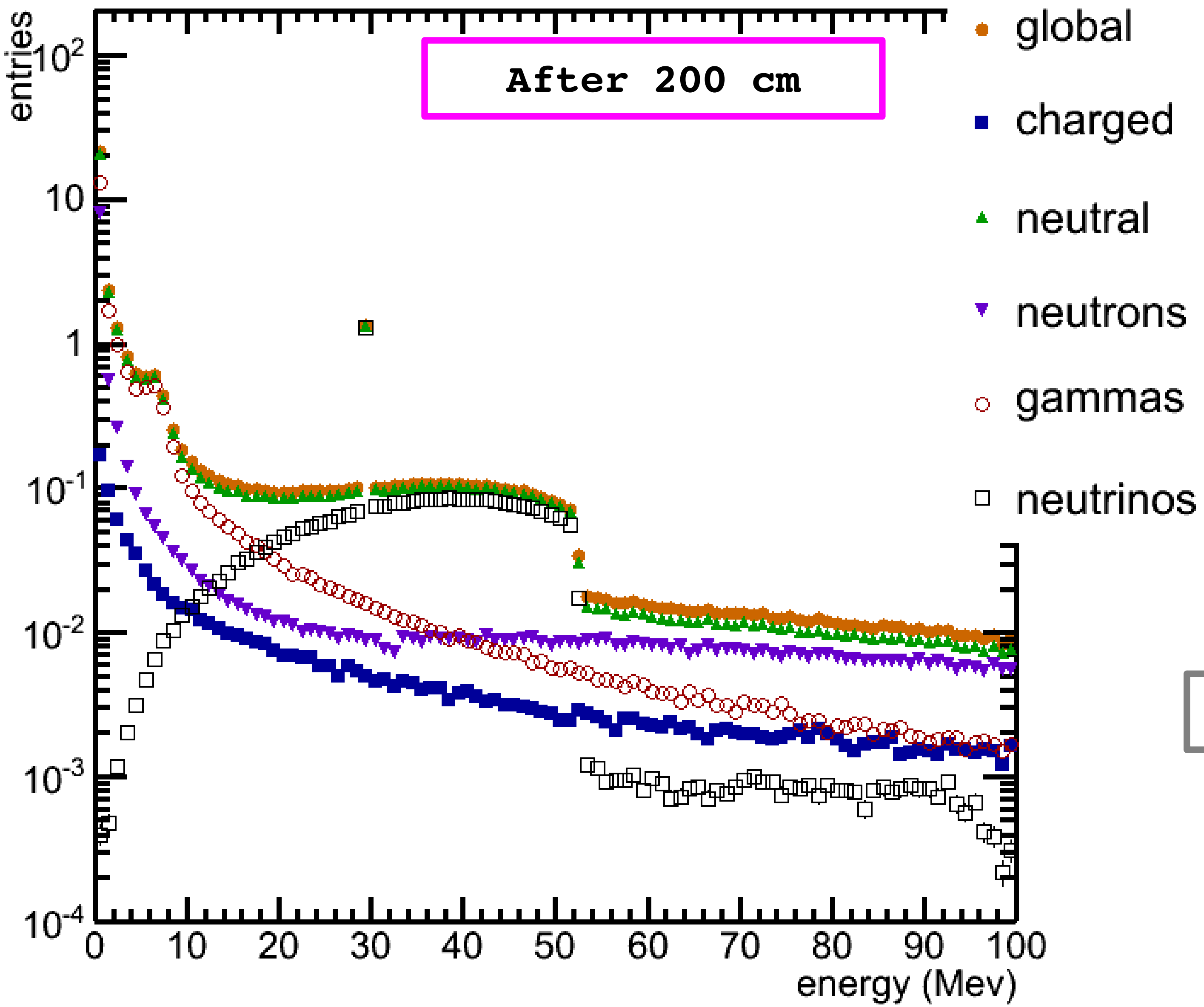

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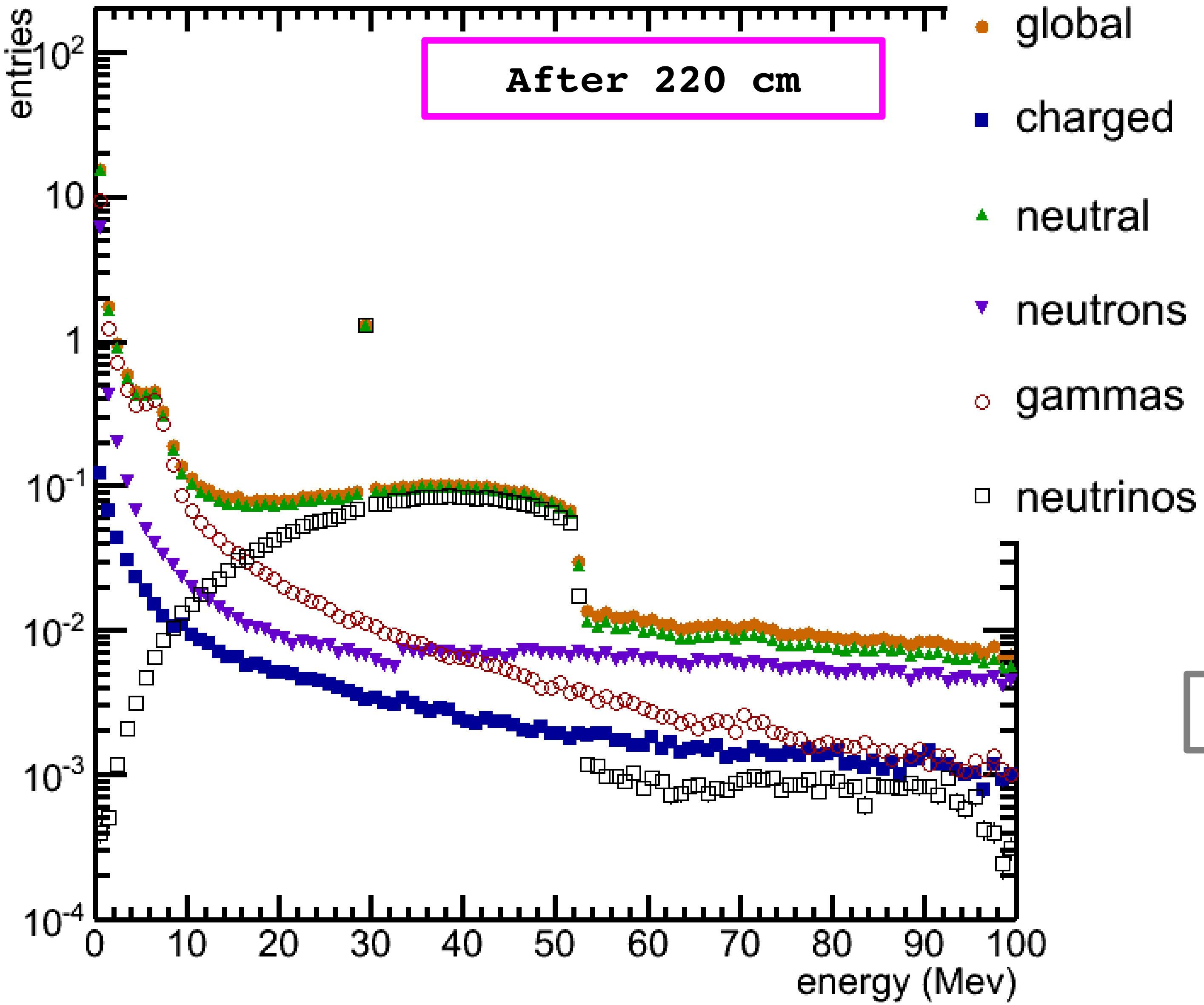

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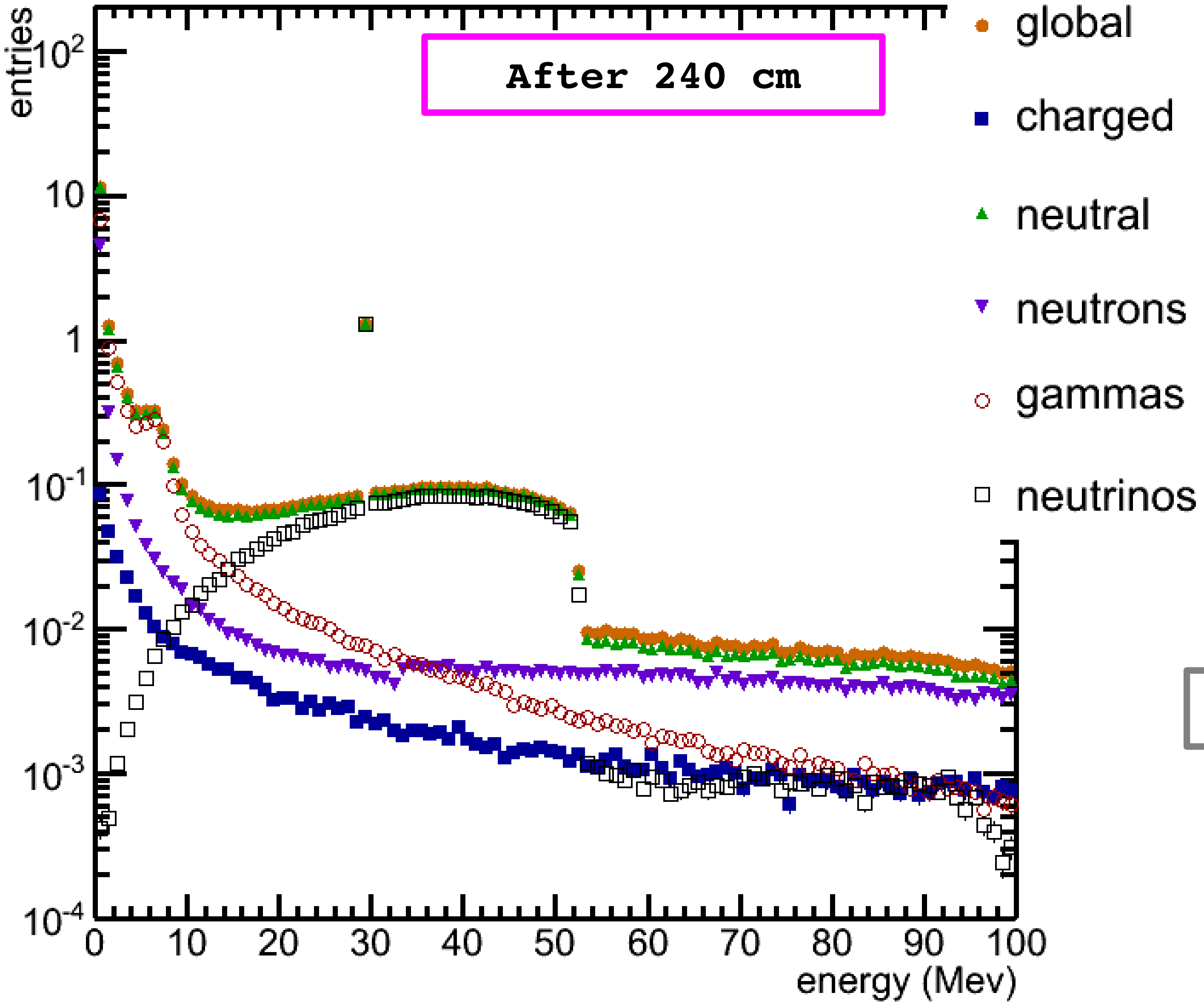

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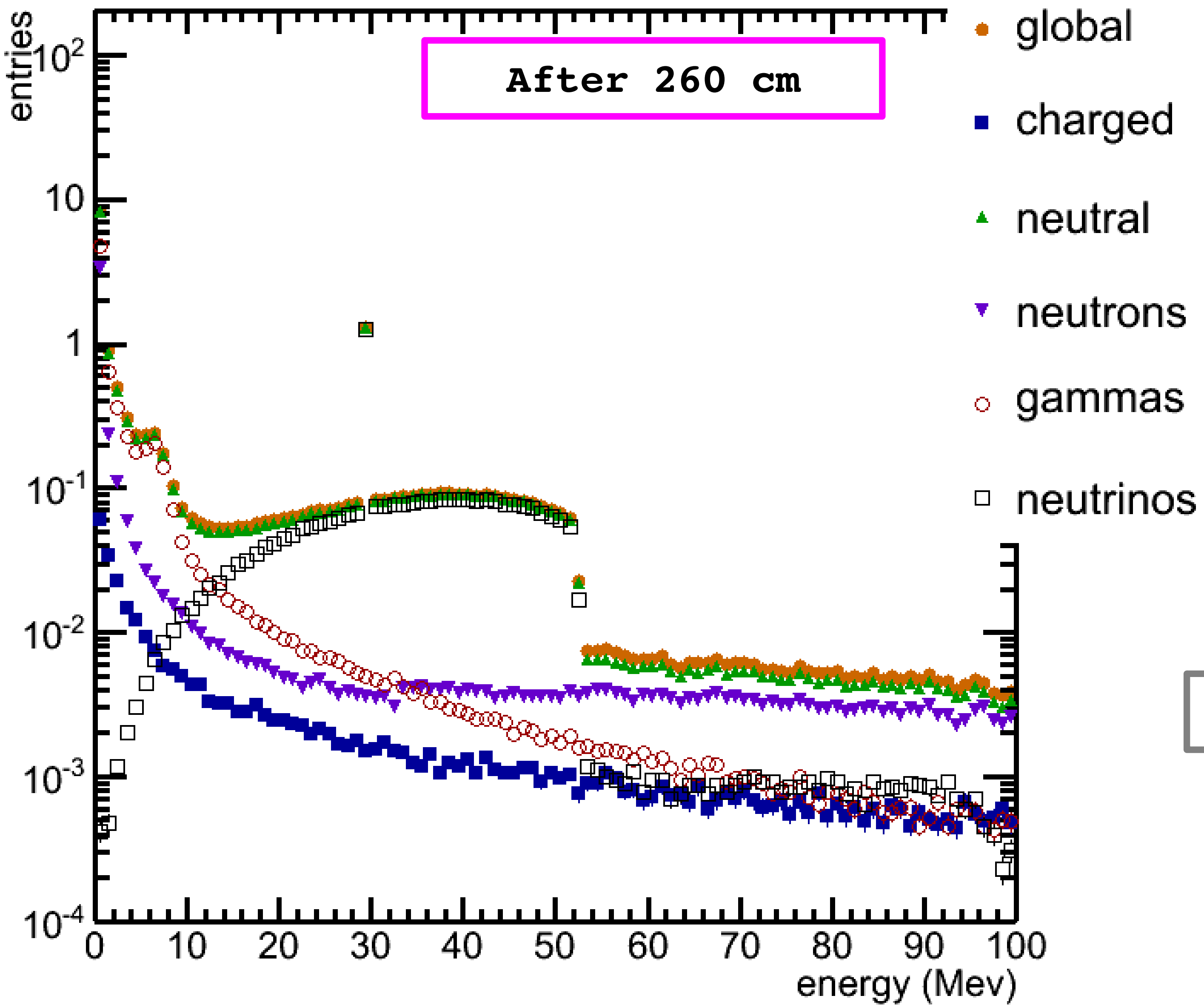

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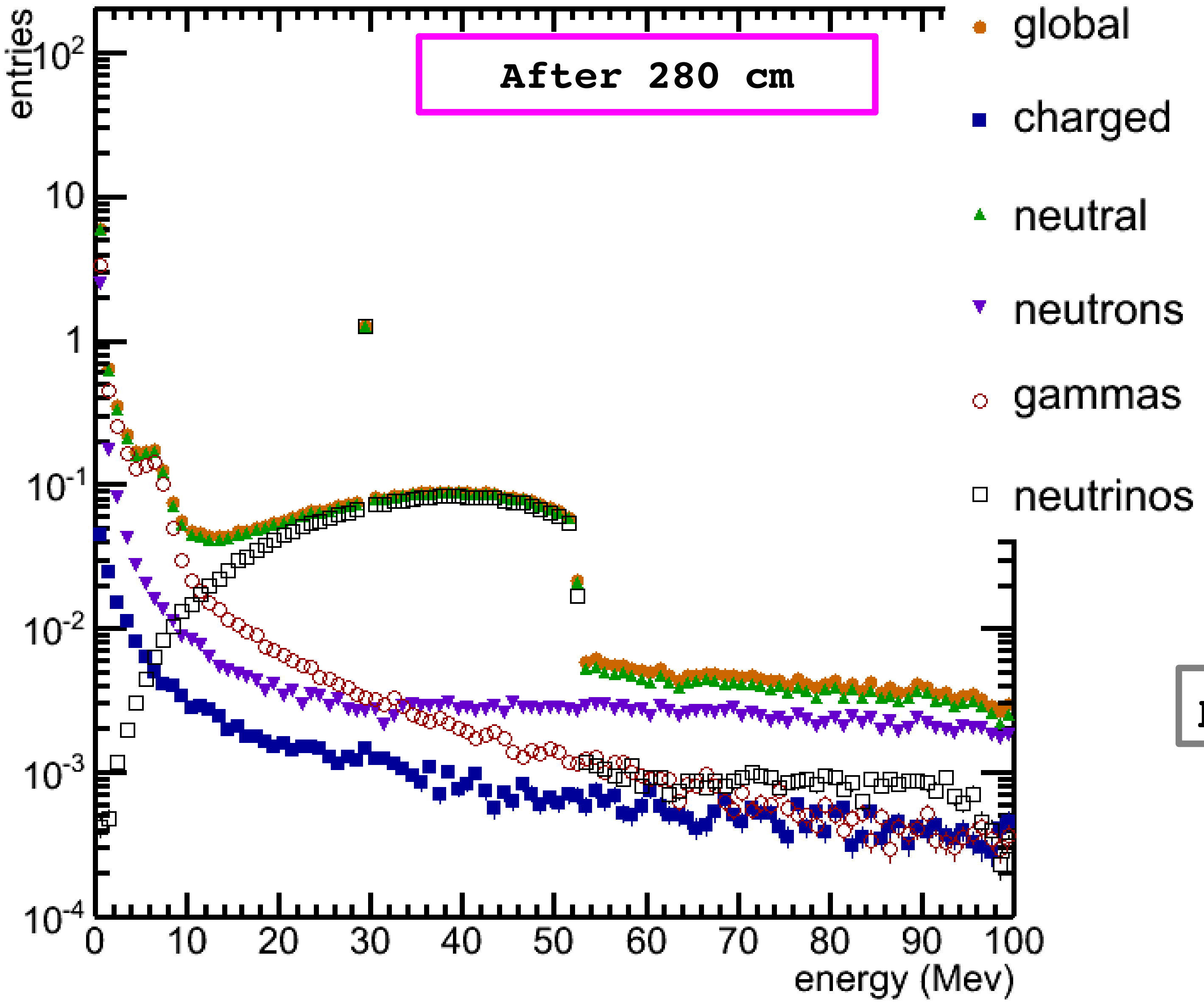

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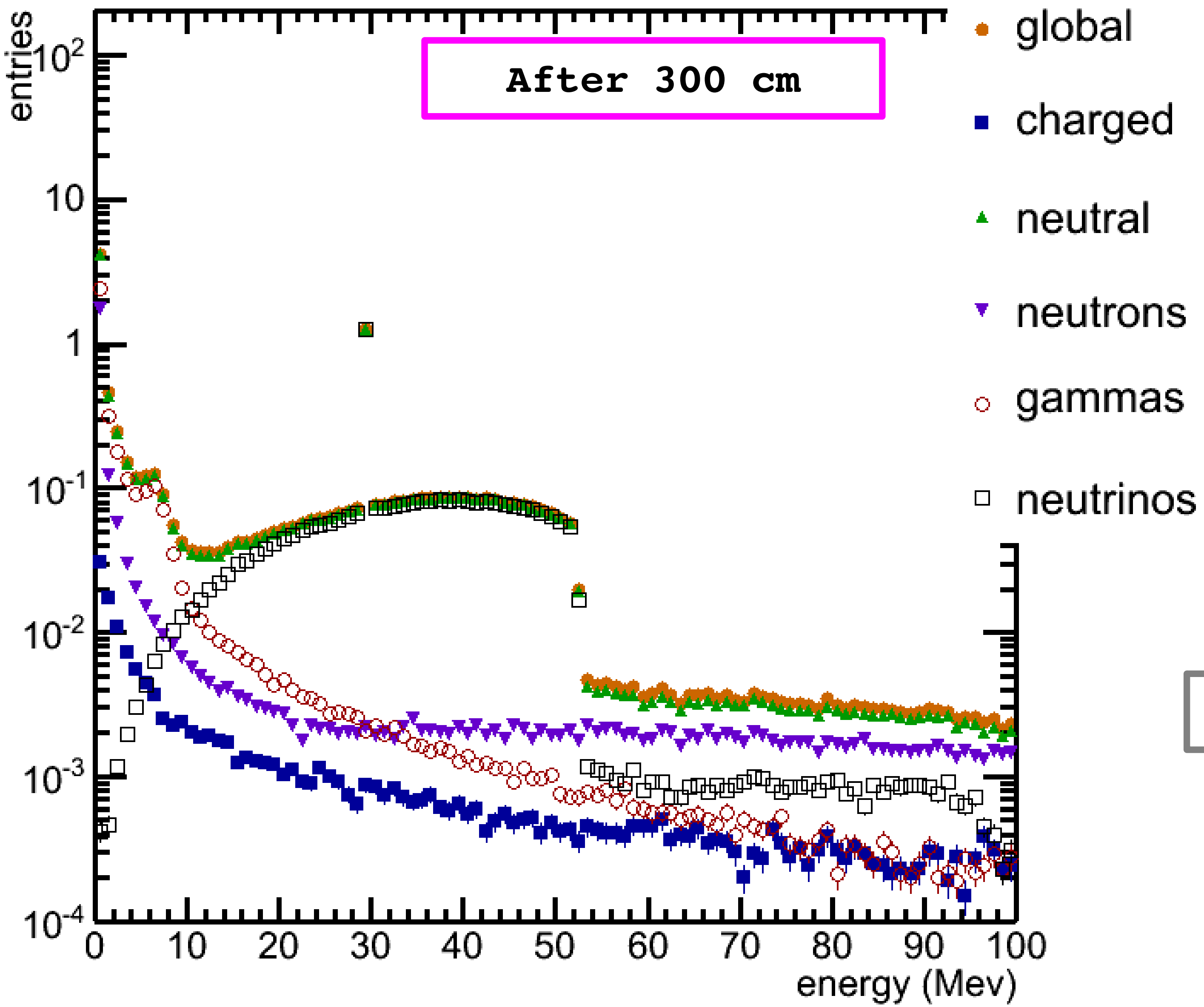

