Background Simulation Study for Deep Underground Cavities

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24th Indian-Summer School of Physics @ Praha

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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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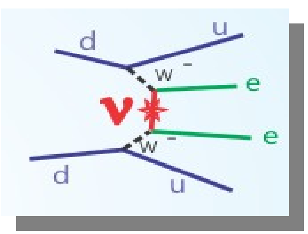
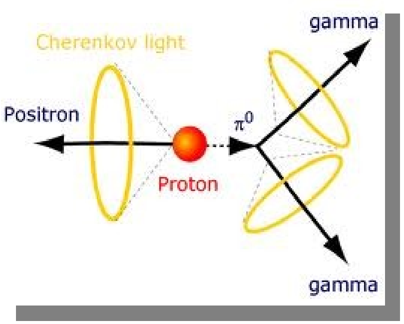
Low Background Experiments

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 counting rates!!
(e.g. $0\nu2\beta$ decay < 0.1 counts/(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

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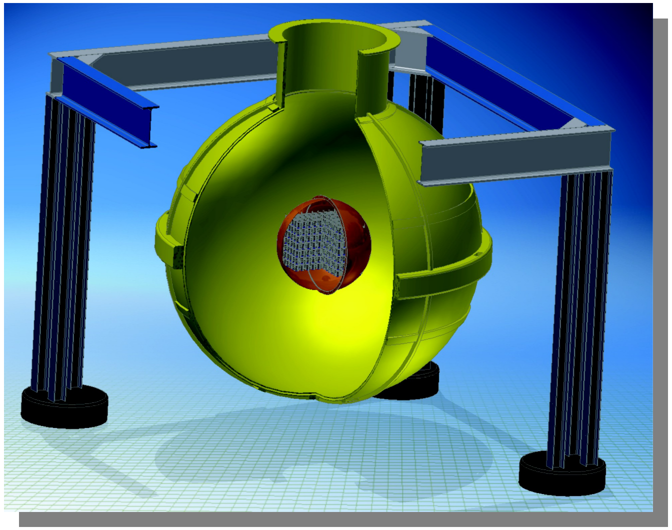


- **Increase the exposure:**

  → increase the data taking period

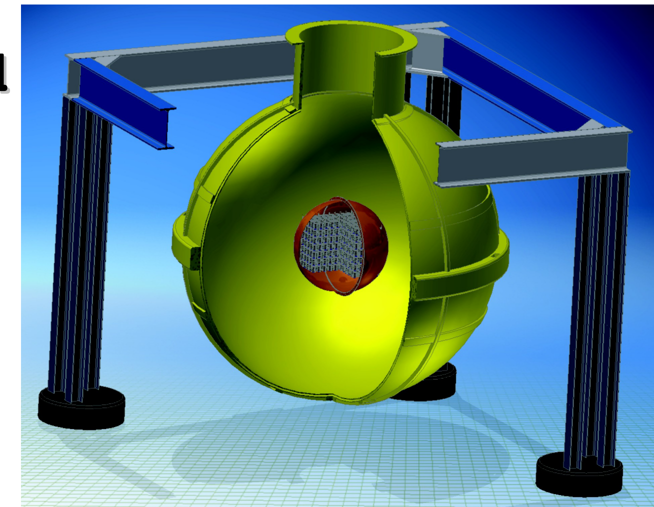
  → increase the mass
  → 1 Ton experiments

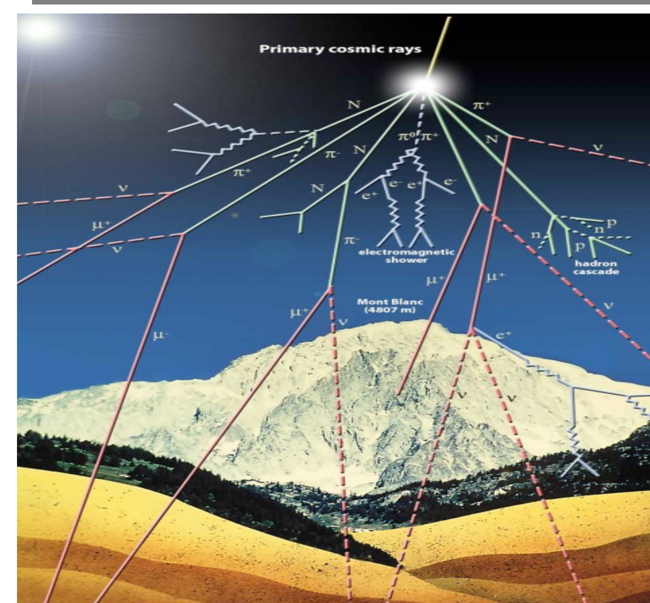
Expected Counting Rate

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/B ratio:**
  - → reduce the background
    → Move deeper Underground
    → Effective Shielding





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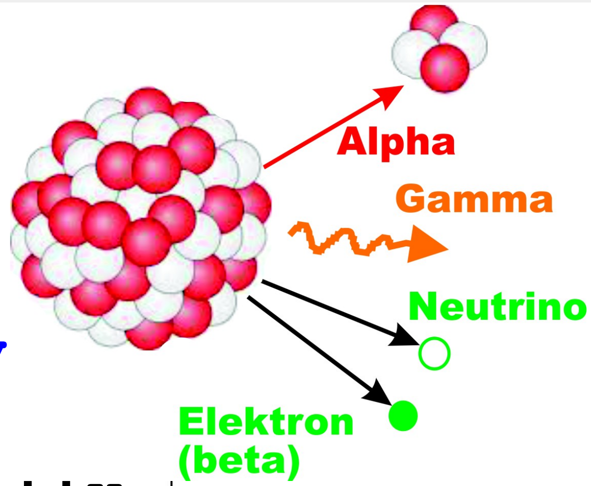
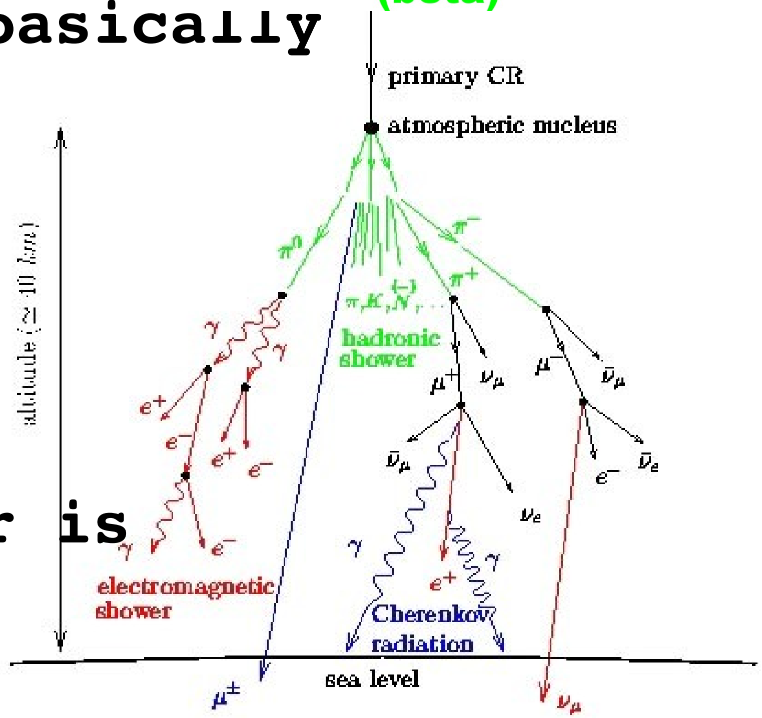
Background Sources

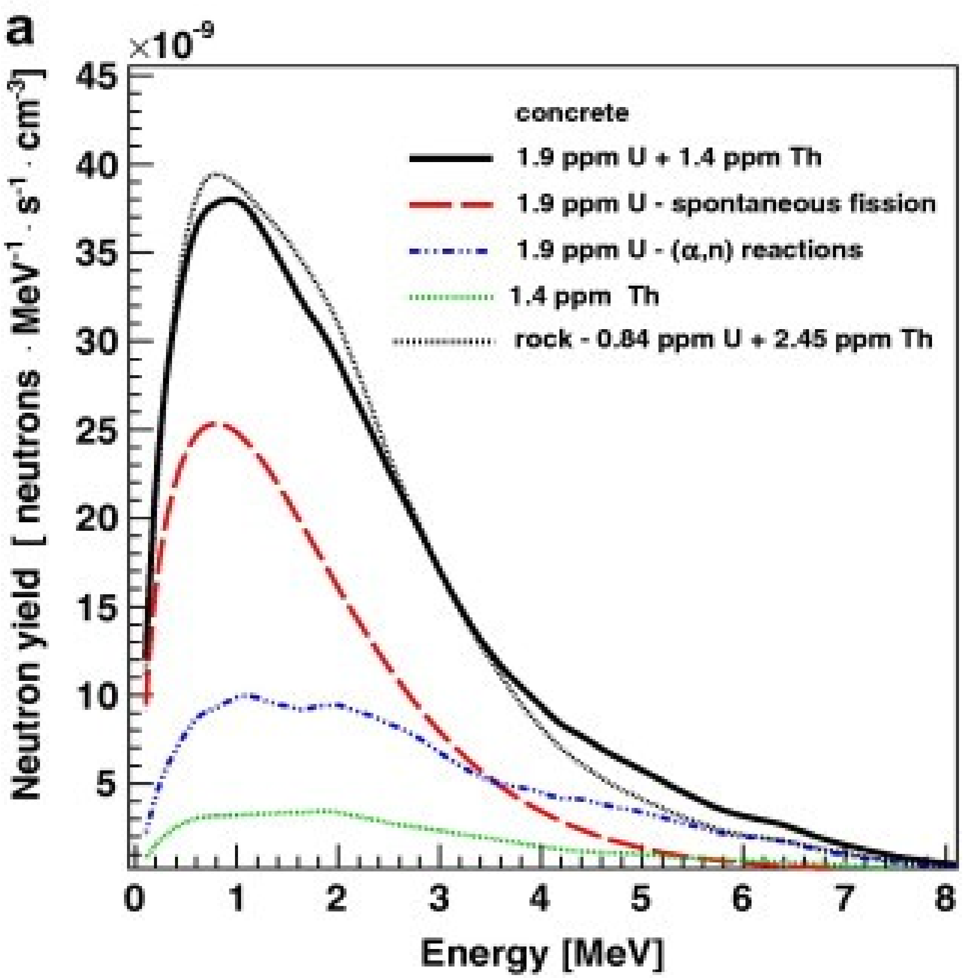
- **Three different sources:**
  - **Intrinsic detector radioactivity**
  - **Environmental Natural radioactivity**
  - **Cosmic Rays-induced showers (basically muon and neutrino-induced)**

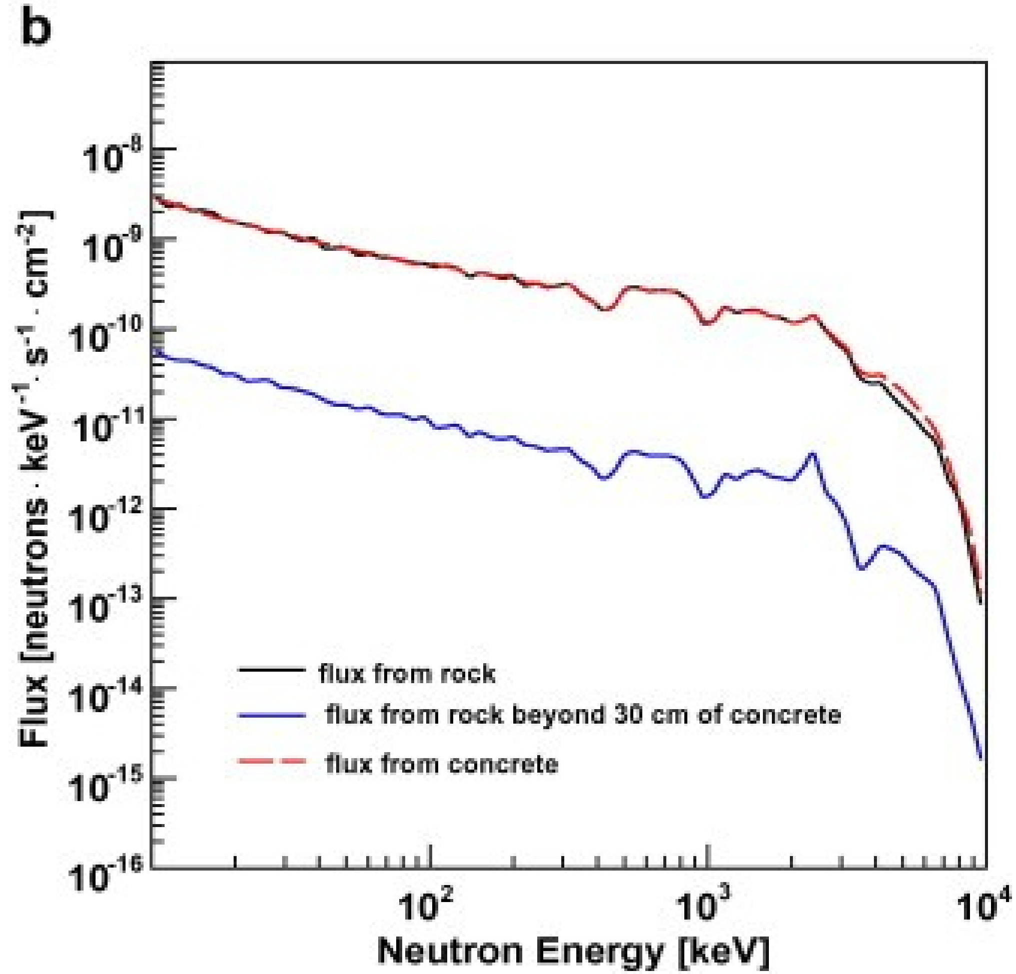


- **Two different components:**
  - **Charged → easy to veto**
  - **Neutral → high shielding power is required (neutron, gammas)**



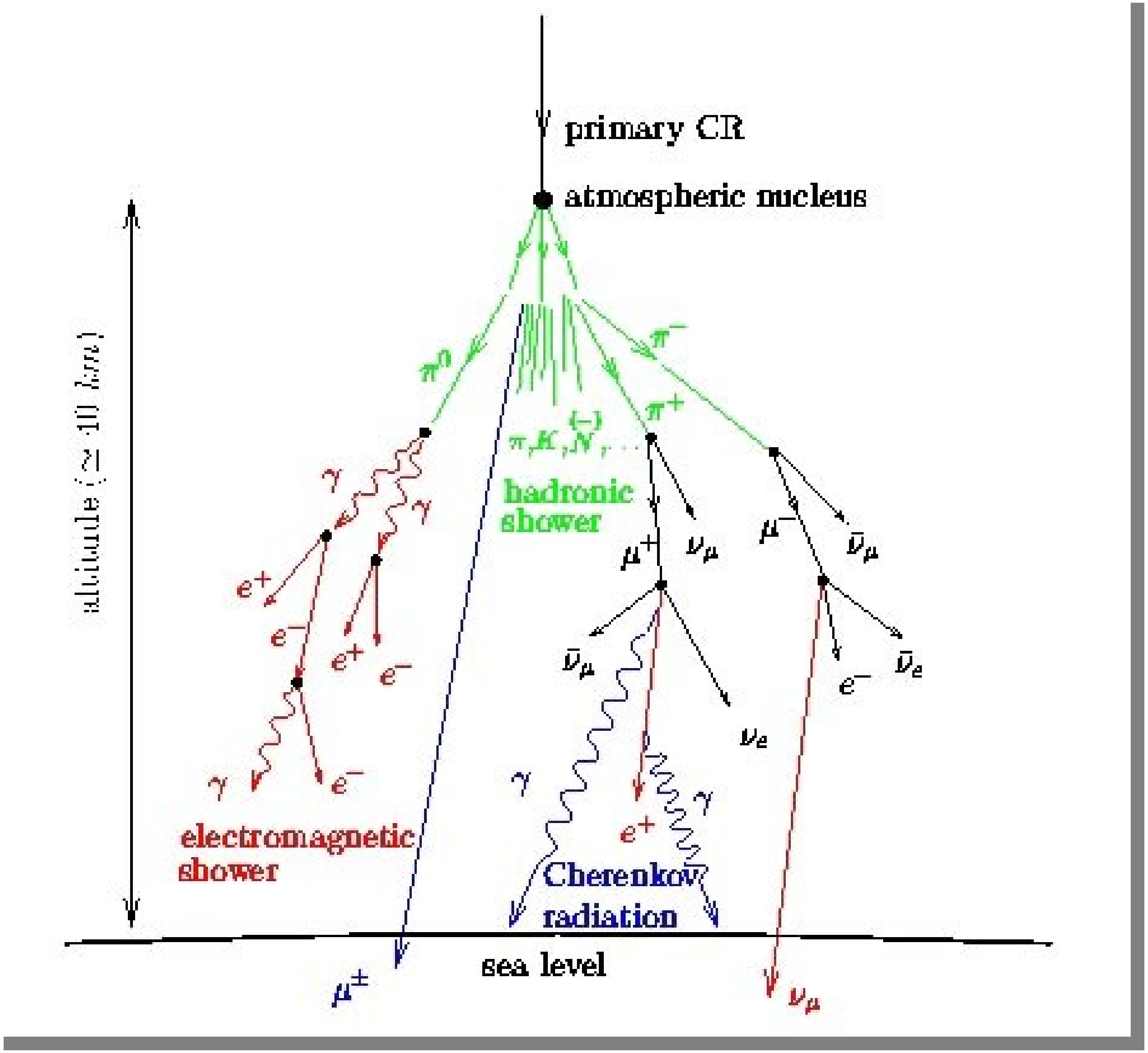
Environmental Natural Radioactivity

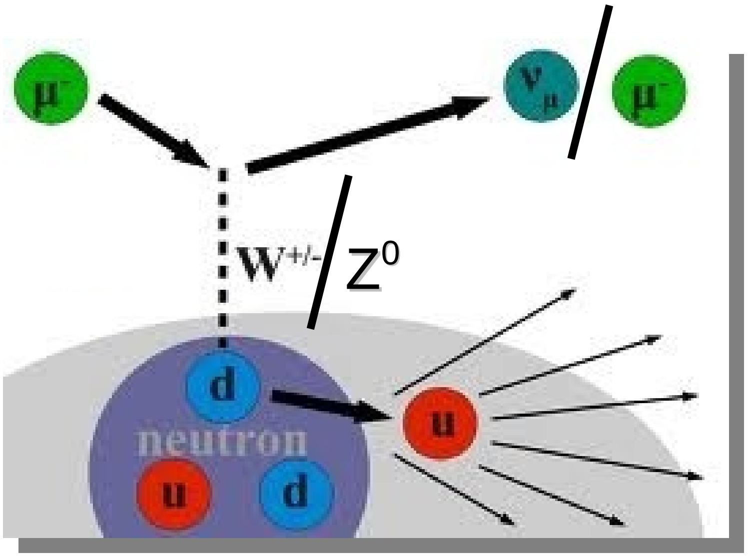


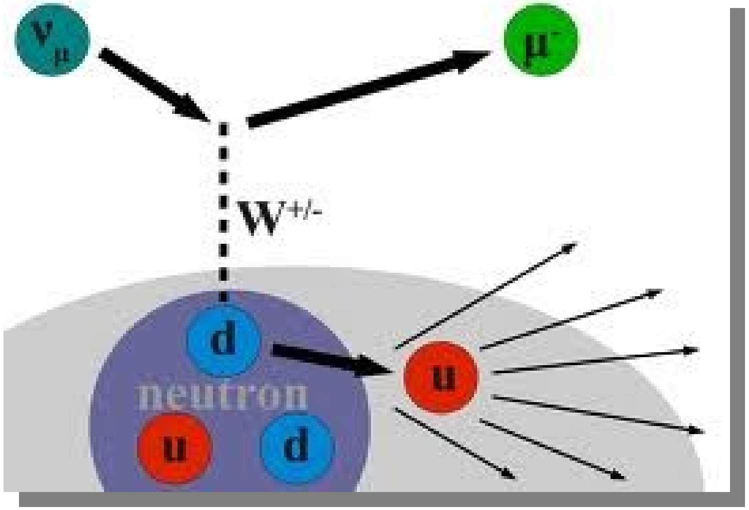


Tomasello et. al., Radioactive background in a cryogenic dark matter experiment, Astro. Phys., Vol 34, 2010

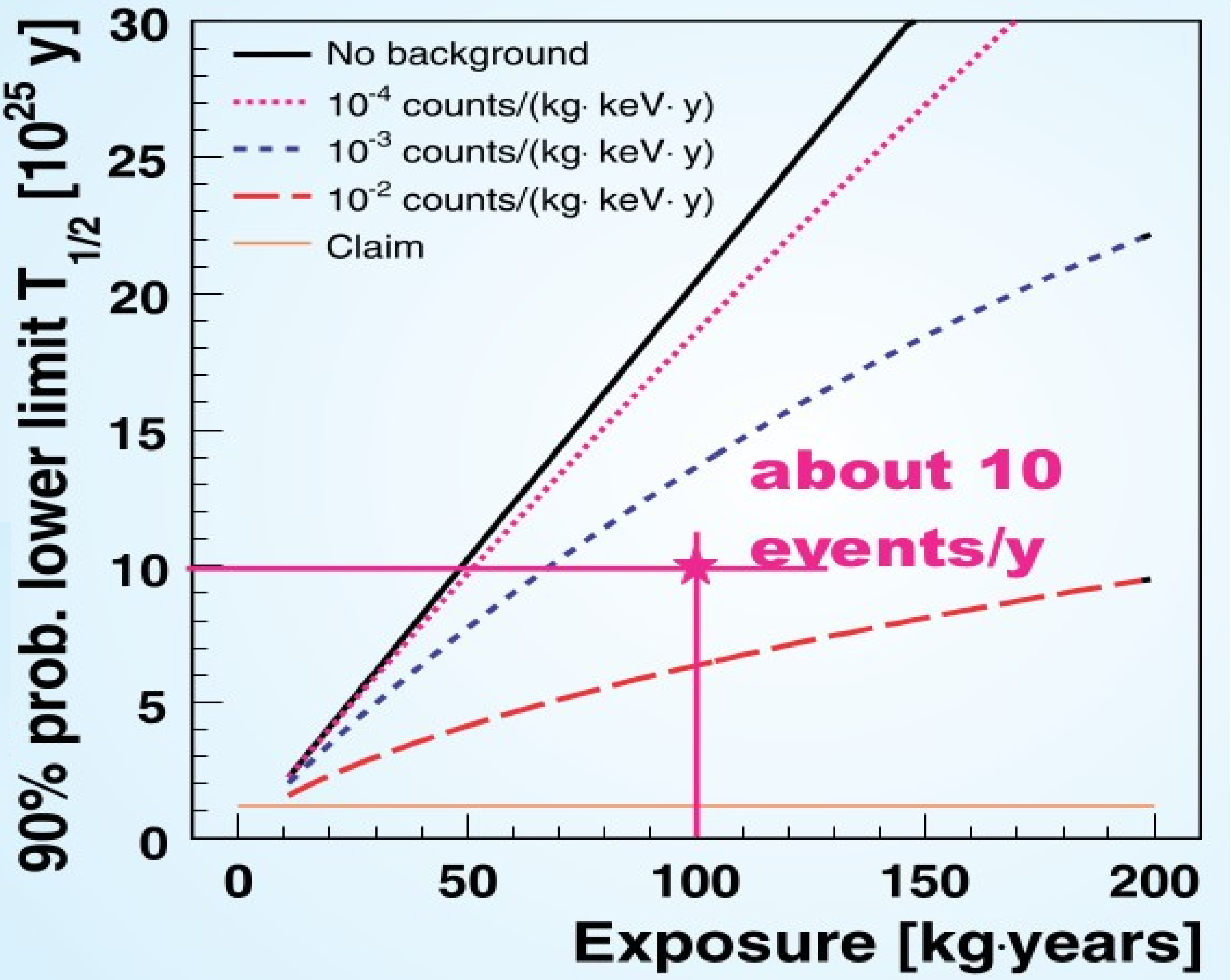
Cosmic Rays Shower







Importance of Background



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

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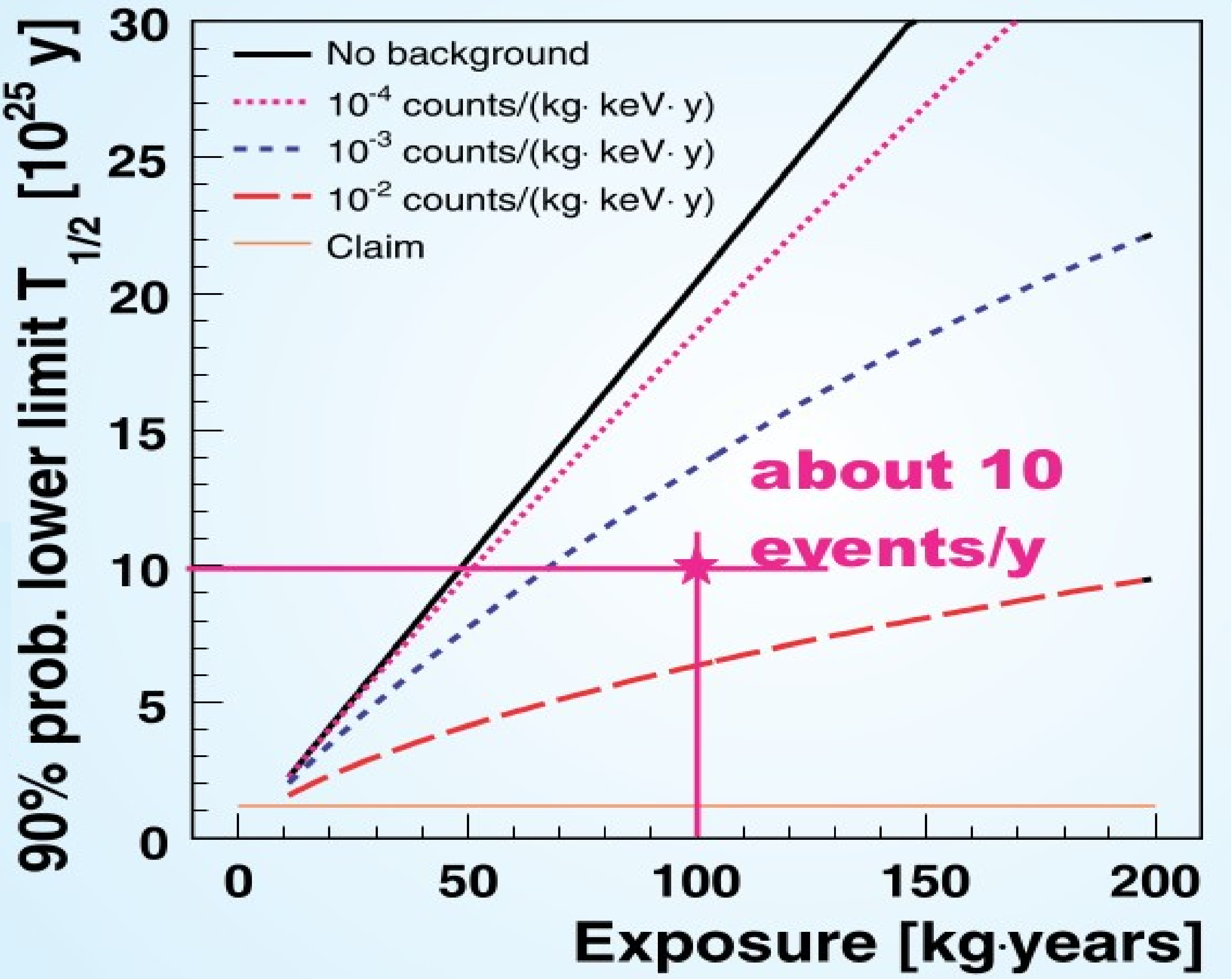

To build an experiment is crucial to know which level of background you can allow and which you can not!

