Measure Cosmic-ray from Different Zenith Angles with Half KM2A

Xishui Tian (田喜水)

tianxs@stu.pku.edu.cn

Department of Astronomy, Peking University

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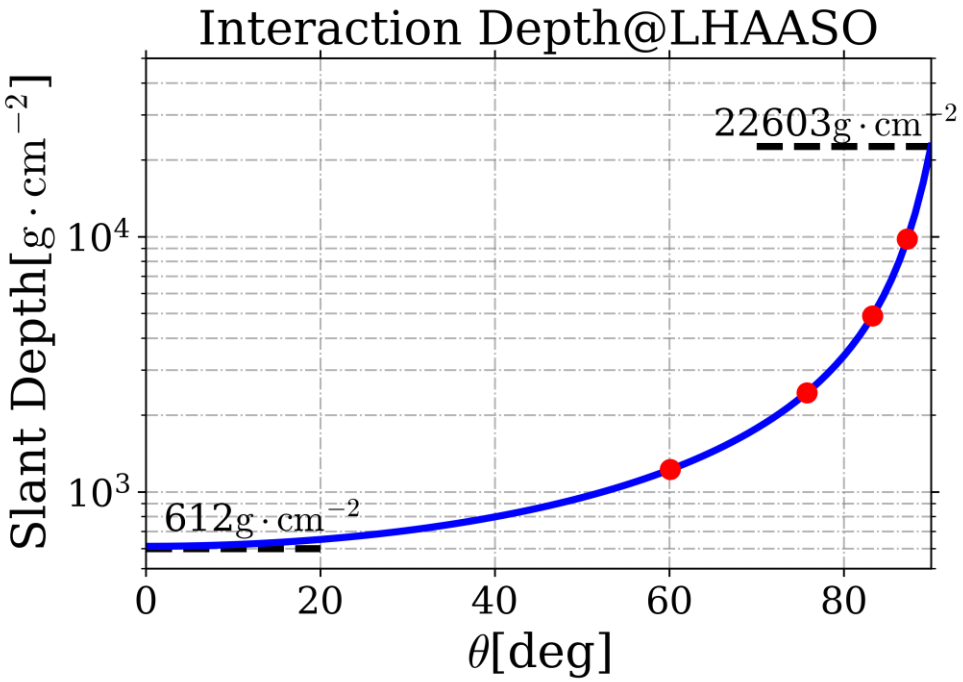
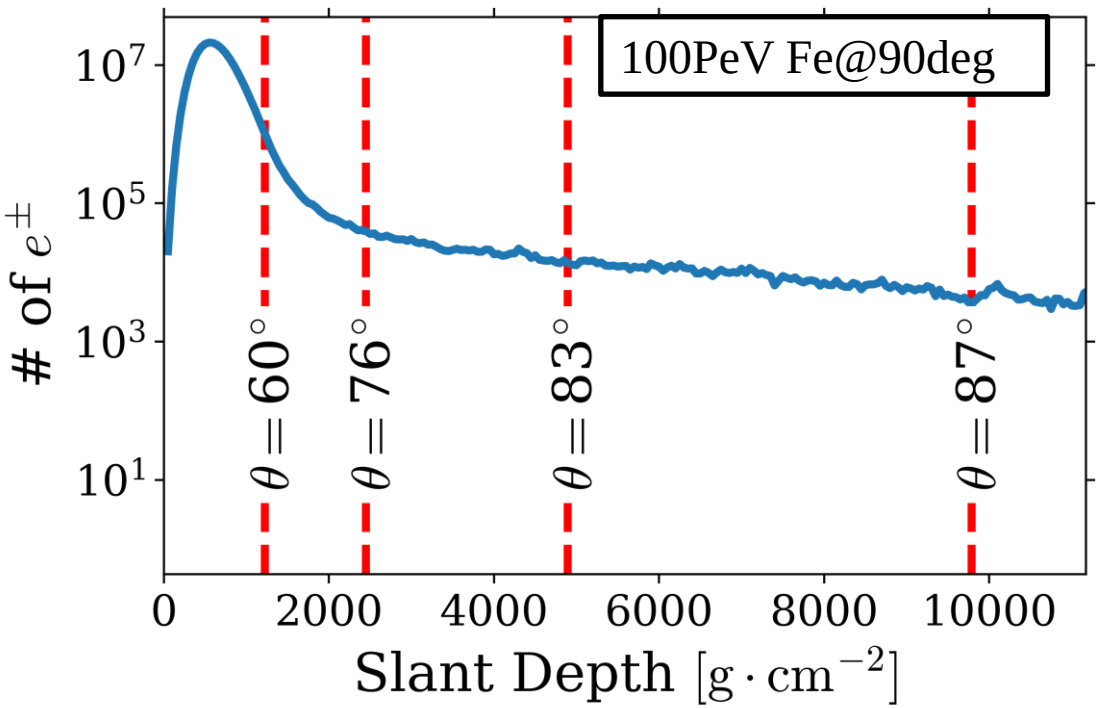
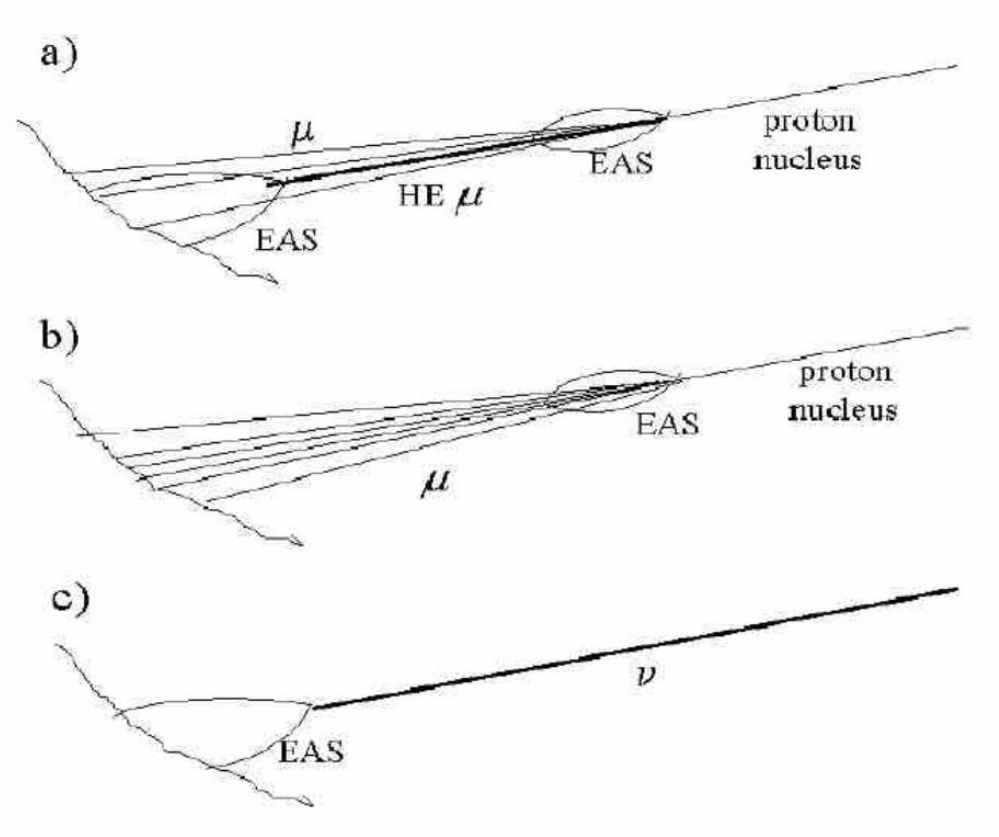
Introduction

