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Layout and performance of RPCs used in the Argo-YBJ experiment

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Abstract

The layout of the RPCs, used in the Argo-YBJ experiment to image with a high space-time granularity the atmospheric shower, is described in this paper. The detector has been assembled to provide both digital and analog informations in order to cover a wide particle

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density range with a time accuracy of 1 ns. The experimental results obtained operating the chambers in streamer mode at sea level with a standard gas mixture are presented.

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Keywords: Gas detector; RPC; Cosmic rays detector

1. Introduction

The use of gas counters with good time resolution for cosmic ray physics has been already pointed out [1]. An RPC [2,3] system allows to cover an active area much larger than other devices to detect Extensive Air Showers (EAS). In this paper the layout of the chambers used in the Argo-YBJ experiment at the YangBaJing Laboratory (Tibet, 4300 a.s.l.) [4] is presented and the performance of the chambers operated in streamer mode by using a standard gas mixture is discussed. The RPCs are known as low noise detector usually operated for triggering and tracking purposes. The layout of the chamber, built for Argo-YBJ, has been optimized for the detection of EAS secondaries, with the following scientific requirements:

1. An extended linearity range in order to measure particle densities from a few to several thousands of particles/m^2 concentrated in a time window of a few nanoseconds. This can be realized by means of a digital information for low multiplicity events (depending on the dimension of the pick-up electrodes) and by means of the analog read-out for high multiplicity events.
2. Low cross-talk between contiguous read-out channels in order to obtain unbiased multiplicity measurements.
3. Accuracy in the time measurement of ~1 ns in order to reconstruct the direction of the primary particle with high angular resolution.

In order to fulfill the above requirements a dedicated chamber has been developed. The measurements presented in this paper have been made at sea level. The chamber layout and the results concerning the digital read-out are discussed. The analog charge read-out of this RPC and its operation at high altitude will be presented in other papers.

2. Chamber layout

In Fig. 1 the chamber layout is shown. Each counter (gas volume) is assembled in a box of $2850 \times 1225 \times 47\,\text{mm}^3$. Two external shaped rigid panels consisting of an Aluminum (200 μm thick) foil, glued on a 1.5 cm foam layer, are used as a protection for the gas volume and to fix the chamber elements. These two panels also realize the Faraday cage for the detector. According to Fig. 1 each chamber consists of the following elements (from bottom to top):

- Rigid panel.
- Copper foil (17 μm thick) glued on a PET foil (190 μm) used for analog read-out of the total induced charge produced in the gas volume (*big pad* in Fig. 1). The copper foil is cut in half in order to obtain two pick-up electrodes of dimension $125 \times 140\,\text{cm}^2$ each.
- 3 mm thick foam layer glued on PET foil (250 μm).
- Gas volume.
- Strip panel.
- Rigid panel.

The two rigid panels which sandwich the elements described above are connected by Aluminum "L" shaped sections. The gas volume operating in streamer mode is realized in the factory of the industrial company "General Tecnica" according to a precise assembling protocol carefully monitored by the scientists involved in the experiment. It consists of two Bakelite foils $2850 \times 1125 \times 2\,\text{mm}^3$ with a resistivity $\simeq 5 \times 10^{11}\,\Omega\,\text{cm}$ assembled to form a gas gap 2 mm wide. A grid of cylindrical spacers (1 cm diameter, with pitch of 10 cm) is used to guarantee that the gas volume planes are flat. The strip panel consists of a sandwich of the following elements, glued each other:

- A 17 μm copper foil glued on a 190 μm PET foil. This copper foil, faced to the gas volume, is cut into 80 strips of width 6.75 cm and length 61.8 cm as shown in Fig. 2.

