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# Feasibility of measurements of cosmic ray composition by means of RPC digital read out in ARGO-YBJ

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**Abstract**

The ARGO-YBJ experiment is currently under construction at the Yangbajing Cosmic Ray Laboratory (4300 m a.s.l.). The detector will cover $74 \times 78\,\mathrm{m}^2$ with a single layer of Resistive Plate Counters (RPCs), surrounded by a partially instrumented guard ring. Signals from each RPC are picked up with 80 read out strips 6.7 cm wide and 62 cm long. The strip read out allows one to count the number of secondary charged particles from air showers induced by cosmic rays with an energy threshold of a few TeV. In this paper, we show that the digital response of the RPC can be used to discriminate between different models concerning the composition of the primary cosmic rays up to an energy of a few hundreds of TeV. In order to extend the dynamical range up to PeV energies, an analog read out has been implemented by instrumenting each RPC with two large size electrodes (Big Pads).



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## 1. Introduction

The energy spectrum of cosmic rays (all particle spectrum) has been observed in a large range ($10^9$–$10^{20}$ eV) with very different techniques. It is well described by a power law ($\mathrm{d}N/\mathrm{d}E \sim E^{-\gamma}$) over several decades of energy, before and after the so called knee region, $10^{15}$–$10^{16}$ eV, where the slope changes from $\approx$2.7 to $\approx$3.1. Due to their low fluxes, primary cosmic rays of energy above $10^{14}$ eV can be studied only indirectly by observing the secondary particles of the atmospheric cascades (Extensive Air Showers, EAS) while at lower energies information on the primary cosmic radiation can be gathered by means of direct measurements (satellite or balloon-borne experiments). The steepening of the size spectrum, observed in EAS data [1], reflects the convolution of the energy spectrum of each primary component. Despite many conjectures its origin is still obscure and therefore it is the subject of many

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speculations concerning the production, acceleration and propagation of galactic cosmic rays [2]. Comparing existing data makes a substantial disagreement evident between the primary cosmic ray composition models provided by different experiments. As an example, the proton spectrum measured by TIBET − AS$\gamma$ [3] changes its slope at an energy ~200 TeV, KASCADE [4] data suggests a steepening at about ~2 PeV while data collected by the balloon-borne experiments, RUNJOB [5] and JACEE [6], do not exhibit any spectral break up to 500 TeV. The ARGO-YBJ experiment offers the possibility to investigate a large energy range from a few TeV up to the knee region by exploiting both the digital and the analog read out of the Resistive Plate Counters (RPCs). In this paper, we show that the digital read out allows us to check different models of primary cosmic rays composition up to hundreds of TeV.

## 2. The ARGO-YBJ detector

The ARGO-YBJ experiment [7], presently under construction at the YangbaJing Cosmic Ray Laboratory (Tibet, 4300 m a.s.l.), consists of a full coverage detector of area $78 \times 74\,\mathrm{m}^2$ realized with a single layer of RPCs of size $125 \times 285\,\mathrm{cm}^2$. This area (central carpet) is surrounded, up to about $100 \times 100\,\mathrm{m}^2$, by a guard ring partially (≈50%) instrumented with RPCs. The proposed layout allows one to achieve a coverage ratio between active and total area of about 92%. The detector is organized in modules of 12 chambers each whose dimensions are $\sim 5.7 \times 7.7\,\mathrm{m}^2$. This group of RPCs (CLUSTER) represents a logical subdivision of the apparatus. The detector consists of 130 CLUSTERs in the central part. Signals from each RPC are picked-up with 80 strips (6.7 cm wide and 62 cm long), for a total of 124,800 in the central carpet. These strips, which represent the space pixels of the detector, are distributed with an average density of $\sim 22\,\mathrm{strips/m}^2$. The FAST-OR of 8 strips defines a logical unit called PAD ($56 \times 62\,\mathrm{cm}^2$): 10 PADs cover each chamber with an average density in the central carpet of $\sim 2.7\,\mathrm{pads/m}^2$. A flexible logic trigger may be used to select events on the basis of PAD multiplicity. A schematic view of the experimental layout is given in Fig. 1. The number of fired strips in the carpet can be used to recover the strip size spectrum while the pads provide the timing information used to reconstruct the direction of the primary cosmic rays.