- “Pathfinder” for analysis of events at large zenith angles (>60deg)
- From small zenith angles to large zenith angles





Motivation



Good for:

a) Searching for muon-induced showers

b) Studying cosmic-ray model around the knee
Studying hadronic interaction model

c) Searching for neutrino-induced showers

Data

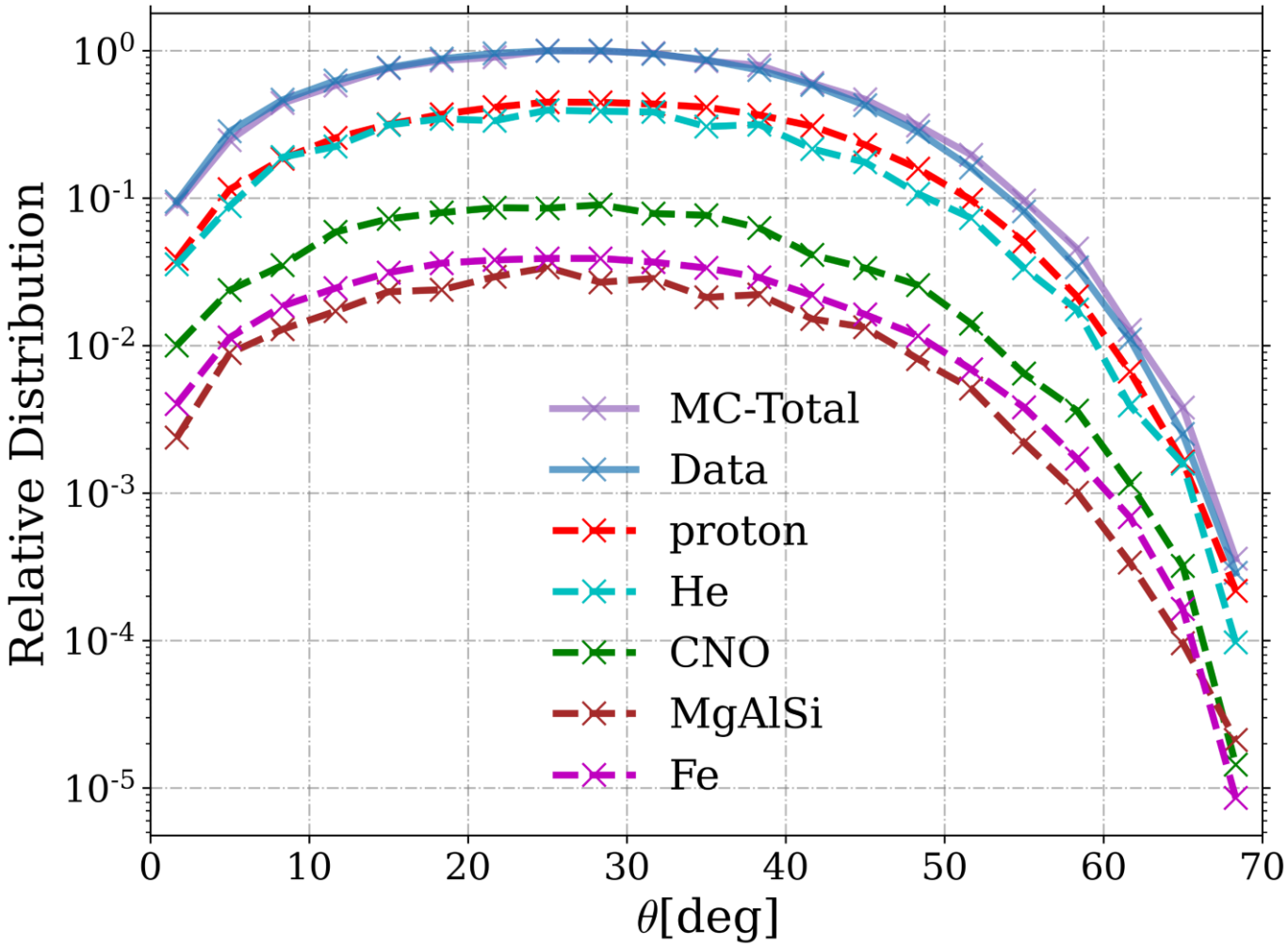
- Experiment data:
  Half KM2A
  1-day data from 2020.01.01
  83M events before cut

