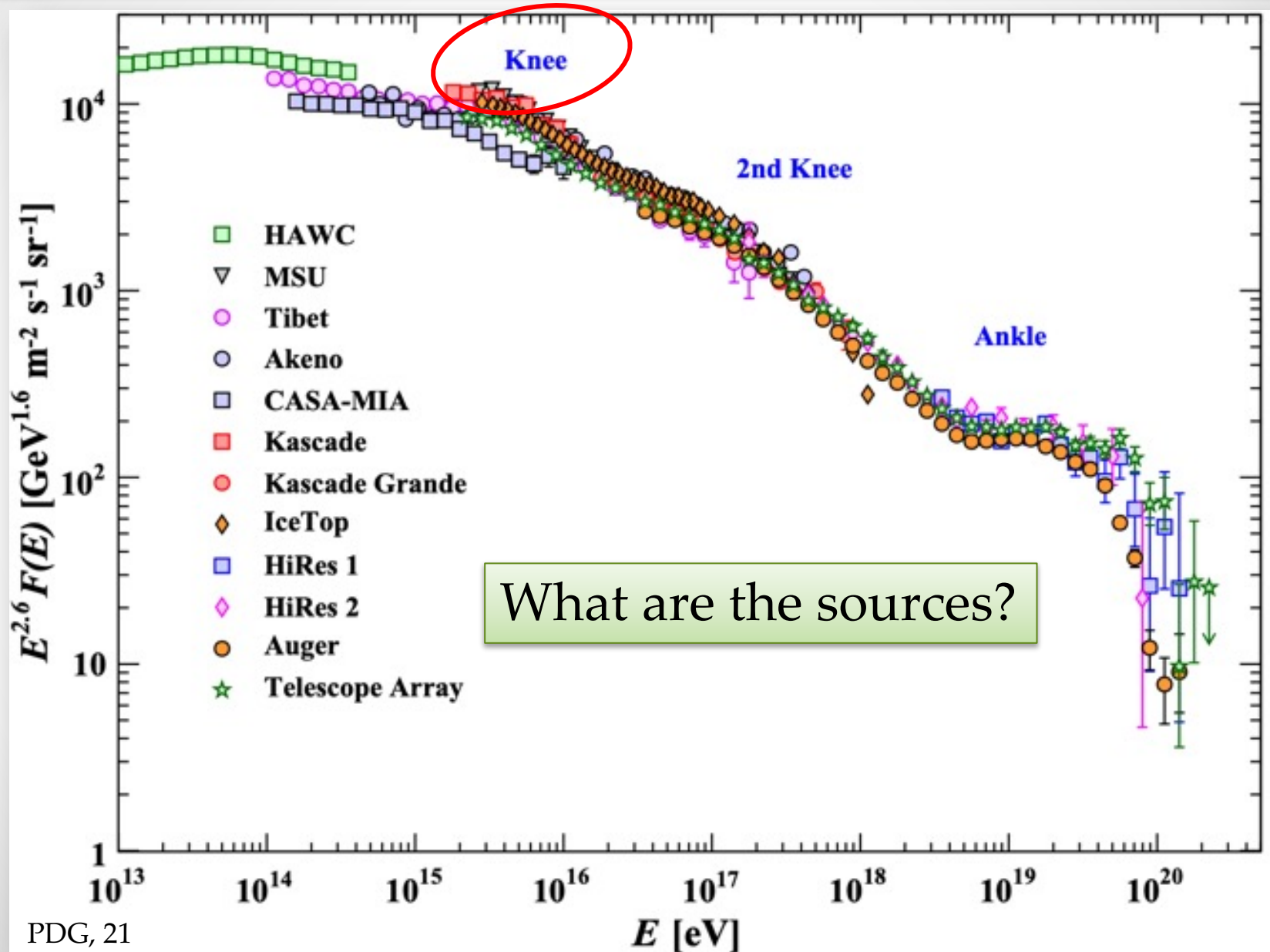# High-pT Muons in Cosmic-Ray Air Showers

Shirley Li (Fermilab)

