ASTROPARTICLE PHYSICS
WITH ARGO-YBJ EXPERIMENT

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Outline

• Detector Layout
• The Moon Shadow
• Cosmic Rays
• Gamma Astronomy
ARGO-YBJ experiment
(Astrophysical Radiation Ground-based Observatory)

ARGO-YBJ

High Altitude Cosmic Ray Observatory @ YangBaJing
Site altitude: 4,300 m a.s.l., ~ 600 g/cm²
Coordinates: longitude 90° 31’ 50” E, latitude 30° 06’ 38” N
ARGO-YBJ detector

Detector layout
(5,800 m²)

Strip = spatial pixel
Pad = time pixel
Time resolution ~1 ns

+ Analog charge read-out on “Big Pads”
Detector status

Detector completely installed since 2007 (central carpet + guard-ring, 153 clusters)

Data taking
Since July 2006 with the central carpet
Since November 2007 with the guard-ring

Setup for analog charge readout installed on central carpet (130 cl)
In data taking with lowest gain scale
(Trigger ≥ 73 hits/cl)
Experiment operation

**Shower mode**

Inclusive Trigger: \( N_{\text{pad}} > 20 \) within 420ns on the central carpet

\[ \Rightarrow \text{rate} \sim 3.6 \text{ kHz ( ~}220 \text{ GBytes/day)} \]

Detection of Extensive Air Showers (direction, size, core ...)

Aims: cosmic-ray physics (threshold \( \sim 1 \) TeV)
VHE \( \gamma \)-astronomy (threshold \( \sim 300 \) GeV)
gamma-ray bursts

**Scaler mode**

counting rates ( \( \geq 1, \geq 2, \geq 3, \geq 4 \) coincidences) for each cluster

Aims: detector and environment monitor
flaring phenomena (gamma ray bursts, solar flares)
with a threshold of few GeV
Shower events

The number of pixels, the time resolution and the full coverage of the central carpet allow to reconstruct the shower with unprecedented details.
The shadow of the Moon
The shadow of the Moon

A deficit in the cosmic ray flux is expected from the Moon direction. Many items are related:

- angular resolution (width of the deficit)
- pointing accuracy (position of the deficit)
- energy calibration (the westward deflection due to the geomagnetic field depends on the energy of cosmic rays)
- proton/antiproton ratio (antiprotons are deflected eastward)

Moon diameter \(\sim 0.5^\circ\)

\[
\Delta \theta \approx \frac{Z \times 1.6^\circ}{E \text{ TeV}}
\]
All data: 2006 $\rightarrow$ 2009

N > 100 \quad \theta < 50^\circ

3200 hours on-source

$\approx 9$ standard deviations / month

The deficit surface is the convolution of the PSF of the detector and the widespread Moon disc.

24/07/2010

Paris, ICHEP'10
Moon Shadow analysis

Measured angular resolution

Measured EW displacement
1. From MC, the fraction of protons to all cosmic rays. 70.9% for 50000>nHit > 100: 73.0% for 100>nHit>60:

2. Considering the Boundary condition: b>=0;
Using Feldman and Cousins statistics:

- 60<nHit<100 (median E ~2 TeV): 90% C.L. Upper limit 4.2%
- 100<nHit<50000 (median E ~5 TeV): 90% C.L. Upper limit 7.4%

Compute the 90% Upper limit!

1. Dashed lines: antistars models for different rigidity, 0.6, 0.7 respectively

2. Dotted line, the heavy DM particle contribution.

Paper being submitted
Cosmic rays
Flux attenuation and p-Air cross section

Shower frequency vs \( (\sec\theta - 1) \):

\[
I(\theta) = I(0) \cdot e^{-\frac{x_0}{\Lambda_{\text{abs}}} \sec(\theta) - 1}
\]

\[\downarrow\]

Measure the flux attenuation

For **fixed energies** and shower ages:

\[
\Lambda_{\text{abs}} = k \lambda_{\text{INT}}
\]

\[
\sigma_{p-\text{Air}}[\text{mb}] = 2.4 \times 10^4 / \lambda_{\text{INT}}[\text{g/cm}^2]
\]

\[\Rightarrow k \text{ is determined by MC simulations, selecting energy and age ranges by means of the actual experimental observables (number of fired strips, hit density, lateral profile)}\]

It depends on the interaction model details, but also on the set of experimental observables, energy, ...

