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STUDY OF SF_6 ADDITION INFLUENCE ON NARROW GAP RPC PERFORMANCE

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Abstract

Ammosov V.V. et al. Study of SF_6 Addition Influence on Narrow Gap RPC Performance: IHEP Preprint 99-53. – Protvino, 1999. – p. 11, figs. 9, tables 1, refs.: 5.

Charge, fired strip multiplicity and arrival time distributions for an induced signal were investigated for the 2 mm gap RPC operating with several tetrafluoroethane ($C_2H_2F_4$) based mixtures with variation of isobutane (iC_4H_{10}) and sulphur hexafluoride (SF_6) concentrations. Suppression of large fast charges for the mixtures containing SF_6 in comparison with the binary $C_2H_2F_4/iC_4H_{10}$ mixture was confirmed. This suppression allows one to have a wide plateau region (≥1 kV) with a small average charge and reduced tail of high charges. Exclusion of isobutane from the mixture with 2% of SF_6 does not change charge distributions.

Аннотация

Аммосов В.В. и др. Изучение влияния добавок SF_6 на работу узкозазорной РПК: Препринт ИФВЭ 99-53. – Протвино, 1999. – 11 с., 9 рис., 1 табл., библиогр.: 5.

Распределения по заряду, множественности сработавших стрипов и времени прибытия для наведенного сигнала были исследованы для РПК с зазором 2 мм, работавшей с различными смесями — с тетрафторэтаном ($C_2H_2F_4$) как основной компонентой и различным содержанием изобутана (iC_4H_{10}) и серного тиохексафторида (SF_6) в ней. Подтверждено подавление больших быстрых зарядов в смесях с SF_6 по сравнению с бинарной $C_2H_2F_4/iC_4H_{10}$ смесью. Это подавление приводит к широкой ($\geq$ 1 кВ) области напряжений, характеризуемой малым средним и подавленнными большими зарядами. Исключение изобутана из смеси с 2%-м содержанием SF_6 не изменяет зарядовых характеристик РПК.

Introduction

A few years ago the Resistive Plate Chambers (RPCs) were proposed as muon trigger detectors work in high rate environment [1,2]. A possibility for high rate RPC operation is mainly defined by the amount of charge produced in a gas gap by the going through charged particle. It is very attractive to have the RPC working mode characterized by the weak gas gain dependence on the applied voltage which can provide approximately the same charge distributions with small average charges and a low probability of large charge appearance in a wide HV plateau range. Small values of the average charge provide a low recovery time and the absence of tail with large charges allows one to reduce a contribution from high pick-up strip multiplicities. It is desirable to have an average charge at a level of a few pC as it is seen for avalanche fraction of charge distributions for the binary tetrafluoroethane (TFE)/isobutane (IB) mixtures in the streamer region [3]. It would be an ideal mode of the RPC operation at high rate environment and we call it a "saturated avalanche" mode.

In the last years intensive attempts were made to find such a mode of the RPC operation. Recently it has been shown that this regime is feasible using the proper gas mixtures [4,5]. It was indicated that the addition of a few percent of sulphur hexafluoride, SF_6, to the binary TFE/IB mixture allowed one to reduce the average fast charge and high charge tail of the charge distribution in the discharge process for a wide plateau region.

Here we attempted to investigate this question with our own approach using several TFE ($C_2H_2F_4$) based mixtures with variation of IB (iC_4H_{10}) and SF_6 concentrations.

1. Experimental set-up

Measurements were made during the December-98 and April-99 runs at the test facility of the IHEP U-70 accelerator in the low momentum (a few GeV) beam of positive particles, mostly hadrons. The experimental set-up is shown on Fig. 1a.

Trigger was worked out by four-fold coincidence of scintillation counters S1-S4 and picked out 1.5(H)×4.0(V) cm^2 area of the tested RPC. The veto scintillation counter V with a 25 mm diameter hole was included in the trigger too. The trigger rate was at a level of 100 triggers/spill with a spill of time about 2 sec. To measure precisely a horizontal coordinate of the triggered particles and to remove analysis multiparticle events in the off-line, the scintillation fiber hodoscope HODO having 10(H)×10(V) cm^2 lateral size and 3 mm fibers, oriented vertically, was used. The test area had high irradiation background at a level of 100 Hz/cm^2.