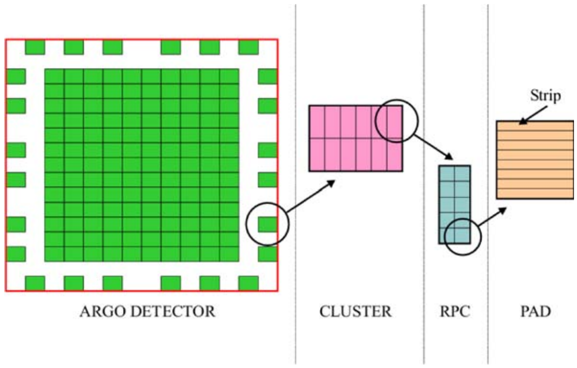


Fig. 1. Schematic view of the ARGO-YBJ detector.

## 3. The digital read out and the strip size spectrum

Simulations have been carried out by means of the CORSIKA/QGSjet code [8] in order to study the energy dependence of the number of fired strips for quasi-vertical showers (zenith angle $\theta < 15°$) with core in a fiducial area $A_\mathrm{f} \sim 260\,\mathrm{m}^2$ at the center of the carpet composed of $2 \times 3$ CLUSTERs. An average strip efficiency of 95% and an average strip multiplicity $m = 1.2$ have been taken into account.

The average strip size $N_\mathrm{s}$ and pad size $N_\mathrm{p}$ are compared in Fig. 2 to the total size $N_\mathrm{e}$ and to the "truncated size" $N_\mathrm{e}^\mathrm{tr}$ sampled by the central carpet for proton-induced air showers. Fig. 2 clearly shows that $\log N_\mathrm{s}$ is a linear function of $\log E$ up to ~100 TeV and "saturates" above 1000 TeV. The point where the strip size deviates from the truncated size defines the saturation energy. Accordingly, the digital response of the RPC can be used to study the primary spectrum up to energies of a few hundreds of TeV. The strip size spectrum is shown in Fig. 3 where we plot for each model of the primary cosmic ray composition (TIBET − AS$\gamma$, KASCADE, JACEE, RUNJOB)

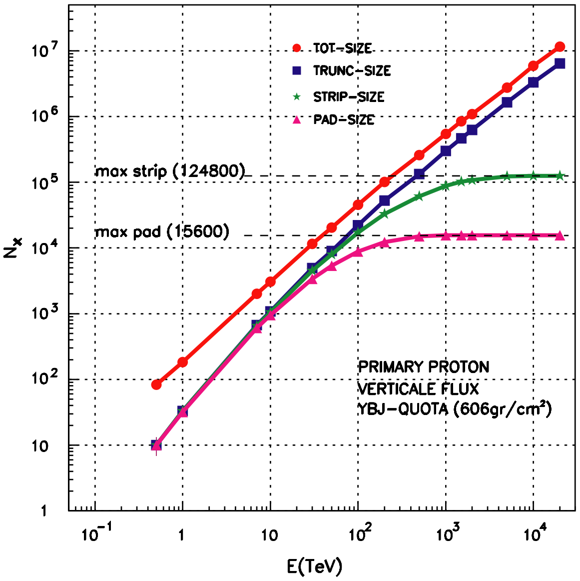


Fig. 2. Average strip size and pad size compared to the total size and truncated size.

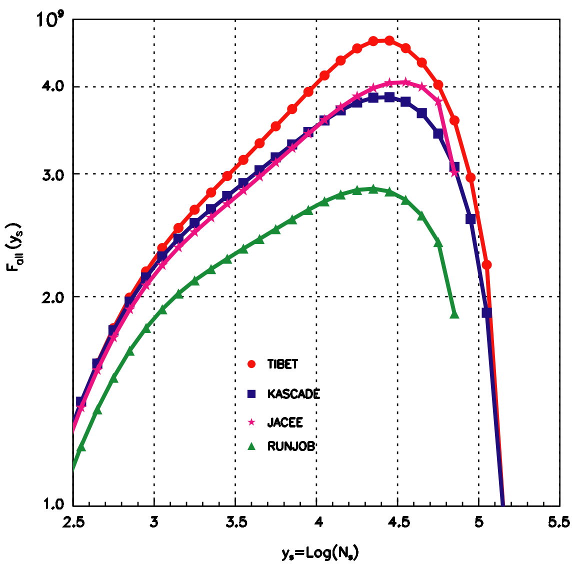


Fig. 3. The strip size spectrum according to different composition models.

the function

$$F_{\mathrm{all}}(y_{\mathrm{s}}) = J_{\mathrm{all}}(y_{\mathrm{s}}) 10^{1.5 y_{\mathrm{s}}} \Gamma \Delta y_{\mathrm{s}} \quad (1)$$

where $y_{\mathrm{s}} = \log N_{\mathrm{s}}$.

