Prospect of Cosmic Ray Energy Spectrum Measured by 1/4 LHAASO

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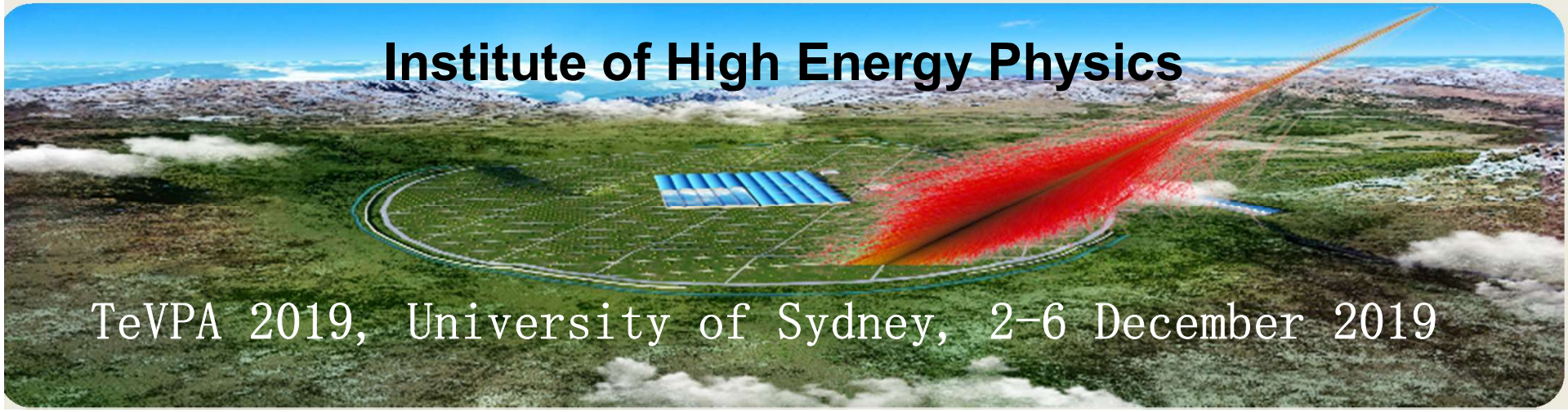
for the LHAASO collaboration

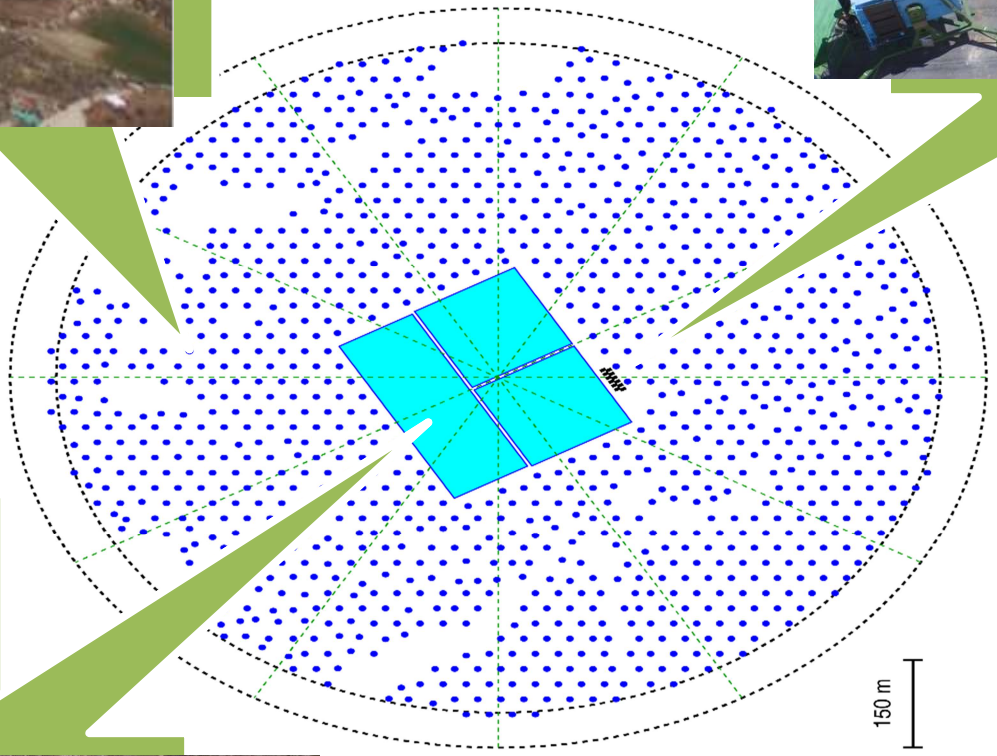
Institute of High Energy Physics



TeVPA 2019, University of Sydney, 2-6 December 2019

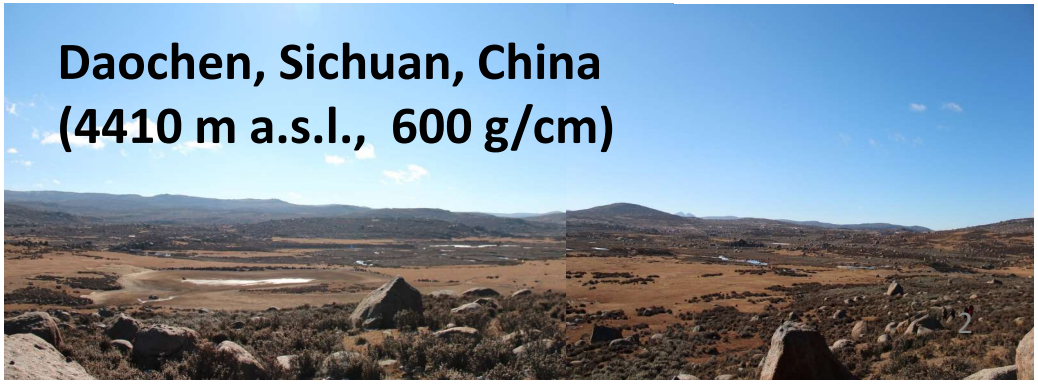
Hybrid Detection of EASs by LHAASO

KM2A:
5195 EDs
1171 MDs



WFCTA:
20 Cherenkov telescopes (1024 pixels/telescope)

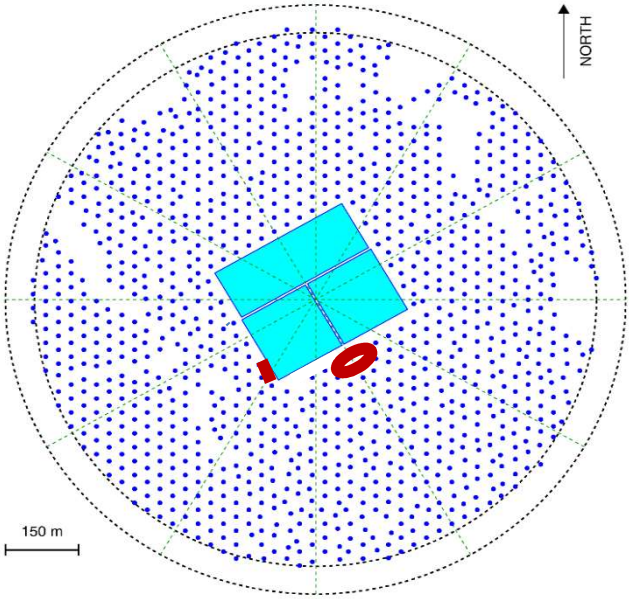
WCDA: 78,000 m^2
3120 cells
(25m^2/cell)

