Institute of High Energy Physics
Chinese Academy of Sciences

The 10th International Workshop on Air Shower Detection at High Altitudes

Cosmic ray spectral measurement around the knee with LHAASO experiment

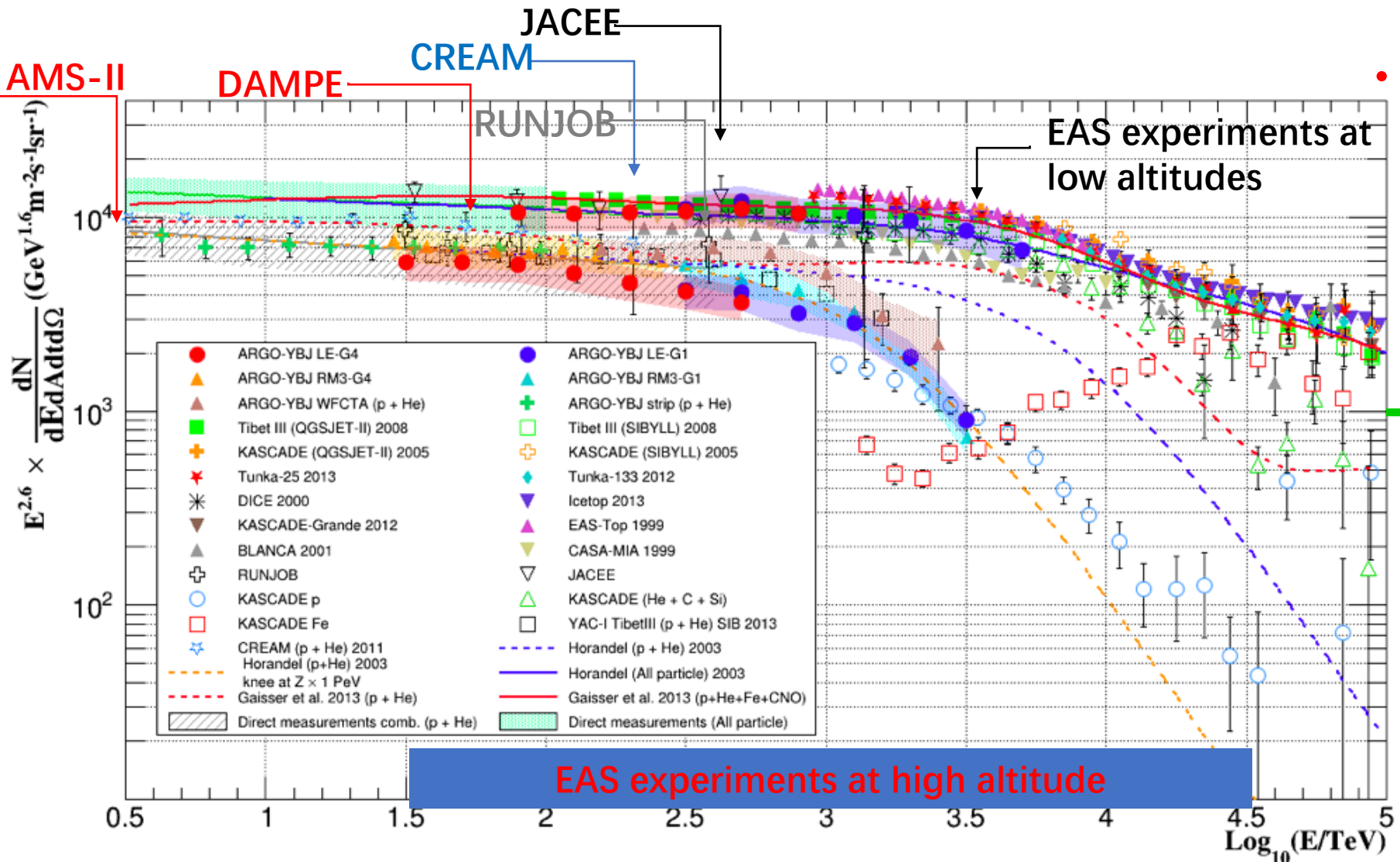
Lingling Ma for LHAASO Collaboration

2020.01 Nanjing

Outline

- Status of cosmic ray spectral measurement
- Introduction of LHAASO
- Energy calibration of LHAASO
- All-particle cosmic ray energy spectrum with LHAASO-KM2A
- Prospect of the knees of proton and helium
- Prospect of the knees of heavy or iron nuclei
- summary

Status of cosmic ray spectra measurement



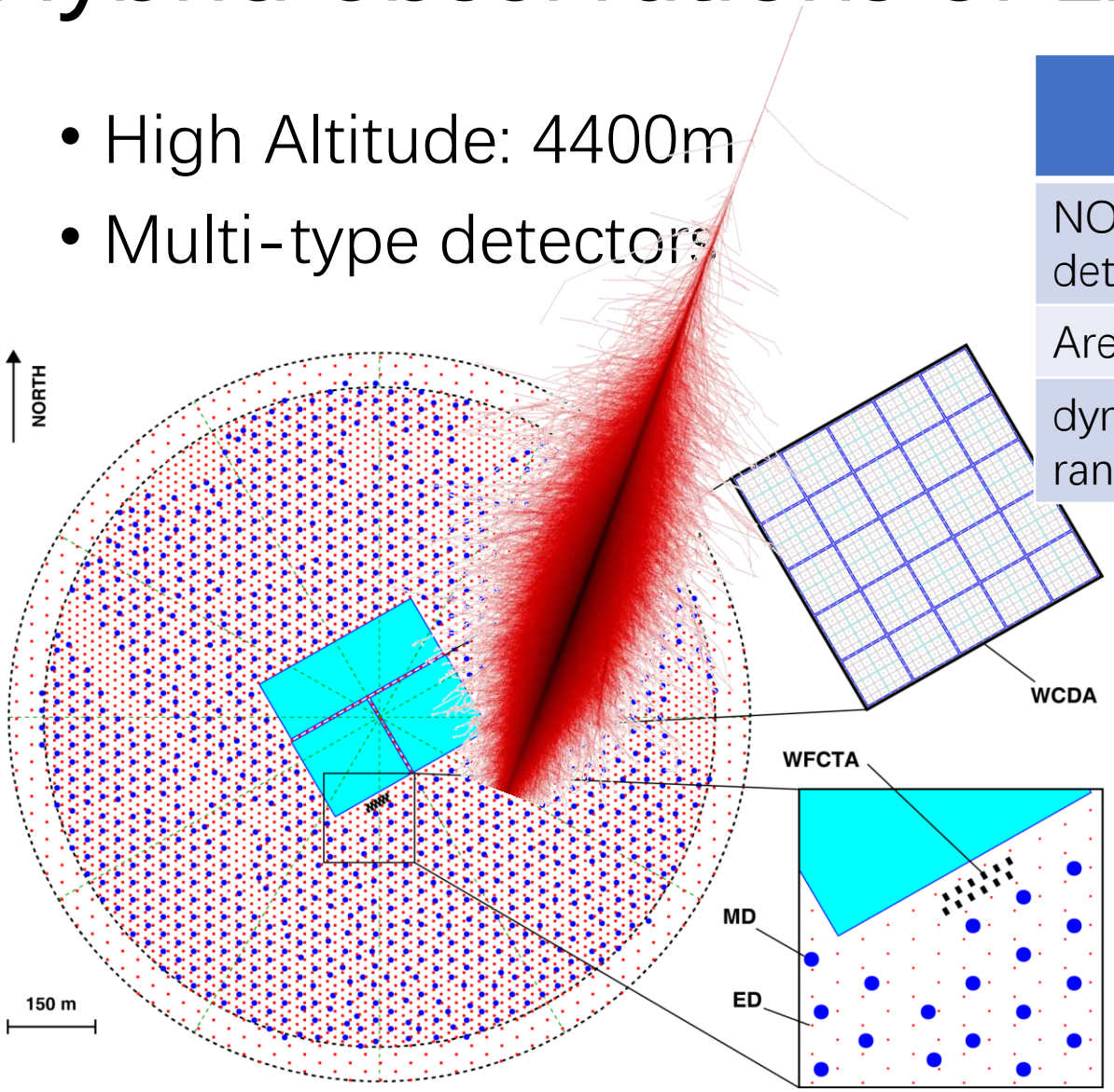
- Go to high altitudes
  - Reduce the energy threshold and get the energy scale
- Multi variable measurements
  - To get the individual composition spectra

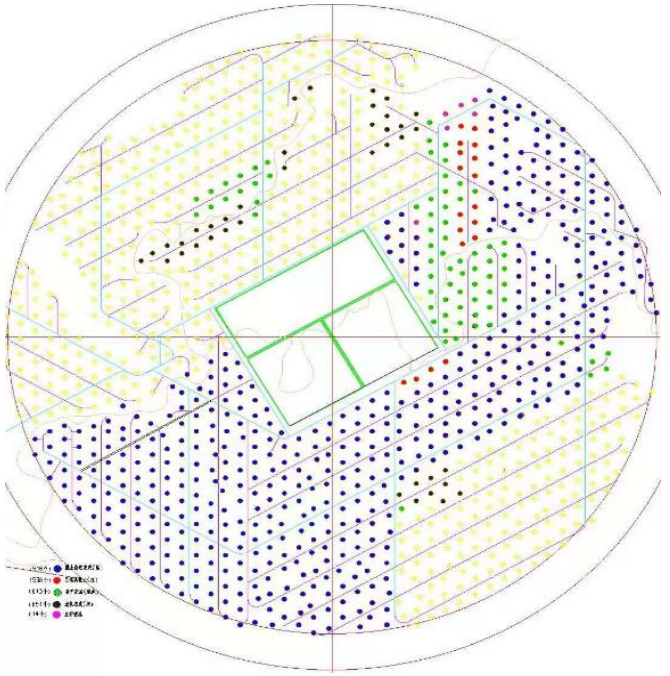
That is LHAASO

Hybrid observations of LHAASO

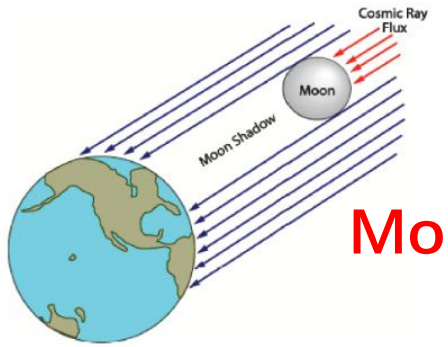
- High Altitude: 4400m
- Multi-type detectors

	WCDA WCDA++	KM2A		WFCTA
		EDA	MDA	
NO. of detector	3120cells	5195	1171	20
Area	3120X25m^2	1km^2	1km^2	0.06X20Sr
dynamic range	10TeV ~10PeV	100TeV ~100PeV	100TeV ~100PeV	15TeV ~100PeV



