Bkg Simulation Study for Underground Labs & n-induced Ge-76 spectra

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Symposium of the Sino-German GDT cooperation @ Tübingen

On behalf of the GeDet group
Max-Planck-Institut für Physik, München

Outline

- **Introduction on Low Background Experiments**

- The main background sources for deep underground labs

- Shower development in rock: the analysis procedure
  - Summary & Outlook

- N-induced Ge-76 Spectra
  - Conclusions

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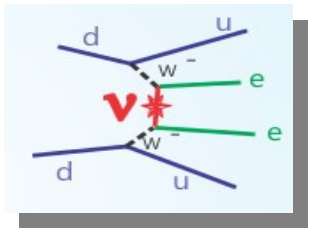
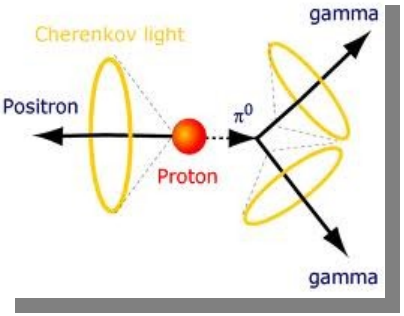
Low Background Experiments

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. 0ν2β 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**

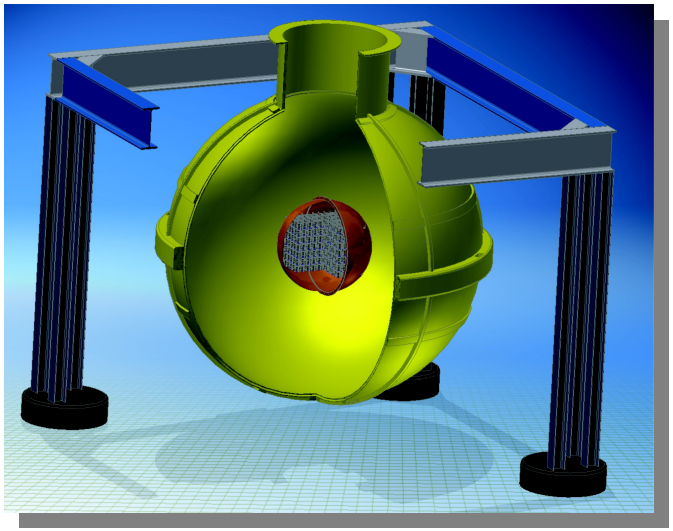
Expected Event Rate

What we can do to enhance the expected event rate?

- **Increase the exposure:**

  → increase the data taking period

  → increase the mass
  → 1 Ton experiments



Expected Event Rate

What we can do to enhance the expected event rate?

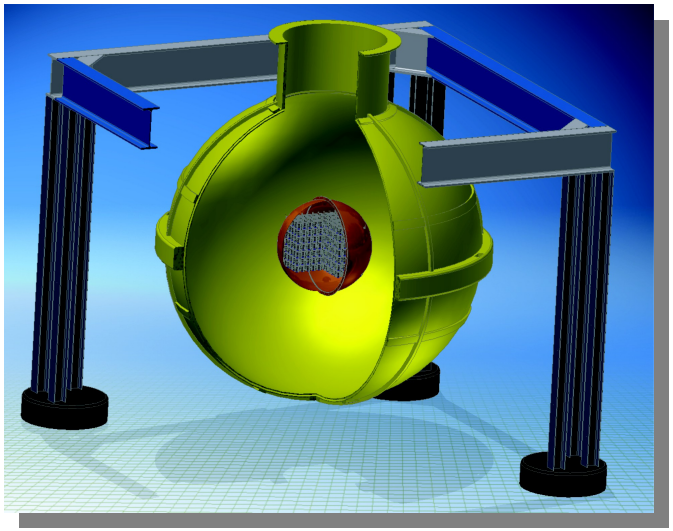
- **Increase the exposure:**

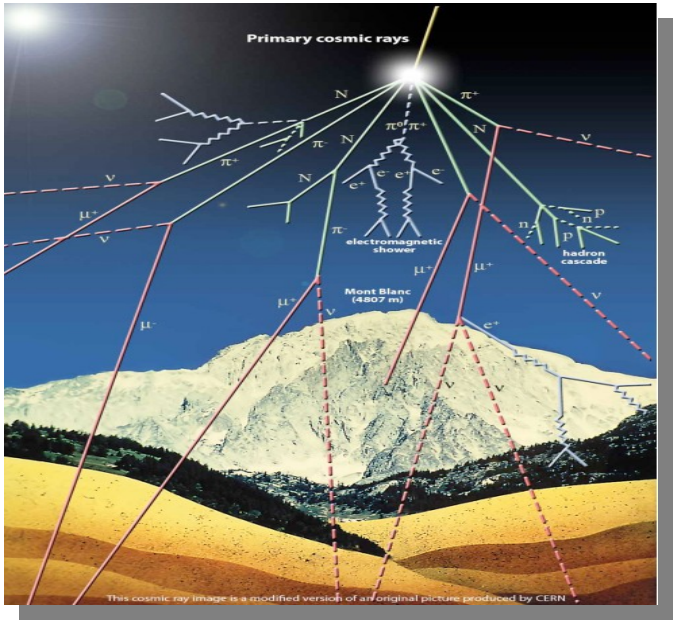
  → increase the data taking period

  → increase the mass
  → 1 Ton experiments

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

  → reduce the background
  → Move deeper Underground
  → Effective Shielding





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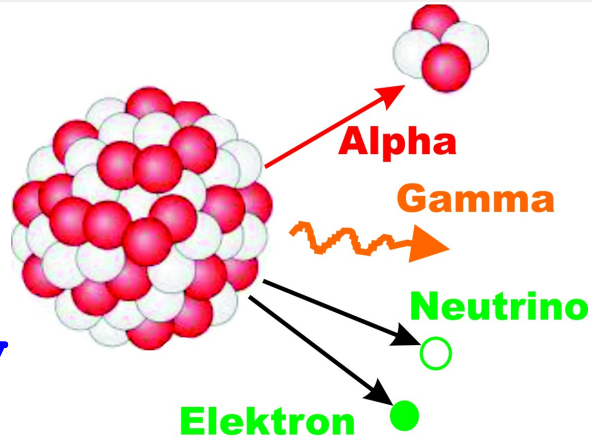
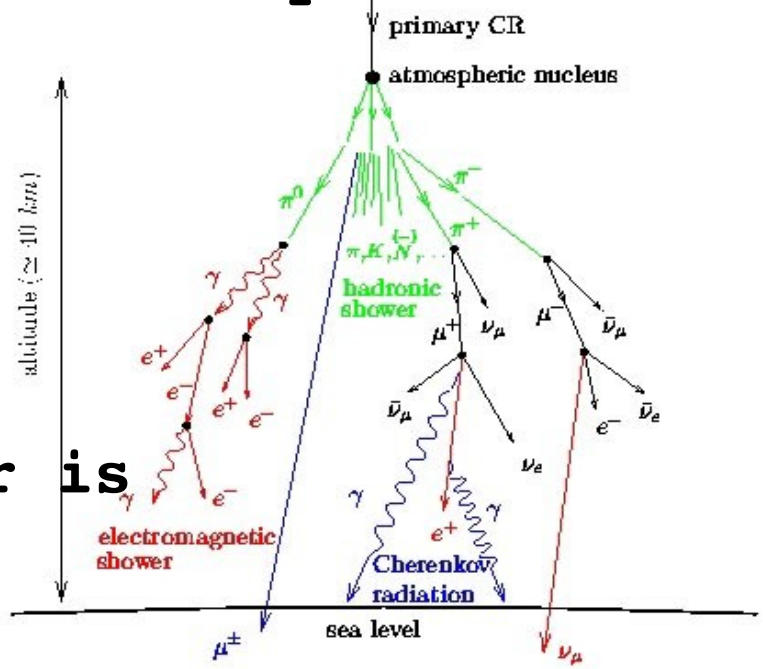
Background Sources

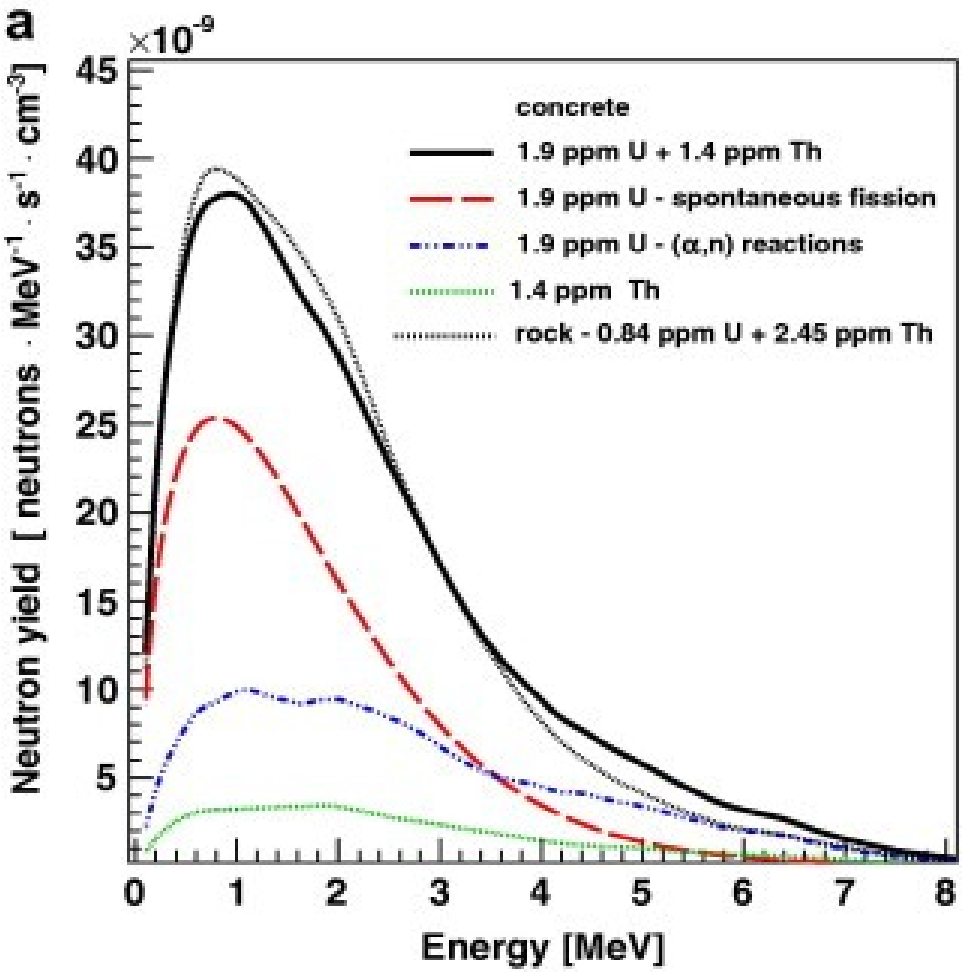
- **Three different sources:**
  - **Intrinsic detector radioactivity**
  - **Environmental Natural radioactivity**
  - **Cosmic Rays-induced showers** (basically muon and neutrino-induced)

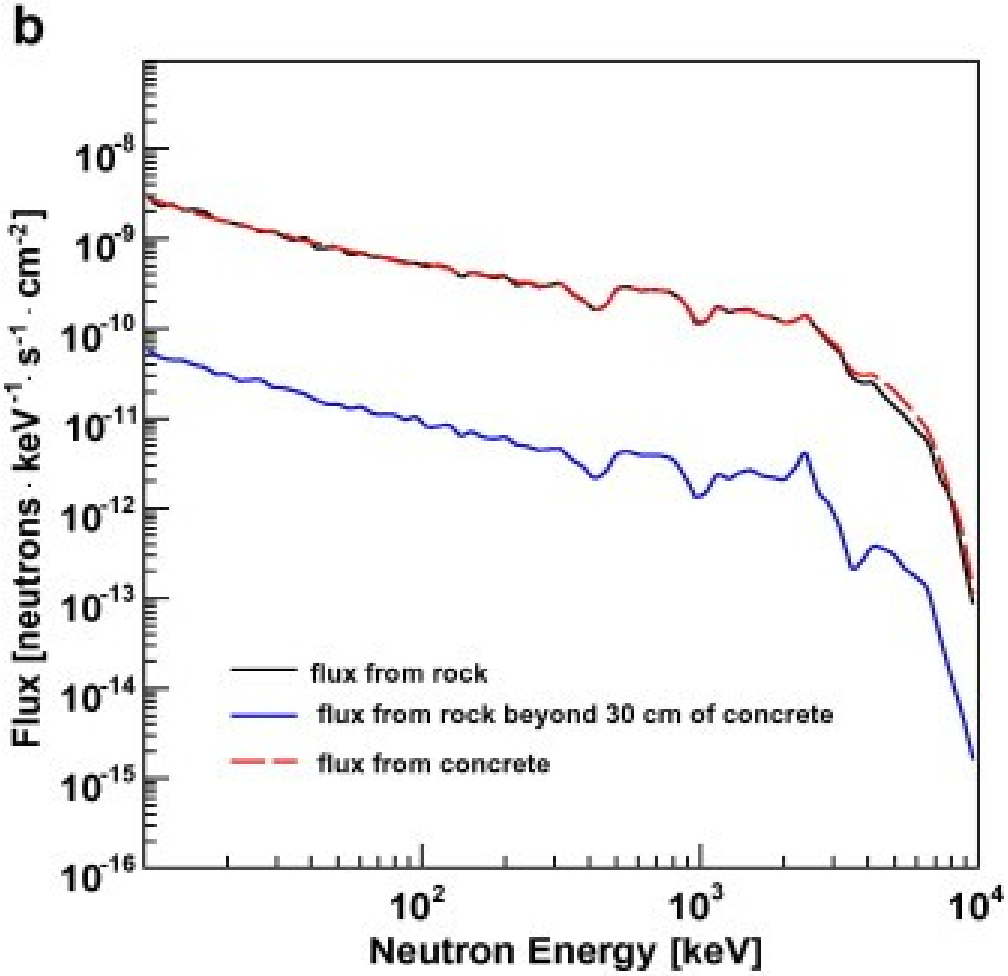


- **Two different components:**
  - **Charged** → easy to veto
  - **Neutral** → high shielding power is required (neutron, gammas)



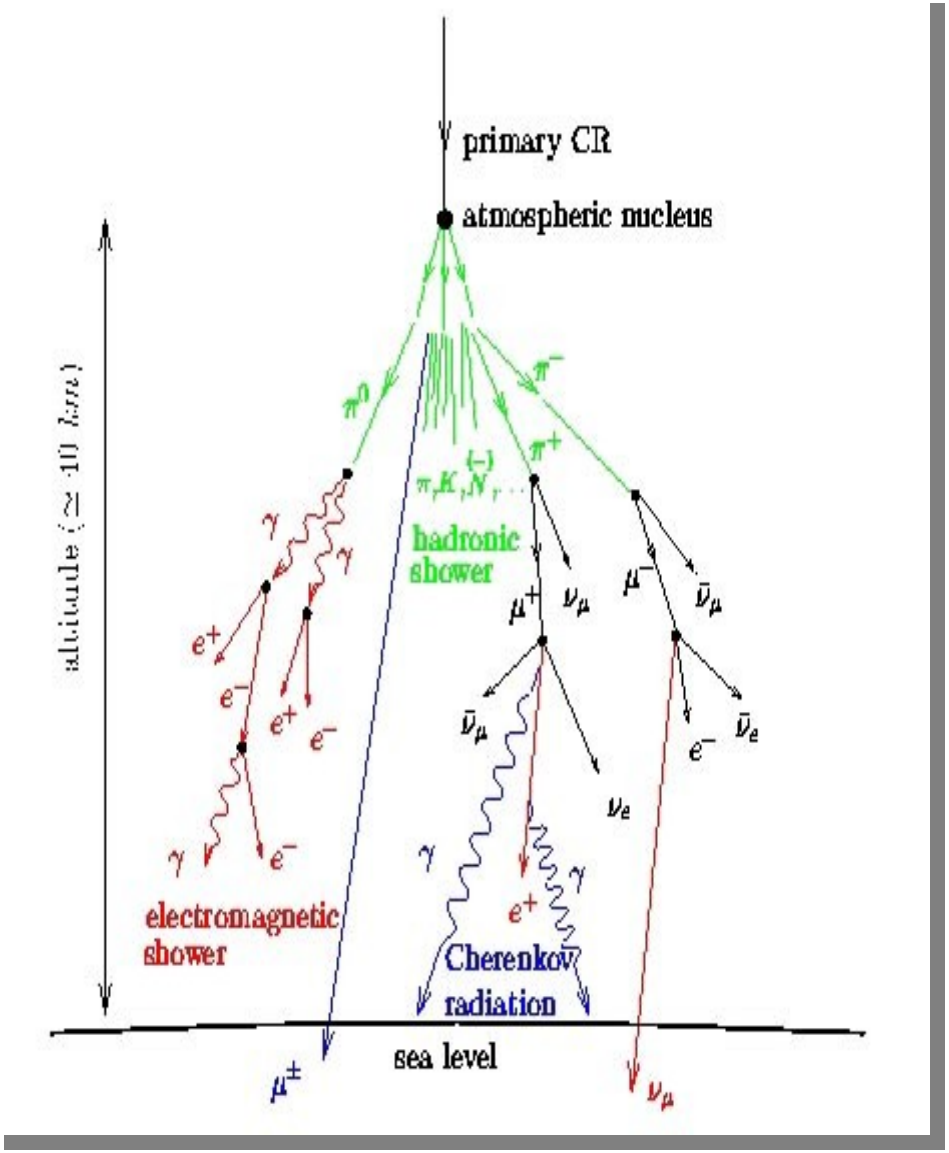
Environmental Natural Radioactivity



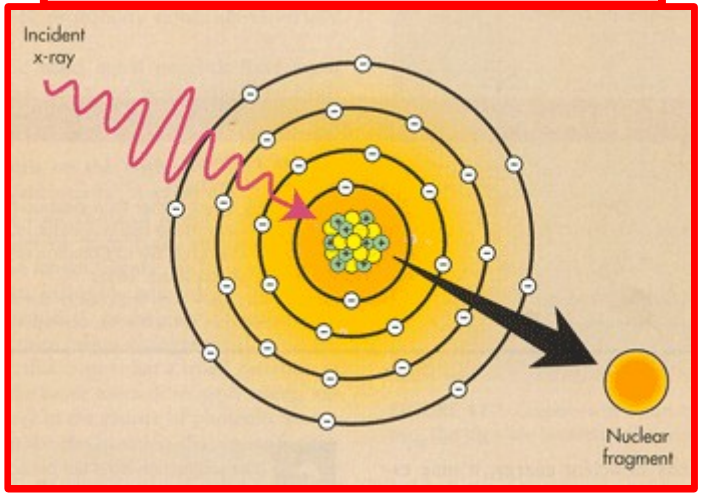


Tomasello et. al., Radioactive background in a cryogenic dark matter experiment, Astro. Phys., Vol 34, 2010

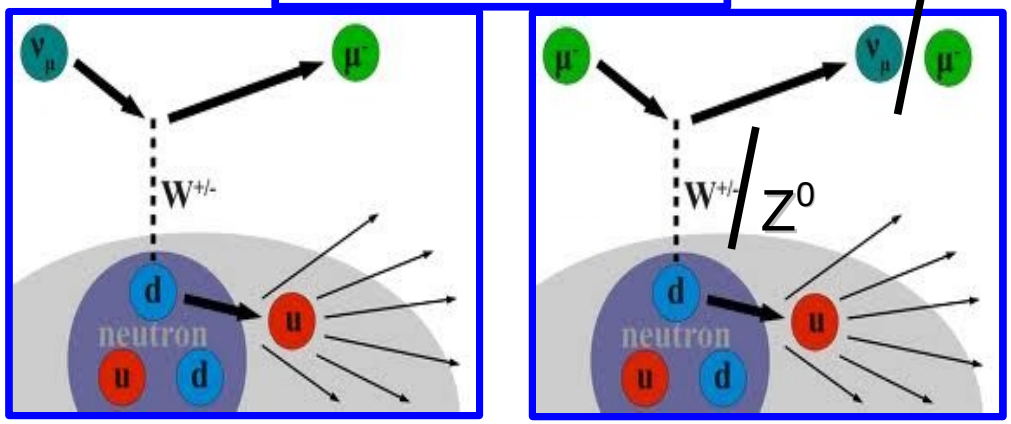
Cosmic Rays Shower



Photodisintegration

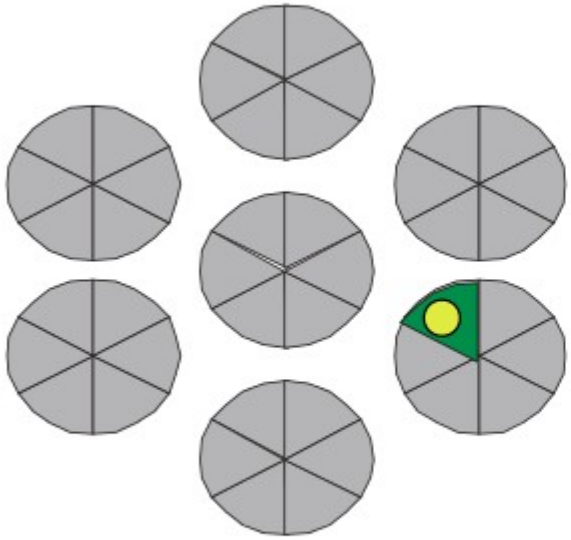


DIS



Background events

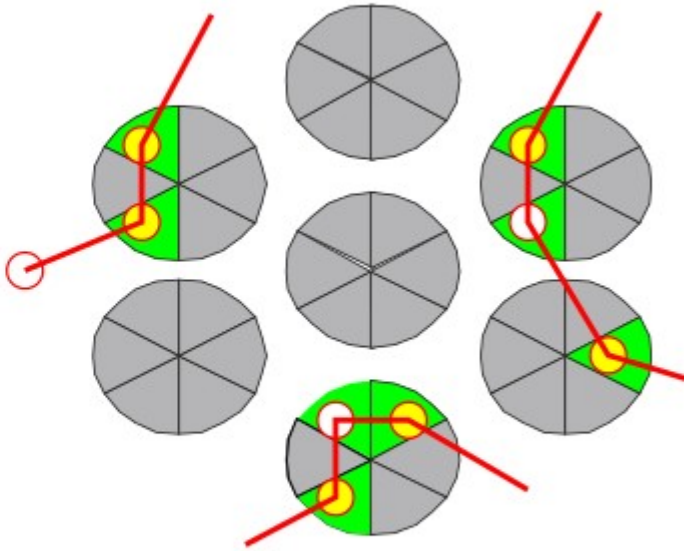
$0\nu\beta\beta$



localized deposit

single site event

γ or 2γ



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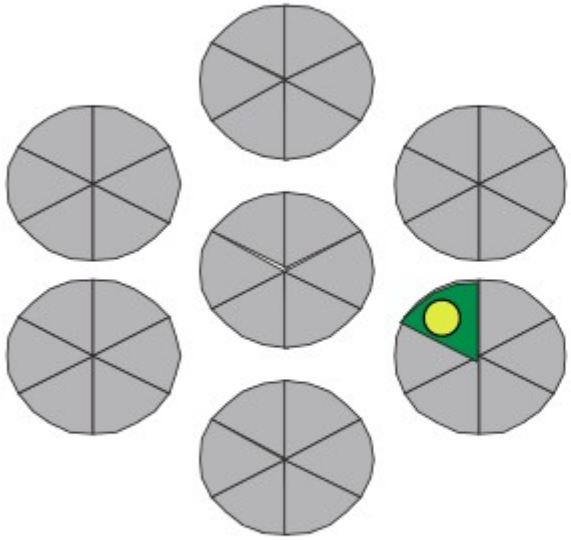

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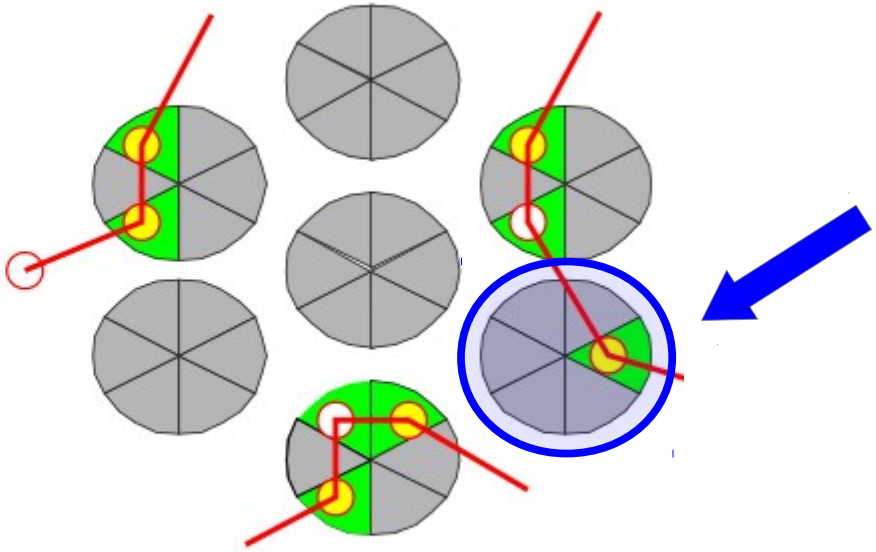
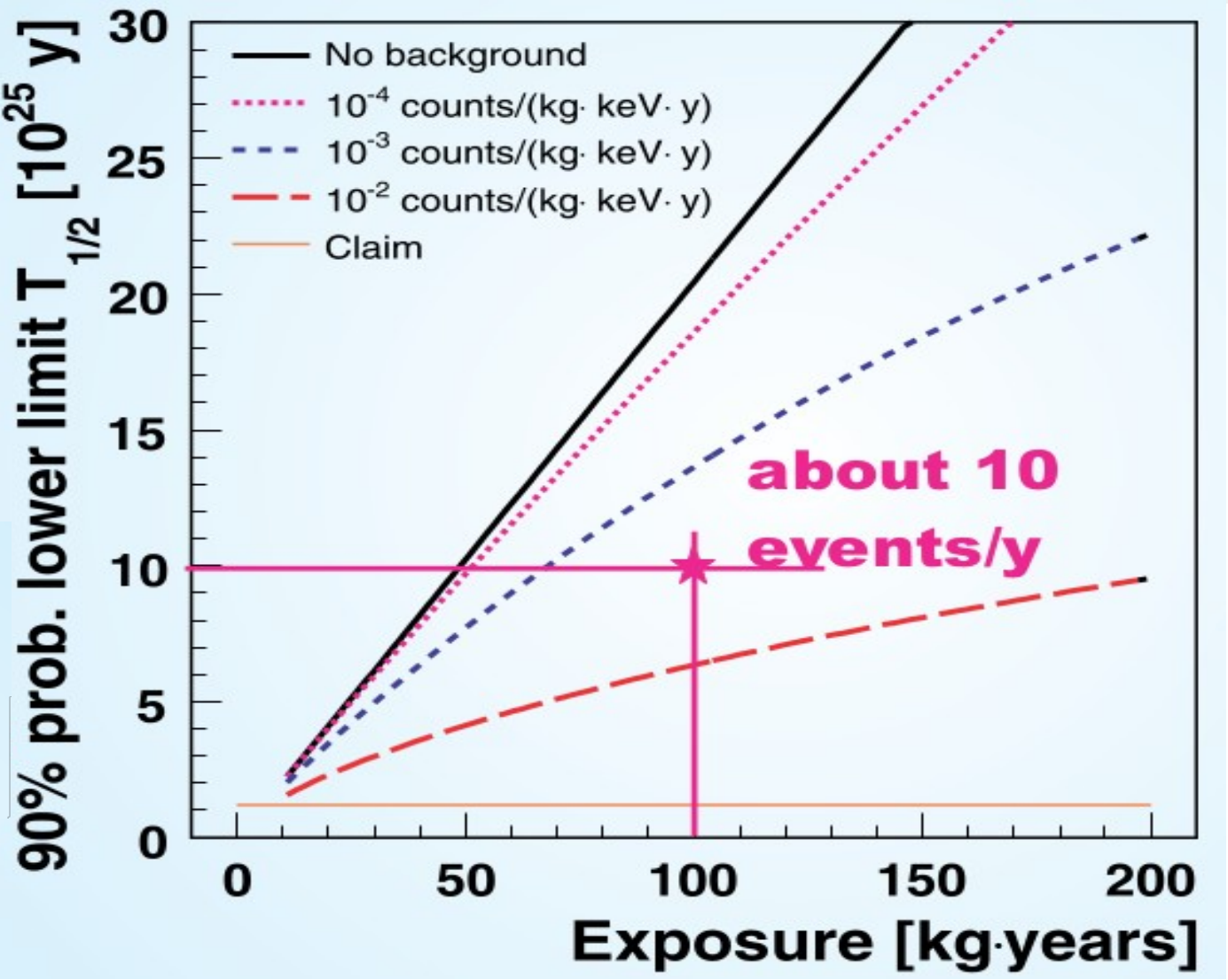


several deposits

multi site event

Importance of Background



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

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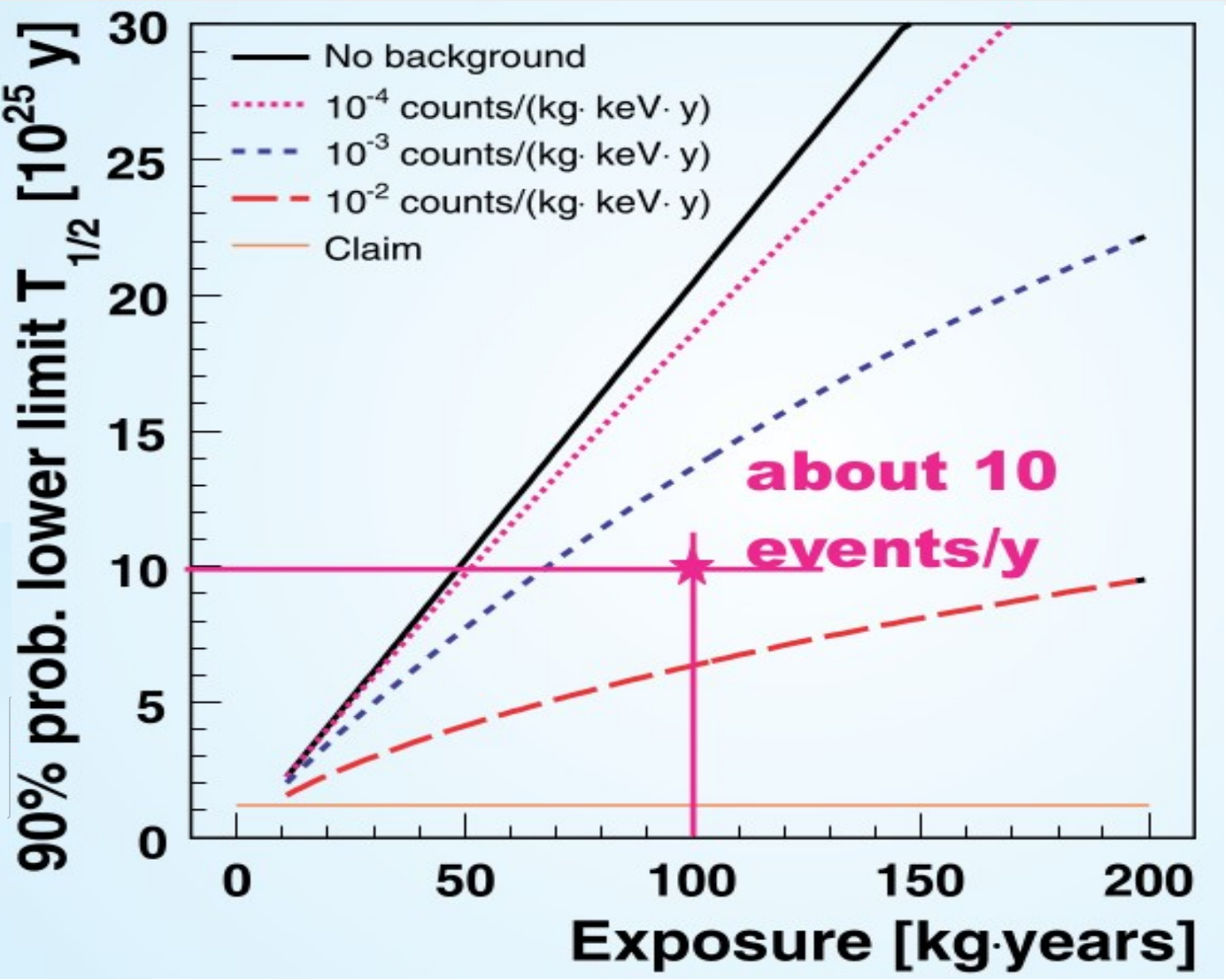

To build an experiment is crucial to know which level of background you can allow and which you can not!

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

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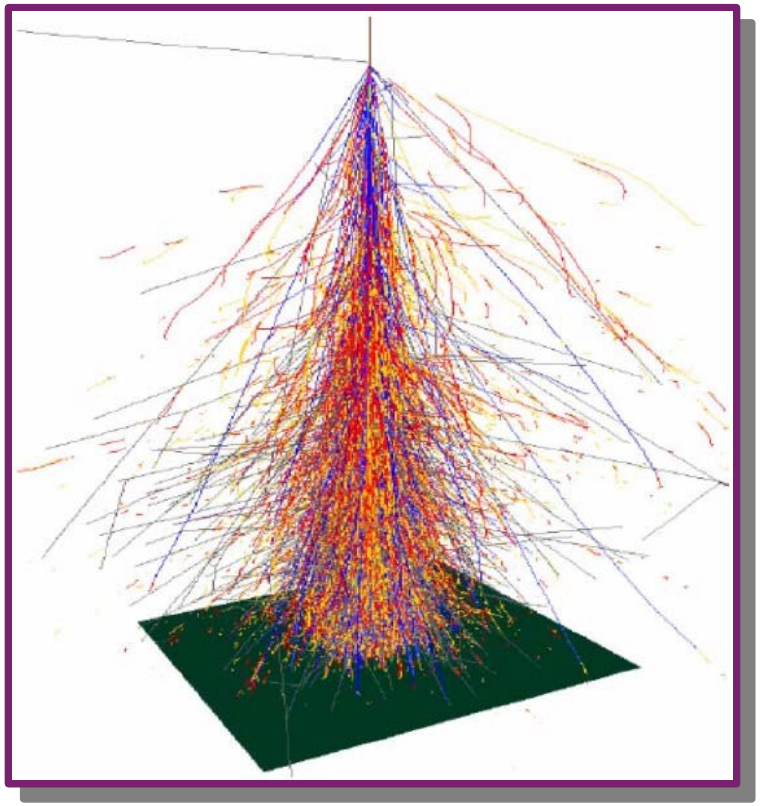
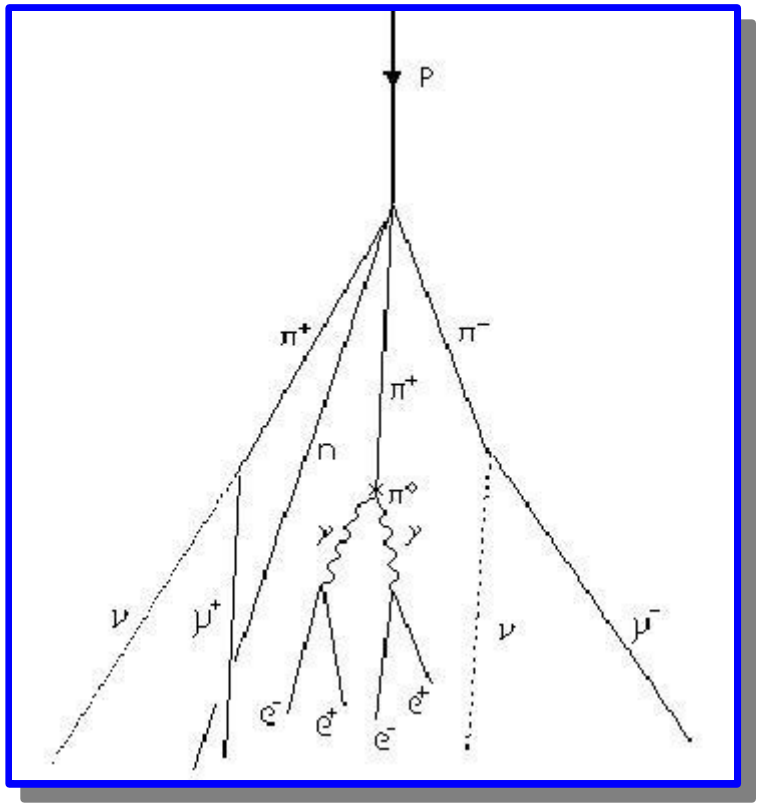
What we want to do?

