The LHAASO observatory

(Large High Altitude Air Shower Observatory)

Francesco Simeone

on behalf of the LHAASO Collaboration
Outline

• Overview of the LHAASO project

• Scientific topics

• Status of the project

• Conclusions
The LHAASO project

The Large High Altitude Air Shower Observatory (LHAASO) project is a new generation all-sky instrument to perform a combined study of cosmic rays and gamma-rays in the wide energy range $10^{11} - 10^{17}$ eV.

The experiment will be located at 4300m asl (606 g/cm²) in the Sichuan province.

**1 KM2A:**
- 5635 EDs
- 1221 MDs

**WCDA:**
- 3600 cells
- 90,000 m²

**SCDA:**
- 452 detectors

**WFCTA:**
- 24 telescopes
- 1024 pixels each

Coverage area: 1.3 km²
Shower at high altitude

High energy: near $X_{\text{max}} \Rightarrow$ large number of particles, lower fluctuation, better $\sigma_e$

Low energy threshold

LHAASO

INFIN Instituto Nazionale di Fisica Nucleare
**Water Cherenkov Detector Array**

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell area</td>
<td>25 m²</td>
</tr>
<tr>
<td>Effective water depth</td>
<td>4 m</td>
</tr>
<tr>
<td>Water transparency</td>
<td>&gt; 15 m (400 nm)</td>
</tr>
<tr>
<td>Precision of time measurement</td>
<td>0.5 ns</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>1-4000 PEs</td>
</tr>
<tr>
<td>Time resolution</td>
<td>&lt;2 ns</td>
</tr>
<tr>
<td>Charge resolution</td>
<td>40% @ 1 PE</td>
</tr>
<tr>
<td></td>
<td>5% @ 4000 PEs</td>
</tr>
<tr>
<td>Accuracy of charge calibration</td>
<td>&lt;2%</td>
</tr>
<tr>
<td>Accuracy of time calibration</td>
<td>&lt;0.2 ns</td>
</tr>
<tr>
<td>Total area</td>
<td>90,000 m²</td>
</tr>
<tr>
<td>Total cells</td>
<td>3600</td>
</tr>
</tbody>
</table>
**Electromagnetic particle Detector**

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Effective area</td>
<td>1 m²</td>
</tr>
<tr>
<td>Thickness of tiles</td>
<td>2 cm</td>
</tr>
<tr>
<td>Number of WLS fibers</td>
<td>8/tile×16 tile</td>
</tr>
<tr>
<td>Detection efficiency (&gt; 5 MeV)</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>1-10,000 particles</td>
</tr>
<tr>
<td>Time resolution</td>
<td>&lt;2 ns</td>
</tr>
<tr>
<td>Particle counting resolution</td>
<td>25% @ 1 particle</td>
</tr>
<tr>
<td></td>
<td>5% @ 10,000 particles</td>
</tr>
<tr>
<td>Aging</td>
<td>&gt;10 years</td>
</tr>
<tr>
<td>Spacing</td>
<td>15 m</td>
</tr>
<tr>
<td>Total number of detectors</td>
<td>5635</td>
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</tbody>
</table>
Muon Detector

<table>
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<th>Item</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Area</td>
<td>36 m²</td>
</tr>
<tr>
<td>Depth</td>
<td>1.2 m</td>
</tr>
<tr>
<td>underneath soil</td>
<td>2.5 m</td>
</tr>
<tr>
<td>Water transparency (att. len.)</td>
<td>&gt; 30 m (400 nm)</td>
</tr>
<tr>
<td>Reflection coefficient</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Time resolution</td>
<td>&lt;10 ns</td>
</tr>
<tr>
<td>Particle counting resolution</td>
<td>25% @ 1 particle</td>
</tr>
<tr>
<td></td>
<td>5% @ 10,000 particles</td>
</tr>
<tr>
<td>Aging</td>
<td>&gt;10 years</td>
</tr>
<tr>
<td>Spacing</td>
<td>30 m</td>
</tr>
<tr>
<td>Total number of detectors</td>
<td>1221</td>
</tr>
</tbody>
</table>
Shower Core Detector Array

425 close-packed burst detectors, located near the centre of the array, for the detection of high energy secondary particles in the shower core region.

Each burst detector is constituted by 20 optically separated scintillator strips of 1.5 cm x 4 cm x 50 cm read out by two PMTs operated with different gains to achieve a wide dynamic range (1-10^6 MIPs).

The burst detectors observe the electron size (burst size) under the lead plate induced by high energy e.m. particle in the shower core region.

