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RPCs for the ATLAS Level-1 muon trigger : Test-beam results

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Abstract

A full-size ($270 \times 90\ cm^2$) and a small-size ($50 \times 50\ cm^2$) RPC trigger tower prototype have been tested at the ATLAS H8 beam facility at CERN. Results on the basic performance of the full-size chambers, operated in avalanche mode, are presented. Dedicated studies have been done on the small-size chambers to measure the collected charge and the streamer probability as a function of the applied voltage and to optimise the front-end amplifier threshold.

Talk presented by Anna Di Ciaccio at the
IV International Workshop on Resistive Plate Chambers
and related Detectors, Napoli,15-16 october 1997.

1. Introduction

To exploit the Large Hadron Collider (LHC) discovery potential, the ATLAS Collaboration[1] has designed a high resolution muon spectrometer, based on three large superconducting air-core toroid magnets, covering the pseudo-rapidity range $|\eta| \leq 2.7$[2]. It is instrumented with stand-alone triggering and momentum measurement capability.

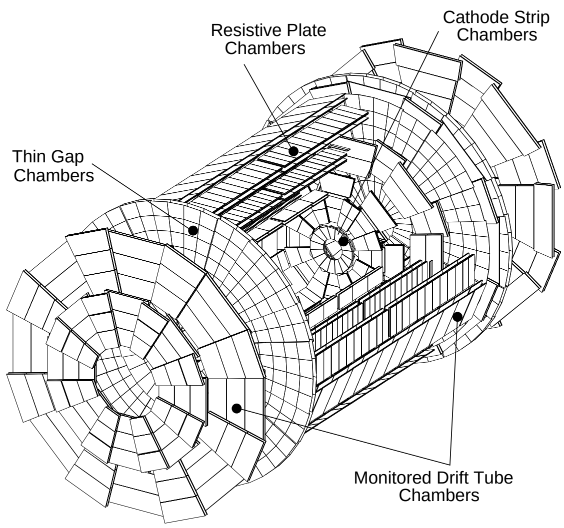

Figure 1: 3-D view of the ATLAS muon system.

High pressure drift tubes (MDTs) in the central region and Cathode Strip Chambers (CSCs) at high rapidity provide a precise measurement of the muon track coordinates in the bending direction. The trigger system consists also of two different technologies: Resistive Plate Chambers (RPCs) in the barrel region and Thin Gap Chambers (TGCs) in the end-cap regions and extends over a total pseudo-rapidity range $|\eta|\leq 2.4$ (see Figure 1).

2. The RPC trigger scheme

The trigger system in the barrel consists of three stations of RPCs: the first two are located on both sides of the middle MDT chambers and provide the low p_t ($p_t \geq 6$ GeV) trigger, the third station is adjacent to the outer MDT chambers. The coincidence of all three stations allows to increase the p_t threshold to 20 GeV. The trigger logic requires three out of four layers in the middle station for the low p_t trigger and in addition, one of the two outer layers for the high p_t trigger (see Figure 2). Due to the high level of low energy particles background, the trigger scheme is implemented in two projections.

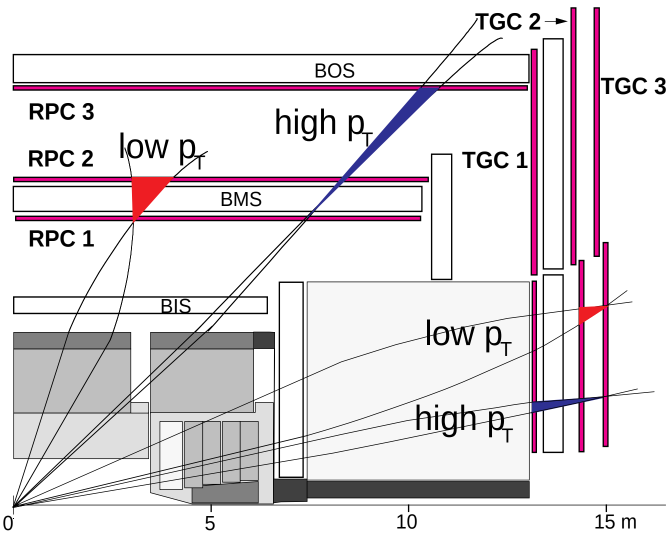

Figure 2: Schematic representation of the triggering scheme.

The ATLAS RPCs chambers cover an area of about 3650 m^2 and extend over a pseudo-rapidity range $|\eta|\leq 1$. The chambers must satisfy three basic requirements:

- bunch-crossing identification (the time between two adjacent bunch-crossings is 25 ns);

- well-defined pt cut-off in moderate magnetic field with a spacial granularity of the order of a cm;
- measurement of the second coordinate in the direction orthogonal to the one measured by the precision chambers with a spacial resolution better than 1 cm.

