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Gamma-ray astronomy with the ARGO-YBJ experiment

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Abstract. The ARGO-YBJ experiment is an Extensive Air Shower detector which combines high altitude location (Tibet, P.R. China, 4300 m a.s.l.) and full coverage with Resistive Plate Counters, resulting in an energy threshold of a few hundred GeV. The large field of view ($\sim$2 sr) and high duty cycle allow the continuous monitoring of the Northern sky, searching for unknown sources and unpredictable events, such as flares in blazar emissions or high energy Gamma Ray Bursts. In this paper I will present some results obtained in γ-ray astronomy with the ARGO-YBJ experiment.

1. The detector

The ARGO−YBJ experiment is located at Yangbajing (Tibet, P.R. China, 4300 m a.s.l.) and consists of a single layer of Resistive Plate Counters (RPCs) on a total area of about ($110 \times 100\ m^2$) [1]. The detector has a modular structure, the basic module being a CLUSTER ($5.7 \times 7.6\ m^2$), made of 12 RPCs. Each RPC is divided into 10 PADs, whose data acquisition is independent and which represent the high granularity pixel of the detector ($56 \times 62\ cm^2$). The digital readout of each PAD is made by means of 8 strips ($6 \times 62\ cm^2$). The detector carpet is connected to two different DAQ systems, which work independently: in shower mode, for each event the location and timing of each detected particle is recorded, allowing the reconstruction of the lateral distribution and of the arrival direction; in scaler mode, the counting rate of each CLUSTER is measured every 0.5 s, with little information on the space distribution and arrival direction of the detected particles. The current trigger of the shower mode is $N_{PAD} \geq 20$ in a time window of 420 ns, with a rate $\sim 3.8\ kHz$. In the scaler mode DAQ, for each CLUSTER four scalers record the rate of counts ≥ 1, ≥ 2, ≥ 3 and ≥ 4 in a time window of 150 ns. The corresponding measured rates are, respectively, $\sim 40\ kHz$, $\sim 2\ kHz$, $\sim 300\ Hz$ and $\sim 120\ Hz$. The use of four different scalers may give an indication of the source spectrum in case of positive detection [2]. The experiment has been taking data with its full layout since November 2007.

The detector angular resolution has been determined studying the deficit in the cosmic ray flux due to the Moon. The result for cosmic ray events is less than 0.6° for $N_{strip} \geq 300$, while an improvement of at least 30% is expected for γ-induced showers because of their better defined time profile [3].

2. Gamma-ray astronomy

Five sky maps for different thresholds of hit pads ($N_{PAD} \geq$40, 60, 100, 200, 300) were obtained analysing the shower data of 424 days. Figure 1 (left) shows the resulting sky map for events with $N_{PAD} \geq 40$, which corresponds to a median primary energy for protons of $\sim$2 TeV. Two large spots appear in the region of the Galactic anticentre, which were already reported by the Milagro experiment [4]. These regions have been interpreted as excesses in the cosmic ray flux ($\sim$0.1%), however their origin is still under debate. These hot spots affect the search for point γ-ray sources, overestimating the significances inside them. Therefore, a procedure to renormalize the background was applied [5] and the map after this correction is shown in Figure 1 (right). The Crab Nebula and the blazar Mrk 421 are visible with statistical significances 7.0 and 8.0 standard deviations, respectively. The resulting Crab energy spectrum is $dN/dE = (3.7 \pm 0.8) \times 10^{-11} E^{-2.67 \pm 0.25}\ ph\ cm^{-2} s^{-1} TeV^{-1}$, in agreement with measurements by other experiments [6].

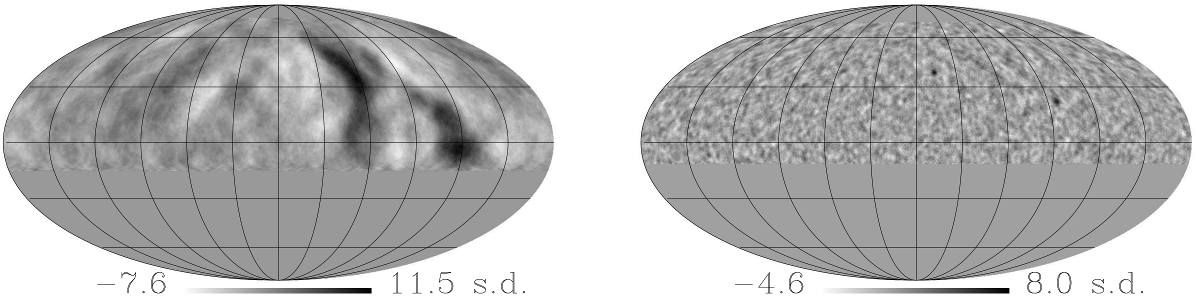

Figure 1. Left: sky map in equatorial coordinates obtained with 424 days of data, for events with $N_{PAD} \geq 40$. The scale gives the statistical significance in standard deviations. Right: sky map after correcting for large size excesses. The γ-ray median energy is $\approx 0.6-2.0$ TeV, depending on the source spectrum.

