The ARGO-YBJ experiment in Tibet

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Abstract

The setting up of the ARGO detector at the YangBaJing Cosmic Ray Laboratory (4300 m a.s.l., Tibet, P.R. China) has been completed during the last spring (2007). It consists of a central carpet made of 130 identical sub-units of 12 RPCs each (a “cluster”), covering a surface of about 5800 m² with 93% active area, and a guard ring of 24 further clusters of the same type surrounding the central carpet with a lower sampling density. 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 ms. The intrinsic modularity of the ARGO detector allowed us to collect data even during the setting-up period, using only the central carpet (or even part of it). Some preliminary results from the analysis of events collected in a few months of data taking are presented.

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1. Introduction

ARGO-YBJ is an Extended Air Shower Detector optimized to work in the TeV range, with a threshold of few hundreds of GeV and a dynamical range extending to the PeV. Its experimental approach is of measuring both charged and gamma ray induced showers on a compact detector covering an equipped area of the order of 10,000 m², located at very high altitude (4300 m a.s.l.) in Tibet. The instrumental requirements of ARGO-YBJ include a good angular resolution, at the level of a fraction of a degree, a field of view of 2 sr, allowing to survey almost completely the northern hemisphere, with a declination range spanning from 70°N to 10°S, a continuous monitoring with a duty cycle only limited by the maintenance and experimental shutdown needs. This paper reports on the preliminary analysis of some of the main physics items addressed by ARGO-YBJ:

- **Gamma ray source detection**: The wide angular range and the high duty cycle enable ARGO to detect both already identified sources as well as still undisclosed emitting sources with a sensitivity of a fraction of the CRAB intensity in the TeV energy range.
- **Cosmic Ray study**: The ARGO energy range overlaps both with the higher end of the direct measurements of satellite experiments and the lower end of sampling ground EAS experiments, ending up in the knee region. Its detection approach enables a detailed study of the shower front structure and therefore a large piece of information is expected as far as the proton–Air cross-section is concerned, as well as the extension of the composition studies above the satellite energy range.
- **Gamma Ray Burst study**: The detection of a sudden increase in the expected background, mainly in connection with GRB detection by satellite experiments within the ARGO field of view can be interpreted and analyzed...
as GRB high energy counterparts with an energy threshold of few GeV.

The preliminary analysis of the data collected during the ARGO-YBJ detector setting-up period will be outlined, as well as the description of the main detector features.

2. The ARGO-YBJ experiment

ARGO-YBJ is located 30°06′38″N, 90°31′50″E, at the Yang Ba Jing Cosmic Ray Laboratory (Tibet, China), at an altitude of 4300 m a.s.l.

2.1. The detector

It consists of a 74×78 m² continuous carpet of Resistive Plate Counters (RPCs), with 93% coverage of the equipped area, surrounded by a guard ring with coarse coverage, extending the equipped area to a total surface of 111×99 m², with 6700 m² of sensitive area, as outlined in Fig. 1.

The RPCs (2.8×1.25 m² each) are operated in streamer mode, and their performance is described in detail in Ref. [1]. The RPCs are logically grouped in “clusters” of 12. The cluster is the fundamental detector module, both for triggering and DAQ purpose. The full ARGO Detector consists of 154 clusters. The central carpet is made by 130 clusters, the guard ring by 24 clusters more. The RPC signal is picked up by means of induction strips, covering the RPC surface. Each strip is 7×56 cm² large. This dimension represents the ARGO space granularity, i.e. the pixel size on which particle hit are digitized and hence counted. The signals of 8 adjacent strips are ORed into an almost squared PAD (62×56 cm² wide) as far as the hit arrival time is concerned. The PAD signal is in fact sent to a TDC converter and represents the time pixel, allowing a resolution of the order of 1 ns in determining the hit arrival time. In order to extend the detector dynamical range beyond the limit imposed by the digitized strips, the charge collected on the chambers is also measured. Each RPC of the central carpet is, therefore, equipped with two BIG PADS (140×125 cm² wide), from which the analog signal proportional to the number of particles is picked up. The resulting signal shows a linearity up to >10⁴ particles/m², corresponding to an energy of ~10 PeV. This feature, which is till date implemented only in 54 clusters, will be extended to the full central carpet by the first half of 2008.