3. Resistive Plate Chambers

The RPC is a gaseous detectors providing a typical space-time resolution of 1 cm×1 ns with digital read-out. The basic RPC unit is a narrow gas gap (2 mm) formed by two parallel resistive bakelite plates, separated by insulator spacers. The primary ionisation electrons are multiplied into avalanches by a high, uniform electric field of typically 4.5 kV/mm. For avalanche operation a non-flammable and environmentally safe gas, tetrafluoretane ($C_2H_2F_4$) has been used[3].

The signal is read-out via capacitive coupling by metallic strips on both sides of the detector. A trigger chamber is made of two detector units, namely two gas gaps, each one read-out by two orthogonal planes of pick-up strips: the η strips are parallel to the MDTs wire and provide the bending view of the trigger detector; the ϕ strips, orthogonal to the MDTs wires, provide the second coordinate measurements. A scheme of a trigger chamber is shown in Figure 3.

4. RPCs experimental set-up at H8

An intensive program of chamber prototype tests has been carried out in 1996 and 1997 at CERN ATLAS H8 test-beam facility in the SPS North Area. The program was driven mainly by two needs:

- to study the basic features of the detector working in avalanche mode;
- to test the performance of full-size chamber prototypes.

A full-size (270×90 cm^2) and a small-size (50×50 cm^2) trigger tower have been tested with muon and pion beams up to a maximum flux of 900 Hz/cm^2. Both towers consisted of six single-gap RPC chambers, arranged in three stations of two chambers each, like it is foreseen in ATLAS. These chamber doublets were located along the beam line, two at a distance of

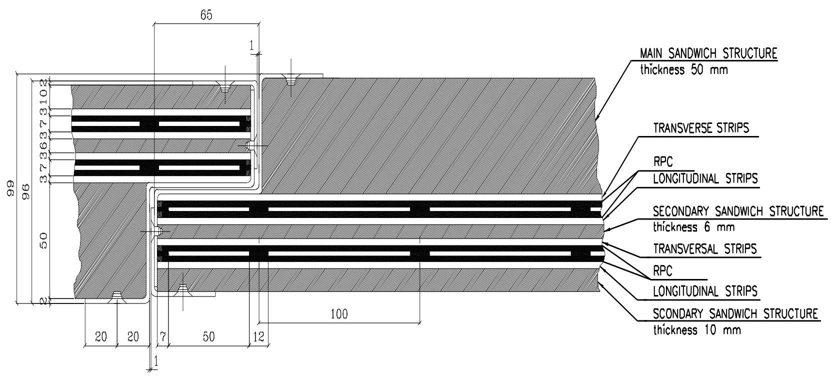

Figure 3: Schematic representation of a trigger station (doublet).

40 cm from each other and the third 200 cm downstream with respect to the second one in order to simulate the low-p_t and high-p_t first-level muon trigger schemes (see Figure 4).

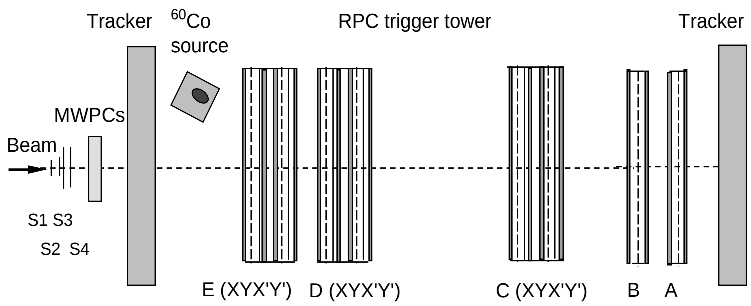

Figure 4: RPC chamber layout in the H8 test-beam facility.

Each gas gap was read out on both sides by 31 mm pitch strips, orthogonal to each other. The front-end electronics consisted of a two-stage voltage amplifier with a gain of about 300 and a bipolar output signal[5]. The amplified strip signals were sent to discriminators with thresholds adjustable between 30 mV and 1 V.

The beam trigger signal was provided by scintillator counters of various dimensions ($2 \times 2, 4 \times 4, 10 \times 10\ cm^2$). A precise and independent reconstruction of the muon tracks along the horizontal direction was obtained in 1996 by means of two trackers, each made out of two matrices of four by four drift tubes, operated in streamer mode[4] and in the 1997 by a BIL MDT prototype: the Calypso chamber[6].

With the aim of simulating the low-energy LHC background conditions, a 14 mCi ^{60}Co source was used to irradiate the upstream RPC with a photon flux producing ∼100 Hz/cm^2 counting rate spread over most of the detector area.

5. Analysis and results of the full-size chambers

The measurement on the full-size chambers concerned the following parameters:

- efficiency;
- time resolution;
- cluster size;
- tracking accuracy.