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





Vertical & Horizontal Safety Distances

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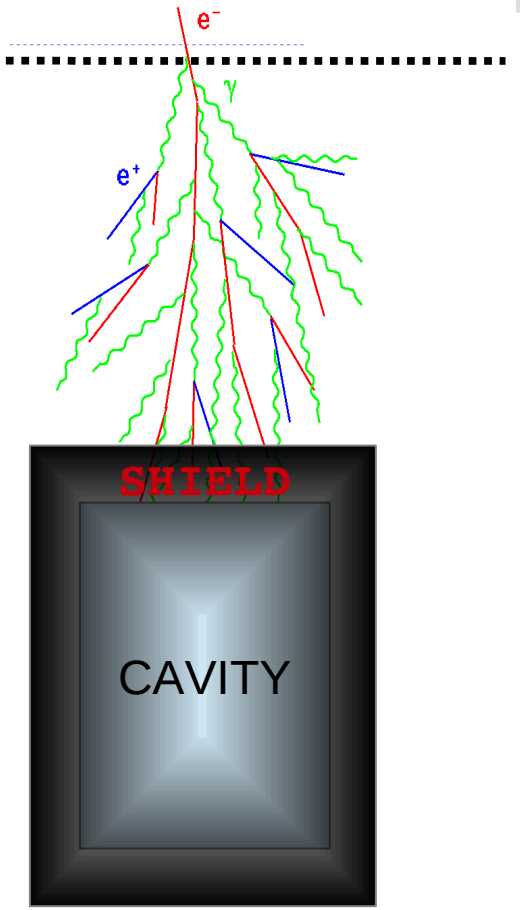

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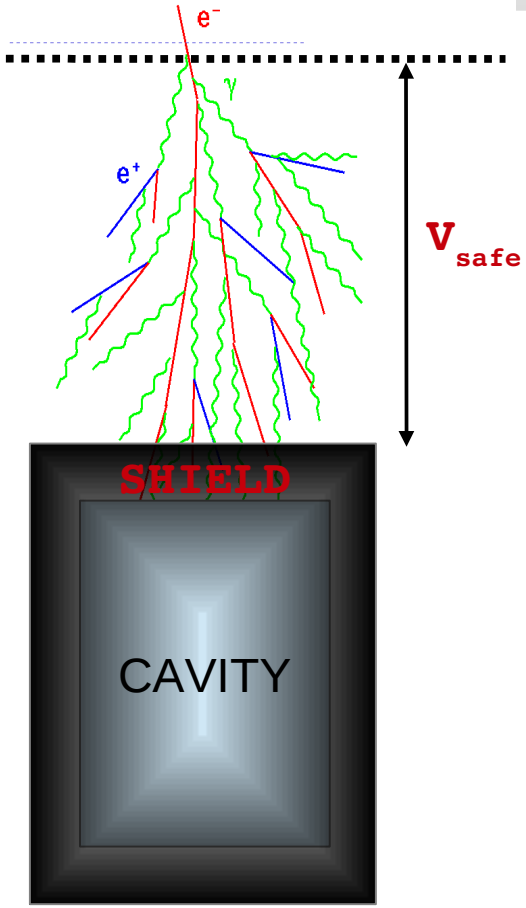
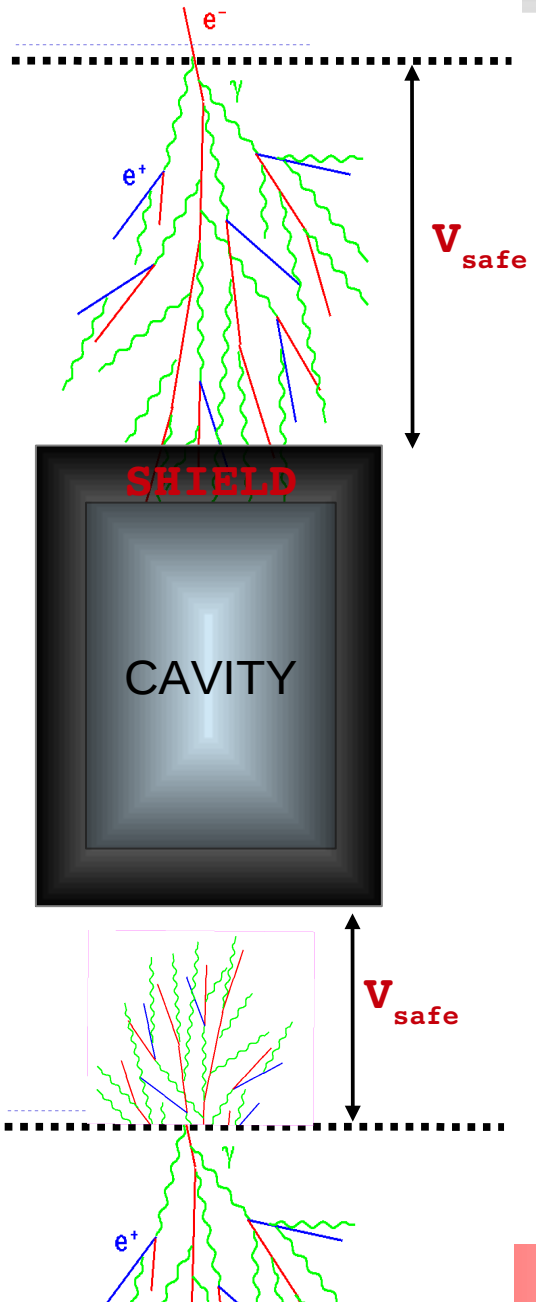


- V_{safe} : vertical distance (from the interaction point) after which the shower has 10 MeV left

Vertical & Horizontal Safety Distances



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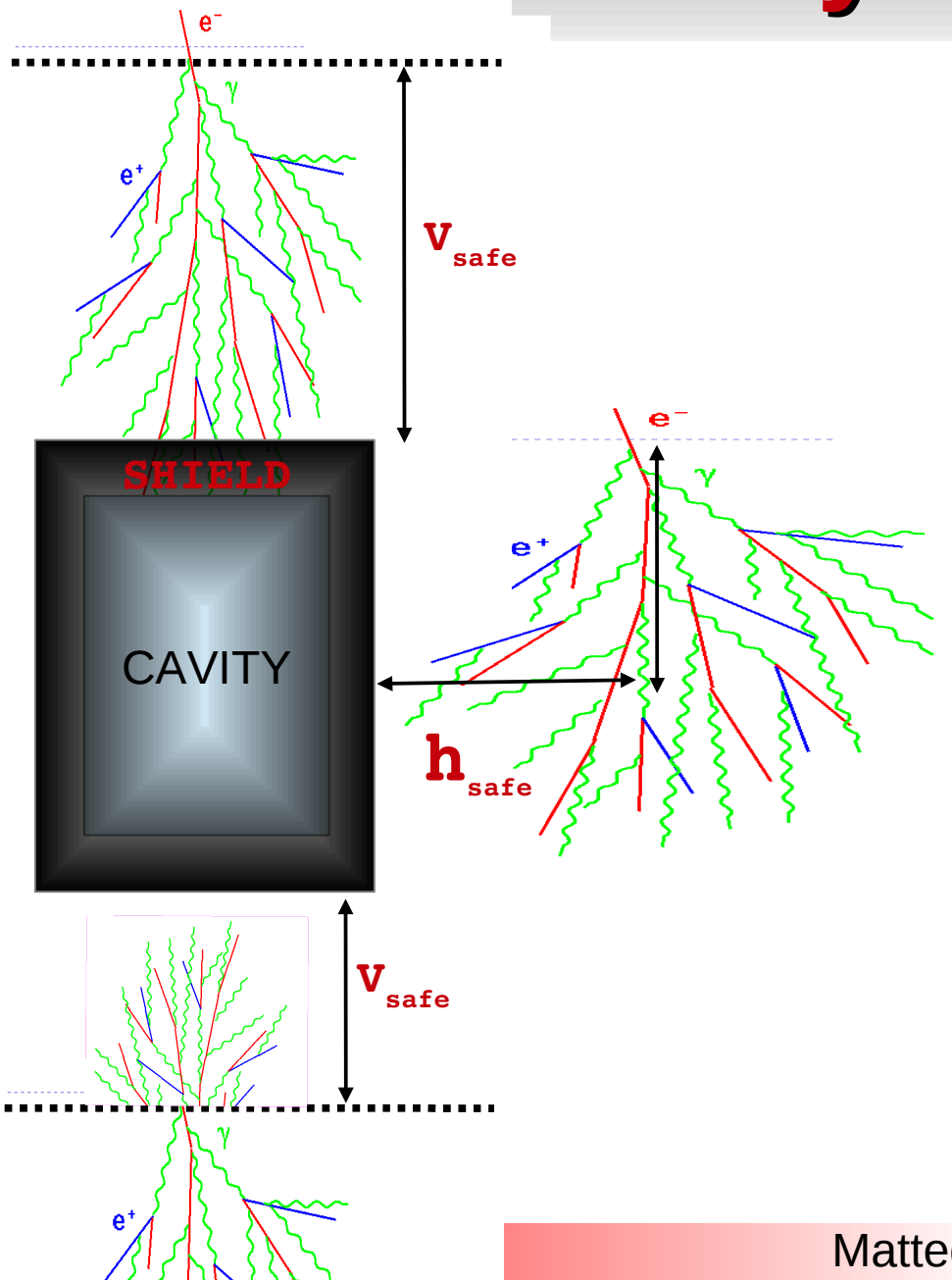
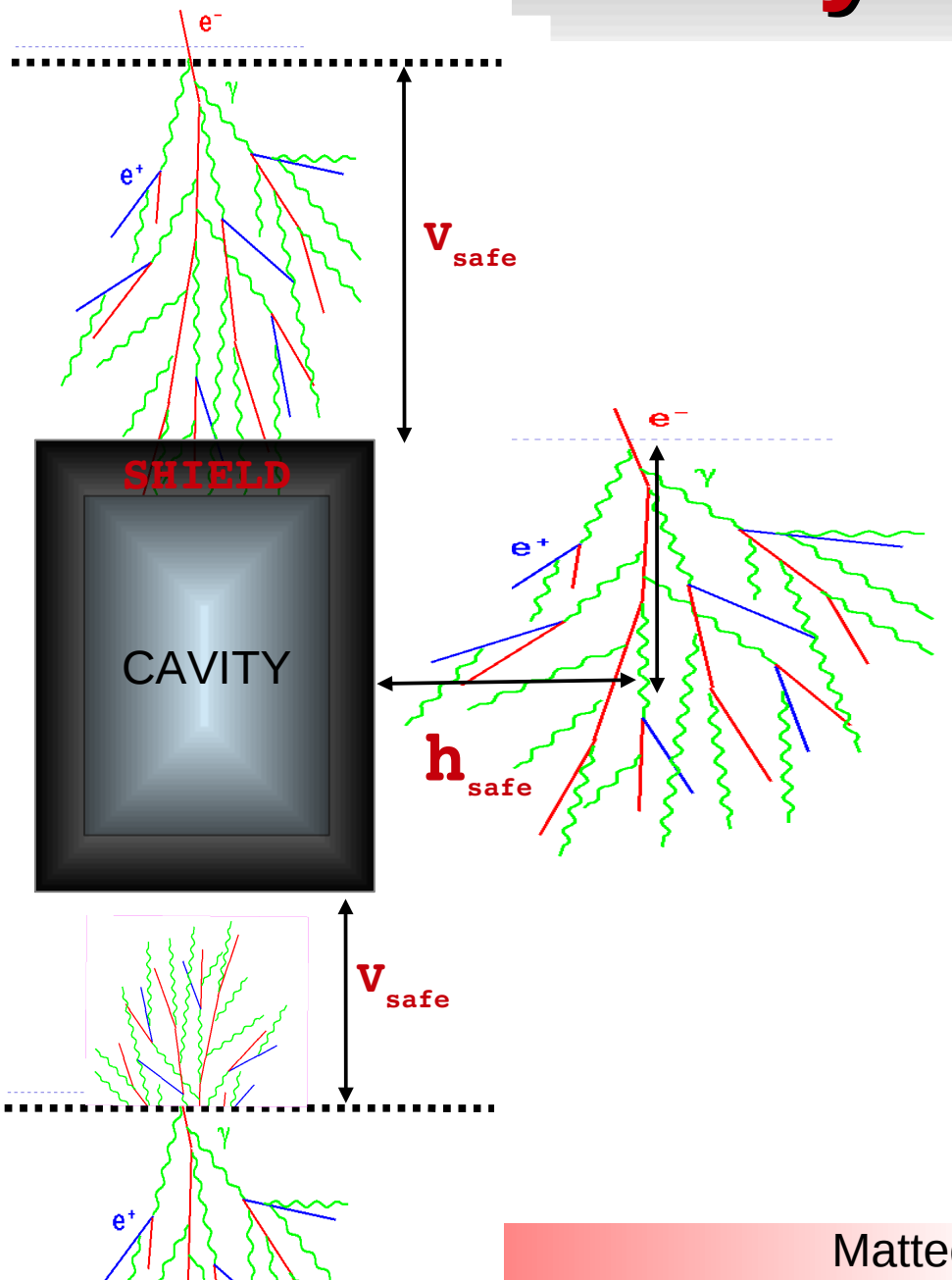
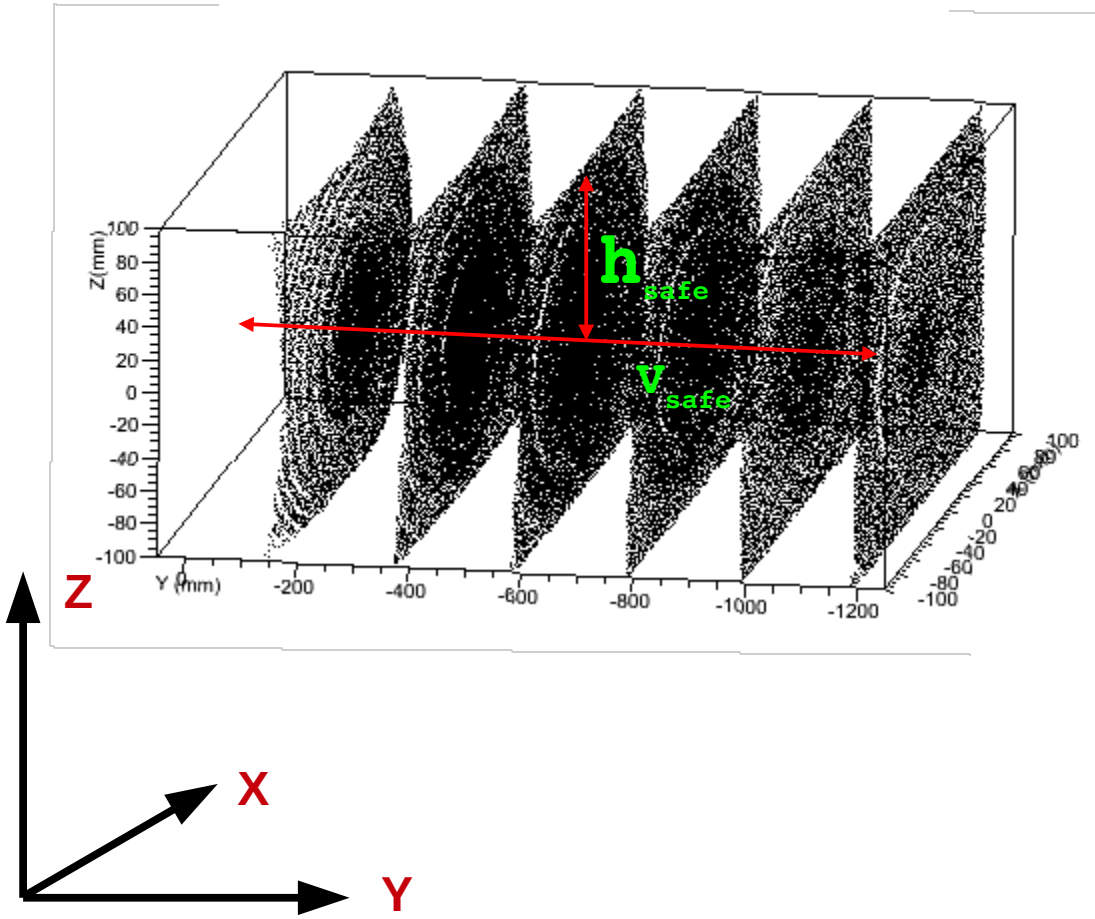


- V_{safe} : vertical distance (from the interaction point) after which the shower has 10 MeV left

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

Vertical & Horizontal Safety Distances



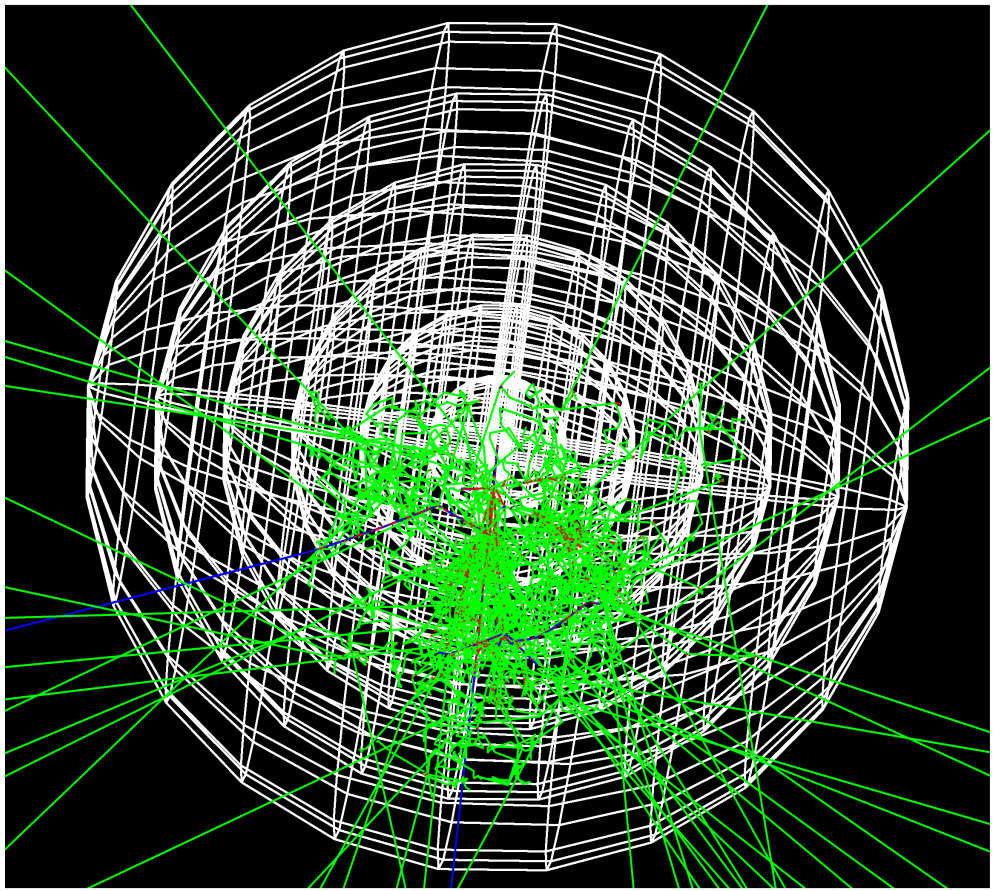


How do we do that? (1)

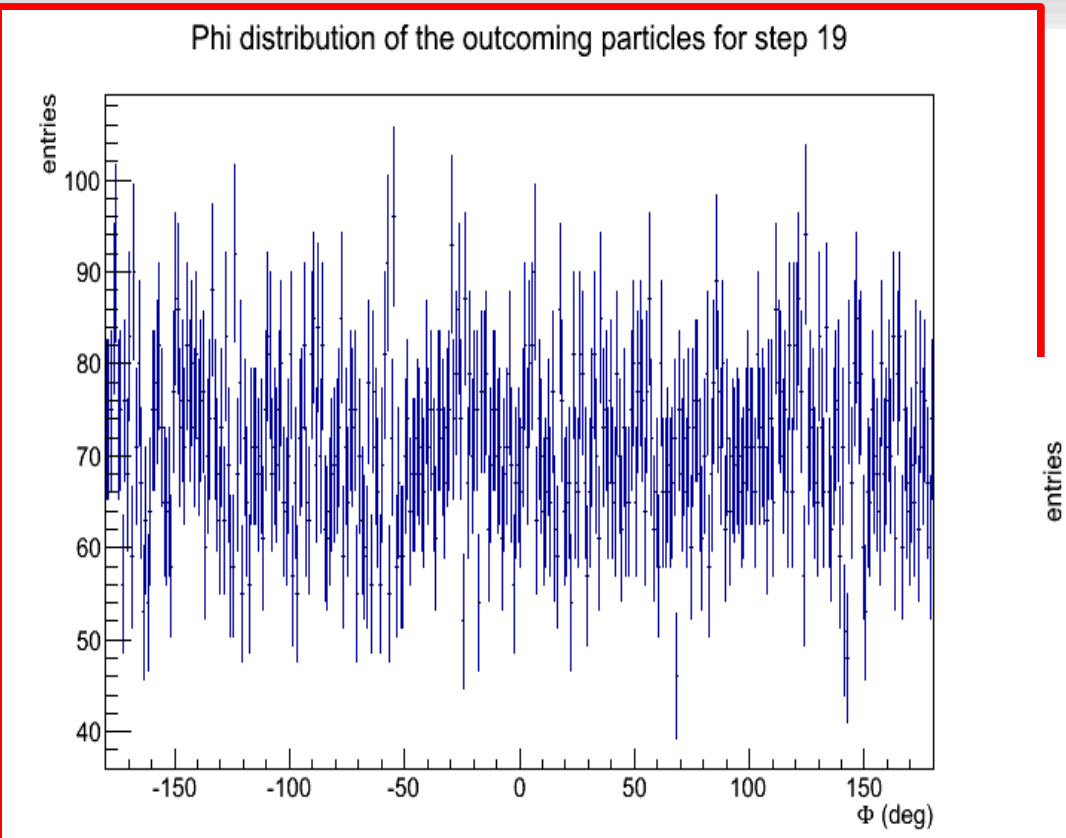
- Shot a particle of certain energy along **-Y** direction

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

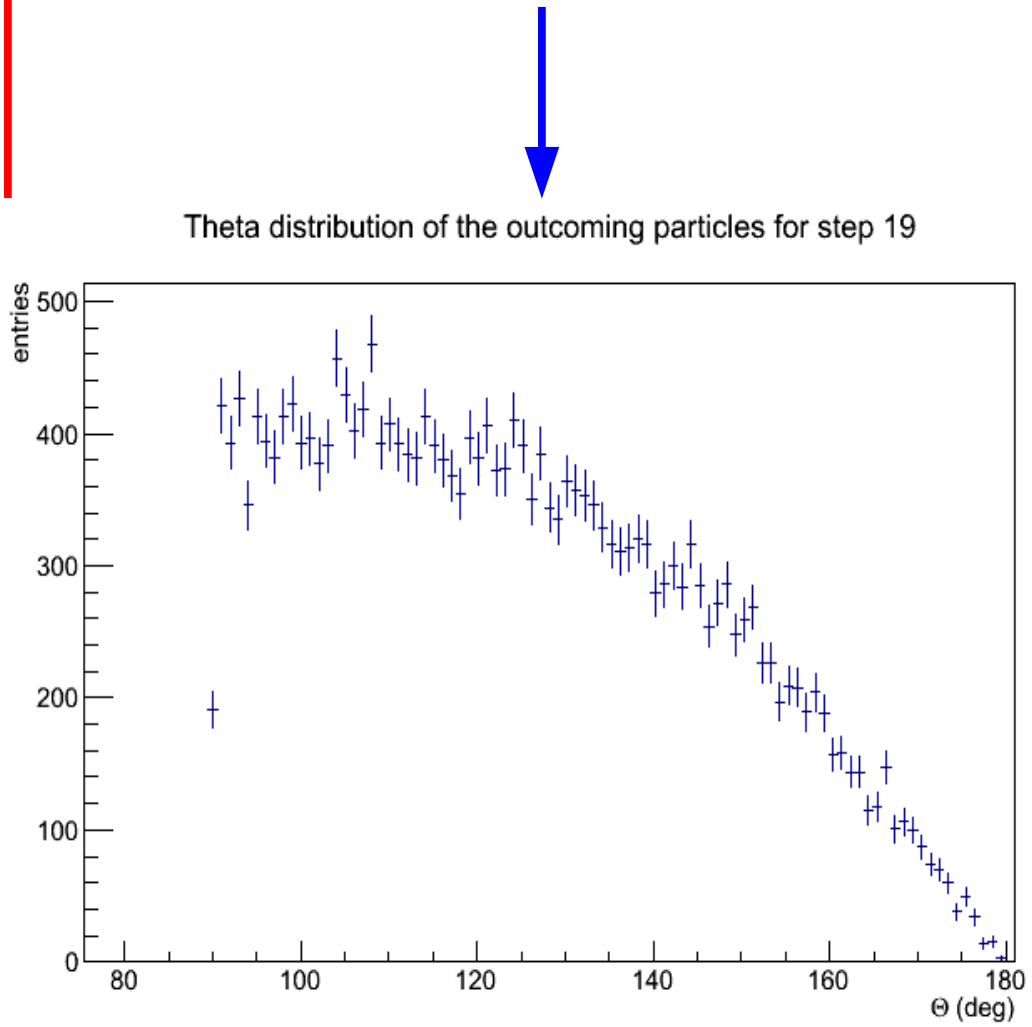
- Record all the particles with their properties (e.g. **position, kinetic energy, charge**, etc.) that arrive at each single sub-sphere surface



How do we do that? (2)

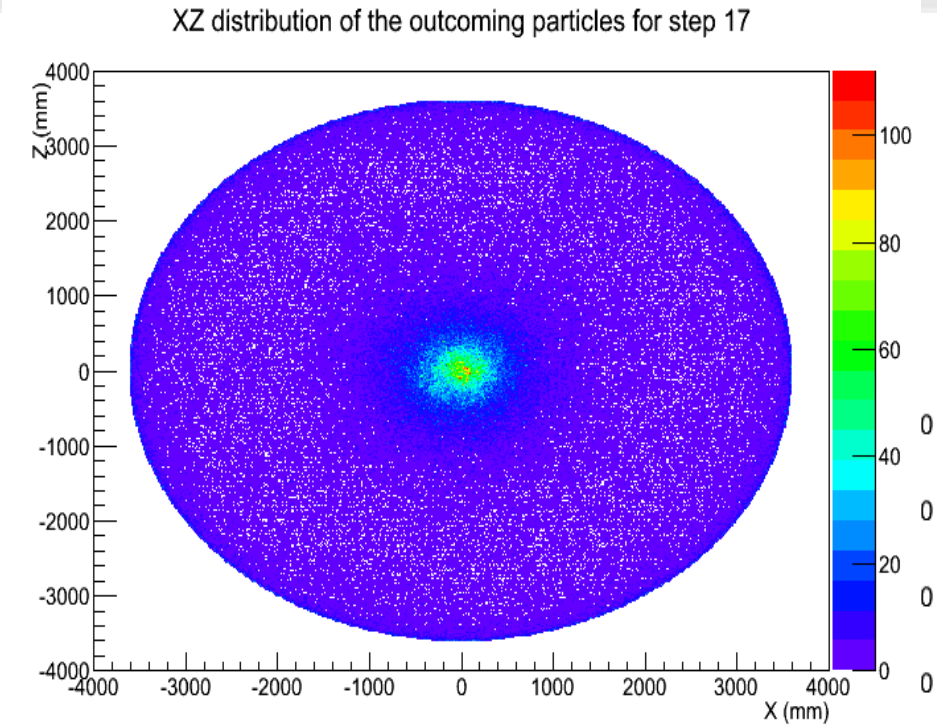


- Looking Forward



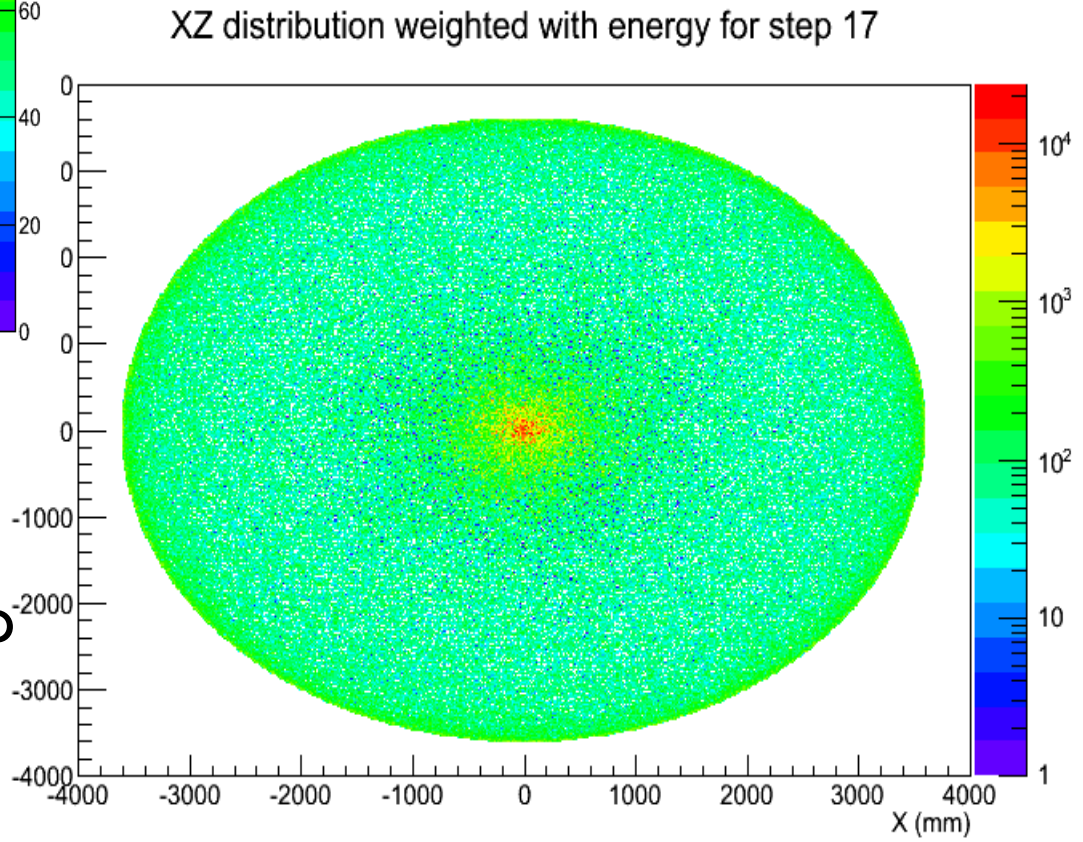
- Isotropically distributed wrt the polar angle on the XZ plane

Position Weighted with Kinetic Energy



- XZ particle distribution for a particular step

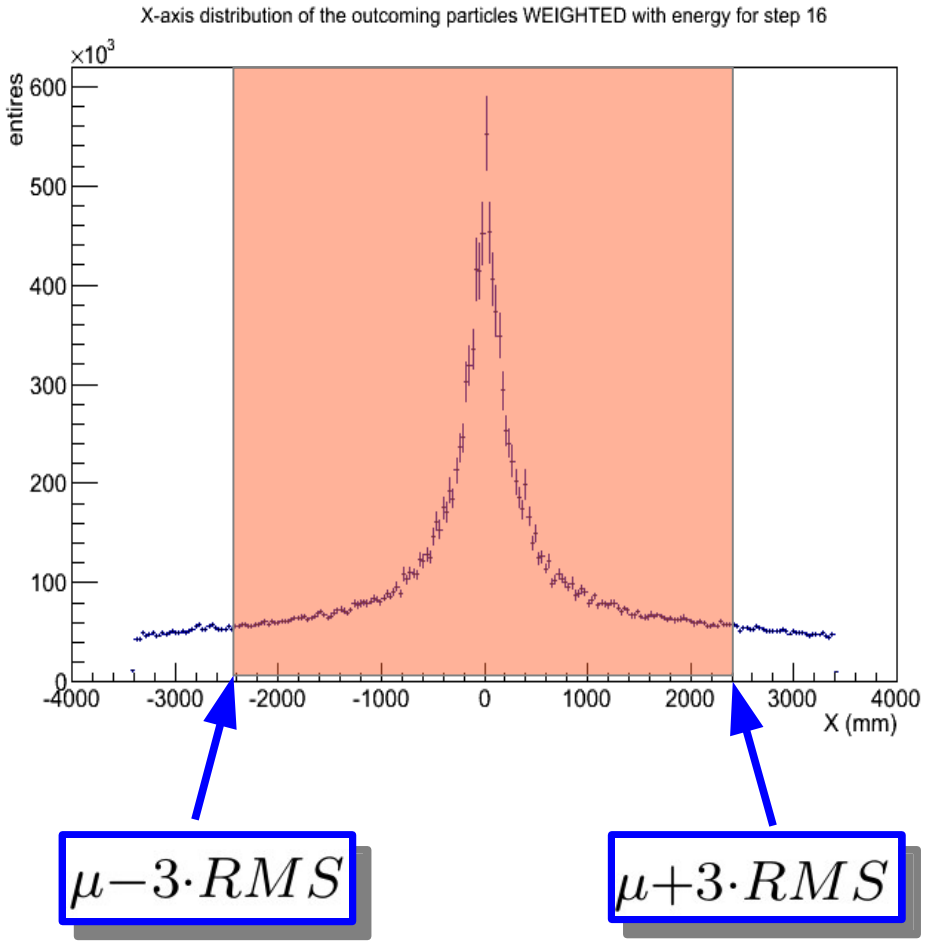
- XZ distribution WEIGHTED with Kinetic Energy



Vertical Distance (1)

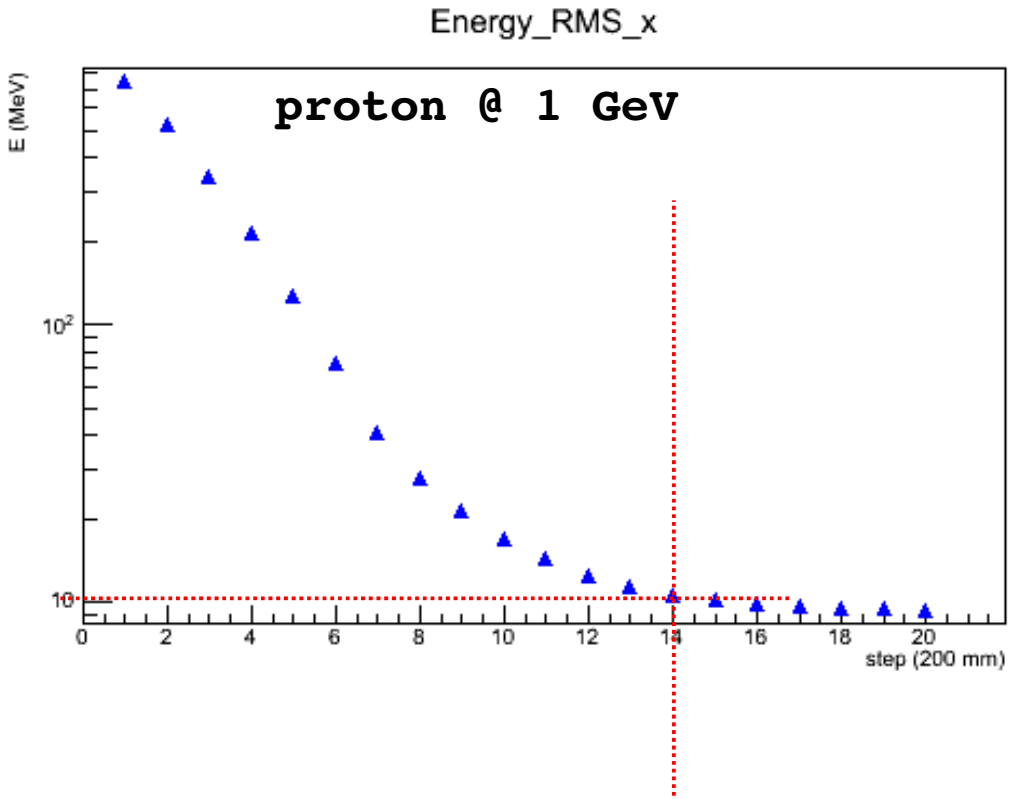
- For each step:
  - Evaluate

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



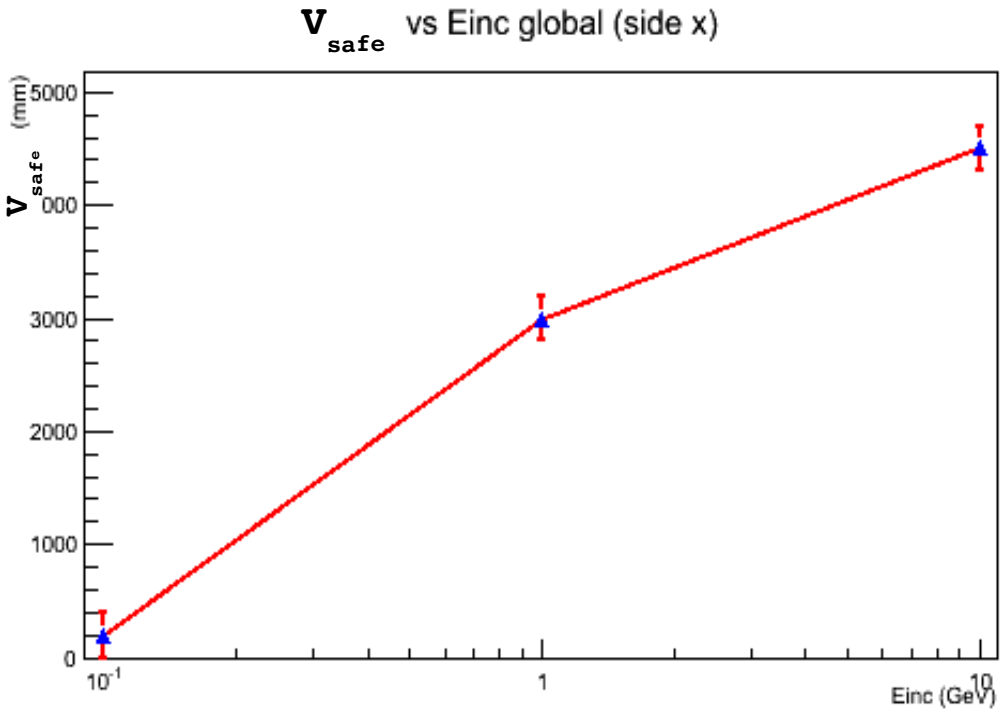
- Then use this quantity to infer the safety vertical distances