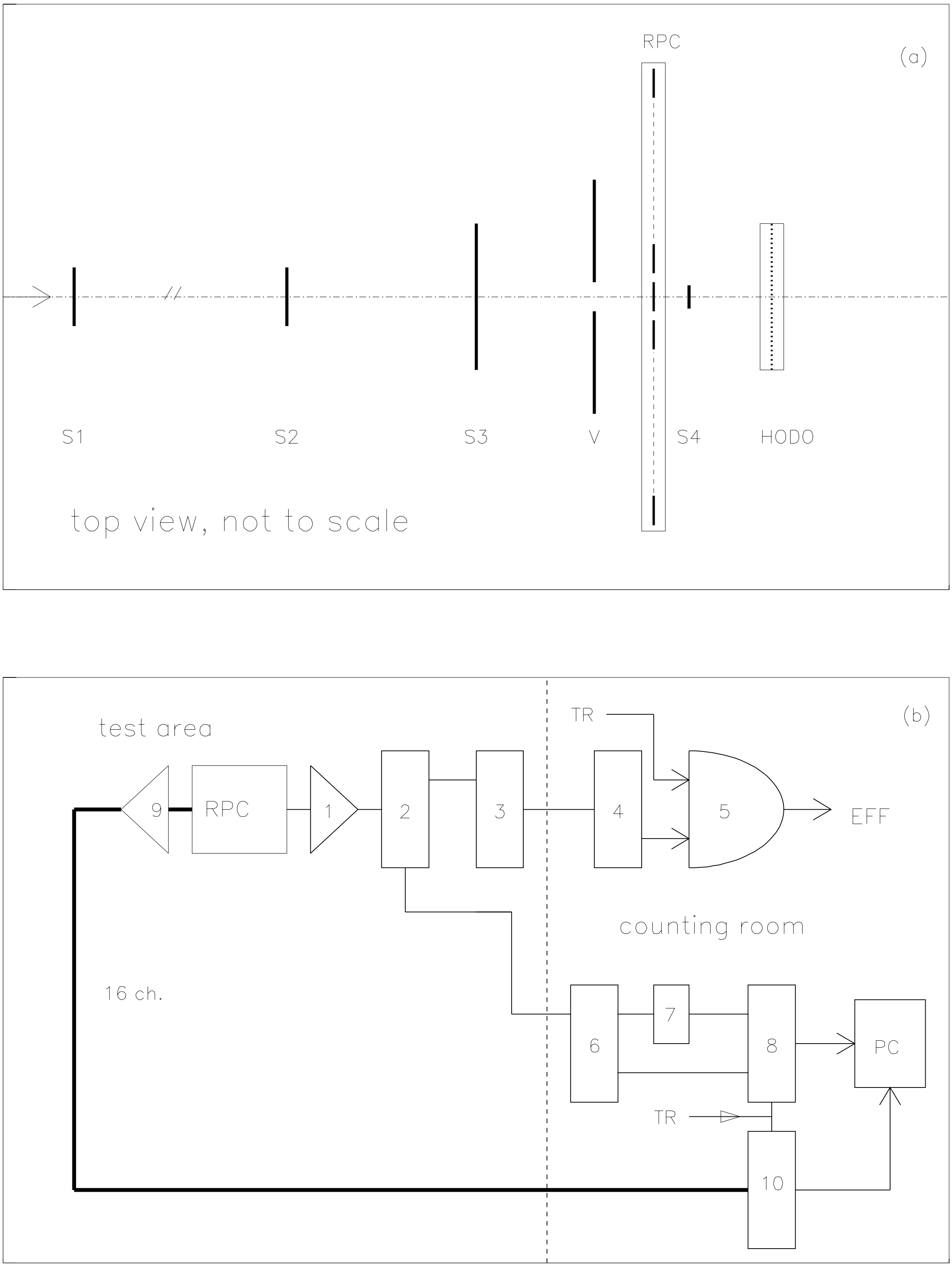

Fig. 1. Experimental set-up: a) scheme of detectors lay-out; b) scheme of data acquisition system. The numbers on fig. b) show: 1 — amplifier 26 dB; 2 — fan-out; 3 — discriminator/shaper 6 mV; 4 — shaper 40 ns; 5 — coincidence unit; 6 — fan-out; 7 — attenuator 20 dB; 8 — QDC; 9 — 16 channel FEE board; 10 — TDC.