The chambers were operated with a gas mixture of isobutane (3%) and tetrafluoroetane (97%) at a beam flux of 350 Hz/cm^2 distributed over an area of $10 \times 10\ cm^2$ with the additional flux of the low energy gammas. The amount of isobutane, 3%, was well below the mixture flammability threshold which is about 5.7%. The front-end amplifier threshold was set at 150 mV for all the channels. The discriminator outputs were sent either to input registers for pattern reconstruction or to 1 ns resolution TDCs for time measurements.

In Figure 5 the detection efficiency is plotted as a function of the operating voltage for all the chambers of the three doublets (C, D, E). All chambers reach an efficiency $\geq$ 98% at about 9.0 kV.

The distribution of the time of flight between two RPCs of the tower is shown in Figure 6. From a Gaussian fit of this distribution we extract a $\sigma = 2$ ns, corresponding to a single-layer time resolution of 1.5 ns, well below the 25 ns LHC bunch-crossing time.

Figure 7 shows the average cluster size for the six RPC chambers of the full-size trigger tower (twelve strip planes) at voltages of 8.8, 9.0 and 9.2 kV around the efficiency plateau knee. The average cluster size, namely the number of contiguous hit strips per event, is 1.5 at a voltage of 9.0 kV where the chambers are fully efficient.

Figure 8 shows the distribution of the residuals coming from a straight line fit of all tracks crossing the full-size trigger tower (six RPC chambers in both views). The measured spatial resolution is 6 mm.

6. Results of the small-size chamber tests

A set of 50×50 cm^2 chambers with similar characteristics, was installed at H8 both in 1996 and 1997 to measure the following parameters:

- avalanche charge;
- streamer charge;
- transition from avalanche to streamer and streamer probability;
- rate capability;
- efficiency for different front-end amplifier thresholds;
- response to particles traversing the gas gap at various angles.

The study of the charge distribution is interesting in order to understand the working regime of the RPCs. Increasing the applied voltage, we observe a transition from the avalanche regime to the streamer regime characterised by a much higher collected charge and its almost independence on the primary ionisation.

To study the avalanche and at the same time the streamer-charge distributions, the strips were read out at both ends. The strip signals from one end were directly sent to the input of an ADC module to measure the streamer-charge (it is big enough to require no amplification). The long duration of the gate signal (250 ns) allowed for possible long delays of the streamers. Instead the signals from the opposite end, were first amplified and then sent to a second ADC module for avalanche-charge measurement. The gate signal in this case was only 70 ns, to exclude possible streamer-signals usually occurring at a much later time.

The avalanche-charge distributions are shown in Figure 9 for operating voltages ranging from 8.6 kV to 9.0 kV in steps of 200 V. They were obtained by summing the charge on the strips that had a 3 σ signal above the pedestal. At 8.6 kV the charge distribution shows an exponential shape as expected for proportional mode operation. At 9.0 kV a peak is clearly visible, suggesting saturated avalanche mode operation. The collected charge is about 0.5 pC and is only 1/2 of the signal extracted because the strips are terminated at both ends with their characteristic impedance (25 Ω). The termination is realized by a 50 Ω cable in parallel with a 50 Ω resistor.

The streamer-charge distributions, obtained summing the strip signals without amplification, are plotted in Figure 10 for operating voltages of 9.0, 9.4, 9.6 KV. The streamer charge is about 20 pC, a factor 40 higher than the avalanche-charge and it is basically independent from the applied voltage. From these distributions we have extracted the streamer probability for applied voltages above the plateau knee.

In Figure 11 the efficiency and streamer probability are reported as a function of the operating voltage for a chamber doublet at a beam flux of 500 Hz/cm^2 and for a front-end threshold of 100 mV for the Y strips and 200 mV for the X strips. The data refer to two different gas mixtures, iso-$C_4H_{10}/C_2H_2F_4$, in ratios of 6%/94% and 1.6%/98.4%. For both mixtures the streamers appear at a voltage about 200 V above the efficiency plateau knee.

We have explored two possible ways, the first in a beam and the second with cosmic-rays in our laboratory in Rome, to increase the high voltage plateau before the appearance of streamers:

- working with a lower amplifier threshold;
- searching for a streamer-less gas mixture[8].

To test the first idea the amplified signals were fed into a standard discriminator module with the threshold adjustable from 30 mV to 1 V. Results on RPCs chamber efficiency and average cluster size versus the operating voltage for 30, 60 and 100 mV thresholds are presented in Figure 12 and Figure 13. A 30 mV threshold is corresponding to a charge seen by the detector of only 20 fC. At a lower front-end threshold we observe an increase of the high voltage plateau (i.e. at 30 mV the plateau knee occurs already at 8.6 kV) but the cluster size is too high at 9.0 KV. In fact it has been shown that an average strip cluster width greater than two could seriously affect the selectivity of the trigger[9].