Vertical Distance (2)



- V_{safe} @ 10 MeV Threshold

V_{safe} for 3 different incoming particle energies



Horizontal Distance (1)

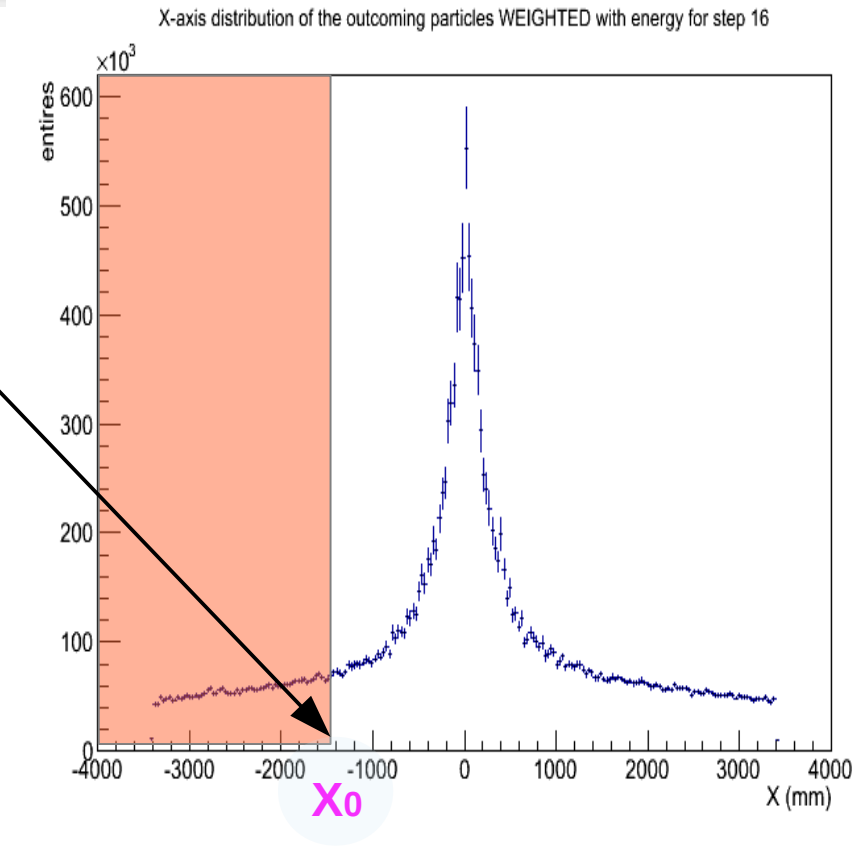
- For each step:
  - Search the point X_0 so that:

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

  - The safety horizontal distance is defined as:

$$h_{safe} = |\mu - X_0|$$

  - Then take the maximum wrt the depth



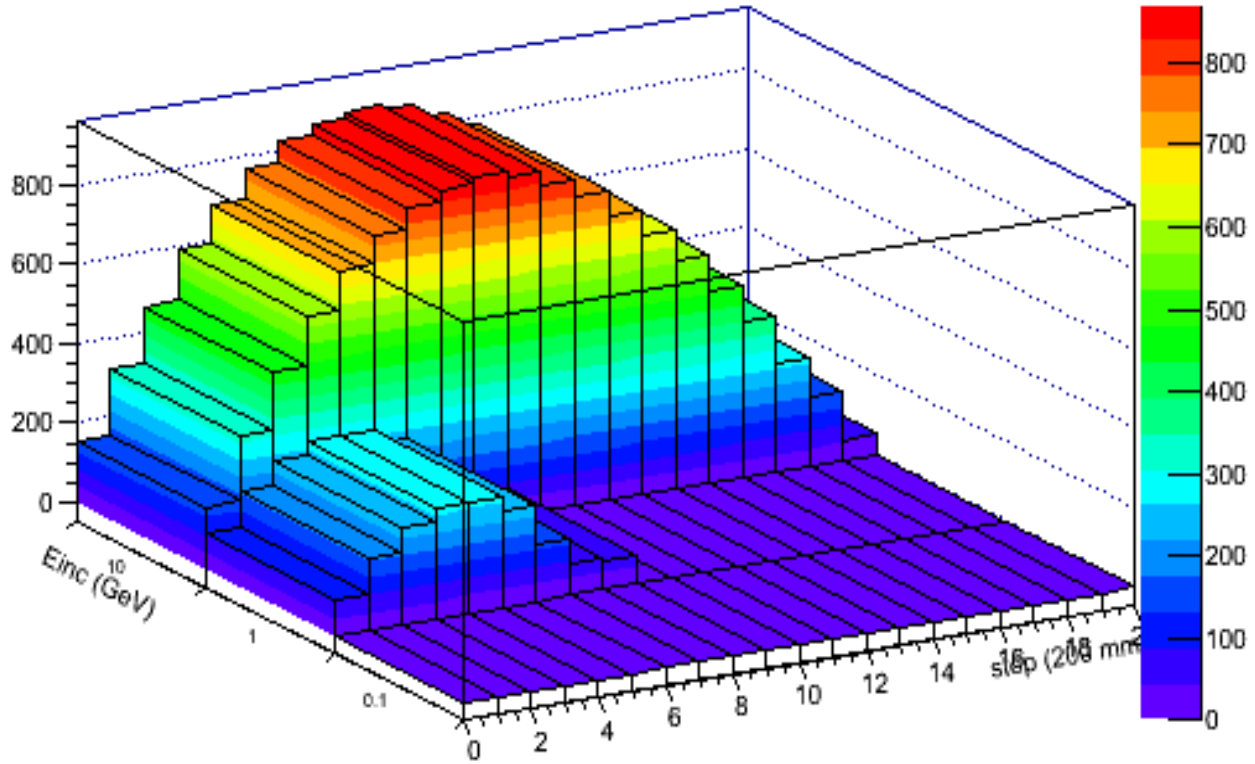
Horizontal Distance (2)

- h_{safe} @ 10 MeV

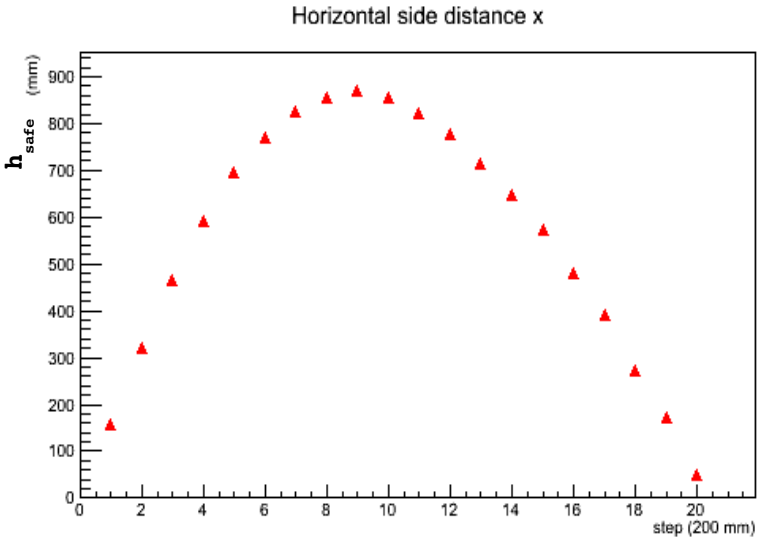
Threshold

Overall components

h_{safe} (x) distribution vs Einc

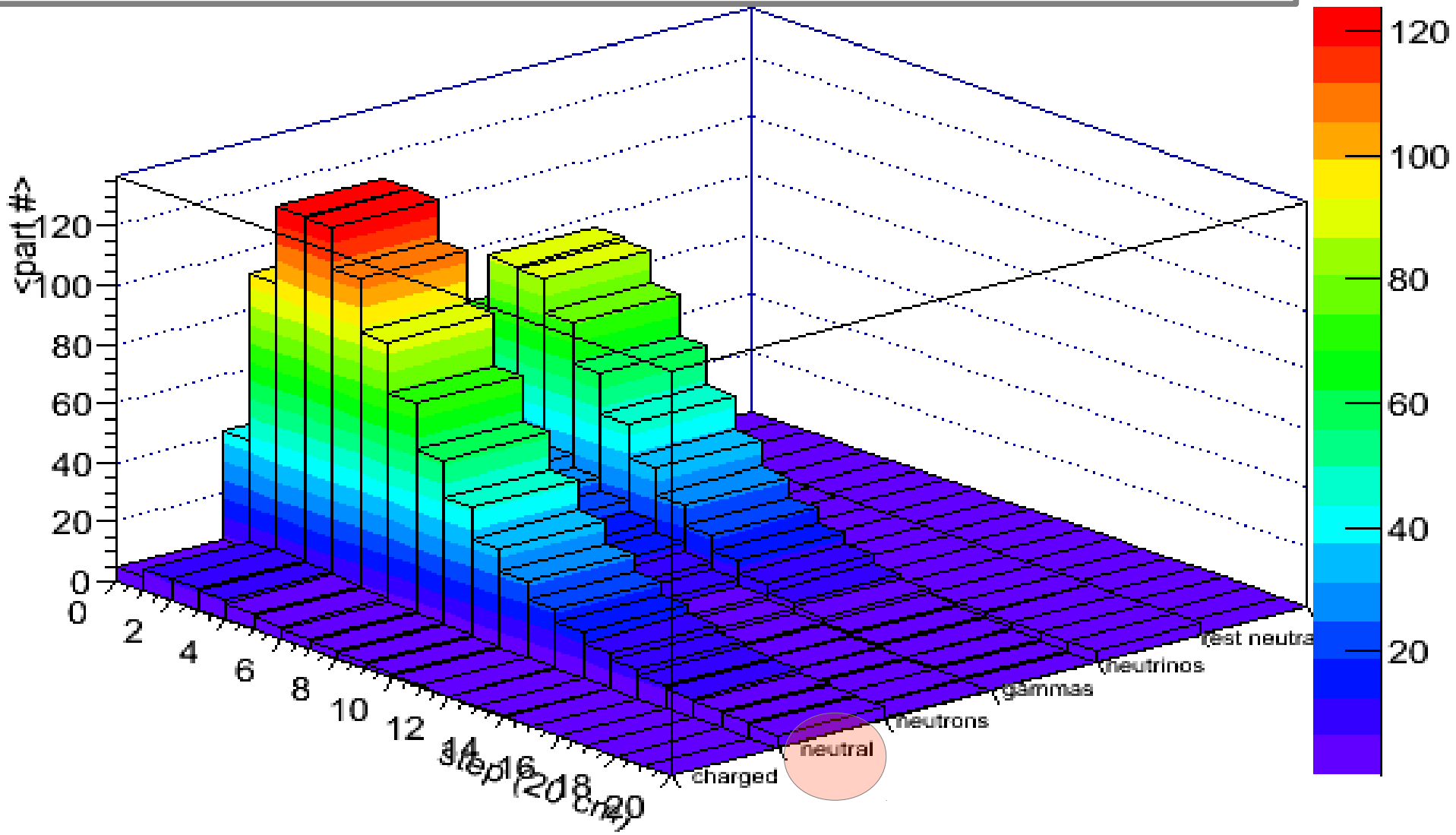


proton @ 10 GeV



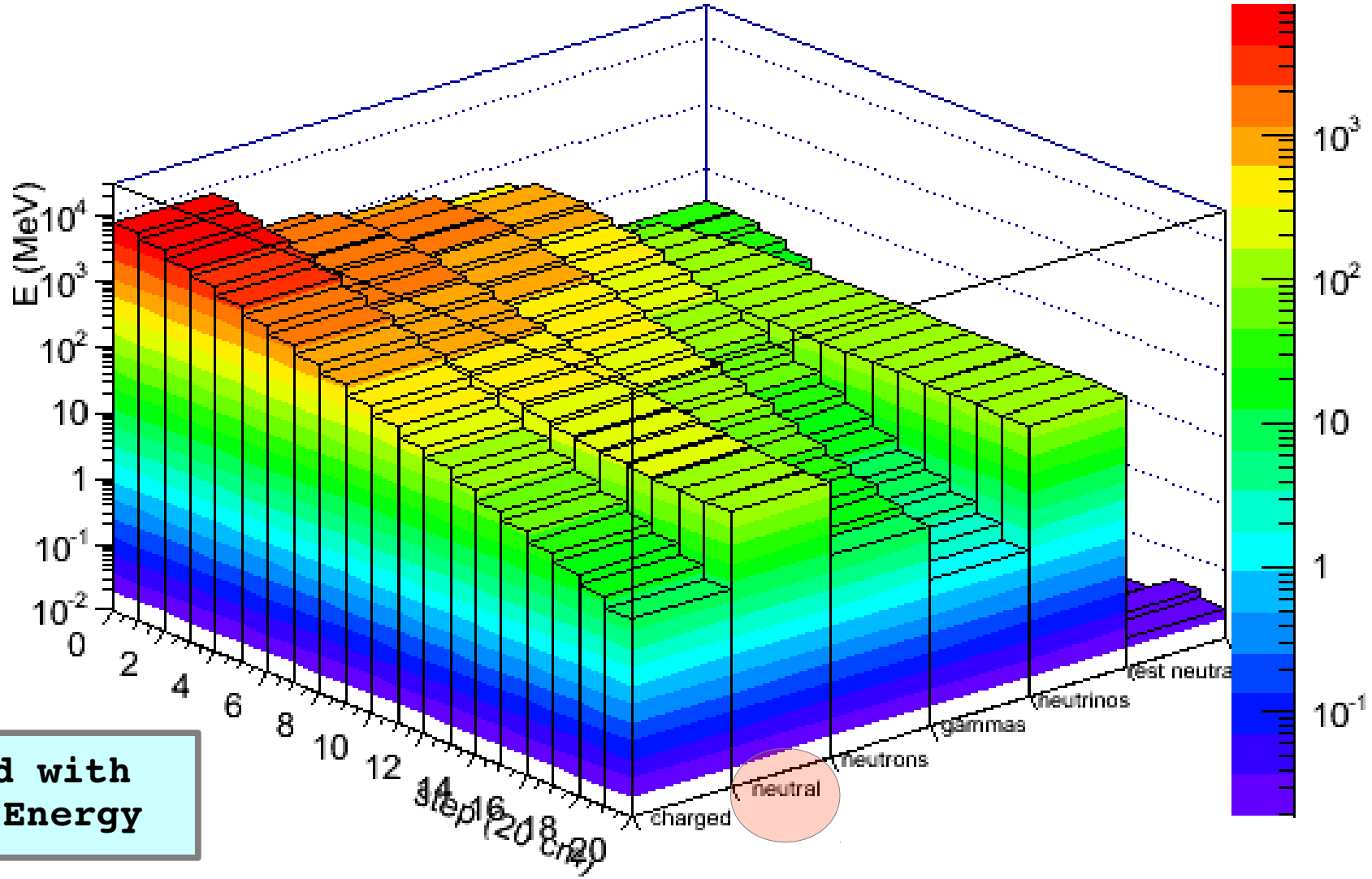
Global Results (1)

proton @ 10 GeV : particles # distribution vs step



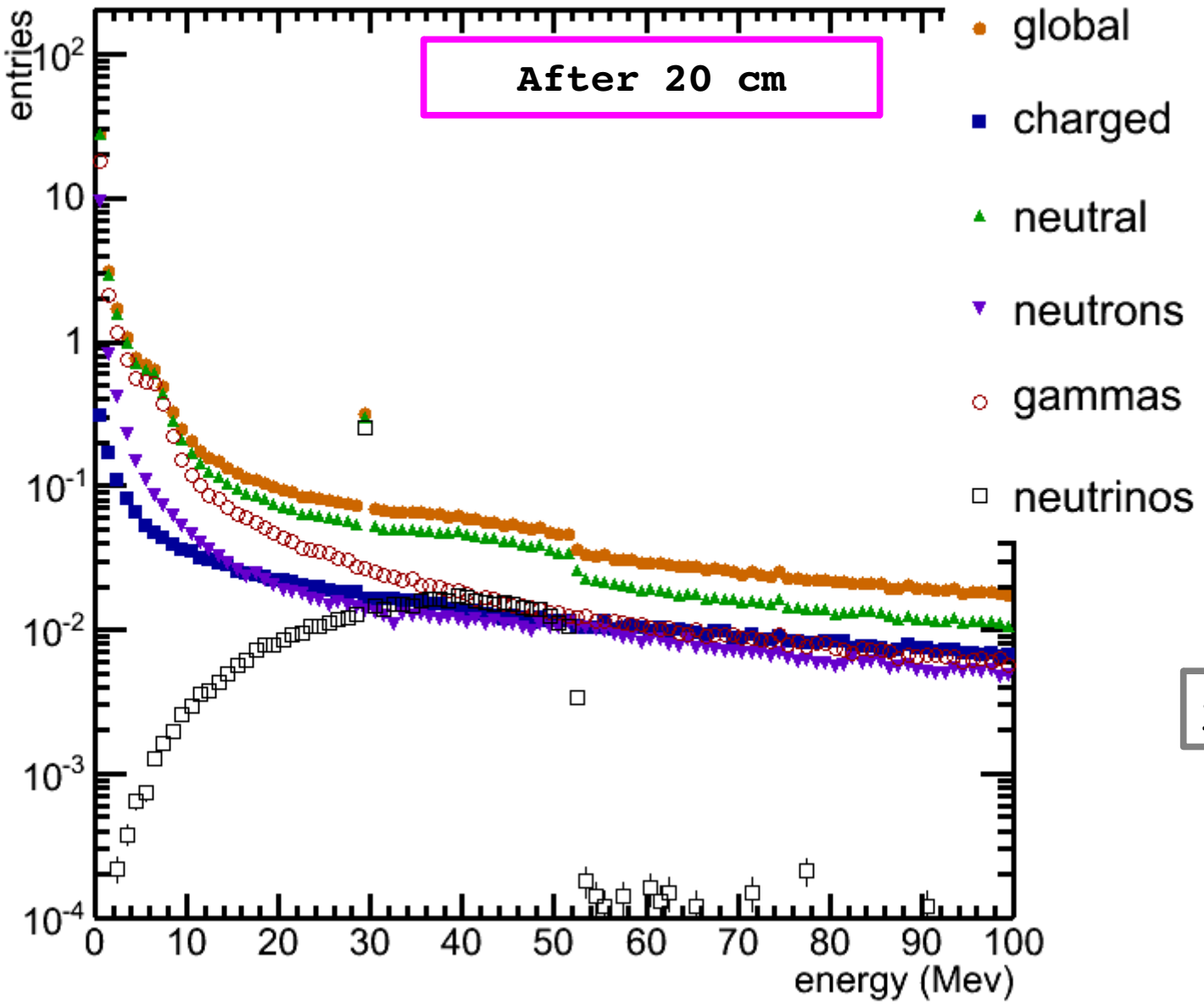
Global Results (2)

proton @ 10 GeV : particles # distribution vs step



Weighted with Kinetic Energy

Global Results: Energy Spectra



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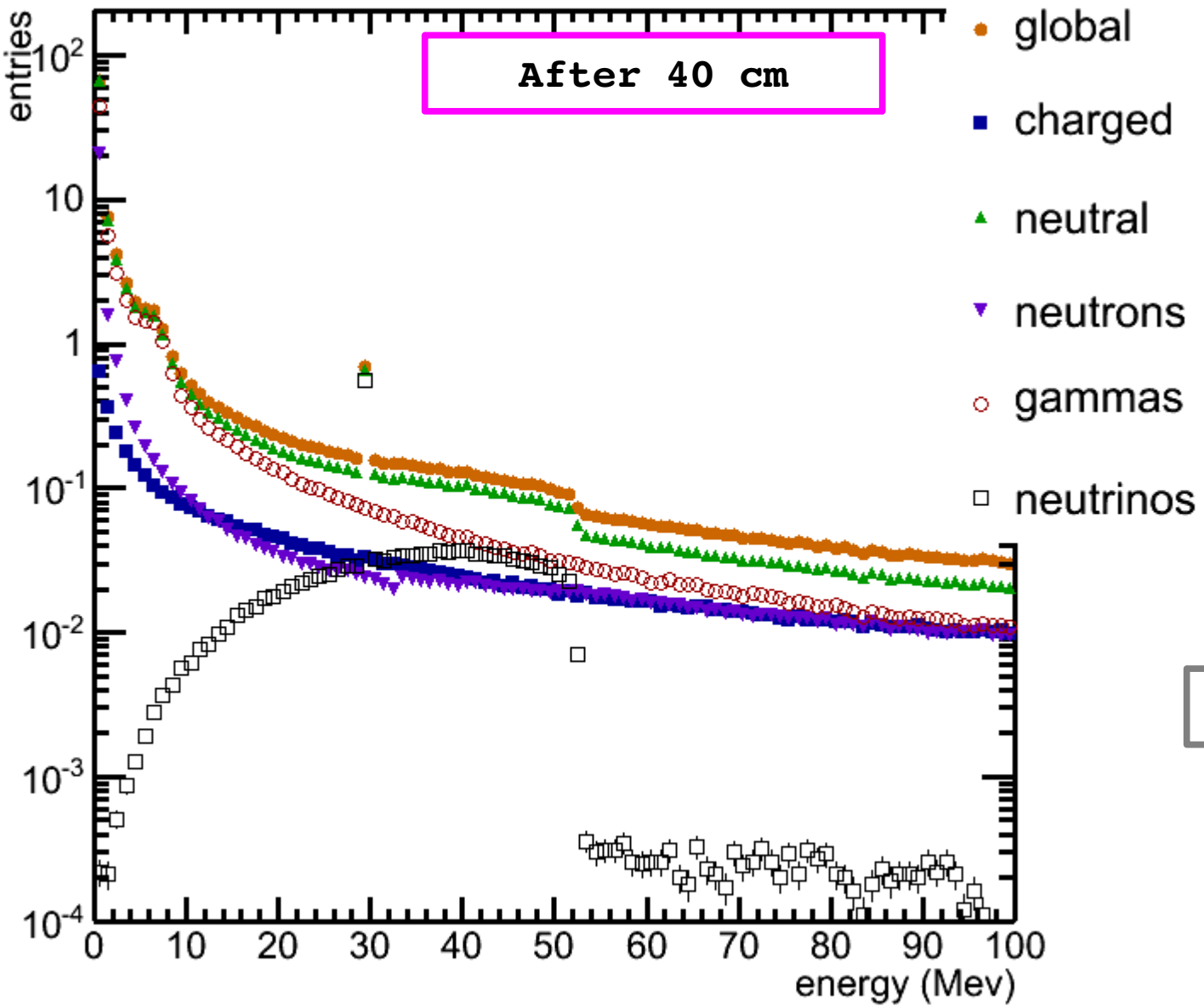

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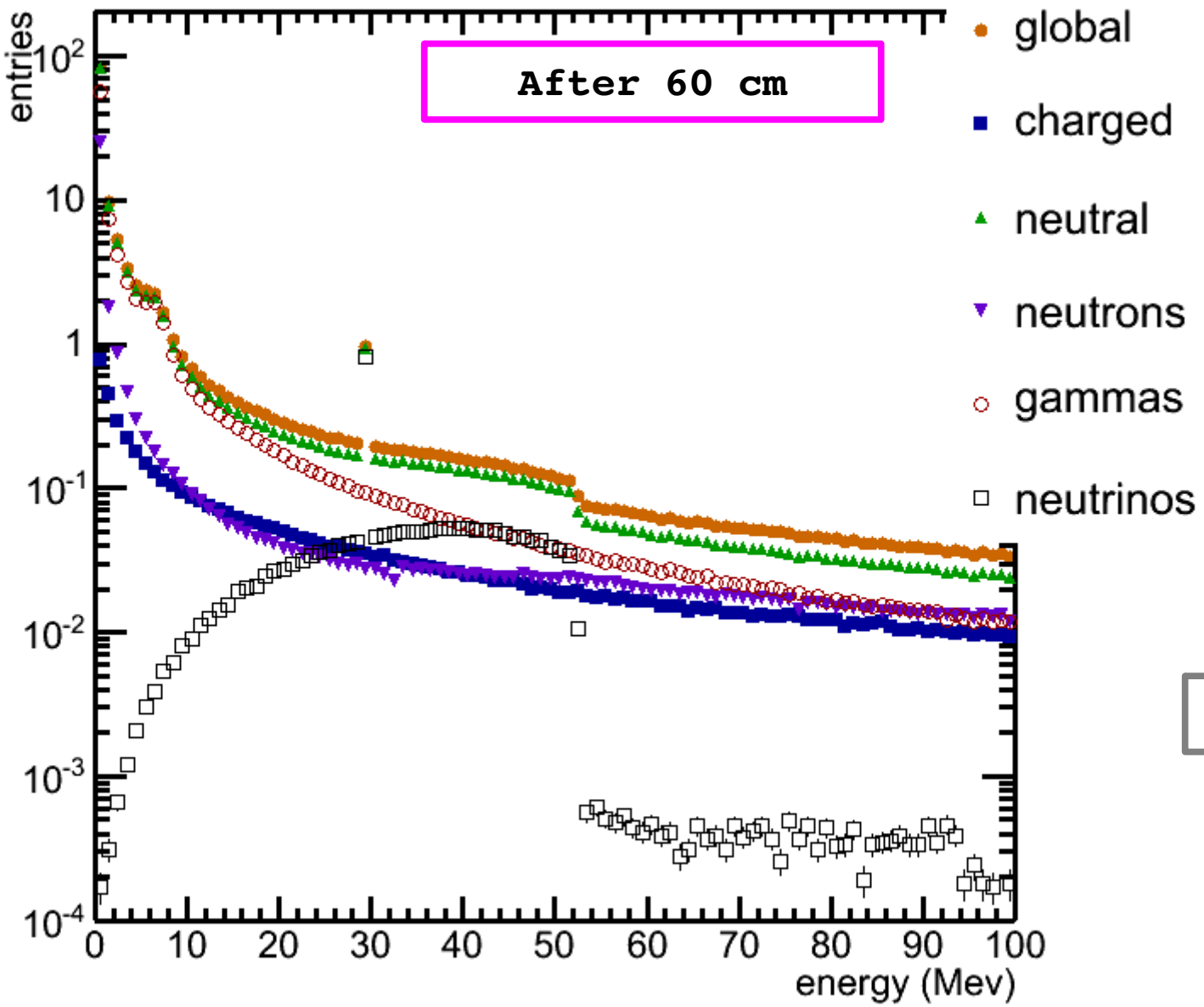

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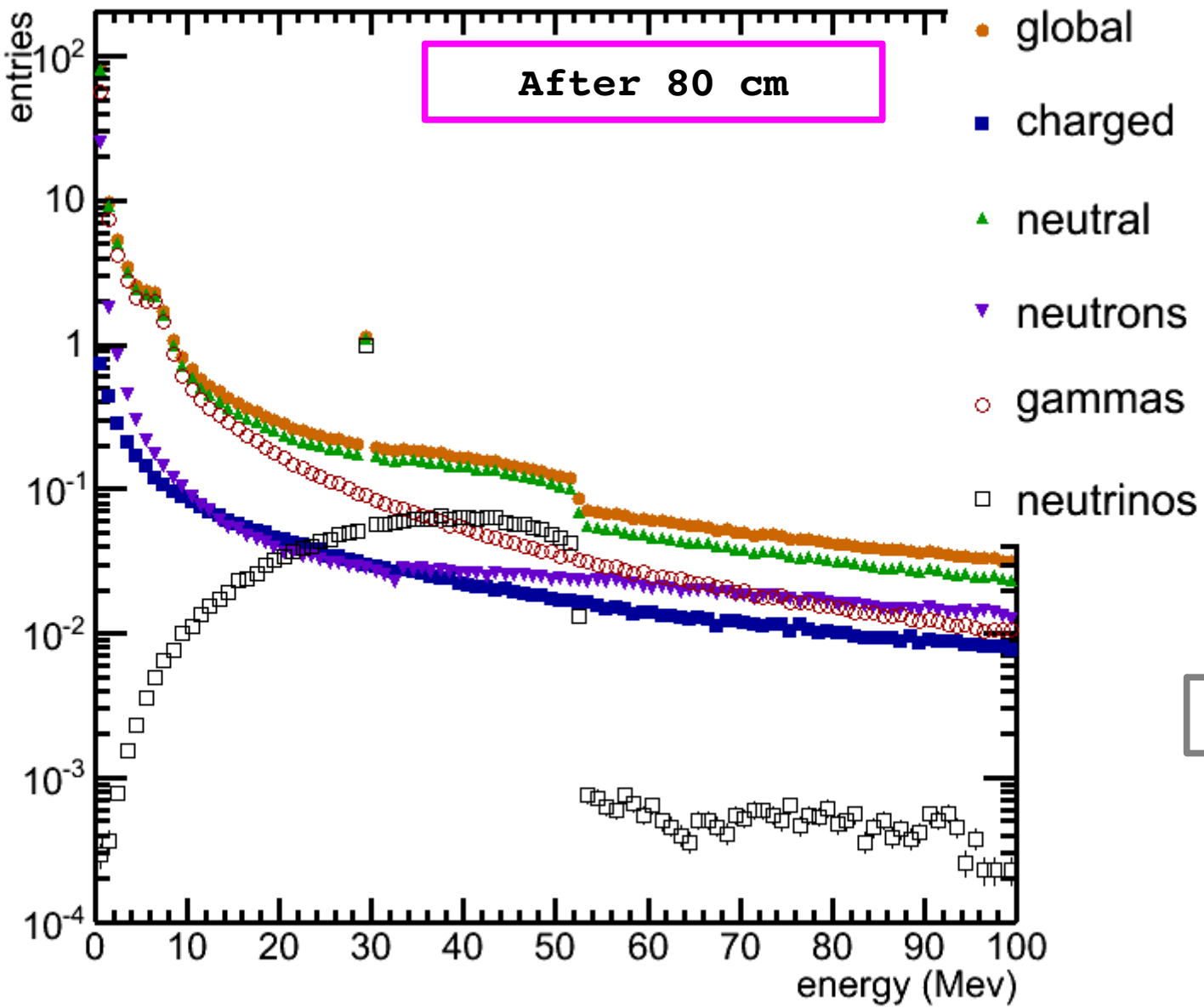

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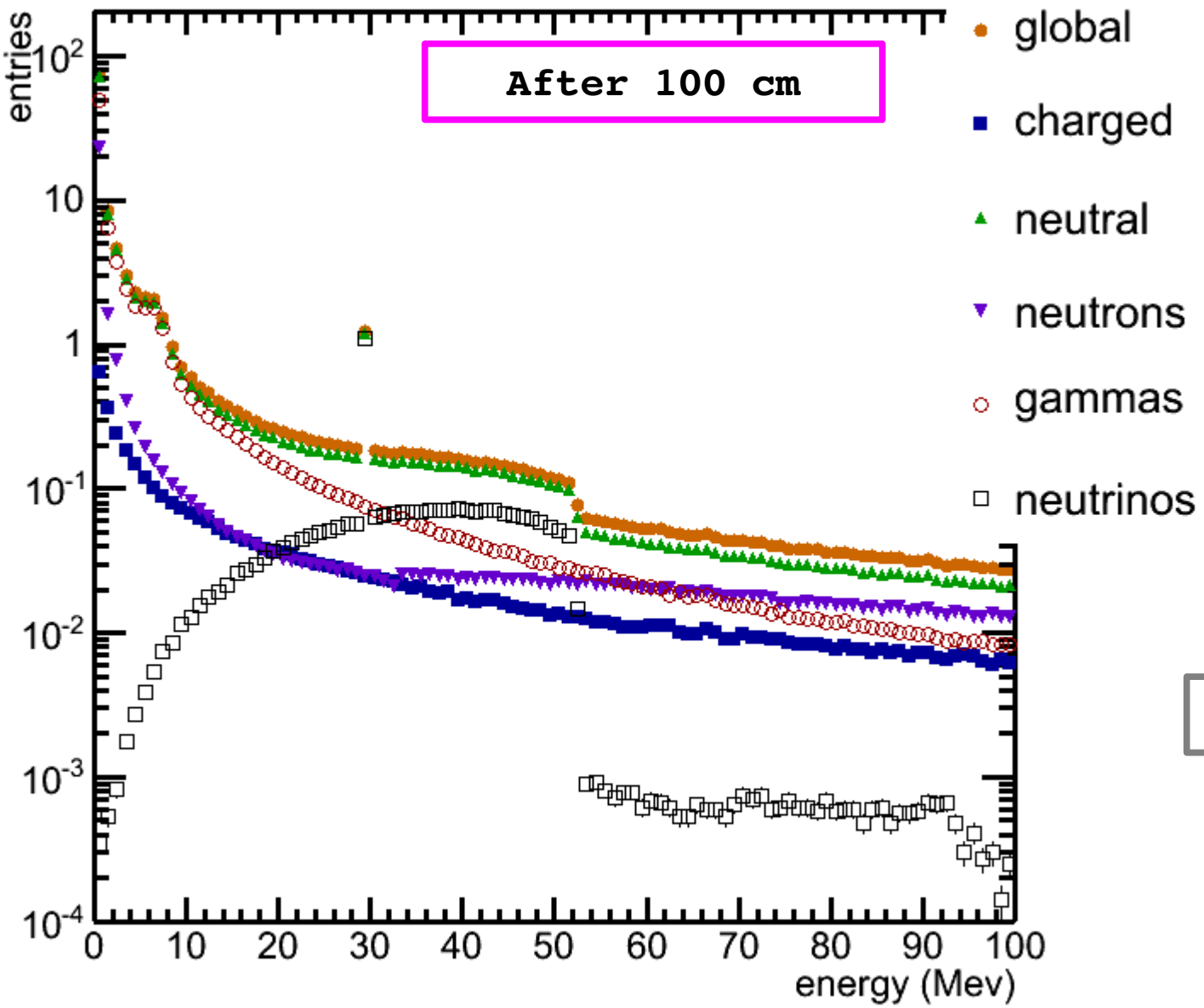

