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Technical Note

Test for YBJ-ARGO RPC working in avalanche mode

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Abstract

The measurement of YBJ-ARGO Resistive Plate Chamber (RPC), working in avalanche mode was performed. With different component of i-C_4H_{10} in $C_2H_2F_4$-based gas mixtures $C_2H_2F_4$/i-C_4H_{10}/SF_6, the behavior of the detector with respect to the high voltage was studied. The experiment confirms that it is possible to operate YBJ-ARGO RPC in avalanche mode. The results show that with the gas mixtures containing 10% of i-C_4H_{10} the detector achieves its optimum performance.

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1. Introduction

The YBJ-ARGO experiment is in a mounting and debugging phase at Yangbajing high altitude cosmic ray laboratory (4300 m a.s.l., 606 g/cm^2, longitude 90°31′50″E, latitude 30°06′38″N), 90 km North to Lhasa (Tibet, P.R. China). The aim of the YBJ-ARGO experiment is the study of fundamental issues in cosmic rays and astroparticle physics, including γ-ray astronomy, Gamma-Ray-Bursts (GRBs) physics at an energy threshold of a few hundred GeV. This very low energy threshold is achieved in two ways:

(1) Operating the detector at very high altitude (>4000 m a.s.l.) to increase the size of low energy air showers.
(2) Using a full coverage layer of resistive plate chambers (RPCs) [1] to get a high granularity sampling of small size shower particles [2–4].

RPCs may be operated in avalanche or streamer mode. The avalanche mode corresponds to the generation of a Townsend avalanche, which follows the release of primary charge by the incoming ionizing radiation. In streamer mode, the avalanche is followed by a very large saturated signal which is known as streamer [5,6]. For the fast signal, a tunable signal charge is around few pC in avalanche mode, and is around 100 pC in streamer mode. Due to the capability to work in a large dynamic range and to work efficiently at much higher particle fluxes, RPCs operated in avalanche mode have been widely studied and used in recent years [7–11].

In YBJ-ARGO experiment, RPCs are single gap chambers operated in streamer mode. To extend the dynamic range, the study of the RPCs operated in avalanche mode is of particular interest for YBJ-ARGO experiment.

The purpose of present paper is to study the possibility of operating YBJ-ARGO RPC in avalanche mode, the RPC with the structure that has been conceived to operate in streamer mode. In view of this, we introduced the following issues in the chamber:

(1) Change the gas mixture mainly by introducing a very small fraction, 0.3%, of SF_6, which could prevent the avalanche to streamer transition [8].
(2) Remove the resistive voltage divider in the input of the front-end electronics which had purpose to reduce the large signal produced in streamer operation mode.

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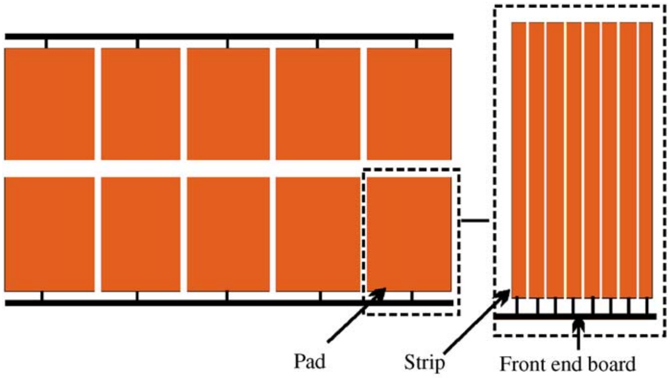

Fig. 1. Layout of the YBJ-ARGO RPC consists of ten PADs. Each PAD is subdivided into eight strips.

(3) Terminate the strip only on the side of the front-end electronics. The opposite side was left open (Fig. 1). Different termination resistances, 12, 15, 20, 27 and 50 Ω were tested; 15 Ω was proved to be the best termination resistance.

The main purpose of the experimental test described in this paper was:

(a) To check that with front-end electronics configuration described in Eq. (3), the chamber could achieve full detection efficiency with a proper choice with the discrimination threshold.
(b) To check that with selected threshold, the chamber could achieve low noise operation.
(c) To test that with a certain amount of i-C_4H_{10} in the investigated gas mixtures $C_2H_2F_4$/i-C_4H_{10}/SF_6, the chamber could get its optimum performance.

2. YBJ-ARGO RPC and test experiment

The YBJ-ARGO RPC is built with volume resistivity of the plate in the range $(0.5–1) \times 10^{12}\,\Omega\,\text{cm}$. It has a 2 mm single gas gap, with an area of $280 \times 112\,\text{cm}^2$. Its readout is made of 80 copper strips, 6.7 cm wide and 62 cm long, glued on a 0.2-mm-thick film of Poly Ethylene-Tereftalate (PET), distributed with an average density of $\sim$22 strip/m^2. Eight strips define a logical unit called PAD with an area of 56 cm × 62 cm. Ten PADs, working like independent functional units, make up a RPC (Fig. 1), with an average density of $\sim$2.7 PAD/m^2. The strip and pad read-out define the space–time pattern of the shower, and give the position and the time of each detected hit (see Refs. [4,12,13]).