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

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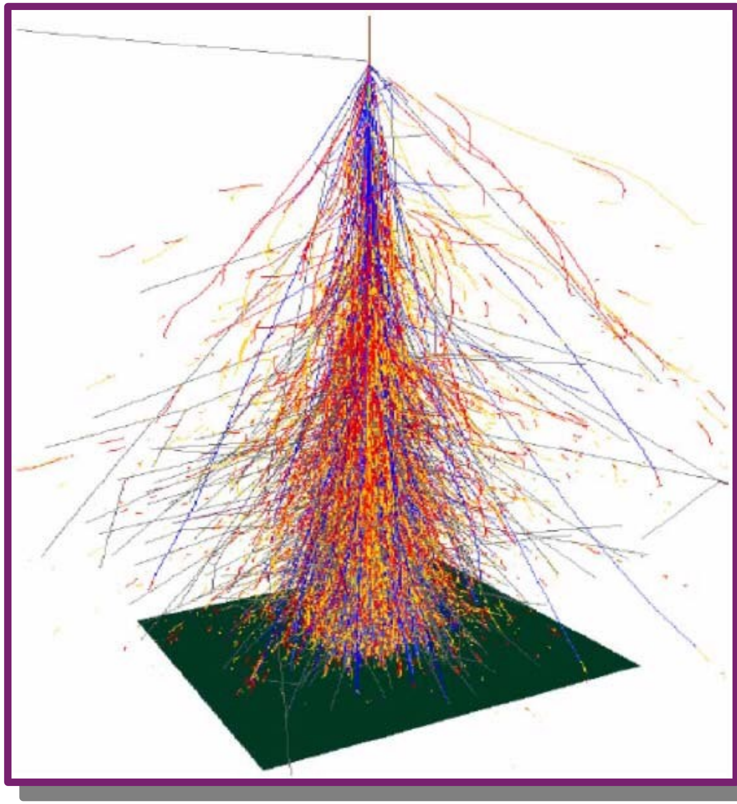
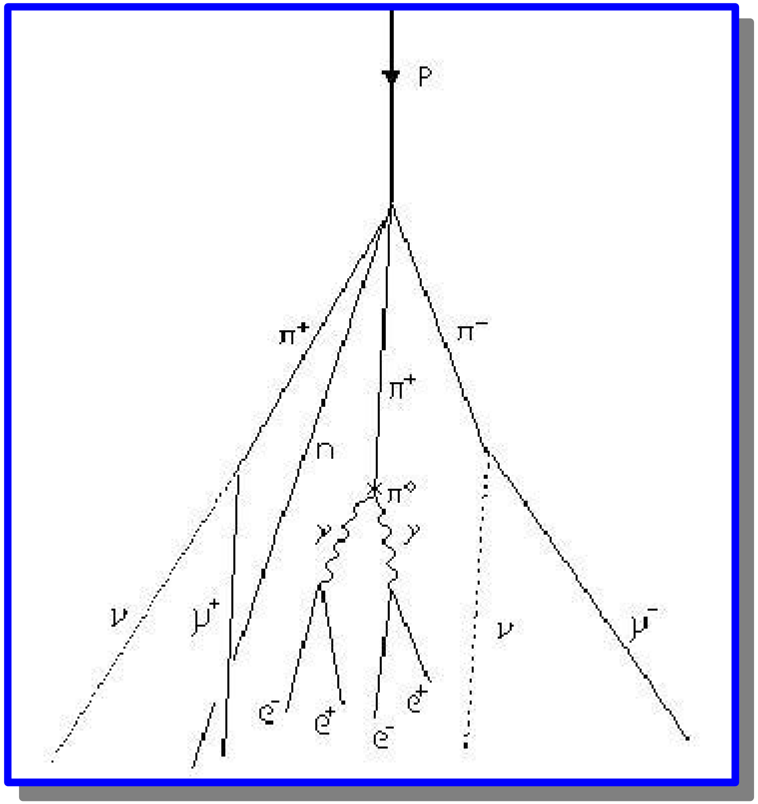
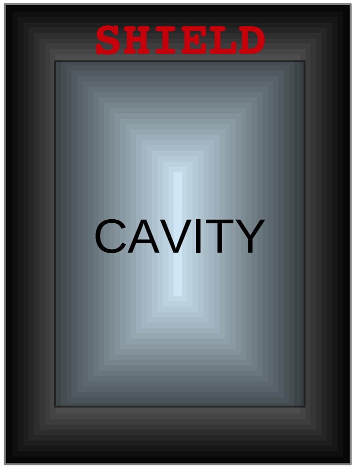
What we want to do?

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





Vertical & Horizontal Safety Distances



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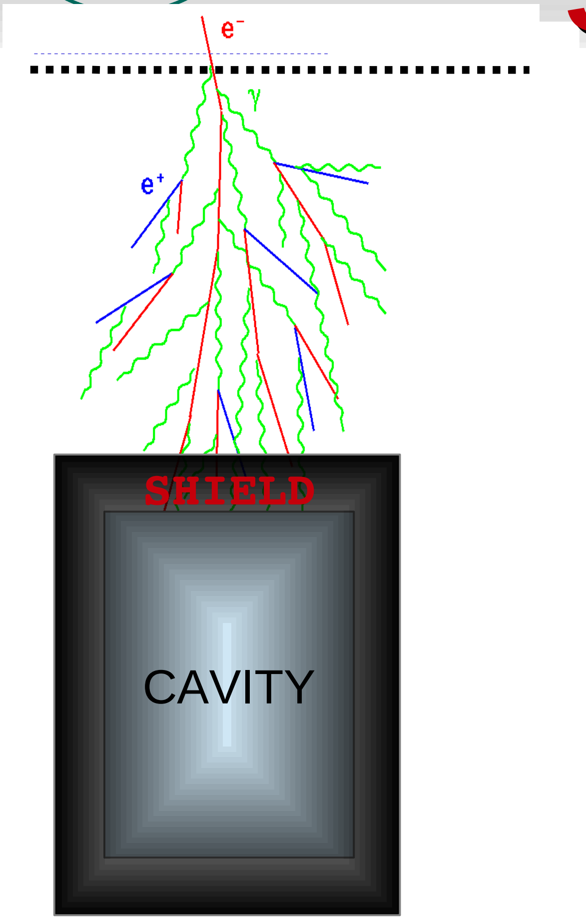

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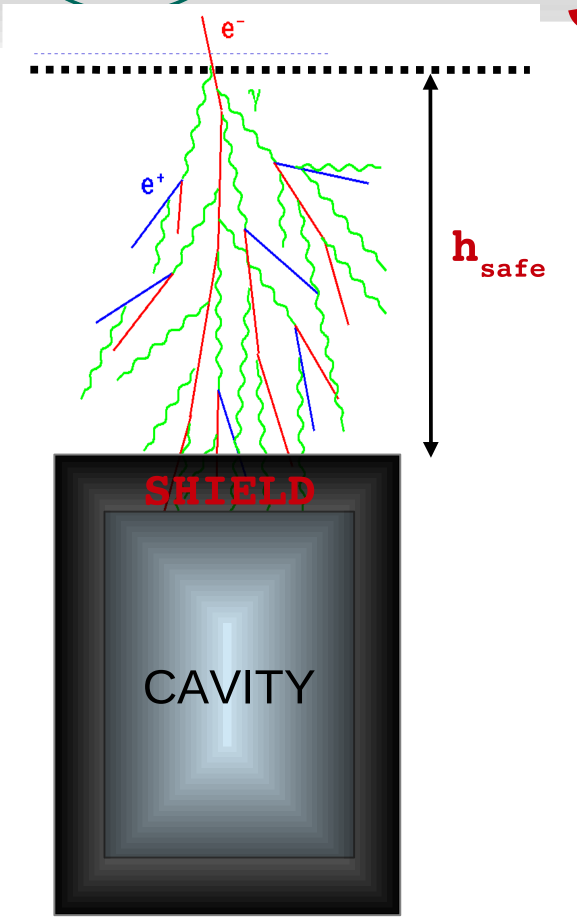

- **h_{safe}** : vertical distance (from the interaction point) after which the shower has 10 MeV left

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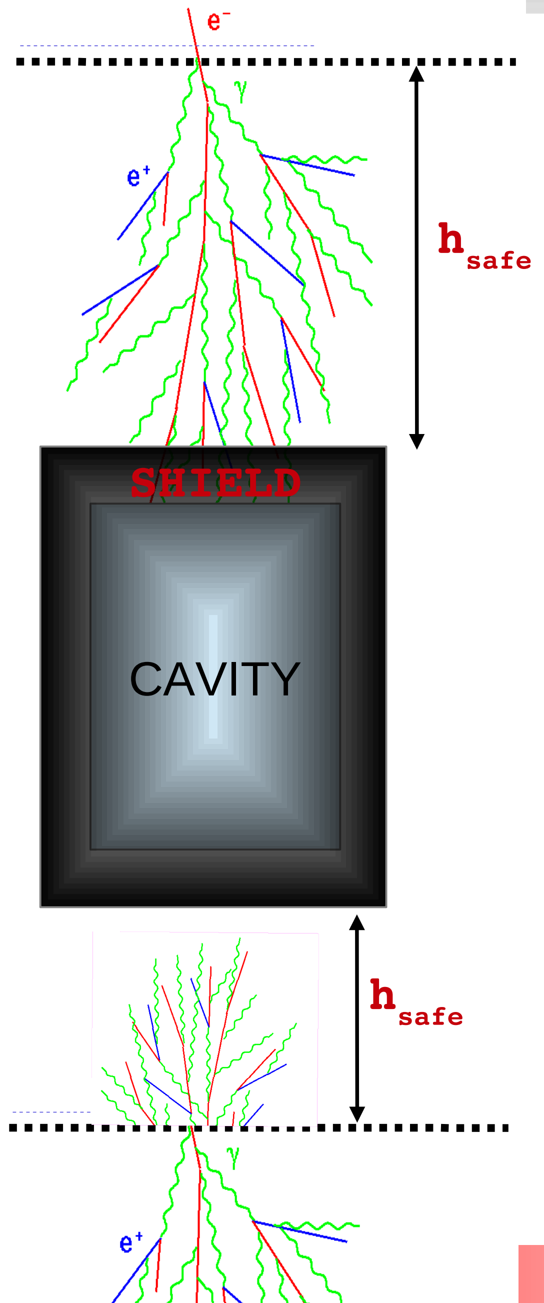

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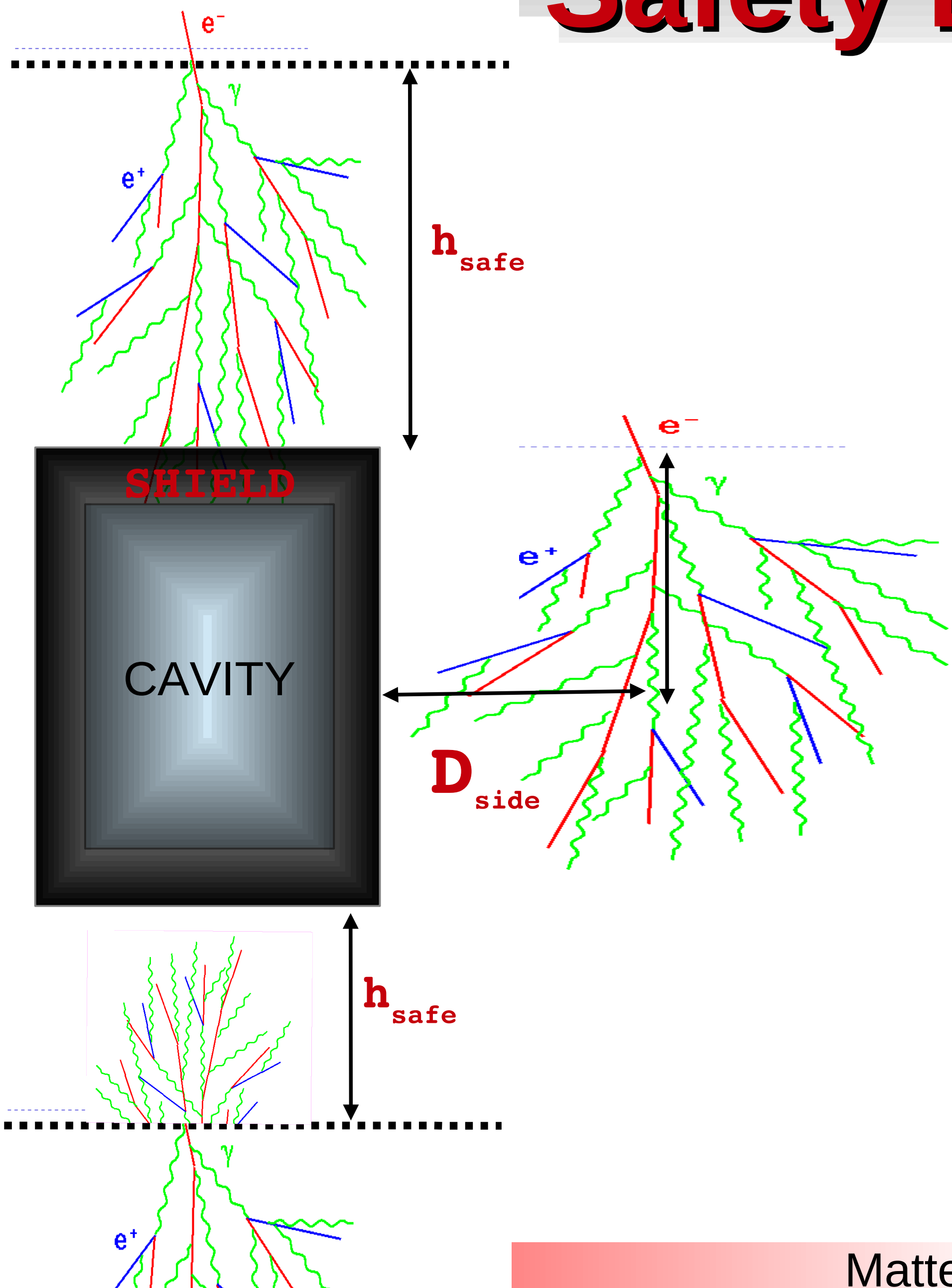


- $\mathbf{h_{safe}}$: vertical distance (from the interaction point) after which the shower has 10 MeV left

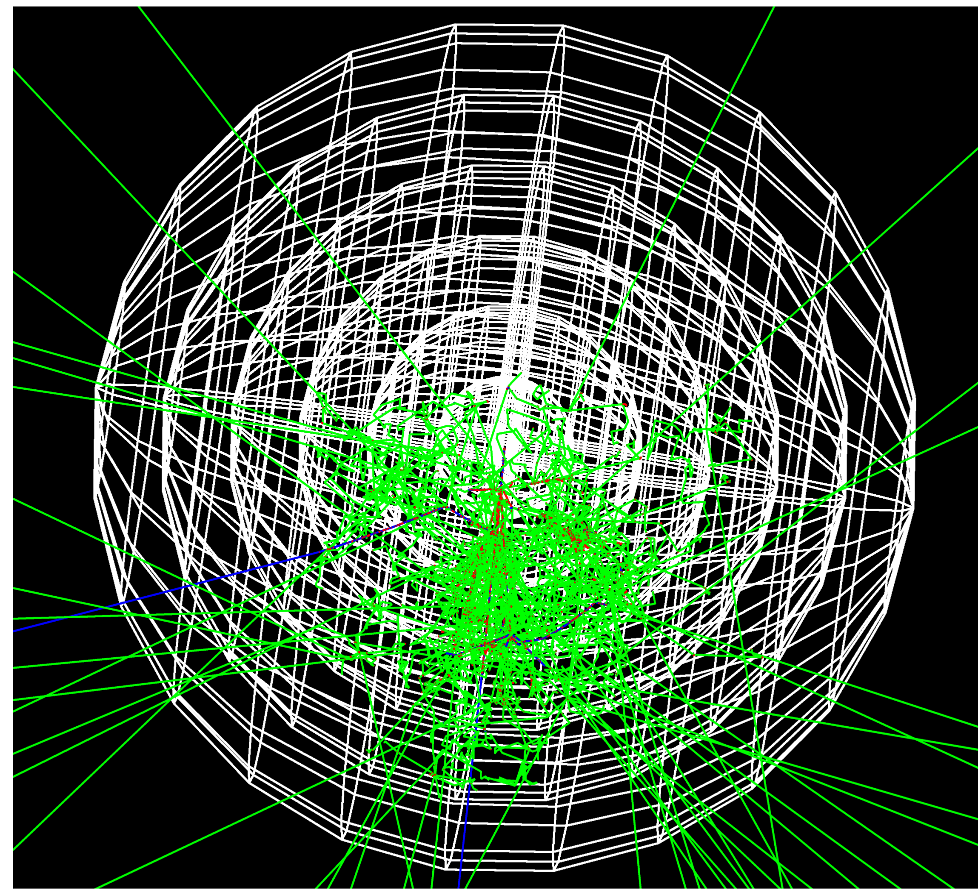
- $\mathbf{D_{side}}$: horizontal distance (from the mean energy position) after which only 10 MeV can reach the shield

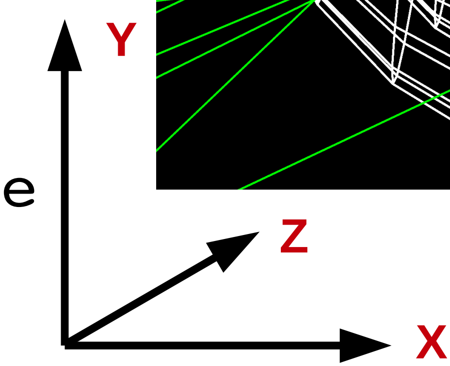
How do we do that?

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

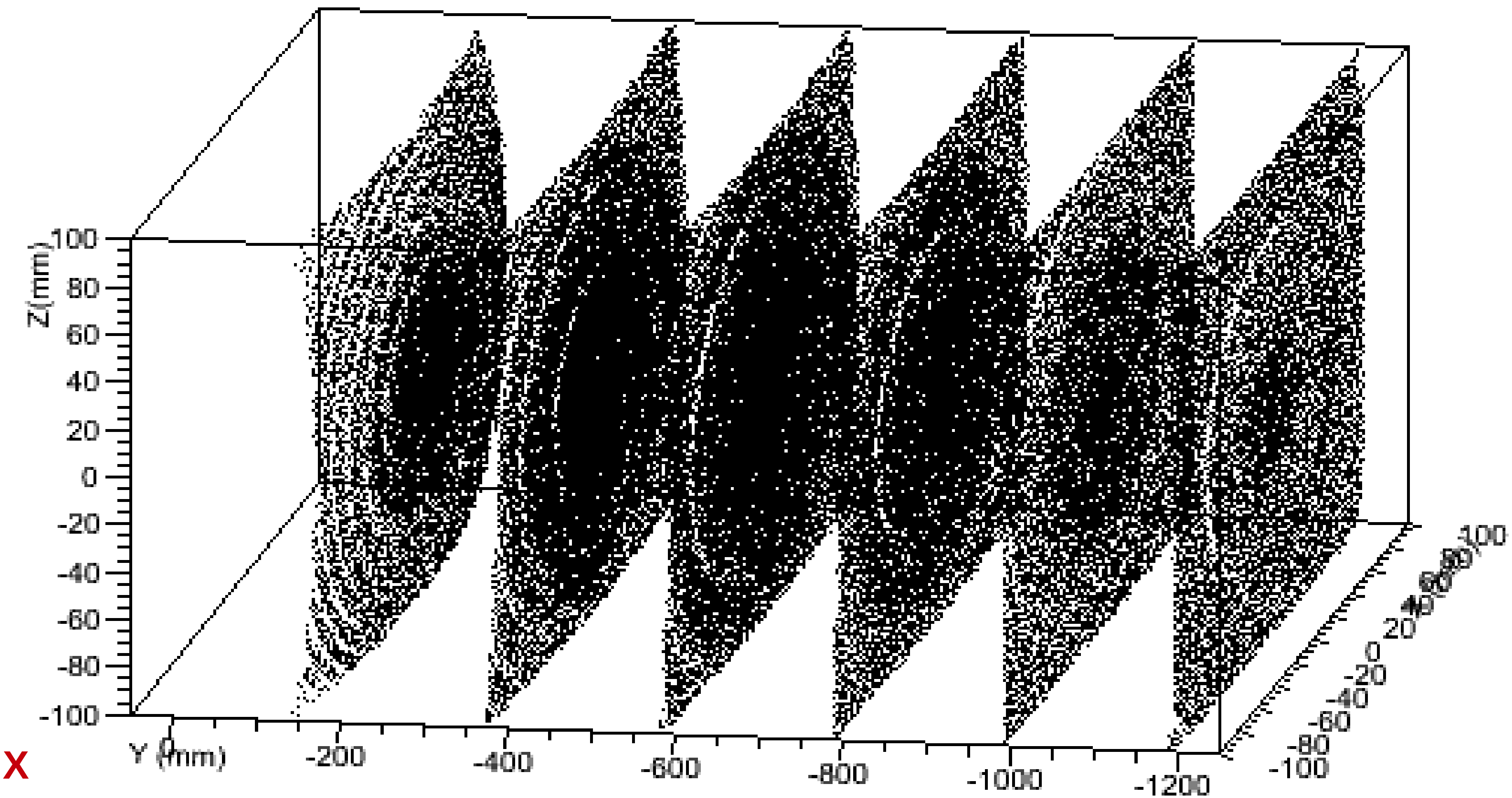
- Let it creates a shower in the center of a rock-made sphere (**divided into sub-spheres**)

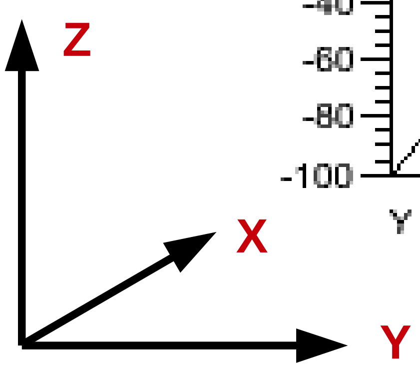
- Record all the particles with their properties (e.g. **position, kinetic energy, charge**, etc.) that arrive at each single sub-sphere surface