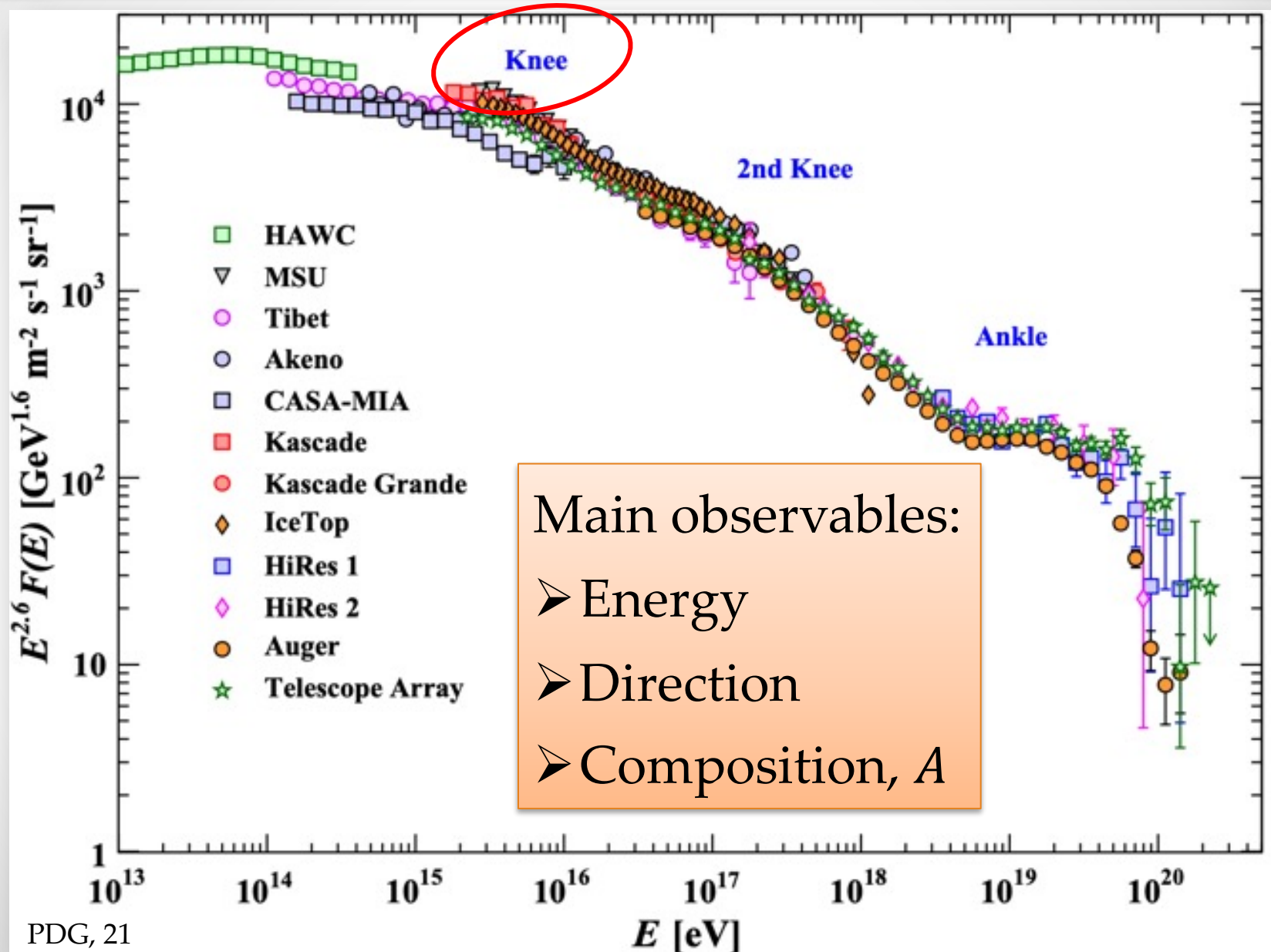# Cosmic-Ray All-Particle Spectrum