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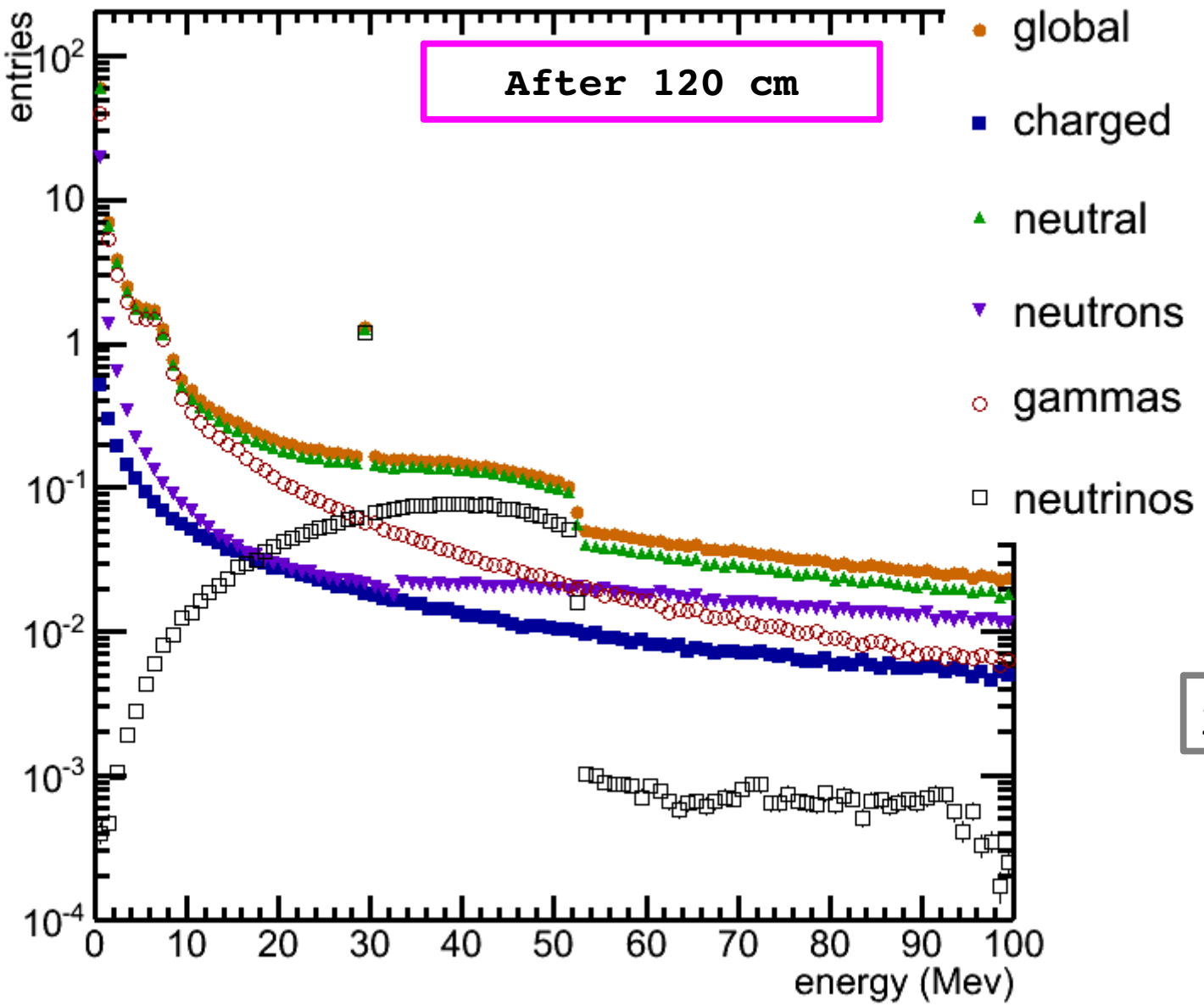

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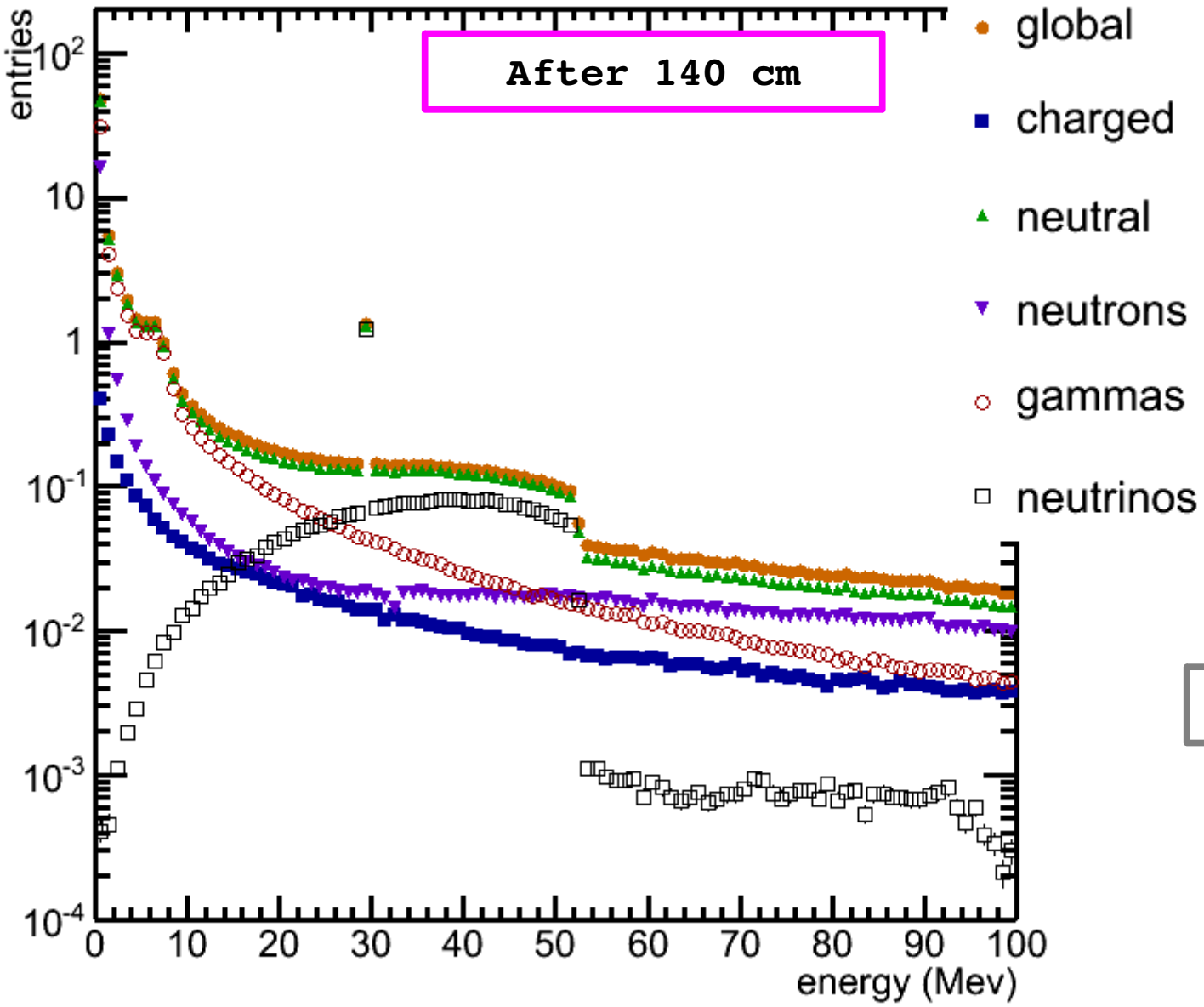

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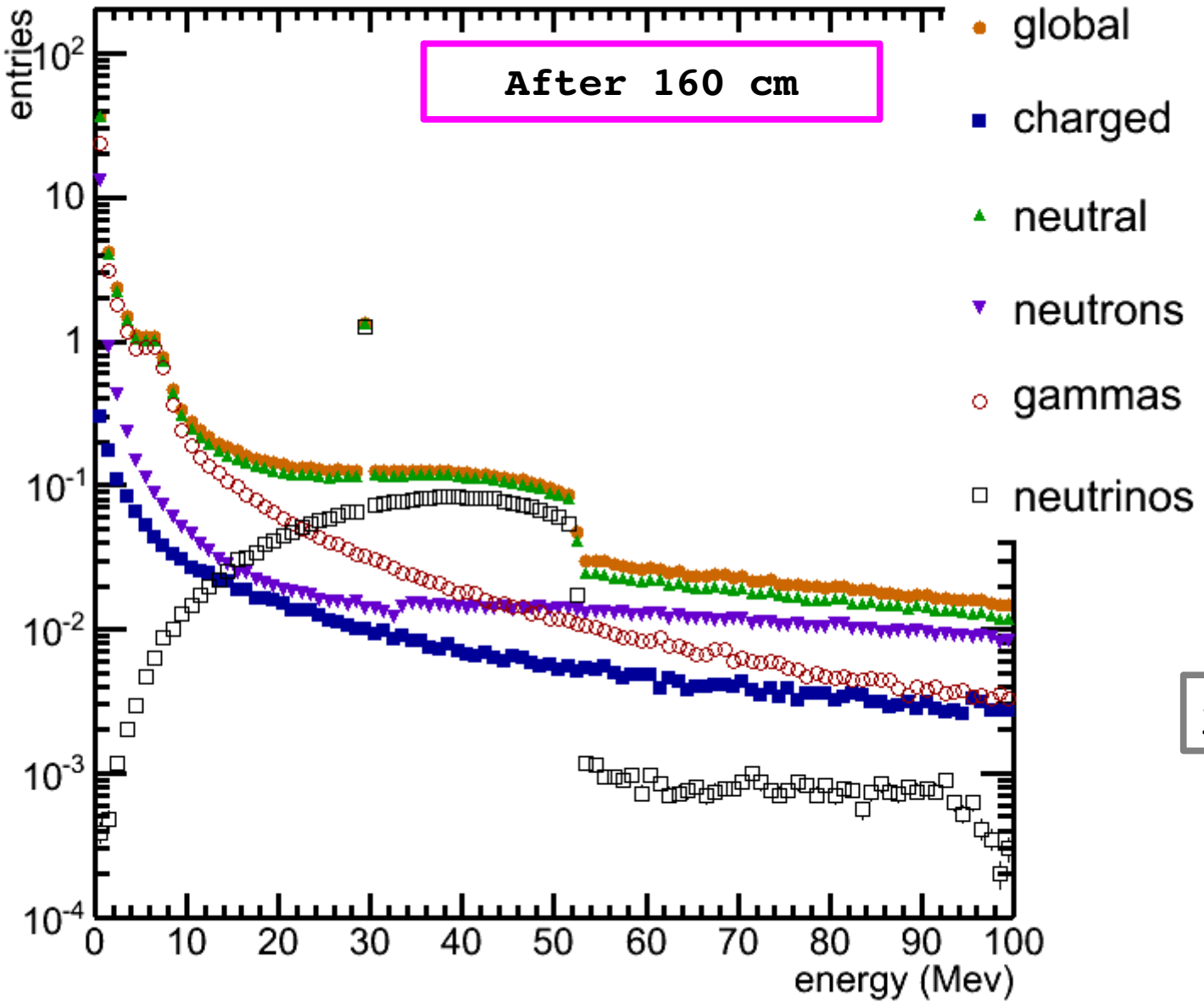

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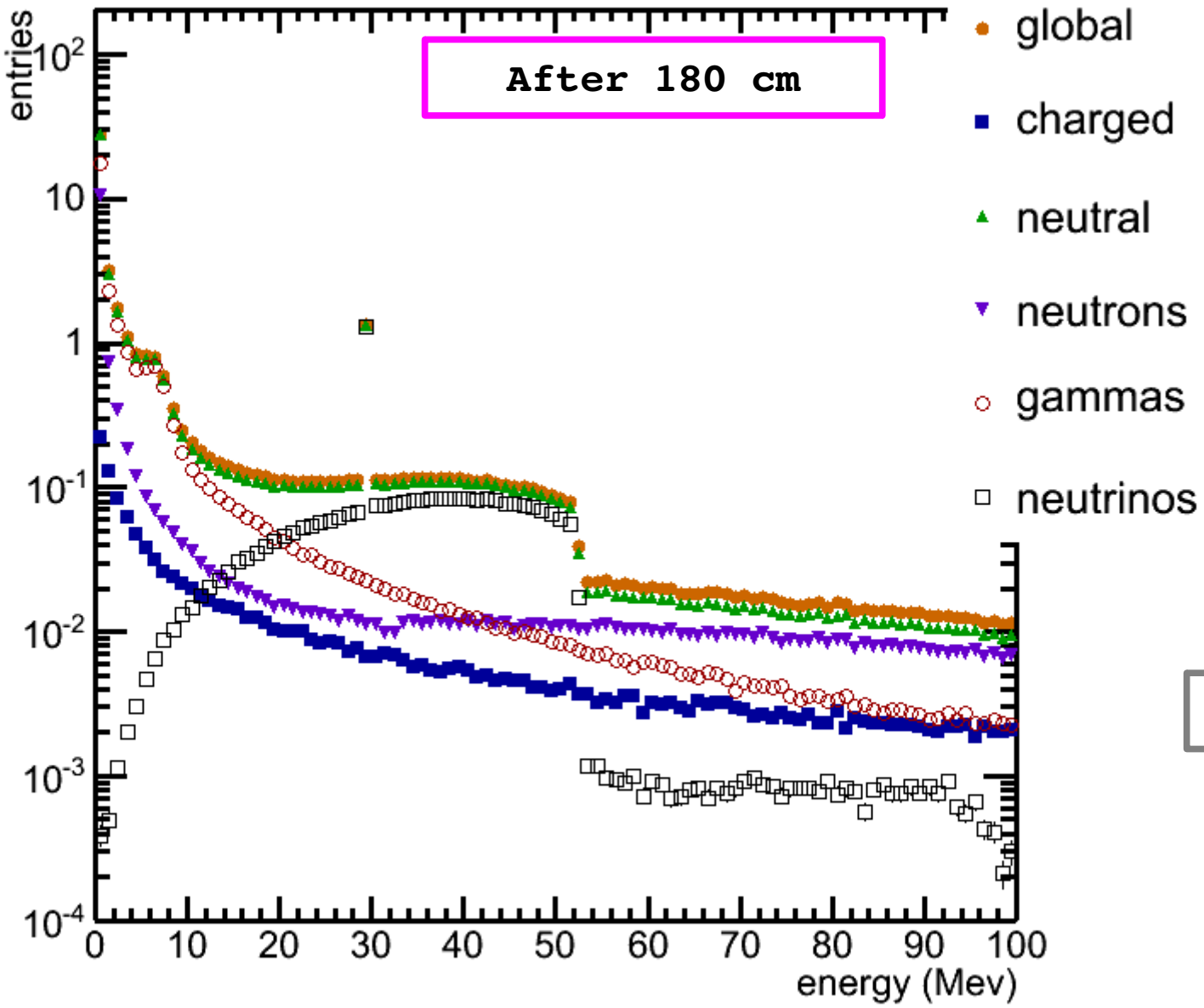
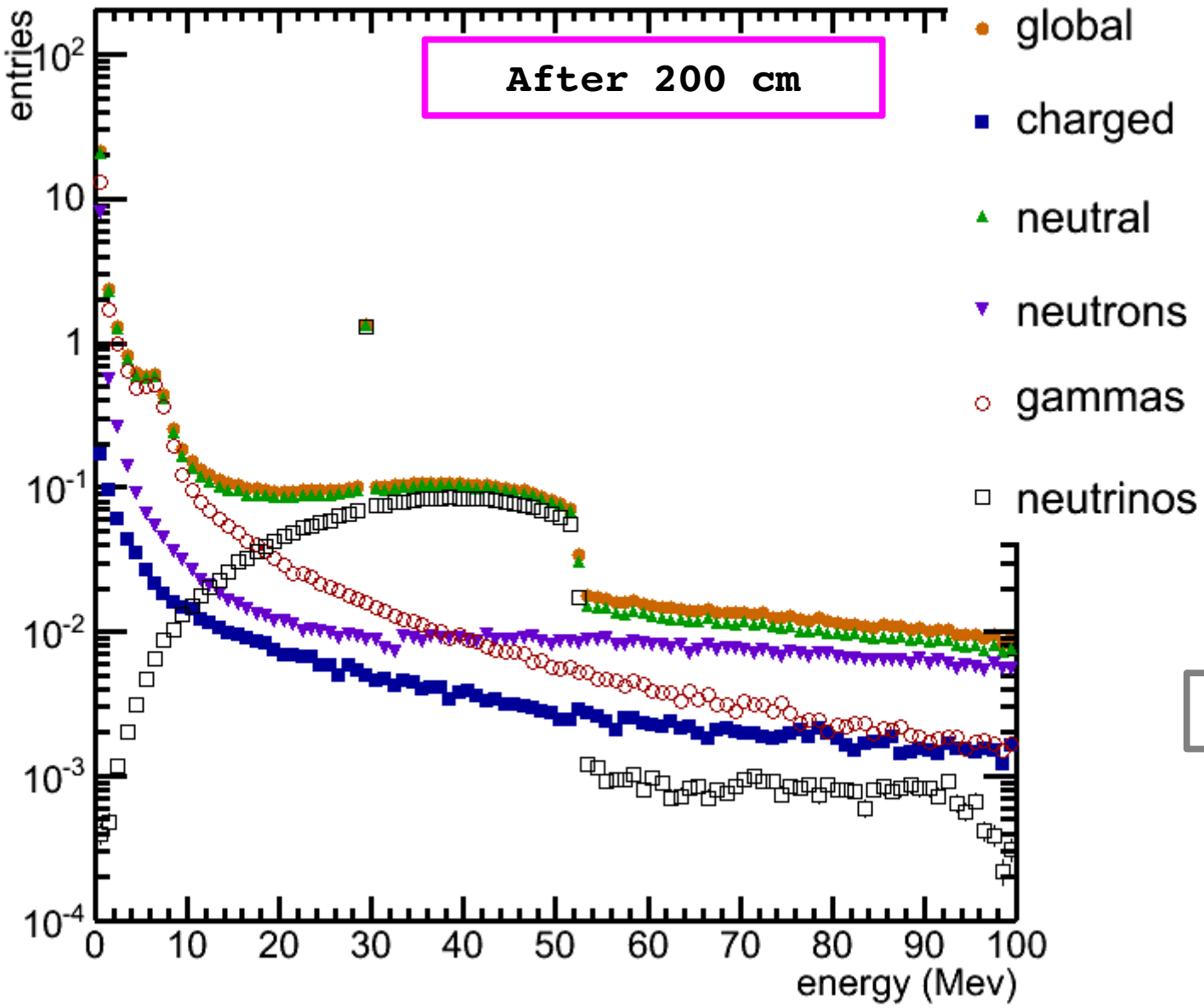


proton @ 10 GeV

Global Results: Energy Spectra



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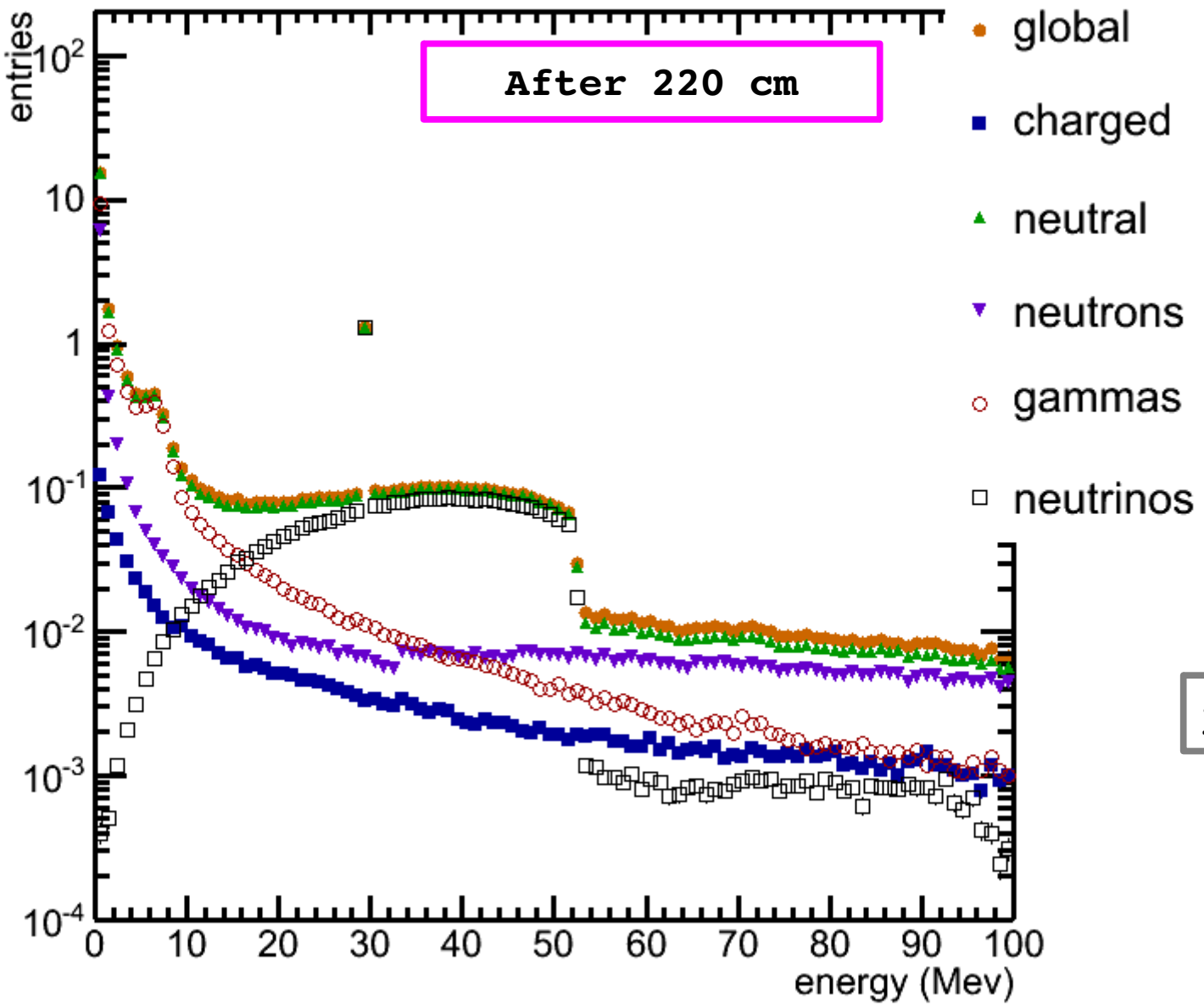

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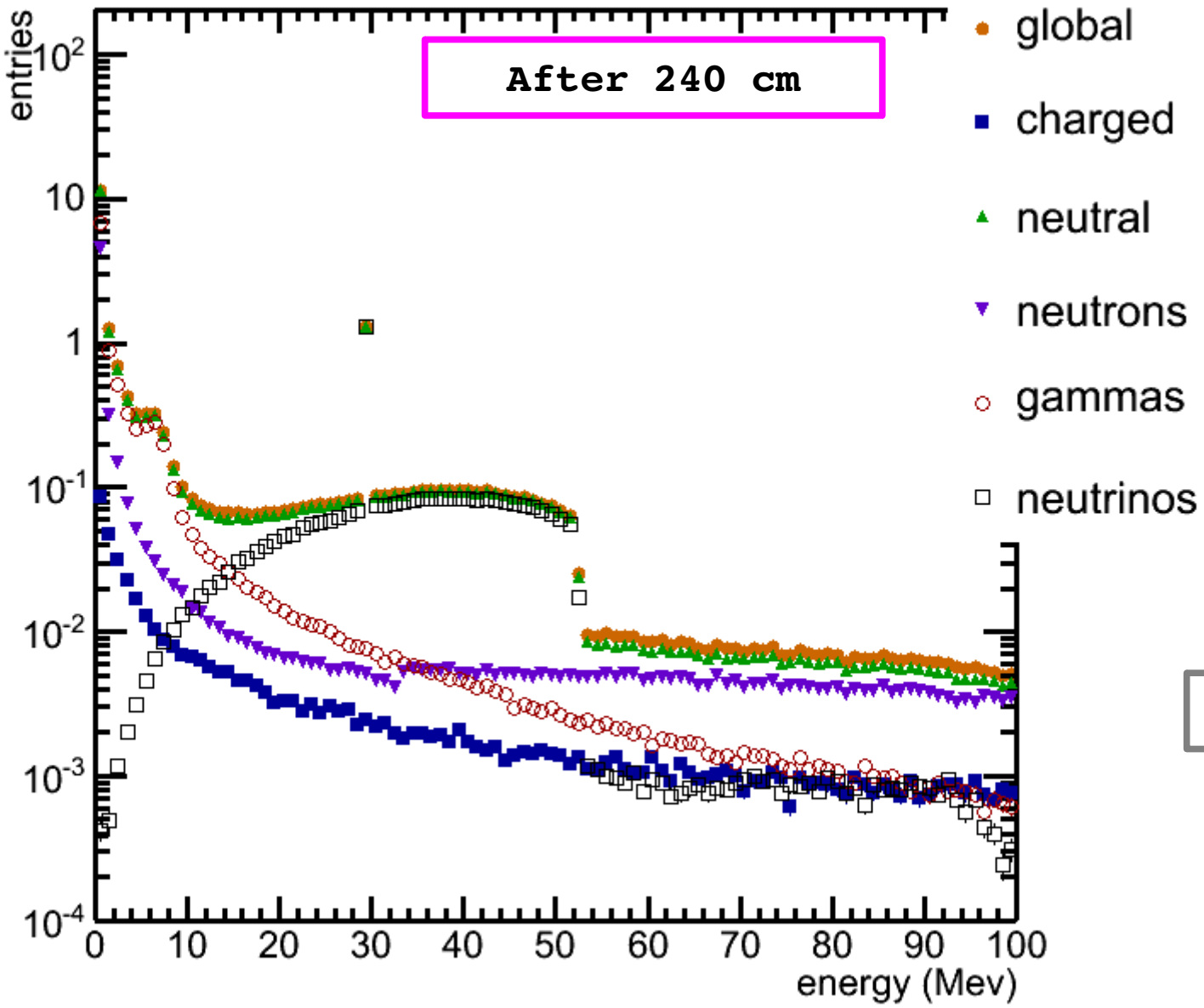

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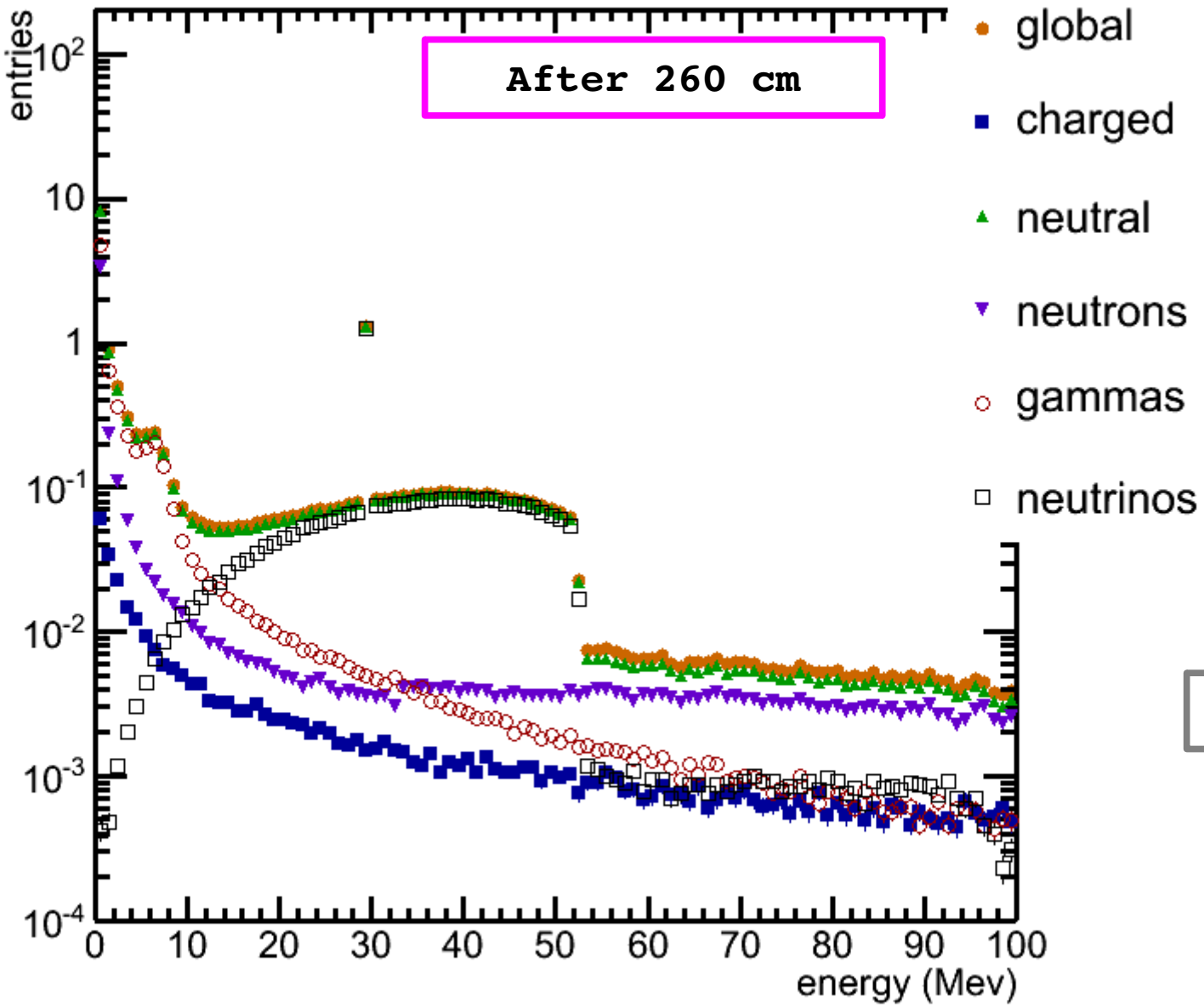

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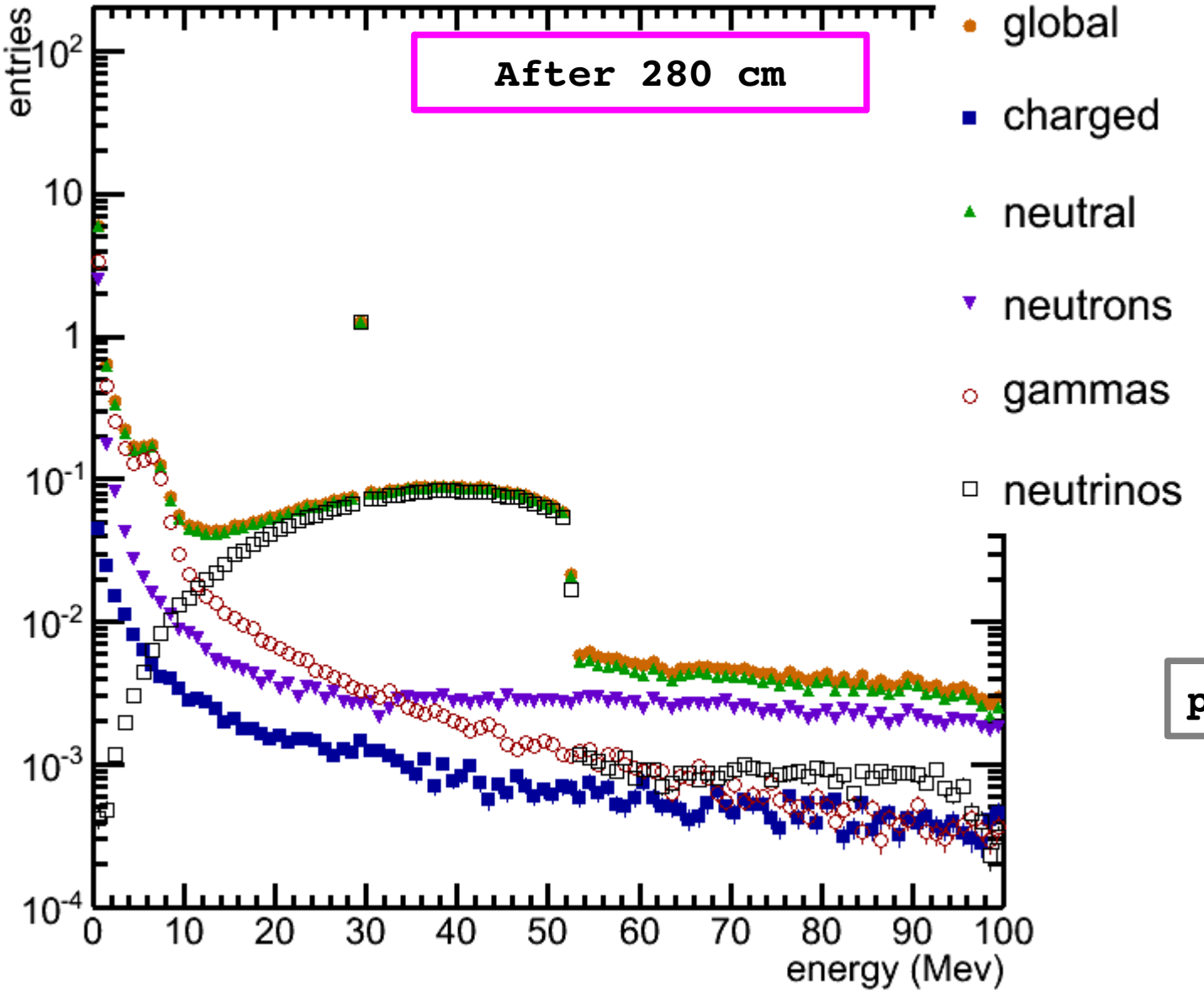

proton @ 10 GeV

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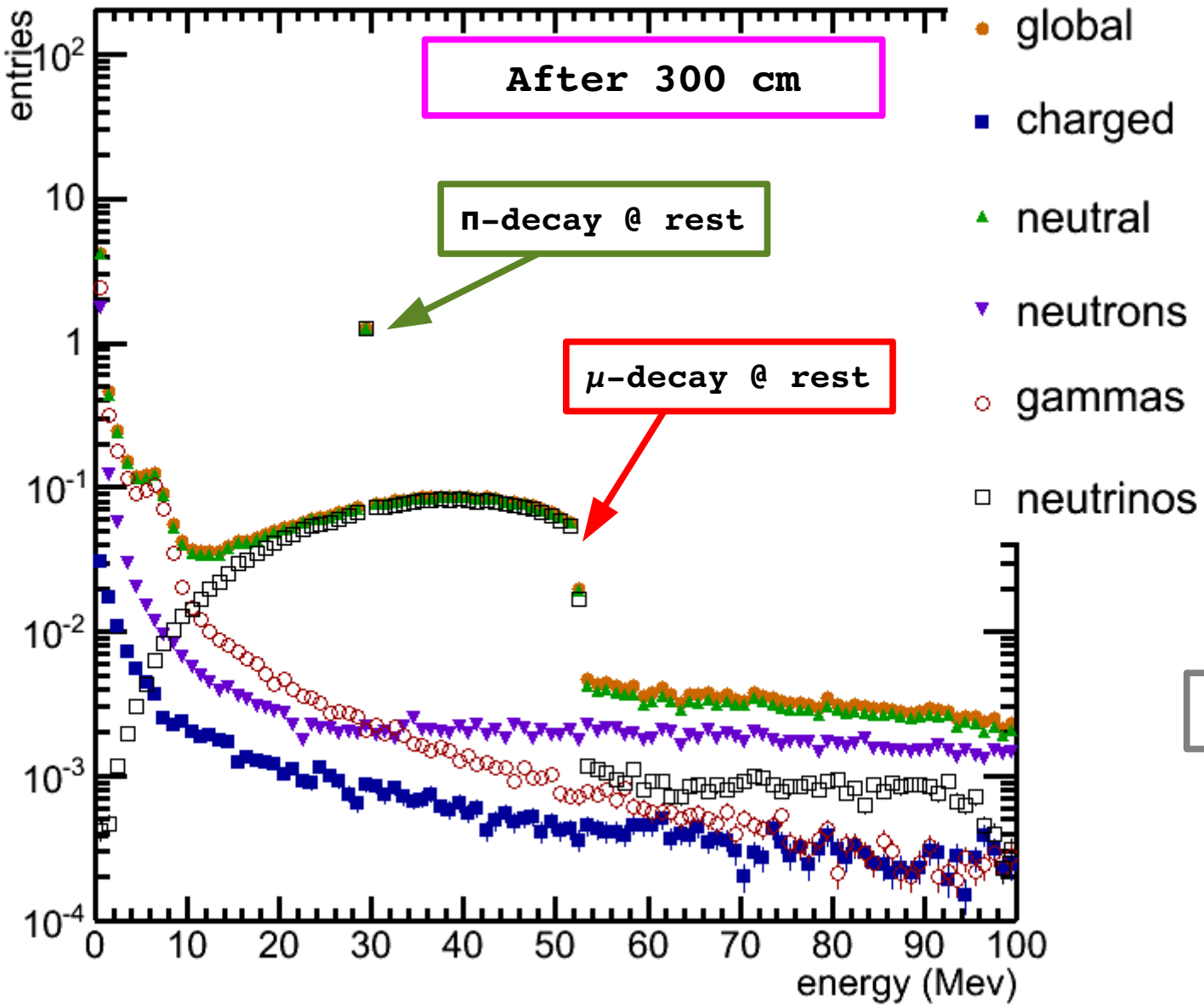