XYZ distribution of the outcoming particles

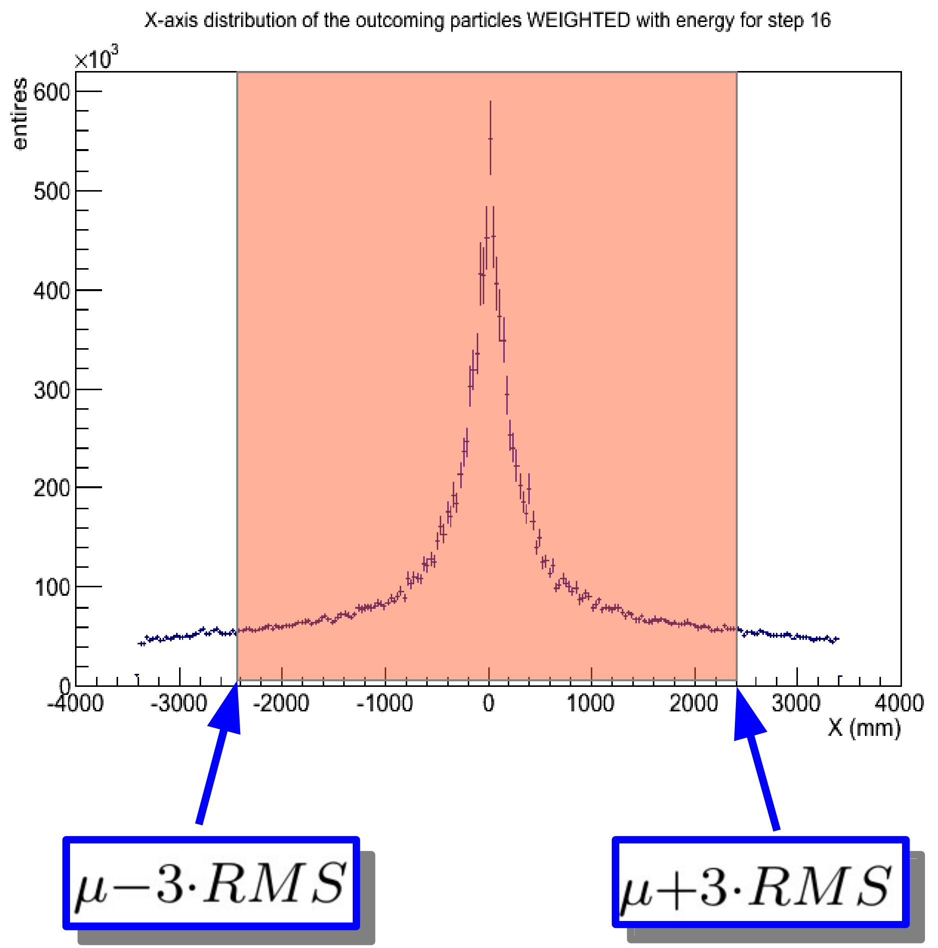




Vertical Distance (1)

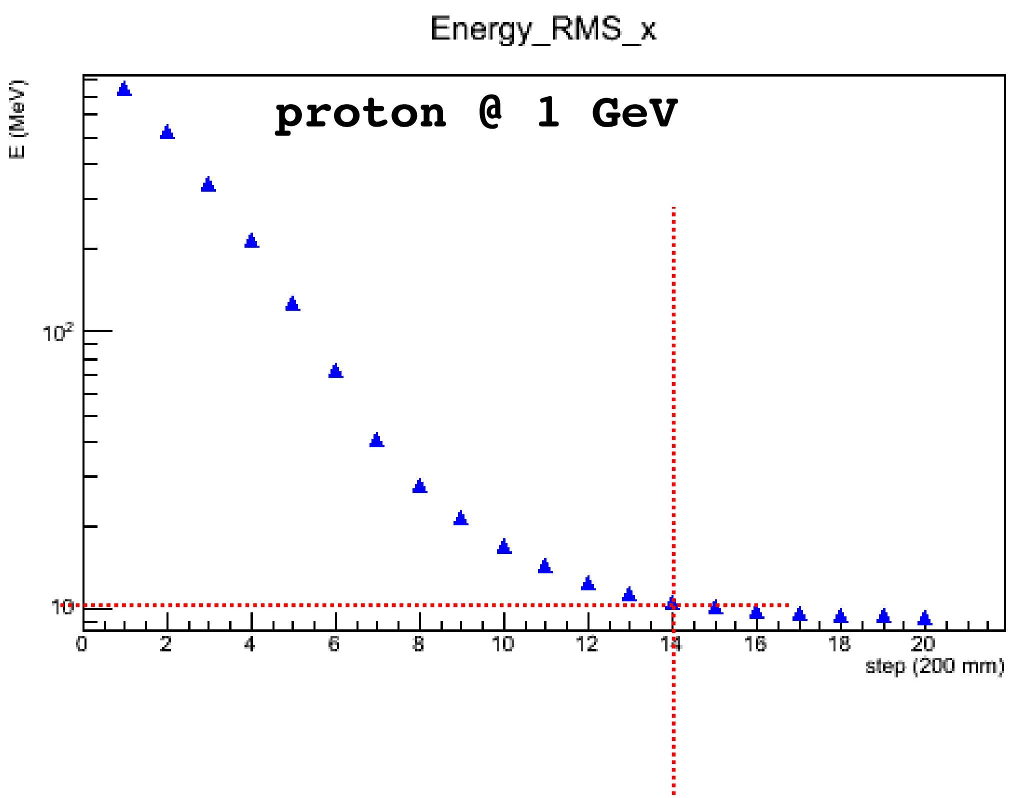
- **For each step:**
  - **Evaluate**

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



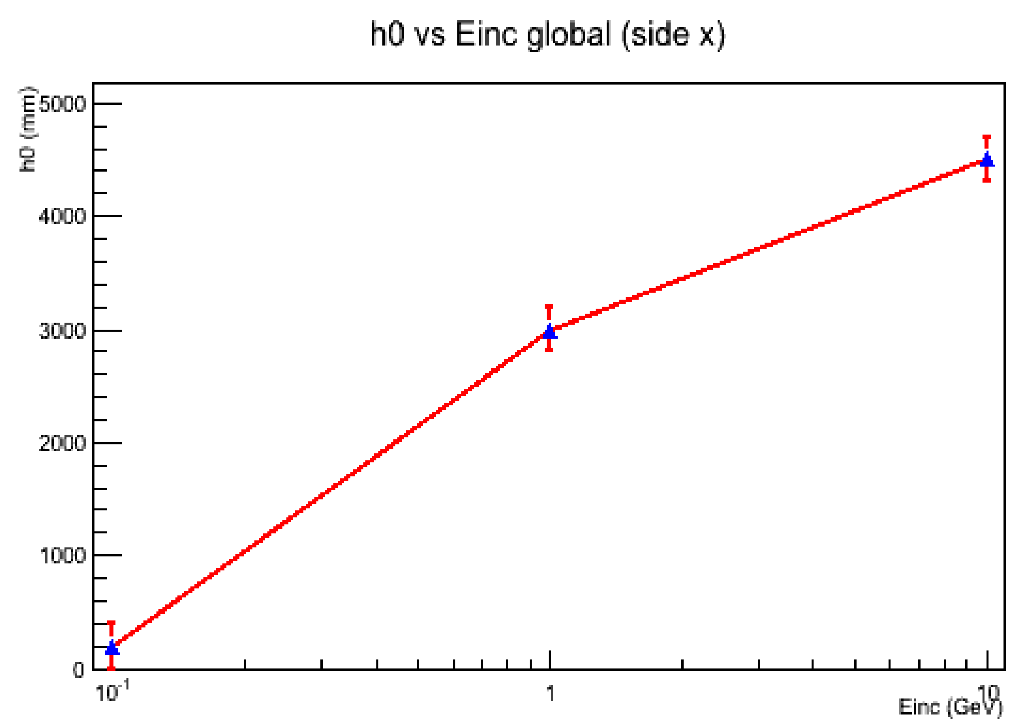
- **Then use this quantity to infer the safety vertical distances**

Vertical Distance (2)



- h_{safe} @ 10 MeV
  Threshold

h_{safe} for 3 different incoming particle energies



Horizontal Distance (1)

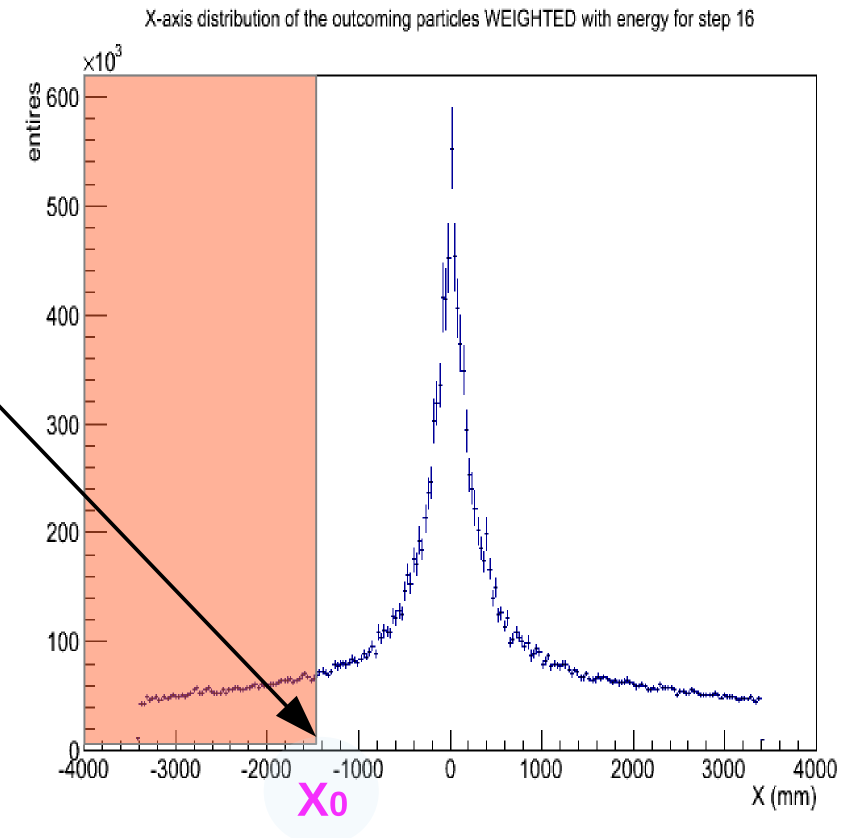
- For each step:
  - Search the point X_0 so that:

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

  - The safety horizontal distance is defined as:

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

  - Then take the maximum wrt the depth

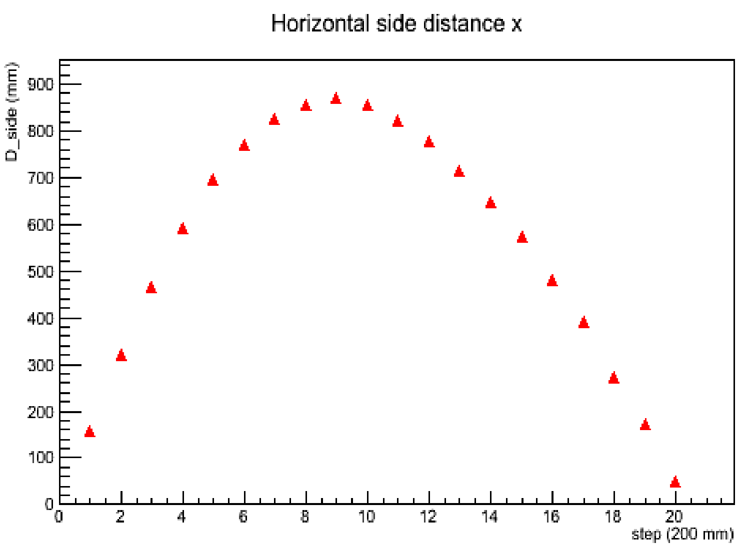


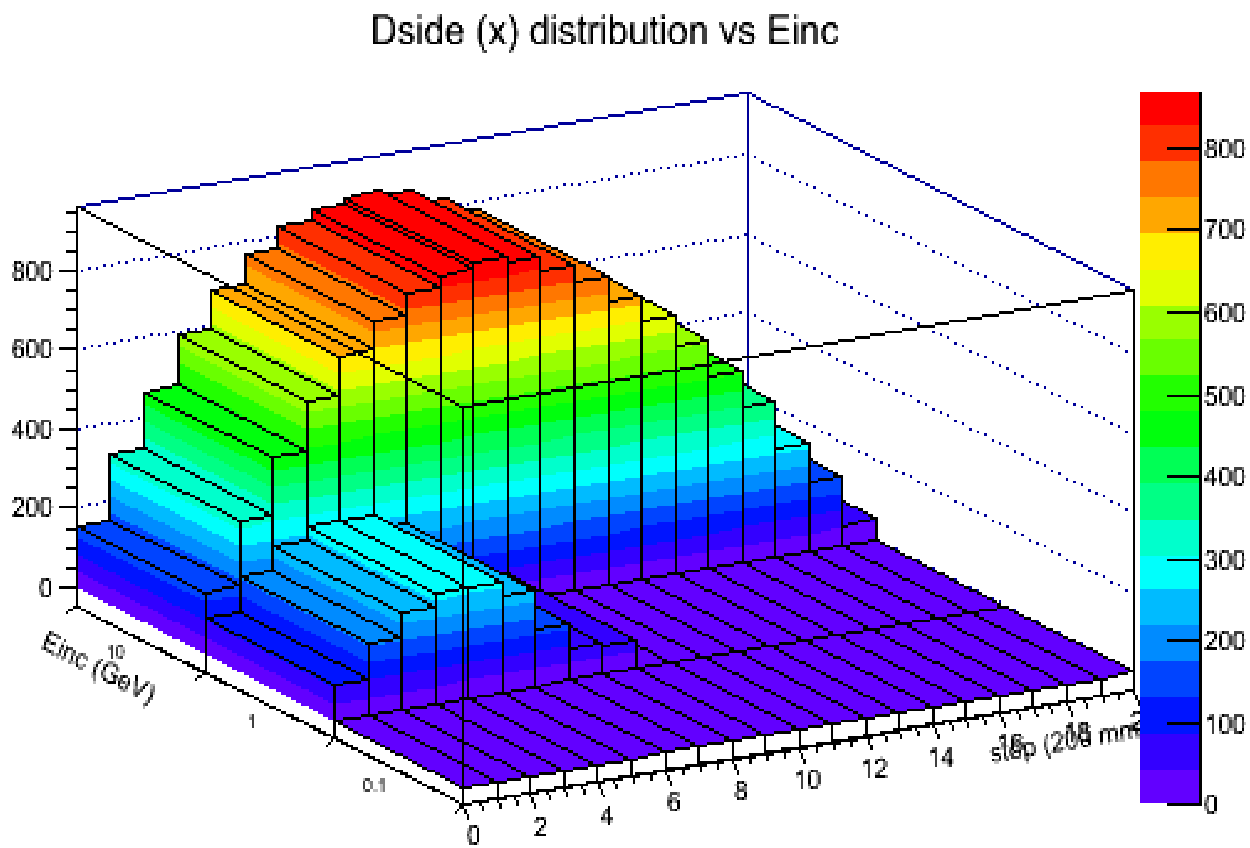
Horizontal Distance (2)

- D_{side} @ 10 MeV Threshold

Overall components

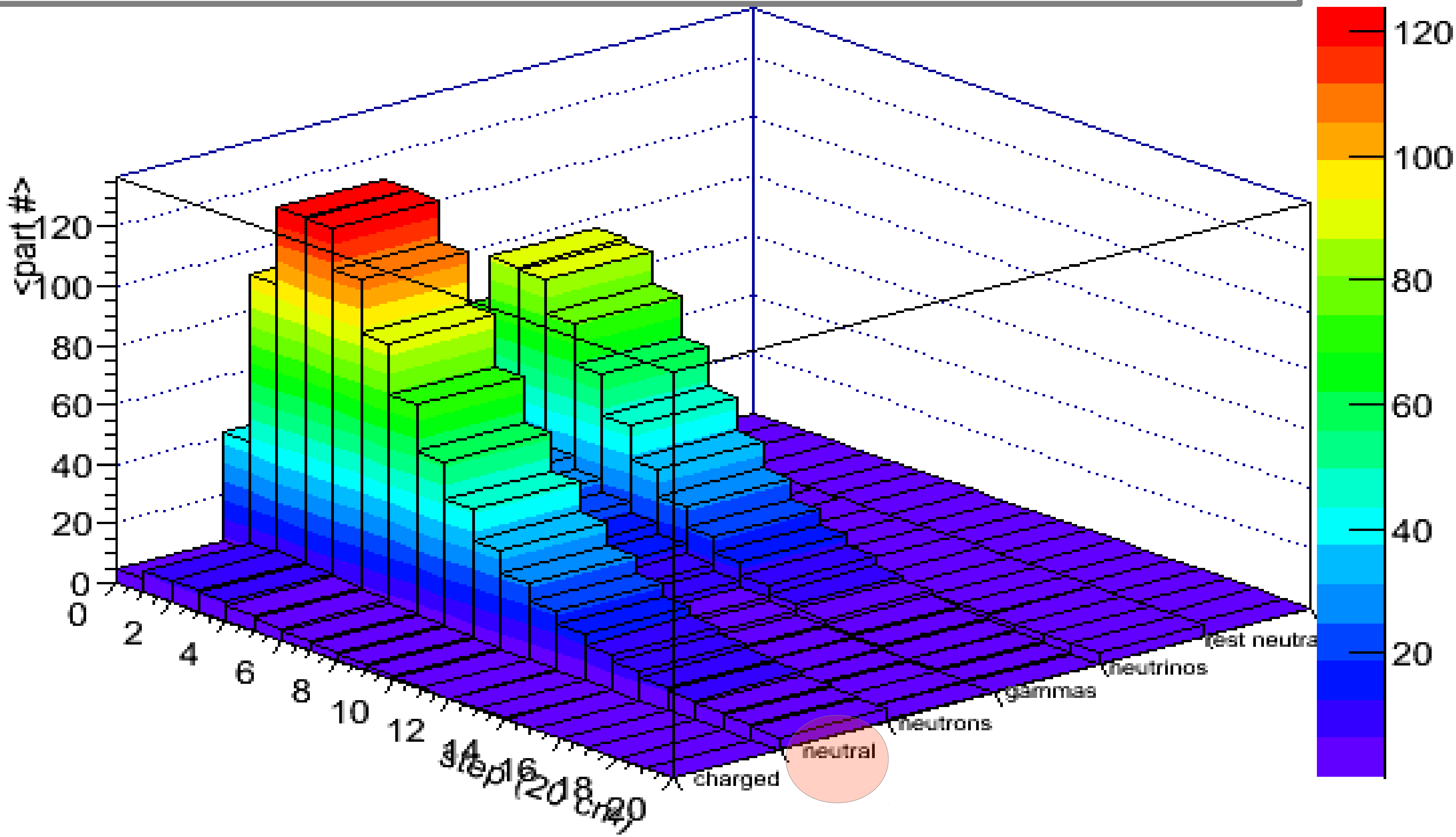
proton @ 10 GeV





Global Results (1)

proton @ 10 GeV : particles # distribution vs step



Global Results (2)

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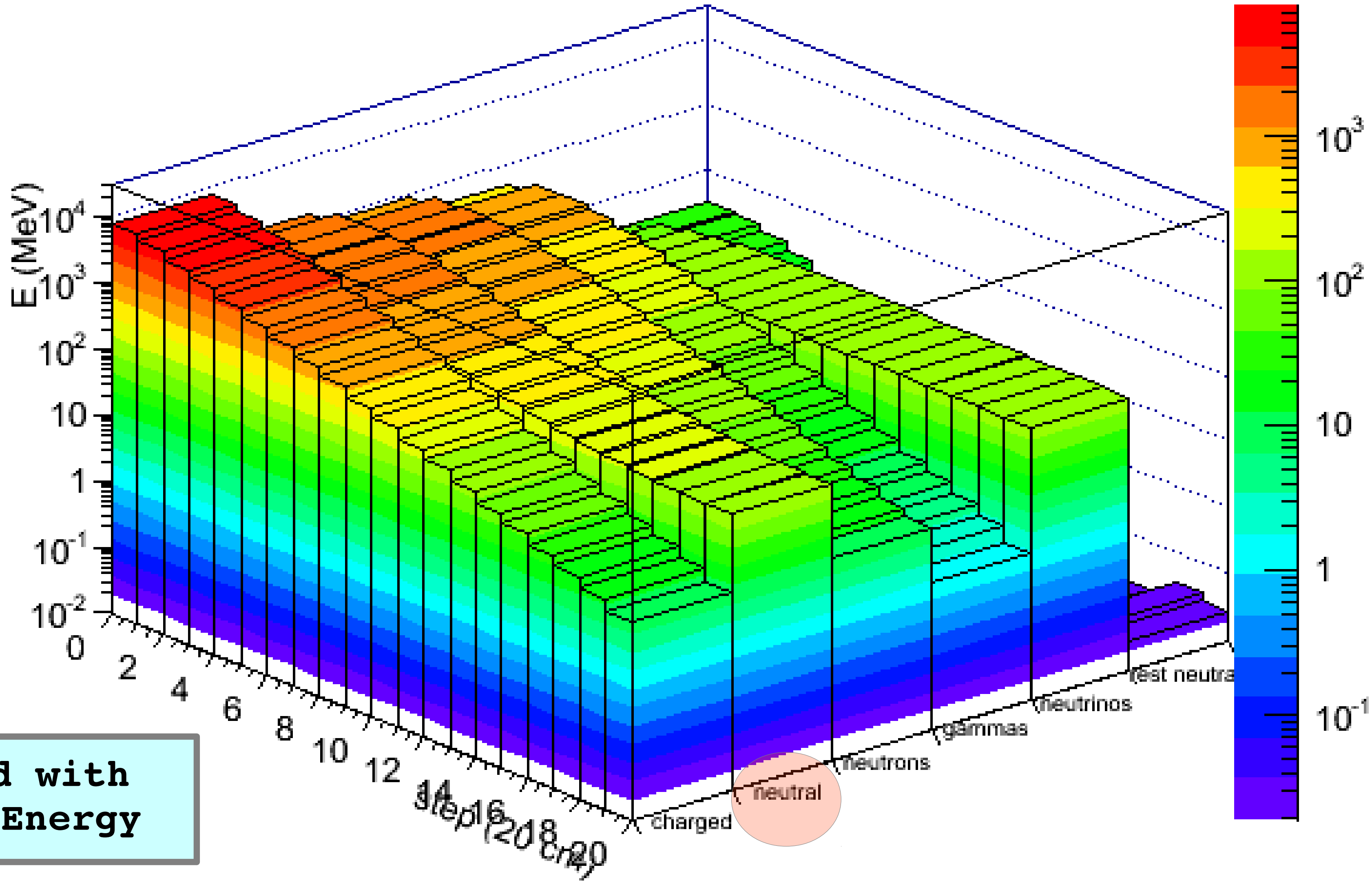
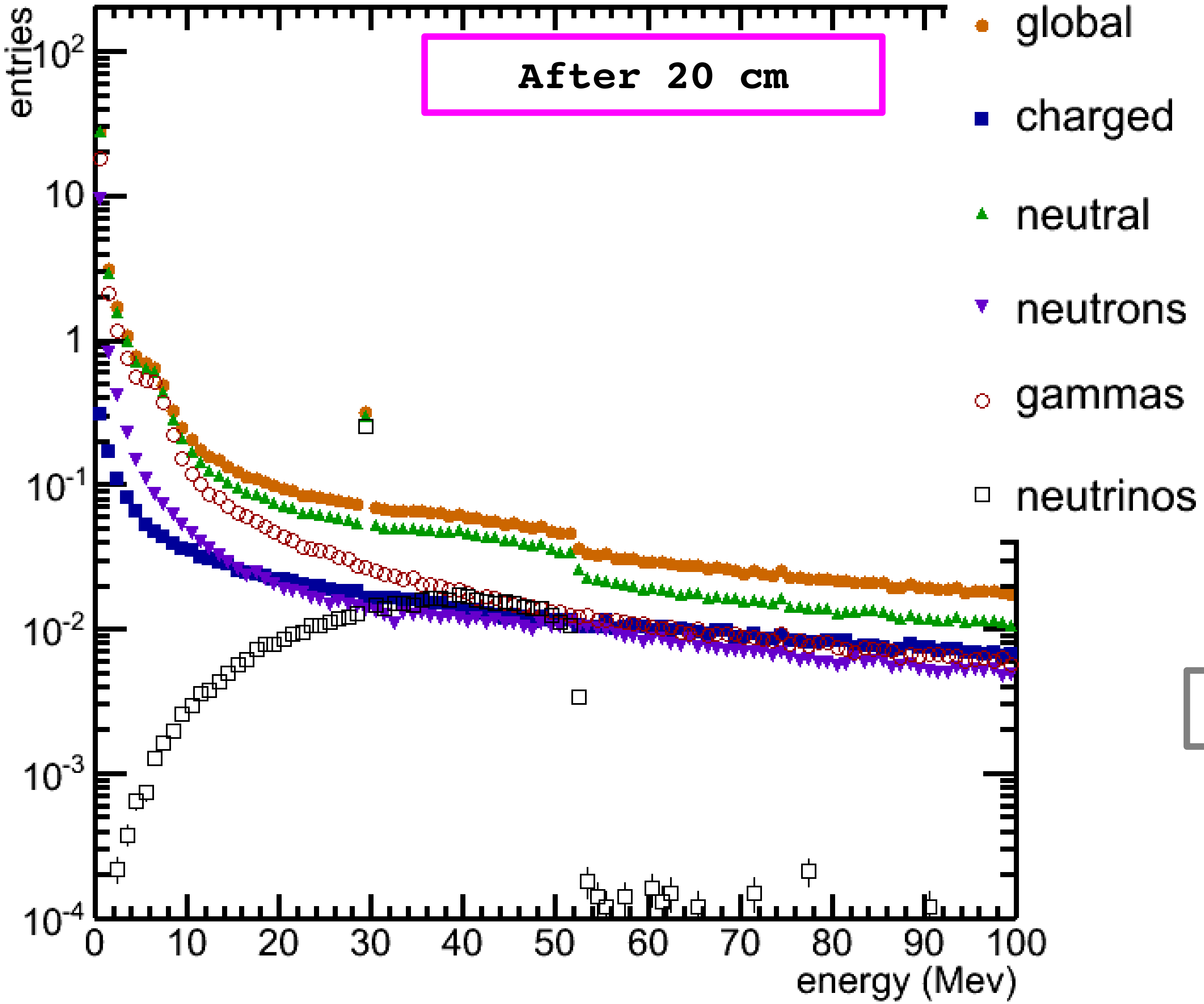


