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First results from the ARGO-YBJ experiment

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Abstract: The central array of the ARGO detector at the YangBaJing Cosmic Ray Laboratory (4300 m a.s.l., Tibet, P.R. China) has been put into operation for physics runs. It is made of 130 identical sub-units of 12 RPCs each ("cluster") covering a surface of about 5800 m^2 with 92% active area. Signals are picked-up by external electrodes of small size, thus allowing the sampling of EAS with high space-time granularity. Shower events are detected at a trigger rate of about 4 kHz. Events with a few particles detected by a single cluster are counted in scaler mode on a time base of 500 milliseconds. Preliminary results from the analysis of events collected in a few months of data taking are presented.

Introduction

The ARGO-YBJ detector consists of a full coverage array made of single layer of Resistive Plate Chambers (RPC) operated in streamer mode of dimension $78 \times 74\ m^2$. This *central carpet* is surrounded by a *sampling ring* with other 1000 m^2 equipped with RPCs[1]. The detector is located near Lhasa in the YangBaJing Cosmic Ray Laboratory (Tibet, P.R. China) at an altitude of 4300 m above the sea level. The basic DAQ unit is the *cluster*, a set of 12 RPCs, read out by a single local station. The detector is logically divided in 154 clusters, 130 of them make the central carpet while the remaining 24 the sampling ring. Each RPC is read out by using 10 PADs ($62 \times 56\ cm^2$), which are divided into 8 strips ($62 \times 7\ cm^2$) [2].

In order to extend the measurable energy range, the RPCs are equipped with 2 large size PADs of dimension $140 \times 125\ cm^2$ each. These electrodes provide a signal whose amplitude is proportional to the number of charged incoming particles. A 0.5 cm thick lead converter will cover the detector in order to improve the angular resolution and lower the energy threshold.

ARGO-YBJ collects data in *shower mode* and in *scaler mode*. The first one works when a minimum number of PADs, fixed by the trigger condition, are fired in a time window of 420 ns.

In the scaler mode, for each cluster, the signal coming from the 120 PADs in a time window of 150 ns is added up giving the rate of counts for 4 different ranges of multiplicity (≥ 1, ≥ 2, ≥ 3 and ≥ 4) [3].

Since July 2006 the central carpet is in data taking both in scaler and shower mode with an inclusive trigger $N_{pad} \geq 20$ for the latter. Since February 2007 a DAQ upgrade allows to sustain a trigger rate of about 4 kHz with a dead time lower than 4 %. The results reported here have been obtained from the analysis of a subset of the collected data.

Detector angular resolution

The use of a full coverage detector with a high space time resolution gives a very detailed image of the shower front. This collection of *images* acquired by ARGO-YBJ in the energy range from a few hundreds of GeV up to about some hundreds of TeV will allow to face a wide range of fundamental issues, the main one being VHE gamma astronomy. For this topic it is fundamental to evaluate the angular resolution of the detector.

As a first step, an offline timing calibration procedure has been set [4]-[5]. This procedure permitted to remove systematic effects due to different cable lengths and to residual misalignment due to the electronic modules transit time. An excellent timing of the different parts of the detector has been obtained and the residual uncertainty in the measured time of the shower particles is of the order of $1\ ns$.

An estimate of the angular resolution of the detector has been obtained using the so called "chessboard method" and comparing the results with $MonteCarlo$ simulations [6]. According to simulations, the distribution of the angle ψ between the true direction of a gamma induced air shower and the reconstructed one, under some conditions, is described by a Gaussian distribution. To quote the angular resolution of the detector the σ of this distribution has been used.

The ARGO-YBJ angular resolution depends on the number of fired PADs, richer events (i.e. events with a larger number of fired PADs) will be reconstructed with higher accuracy.

Experimental results obtained with the chessboard method show that the events with PADs multiplicity larger that a few hundreds are reconstructed with an angular resolution of about 0.5^o[6].

Then, a check of the detector angular resolution has been done by studying the Moon shadow in the cosmic ray flux.