# Cosmic-Ray All-Particle Spectrum

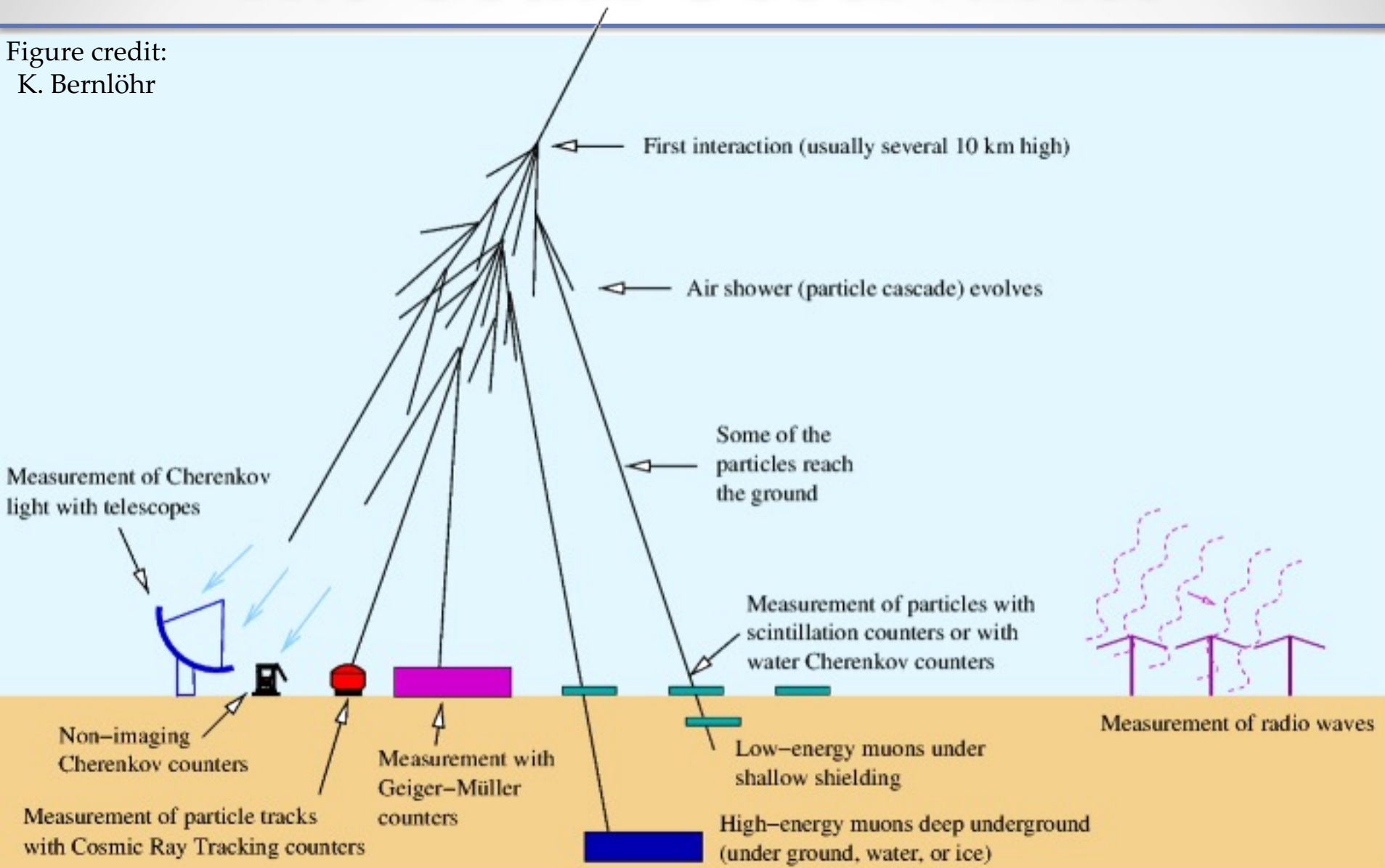