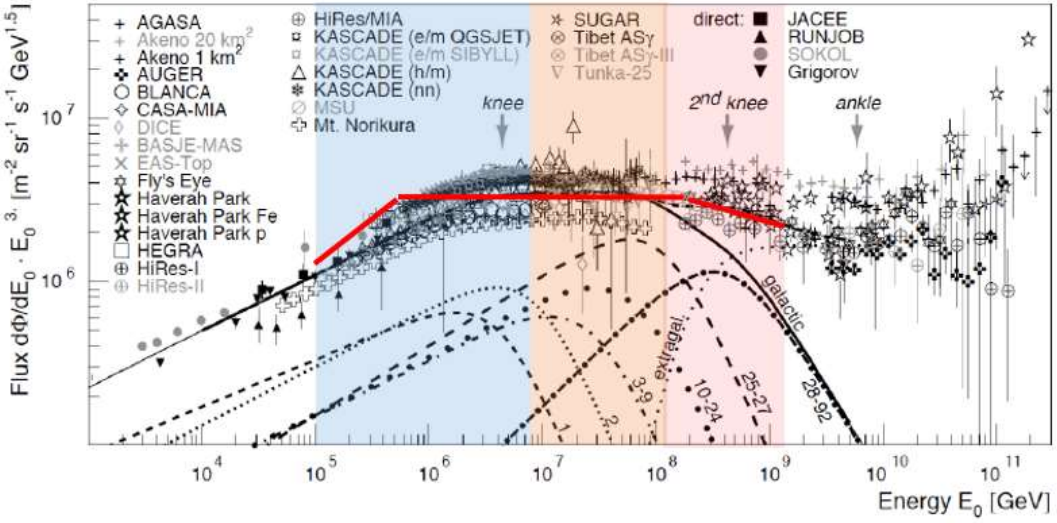


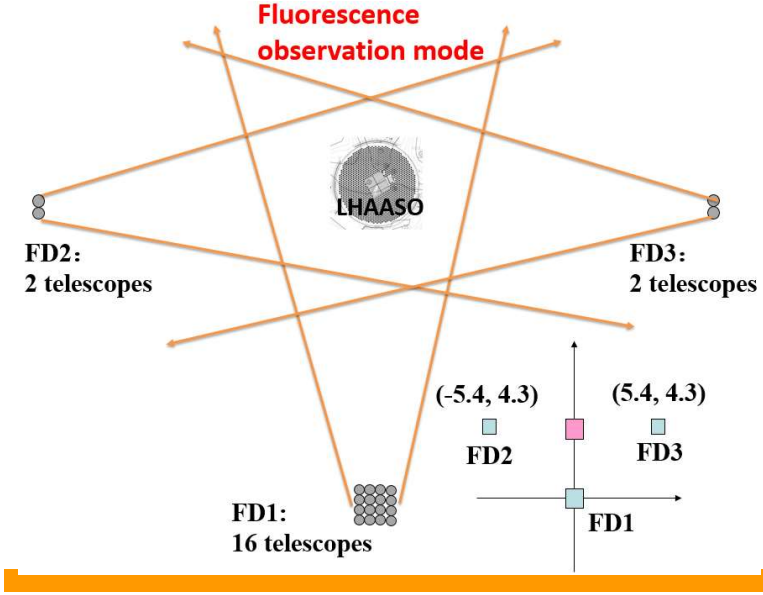
LHAASO science in cosmic ray measurement

- Measure individual species spectra from 10TeV to EeV
- Multi-parameters, Multi-stages

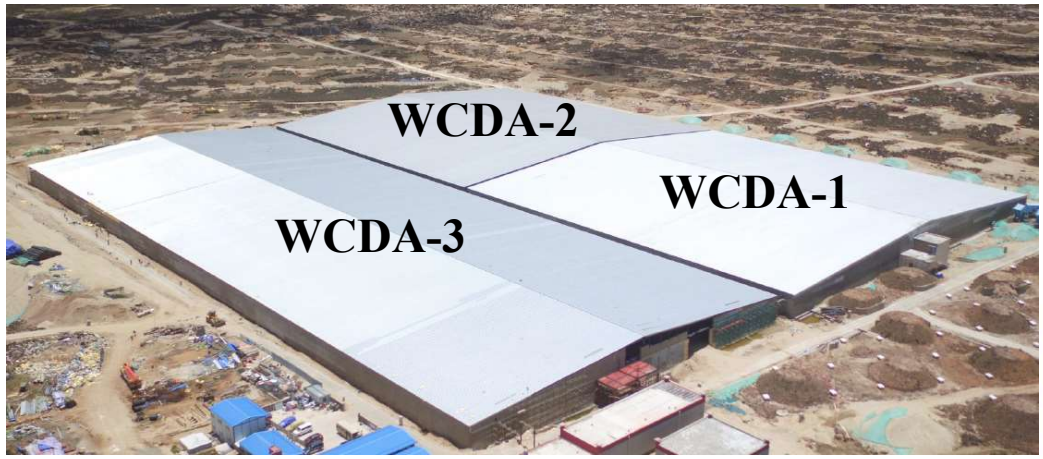
- 10TeV - 10 PeV (Cherenkov mode)
  - pure proton and light nuclei (P+He) spectra
  - LHAASO 1/4 detector array
- 1PeV - 100 PeV (Cherenkov mode)
  - Pure iron or heavy nuclei spectra
  - 18 telescopes + scintillator detectors + muon detectors array
- >100 PeV (fluorescence mode)
  - 2nd knee
  - 20 telescopes + muon detectors array

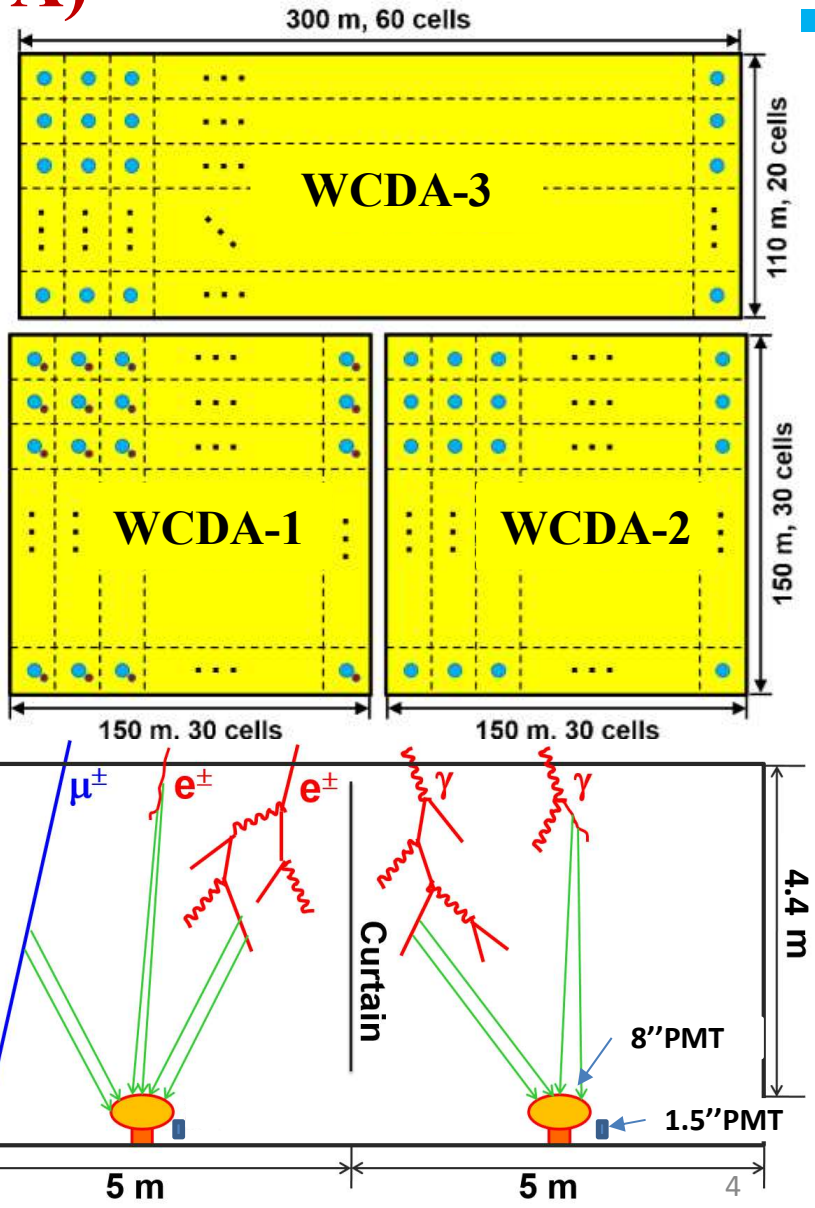






Water Cherenkov Detector Array (WCDA)

