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Physics and astronomy results with the ARGO-YBJ experiment

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Abstract. The ARGO-YBJ detector, installed at the Yangbajing Cosmic Ray Laboratory (Tibet, China), at 4300m a.s.l., is a full coverage layer of Resistive Plate Counters with an area of about 6.700 m^2. The high space-time granularity, the full-coverage technique and the high altitude location make this detector a unique device for a detailed study of atmospheric shower characteristics and allow the investigation of a large variety of astrophysical phenomena. In this work a status report on ARGO-YBJ physics and astronomy results will be presented.

1. The ARGO-YBJ detector

The ARGO-YBJ (Astrophysical Radiation with Ground-based Observatory at YangBaJing) experiment is operating at the Yangbajing High Altitude Cosmic Ray Laboratory (4300 m a.s.l.), 90 km North to Lhasa (Tibet, P.R.China), as an Italian-Chinese collaboration project. It is fully operating since November 2007 with the aim of studying cosmic rays, mainly cosmic γ radiation, at an energy threshold of a few hundreds GeV, by detecting small size air showers at high altitude with wide aperture and high duty cycle. It is made of a single layer of Resistive Plate Counters (RPCs)[1] fully covering an area 74x78 m^2. In order to improve the apparatus performance in the detection of showers with the core outside the full coverage carpet, the effective area is enlarged by partially surrounding the central detector with a guard ring of RPCs, up to 100x110 m^2.
The detector is organized in modules of 12 RPCs, each RPC of dimensions 280x125 cm^2. This group of RPCs, called 'Cluster', is the basic detection and Data Acquisition unit in a logical subdivision of the apparatus. The percentage of active area in the central detector, made of 130 Clusters, is 92%. Each RPC is divided in 10 digital pick-up pads 56x62 cm^2 (subdivided in 8 strips) with a time resolution of ~1 ns, well suited to detect small energy showers. In order to extend the energy range of the detector, each RPC is also implemented by two 'big pads' for the analogical readout of the collected charge.
The detector is operating in 'Shower Mode' and in 'Scaler Mode'. In Shower Mode, for each event the location and timing of every detected particle is recorded, allowing the lateral distribution and arrival direction reconstruction. The trigger is set to a multiplicity ≥ 20 hits in 420 ns, generating events at a rate of ~ 3.7 kHz. In Scaler Mode the total counts are measured every 0.5 s, without information on both the space distribution and arrival direction of the detected particles.

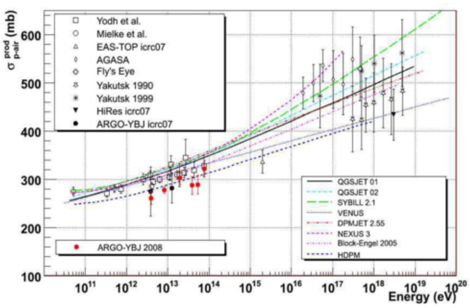

Figure 1. p-p cross section

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For each cluster, the signal coming from the 120 pads is added up and put in coincidence in a narrow time window (150 ns), giving the counting rates of ≥1, ≥2, ≥3, ≥4 pads, that are read by four independent scaler channels. The corresponding measured rates are, respectively, ~40 kHz, ~2 kHz, ~300 Hz and ~120 Hz for each cluster [2]. A detailed status report of the experiment can be found in [3].

2. Cosmic Rays

The high space-time granularity of the ARGO-YBJ detector gives the opportunity to detect several kinds of events, characterized by different topologies and time structures and a fine sampling of the shower front close to the core [4].
The proton-air cross section has been measured for proton energies in the range between 1 and 100 TeV. The analysis is based on the flux attenuation for different atmospheric depths (i.e. zenith angles) and can exploit the detector capabilities of selecting the shower development stage by means of the hit multiplicity, density and lateral profile measurements at ground. The effects of shower fluctuations and the contribution of heavier primaries have been also considered. Details of the analysis can be found in [5], [6]. Preliminary results are reported in Fig.1, together with what has been published by other experiments. The predictions of some hadronic interaction models are also shown. The implementation of the analog RPC readout will extend these studies to collisions with energies up to the PeV region.

3. Moon and Solar Shadows

Cosmic rays are hampered by the Moon and the Sun, therefore a deficit of flux in their direction is expected (the so-called ”Moon and Solar shadows”). The Moon shadow is an important tool to calibrate the performance of an air shower array. In fact, the size of the deficit allows a measurement of the angular resolution and its position allows the evaluation of the absolute pointing accuracy of the detector. In addition, positively charged particles are deflected towards East due to the geomagnetic field by an angle $\Delta\theta \sim 1.6^o/E(TeV)$. Therefore, the observation of the displacement of the Moon provides a direct check of the relation between shower size and primary energy thus allowing the detector calibration.

The ARGO-YBJ experiment is observing the Moon shadow with a sensitivity of about 10 standard deviations per month at a multiplicity $N_{hit}>40$, and zenith angle $\theta<50^o$ (corresponding to a proton median energy $E_{50}\sim1.8$ TeV). The Moon shadow has been observed in the period December 2007 - August 2008 (802 hours on-source) at significance of 26σ.
The shadow of the Sun has been measured in the period December 2007 – August 2008 (954 hours on-source with $\theta<50^o$) for events with Nhit>40 at a significance of the maximum event deficit of about 25σ.