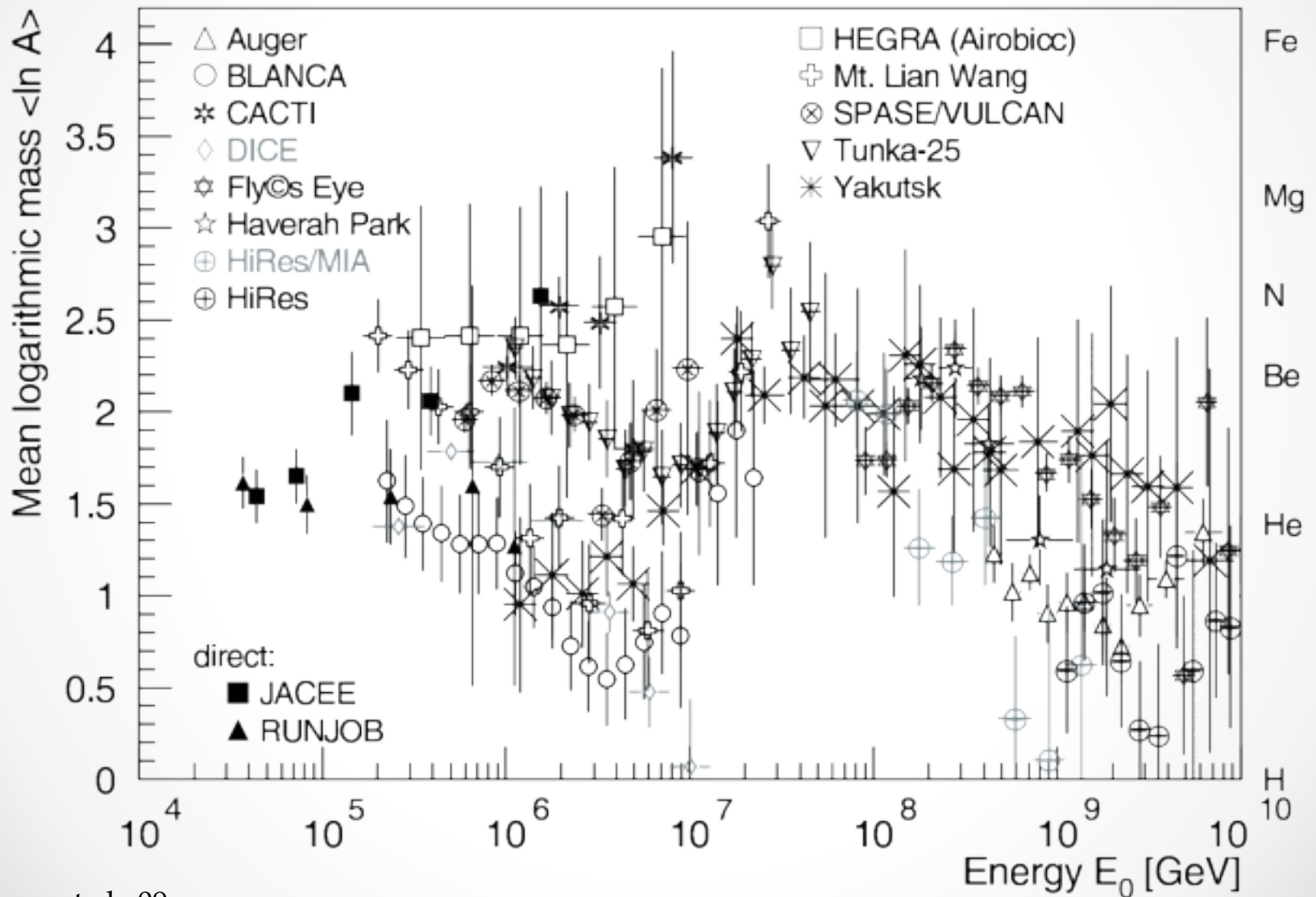# Cosmic-Ray All-Particle Spectrum