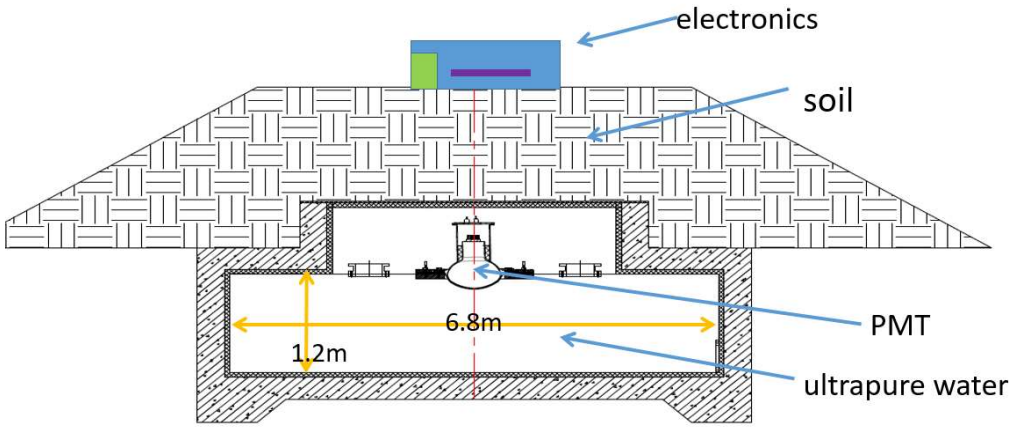


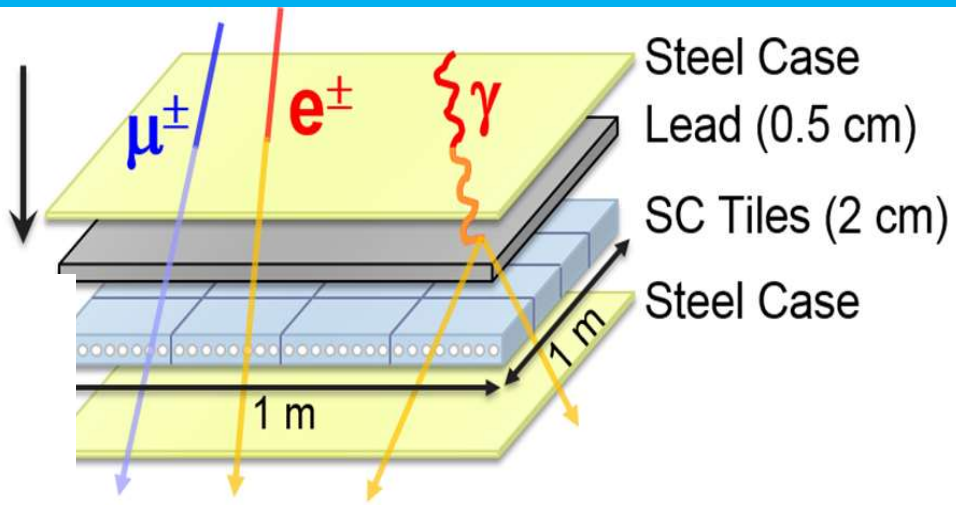


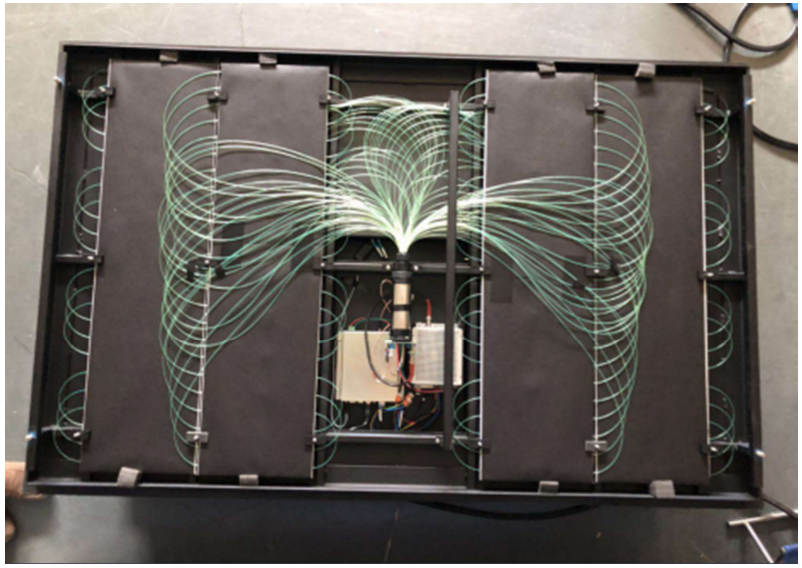
- **Total area: $78,000m^2$**
- **Total units: 3,120**
- **Unit size: $5m \times 5m \times 4.4m$**
- **Two type of PMTs in first pool:**
  - **8 inches**
  - **1.5 inches:** extend the energy to 10PeV

Scintillator Detectors （ED）and μ detector（MD）

2.5m thick soil above the water bag







Inner View of one ED

Wide Field of View Cherenkov Telescope (WFCTA)

