

# Measurement of the cosmic ray H&He spectrum above 100TeV by the LHAASO experiment

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# Outline

- **Hybrid Experiment**
- **Data Selection**
- **Simulation**
- **Shower Reconstruction**
- **Energy Reconstruction**
- **Composition Discrimination**

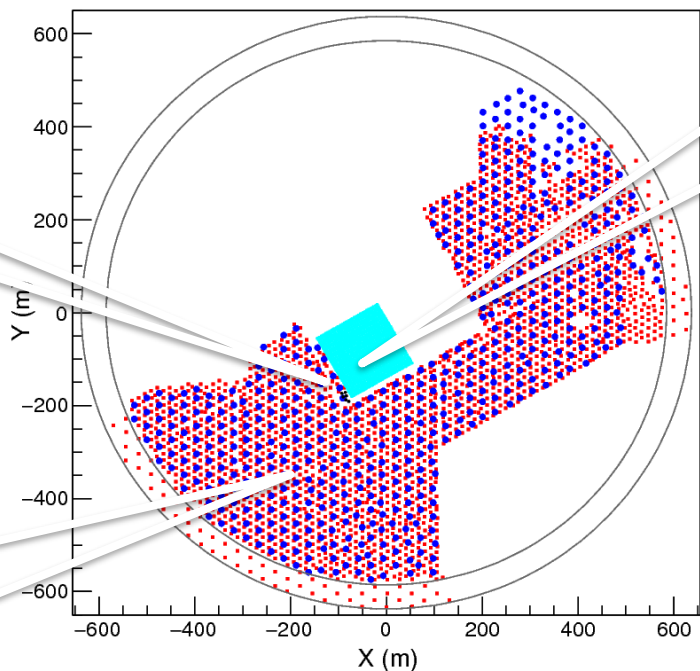
# Hybrid Experiment



**WFCTA:**  
Wide Field of view  
Cherenkov Telescope Array  
(Equipped with SiPM)



**WCDA: (78,000m<sup>2</sup>)**  
Water Cherenkov  
Detector Array  
(Full Array)



**KM2A: (ED, MD, 1.3 km<sup>2</sup>)**  
Electromagnetic Detector (spacing of 15 m)  
Muon Detector (Muon content, spacing of 15 m)

**Mt. Haizi, Daocheng, Sichuan**  
**29°21' 31'' N, 100°08'15'' E**  
**4410 m a.s.l., 600 g/cm**

- Hybrid measurement  
(Multiple parameters)
- Large aperture (high statistics)



# Data Selection

## ➤ Period:

- 2020.11 ~ 2021.03 (Core in WCDA, WFCTA $\oplus$ WCDA $\oplus$ KM2A)
- 2020.11 ~ 2021.04 (Core in KM2A, WFCTA $\oplus$ KM2A)

Selections of WFCTA, KM2A and WCDA:

## ➤ WFCTA:

- More than 10 tubes are saved after image clean
- Centroid of image limited in  $5^\circ$  (Image contained in the telescope)

## ➤ KM2A:

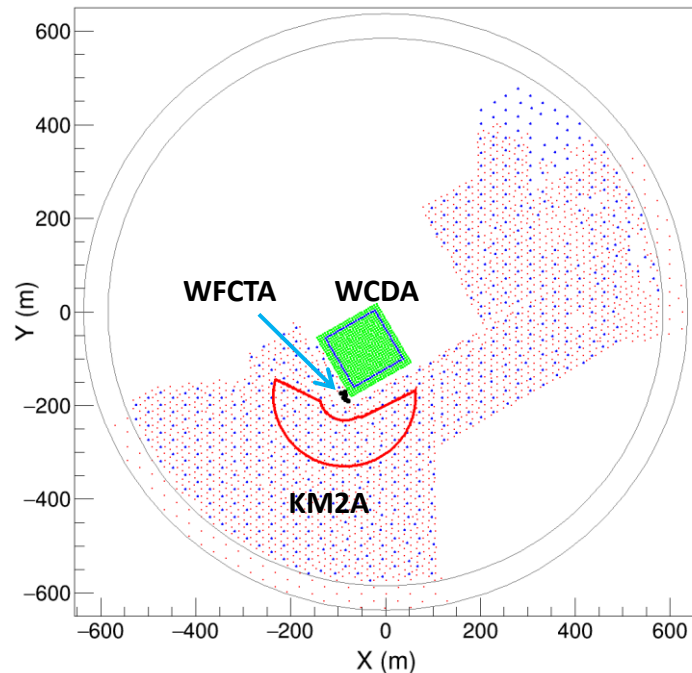
- Reconstruction shower core located in KM2A
- More than 20 ED fired and  $Npe_{40-100m} > 20$

