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THE ARGO-YBJ EXPERIMENT: A FULL COVERAGE ARRAY FOR γ-RAY ASTRONOMY

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The ARGO-YBJ experiment is an Extensive Air Shower (EAS) array which combines high altitude location and full coverage active area in order to reach low energy threshold at a level of few hundred of GeV. The large field of view (≈ 2 sr) and the high duty cycle ($\geq 90\%$) allow the continuous monitoring of the sky searching for unknown sources and unpredictable events, such as flares in blazar emissions and high energy Gamma-Ray Bursts (GRBs). In this paper I will briefly report on the detector performance and on some preliminary results achieved in γ-ray astronomy.

Keywords: Extensive air showers; gamma rays; gamma-ray burst.

1. The Detector

The Astrophysical Radiation with Ground-based Observatory at YangBaJing (ARGO-YBJ) is located at 4300 m a.s.l. (vertical atmospheric depth 606 g/cm^2) at the YangBaJing Cosmic Ray Laboratory ($30^0.11$ N, $90^0.53$ E, Tibet, P. R. of China). The detector is composed of a single layer of Resistive Plate Chambers (RPCs) operated in streamer mode[1] and grouped in 153 units, called clusters, of area $5.7 \times 7.6\,\mathrm{m}^2$ each. A cluster is made of 12 RPCs ($1.225 \times 2.850\,\mathrm{m}^2$) each read by 10 pads ($55.6 \times 61.8\,\mathrm{cm}^2$) representing the space and time pixels of the array. The clusters are organized in a central full coverage carpet (130 units, $5600\,\mathrm{m}^2$, 93% active surface) enclosed by a guard ring with partial coverage, which allows the extension of the instrumented area up to $100 \times 110\,\mathrm{m}^2$, the increase of the fiducial area and the improvement of the accuracy in the core position determination. The detector has two independent DAQ systems corresponding to the shower and scaler operational modes. In shower mode the arrival time and location of each particle are recorded using the pads allowing the detailed reconstrunction of the shower lateral distribution function and arrival direction. The on-line trigger is set

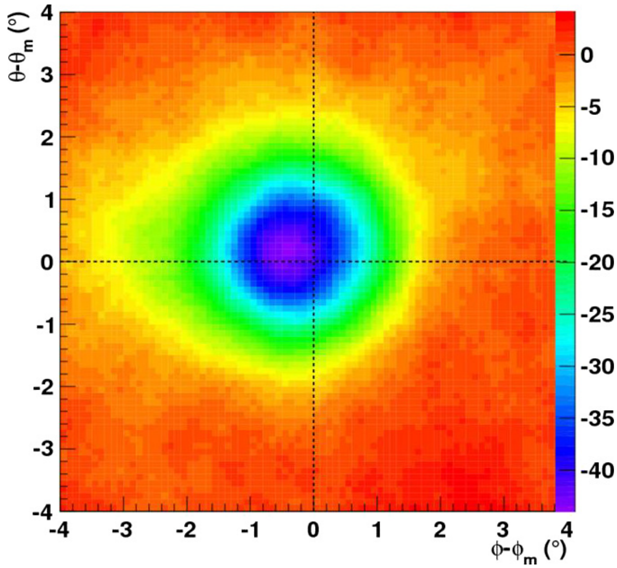

Fig. 1. The Moon Shadow observed in 2063 h: a 43 σ detection is achieved. (Color online)

to 20 fired pads equivalent to an energy threshold for γ-rays of a few hundred of GeV: the mean trigger rate is 3.8 kHz. In scaler mode the total counting rate of each cluster is integrated continuously in a $\delta t = 0.5\,$s window and recorded for 4 different multiplicity channels ≥ 1, ≥ 2, ≥ 3 and ≥ 4 (150 ns coincidence window).[2] Although this technique does not provide information about the energy and arrival direction of the primary cosmic ray, it allows a very low energy threshold of 1 GeV overlapping the highest energy region directly investigated by satellite experiments. Moreover the use of four different channels sensitive to different energies will provide, in case of positive detection, information on the high energy spectrum slope and the energy cut-off could be obtained.[3]

ARGO-YBJ is taking data with its full layout since November 2007 with a mean duty cycle $\geq 90\%$. The performance of the ARGO-YBJ detector (i.e. the angular resolution and the pointing accuracy) has been checked looking at the Moon shadow. Since cosmic rays are hampered by the Earth satellite, a deficit in the particle rate is expected. The size of the deficit allows the direct measurement of the angular resolution while the position of the deficit allows the estimate of the absolute pointing accuracy. ARGO-YBJ is observing the Moon shadow with a sensitivity of about 10 standard deviations per month at a multiplicity $N_{\rm pad} \geq 40$ with a zenith angle $\theta \leq 50^0$, corresponding to a median energy for proton primaries of $E_{50} \simeq 2\,$TeV. Figure 1 shows the Moon shadow observed in 2063 h with a total sensitivity of 43 σ. In Fig. 2 the angular resolution is compared to a MC simulation.