- Simulation
  From public directory
  Composition: p He CNO MgAlSi Fe
  Energy: 1TeV-10PeV
  Zenith Angle: 0-70 degree
  Interaction model: QGSII+gheisha
  Cosmic-ray model: Gaisser H3a

Cut: $\mathrm{dr} > 65, \mathrm{NpE1} > 100, \mathrm{NuM1} > 10, \mathrm{NtrigE} > 50, 1.1 < \mathrm{age} < 2, \mathrm{NpE1} > 2\mathrm{NpE2}$

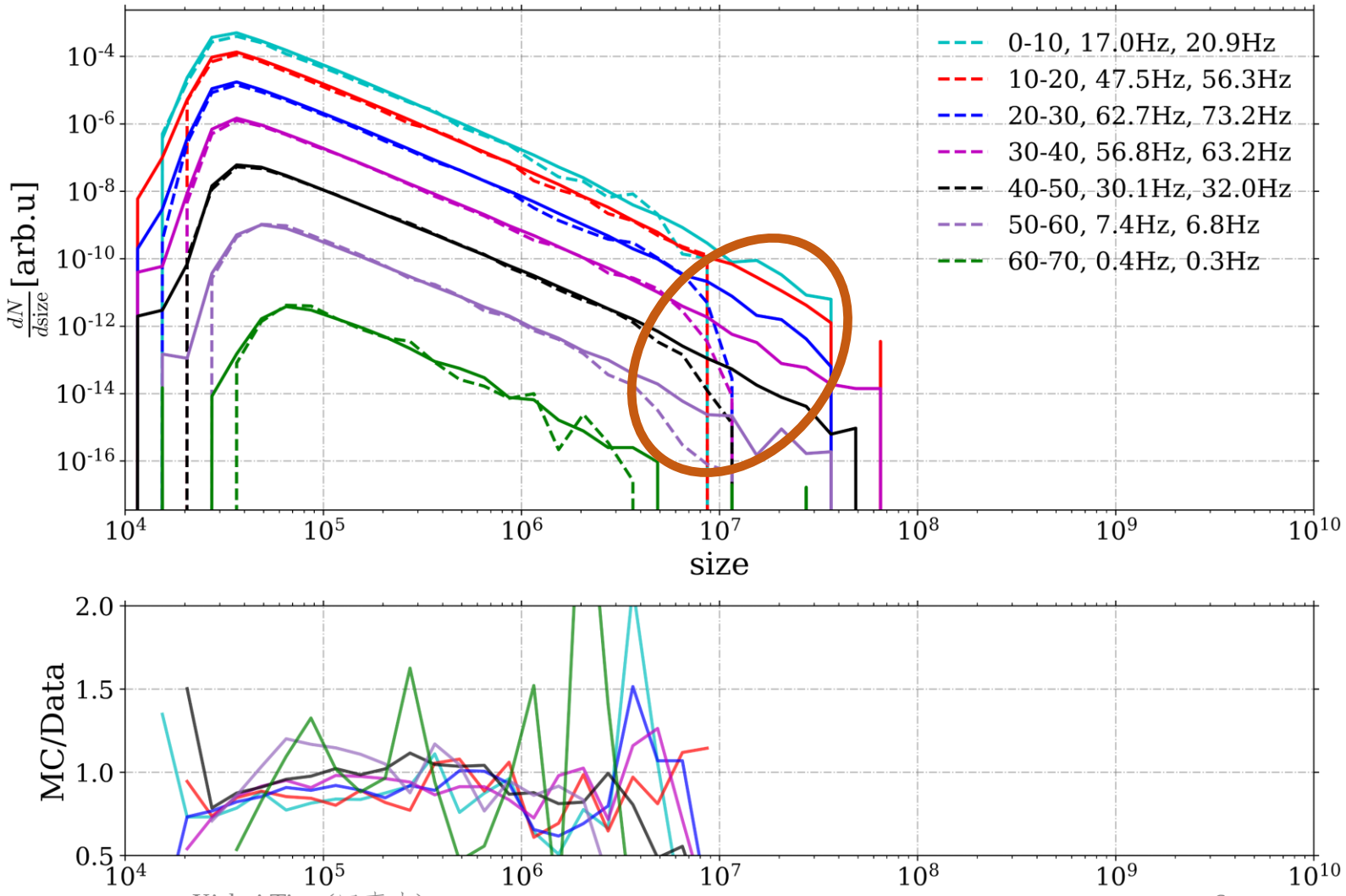
Zenith Angle Distribution

- Rapid decay at large zenith angles
  - ➢83M events per day, 68k events with reconstructed zenith >60deg (0.8‰).
- Dominated by proton and helium within 70deg
  - ➢Increasing contribution from heavier compositions at large zenith angles



