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ARGO-YBJ experiment and TeV gamma astronomy

P. Bernardini [a]
(on behalf of the ARGO-YBJ Collaboration)

[a]Dipartimento di Fisica dell'Università del Salento and Sezione INFN, 73100 Lecce, Italy

The ARGO-YBJ detector is an extensive air shower array consisting of a carpet of Resistive Plate Chambers (RPCs). Very high energy (VHE) gamma ray astronomy is the main scientific goal of this Chinese-Italian experiment. High altitude and full coverage ensure a low energy threshold (few hundreds of GeV for primary photons), high duty-cycle and large field of view allow a continuous sky survey in the declination range from $-10°$ to $+70°$. Also many features of the high energy cosmic rays are studied by ARGO-YBJ exploiting the unprecented shower reconstruction.

1. The ARGO-YBJ detector

The ARGO-YBJ (Astrophysical Radiation Ground-based Observatory at YangBaJing) experiment is located in Tibet at an altitude of 4300 m [1]. The detector consists of a single layer of RPCs operated in streamer mode, on a total area of about 110×100 m^2. The central part (78×74 m^2) is fully covered by RPCs and is surrounded by a sampling ring with other 1000 m^2 (20% of the ring) equipped with RPCs. The experiment is in data-taking with the central carpet since June 2006. The sampling ring has been completely mounted and will be put in data acquistion quite soon. In the summer 2007 the RPC layer will be covered with a lead layer as photon preconverter, in order to enhance the experimental sensitivity.

The digital read-out of the RPCs is performed by means of inductive strips (6×62 cm^2) well suited to detect small air showers. In order to extend the measurable energy range, each RPC is equipped with two large pads. These electrodes, called "Big Pads", provide an analog signal proportional to the collected charge.

The fast-OR of eight strips (56×62 cm^2) is called pad and defines the space-time pixel of the detector, with a time resolution of ~ 1 ns. The detector is logically divided in 154 clusters each made by 12 RPCs, and read-out by a dedicated Local Station.

ARGO-YBJ collects data in "shower mode" and in "scaler mode". The first one works when the number of pads fired in a time-window of 420 ns exceeds the multiplicity required by the trigger condition. The event (arrival direction, core position and so on) is fully reconstructed by means of the space-time pattern (see Fig. 1). The "scaler mode" does not require any trigger, it records the rate for four multiplicities (≥ 1, ≥ 2, ≥ 3 and ≥ 4) on each cluster in a time window of 0.5 s.

The high altitude location, the full coverage with high granularity, and the RPC time resolution allow an angular resolution of $\sim 0.5°$ for a primary of 1 TeV and reduce the energy threshold in "shower mode" to few hundreds of GeV. The continuous sky survey in the declination band from $-10°$ to $+70°$ is possible thanks to the duty-cycle close to 100% and the field of view greater than 2 sr.

The "scaler mode" allows the detection of low energy transient phenomena (e.g. GRBs and solar flares) observed as non-statistical fluctuations of the background, after a preliminary data reduction needed to take into account the influence of environmental parameters, such as atmospheric pressure and detector temperature. A rough estimate of the energy is performed looking at the signal on the four different scalers.

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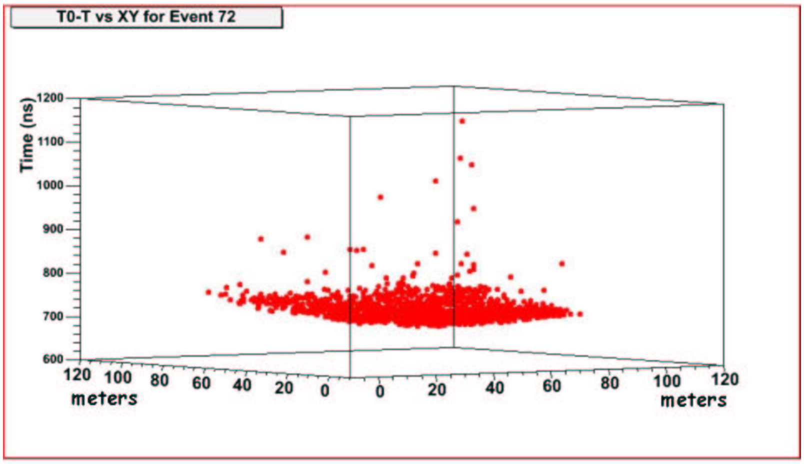

Figure 1. An extensive air shower reconstructed by the ARGO-YBJ detector.

