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Measurement of strip size spectrum with the ARGO-YBJ experiment

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In this paper we present the $strip\ size\ spectrum$ measured with a portion of the ARGO-YBJ detector ($\sim$ 1900 m^2 out of $\sim$ 6700 m^2) currently in data taking at the Yangbajing Cosmic Ray Laboratory (4300 m a.s.l.). Events with core located in a small fiducial area at the centre of the apparatus have been selected. The measured spectrum is due to primaries with energies extending from few TeV up to about 100 TeV, an energy range where direct measurements are available. It is compared with those expected according to RUNJOB and JACEE composition models of the primary cosmic rays.

1. Introduction

As well known, all measurements in the knee region of the primary cosmic ray spectrum are only of indirect character, based on the reconstruction and interpretation of EAS observables like the size spectrum of electrons and muons. Despite large progress in building of multi-component EAS experiments and in the related analysis techniques, there is a not a general consensus about the energy spectrum of each elemental component at energies above 100 TeV. At lower energies the main information comes from balloon born experiments which are able to identify, with a good resolution, the nature of the primary particle. On the other hand, in these experiments, fluxes are obtained adding data collected in many fligths, an approach usually not free from normalization problems. Accordingly, the extension of the low energy data to energy range of EAS experiments is not straightforward, and matching "direct" and "indirect" measurements is a problem not completely solved.

ARGO-YBJ experiment [1] offers a unique opportunity to investigate a large energy range because of its ability to operate down to a few TeV by measuring small size air showers (strip or digital read-out [2]) and up to the PeV region by measuring the RPCs charge (analog read-out [3]). In this way ARGO-YBJ allows indirect study of a wide class of phenomena in cosmic rays and astroparticles physics in a range that overlaps with direct measurements.

In this paper we present the strip size spectrum measured with $\sim 1900\ m^2$ of the detector (out of $\sim 6700\ m^2$) presently in data taking and we compare the measured spectrum with those expected according to composition models of primary cosmic rays from balloon born experiments. The technique of counting the number of fired strips corresponds to operate in the energy primary range beetwen a few TeV to hundreds of TeV.

2. The ARGO-YBJ detector and the digital read-out

The ARGO-YBJ apparatus will consist of a single layer of Resistive Plate Counters (RPCs) operating in streamer mode (78 × 74 m^2 size), surrounded by a guard ring. The signals from each RPC are picked-up with 80 read-out strips (6.7 cm wide and 62 cm long) with a density of 22 $strips/m^2$ for a total of 124800 strips in the central carpet. The FAST-OR of 8 contiguous strips defines the logical pad whose signal is used for timing and trigger purposes. The high strips density and the $\sim 1\ ns$ time resolution provide a very detailed space-time representation of the shower front [4]. The detector is organized in units of 12 chambers (clusters) that represent a logical subdivision of the apparatus. It consists of 130 clusters in the central carpet. A

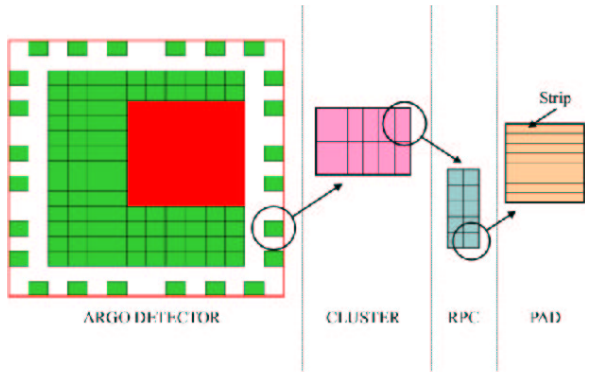

Figure 1. Layout of the ARGO-YBJ detector showing the definition of cluster, RPC, pad and strip.