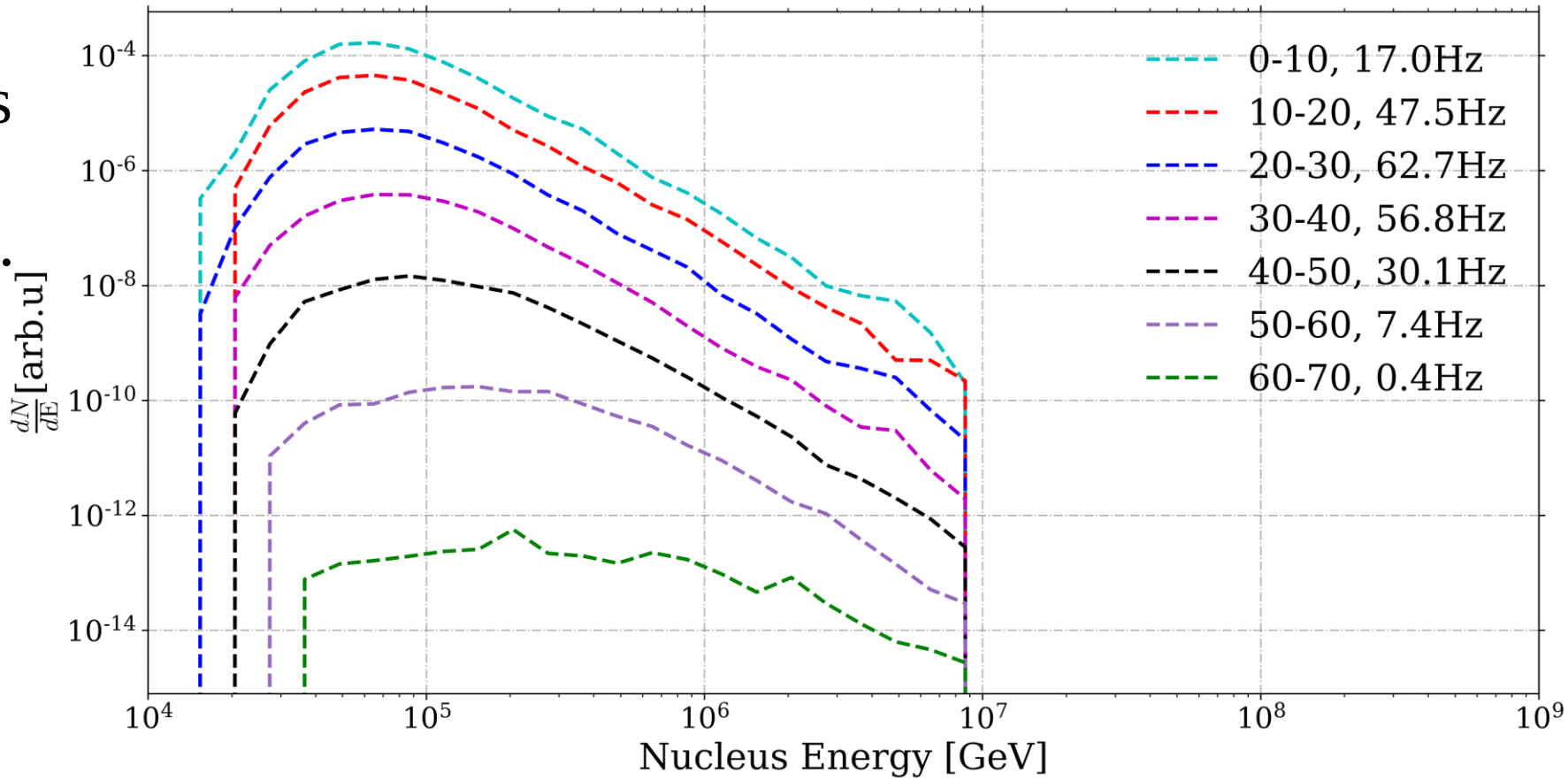
Size Spectrum of ½ KM2A

- Solid: data, dashed: MC
- Different curves are scaled for visualization.
- Upper limit of simulation energy causes the deficiency at large size end.