2.2. Data taking

As far as data taking is concerned, ARGO-YBJ operates in two modes, the “shower mode” and the “scaler mode”. The shower mode consists essentially of a majority trigger logic: a number of fired pads \( N_{\text{pad}} \geq N_{\text{trig}} \) in the central carpet, within a time coincidence window of 420 ns triggers the “shower” data taking. The current threshold is set to \( N_{\text{trig}} = 20 \), which corresponds to a gamma energy threshold of a few hundreds of GeV. The trigger rate is of ~4 kHz in this configuration.

To reconstruct the shower direction and the core position from the collected data the calibration of the
18,480 PADs has to be kept under careful control [2] and has to be periodically repeated to prevent any time dependence introducing dangerous systematics in the reconstructed data. In Fig. 2 an example of the hit space and time pattern of a triggered event is shown, after taking into account the calibration correction.

In the “scaler mode” the counting rate of each cluster is continuously recorded every 0.5 s, for four different level of hit majority in a single cluster: \( n \geq 1 \), \( n \geq 2 \), \( n \geq 3 \), \( n \geq 4 \) in a coincidence window of 150 ns. The recorded counting rates, for the different levels of coincidence, are respectively, 40, 2 kHz, 300 kHz and 120 Hz per cluster. Showers initiated by primaries with an energy threshold of the order of 1 GeV, unable to trigger the detector in shower mode, can produce such a faint signal. These events are analyzed for a sudden increase in their rate, to provide an evidence for \( > 1 \) GeV counterparts in time coincidence with GRBs detected by satellites at the time of the event detection. Also Solar Ground Level Enhancements and cosmic ray modulation due to the solar activity can be monitored in this mode. No direction measurement is obviously possible for such events. The detector is taking data with the full central carpet since July 2006. The guard ring, whose setting up has been completed during the spring 2007, is actually being tested for its addition to data taking at the end of this year. The results presented in this paper, therefore, refer to a preliminary data taking performed in the period July 2006–March 2007 in shower mode (130 active clusters) and December 2004–April 2007 (with an increasing detector active surface from \( \sim 700 \) m\(^2\) to 5500 m\(^2\)) as far as the scaler mode is concerned.

### 2.3. The detector performance

#### 2.3.1. The angular resolution

ARGO angular resolution has been estimated using three independent ways and, cross-checking the results, we found a rather good agreement.

The first method was a pure Monte Carlo one, obtained estimating the angular distance between injected events and reconstructed direction.

The second one is based on the data, using the so-called chessboard method. The direction of a single triggered shower is derived by using alternatively the data from the even-numbered PADs and those from the odd-numbered PADs. The consistency of the two measurements gives an estimate of the angular resolution.

Figs. 3 and 4 show the result as a function of the number of fired PADs in the event. The angular resolution estimator is \( \psi_{72} \), defined as the angular spread, which contains the 71.5\% of the events. For a Gaussian behavior of the point spread function, \( \psi_{72} \) is the radius of the observation window which maximizes the signal-to-noise ratio for the signal centered on a point-like source. The angular resolution is correlated to the \( \psi_{72} \) parameter by a factor \( \sigma = \psi_{72}/1.58 \).

**Fig. 3.** The angular resolution estimator \( \psi_{72} \) as a function of the number of PAD hit in the event.

**Fig. 4.** \( \psi_{72} \) as a function of the number of hitted PADs for proton and photon induced showers.
The presence of any systematics causes a deviation from this factor 2.

A detailed discussion of the ARGO angular resolution can be found in Ref. [4].

Fig. 4 shows the expected behavior of the angular resolution as a function of the number of hitted PADs both for proton and photon induced showers.

