Probing Ultra-High-Energy Hadronic Interactions using the Earth's Magnetic Field

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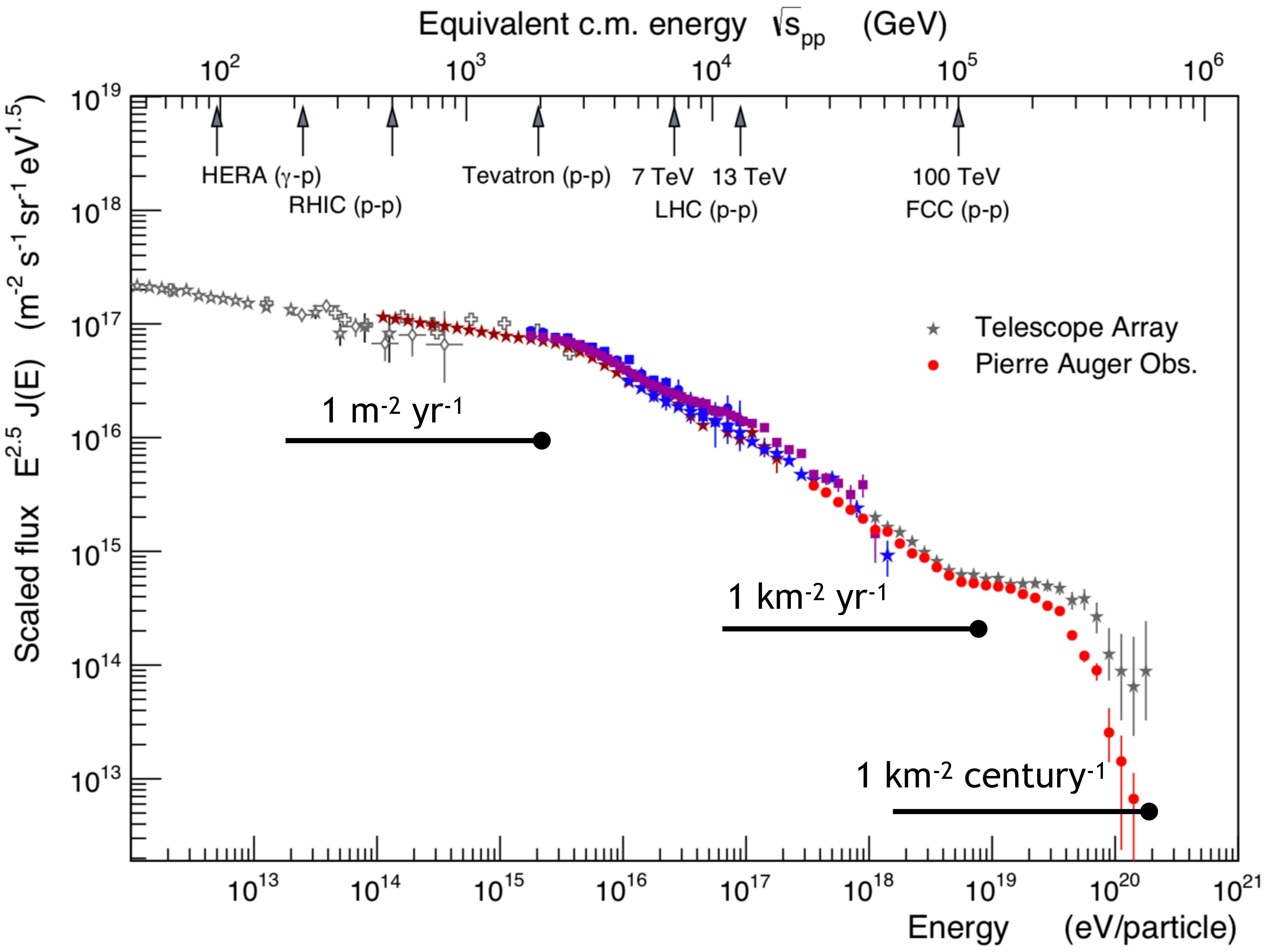
Ultra High Energy Cosmic Rays (UHECRs)

