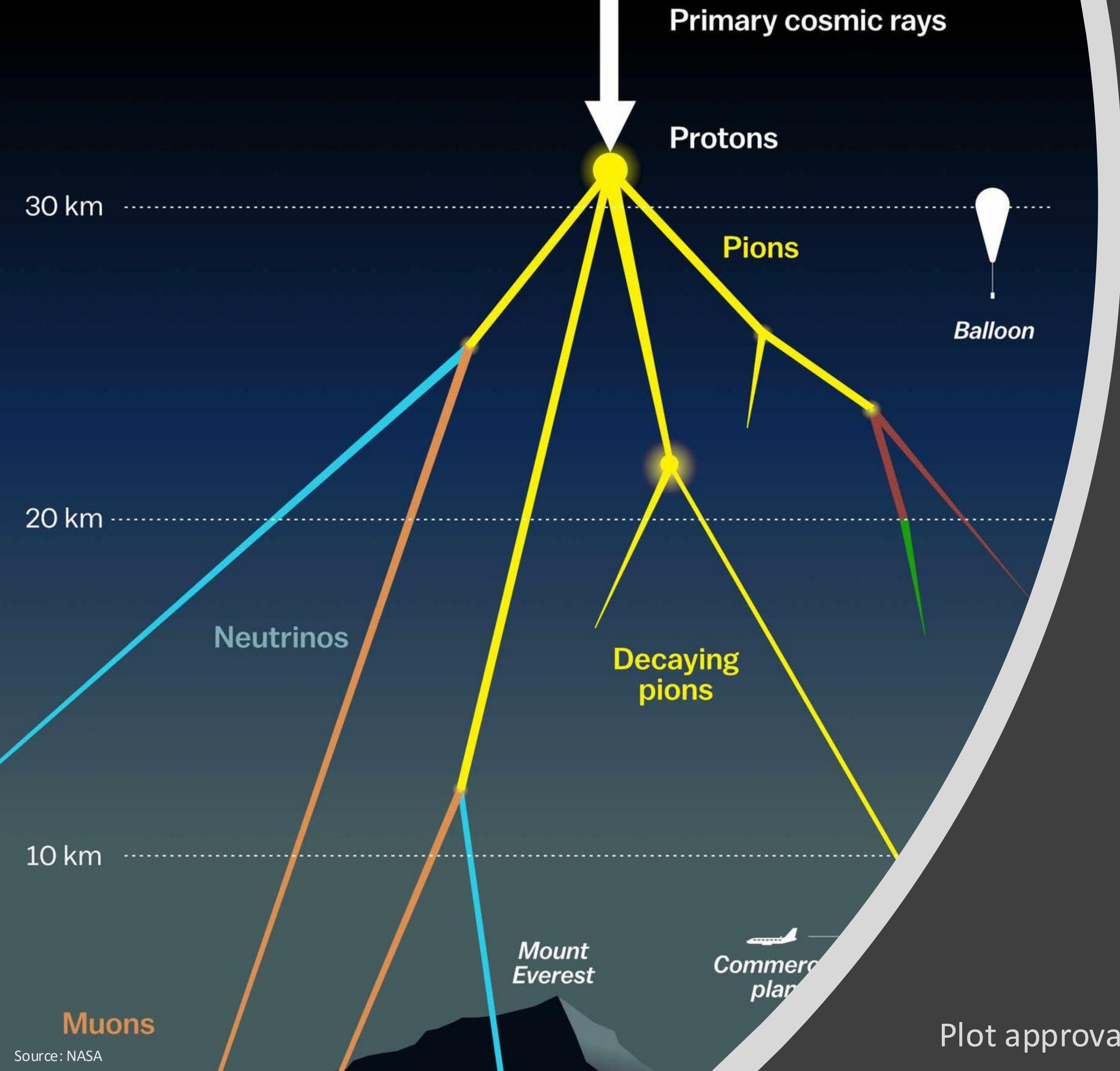

Source: NASA

# Unfolding the Atmospheric Muon Flux with IceCube: Investigating Stopping Muons and High-Energy Prompt Contributions

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# Abstract

Atmospheric muons produced in cosmic-ray air showers are classified as conventional muons from pion and kaon decays and prompt muons from heavy hadron decays. Conventional muons dominate at lower energies, and the prompt component becomes more significant at PeV energies and above. Precisely measuring the atmospheric muon flux from a few GeV to several PeV is valuable for advancing our understanding of cosmic-ray interactions and testing hadronic interaction models. Low-energy muons that stop within the IceCube in-ice array provide valuable information about the energy spectrum of muons from a few 100 GeV up to 10 TeV.