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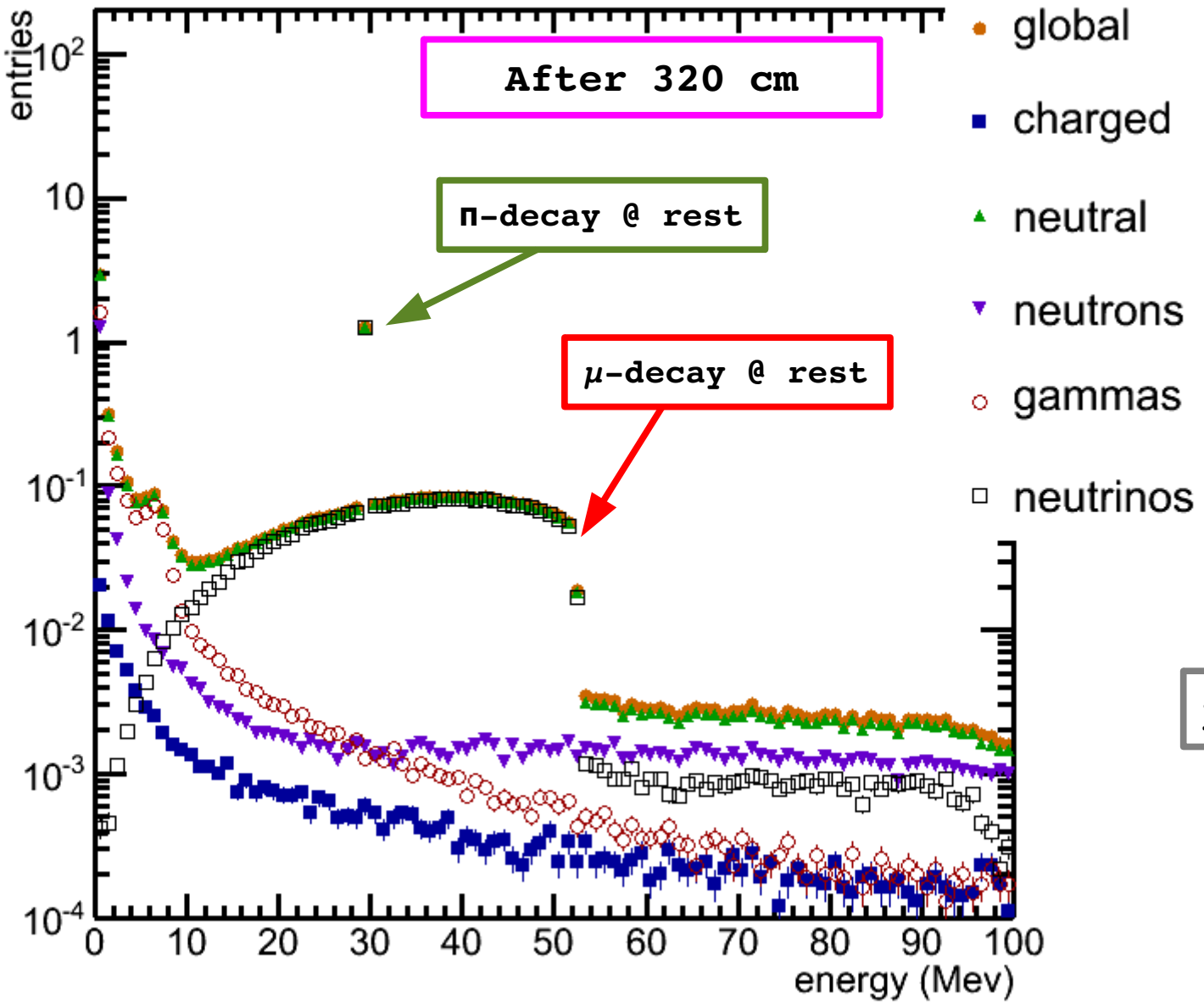

proton @ 10 GeV

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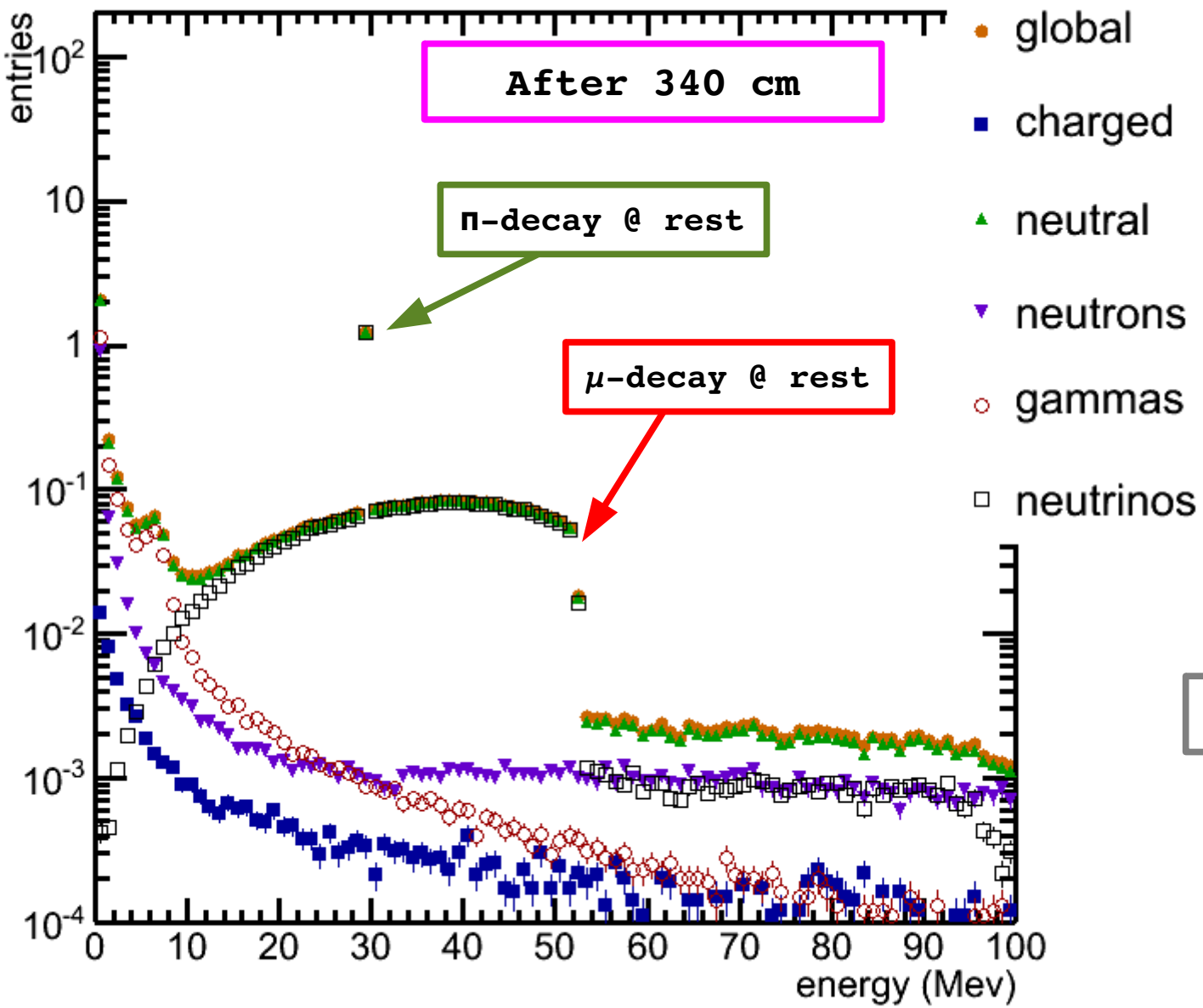

proton @ 10 GeV

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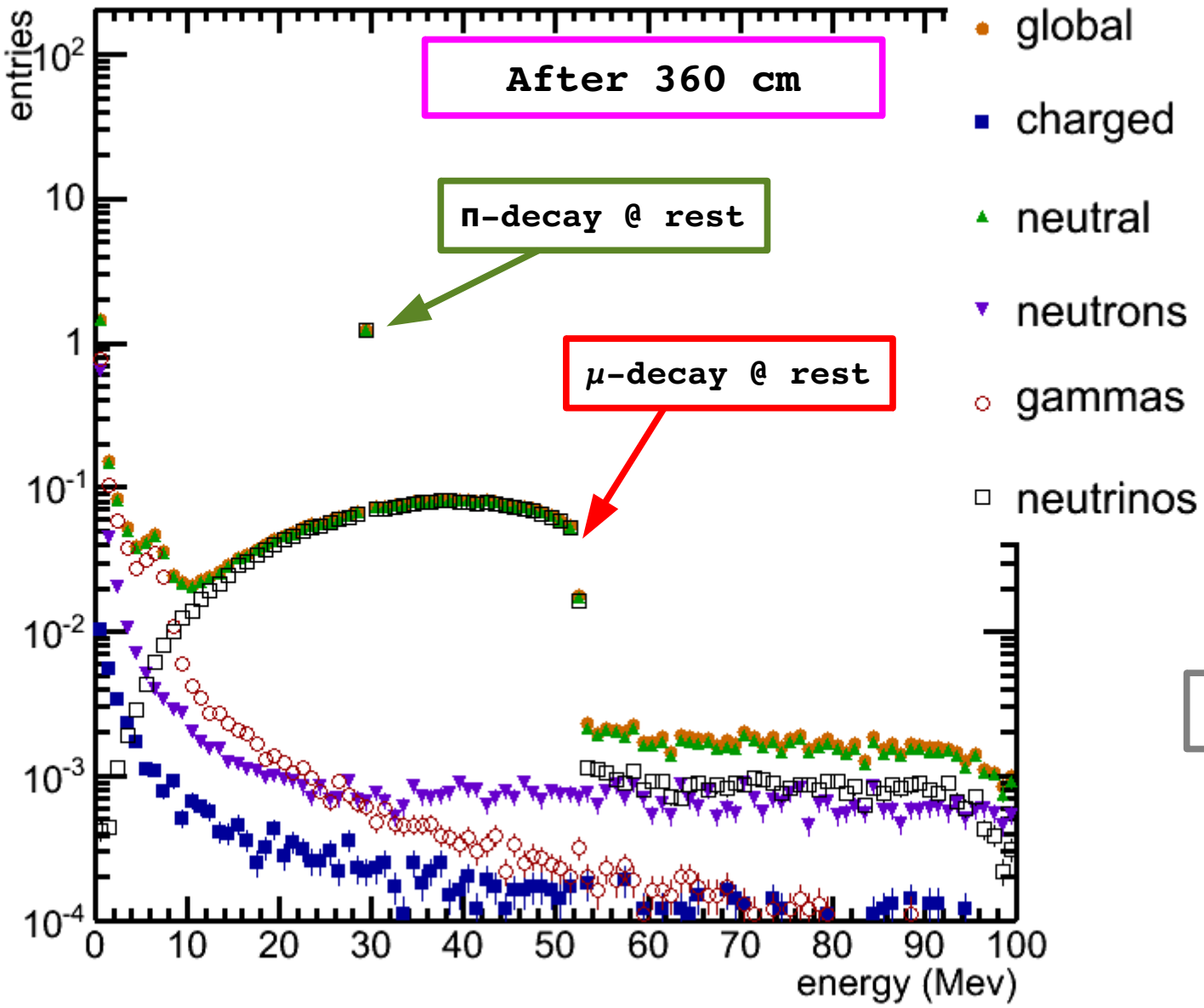

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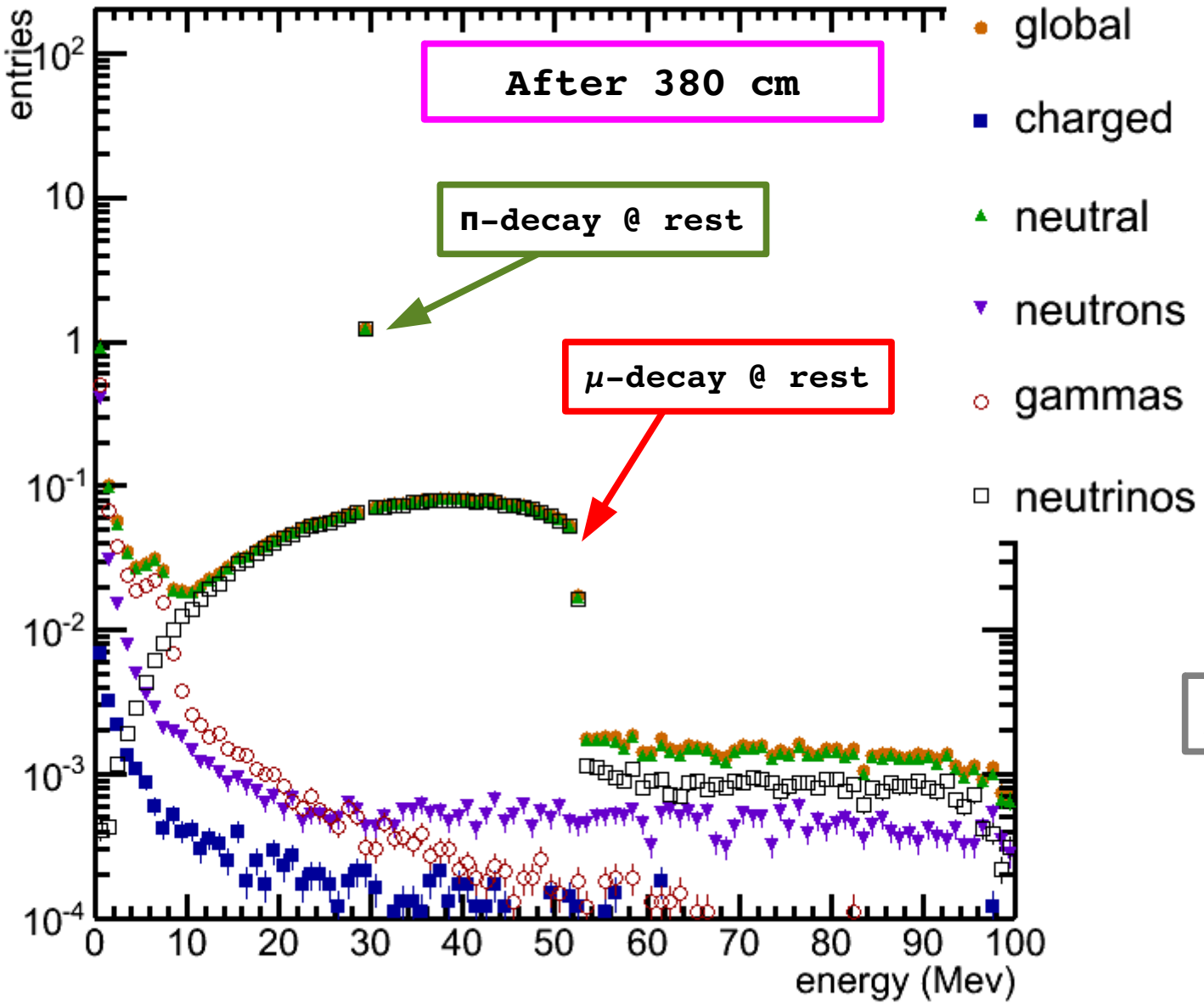

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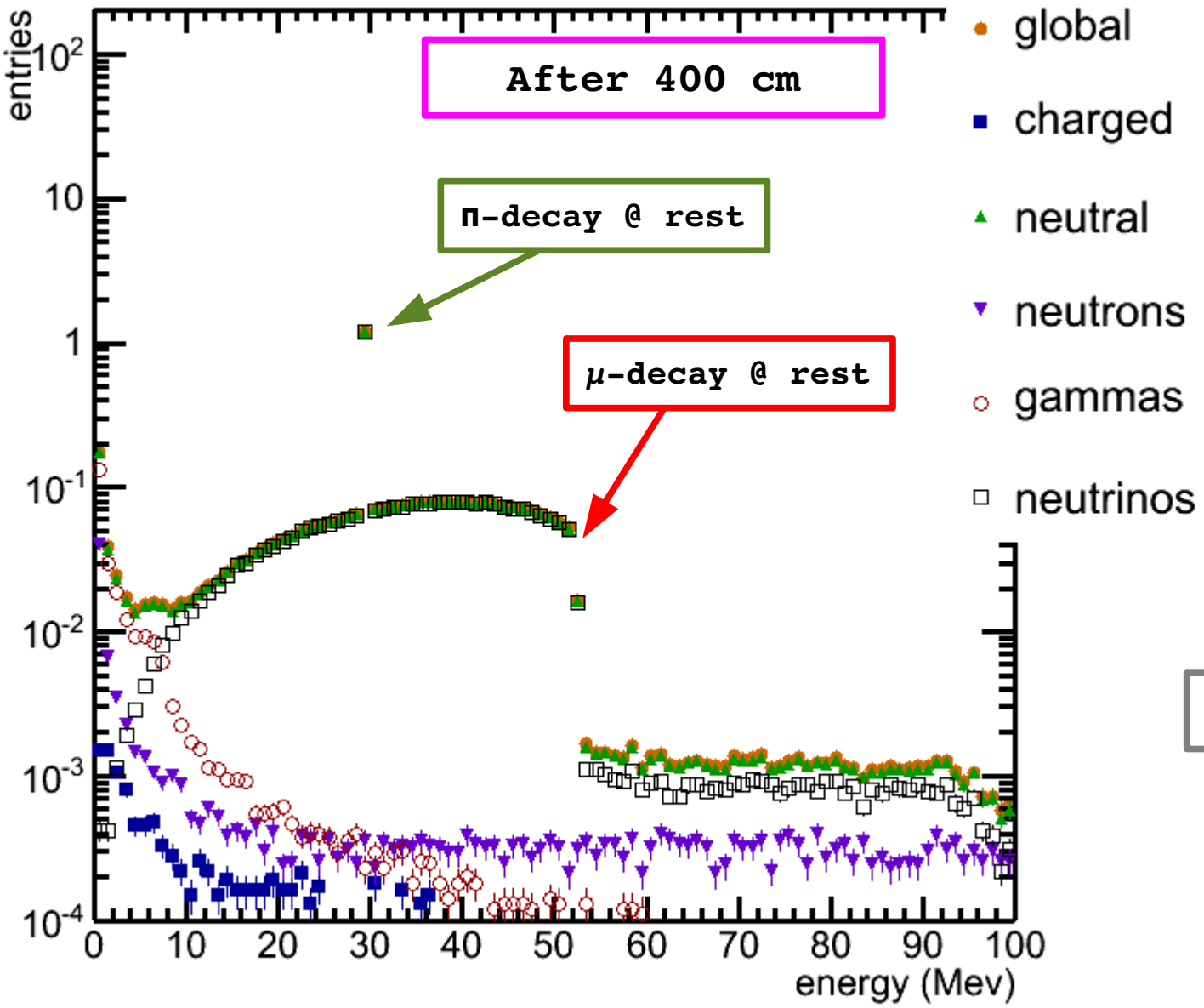

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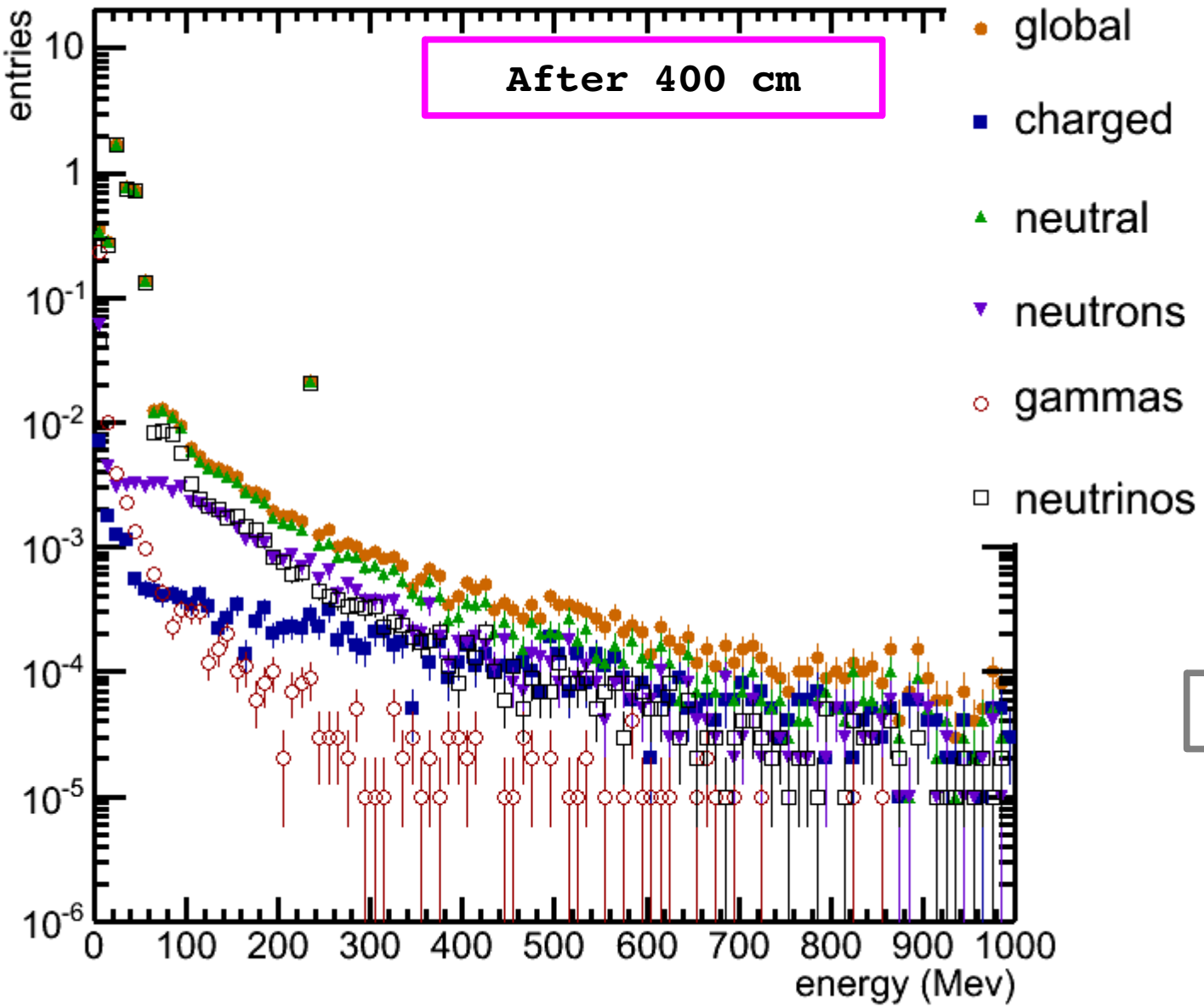

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Outline

- Introduction on Low Background Experiments
- The main background sources for deep underground labs
- **Shower development in rock: the analysis procedure**
  - **Summary & Outlook**
- N-induced Ge-76 Spectra
  - Conclusions

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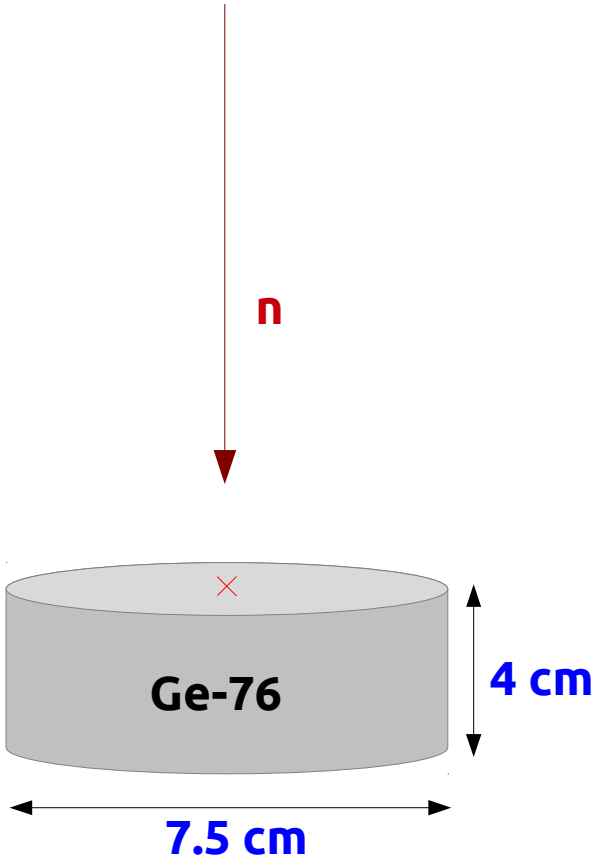
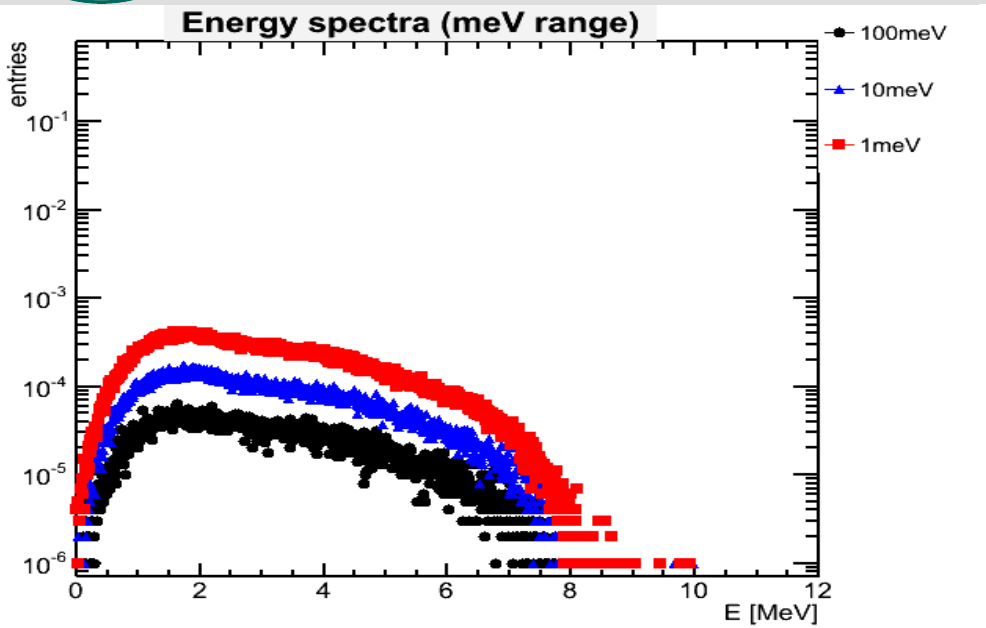
Simulation

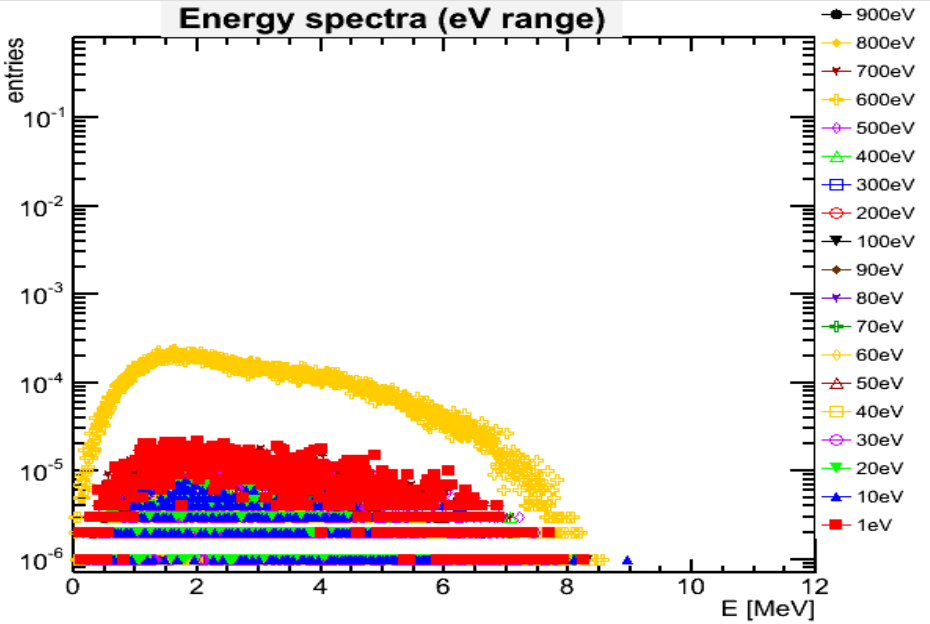


- **Energies:**
  - meV: 1,10,100
  - eV: 1,10-100 (10 eV step)
  - eV: 100-900 (100 eV step)
  - keV: 1,10-100 (10 keV step)
  - keV: 100-900 (100 keV step)
  - MeV: 1,10-100 (10 MeV step)
- **1 million events**
- **Total energy deposition (Thr 1 keV)**