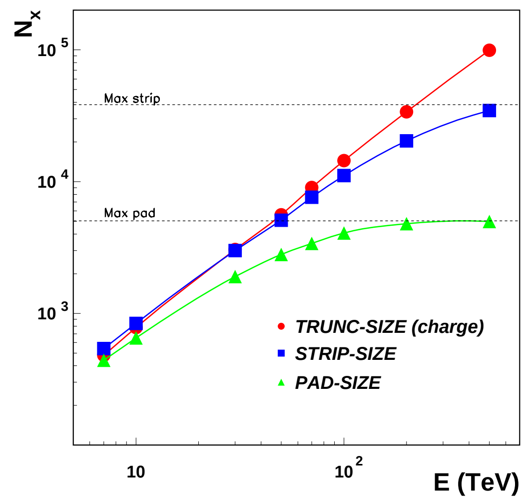

Figure 2. Average strip and pad sizes compared to the total and truncated size for proton-induced air showers.

schematic view of the experimental layout is given in Fig 1. For the time being 78 clusters ($\sim 3500\ m^2$) have been assembled and 42 of them ($\sim 1900\ m^2$) are in data taking since December 2004.

By means of the CORSIKA/QGSjet code [5] matched to the program which simulate the detector response (based on GEANT code), a full MonteCarlo simulation of the 42 cluster performance has been carried out in order to study the energy dependence of the number of fired strips for quasi-vertical showers (zenith angle $\theta \leq 15^o$) with core in the fiducial area $A_f \simeq 260\ m^2$ of the 6 central clusters. The average strip size (N_s) and pad size (N_p) are compared in Fig 2 to the size sampled by the carpet ("truncated size" N_e^{tr} or "charge") for proton-induced air showers. Fig 2 clearly shows that $Log(N_s)$ is a linear function of $Log(E)$ up to $\sim 100\ TeV$ and then starts to "saturate" above this energy. Accordingly, the digital response of the detector can be used to study the primary spectrum up to energies of a few hundreds TeV.

3. Measurement of the strip size spectrum

The current sample of data in the ARGO-YBJ experiment consists of shower events with at least 60 fired pads on the whole detector [6]. The $strip\ size\ spectrum$ has been obtained selecting a subset of quasi-vertical events with core located in the fiducial area (A_f). To select this sample of events the following chain of conditions has been applied:

1) a trigger requiring at least 16 fired pads inside A_f;

2) a filter to reject events with core outside A_f: for each triggered event the cluster with the maximum strip density must be inside A_f;

3) only events with reconstructed core in A_f and zenith angle $\theta \leq 15^o$ have been considered.

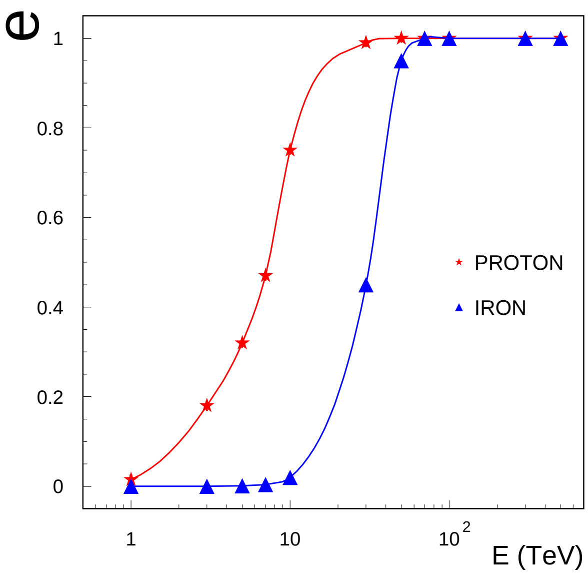

Figure 3. Fraction of triggered and recostructed events with core in the fiducial area for proton- and iron-induced air shower.