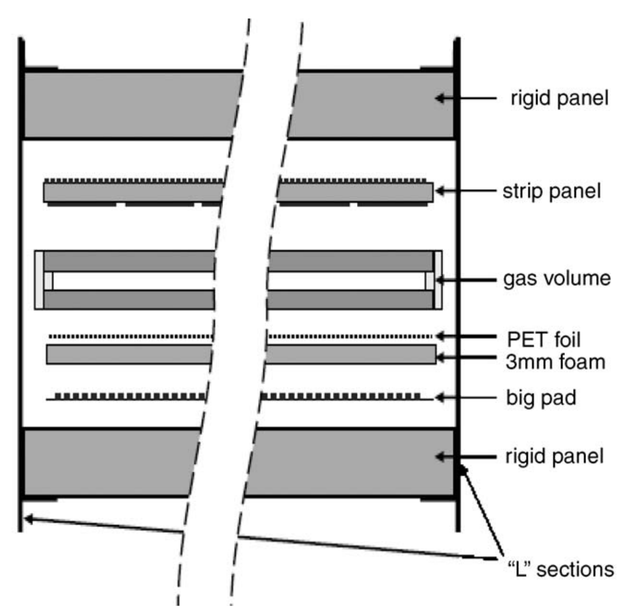

Fig. 1. Cross-view of the Argo-YBJ chamber.

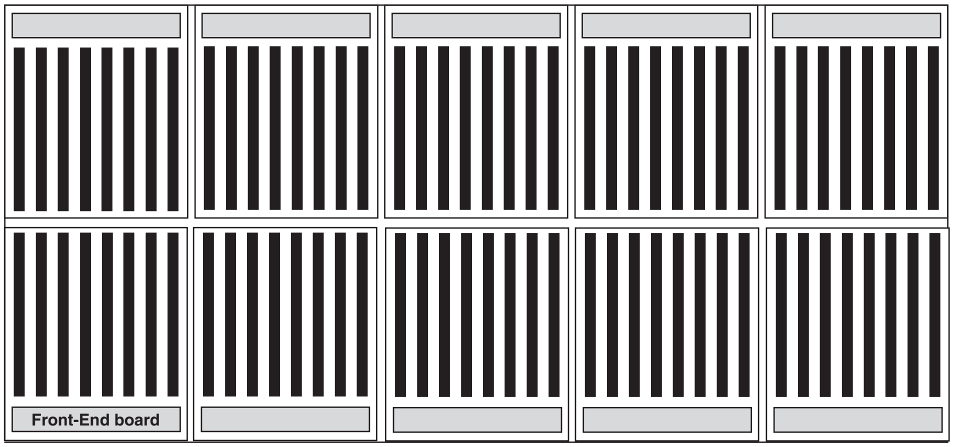

Fig. 2. Sketch of the strip panel used for read-out of the RPC.

In the same figure the electronic boards connected to the edge of each strip are also shown.

- A 3 mm foam layer.
- A 17 μm copper foil, glued on a 50 μm PET foil. This copper foil is used as reference ground for the picked-up signals.

Eight contiguous strips form a logical *pad* ($55.6 \times 61.8\,\mathrm{cm}^2$); the OR of these strips is used for triggering purposes and produces the time signal to be measured by the TDC. As a result the output of each chamber consists of:

- A digital read-out from the pads with space granularity ($55.6 \times 61.8\,\mathrm{cm}^2$), used for timing and triggering.
- A pattern of fired strips which allows one to count the number of particles for low density events.
- An analog read-out with charge information collected by two big-pads $125 \times 140\,\mathrm{cm}^2$.

We note that since the average strip density is about $22\,\mathrm{strips/m}^2$, the digital read-out will have good linearity at least up to a particle density of $10\,\mathrm{particles/m}^2$.

3. Digital read-out

The front-end electronics (Fig. 3) is based on the GaAs custom chip [5], which consists of eight discriminator channels, each with an output of single-ended ECL level. The output is a shaped signal, 6 ns wide and connected in AC mode to a receiver system via flat cable. This scheme allows for a very low power consumption ($\simeq 25$ mW per channel). The threshold of each channel is adjustable in the range 10–30 mV. Since the chamber, operated in streamer mode, produces a total charge of $\simeq 1$ nC per streamer, very high energy events, where 10^3 particles or more strike on a single strip, can induce, at the input of the front-end, a signal even larger than 1 kV. As a protection, two zener diodes have therefore been added between the board input and ground. This solution (see Fig. 3), which has been widely tested, is able to protect the front-end electronics up to $\simeq 8$ kV large input signals. The High Voltage (HV) and Low Voltage (LV) distributions, together with the grounding connections, are shown in Fig. 4. The HV is decoupled from the ground system by a $5\,\mathrm{k}\Omega$ resistor, while the LV consists of a floating and linear power supply in order to minimize the electronic noise. This kind of scheme reduces