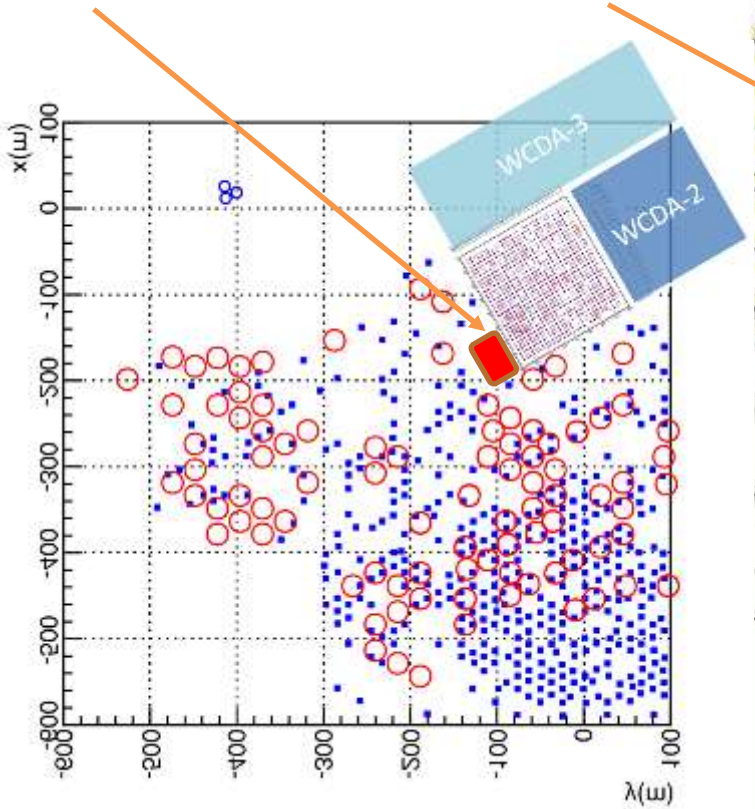
20 Telescopes

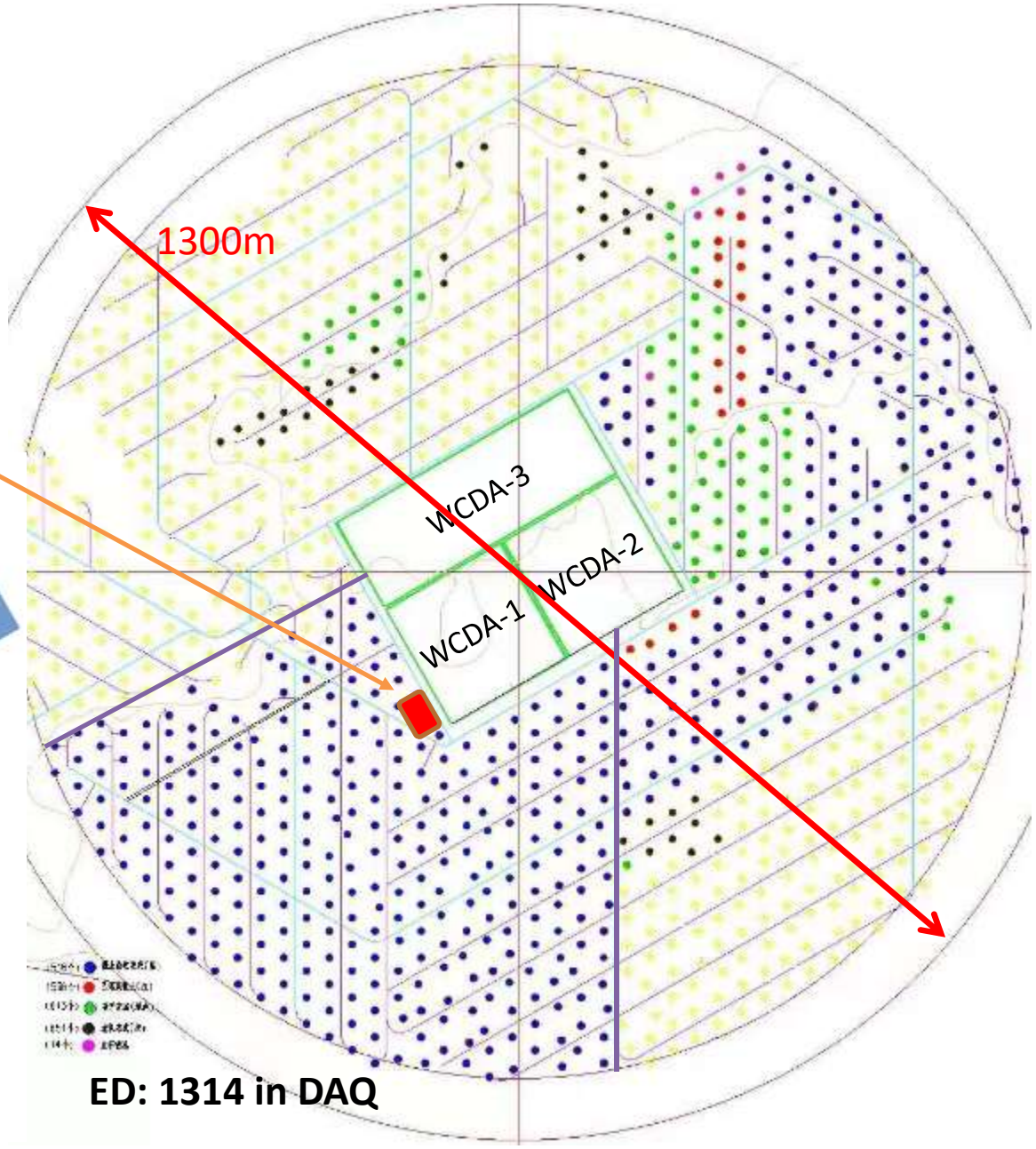
- 5m^2 spherical mirror
- Camera: 32×32 SiPMs array
- FOV: 16° × 16°
- Pixel size: 0.5°

¼ LHAASO is in stable operation in October 2019

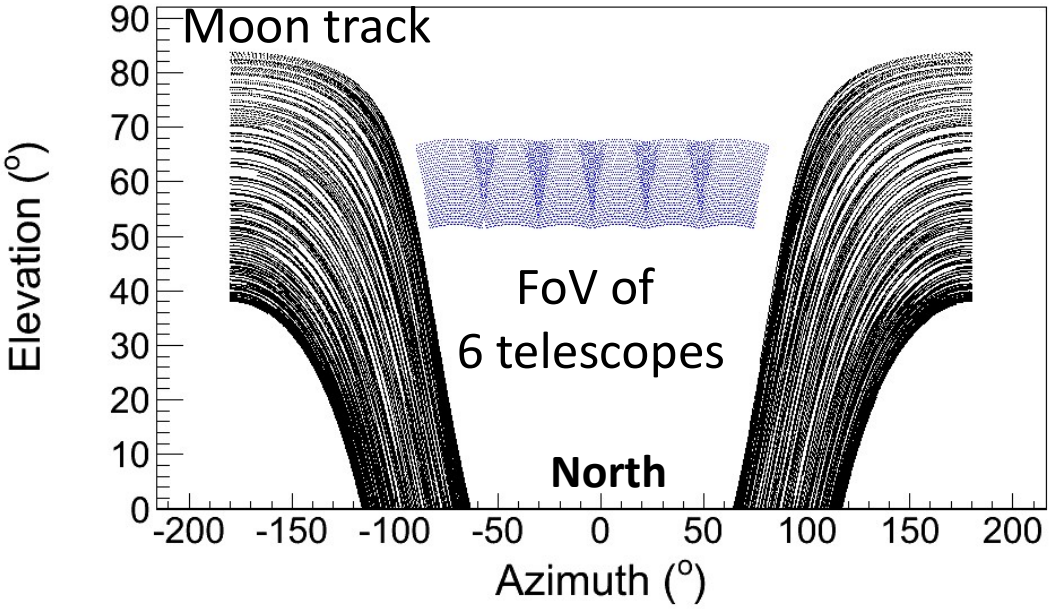
1. Muon detector: 304
2. Scintillator detector: 1200
3. WCDA-1: 150 m × 150m

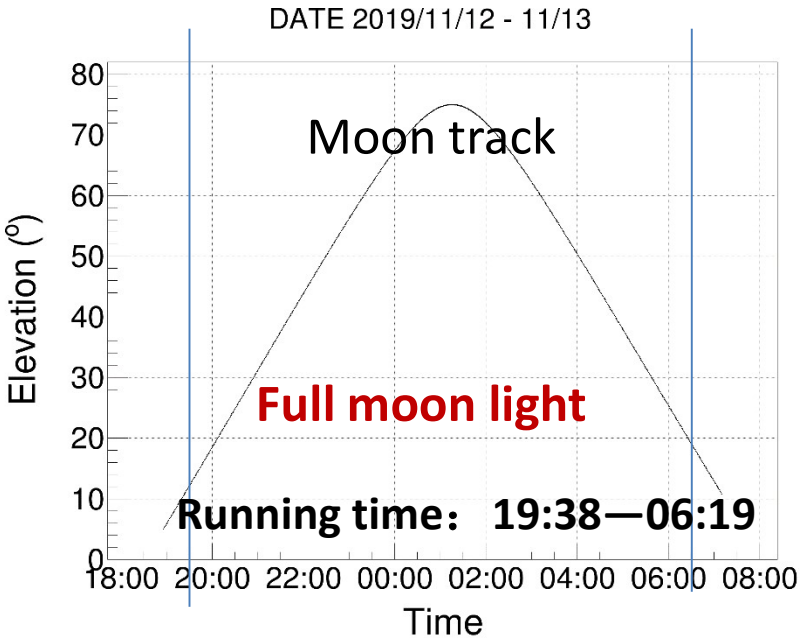
4. 6 Cherenkov telescopes





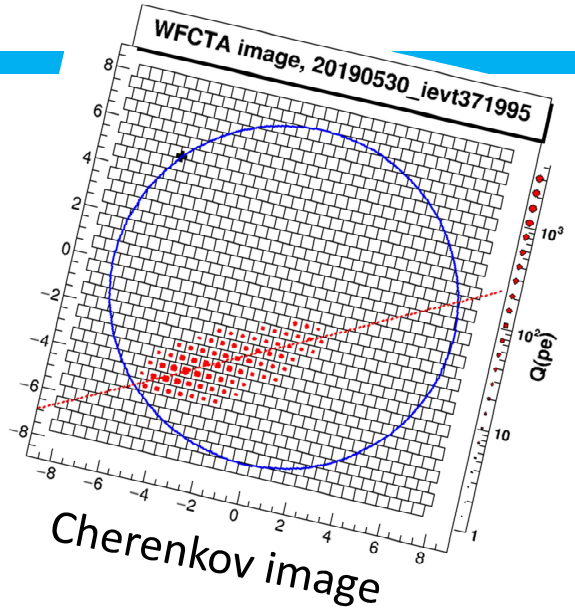
ED: 1314 in DAQ



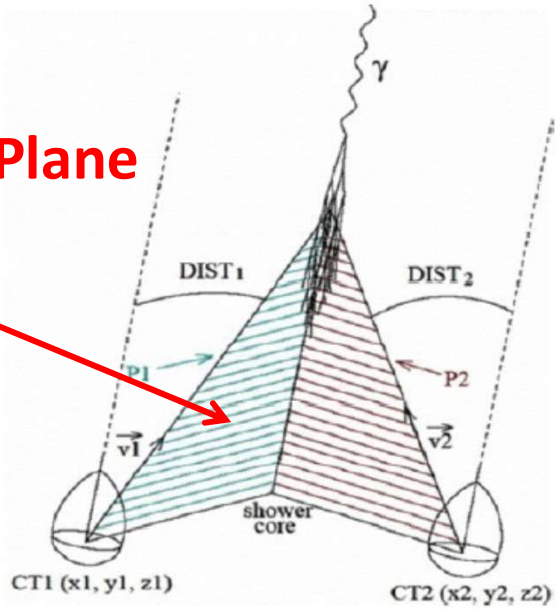


- **FoV of 6 telescopes**
  - **zenith angle: 22° - 38°**
  - **azimuth angle: -80° - +80° (north=0°)**
- **SiPM not aging due to strong light exposure;**
- **SiPM-based Cherenkov telescope successfully operated with moon light;**
- **Duty cycle： >30%.**

