Simulation Studies on Shower Development in Rock

Matteo Palermo

Young Scientist Workshop 2012 @ Ringberg Castle

On behalf of the GeDet group, MPI for Physics, Munich

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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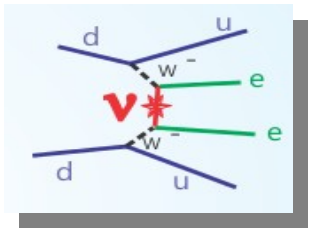
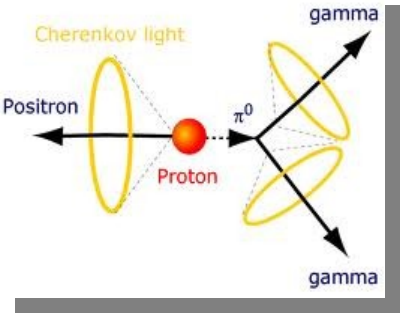
Low Background Experiments

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 counting rates!!
(e.g. 0ν2β decay < 0.1 counts/(keV kg y))

They ALL need a very low background!!

Expected Counting Rate

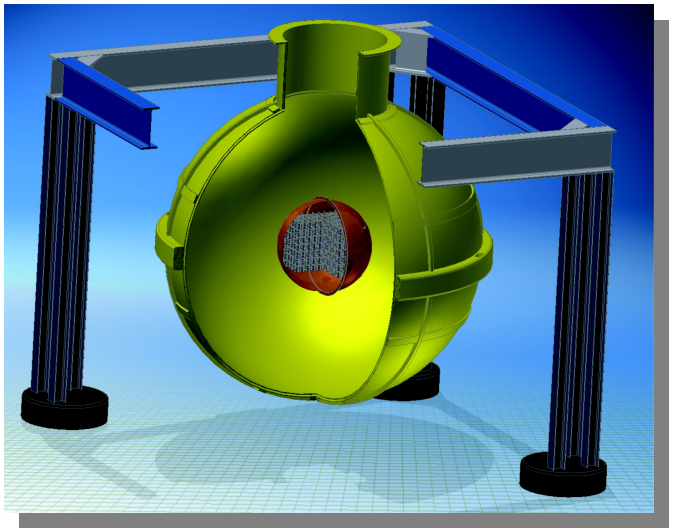
What we can do to enhance the expected counting rate?

- **Increase the exposure:**

  → **increase the data taking period**

Expected Counting Rate

What we can do to enhance the expected counting rate?



- **Increase the exposure:**

  → increase the data taking period

  → increase the mass
  → 1 Ton experiments

Expected Counting Rate

What we can do to enhance the expected counting rate?

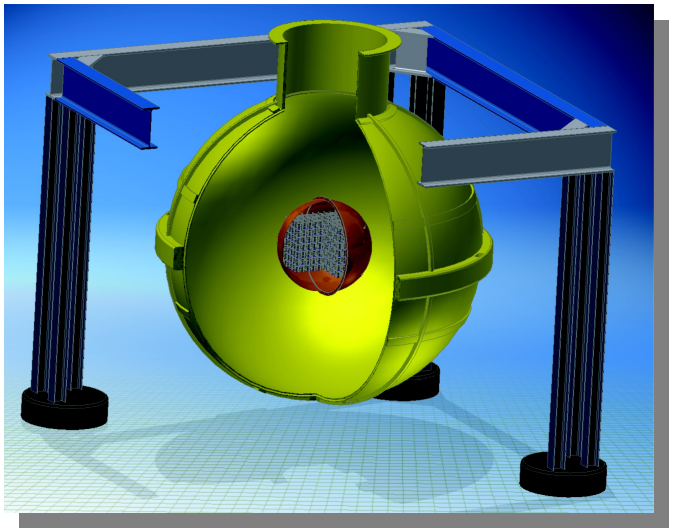
- **Increase the exposure:**

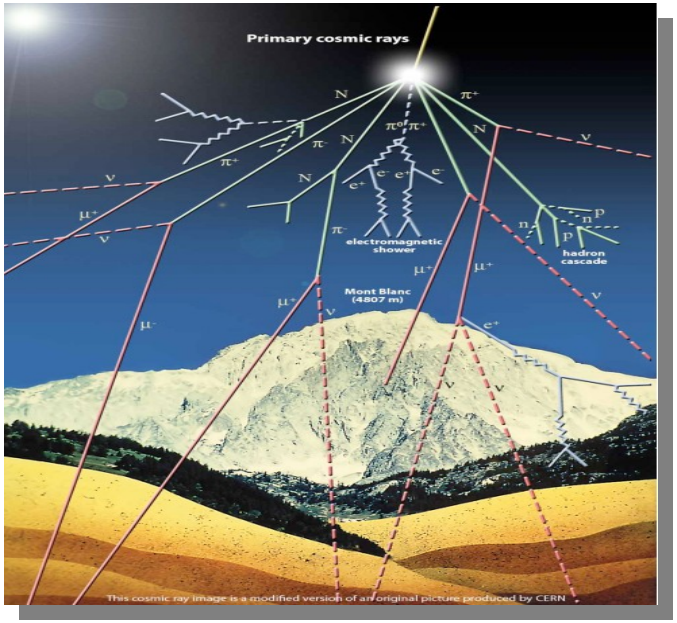
  → increase the data taking period

  → increase the mass
  → 1 Ton experiments

- **Increase the S/N ratio:**

  → reduce the background
  → Move Underground
  → Effective Shielding





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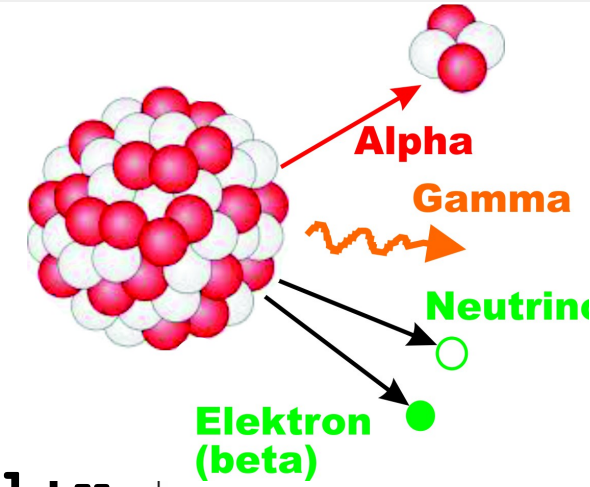
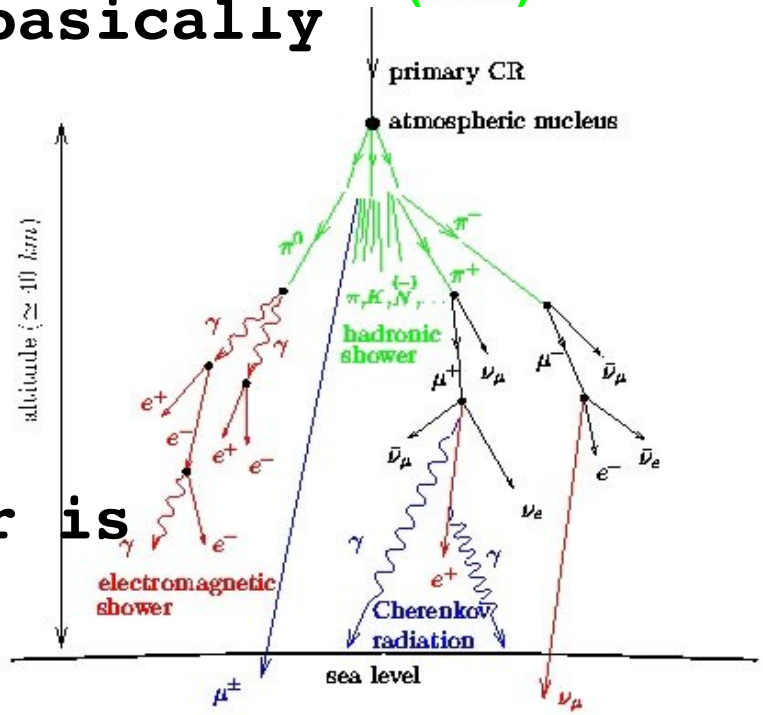
Background Sources

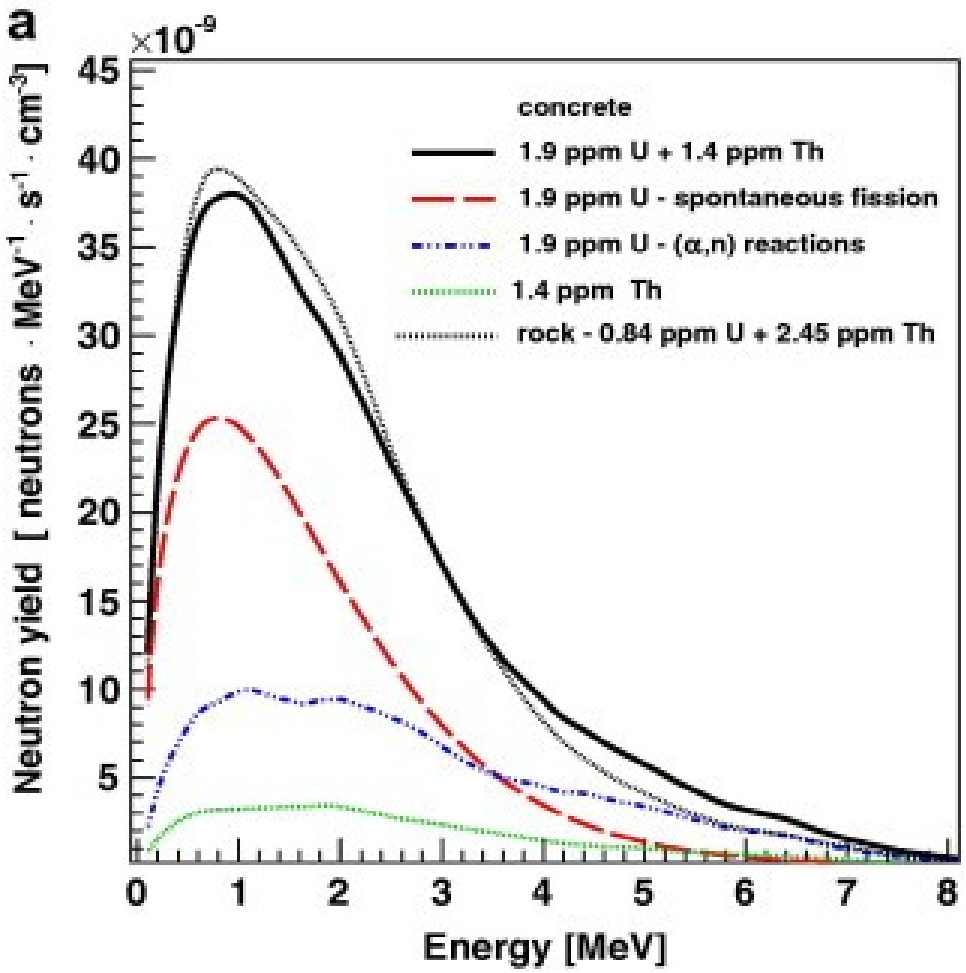
- **Three different sources:**
  - **Intrinsic detector radioactivity**
  - **Environmental Natural radioactivity**
  - **Cosmic Rays-induced showers** (basically muon and neutrino-induced)

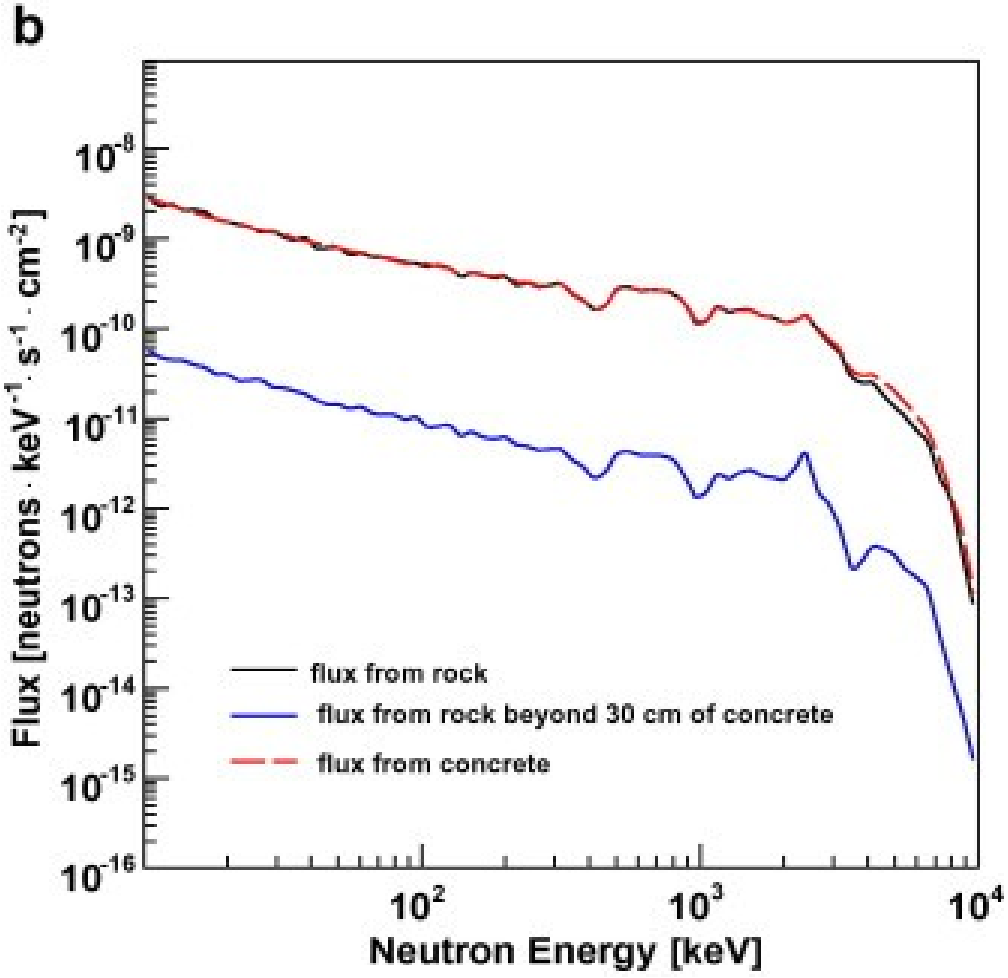


- **Two different components:**
  - **Charged** → easy to veto
  - **Neutral** → high shielding power is required (neutron, gammas)



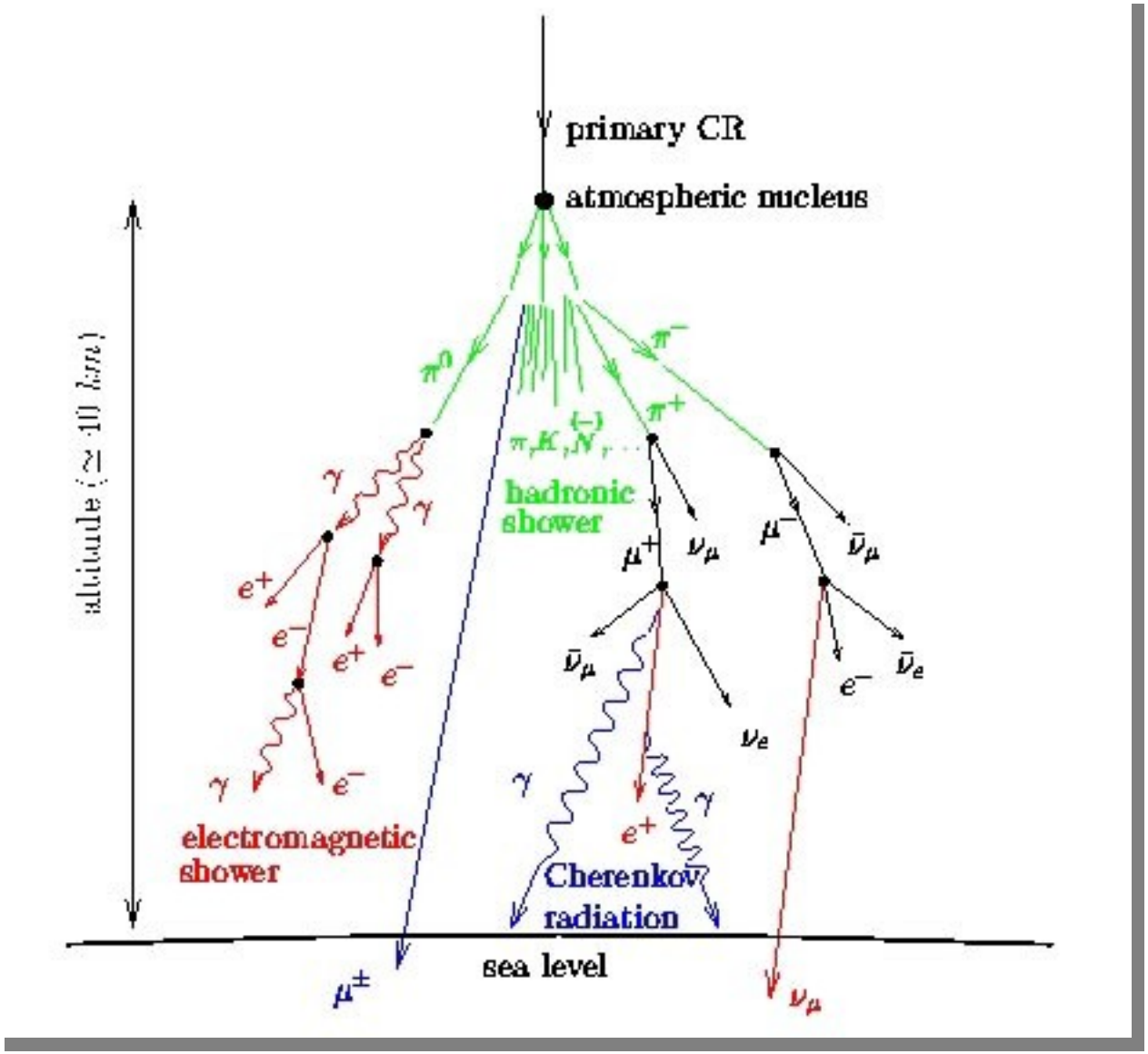
Environmental Natural Radioactivity

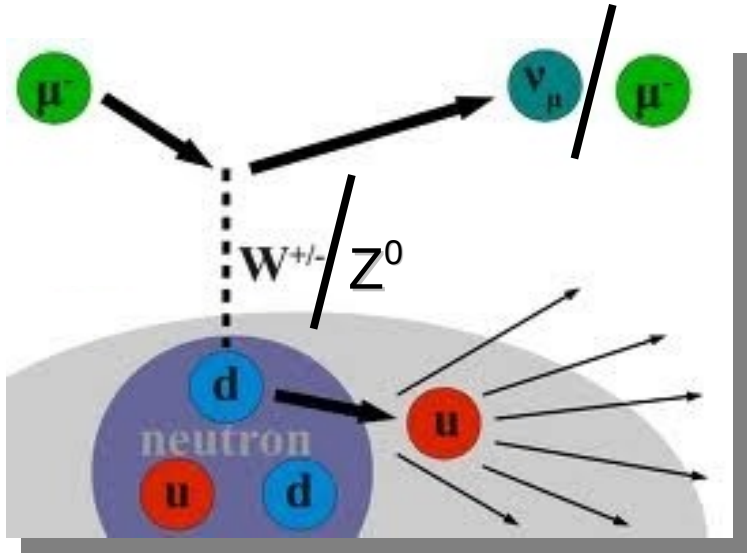


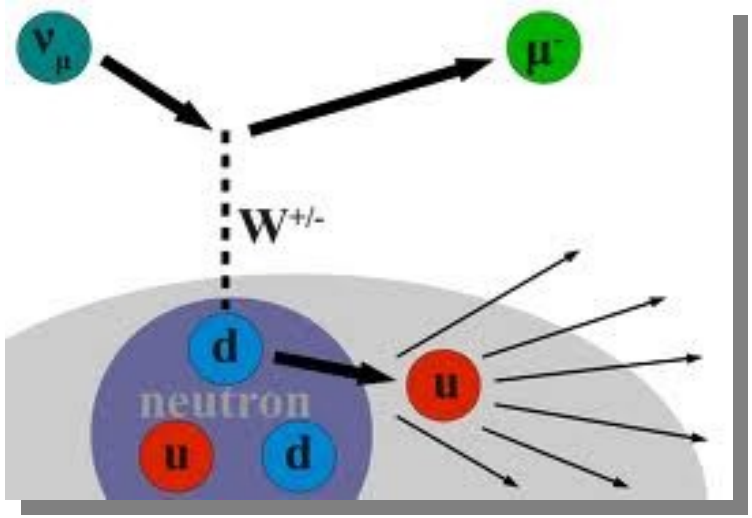


Tomasello et. al., Radioactive background in a cryogenic dark matter experiment, Astro. Phys., Vol 34, 2010

Cosmic Rays Shower

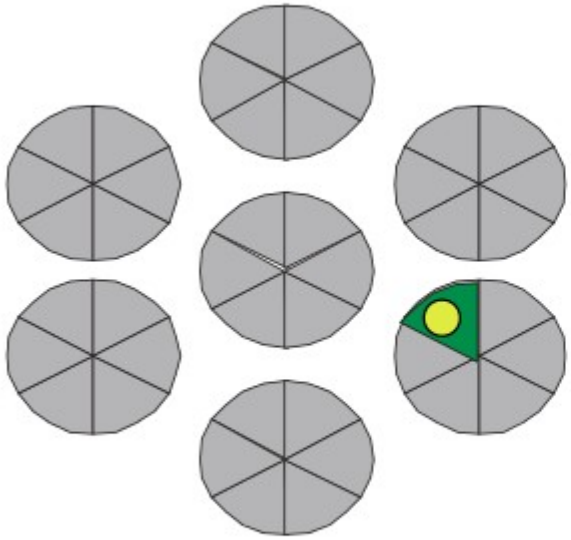






Background events

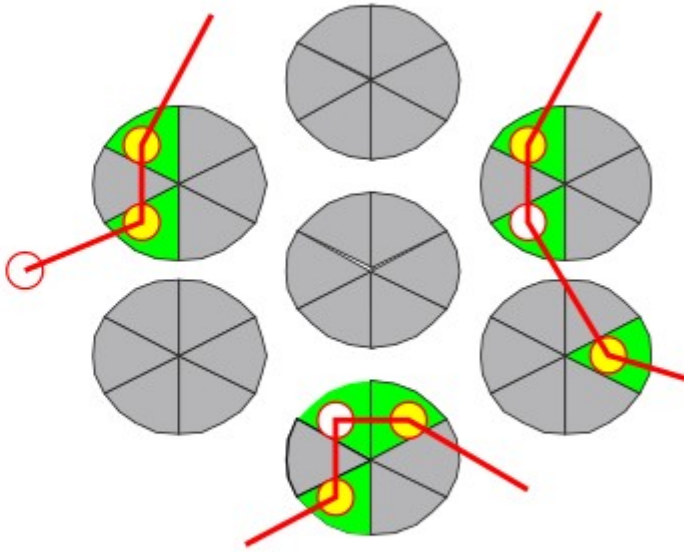
$0\nu\beta\beta$



localized deposit

single site event

γ or 2γ



several deposits

multi site event

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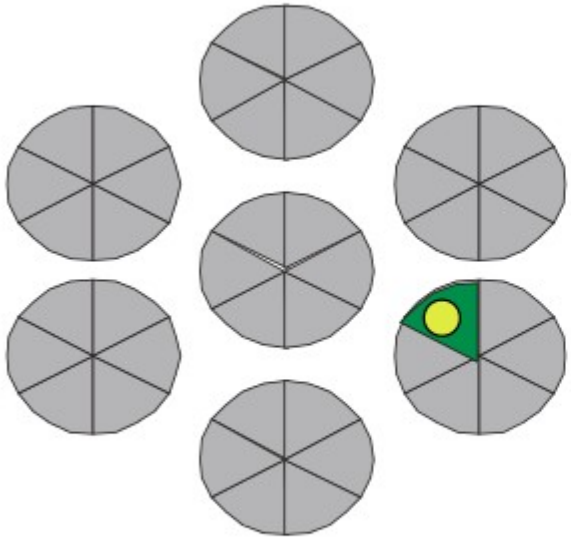