Weighted with Kinetic Energy

Global Results: Energy Spectra



proton @ 10 GeV

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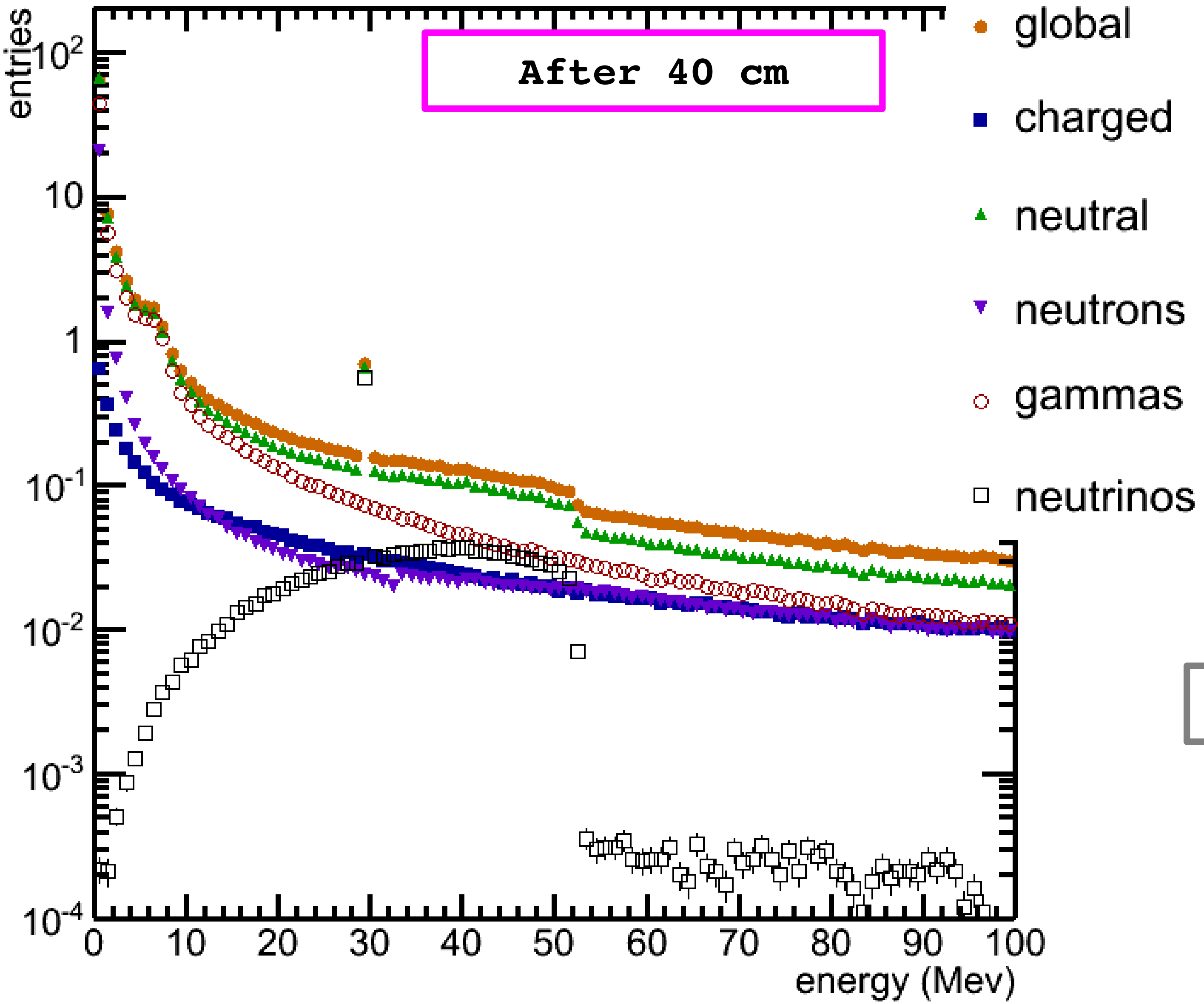

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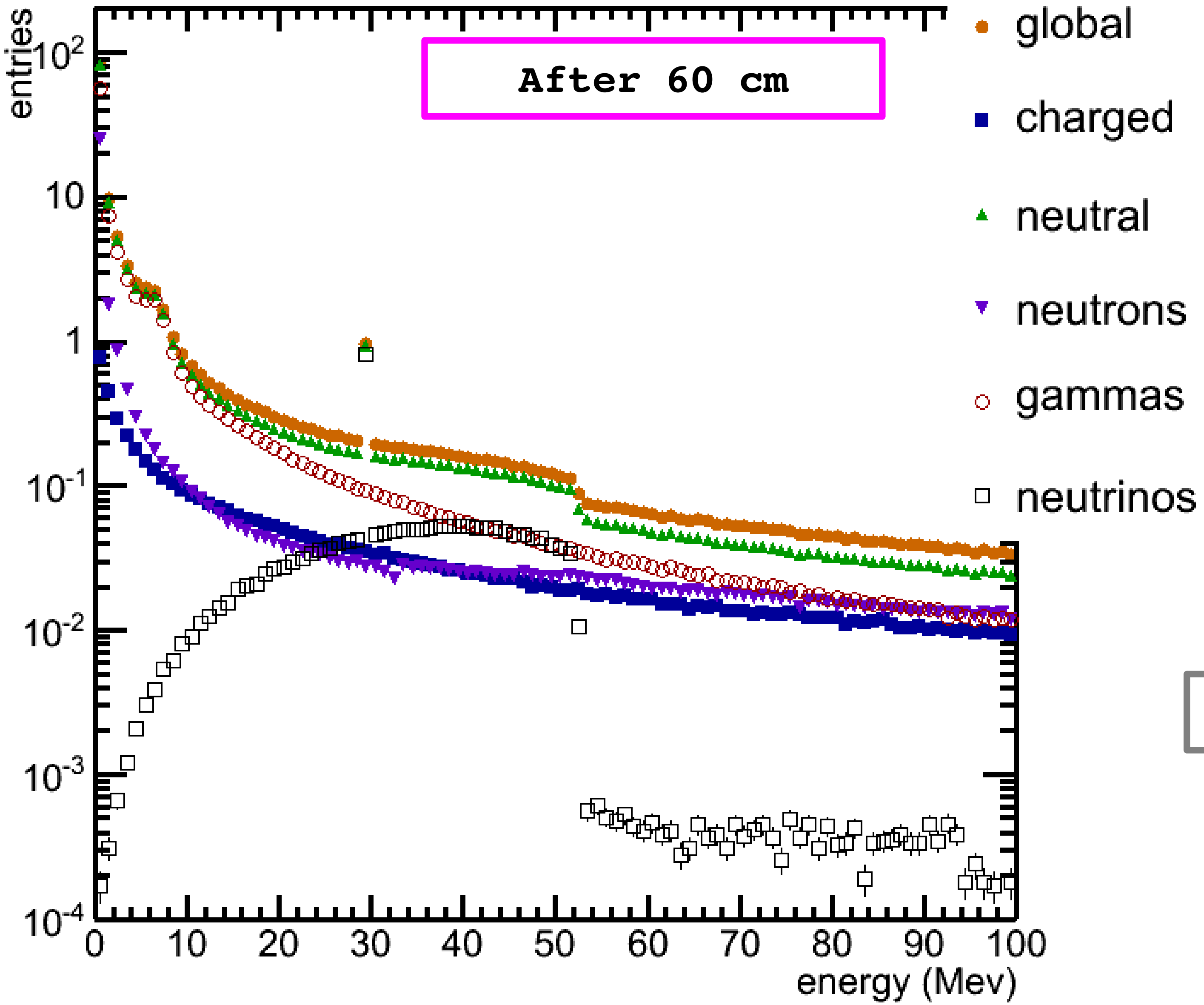

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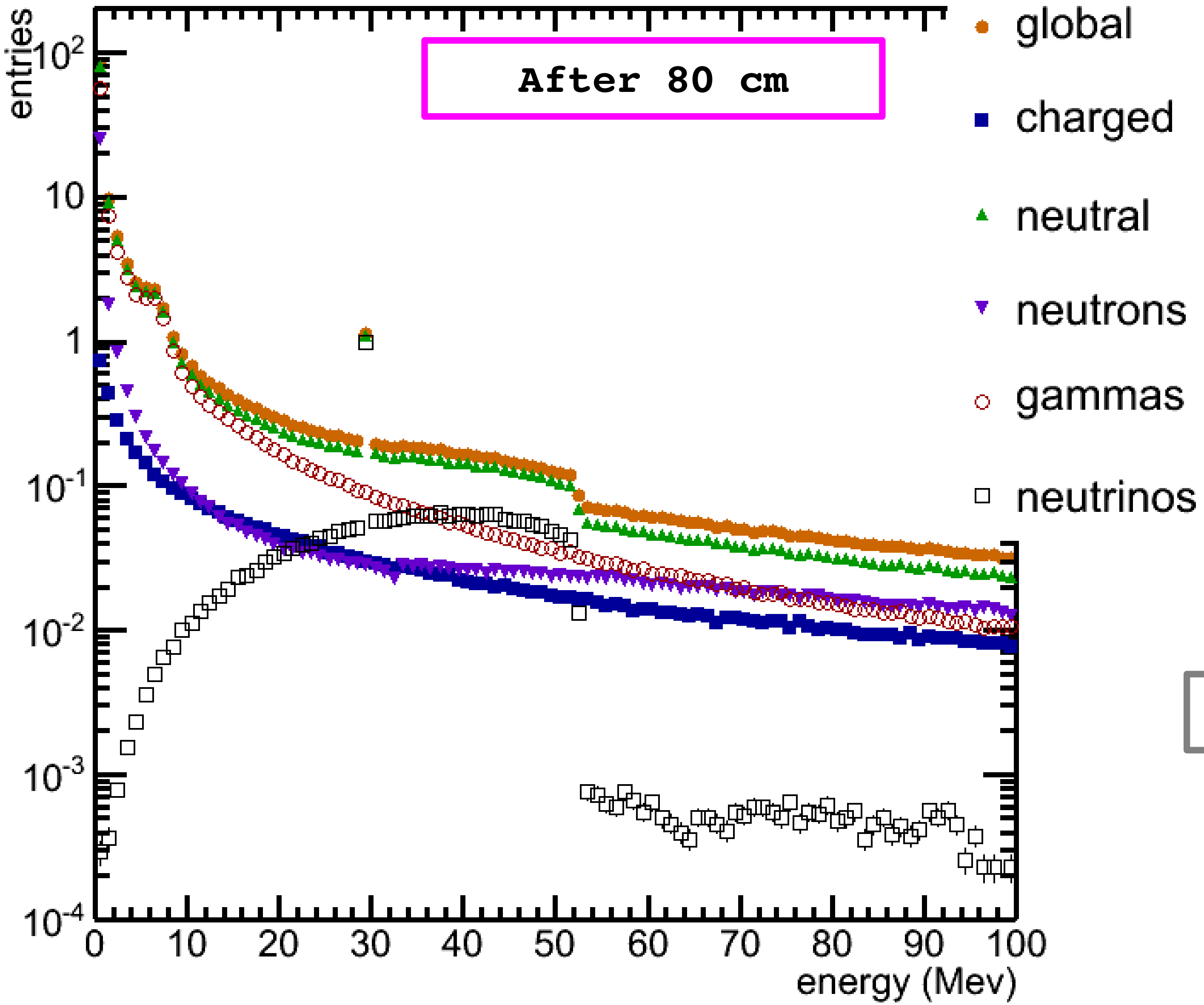

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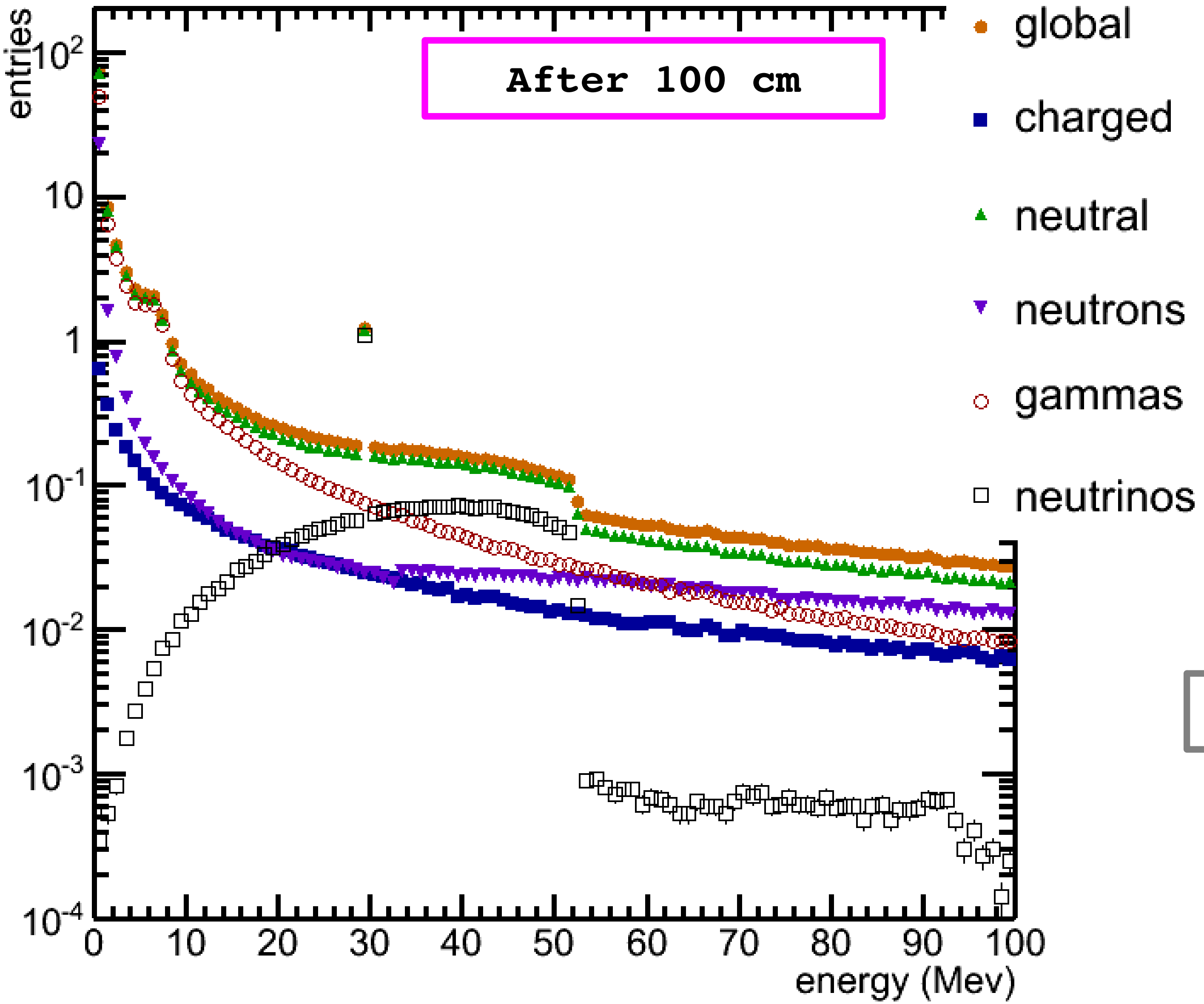

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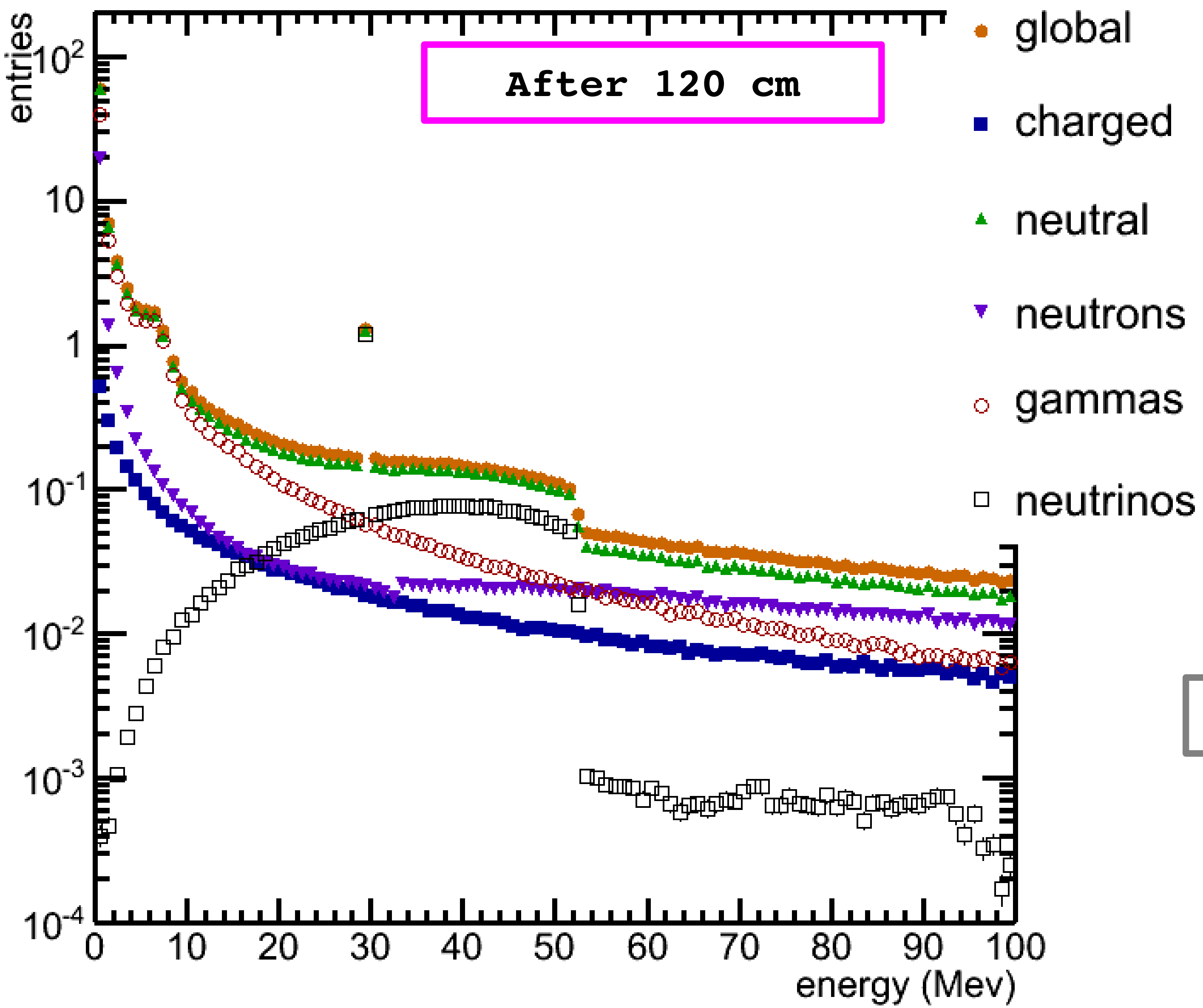

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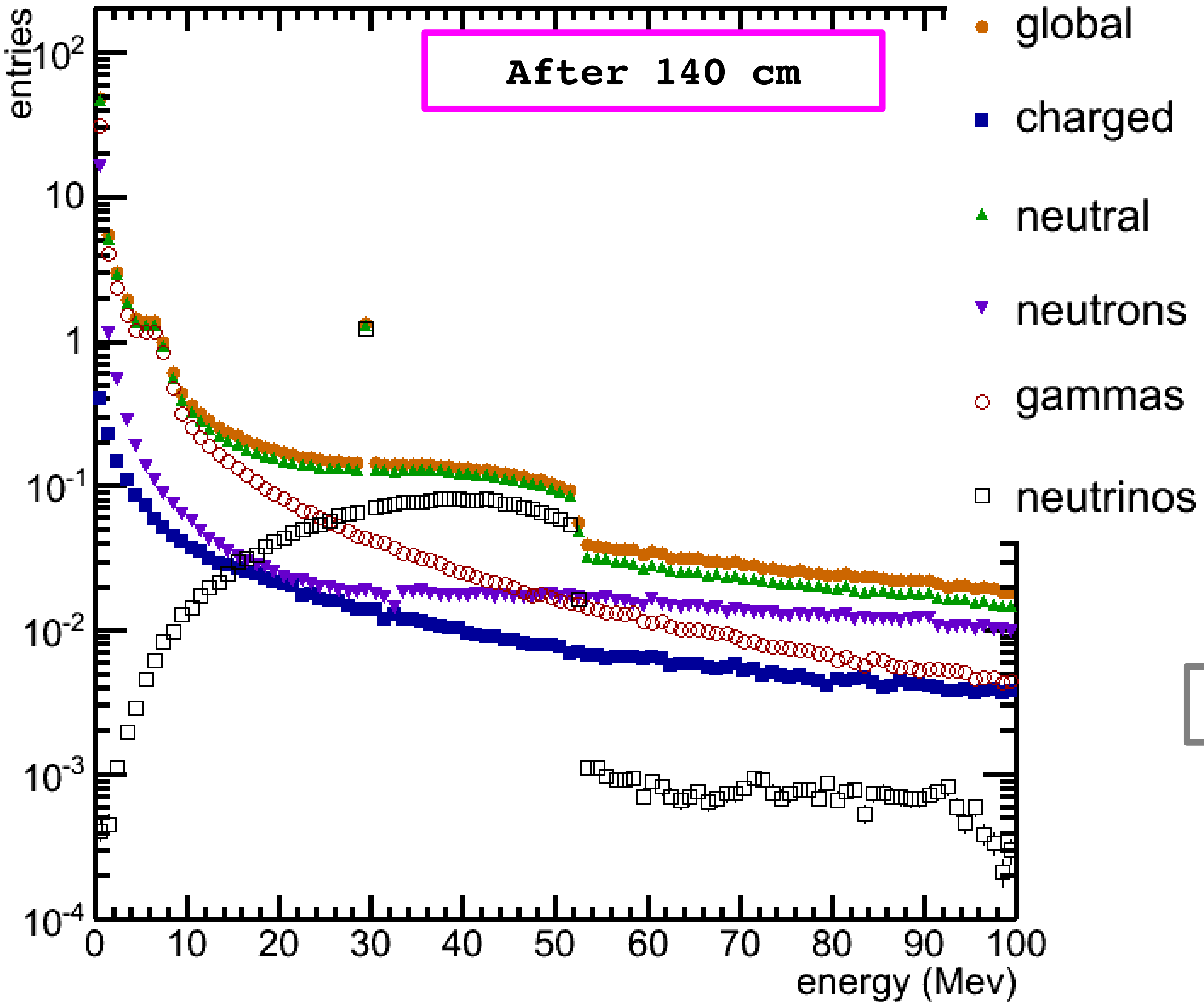