LHC $\sim 10^{17}$ eV Vs. UHECRs $\sim 10^{20}$ eV

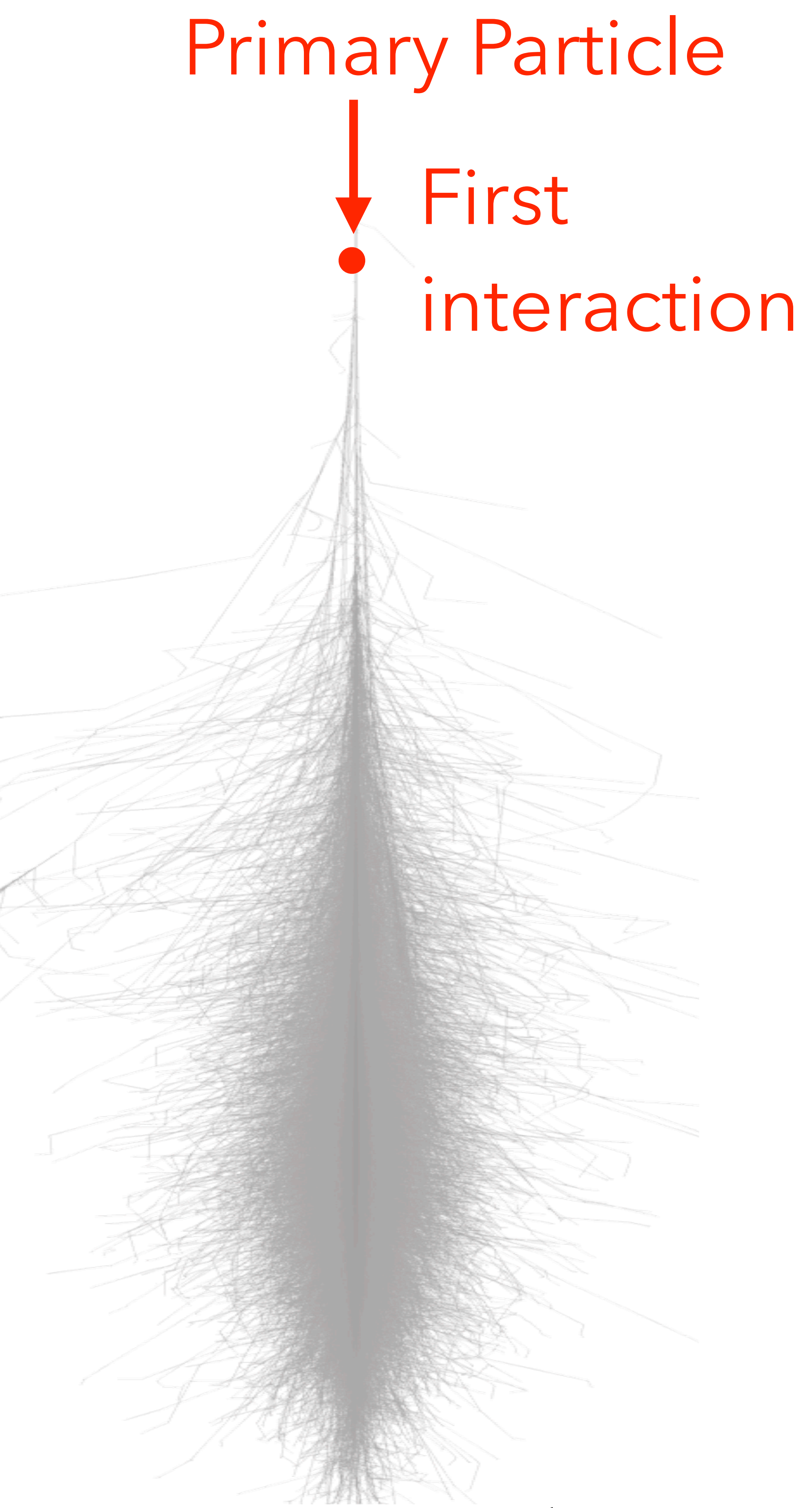
PIERRE AUGER
OBSERVATORY

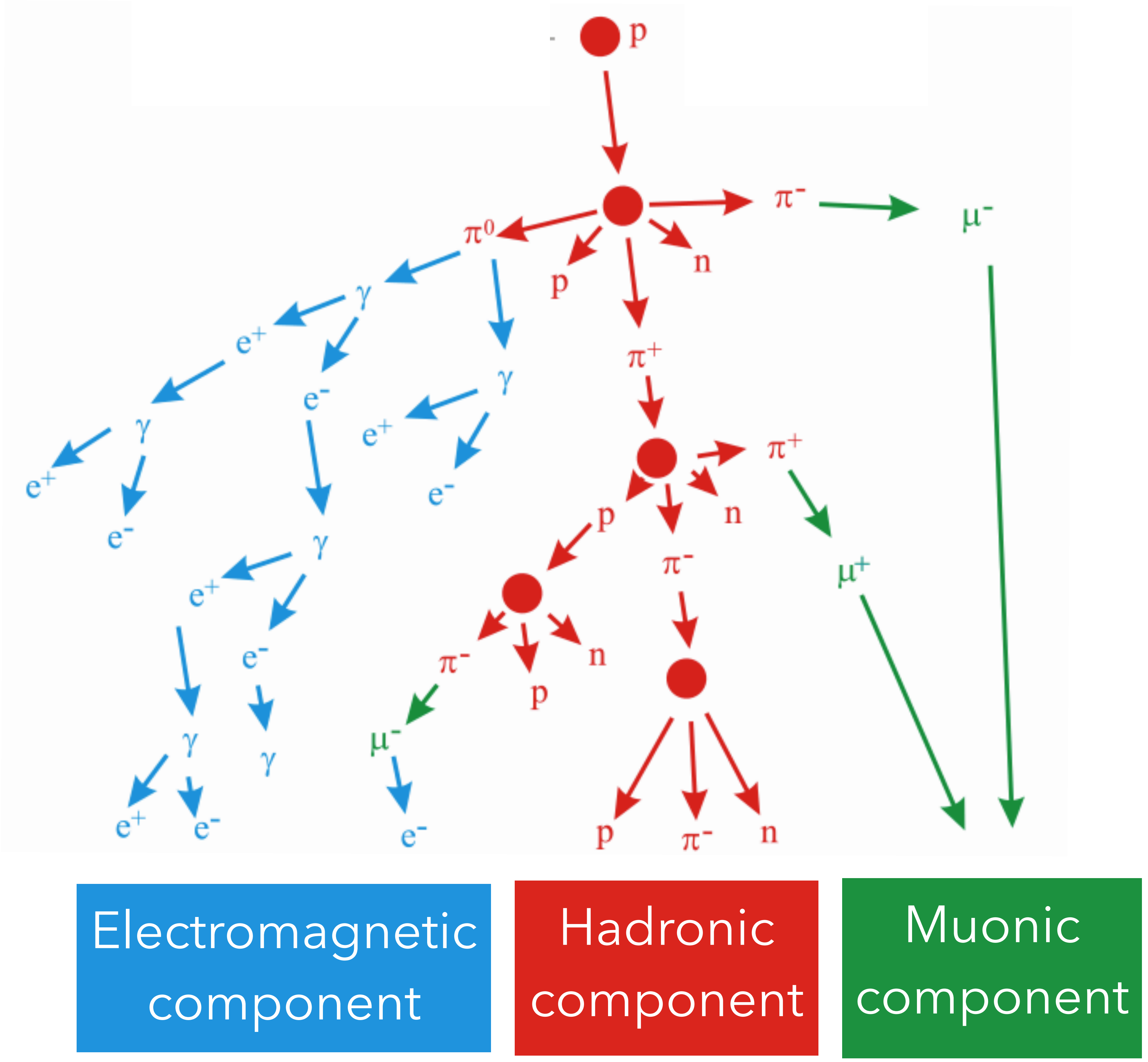
Hybrid Detectors:

1. Surface Detectors (SD)
2. Fluorescence Detectors (FD)

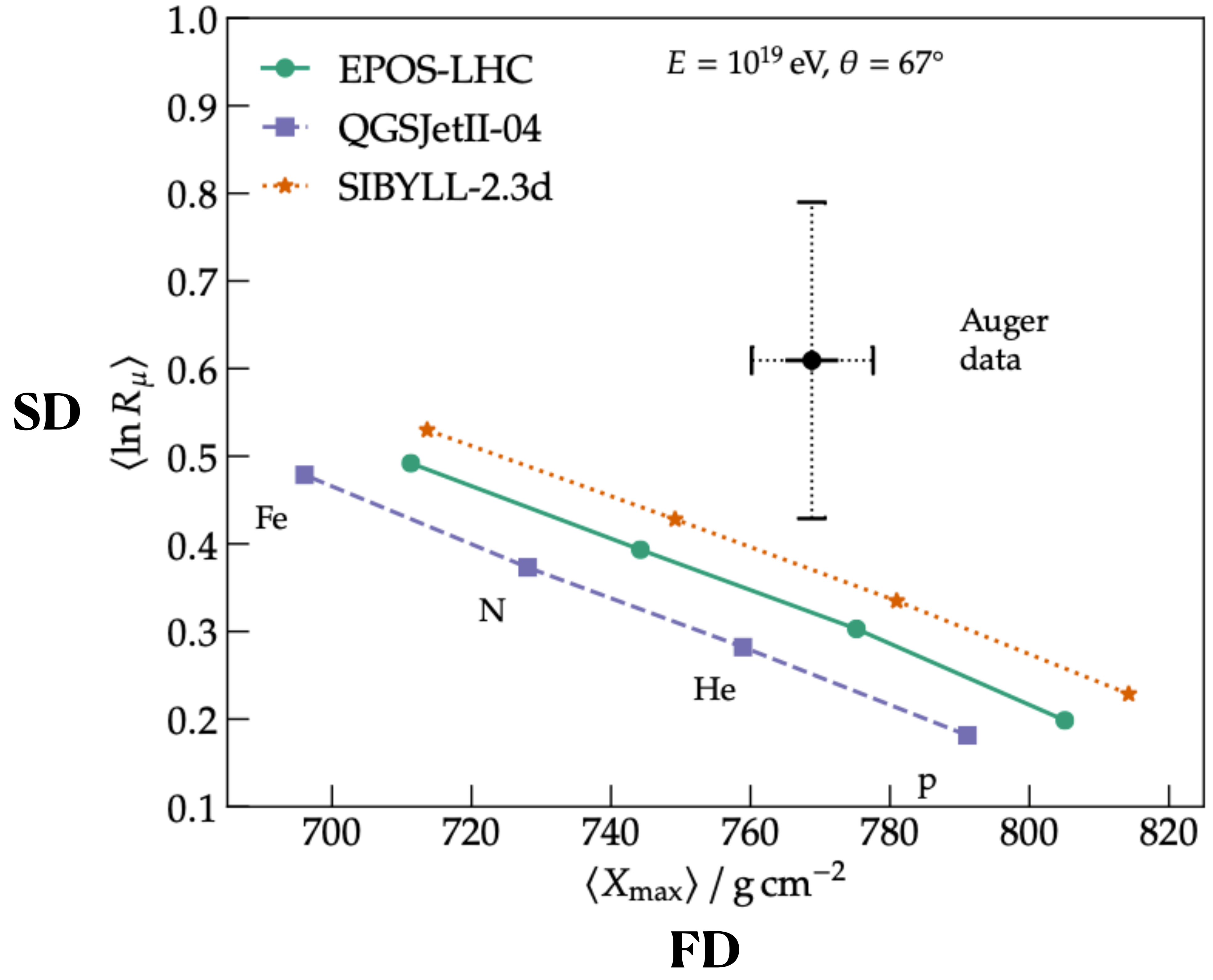


Extensive Air Showers





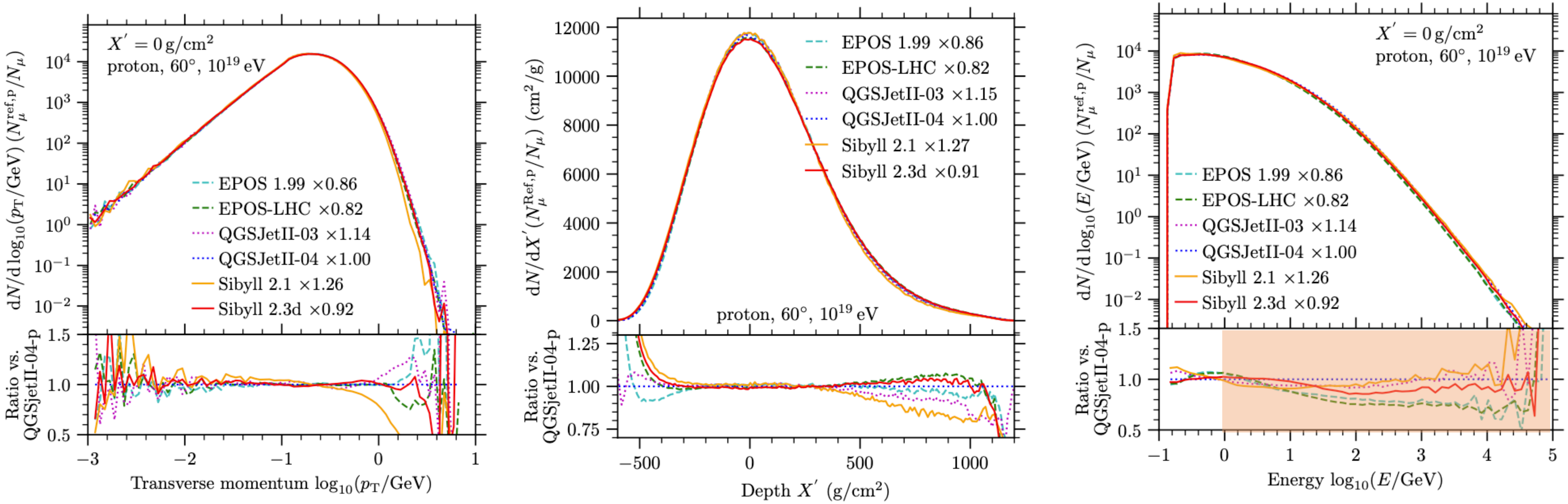
Muon Puzzle



The cosmic ray energy, direction and nature can be inferred from the EAS properties

