Calibration of the RPC charge readout in the ARGO-YBJ experiment

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***Abstract*. In the ARGO-YBJ experiment, the charge readout is performed on two Big Pads equipped in each RPC to measure the charged particle density of the shower front up to 10^4/m^2, enabling the study of primaries with energies in the "Knee" region. It's the first time for RPCs being used this way. To calibrate the number of charged particles injected on one RPC versus its charge readout, a telescope is setup with RPCs to be calibrated and scintillation detectors to measure the number of injected charged particles. Shower secondary particles are taken as the calibration beam. The telescope was tested at sea level and then moved to ARGO-YBJ site for coincident operation with ARGO-YBJ experiment. The charge readout shows good linearity with the particle density in the dynamic range. Using the data of the ARGO-YBJ experiment, all the Big Pads can be calibrated relatively to that of the RPCs in the telescope, thus the absolute calibration is propagated to the whole array.**

***Keywords*: RPC, charge readout, calibration**

I. Introduction

The ARGO-YBJ experiment, located at Yangbajing Cosmic Ray Observatory (Tibet, P. R. China, 4300 m a.s.l.), is consisted of a full coverage of a single layer of Resistive Plate Chambers (RPCs) operated in streamer mode. Each RPC (2.8×1.25m^2) is read by 80 strips of $6.75{\times}61.8cm^2$, logically organized in 10 independent pads of 55.6×61.8cm^2 (digital readout)[1]. Twelve RPCs are grouped into a so-called cluster (5.7×7.6m^2). The whole detector is composed of 130 clusters in the central carpet and 23 clusters in the guard ring with a total active area of about $6700m^2$.

Due to a strip density of about 22 strips/m^2, the particle density measurement saturates at about 20 particles/m^2, corresponding to a primary energy of 200TeV. In order to extend the dynamic range to PeV region where the knee of the cosmic ray spectrum is located, which requires a measurement of the secondary particle density up to ∼10^4/m^2[2], a charge readout is implemented by instrumenting every RPC with two large size pads of dimension of 140×125cm^2 each, the so-called "Big Pads". The system unit to read out the charge signals is a MINICRATE that has two sections, each one hosting 3 readout cards and 1 Control Board and serving for one Cluster[3][4][5][6].

Using charge readout from Big Pads to measure particle density has never been performed on RPCs. This is the first time for RPCs being used this way in ground-based EAS experiments at high altitude. The behavior of RPC charge readout cannot be foreseen at such a high particle density. For a gaseous detector working at high altitude, a co-site calibration is strongly recommended. In this proceeding, a calibration telescope is described. Preliminary results show good linearity between the particle densities and the corresponding charge readout of RPCs. A reliable method is developed to propagate the absolute calibration to all the RPCs in the array.

II. Experiment setup and Data taking

The key points in this calibration lie on the availability of charged particle beams and the determination of the exact number of charged particles impinging on the RPC to be calibrated. A calibration project was brought forward using the accelerator beams of $DAF\Phi NE$ in Italy. To perform a co-site calibration of the ARGO-YBJ RPCs, a telescope (Fig.1) is setup with 2 scintillation detectors to measure the number of charged particles impinging on them and 5 PRCs. The RPC between the two scintillation detectors (RPC3) acts as the one to be calibrated and the other two (RPC2 and RPC4) provide pad and strip information and can also be used to check the calibration. RPC0 and RPC1 help to pick up coincident events from ARGO-YBJ data. Secondary particles in extensive air showers (EASs) are taken as the calibration beam.

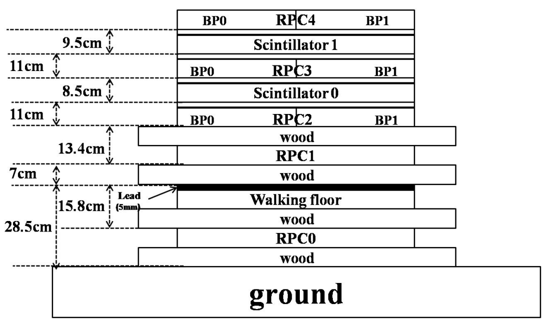

Fig. 1: Sketch map of the calibration telescope. Three RPCs (RPC2, RPC3, RPC4) act as the detectors to be calibrated.

Each scintillation detector with a size of 275cm×125cm consists of 5×11 the so-called tiles, 25cm×25cm×2cm each, covering the dimension of one RPC (the difference is less than 2%, which can be corrected). Lights generated due to energy loss by charged particles in a tile are collected by 8 double cladding fibers glued into grooves at the tile surface. A total of 440 fibers from one scintillation detector is coped with one photomultiplier tube(PMT).