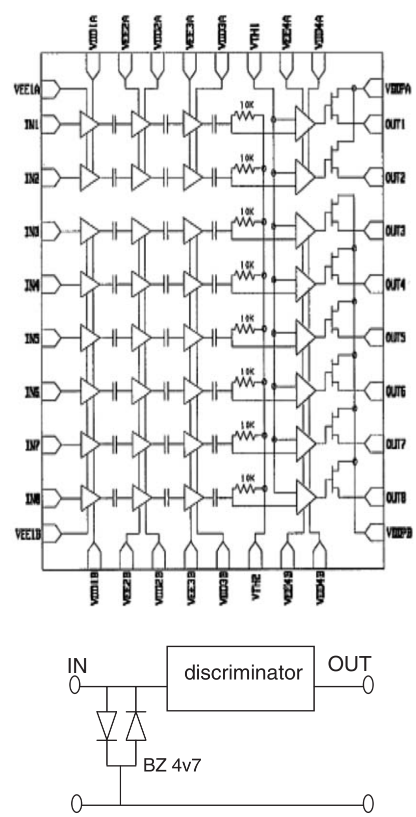

Fig. 3. Block diagram of the front-end chip (top) with eight analog input channels (IN1–IN8) and eight digital output (OUT1–OUT8) and scheme of the ESD protection mounted on the front-end board (bottom).

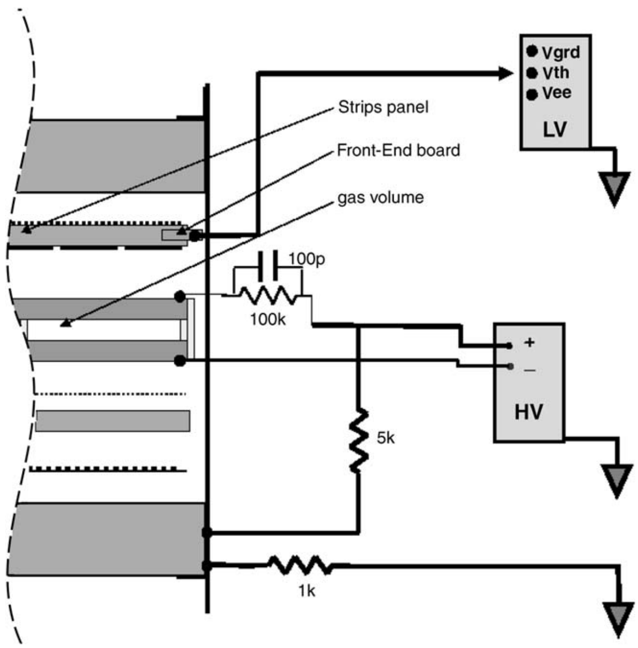

Fig. 4. Diagram of High Voltage, Low Voltage and grounding connections.

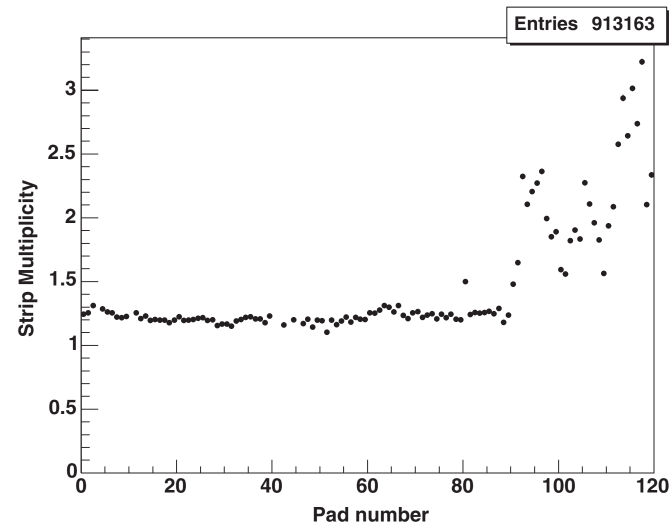

Fig. 6. Strip multiplicity obtained with the Argo-YBJ chambers crossed by EAS particles. The multiplicity values for pad numbers 1–90 refer to 9 RPCs with 3 mm foam layer, while those obtained for pads from 91 to 120 are measured with three RPCs without the 3 mm foam layer.