With the purpose of correlating the observed cluster size with the track position, we have reconstructed the muon trajectories using a high spacial resolution detector ($\sigma < 100$ μm), the Calypso chamber[6]. The distribution of the track impact points on a RPC strip plane is presented in Figure 14 for events with cluster size one, two and three and for 30 mV threshold.

The distribution pattern fits the 3 cm strip pitch: events with cluster size two are occurring when the particle hits the detector around the edge of two contiguous strips, while the cluster size is one when the strip is hit around its centre. Events with cluster size three, pretty abundant for the 30 mV threshold, are understood as due to a large induced charge extending over three neighbouring strips.

The comparison of the efficiency at beam fluxes of 500 and 900 Hz/cm^2 over a 10×10 cm^2 area and in presence of a counting rate of ~100 Hz/cm^2 from low energy photons, spread over most of the chamber, is plotted in Figure 15. We conclude that RPCs have a rate capability up to 1 kHz/cm^2 with a threshold as high as 100 mV.

Figure 16 shows the efficiency and the streamer probability for particles entering the gas gap at 30^0, 40^0, 60^0 angles. To account for temperature and pressure variation during the data taking we have normalised the operating voltages to arbitrary defined values for the temperature and pressure (T = 293 K and P=1010 mbar). We can remark that an angle is influencing the efficiency response, but not much the streamer probability, suggesting that a 0^0 angle is less favourable for the avalanche-streamer separation.

7. Conclusions

The analysis of the 1996 and 1997 H8-beam data, in parallel with the work in our laboratory, has provided a better knowledge of the avalanche-working mode of the RPCs. We believe that the actual performance of the detector could insure an efficient ATLAS muon LVL1 trigger at LHC.

The still open question, emerging from these data, of a better separation between the avalanche and the streamer regime in the plateau region, has been solved by very recent laboratory test-results. They show that the addition to the 'standard' gas of 1% of sulphur exaflouride (SF_6) reduces dramatically the streamer formation[10].

8. Acknowledgements

We would like to thank L.Di Stante for the precious help in setting up the RPC chambers.

9. References

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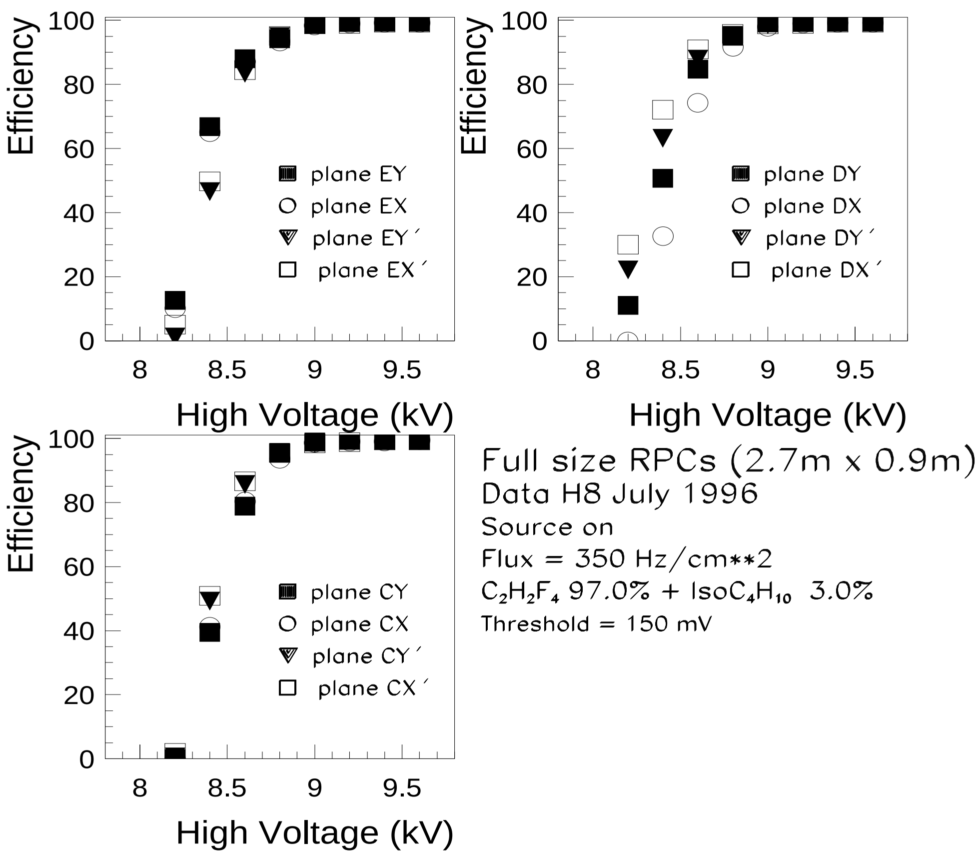

Figure 5: Detection efficiency vs. operating voltage for a full size trigger tower (three chamber doublets).