The RPC had one gas gap 2.1 mm wide with a sensitive area 0.5(H)×2.0(V) m^2. The triggered particles hitted the centre of the sensitive area. Electrodes of the RPC were made from 1.6 mm thick phenol-melamine bakelite plates with (1-3)×10^{12} Ω·cm volume resistivity. No additional treatment was applied to the inner surfaces of the gas gap. HV was spread over outer bakelite surfaces with graphite coating having about 50 kΩ/square surface resistivity.

The chamber had X and Y read-out strip panels, strip width being 28 mm with 30 mm pitch. Two types of strip panels were used. The former one was a usual strip panel. The latter one had screening tiny strips 1 mm wide between usual sensitive strips These tiny strips were terminated with resistors equal to their measured impedance of 130 Ω. Only vertically oriented 2 m long strips were used for measurements. Comparison of the cross talks for these different strip panels is a subject-matter of the forthcoming note.

The read-out scheme of our measurements is shown in Fig. 1b. For efficiency, singles rate and charge measurements, only one strip was usually used. For charge measurements in an avalanche region the commercial amplifier U3-33 with maximal amplification of 20 was used. The amplified signal was attenuated when it was needed to fit QDC range. QDC had sensitivity of 0.25 pC/count and the gate width was varied from 100 to 500 ns. Efficiency of a picked out strip was obtained using a variable threshold discriminator and mostly corresponded to 0.3 mV threshold for an induced signal.

For pick-up strip multiplicity and arrival time measurements, the 16-channel front-end electronic (FEE) boards with variable threshold were used. Each channel consisted of two-stage amplifier and comparator. Outputs of FEE boards were fed to TDCs with about 0.7 ns binning. Other ends of all strips were terminated with resistors, equal to their characteristic impedance of 24 Ω, or connected to amplifiers for simultaneous charge measurements with QDCs. Both amplifiers and FEE boards had 50 Ω inputs.

The charge data presented here refer to the total fast charge induced on the strip.

2. Experimental results

From the practical point of view it is very desirable to have a 1 kV plateau region for the "saturated avalanche" mode of the RPC operation. Having such kind of RPC operation region, one may choose the working point at 0.5 kV above the knee and possible plateau range of ±0.5 kV. If nominal HV is about 10 kV, this corresponds roughly to ±5% of the field strength variation which can provide soft requirements for electrode resistivity and gas gap width tolerances, possible drifts of these values with time, ambient temperature and pressure variations and so on.

First of all the influence of the SF_6 was studied. The value of the IB was fixed to be 3% and the concentration of SF_6 was varied from 0% to 5%. The drastic change of charge distributions was found for the HV range above V_{knee} (the V_{knee} was defined as the point with efficiency 98%). To illustrate and stress this effect Fig. 2 shows charge distributions for selected mixtures at value $\triangle V = V - V_{knee}$ =1 kV. The transformation of charge distribution shapes with increasing SF_6 amount is clearly seen. If for the binary TFE/IB mixture the well known distribution is observed with clear "streamer" peak well separated from the "avalanche" one, then for the mixtures containing SF_6 there is an obvious tendency for merging the "streamer" and "avalanche" parts of the charge distributions with increasing the SF_6 fraction. It seems that the "streamer" charge is moving to lower values and the "avalanche" part of the charge distribution becomes broader. Therefore, there is no sense to study the "avalanche" and "streamer" charges separately.