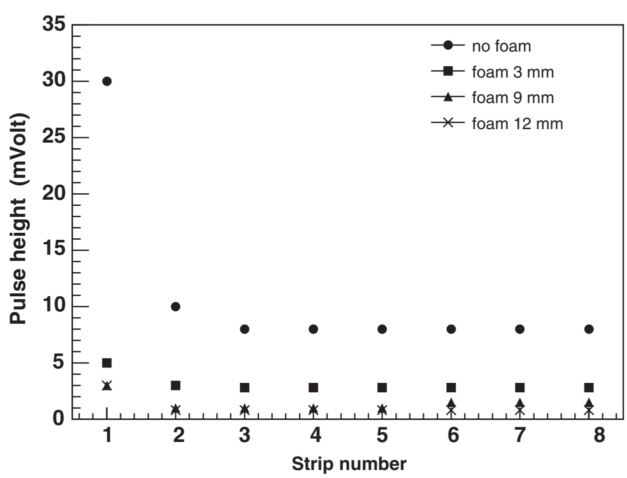

Fig. 5. Pulse height of the signal on the strips contiguous to that crossed by EAS particles for different distances between the strip panel and the ground plane.

the noise produced by the external switching power systems and therefore improves the analog read-out capability. In order to perform unbiased measurements of particle density in EAS, special care must be taken to minimize cross-talk effects. A 3 mm foam layer has been inserted in the layout, as shown in Fig. 1, to reduce the cross-talk between contiguous strips to a negligible amount, leaving unchanged the RPC performance. The cross-talk effect in fact has been found to be rather strongly dependent on the distance between the strip panel and the ground plane (bottom rigid panel shown in Fig. 1). In Fig. 5 the signal pulse height, as registered in the eight strips contiguous to the fired one, is shown for different values of thickness of the foam inserted between the strip panel and the ground plane. Adding to the gas volume (6 mm thick by itself) a layer of 3 mm thick foam, reduces the cross talk to the requirements as it is clearly shown in Fig. 6. The graph shows the strip multiplicity measured on pads for RPCs exposed to air showers with and without the foam layer. Showers with particle density in the range 0.3–15 particles/m^2 have been selected. The distribution of the strip multiplicity obtained, with the 3 mm foam layer, as shown in Fig. 6 is quite narrow and is found in fine agreement with the Monte Carlo prediction (1.22 ± 0.03).

The front-end electronics has two tuning parameters: V_{ee} and V_{th}. The V_{ee} voltage provides the power level and the main reference threshold, while the V_{th} voltage allows one to adjust the threshold. Accordingly, the effective threshold for the streamer signals depends on both V_{ee} and V_{th} and is about 15 mV. Extensive measurements have shown that stable working conditions are reached by setting $V_{ee} = 6.0\,V$ and $V_{th} = 2.0\,V$. The performance of the RPCs is not affected by variations of $\pm 10\%$ on V_{ee} and $\pm 60\%$ on V_{th} with respect to these setting values.