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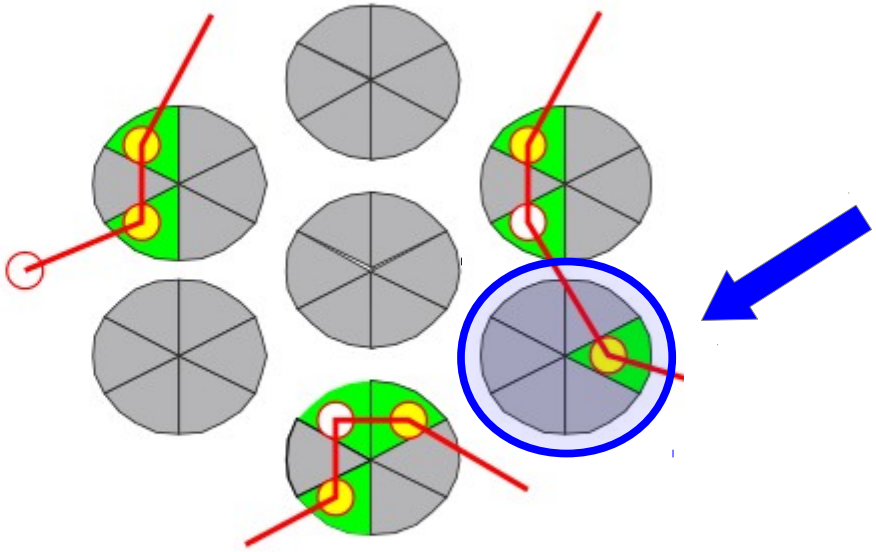
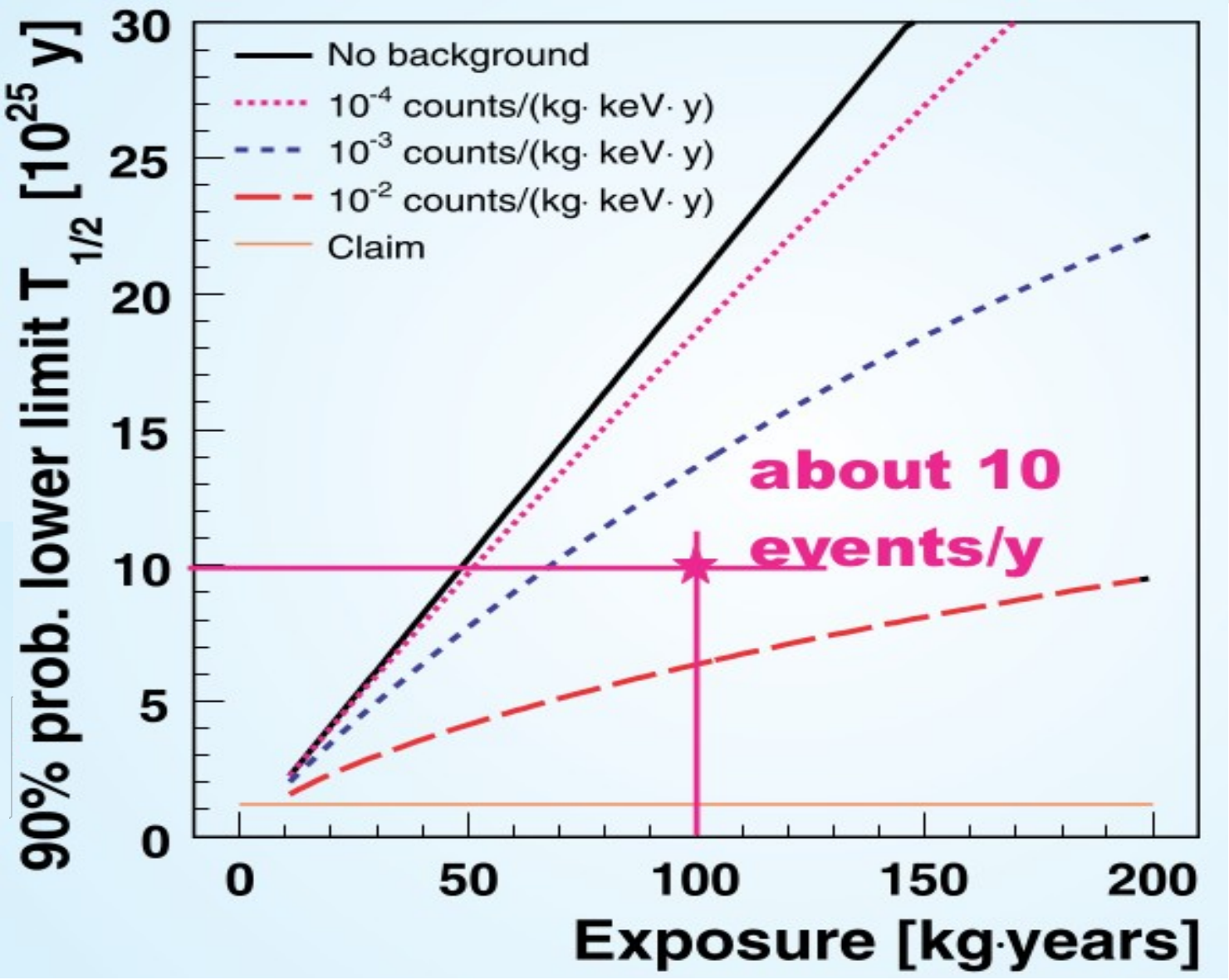


several deposits

multi site event

Importance of Background



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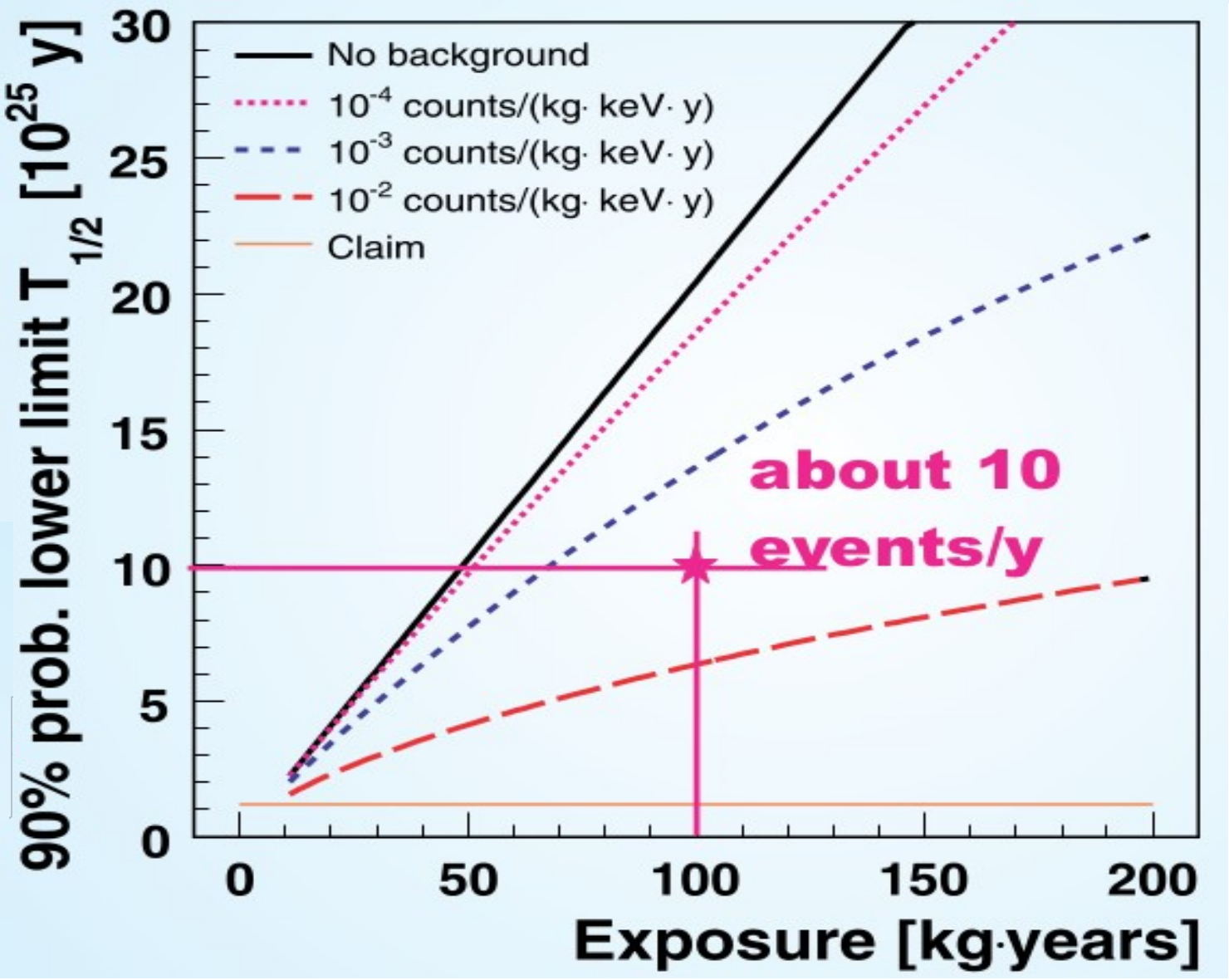

To build an experiment is crucial to know which level of background you can allow and which you can not!

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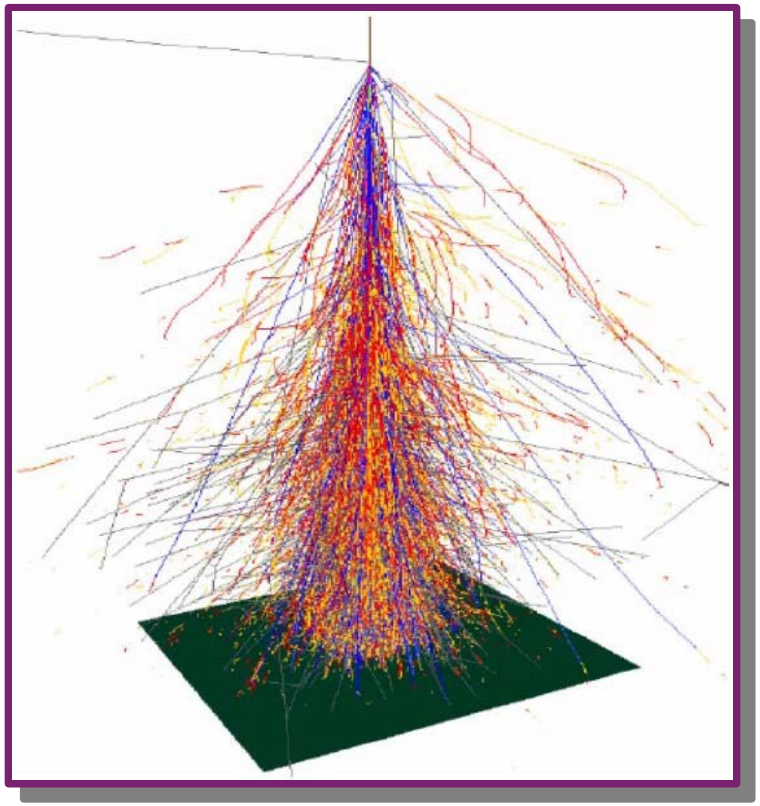
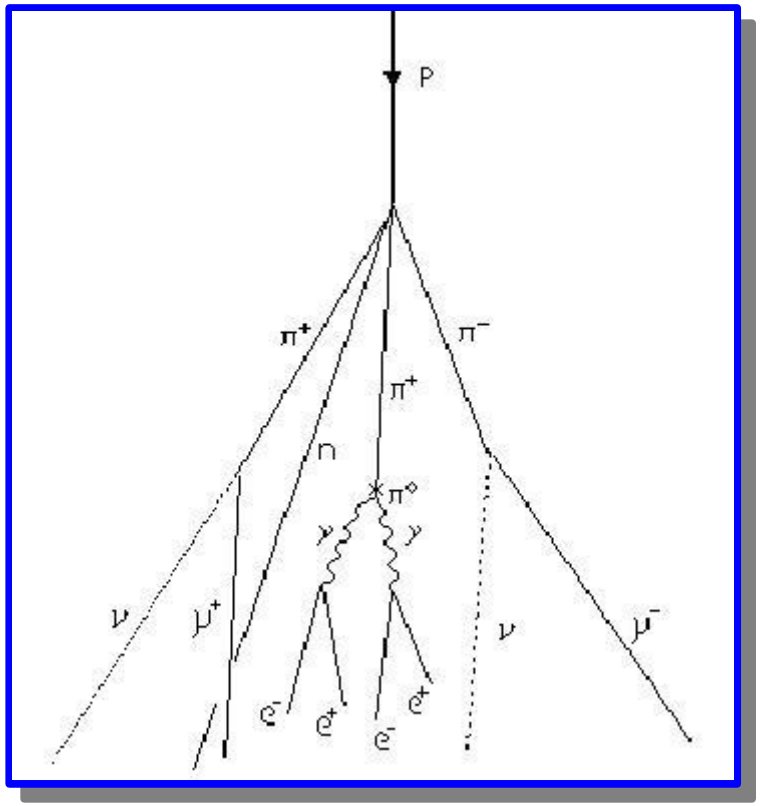
What we want to do?

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





Vertical & Horizontal Safety Distances

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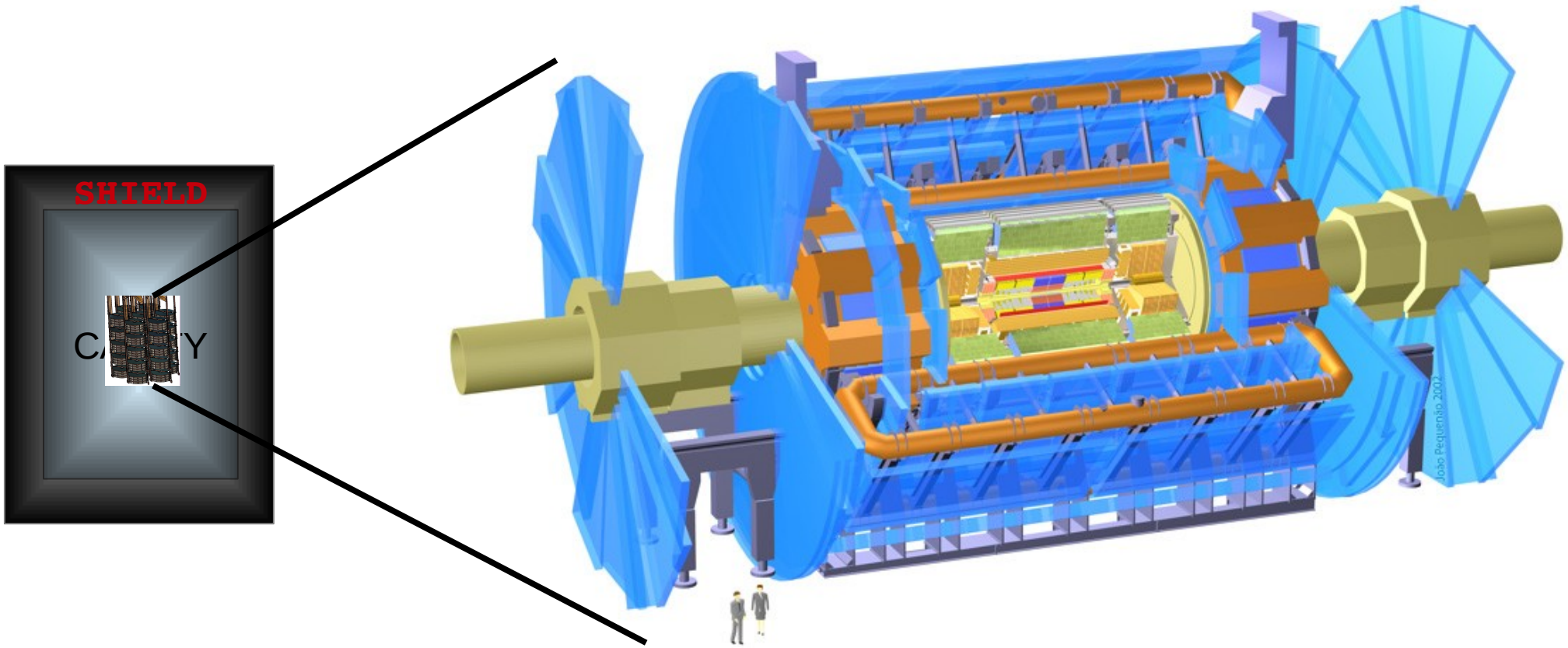

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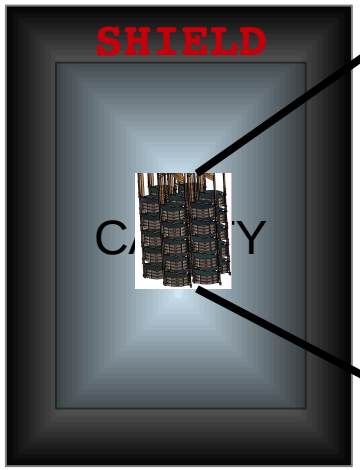

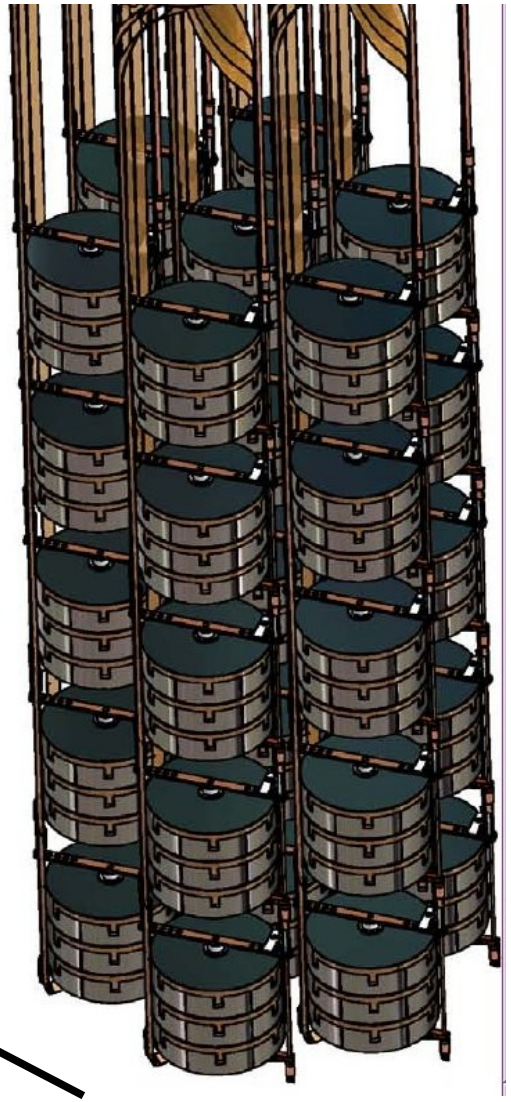

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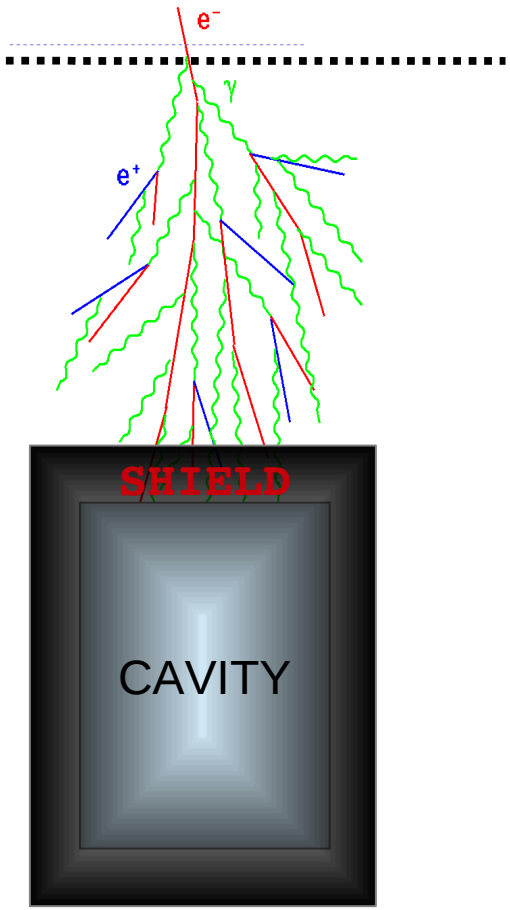

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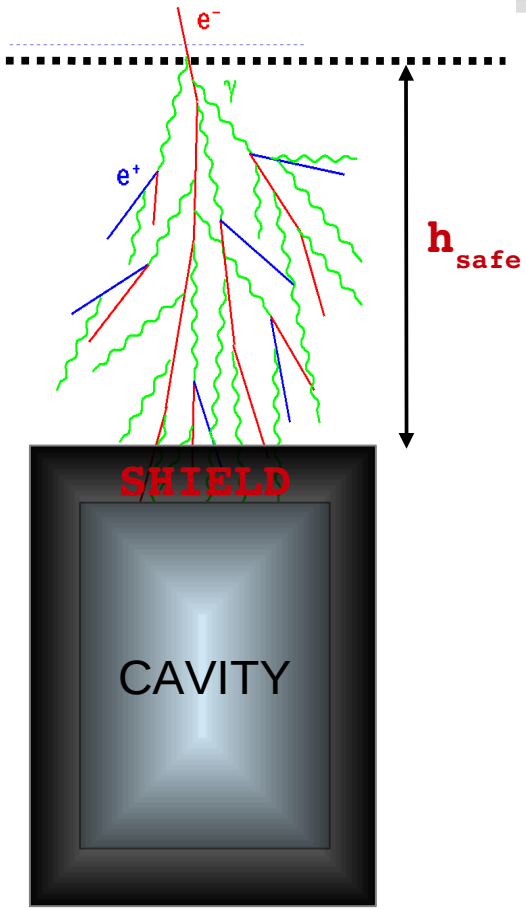
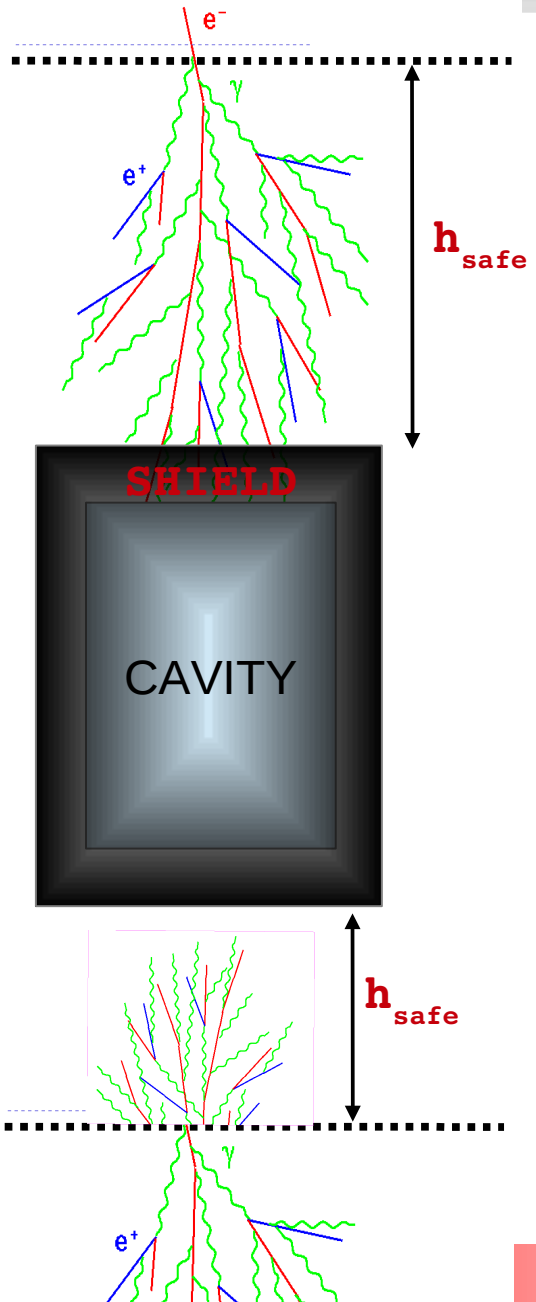


- h_{safe} : vertical distance (from the interaction point) after which
  - The shower has 5% of the incoming particle energy left
  - The shower has 10 MeV left

Vertical & Horizontal Safety Distances



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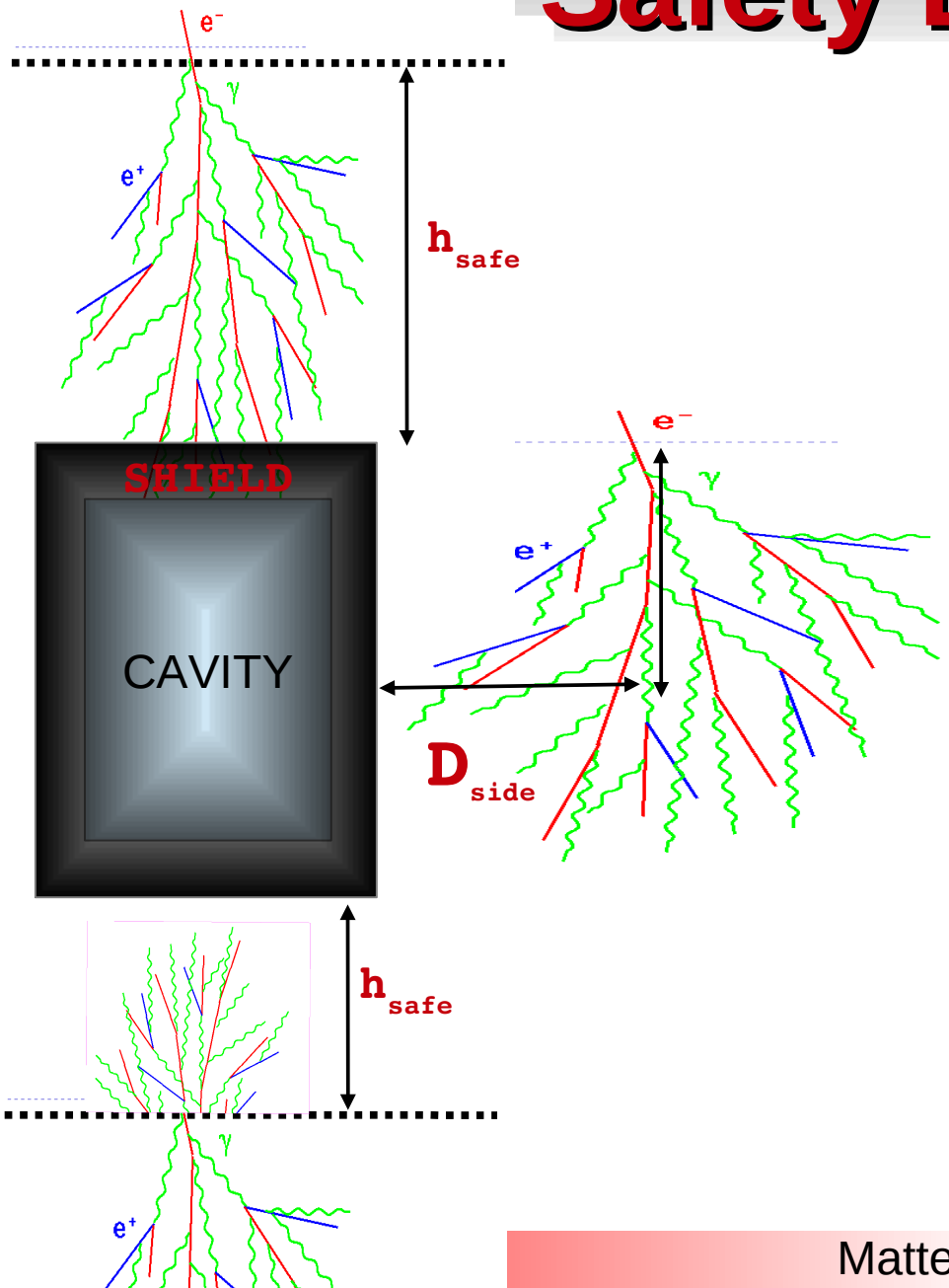