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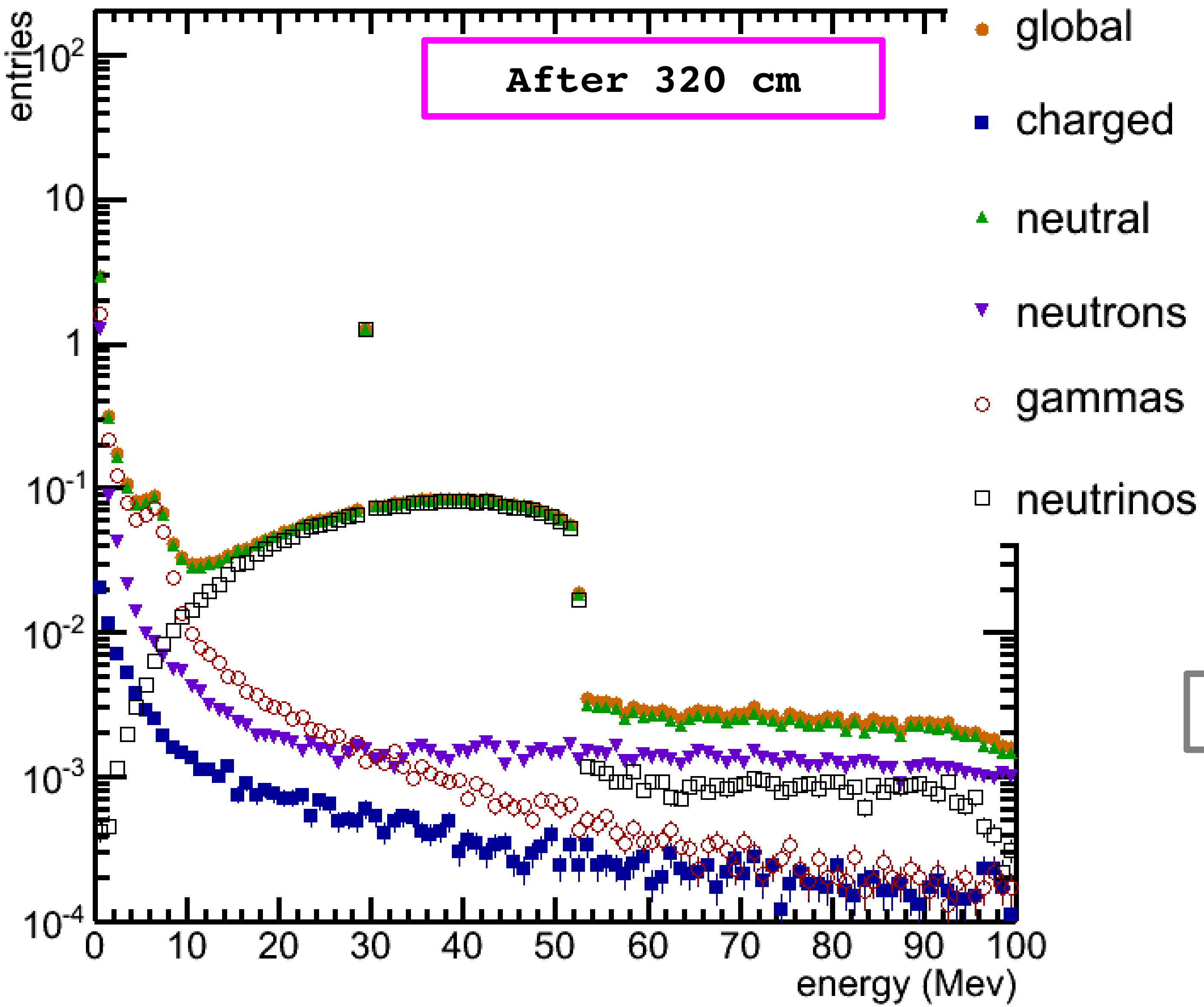

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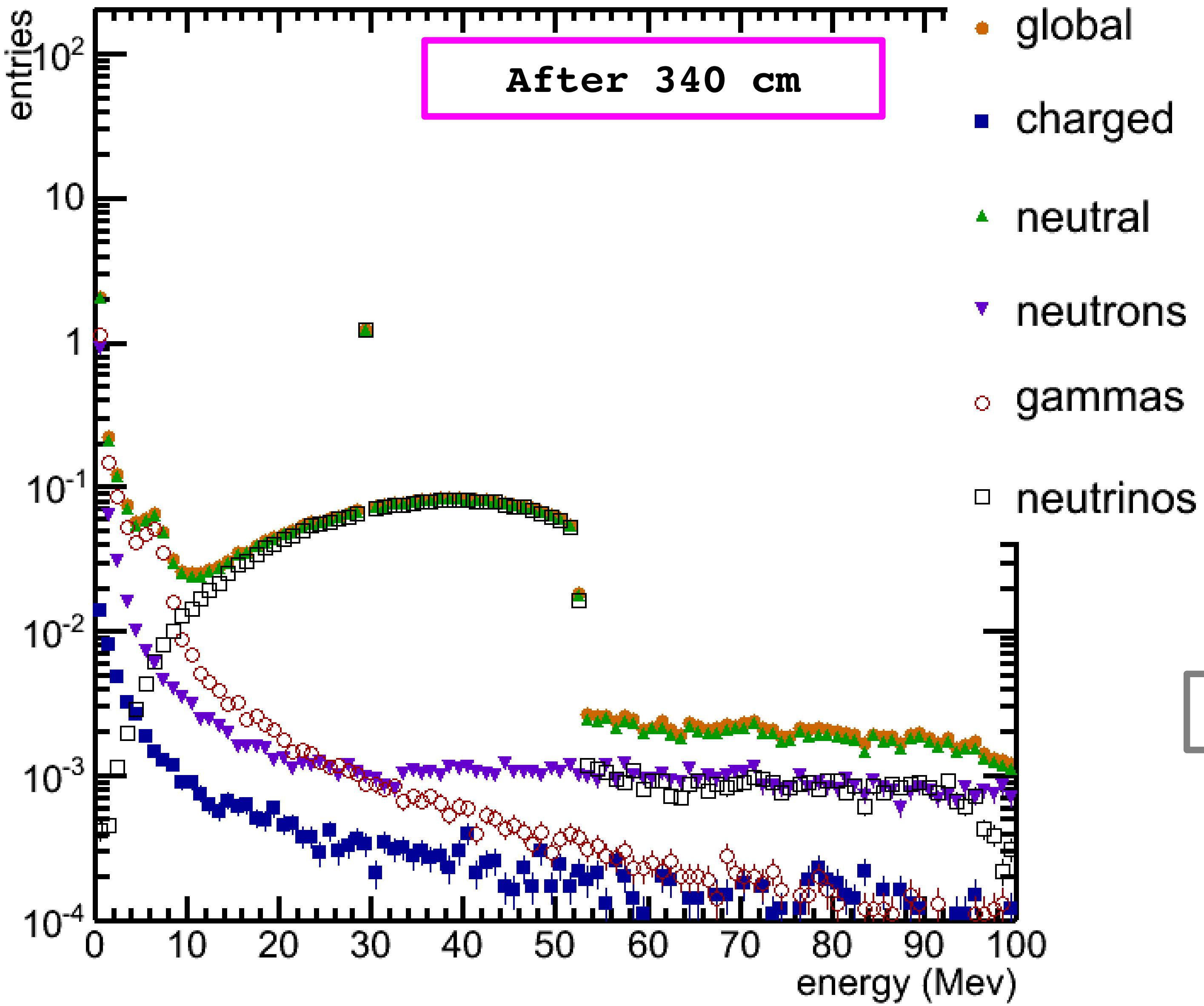

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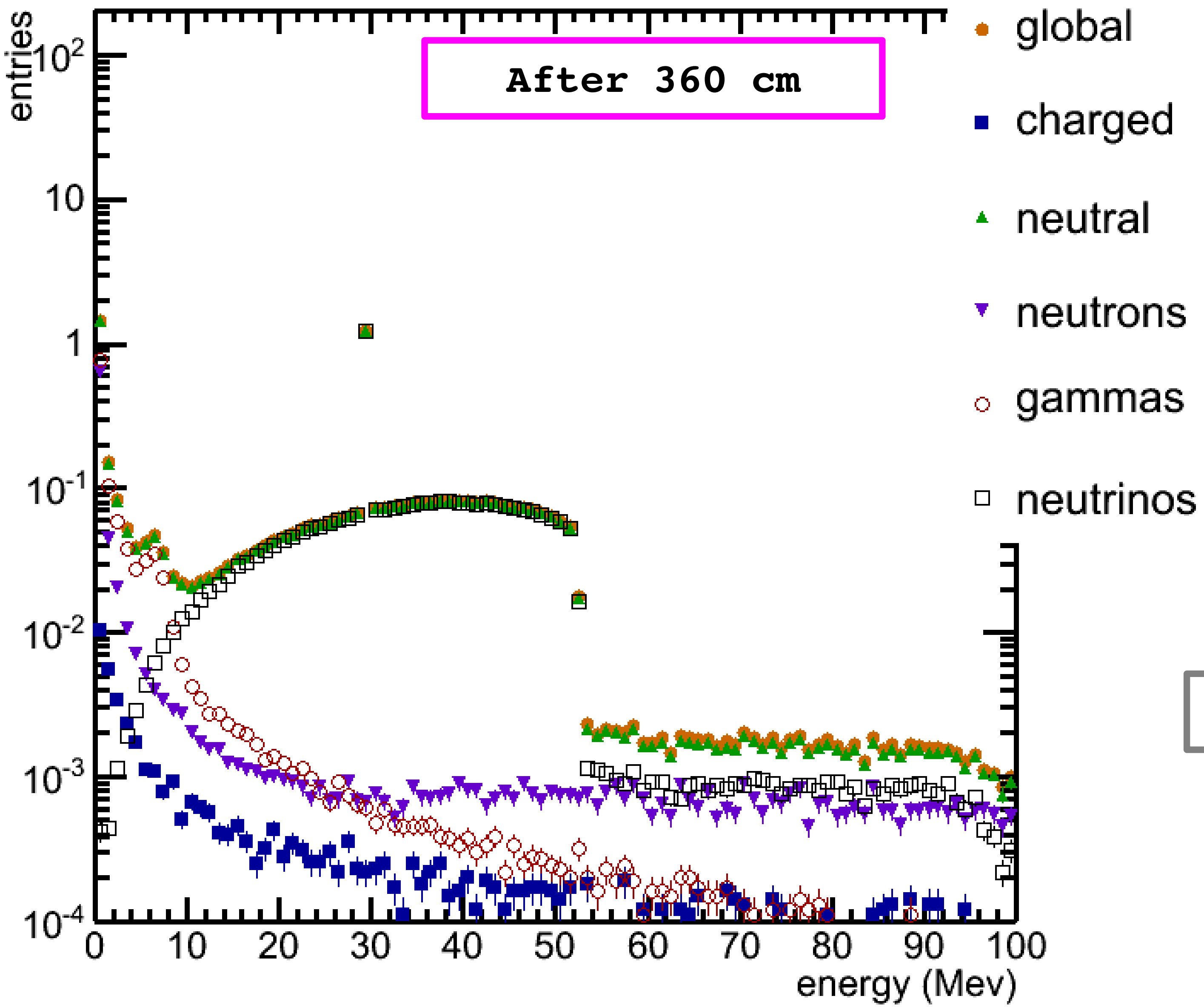

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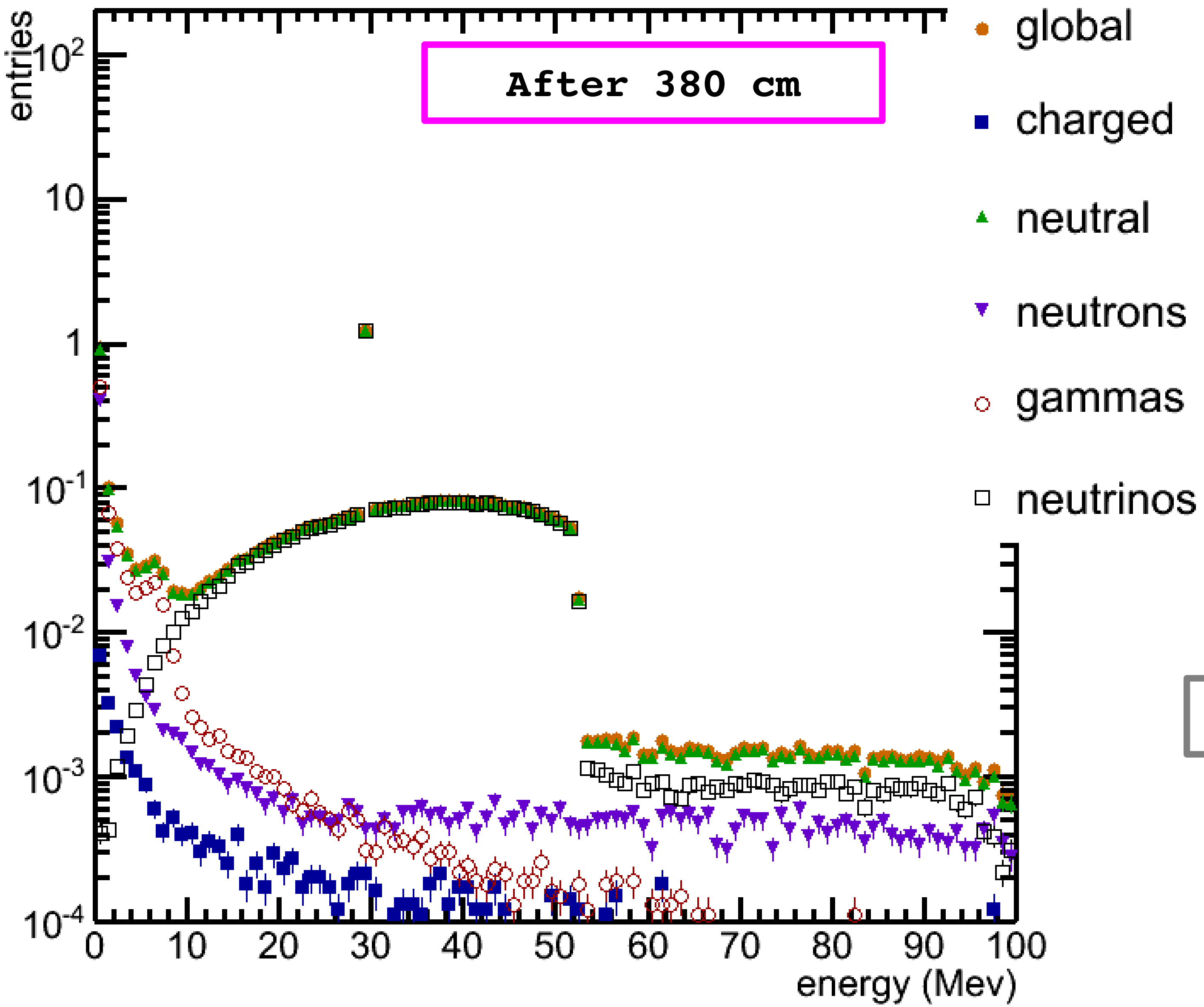

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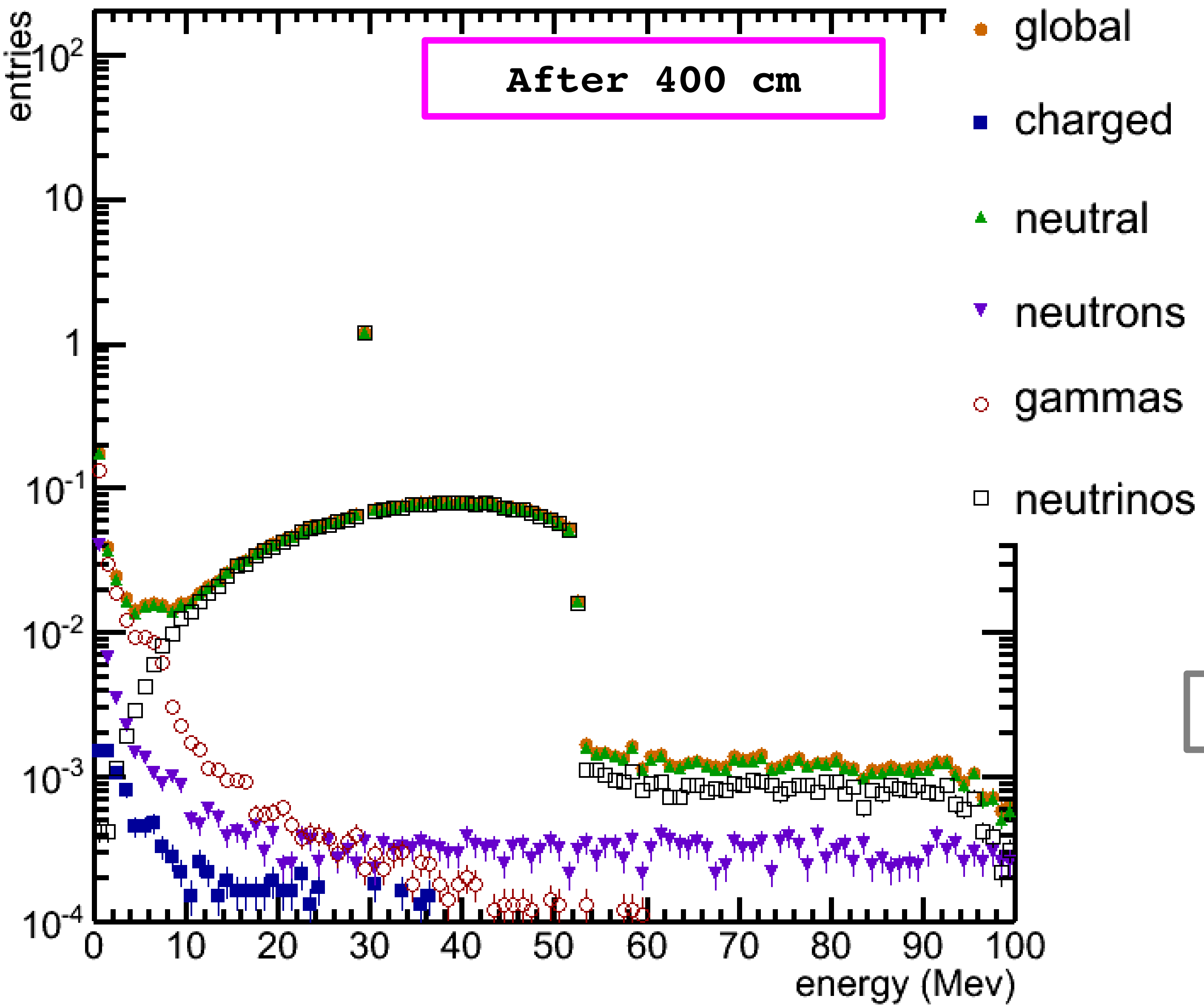