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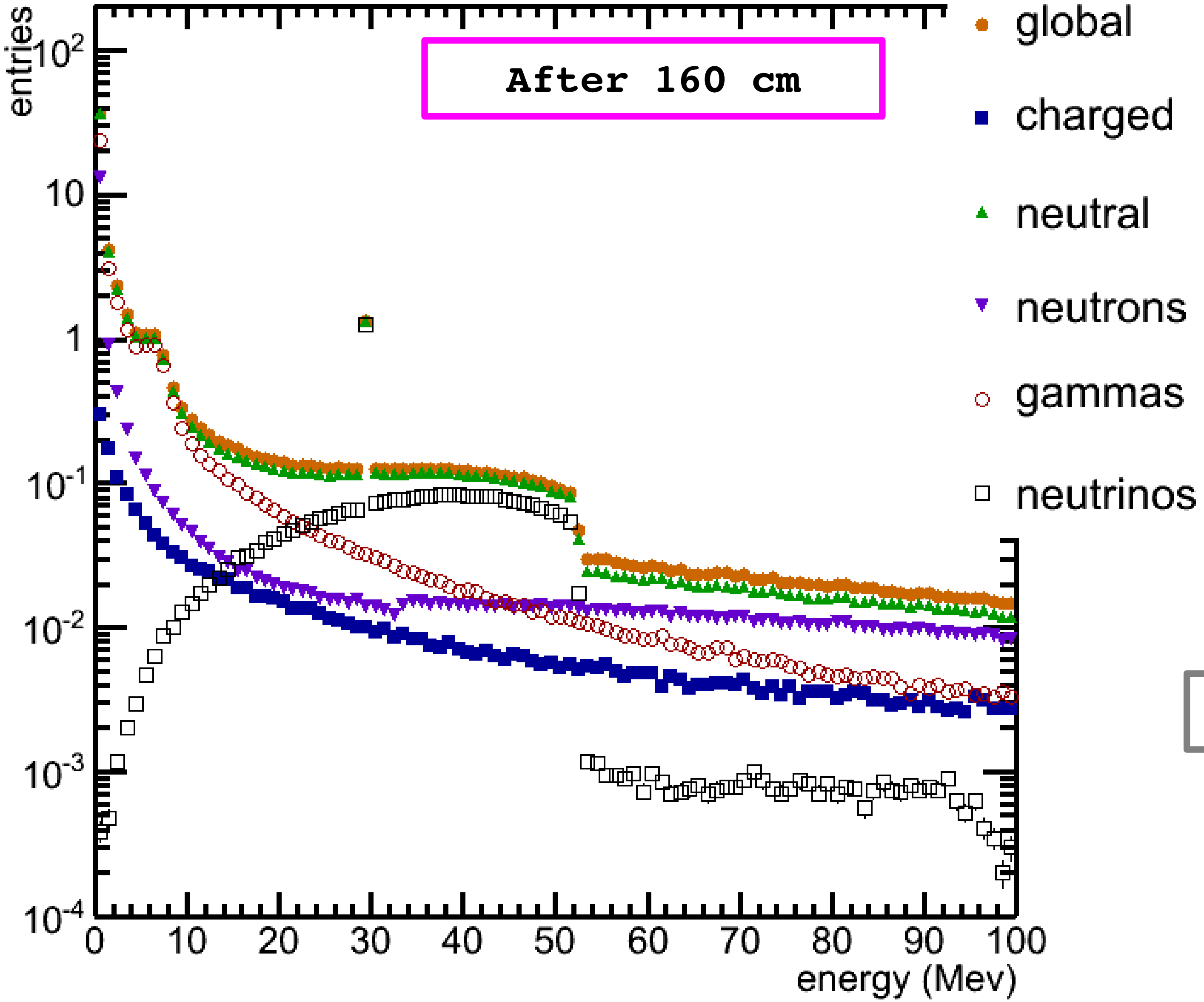

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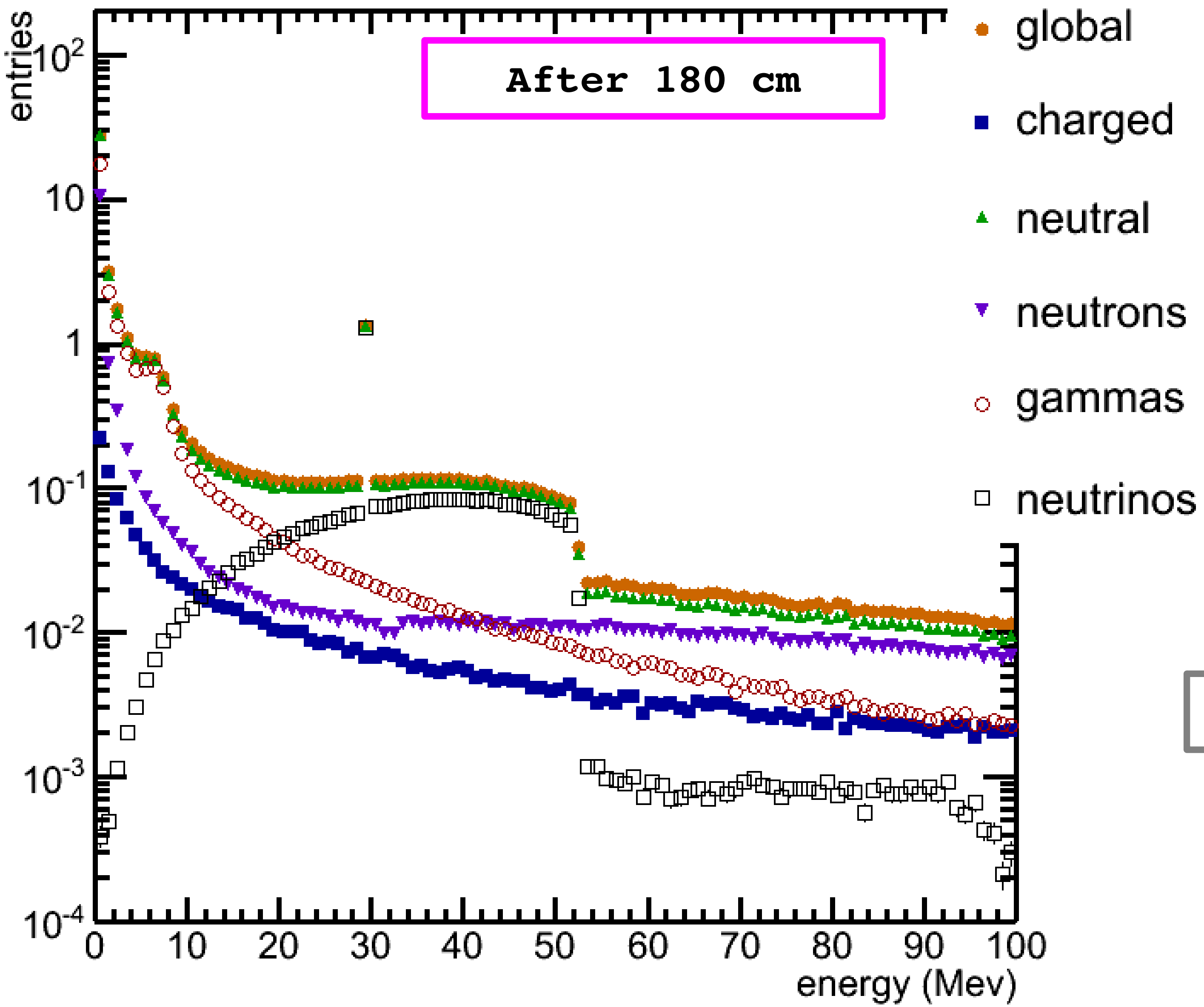

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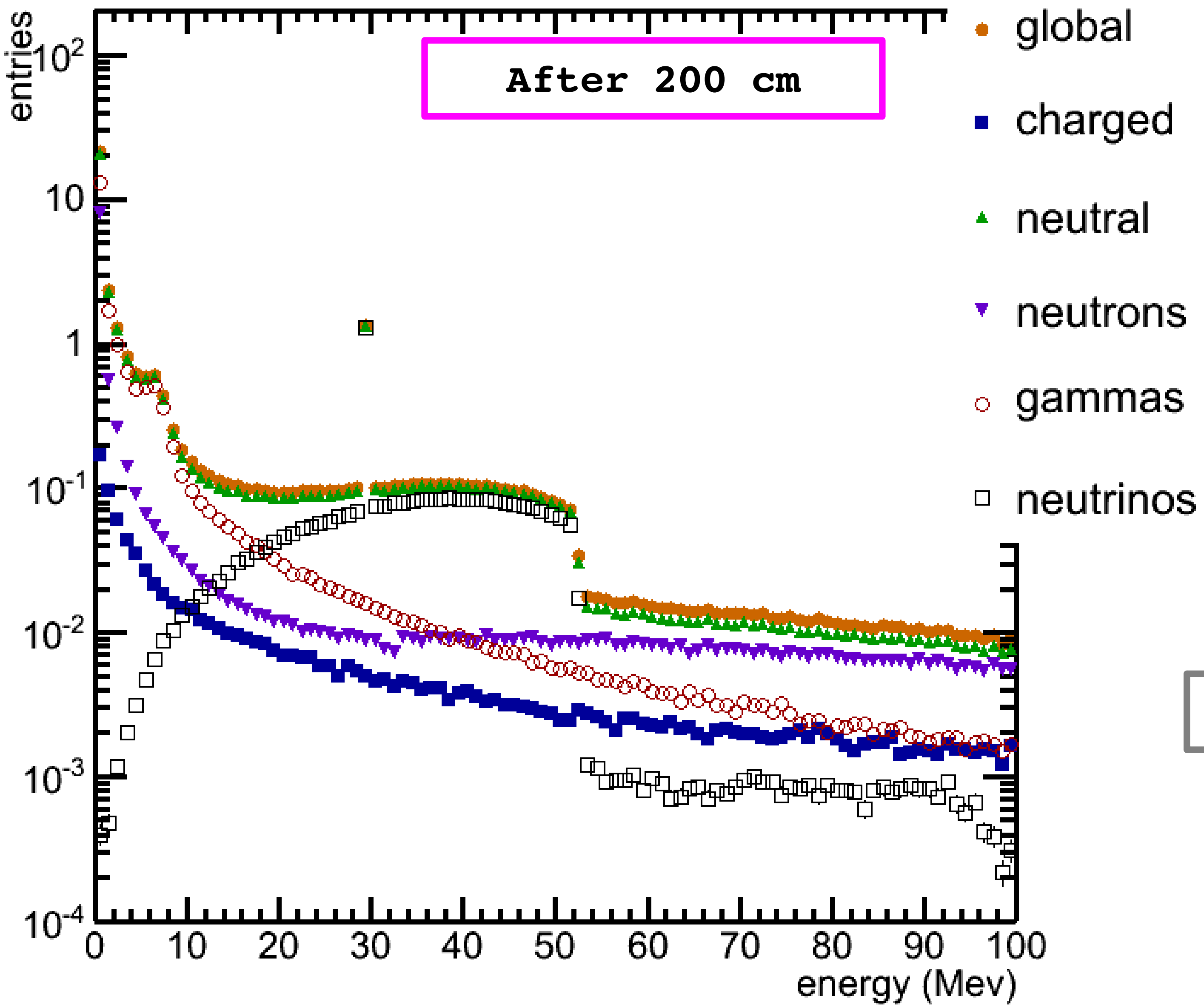

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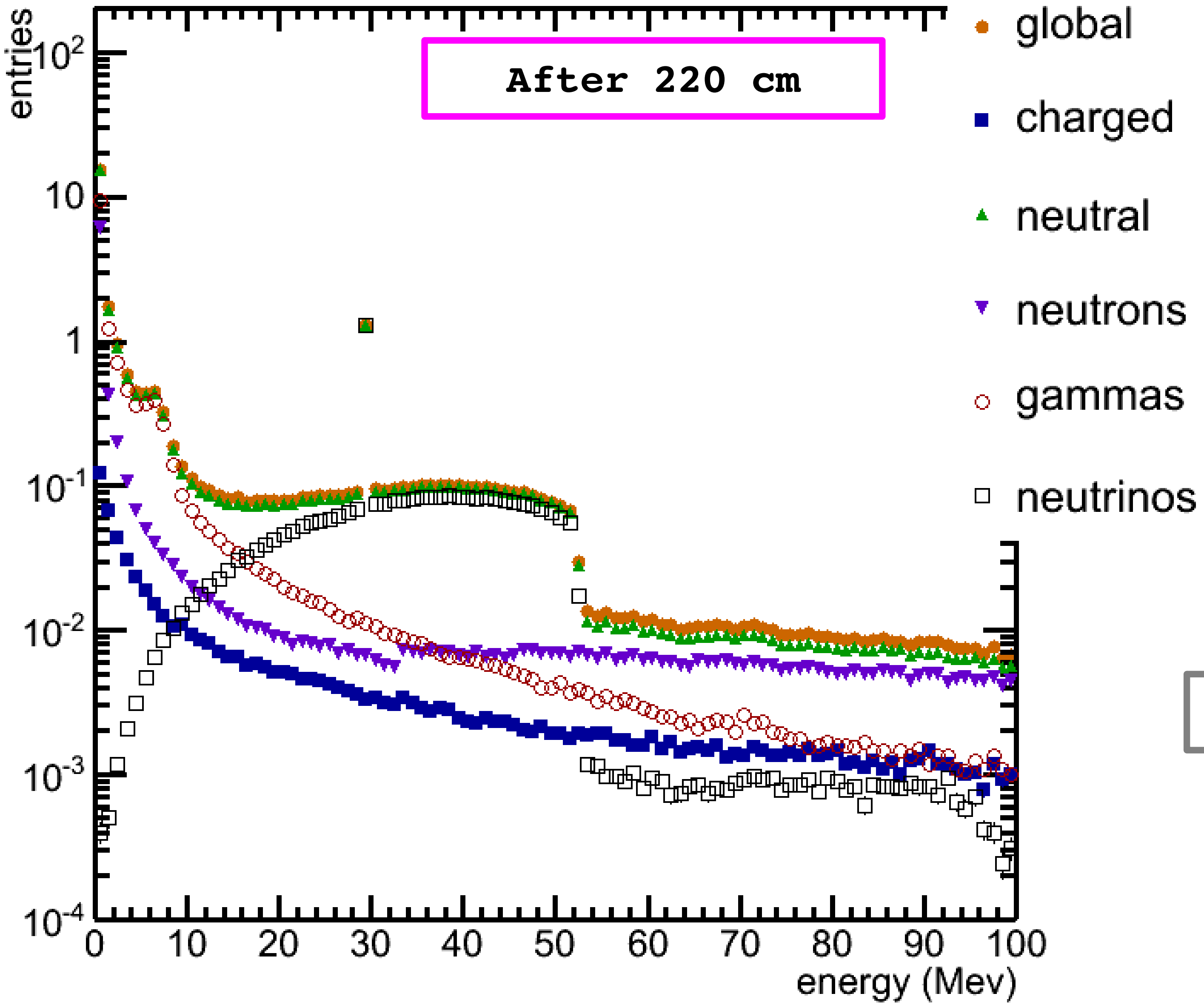

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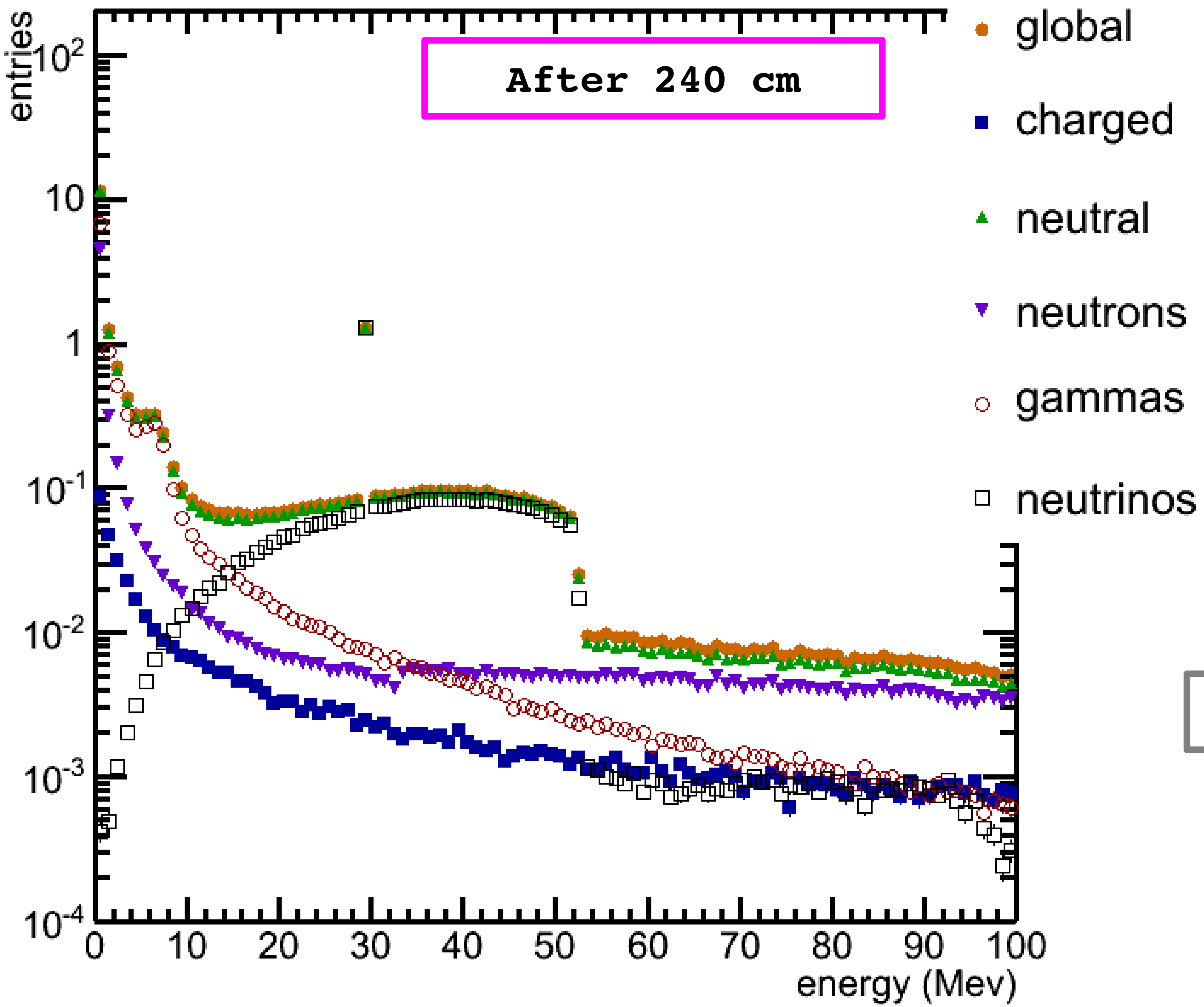

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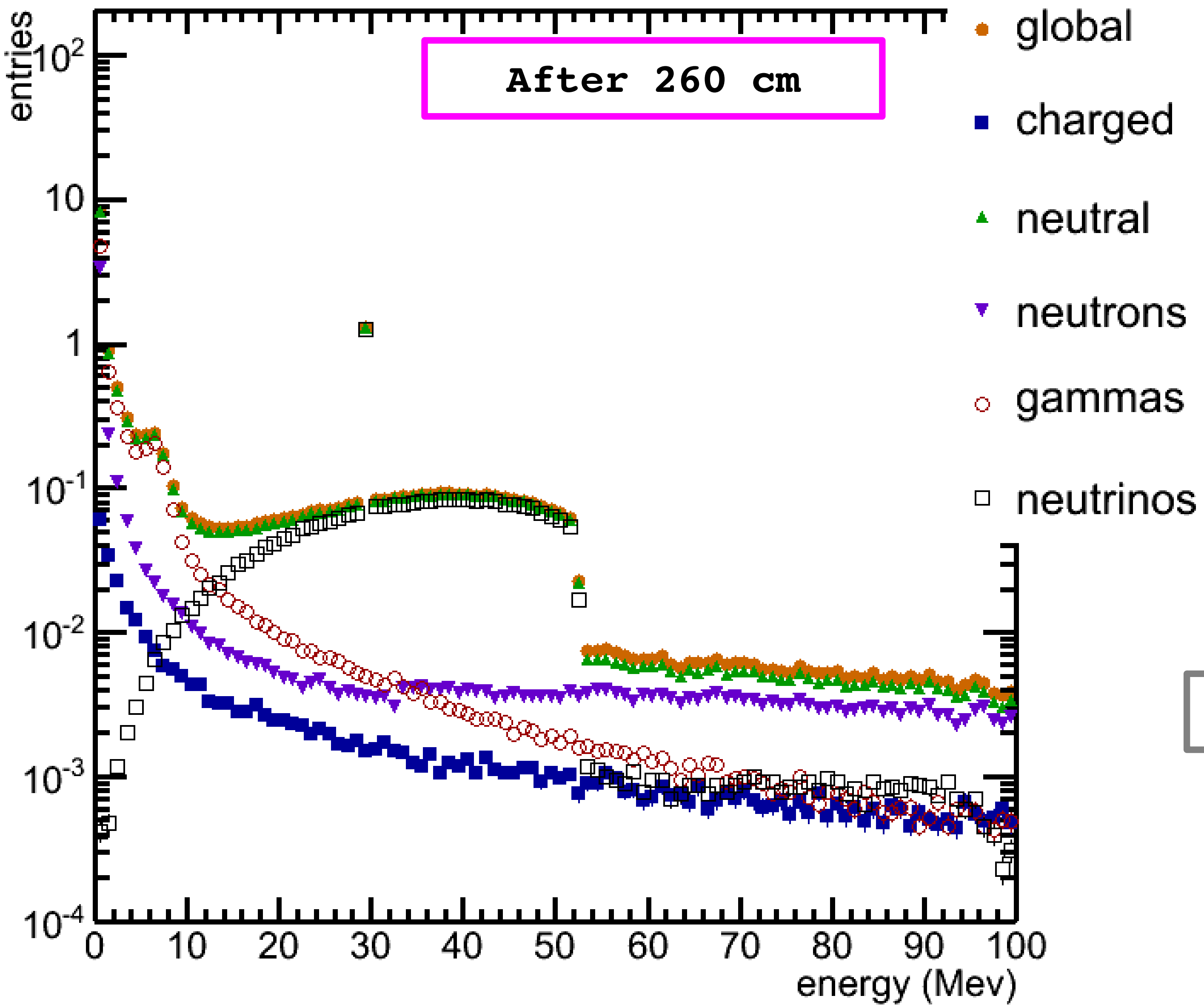

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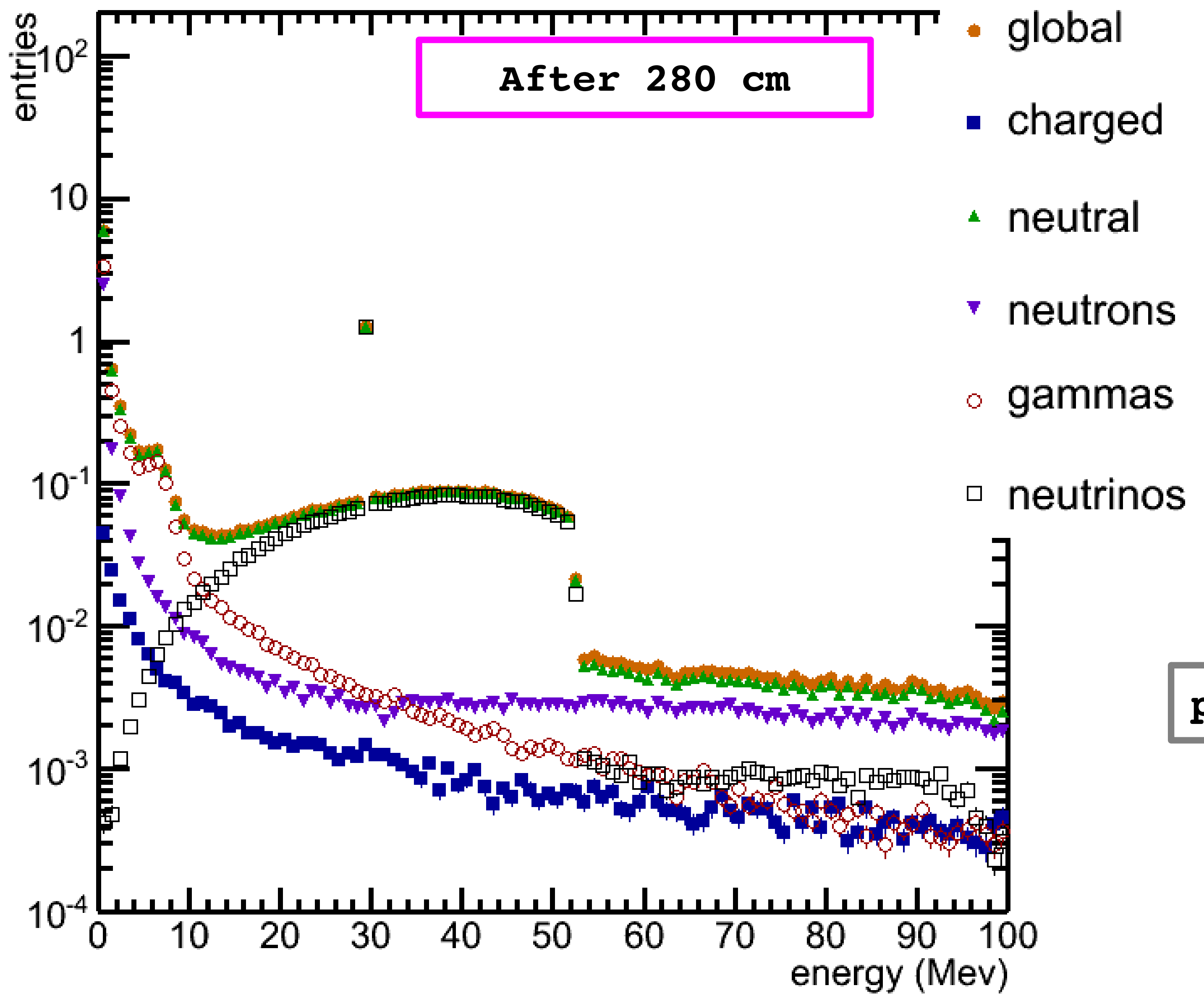