- h_{safe} : vertical distance (from the interaction point) after which
  - The shower has 5% of the incoming particle energy left
  - The shower has 10 MeV left

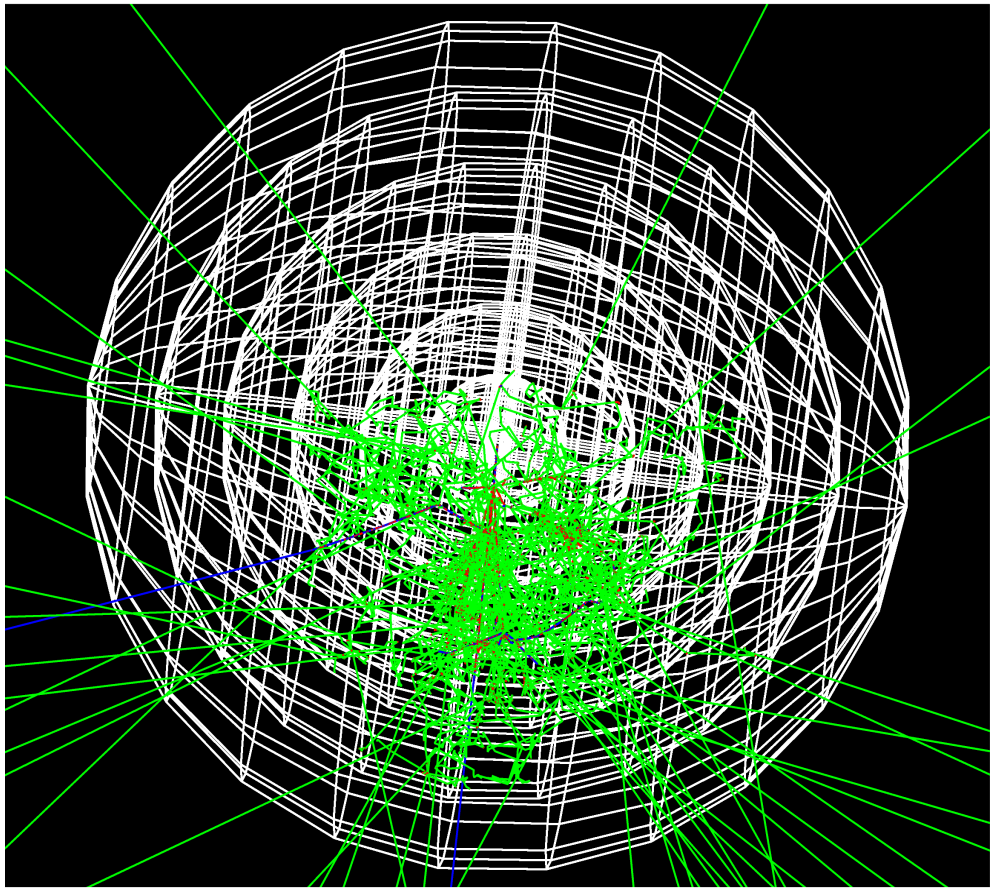
- D_{side} : horizontal distance (from the mean energy position) after which
  - The shower leaves 95% of the incoming particle energy
  - Only 10 MeV can reach the shield

How do we do that? (1)

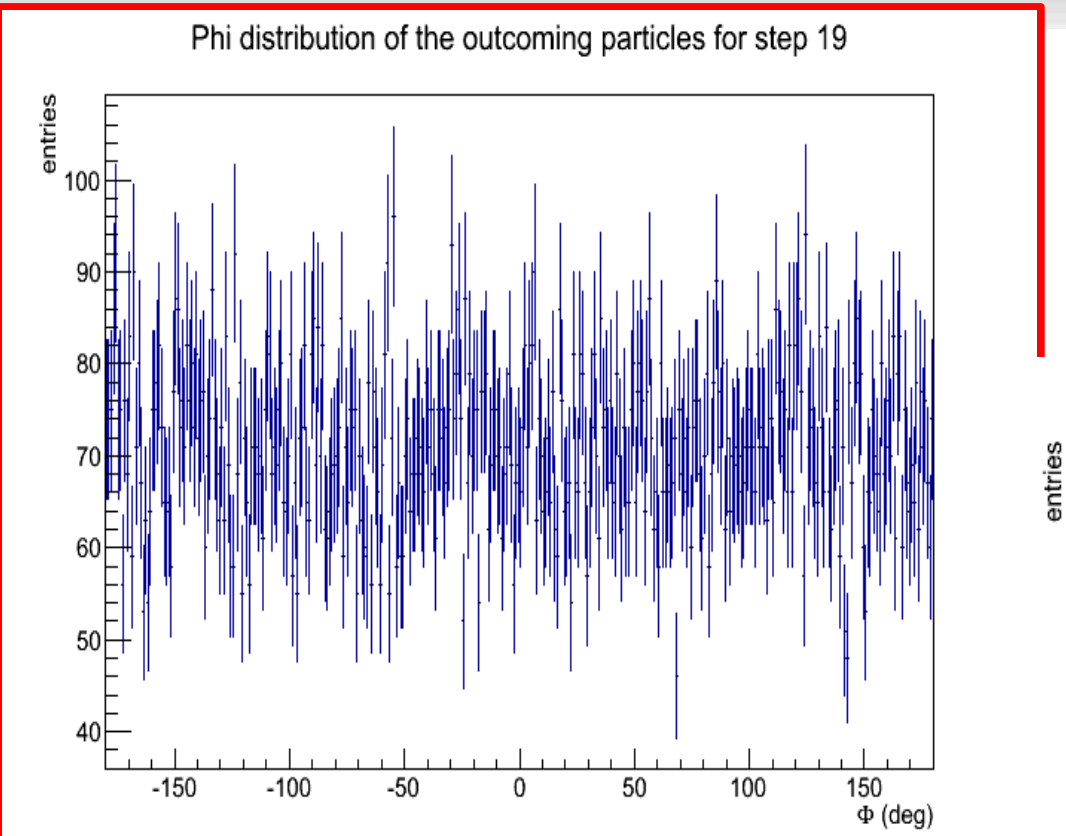
- Shot a particle of certain energy along **-Y** direction

- Let it creates a shower in the center of a rock-made sphere (**divided into sub-spheres**)

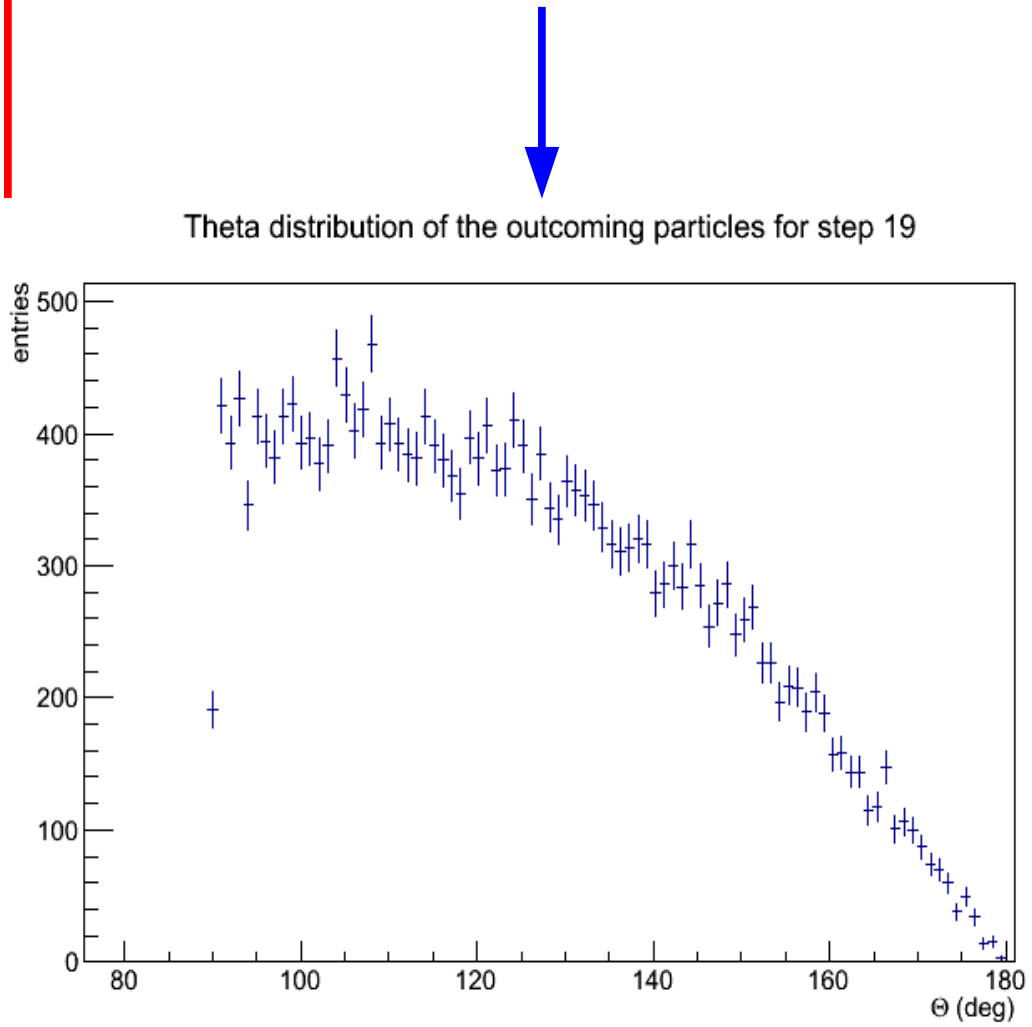
- Record all the particles with their properties (e.g. **position, kinetic energy, charge**, etc.) that arrive at each single sub-sphere surface



How do we do that? (2)

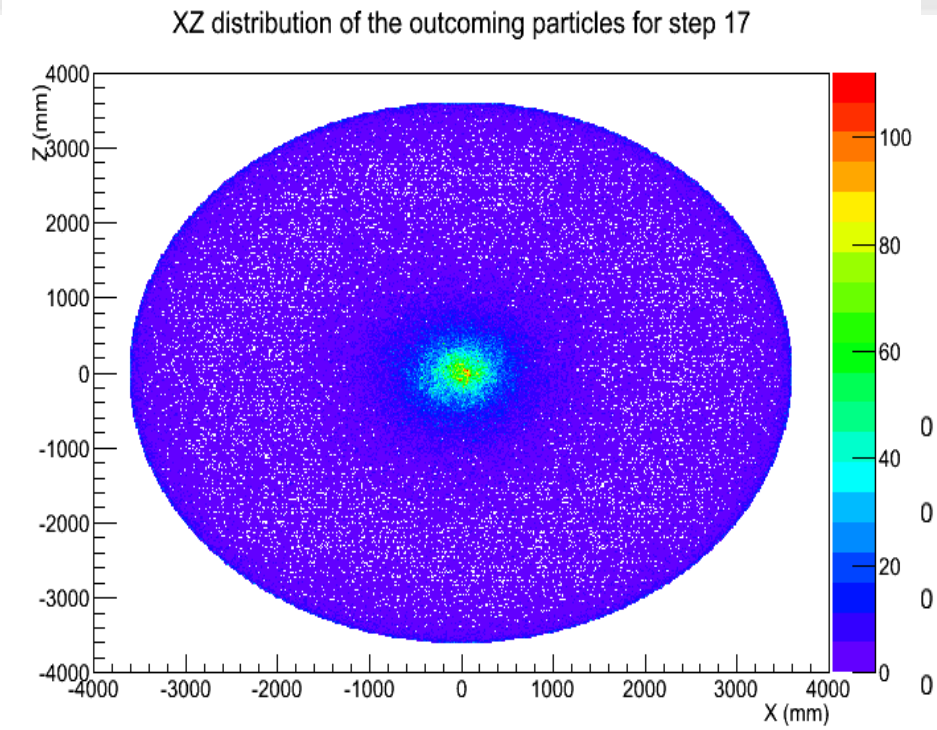


- Looking Forward



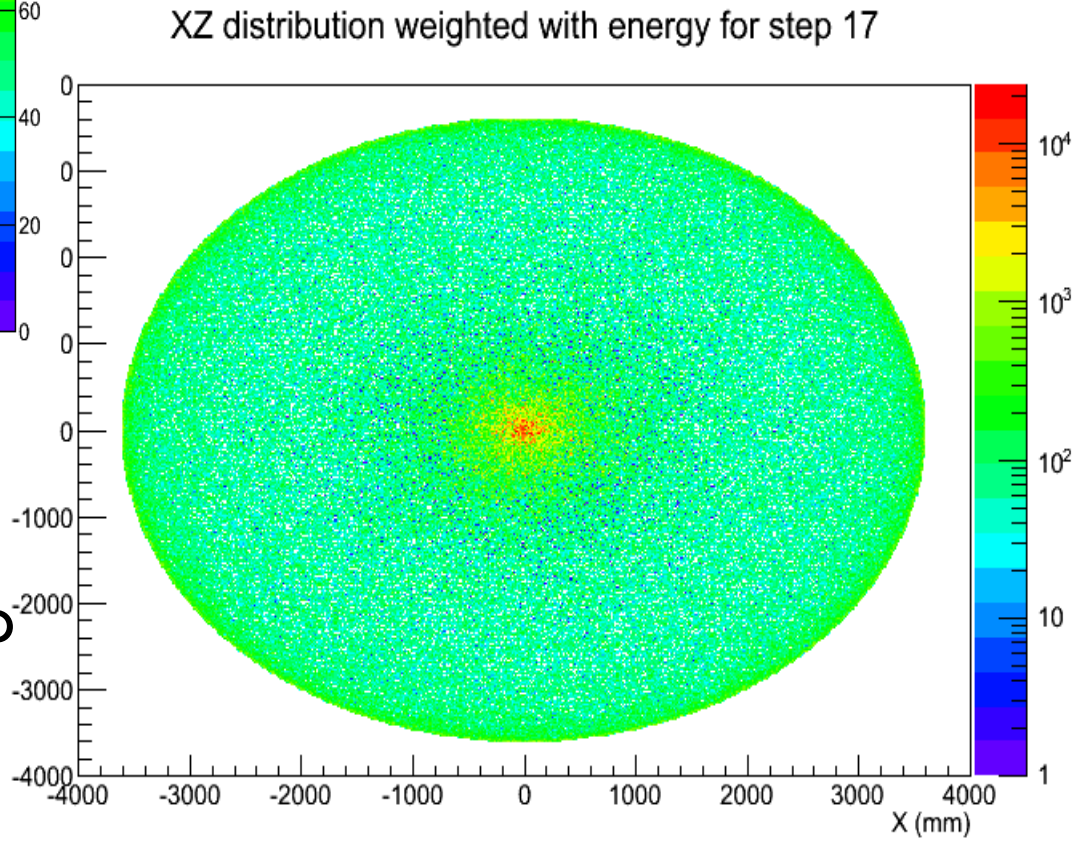
- Isotropically distributed wrt the polar angle on the XZ plane

Position Weighted with Kinetic Energy



- XZ particle distribution for a particular step

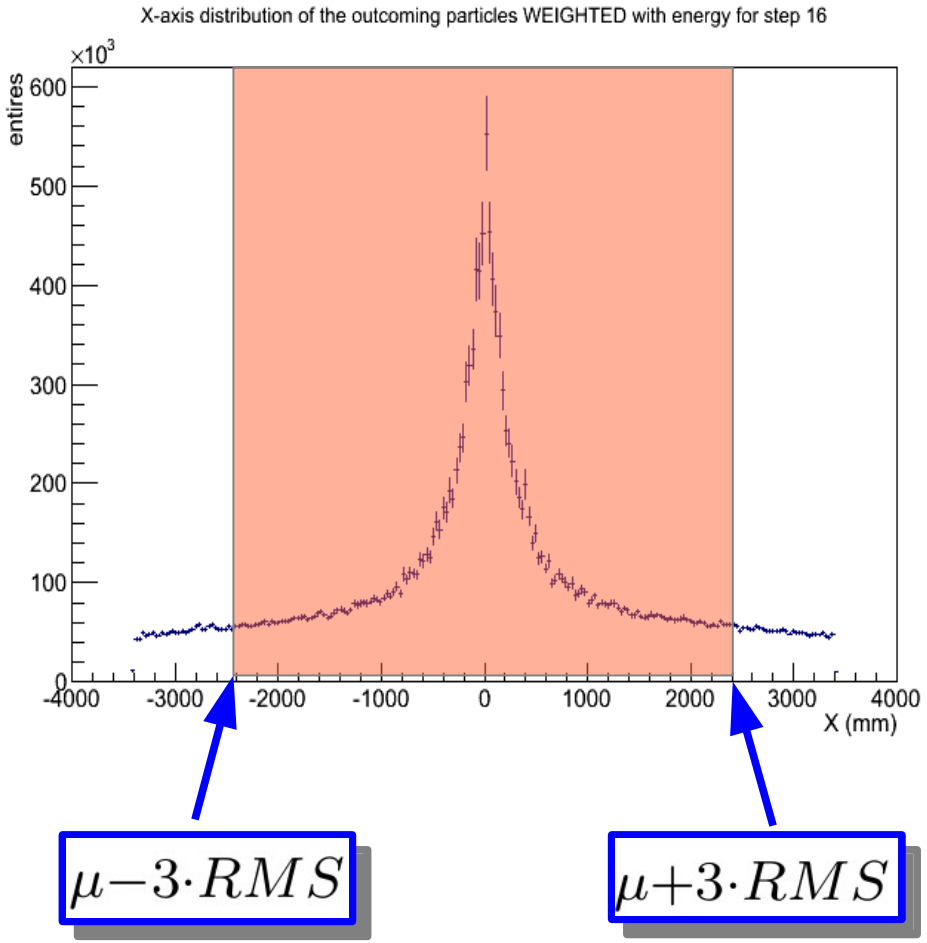
- XZ distribution WEIGHTED with Kinetic Energy



Vertical Distance (1)

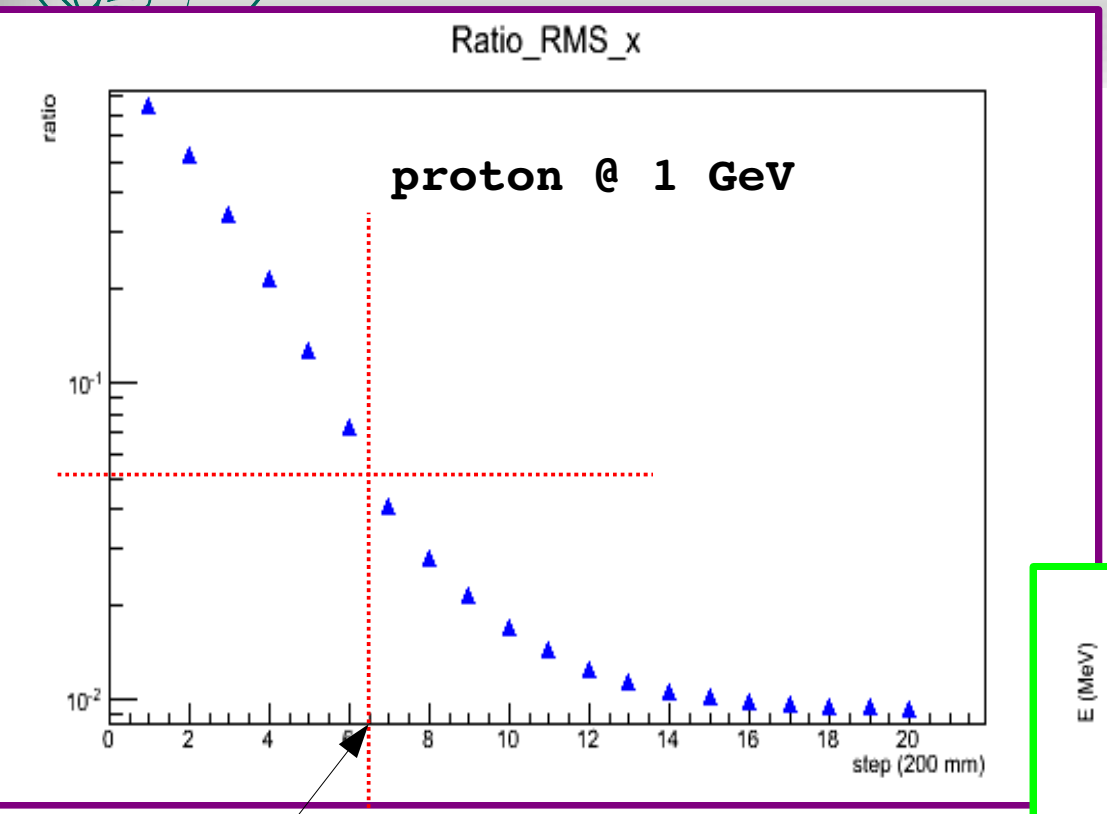
- For each step:
  - Evaluate

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



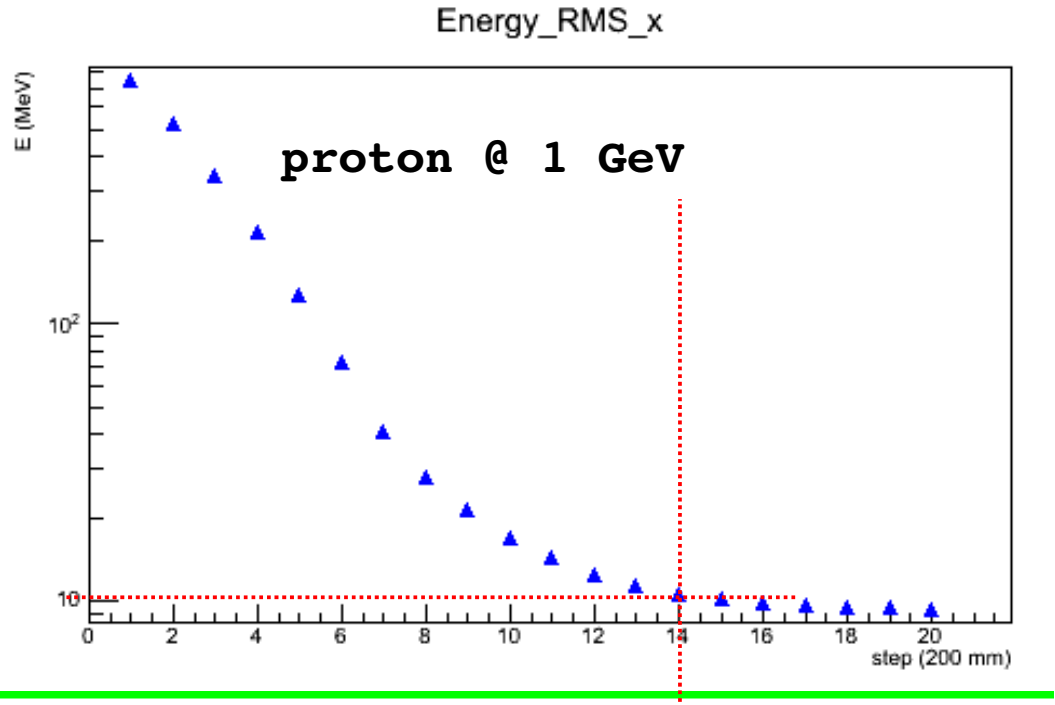
- Then use this quantity to infer the safety vertical distances according to the definitions

Vertical Distance (2)