Finally, the third method relies on the accuracy of the reconstruction of the Moon position, as derived from its shadowing effect on the incoming cosmic ray flux. Fig. 5 shows the width of the Moon shadow as preliminarily observed from the analysis of ARGO real data. The consistency of the observed width and of its position is an important cross-check of the calibration and reliability of the first collected data.

The observed deviation from the nominal Moon position is 0.14° in the North–South direction, where there is no magnetic deflection and the expected position coincides, therefore, with the nominal one, and 0.04° Westward, to be compared with an expected shift of ∼0.3° Westward, due to the magnetic deflection on the charged component. The study of the systematics and the careful analysis of the residual deviation from the expected nominal position are in progress [5]. A further improvement of the angular resolution is expected adding a 0.5 cm thick lead pre-converter on top of the RPC layer. This upgrade is scheduled during 2008.

2.3.2. Duty cycle

After the setting-up period, an encouraging result of 86% for the ARGO duty cycle has been obtained during the month of May 2007, confirming thus the expected performance.

3. Experimental results

We report in this section the preliminary results obtained analyzing the ARGO data taken in the setting-up period.

3.1. Moon and Sun shadows

The Moon shadowing effect, mainly used for calibration purposes and angular resolution cross-check, has been clearly observed during the period July 2006–March 2007.

![Fig. 6. Map of the Moon region. The color scale indicates the significance of the deficit/excess with respect to the mean flux. The axes show the distance in degrees with respect to the nominal position.](image)
3.2. Gamma ray sources

VHE gamma ray astronomy is one of the main scientific topics addressed by ARGO-YBJ. Amongst the known sources the Crab Nebula has a well-studied spectrum and is often used as a standard candle to calibrate the experimental sensitivity. Fig. 8 shows the result obtained selecting the direction of the Crab out of the ARGO data, integrating 50 transits corresponding to a minimum number of PADs to be hit, \( N_{\text{pad}} \geq 500 \), corresponding to a median energy \( E \approx 5 \text{ TeV} \).

Fig. 7 shows the Sun shadow, obtained with the same technique. A shorter observation time has been selected in this case, selecting only 208 h in the 2006 period corresponding to a minimum in the solar activity, in order to minimize the effect due to the high variability of the solar magnetic field. A signal with \( 6\sigma \) statistical significance shows up in this case.

3.3. Cosmic ray analysis

Another of the main topics addressed by ARGO is the detailed analysis of the cosmic ray flux, in the energy region overlapping the highest range of satellite measurements and the typical range of ground based Extended Air Showers experiments, up to the knee region. A totally preliminary result has been obtained analyzing the collected data to work out the estimate on inelastic p–Air cross-section.

The method is based on the assumption of a behavior of the shower intensity as a function of the zenith angle:

\[
I(\theta) = I(0)e^{-(\theta/\lambda)\sec \theta}, \quad A = k\lambda_{\text{air}}
\]

where the intensity \( I(\theta) \) is derived from the data and the parameter \( k \) is deduced from Monte Carlo simulation, as it...
is dependent from the shower development and its fluctuations, folded to the detector response. It is only slightly dependent on the interaction model. \( \lambda_{\text{int}} \), the proton–Air interaction length, is the free parameter determined by the data. The cosmic proton contamination by means of heavier primary has obviously to be taken into account. Finally one can get

\[
\sigma_{\text{inel}}(p/\text{Air})(\text{mb}) \approx 2.4 \times 10^4/\lambda_{\text{int}}.
\]

A detailed discussion of the analysis can be found in Ref. [7]. Fig. 10 shows the result, obtained in two primary energy bins, defined by selecting the \( N_{\text{pad}} \) range of the reconstructed showers: \( 300 < N_{\text{pad}} \leq 1000 \), with an estimated median energy \( E \approx 4 \) TeV, and \( N_{\text{pad}} > 1000 \), corresponding to a median energy \( E \approx 13 \) TeV of the cosmic primary.