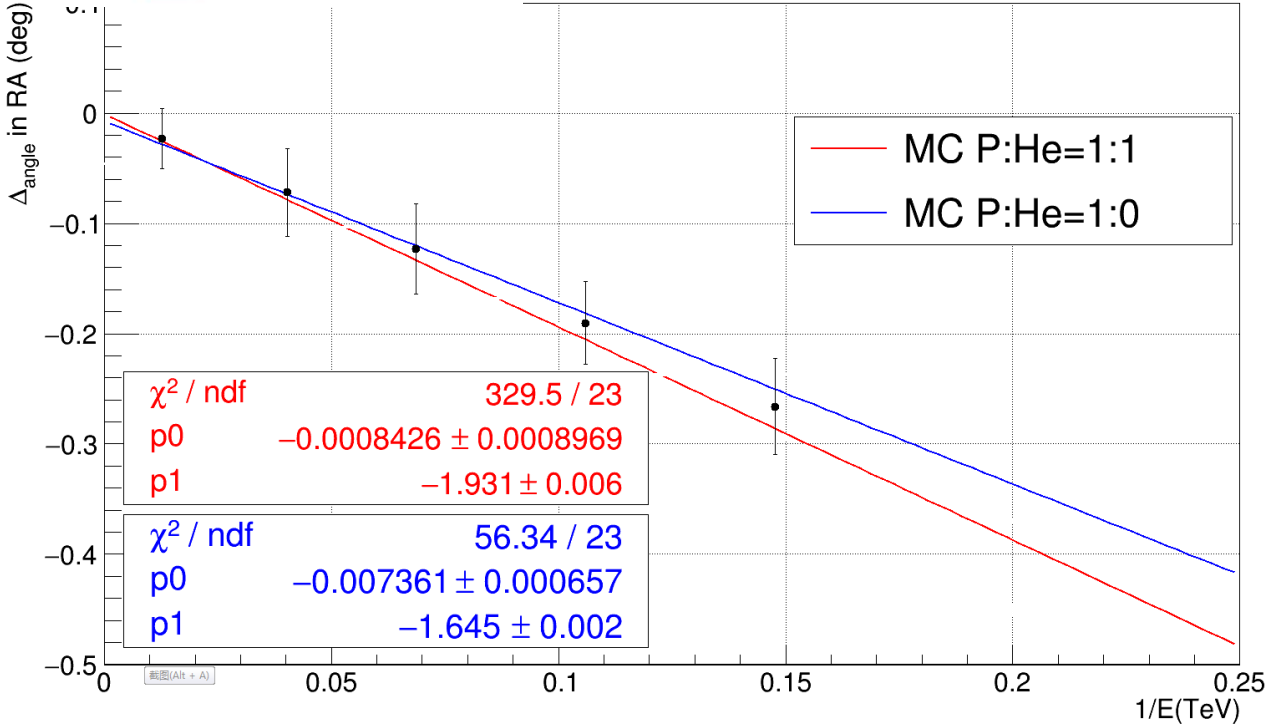


Energy calibration of WCDA

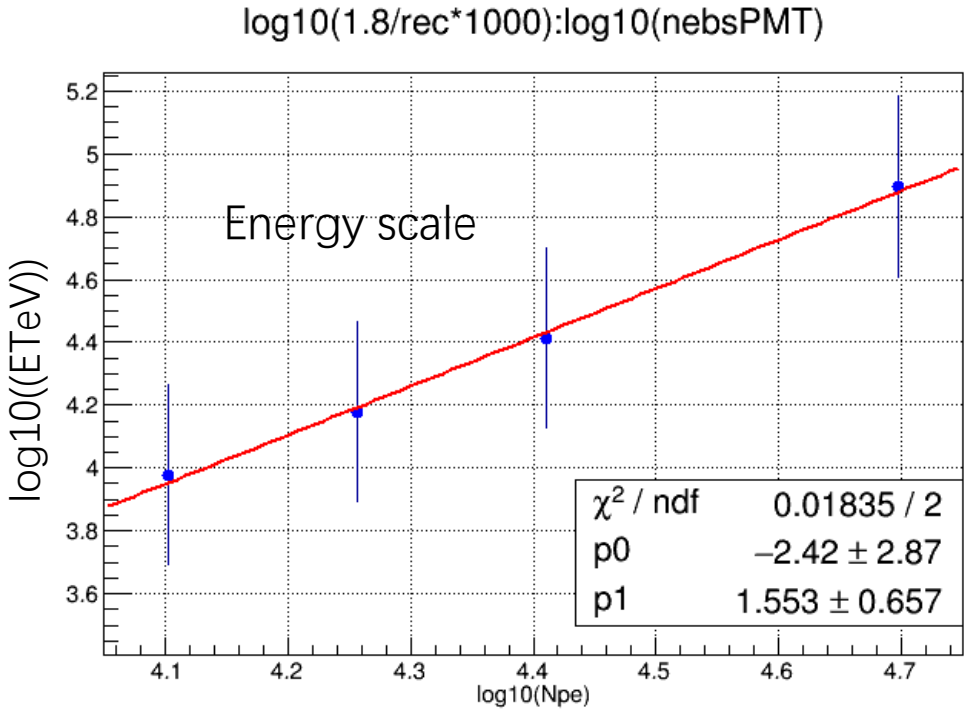


Moon Shadow displacement

energy calibration curve



Angular displacement V.S. Energy

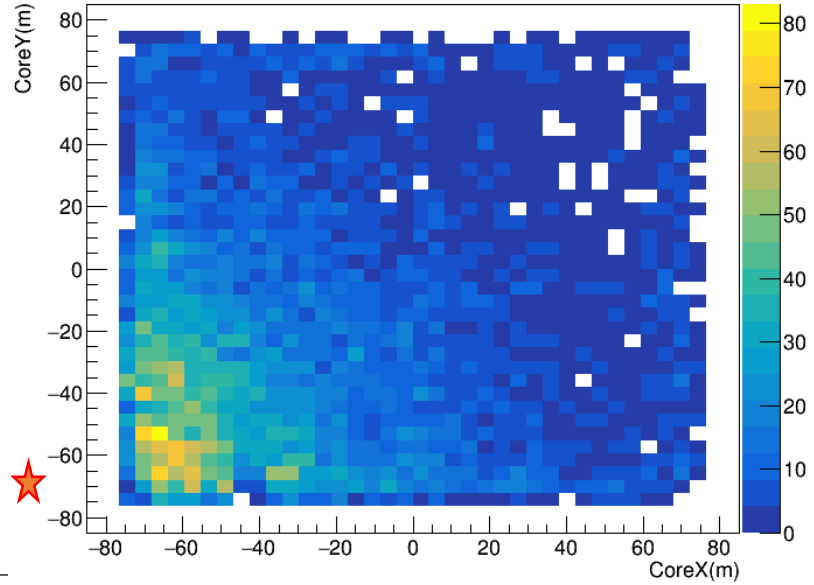


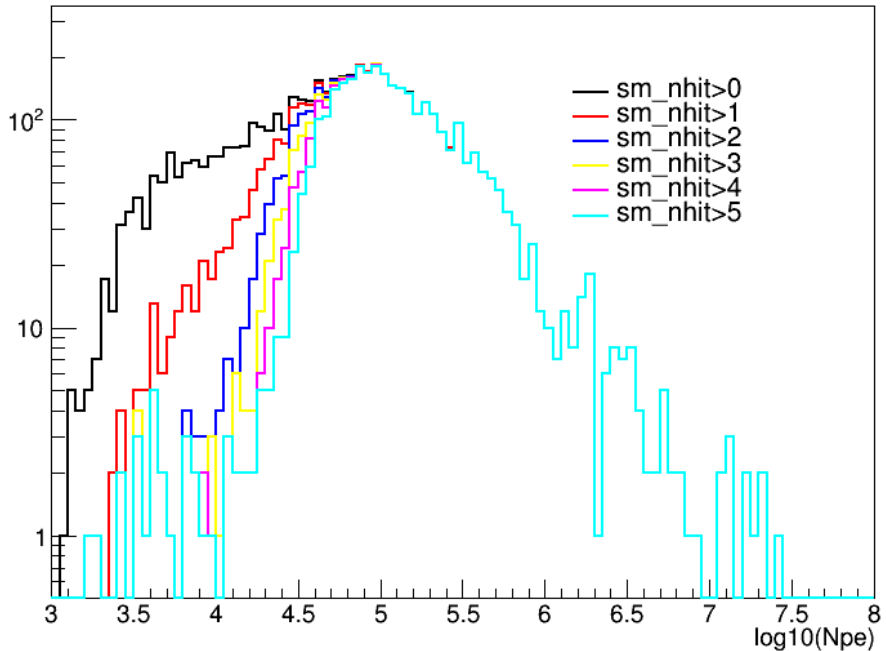
$E=0.0038*N^{1.55}$ (TeV)

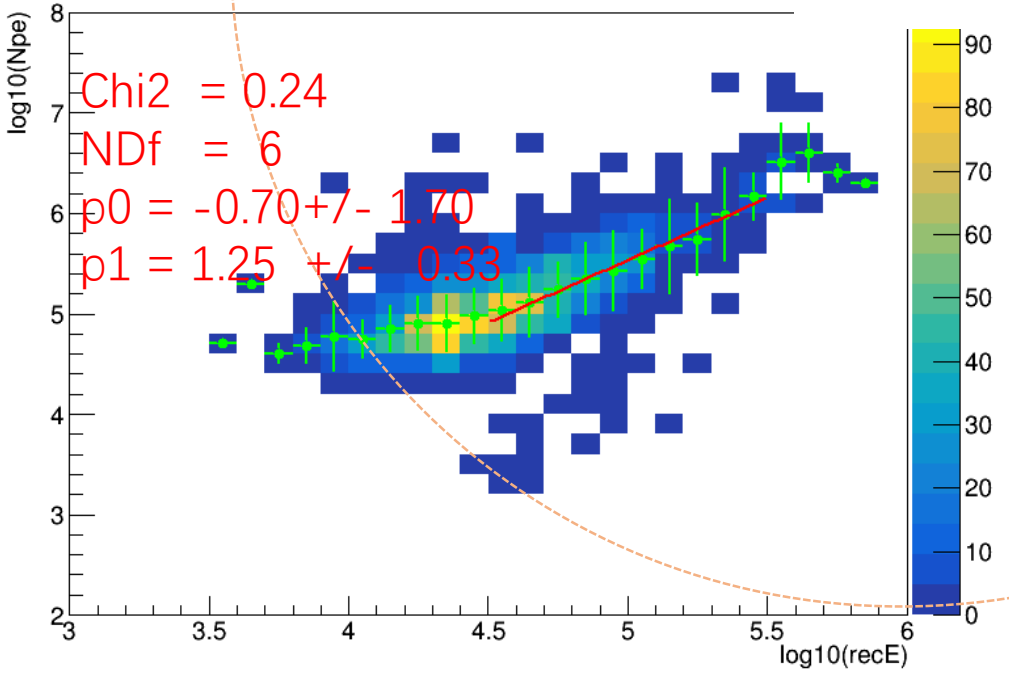
- the assumed primary CR chemical composition (5%)
- the uncertainties of different hadronic models (2%)
- statistical uncertainty (1%)

Energy Calibration of WFCTA with WCDA

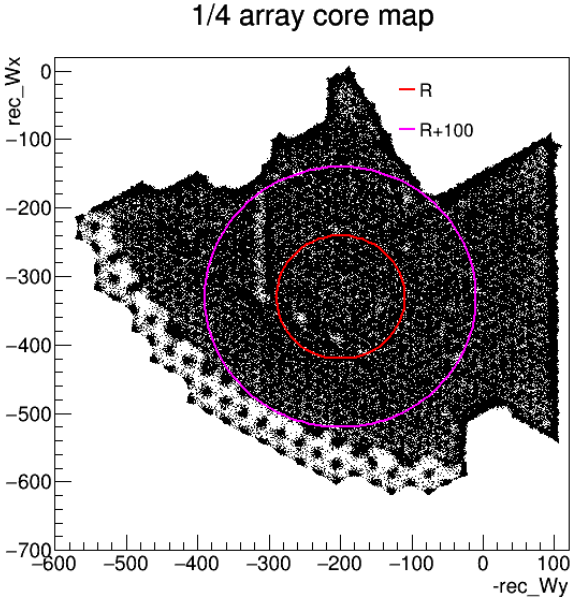
- By hybrid events observed by WCDA and WFCTA
- Inner core events are selected
  - Small PMTs are triggered in WCDA







All-particle cosmic ray energy spectrum with 1/4 LHAASO-KM2A



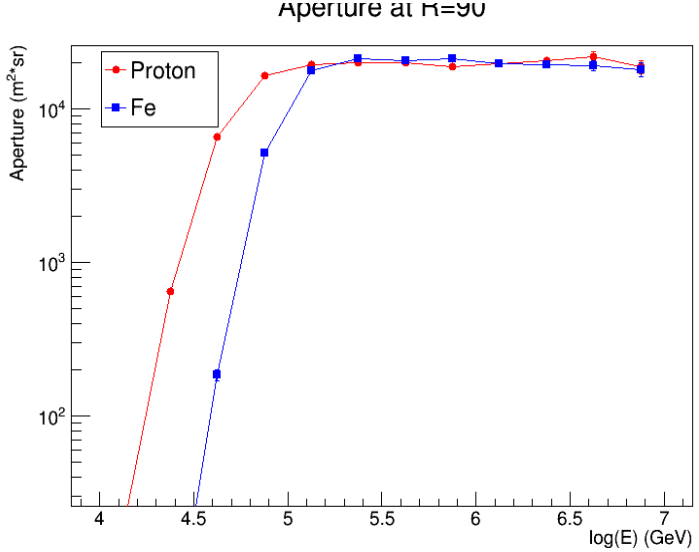
NpE2: the numbers of secondary particles recorded within the circle of 40m-100m.
NuM2: the numbers of muons recorded within the circle of 40m-100m.