Main observables:

➢ Energy

➢ Direction

➢ Composition, *A*

Figure credit:
 K. Bernlöhr



First interaction (usually several 10 km high)

Air shower (particle cascade) evolves

Some of the
particles reach
the ground

Measurement of Cherenkov
light with telescopes

Measurement of particles with
scintillation counters or with
water Cherenkov counters

Non–imaging
Cherenkov counters

Measurement with
Geiger–Müller
counters

Measurement of particle tracks
with Cosmic Ray Tracking counters

Low–energy muons under
shallow shielding

Measurement of radio waves

High–energy muons deep underground
(under ground, water, or ice)

## Sensitive to forward physics

# Large Uncertainties



Blümer et al., 09

Figure credit:
  IceCube

IceCube, 20

IceCube
SOUTH POLE NEUTRINO OBSERVATORY

50 m

IceTop

IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison

86 strings of DOMs, set 125 meters apart
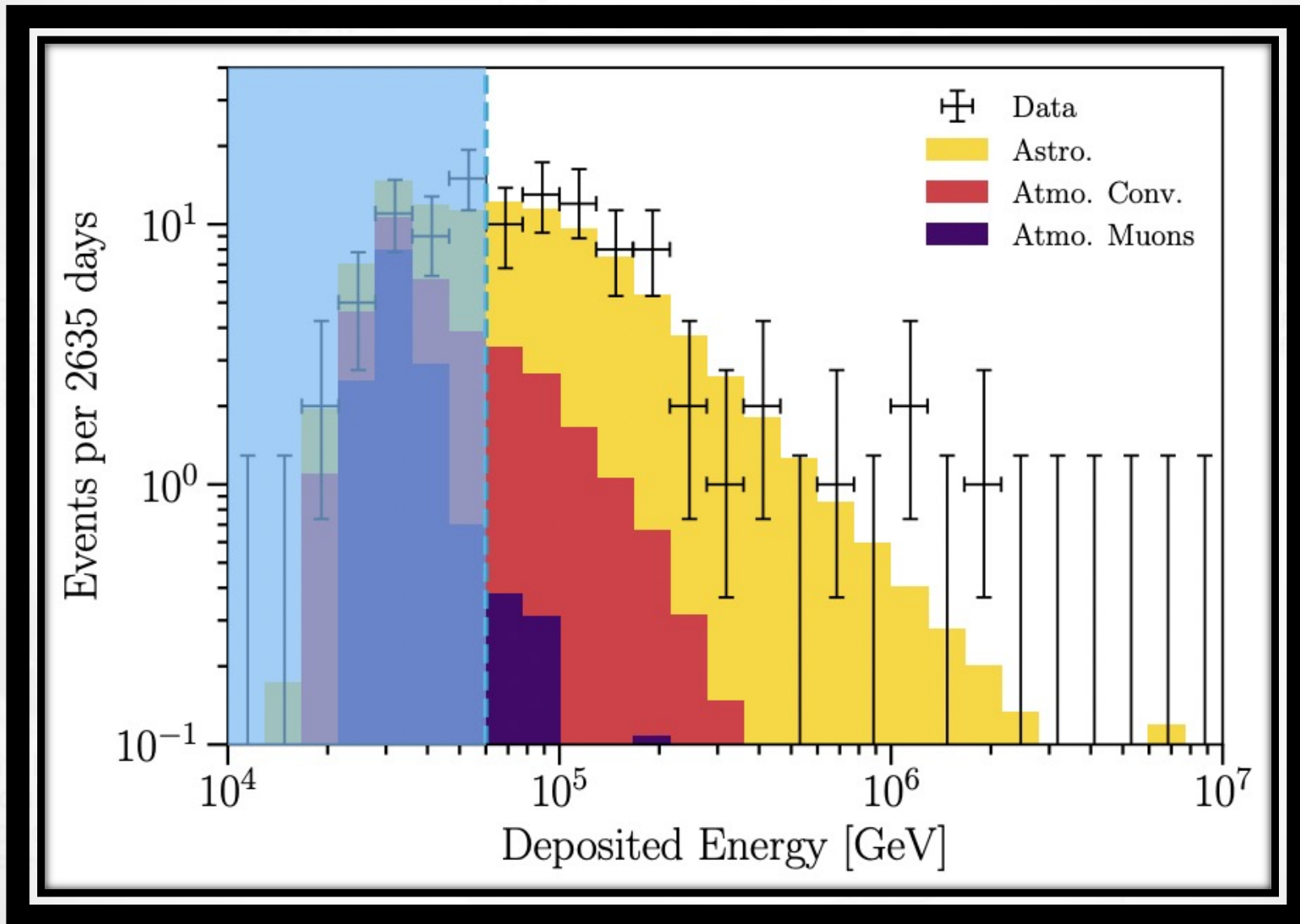
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility