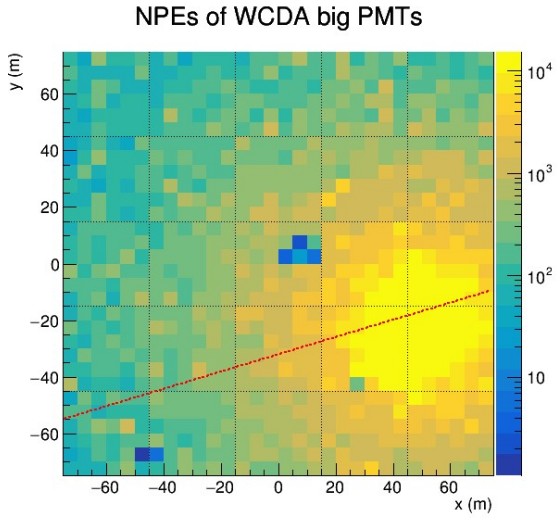
An event observed in coincidence by WCDA and WFCTA



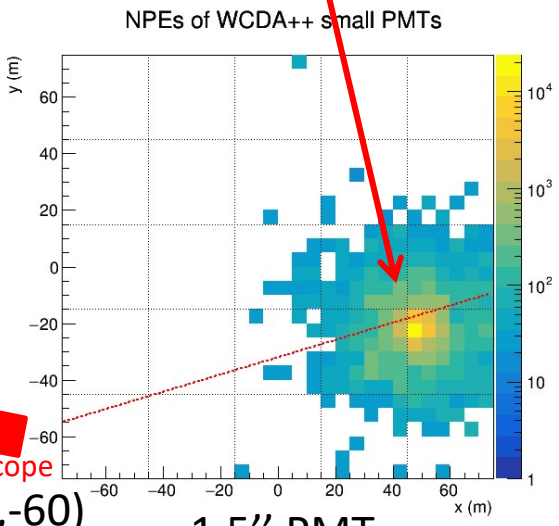
Shower Detector Plane (SDP)



Shower Core

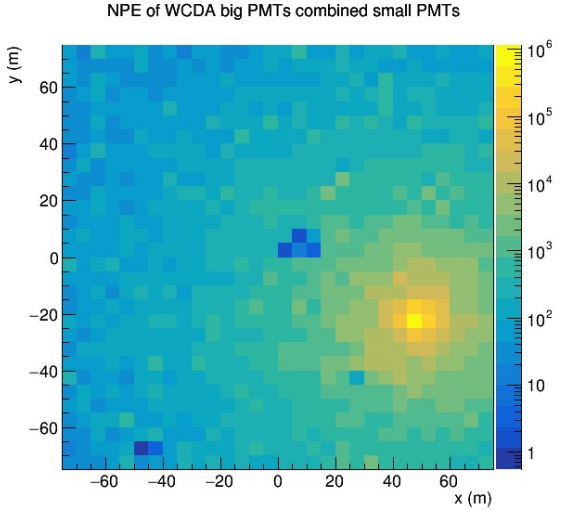


8'' PMT



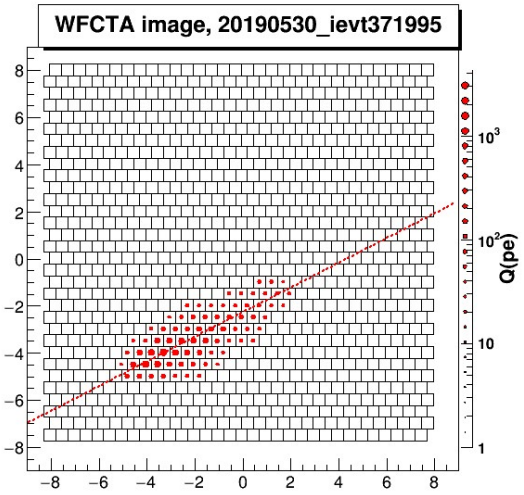
telescope (-80,-60)

1.5'' PMT



8'' PMT+1.5'' PMT

Discrimination variables for composition studies



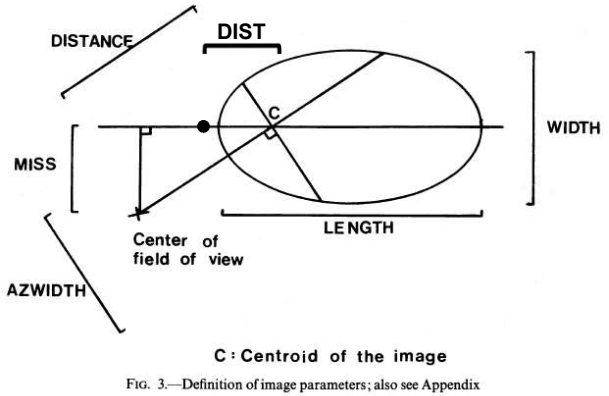
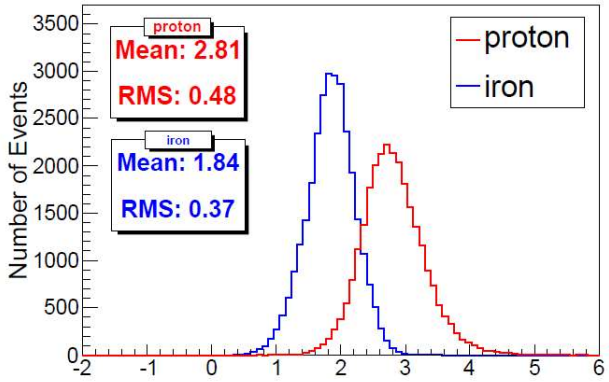
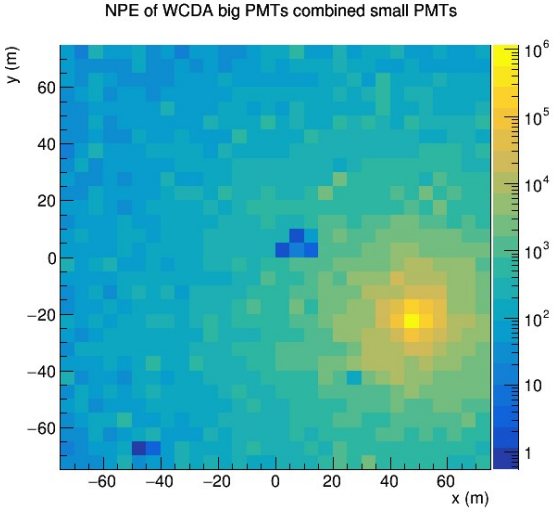


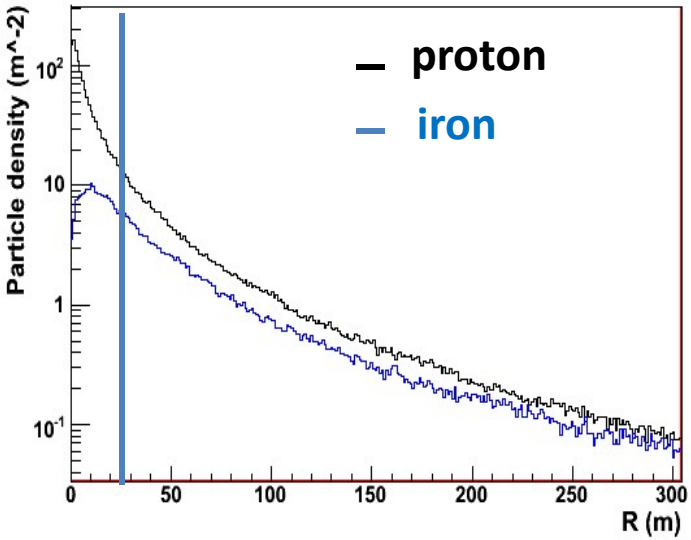
FIG. 3.—Definition of image parameters; also see Appendix