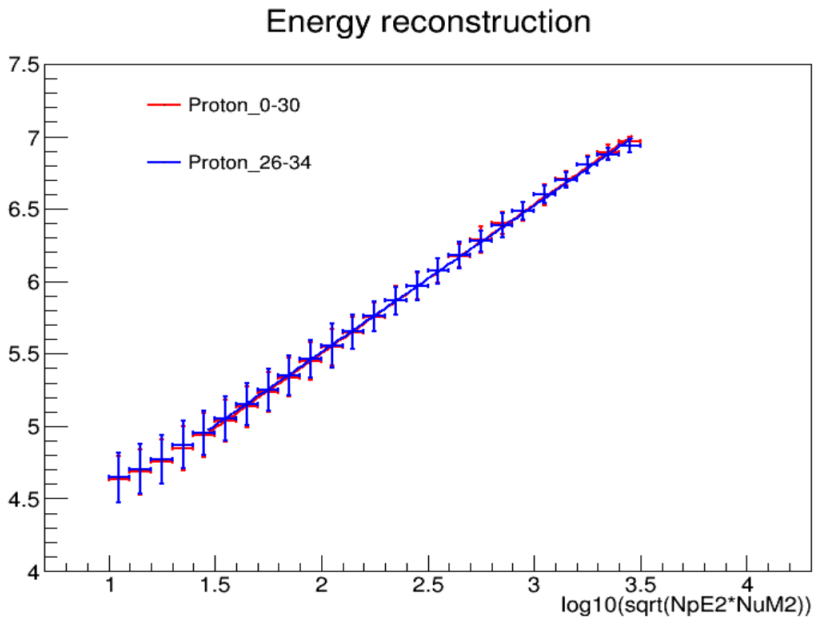
Data selection:

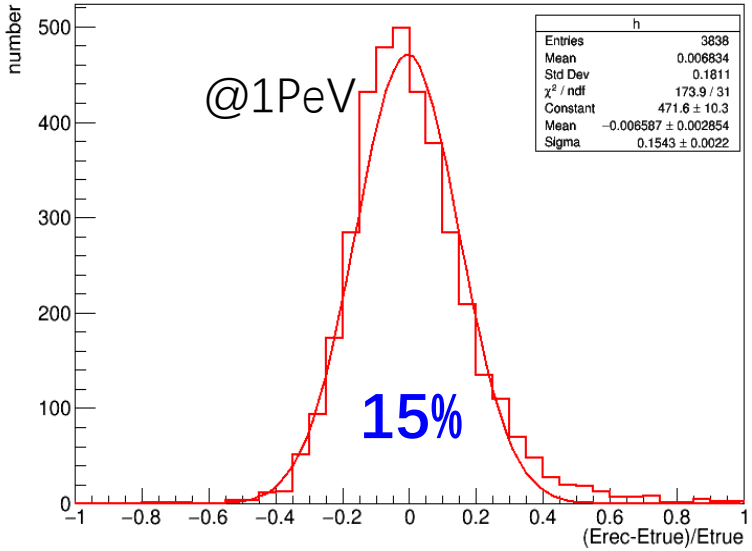
>4 EDs hit; NpE2>30; $log10\left(\sqrt{NpE2 * NuM2}\right) > 1$;

The reconstructed zenith Angle is in the range of $0^{\circ} - 30^{\circ}$

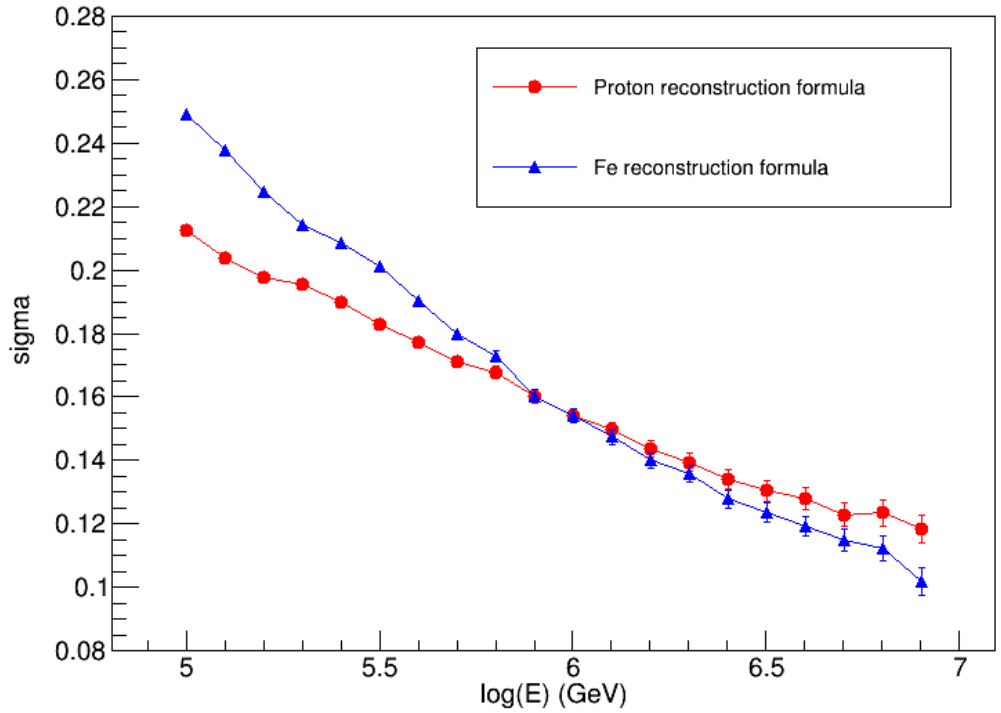
The reconstructed cores are in a circle centered with the center 1/4 LHAASO-KM2A and the radius 90 m.