$$\frac{Npe|_{0-40m}}{Npe|_{0-100m}} > 0.5$$

## ➤ WCDA:

- Reconstruction shower core located in WCDA
- The brightest cell  $> 4000$  Npe

$$\frac{Npe|_{0-10m}}{Npe|_{0-30m}} > 0.3$$



## ➤ Observation time and Events:

- 750 hours, 0.7 million events (Core in WCDA)
- 970 hours, 2.8 million events (Core in KM2A)

# Simulation

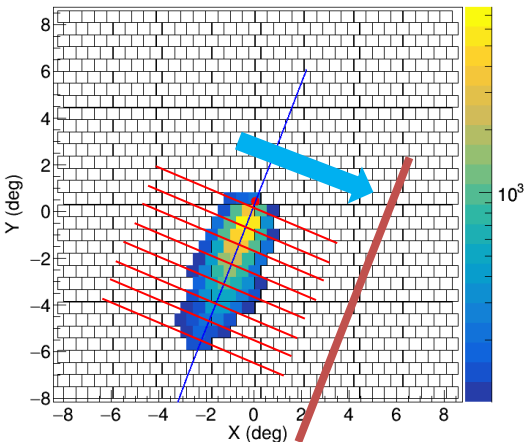
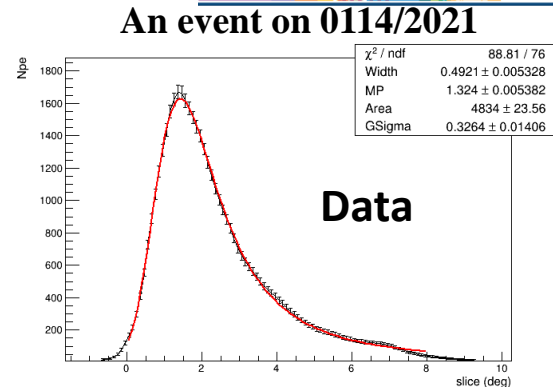
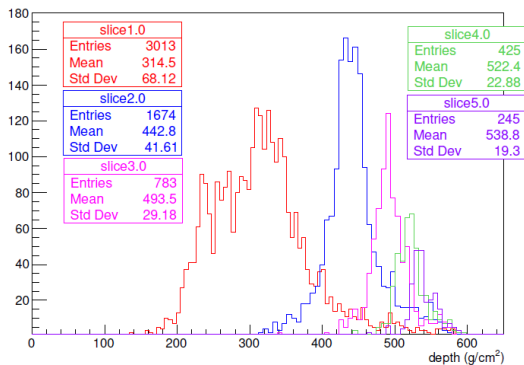
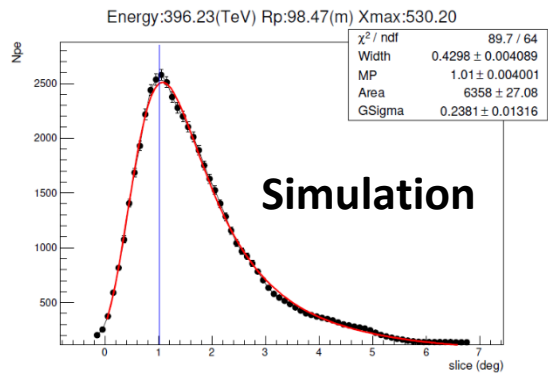
## Simulation Sample:

- Interaction model: QGSJETII04+FLUKA
- Primary particles: proton, helium, CNO, MgAlSi, iron
- Energy range: 10 TeV ~ 10 PeV
- Geometry:
  - azimuth:  $95^\circ \sim 275^\circ$ ;
  - zenith:  $20^\circ \sim 40^\circ$
  - core:  $\pm 300\text{m}$

## Geometry Reconstruction:

- |                                     |                                      |
|-------------------------------------|--------------------------------------|
| ➤ Core resolution:                  | ➤ Angular resolution:                |
| • $<3\text{m}@100\text{TeV}$ (KM2A) | • $<0.3^\circ @100\text{TeV}$ (KM2A) |
| • $<3\text{m}$ above 100TeV (WCDA)  | • $<0.2^\circ$ above 100TeV (WCDA)   |

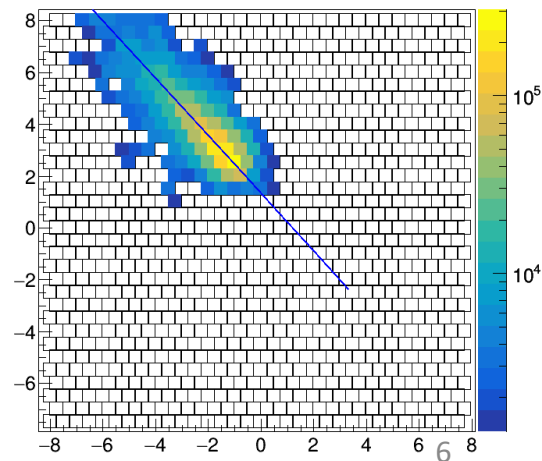
# Shower Reconstruction



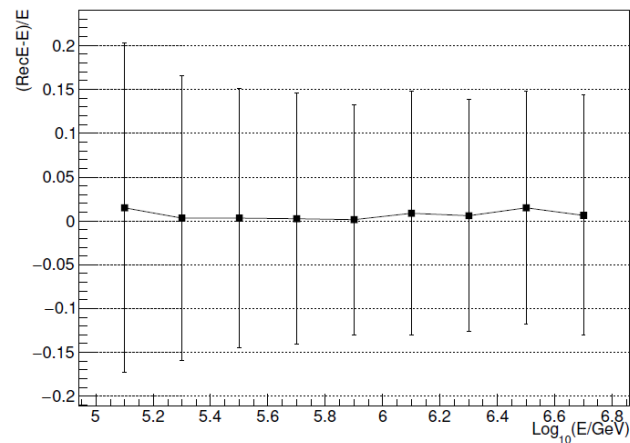
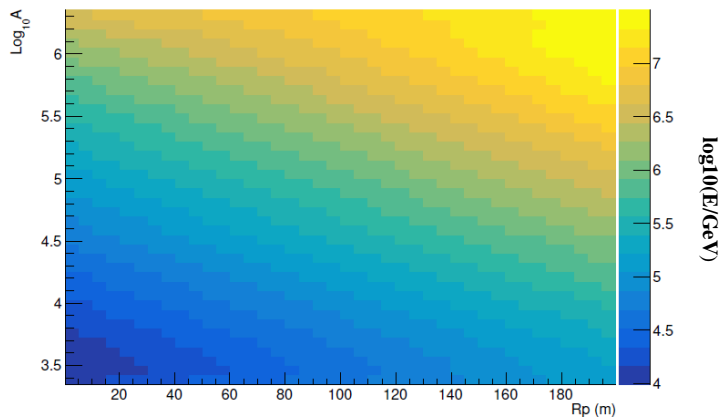
$$f(x, \Delta, MPV, A, \sigma_g) = A \int_{-\infty}^{+\infty} \text{Landau}(x', \Delta, MPV) \times \text{Gaus}(x', \sigma_g) dx'$$