This experiment, performed at Rome2 University, INFN section, investigated the possibility of operating YBJ-ARGO RPC in avalanche mode. The gas mixtures were composed of a small percentage of sulphur hexafluoride (SF_6), an addition of i-C_4H_{10}, and a main component $C_2H_2F_4$. SF_6 has high electron negativity, can extend the stream-free operation region and appreciably suppresses the transition to streamer operation mode in the HV region available for avalanche operation mode [8]. i-C_4H_{10} is a quenching gas and can absorb energetic photons. $C_2H_2F_4$ has a moderately high density, i.e. high primary ionization and a low operating voltage and is a component selected in the framework of the search for relatively environmental safe and non-flammable gases that are required by the current safety rules of most laboratories. In addition to these positive safety characteristics, $C_2H_2F_4$ is easy to be found [9].

To meet the requirements in detecting small avalanche signals, besides the changes mentioned above, the detectors were equipped with high-gain amplifiers and low-threshold discriminators.

To investigate the dependence of detector performance on the component of i-C_4H_{10} in $C_2H_2F_4$-based gas mixtures, in the experiment, some parameters that might influence the results were fixed. The component of SF_6 was fixed at 0.3%; the gas flow rate was fixed at four times gas volume per day. The physical threshold of the tested chamber was fixed at 6 mV (corresponds to 1.9 V polarization volts).

3. Results

In this paragraph we report the result of the chamber performance with the difference of i-C_4H_{10} components, 5%, 10%, 15% and 25%. For each gas mixture we studied the single counting rates with high voltage as the main source of information concerning the noise and two fold coincidence counting rates as the main source of information concerning the detection efficiency.

The single counting rates of the OR of ten PADs belonging to the same RPC is shown in Fig. 2 as a function of HV:

(1) Below 9 kV, the single counting rates are essentially zero, the chamber does not produce any signals, which

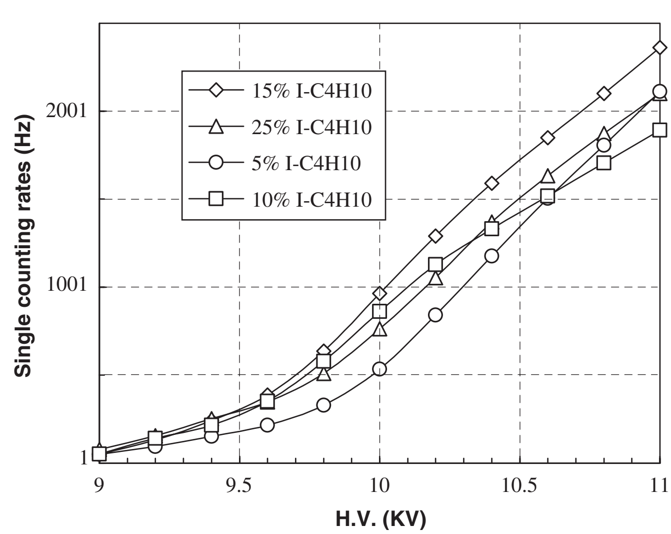

Fig. 2. Single counting rates vs. applied voltage at fixed threshold.

shows that the signals are too small to be tested, and they are almost noise.

(2) From 9 to 10.6 kV, the single counting rates increase greatly and show a modest change of the slope. The change of the slope is caused by the gas-working mode. From 9 to 9.6 kV the chamber works in the ionization region; from 9.6 to 10.2 kV the chamber works in the proportional region; above 10.2 kV, the chamber works in the limited proportional region; around 10.6 kV, the operating voltage corresponds to the knee of the plateau of two-fold coincidence counting rates.

(3) At an operating voltage much above the knee, the single counting rates of the chamber still remain modest. They are around $2000\,Hz/(3.5\,m^2) = 571\,Hz/m^2$.

(4) If we refer to the difference of i-C_4H_{10} components, we see that at above 10.2 kV the slope of the single counting rates vs. HV measured with different gas mixtures does not have the same tendency. With 5% of i-C_4H_{10} the slope is big; with 15% and 25% of i-C_4H_{10} the slopes are of middle values, and with 10% of i-C_4H_{10} the slope is small. This shows that at above 10.2 kV the chamber works in avalanche available region and is more sensitive to the gas mixtures.

(5) With gas mixture $C_2H_2F_4/i$-$C_4H_{10}/SF_6 = 89.7/10/0.3$, the slope of the single counting rates vs. HV changes a lot from below 10.2 kV to above 10.2 kV. At above 10.2 kV it is much smaller than that obtained with the other gas mixtures, but its contribution to the avalanche charge is greater than that obtained with the other gas mixtures (refer to Fig. 3). It implies that with this gas mixture the detector is more efficient.

