Origin of cosmic rays with LHAASO and Auger

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About the thesis

• 2\textsuperscript{nd} year PhD student in IPN-Orsay
• Working for LHAASO and the Pierre Auger Observatory

LHAASO and Auger are both scientific projects aiming to search for the cosmic-ray origin

**LHAASO**
(Large High Altitude Air Shower Observatory)
Energy range of air shower detection: $10^{14}\text{eV}$ to $10^{18}\text{eV}$ (around “knee” region)

**Auger**
Energy range of air shower detection: above $10^{18}\text{eV}$
WFCTA in LHAASO

WFCTA: (Wide Field of View Cherenkov Telescope Array)

Three phases:
30\(TeV \sim 10\,PeV\) in Cherenkov mode
10\(PeV \sim 100\,PeV\) in Cherenkov mode
100\(PeV \sim 1\,EeV\) in Fluorescence mode

WFCTA:
32\times32\) PMTs in each camera
16° × 14° field of view
~0.5° pixel size
12 (or 18) telescopes
WFCTA Layout

Hybrid observations together with WCDA (Water Cherenkov Detector Array) and KM2A (1km² Array), 1/4 of the WCDA used as shower core detector.

WFCTA location

WCDA

Shower core detection

West

north

150m

150m

300m
Single Telescope Simulations

Shower simulation by CORSIKA:

Primary Energy: $100TeV \sim 10PeV$
Slope of energy spectrum: $-2.7$
Zenith: $24^\circ \sim 38^\circ$
Azimuth: $77^\circ \sim 103^\circ$
Particle type: p, He, CNO, MgAlSi, iron

Telescope simulation:

- Pointing ($\theta_{\text{zenith}}, \varphi_{\text{azimuth}}$) = (30°, 90°)
- Optical ray-tracing to each PMT in the camera (by L.L.Ma)
- Signal response & process in PMT & Electronics
- Different shaping and tube-trigger modes for both traditional and ASIC-based front-end electronics
- Event pattern trigger in camera (by B.Y.Bai)
WFCTA image and parameterization

Main Parameters:

SIZE:
Total p.e. number

Rc:
Distance from telescope to shower core

Length, Width:
Lengths of the Hillas ellipse axes

Distance:
Distance from image centroid to camera center

δ:
Angle between long axis of the ellipse and the Y axis of camera
Reconstruction: Primary Energy

\[ \log_{10}\text{recEnergy} = f(\log_{10}\text{SIZE}, R_c, \delta, \text{dist, core}) \]
\[ = f_1(\log_{10}\text{SIZE}, R_c) + f_2(\delta, \text{dist, core}) \]

Results for proton:

\[ \frac{\text{recE} - E}{E} \times 100\% \]

**$E$ resolution $\sim 20\%$**

**Bias $< 6\%$**
Reconstruction: Incident Angle

\[(\theta_{zenith}^{\text{rec}}, \phi_{azimuth}^{\text{rec}}) = f(\text{TelPointing}, \text{Centroid}, \text{Core}, \text{distance})\]

\[\theta_{zenith} - \theta_{zenith}^{\text{rec}}: \text{Resolution: } \sim 0.3^\circ\]

\[\phi_{azimuth} - \phi_{azimuth}^{\text{rec}}: \text{Resolution: } \sim 1^\circ\]
Tests and R&D for Auger Upgrade

The key element of Auger upgrade will be the installation of a **Scintillator Surface Detector (SSD)** on top of each existing **Water Cherenkov Detector**. It will provide a measurement of primary composition by deducing **electromagnetic and muonic components of the shower**.

We tested different scintillator/fiber configurations and developed a fiber/PMT coupling method for SSD. April 2016, the detector with IPNO coupling was assembled and tested in KIT and will be installed in the Engineering Array on the observatory side.
Preliminary results

Signal of charge = 6.52 pC
32.6 p.e./MIP

Peak to Valley ratio > 40
Conclusions:

• **LHAASO-WFCTA**
  
  Single WFCTA telescope simulation finished
  
  Reconstruction results:
  
  Primary Energy: $\sim 20\%$, bias $< 6\%$
  
  $\theta_{\text{zenith}}$: $\sim 0.3^\circ$
  
  $\phi_{\text{azimuth}}$: $\sim 1^\circ$

• **Auger Upgrade SSD**
  
  Tests to optimize SSD scintillator/fiber/optical coupling configuration are finished
  
  One SSD detector in the Engineering Array (EA) is equipped with IPNO coupling. The preliminary test results show that it has a good performance.

Next steps:

• **LHAASO-WFCTA:**
  
  Multi-telescope simulations & Hybrid analysis with WCDA and KM2A

• **Auger Upgrade SSD:**
  
  EA data analysis & Long term performance of the SSD detectors in the EA