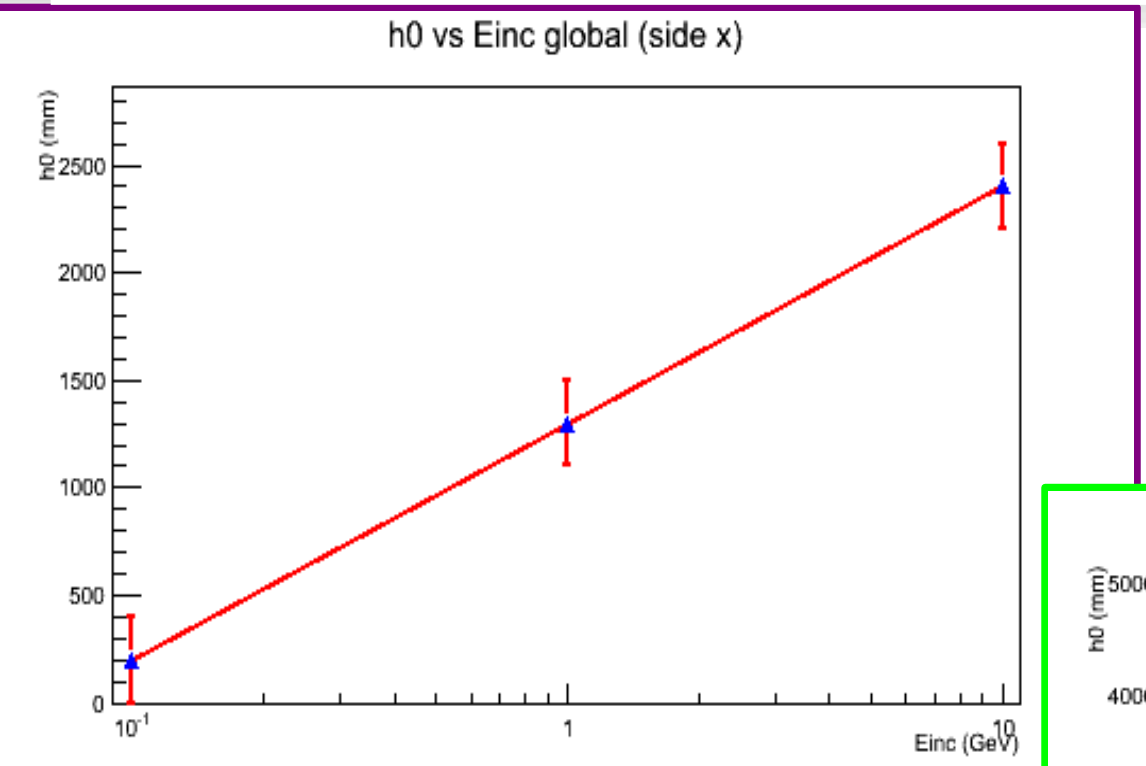
- h_{safe} @ 5% $E_{incoming}$ **Threshold**

- h_{safe} @ 10 MeV **Threshold**



Vertical Distance (3)

h_{safe} for 3 different incoming particle energies

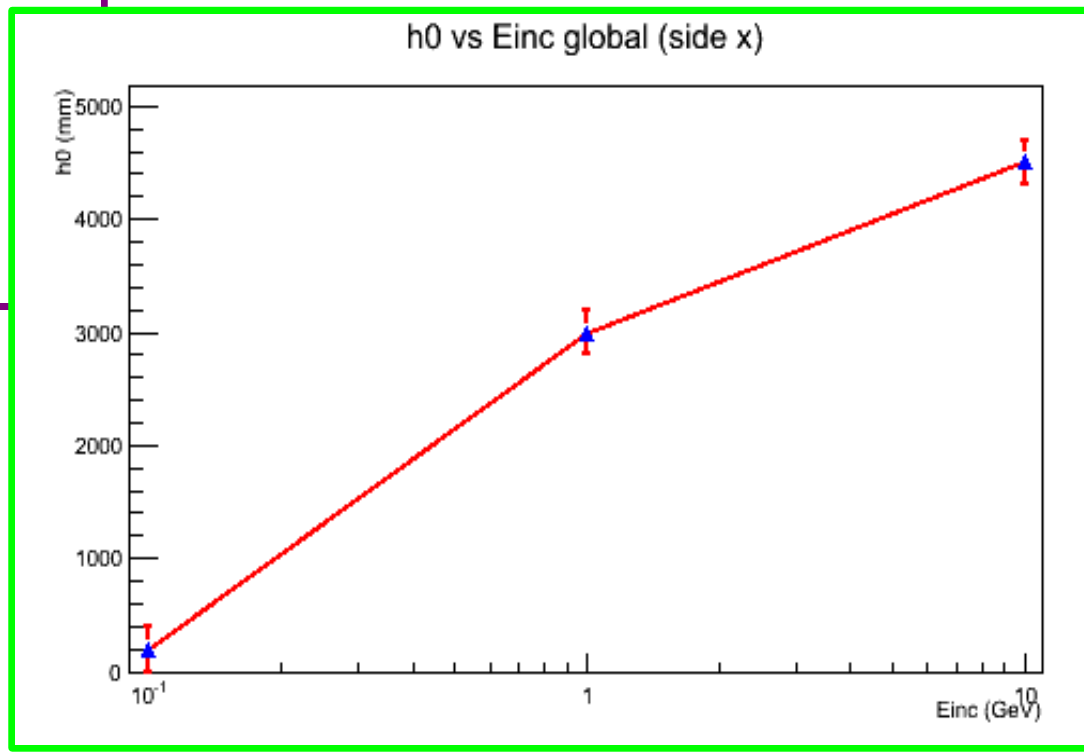


- h_{safe} @ 10 MeV

Threshold

- h_{safe} @ 5% $E_{incoming}$

Threshold



Horizontal Distance (1)

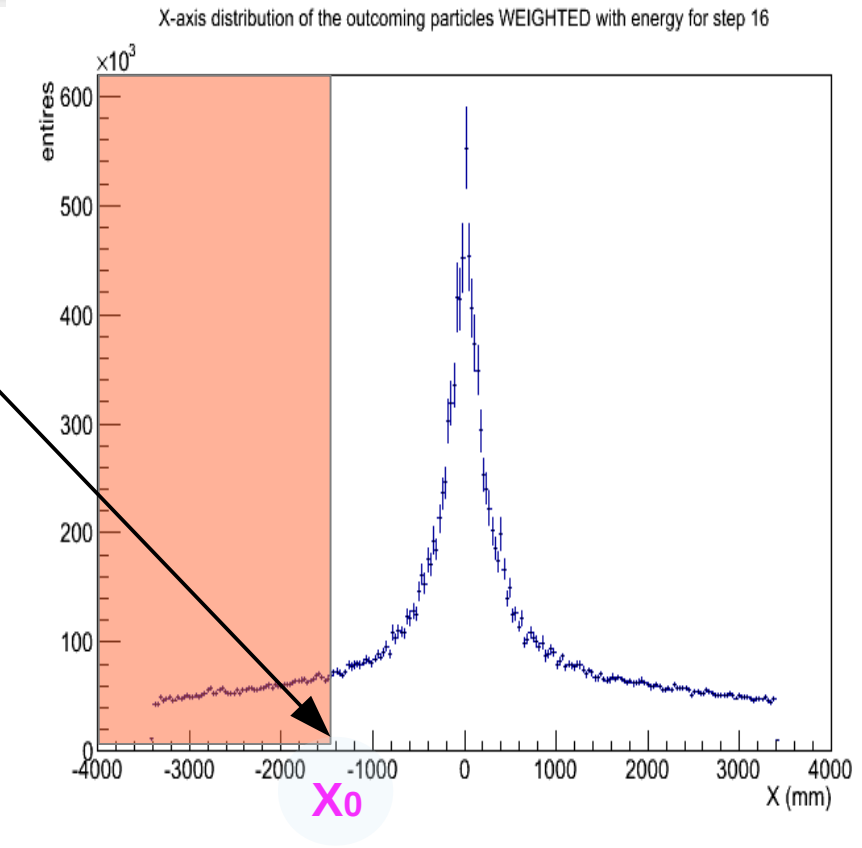
- For each step:
  - Search the point X_0 so that:

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

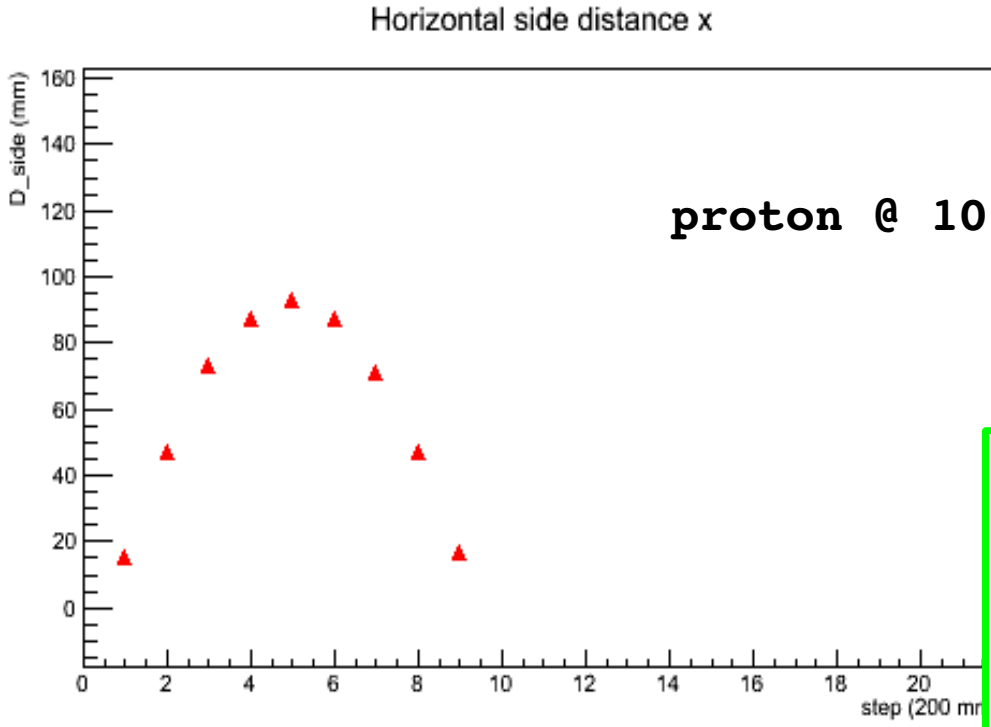
  - The safety horizontal distance is defined as:

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

  - Then take the maximum wrt the depth



Horizontal Distance (2)



- D_{side} @ 10 MeV

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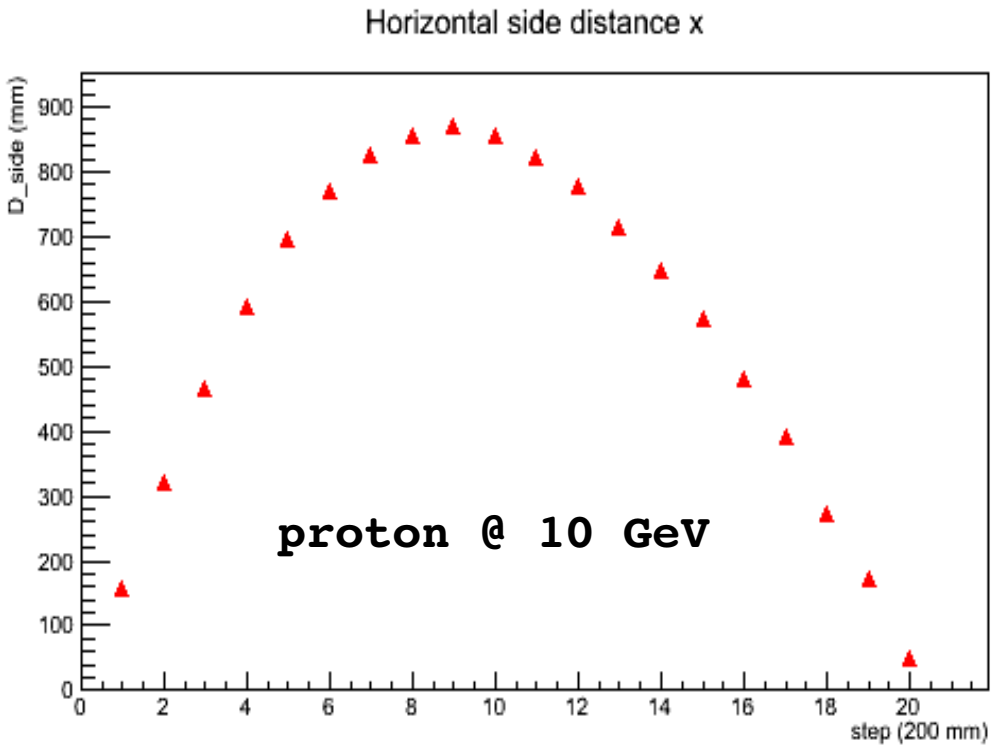
Threshold



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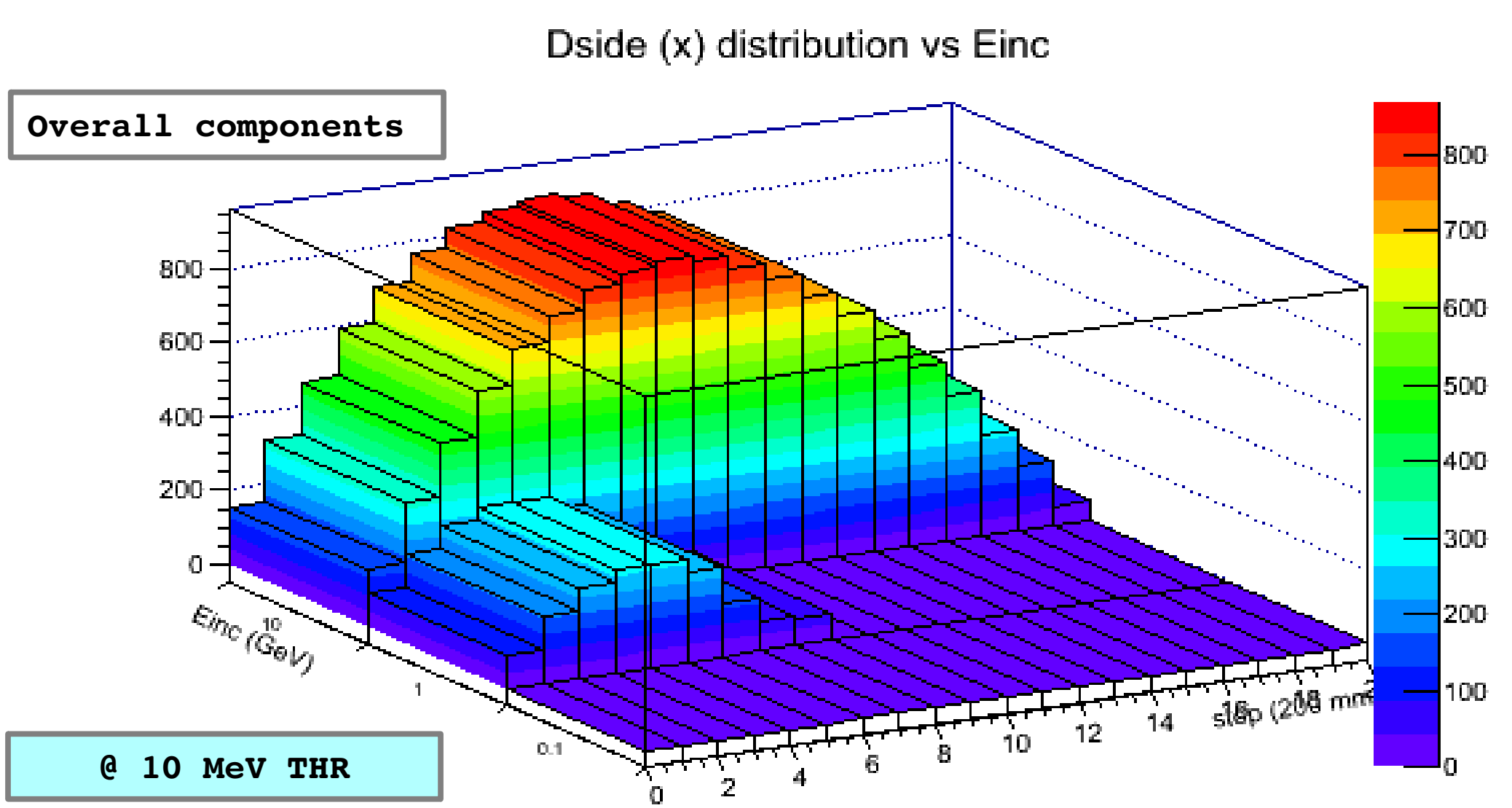
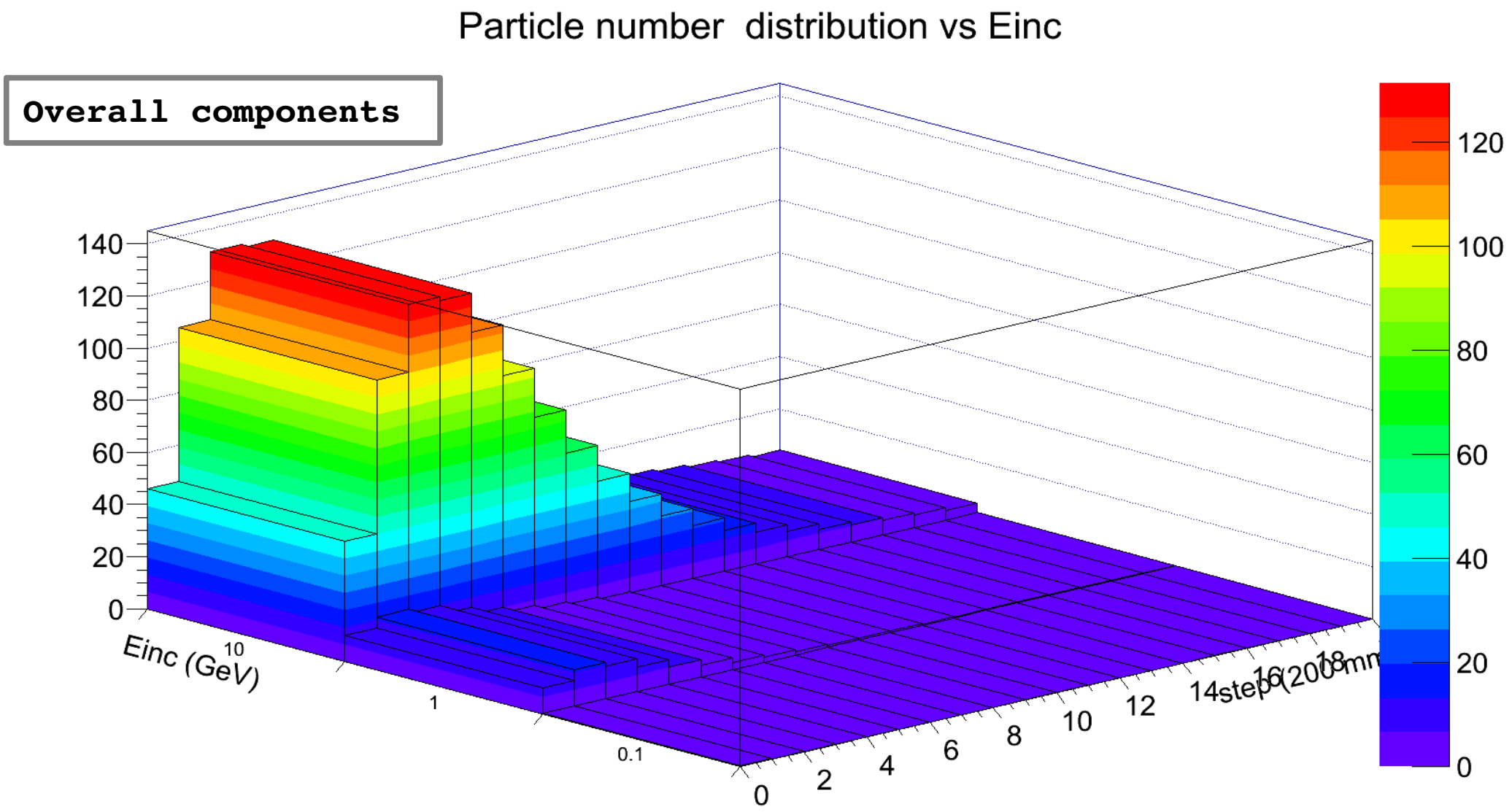
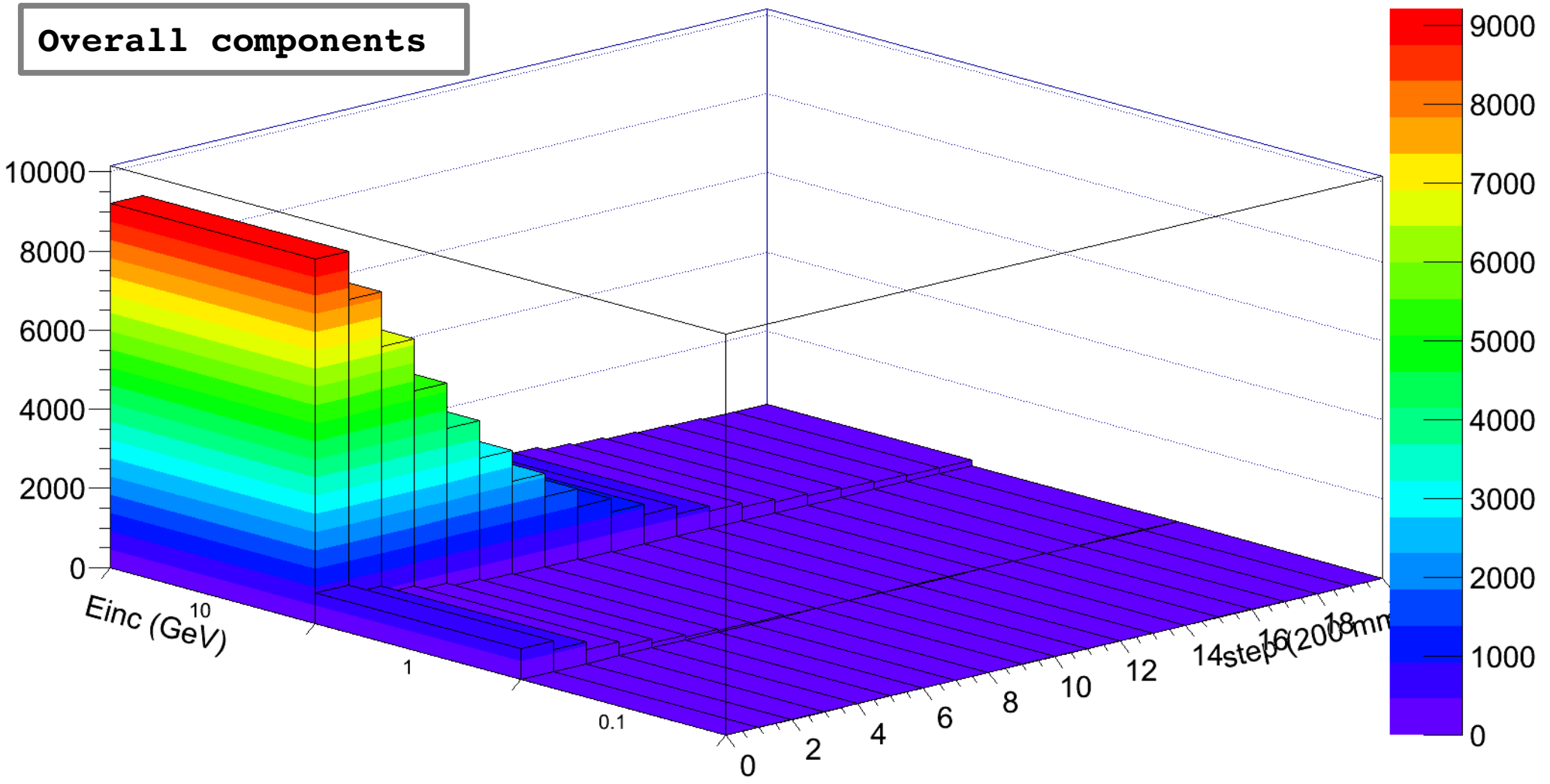


Global Results (1)