2. Cosmic ray studies

The features of the ARGO-YBJ detector offer a unique chance to study deeply the hadronic component of cosmic rays in the energy range (1-1000 TeV) connecting direct and EAS measurements. Many analyses are in progress. The strip size spectrum is used to investigate the consistency with the JACEE and RUNJOB measurements [2]. The high space-time granularity allows unprecedented studies on EAS phenomenology (different topologies and time structures) [3].

The decrease of the shower frequency with the zenith angle (Fig. 2), when primary energy and shower age are determined, gives a measurement of the flux attenuation at that energy. The flux attenuation is controlled by the absorption length, related to the interaction length. Therefore it is possible to estimate the $p - air$ and $p - p$ cross sections. Presently this analysis has been made on data collected with only 42 clusters (ARGO-42). Two sub-samples of events with mean energy of 3.67 and 14.3 TeV have been selected. The results of this analysis are shown in Fig. 3 and, altough preliminary, they are in agreement with other measuremements. Extension of this measurement to unexplored regions is possible, selecting higher energies by means of the charge analog read-out.

3. VHE gamma-astronomy

The main topics of VHE gamma-astronomy are the study of supernova renmnants (SNRs) as cosmic ray source, the search for active galactic nuclei (AGN) and the high energy emission from gamma-ray bursts (GRBs). Presently the fast growth of this research field [4] is mainly due to the Imaging Air Čerenkov Telescopes (IACTs) with excellent angular and energy resolution and a quite good gamma/hadron discrimination. However the limits of the IACTs are the limited duty-cycle ($\sim$ 10%) and a small field of view ($\sim$ 20 msr), partially compensated by the possible fast changing of the search direction. On the contrary, the full-coverage detectors [5,6] have a field of view larger than 2 sr and in principle a data-taking efficiency of 100%. Therefore they are particularly suited to discover new sources, to look for transient phenomena, such as GRBs, and to observe sources larger than the IACT field of view (for istance, the VHE gamma-signal from the Cygnus region detected by Milagro [6]).

The ARGO-YBJ data analyzed so far confirm the detector capability as a gamma-telescope. The angular resolution results lower than 0.5° for a multiplicity of fired pads higher than 500 [7]. The data collected with ARGO-42 have been analyzed looking for the Moon shadow, which has

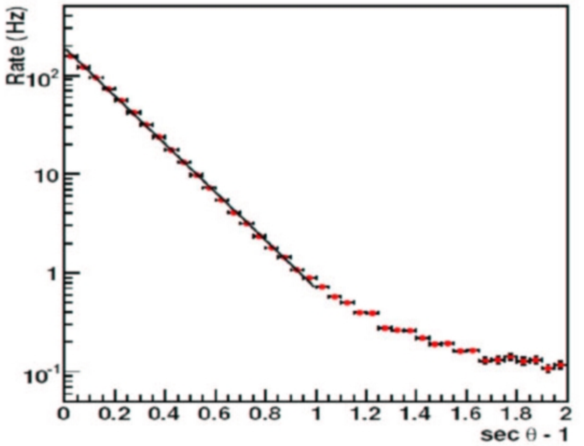

Figure 2. The shower detection rate as a function of $\sec\theta$. It can be well fitted by an exponential up to about 60°.

been observed with the expected statistical significance of $\sim 5\sigma$. A systematic displacement of 0.7° West and 0.5° North has been observed with respect to the expected position, which is currently being investigated using a larger statistics and the full detectore data, also to pinpoint the sources of systematic uncertainties in the experimental and in the analysis technique.

The arrival directions of the events collected in "shower mode" with ARGO-42 (Fig. 4) have been analyzed looking for any excess on the cosmic ray background. As expected from the Monte Carlo sensitivity estimate, no significant excess has been observed [8].