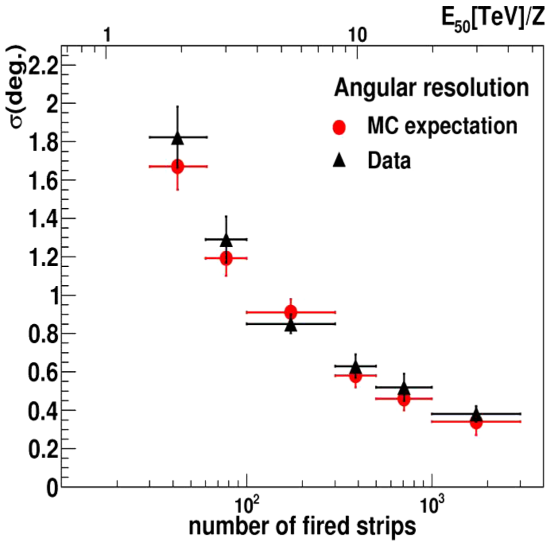

Fig. 2. The angular resolution of the ARGO-YBJ detector.The upper scale refers to the median energy for proton primaries.

2. γ-ray Astronomy

The data collected in shower mode have been analyzed searching for γ sources in the declination band ranging from -10 to 70 degrees. With the events selected by ad hoc quality cuts, five sky maps in celestial coordinates are built for different numbers of fired pads, $N_{\rm pad} \geq 40, 60, 100, 200, 300$ (i.e. for different energy thresholds) using the HEALPix (Hierarchical Equal Area isoLatitude Pixelization) package.[4] After the evaluation of the background with the *time swapping* method,[5] both the *event* and *background* maps are integrated over a circular area of radius ϕ depending on the detector angular resolution and finally the signal map is obtained by subtraction.[6] Figure 3 shows the sky map obtained in 424 days of data taking for events with $N_{\rm pad} \geq 40$ with a large smoothing radius $\phi = 5^o$. Two large hot spots are observed in the region of the Galactic anti-center, already reported by the MILAGRO experiment[7] and interpreted as excesses in the cosmic ray flux ($\approx 0.1\%$), however their origin is still under debate.[8] These large scale anisotropies affect the search for point-like γ-ray sources. A procedure to renormalize the background has been applied and the resulting map is shown in Fig. 4. The Crab Nebula and the blazar Mrk 421 are observed with statistical significance of 7.5 and 8 σ, respectively. The resulting Crab energy spectrum, obtained in the [0.5–10] TeV range, is $dN/dE = (3.7{\pm}0.8){\times}10^{-11}E^{-2.67\pm0.25}\,\gamma\,{\rm cm}^{-2}{\rm s}^{-1}{\rm TeV}^{-1}$, in agreement with measurements by other experiments. Thanks to its continuous sky monitoring, ARGO-YBJ was able to detect the flaring activity of Mrk 421 in 2006 and 2008. In particular the observations in 2008 (days 41–180) resulted in the energy spectrum in the [0.5–10] TeV

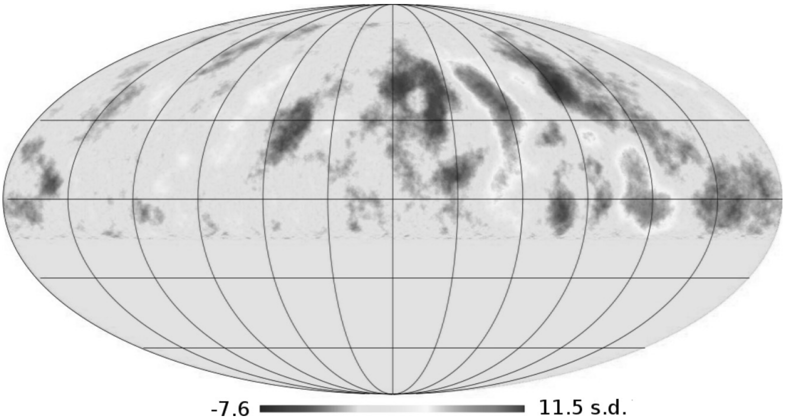

Fig. 3. Sky map at large scale (smoothing radius $\phi = 5°$) in 424 days of observation with $N_{\rm pad} \geq 40$. The color scale indicates the sensitivity in standard deviations. (Color online)