Courtesy of B. Doenmez, MPP Muenchen

Results


Energy spectra (meV range)
entries
E [MeV]
100meV
10meV
1meV


Energy spectra (eV range)
entries
E [MeV]
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700eV
600eV
500eV
400eV
300eV
200eV
100eV
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60eV
50eV
40eV
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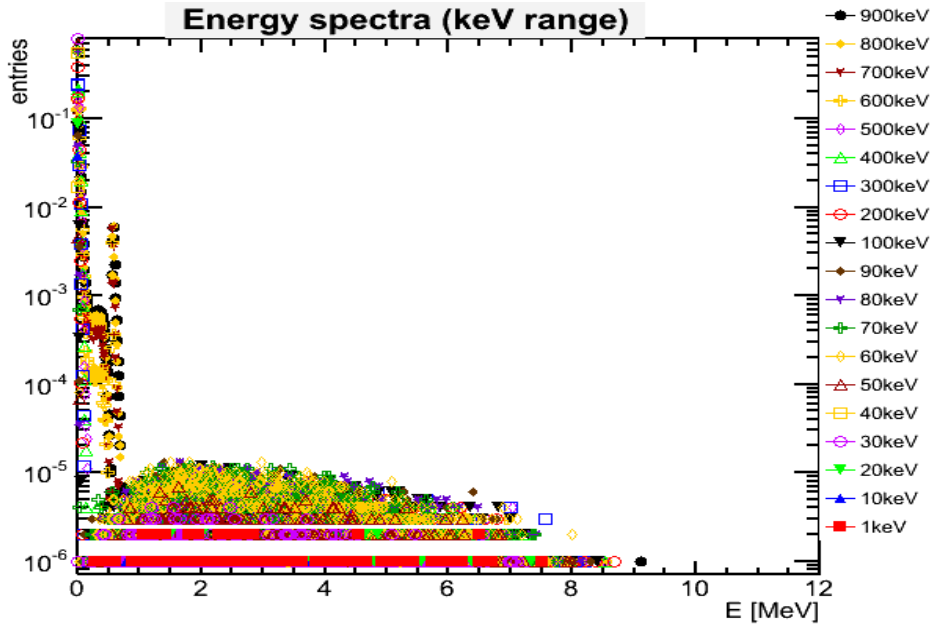
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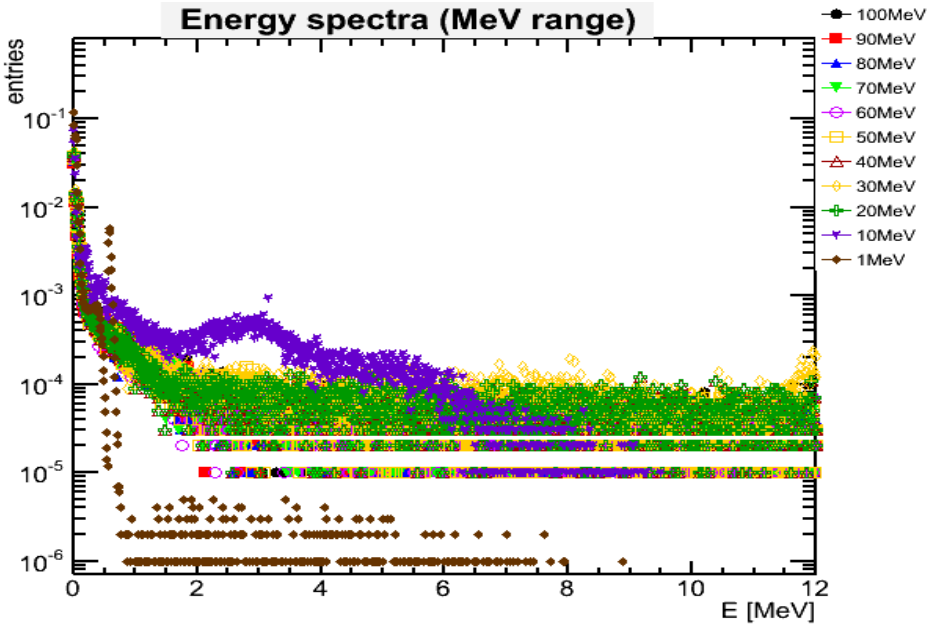
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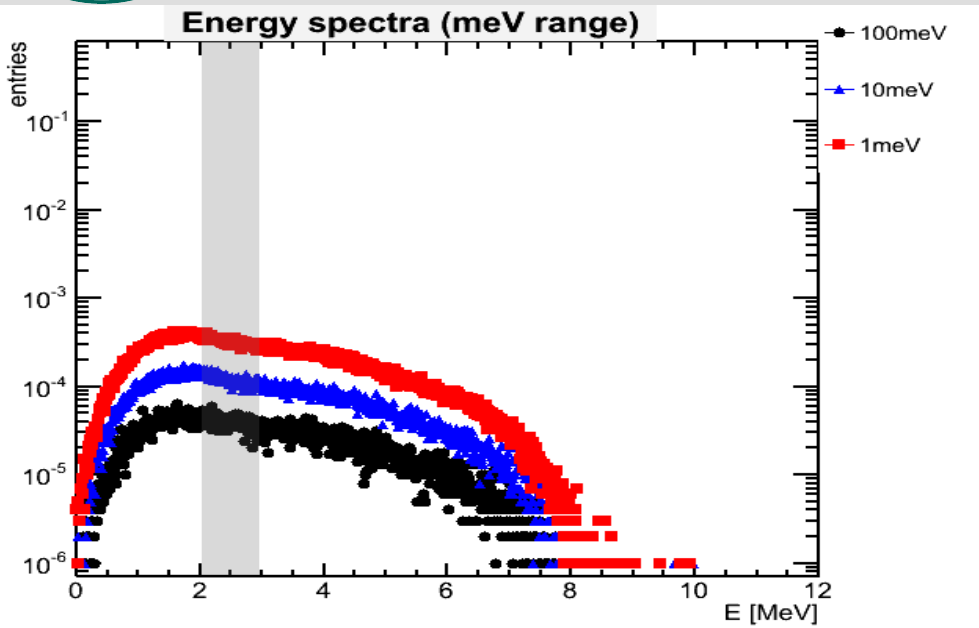
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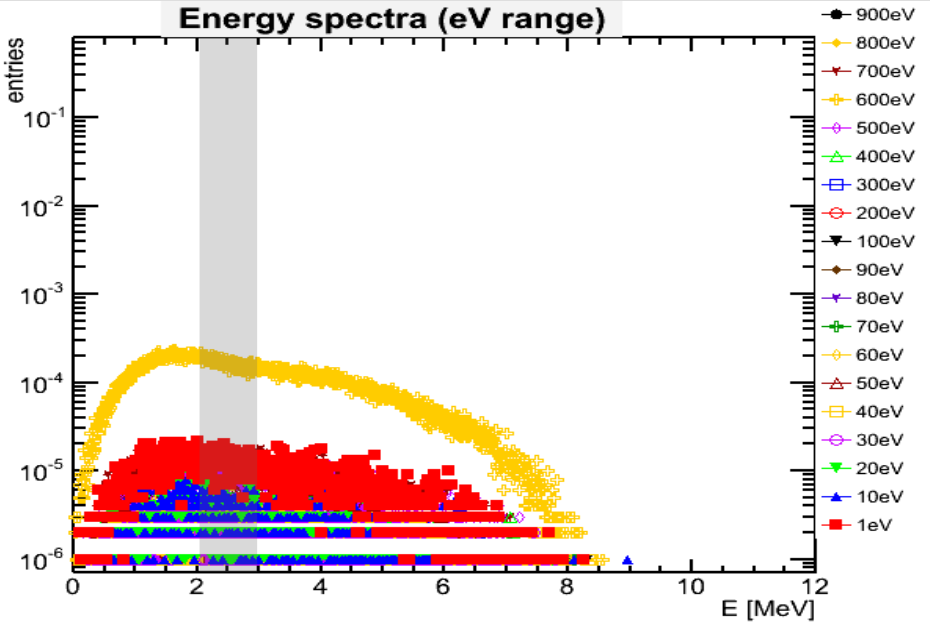
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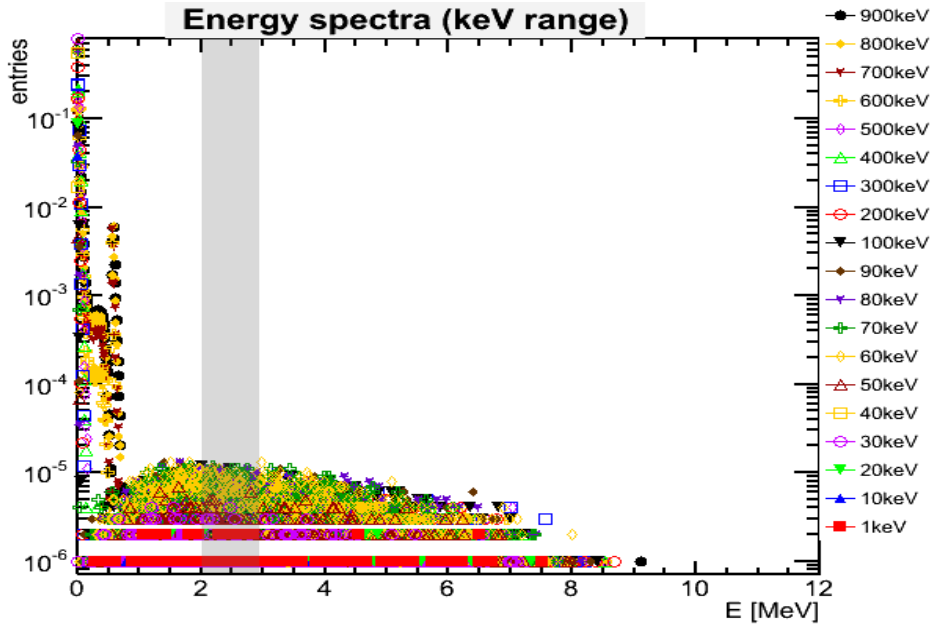
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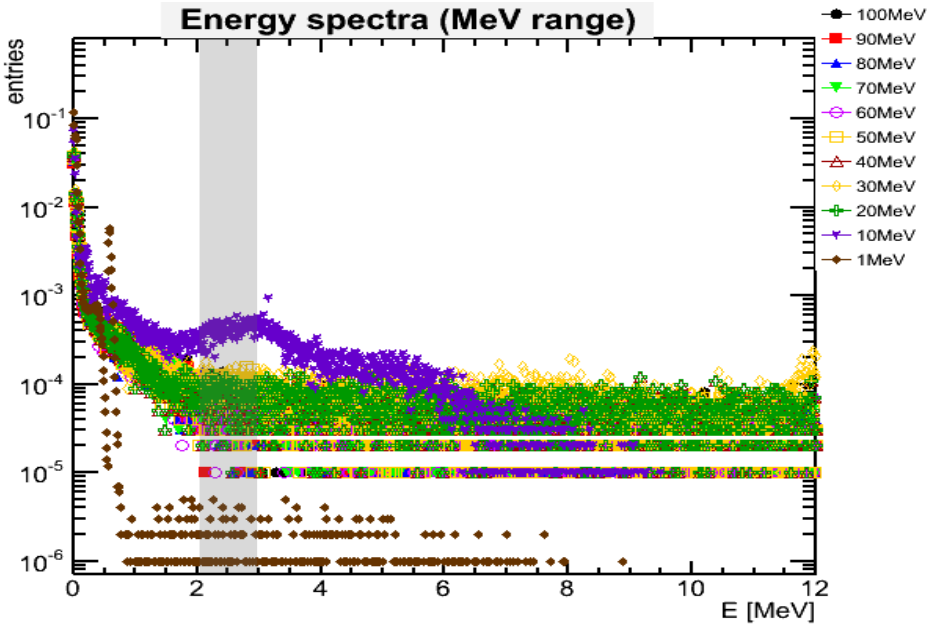
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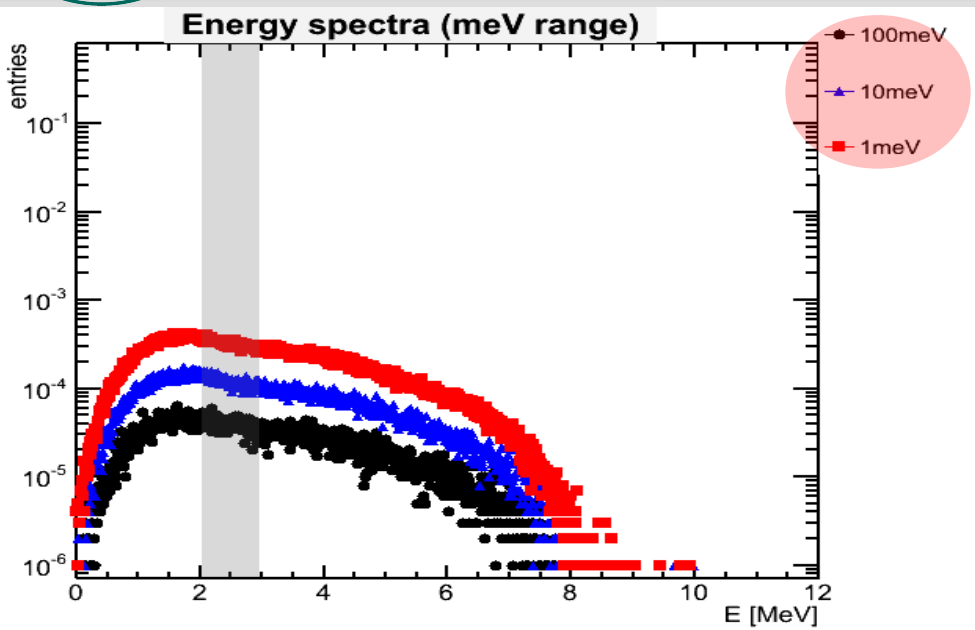
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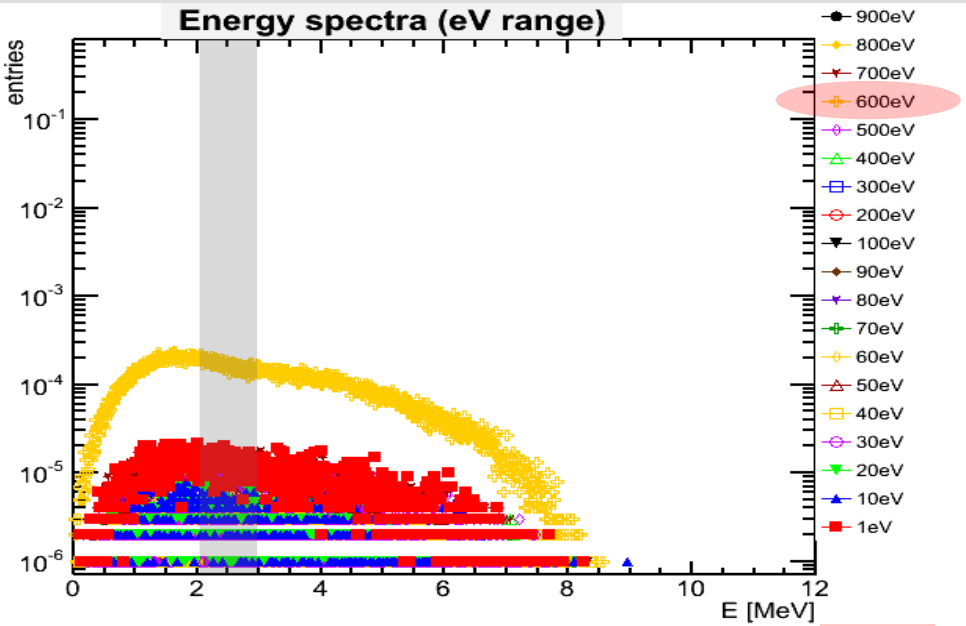
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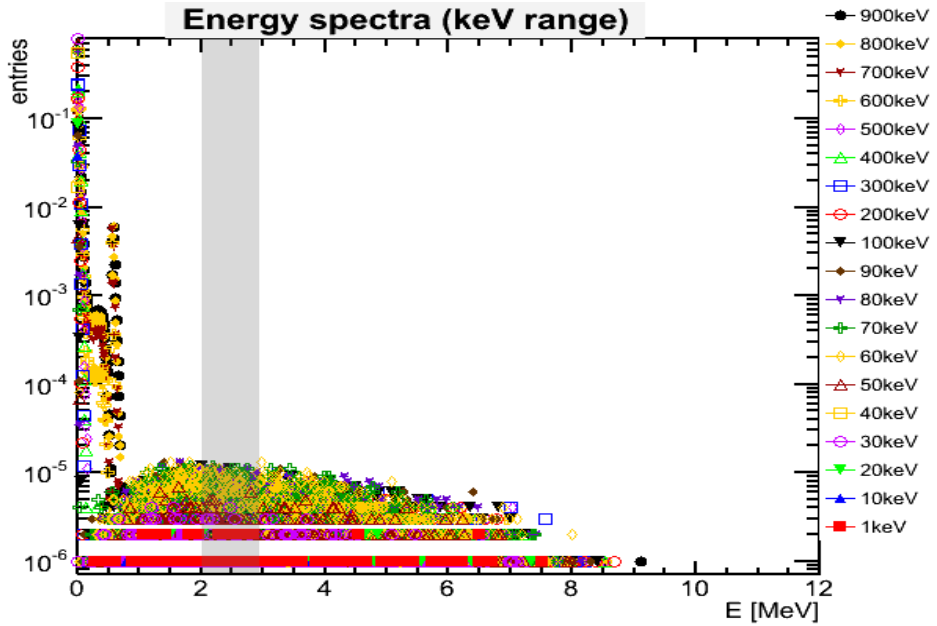
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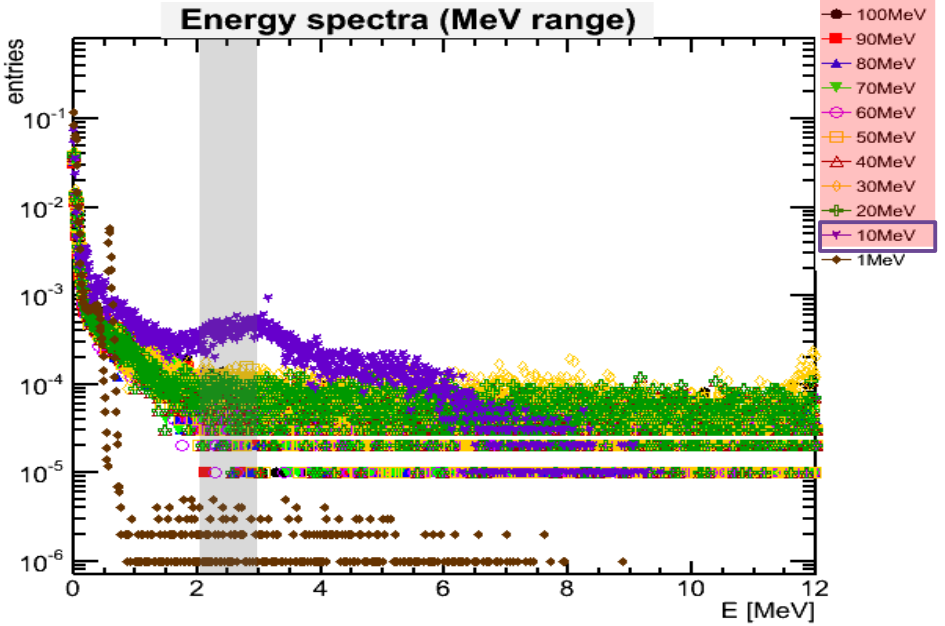
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Conclusions

In terms of background contribution due to neutrons in the ROI for **0ν2β decay** the neutron energy ranges of **meV** and **MeV (+600 eV)** are **basically the same**

BUT

we expect less neutrons in the MeV range than in the meV range

THEREFORE

It might be better to keep few MeV neutrons rather than several meV neutrons

To be kept in mind in the choice of the shielding!

Proposal: Muon-induced Neutron Flux

A neutron detector, which is able to measure the neutrons energy, can be used to:

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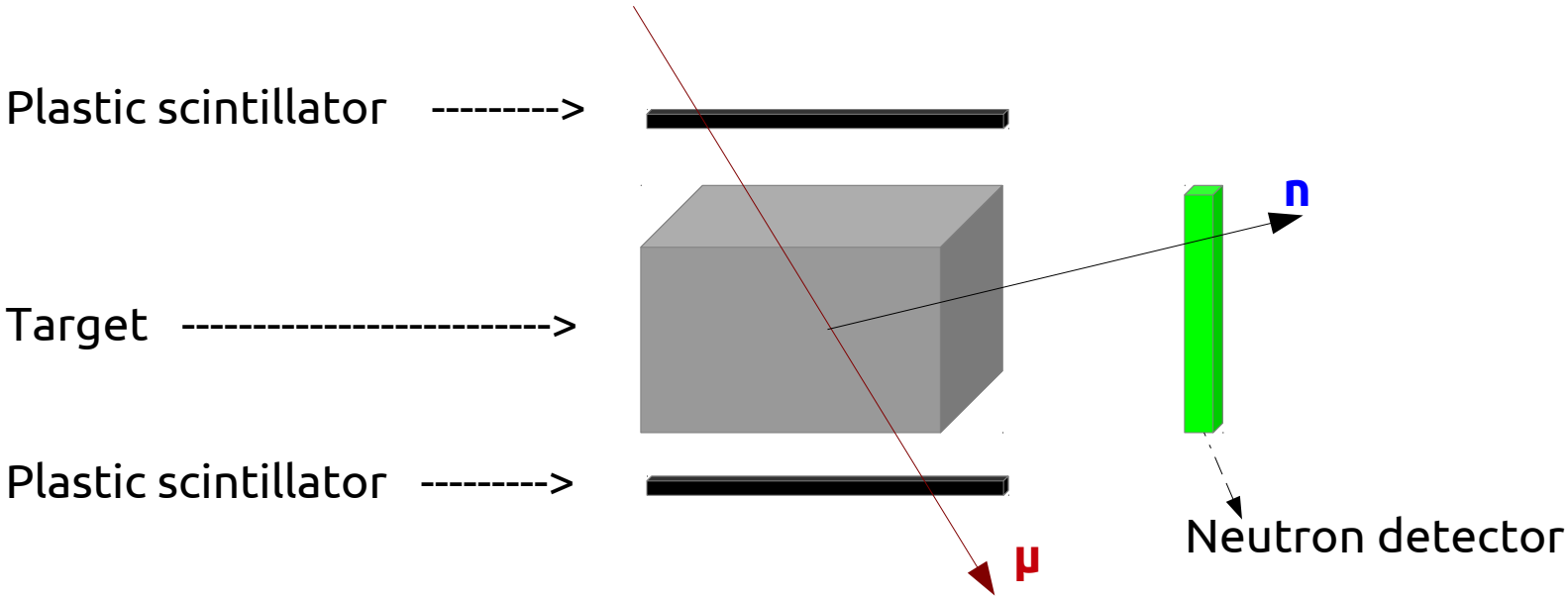

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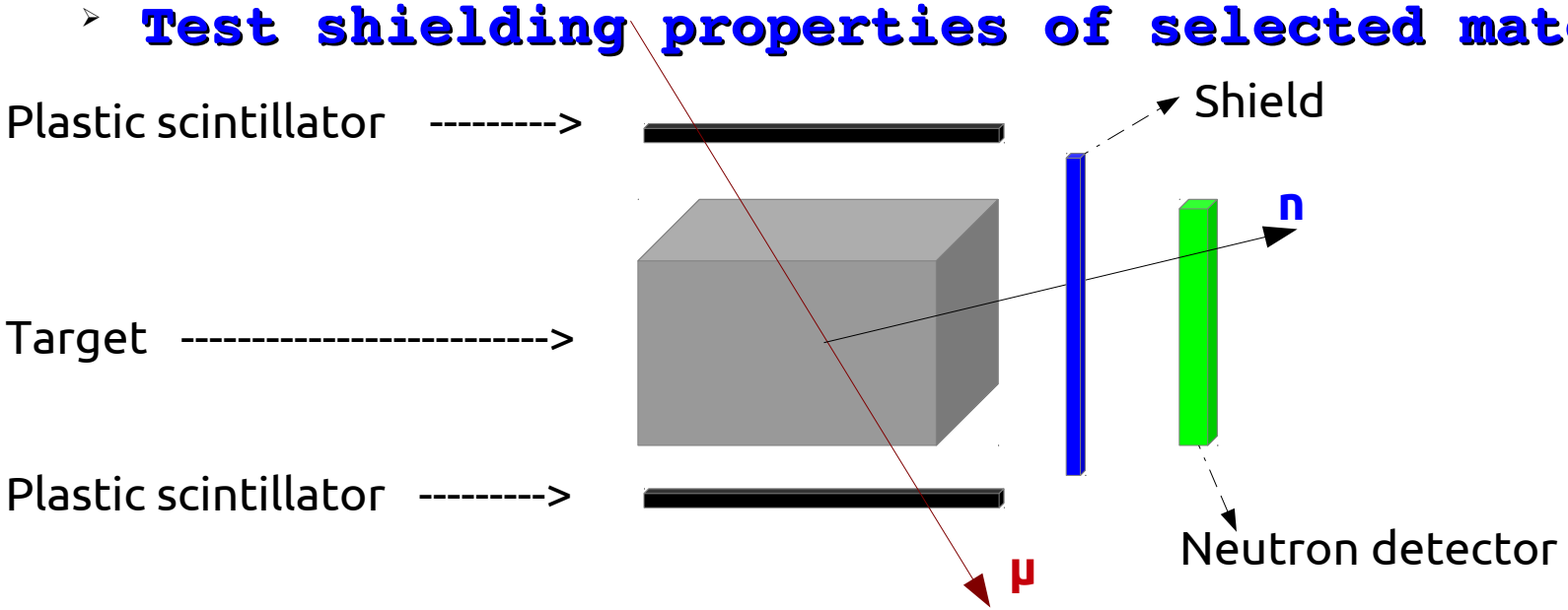
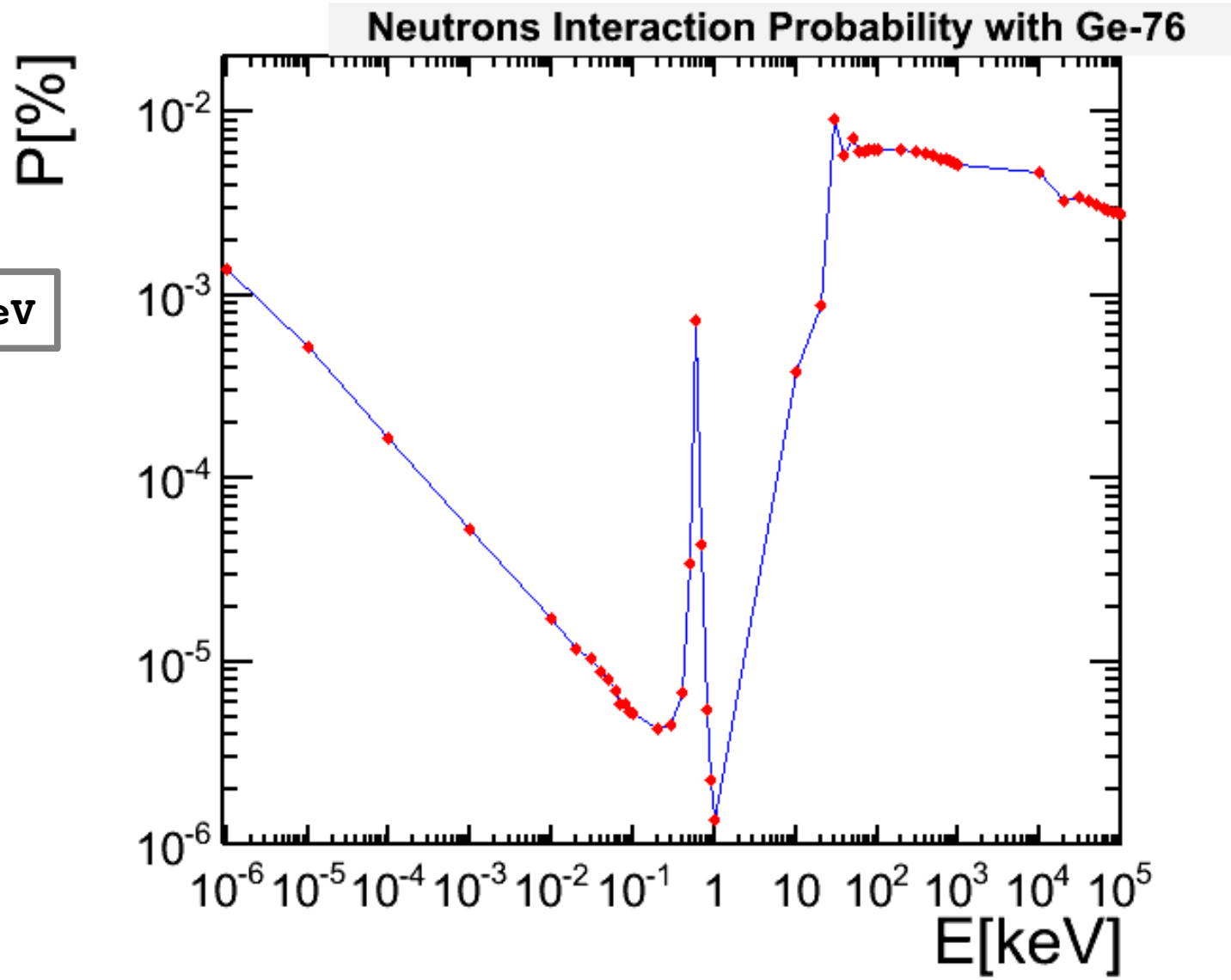
- **Test shielding properties of selected materials**




Thank You for The Attention!

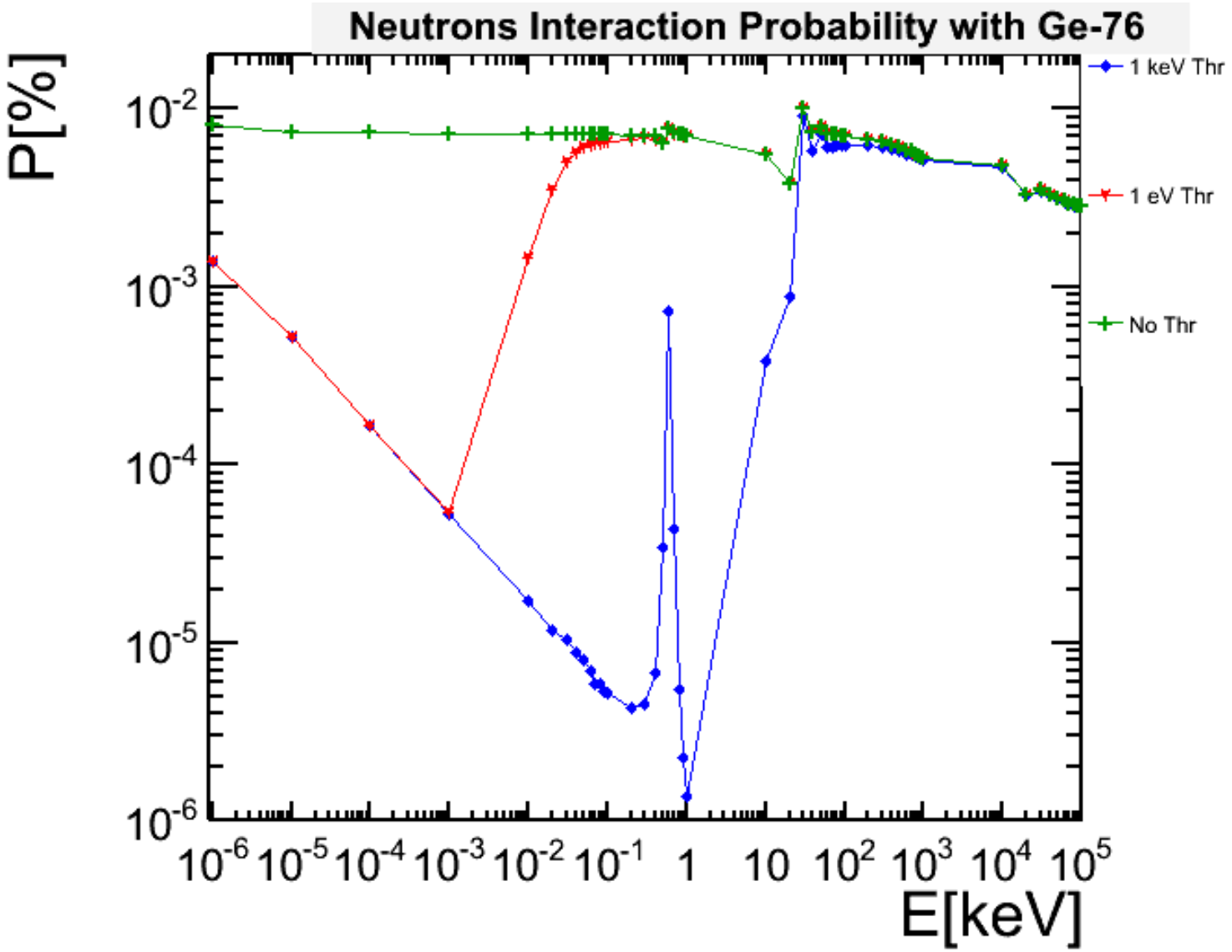
Backup

Neutrons Interaction Probability

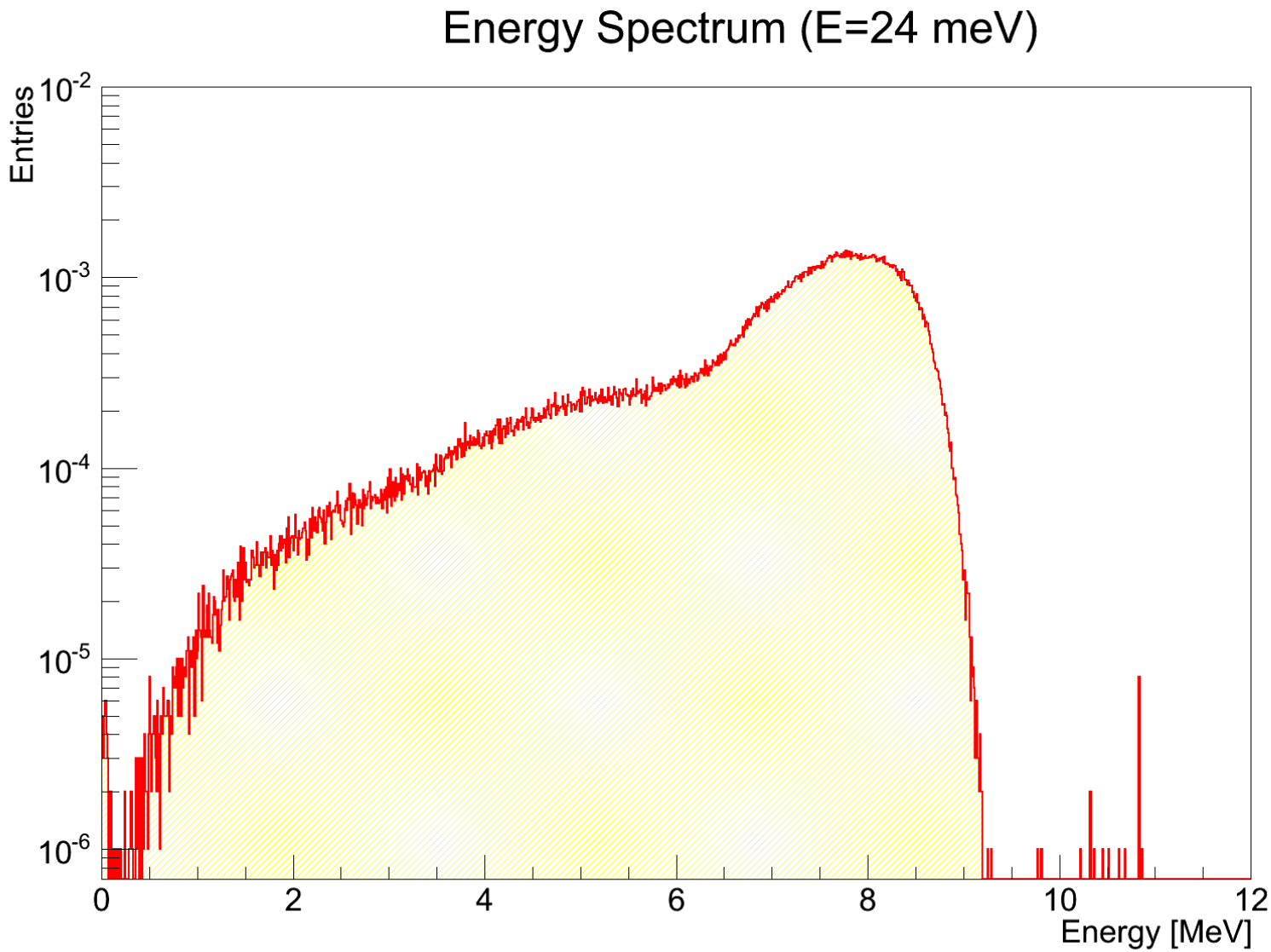


Thr @ 1 keV

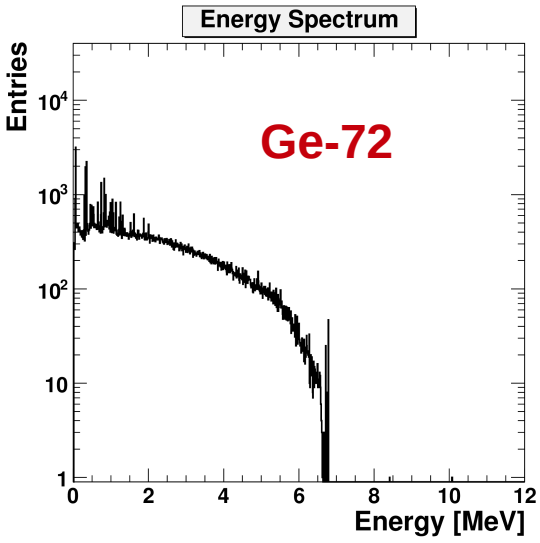
Neutrons Interaction Probability

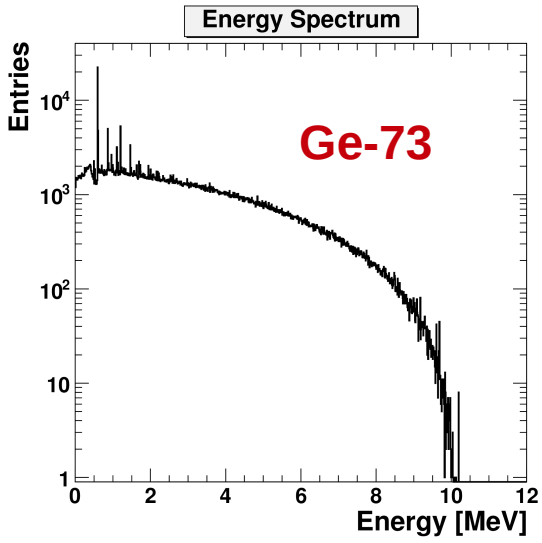


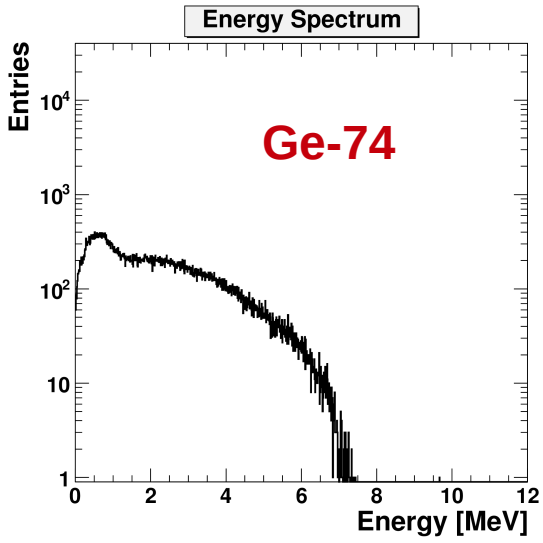
Energy Spectrum for 50x50x50 cm^3 Ge-76 Crystal

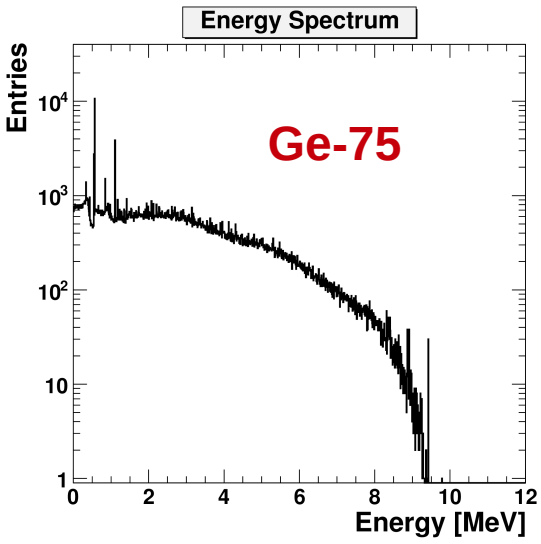


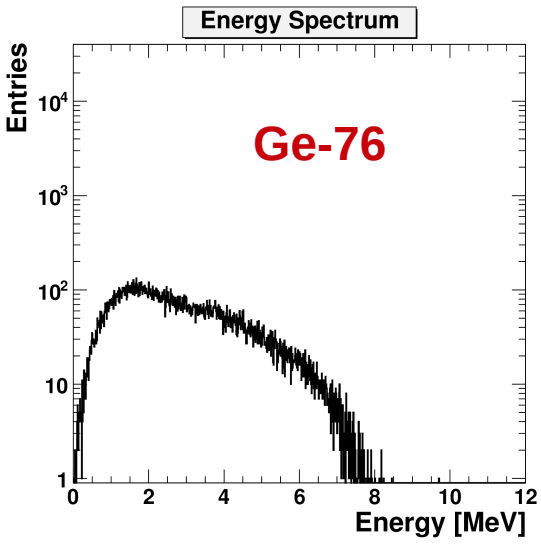
Thermal Neutrons in Ge





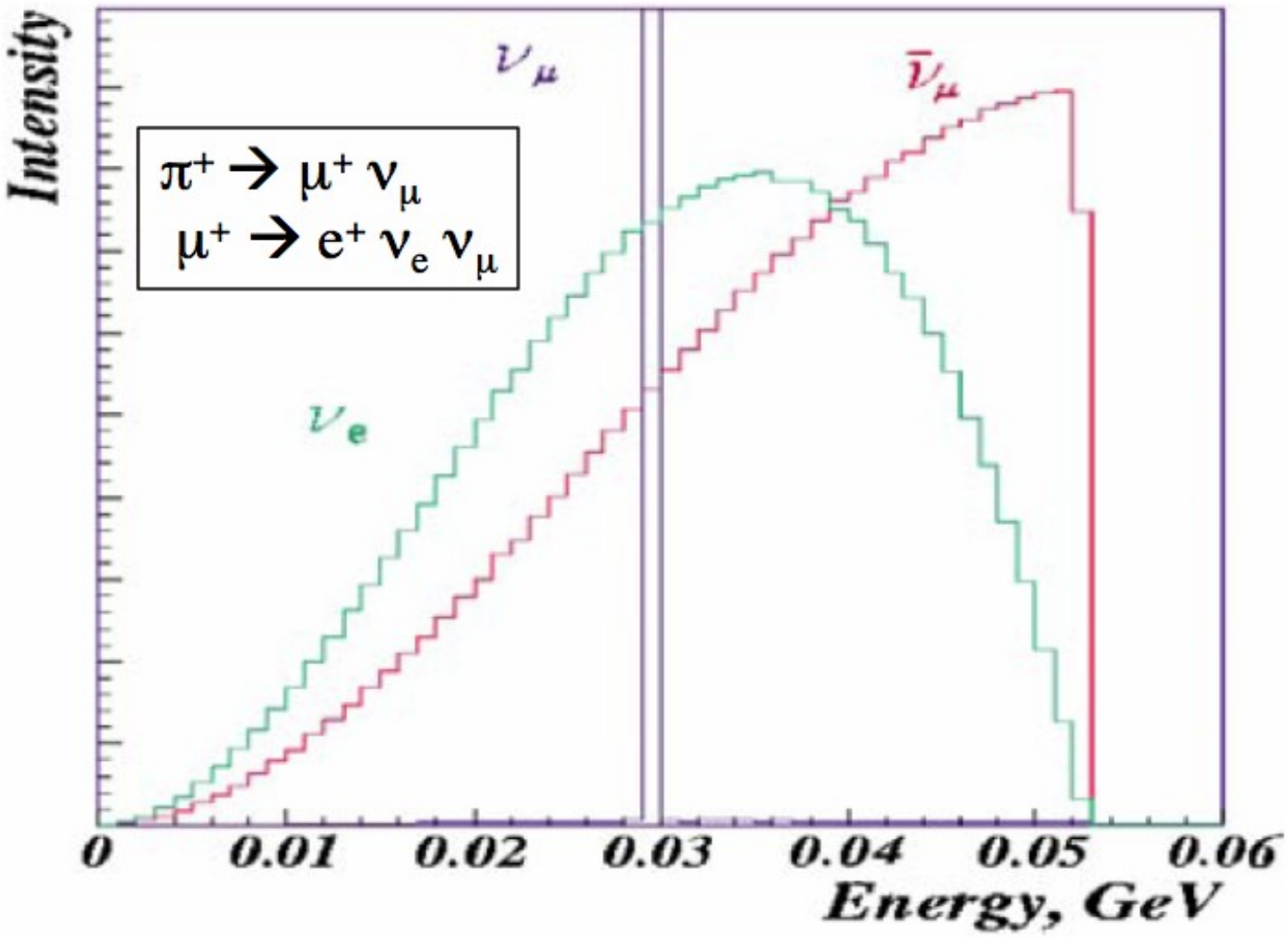






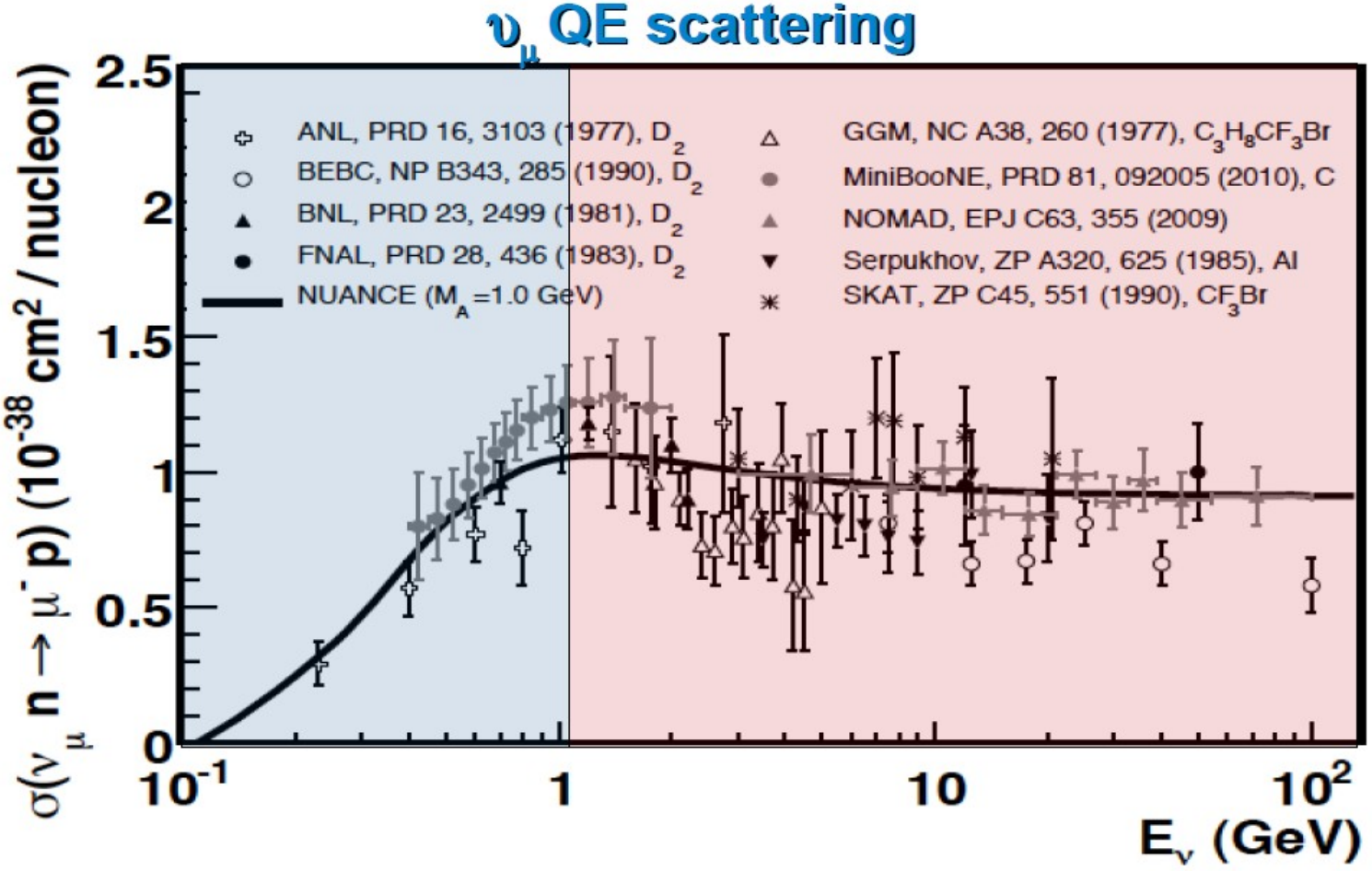
Courtesy of B. Doenmez, MPP Muenchen: 5x5x5 cm^3, E=0.024 eV, 1 million neutrons