The GRB spectra, well studied by satellite detectors in the keV-MeV range, are still quite unknown at higher energies. Only two observations indicate some emission in the GeV range [9,10]. By means of the acquisition in "scaler mode" the ARGO-YBJ detector covers the energy range from 1 to 100 GeV range. A first search for VHE signals in coincidence with GRB satellite observations has been performed [11]. No significant emissions have been detected and fluence upper limits ($\sim 10^{-4} \div 10^{-5}$ erg/cm^2) were set for GRBs in the ARGO-YBJ field of view (the list is not reported for space lack).

4. Conclusions

The ARGO-YBJ experiment has been completely installed and is collecting data. The detector performance are the expected ones and the data analyses are in progress. The preliminary results about cosmic rays range from the measurement of $p-p$ cross section to the cosmic ray spectrum. ARGO-YBJ will contribute to the exciting growth of the VHE gamma-astronomy, thanks to its low energy threshold with respect to EAS sampling arrays and to its duty-cycle and field of view with respect to IACTs. The main contributions are expected in the study of extended sources, the discovery of new ones and the observation of possible temporal variations. The introduction of γ-proton discrimination criteria based on the shower pattern will improve the sensitivity of the experiment to γ sources.

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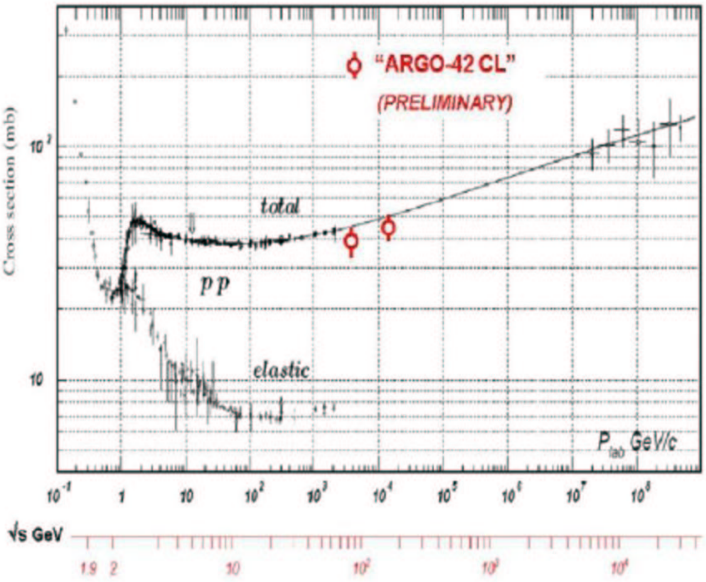

Figure 3. Preliminary ARGO-42 measurement of the $p-p$ cross section (open circles) compared to other experimental values. The error bars include both statistical and systematical uncertainties.

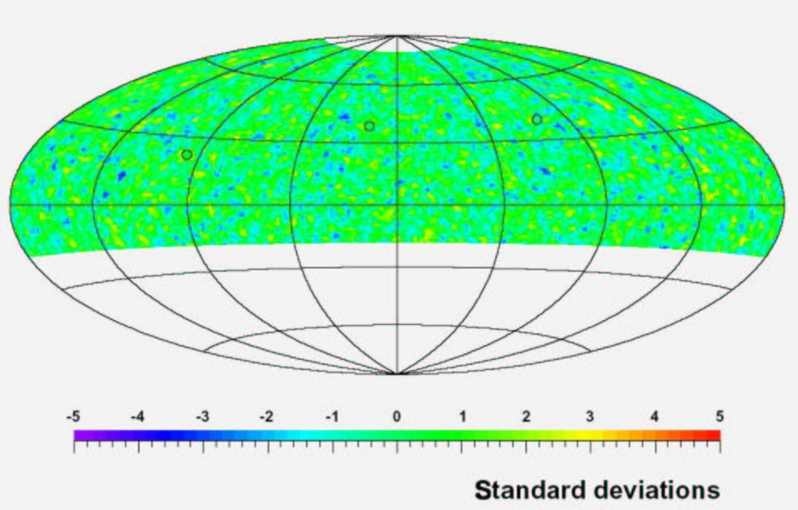

Figure 4. Sky-map obtained from 1000 hours of data-taking with ARGO-42. The small circles indicate the position of the Crab Nebula, Mrk 421 and Mrk 501 (from left).