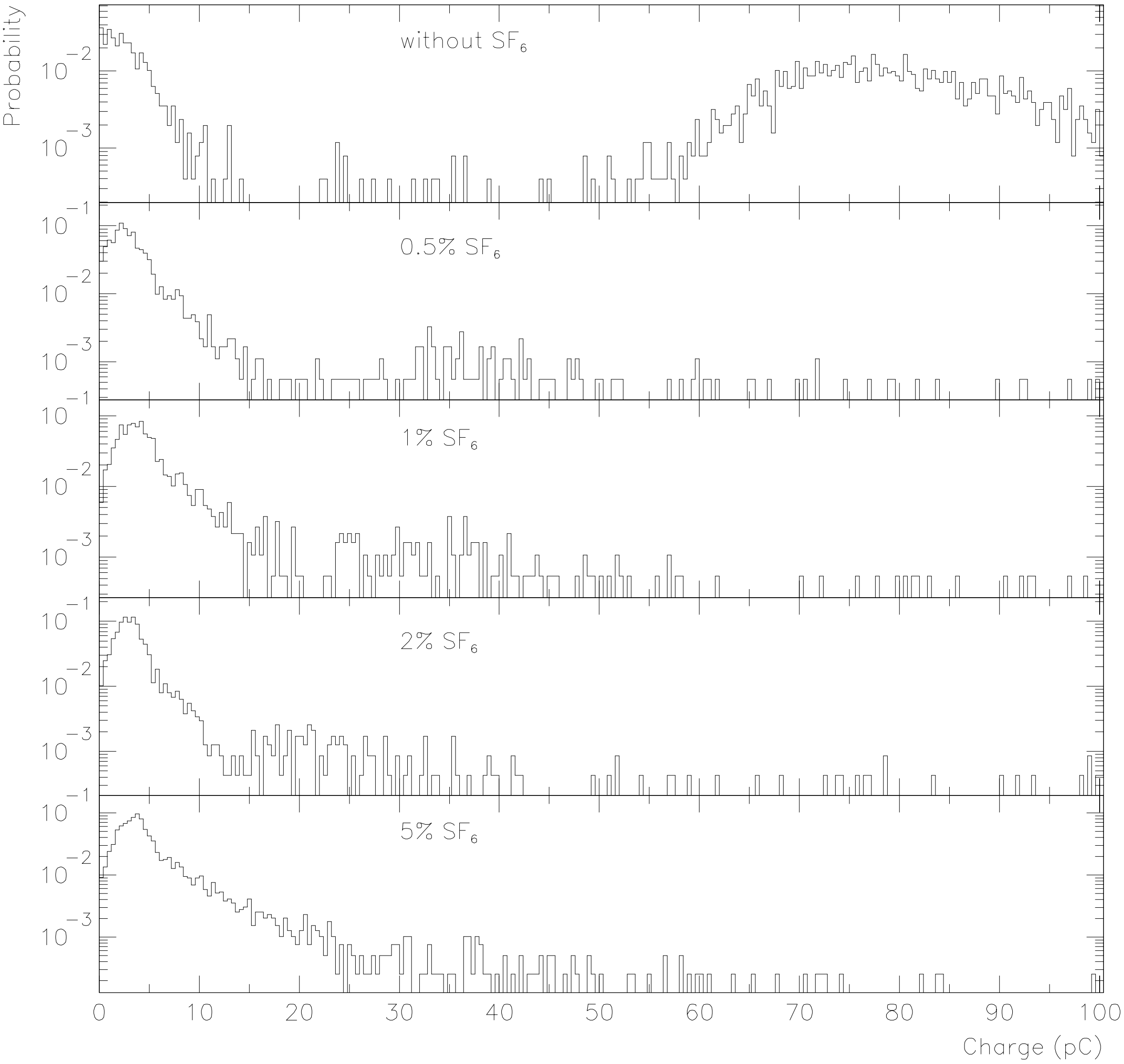

Fig. 2. Charge distributions for the triggered strip at ΔV =1 kV for TFE/IB/SF_6 mixtures with 3% if IB and different SF_6 concentrations.

Fig. 3 shows the behaviour of the average total charge for these mixtures as a function of $\triangle V$. For the binary TFE/IB=97/3 mixture the average "avalanche" charge is also plotted as a reference which shows a minimal achievable charge deposition providing minimal recovery time. Above the knee the binary TFE/IB mixture retains its behaviour as in the "avalanche" region while the growth of $< q >_{tot}$ for mixtures containing SF_6 becomes slower and compatible with reference "avalanche" charge growth above the knee. The higher the SF_6 concentration, the longer $<$q$>_{tot}$ keeps such behaviour. It is seen that such behaviour is practically saturated at 2% of SF_6.

A universal behaviour of average charge as a function of $\triangle V$ for different mixtures in the "avalanche" region (below knee) is clearly observed. It means that the IB and SF_6 additions do not change significantly the dependence of the effective Townsend coefficient as a function of the field strength in comparison with the binary TFE/IB mixture.