The useful data sample for this analysis corresponds to ~ 560 hours of Moon observation with a zenith angle $\leq 45^o$.

Moon shadow

Because almost all the cosmic rays are positively charged, the Moon shadow is bent westward from the real position by the geomagnetic field. Since the geomagnetic field between the Earth and the Moon is well known and both the energy spectrum and composition of the cosmic rays directly measured by satellites, the observed position and dimension of the Moon shadow can be used as an independent measurement of the angular resolution of the detector. Two independent analyses are performed in order to detect this shadow. They are in good agreement with each other.

Figure 1 shows the deficit significance obtained selecting events with more than 500 fired PADs corresponding to a median primary energy of $\sim 5\ TeV$. The maximum significance of the signal is $10\ \sigma$ and is found shifted westward of 0.04^o and northward of 0.14^o [7]. The angular resolution obtained from the observed shape of the shadow is about 0.5^o in good agreement with the estimate obtained with the chessboard method [6].

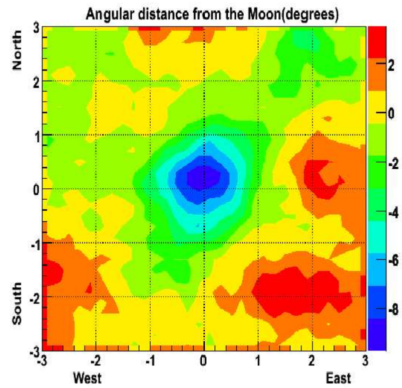

Figure 1: Moon shadow significance map centered on the true location. The color scale is in standard deviations.

First VHE gamma sources observation

Using the data collected with 130 clusters since July 2006 a preliminary investigation of possible signals from Crab Nebula and Markarian 421 has been performed. In both cases an excess of events has been found. Only a small fraction of the acquired data is reliable for these analyses because they have been collected during the debugging phase of the detector. Therefore these results are preliminary, more detailed studies are in progress and will be presented at the Conference.

The data samples used for this analysis correspond to a period of about two months of observation. The search for a signal from Mkn421 has been focused on the period July - August 2006 when a *X-ray* excess from this source has been observed by RXTE.

In figure 2 the excess significance in the Mkn421 region is shown. It has been obtained selecting events with more than 60 PADs fired corresponding to a median gamma energy of $\sim 500\ GeV$. The maximum significance of the signal is $5.4\ \sigma$. During the same period an excess of about $4\ \sigma$ significance has been observed in the Crab direction.

A detailed analysis of the duty cycle and of the possible systematics is in progress, in order to estimate both the sensitivity and the expected maximum shift, with the aim of confirming and updating these preliminary results at the Conference time.

GRB Search

ARGO-YBJ working in scaler mode can detect GRBs in an energy range of $1 - 1000\ GeV$. The GRB search is done in coincidence with satellite experiments (mainly SWIFT) and has been performed since December 2004.

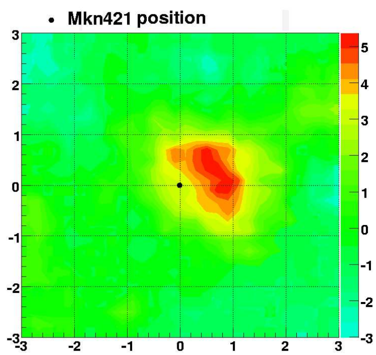

Figure 2: Markarian 421 region significance map centered on the true location.

Data have been collected during mounting phase of the detector, with an active area increasing from $\sim\ 700\ m^2$ for the first GRBs analyzed up to $\sim\ 5800\ m^2$ for the more recent ones. Moreover, not all of the GRBs detected by satellites in the field of view of ARGO-YBJ (zenith $\leq\ 45^o$) have been investigated due to the stop of the data taking during the mounting operations.

29 GRBs have been observed up to now and no significant excess in the scaler counts was measured. The corresponding $4\ \sigma$ upper limits to the fluence have been estimated in the $1 - 100\ GeV$ energy range.