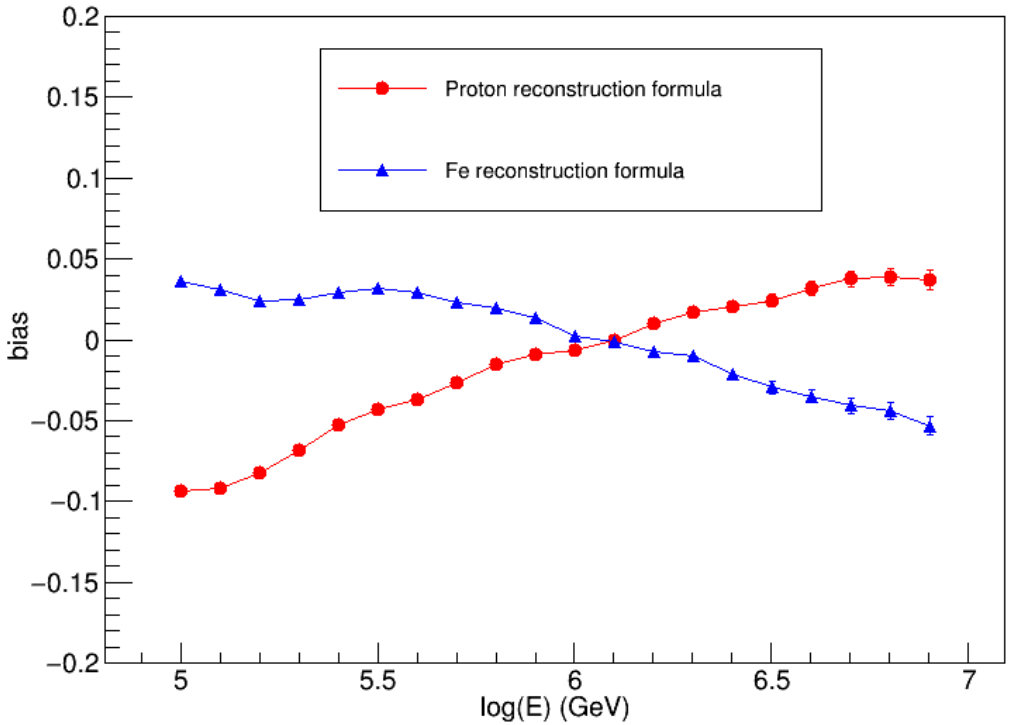




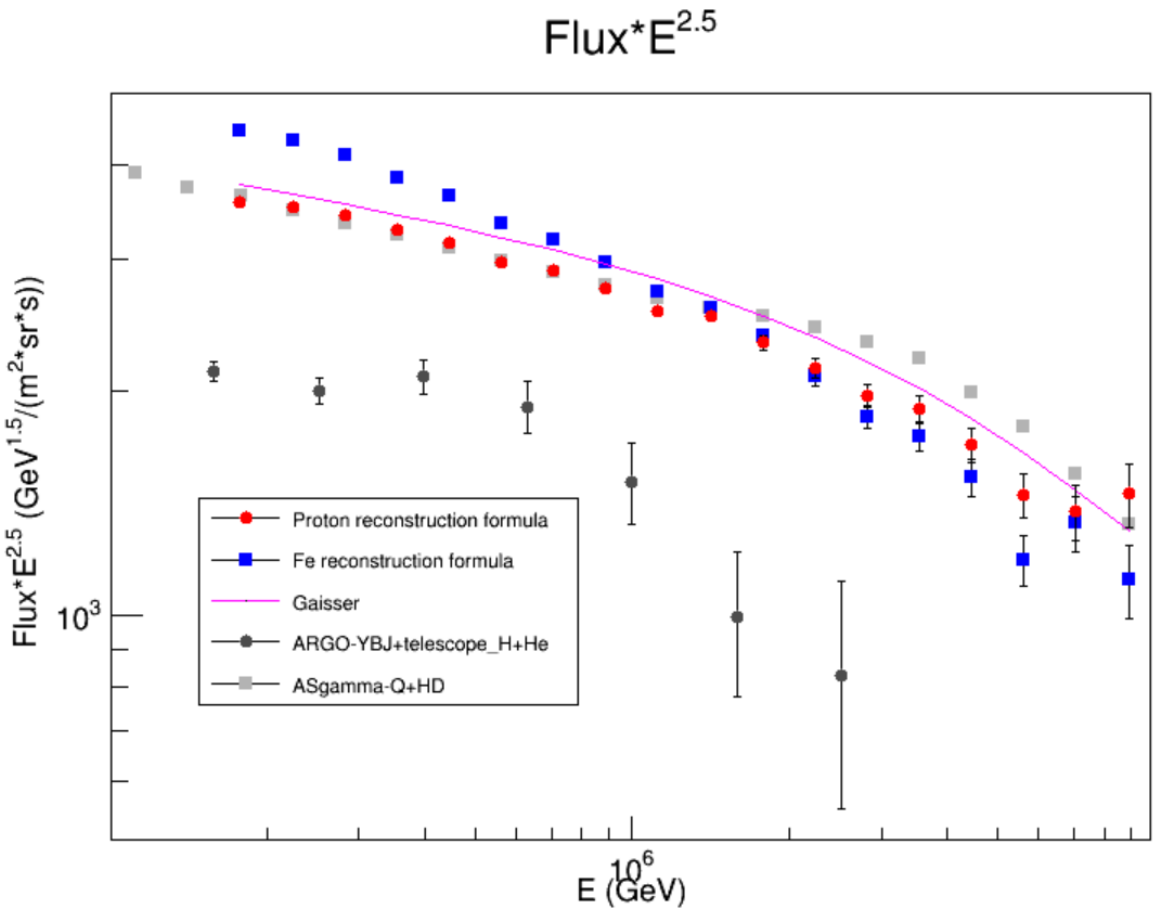


Energy Resolution and bias





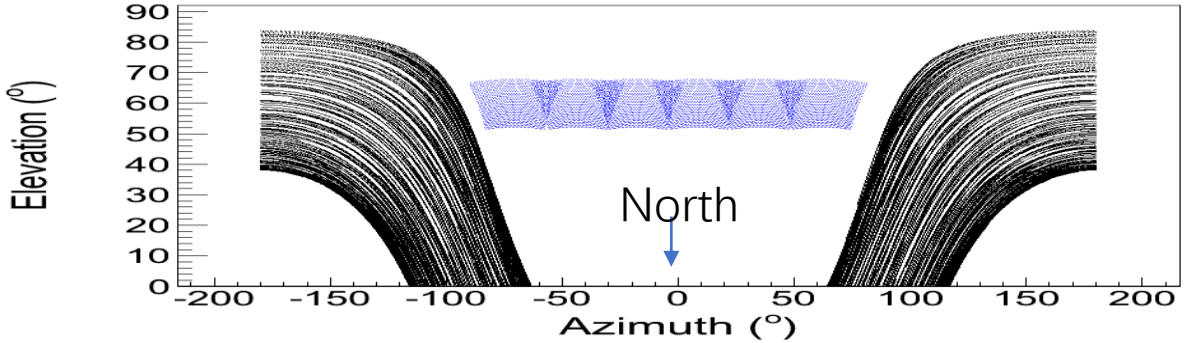
- Varying from about 20% to 10%.
- The bias is within ±0.1.

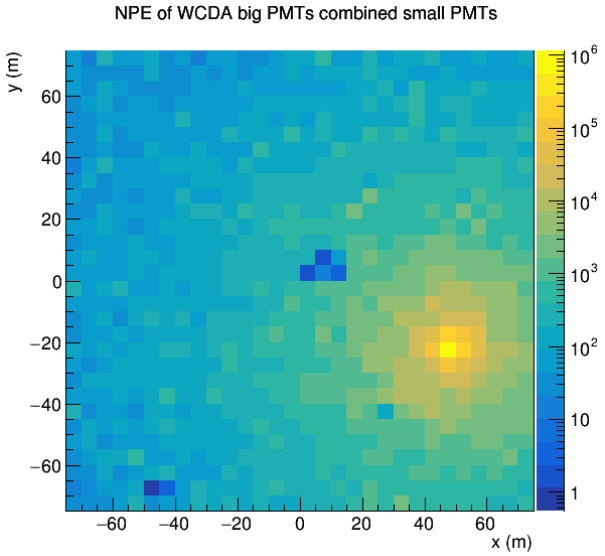


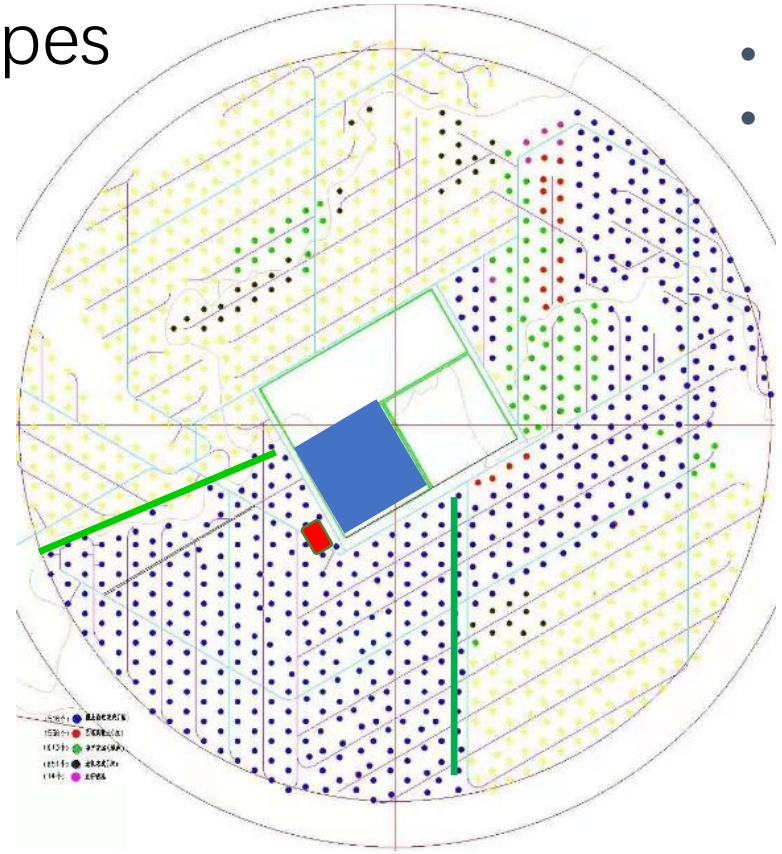
All particle energy spectrum obtained with five days of data

Measurements of the knees of proton and helium

1. Muon detector: 304
2. Scintillator detector: 1200
3. WCDA-1: 150 m×150m
4. 6 Cherenkov telescopes

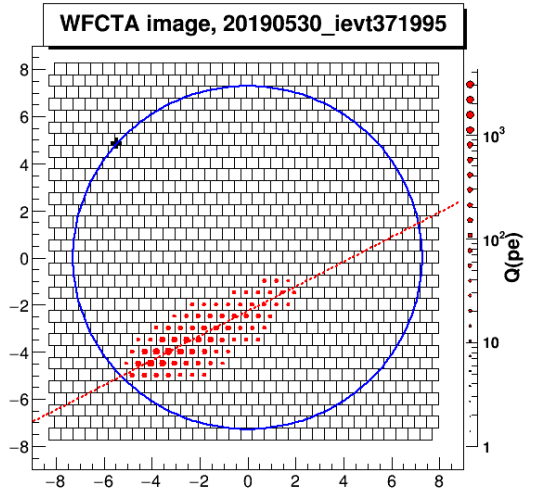




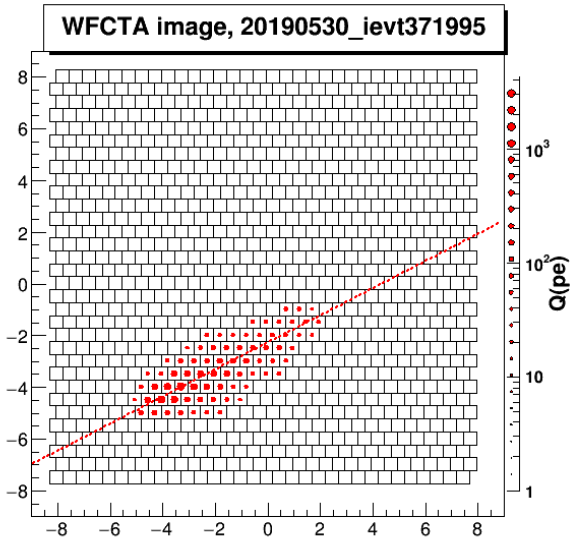


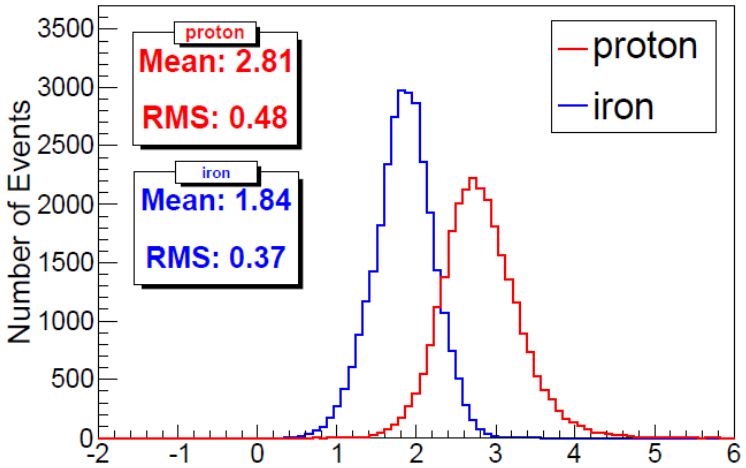
- zenith angle: 22° - 38°
- azimuth angle: -80° - +80°

SiPM-based Cherenkov telescope successfully operated with moon light

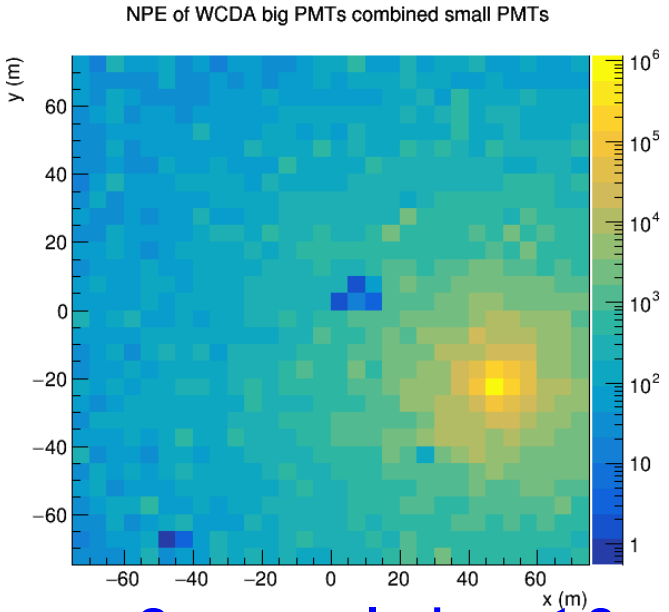


Discrimination variables for composition studies by MC



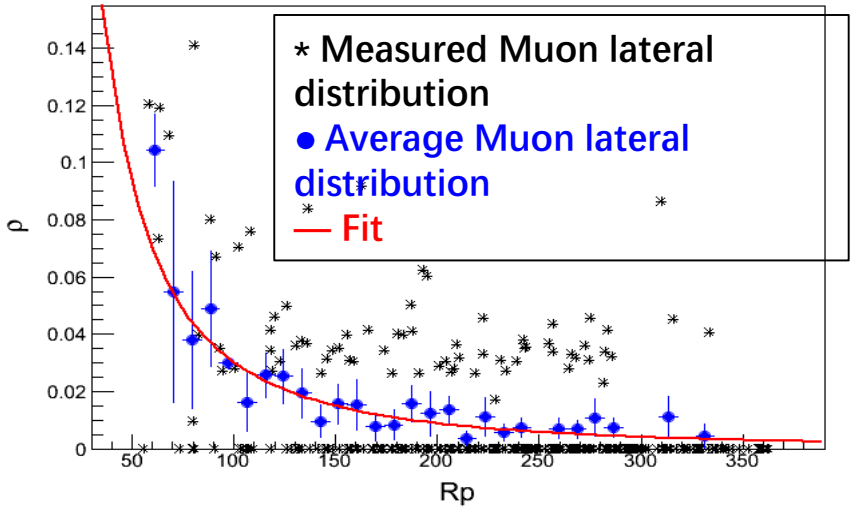


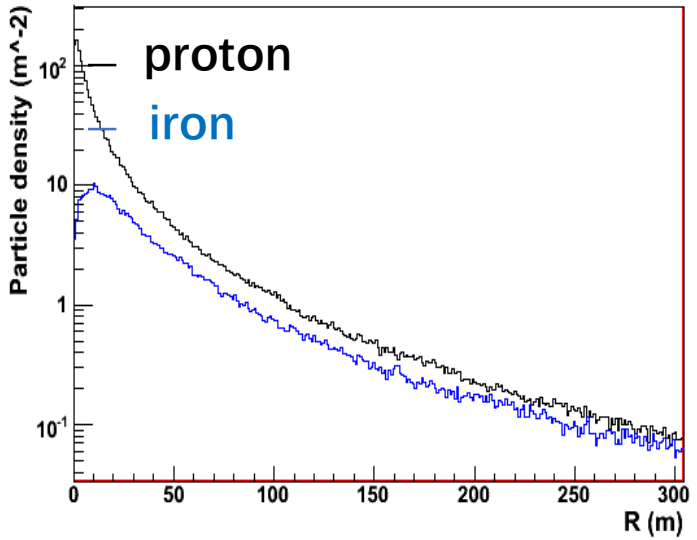
$$P_c = \left(\frac{Length}{Width}\right)\Big|_{normalized}$$