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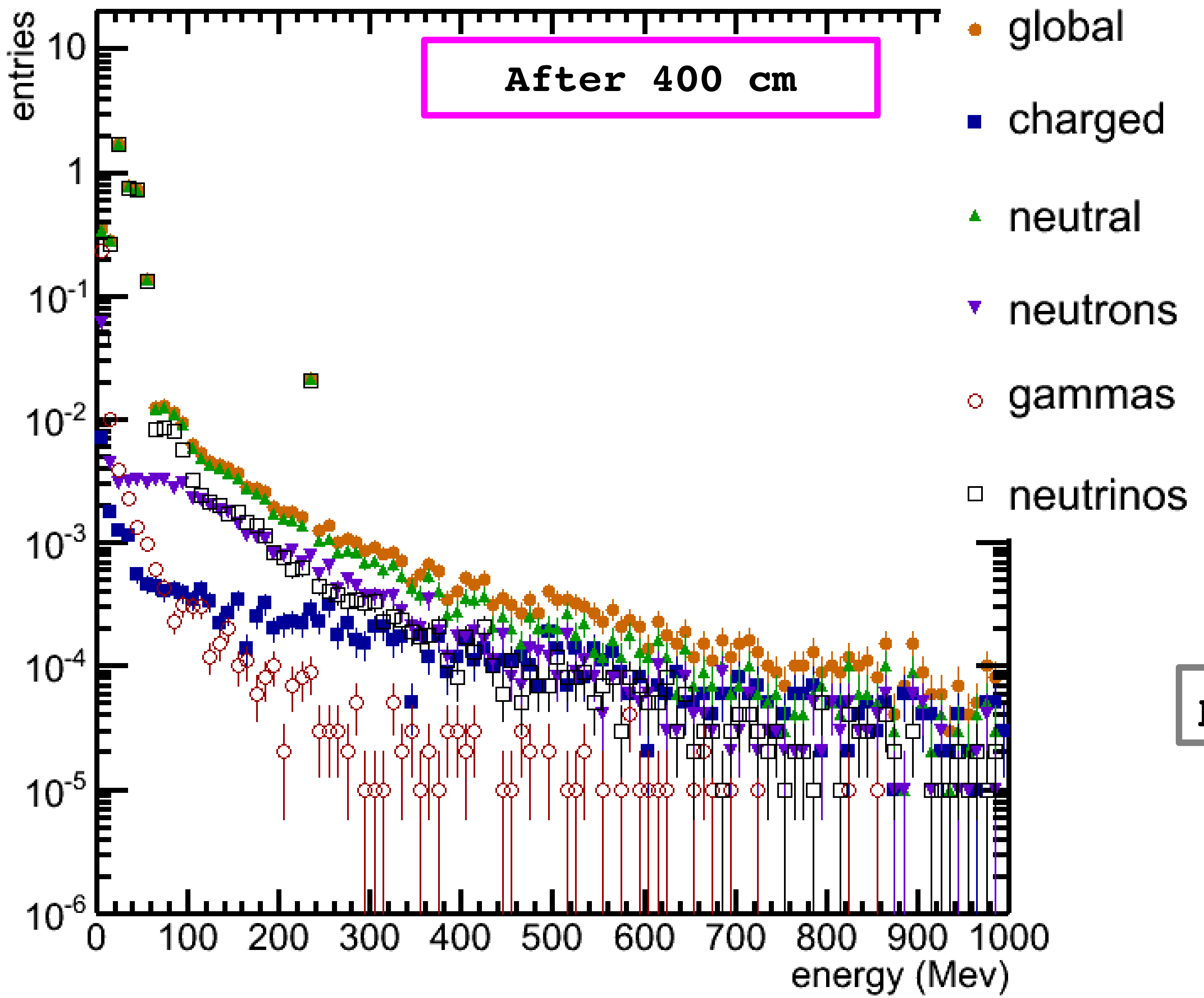

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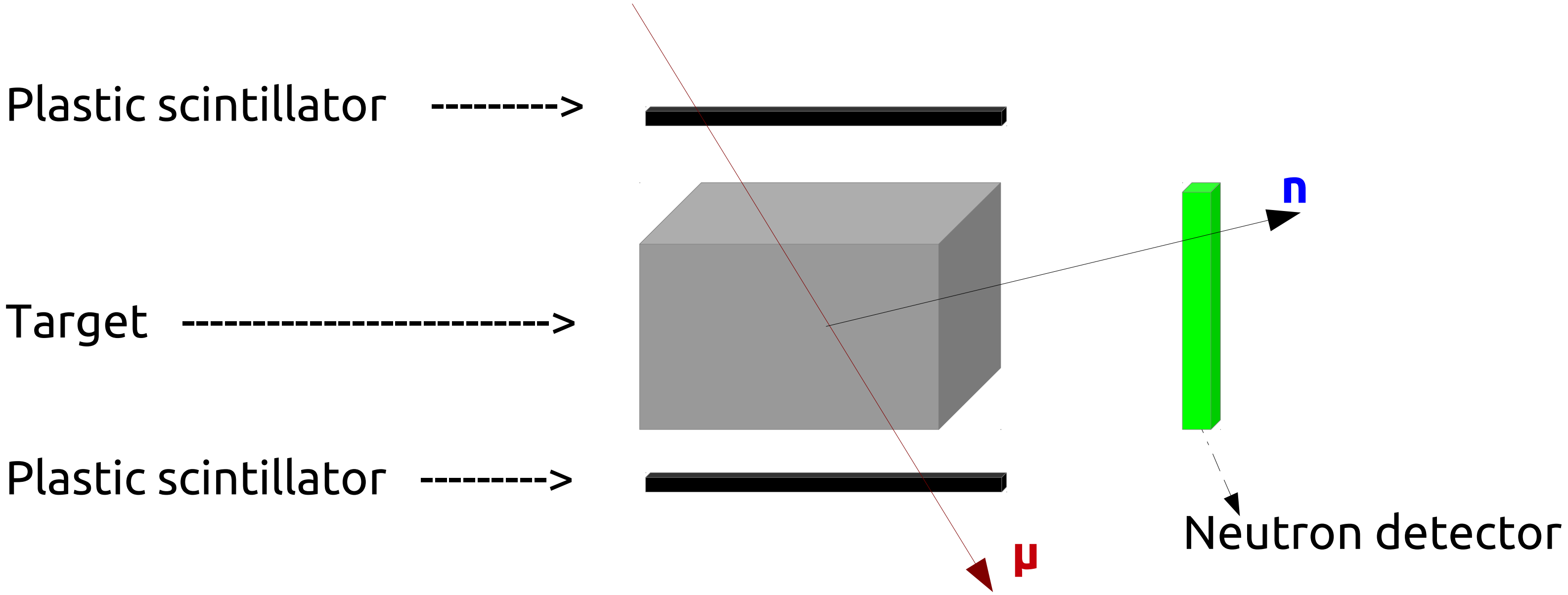
Muon-induced Neutron Flux

A neutron detector from UMD/NIST (USA) will be used to:

- Improve the understanding of muon-induced shower via measuring the neutron flux emanating from:
    - Lead
    - Copper
    - Cryogenics Liquid
    - Rock



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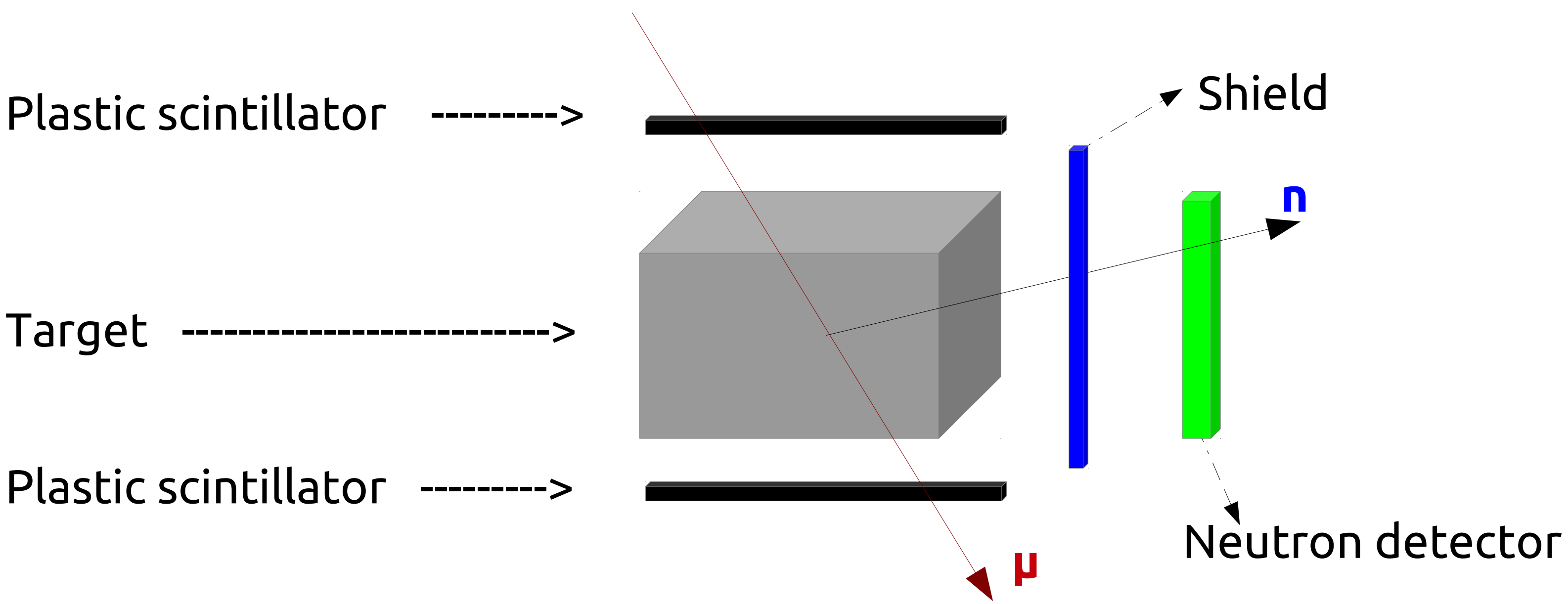
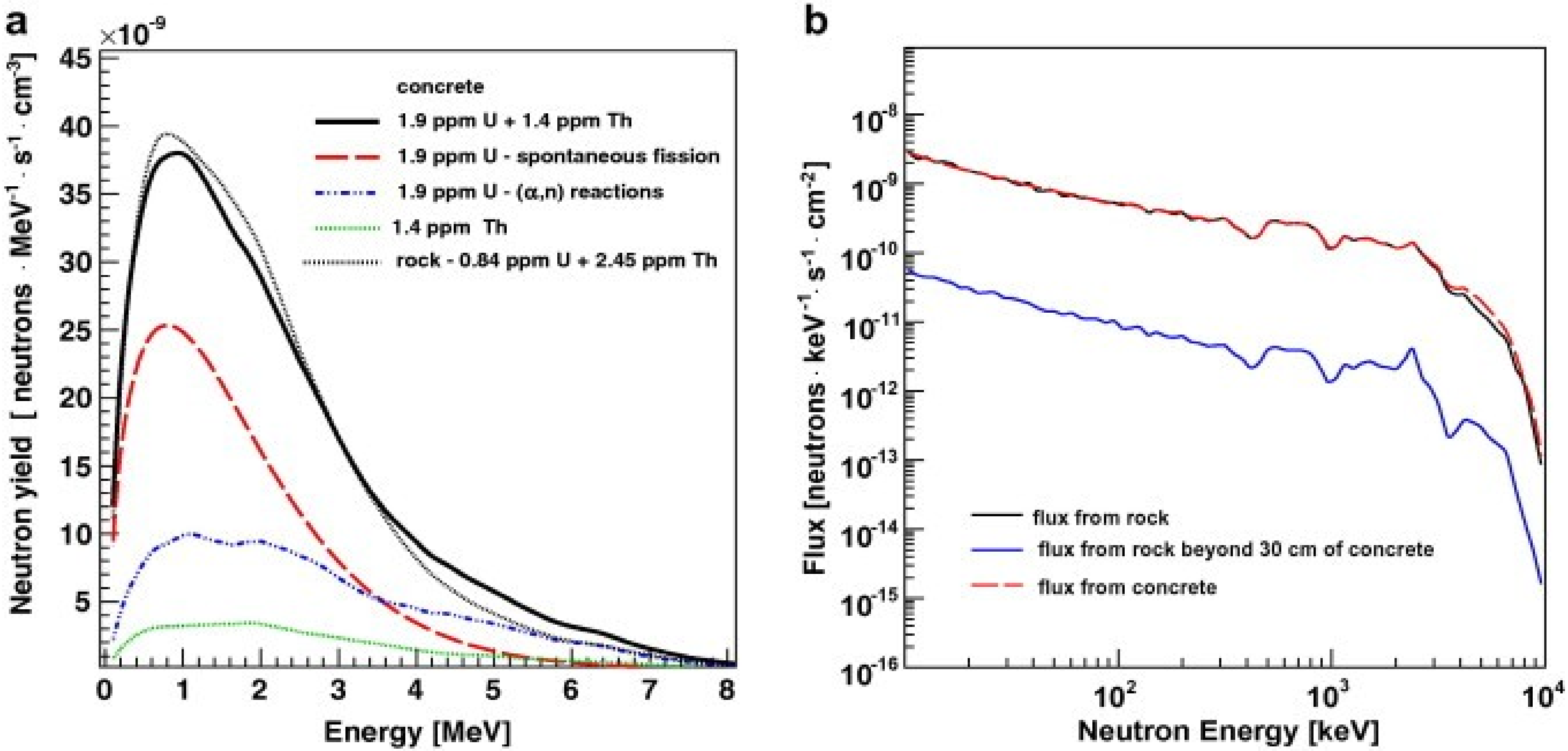
  - Rock
- **Test shielding properties of selected materials**




Thank You for The Attention!

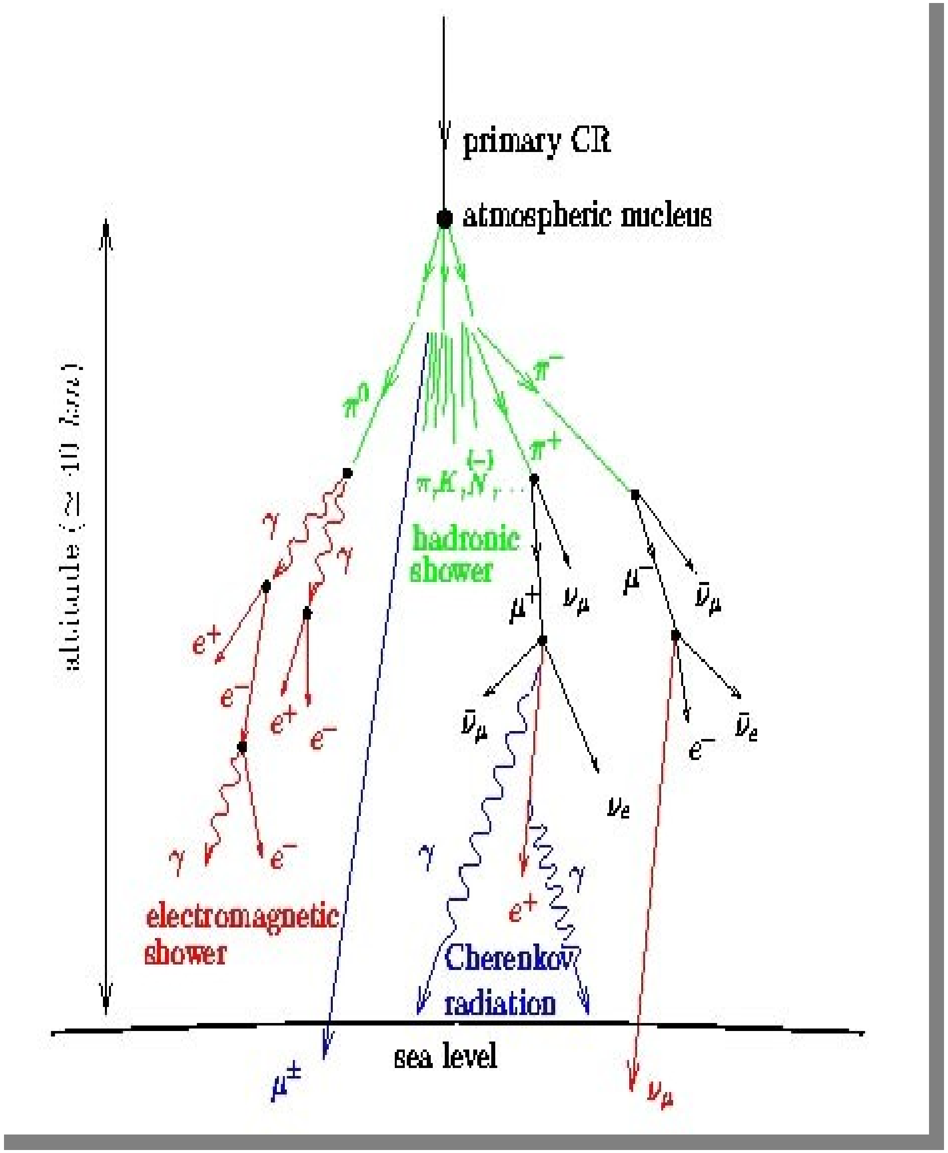
Backup

Environmental Natural Radioactivity

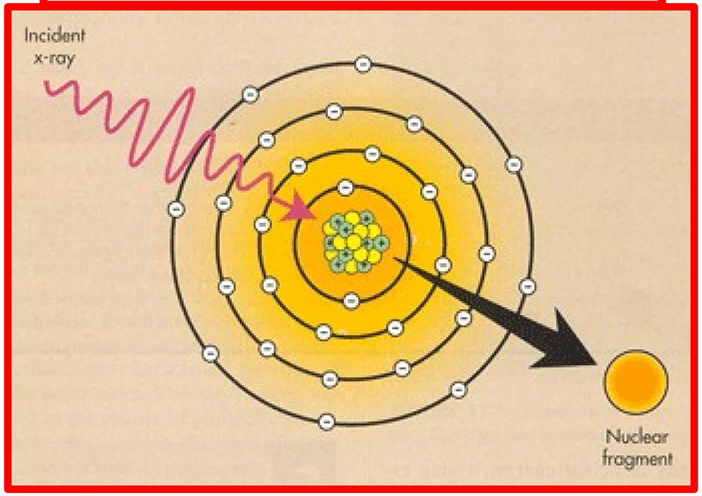


Tomasello et. al., Radioactive background in a cryogenic dark matter experiment, Astro. Phys., Vol 34, 2010

Cosmic Rays Shower



Photodisintegration



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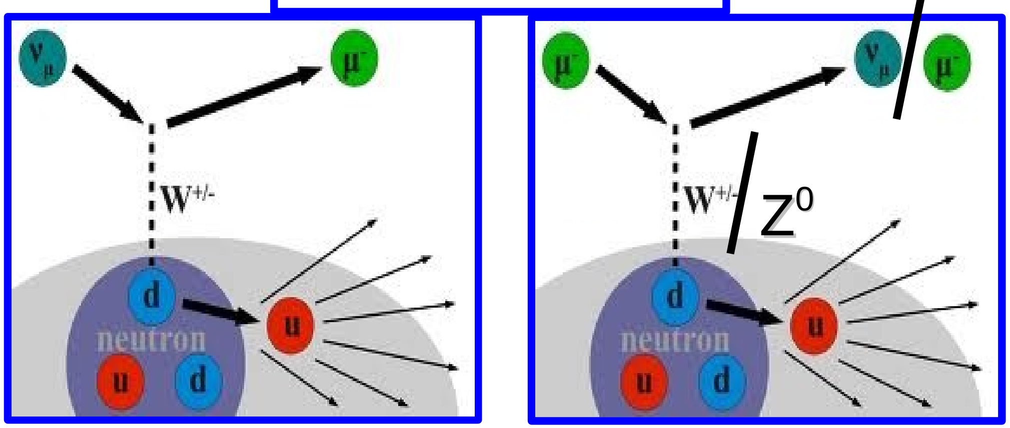
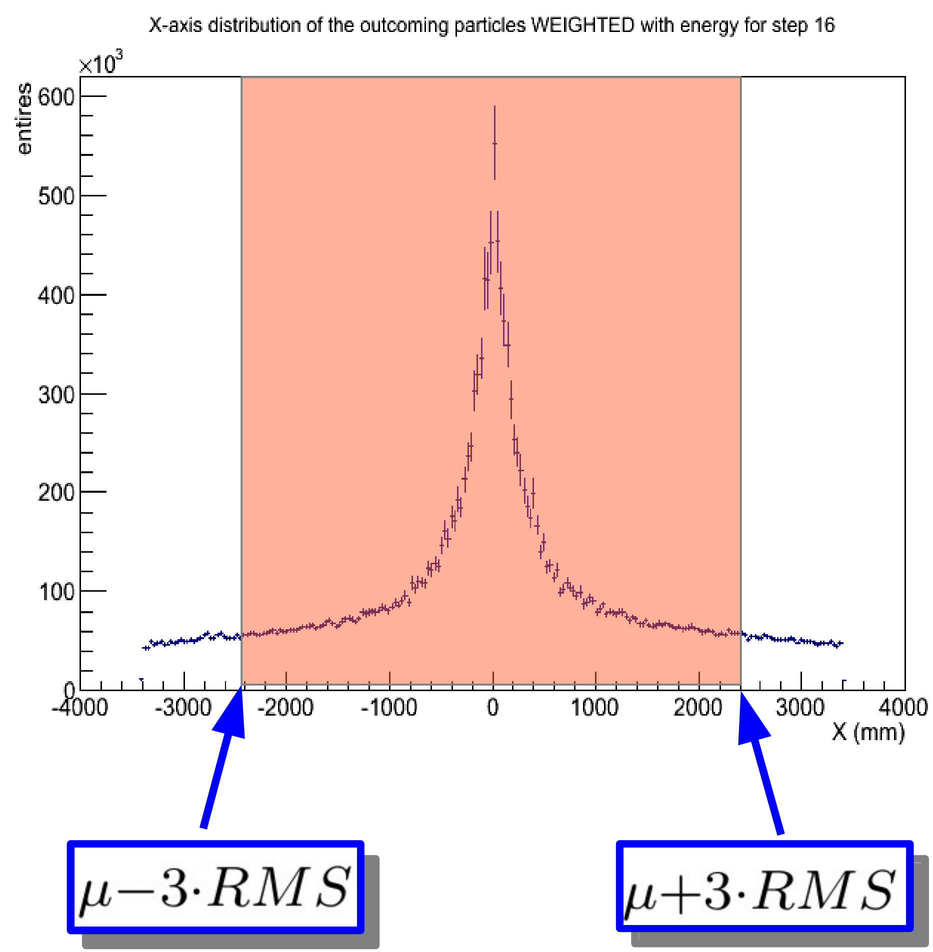