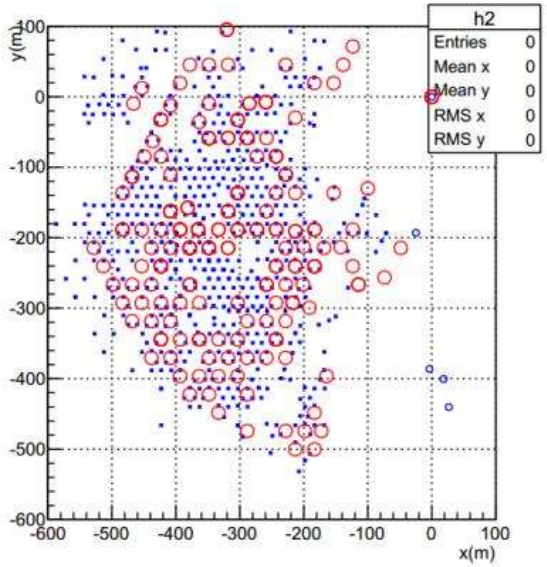
$$P_c = \left(\frac{Length}{Width}\right)\Big|_{normalized}$$

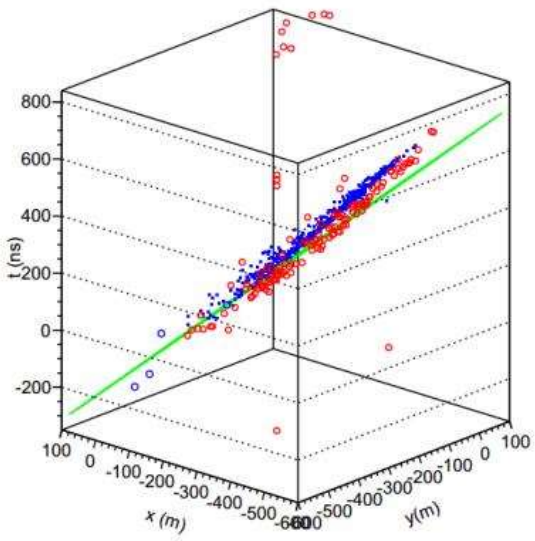
- **Length/Width**
- **Dist (related to X_{max})**
- **Particle numbers near the shower core**
- ***Number of muons***





Discrimination variables for composition studies



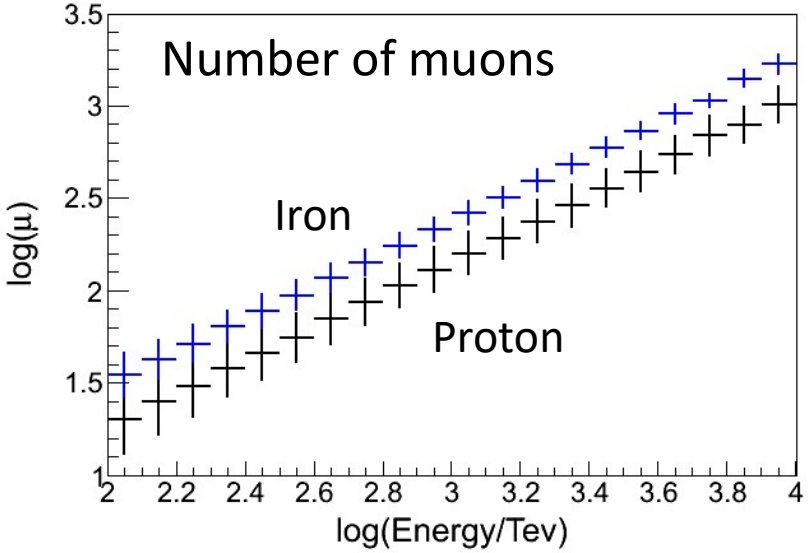


An events measured by scintillators and muon detectors.

Muon: red circle

Scintillator: blue dot

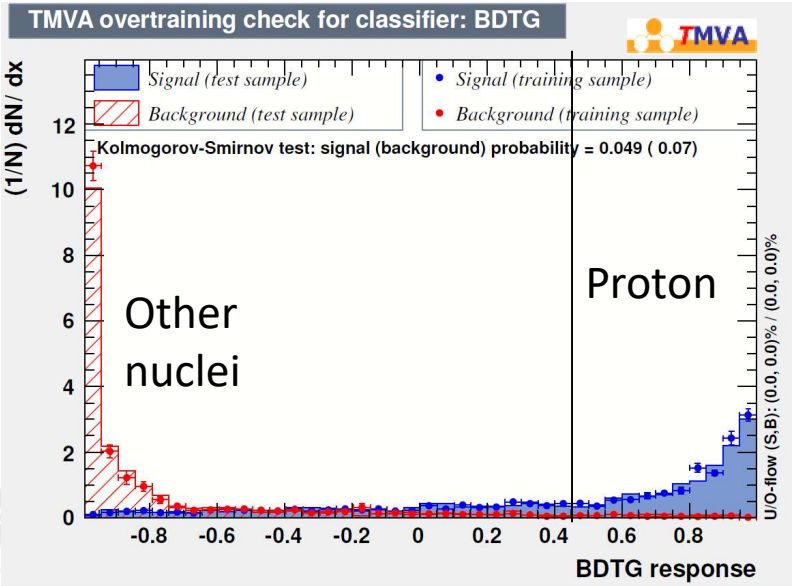
- **Length/Width**
- **Dist (related to X_{max})**
- **Particle numbers near the shower core**
- ***Number of muons***