### 3.4. The Gamma Ray Burst analysis

The scaler mode technique is used to monitor the behavior of the single particle rate in the ARGO detector. Each cluster is continuously monitored and the single particle counting rate is registered every 0.5 s, as well as the \( n \)-particle majorities \( n \geq 2 \), \( n \geq 3 \), \( n \geq 4 \), within a time coincidence window of 150 ns. A primary gamma ray of \( E > 1 \) GeV can produce such a weak signal in the detector and a sudden increase of their rate, in a limited period of time, uniformly in the detector, could be interpreted as a signature for the high energy tail of a Gamma Ray Burst. The arrival direction of the event cannot, however, be reconstructed.

A temporal coincidence with a GRB detection by the existing satellites is, therefore, searched for, as a further signature for interpreting the recorded signal as the evidence for the detection of a GeV counterpart of the Gamma Ray Burst. This analysis is presented in detail also at this conference [8], as well as the statistical significance of the recorded excesses. No evidence is detected analyzing 26 GRB detected by satellites (mainly SWIFT) while orbiting within the ARGO field of view in the period December 2004–April 2007. An existing excess is searched for, both in exact time coincidence and in a time interval preceding or following the satellite detection time, to look for a delayed/anticipated emission of the possible high energy counterpart. Fig. 11 summarizes the fluence limit for \( E > 1 \) GeV, with reference to these 26 GRB, as a function of the zenith angle, assuming for the emission spectral index in the 1–100 GeV range the value measured by satellites in the keV–MeV region. Full dots identify GRBs with unknown redshift. For GRBs whose redshift is given (triangles) the spectrum is corrected for extragalactic absorption.

### 4. Conclusion

ARGO-YBJ experiment is taking data since July 2006 with its central carpet (130 clusters covering \( \approx 5500 \) m\(^2\) with 93% active area).

During the first half of year 2007 the installation of an external guard-ring including 24 clusters with coarse active area (\( \approx 42\% \)) has been completed. They will be included in data taking by the end of year 2007.

The data collected in the period July 2006–Spring 2007 have been used for a preliminary analysis, with the main goal of checking the experimental performance and calibrate the detector.

The angular resolution, checked with the chessboard method on the experimental data fits the expectations, as
well as the accuracy of the Moon deficit reconstructed position and width. A fine analysis of the residuals is still in progress.

The Moon and Sun deficit are observed with, respectively, 10σ and 6σ statistical significance.

As far as the Gamma ray sources is concerned, the Crab Nebula signal has been worked out with 5σ significance, integrating ~290 observation hours. The Markarian 421 flare, observed in ASM/RXTE data, has been confirmed by the preliminary analysis of ARGO data, showing-up an energy threshold well below the TeV.

The study of the charged cosmic rays flux allowed a preliminary estimate of the p–Air cross-section. The collection of more data will allow both to reduce the experimental error and to increase the energy range of the measurements.

As a general remark, the improvement of the analysis procedure is still in progress, mainly to fully exploit the compactness of ARGO and its capability of carefully describing the details of the pattern of the shower front, both in terms of space and time distribution of the incoming secondaries.

The scaler mode finally allowed to work out an upper limit for the GRB fluence (between $6 \times 10^{-6}$ and $2 \times 10^{-2}$ erg cm$^{-2}$ as a function of the zenith angle) for $E>1$ GeV. The result refers to the analysis of 26 GRB detected in the period December 2004–April 2007 by satellites (mainly SWIFT). The expected improvement of the ARGO Detector has been also outlined, including:

- The extension of the actual detector to 6700 m$^2$ of active area through the inclusion of the guard ring in the data taking by the end of this year.
- The completion, during the first months of 2008, of the analog read-out system of the whole central carpet, with the aim of extending the dynamic range up to $10^{15}$ eV.
- The addition of a layer of lead preconverter (0.5 cm thick) to the central carpet RPCs, with the aim of improving the detector angular resolution mainly for low energy showers, to be completed at the end of 2008.

References