24/07/2010

Paris, ICHEP’10
Event selection based on:

(a) “shower size” on detector, \( N_{\text{strip}} \) (strip multiplicity)
(b) core reconstructed in a fiducial area (64 x 64 m\(^2\))
(c) constraints on Strip density (> 0.2/m\(^2\) within \( R_{70} \))
   and shower extension (\( R_{70} < 30 \text{m} \))

\( N_{\text{strip}} \) is used to get different E sub-samples

Full Monte Carlo simulation:
Corsika showers
QGSJET I and II, SYBILL interaction models
GEANT detector simulation
Proton-Air cross section measurement

Total p-p cross section
(inferred by means of the Glauber theory)

- No data from accelerators available at these energies
- The \( \log^2(s) \) asymptotic behaviour is favoured

Light-component spectrum of CRs

Measurement of the light-component (p+He) spectrum of primary CRs in the energy region (5 – 250) TeV via a Bayesian unfolding procedure

CNO < 2%

ARGO data agree with CREAM results

Evidence that the proton spectrum is flatter than in the lower energy region
Proton Sky Map: Medium Scale Anisotropy

Smoothing radius = 5
584 days
9 \cdot 10^{10} \text{ events}

two large hot spots

\approx 0.06 \%

\approx 0.1\%

N_{PAD} > 40 \rightarrow \text{Proton median energy} \approx 2 \text{ TeV}
All sky survey result

- Method: Direct Integral method to estimate background.
- 3 sources with significance >5\(\sigma\)
- Crab 14.5 \(\sigma\), Mrk421 11.9 \(\sigma\), MGRO1908+06 5.4 \(\sigma\)
Crab Nebula

\[ \frac{dN}{dE} = (3.73 \pm 0.80) \times 10^{-11} \cdot E^{-2.67 \pm 0.25} \text{ ev cm}^{-2} \text{s}^{-1} \text{TeV}^{-1} \]

<table>
<thead>
<tr>
<th>N_{PAD}</th>
<th>Events/day</th>
<th>E_{med} (TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 – 100</td>
<td>128 ± 24</td>
<td>0.85</td>
</tr>
<tr>
<td>100 – 300</td>
<td>17.9 ± 6.3</td>
<td>1.8</td>
</tr>
<tr>
<td>&gt; 300</td>
<td>9.2 ± 2.3</td>
<td>5.2</td>
</tr>
</tbody>
</table>

\~ 14.5 s.d. in \~ 800 days

NO selection

NO \gamma/h discrimination

Absolute measurement

\~ 50 \% Crab/year
Mrk421

AGN monitored by ARGO-YBJ on a long time scale.

Several big flares have been observed:
1. June 2006
2. Oct. 2006
3. Feb.-Mar 2008
4. June 2008
5. June 2009
6. Feb 2010

The total significance is 12σ. So, Mrk421 is the best candidate for ARGO-YBJ to study the Blazar emission mechanism.
Mrk421 spectrum
days 41 - 180, 2008

Integral flux (E > 1 TeV):
\[(4.9 \pm 2.0) \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1} \approx 2 \text{ Crab units}\]

Raue, M. & Mazin, D. 2008,
Int. J. Mod. Phys. D 17, 1515

Spectrum + EBL absorption
\[
dN/dE = (7.5 \pm 1.7) \times 10^{-11} E^{-2.51\pm0.29} e^{-\tau(E)} \text{ cm}^{-2} \text{ s}^{-1} \text{ TeV}^{-1}
\]
Mrk421: June 2008 flares

Observed from optical to TeV energies

- GASP-WEBT (R-band; May 24-June 23)
- SWIFT (UVOT & XRT; June 12-13)
- AGILE (E > 100 MeV; June 9-15)
- MAGIC and VERITAS (E > 400 GeV; May 27-June 8)

complemented by public data by RossiXTE/ASM (2-12 keV) and Swift/BAT (15-50 keV)

No VHE Cerenkov data after June 8
Mrk421: 2008 emission

June 5-7
2.0 \sigma

June 11-13
3.8 \sigma

10 days average

N_{PAD} > 100

24/07/2010

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MGRO1908+06

- Discovered by Milagro, confirmed by HESS and VERITAS.
- Associated to the LAT pulsar with nebula PSR J1907.5+0602
- First Milagro result: compatible with point-like and extended source
- HESS result: shows that intrinsic extension is 0.34 deg and its spectral index is $-2.1$ up to 20TeV without cutoff.
- But, Milagro result shows a spectrum cutoff at about 14 TeV and a flux higher than HESS result.
- ARGO-YBJ measurement about this source very important.
- A detailed systematic analysis aiming better understanding of spectra between experiments is undergoing.
Conclusions

✓ ARGO-YBJ detector (central carpet + guard ring) is taking data since November 2007 (duty-cycle > 90%, 3.6 kHz rate)

✓ First results on Cosmic Rays (p-p cross section, anisotropies, limit on antiproton flux ...)

✓ First results on $\gamma$-astronomy (mainly 2-year data)
  - angular resolution as expected (Moon shadow)
  - Crab Nebula $\gamma$-spectrum in agreement with other measurements
  - continuous monitor of Markarian 421, flares observed in 2006, 2008, 2009 and 2010 VHE $\gamma$-flux correlated with x-emission
  - MGRO sources survey

✓ Studies to increase the sensitivity are in progress (data quality, $\gamma$-hadron separation)