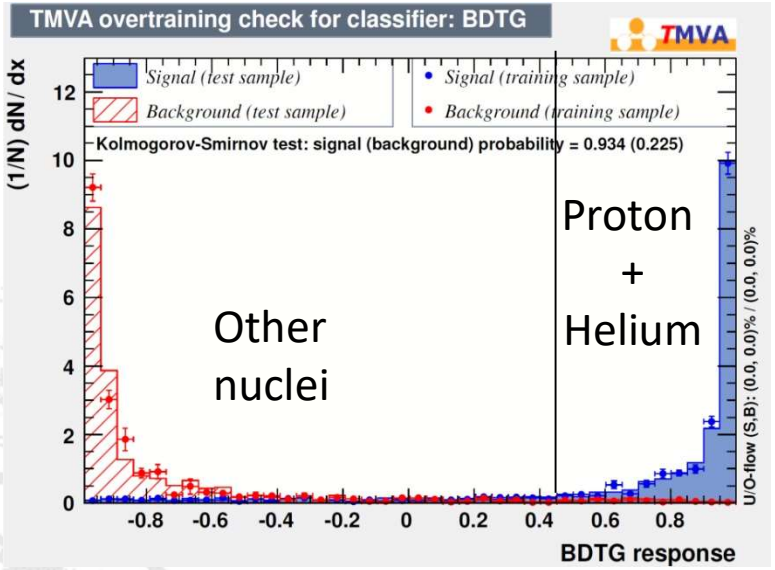


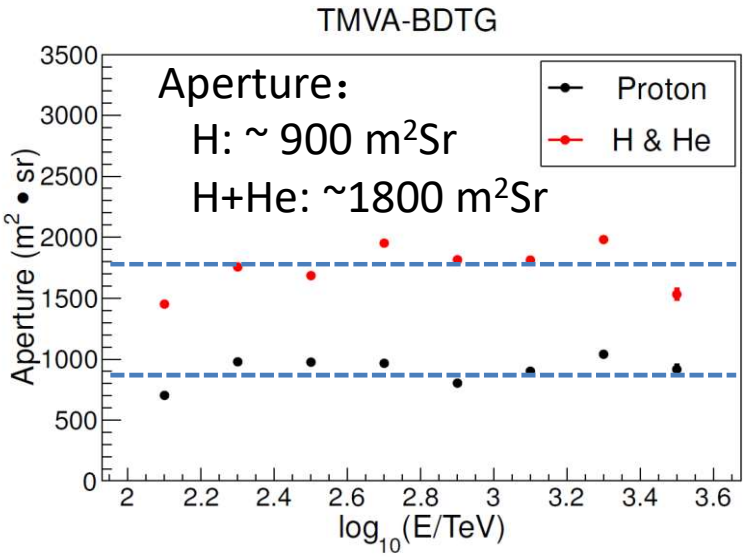
Energy measured by Cherenkov telescopes

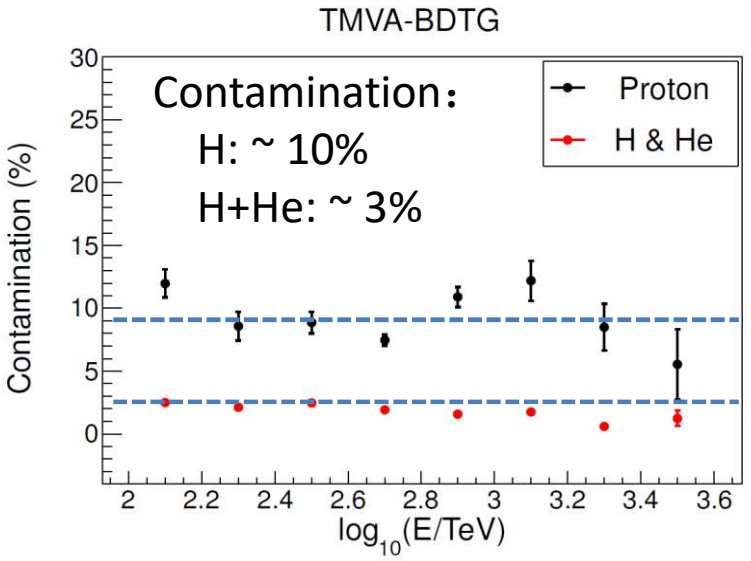
Multi-parameters analysis

TMVA(Toolkit for Multivariate Data Analysis with ROOT)





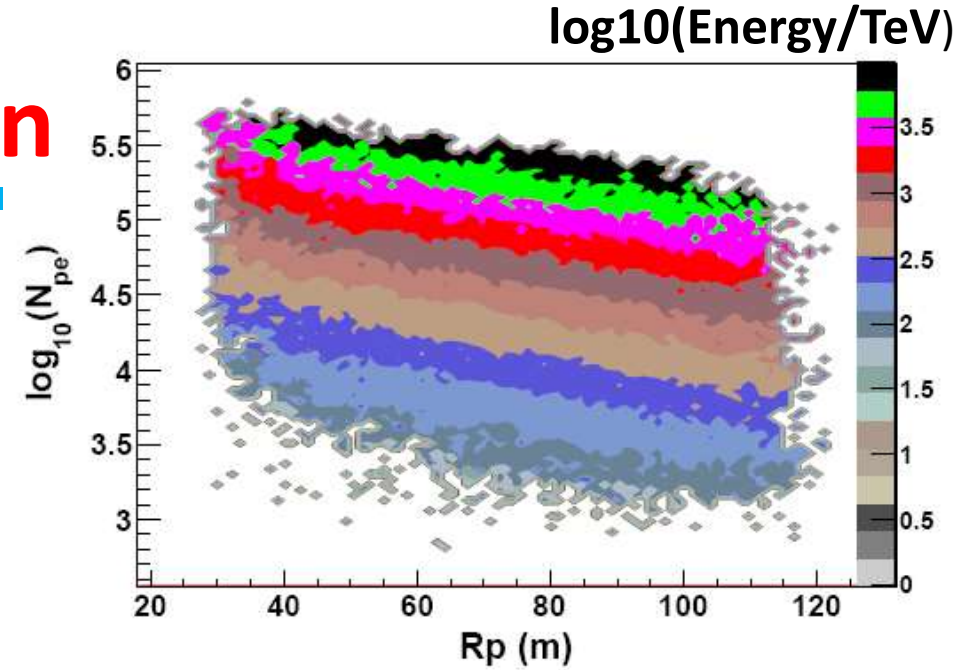


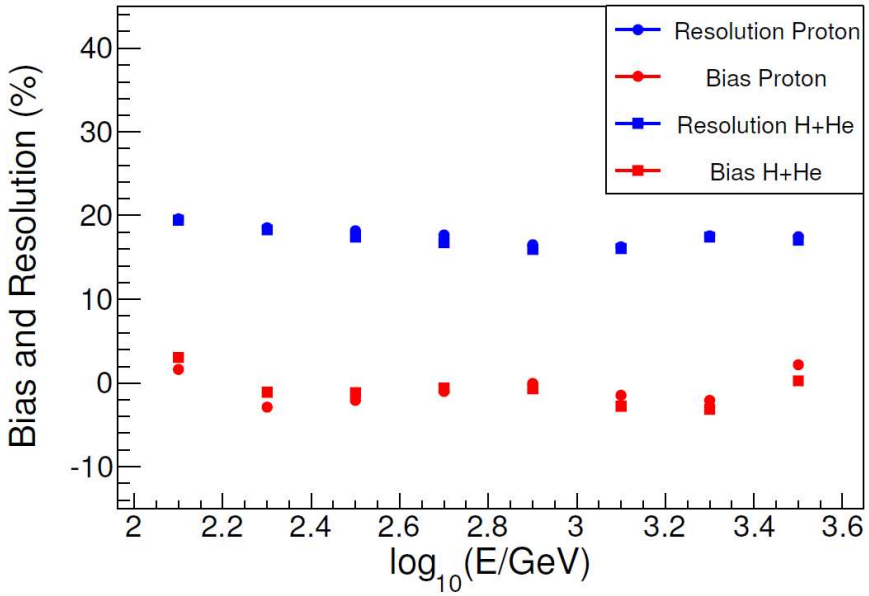


Energy reconstruction

Look-up table

- $\sum N_{pe}$ in Cherenkov image
- Shower direction and core reconstructed by WCDA
  - Core resolution: < 3 m
  - Angular resolution: < 0.3° @ >10TeV
- Energy resolution: ~20% with bias less than 3%.