But, it has been shown that the hadronic interactions are not fully understood

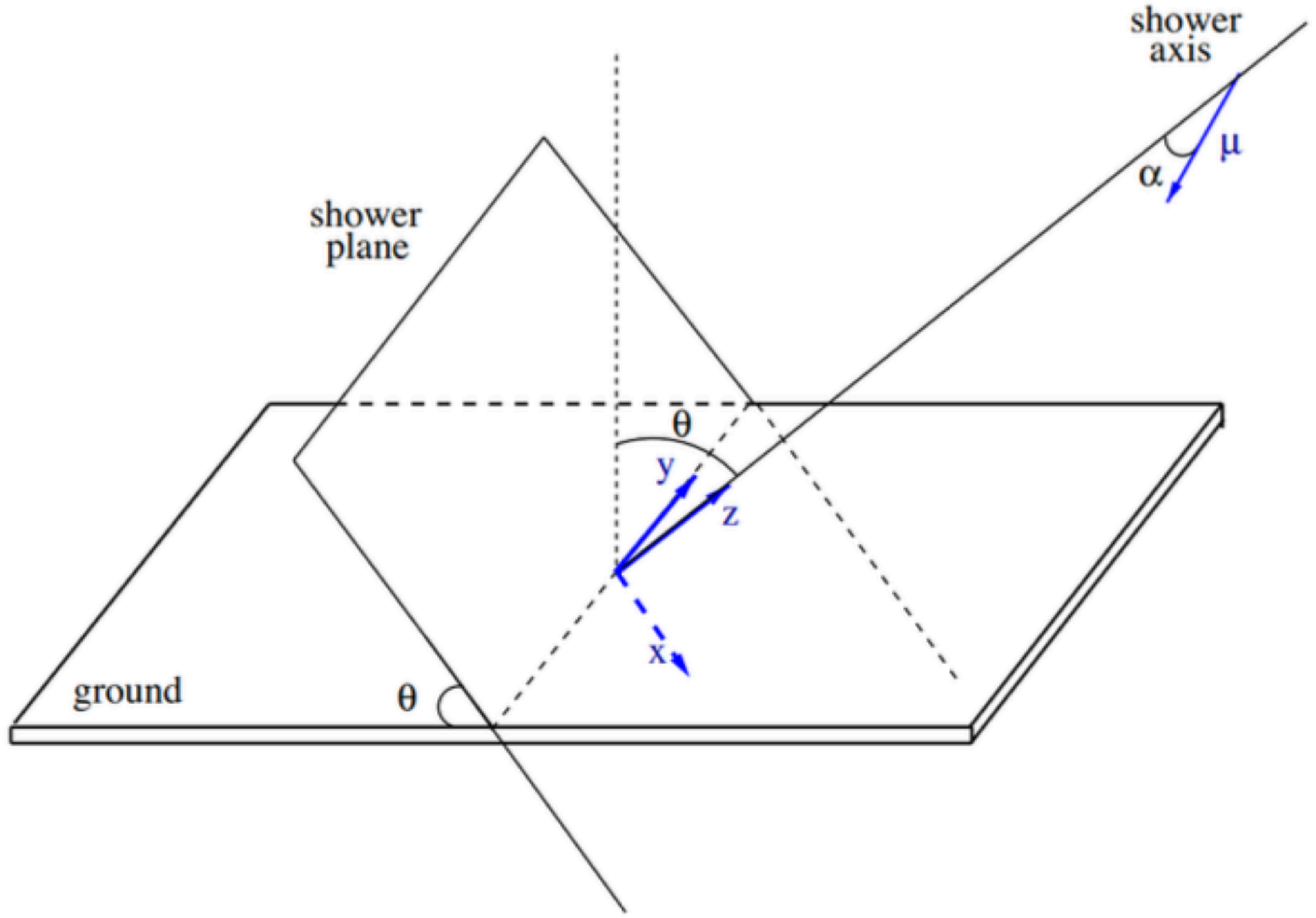
Shower Universality

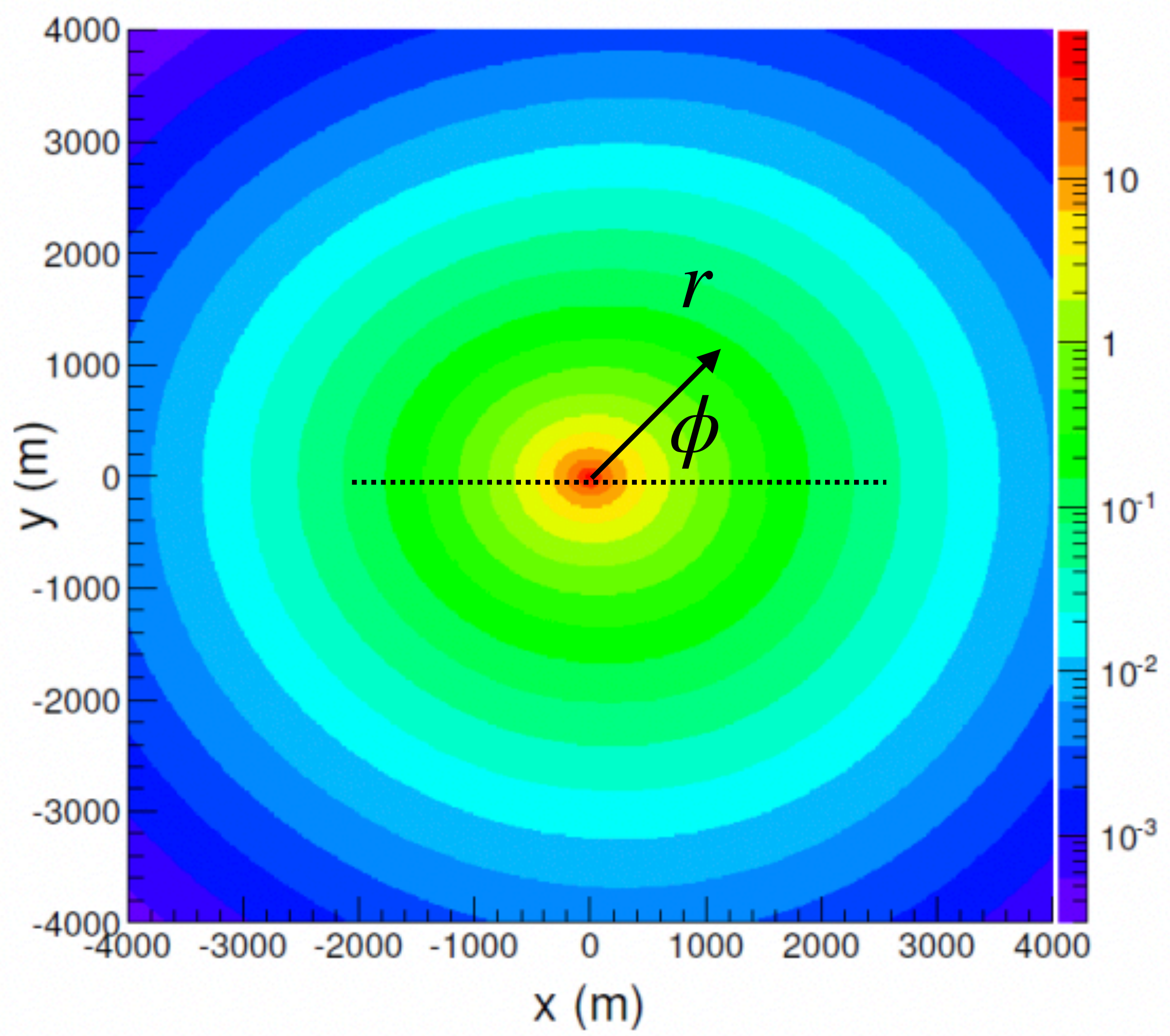


Three key components to characterise muons in a shower:

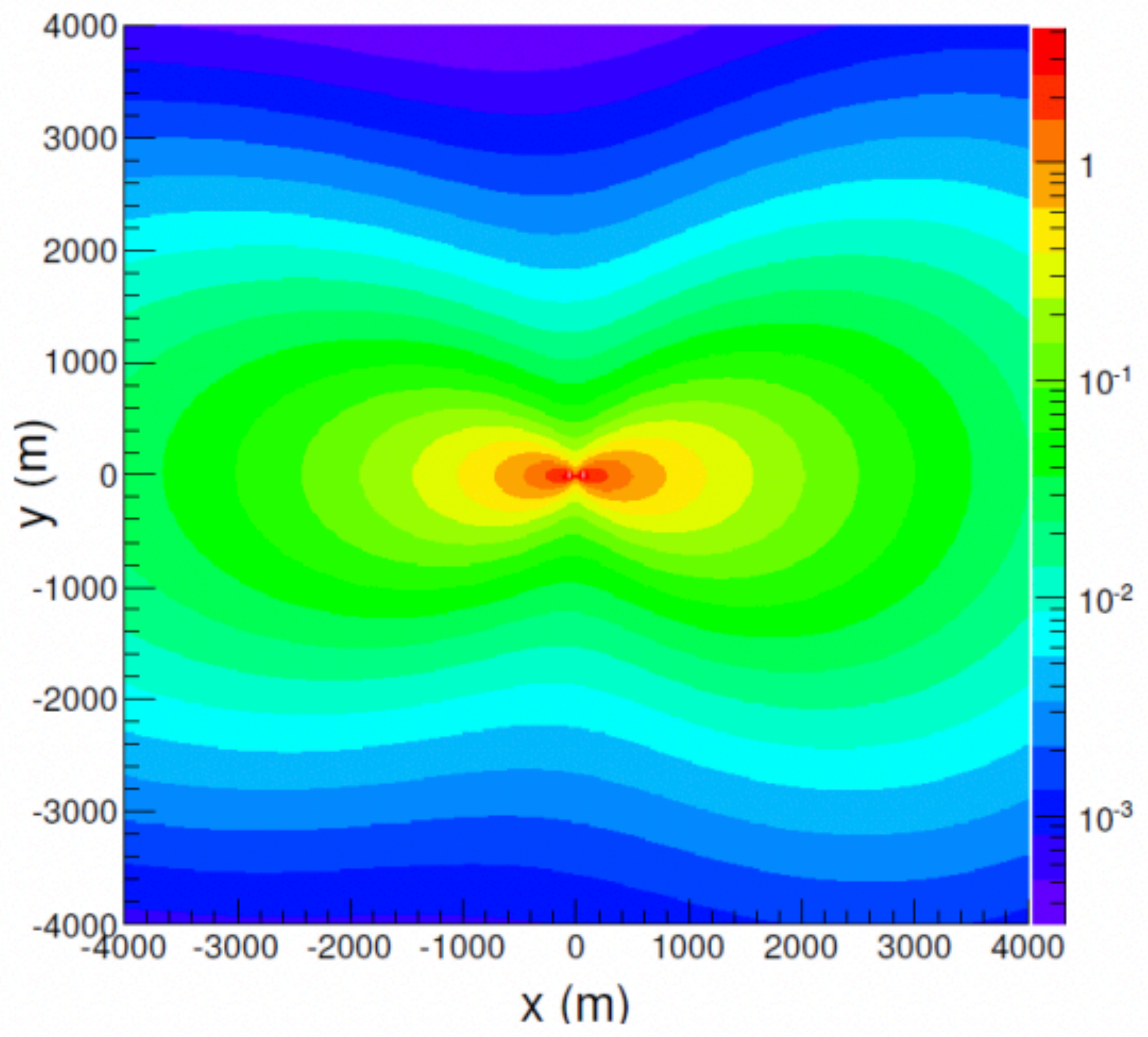
- P_T - indicates lateral spread of the shower
- X' - explains the longitudinal profile of muons produced during the shower development
- E - energy spectrum of the muons in the showers