The RPCs are operated at a high voltage of 7200V at YBJ with a gas mixture of Argon(15%), tetrafluoroethane (R134A,75%) and isobutane (10%), with an efficiency of more than 96%.

The digital readouts of all the 5 RPCs in the telescope are merged into the ARGO-YBJ data acquisition system (DAQ) with the telescope acting as a normal cluster. Furthermore dedicated electronics and a DAQ independent of the ARGO-YBJ experiment are designed for the calibration. Signals from Big Pads of RPC2-4 and scintillation detectors are filtered and shaped. Then they are split into two channels with respectively low gain (LG) and high gain (HG) amplifiers, achieving a dynamic range of 3.5 orders of magnitude. Signals from HG/LG amplifiers are digitized by 16 Flash ADCs (FADCs, 10 bits, 50MHz). A Field Programmable Gate Array (FPGA) collects and analyzes the resulting digital data from FADCs. A channel is fired if the amplitude exceeds the preset threshold. If RPC3 and both scintillation detectors are fired a trigger is generated and the data are pushed into a buffer in the FPGA. An embedded computer polls the buffer through its PC104 bus and transfers the data when valid. On receiving a trigger, a GPS-based timing system will record the event time with a precision of better than 100ns (See Fig.2) for purpose of off-line coincidence with ARGO-YBJ experiment.

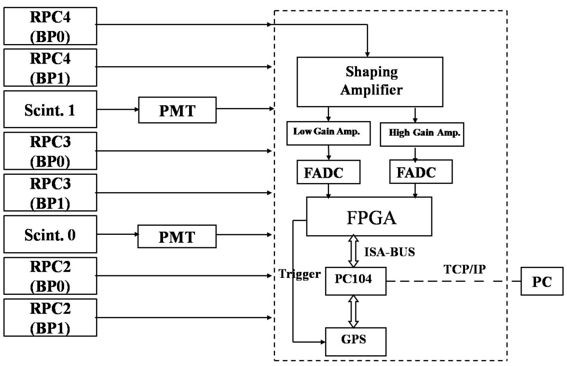

Fig. 2: Schematic diagram of the electronics and DAQ.

The linearities and High Voltage (HV) responses of PMTs and amplifier gains were been calibrated in detail. The HV responses of PMTs show a nonlinearity less than 1% from 350V to 750V (Fig.3). The nonlinearities of PMTs are less than 5% in 2.5 orders of magnitude. The calibration is done in two steps, below 200/m^2 and above 100/m^2, with the PMTs working at different HVs, 500V and 400V respectively, thus covering the whole needed dynamic range which is 4 orders of magnitude.

The telescope was tested and optimized at sea level at IHEP and then moved to Yangbajing, installed in the guard ring in south of the ARGO-YBJ hall, to perform coincident observation of air showers with ARGO-YBJ experiment.

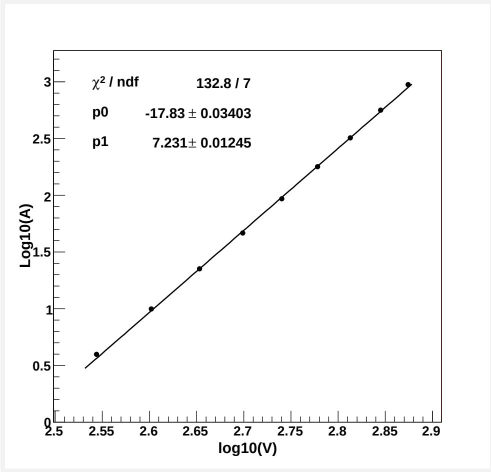

Fig. 3: High Voltage response of one PMT, superposed with a linear fit.

III. Data analysis and Results

A match between the telescope events and the ARGO-YBJ ones in a time window of 1 microsecond are performed off-line basing on the event times. In case of a match, ARGO-YBJ data provide general information of an air shower such as fired pads and strips, reconstructed primary direction and core location, etc. Only matched events are used in the following data analysis. The measured amplitudes of Big Pads and scintillation detectors of the telescope are corrected according to the above mentioned calibration results.

When charged particles pass through a RPC, charges are induced in both Big Pads, i.e. the total induced charges are shared by the two Big Pads. In the following analysis, the charges of the two Big Pads in one RPC are summed as the total charges induced in one RPC.