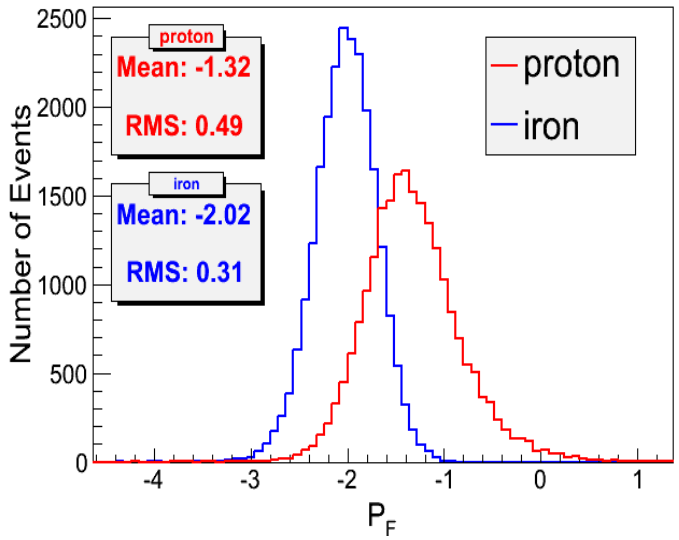
Core resolution: ≤ 3m

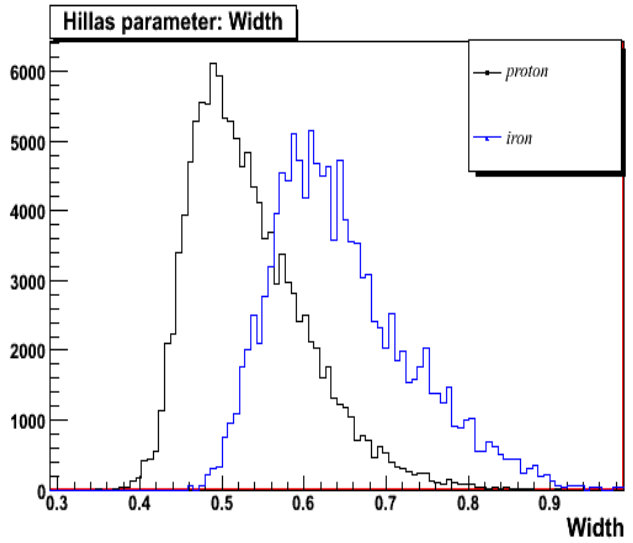
- **Length/Width**
- **Dist (related to X_{max})**
- **Particle numbers near the shower core**
- ***Number of muons***