4. Gamma Astronomy

Among the steady TeV gamma ray sources, the Crab Nebula is the most luminous and it is used as a standard candle to check the detectors sensitivity. A map of the Crab Nebula region has been obtained by ARGO-YBJ using the events with different Nhit selections and zenith angle<40^o recorded in 1190 hours of observation, equivalent to 203 transits of the source (one transit lasts 5.8 hours). The Crab is visible with a significance of more than 5 standard deviations.

The AGN Markarian 421 has been observed since day 347 of 2007 to day 229 of 2008 (1217 hours). In that period the source underwent an active period, with a rather strong increase of the X-ray flux. As observed in many occasions during the past years, the X-ray flux increases are generally associated to increases in the TeV band that can reach a flux several times larger than the Crab Nebula one.

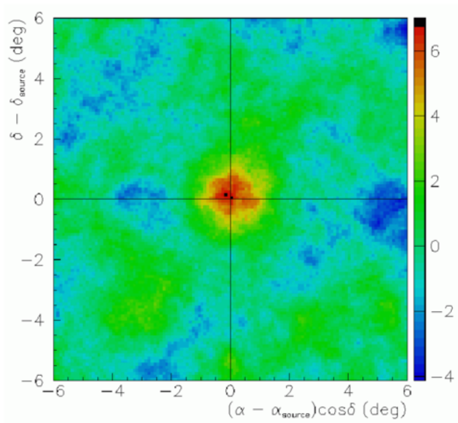

Figure 2. Mrk 421

Mrk421 was flaring again during the first months of 2008 and the ARGO-YBJ experiment reported evidence for a TeV emission in correlation with the X-ray flares. The significance map of the Mrk421 region is shown in Fig.2: a clear signal at about 7 standard deviations level is visible during 2008. The observation refers to a multiplicity $N_{hit} > 60$. A correlation of TeV photons detected by the ARGO-YBJ experiment with the X-ray events detected by the Rossi RXTE Satellite[7] is evident in Fig.3 for two different multiplicity values. We note that an all-sky VHE gamma-ray telescope as the ARGO-YBJ experiment is able to monitor the Mrk421 in a continuous way.

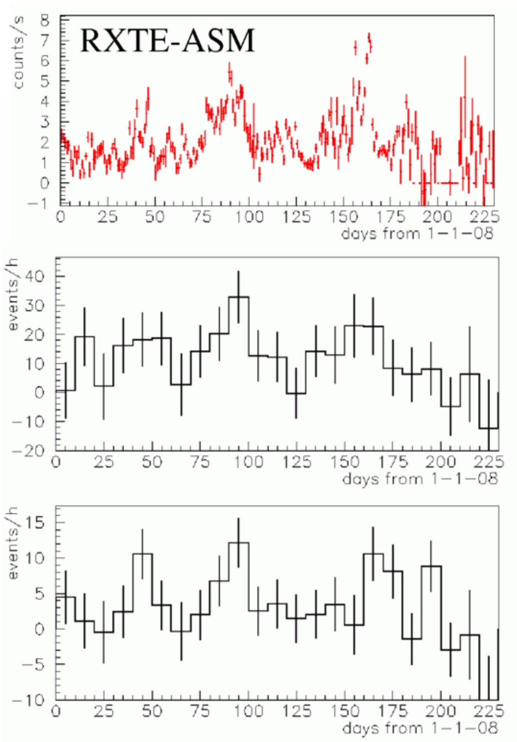

Figure 3. Comparison of Mrk 421 X-ray fluxes (top) with gamma fluxes at two different multiplicities (center nhit>40, bottom nhit>100)

The scaler mode technique offers a unique tool to study Gamma Ray Bursts (GRBs) in the GeV energy range, where gamma rays are less affected by the absorption due to pair production in the extragalactic space. The search for emission has been done in coincidence with 38 GRBs detected by satellites (mainly by Swift). No excess has been found either in coincidence with the low energy detection, nor in an interval of 2 hours around it [8]. The corresponding fluence upper limits for the 38 GRBs in the energy range 1- 100 GeV during the satellite time detection, obtained assuming a power law spectrum with a differential index α=-2.5, are of the order of $10^{-6}\div10^{-4}$ erg/cm^2.

5. Conclusions

The ARGO-YBJ detector has been completely installed and is taking data with a duty cycle > 95% since November 2007. Results from data go from p-air and p-p cross section measurement to Moon and Solar shadows observation, Mrk421 flare observed in 2008, Crab Nebula observed at > 6 s.d.. An all sky survey is going on and upper limits to GRBs flux at GeV energies have been calculated. For the future the collaboration is optimizing the shower reconstruction and studying algorithms for gamma-hadron discrimination to enhance its sensitivity to gamma sources.

ARGO-YBJ is now working with a digital readout which allows physics studies up to 100 TeV. Next year also the analog readout will be operated, allowing the extension of the cosmic ray studies up to the 'knee' region, with unprecedented resolution.

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