Machine learning techniques are employed to enhance event reconstruction and selection to provide insights into the conventional and prompt components. This contribution presents the unfolding of the energy spectrum of stopping muons in IceCube as well as the unfolding of high-energy muons to probe the prompt component.

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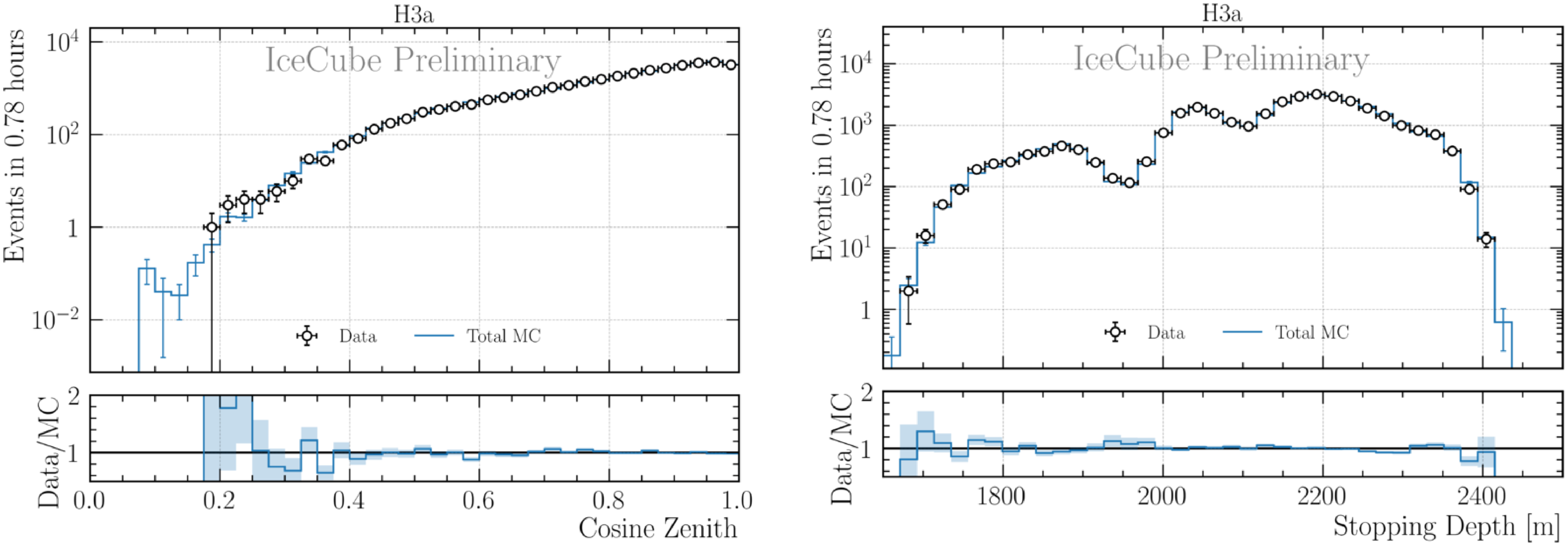
# Outline