Shower Footprint





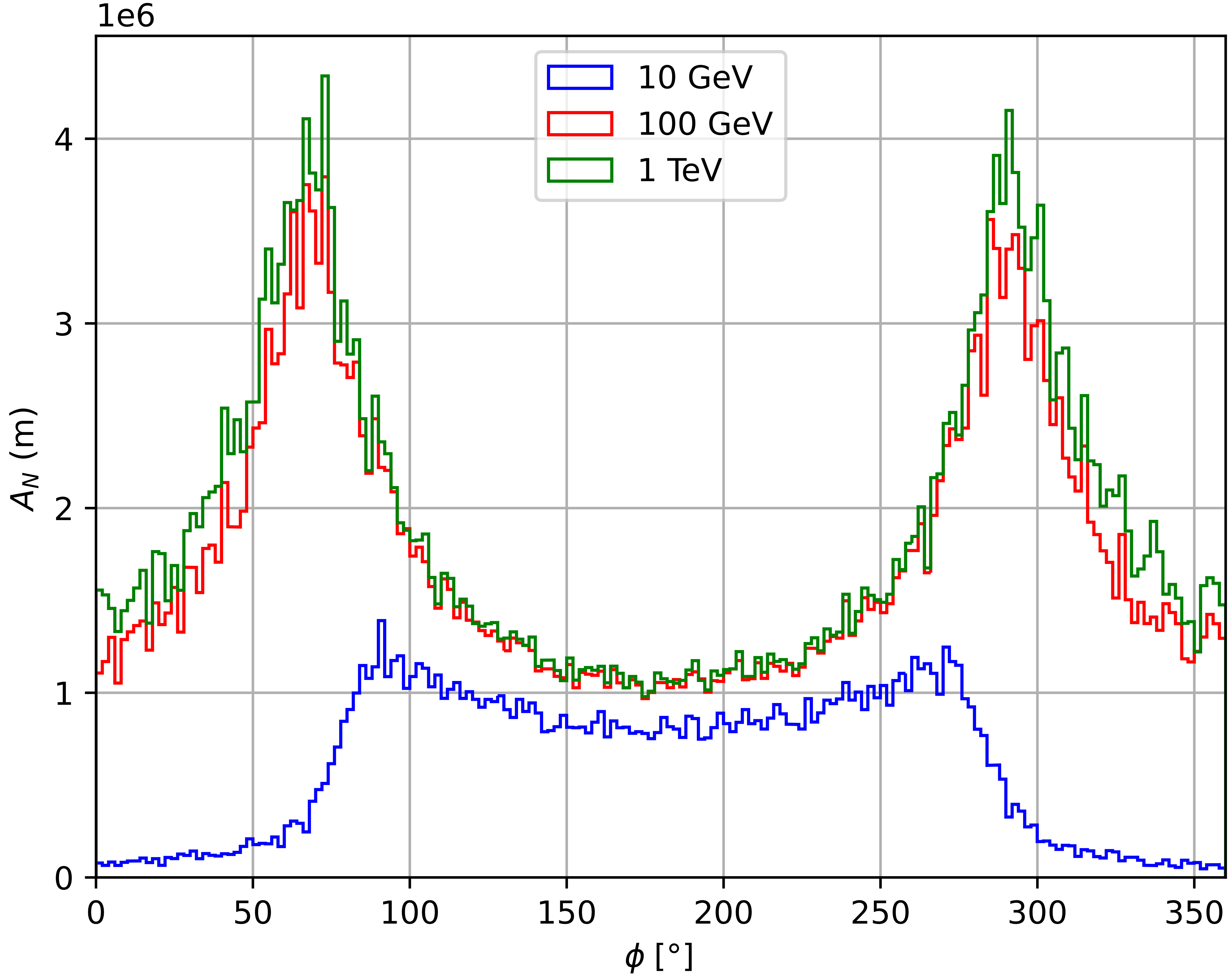
$\theta = 70°$



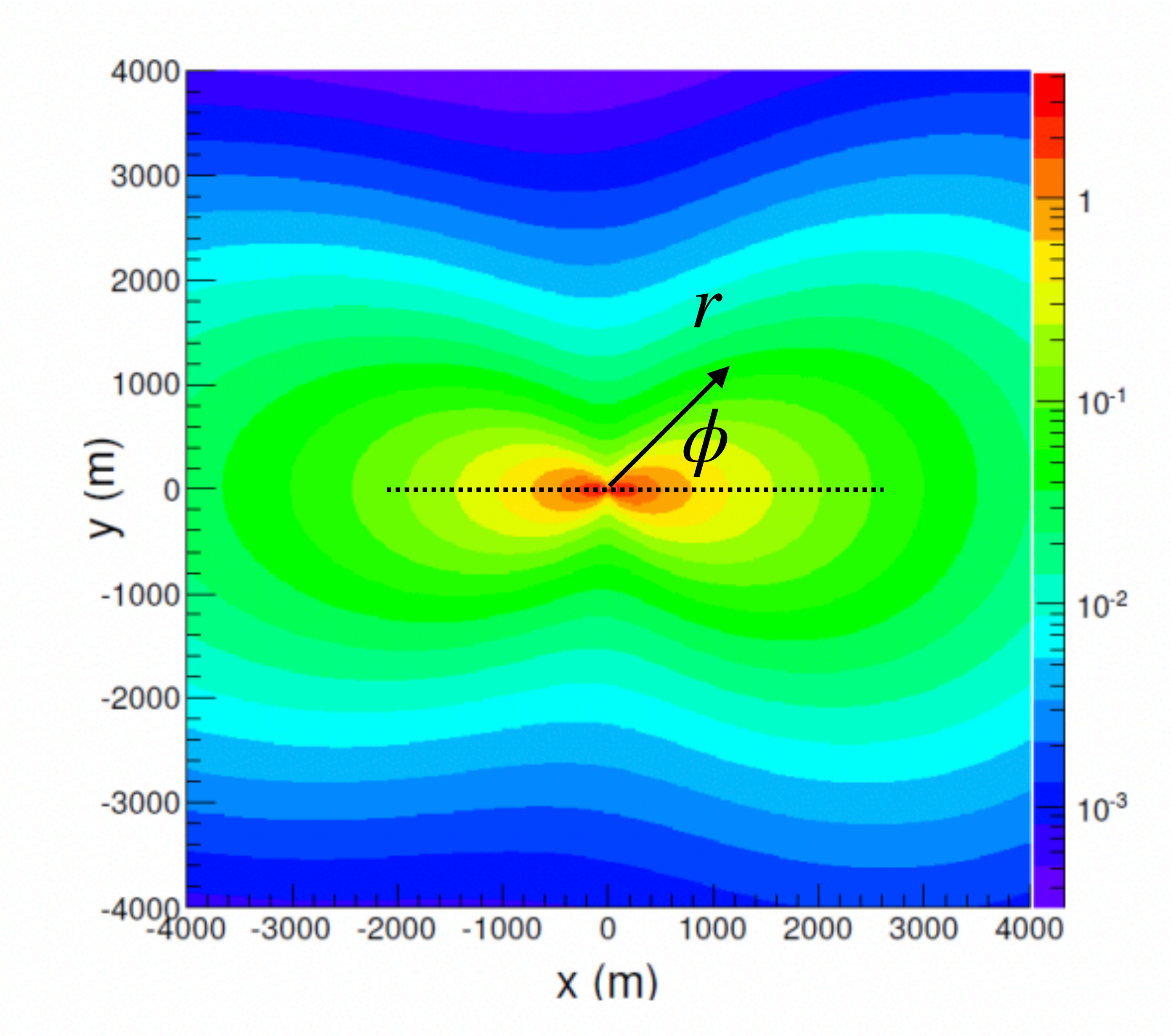
$\theta = 84°$

Shower muons footprint at the ground is sensitive to the Earth's magnetic field

Muon Azimuthal Distribution

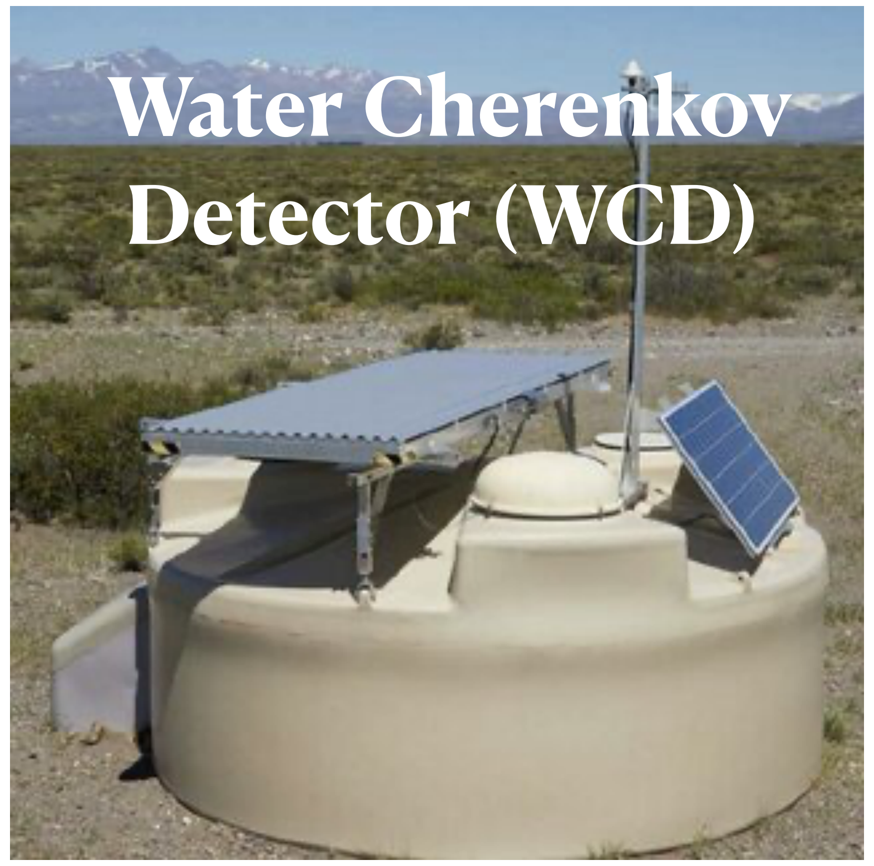


$$A_N(\phi) = \sum_j r_j \, n_j(\phi, r_j)$$