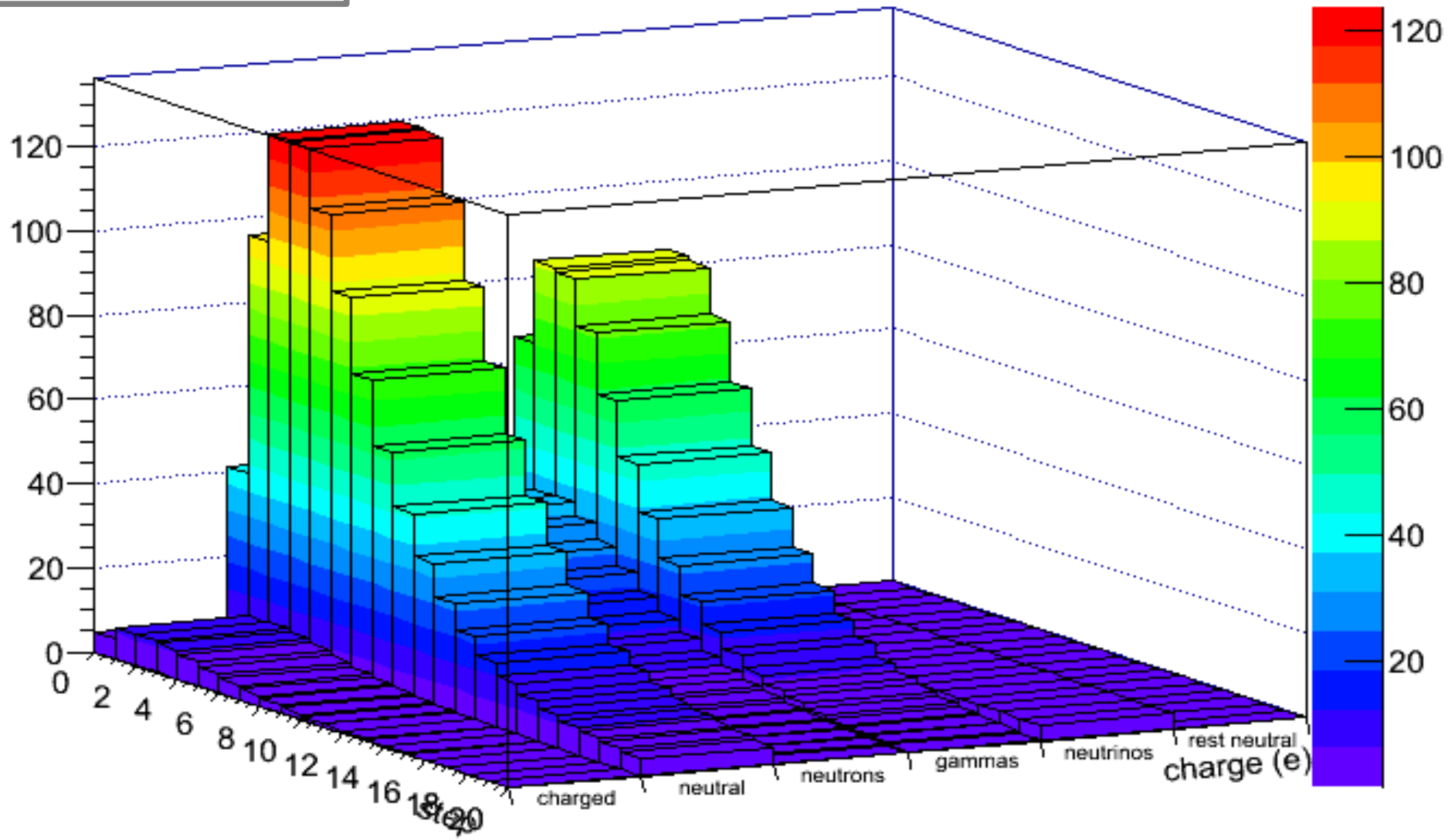
Global Results (2)

Particle number weighted with ENERGY distribution vs Einc



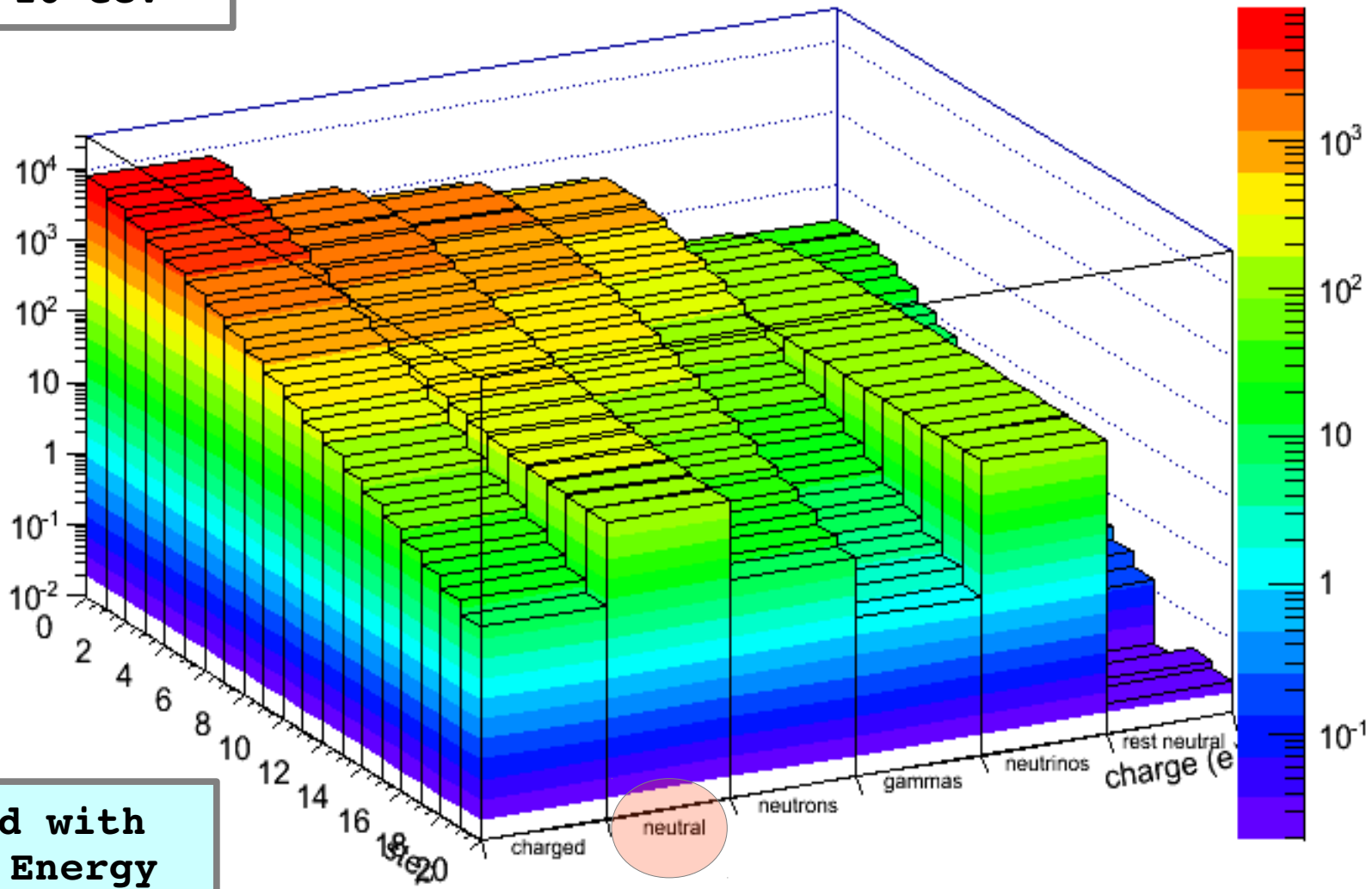
Global Results (3)

proton @ 10 GeV



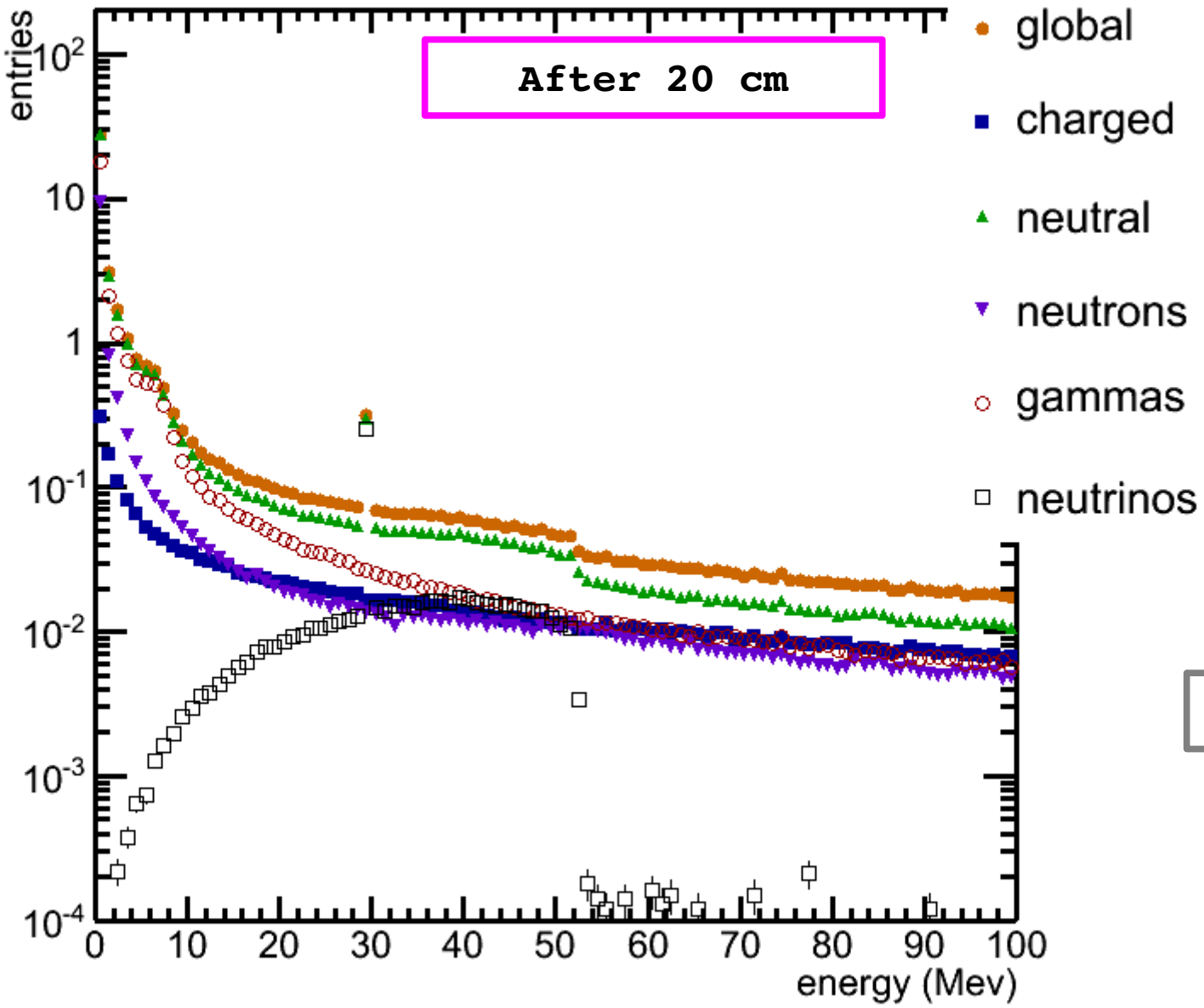
Global Results (4)

proton @ 10 GeV



Weighted with Kinetic Energy

Global Results: Energy Spectra



proton @ 10 GeV

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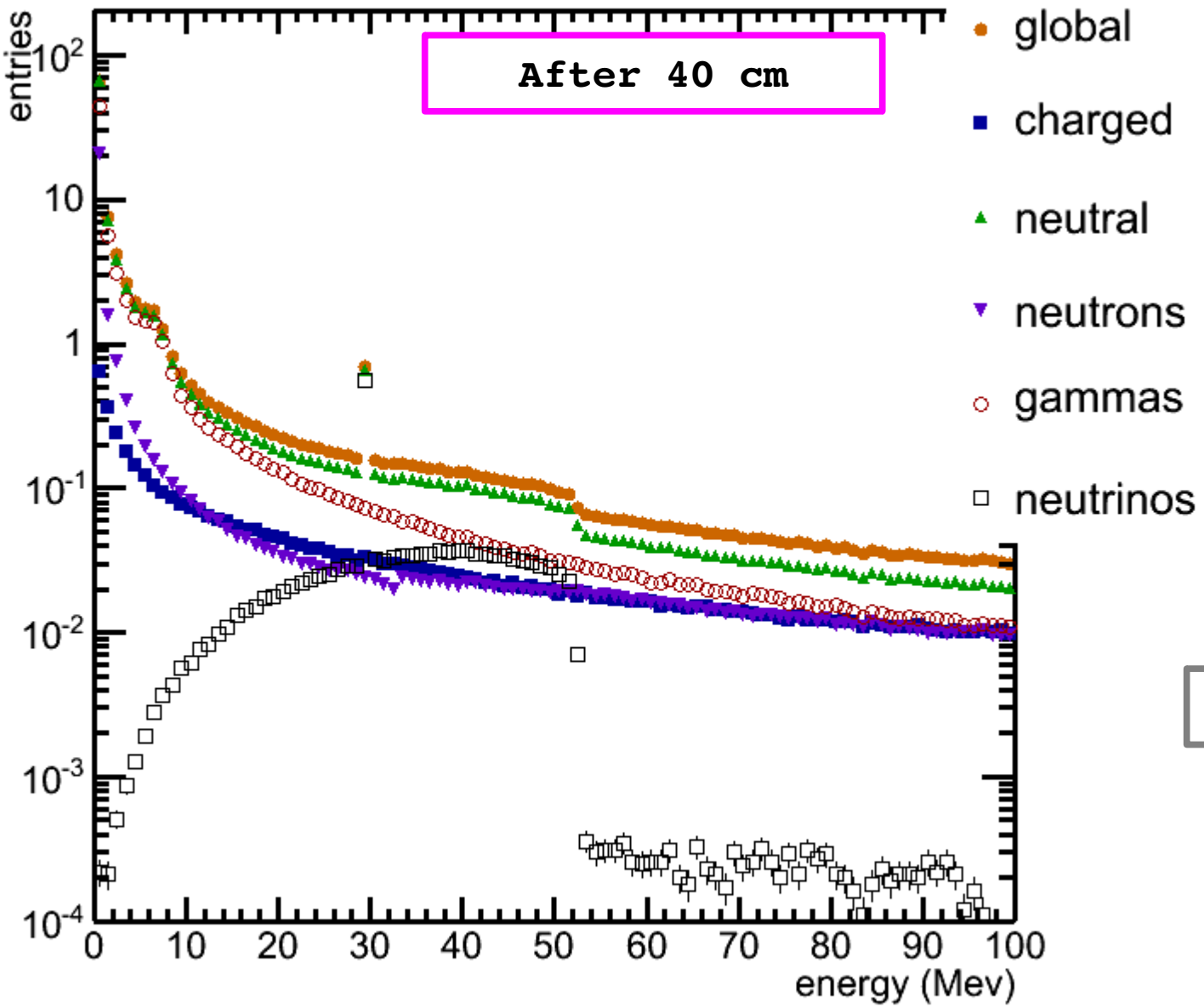

proton @ 10 GeV

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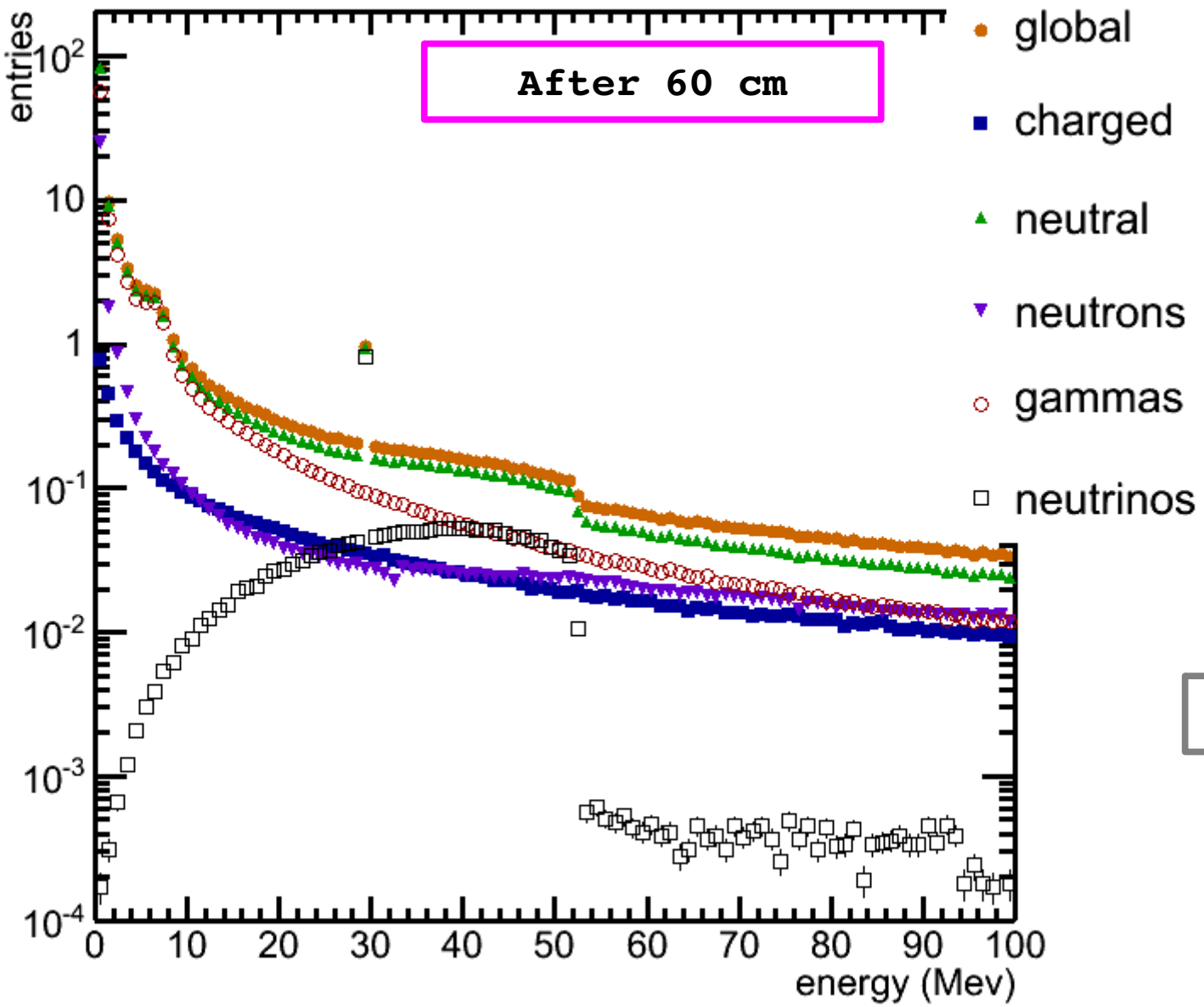

proton @ 10 GeV

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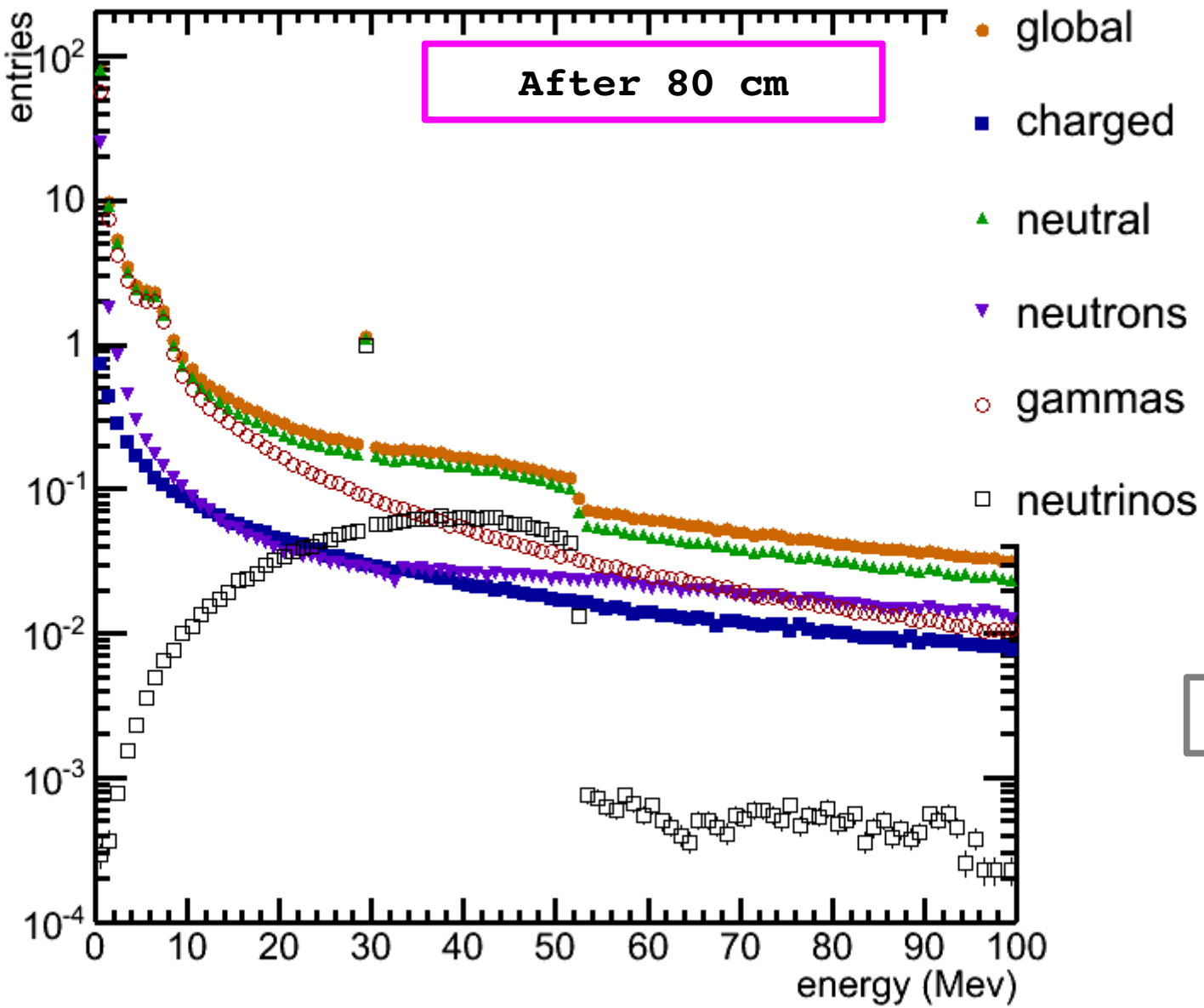

proton @ 10 GeV

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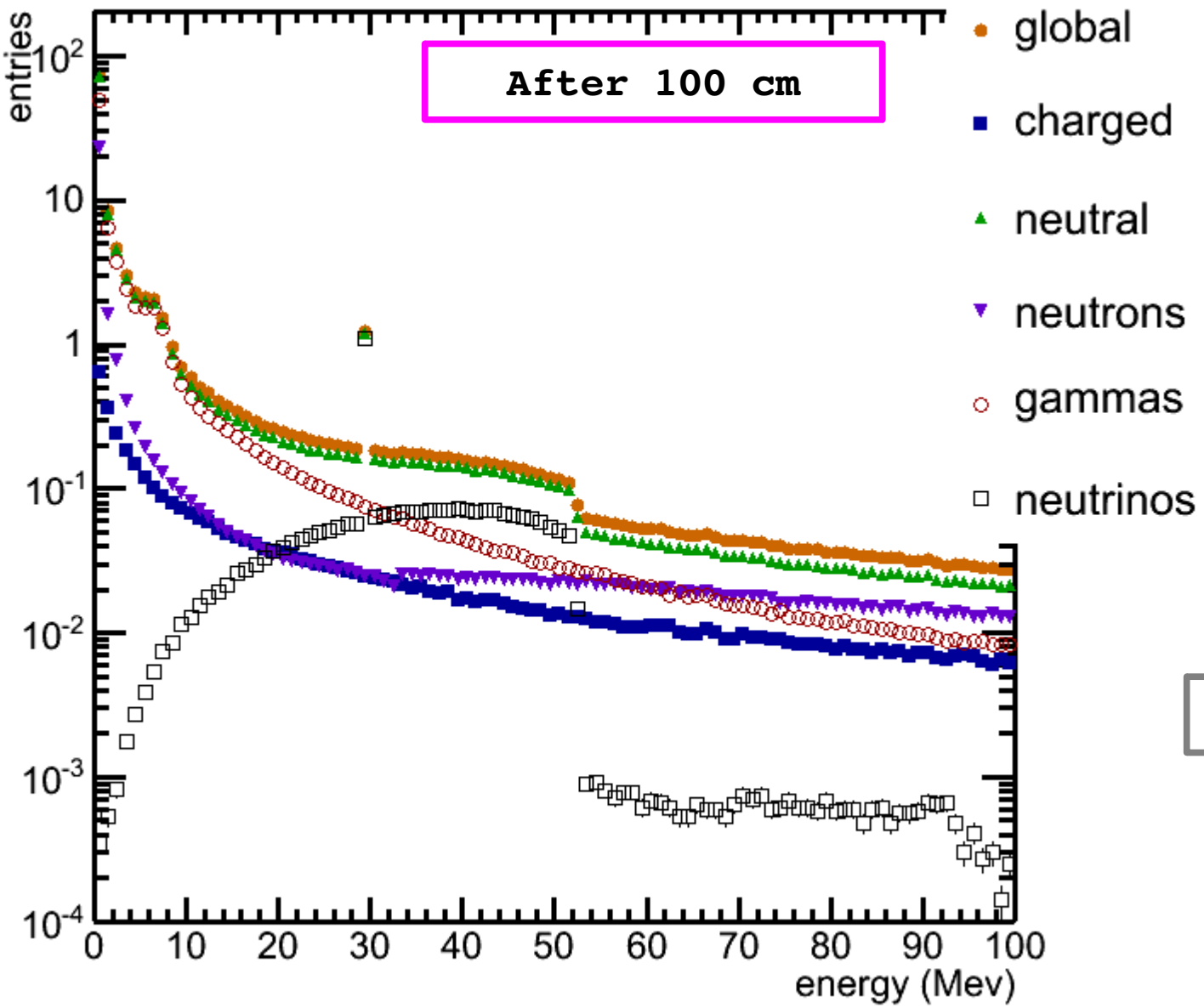
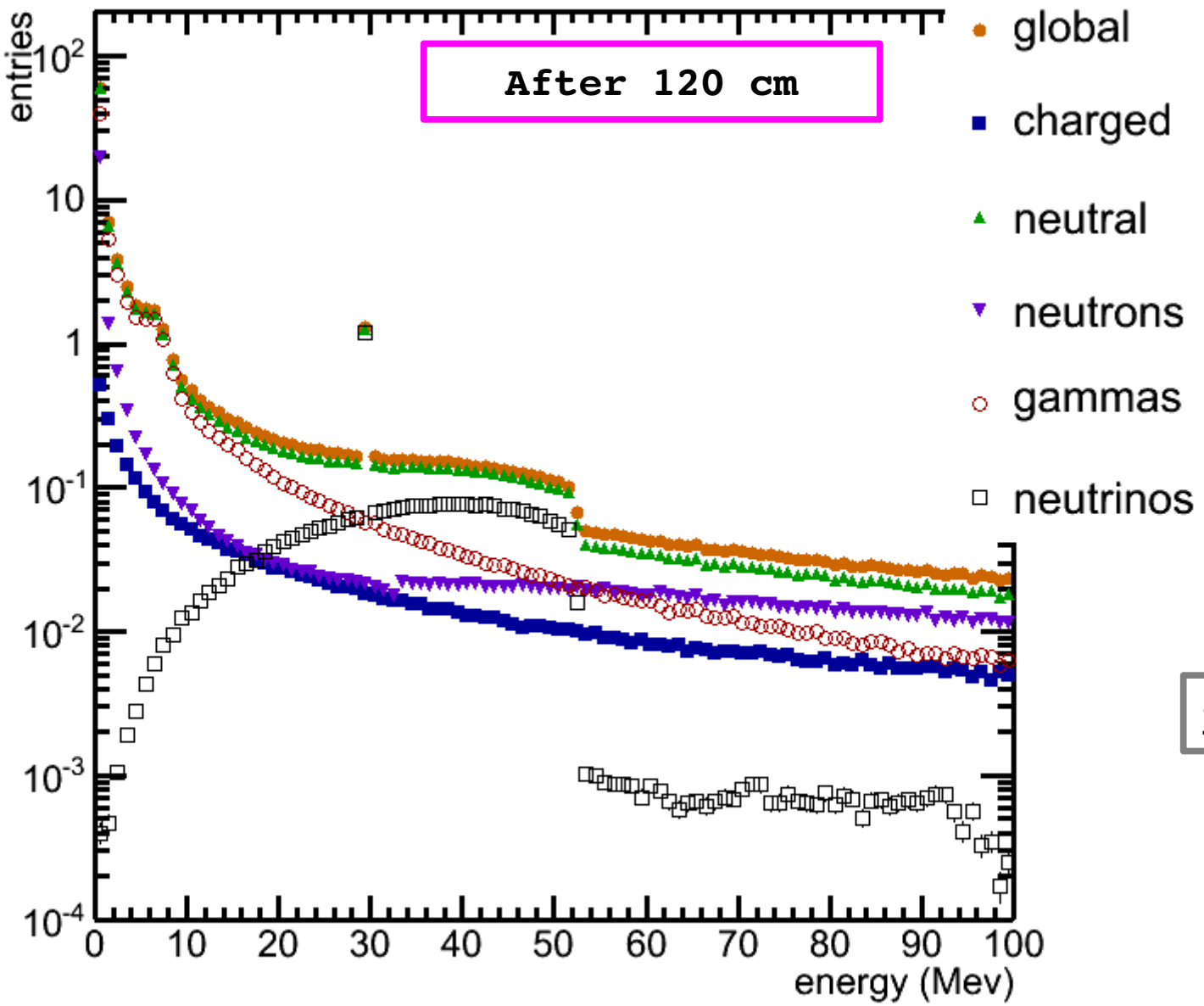