# Data-MC: Stopping Muons



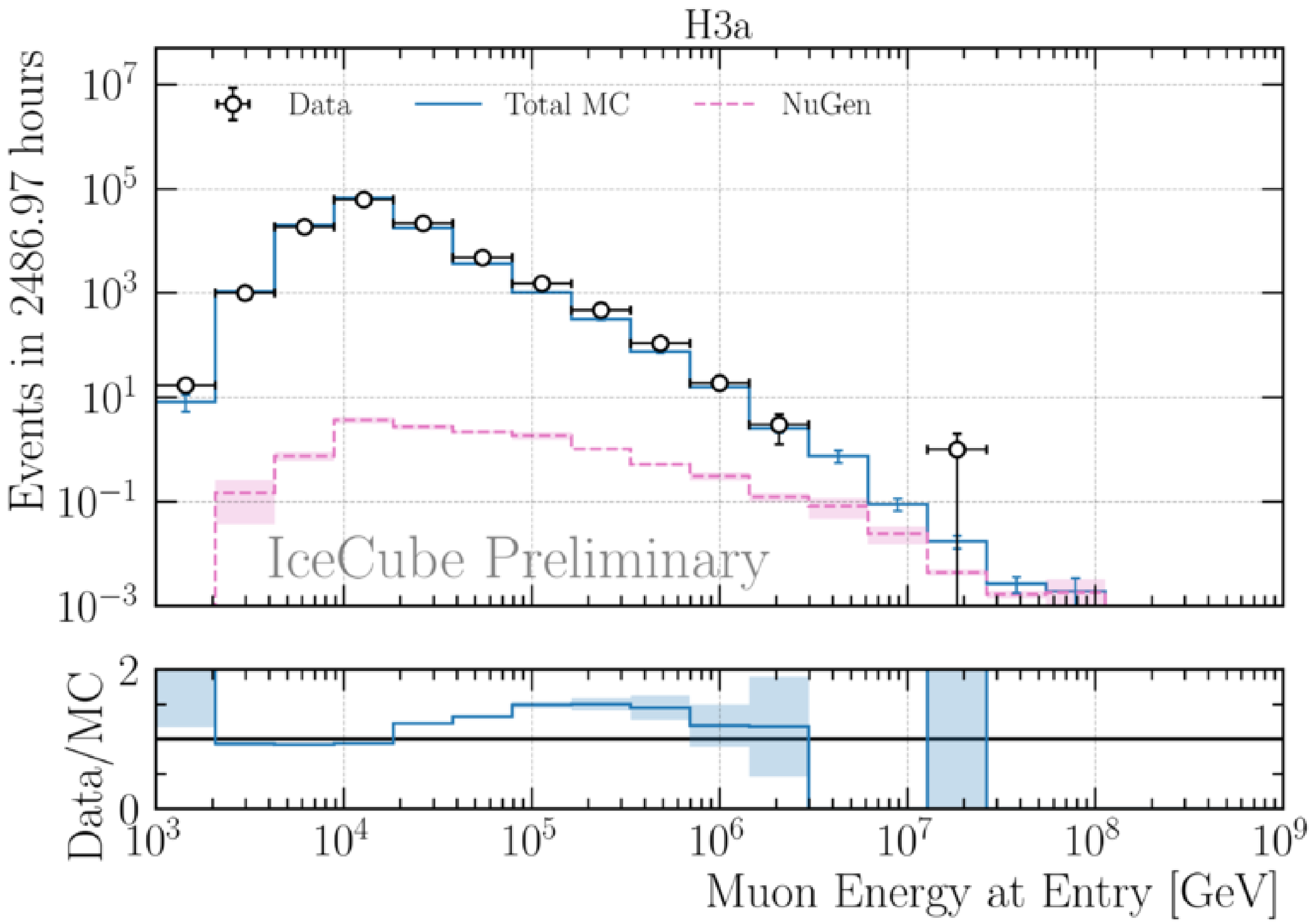

a) Vertical Stopping Depth.

b) Zenith angle.

Figure 1: Data--MC agreement for the reconstruction of the vertical stopping depth and the zenith angle. To match the total number of MC events with data, CORSIKA is up-scaled by a factor of 1.1.