Vertical Distance (1)

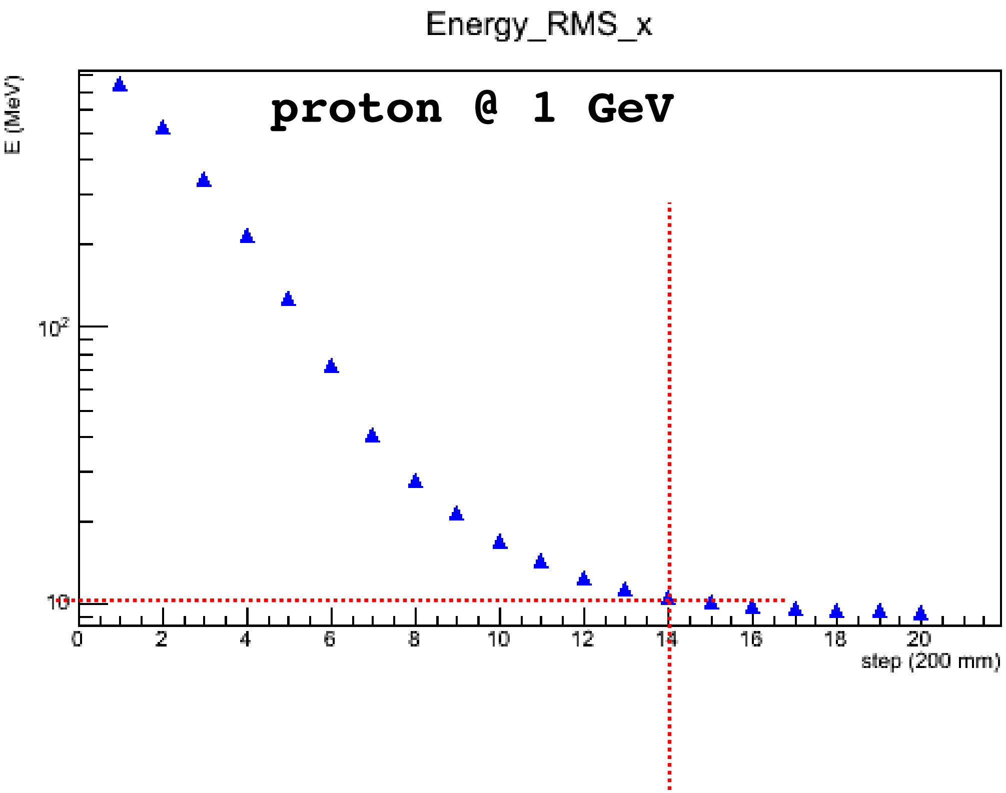
- **For each step:**
  - **Evaluate**

$$E = \int_{\mu-3\cdot RMS}^{\mu+3\cdot RMS} f(x, E)\, dx$$



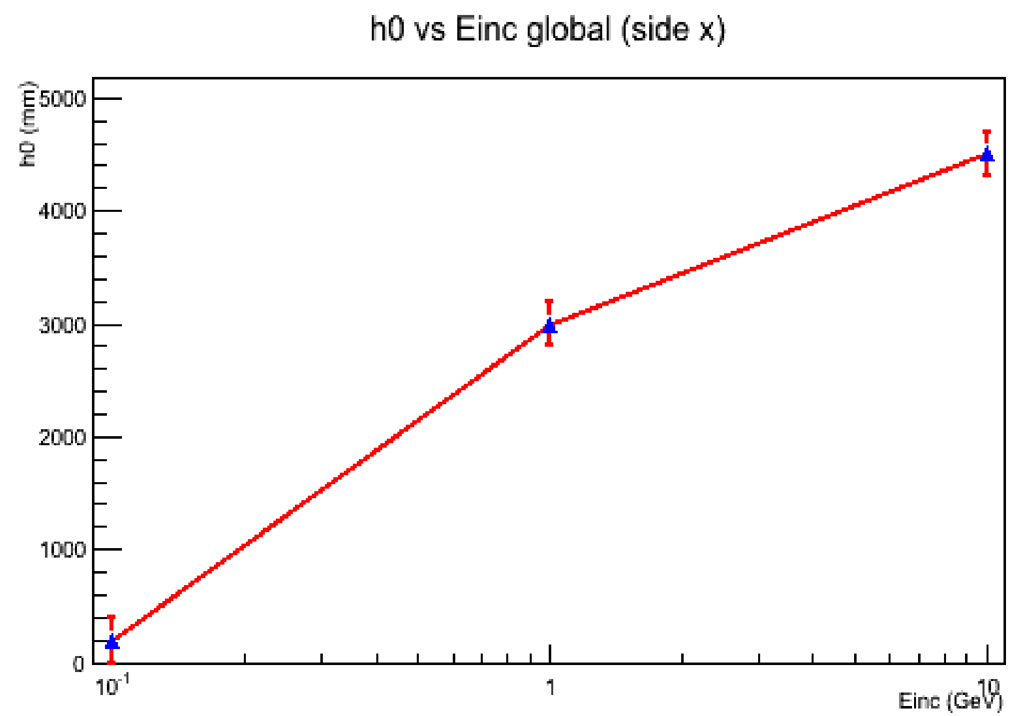
- **Then use this quantity to infer the safety vertical distances**

Vertical Distance (2)



- h_{safe} @ 10 MeV Threshold

h_{safe} for 3 different incoming particle energies



Horizontal Distance (1)

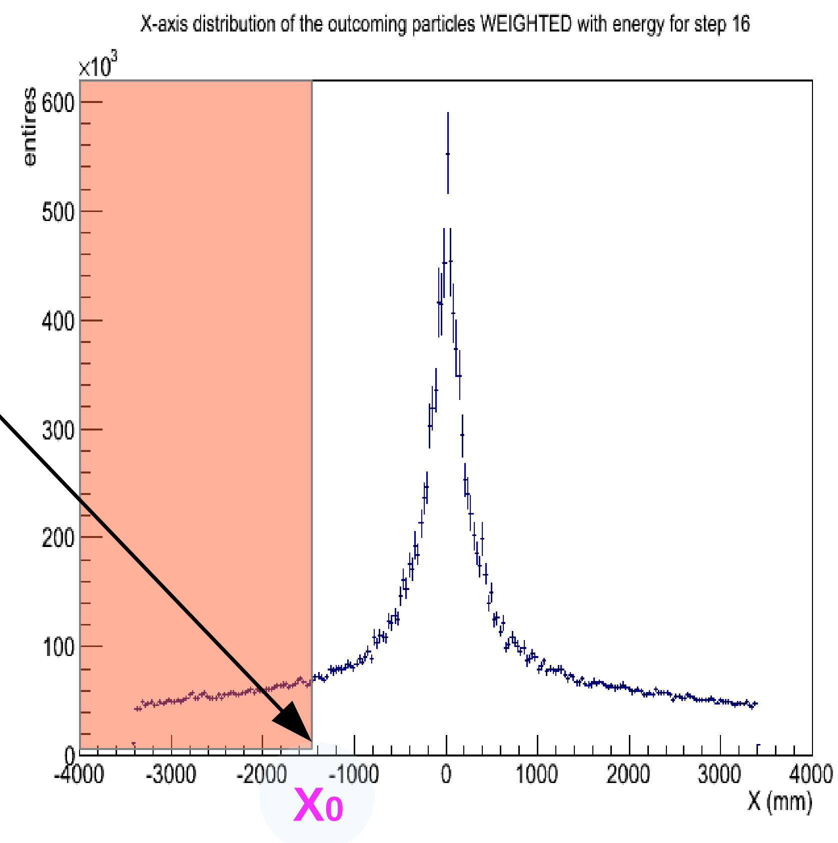
- **For each step:**
  - **Search the point X_0 so that:**

$$\int_{-\infty}^{X_0} f(x,E)\,dx \leq \text{Threshold}$$

  - **The safety horizontal distance is defined as:**

$$D_{side} = |\mu - X_0|$$

  - **Then take the maximum wrt the depth**

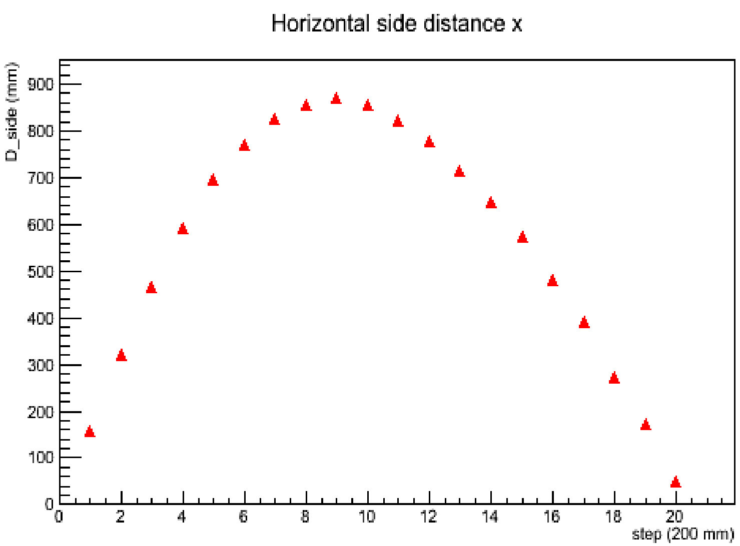


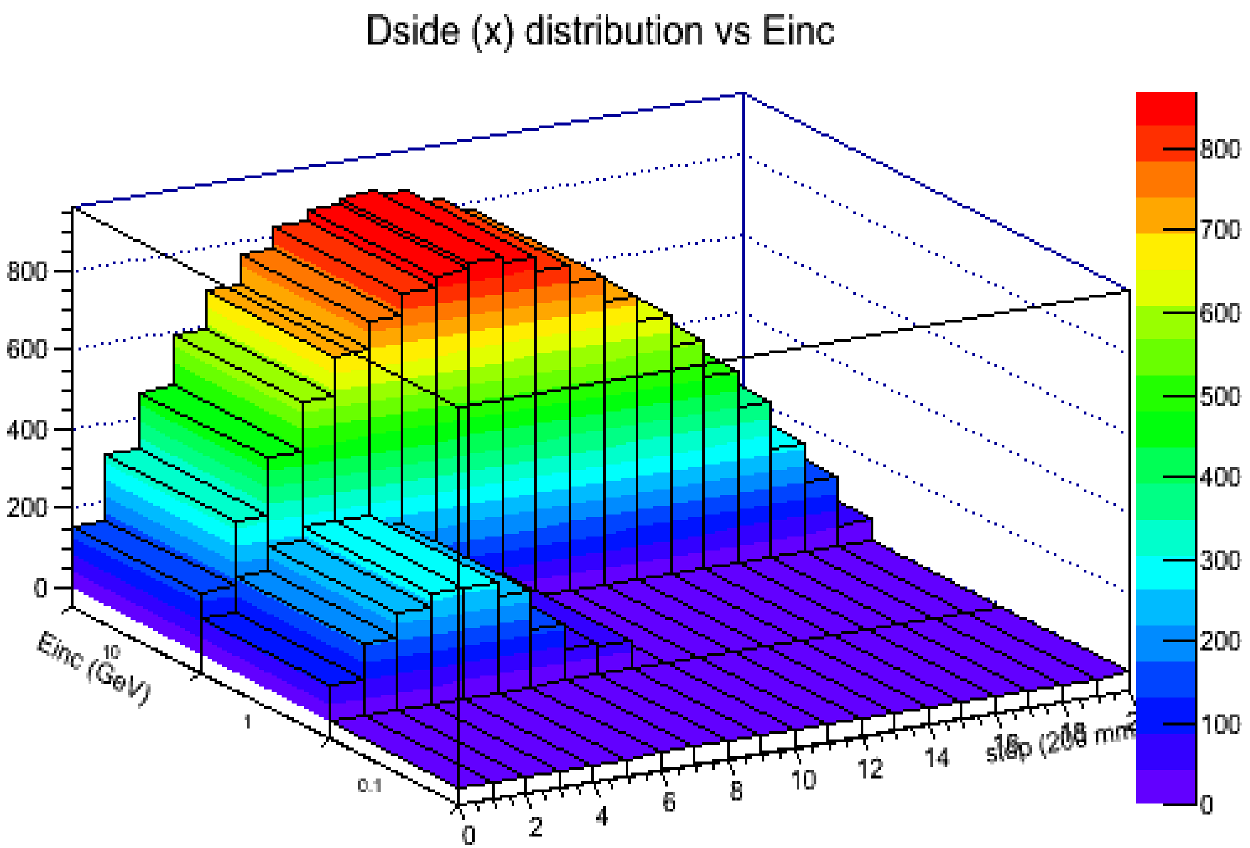
Horizontal Distance (2)

- D_{side} @ 10 MeV Threshold

Overall components

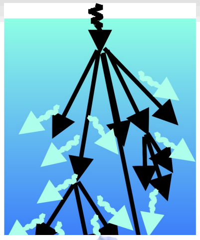
proton @ 10 GeV



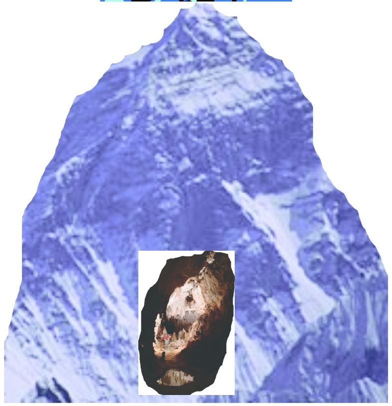


The Problem

- **Low Background Experiments:** very low expected rate (e.g. $0\nu2\beta$ decay rate 0.1 counts/(keV Kg y))

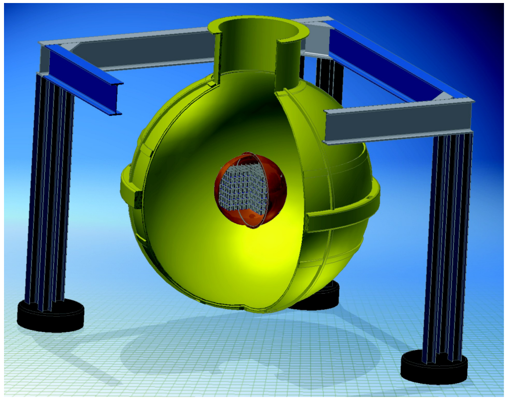


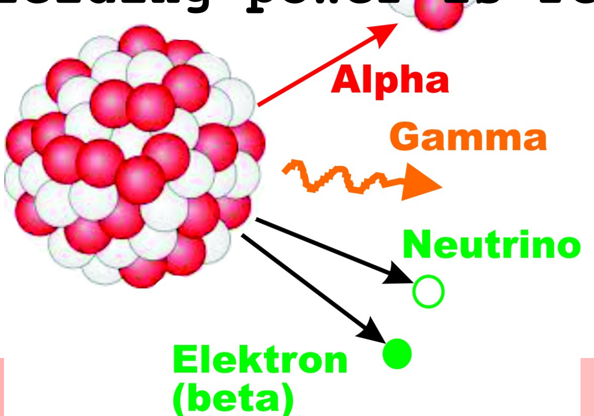
- To enhance the expected counting rate:
  - Increase the mass → 1 Ton experiments
  - Increase the S/N ratio → Move underground



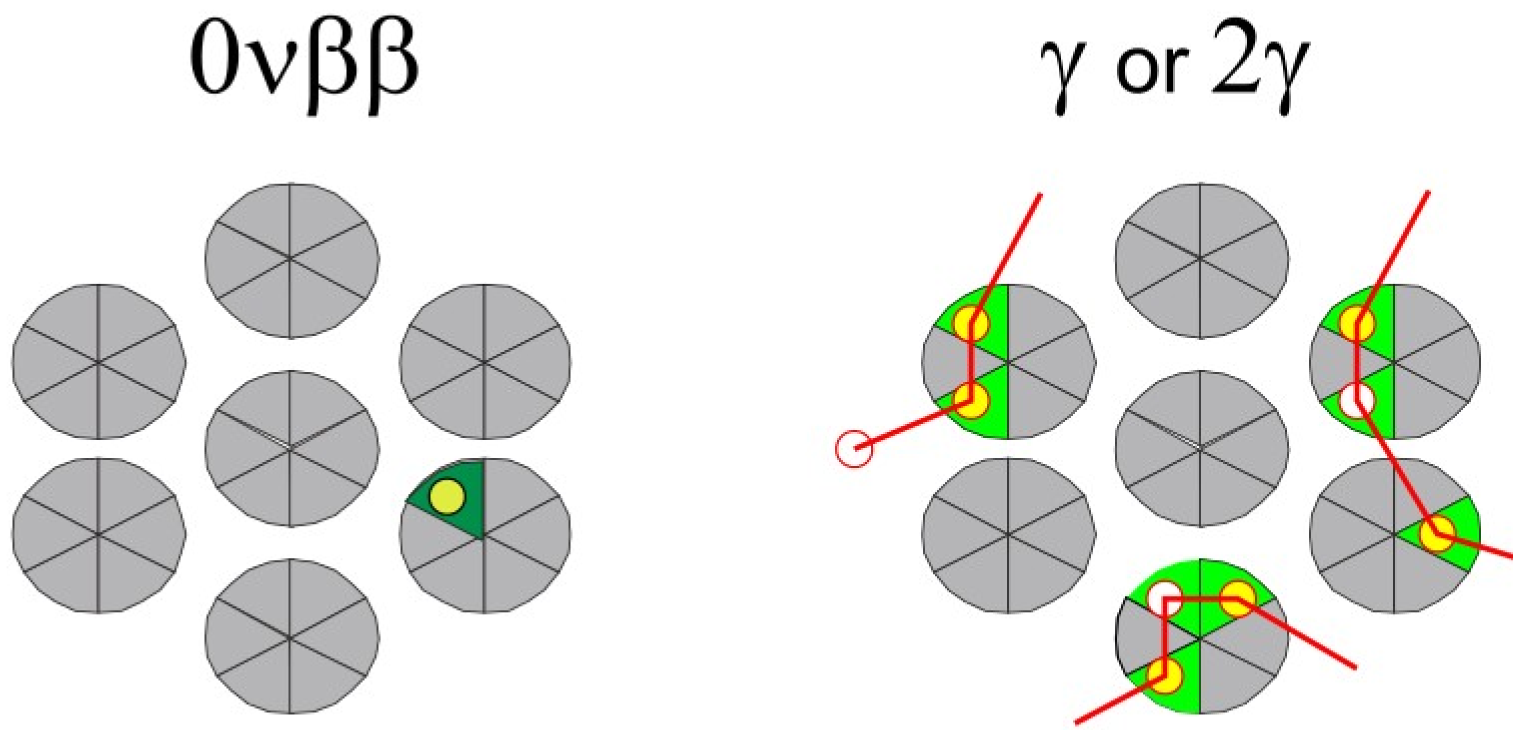
- Also an **effective shielding** is needed against:
  - Environmental Natural Radioactivity
  - CR-induced shower (basically muon and neutrino-induced)

- **Two different components:**
  - Charged → easy to veto
  - Neutral → high shielding power is required