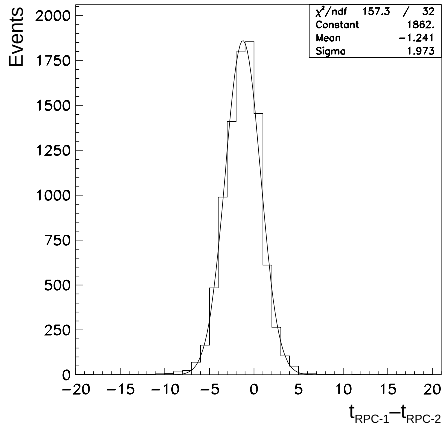

Figure 6: Distribution of time of flight between two RPC chambers.

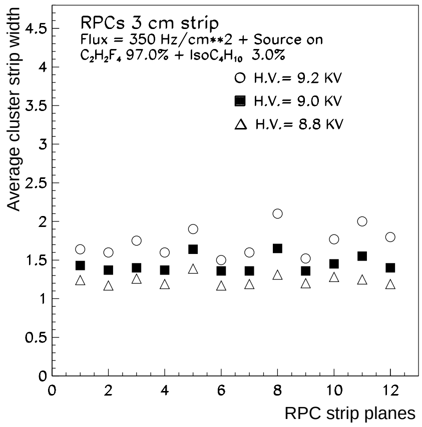

Figure 7: Average cluster size widths for the full size RPCs.

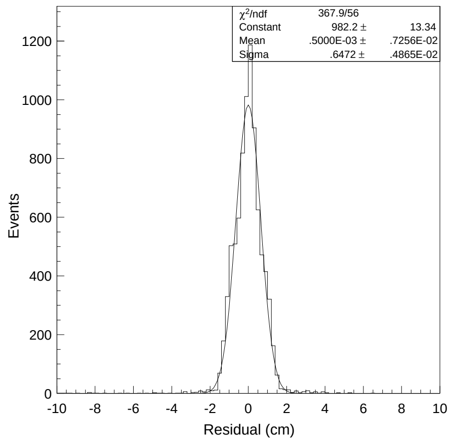

Figure 8: Distribution of RPC residuals with respect to the reconstructed hit positions provided by external trackers.

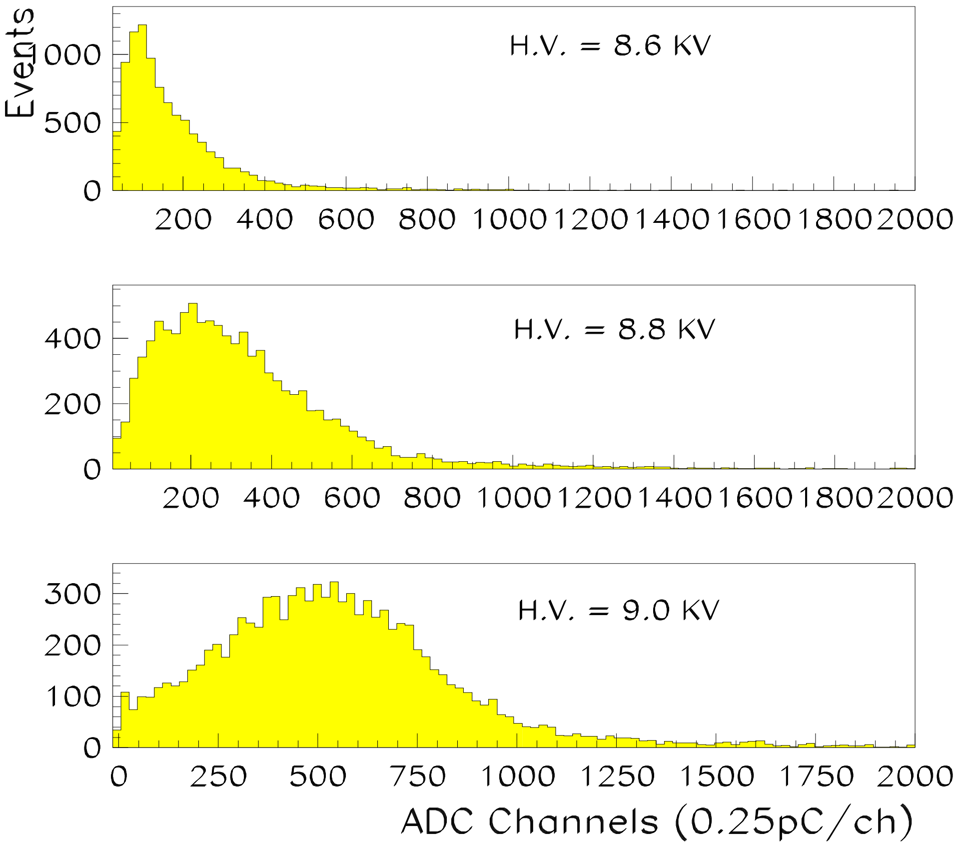

Figure 9: Avalanche charge distributions at various operating voltages around the plateau knee. The distributions are obtained summing the charge on the strips with a signal of 3 σ above the pedestal.