1450 m

60 DOMs on each string

Digital Optical Module (DOM)
5,160 DOMs deployed in the ice

IceCube detector

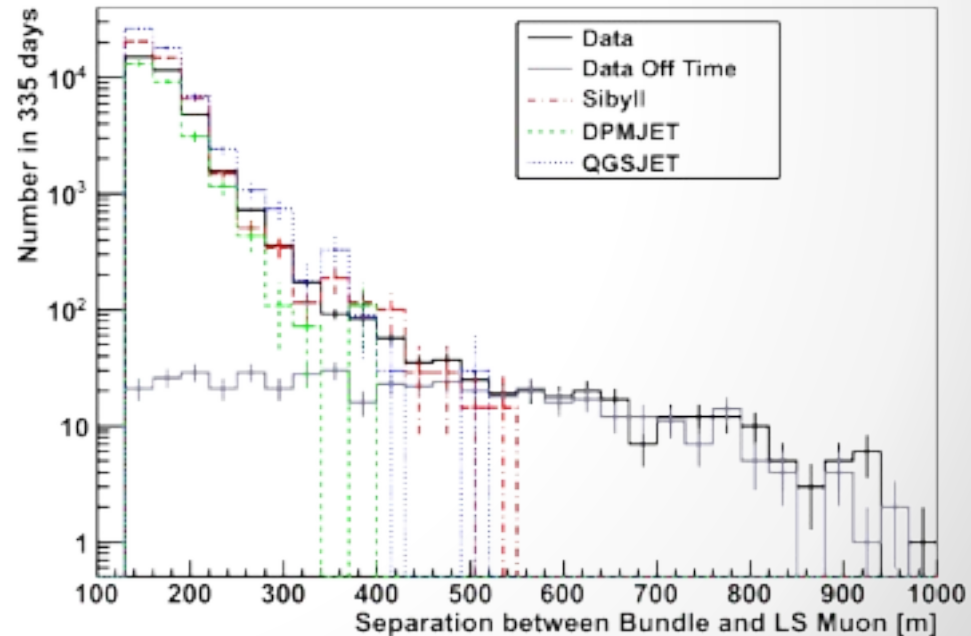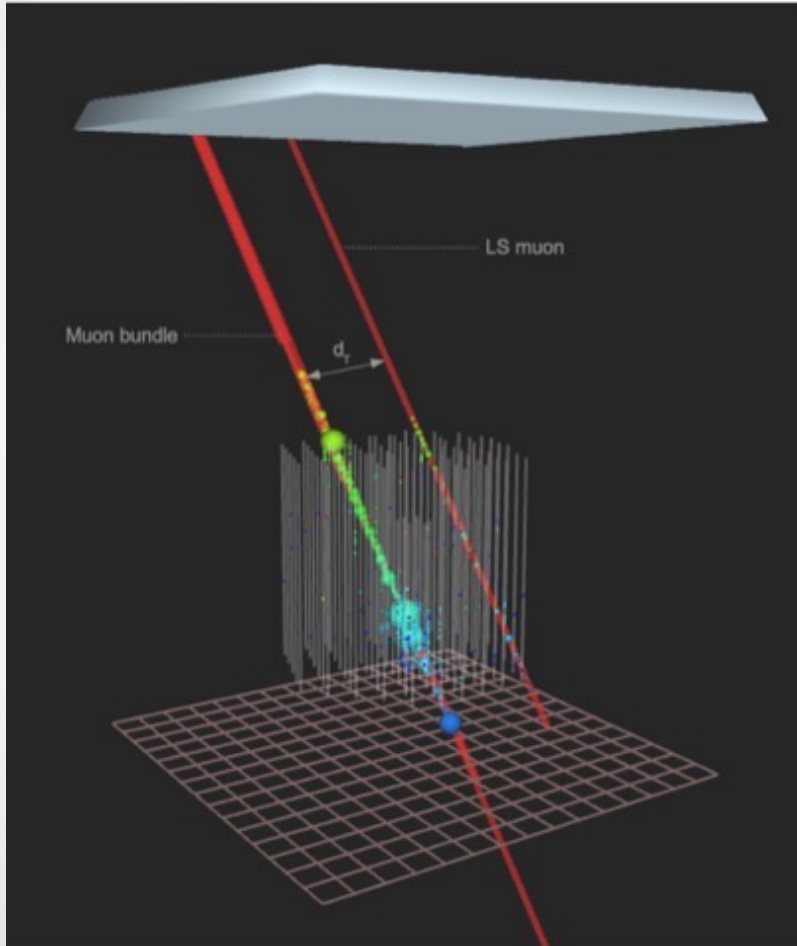DeepCore