# Data-MC: High Energy Muons

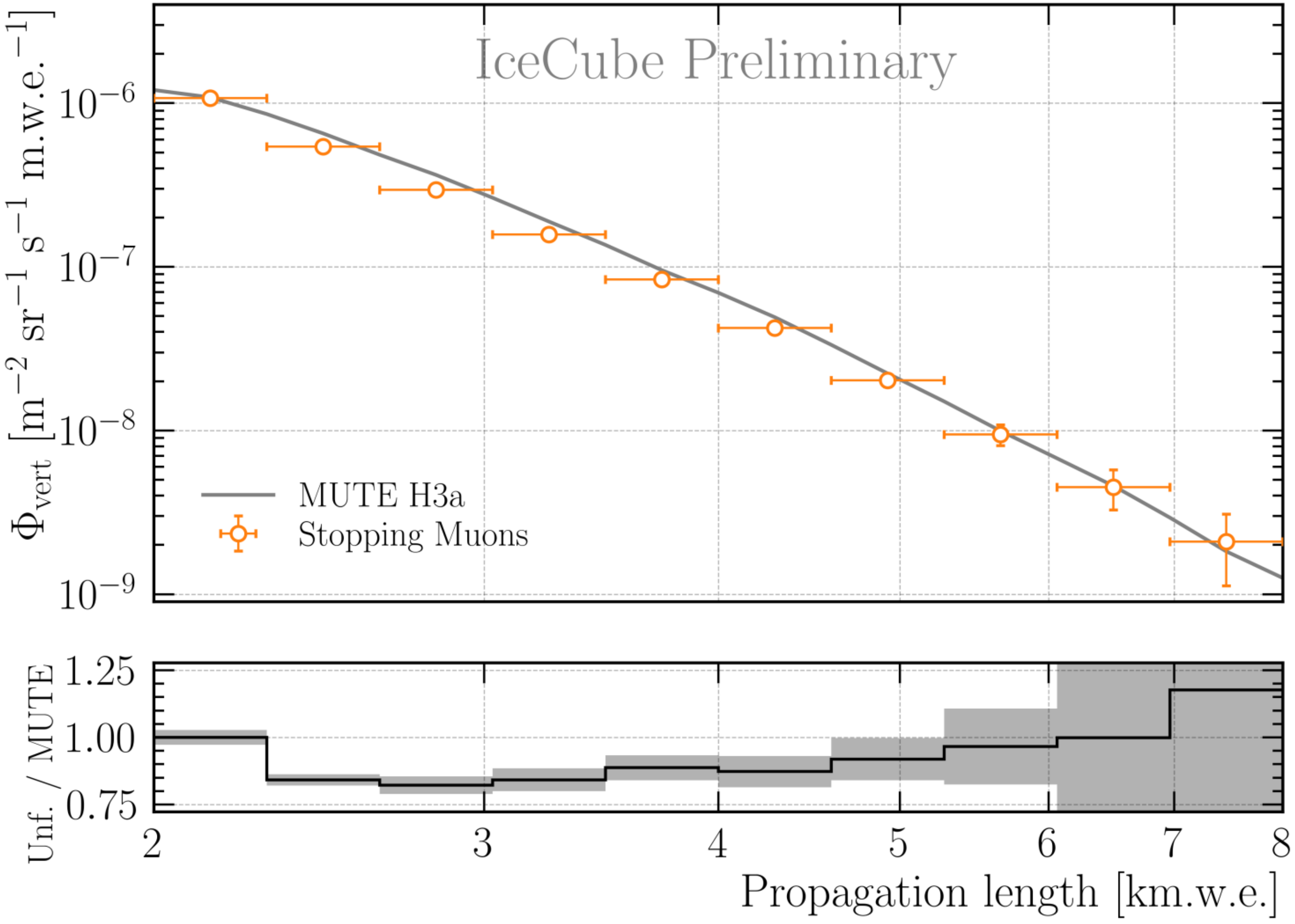
Figure 3: Data--MC agreement is shown for the reconstruction of the leading muon energy at the entry of the detector. Total MC includes the CORSIKA simulation and the neutrino simulation (NuGen) to estimate the background assuming a single power law \cite{DiffuseFluxIceCube2023}. To match the total number of MC events with data, CORSIKA is down-scaled by a factor of 0.82.




