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Nuclear and Particle Physics Proceedings 279–281 (2016) 7–14

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Cosmic ray physics with ARGO–YBJ

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Abstract

The ARGO–YBJ experiment has been in stable data taking for more than five years at the Yangbajing cosmic ray observatory (Tibet, P.R. China, 4300 m a.s.l.). The detector collected about 5×10^{11} events in a wide energy range from few TeVs up to the PeV region. In this work we summarize the latest results in cosmic ray physics particularly focusing on the cosmic ray energy spectrum. The results of the measurement of the allparticle and proton plus helium energy spectra in the energy region between $10^{12} - 10^{16}$ eV are discussed. A precise measurement of the cosmic ray energy spectrum and composition in this energy region allows a better understanding of the origin of the knee and provides a powerful cross–check among different experimental techniques.

Keywords: Cosmic Rays, EAS, Energy spectrum, Anisotropy

1. Introduction

The ARGO–YBJ experiment is a full–coverage EAS detector that has been in operation for more than five years at the Yangbajing International Cosmic Ray Observatory (Tibet, P. R. China, 4300 m a.s.l.). The detector has been designed in order to face several open problems in cosmic ray physics and γ–ray astronomy. The detector operated simultaneously as a wide field of view γ ray telescope at the TeV region and as a high resolution cosmic ray (CR) detector in a wide energy range from TeV up to 10 PeV. The full–coverage technique, combined with high–altitude operation and high segmentation, allow the detection of showers produced by primaries in the TeV region, so far investigated only by satellite or balloon–borne experiments.
In this paper the latest results obtained by ARGO–YBJ on CR physics are briefly summarized and discussed.

2. The ARGO–YBJ experiment

The ARGO–YBJ experiment is a full–coverage detector made of a single layer of resistive plate chambers (RPCs) with ~ 93% active area, surrounded by a partially instrumented (~ 20%) guard ring. The 1836 RPCs are arranged in 153 clusters each made of 12 chambers. The detector has been equipped with two independent readout systems: each RPC is simultaneously read–out by 80 copper strips ($6.75 \times 61.80\,\mathrm{cm}^2$) logically arranged in 10 independent pads ($55.6 \times 61.8\,\mathrm{cm}^2$) and by two large pads called Big Pads ($139 \times 123\,\mathrm{cm}^2$). Each strip represents the space granularity of the detector, i.e., the pixel used to sample the particles of the shower front [1]. Each pad signal is sent to a time–to–digital converter and represents the time pixel, allowing a resolution of about 1.8 ns in measuring the particle arrival time. The installation of the central full–coverage carpet was completed in June 2006. The guard ring was completed during spring 2007 and connected to the DAQ system in November 2007. A trigger logic based on the time coincidence between the pad signals have been implemented. The detector has been in operation from November 2007 up to February 2013 with a trigger threshold $N_{pad} = 20$, corresponding to a trigger rate of about ~ 3.5 kHz with a dead time ~ 4%. The Big Pads collect the total charge developed by the particles hitting the detector surface and extend the detector operating range up to the PeV region [2, 3]. The whole system can be operated at eight different gain scales (G0, ...,

http://dx.doi.org/10.1016/j.nuclphysbps.2016.10.003

G7) thus extending the detector operating range up to $\sim$ 10 PeV. Data from the highest gain scale (G7) have been used for calibration purposes. The intermediate gain scale (G4) overlaps with the digital readout data in a wide energy range between 10 and 100 TeV, providing a cross–calibration of the two techniques. Data from lowest gain scales (G1 and G0) allow the detection of showers with more than 10^4 particles/m^2 in the core region.

3. Cosmic ray energy spectrum

The all–particle energy spectrum of cosmic rays can be roughly described as a single power law with a *knee* at energies around 3.5 PeV. Supernova remnants (SNR) are commonly identified as the sources of Galactic cosmic rays up to the knee region. The origin of the knee and the transition between galactic and extragalactic origin are still under discussion. In the standard picture the origin of the knee is related to a decrease of the flux of protons and He nuclei [4]. Several experiments reported an evidence that the knee of the all–particle spectrum is due to nuclei heavier than Helium. The determination of the elemental composition around the knee therefore plays a key role in the understanding of the origin and acceleration of cosmic rays. The ARGO–YBJ experiment is able to explore the energy region from few TeV up to several PeV. Measurements of the all–particle and light component (protons plus Helium nuclei) energy spectra are currently under way in this energy range. In order to explore such a wide energy range different approaches have been used:

- *Digital Analysis*. It is based on the RPC digital readout data (i.e. the strip multiplicity) and covers the 3 − 300 TeV energy range [5, 6].
- *Analog Analysis*. It uses the information coming from the RPC analog readout and explores the 30 − 30000 TeV energy range. In this case two approaches have been followed starting from the observed particle distribution at ground level: energy reconstruction on a statistical basis using a bayesian unfolding technique [7] and energy reconstruction on an event by event basis [8].
- *Hybrid Analysis*. It combines the data coming from ARGO–YBJ and a wide field of view Cerenkov telescope [9, 10].

3.1. Digital analysis

The analysis have been performed on the data collected during the period January 2008 – December 2012. As widely described in [5, 6], by requiring quasi–vertical ($\vartheta \leqslant 35°$) showers in an area of about 40×40 m^2 centered on the detector and applying a selection criteria based on the lateral particle density, a sample of showers mainly produced by light elements has been selected. The energy spectrum has been reconstructed starting from the multiplicity distribution by using an bayesian unfolding technique [11, 12]. The spectrum measured by ARGO–YBJ is shown in figure 1. The value of the spectral index of a power–law fit to the ARGO–YBJ data is −2.64±0.01. The ARGO–YBJ data are in good agreement with the CREAM proton plus helium spectrum. At energies around 10 TeV and 50 TeV the fluxes differ by about 10% and 20%, respectively. This analysis demonstrates the excellent stability of the detector over a long period. For the first time a ground–based measurement of the CR spectrum overlap with the results obtained by balloon–borne experiments.

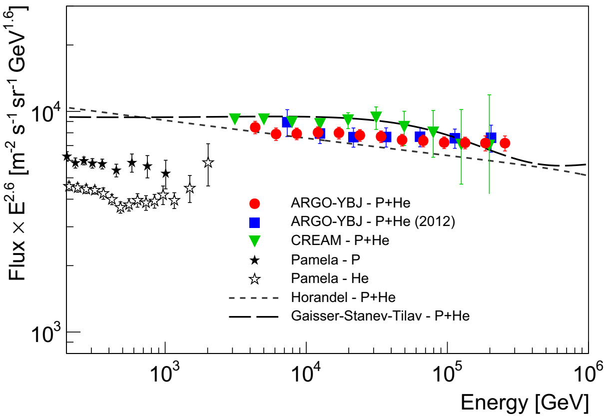

Figure 1: The light–component spectrum measured by ARGO–YBJ in the 3–300 TeV energy range compared with other experimental results. The ARGO 2012 data refers to the first results published in [5]. Results from PAMELA [13], CREAM [14] and the models by Hörandel [15] and Gaisser, Stanev and Tilav [16] are also shown.

3.2. Analog analysis

The RPC charge readout of the ARGO–YBJ experiment allows the measurement of the particle density in the shower core region up to 10^4 particles/m^2. This system allows the detection of CR in the PeV energy range and therefore the extension of the CR spectrum measurements up to the highest energies. The high segmentation of the whole system allows a detailed study of the lateral distribution of particles, which can be exploited in order to discriminate among showers produced by primaries of different masses.