DOMs are 17 meters apart

2450 m

Antarctic bedrock

Figure credit: IceCube

# High pT Muons

$$p_T = \sqrt{p_x^2 + p_y^2} \text{ for shower along z direction}$$



Muons far away from shower cores



IceCube, 12

Largely depend on pQCD

# Puzzling Discrepancy

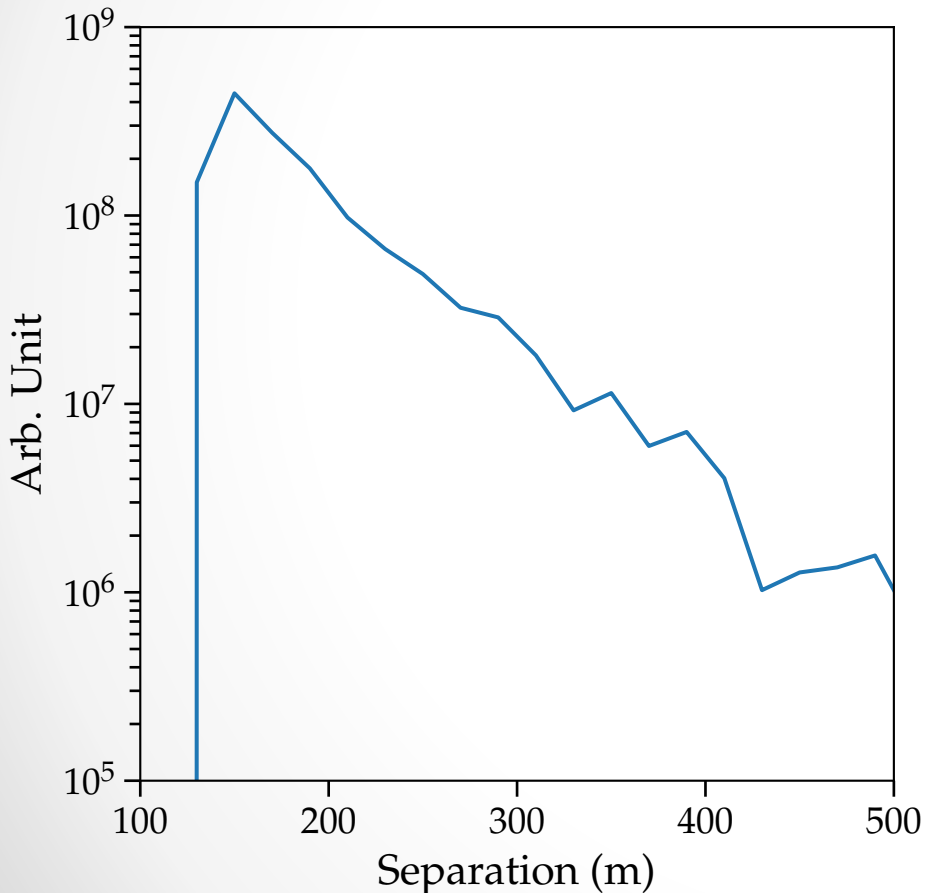Angular distributions of showers
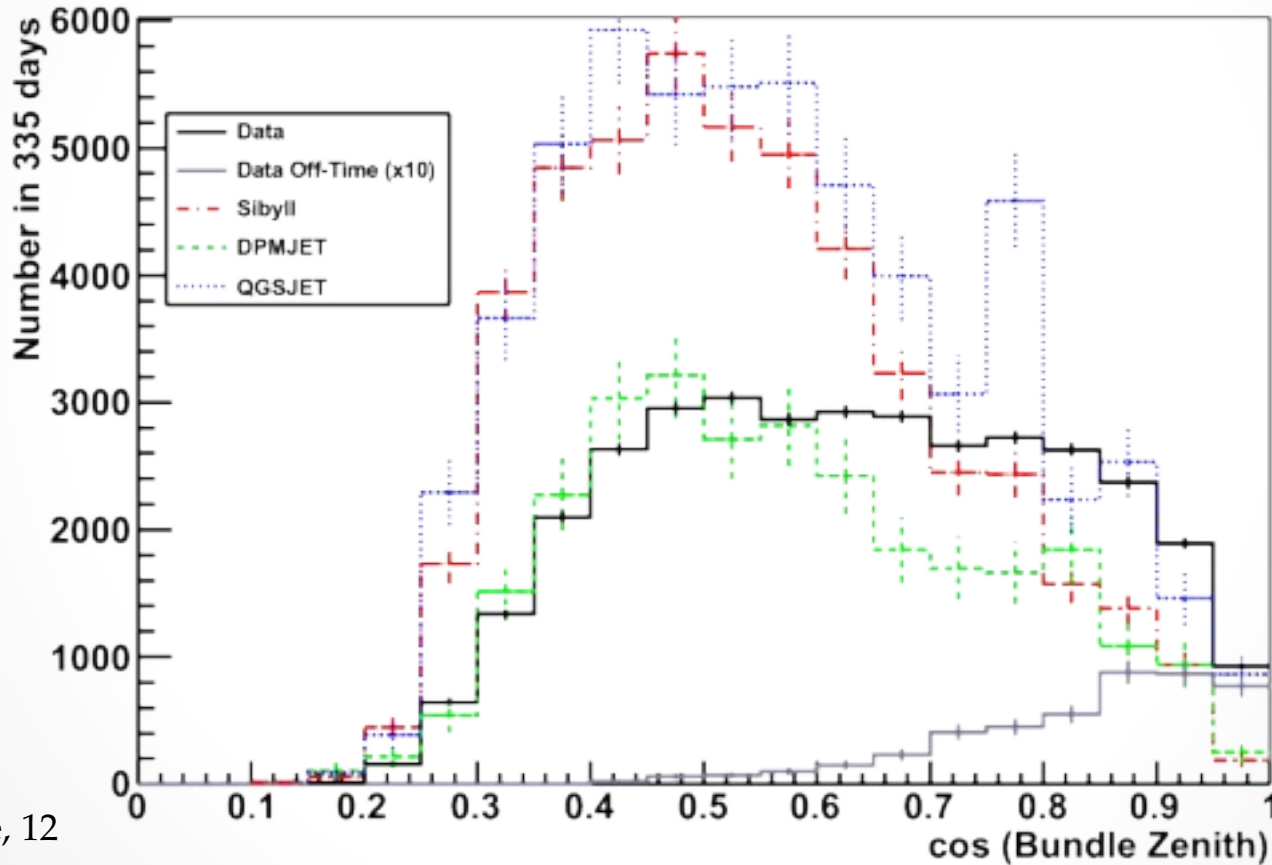