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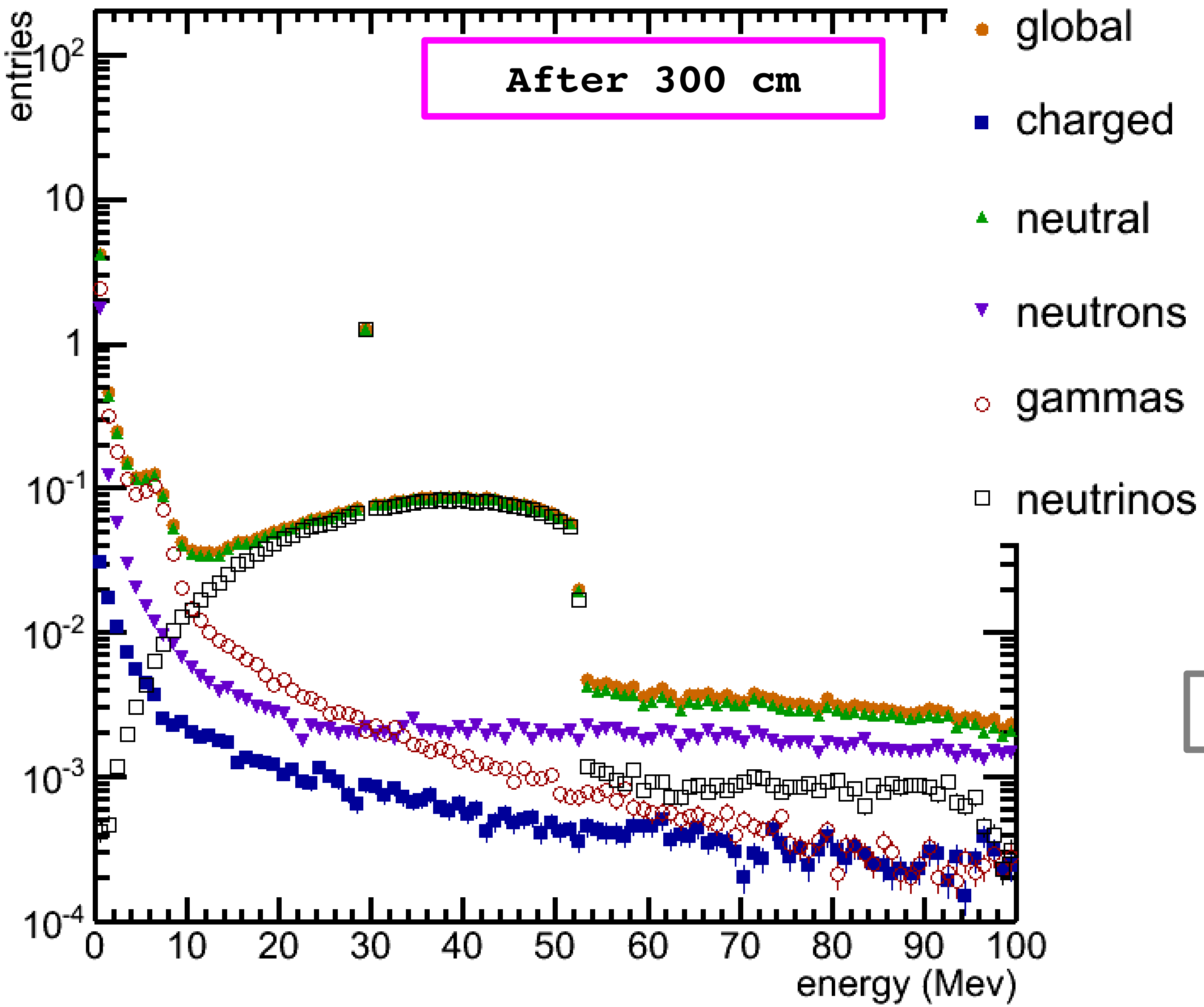

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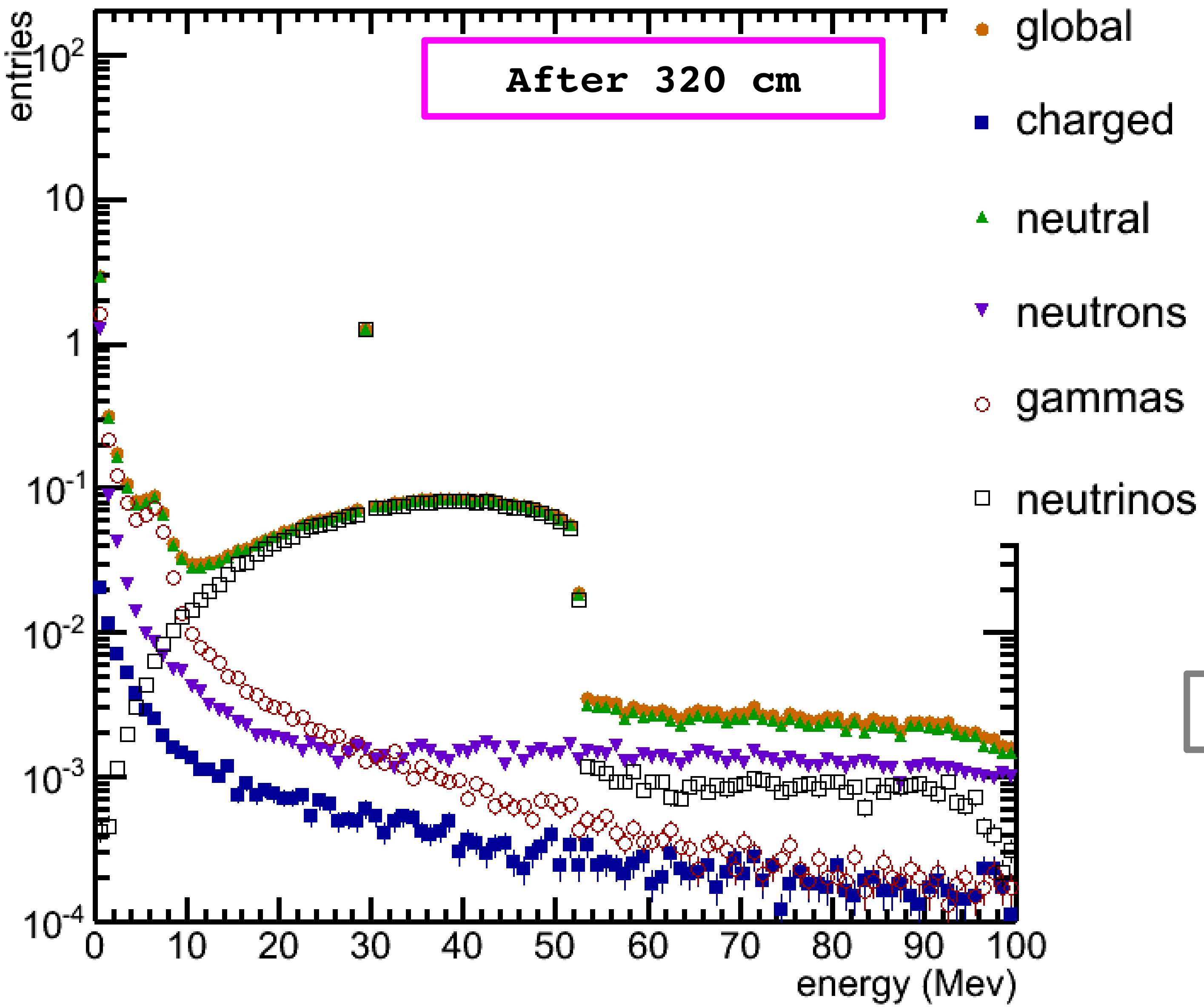

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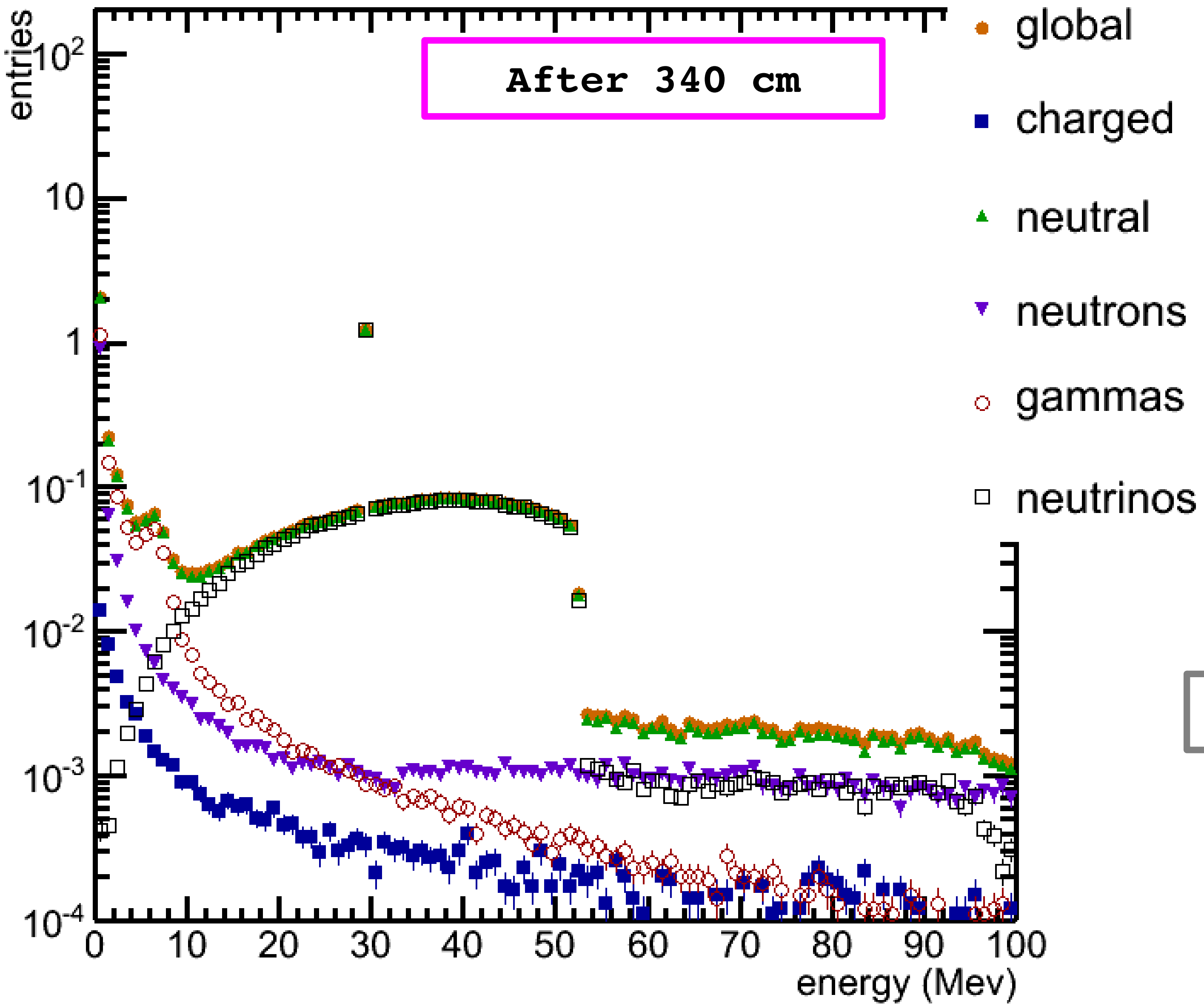

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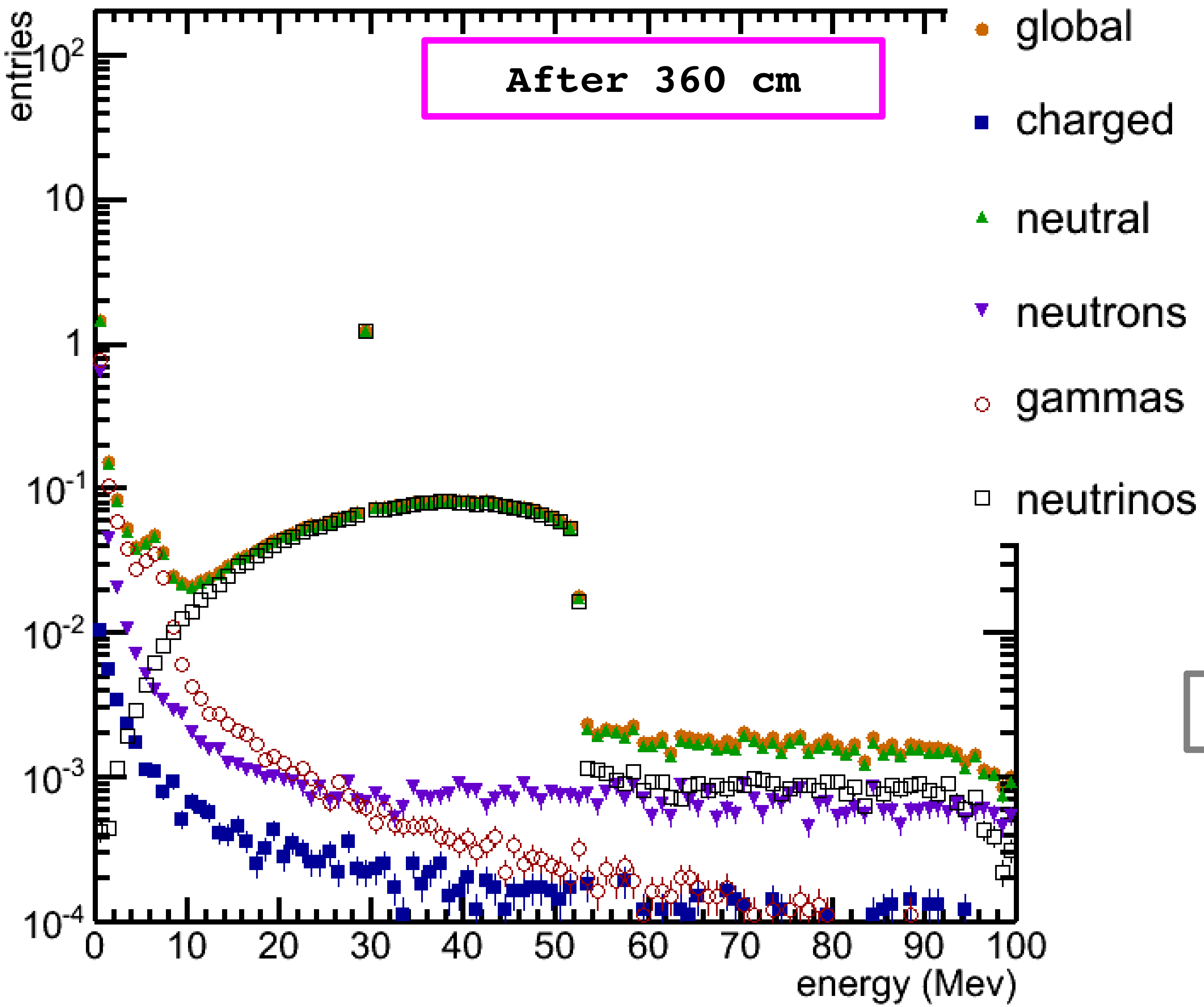

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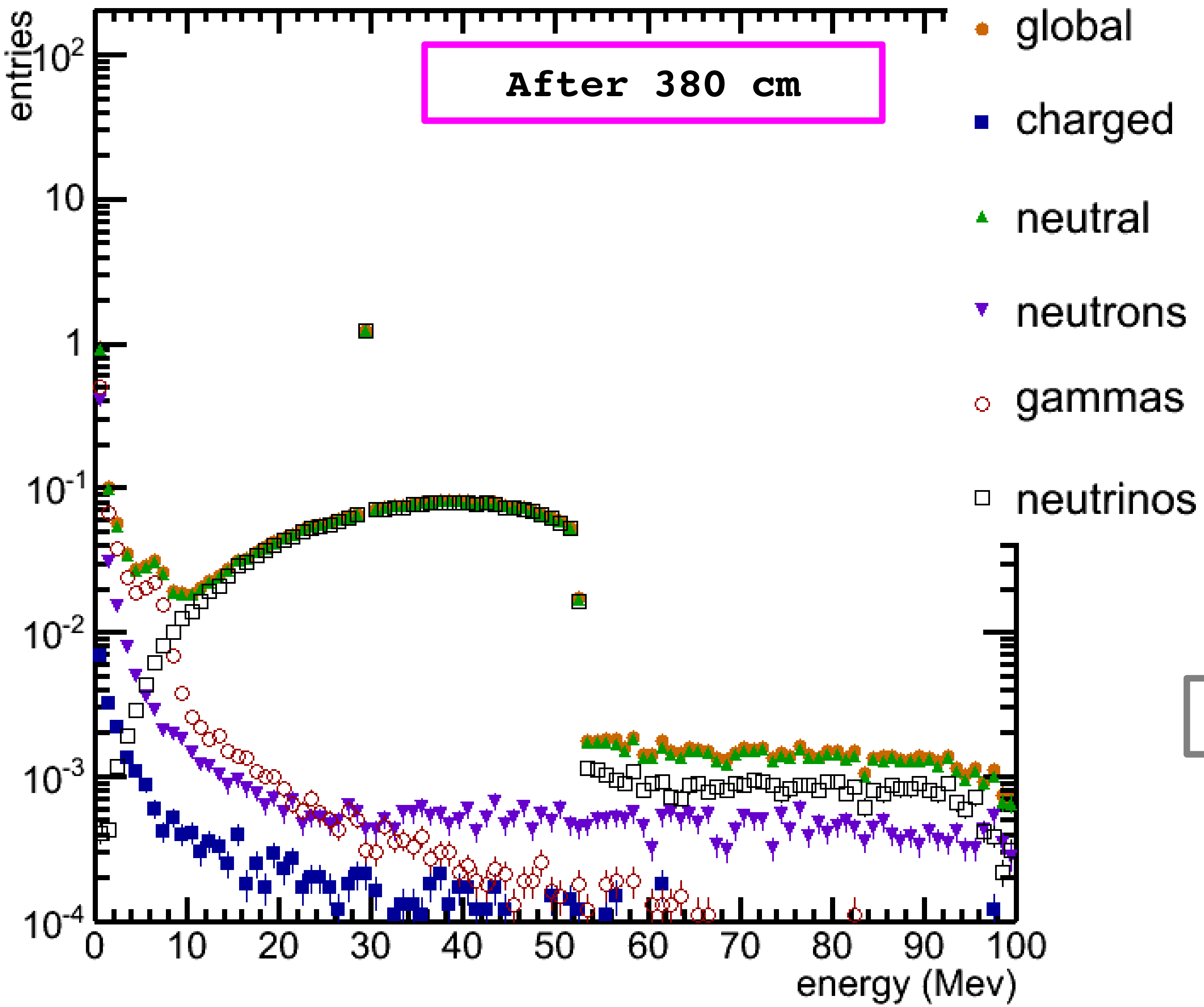

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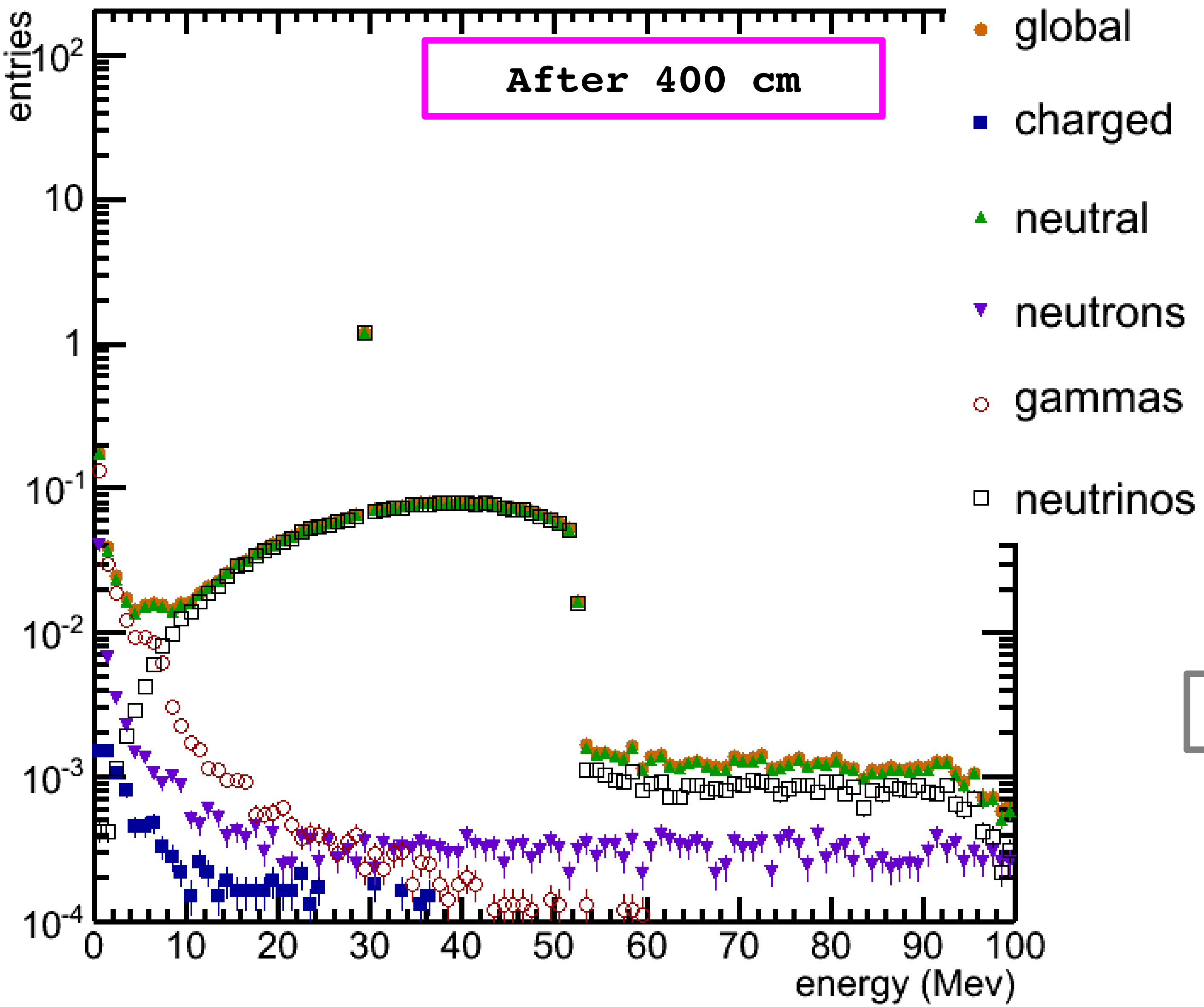

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    - Reject some BKG events
  - Most of the particles produced in a hadronic shower are neutral (mostly neutrons and gamma)
  - Besides neutrinos most of the energy left over after 4 m of rock belongs to neutron

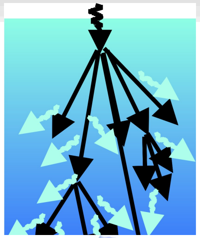
- **Outlook:**
  - Probe higher energies
  - Use muons and neutrinos as incoming particles
  - Probe with underground measured muons spectra
  - Background flux estimation
  - Shielding

Thank You for The Attention!