**A:** Total Npe of WFCTA  
(related to Impact parameter (Rp) ,  
primary energy)

**$\Delta$ :** scaling parameters,  
is related to shower maximum  
(related to Rp)



# Energy Reconstruction

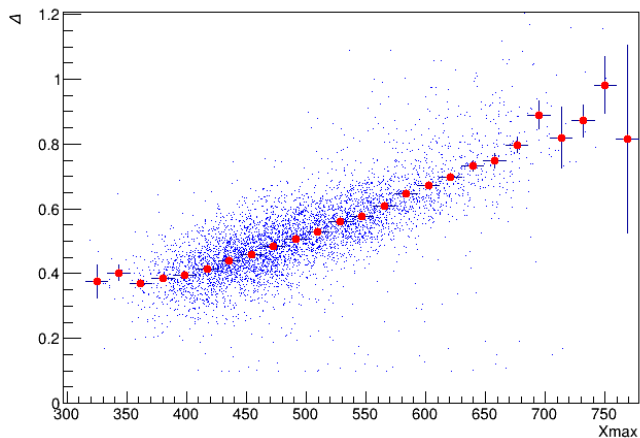


Reconstruction:

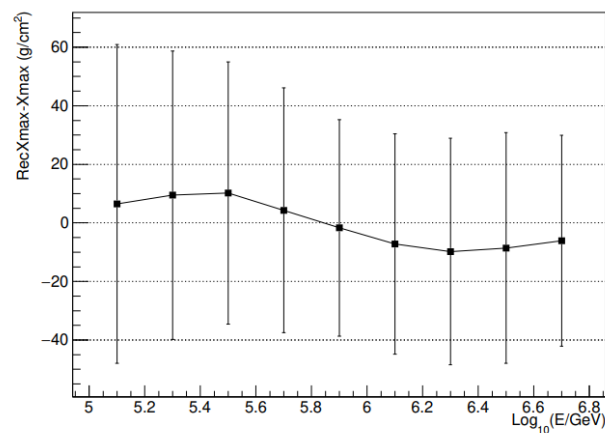
- $\log(A)$  bin: 0.1/bin
- $R_p$  bin : linear fit
- interpolation

**E resolution: 15% above 300 TeV**  
**Systematic bias: <2%**

# Xmax Reconstruction



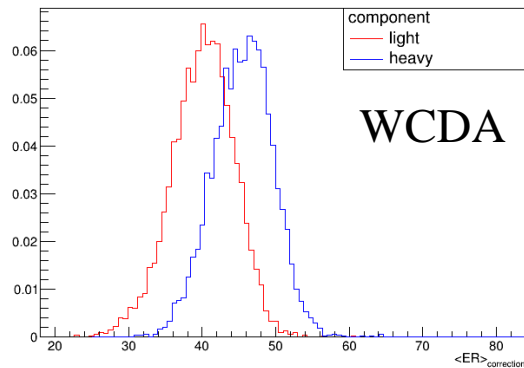
$\Delta$  vs.  $X_{max}$  (Rp:120m~125m)



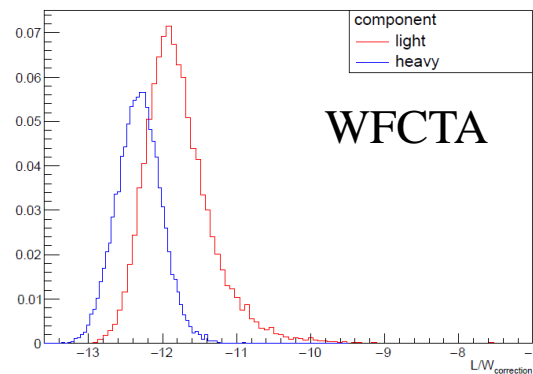
**Xmax resolution:  $40 g/cm^2$  above 300 TeV**  
**Systematic bias:  $< 10 g/cm^2$**