- Proxy variable for unfolding
- MC scaled by a factor of 0.82 (number events exp/MC)
- Use data up to 1 PeV

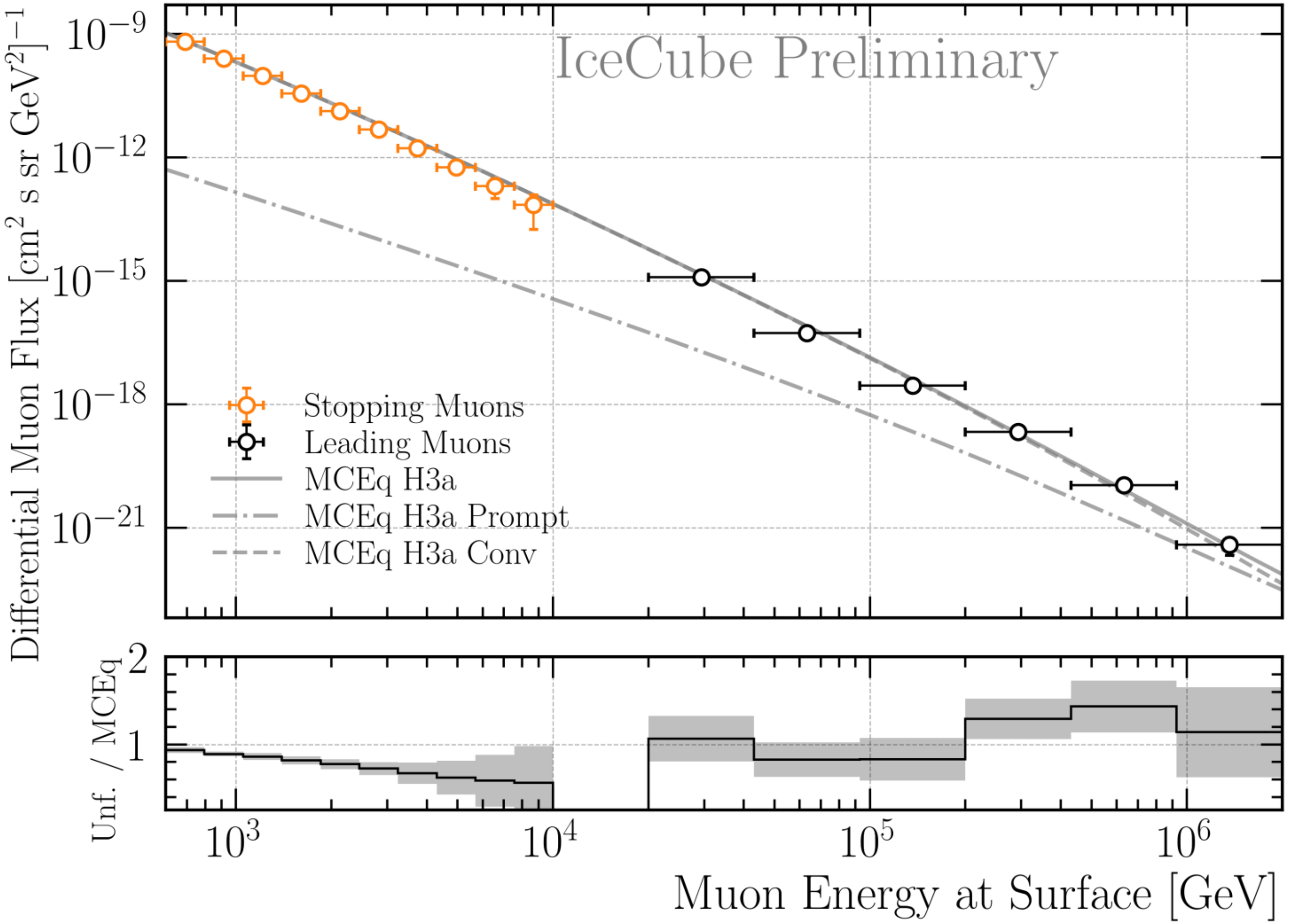
# Unfolding Propagation Length

Figure 4: Top: Unfolded depth intensity obtained from 0.78 h of IceCube data together with the expected result from MUTE \cite{mute}. Bottom: Ratio of the unfolded result to the MUTE prediction.



# Unfolding Muon Flux

Figure 5: Top: Unfolded muon flux at surface obtained from 2486.97 h of IceCube data together with predictions from MCEq. Bottom: Ratio of the unfolded result to MCEq prediction.



# Thank you for your comments