Neutrino Spectra from DAR



J.R. Alonso, High Power, High Energy Cyclotrons for Decay-At-Rest Neutrino Sources: The DAEδALUS Project, DPF-2011 Conference

Nu-nucleus Cross Section

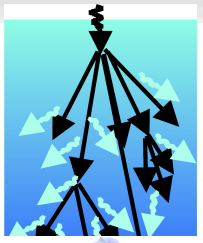


- **linear rising** for **E < 1 GeV** but **damped** for **E > 1 GeV** ← form factors
- even more modern experiment have **flux normalization uncertainty:**
  - **NOMAD** and **MiniBooNE** curves: **30% difference on normalization**

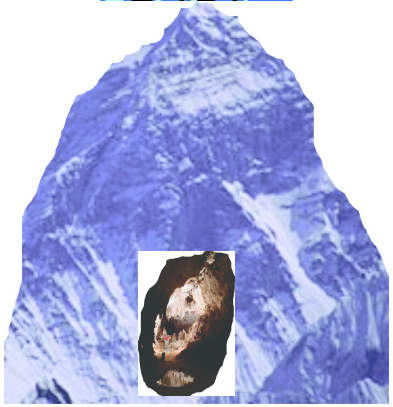
Private communication: J. Formaggio to be published in Rev. Mod. Phys. (2012)

The Problem

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

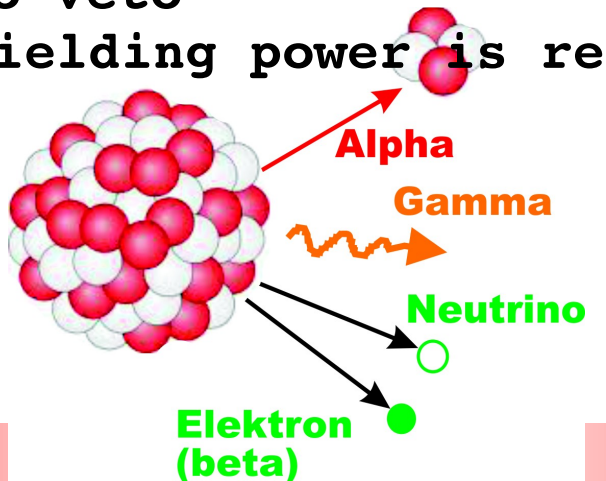


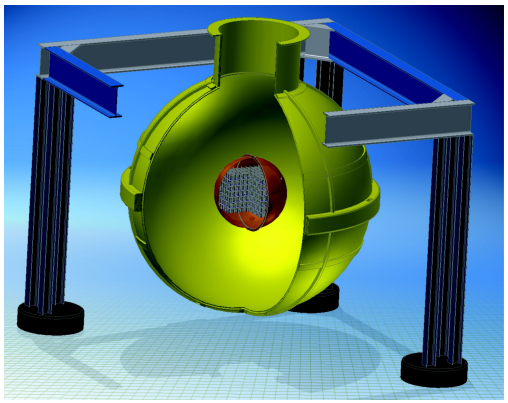
- To enhance the expected counting rate:
  - Increase the mass → **1 Ton experiments**
  - Increase the S/N ratio → **Move underground**



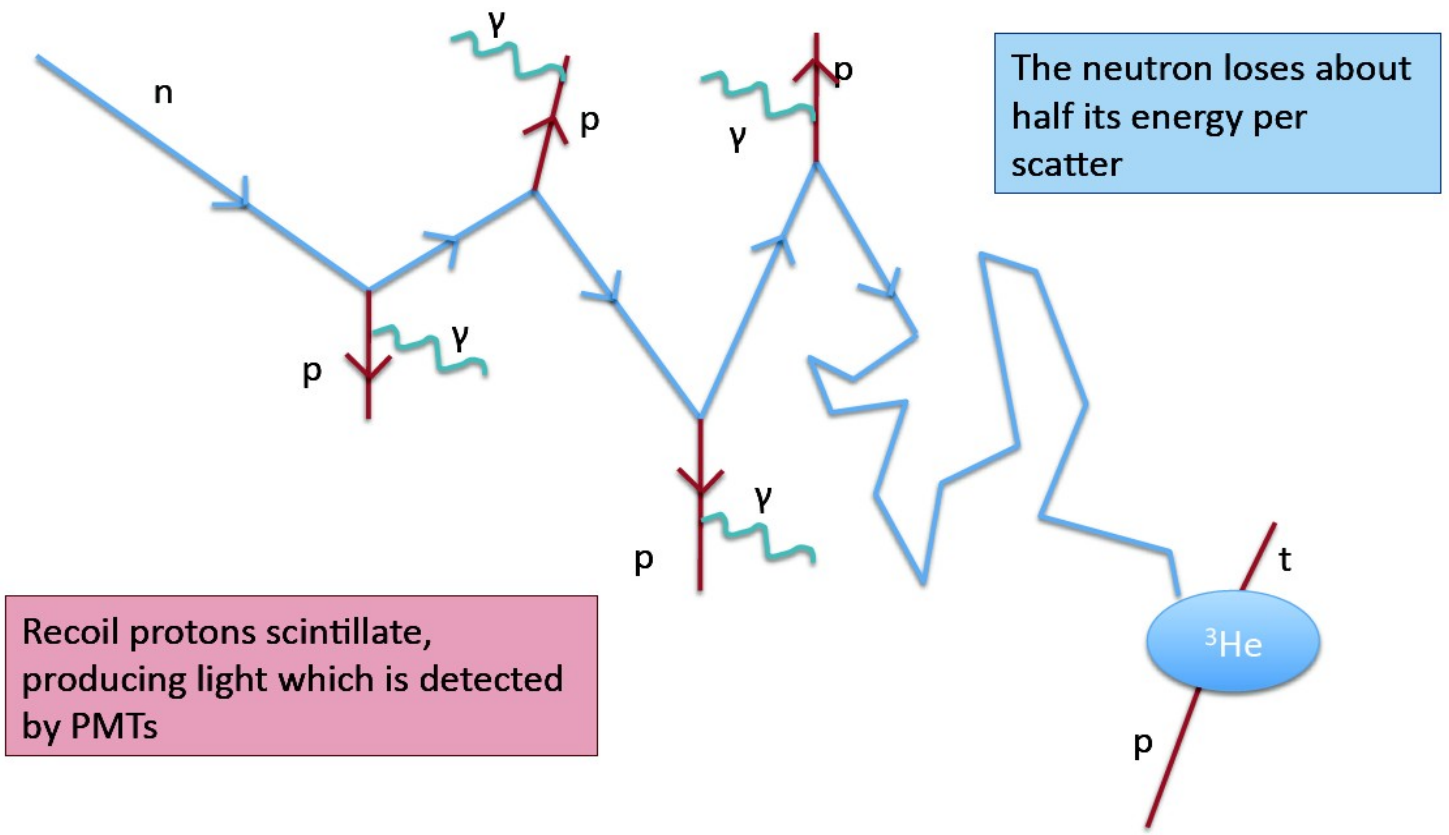
- Also an **effective shielding** is needed against:
  - Environmental Natural Radioactivity
  - **CR-induced shower** (basically muon and neutrino-induced)