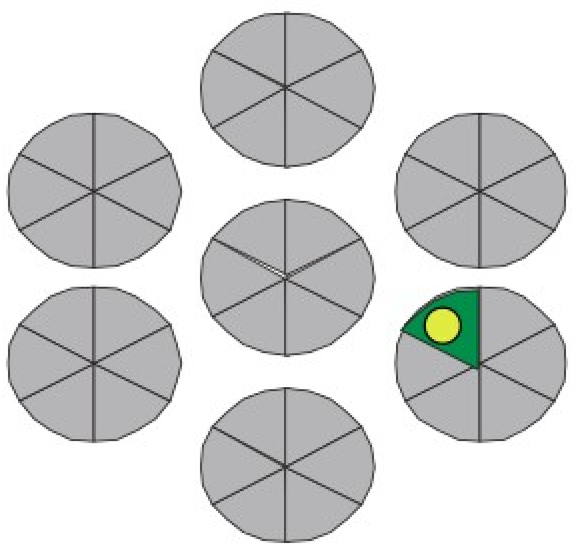
Background events

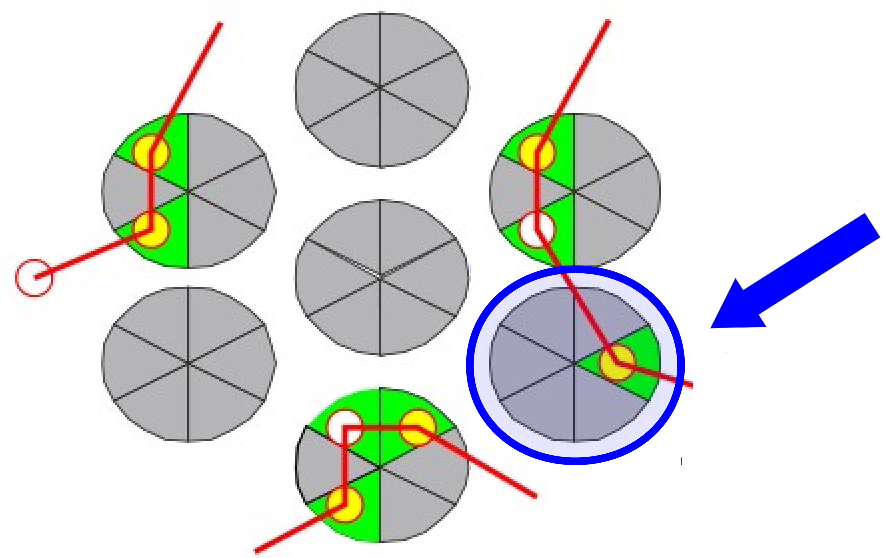


localized deposit
single site event

several deposits
multi site event

$0\nu\beta\beta$ γ or 2γ

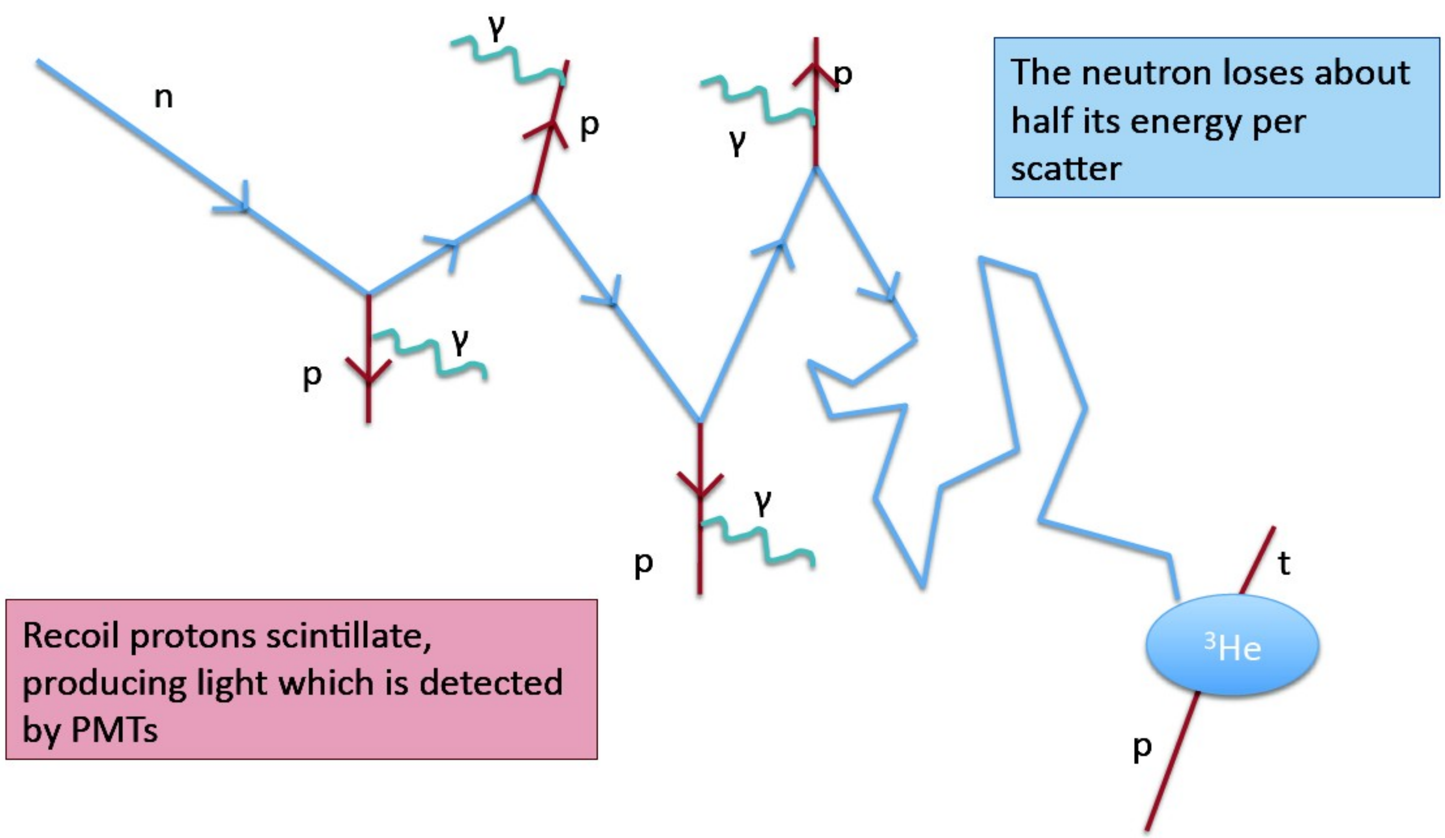




localized deposit
single site event

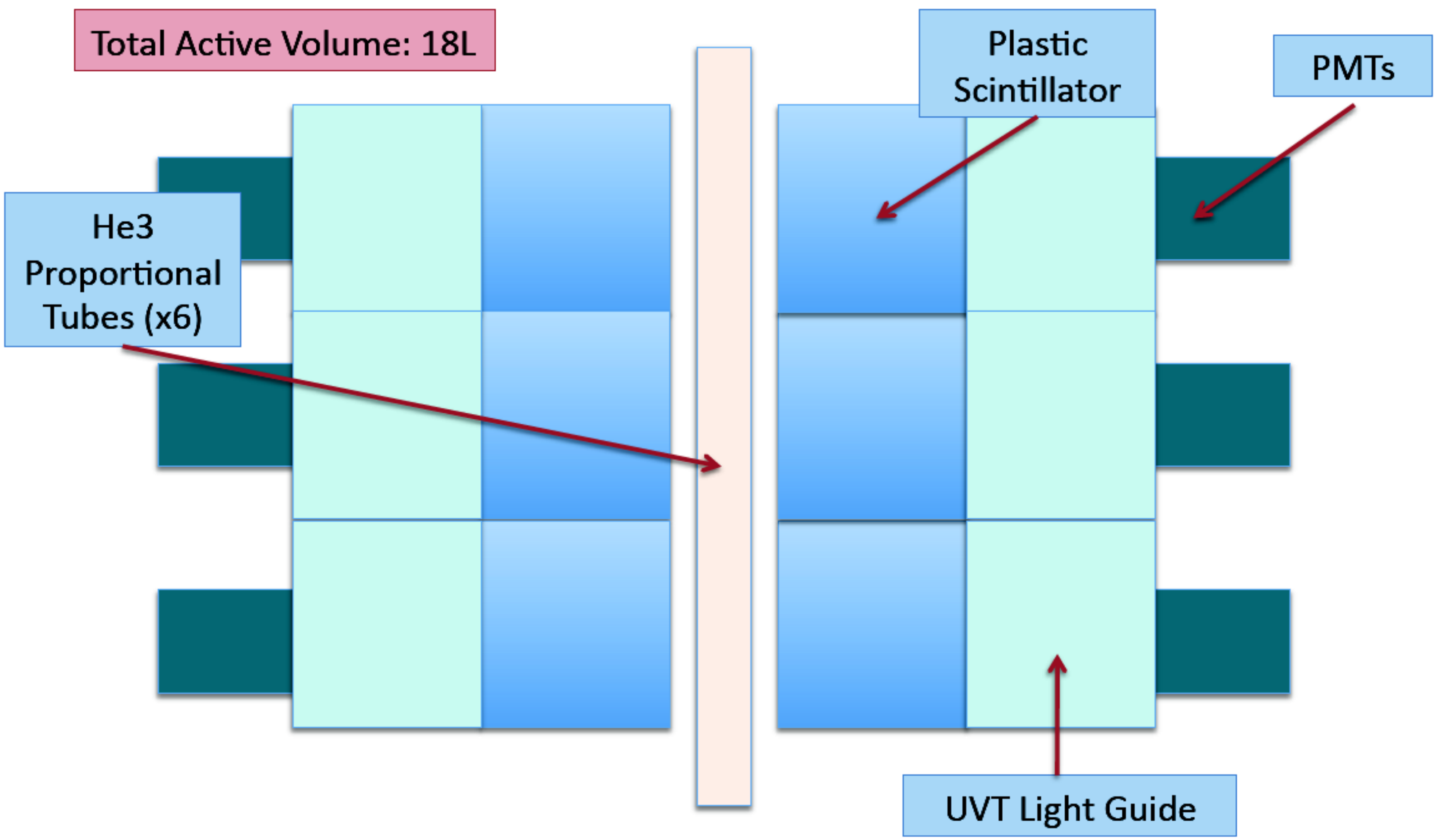
several deposits
multi site event

Neutron detection principle

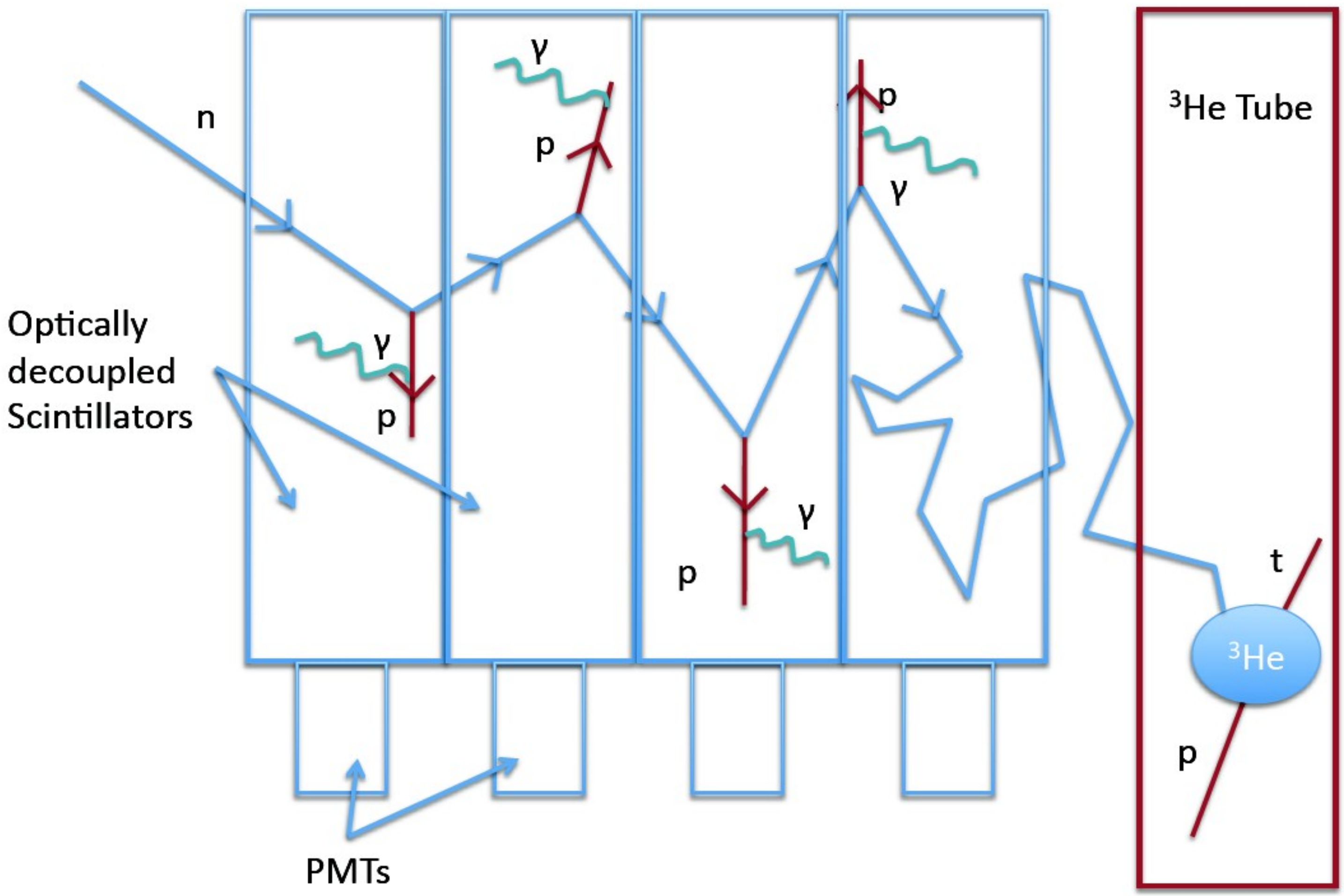


Neutron detector

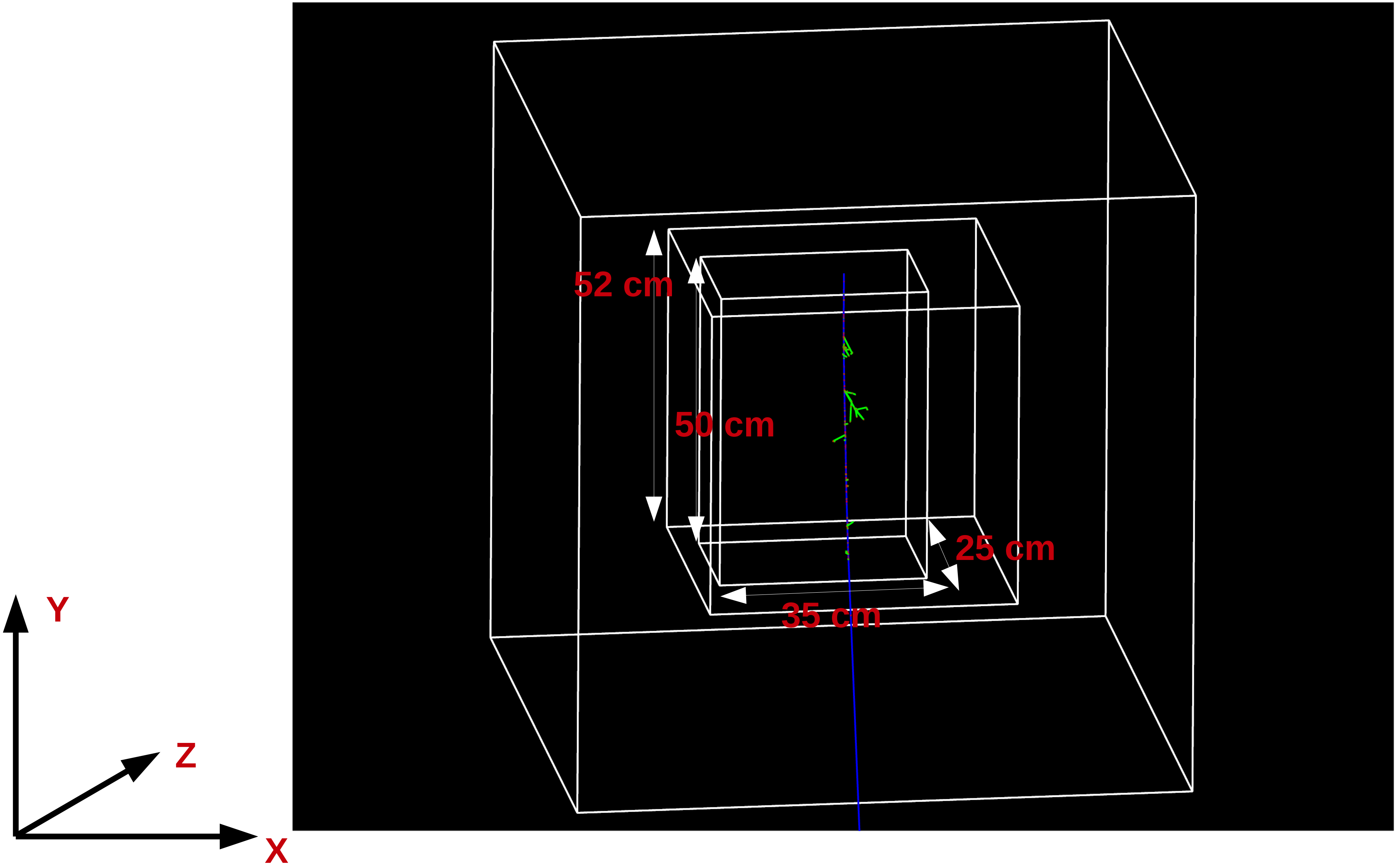
The UMD-NIST Fast Neutron Spectrometer



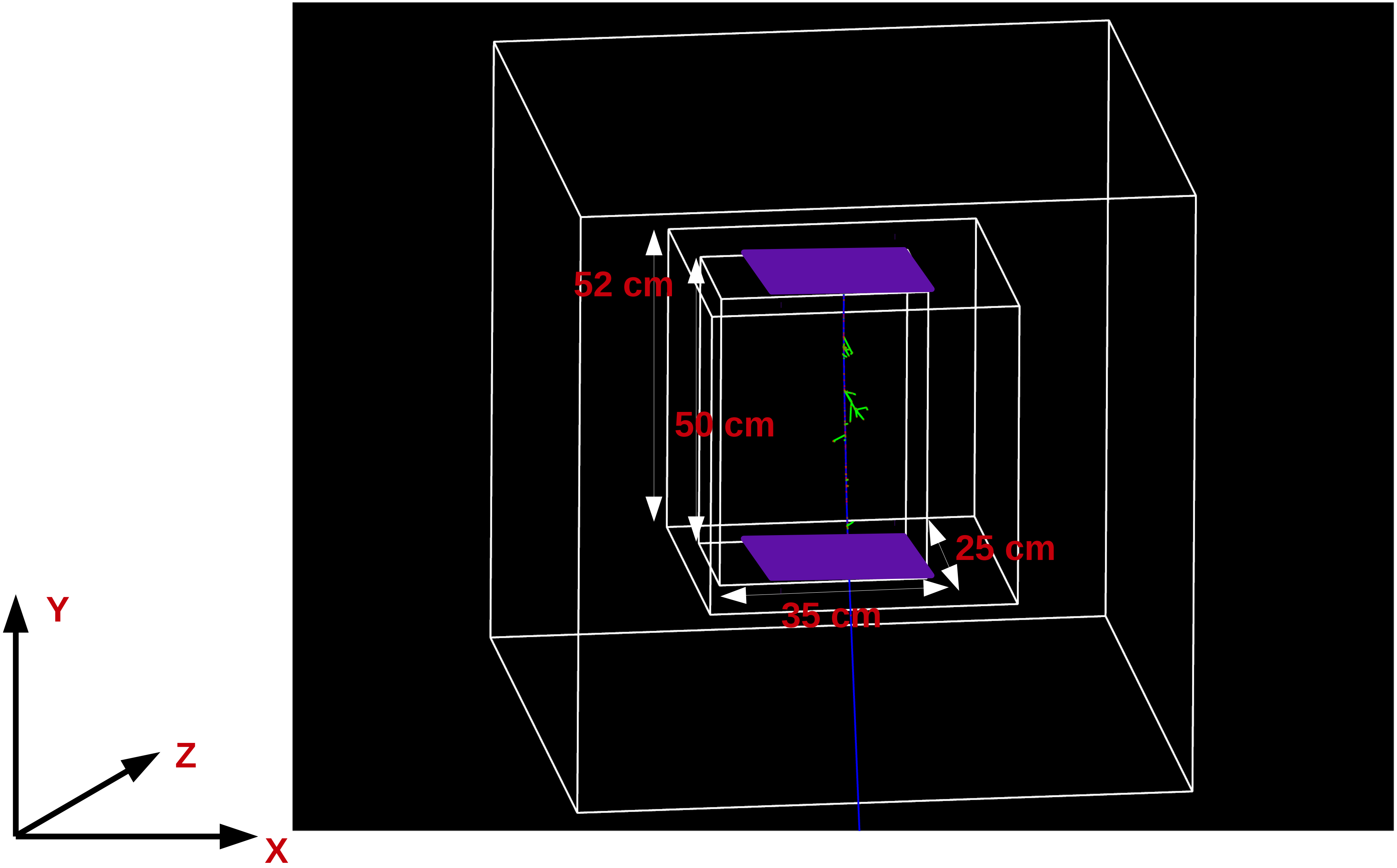
Segmentation



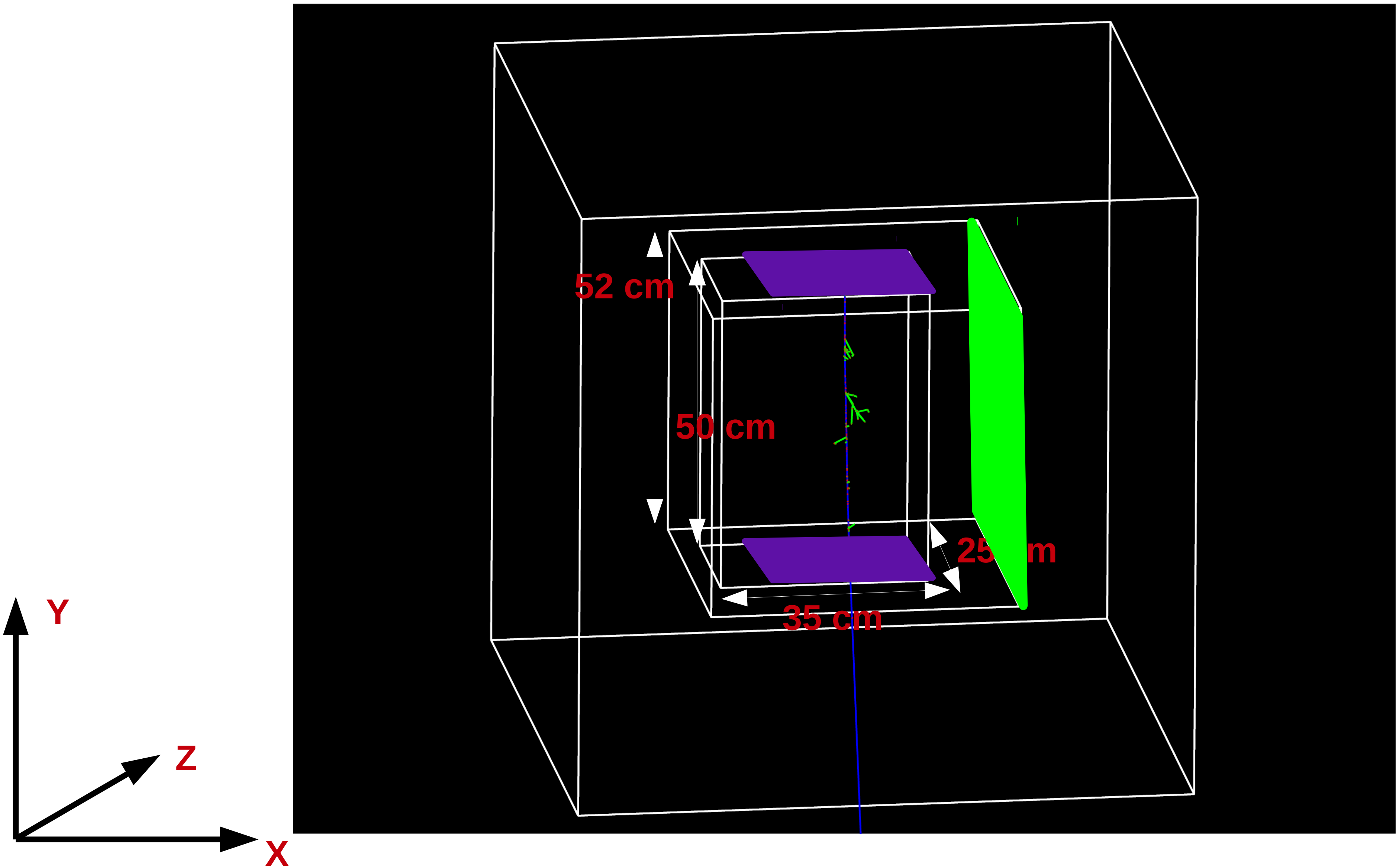
Geometry



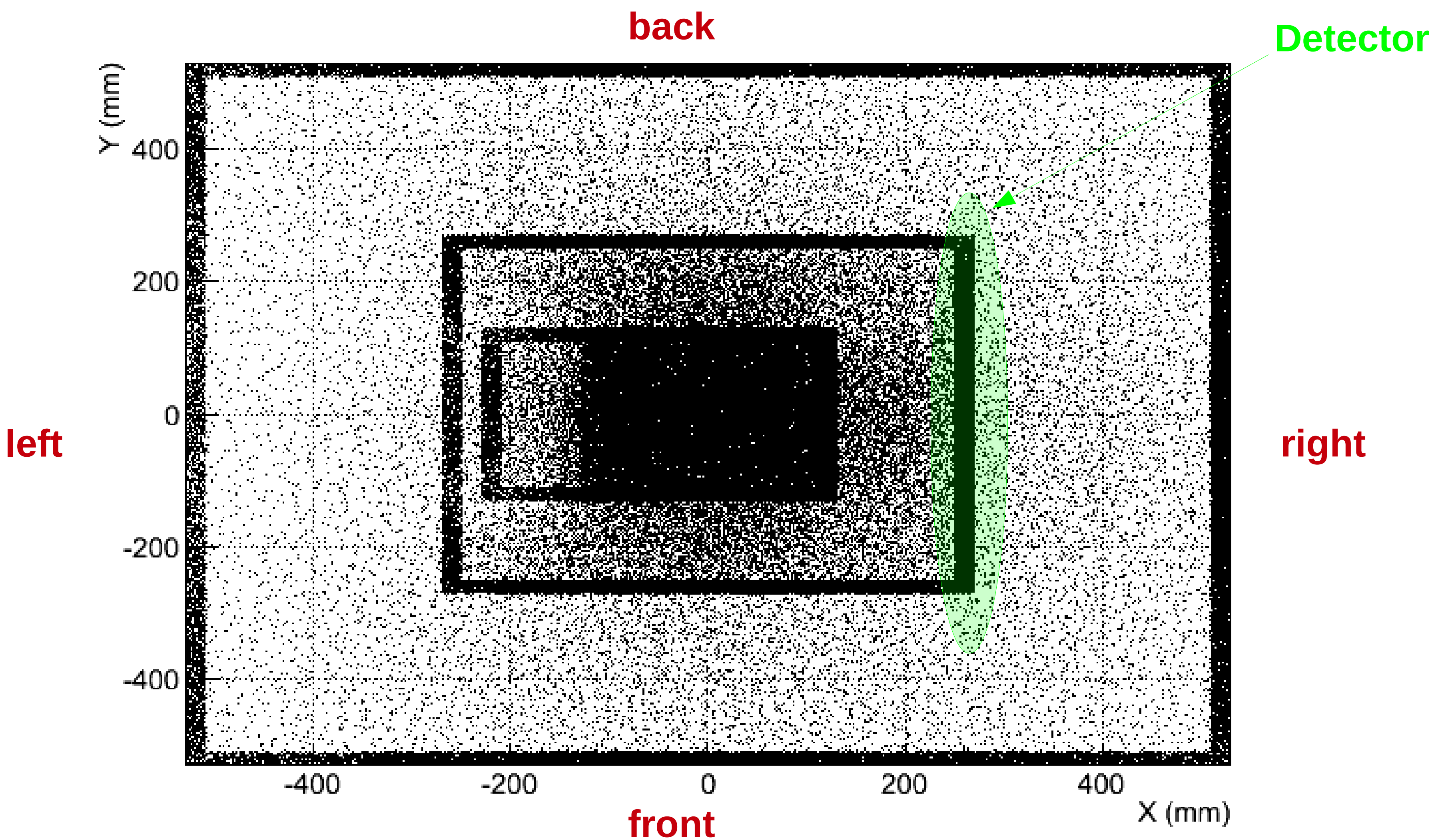
Geometry



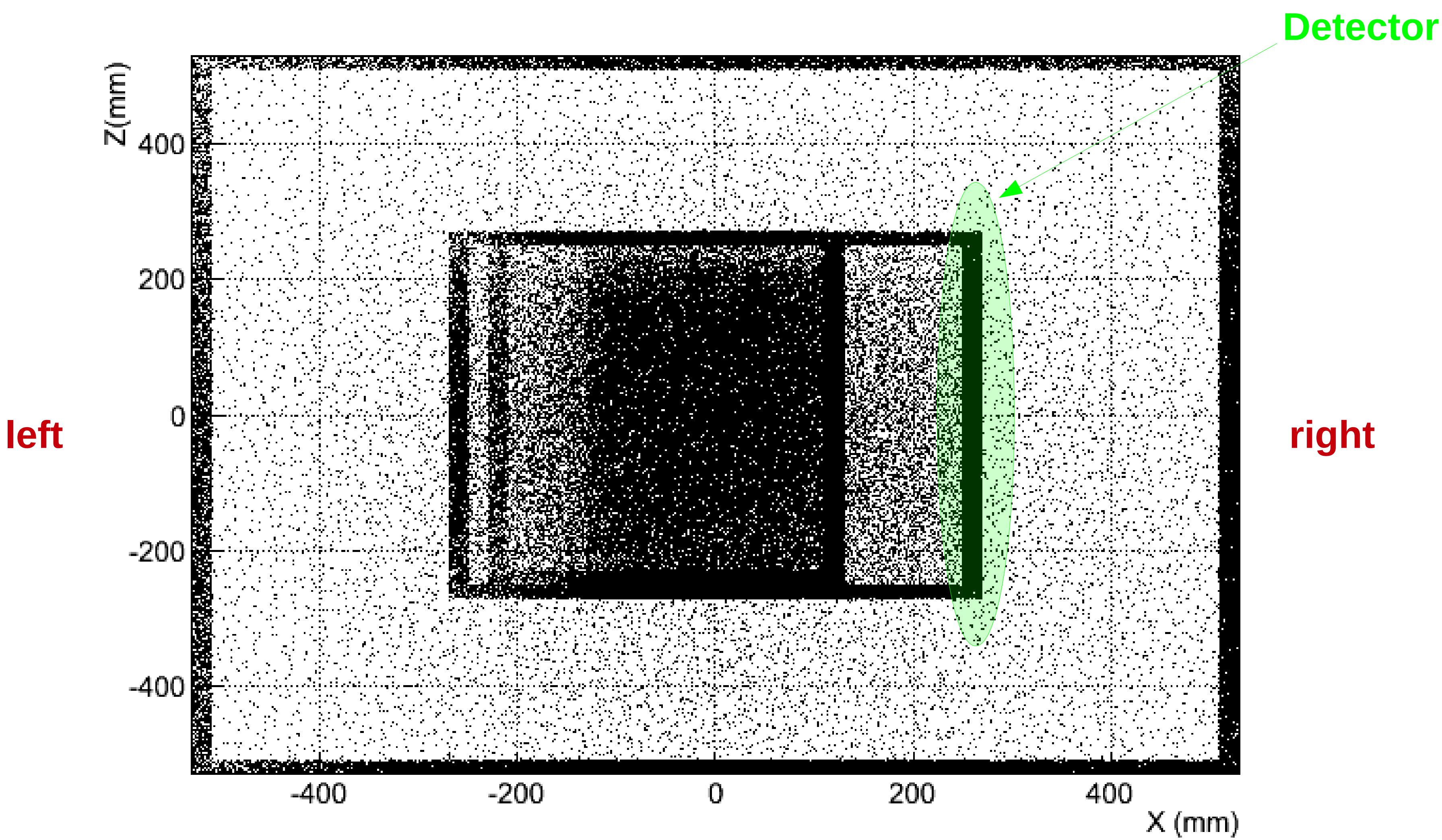