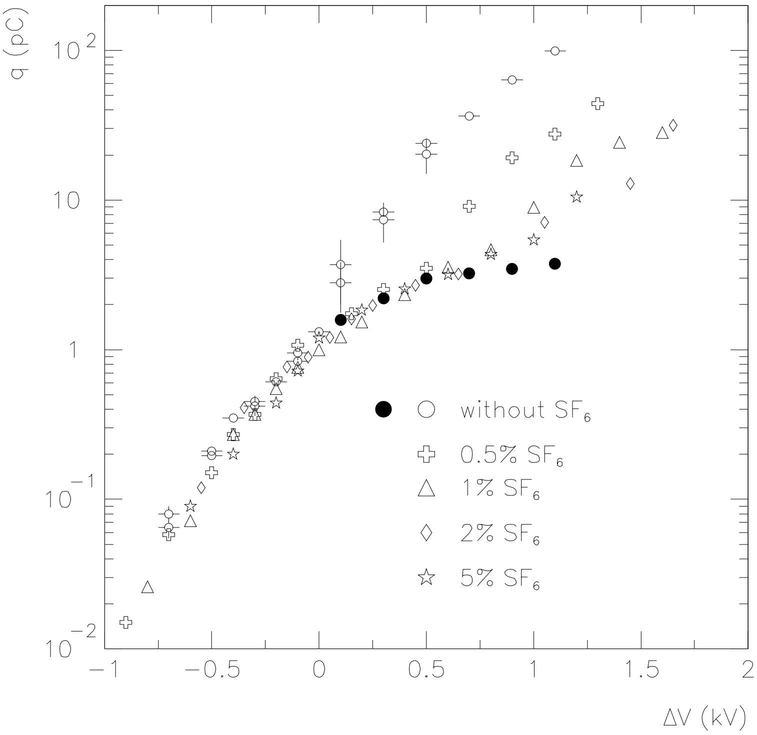

Fig. 3. Average charge for the triggered strip as a function of $\triangle V$ for TFE/IB/SF_6 mixtures with 3% of IB and different SF_6 concentrations. Open and full circles show total and avalanche average charges, respectively, for the TFE/IB=97/3 mixture.

Now it is interesting to clarify a true role of the IB addition which is the flammable gas in these gas mixtures. Therefore we have investigated this point separately. Fig. 4 shows charge distributions for TFE/IB/SF_6 = 93/5/2 and 98/0/2 mixtures at $\triangle V = 1\ kV$. Fig. 5 shows the behaviour of average total charge for these mixtures as a function of $\triangle V$. As one can see there is no significant difference between these two mixtures.

In Table 1 the values of the V_{knee}, average charges and average efficiencies above the knee are listed for all the mixtures for some specific $\triangle V$ points. If for the binary TFE/IB mixture drastic increasing of $<q>_{tot}/<q>_{av}$ ratio from ~ 1 at $\triangle V$ = 0.0 kV to ~ 30 at $\triangle V$ = 1 kV is seen, for the 2% SF_6 mixture this value is approximately constant in the whole 1 kV plateau range and $<q>_{tot}$ is only about 2 times higher than the reference $<q>_{av}$ at $\triangle V$ = 1 kV (see Table 1). It seems that good approximation for a “saturated avalanche” mode is achieved.

Table 1. The values of HV at the knee, average efficiency at the plato and average charges at some $\triangle V$ points for all tested mixtures.

Charge	Mixture	V_{knee}	ε(%)	<q> (pC) at $\triangle V = V - V_{knee}(kV)$			
	$C_2H_2F_4/iC_4H_{10}/SF_6$	(kV)	above knee	-0.1	0.	0.5	1.0
Total	97/3/0	9.9	97.9	0.84	1.3	24.0	108.0
	96.5/3/0.5	9.9	98.4	1.07	1.4	3.8	23.0
	96/3/1	10.2	99.2	0.75	1.2	3.5	8.9
	95/3/2	11.0	99.3	0.83	1.0	3.3	7.1
	92/3/5	11.6	99.1	0.72	1.2	3.0	5.5
	98/0/2	11.8	98.3	0.95	1.2	3.1	7.1
Avalanche	97/3/0	-	-	0.84	1.2	3.0	3.6