A. *Amplitude spectra induced by single particles*

Events with only one particle passing through the telescope are picked up by using the pad information (digital readout), i.e. only one pad is fired in each of the 3 RPCs (RPC2, 3, 4). The amplitude distribution of one scintillation detector induced by single particles is shown in Fig.4, which approximately follows a Landau distribution.

The distribution of charge readout of one RPC in case of single particles impinging on it is shown in Fig.5, where the first peak corresponds to cases with only one streamer generated in the gas chamber (single streamer peak), while the tail of the distribution shows that multiple streamers are generated with one particle passing through the gas chamber. The single streamer peak follows a Gaussian distribution and contains about 90% of the total single particle events with a resolution

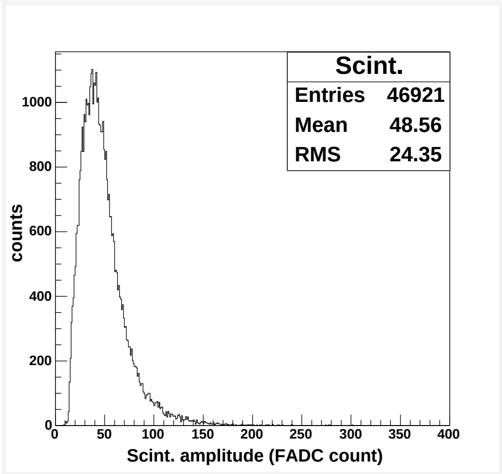

Fig. 4: Amplitude distribution of one scintillation detector in case of single particles (HV=610V).

of about 14%, while the single particle resolution is worse due to the contribution of multiple streamers.

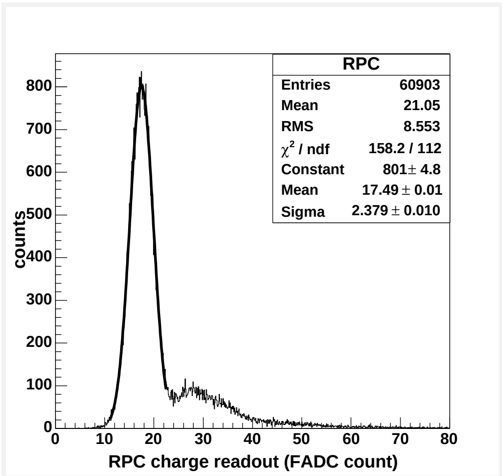

Fig. 5: Charge readout of one RPC in case of single particles. The black curve presents a Gaussian fit to the single streamer peak.

B. Absolute calibration of charge readout of RPC

Since secondary particles in air showers act as the calibration beam, the number of triggered events decreases with secondary particle density. In the analysis the RPC charges are binned with increasing bin width for statistical consideration. For each RPC charge bin, the number of particles is predicted from the scintillation amplitude distribution of events falling in the bin. Since particle densities less than 20/m^2 are covered by digital readout, this calibration focuses on higher particle density region ($> 20/m^2$). When n ($n > 20$) charged particles imping on the scintillation detector, according to the Central Limit Theorem, its amplitude distribution well follows a Gaussian one with the mean μ and variation being $n\mu_0$ and $\sqrt{n}\sigma_0$ respectively, where μ_0 and σ_0 are respectively the mean value and RMS of the single particle amplitude distribution of scintillation detector. So the number of particles can be calculated as:

$$n = \frac{\mu}{\mu_0} \tag{1}$$

with the error estimated as:

$$\sigma_n = \frac{\sqrt{\sigma^2 - n\sigma_0^2}}{\mu_0\sqrt{N}} \tag{2}$$

where σ represents the RMS of the scintillation amplitude distribution, and N is the number of events in this bin.

With data acquired in about 10 days the calibration reached a particle density of about 200particles$/m^2$ with errors less than 3% (Fig.6) and a nonlinearity of less than 5%(Fig.7). From Fig.6 one can read (the reversal of the slope) that the average charge readout induced by one particle is 21.3 FADC counts, which is consistent with the mean value of the RPC single particle spectrum (Fig.5).

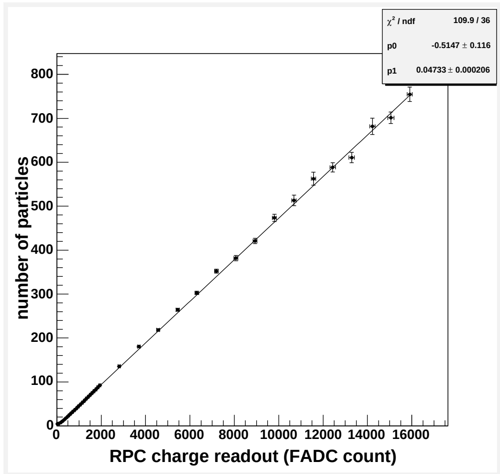

Fig. 6: Number of charged particles VS. RPC charge readout, a linear fit is performed to the data.