Geometry



Top view

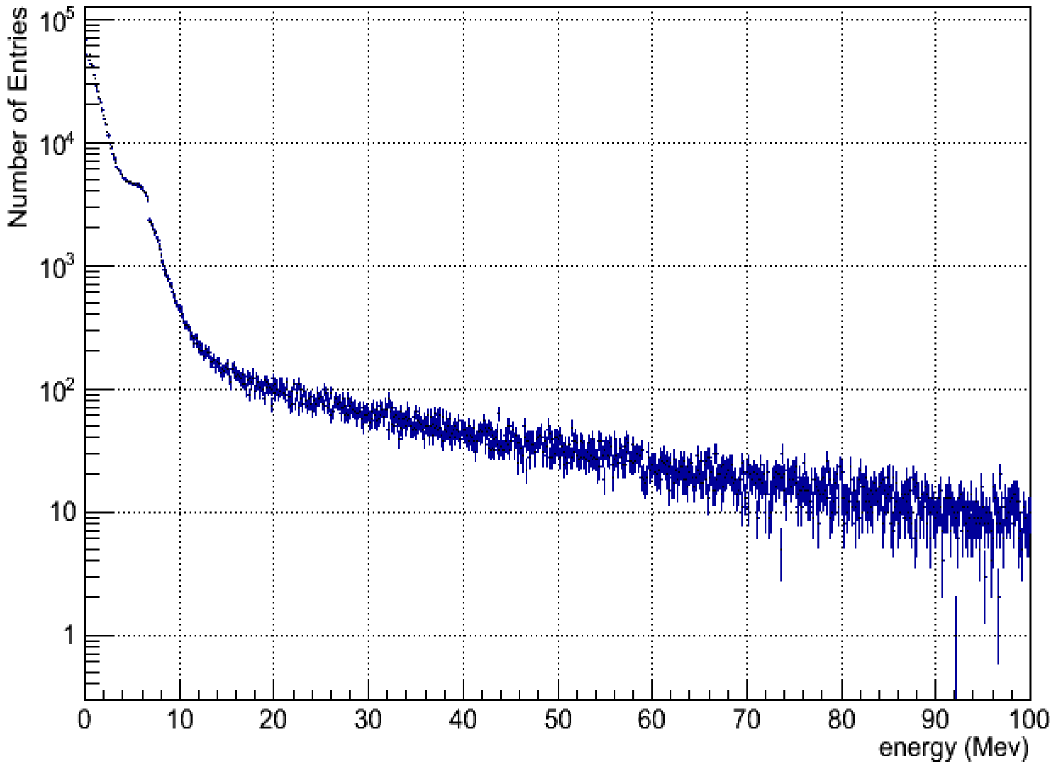

back
Detector
Y (mm)
400
200
0
-200
-400
-400
-200
0
200
400
X (mm)
left
right
front

Side view



Some Results & Predictions

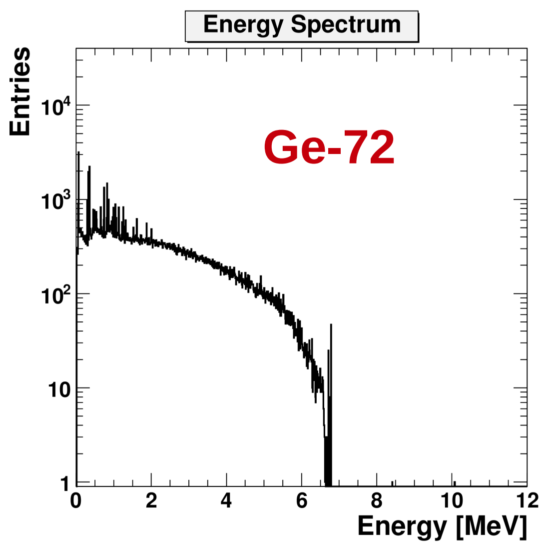
Neutron spectrum @ the detector surface

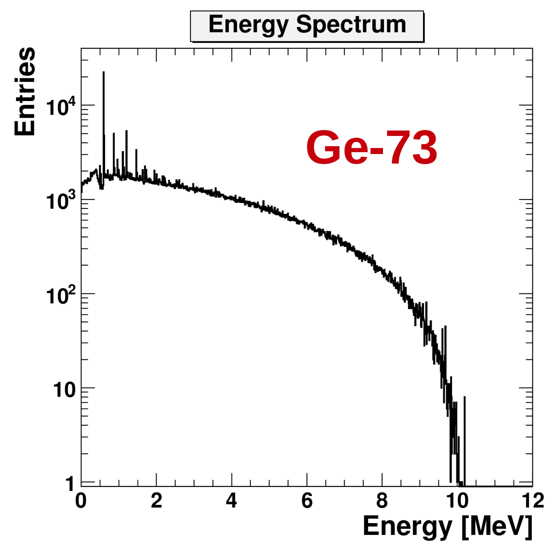


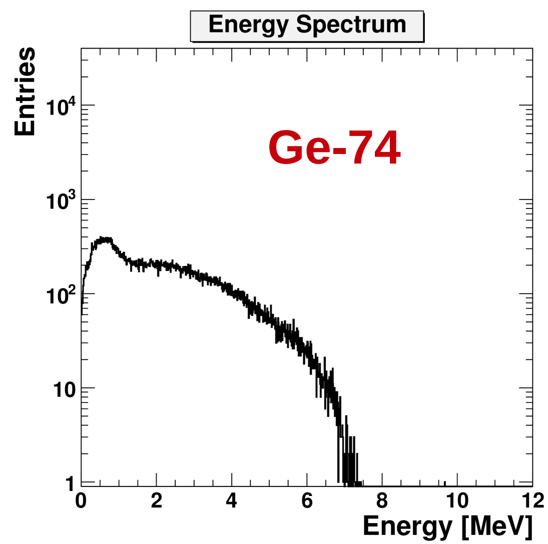
- Generated muons ~ 10^8
- Neutrons at surface ~ $6x10^5$
- Probability to have a neutron onto the detector ~ $6.2x10^{-3}$
- Expected trigger rate ~ 1 Hz
- Detector efficiency between 0.01 – 0.1
- Neutrons measured after one week ~ 38 - 385

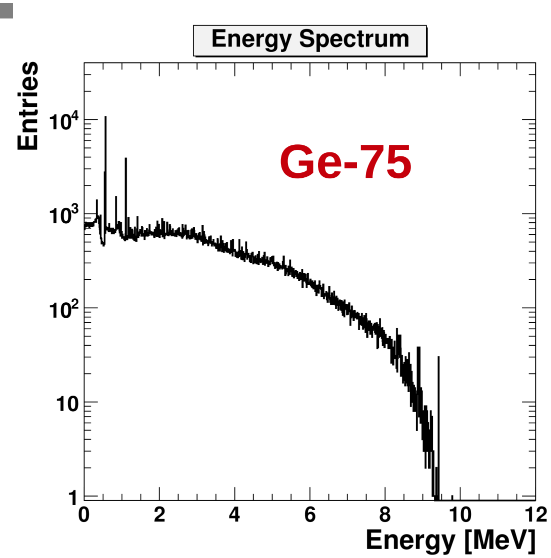
Possible idea to enhance the rate: having a bigger trigger surface