proton @ 10 GeV

Global Results: Energy Spectra



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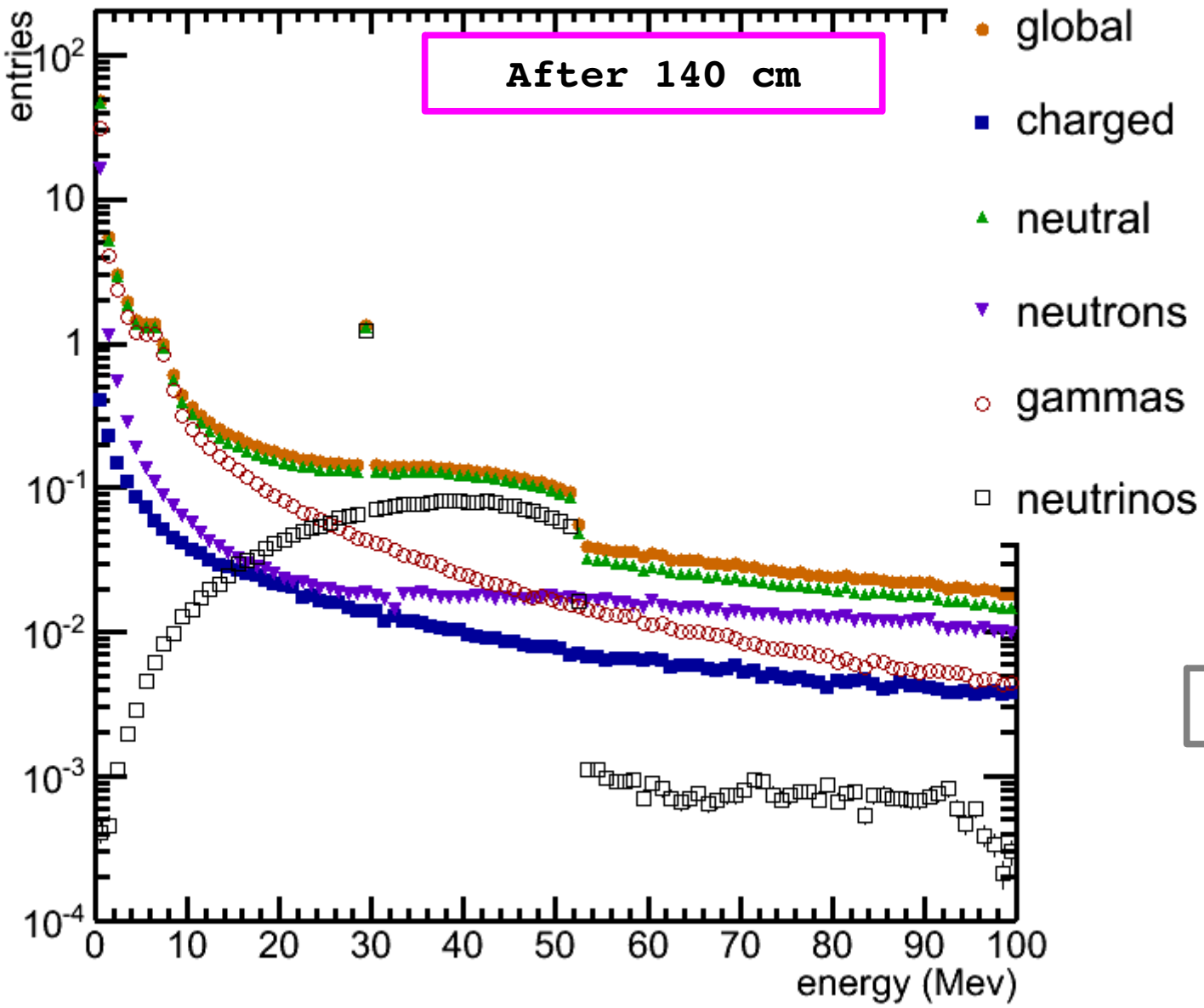

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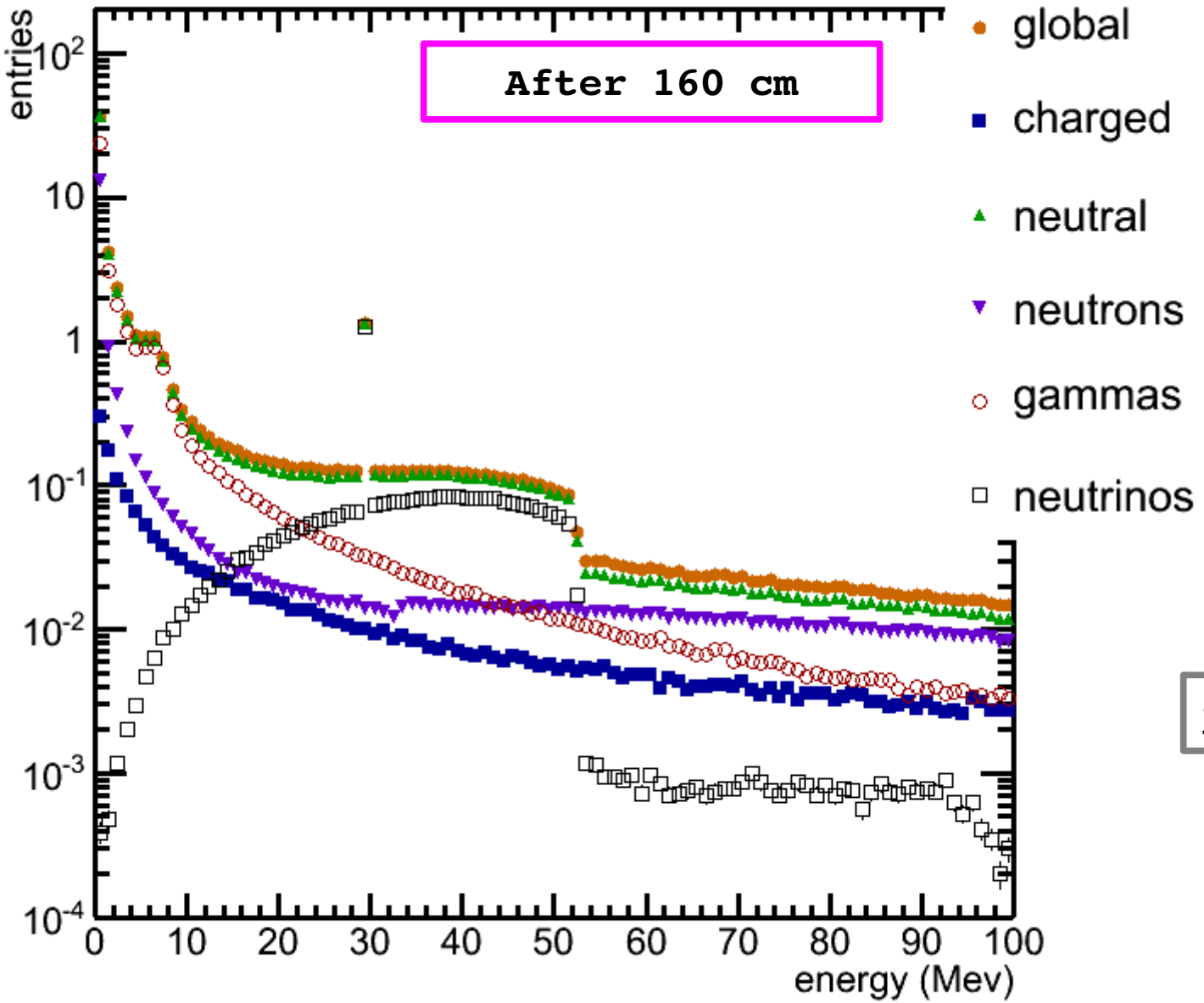

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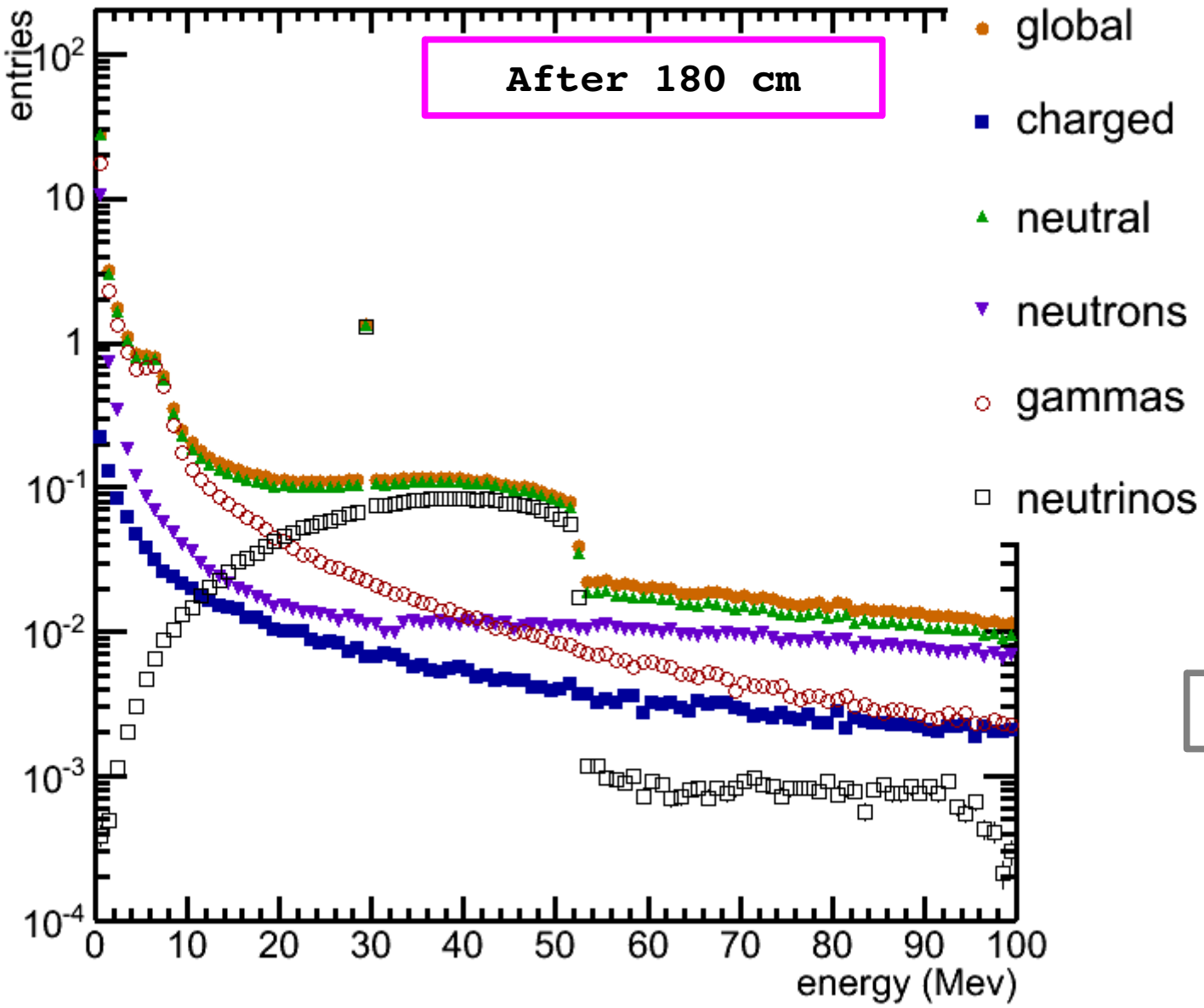

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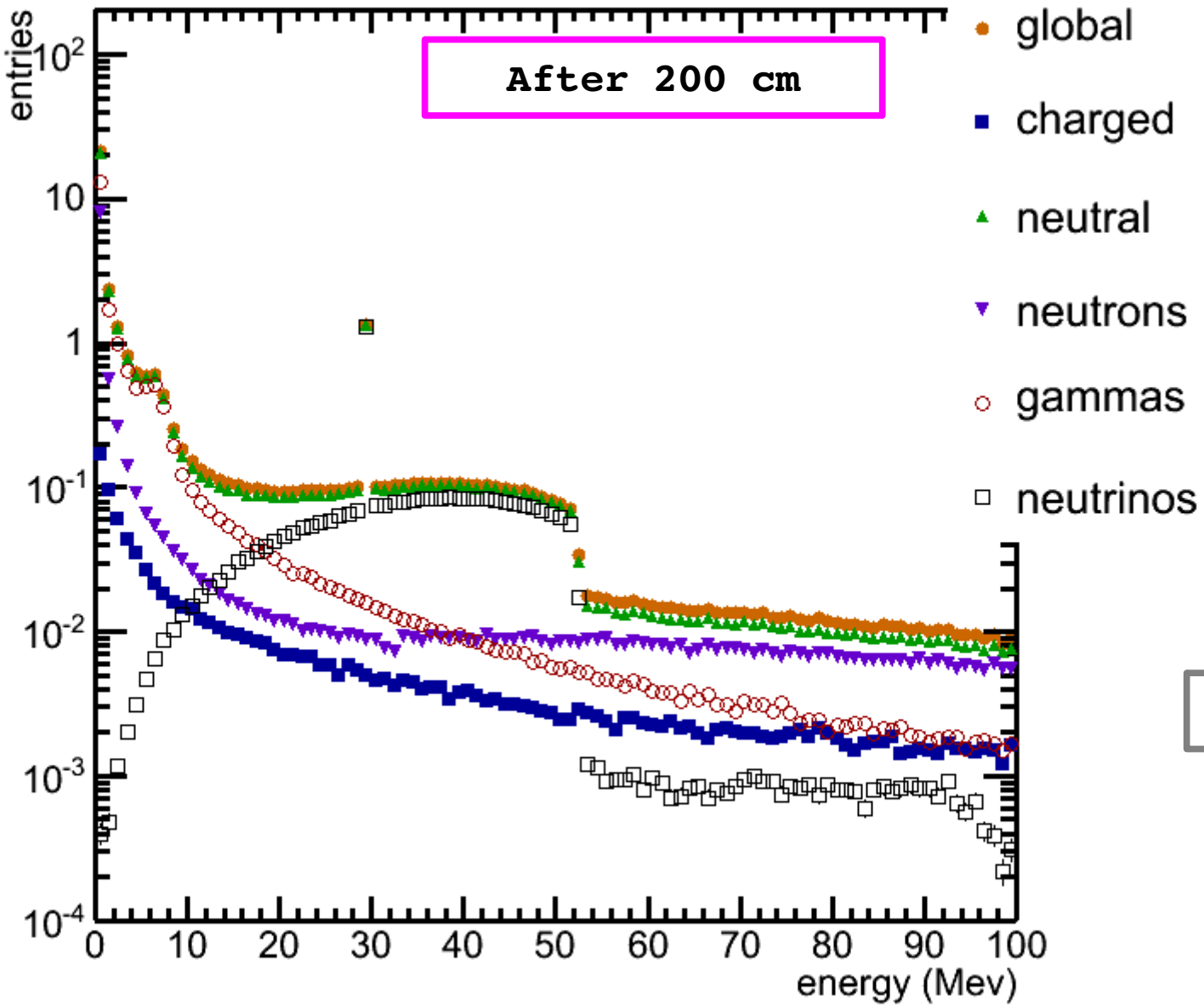

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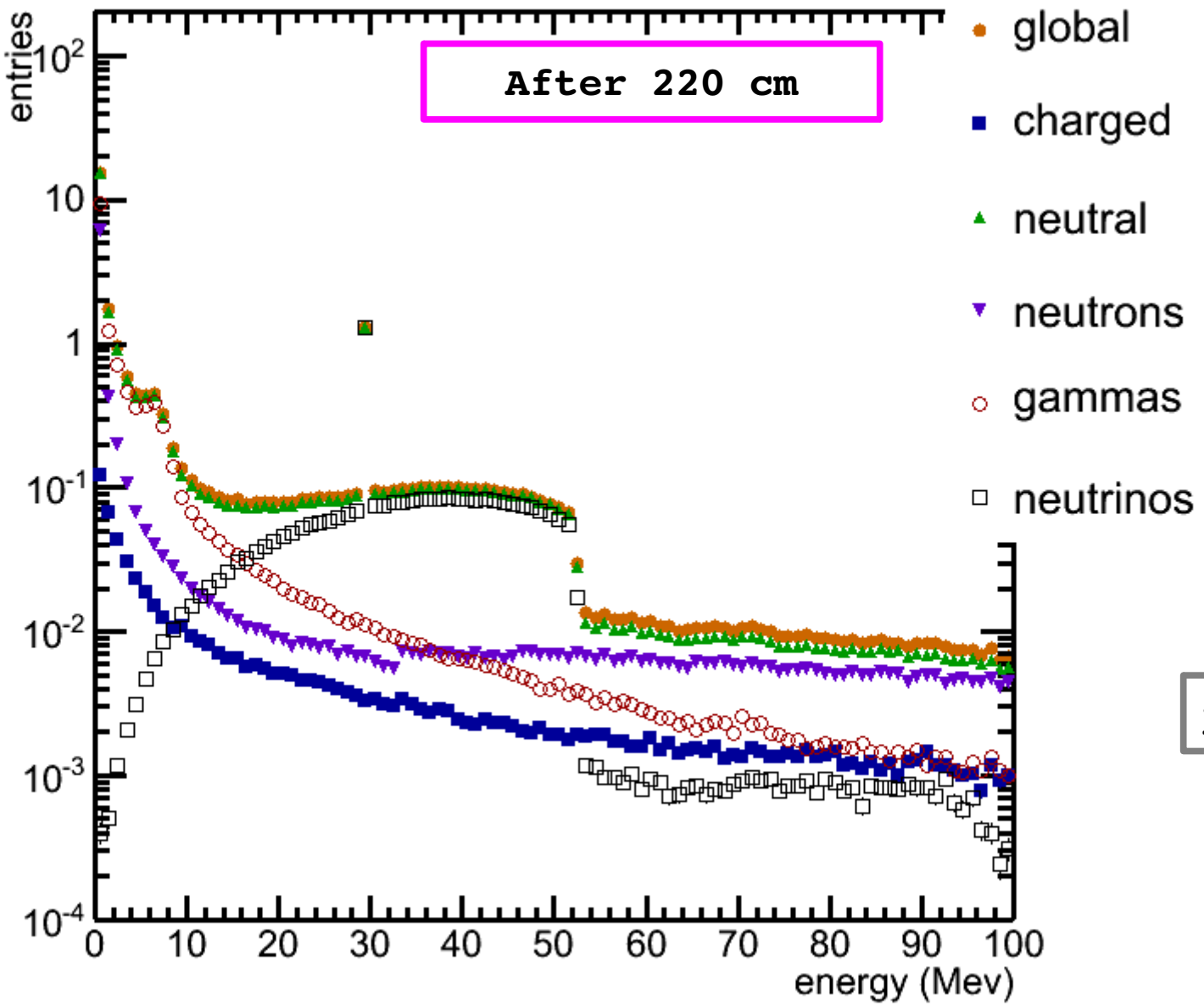

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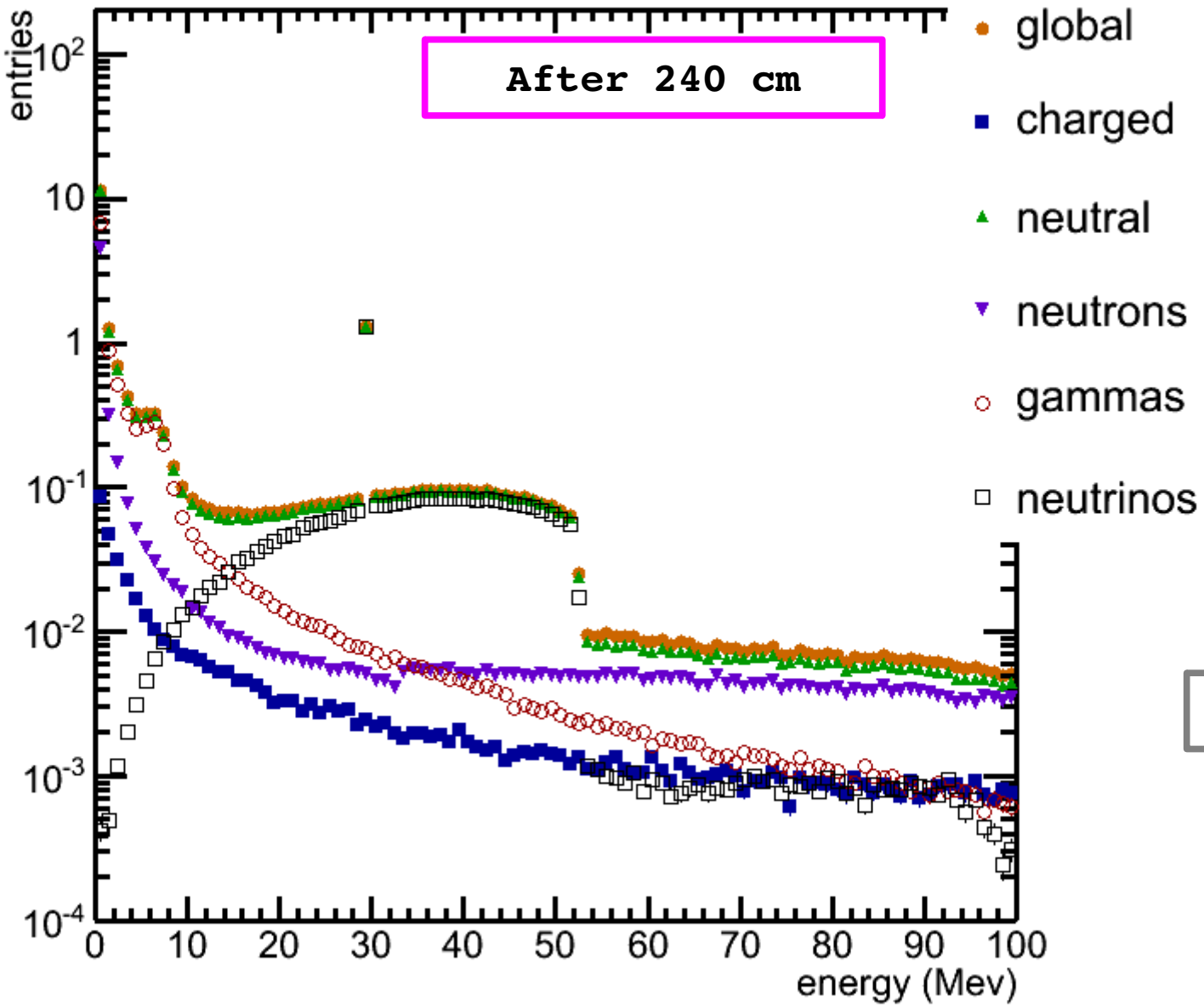