Number of SCD: 0.5m² x 452
Cover Area: 5170m²
Energy region: 30 TeV - 10 PeV
Core position resolution: 1.5 m @50 TeV
Wide field of view Cherenkov Telescope Array

24 telescopes (Cherenkov/Fluorescence)
  • 4.7 m² spherical mirror
  • 32x32 PMT array
  • FOV: 16°x 16°
LHAASO timing distribution

- Distribution of synchronous ADC clock with <100ps skew
- Time stamp of more than 7000 nodes aligned better than 500ps (rms)
- Compensation of time delay, due to environmental condition, in real time

The LHAASO timing distribution is based on a network of White Rabbit switches to distribute the clock to the front end electronic modules.
Each LHAASO acquisition node implement a TCP/IP White Rabbit core, to perform time synchronization and data transmission.

Charge/ADC:
- shaping with $(RC)^2$
- peak seeking with FPGA

Time/TDC:
- leading edge of anode signal
- time being measured with FPGA-TDC (binsize 0.333 ns).
WFCTA ASIC

PARISROC 2 is designed by OMEGA Group

- Dual-gain Preamplifiers
- 16 Channels (neg.)
- 4x4 PMTs
- Input range -0.8 V to 4.1 V
- Auto-trigger design
- Charge measurement: 50 fC ~ 100 pC
- Technology: 0.35μm
- Time measurement: tagging < 1 ns
- 10 bit ADC internal conversion
- CQFP160 5mm X 3.4mm
- 278 slow control parameters
- 15 mW / channel

HV base
LHAASO online DAQ architecture

- Total data rate <50Gbps
- Event data rate ~1Gbps
- Triggered data rate ~5Gbps
- No data reduction, just organization
Time slicing mechanism

Continuous data stream from a fixed set of WR nodes

Each Time Slicer collects the hits generated in a time window and sends them to a Trigger Unit.

Each Trigger Unit receives the hits generated by the whole apparatus in a common time window and applies selection criteria on it.

Selected time window will be send to the to Event Builders.

Time Window K-1
Time Window K
Time Window K+1

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LHAASO online DAQ architecture

- Total data rate <50Gbps
- Event data rate ~1Gbps
- Triggered data rate ~5Gbps
- No data reduction, just organization
LHAASO integral sensitivity

Angular resolution:
- 30 TeV ~0.4°
- 100 TeV ~0.3°

Energy resolution:
- 30 TeV ~30%
- 100 TeV ~20%

KM2A discrimination
Ground-based Gamma-Ray Astronomy

Very low energy threshold (≈50 GeV)
Excellent bkg rejection (>99%)
Excellent angular resolution (≈0.05 deg)
Good energy resolution (≈15%)
High Sensitivity (< % Crab flux)
Low duty-cycle (≈10%)
Small field of view (4-5 deg)

Higher energy threshold (≈300 GeV)
Good bkg rejection (>80%)
Good angular resolution (0.2-0.8 deg)
Modest energy resolution (≈50%)
Good Sensitivity (5-10% Crab flux)
High duty-cycle (≈100%)
Large field of view (≈2 sr)
LHAASO energy range

A bridge from direct measurements to the most energetic CR particles
**TeV Cosmic Rays**

*Photons > 100 GeV!*

Gammas from Galactic Cosmic Rays: $E_\gamma \sim E_{\text{CR}}/10$

$\quad p \ (p, \gamma) \rightarrow \pi^0 + \text{rest}$

$\quad \rightarrow \gamma\gamma$

But smoking gun still missing…

leptonic ?

hadronic ?

Complex scenario: each source is individual and has a unique behaviour. In general one expects a combination of leptonic and hadronic emission!
PeV Cosmic Rays
Photons > 100 TeV!

Where are the CR PeVatrons?

A power law spectrum reaching 100 TeV without a cutoff is a very strong indication of the hadronic origin of the emission

Bonus @ 100 TeV:
Hadronic spectra: hard
Leptonic spectra: soft
No hard IC gamma rays
>100 TeV IC in deep Klein-Nishina
Scientific topics

Cosmic Ray sources (‘PeVatrons’)  Still open
NO smoking guns from TeV gamma-ray astronomy!

Composition at the knee?  Still open
Rigidity – dependent knee?

Results still conflicting in the knee energy region!

Anisotropy?  Totally open
No theory of CRs exists yet to explain observed anisotropy!

End of Galactic spectrum?  Open
Transition galactic - xgalactic?

