Highlights from the ARGO-YBJ Experiment

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On behalf of the ARGO-YBJ Collaboration
The ARGO-YBJ experiment

High Altitude Cosmic Ray Observatory @ YangBaJing, Tibet, China
Site Altitude: 4,300 m a.s.l., ~ 600 g/cm²
ARGO-YBJ physics goals

- **VHE γ-Ray Astronomy:**
  (search for)/(study of) point-like (and diffuse) galactic and extra-galactic sources at few hundreds GeV energy threshold

- **Cosmic ray physics:**
  spectrum and composition \( E_{th} \) few TeV),
  study of the shower space-time structure,
  flux anisotropies at different angular scales (see Di Sciascio’s talk)
  p-Air cross section measurement and hadronic interaction studies
  anti-p / p ratio at TeV energies,
  …..

- **Search for GRB’s** (full GeV / TeV energy range)
- **...**

  through the…

Observation of *Extensive Air Showers* produced in the atmosphere by primary \( \gamma \)'s and nuclei
The ARGO-YBJ detector

Strip = space pixel
Pad = time pixel
Time resolution ~1.7 ns

1 CLUSTER = 12 RPC
(~43 m²)
10 Pads (56 x 62 cm²)
for each RPC
8 Strips (6.5 x 62 cm²)
for each Pad

+ Analog charge read-out on “Big Pads”
EAS reconstruction

Event Rate $\sim 3.5$ kHz for $N_{\text{hit}} > 20$

- High space/time granularity
- Full coverage
- High altitude

Detailed study on the EAS space/time structure with unique capabilities

86% duty cycle

3-D view of a detected shower

Top view of the same shower
The Moon Shadow

ARGO-YBJ coll., PRD 84 (2011) 022003

$N_{\text{pad}} > 100, 71$ s.d.

- Size of the deficit $\Rightarrow$ angular resolution
- Position $\Rightarrow$ pointing accuracy
- West displacement $\Rightarrow$ Energy calibration (Geomagnetic bending $\approx 1.57^\circ / E \text{ (TeV)}$)
- Antiprotons should give a shadow on the opposite side $\Rightarrow$ Upper limit
VHE gamma-ray astronomy

All sky survey (from -10° up to 70° in declination) above 0.1 TeV

- 4 sources with significance >5 σ in
  - Crab 17 σ, Mrk421 12 σ, MGRO J1908+06 6 σ, MGRO J2031+41 6.3 σ

- Interesting results on long term variabilities, correlation with Xrays, spectra,....

Excluding regions close to Crab, Mrk421, MGRO J1908+06, MGRO J2031+41

All directions

The CRAB

3.5 yrs
17 s.d.
CRAB flaring at TeV energies?

**AGILE discovered** a flare at $E > 100$ MeV in 19th-21st September 2010 (ATel#2855)

**Fermi LAT confirmed** (ATel#2861).

**TeV emission enhancement** ($\sim 3$ -4 times) observed with 4.1 s.d. by ARGO-YBJ in ~54 h observation from 18th to 27th Sep. 2010 (ATel#2921).

**Not confirmed by MAGIC and VERITAS** with short observations from 17th to 20th Sep. 2010 (ATel#2967, 2968).

**ARGO-YBJ significance map** in the same 6 days:
- Expected 0.62 s.d.
- Observed 3.5 s.d
- At $E \approx 3$ TeV

**AGILE light curve** ($E > 100$ MeV)
- 6 days

April 2011
MGROJ1908+06

Observed for 3 yrs above 1 TeV
6 s.d. excess above background

Extended source: gaussian profile with
\( \sigma = (0.50 \pm 0.35)° \) (HESS gives 0.34±0.04°)

The large size supports the identification with
the wind nebula associated with the Fermi
pulsar PSR J1907+0602

Flux (between 2 and 30 TeV):

\[
\frac{dN}{dE} = (2.2 \pm 0.4) \times 10^{-13} \left( \frac{E}{7 \text{TeV}} \right)^{-2.3 \pm 0.3} \text{photons/cm}^2\text{s}^{-1}\text{TeV}^{-1}
\]

Flux in agreement with Milagro but a factor 3 larger
than HESS measurement

Complex source morphology ?

Diffuse galactic flux contamination ?

Flux variability ?

Mrk421 Observations

Source detected with more than 12 s.d.
Flaring activity, continuously monitored since 2008
Good correlation with X and gamma rays
No other continuous observation at TeV energies

Mrk421 Observations

Both X-ray and TeV spectra are observed to harden as the flux increases.

Observations are compatible with a SSC model with flares being due to hardening of the electron injection spectrum.


February 16, 2010

April 28, 2010
Light-component spectrum of CRs

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

For the first time direct and ground-based measurements overlap for a wide energy range thus making possible the cross-calibration of the experiments.