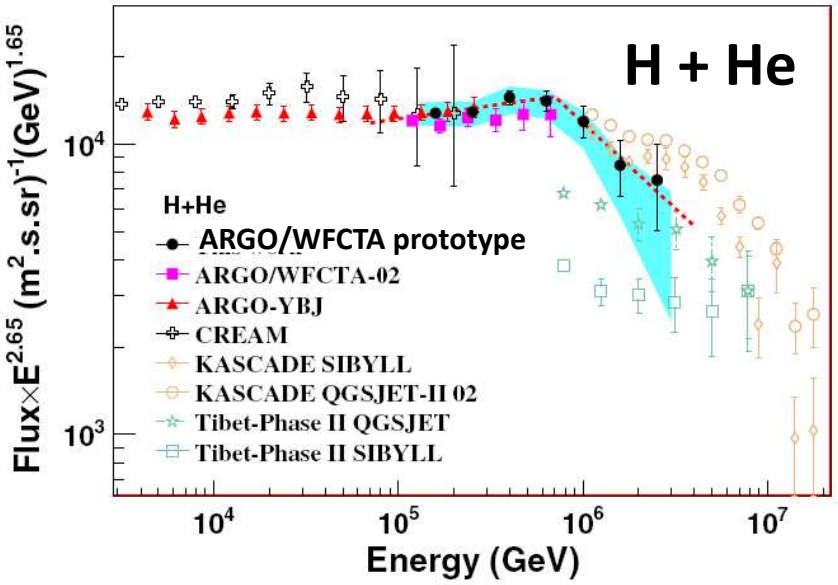


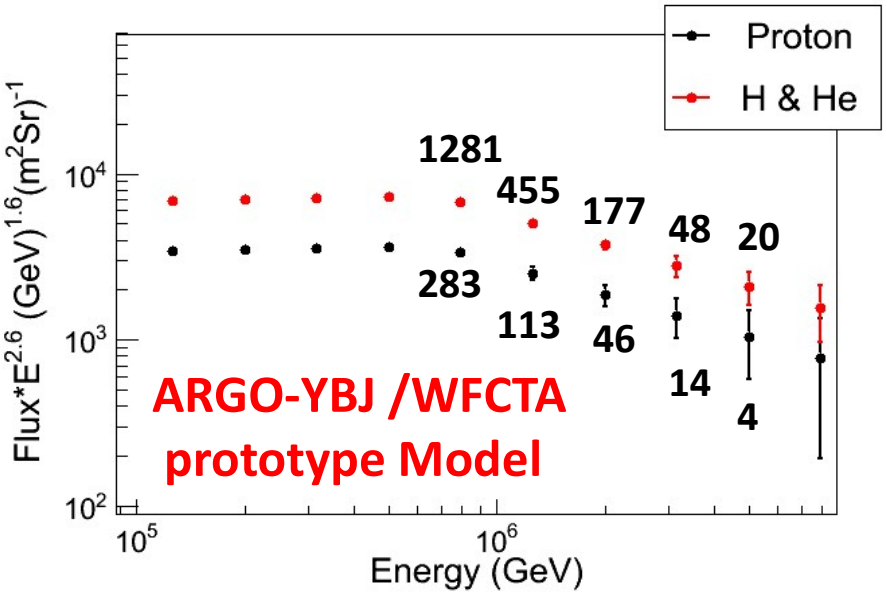


Number of good events expected in the hybrid observation with C-telescopes and WCDA or KM2A

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

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





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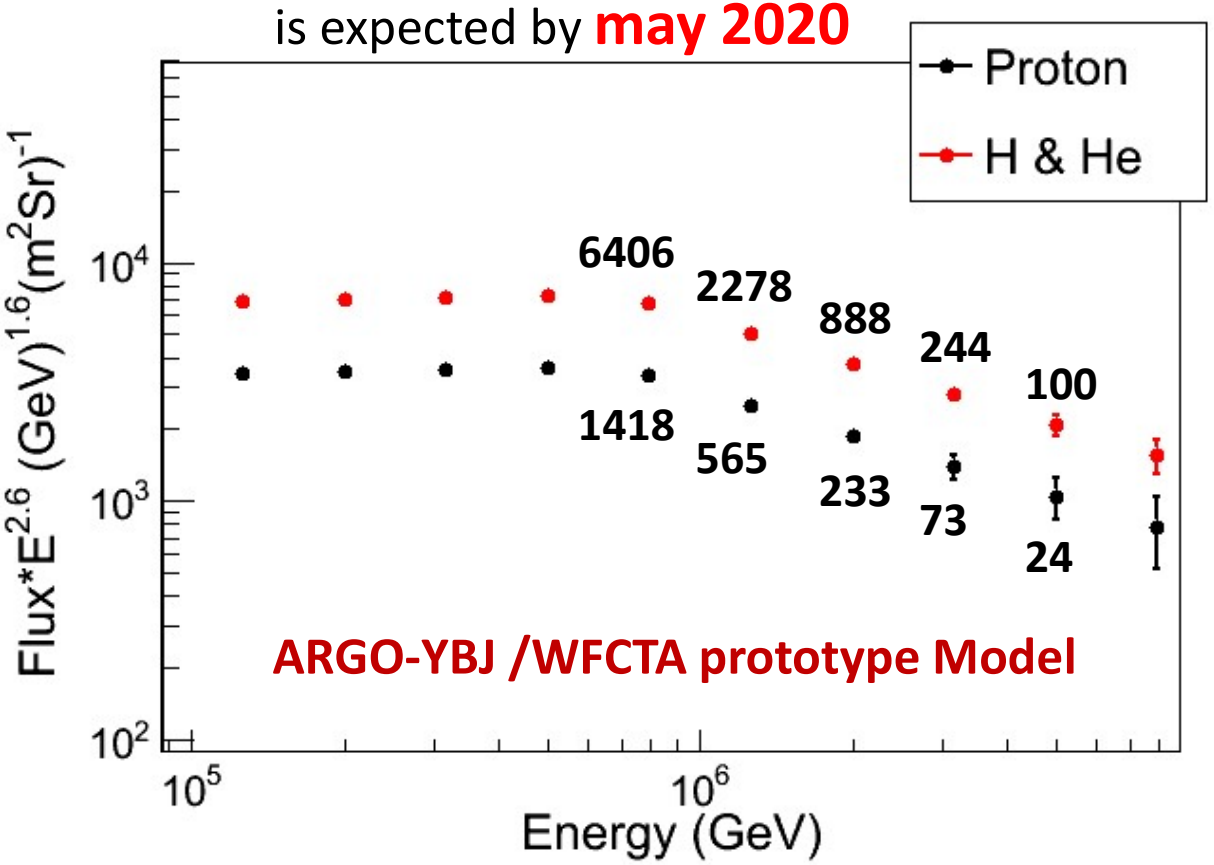
Number of good events expected in the hybrid observation with C-telescopes and WCDA or KM2A

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

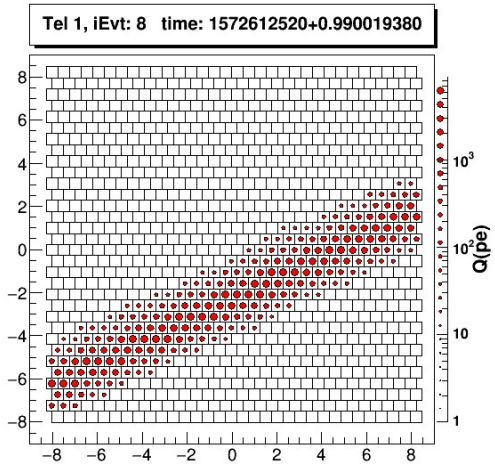


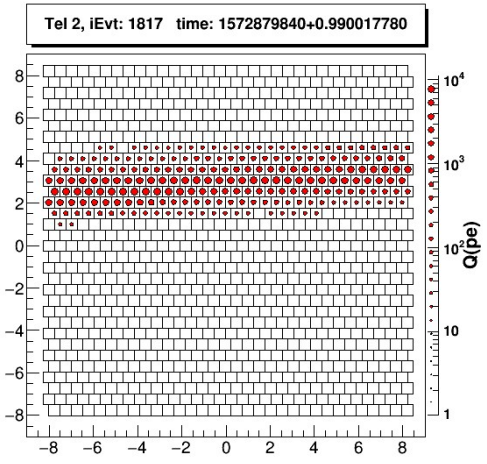
Pure H and H+He knees will be accurately measured using ¼ LHAASO by May 2020.

Calibration and Atmosphere Monitoring

Device	Parameters
N_2 laser	Wave length=337nm Energy：~170μJ
YAG laser	Wave length=355nm Energy: ~2mJ

- Absolute Calibration
- Atmospheric transparency monitoring
- Laser scanning the FoV of 6 telescopes every night: 24 minutes/cycle.





Summary and future plan

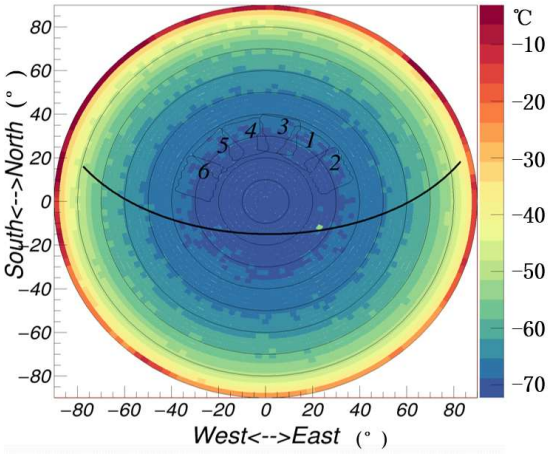
- ¼ LHAASO is in stable operation in October 2019
  - 6 Cherenkov telescopes
  - one 150m×150m water pool of WCDA
  - 1200 scintillator detectors and 304 muon detectors
- Data analysis is in progress.
- Pure H and H+He knees will be accurately measured using ¼ LHAASO by May 2020.

Thanks!

Energy spectrum expectation of ¼ LHAASO

- ¼ LHAASO
  - 6 telescopes
  - one 150m×150m water pool of WCDA
  - 1200 scintillator detectors and 304 muon detectors
- Combination running time
  - 2019.10.16 – 2019.11.30： ~318 hours
  - After good weather selection： ~188 hours

Cloud monitor



Distribution of infrared temperature in the whole sky