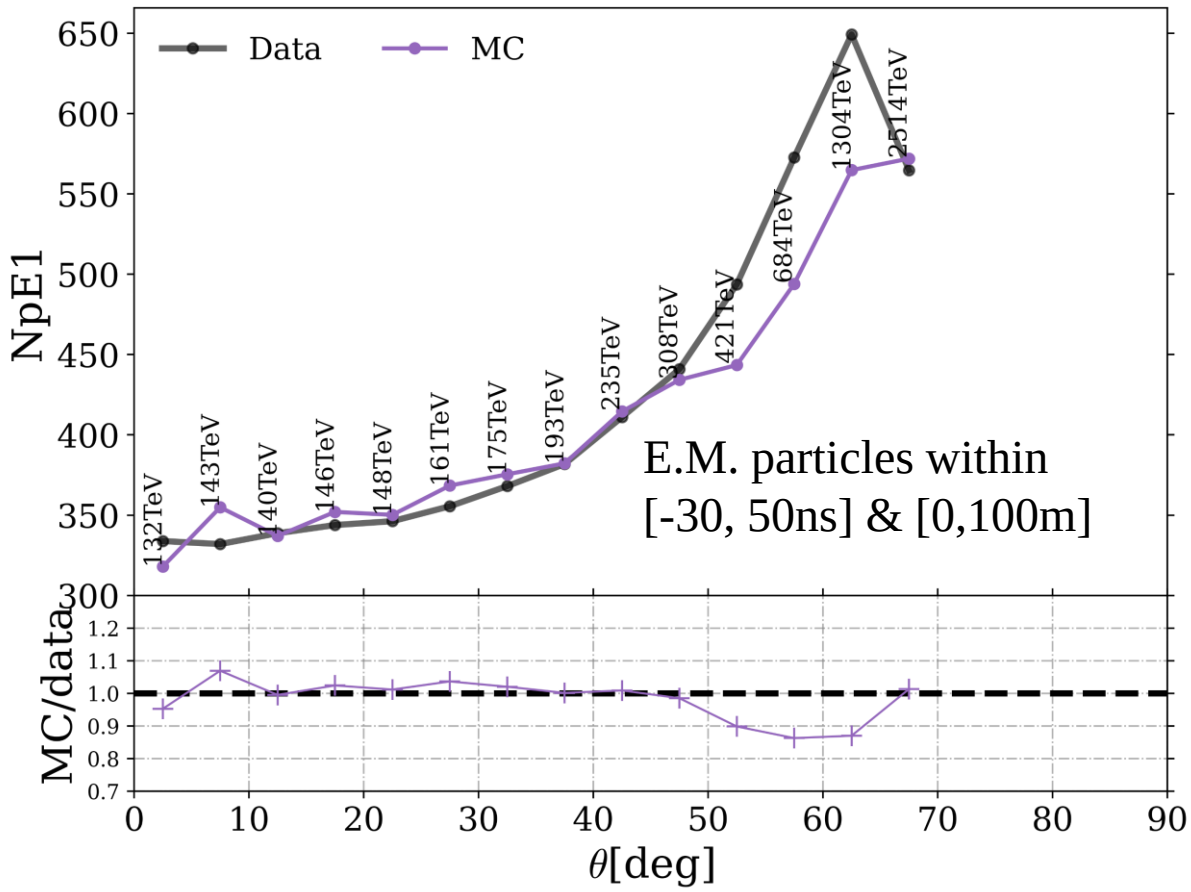


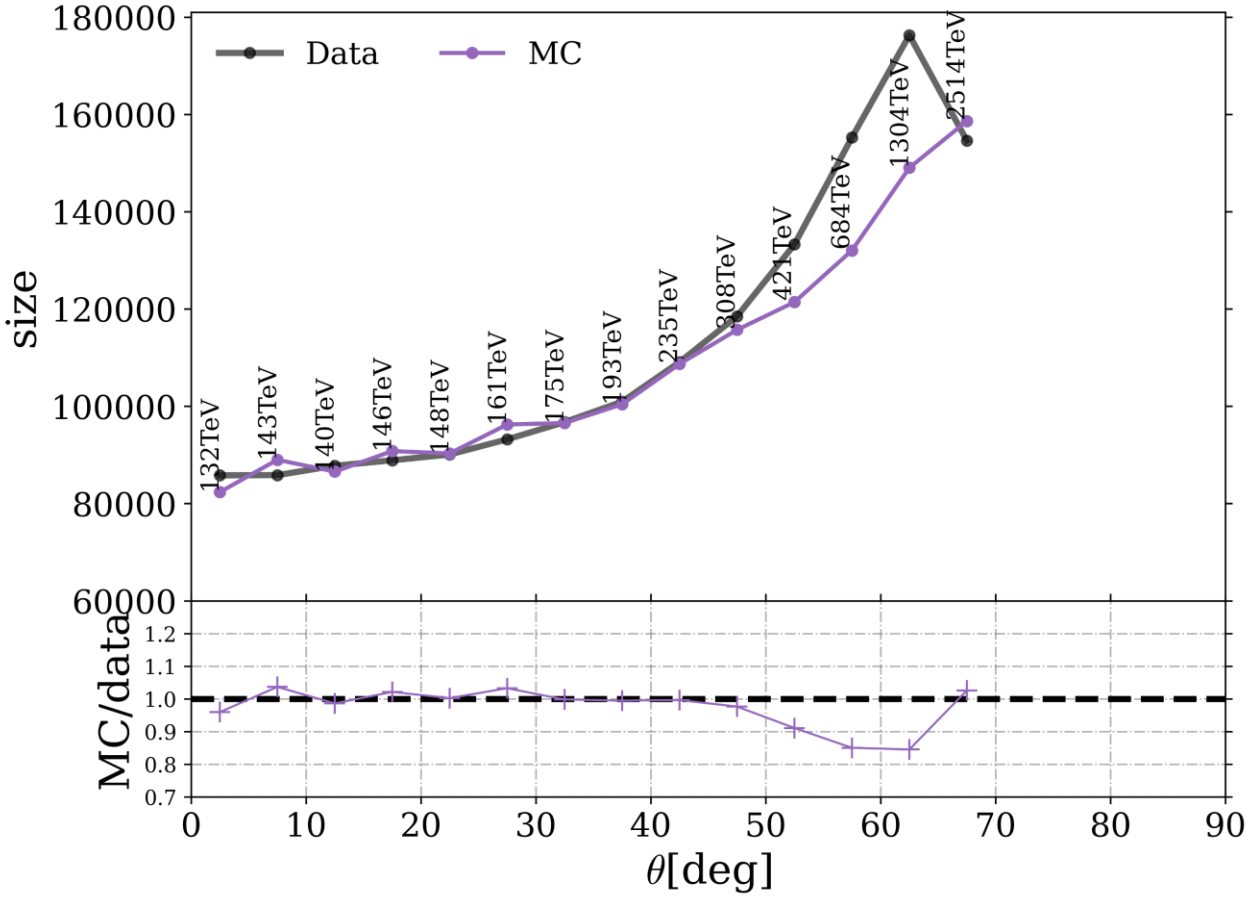
Energy Spectra from Simulation

- The absorption of atmosphere causes the hardening of the energy spectra.
- At large zenith angles (>60deg), full efficiency is obtained above 1PeV.