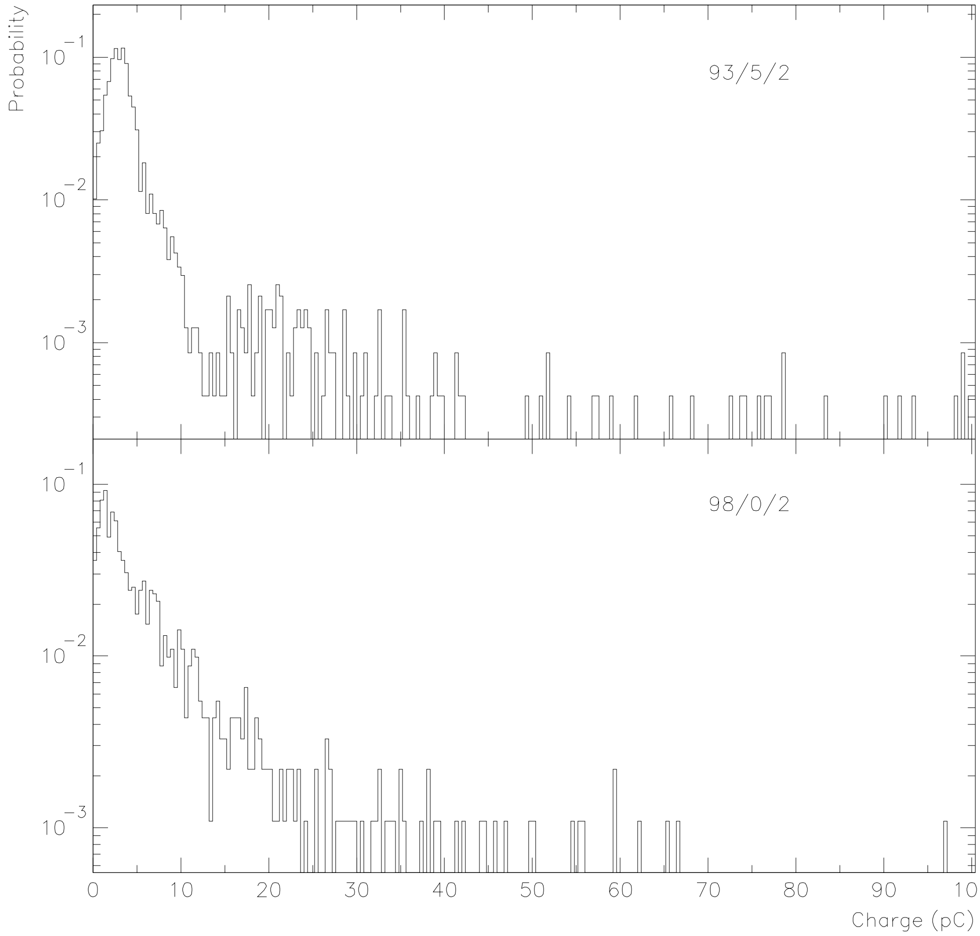

Fig. 4. Charge distributions for the triggered strip at $\triangle V$ =1 kV for TFE/IB/SF_6 mixtures with 2% of SF_6 and different IB concentrations.

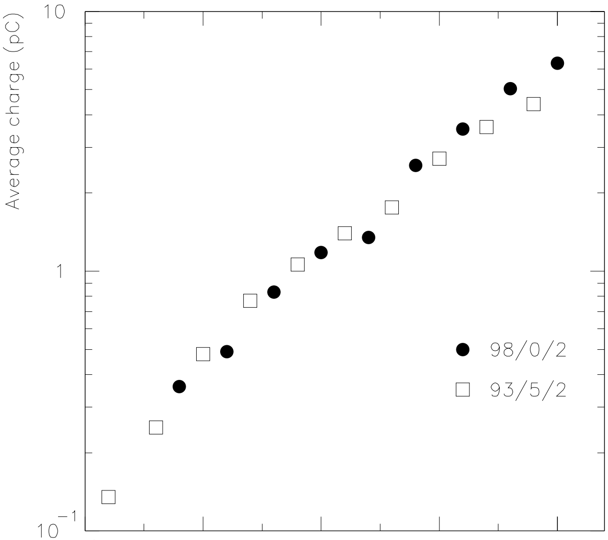

Fig. 5. Average charge as a function of $\triangle V$ for TFE/IB/SF_6 mixtures with 2% of SF_6 and different IB concentrations.

As first glance to understand the correlation between the shape of charge distributions and the pick-up strip multiplicity we have plotted the cumulative distribution

$$P(R_0) = \int\limits_{r \geq R_0} \rho(r) \cdot dr \;/ \int\limits_{r \geq 1} \rho(r) \cdot dr$$

as a function of $r = q/q_{th}$ for the fixed threshold charge q_{th} . Here $\rho(r)$ is charge distribution density and $R_0 = q_0/q_{th}$. This distribution shows probabilities to have a tail of the distribution with $q > r \cdot q_{th}$.

Fig. 6 shows these distributions for selected mixtures for $\triangle V = -0.3,\ 0.0,\ 0.5$ and 1.0 kV at $q_{th} = 0.1$ pC.