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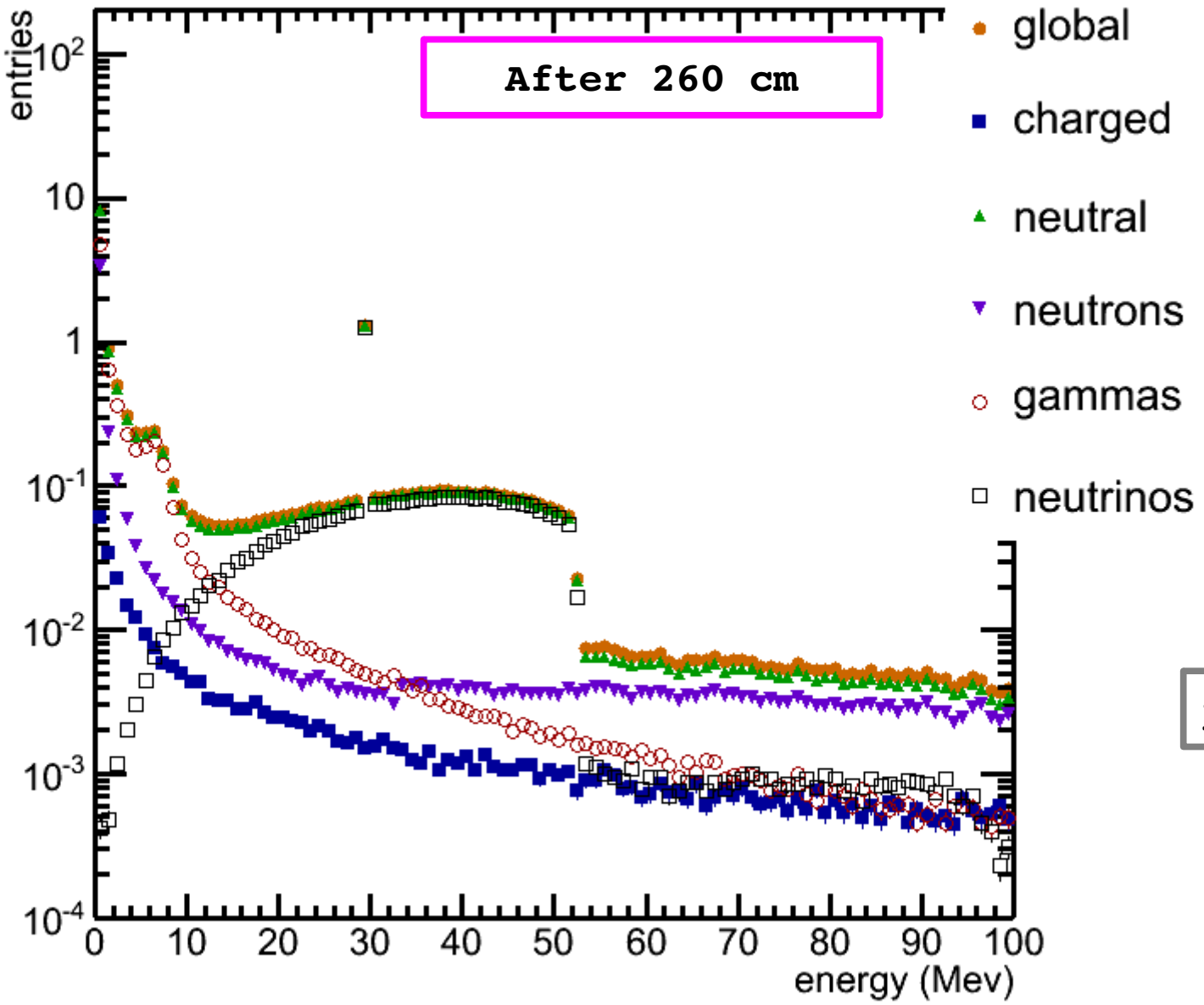

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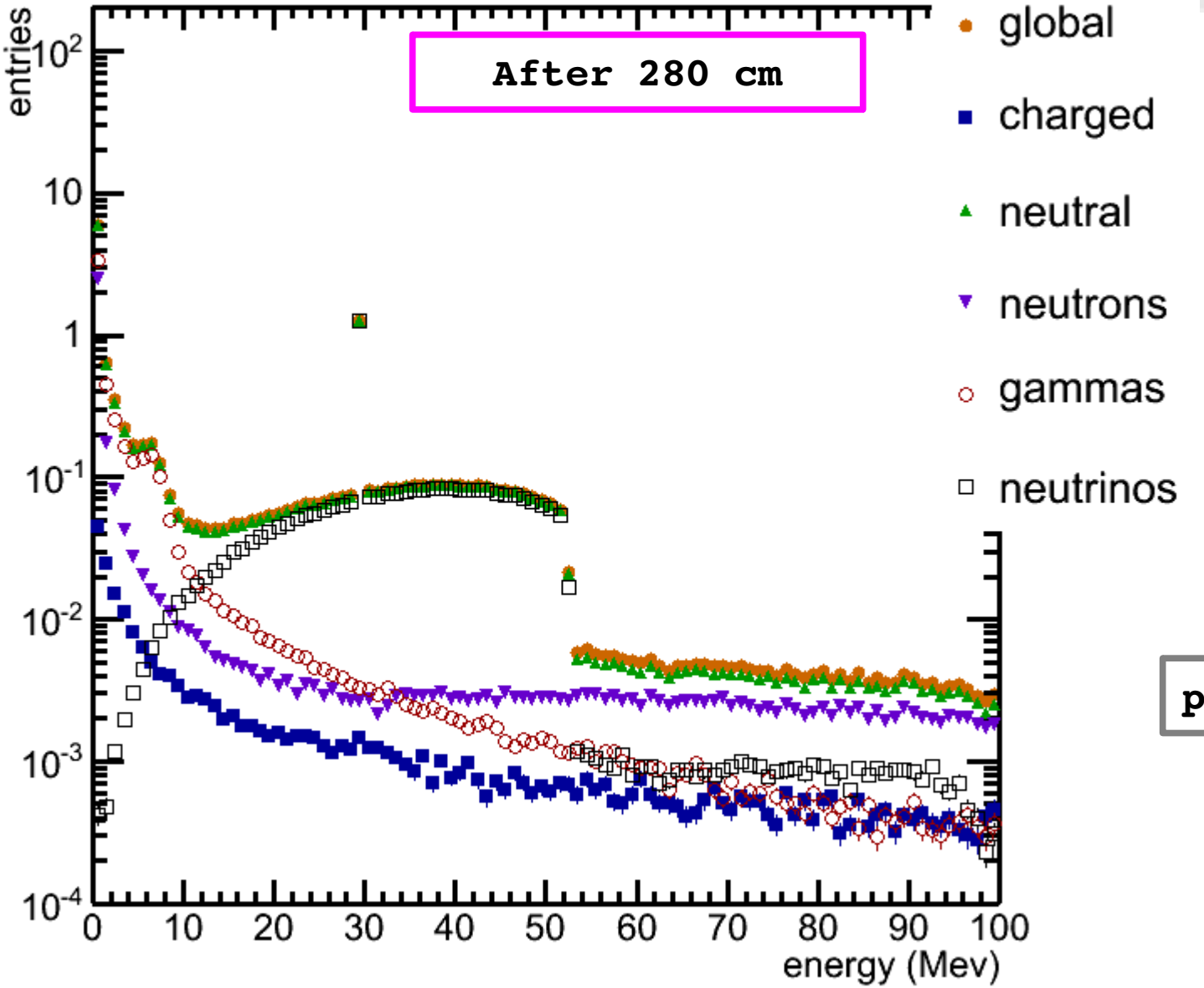

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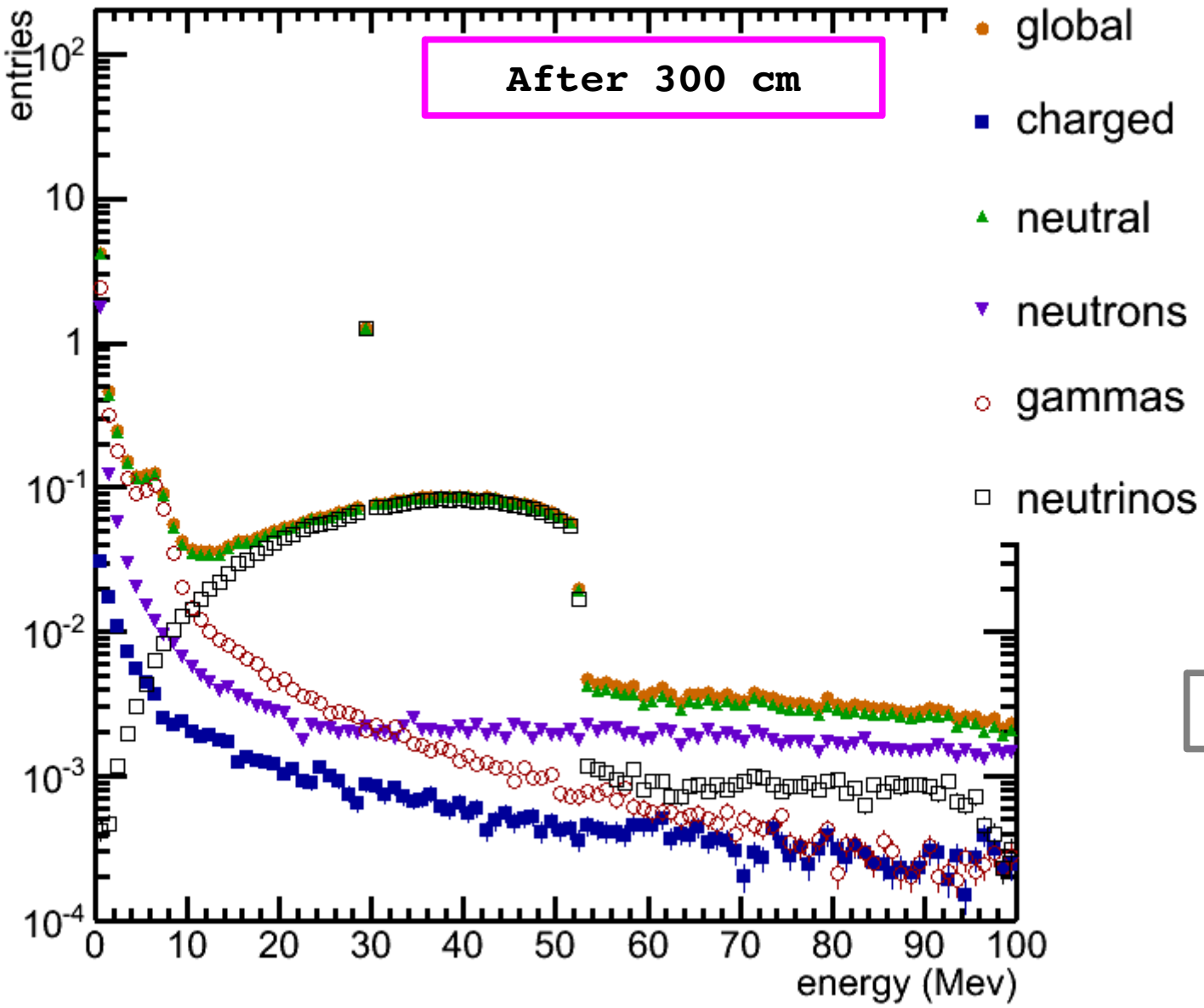

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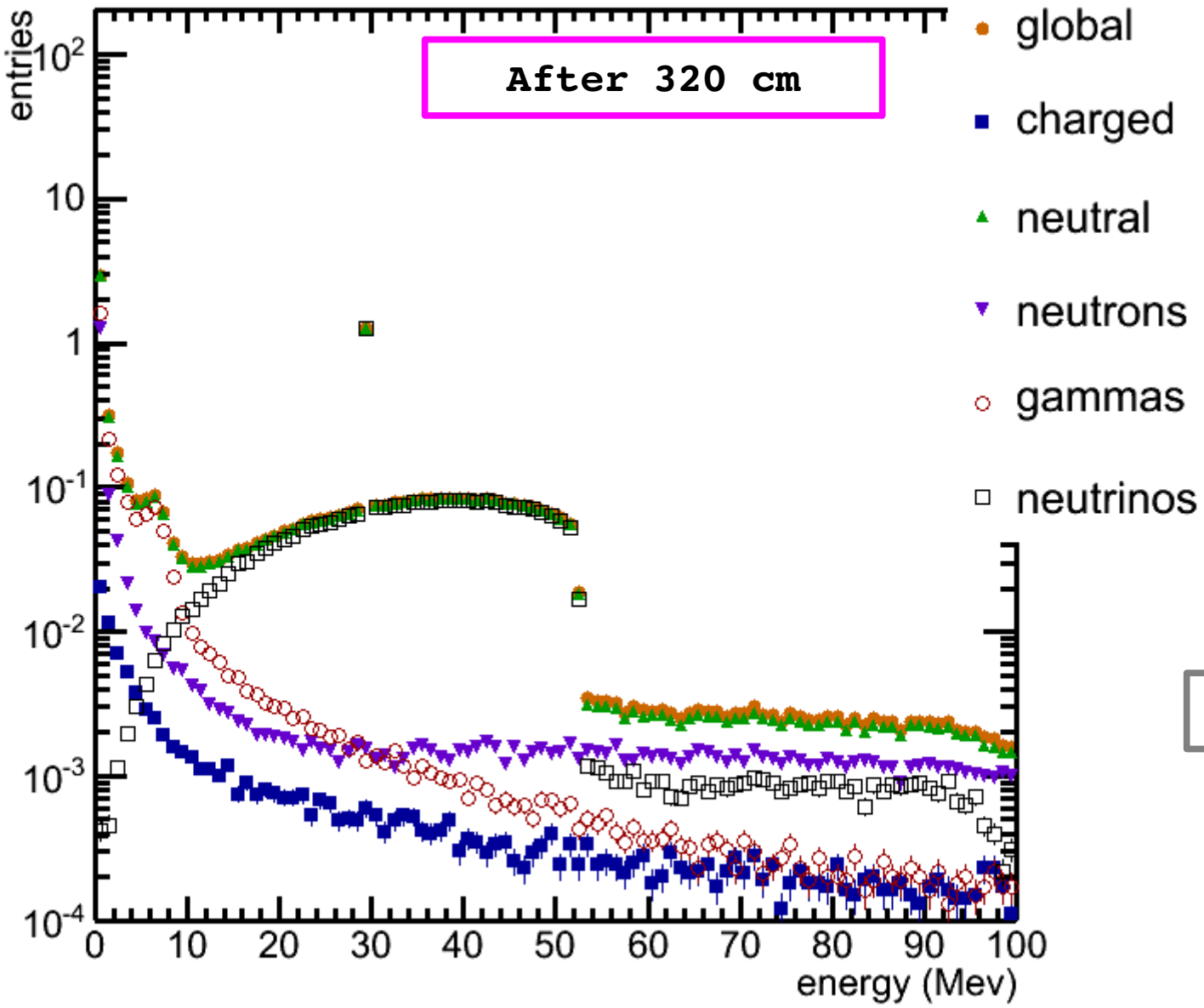

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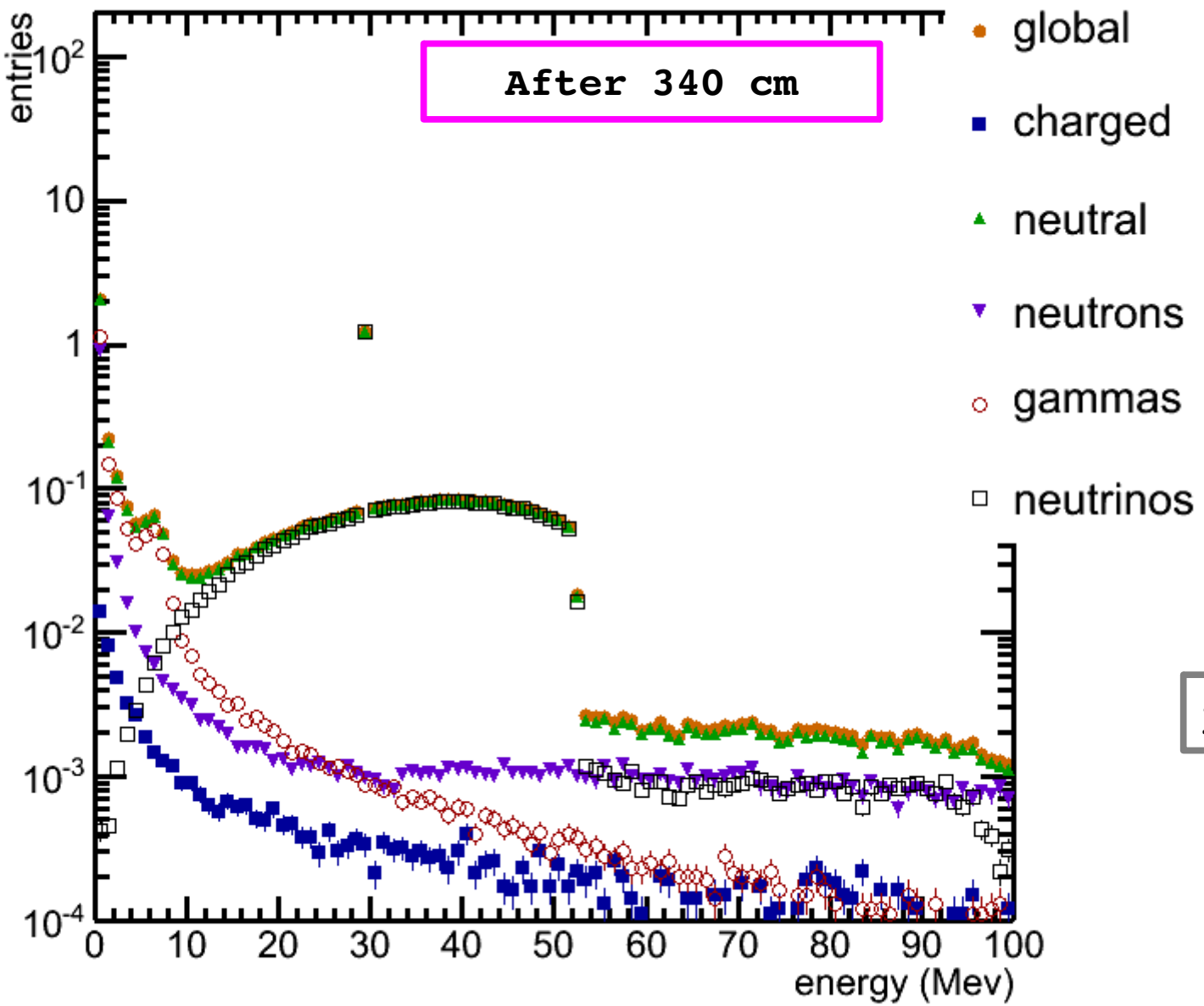

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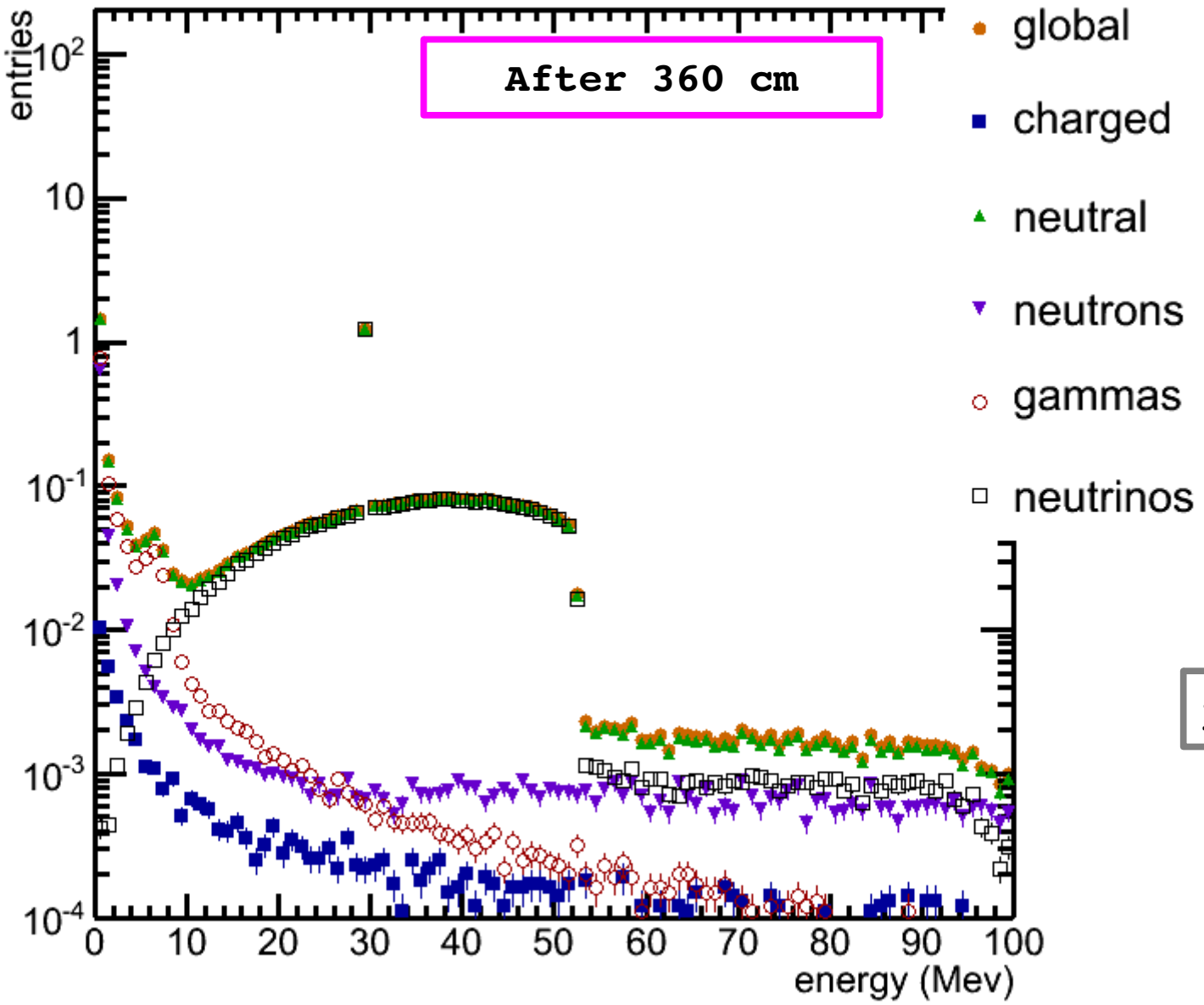

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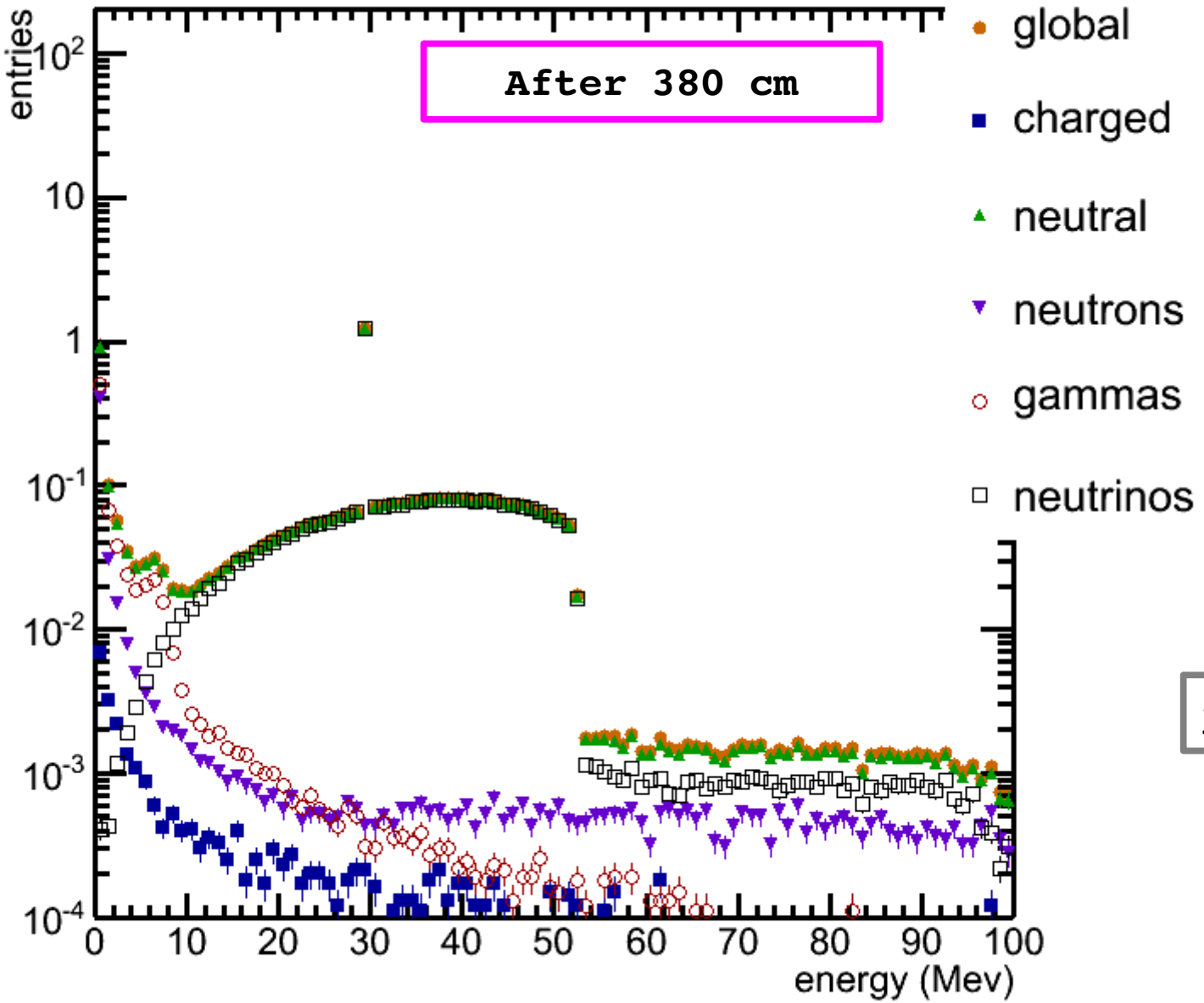