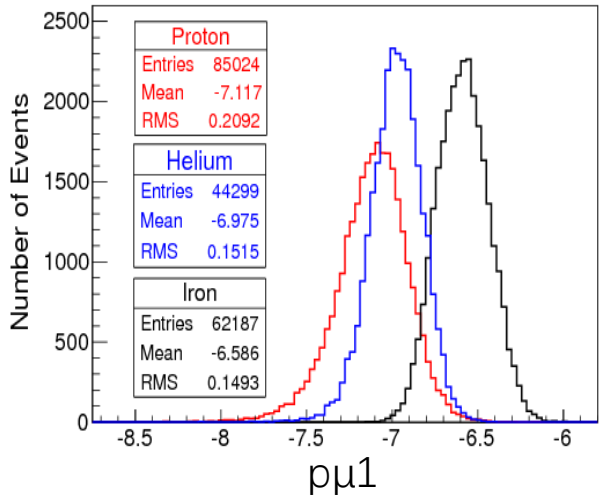


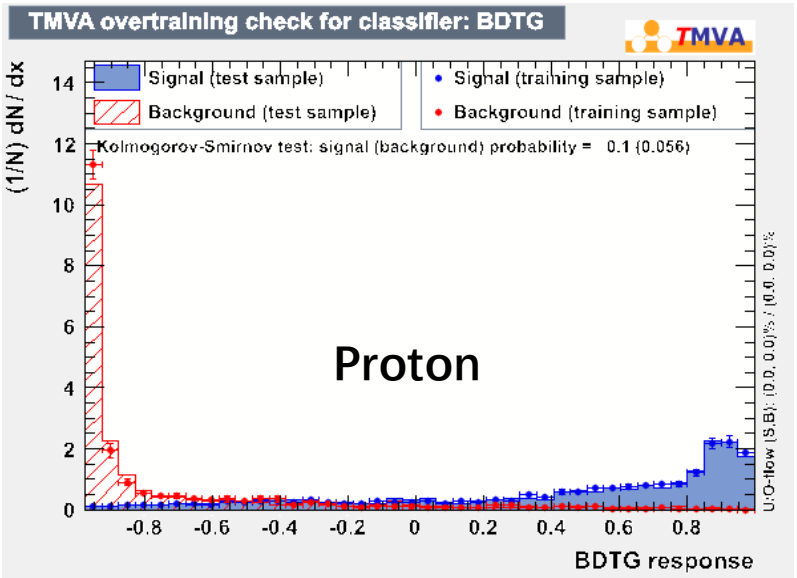


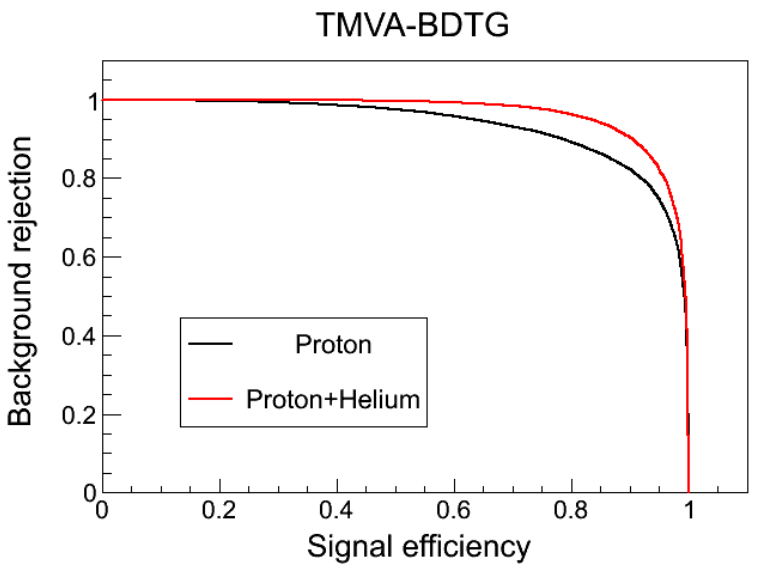
Particle Identification

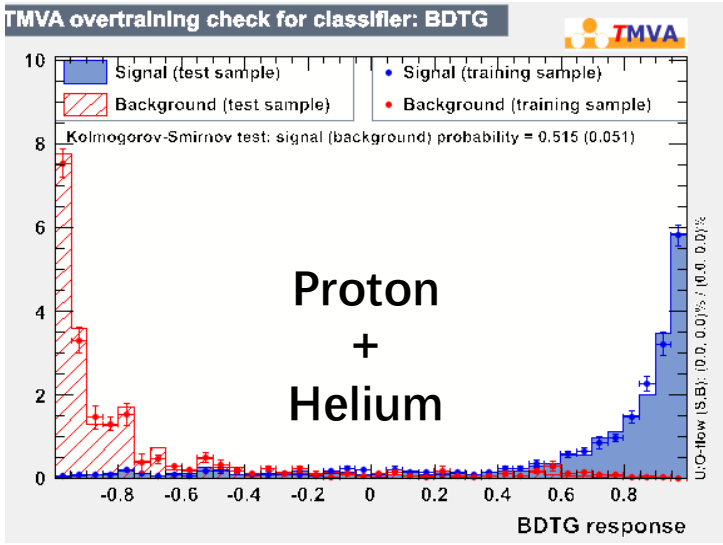




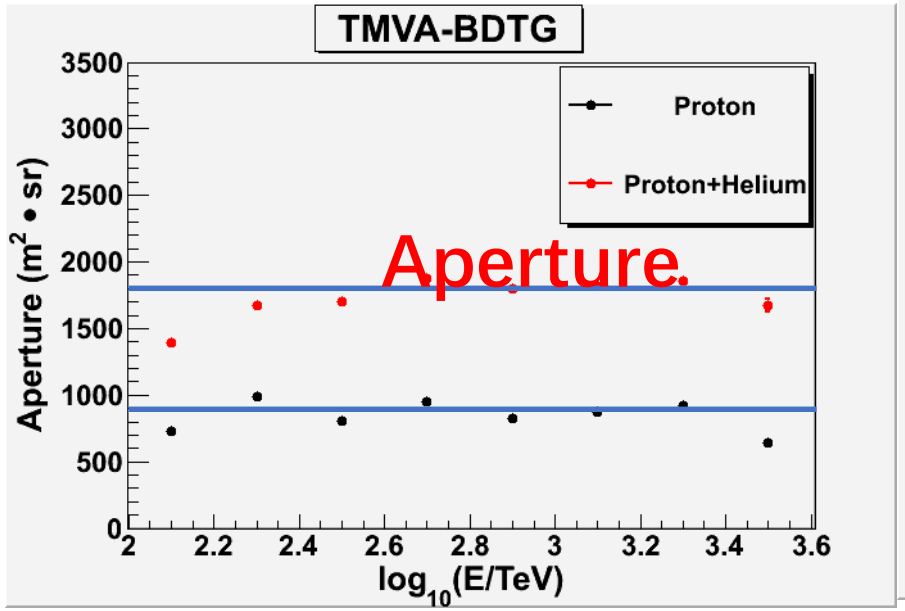


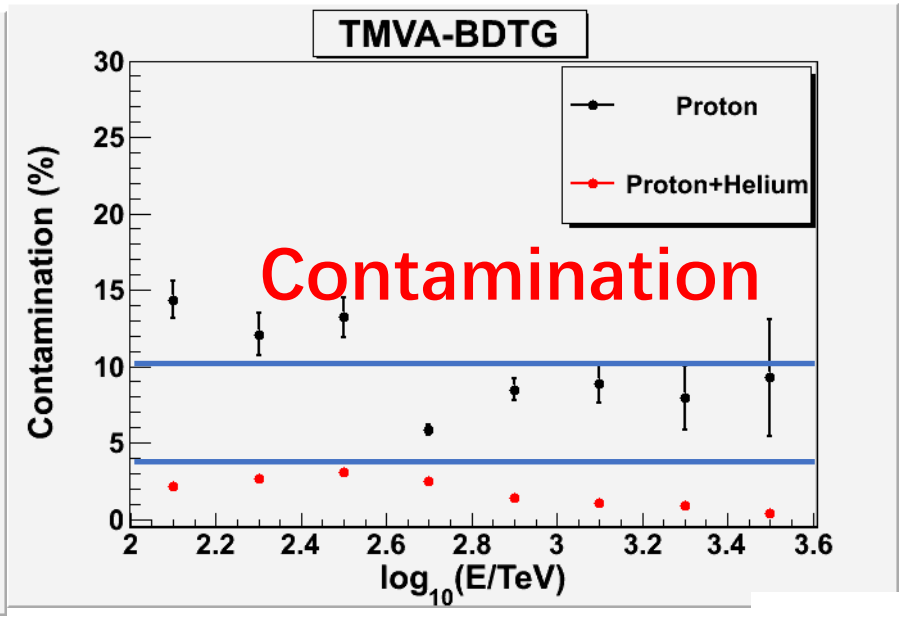






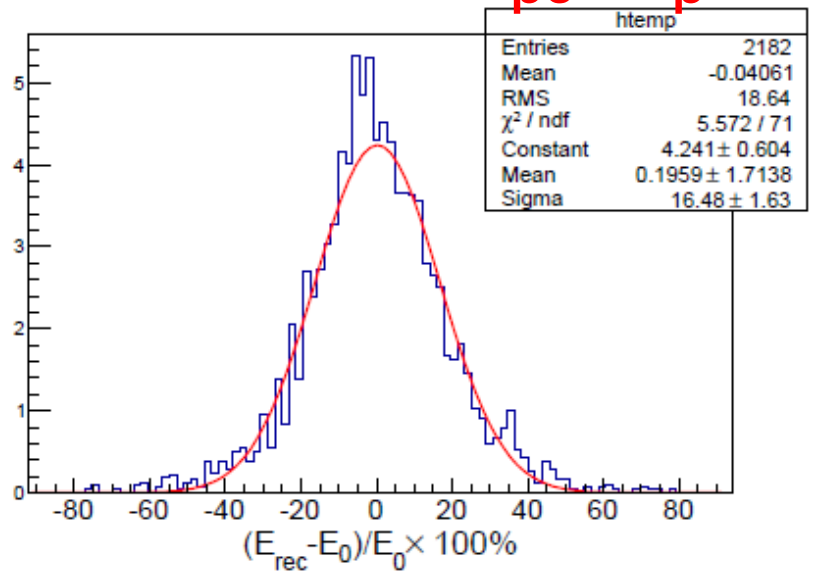
Aperture and energy Resolution





	Proton	Proton+Helium
Aperture	~900	~1800
Contamination	~10%	<4%

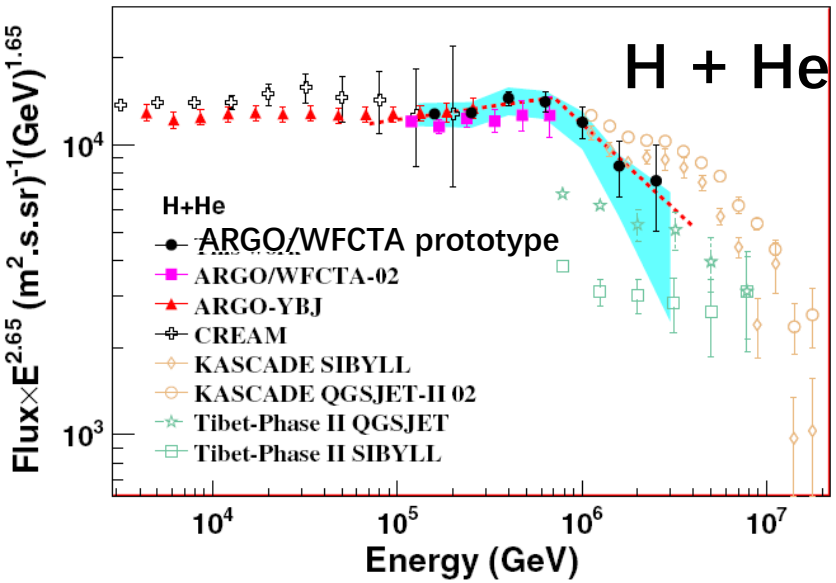
$$E = E(\Sigma N_{pe};\ R_p,\ \alpha)$$

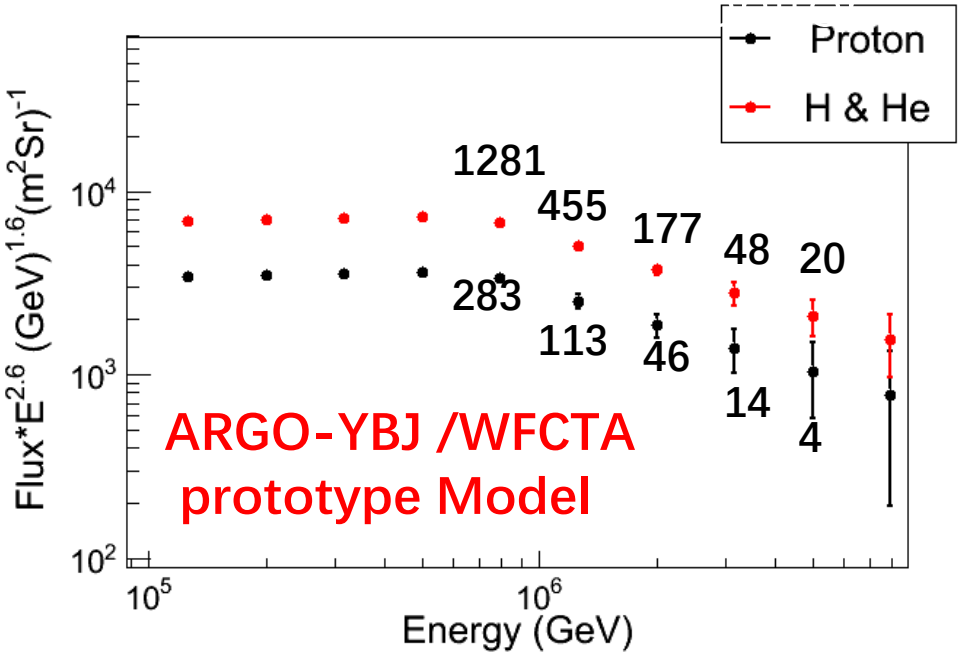


Number of good events expected in the hybrid observation with C-telescopes and WCDA or KM2A

- ¼ LHAASO is in stable operation in October 2019
  - 6CTs+1WCDA
- Hybrid observation time:
  - 2019.10.16 – 2019.11.30: ~318 hours
  - **The exposure time with good weather:**

$$6.5 \times 10^5 \text{ s} = 180 \text{ hours}$$

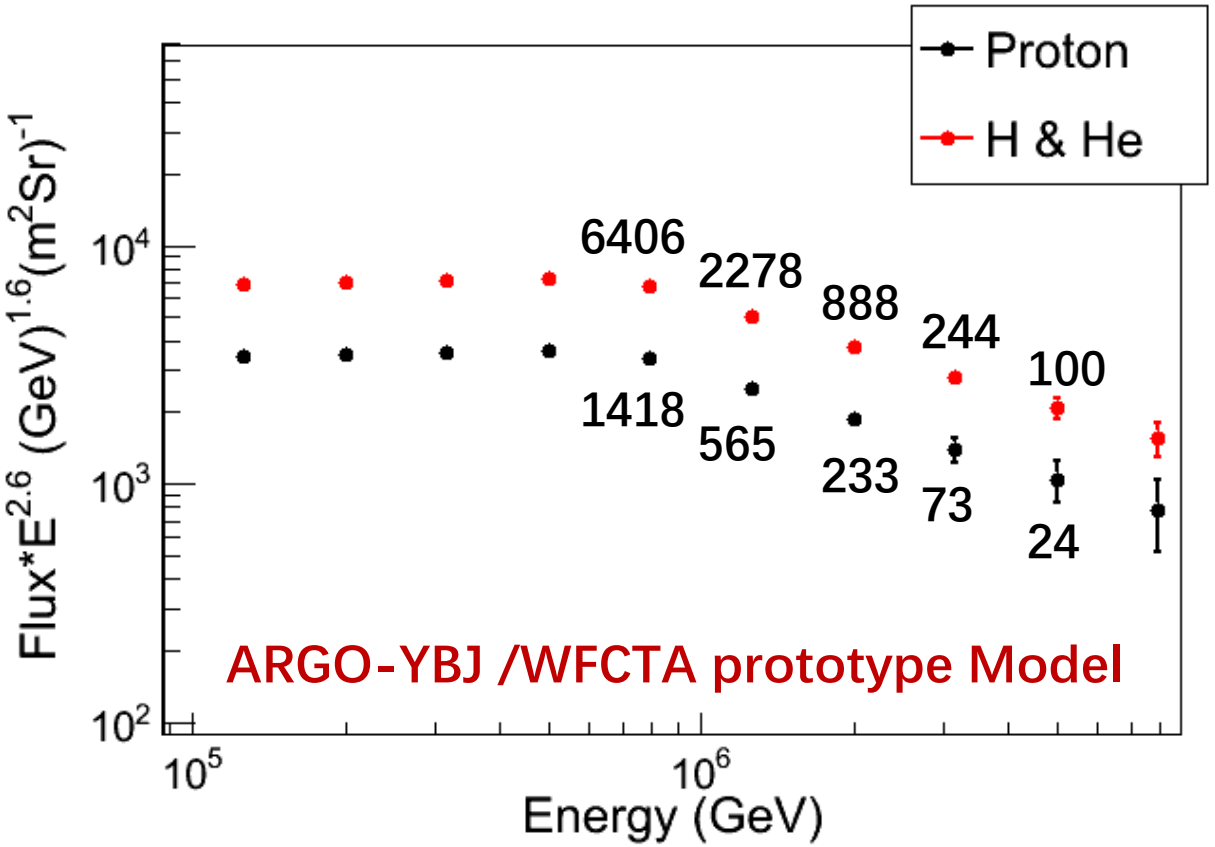




PHYSICAL REVIEW D 92, 092005 (2015)

Number of good events expected in the hybrid observation with C-telescopes and WCDA or KM2A

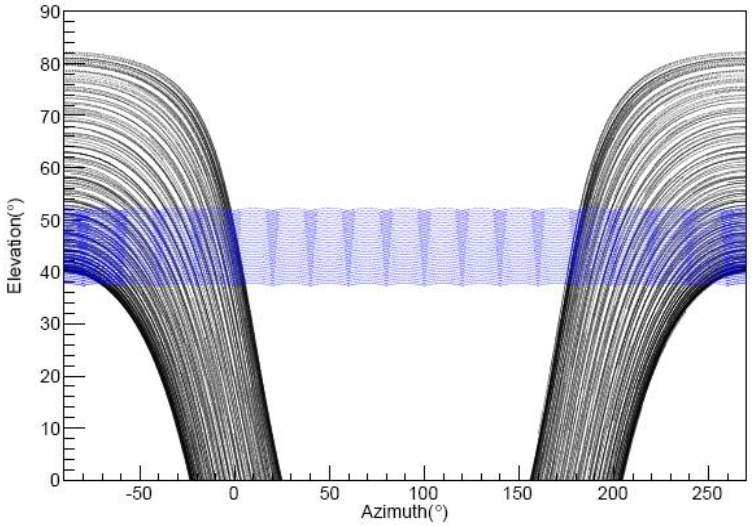
3.1×10^6 s $= 876$ hours of exposure time with good weather is expected by **summer 2020**



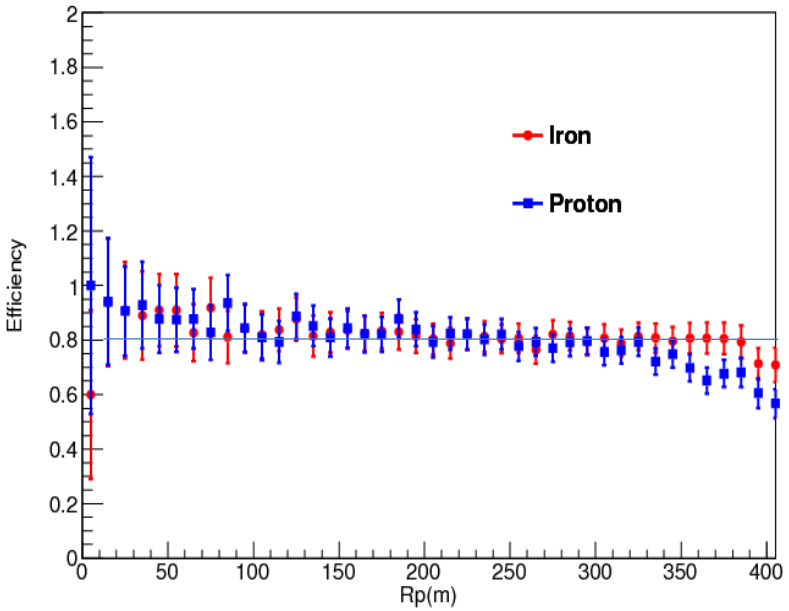
Pure H and H+He knees will be accurately measured using ¼ LHAASO by summer 2020.