IceCube, 12

Disagreement between theoretical predictions and data
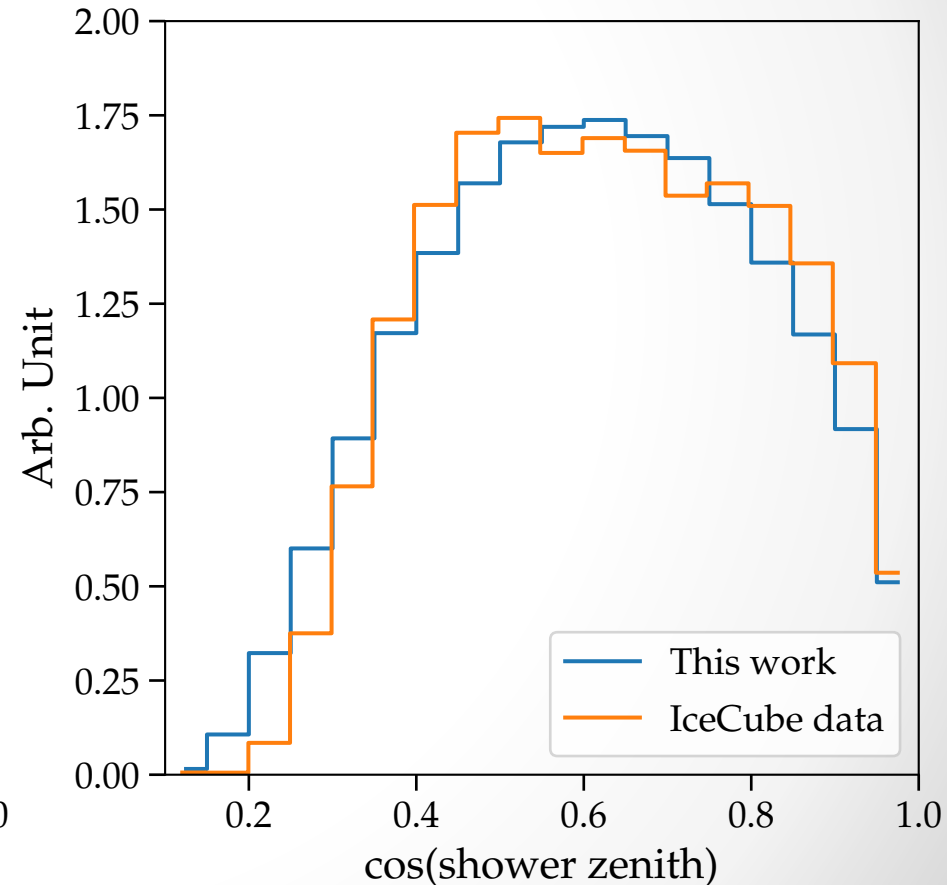
MY MUONS

# PRELIMINARY Results

## Muon separation



## Shower angle



Reasonable agreement with data

# Conclusions

1. Cosmic-ray composition is an important observable

2. Measurements suffer from large non-perturbative uncertainties

3. High-pT muons are promising observables

4. Aim to resolve discrepancy in angular distribution to utilize for composition measurement

# Thank you

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