The shower footprint shape is sensitive to the muon energy

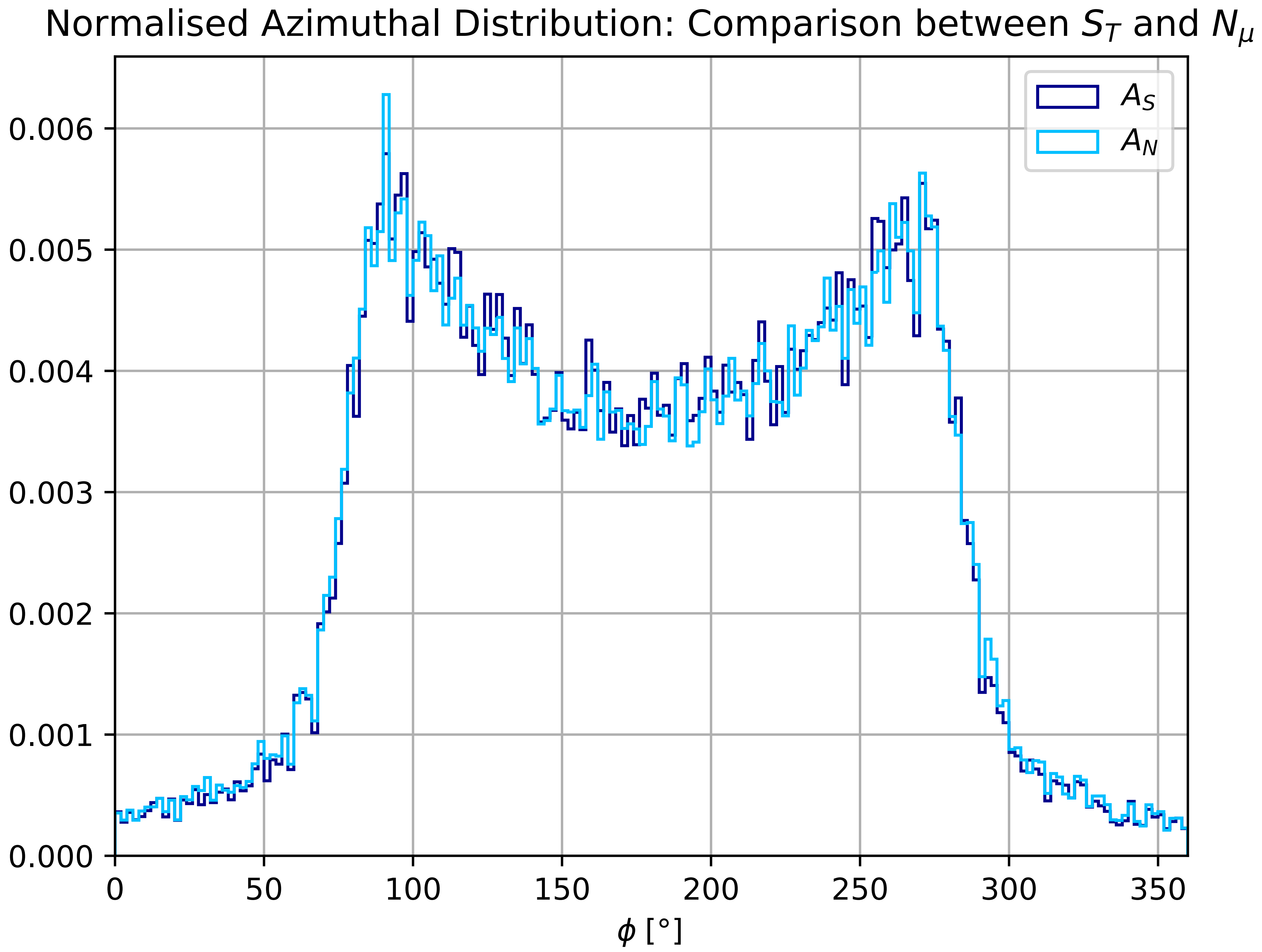
Applying this analysis to Auger



$$A_N = \sum_j r_j \, N(\phi, r_j)$$

vs.

$$A_S = \sum_j r_j \, S(\phi, r_j)$$

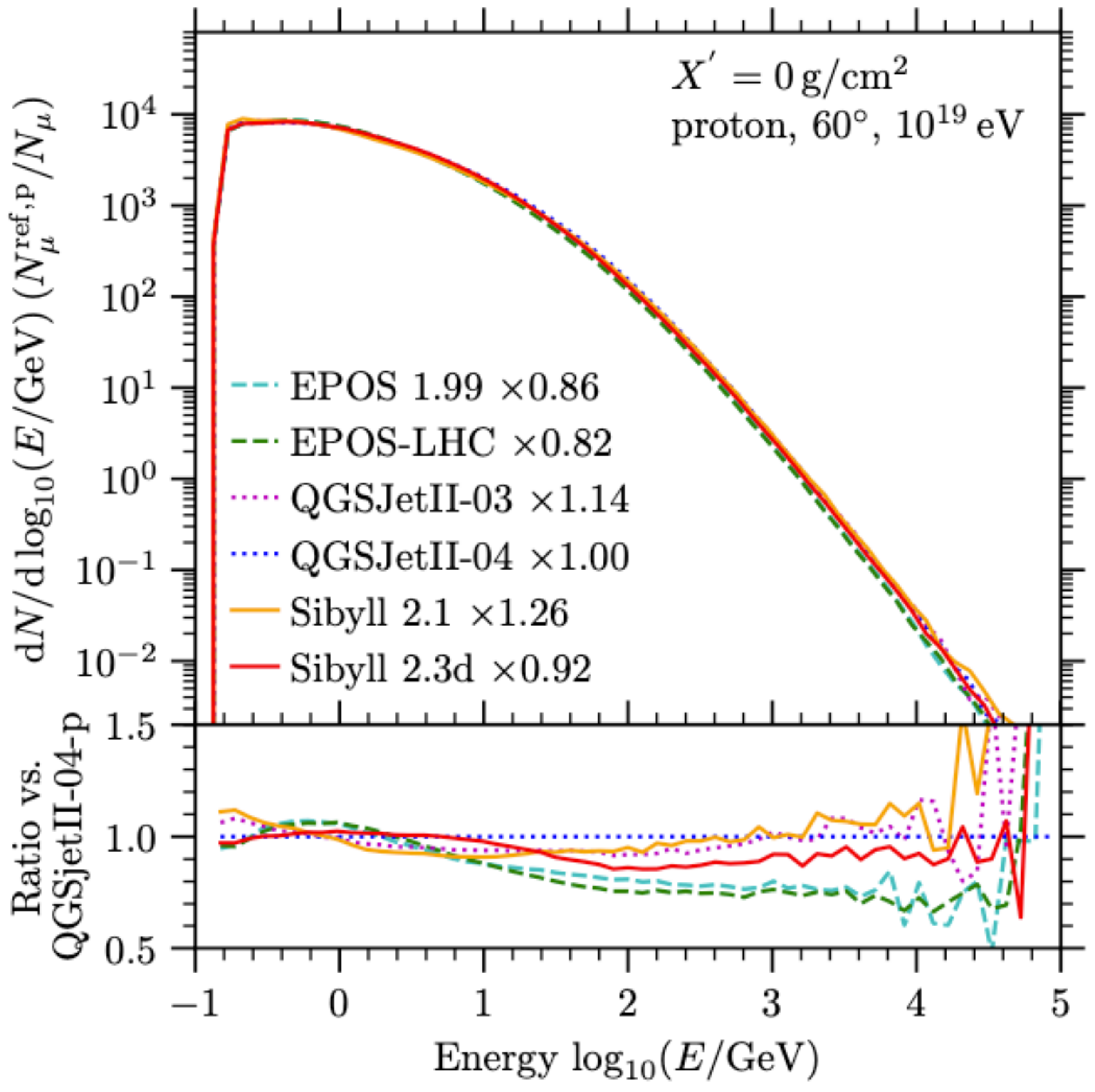


The muon azimuthal distribution computed from muons shows the same behavior as when derived from the WCD signal (all particles).