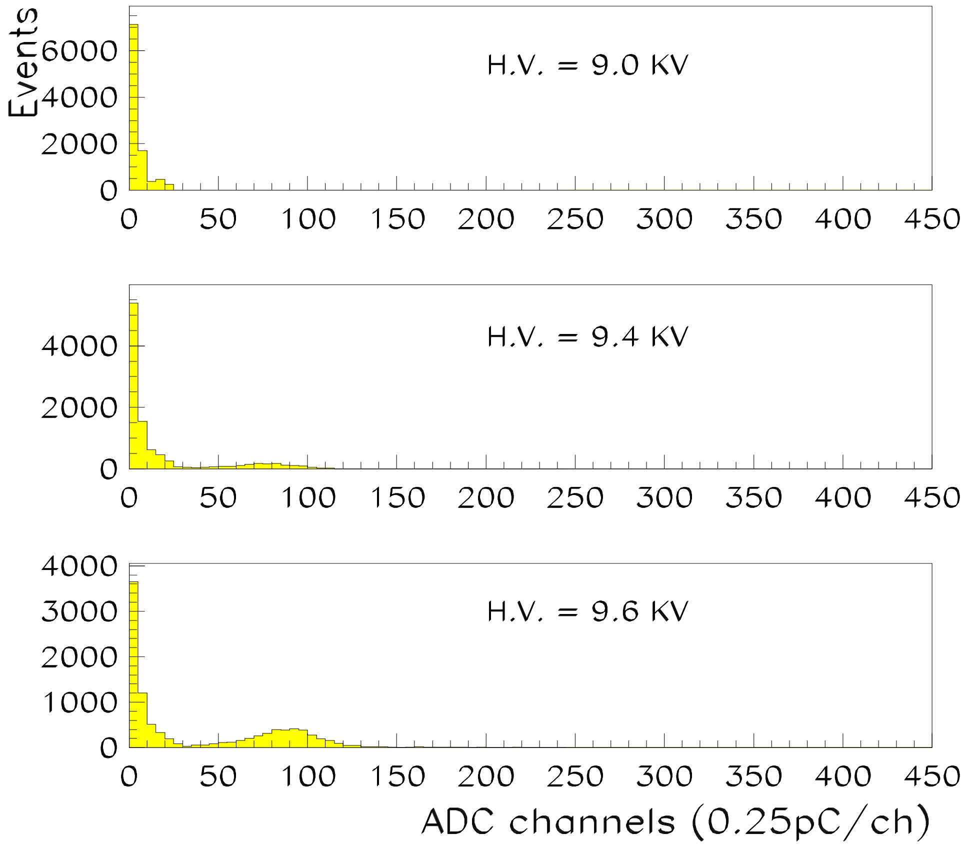

Figure 10: Streamer charge distributions at 9.0, 9.4, 9.6 KV above the plateau knee.