Thanks to its continuous sky monitoring, ARGO-YBJ was able to detect the flaring states of Mrk 421 in 2006 and 2008. In particular, the observations from day 41 to 180 of 2008 provided a spectrum $dN/dE = (7.5 \pm 1.7) \times 10^{-11} E^{-2.51 \pm 0.29} e^{-\tau(E)}\ ph\ cm^{-2} s^{-1} TeV^{-1}$, where the exponential factor $e^{-\tau(E)}$ takes into account the absorption of γ-rays in the Extragalactic Background Light (EBL). The resulting flux above 1 TeV was about twice that of the Crab Nebula, and the emission appeared to be correlated with X-rays [7]. An extraordinary set of simultaneous data, covering twelve decades of energy from optical to γ-rays, was available for the first of two flares in June 2008 [8], while during the second and more intense one observations by Cherenkov telescopes were hampered by the moonlight. Therefore in this case ARGO-YBJ completed the multiwavelength information, detecting a signal with a significance of 4.2 standard deviations and a flux of about 7 Crab units in the period June 11-13. The resulting spectrum is consistent with the prediction of the synchrotron self-Compton model. This is the first time that an air shower array is able to detect a sub-TeV γ-ray flare in a few days period.

3. Search for emission from Gamma Ray Bursts

In scaler mode, the energy threshold for photons is about 1 GeV, lower than the highest energies detected by satellite experiments. Moreover, the modular structure of the ARGO-YBJ detector allowed the collection of data during the different mounting phases. Therefore a search for emission from Gamma Ray Bursts (GRBs) in coincidence with satellite detections started in November 2004, when Swift was launched [9]. Until September 2009 a sample of 83 GRBs was analysed, 14 of them with known redshift z. Since no significant signal was found in the data, the fluence upper limits in the 1-100 GeV energy range were determined at 99% confidence level assuming two different power law spectra: a) extrapolation of the keV-MeV index measured by satellites; b) differential index -2.5. For the set of 14 GRBs with known redshift the ranges of upper limits between the values corresponding to the two spectral assumptions are represented by rectangles in Figure 2, while a simple arrow is shown if the low energy spectrum is a cutoff power law, and thus only case b) is considered. Moreover, an upper limit on the GRB cutoff energy E_{cut} can be set by the intersection of the fluence upper limit, as a function of E_{cut}, with the extrapolation of the fluence measured by satellites. Figure 3 reports the E_{cut} upper limits for the 18 GRBs for which the intersection occurs in the 1-100 GeV range, as a function of the differential spectral index.

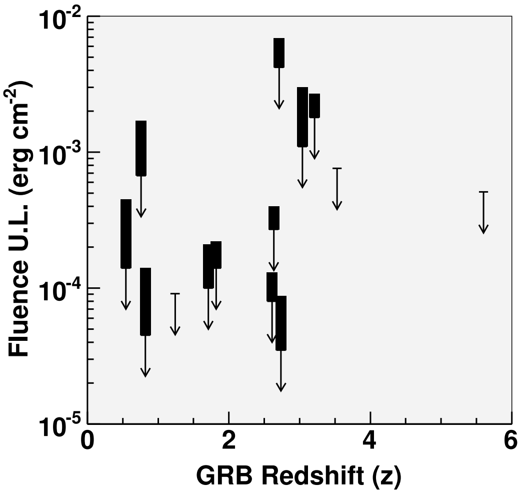

Figure 2. Fluence upper limits in the 1-100 GeV range for the 14 GRBs with known redshift, obtained with differential spectral indexes ranging from the value measured by satellites to -2.5 (only this latter case is considered for cutoff power law spectra).

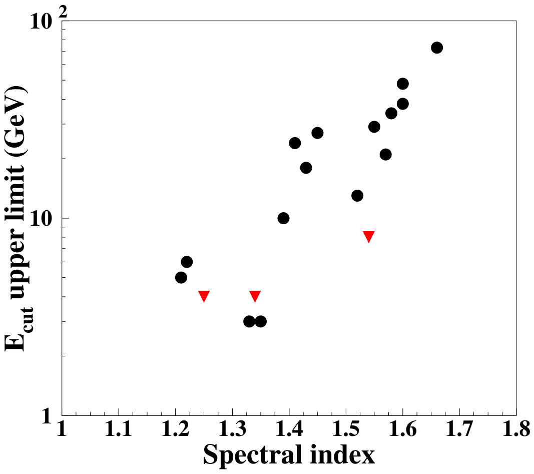

Figure 3. Cutoff energy upper limits as a function of the spectral index obtained extrapolating the measured keV-MeV spectra. The values represented by triangles are obtained taking into account the extragalactic absorption at the known GRB redshift, for the others z=1 is assumed.

Also the shower mode data have been analysed in a search for directional signals from GRBs detected by satellites, and fluence upper limits were set in the two energy ranges 10-100 GeV and 10 GeV-1 TeV [10].

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