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



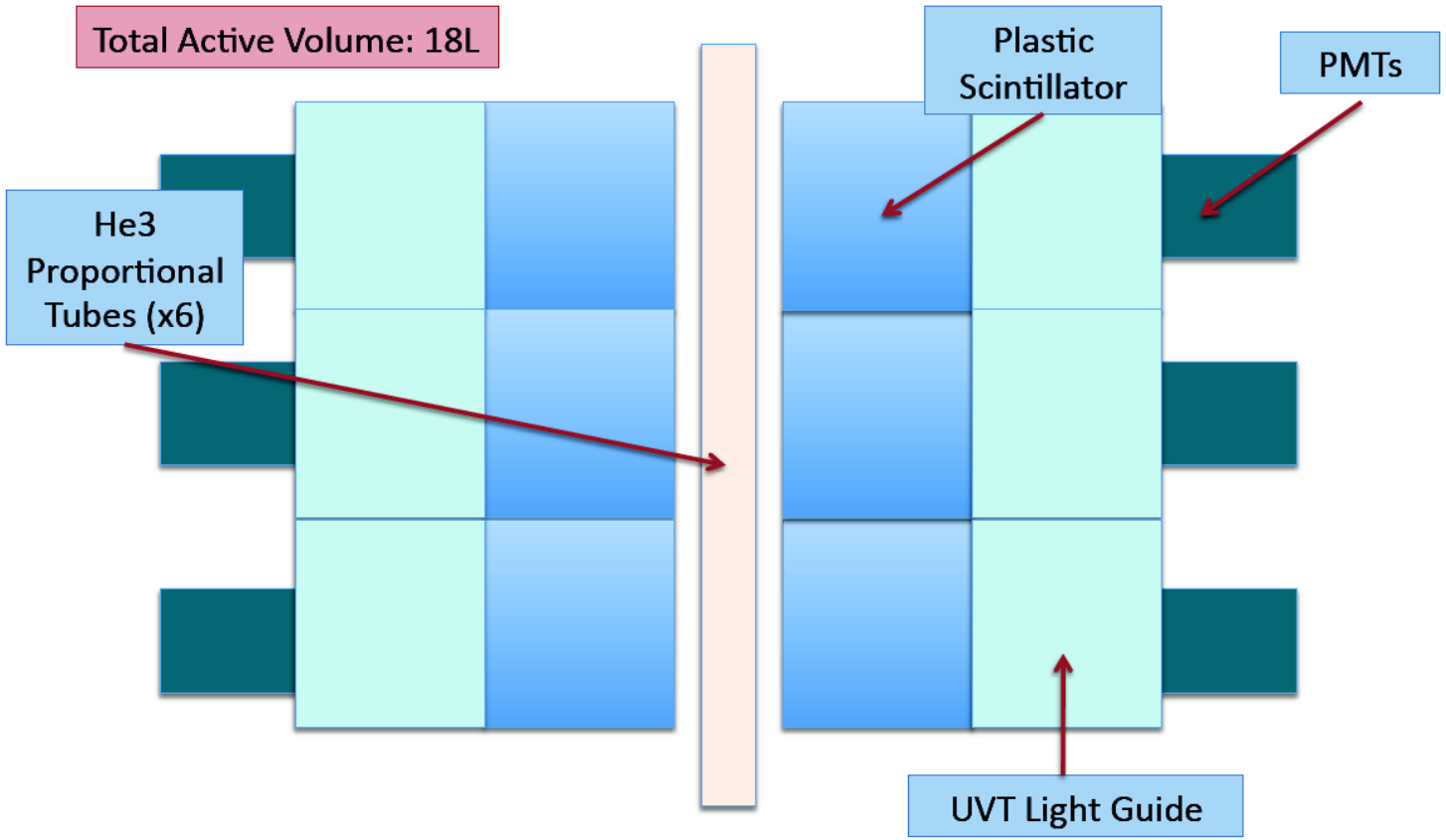


Neutron detection principle

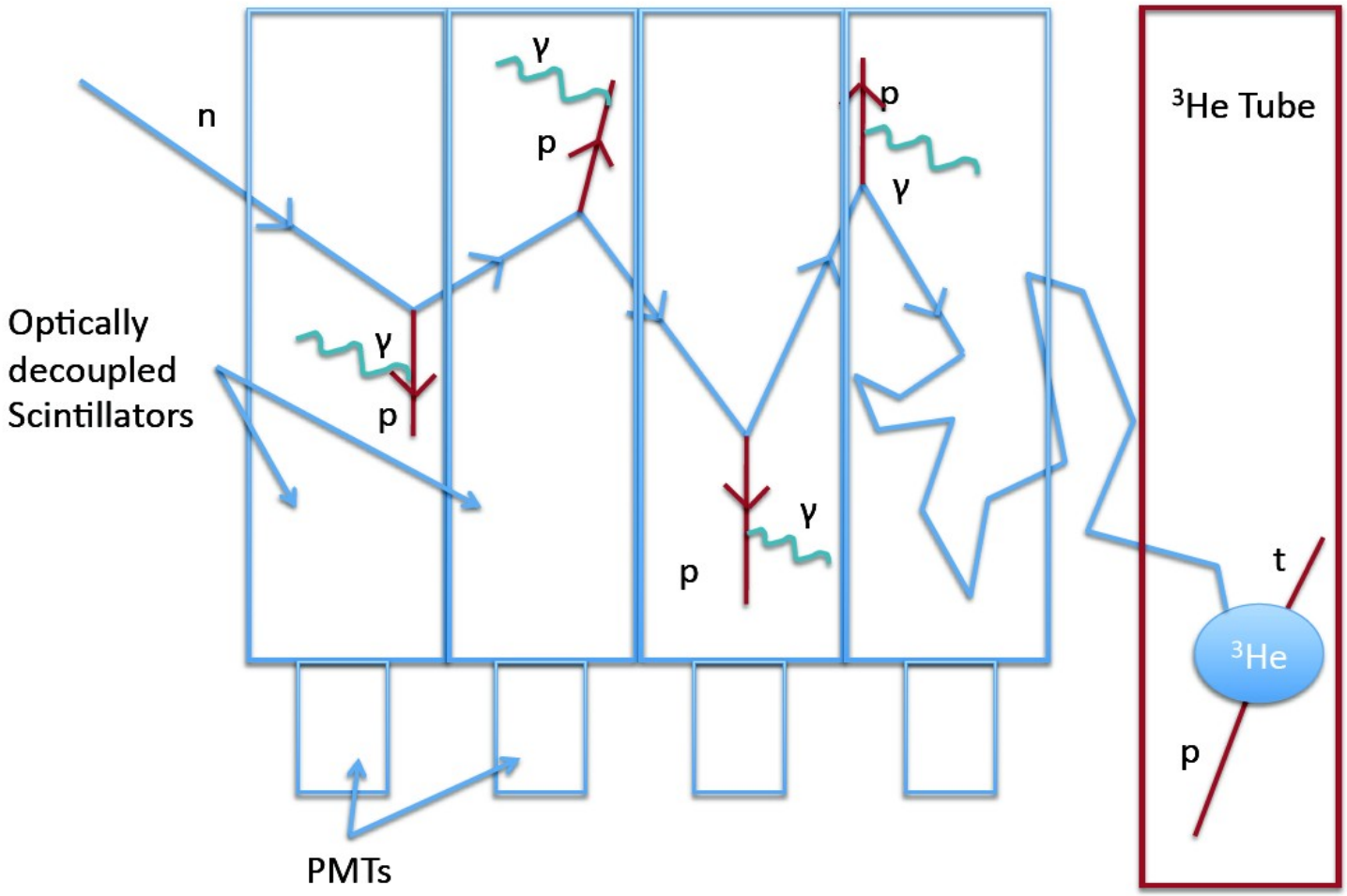


Neutron detector

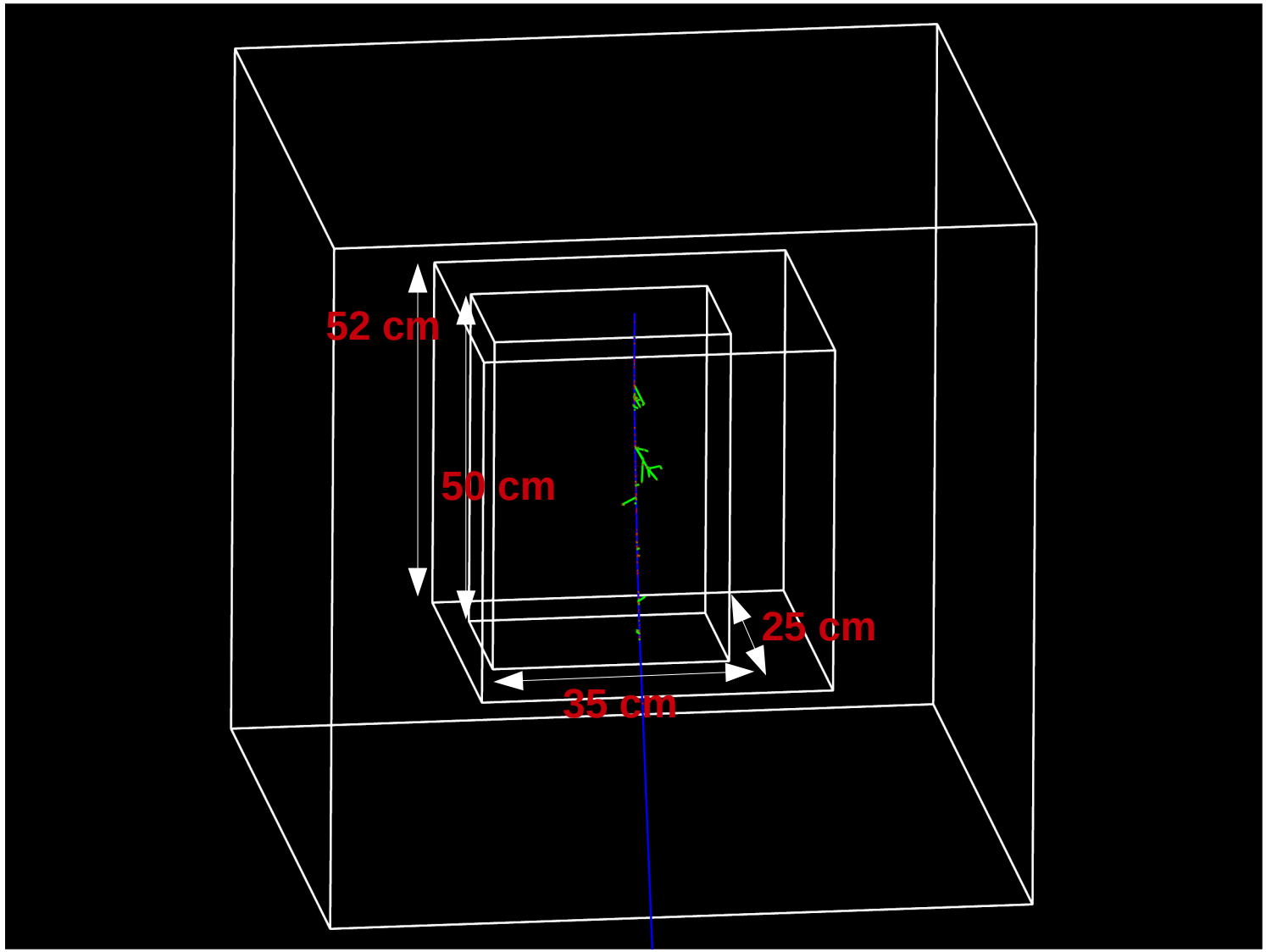
The UMD-NIST Fast Neutron Spectrometer

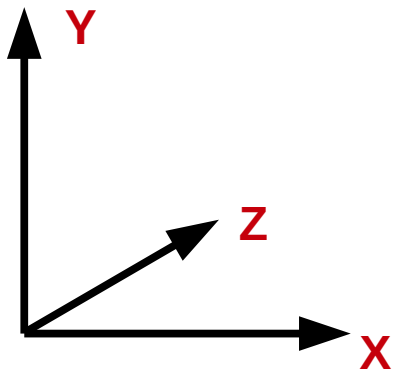


Segmentation

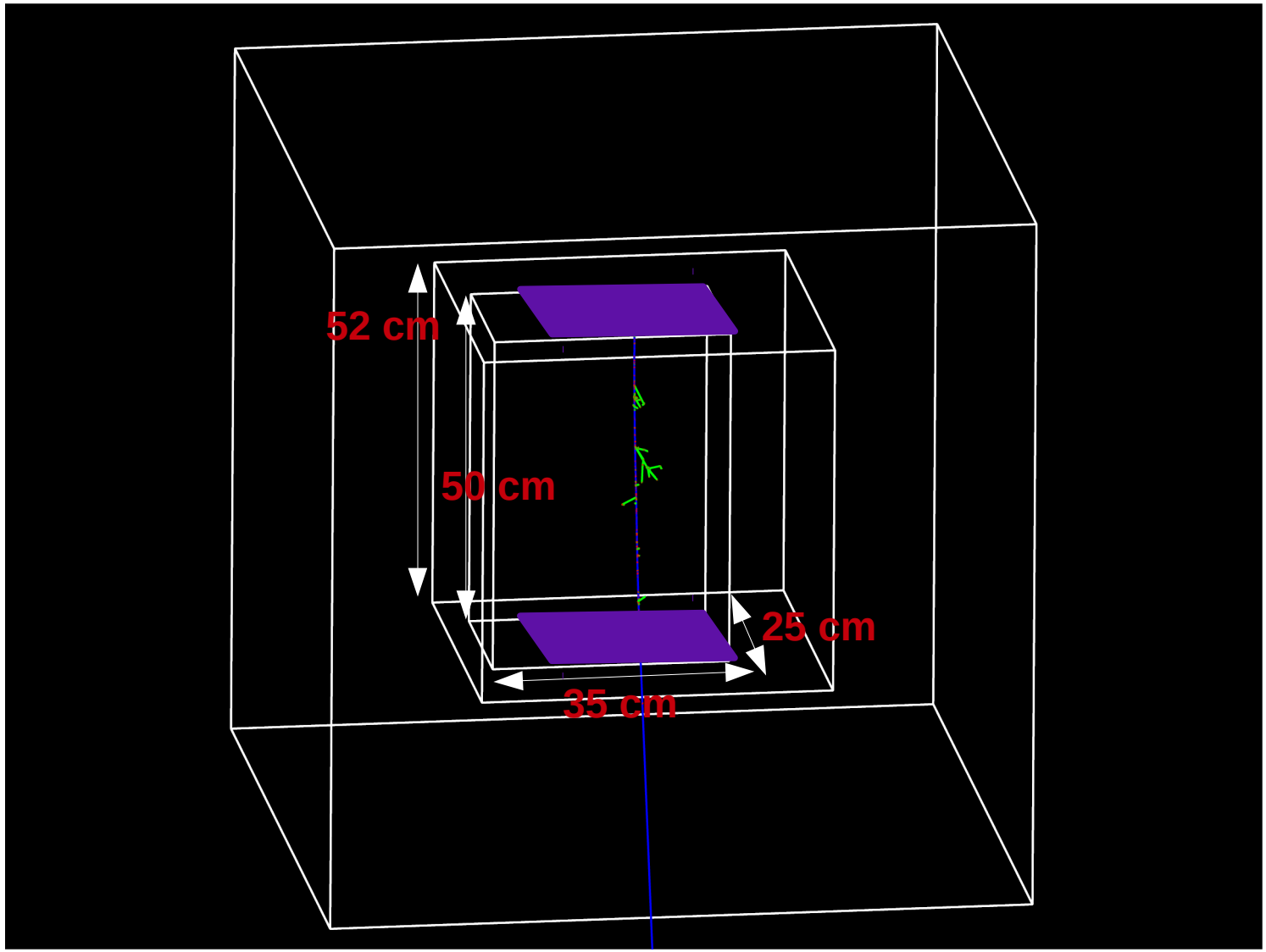


Geometry

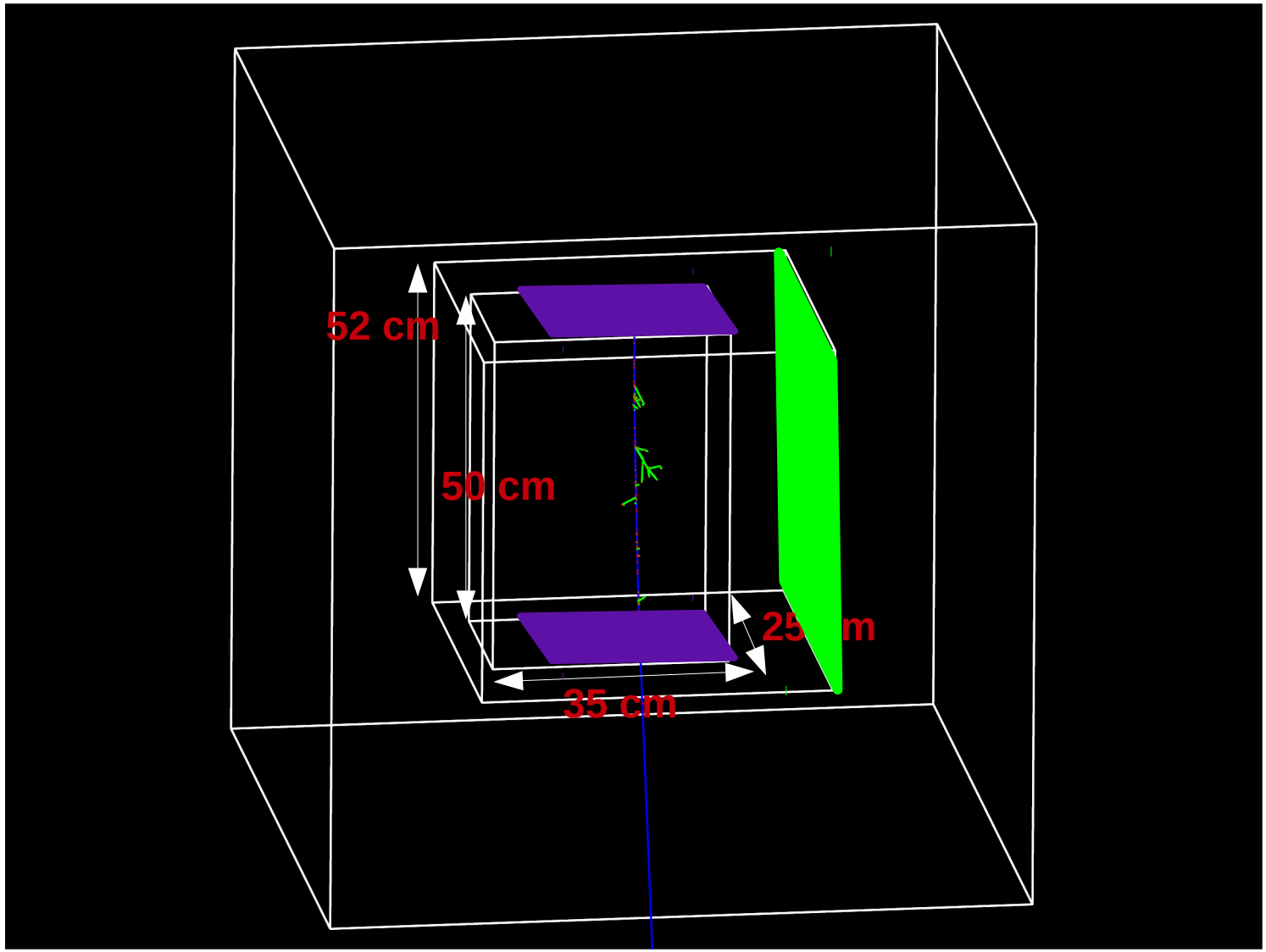




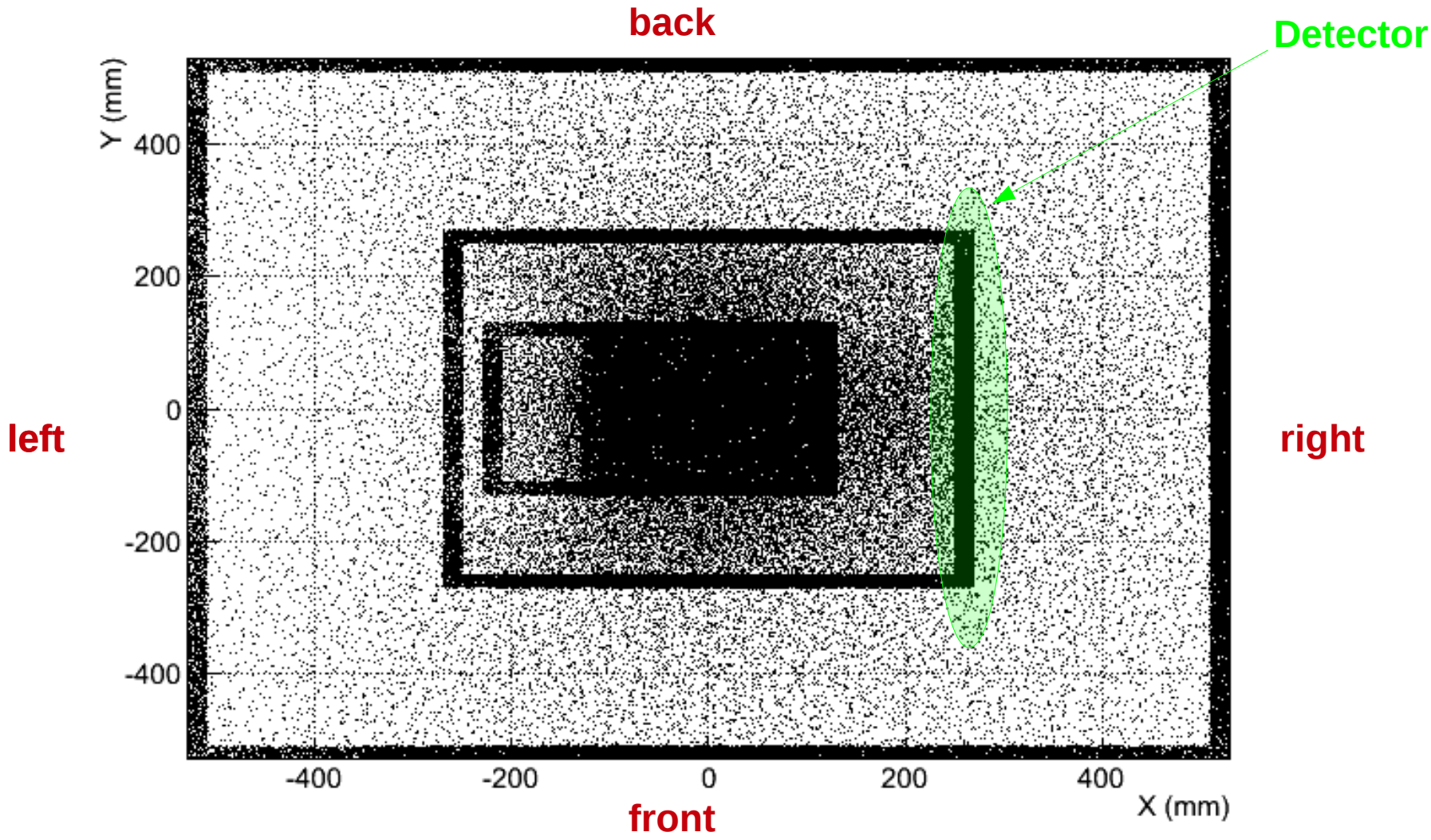
Geometry



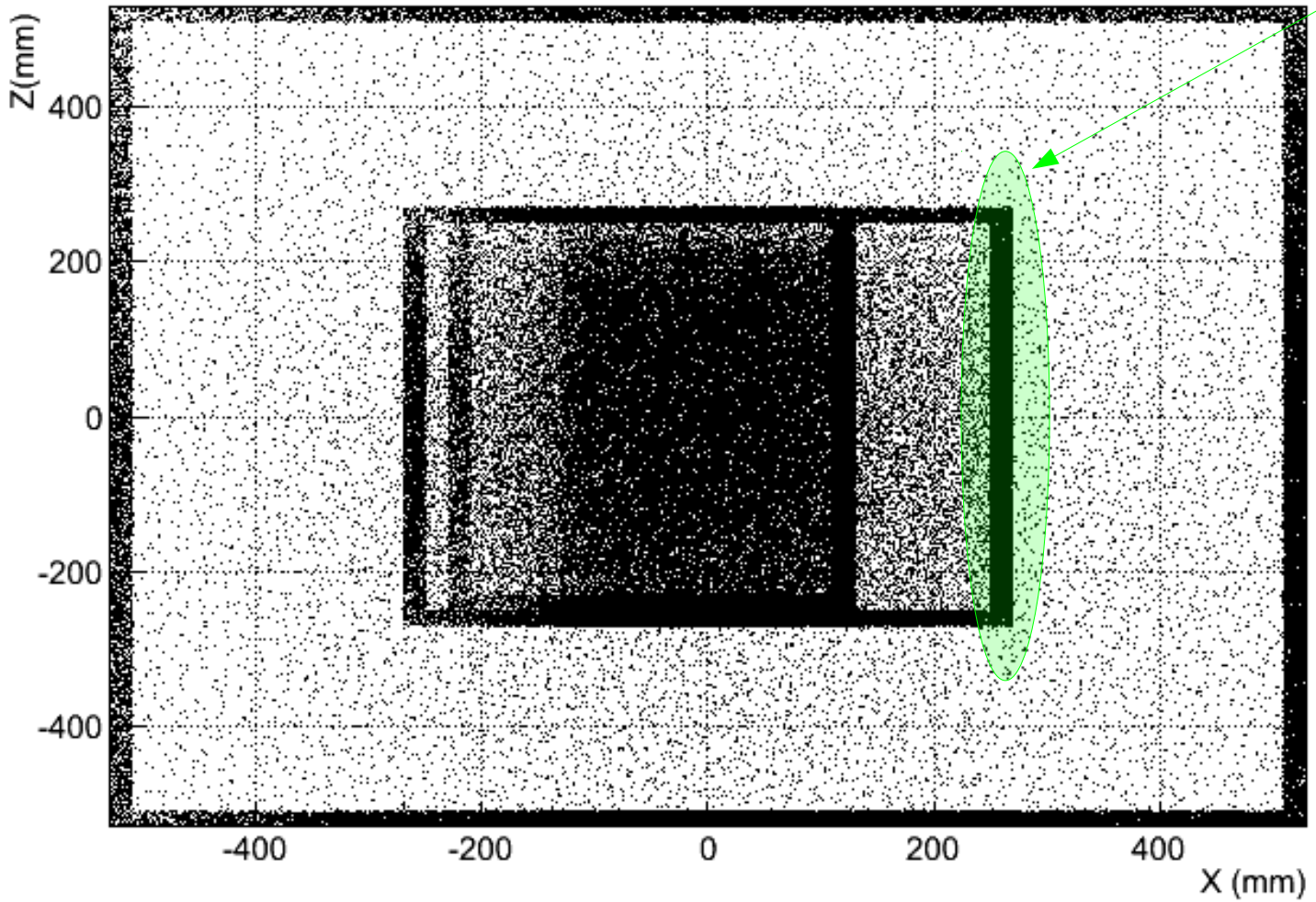
Geometry



Top view


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

Side view

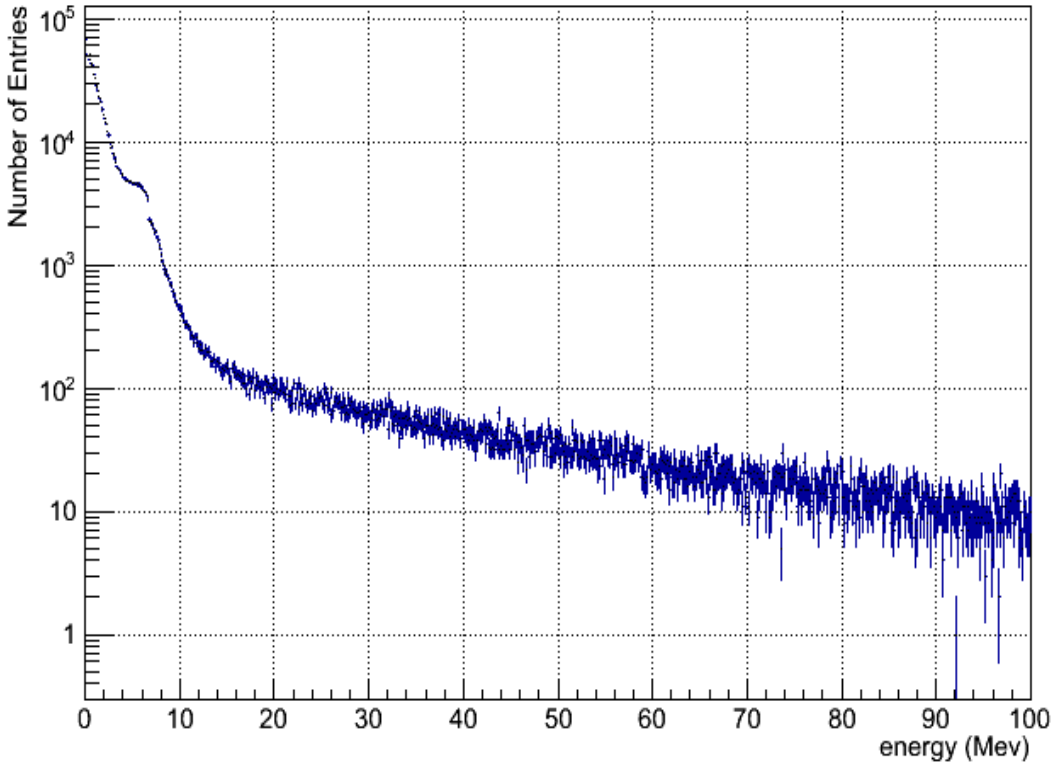


left

right

Some Results & Predictions

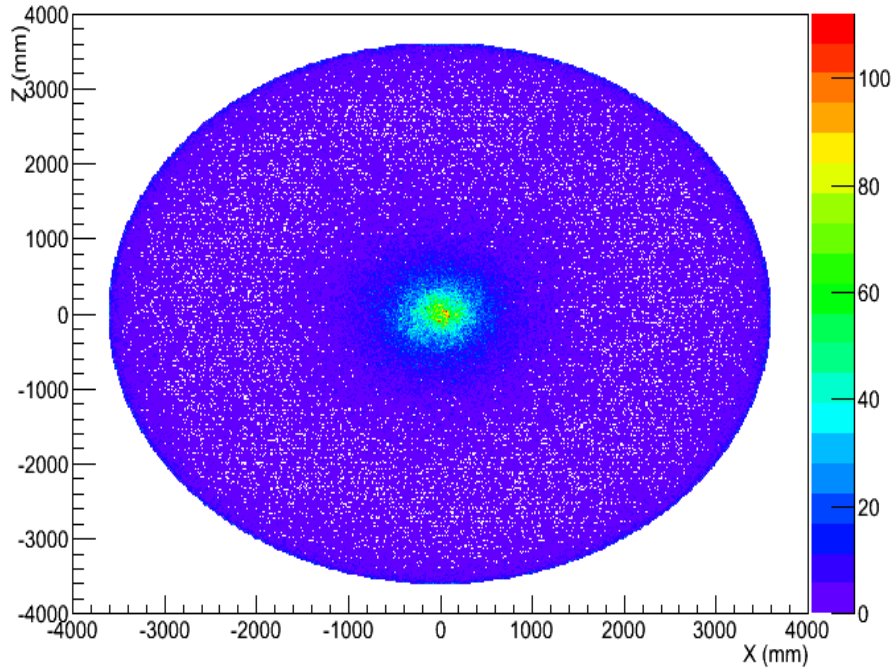
Neutron spectrum @ the detector surface



- 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

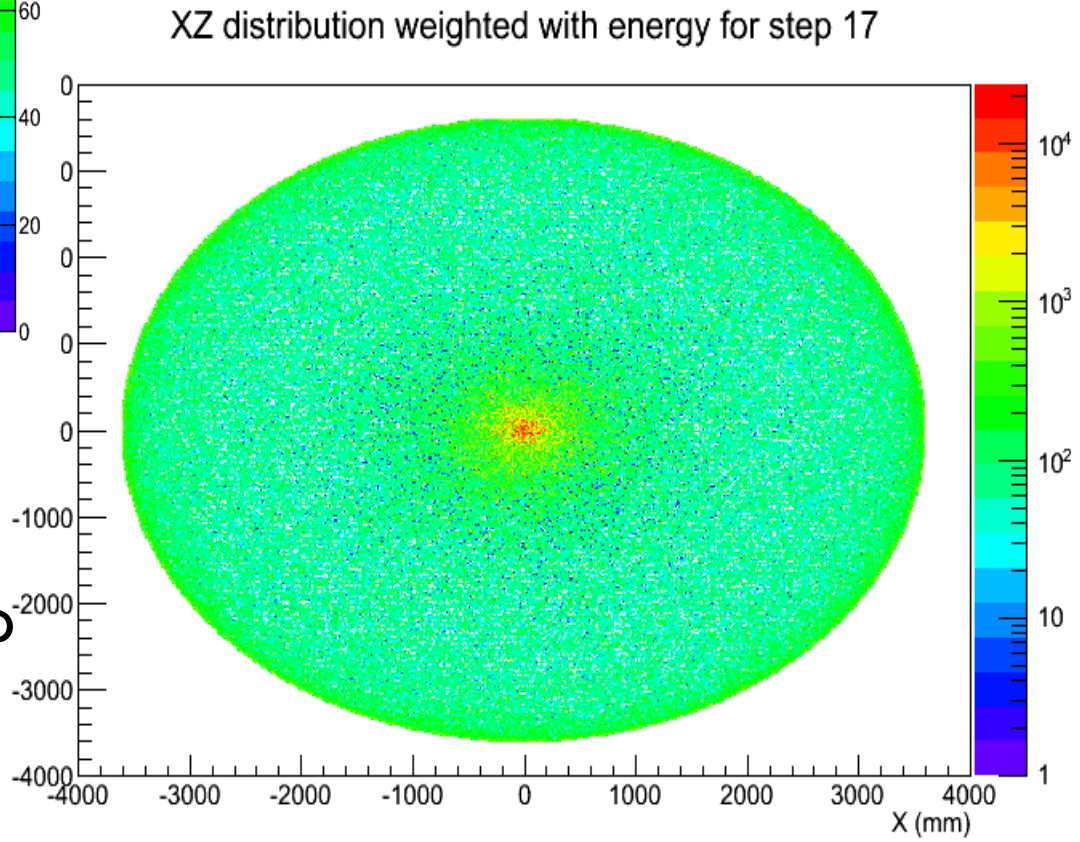
Possible idea to enhance the rate: having a bigger trigger surface

Position Weighted with Kinetic Energy

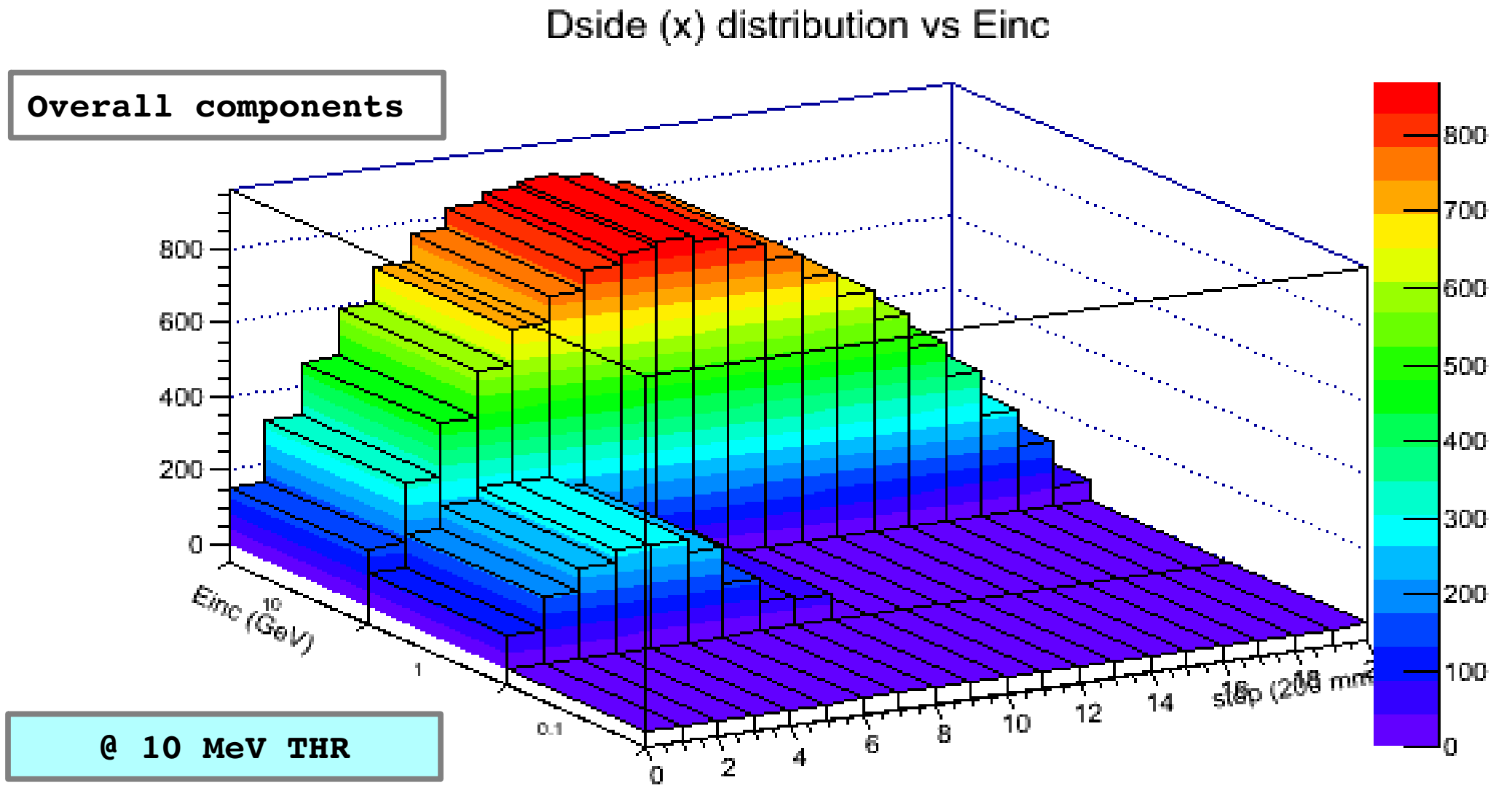


- XZ particle distribution for a particular step

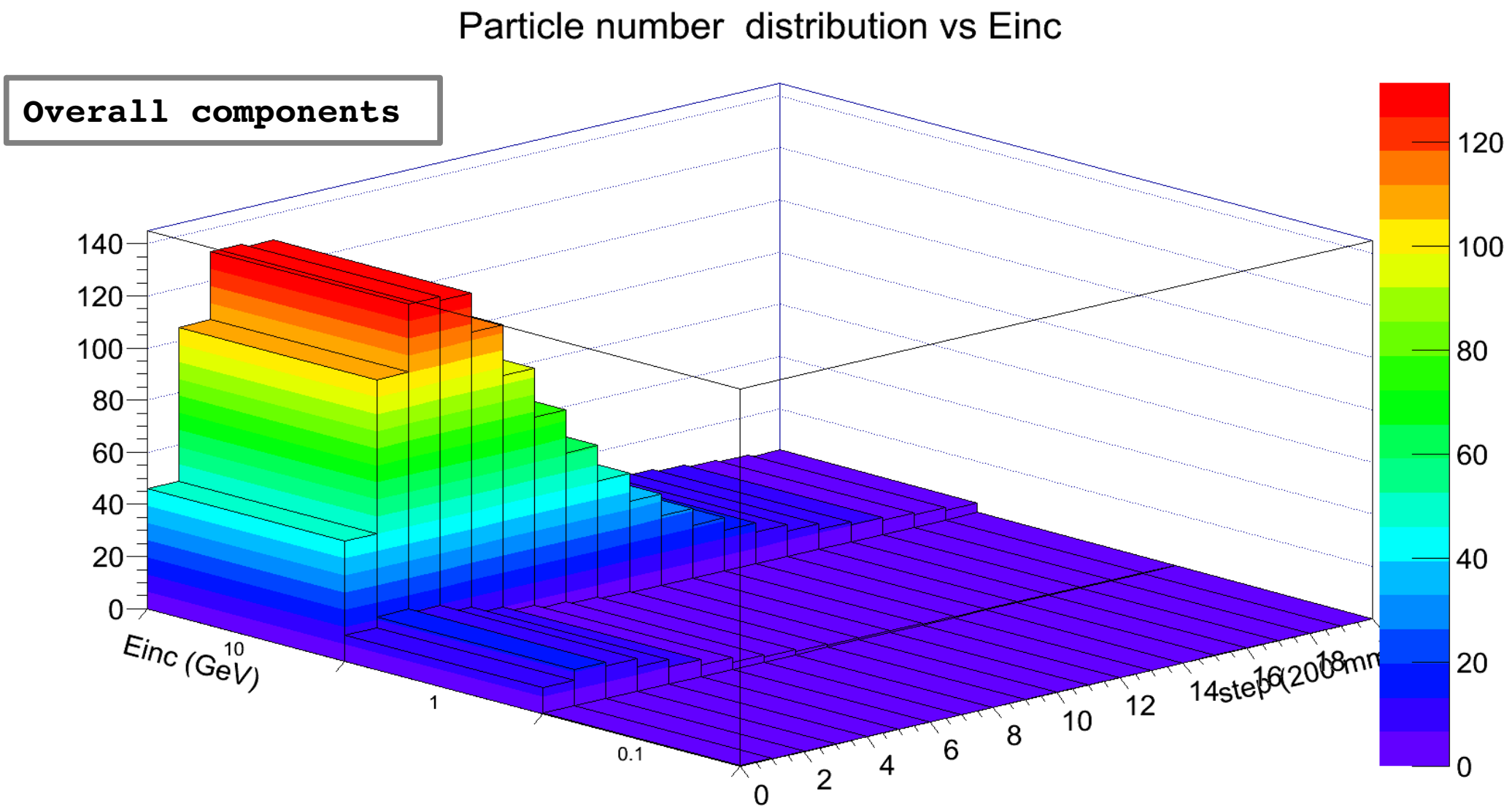
- XZ distribution WEIGHTED with Kinetic Energy



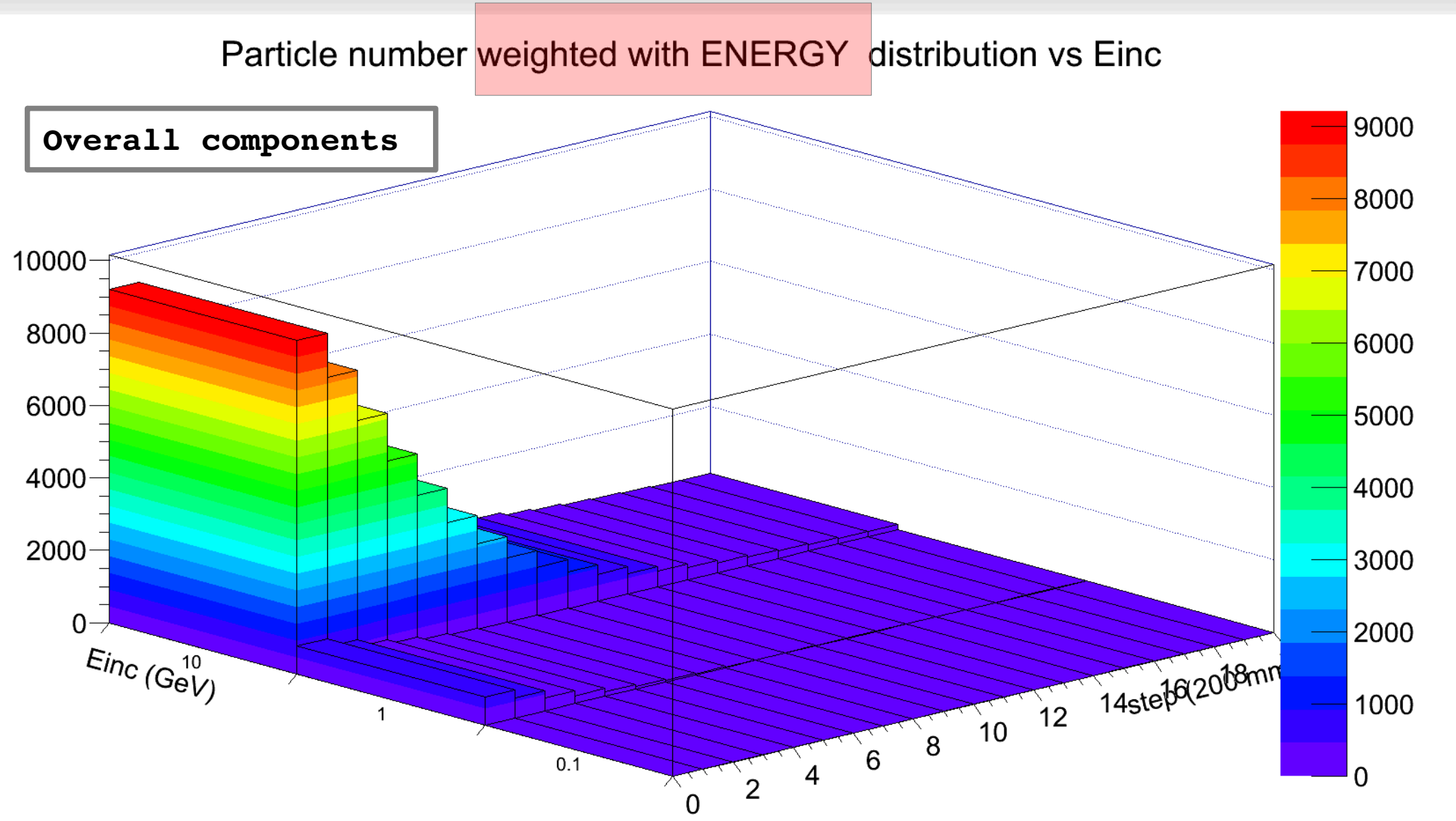
Horizontal Distance (3)



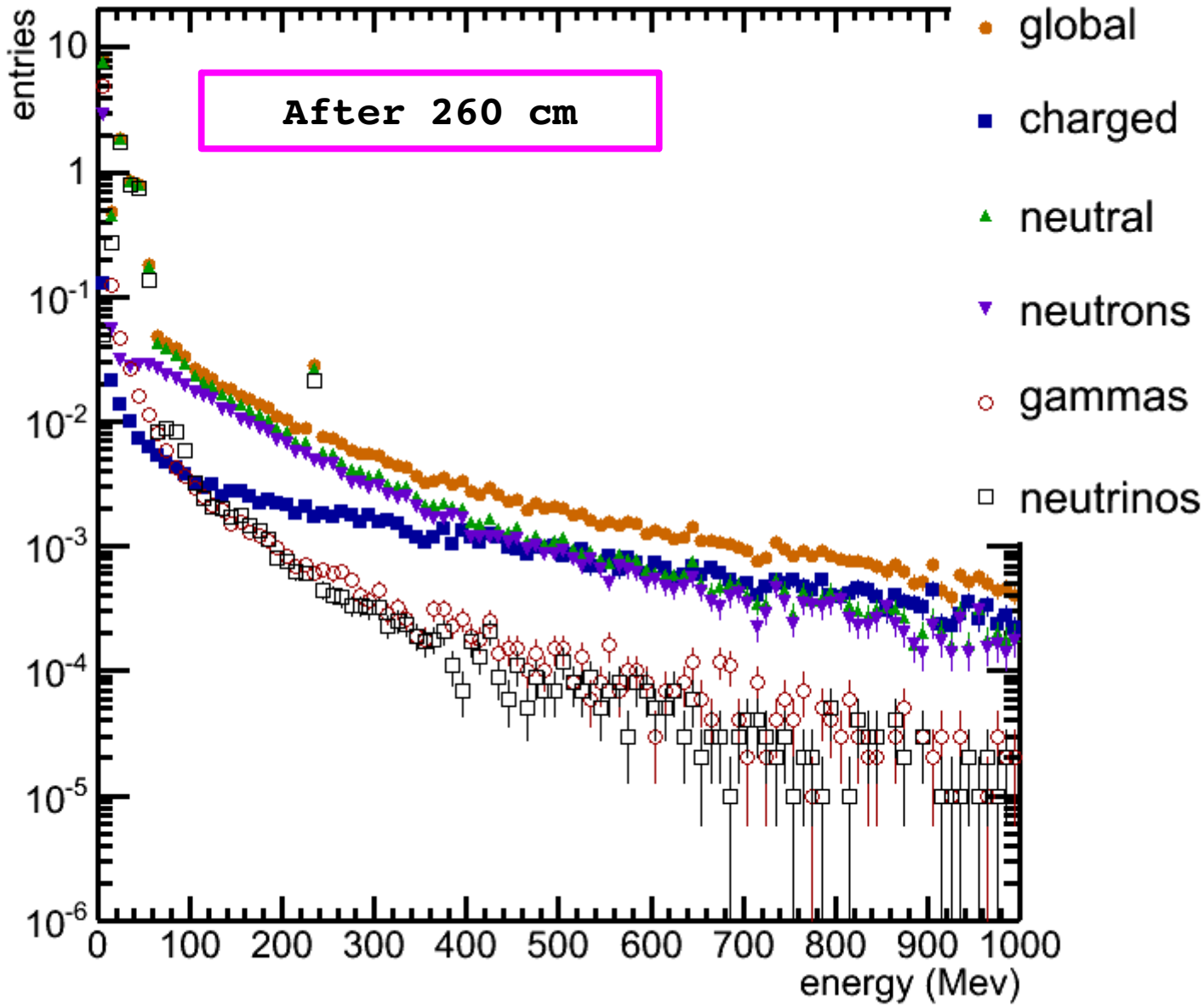
Global Results (1)



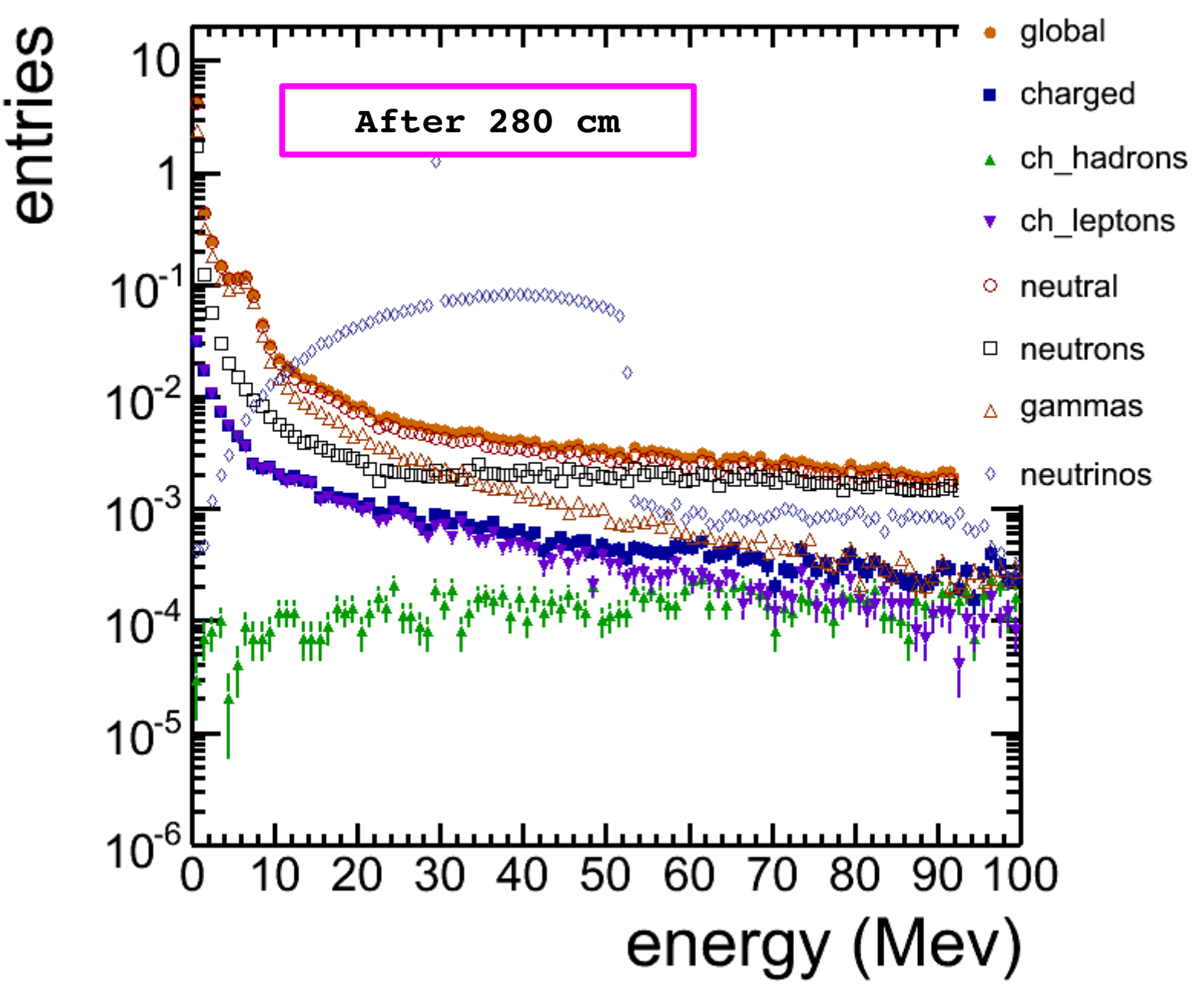
Global Results (2)



Global Results (3)

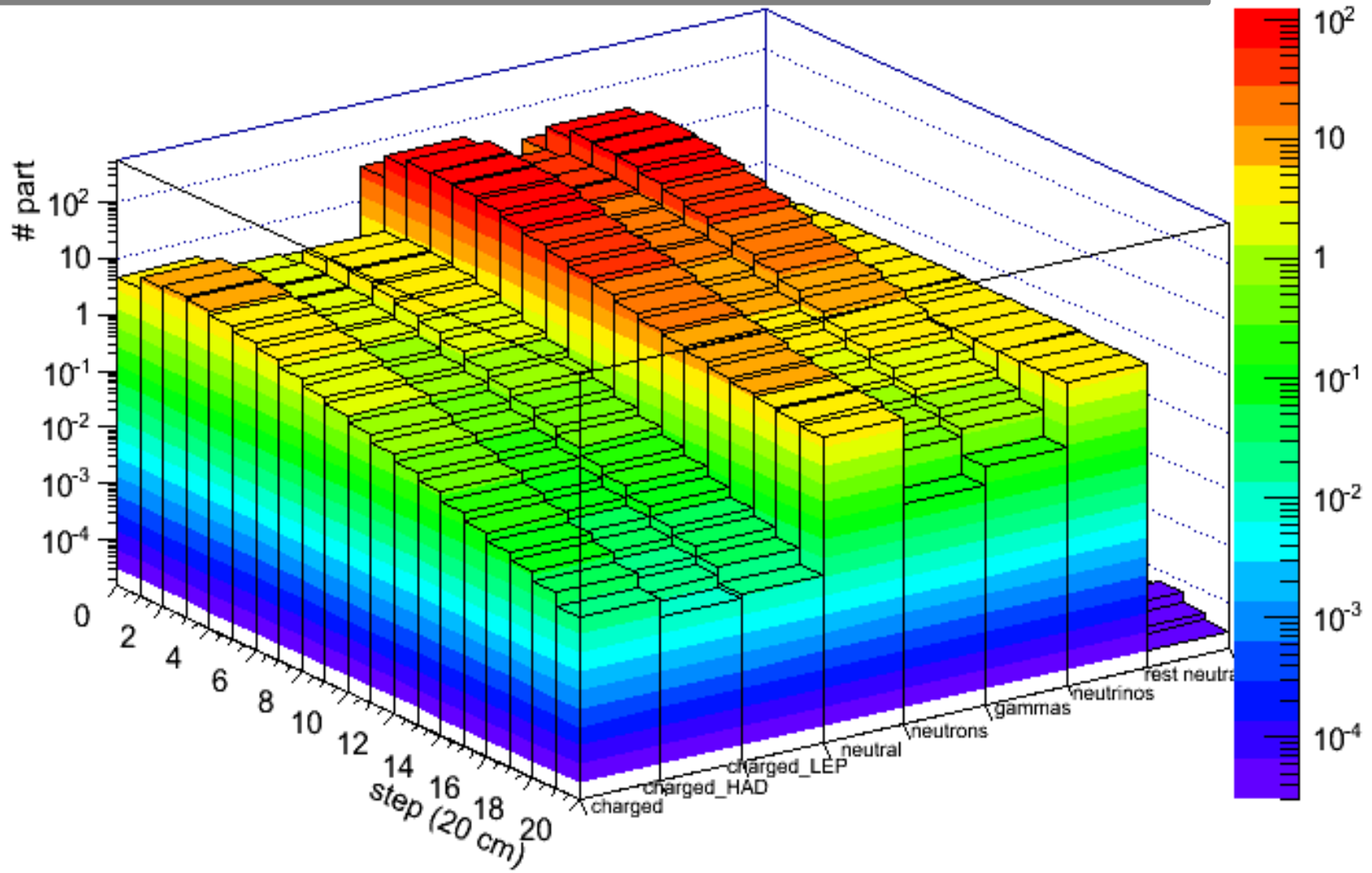


Global Results (4)



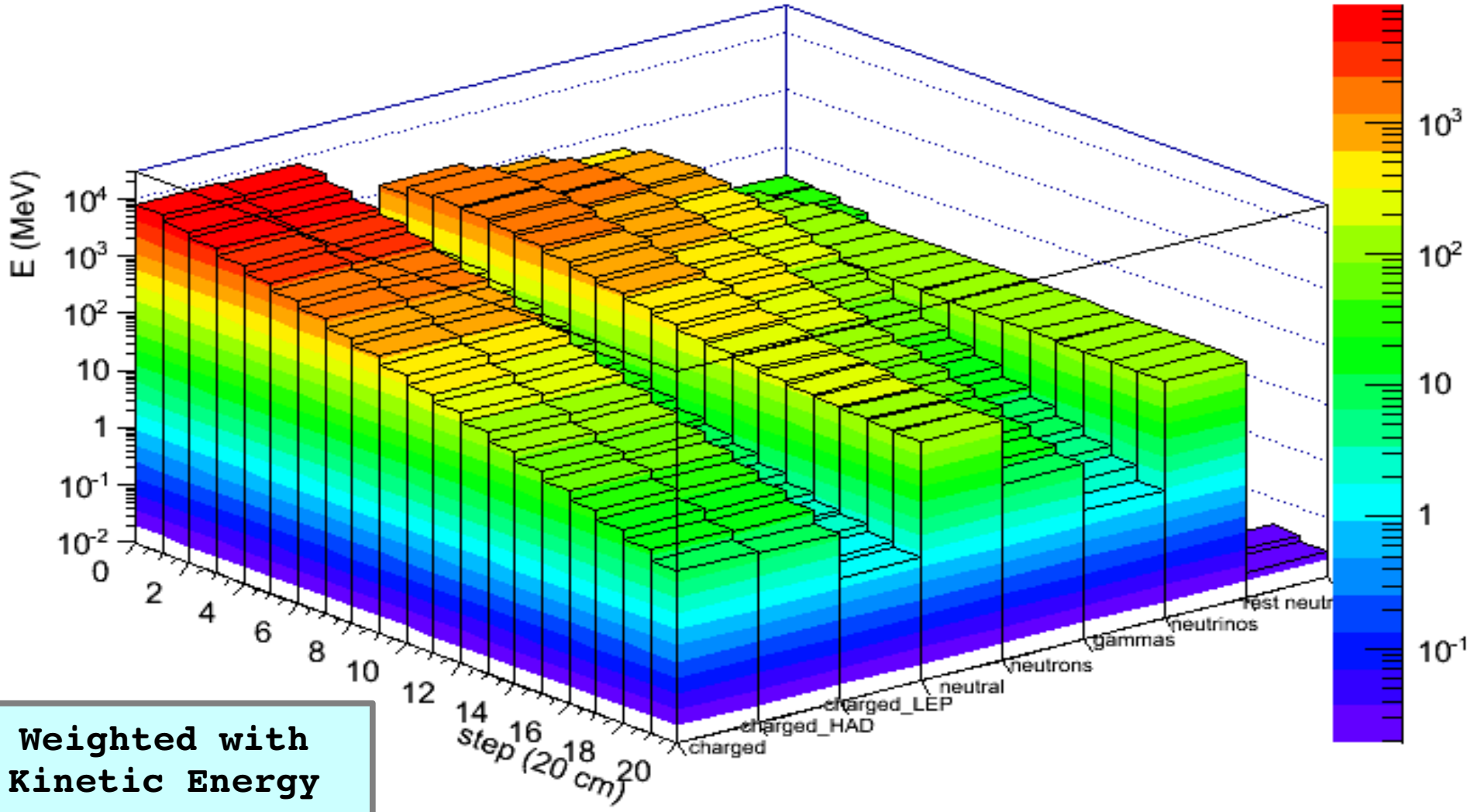
Global Results (5)

proton @ 10 GeV : particles # distribution vs step



Global Results (6)

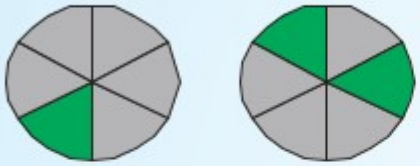
proton @ 10 GeV : particles # distribution vs step



Weighted with Kinetic Energy

How do we do that?

Segmented detectors can identify background events by counting.

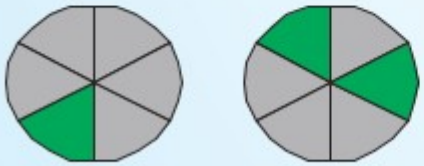


factor ≈ 10

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.