Prospects of iron knee from 10PeV to 100PeV

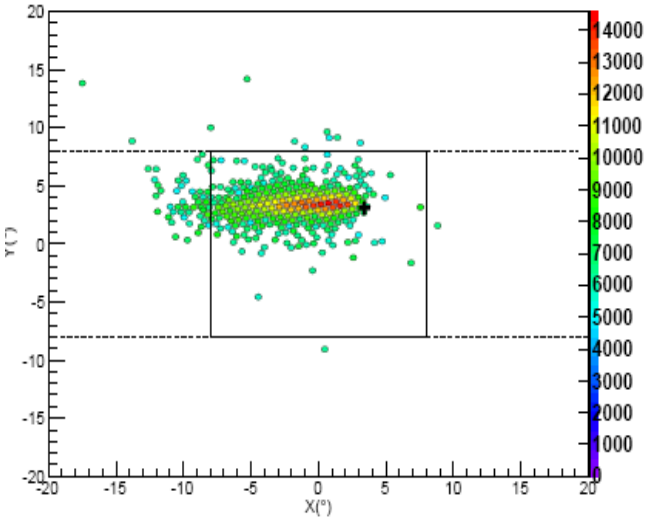
- **WFCTA:**
  - **18 Tels**
  - Xmax →mass sensitive
  - Size → Energy related



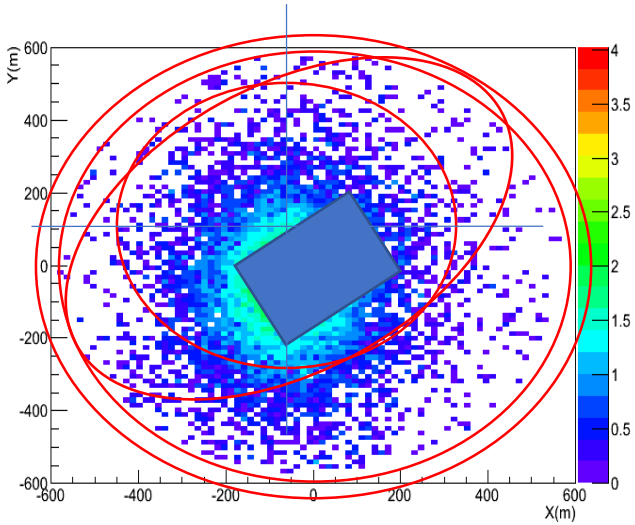
Elevation of 45° toward North with full-moon duty cycle >30%



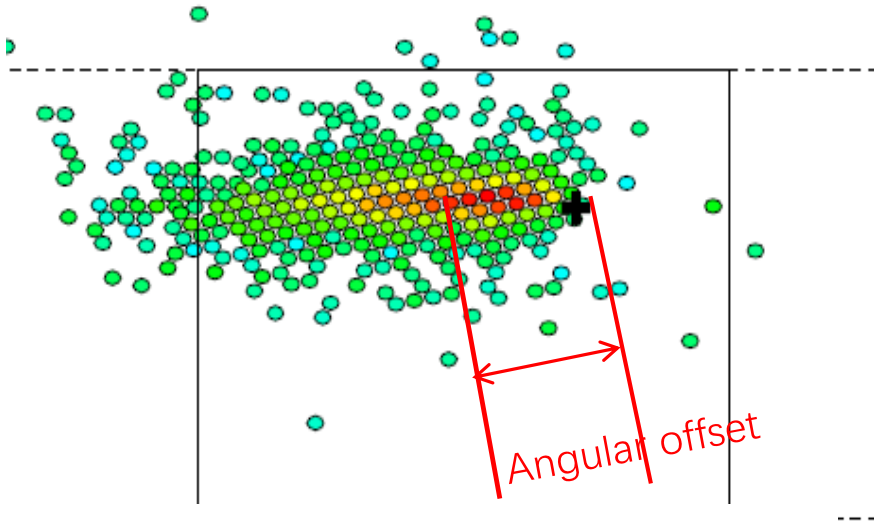
Trigger efficiency for E>7 PeV: >80% up to 350 m

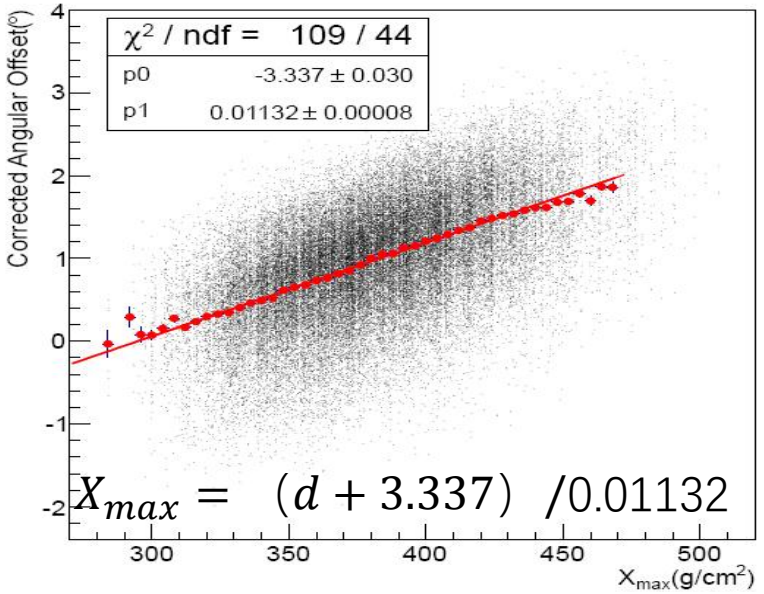


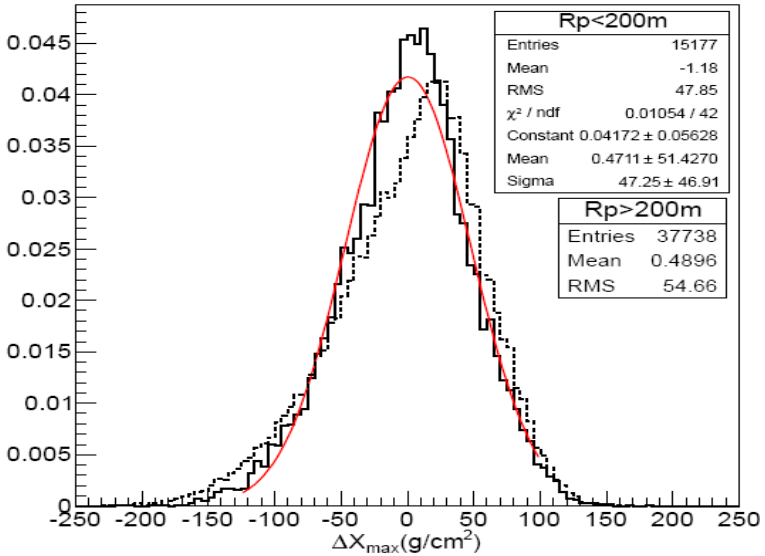
Energy resolution: ~20%

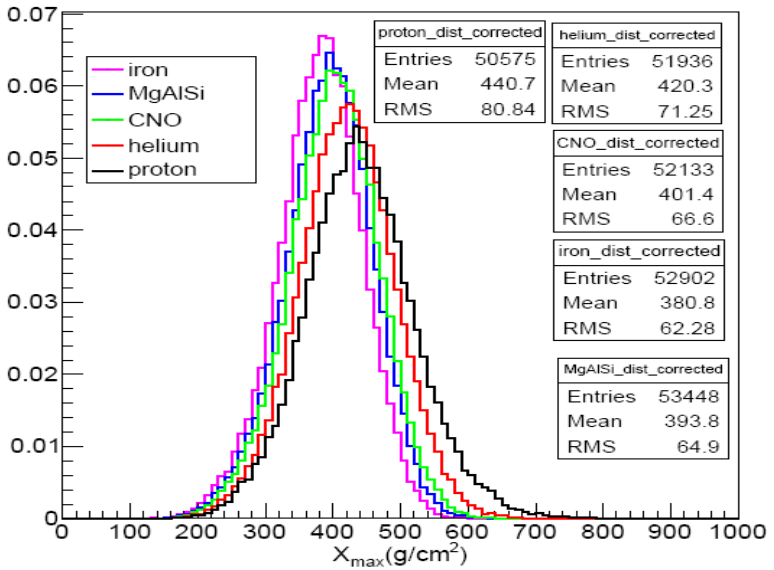


X_{max} reconstruction



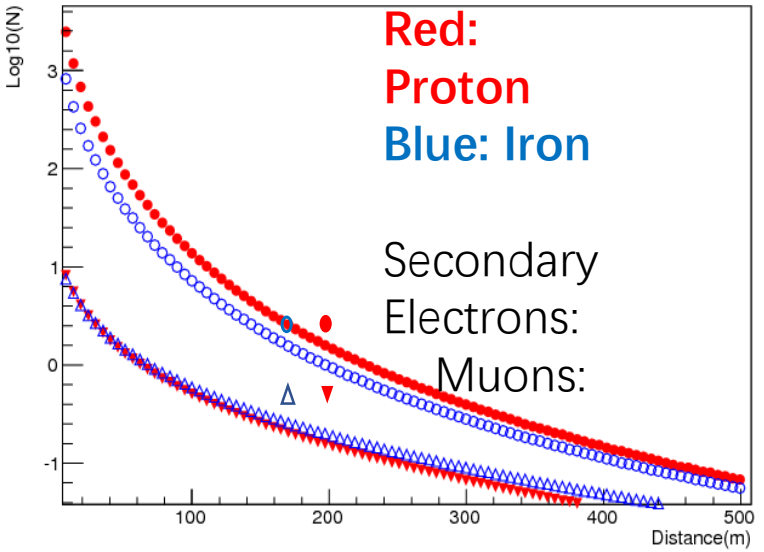




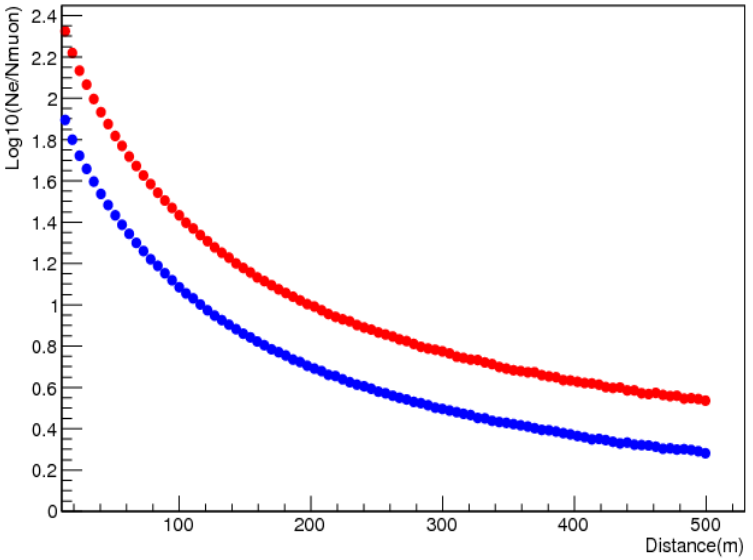


- **KM2A:**
  - Core resolution: ⩽ 3m
  - arrival direction resolution: ⩽0.2°

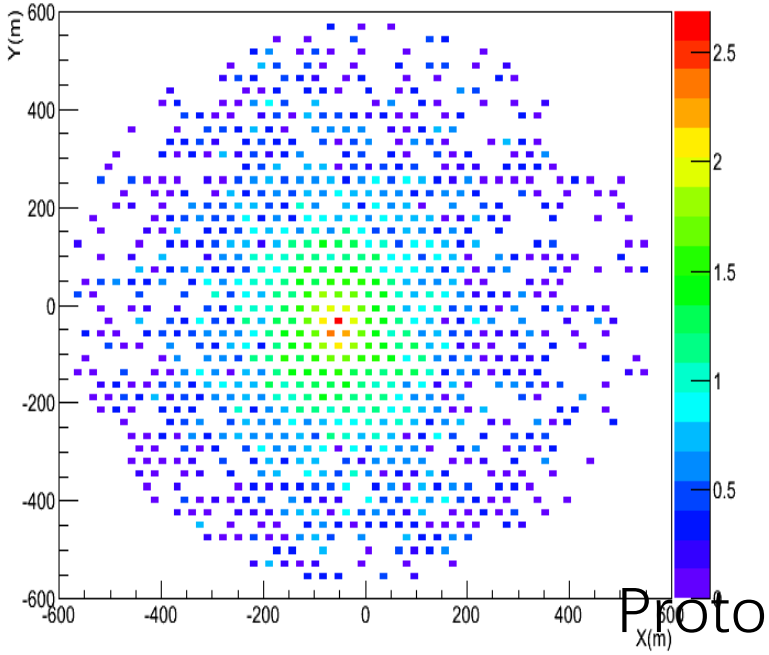
The Muon content can be measured very well