The contribution of heavier nuclei to the trigger is a few %

ARGO data agree with CREAM results
Proton-air cross section measurement

Use the shower frequency vs \((\text{sec}\theta -1)\)

\[
I(\theta) = I(0) \cdot e^{-\frac{h_0}{\Lambda} (\text{sec}\theta -1)}
\]

for fixed energy and shower age.

The length \(\Lambda\) is not the p interaction length mainly because of collision inelasticity, shower fluctuations and detector resolution.

It has been shown that \(\Lambda = k\lambda_{\text{int}}\), where \(k\) is determined by simulations and depends on:

- hadronic interactions
- detector features and location (atm. depth)
- actual set of experimental observables
- analysis cuts
- energy, ...

Then:

\[
\sigma_{\text{p-Air}} \text{ (mb)} = 2.4 \times 10^4 / \lambda_{\text{int}} \text{ (g/cm}^2\text{)}
\]
The total p-p cross section

- No p-p (and pbar-p) accelerator data available at these energies
- The log^2(s) asymptotic behaviour is favoured

Extending the energy range with the analog readout

ARGO-YBJ Coll.
Info from the analog readout

- Extend the covered energy range
- Access the LDF down to the shower core
- Sensitivity to primary mass
- Info/checks on Hadronic Interactions
Summary and Outlook

- Full detector in stable data taking since Nov. 2007 (first data in 2006)
- Trigger Rate ~3.5 kHz - Dead time 4%
- 220 GB/day transferred to IHEP (China) / CNAF (Italy) data centers
- Detailed analysis of the Moon shadowing effect (pointing, energy scale)
- Long-term monitoring of Crab and Mrk421
- MGRO J1908+06 and MGRO J2031+41 observed above 5s.d.
- Fluence upper limits on 110 GRB ($\Delta E=1-100\text{GeV}$)
- Measurement of CR light component energy spectrum below 100TeV
- Study of the CR anisotropy at different angular scales
- Measurement of the CR antip/p flux ratio in TeV energy range
- Monitoring of the IMF by the Sun shadow displacement
- Measurement of the p-air and p-p cross sections up to 100TeV
- Data taking planned up to December 2012
- Updating current results and data reprocessing with $\gamma/h$ discrimination
- Extending the energy range to the CR knee region by the RPC charge readout
- LDF near the shower core and hadronic interactions and primary mass sensitivity
More stuff....
RPC performance and linearity range

By means of the RPC analog readout

Time resolution (ns)

Efficiency (%)

Temperature (°C)

Day in 2008

Space (digital) pixel (6.7 × 62 cm²) #146880

Big Pad for charge read-out

Time pixel (56 × 62 cm²) #18360

\[
\chi^2 / \text{ndf} = 105.5 / 36
\]

\[
p_0 = -5.147 \pm 0.116
\]

\[
p_1 = 0.04733 \pm 0.000206
\]
The cumulative sensitivity to the Crab like source is 28% Crab unit.
The Cygnus region

MGRO J2031+41
_detected at 6.3 s.d. level
Location consistent with TeV J2032 + 4130
Size compatible with MAGIC and HEGRA observations
Much higher flux than observed by IACT's

MGRO J2019+37 not confirmed

Flux variability?

Observations made after about 5 years on average
VERITAS: a survey with an exposure of 0.1 Crab unit, there is no significant signal was found in the direction of MGRO J2019+37
VERITAS: a deeper survey of 0.01 Crab unit, some faint sources are found in this region.
Large scale CR anisotropy vs energy

The tail-in broad structure appears to dissolve to smaller angular scale spots.
Medium scale anisotropy

MILAGRO

Proton median energy ≈ 10 TeV

Many explanations proposed:
Diffusion from nearby sources
Magnetic funneling
CR acceleration from magnetic reconnection in the solar magnetotail

ARGO-YBJ

Proton median energy ≈ 2 TeV

Deficit: 45 standard deviations (903 days)

The position of the Sun shadow moves according to the IMF pattern

Bisector pattern

4-sector pattern

data in 12 groups according to the Earth position (Carrington longitude)

expected displacement (IMF model, Amenomori 2000)
Search for GRBs in the GeV-TeV range

110 GRBs in the ARGO f.o.v. from Dec 2004 to Apr 2011

- With known redshift: 18
- Discovered by Fermi/GBM: 26
- Detected by Fermi/LAT: 4
- Long duration GRBs (>2s): 97
- Short duration GRBs (≤2s): 13

No evidence of coincident signal over the GRB T90 duration
In stacked analysis no evidence for any integral effect

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- 18 GRBs with known redshift
- EBL according to Kneiske 2004
- Spectral index ranging from -2.5 to the value measured by satellite

Fluence measured by Fermi for GRB090902B
Lateral Distribution Function

With the analog data we can study the LDF without saturation near the core.

Tests are in progress in order to have:

- Better resolution on \( X_{dm} \) and then lower systematics on the cross section measurement
- Better energy determination / shower reconstruction
- Some sensitivity to the hadronic interaction model
- Sensitivity to primary mass
Multicore events with analog data

Preliminary results show the feasibility of these studies.

Analysis is in progress..