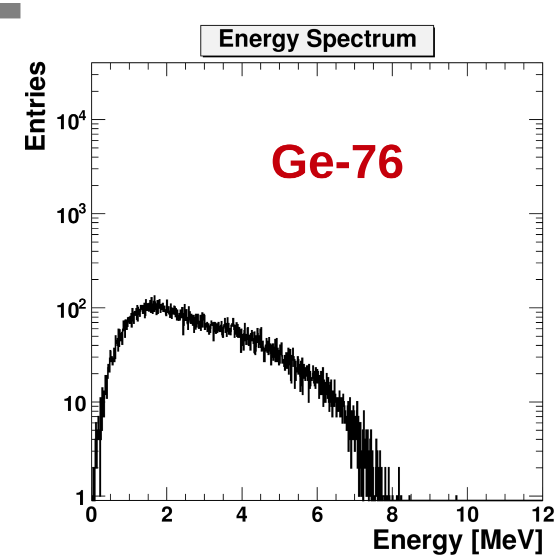
Thermal Neutrons in Ge





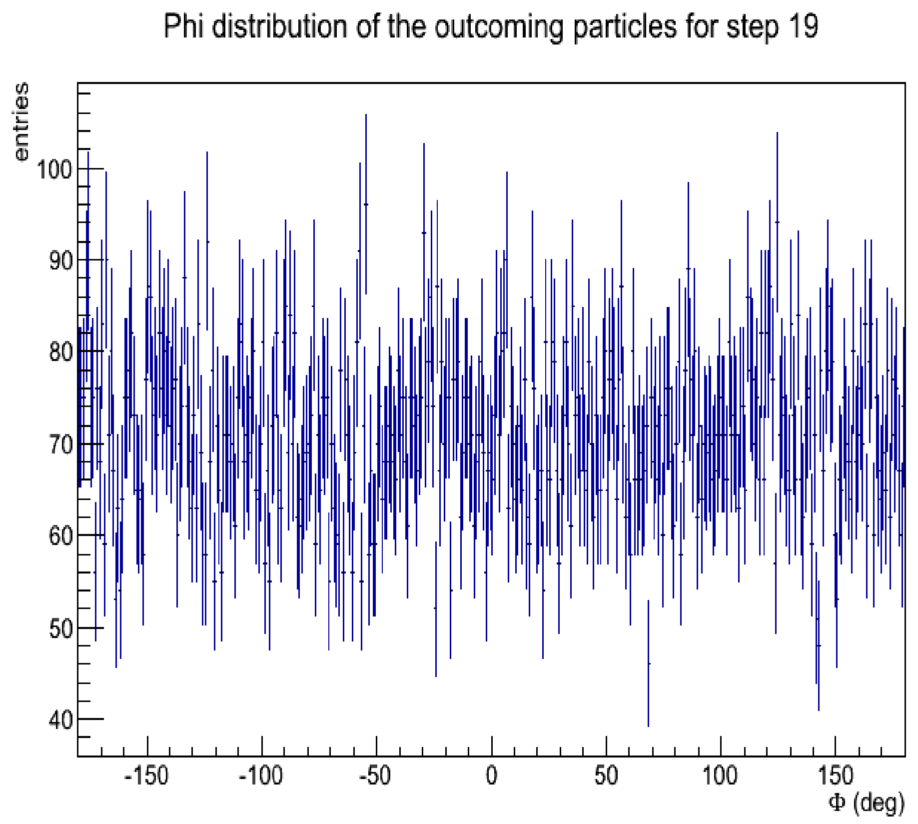






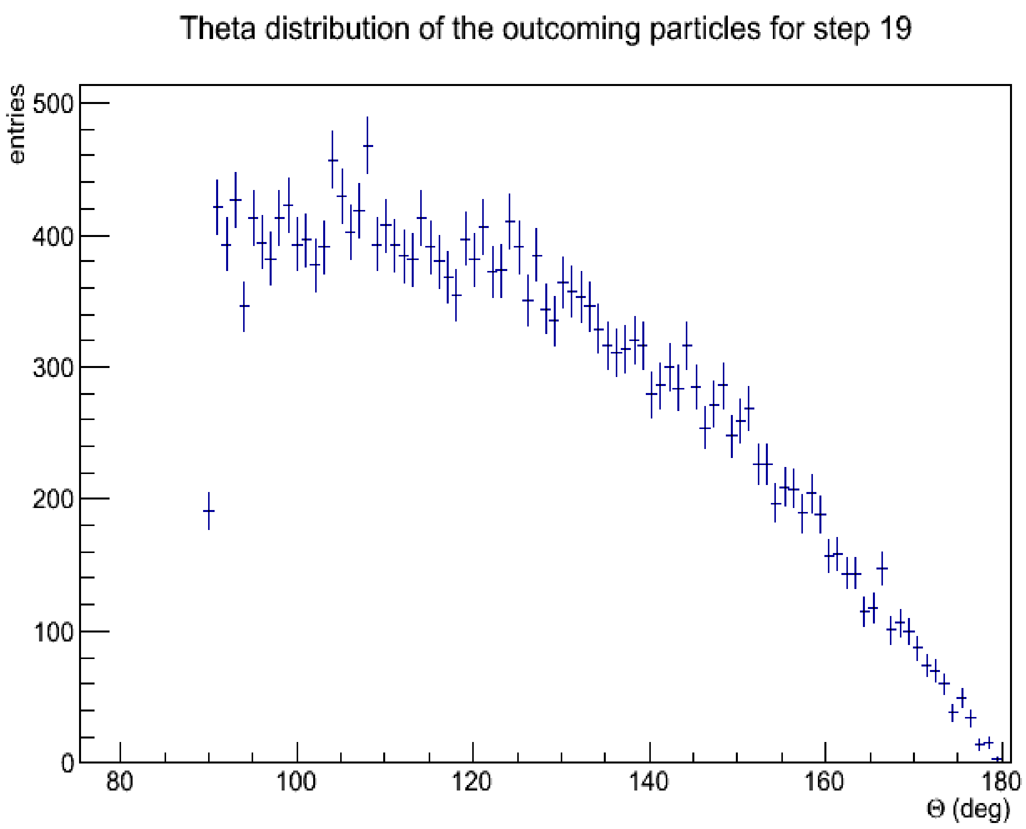
Courtesy of B. Doenmez, MPP Muenchen: 5x5x5 cm^3, E=0.024 eV, 1 million neutrons

How do we do that? (2)

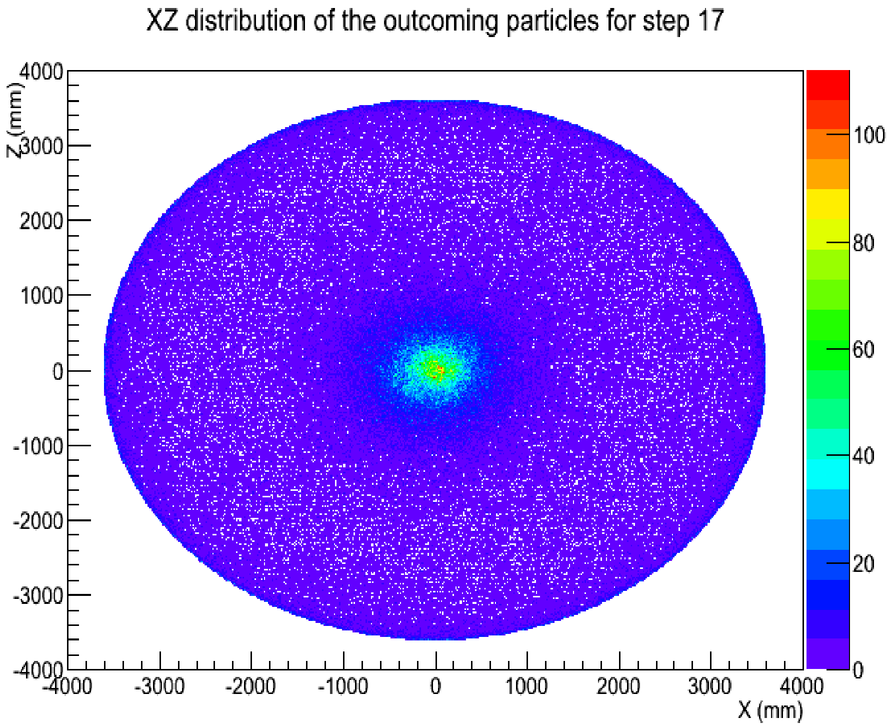


- Isotropically distributed wrt the polar angle on the XZ plane

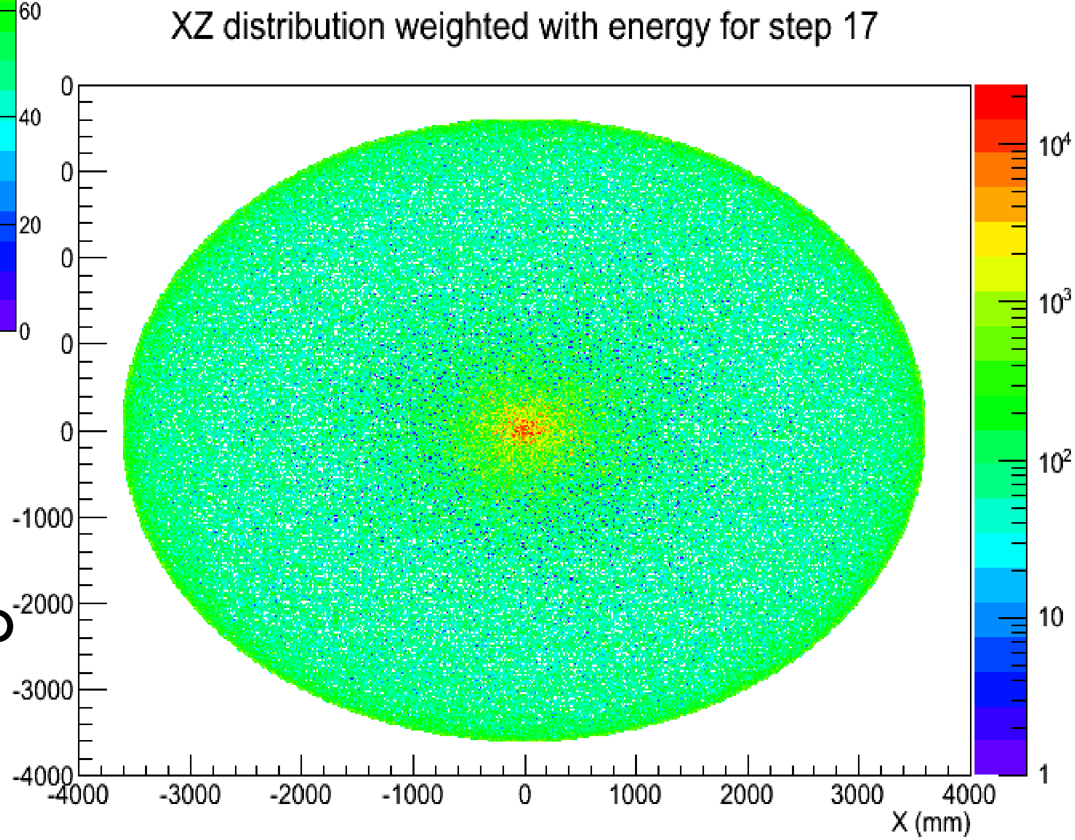
- Looking Forward



Position Weighted with Kinetic Energy



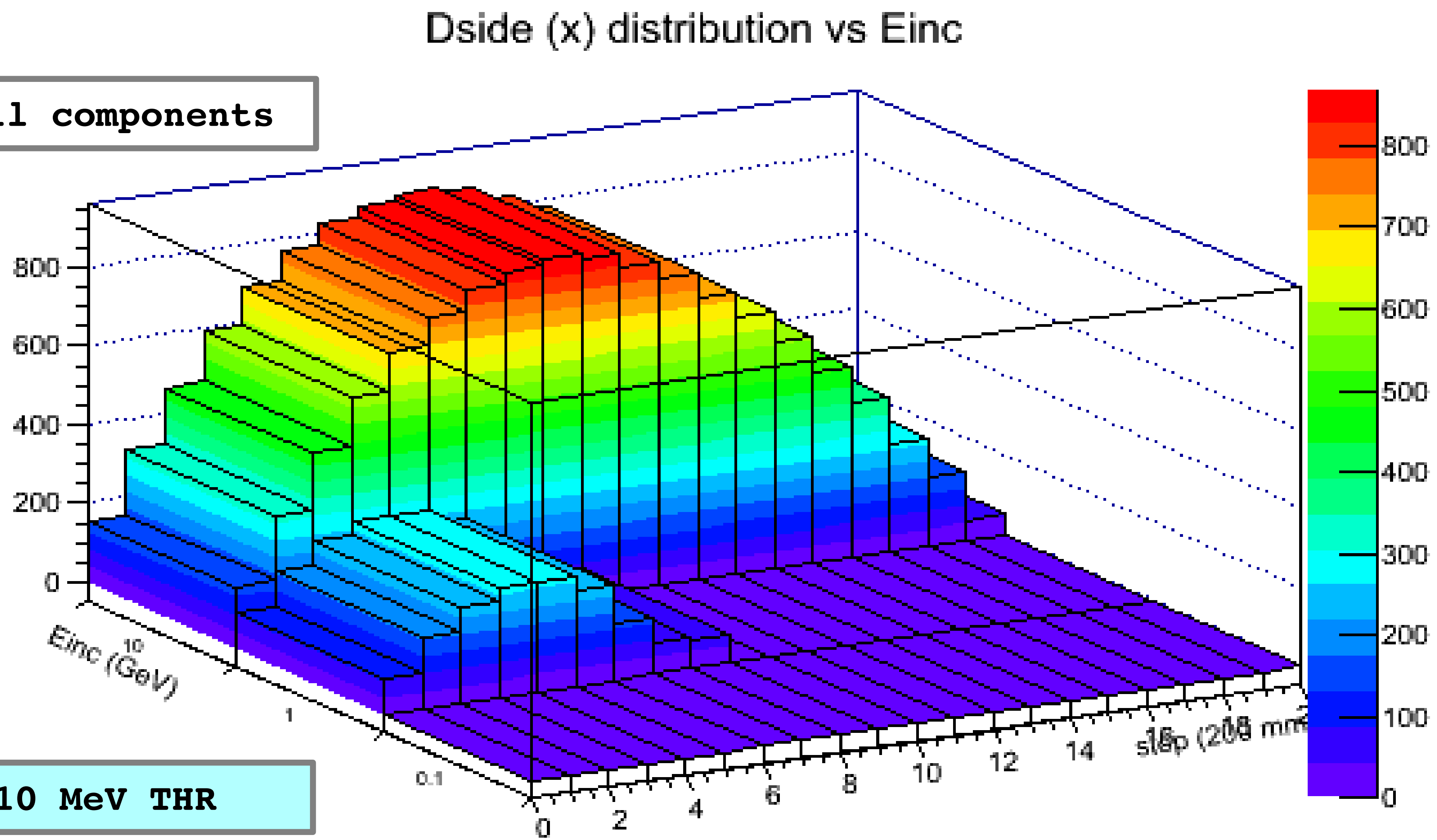
- XZ distribution WEIGHTED with Kinetic Energy



- XZ particle distribution for a particular step

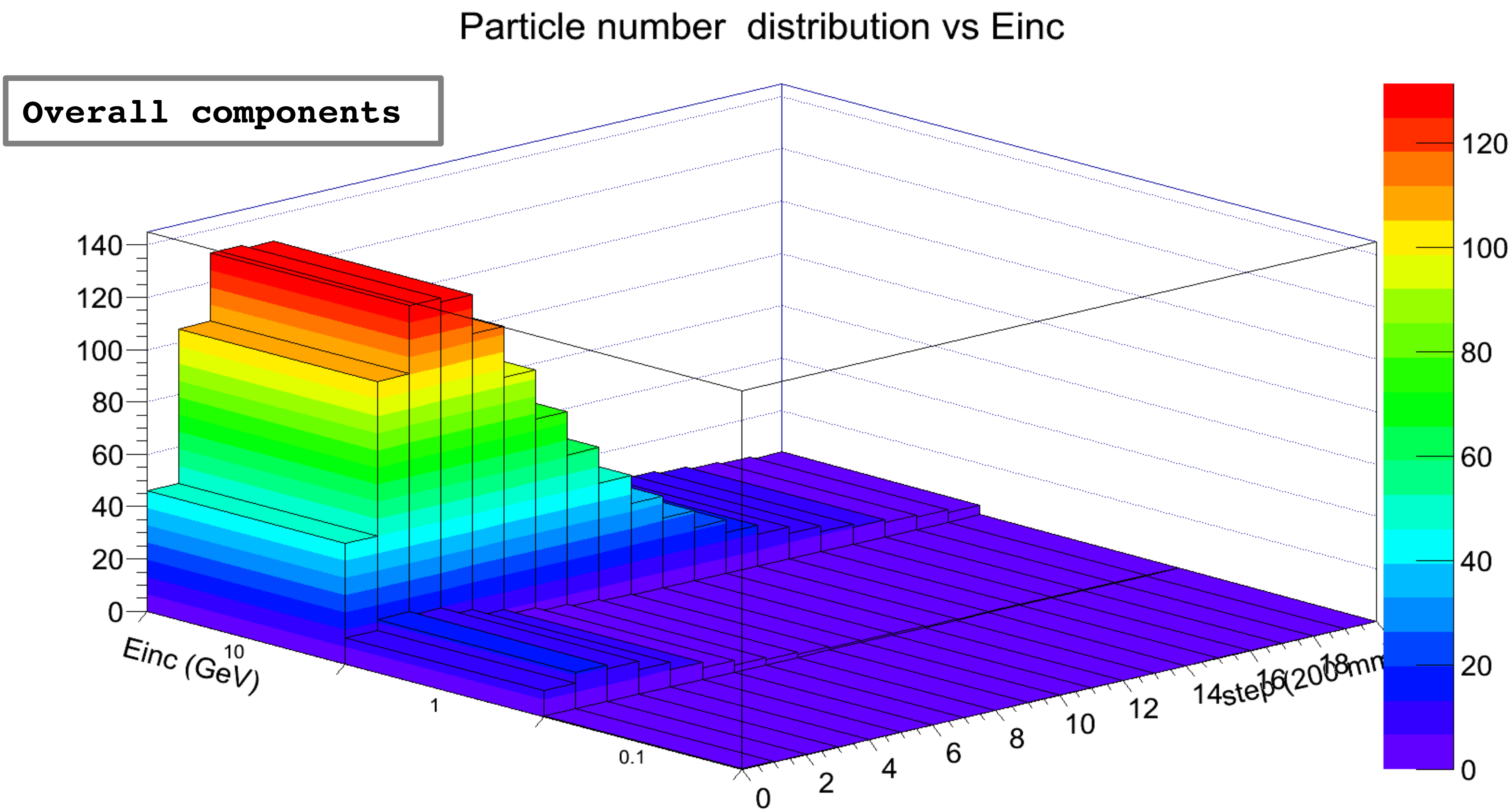
Horizontal Distance (3)

Overall components



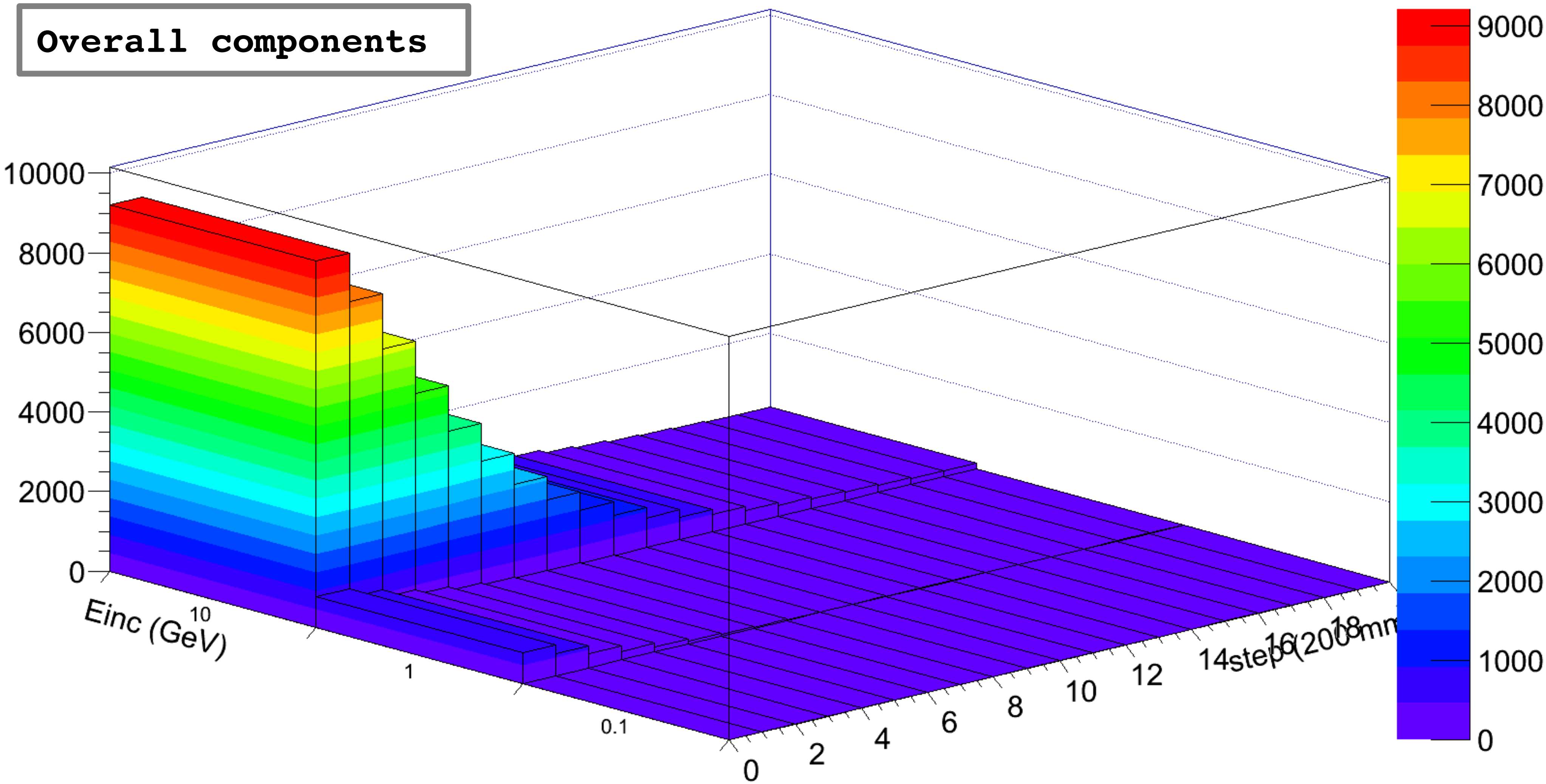
@ 10 MeV THR

Global Results (1)