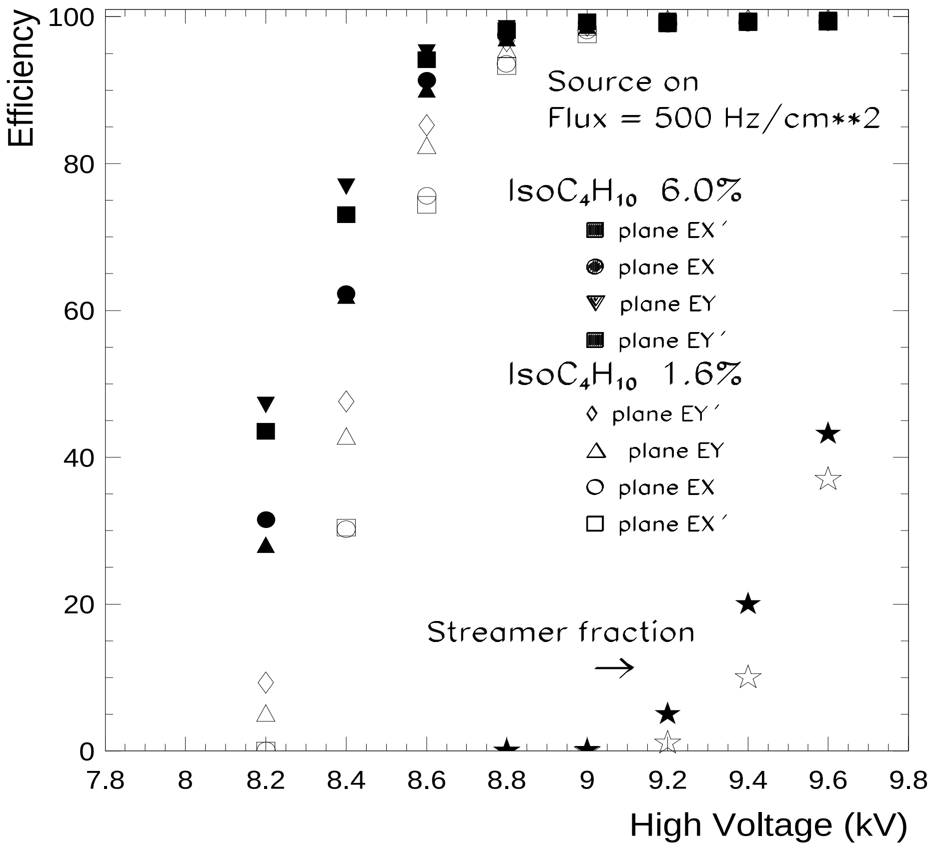

Figure 11: Efficiency curves and streamer probabilities vs. applied voltages for a 50x50 cm^2 doublet. Each doublet consists of four strip planes (X,Y,X',Y'). The closed and open symbols refers to 6% iso-C_4H_{10} and to 1.6% iso-C_4H_{10}.

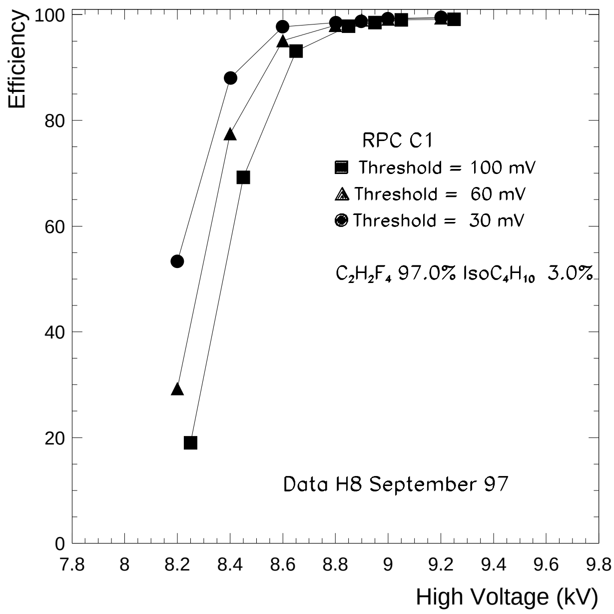

Figure 12: Efficiency curves for 30, 60,100 mV front-end thresholds vs operating voltages.

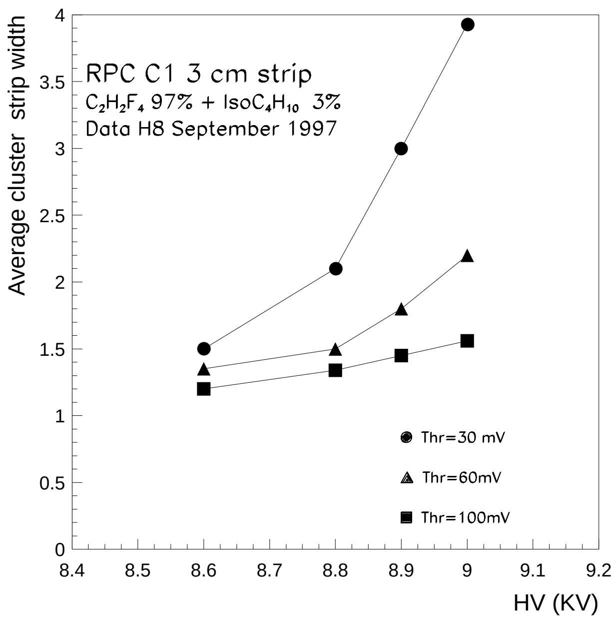

Figure 13: Average cluster size widths vs. operating voltages for 30, 60, 100 mV front-end thresholds.