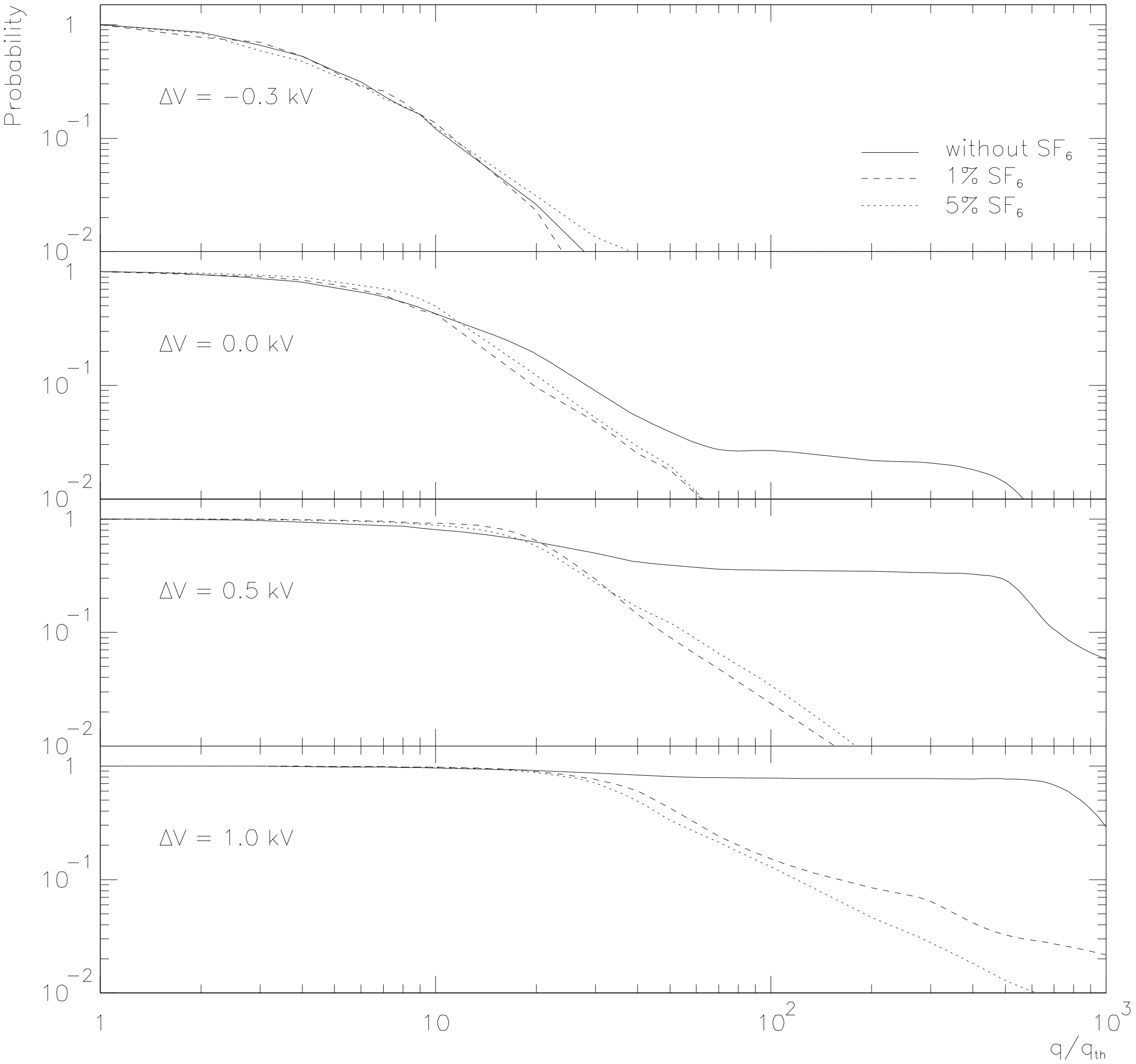

Fig. 6. Cumulative charge distributions at different $\triangle V$ for TFE/IB/SF_6 mixtures with 3% of IB and different SF_6 concentrations.