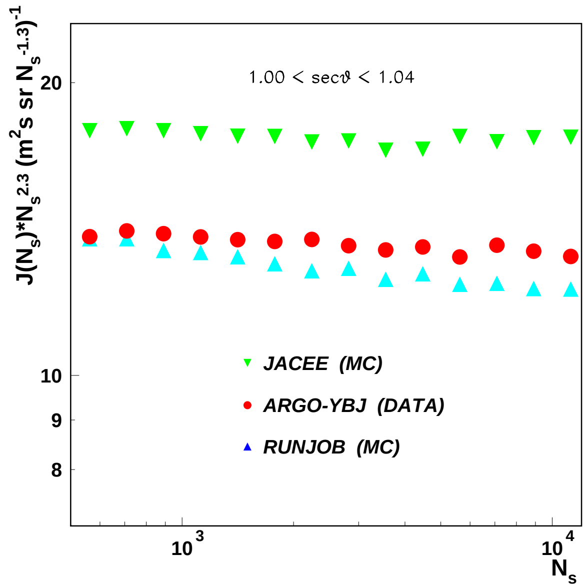

Figure 4. ARGO-YBJ strip size spectrum compared with ones expected according to RUNJOB [7] and JACEE [8] composition models of primary cosmic ray .

The shower core has been reconstructed with the centre of mass method using the pad position and weighting them with the fired strip content, while the arrival direction has been determined with a conical fit to the air shower front.

From a full simulation (CORSIKA/QGSjet + detector response) we note that the above selections give back the right number of triggered events with core in A_f. In particular, due to the limited resolution in the core recostruction, near the border of A_f we observe a loss of internal events compensated by a comparable contamination of external events. The strip multiplicity of the selected events is not significantly modified by this effect. Then the efficiency ε of this selection procedure represents the fraction of events which fulfil the trigger condition.

The efficiency ε versus the primary energy E is shown in Fig 3 for proton- and iron-induced air showers. The energy corresponding to 50% efficiency is ∼7 TeV for proton and ∼30 TeV for iron showers. This result reflects the fact that the iron showers start to have a well defined core at larger primary energies than proton showers.

The strip size spectrum, reported in the form:

$$F(N_s) \equiv \frac{dN_{evt}}{dN_s} \cdot N_s^{2.3} \equiv J(N_s) \cdot {N_s}^{2.3} \qquad [m^2 ssr N_s^{-1.3}]^{-1} \tag{1}$$

is shown in Fig 4. It has been obtained "filtering" a sample of $\sim 50 \cdot 10^6$ events collected in about 100 hours of data taking.

In the same figure we report the strip size spectra as expected according to RUNJOB [7] and JACEE [8] composition models of primary cosmic rays. These models include the proton and helium energy spectra as given by the authors and the energy spectra of the CNO, NeMgSi, Fe groups as obtained fitting their data

[7, 2]. To get these strip size spectra we have used CORSIKA/QGSjet code to generate showers according to the composition models. Then, these data have been processed to take into account the detector response and the selection criteria. Finally, the simulated spectra as well as the experimental one have been corrected for trigger efficiency.

We point out that the actual number of fired strips depends on the RPC efficiency and the strip multiplicity which are known with an uncertainty of 1% and 5% respectively, Thus, the simulated spectra of Fig 4 could be affected of a systematic error $\leq 10\%$ [2].

4. Discussion and Conclusions

From the results of Fig 4 we can draw the following conclusions:

i) for the given trigger and the considered geometry, the strip size multiplicity N_s ranges from 600 to 10000. The number of events in each size bin ($\Delta Log(N_s) = 0.1$) is enough to make negligibile the statistical uncertainty.

ii) in this range the RUNJOB composition model predicts a softer spectral index with respect to the JACEE model ($\sim$ 2.34 and $\sim$ 2.31 respectively) while the counting rate expected according to the JACEE model is higher than the one predicted by RUNJOB model, running from $\sim$ 25% at N_s $\sim$1000 up to $\sim$ 35% at N_s $\sim$10000. The ARGO-YBJ spectrum has a spectral index of $\sim$ 2.32 and the flux is closer to that expected from the RUNJOB composition model especially at low multiplicities where the main contribution comes from proton and helium nuclei.

In conclusion, the size strip spectrum measured by a subset of the ARGO-YBJ detector has been compared with the strip size spectra as expected according to RUNJOB and JACEE composition models of primary cosmic rays. This preliminary comparison shows a fair agreement with the data of direct measurements (intensity and spectral slope), the RUNJOB model being favoured in particular at low energies $\leq$50 TeV. In this way ARGO-YBJ does realize, with an unprecedented result for a ground based array, a “bridge” between direct and indiect measurement.

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