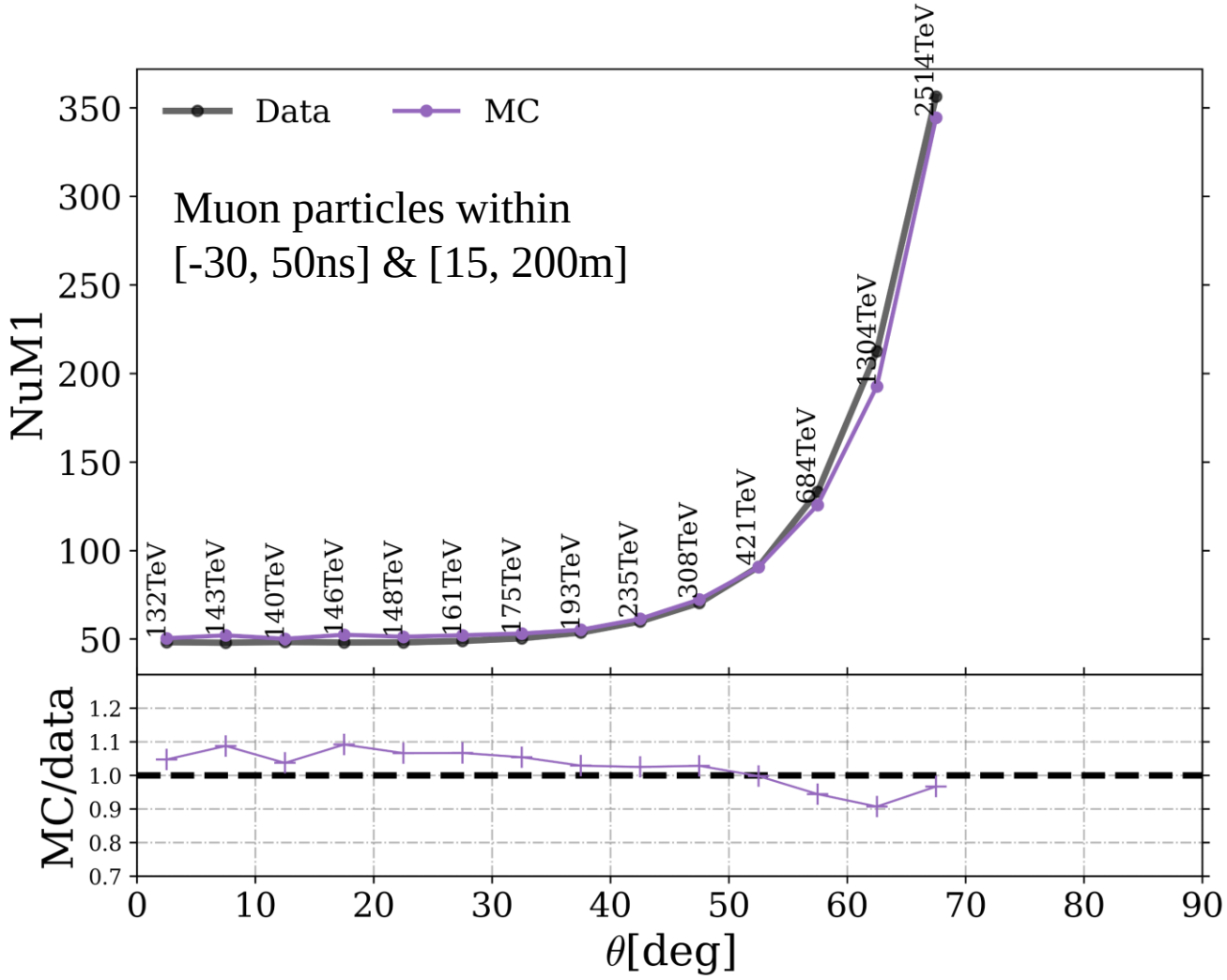
Average Value





Average Value

- ⟨NpE1⟩, ⟨size⟩ and ⟨NuM1⟩ are consistent below 70deg between MC and data within 10%.
- There is a decrease (pit) in MC/data above 50deg.