Figure 3 shows the fluence upper limits obtained versus the GRB differential spectral index measured by the satellites [3].

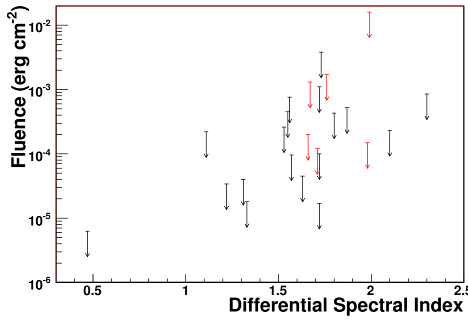

Figure 3: Fluence upper limits versus the corresponding differential spectral index. Red arrows indicate upper limits for GRBs with measured redshift obtained taking into account the extragalactic absorption.

Inelastic P-Air Cross Section

The decrease of the detected shower flux with the zenith angle θ for fixed primary energy and shower age can be used to perform a measurement of the inelastic *p-Air* cross section.

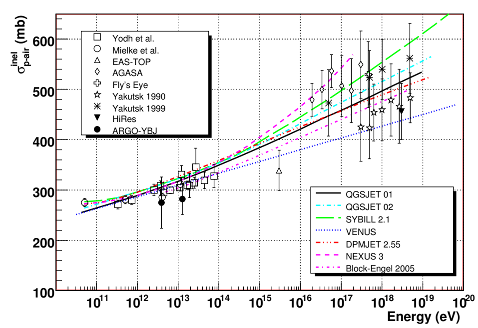

Figure 4: Inelastic $p - Air$ cross section measured by different experiments. In this plot ARGO-YBJ data points have been corrected for the contribution of the primaries heavier than protons.

For sufficiently large X_{max} values (X_{max} = position of the shower maximum), the $\sec\theta$ distribution follows a simple exponential law, with an attenuation length $\Lambda = k\lambda_p$, where $\lambda_p \sim 2.4 \cdot 10^4/\sigma_{p-Air}$. The parameter k depends on the shower development in the atmosphere, on its fluctuation and on the detector response and it must be evaluated by detailed $MonteCarlo$ simulations.

To perform this analysis, the collected sample of events has been divided into 2 sub-samples (selecting different ranges of PADs multiplicity) each of them is characterized by a different average primary energy ($3.9 \pm 0.1\,TeV$ and $12.7 \pm 0.4\,TeV$) For each sub-sample, from the shower flux attenuation, the Λ parameter has been estimated and then the corresponding $p - Air$ cross section determined. Finally, the contribution of heavier primaries has been take into account [8].

Figure 4 shows the $p - Air$ cross section versus the energy obtained in this analysis compared with some other measurements. These results are in good agreement and suggest the possibility to extend the investigation in an energy range (up to $10^3\ TeV$) that is still unexplored.

Conclusions

ARGO-YBJ is fully deployed and its central carpet is in data taking since July 2006. The preliminary results obtained analyzing a first sample of data collected with the central carpet have been presented. The angular resolution estimated by using the chessboard method and confirmed by the analysis of the moon shadow is about 0.5^o for proton induced air showers of TeV energies, makes us confident that ARGO-YBJ will observe the sky with excellent sensitivity. Moreover, an improvement of the angular resolution is expected by adding the lead plates.

A first analysis of the Crab Nebula and Markarian 421 regions has been performed finding in both cases a significant excess of events. This analysis is in a preliminary phase, therefore, the not perfect agreement between the source location and the position of the excess is under investigation.

The scaler operation mode of the detector has been used to investigate the high energy component of the GRBs. The analysis performed in coincidence with 29 GRBs detected by satellites shows no evidence of a significant signal. The most stringent fluence upper limits are of the order of $10^{-5}\ erg/cm^2$. Finally, we have very promising results from the measurement of the inelastic $p - Air$ cross sections at a few TeV by exploiting a technique that could be extended to the PeV region.

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