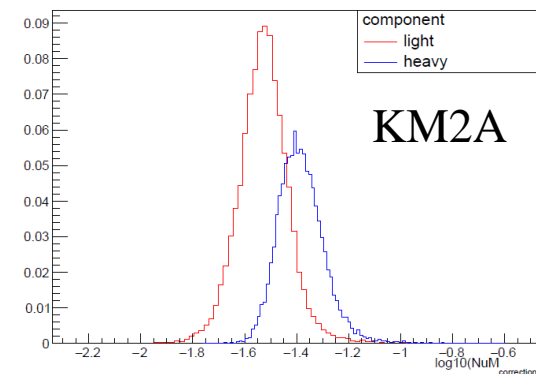
# Composition Discrimination



$P_F$



$P_C$



$P_\mu$

$$\log_{10} Size_0 = \log_{10} Size + 0.00837 \times R_p$$

**WCDA**  $P_F = \langle ER \rangle + 4.844 \times \log_{10} Size_0$

$$\langle ER \rangle = \frac{\sum (R_i \times Pe_i)}{\sum Pe_i}$$

Combine these parameters

**WFCTA**  $P_C = (L/W - 0.0116 \times R_p) + 0.371 \times (\log_{10} Size_0)^2 - 4.495 \times (\log_{10} Size_0)$

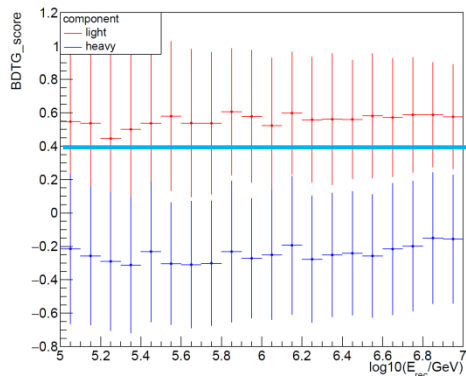
$$P_F \oplus P_C \oplus P_\mu \text{ (Core in WCDA)}$$

$$P_C \oplus P_\mu \text{ (Core in KM2A)}$$

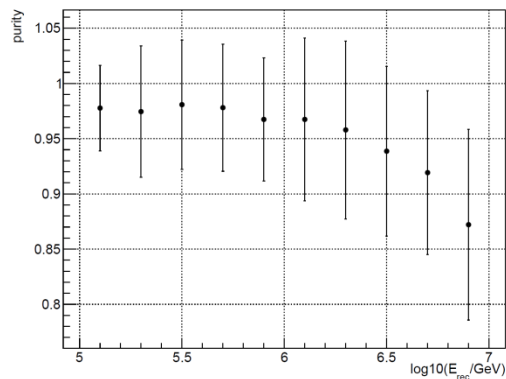
**KM2A**  $P_\mu = \log_{10}(N_{\mu|30-380}) - 0.0916 \times (\log_{10} \sqrt{N_{e|40-100} \times N_{\mu|40-200}} + 3.44)$

# Composition Discrimination

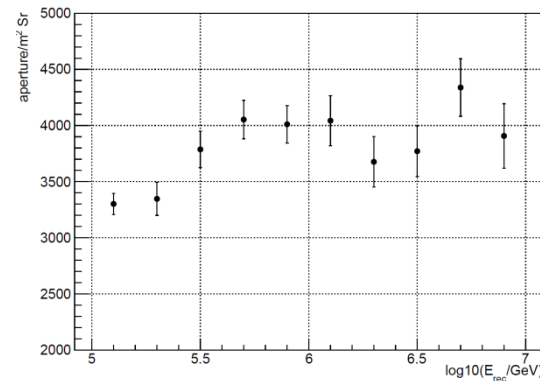
Sore > 0.4



$P_C + P_\mu$  (Core in KM2A)



$$\text{Purity} = \frac{N_{\text{light}}}{N_{\text{light}} + N_{\text{heavy}}}$$



$$\text{Aperture} = \frac{N_{\text{select}}}{N_{\text{throw}}} \times S_{\text{throw}} \times \Omega$$

# Summary and future work

- The hybrid experiment can also operate on moon night. For events fall on WCDA and for events fall on KM2A, the observation time and events: 750 hours, 0.7 million events and 970 hours, 2.8 million events, respectively. Duty cycle of hybrid experiment is about 25%.
- With the core resolution better than 3m and angular resolution better than  $0.3^\circ$  above 100 TeV, the energy resolution of WFCTA is 15% above 300 TeV
- Component parameters based on QGSJETII04+FLUKA is studied. For Core in KM2A events, Purity better than 85%, Aperture is  $4000/m^2 Sr$ .
- Next: events of Core in WCDA and more composition sensitive parameters such as RecXmax will be studied. Other simulation events based on EPOS+FLUKA is being created.