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

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Hybrid Detection of EASs by LHAASO

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

**WFCTA:**
20 Cherenkov telescopes (1024 pixels/telescope)

**KM2A:**
5195 EDs
1171 MDs

Daochen, Sichuan, China
(4410 m a.s.l., 600 g/cm)
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

- 5m² spherical mirror
- Camera: $32 \times 32$ SiPMs array
- FOV: $16° \times 16°$
- 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
Running time: 19:38—06:19

Full moon light

- 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

NPEs of WCDA big PMTs

NPEs of WCDA++ small PMTs

NPE of WCDA big PMTs combined small PMTs

8'' PMT

1.5'' PMT

8'' PMT+1.5'' PMT
Discrimination variables for composition studies

- Length/Width
- Dist (related to $X_{\text{max}}$)
- Particle numbers near the shower core
- \textit{Number of muons}
Discrimination variables for composition studies

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

An events measured by scintillators and muon detectors.

Muon: red circle  
Scintillator: blue dot

Energy measured by Cherenkov telescopes
Multi-parameters analysis

TMVA (Toolkit for Multivariate Data Analysis with ROOT)

Aperture:
H: ~ 900 m²Sr
H+He: ~1800 m²Sr

Contamination:
H: ~ 10%
H+He: ~ 3%
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° @ >10 TeV

- 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:
    \[ 6.5 \times 10^5 \text{ s} = 180 \text{ hours} \]
Pure H and H+He knees will be accurately measured using ¼ LHAASO by May 2020.
Calibration and Atmosphere Monitoring

<table>
<thead>
<tr>
<th>Device</th>
<th>Parameters</th>
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</thead>
<tbody>
<tr>
<td>N\textsubscript{2} laser</td>
<td>Wave length=337nm Energy: ~170\mu J</td>
</tr>
<tr>
<td>YAG laser</td>
<td>Wave length=355nm Energy: ~2mJ</td>
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- 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

Infrared camera

Distribution of infrared temperature in the whole sky