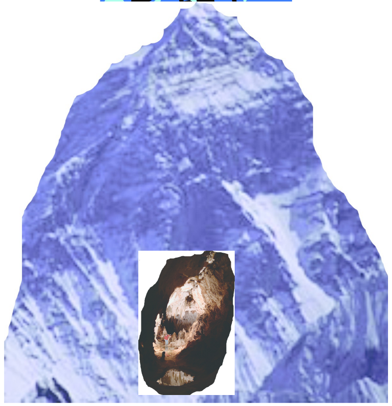
Backup

The Problem

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

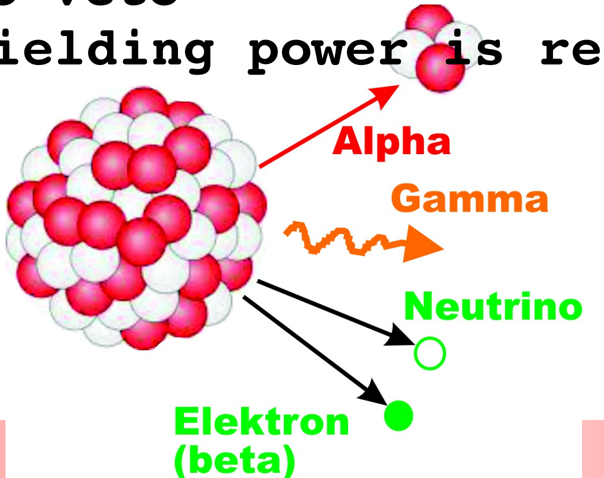


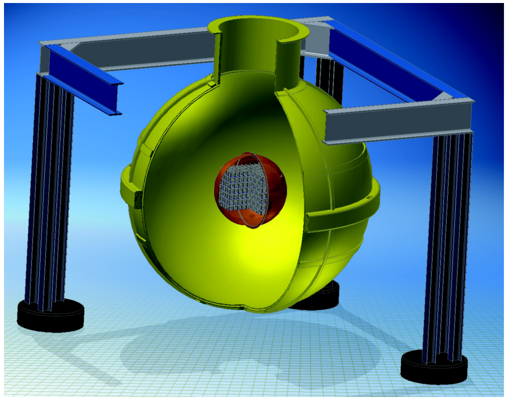
- To enhance the expected counting rate:
  - Increase the mass → 1 Ton experiments
  - Increase the S/N ratio → Move underground



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

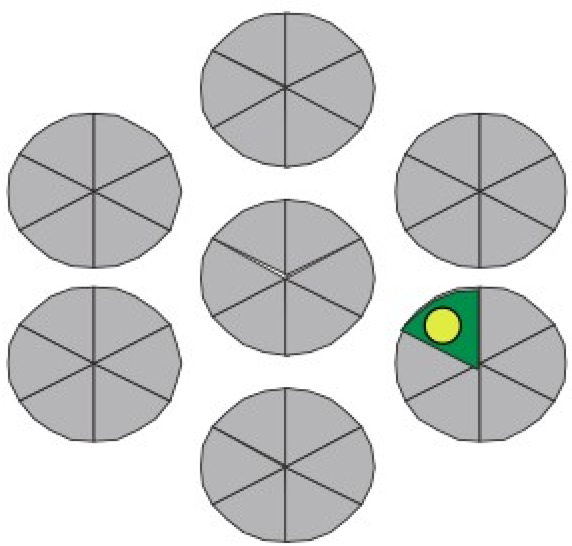
- Two different components:
  - Charged → easy to veto
  - Neutral → high shielding power is required





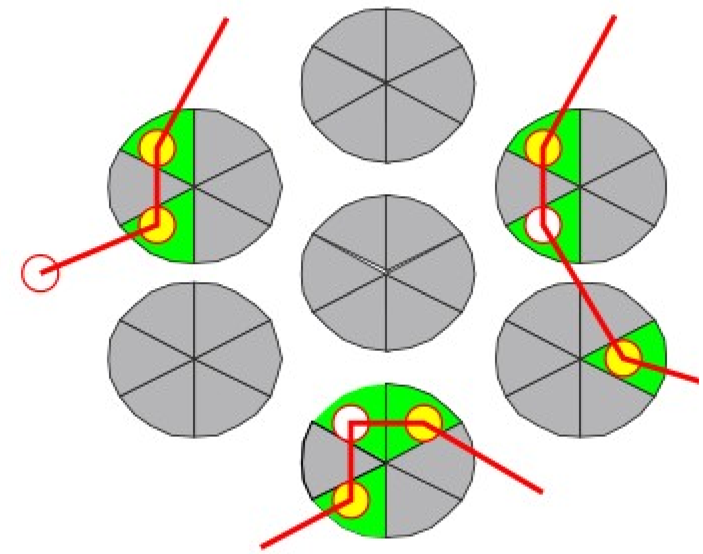
Background events

$0\nu\beta\beta$



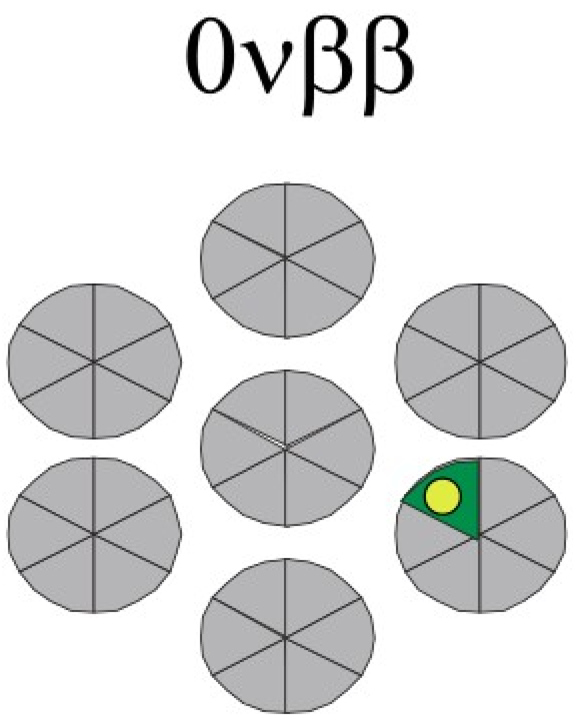
localized deposit
single site event

γ or 2γ

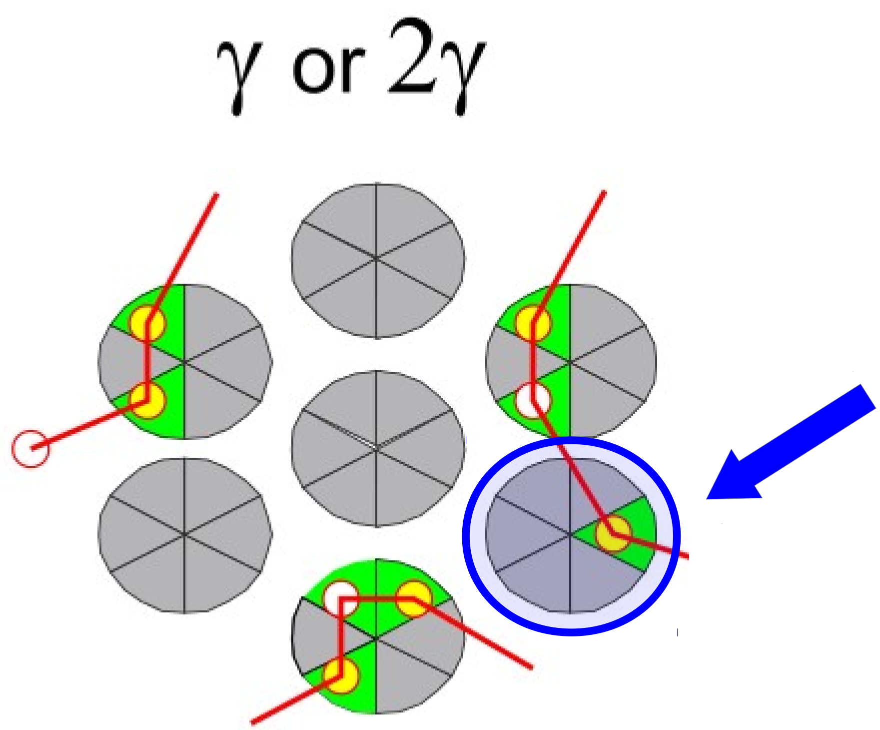


several deposits
multi site event

Background events

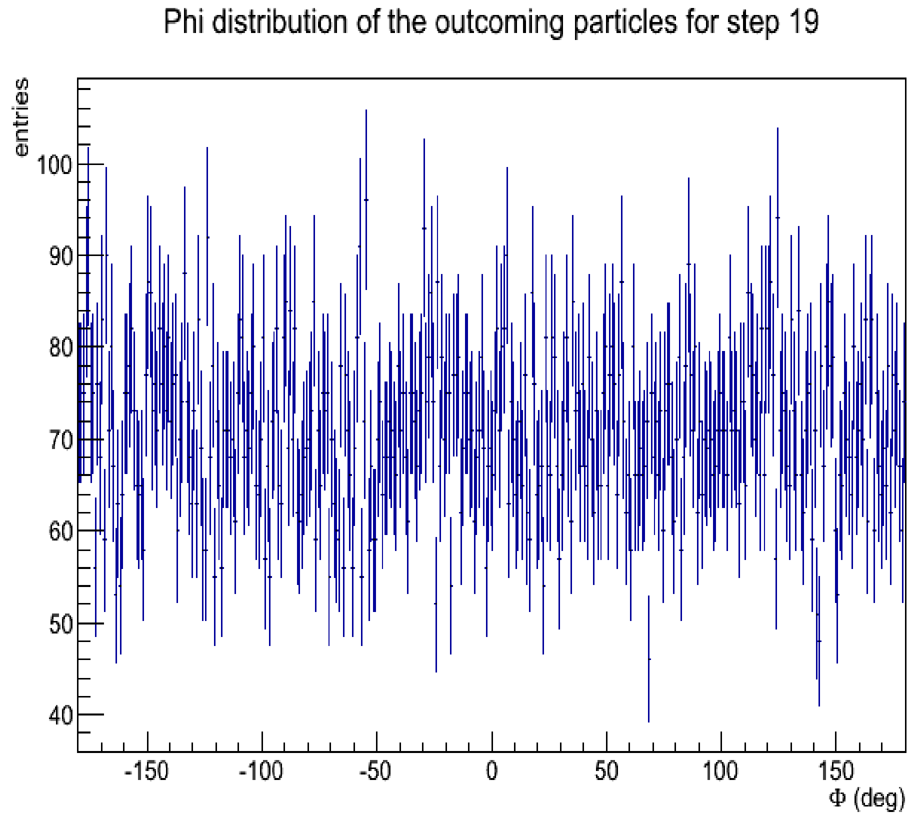


localized deposit
single site event



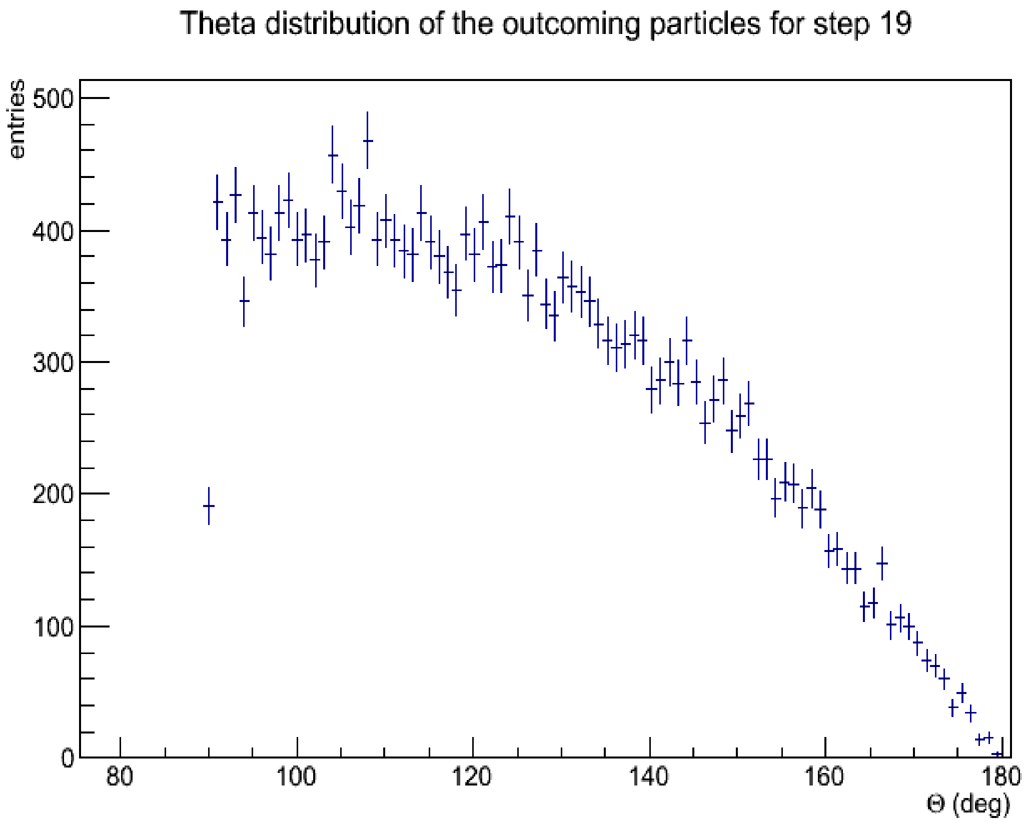
several deposits
multi site event

How do we do that? (2)

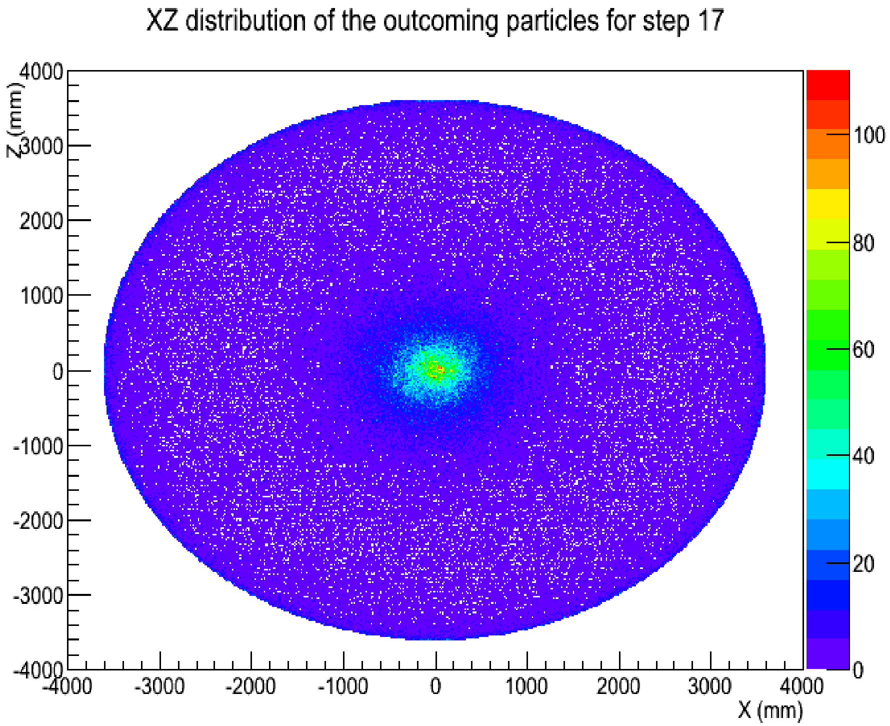


- Isotropically distributed wrt the polar angle on the XZ plane

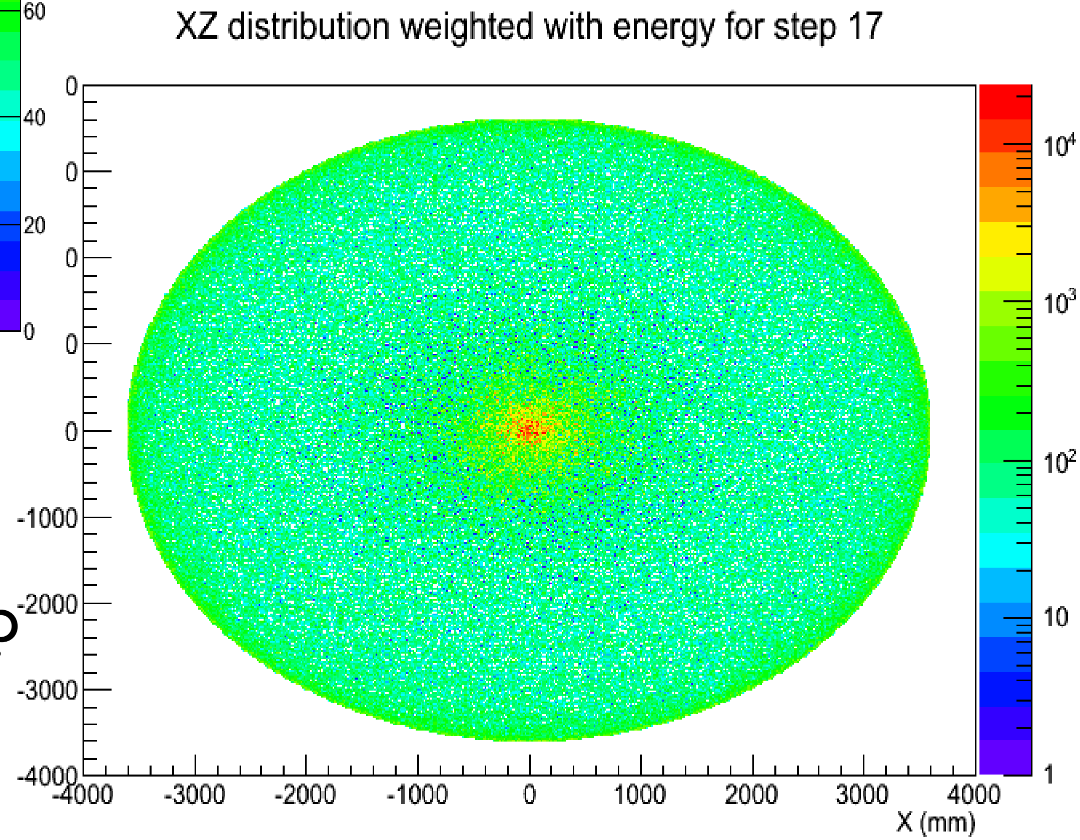
- Looking Forward



Position Weighted with Kinetic Energy

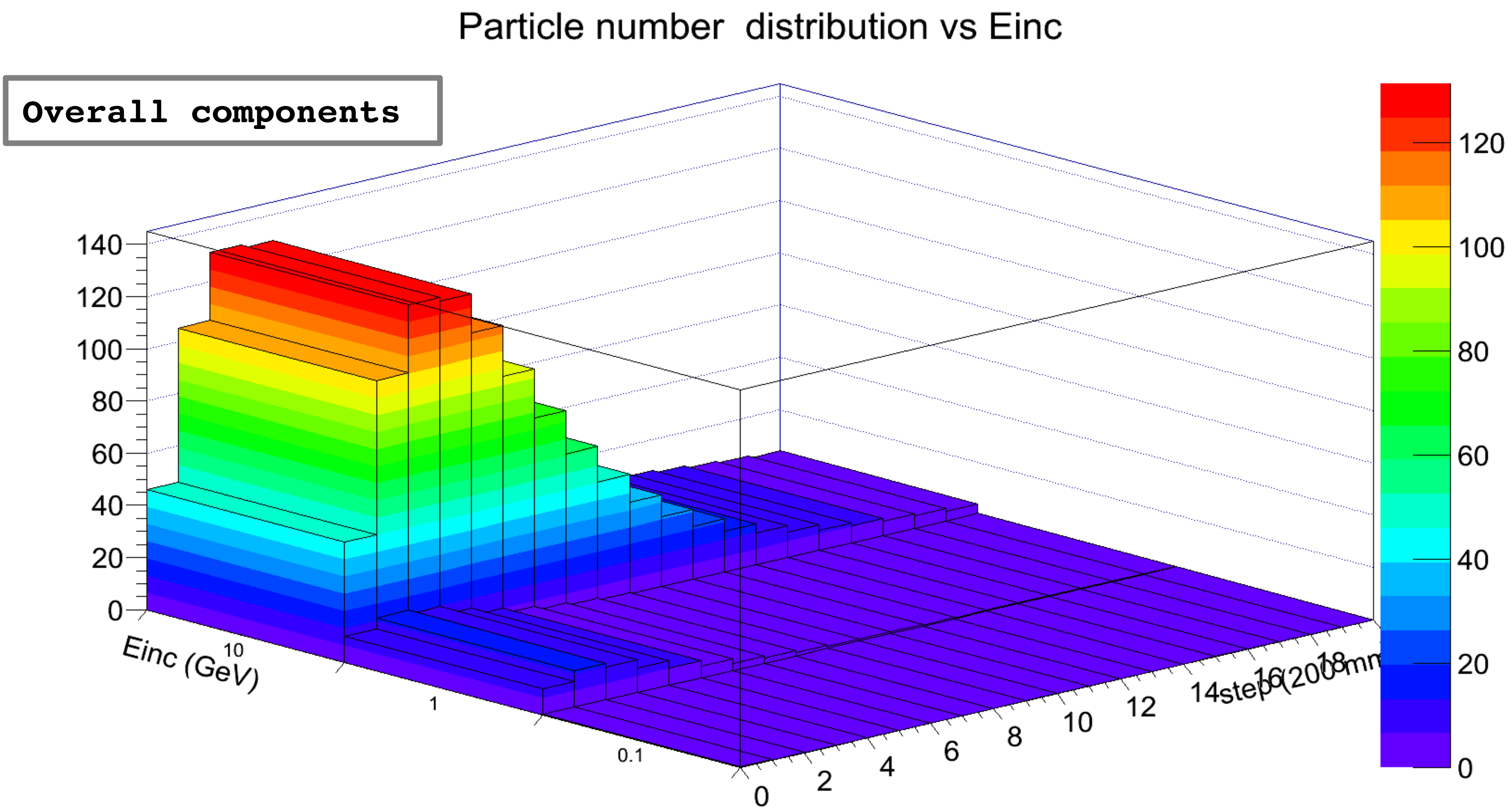


- XZ distribution WEIGHTED with Kinetic Energy



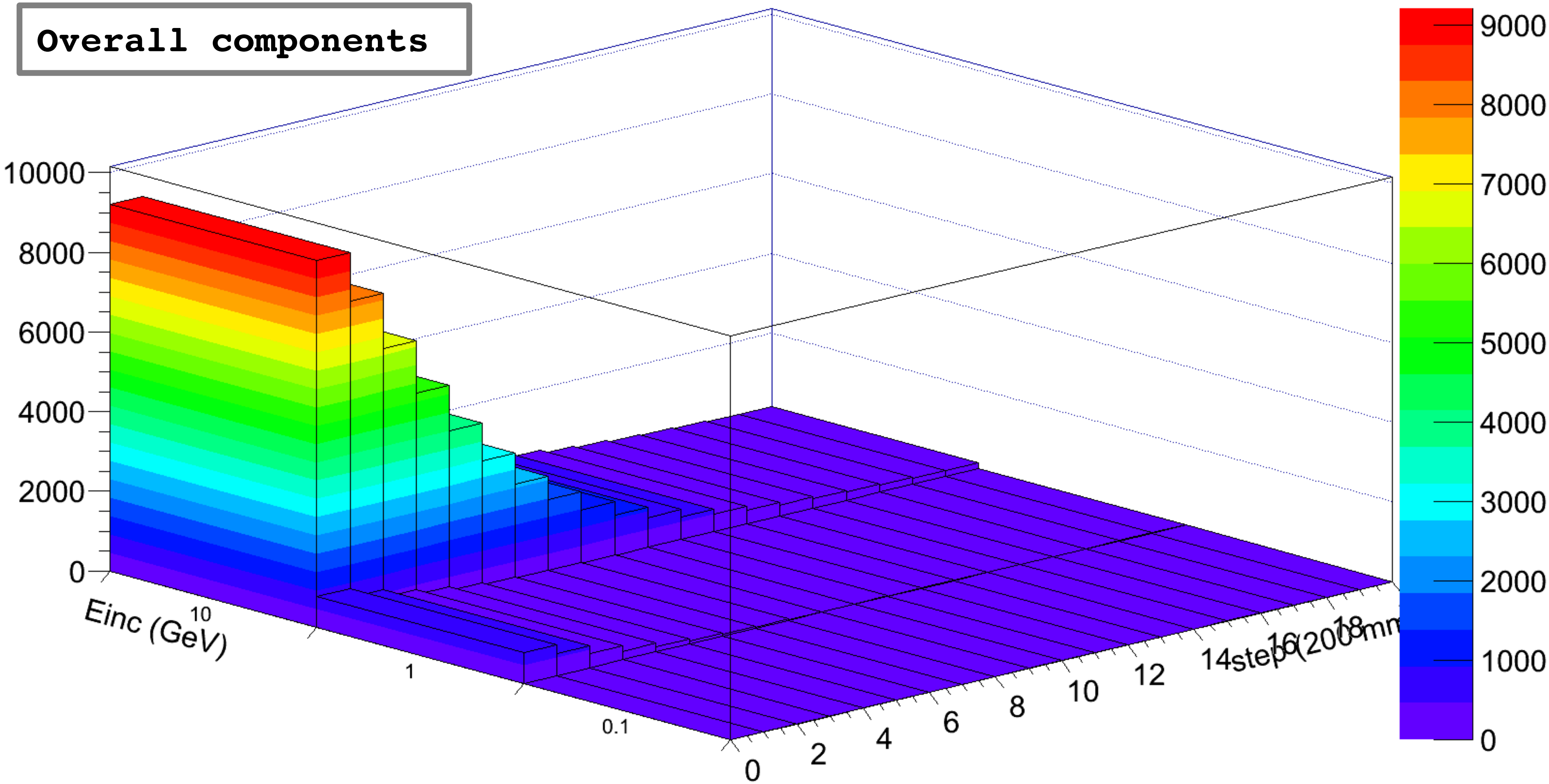
- XZ particle distribution for a particular step