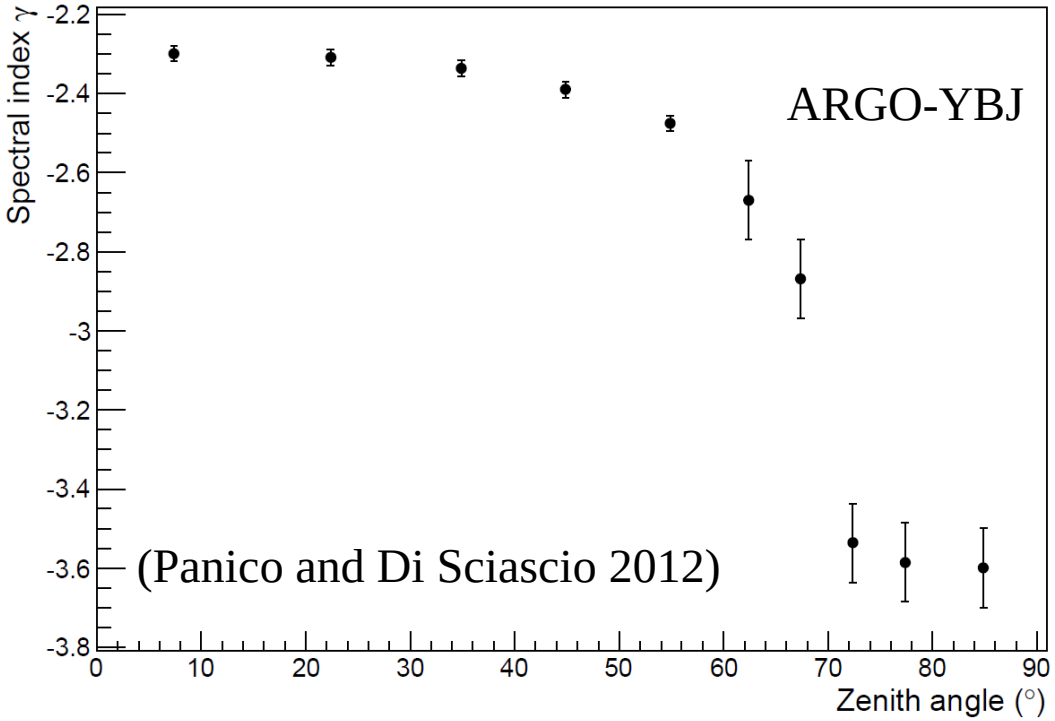


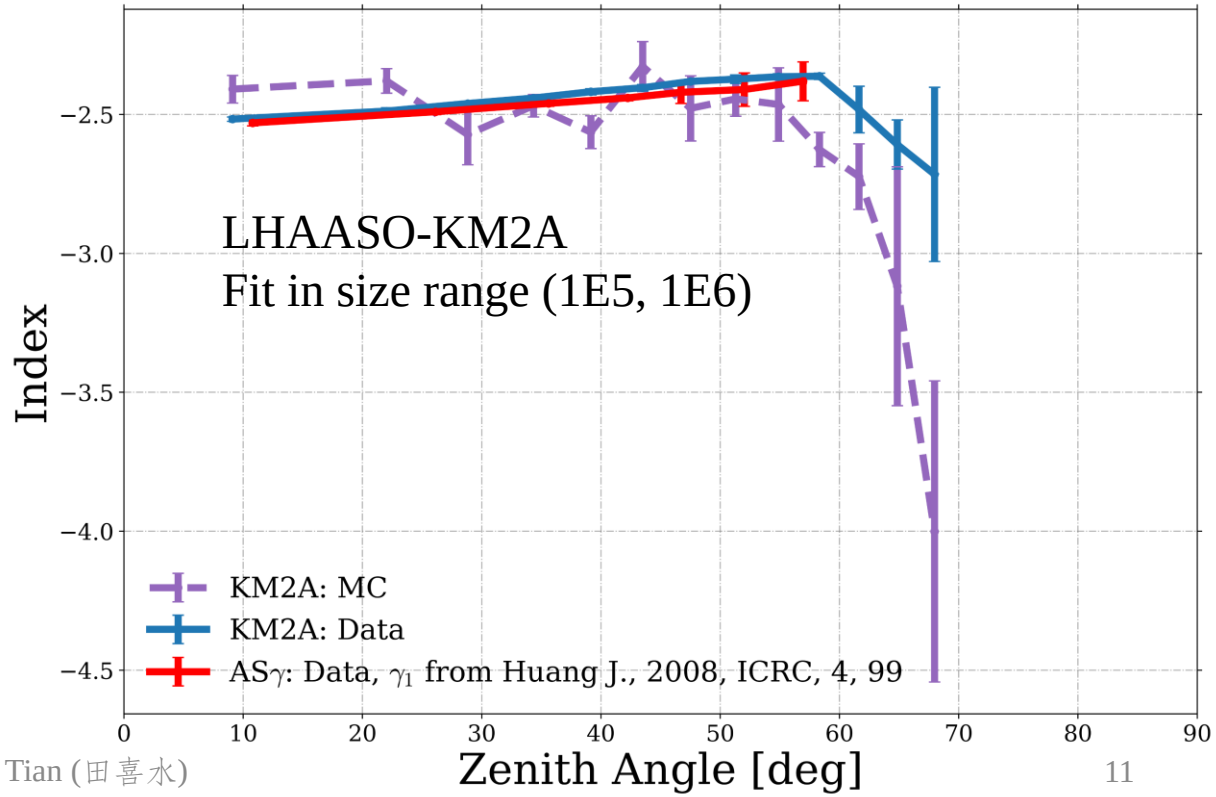
Possible Explanations of the Pit

- Absence of high energy simulation
  With a **harder spectra** at larger zenith, the contribution from high energy showers are increasing. Lack of high energy showers results in a MC/data ratio smaller than 1.
- Compositions around the knee
  The analysis is based on Gaisser H3a model. At large zenith angles (>60deg), the average energy of observed events are around the knee.

Index vs. Zenith Angle

- **Index of size spectrum** within 60deg is in marginal agreement between MC and data.
- Different from ARGO, consistent with ASγ (within 60deg)