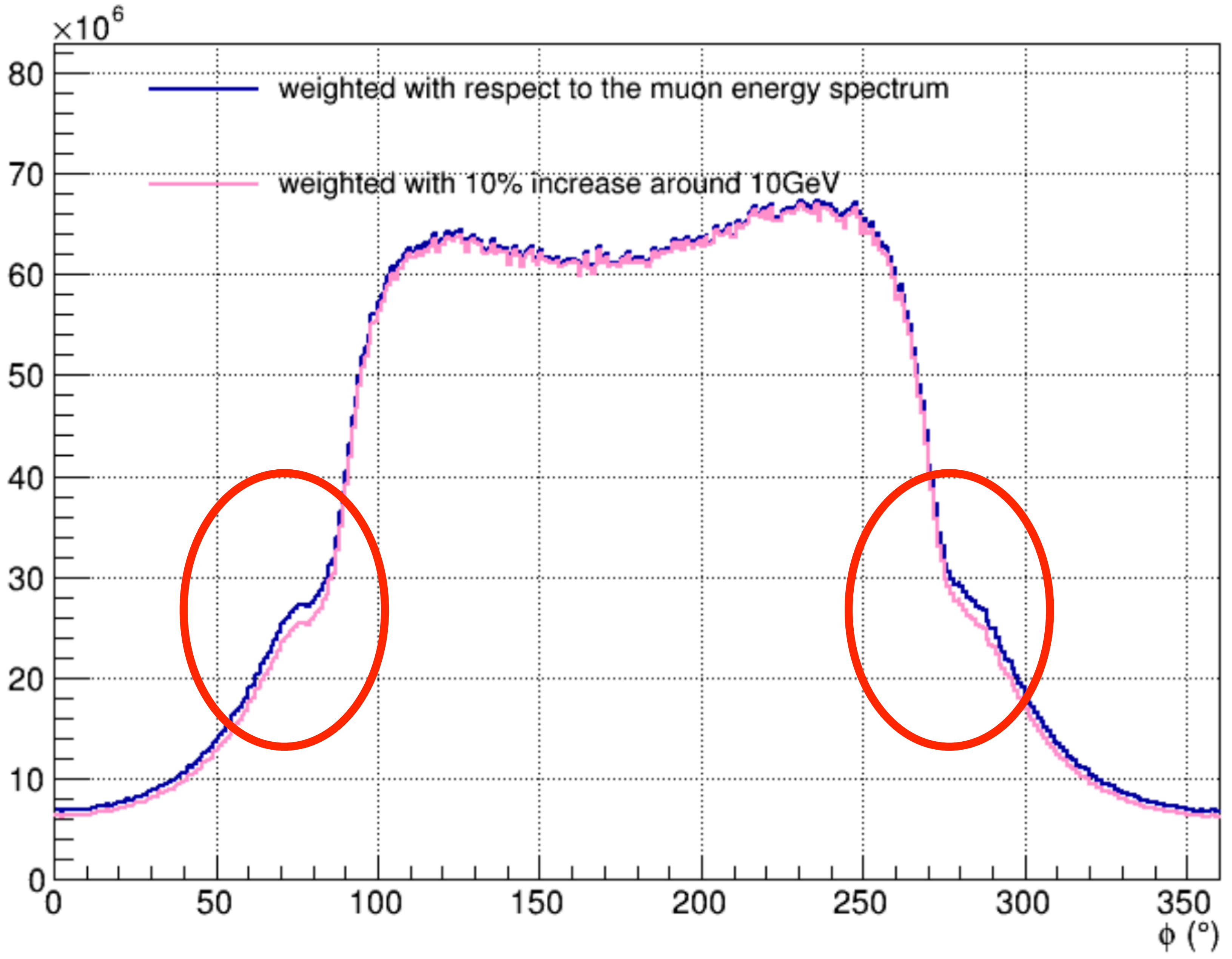
Muon energy spectrum sensitivity

Emulate a shower injecting muons at different heights and energies

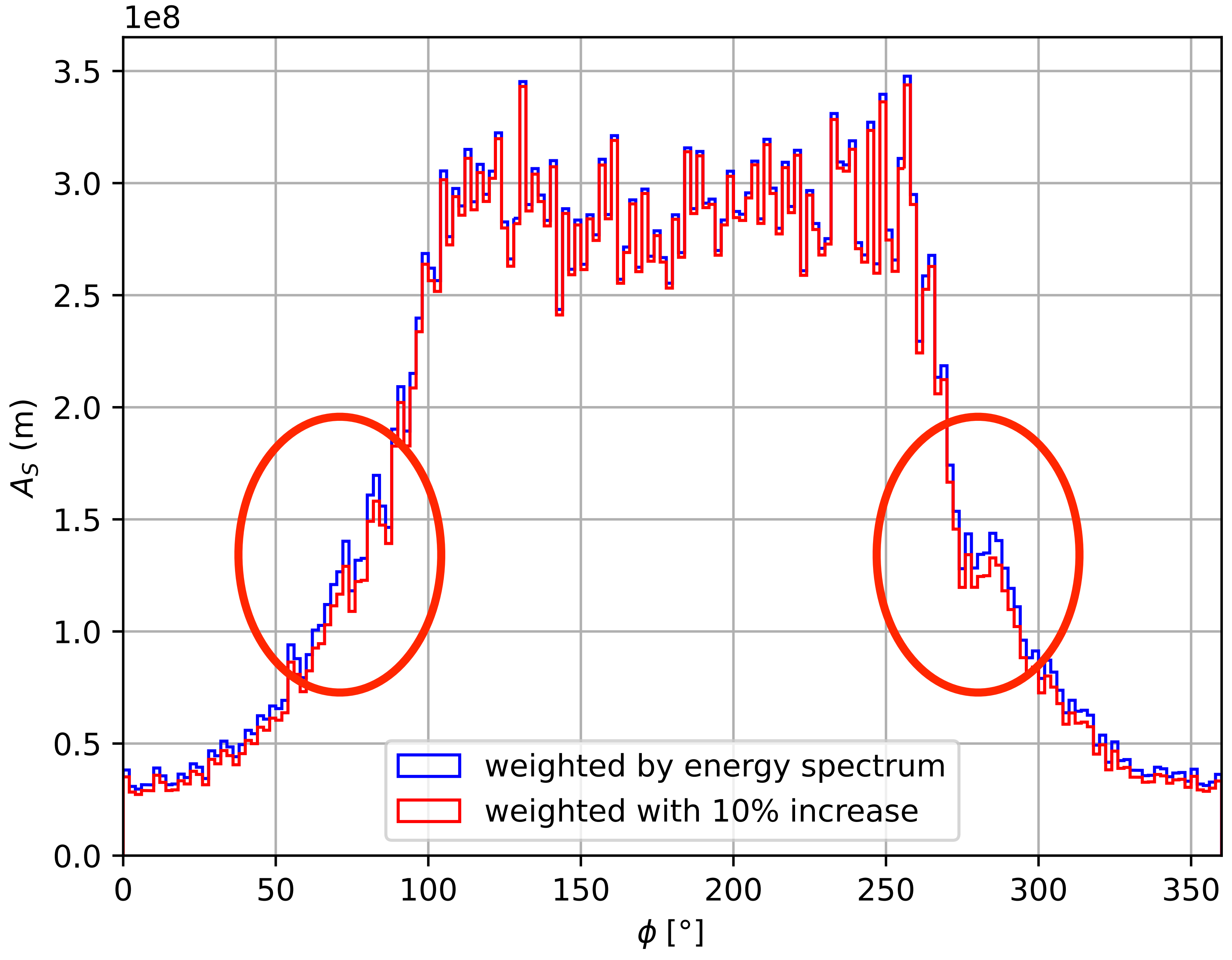
Muon energy spectrum



Muon footprint



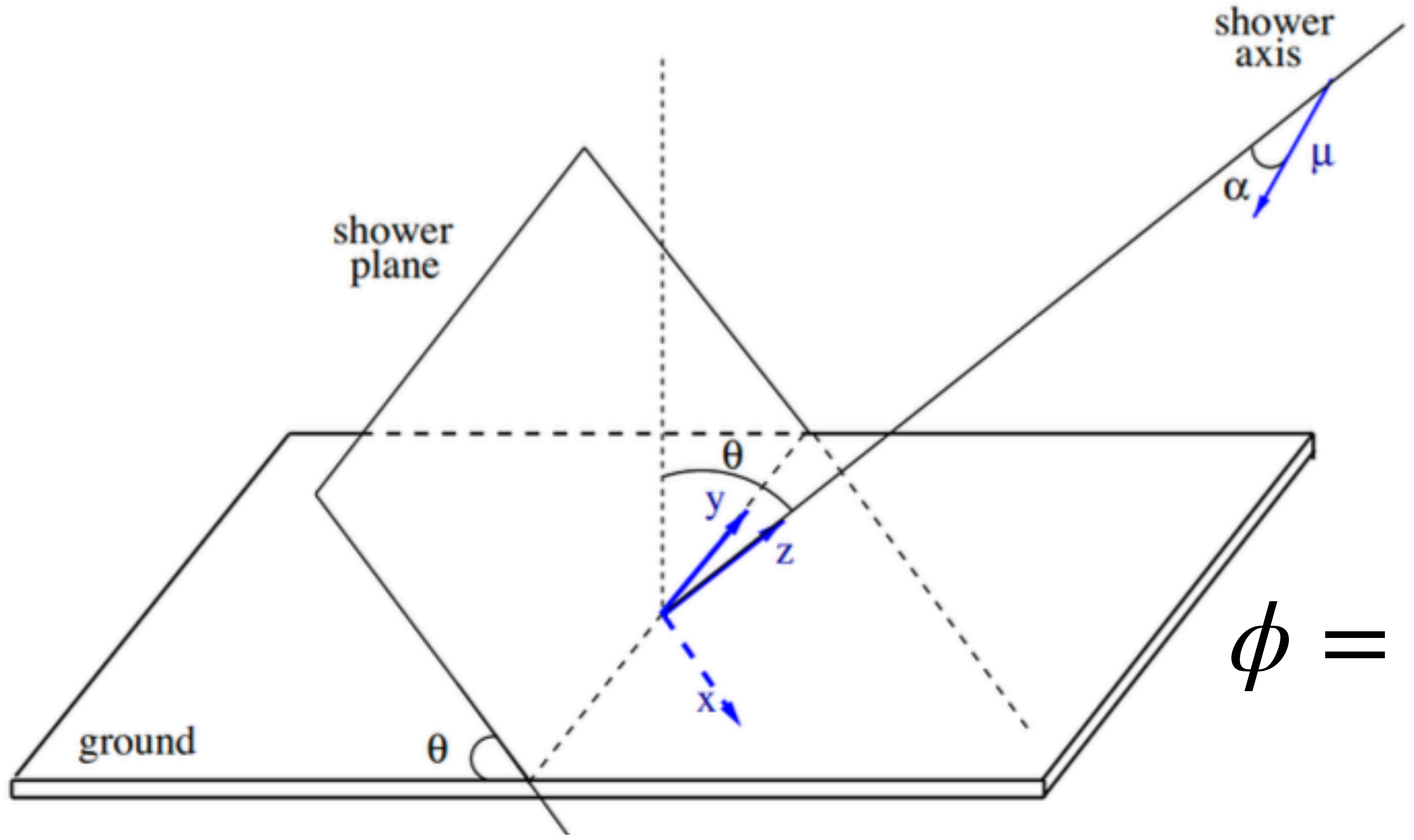
WCD footprint



When changing the energy spectrum by 10% at lower energies (10 GeV) there's a noticeable effect on the shower footprint - **Possibility to measure Muon EAS energies at Auger!**