This function provides in a simple way the counting rate of collected events, $C_{\mathrm{s}}(y_{\mathrm{s}})$, integrated in the bin $\Delta y_{\mathrm{s}} = 0.1$ for an exposure $\Gamma = 10^8\,\mathrm{m}^2\,\mathrm{s\,sr}$, corresponding to about 1 month of taking data for quasi-vertical showers with core selected in a central area $A_{\mathrm{f}} \sim 260\,\mathrm{m}^2$

$$C_{\mathrm{s}}(y_{\mathrm{s}}) = \frac{F_{\mathrm{all}}(y_{\mathrm{s}})}{10^{1.5 y_{\mathrm{s}}}} \quad (2)$$

and the slope of the strip size spectrum ($J_{\mathrm{all}}(N_{\mathrm{s}}) \propto N_{\mathrm{s}}^{-\alpha_{\mathrm{s}}}$) in the range $y_{\mathrm{s}_1} - y_{\mathrm{s}_2}$,

$$\alpha_{\mathrm{s}} = 2.5 - \frac{\log[F_{\mathrm{all}}(y_{\mathrm{s}_2})/F_{\mathrm{all}}(y_{\mathrm{s}_1})]}{y_{\mathrm{s}_2} - y_{\mathrm{s}_1}}. \quad (3)$$

For RUNJOB and JACEE compositions we considered the extrapolation of data fit in the energy range 1–1000 TeV, while for TIBET – AS$\gamma$ and KASCADE model the range was extended down to 10 TeV.

From Fig. 3 we note that:

1. the strip size spectra pile up beyond $y_{\mathrm{s}} \simeq 4.2$ ($\langle E_{\mathrm{p}} \rangle \simeq 100\,\mathrm{TeV}$, $\langle E_{\mathrm{Fe}} \rangle \simeq 320\,\mathrm{TeV}$), due to the saturation of the digital read out, and fall down below $y_{\mathrm{s}} \simeq 3$ ($\langle E_{\mathrm{p}} \rangle \simeq 10\,\mathrm{TeV}$, $\langle E_{\mathrm{Fe}} \rangle \simeq 40\,\mathrm{TeV}$), owing to a substantial decrease of the trigger efficiency;
2. in the range $y_{\mathrm{s}} = 3$–$4$ the JACEE data and the KASCADE model predict the same strip size spectrum with $\alpha_{\mathrm{s}} \simeq 2.35$. This is mainly due to the fact that in these models the spectrum of the light component (protons and helium nuclei) is quite similar;
3. the largest difference is found between the strip size spectra obtained using the TIBET – AS$\gamma$ and RUNJOB models. The spectral index is $\simeq 2.27$ and $\simeq 2.37$, respectively, and the counting rate expected according to the TIBET – AS$\gamma$ spectrum is higher than the one predicted by the RUNJOB data, the difference increasing from $\sim 30\%$ at $y_{\mathrm{s}} \simeq 3$ to $\sim 55\%$ at $y_{\mathrm{s}} \simeq 4$;
4. the number of events in each size bin is enough to make the statistical uncertainty negligible. On the contrary, any systematic error $\delta N_{\mathrm{s}}/N_{\mathrm{s}}$ in reconstructing the strip size