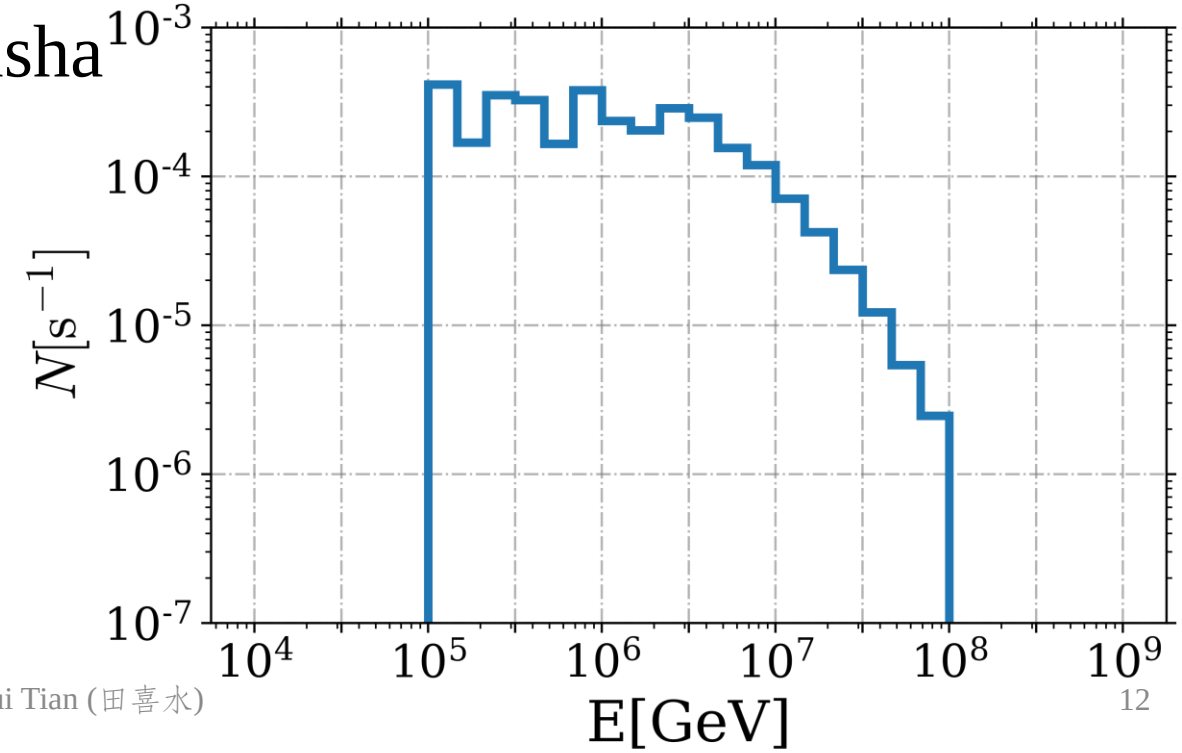




Progress on HAS Simulation

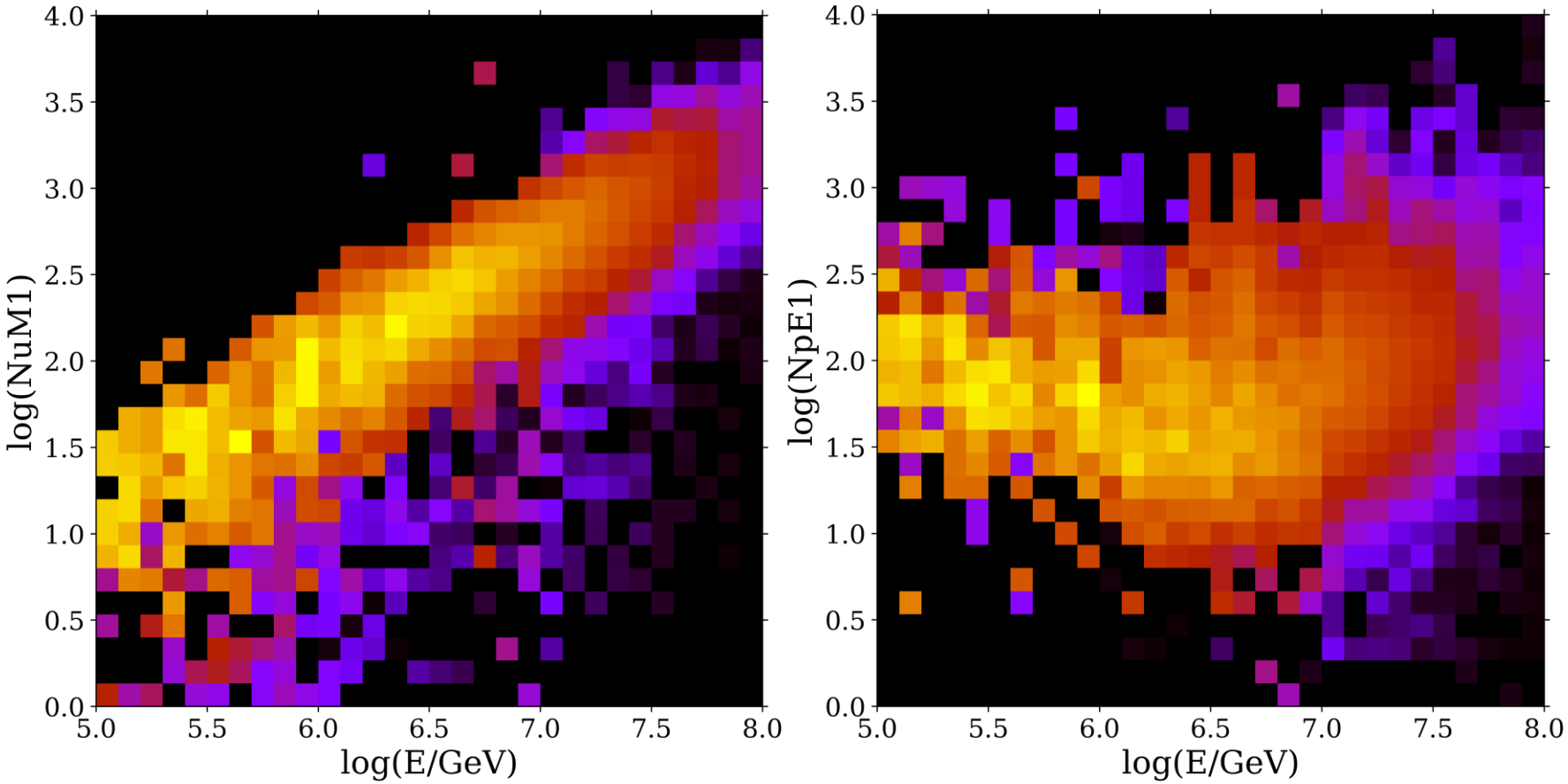
Collaborators: Qinyuan Zhang (PKU), Zihan Yang (IHEP)

- **Proton** showers at large zenith angles are produced with **CURVED** option in CORSIKA.
- **THINNING** algorithm is used for showers >10PeV.
- Interaction model: QGSII + gheisha
- Energy: 100TeV-100PeV
- Zenith angle: **70-89 degree**
- 14868 events (unweighted)



Proton Showers Above 70deg

- No cut applied
- Correlation of NuM1-E is better than NpE1-E relation at large zenith angles
- From data, there are around 1000 events/day with NuM1>100 above 70deg for half KM2A.



Summary

1. MC and data are in good agreement within 70deg for half KM2A (despite of a pit around 50deg).
2. Energy spectra is hardening towards large zenith angles.
3. Simulation of >10PeV showers should be considered at large zenith angles.
4. Simulations of all compositions at large zeniths (up to 100PeV) have been conducting.