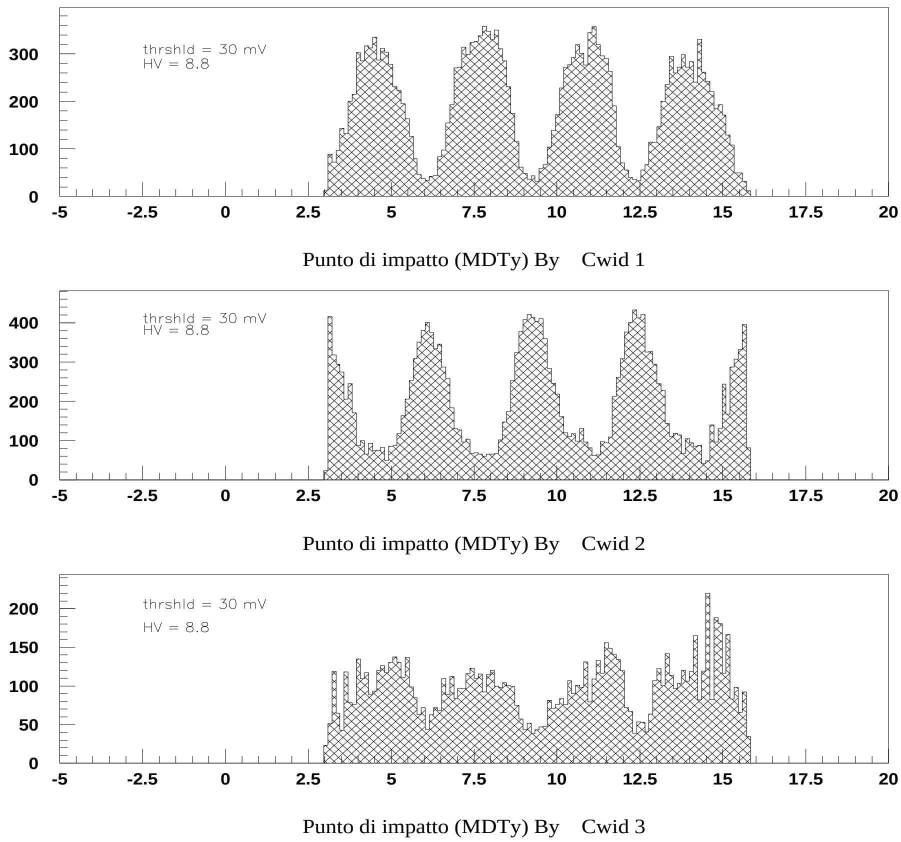

Figure 14: Impact points on a RPC strip plane of the tracks reconstructed with the Calypso chamber for events with cluster size one (top), two (center) and three (bottom).

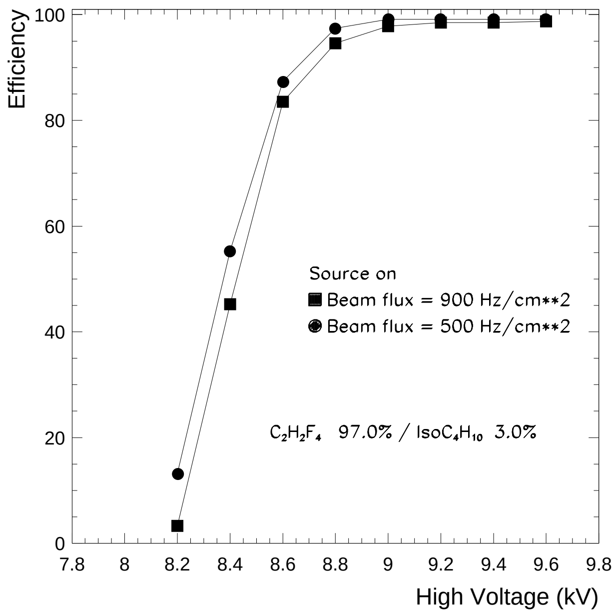

Figure 15: Efficiency curves at beam fluxes of 500 and 900 Hz/cm^2.

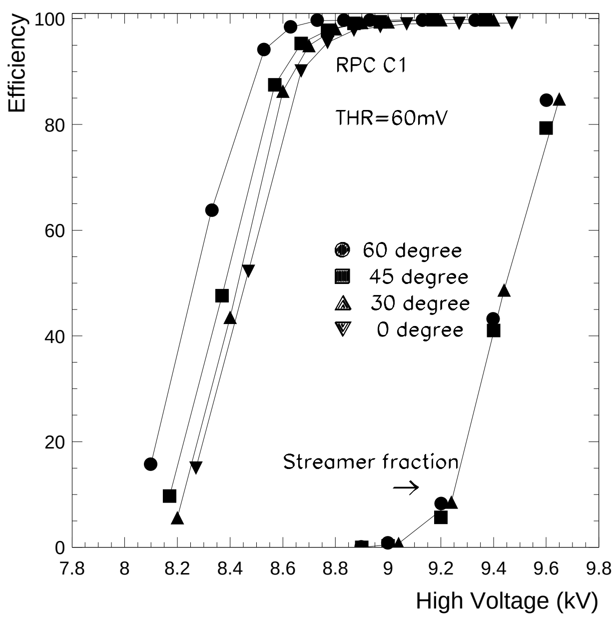

Figure 16: Efficiency curves vs. applied voltage for 0^0, 30^0, 45^0, 60^0 incidence angle to the RPC. The streamer probabilities vs the applied voltages are also plotted.