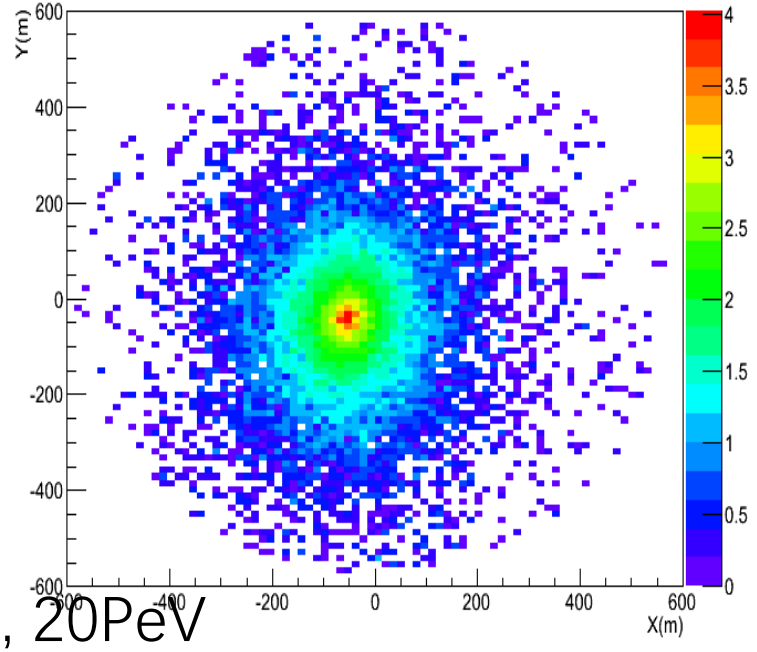


Lateral distribution of e/γ and μ

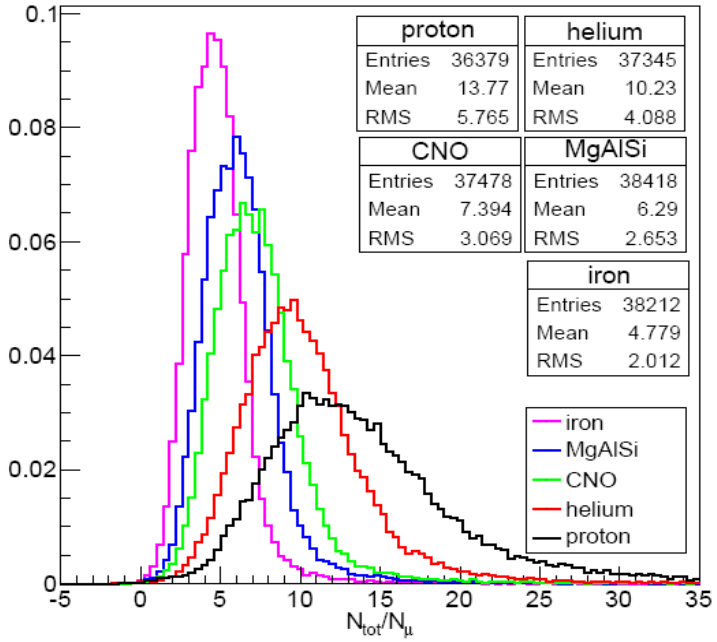


Lateral distributions of Log10(N_{ch}/N_{μ})





Proton, 20PeV

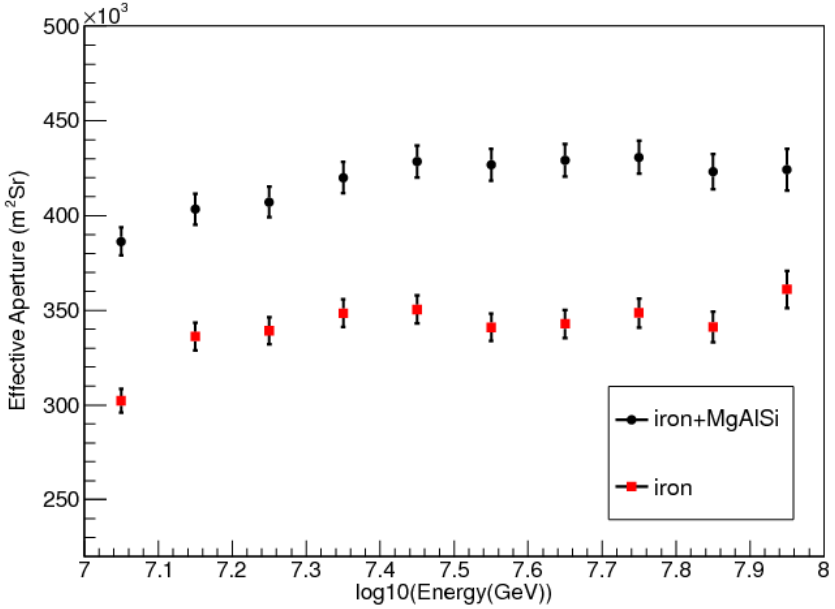


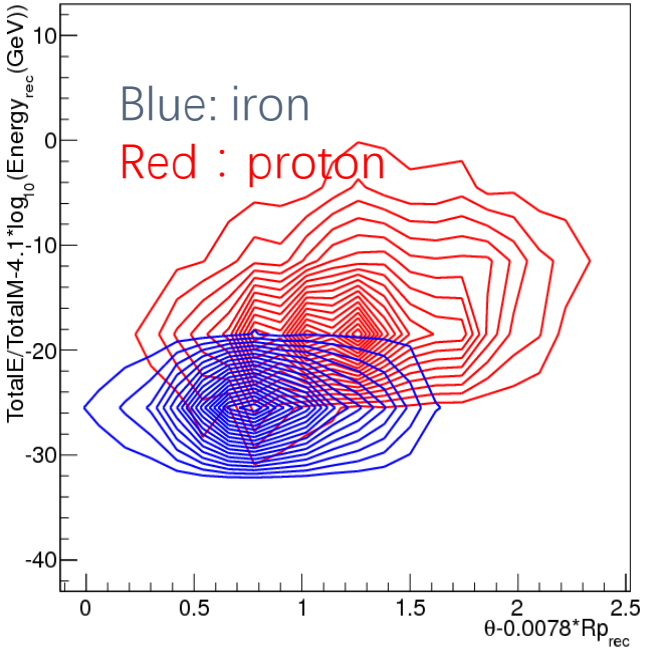
Aperture: ~0.3X10^6 m^2sr

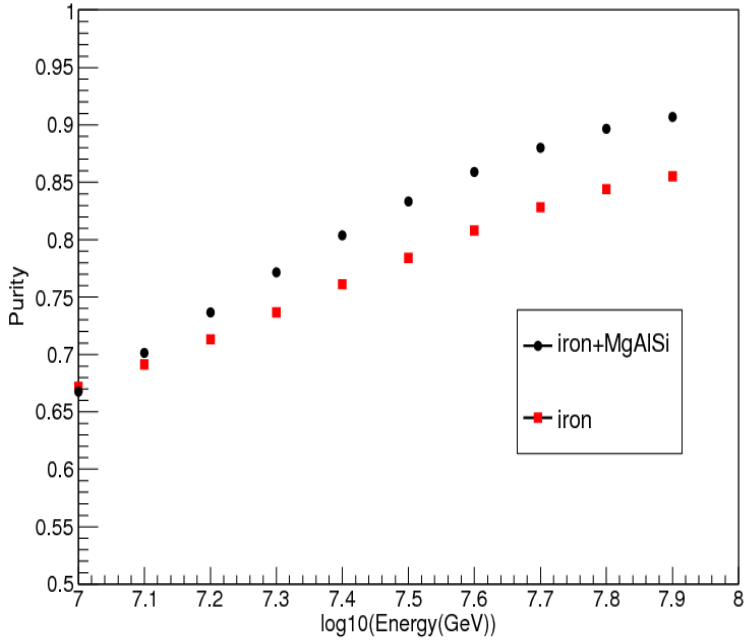
Iron selection:

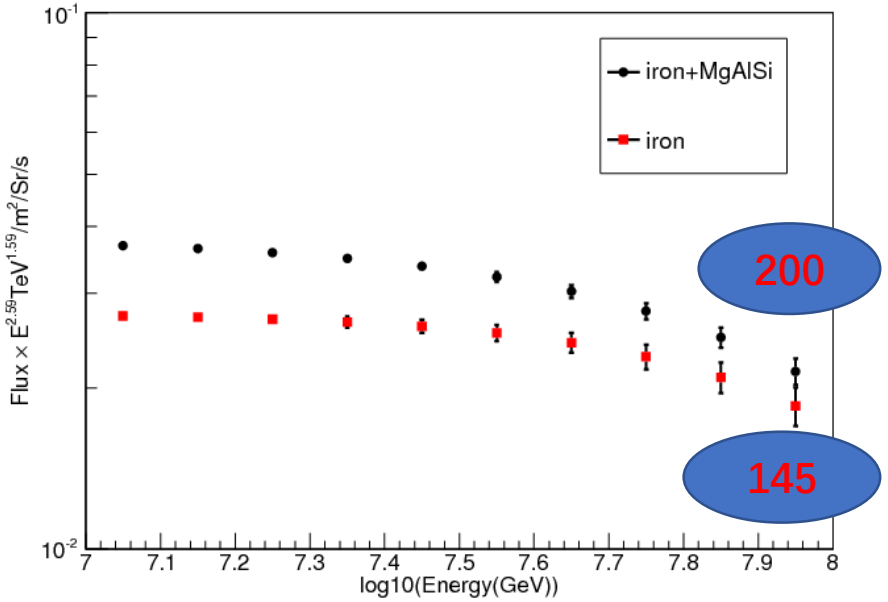
- μ-content and X_{max} 2-variable analysis
- 145events@100PeV for iron per year with a duty cycle of 30%

the spectrum of pure Fe or mixed heavy components and their knees should be measured









Summary

- The energy scale of WCDA with ~8% uncertainty will be established below 30 TeV by using moon shadow of the pure composition cosmic rays
- The energy scale can be transferred to WFCTA by hybrid observation
- Individual mass groups will be separated below 100PeV, knees of their spectra will be well measured with high statistics, high purity

THANKS