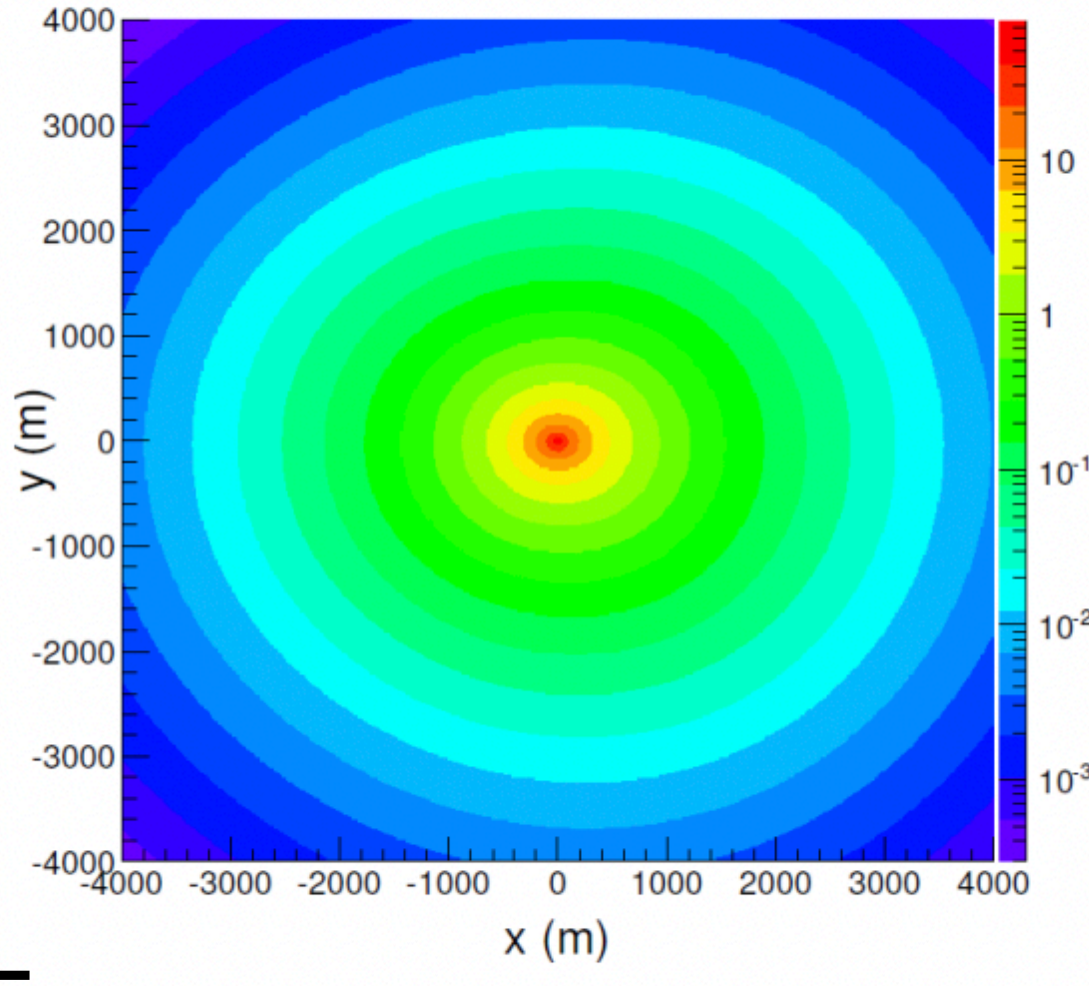
BACKUP SLIDES

Shower Footprint

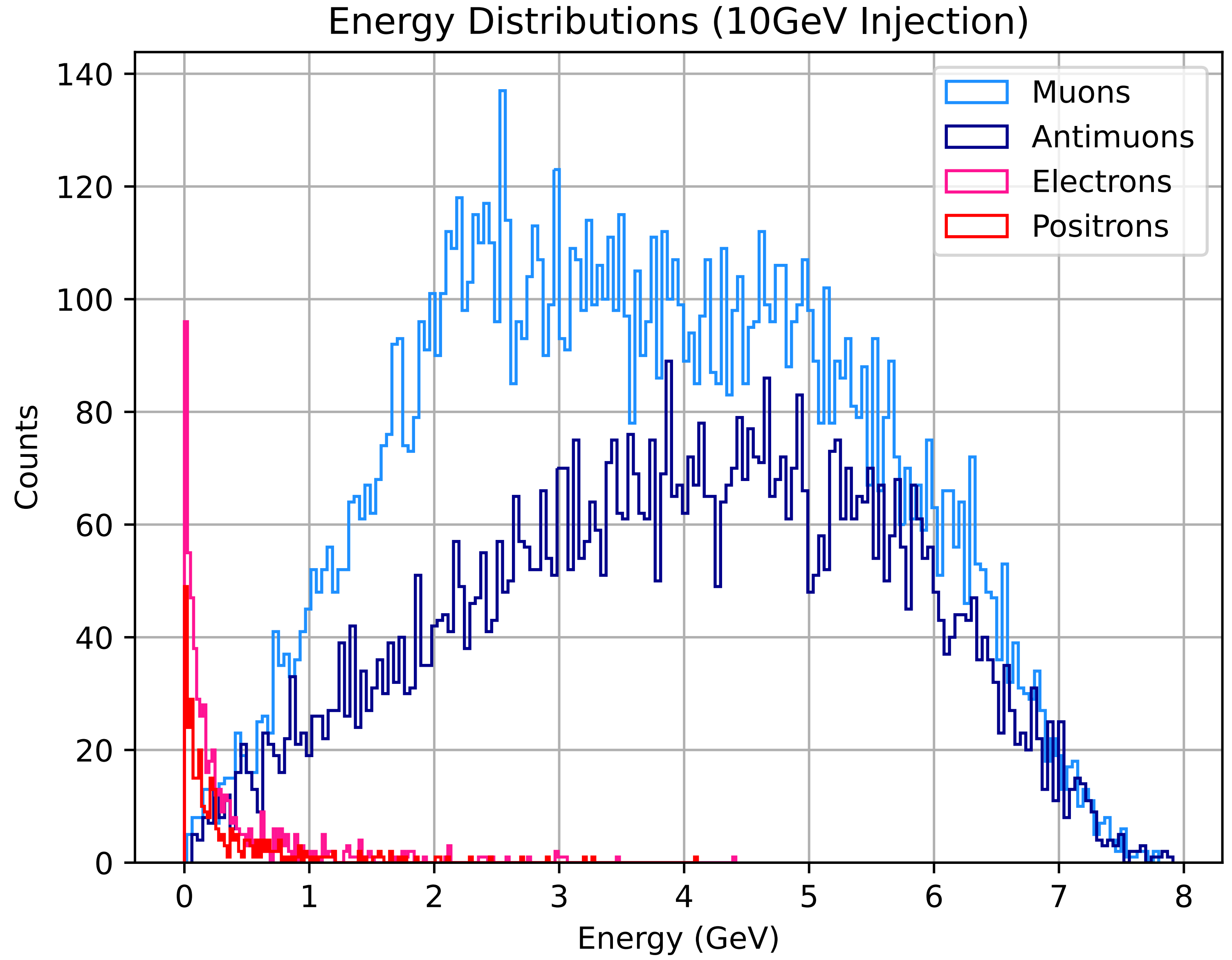


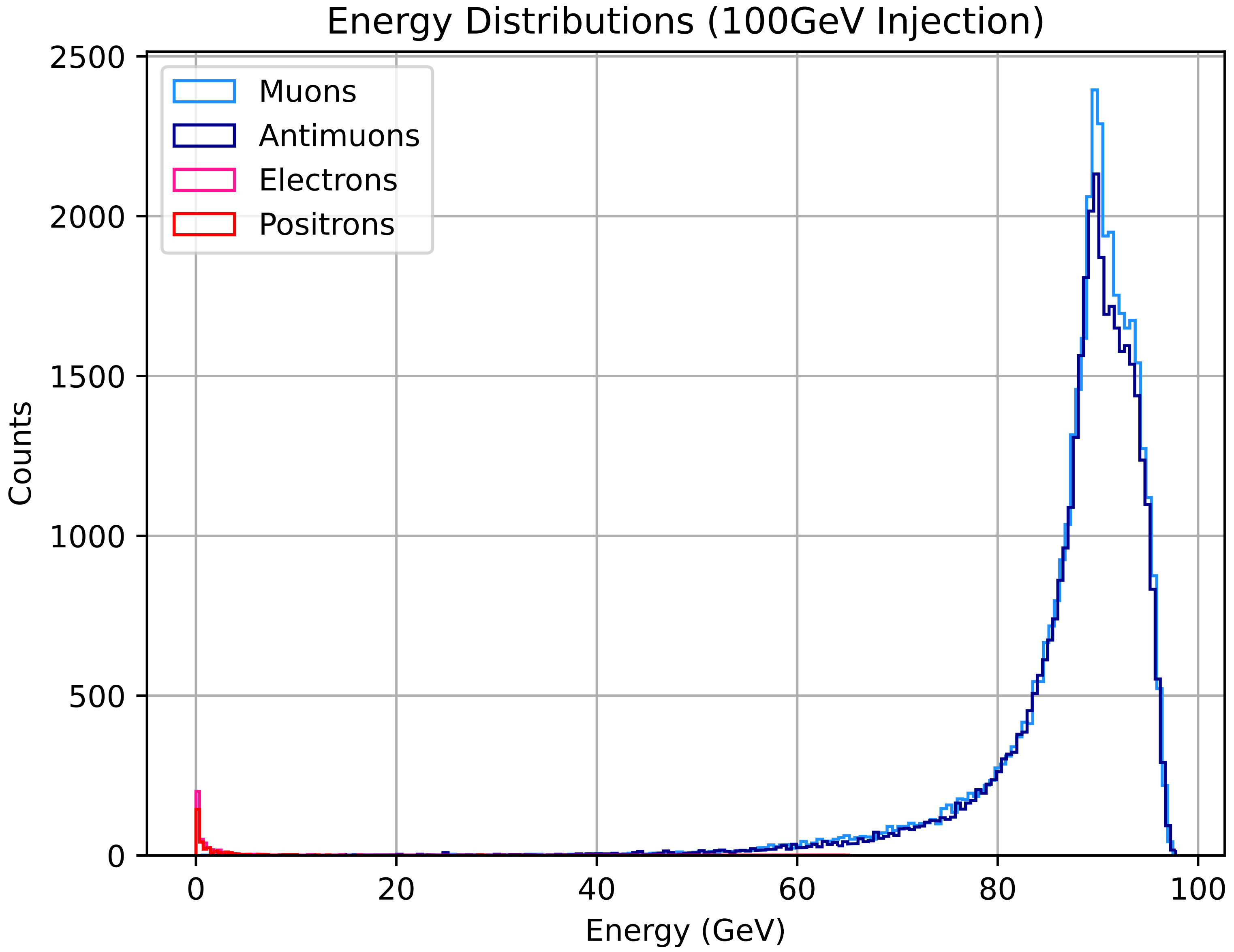
$$A_N(\phi) = \sum_j r_j\, n_j(\phi, r_j)$$