4. Chamber performance

The chamber efficiency and time resolution have been measured at sea level with a telescope (see Fig. 7) realized by three scintillation counters and two RPCs of the type described in the previous sections. The coincidence of the three scintillators and the RPC2 defines the trigger signal used as a common stop for the TDC board. The efficiency has been measured on RPC1, the time resolution is

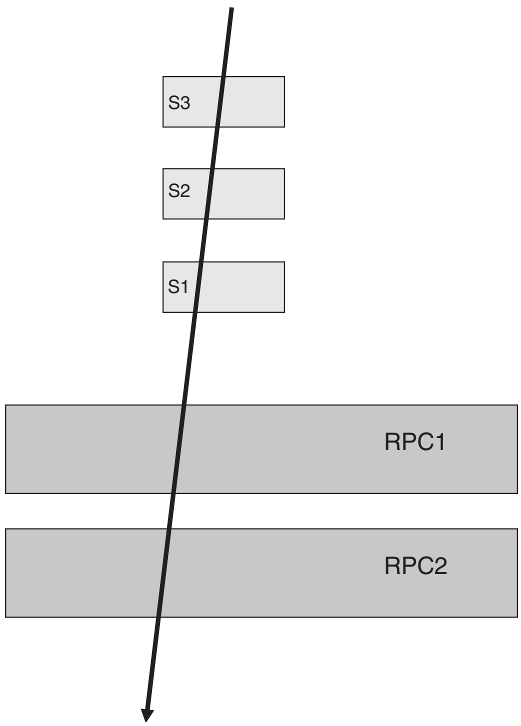

Fig. 7. Sketch of the telescope used to measure efficiency and time resolution of the RPCs.

obtained by the distribution of the flight time between RPC1 and RPC2. The performance of the RPC1 has been measured as a function of the applied HV. All measurements have been carried out operating the RPCs in streamer mode with the standard gas mixture (Argon = 15%; Isobutane = 10%; TetraFluoroEthane = 75%) and have been repeated by using a large sample of RPCs. Our results concerning efficiency and time resolution are shown in Fig. 8. The plot shows an efficiency curve with a well defined and wide plateau starting at ~10 kV ("knee" value). The efficiency measured in the plateau region is greater than 97%, very close to the value expected from the geometrical acceptance, while the time resolution obtained is $\simeq 1$ ns at a high voltage of ~500 V greater than the knee value. This high time resolution and the space granularity of the digital read-out allow for a very detailed image of the shower profile. A good capability of reconstructing the primary particle direction through the shower image is necessary to accomplish the Argo-YBJ design sensitivity to gamma-ray sources. The angular resolution measured with a fraction of the detector operated in 2005 is in fine agreement with the Monte Carlo prediction [6] confirming the results expected from the RPC time resolution presented in this paper.

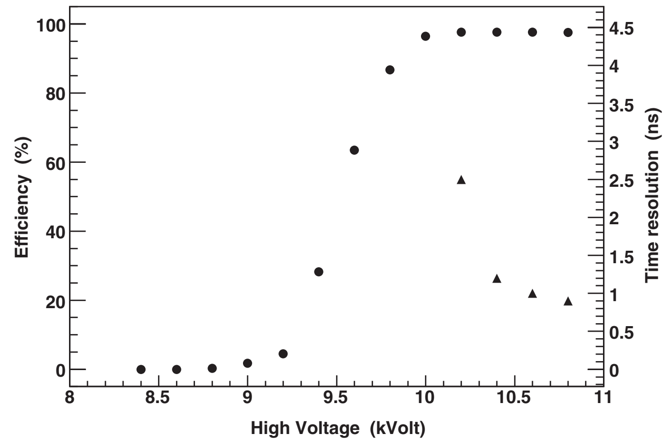

Fig. 8. Efficiency (circles) and time resolution (triangles) of the Argo-YBJ chamber at sea level.

5. Conclusions

RPCs devoted to the detection of air shower particles have been assembled for the Argo-YBJ experiment. These chambers, operated in streamer mode, exhibit high efficiency and excellent time resolution. Both digital and analog read-out have been accomplished in order to perform particle density measurement over a very large range. Special care has been taken to reduce the cross talk effect between contiguous read-out channels in the same chamber. The digital information has been designed to allow for a high granularity imaging of the space-time structure of the shower front. This is confirmed by the very detailed images of the atmospheric showers provided by the Argo-YBJ RPCs carpet [7]. The performance of the Argo-YBJ RPCs presented in this paper accounts for the results of the measurements on the digital read-out performed at sea level. The charge read-out as well as the operation of these RPCs at the YangBaJing altitude (4300 m a.s.l.) will be presented elsewhere.

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