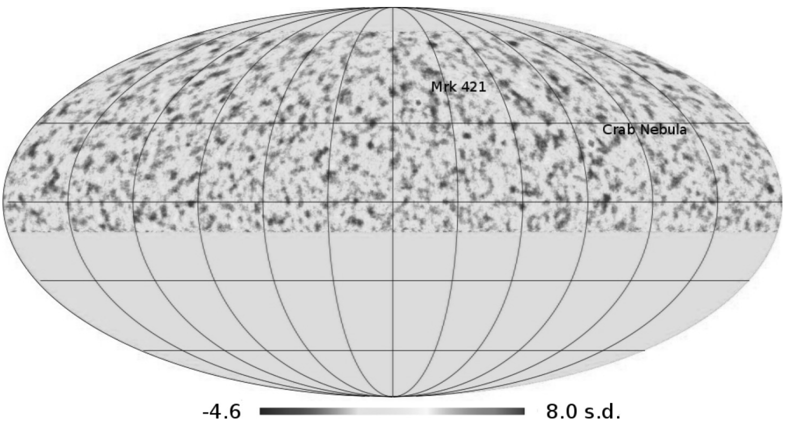

Fig. 4. Sky map after the large scale anisotropy correction. Crab Nebula and Mrk 421 excesses are visible in the right side of the map. (Color online)

range: $dN/dE = (7.5 \pm 1.7) \times 10^{-11} E^{-2.51 \pm 0.29} e^{-\tau(E)}\ \gamma\,{\rm cm}^{-2}\,{\rm s}^{-1}\,{\rm TeV}^{-1}$, where the exponential factor $e^{-\tau(E)}$ takes into account the absorption in the Extragalactic Background Light(EBL). According to this spectrum the flux above 1 TeV was about twice that of the Crab Nebula, and the emission appeared to be strongly correlated with the X-rays observed by satellites.[9]

3. Gamma Ray Burst Monitoring

The GRB monitoring by ARGO-YBJ is carried out by both the scaler and the shower mode techniques with different energy thresholds and sensitivities. A reduced data set is available for the latter one since the stable shower mode DAQ started later. In scaler mode, the energy threshold for photons is about 1 GeV, lower

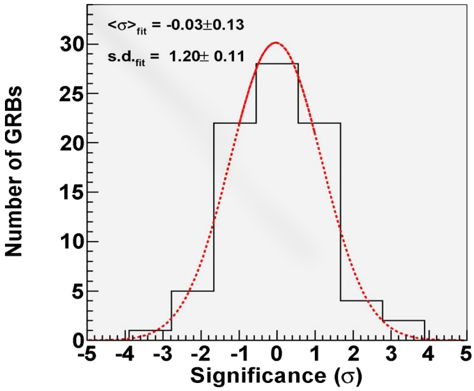

Fig. 5. Distribution of the statistical significance of the 83 GRBs compared with a Gaussian fit.

than the highest energies directly investigated by satellite experiments. Moreover, the modular structure of the array allowed the collection of data even during the different mounting phases of the detector with a progressively increasing active surface. Therefore the search for prompt emission from GRBs in coincidence with satellite detections started in November 2004 at the time of Swift launch. Until October 2009 a sample of 83 GRBs was analyzed (14 with known redshift) searching for a counterpart in the ARGO-YBJ single particle counting rate in the T_{90} window duration. Since no significant signal was found (see Fig. 5), the fluence upper limits in the 1–100 GeV energy range were calculated at 99% c.l. assuming two different power law spectra[3]: (1) the extrapolation of the keV–MeV index α measured by satellites and (2) the value $\alpha = -2.5$. For the subset of 14 GRBs with known redshift the ranges of upper limits between the two spectrum hypotheses (1) and (2) are shown in Fig. 6 by rectangles while a simple arrow is used in case (2) alone.

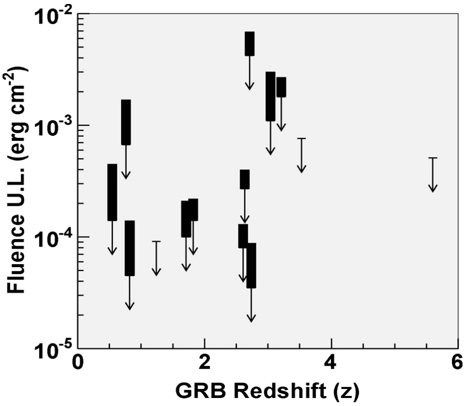

Fig. 6. Fluence upper limits in the 1–100 GeV range for the 14 GRBs with known redshift. See text for details.

Also the shower mode data have been analyzed looking for a directional signal in coincidence with the satellite trigger. No signal has been found and fluence upper limits were set in the two energy ranges 10–100 GeV and 10–1000 GeV.[10]

4. Conclusions

The performance of the ARGO-YBJ detector in γ-ray astronomy has been presented. Some selected results in the TeV range and on the GRB monitoring in the GeV range have been discussed. Data acquisition is currently going on with stable conditions and high efficiency. Further studies to improve the detector sensitivity are in progress, both in the direction of a better angular resolution and of a rejection of the cosmic ray background, e.g. implementing gamma-hadron separation algorithms.

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