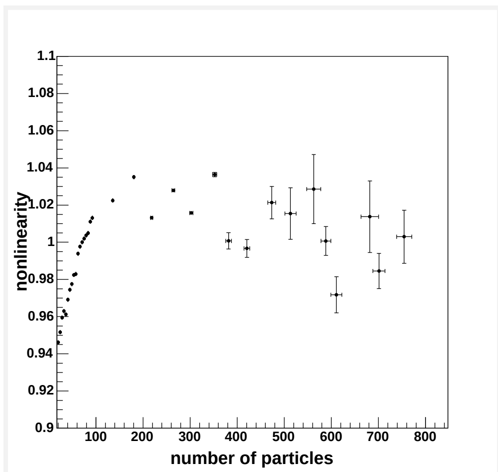

Fig. 7: Nonlinearity of the calibration.

As the first step of the calibration, the dynamic range below $200/m^2$ is considered. At higher particle densities the statistic is still poor due to the dead time of the telescope DAQ caused by the high trigger rate of low particle density events. In the next step, the single channel thresholds will be increased to decrease the event rate thus decreasing the dead time. That promises the needed statistic at high particle densities.

It should be pointed out that some secondary particles with low energy may stop before reaching RPC3. Furthermore for high particle density events, i.e. events with high primary energies, there exist abundant high energy secondary particles that have a chance to shower when traversing the telescope, generating more particles. The number of particles traversing RPC3 might be slightly different from that measured by either scintillation detector. Since RPC3 is sandwiched between the two scintillation detectors, the average over the measurements of the two scintillation detectors can be a better estimate to the number of particles traversing RPC3. Works on that is still undergoing.

C. Calibration propagation to the whole array

The absolutely calibrated RPC provides an absolute calibration scale to the 1836 RPCs in the ARGO-YBJ array. Basing on the axial symmetry of the shower lateral distribution, the uniformity of the RPCs in the array can be retrieved by using ARGO-YBJ shower data, thus propagating the calibration scale to the whole array.

For each air shower event j, the particle density ρ_i^j measured by RPC i at a distance r to the shower core is compared with the average $< \rho_r^j >$ of that over all the RPCs at the same distance r to the shower core by defining a ratio R_i^j as:

$$R_i^j = \frac{\rho_i^j}{< \rho_r^j >}. \tag{3}$$

Due to the axial symmetry of the shower lateral distribution, R_i^j should have an expected mean value of 1 if the set of RPCs at r is relatively consistent. With N events whose cores randomly distributed in the whole array, RPC i is compared relatively with different sets of RPCs and a mean value of R_i^j can be achieved for RPC i:

$$R_i = \frac{1}{N} \sum_{j=1}^{N} R_i^j. \tag{4}$$

With N large enough, the resulting set $\{R_i\}$ represents the uniformity of all the RPCs in the array. The absolute calibration scale can be propagated to the whole array by using the uniformity of a RPC absolutely calibrated.

A Monte Carlo simulation driven by Corsika [7] is carried out to test the above method. A total of 31500 proton showers is generated with primary energies in 100TeV-1PeV, zenith angles in $0 - 45^o$ and azimuth angles in $0 - 360^o$, The shower core is uniformly thrown in the ARGO-YBJ array. With fully consistent RPCs, the resulting uniformities follow a Gaussian distribution with a mean value of 1 and a width of 0.01. With a preset uniformity randomly picked in 0.9-1.1 for each RPC, the resulting uniformities are compared with the preset ones. The width of the difference distribution is 0.02. Monte Carlo simulation results show high reliability of the method. Using the method on ARGO-YBJ data in 2007 indicates that the non-uniformity is less than 14%.

IV. Conclusion and discussion

A telescope is setup inside the ARGO-YBJ array to absolutely calibrate the RPC charge readout by coincident measurement of air showers with the ARGO-YBJ experiment. The nonlinearity of RPC charge readout versus the number of charged particles (up to 200/m^2) passing through the RPC is less than 5%. The calibration up to 10,000/m^2 will be done when more data are available. Injection angle effect on the scintillation detector will be corrected by using the primary direction reconstructed from ARGO-YBJ data. A method is developed to propagate the absolute calibration scale to the whole array. Four more telescopes will be installed in the ARGO-YBJ hall for the calibration propagation and cross check.

V. Acknowledgements

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