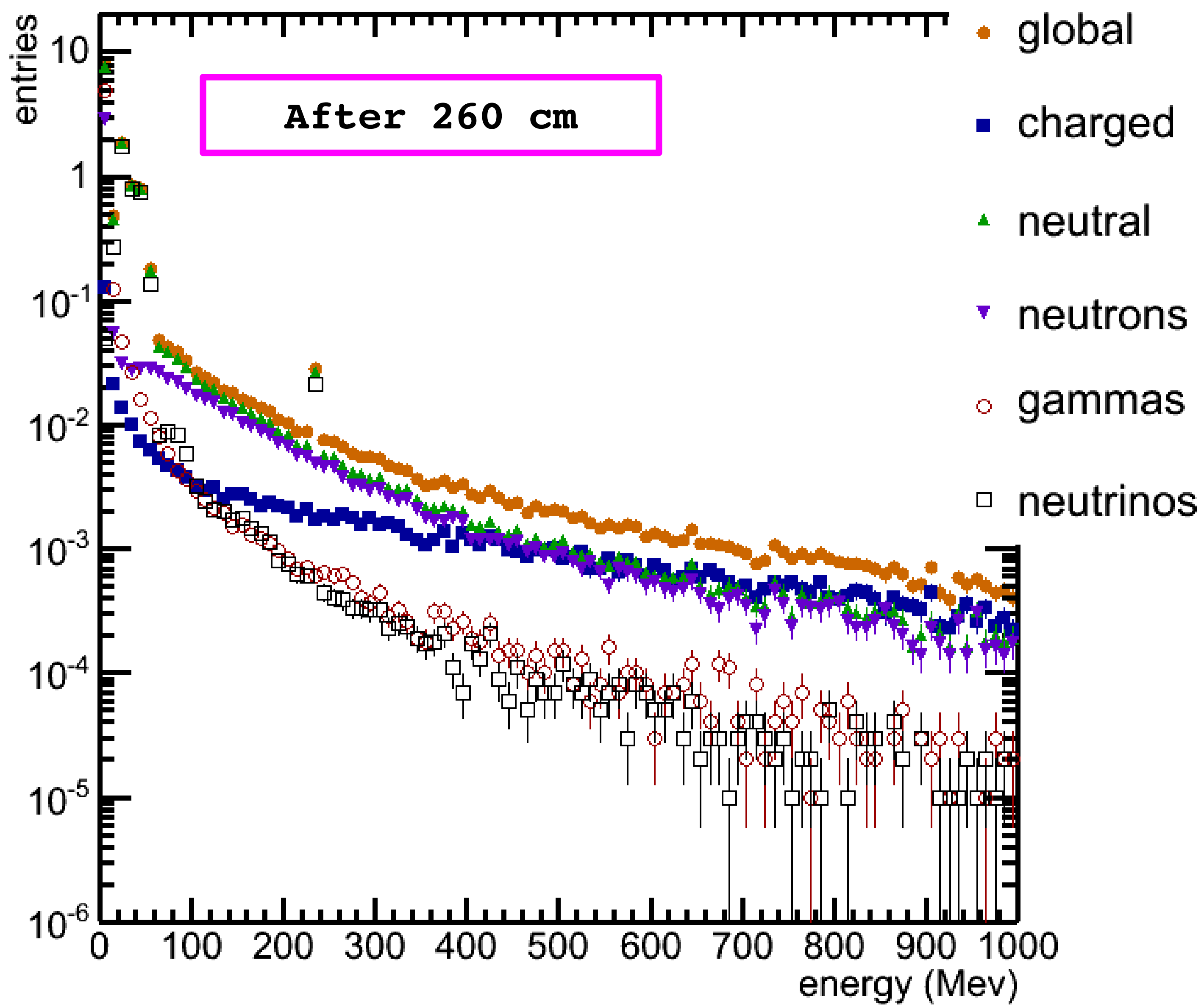


Global Results (2)

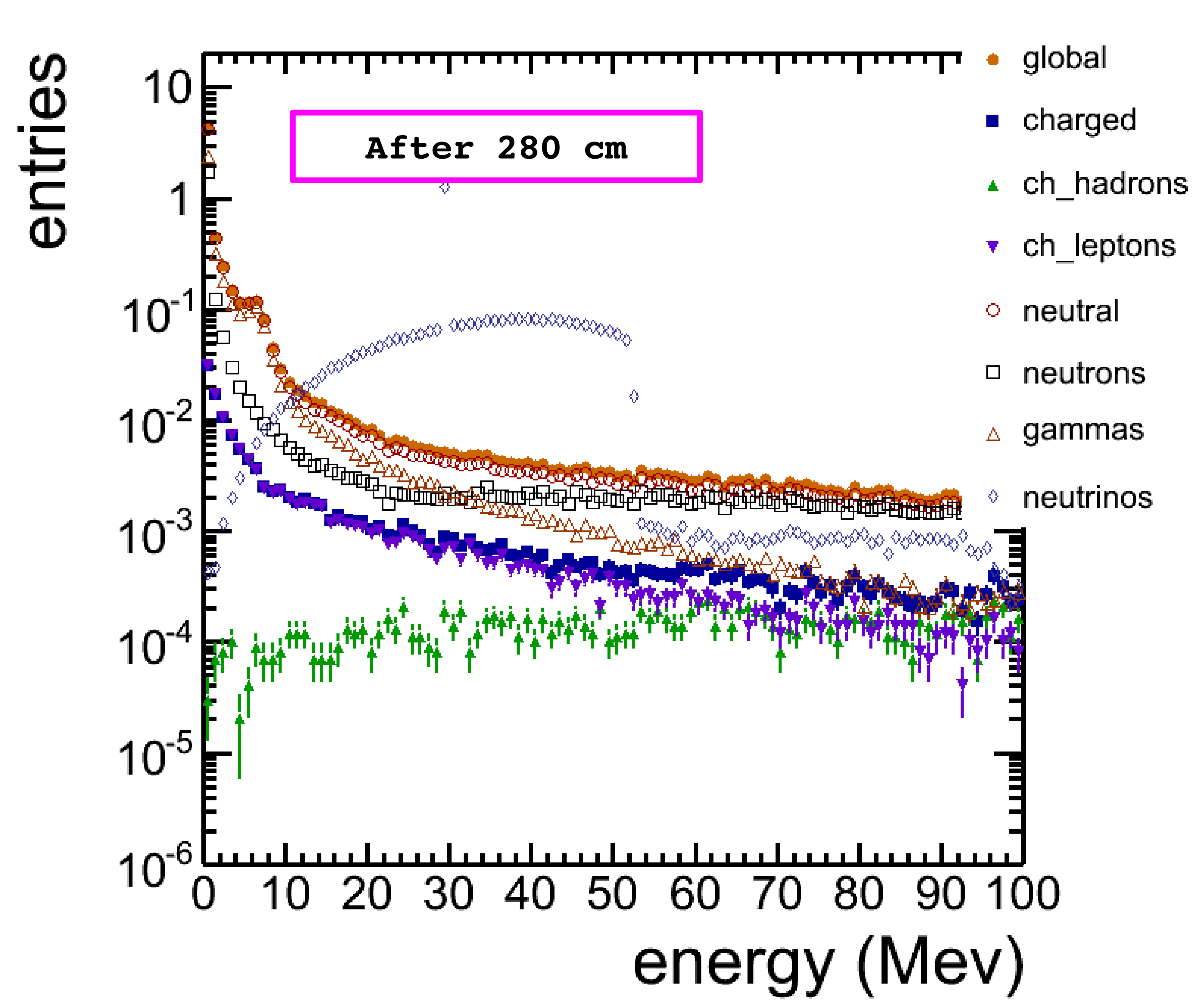
Particle number weighted with ENERGY distribution vs Einc



Global Results (3)

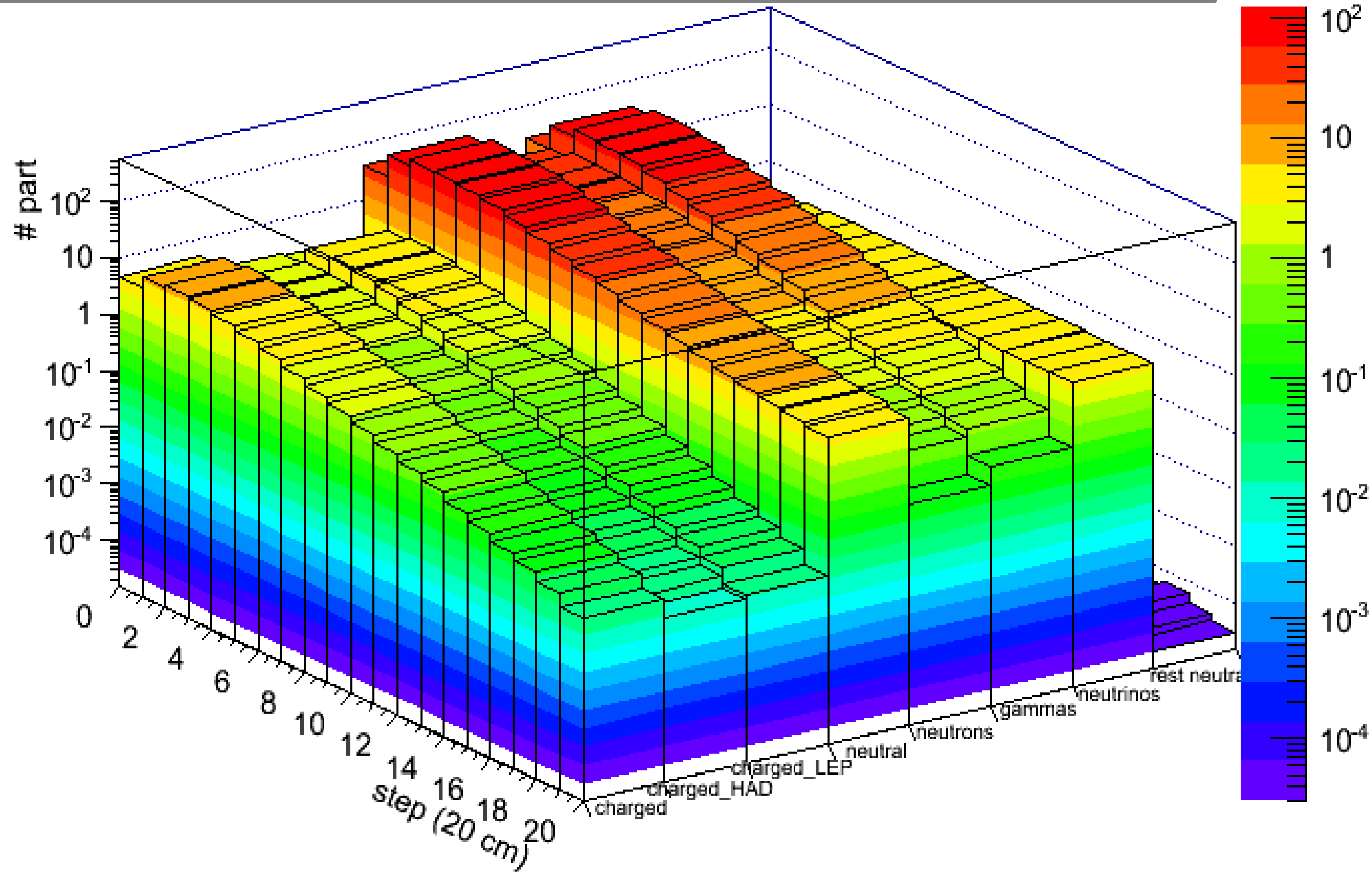


Global Results (4)



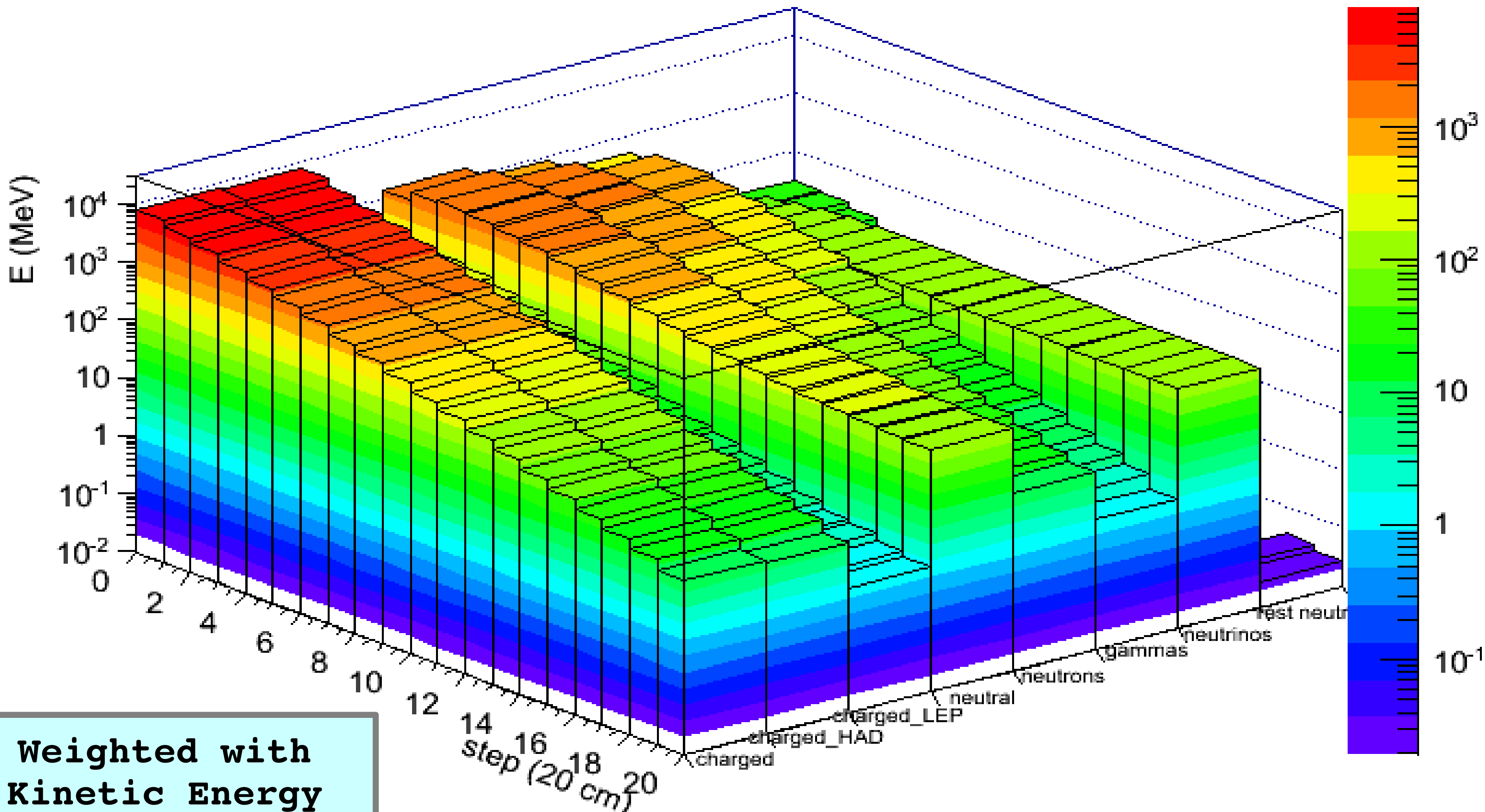
Global Results (5)

proton @ 10 GeV : particles # distribution vs step



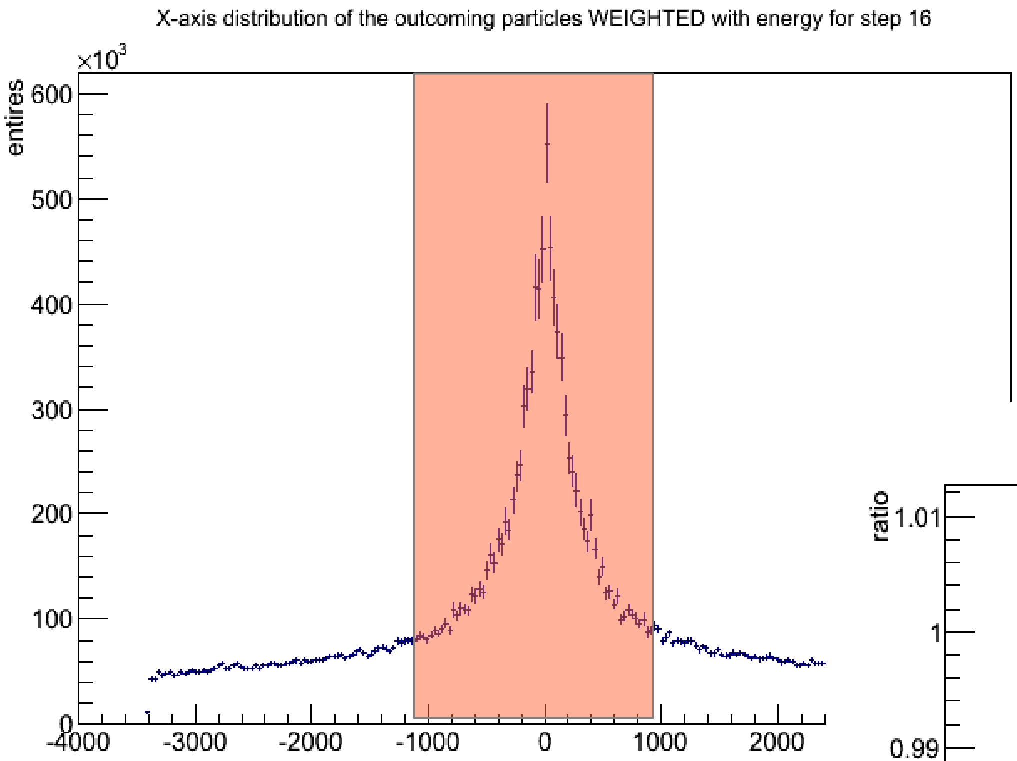
Global Results (6)

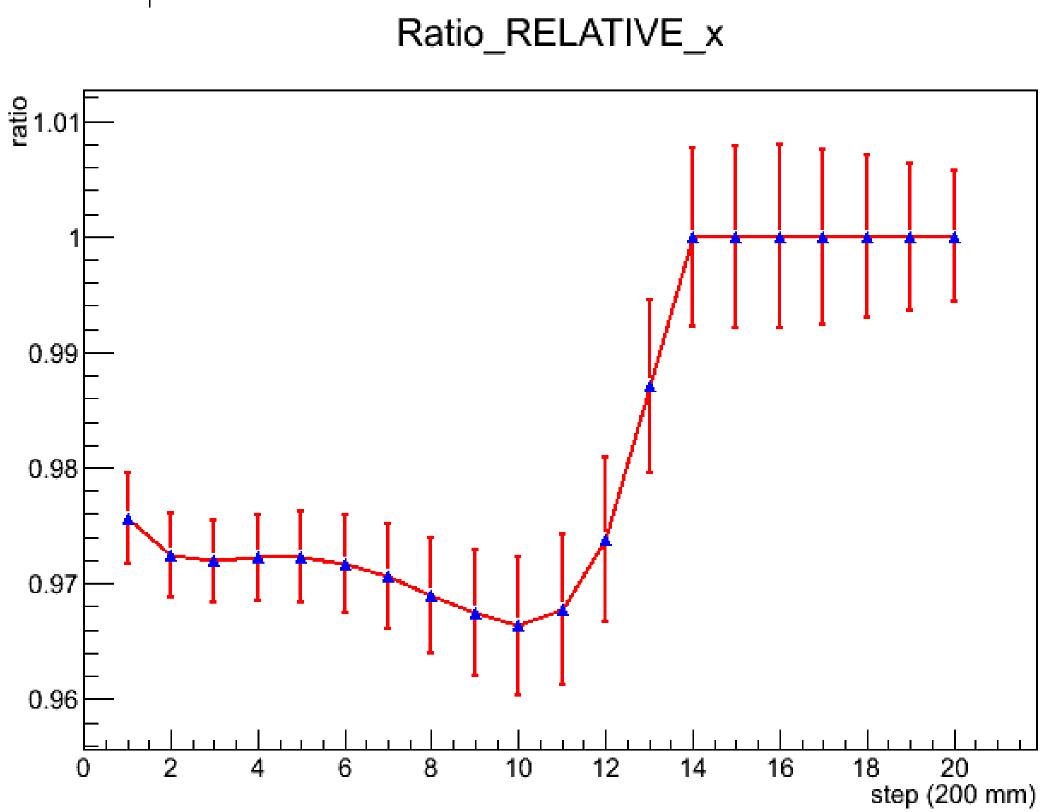
proton @ 10 GeV : particles # distribution vs step



Weighted with Kinetic Energy

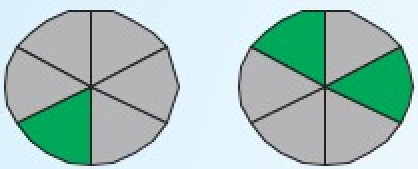
How do we do that?





How do we do that?

Segmented detectors can identify background events by counting.

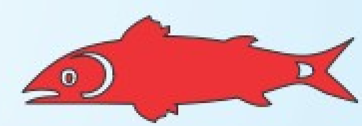


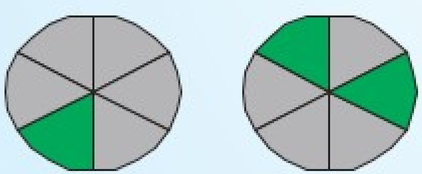
factor ≈ 10

This is robust, can be simulated and does not require extremely good energy resolution, i.e. a lot of fiddeling with electronics.

It requires extra cables... .

Pulse Shape Analysis is often seen as a cableless saviour.





≈ 1.4   4~5

This is tricky, needs a lot of input to be simulated and requires good bandwidth, i.e. a lot of fiddeling with cables & electronics.