Comparing with the two-fold coincidence counting rates in Fig. 3, we see that among those investigated gas mixtures the one with highest single counting rates does not have the highest two-fold coincidence counting rates. It suggests that single counting rates contain the information of signals with an amount of noise, i.e. single counting rates play a role in investigating the noise of the RPC. It also suggests that with gas mixture $C_2H_2F_4/i$-$C_4H_{10}/SF_6 = 89.7/10/0.3$ the detector has the smallest noise and has very modest single counting rates.

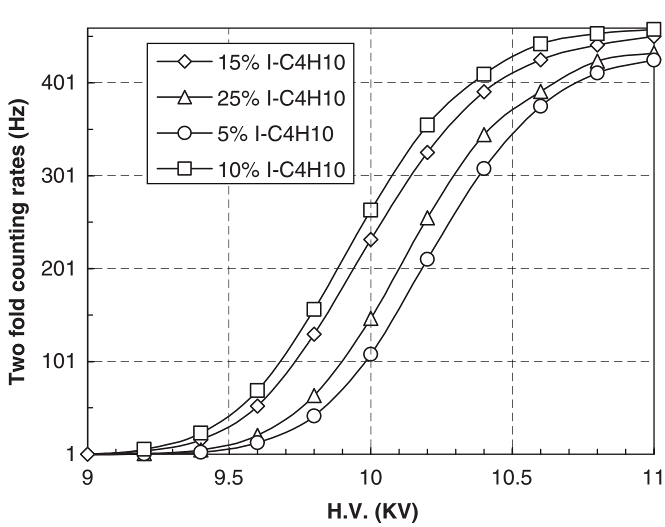

Fig. 3. Two-fold coincidence counting rates vs. applied voltage at fixed threshold and reference chamber.

Table 1
Working voltage vs. i-C_4H_{10} concentration at 50% of the plateau

i-C_4H_{10}	5%	10%	15%	25%
HV (kV)	10.2	9.9	10.0	10.1

Fig. 3 shows the function of two-fold coincidence counting rates vs. HV obtained with four different gas mixtures. The applied working voltage of the reference chamber was fixed at 10.8 kV; the physical threshold of the reference chamber was fixed at 6 mV corresponding to 1.9 V polarization volts. From Fig. 3 we see:

(1) Two-fold coincidence counting rates start to grow at 9.2 kV; zero is at 9.0 kV, just above the point of the single counting rates. The two-fold coincidence counting rates increase regularly and reach plateau around 10.7 kV. The flat behaviour of the two-fold coincidence counting rates above 10.6 kV shows that the chamber reaches its full efficiency for minimum ionizing particles like cosmic ones crossing both chambers.

(2) Two above plots corresponds to about $130\,Hz/m^2$. It is roughly in agreement with the standard cosmic ray flux at sea level.

(3) The operating voltage is not a monotonic function of i-C_4H_{10} concentration. Indeed if we refer to the two-fold coincidence counting rates of 50% of the plateau, in Table 1, we see that the operating voltage decreases by 300 V when i-C_4H_{10} concentration increases from 5% to 10%, and increases by 100 V when i-C_4H_{10} concentration increases from 10% to 25%.

(4) Above 10.6 kV the avalanche plateau appears, it shows that the detector works in full efficiency region, not in low efficiency region; which convinces it is possible to operate YBJ-ARGO RPC in avalanche mode.

Furthermore, among investigated gas mixtures, with 10% of i-C_4H_{10}, the detector has the highest two-fold coincidence counting rates. Since two-fold coincidence counting rates correspond to signal charge, the influence of the two main components, i-C_4H_{10} and $C_2H_2F_4$, comes out clearly. With the gas mixtures containing 10% of i-C_4H_{10} and 89.7% of $C_2H_2F_4$ the detector gets the highest total avalanche charge.

The mechanism that causes the optimum performance of the investigated gas mixtures ($C_2H_2F_4/i$-C_4H_{10}/SF_6) is related to the average behaviour of the avalanche growth, which is governed by the gas first Townsend coefficient and by the attachment coefficient. In order to calculate the avalanche charge inside the chamber for the investigated gas mixtures, we should know exactly the Townsend coefficient and the space charge effects which depend on the numbers of molecules per chamber volume, the gas mixtures; and make an accurate simulation of the discharge development in the investigated gas mixture including the space charge and saturation phenomena. This simulation is beyond the limits of present work. The aim of present work was to study the possibility of operating YBJ-ARGO RPC in avalanche mode. It has been achieved.

4. Conclusions

By using $C_2H_2F_4$-based gas mixture, including i-C_4H_{10} and 0.3% of SF_6, the streamer mode operation has been replaced by the avalanche mode operation. The avalanche plateau of the two-fold coincidence counting rates above 10.6 kV shows that the chamber reaches its full detection efficiency, which confirms that it is possible to operate an YBJ-ARGO RPC in avalanche mode. The results show that with 10% of i-C_4H_{10} in the investigated gas mixtures $C_2H_2F_4$/i-C_4H_{10}/SF_6, the chamber has the lowest noise and the highest avalanche charge, i.e., it achieves its optimum performance.

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