Only hypotheses

Hadronic interaction models?  Still uncertain
cross sections, diffractive, inelasticity
**LHAASO potential**

**Gamma-ray astronomy** ($10^2$ – $10^6$ GeV)
- Full sky continuous monitoring at $\approx 0.01$ of the Crab flux
  - Transient sources
  - Complementary with CTA
  - Complementary with HAWC
- Unprecedented sensitivity above 30 TeV -> search for PeV cosmic ray sources

**Cosmic ray** ($10^3$ – $10^8$ GeV)
- CR energy spectrum
- Elemental composition
- Anisotropy
Prototype of LHAASO at ARGO site

About 1% of LHAASO

• 42 EDs
• 2 MDs
• 9-unit WCDA
• 2 telescope
• 100 shower core detectors

Fully implement the LHAASO design, including White Rabbit based clock distribution

Has been operating since two year
Shower example
LHAASO is one of the *Five top priorities* projects of the Strategic Plan of IHEP approved by the Chinese Academy of Sciences (CAS). The National Reform and Development Commission (NRDC) and the Finance Ministry (FM) allocated for LHAASO 1 Billion CNY (about 160 M US$) “Flagship Project”. The government of Sichuan province will cover the total cost of the infrastructure construction: 300 M CNY.

**Foreseen time schedule**

- **Sept. 2015**: start of construction of infrastructures.
- **Spring 2016**: start of construction of first quarter of WCDA, KM2A.
- **Spring 2017**: installation of PMTs in the first pond.
- **Spring 2018**: start scientific operation of the first quarter of LHAASO.
- **2021**: conclusion of installation of main components.
LHAASO collaboration

Domestic collaboration

18 institutions

LHAASO

Clock Distr. & WR protoc.

1. Optic Inst.

2. Mechanic Structures

Surface ED: PMT & detector test facility

Telescope Electronics

Telescope Camera

INFN

Instituto Nazionale di Fisica Nucleare
LHAASO international collaboration

- Collaboration with INFN (Online DAQ system)
- Collaboration with IPN-Orsay and OMEGA (PARISROC)
- Collaboration with Russian colleagues (neutron detector)
- Collaboration with Thailand solar CR group
Conclusions

• LHAASO is able to deal with all the main open problems of cosmic ray physics at the same time.

• LHAASO is a tool of great sensitivity - unprecedented above 30 TeV - to monitor 'all the gamma sky all the time'

• Complementary to CTA in gamma astronomy

• Complementary to HAWK in time coverage of the north sky

• Prototype array ~1% LHAASO have been in operation at YBJ for more than 2 years

• The infrastructures construction is starting

• The detector deployment will start by the end of next year
Angular and energy resolution

Energy resolution

Angular resolution

WCDA angular resolution

KM2A

WCDA

Energy resolution

Down trend: effect of the trigger threshold

KM2A

WCDA

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LHAASO sensitivity to extended sources

Sensitivity of LHAASO WCDA to extended sources as a function of size.
(The angular bin is optimized for the WCDA only.)
MD Water Temperature

- Soil temperature
- Temperature vs. Day (0-4.2m)
- Temperature vs. Year

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The experiment will be located at 4300 m asl (606 g/cm²) in the Daocheng site, Sichuan province

Coordinates: 29° 21' 31'', 100° 08' 15''

700 km to Chengdu
50 km to Daocheng City (3700 m asl, guest house !)
10 km to airport

Complementary to HAWK.
With LHAASO cover the north sky continuosly
Each block is a complex structure.

The decision of the slow control parameters is the crucial point and it is experiment-dependent.

5 mm X 3.4 mm
Each packet contains:
- Source and destination addresses
- Absolute time
- “Hit” info

Water Cerenkov Detector Array (WCDA)
3600 PMTs
400 WR nodes

Shower Core Detector Array (SCDA)
452 shower core detectors
452 WR nodes

Wide FOV Cherenkov Telescope Array (WFCTA)
24 telescopes
24 WR nodes

LHAASO raw data-rate

Each white rabbit node produces ethernet packets

< 25 Gbps

< 1 Gbps

< 8 Gbps

< 15 Gbps

< 50 Gbps
LHAASO online DAQ layout

- Last layer of white rabbit switches
- Switches used to collect many 1Gbps links into few 10Gbps ones
- ~100 fibers
- 10 Gbps fibers
- Server rack (Time Slicers)
- 10 GbE Network
- Datacenter class 40 GbE Modular Switch
- Servers rack (Trigger Units and Event builders)

Shangri-La, Yunnan, China, 4326 m asl.
The standard model:

• Knee attributed to light component

• Rigidity-dependent structure (Peters cycle): cut-offs at energies proportional to nuclear charge

• The sum of the flux of all elements with individual cut-off makes up the all-particle spectrum

• Not only the spectrum becomes steeper due to such cut-off but also heavier

Energy spectrum, elemental composition and anisotropy are crucial to understand origin, acceleration and propagation of the CR.

Experimental results still conflicting
KASCADE-Grande

- spectrum all-particle not a single power law
- hardening of the spectrum above $10^{16}$eV
- steepening close to $10^{17}$eV (2.1 $\sigma$)

- steepening due to heavy primaries (3.5 $\sigma$)
- hardening at $10^{17.08}$eV (5.8 $\sigma$) in light spectrum
- slope change from $\gamma = -3.25$ to $\gamma = -2.79$!