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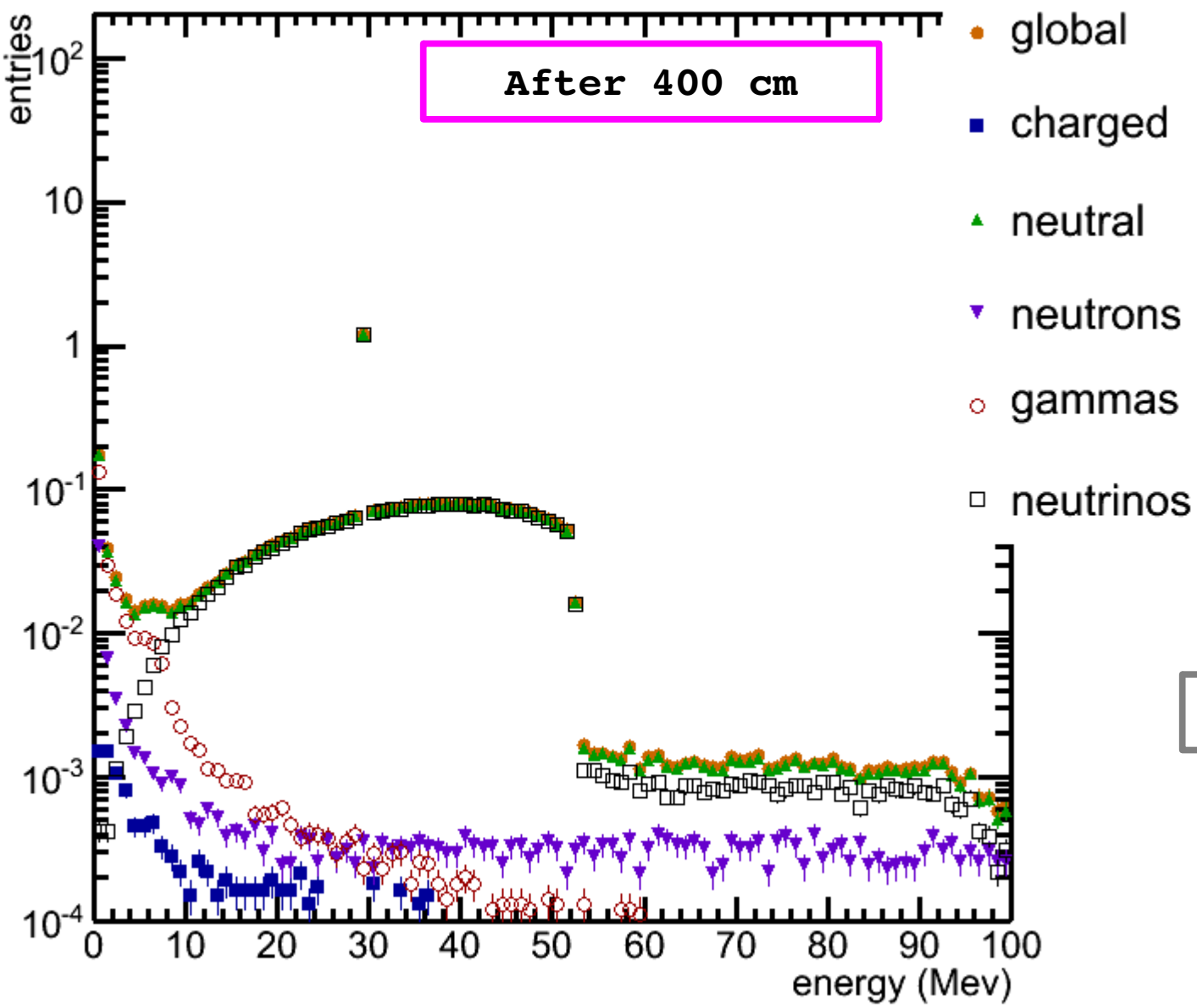

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Outline

- 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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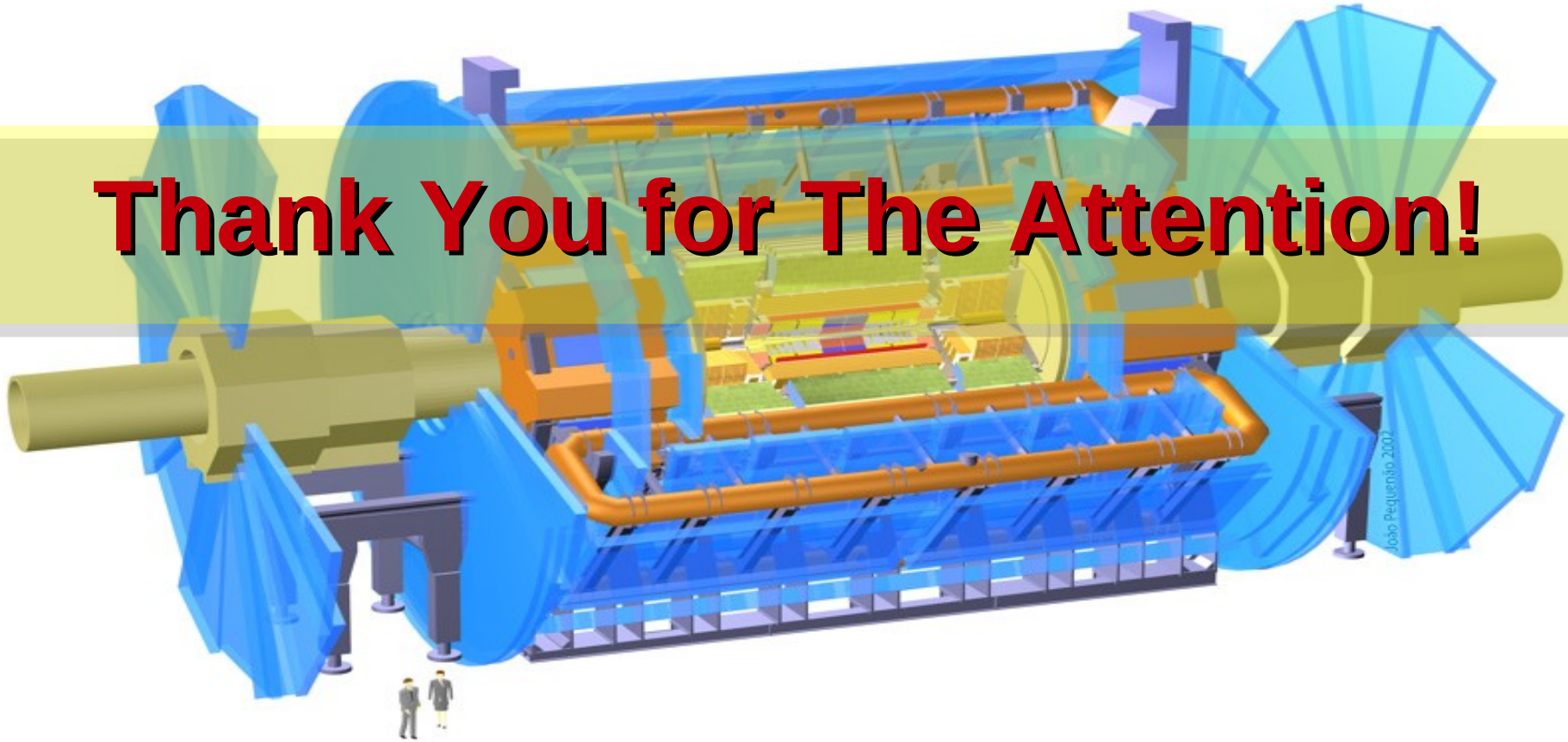

Thank You for The Attention!


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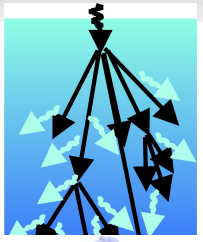
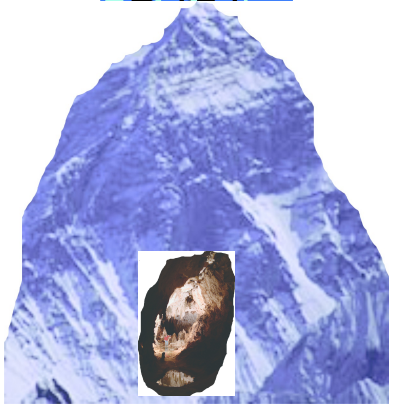
Backup

The Problem

- **Low Background Experiments:** very low expected rate (e.g. **0ν2β decay rate 0.1 counts/(keV Kg y)**)

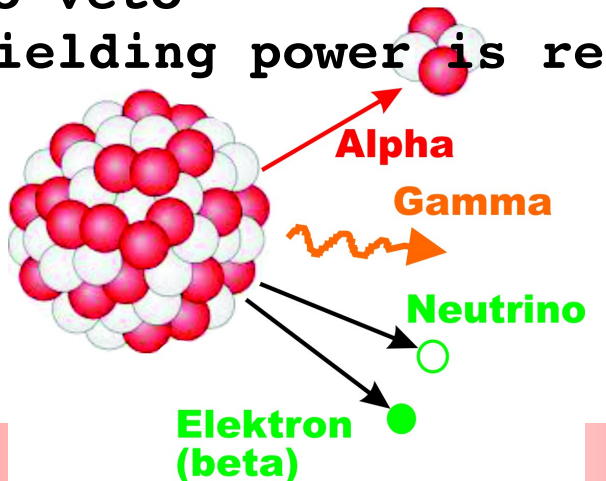


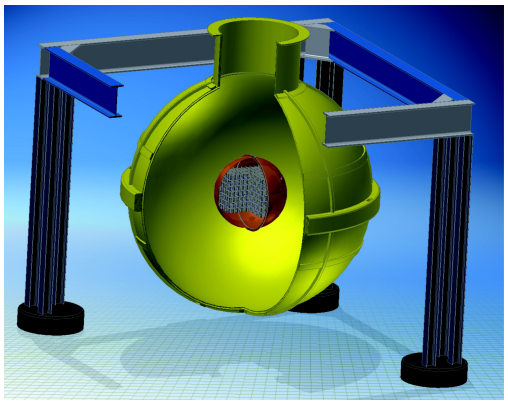
- To enhance the expected counting rate:
  - Increase the mass → **1 Ton experiments**
  - Increase the S/N ratio → **Move underground**



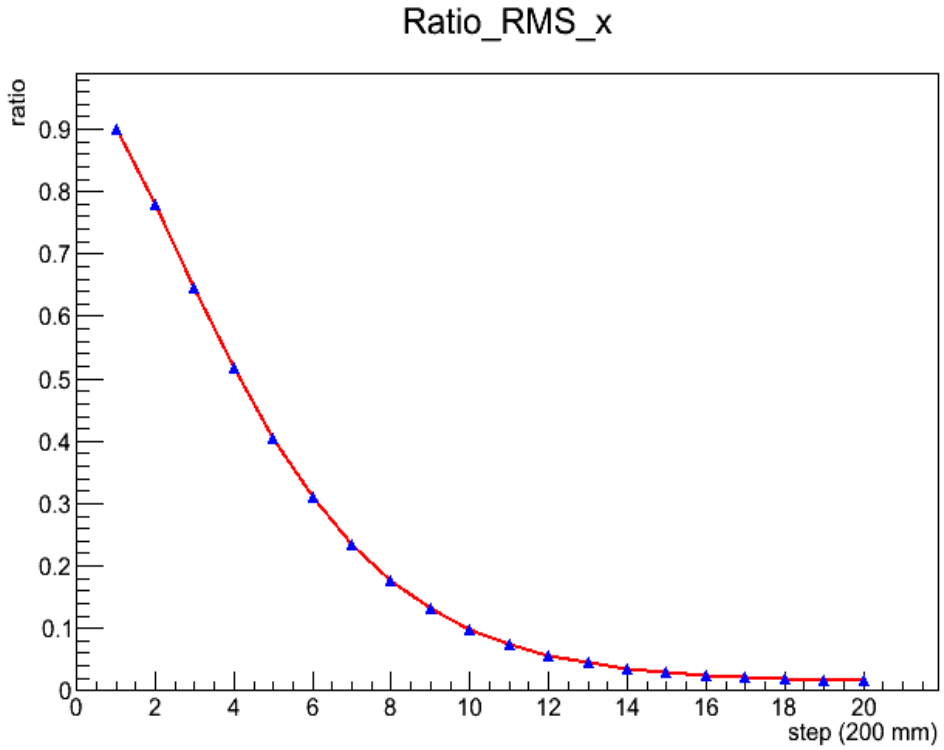
- Also an **effective shielding** is needed against:
  - Environmental Natural Radioactivity
  - **CR-induced shower** (basically muon and neutrino-induced)

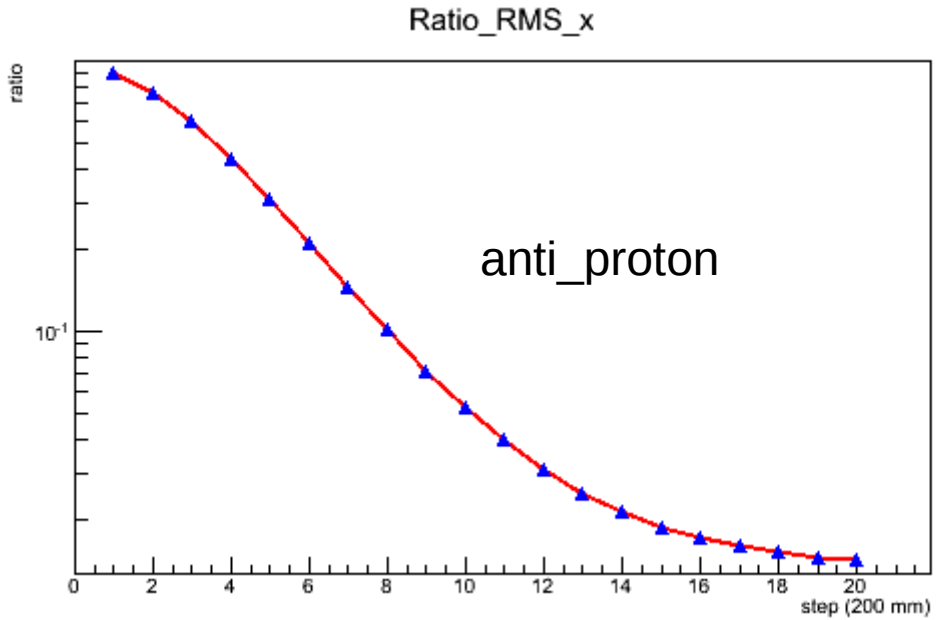
- **Two different components:**
  - **Charged** → easy to veto
  - **Neutral** → high shielding power is required





How do we do that?





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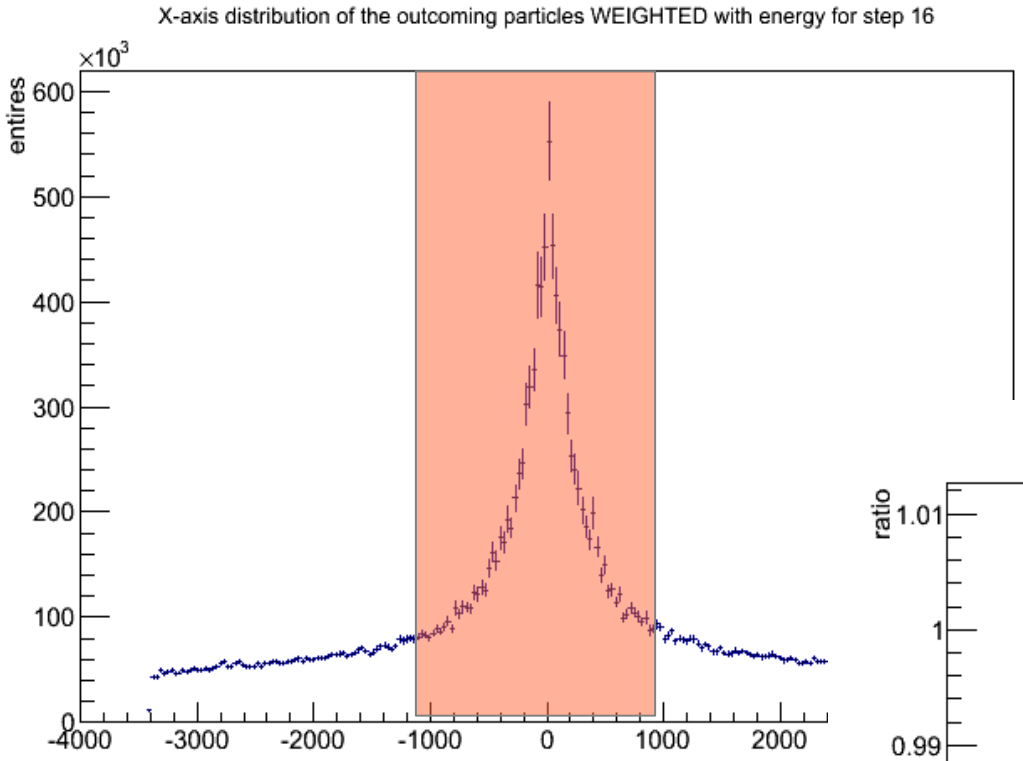

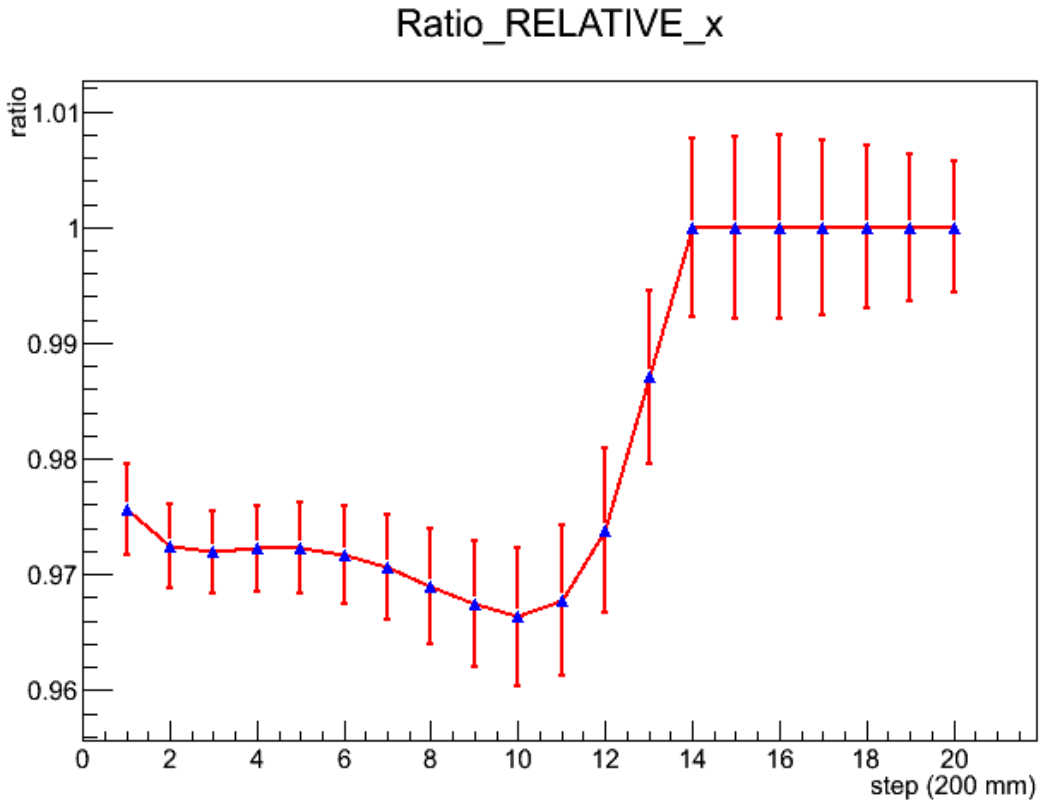

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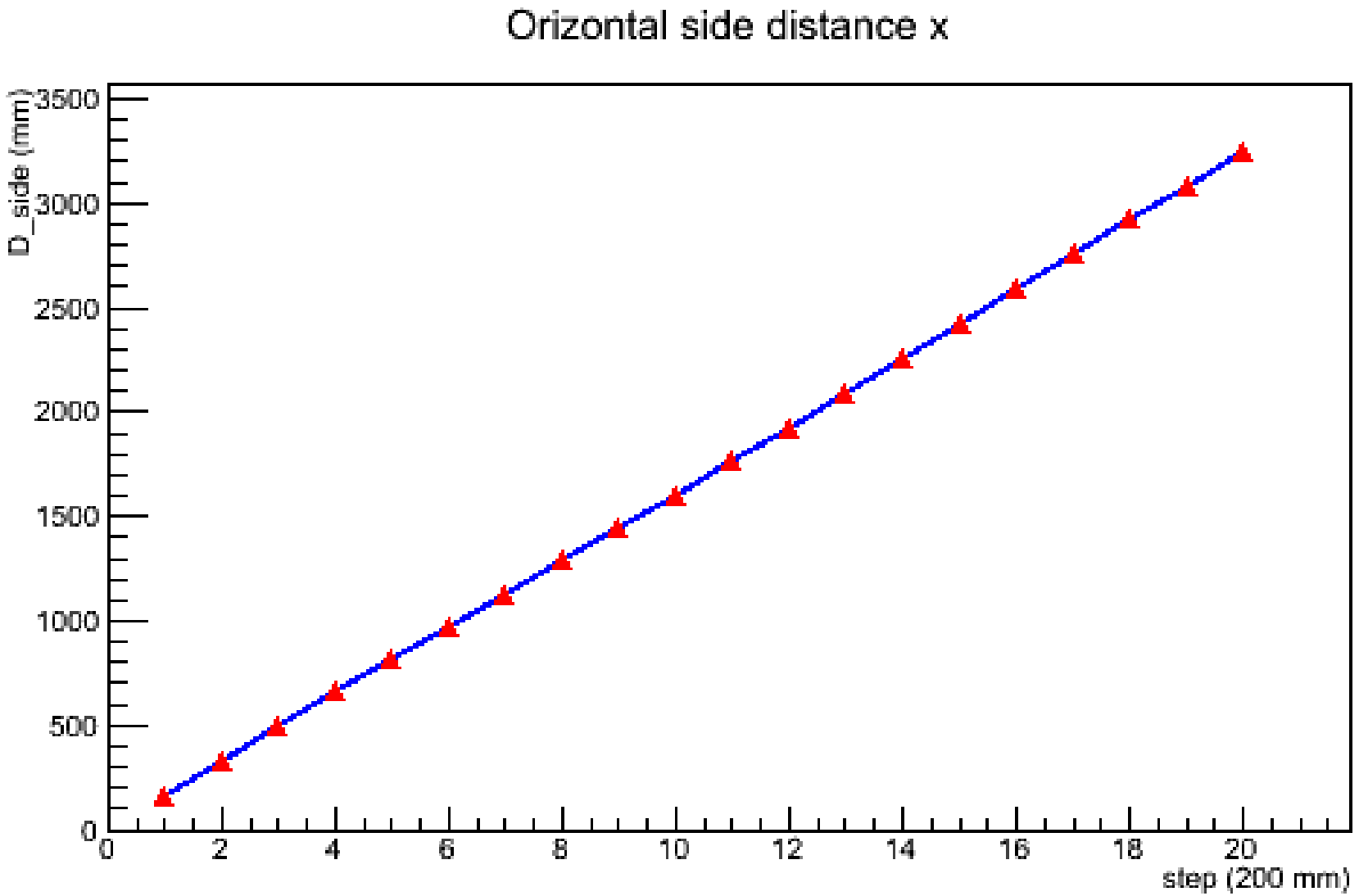
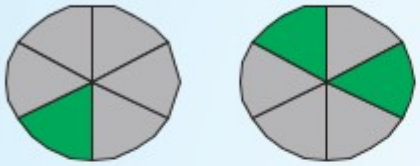


How do we do that?

Segmented detectors can identify background events by counting.

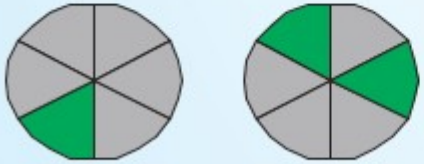


factor ≈ 10

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.

How do we do that?