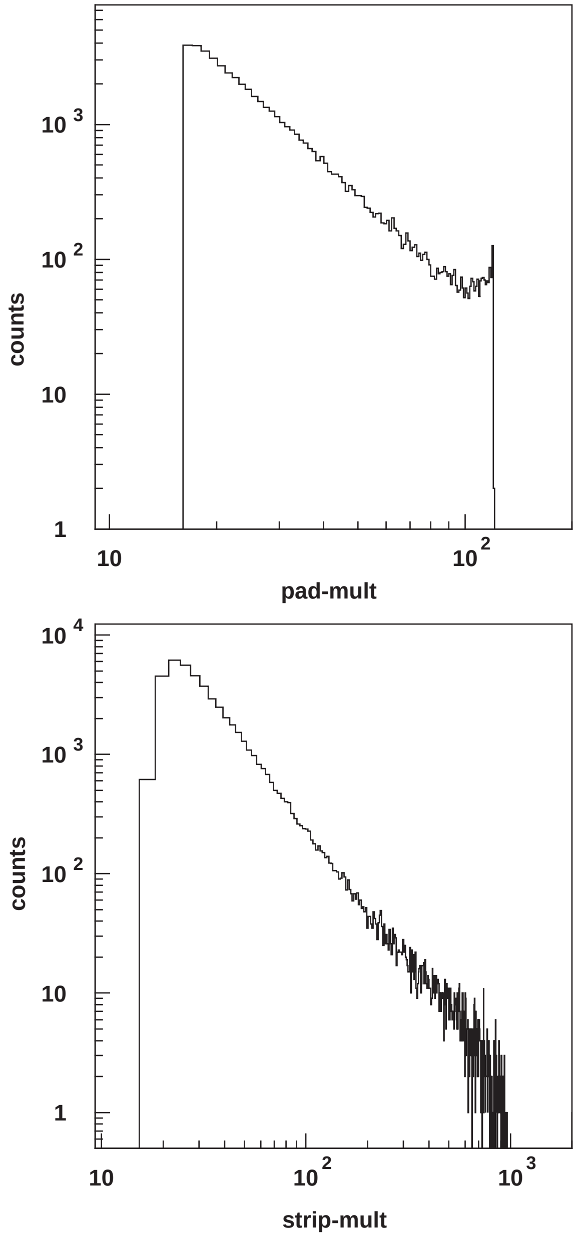


Fig. 4. Distributions of pad(a) and strip(b) multiplicity in one cluster for a trigger condition $N_{\mathrm{trig}} \geqslant 16$.

spectrum determines a shift

$$\Delta F_{\mathrm{all}}/F_{\mathrm{all}} = (\delta N_{\mathrm{s}}/N_{\mathrm{s}} + 1)^{\alpha_{\mathrm{s}}-1} - 1. \tag{4}$$

Thus, a control of the detector performance at a level better than 10% is required in order to reduce any systematic effect below 15%.

It is important to notice that the digital read out of ARGO-YBJ investigated in this paper should allow to scan, in a simple way, the energy range from ~10 to a few hundreds of TeV where direct and indirect measurements partially overlap.

Due to the saturation effect, it is not possible to investigate with the digital read out the size spectrum at higher energies. The saturation effect is visible in Fig. 4, where the pad and strip multiplicity distributions are shown. The data refers to one cluster out of 6 which have been put in data acquisition last year. The trigger condition requires at last 16 fired pads. In the strip multiplicity distribution the saturation effect is, as expected, less evident.

In order to extend the dynamical range, an analog read out has been implemented by instrumenting each RPC with two large size pads each of dimension $140 \times 125\,\mathrm{cm}^2$ ("Big Pad"). These big electrodes represent a powerful tool to investigate high-energy shower induced by primary energy particles up to a few PeV. As shown in Fig. 5, where the lateral distribution density for proton induced air showers is reported, in order to investigate the PeV energy region we need to detect air showers with secondary charged particles density of $\approx 10^3\,\mathrm{particles/m}^2$. An analog read

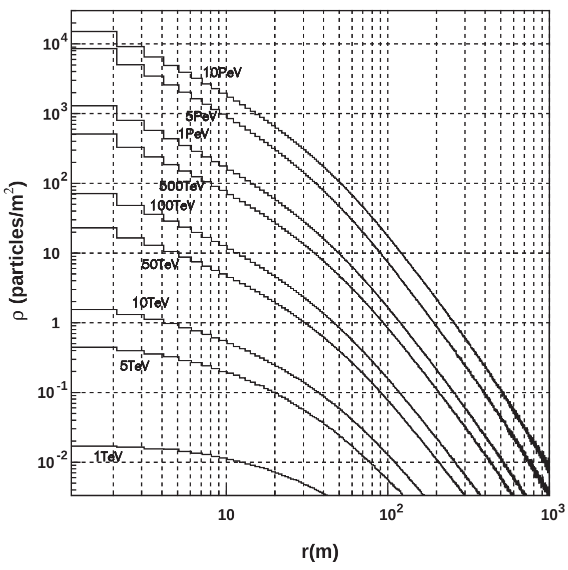


Fig. 5. Lateral density distribution for proton induced air showers at Yangbajing.

out system has been almost completed and we are testing it for optimization using vertical muons and shower trigger. Preliminary results can be found in Ref. [9].

## 4. Conclusions

The use of RPCs in the ARGO-YBJ experiment allows us to investigate a large energy range, namely from a few TeV up to a few PeV using both the digital and analog read out. In this range the direct and indirect measurement partially overlap. Our Monte Carlo simulations show that the pads allow us to measure particles density up to $\sim 1/\mathrm{m}^2$ corresponding to primary energies up to 10 TeV, while the strip read out extends the measurable primary energy range up to a few hundreds of TeV. This digital read out may permit to discriminate between different cosmic ray composition models.

The charge read out of the RPCs is expected to be sensible to particle densities up to $\approx 10^3$ particles/$\mathrm{m}^2$ allowing a further extension of the energy range up to the knee region and beyond.

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