Global Results (1)

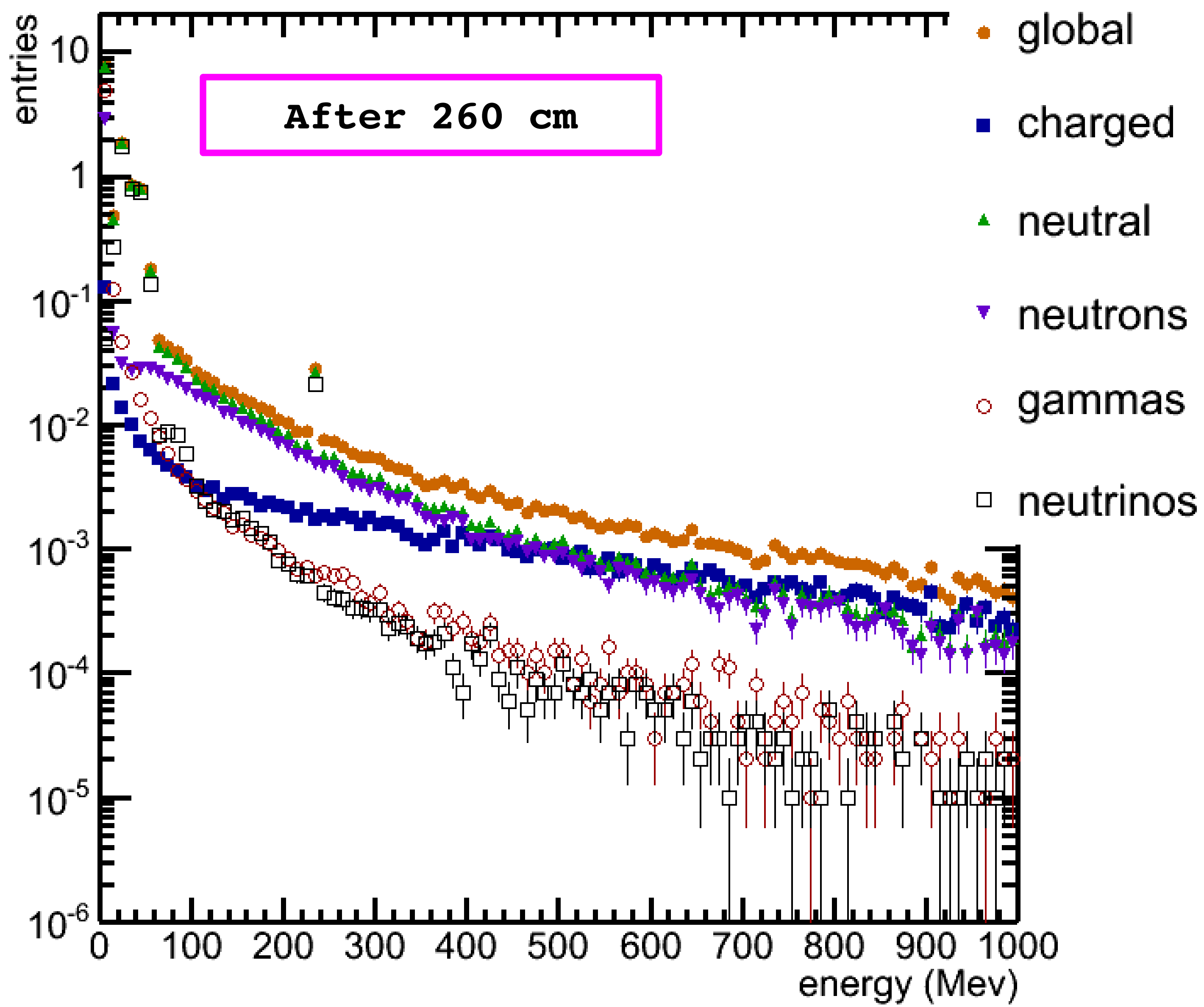


Global Results (2)

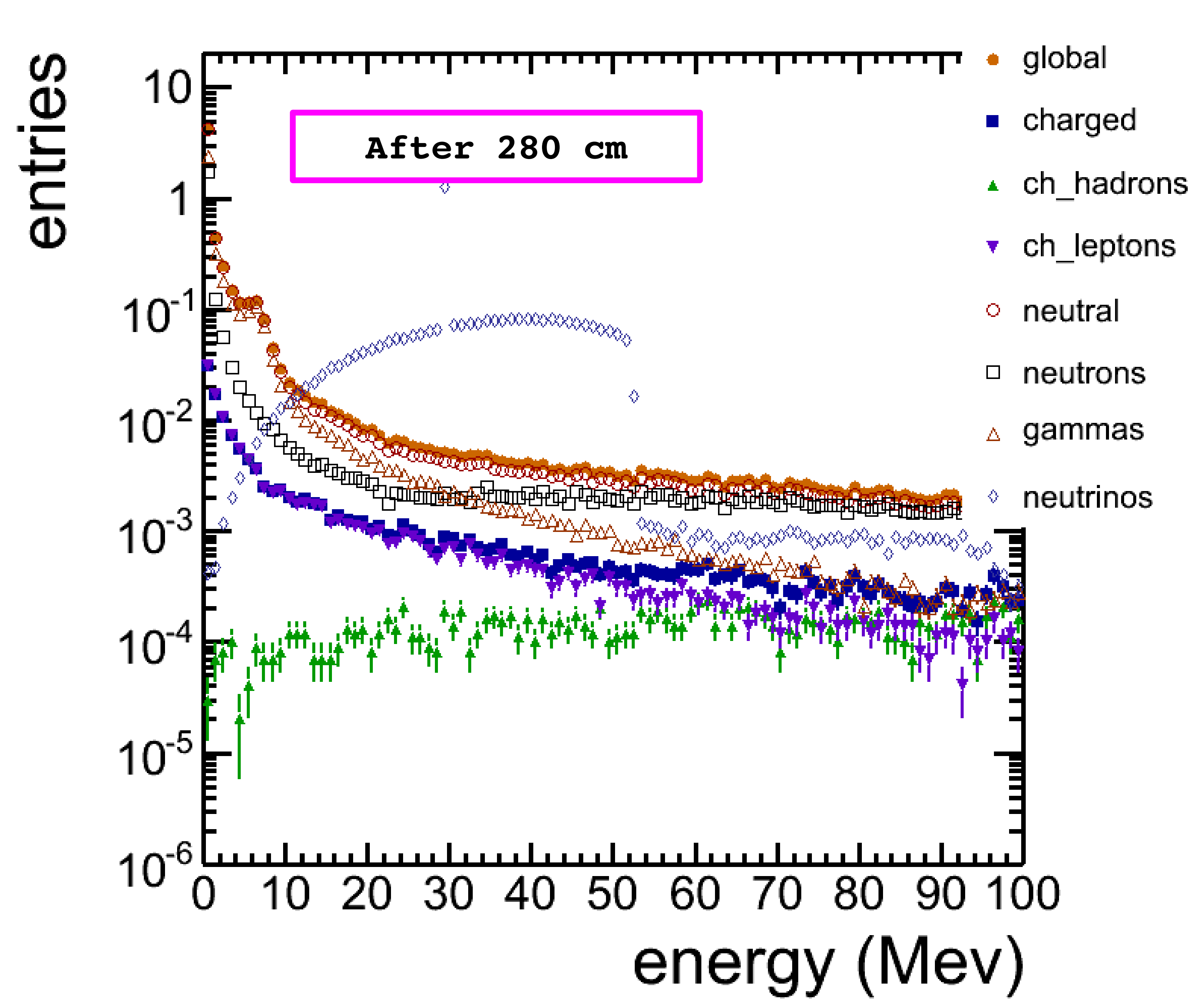
Particle number weighted with ENERGY distribution vs Einc



Global Results (3)

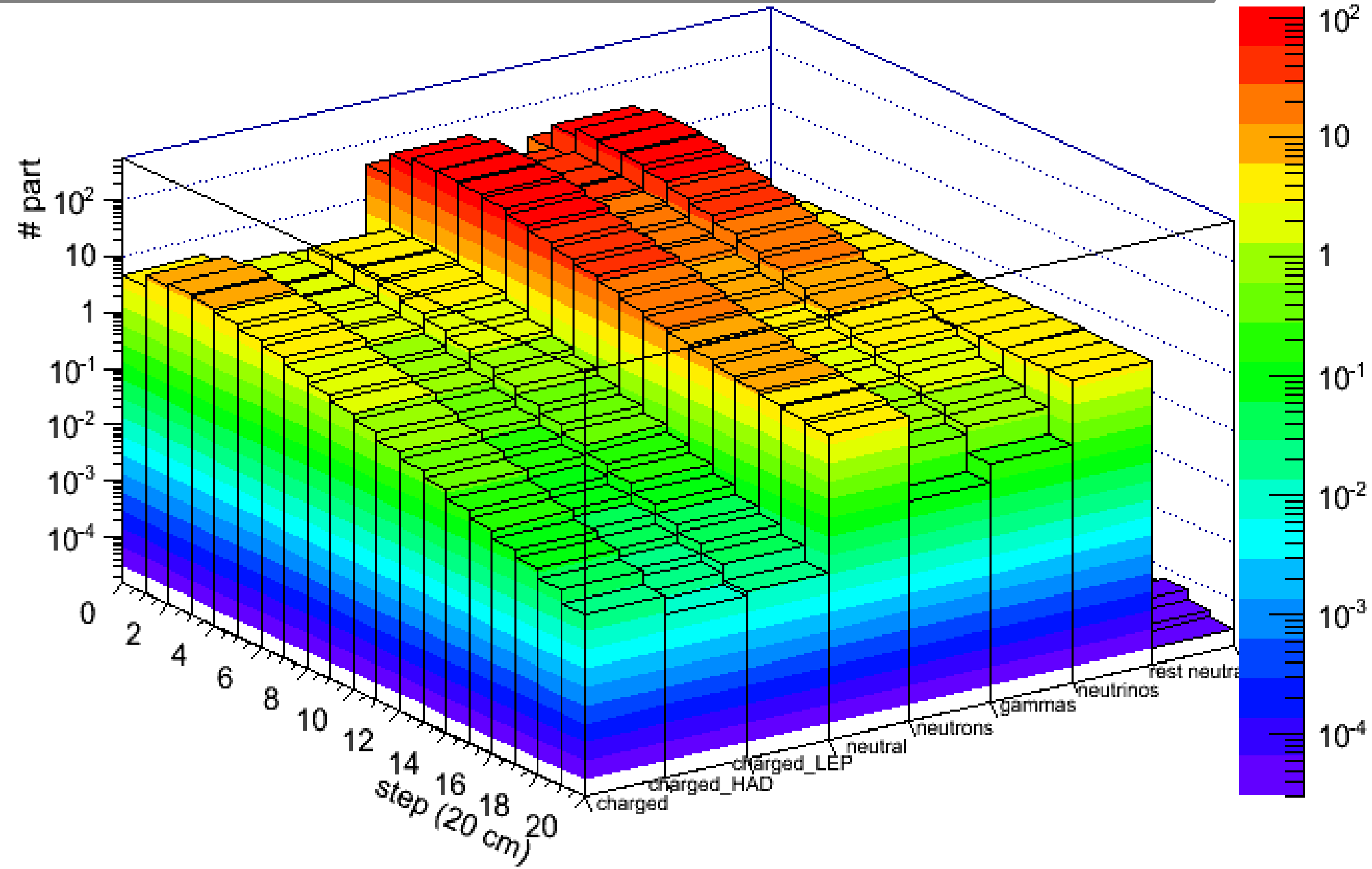


Global Results (4)



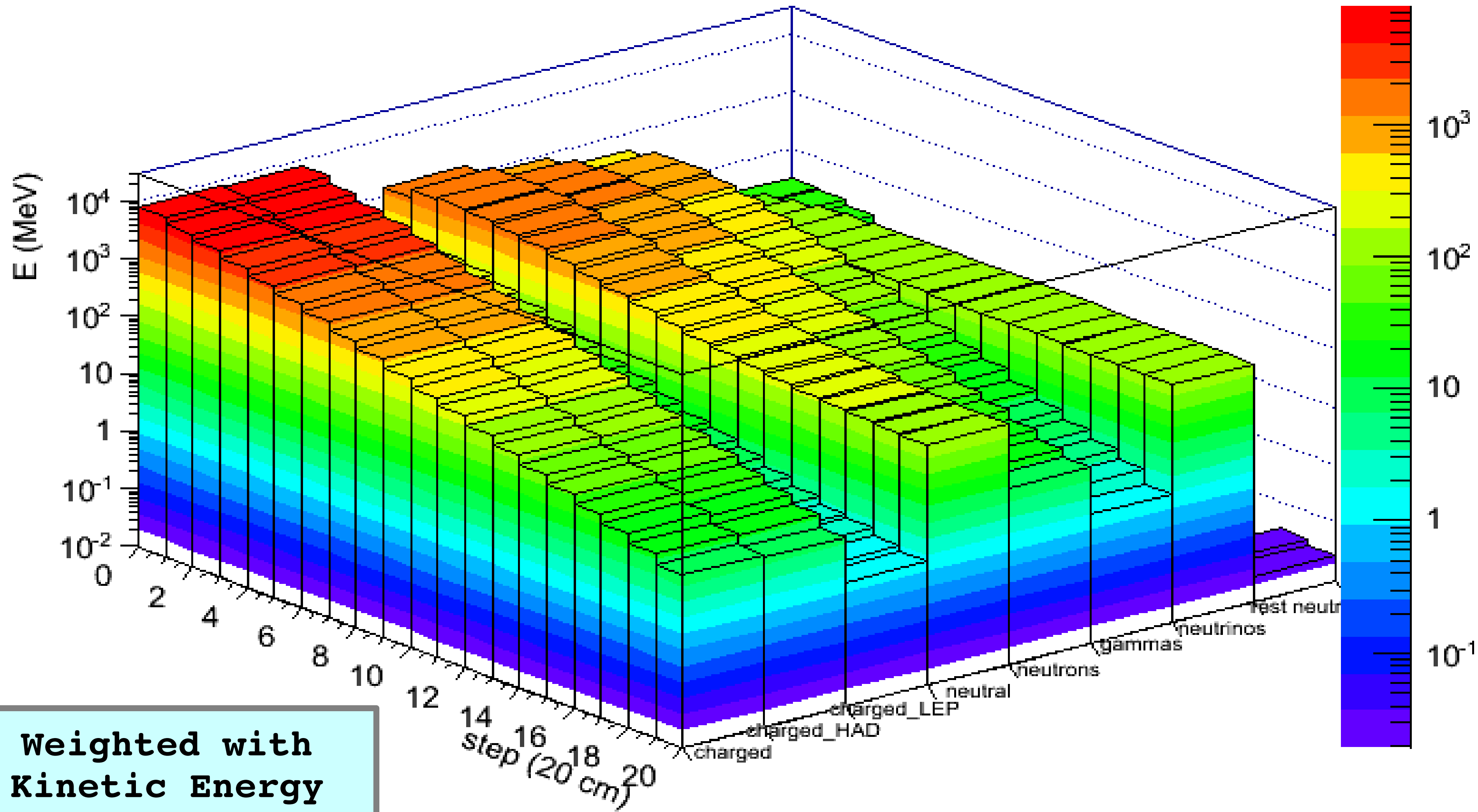
Global Results (5)

proton @ 10 GeV : particles # distribution vs step



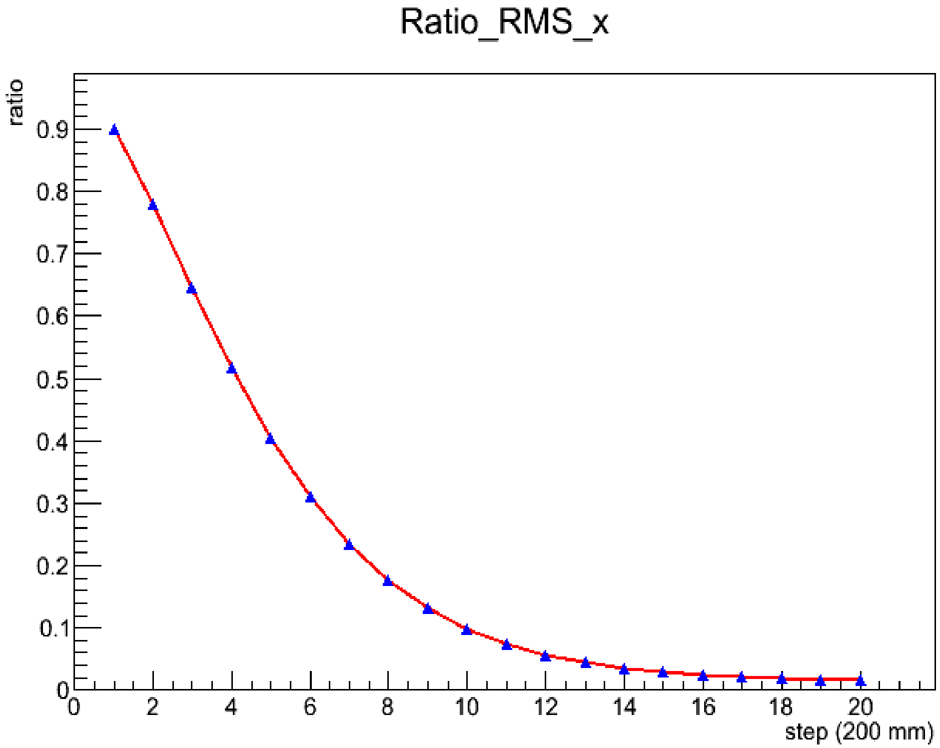
Global Results (6)

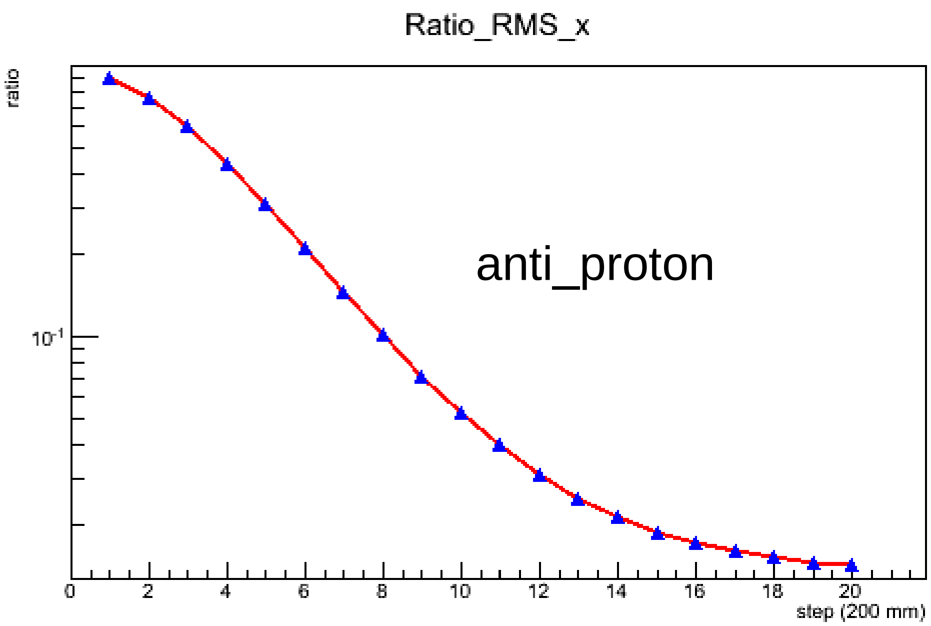
proton @ 10 GeV : particles # distribution vs step



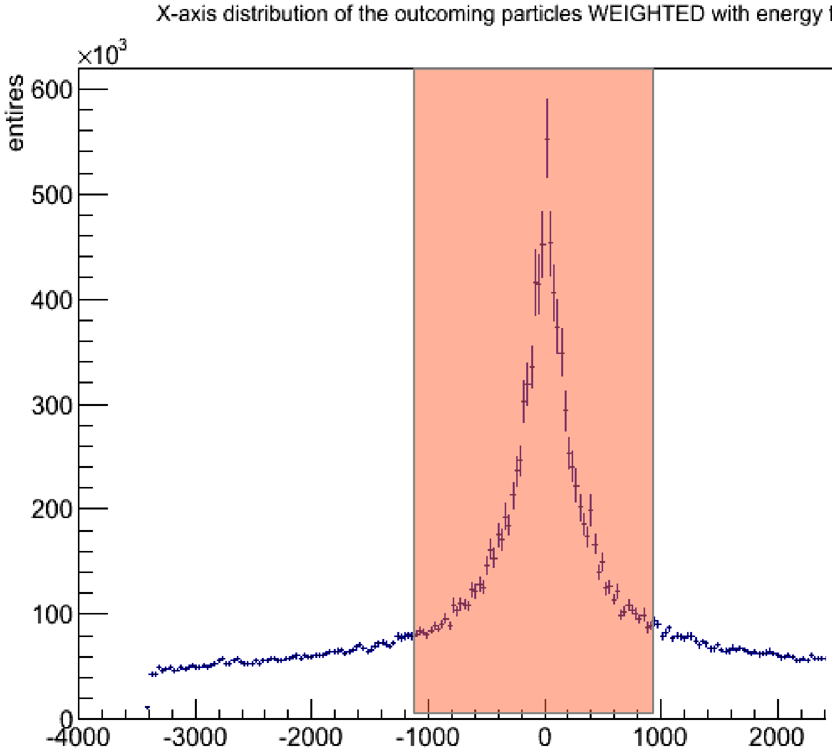
Weighted with Kinetic Energy

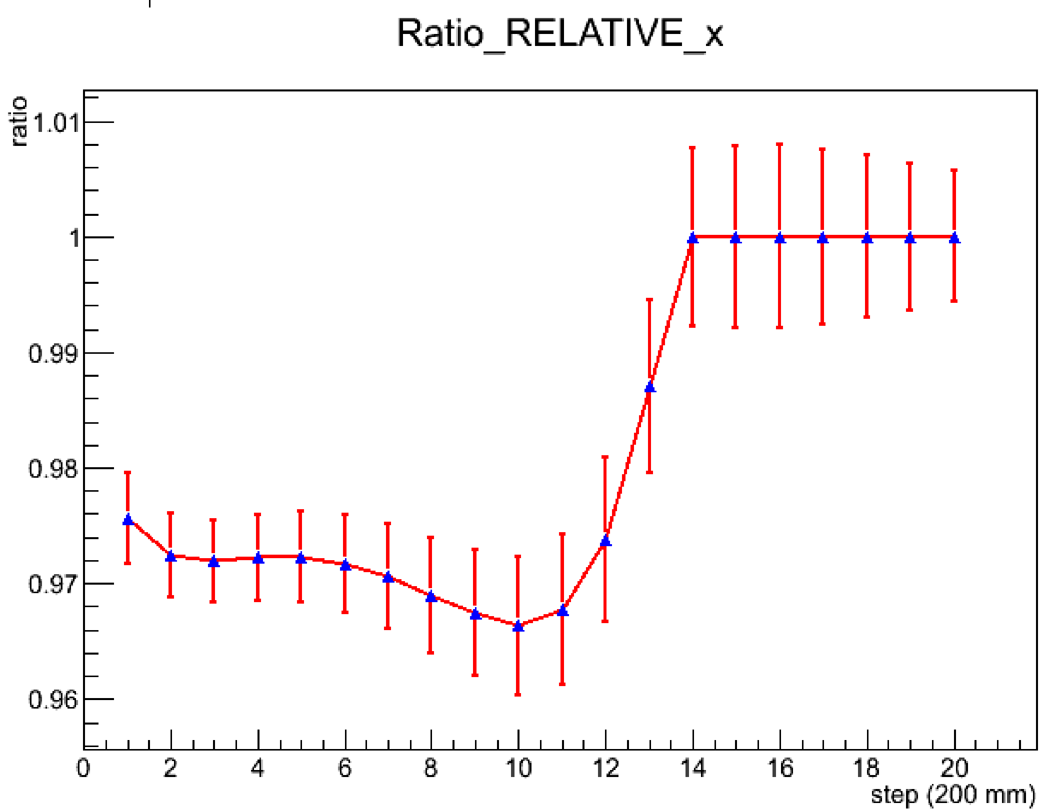
How do we do that?





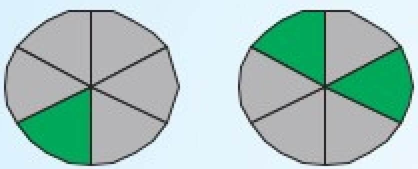
How do we do that?





How do we do that?

Segmented detectors can identify background events by counting.

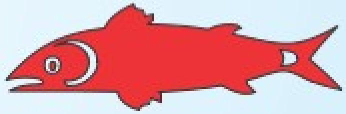


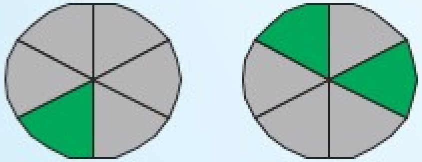
factor $\approx$ 10

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.





$\approx$ 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.