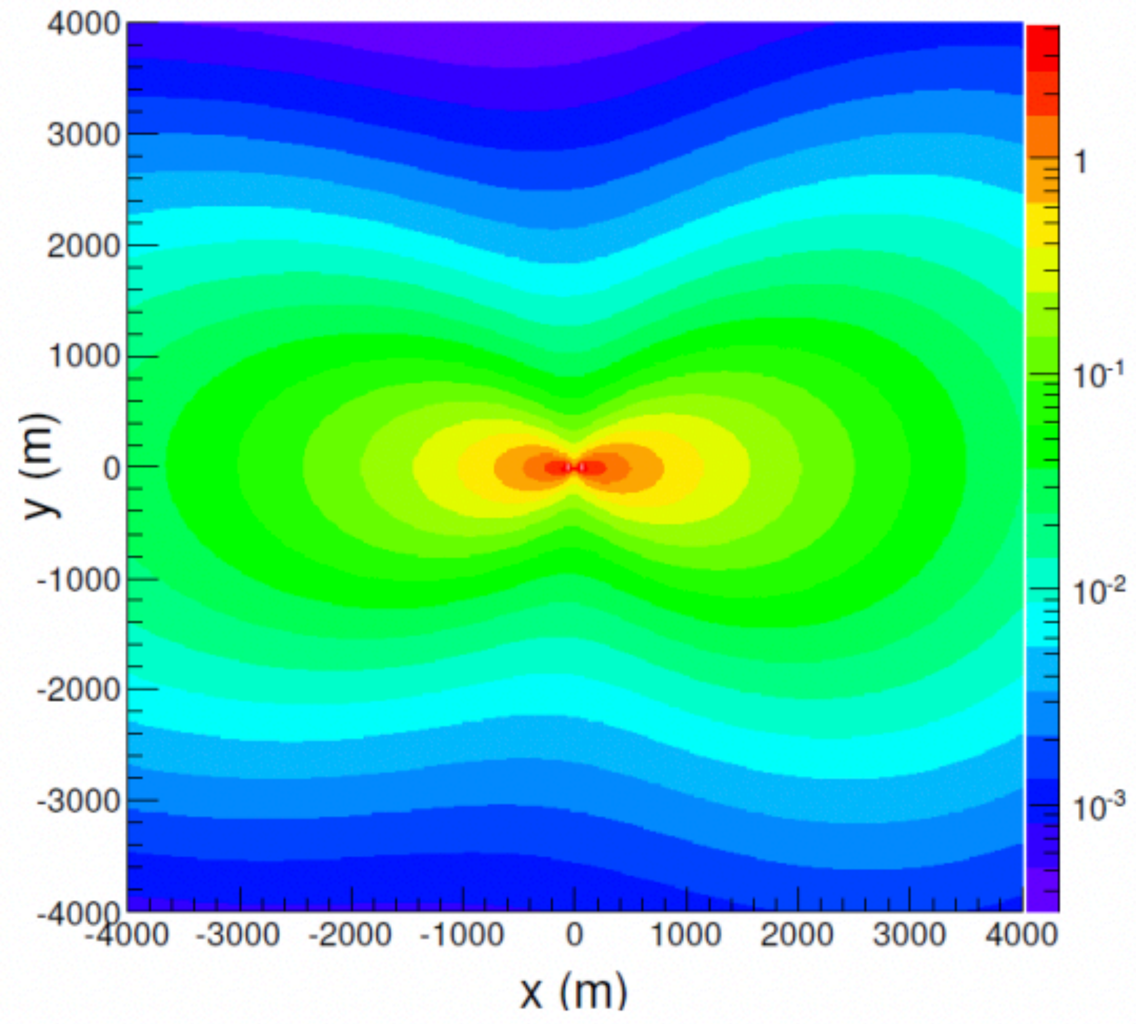
$$\phi = \arctan\left(\frac{Y_{\mathrm{sh}}}{X_{\mathrm{sh}}}\right) \quad \& \quad r = \sqrt{{X_{\mathrm{sh}}}^2 + {Y_{\mathrm{sh}}}^2}$$



70°







84°

Distribution Sensitivity