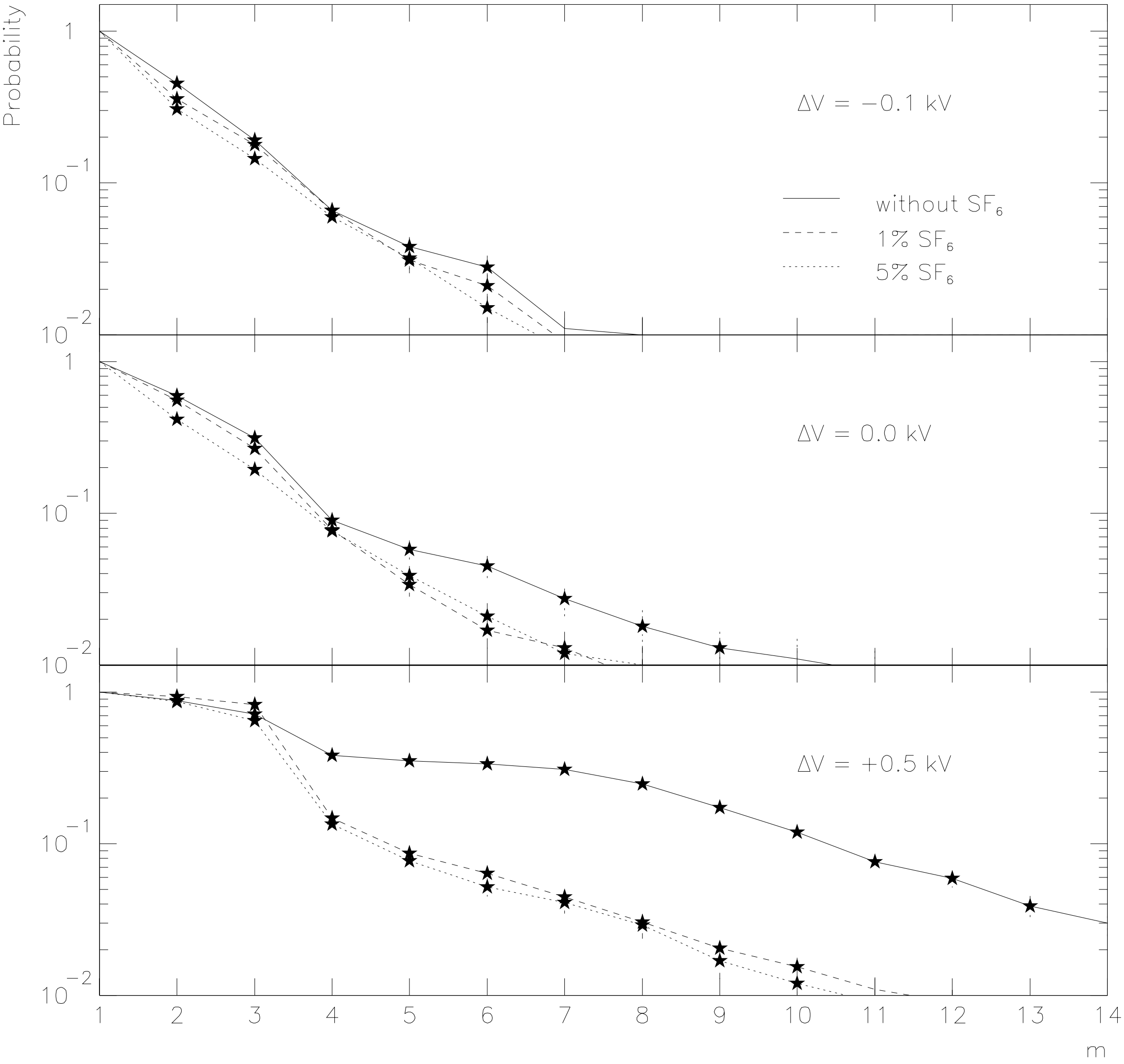

Fig. 7. Average multiplicity as a function of $\triangle V$ for a) low (0.5 mV) and b) high (1 mV) FEE thresholds for TFE/IB/SF_6 mixtures with 3% of IB and different SF_6 concentrations.

The data for $\triangle V = -0.3$ kV show that the shapes of charge distributions are approximately the same for all the mixtures in the avalanche region. It means that the universal behaviour observed for averages of charge distributions for different TFE mixtures as a function of $\triangle V$ in the avalanche region is also valid for charge distributions themselves.

For the plateau region ($\triangle V \geq 0\ kV$) it seems that for $r \sim 10 - 20$ the distributions are the same. But for $r \sim 100$ the mixtures containing SF_6 give roughly 10 times better suppression compared with the binary TFE/IB mixture.

It is interesting to check these conclusions considering the real case — pick-up strip multiplicity per one through going particle. The value of

$$P(m) = \sum_{i \geq m} n_i / \sum_{i \geq 1} n_i$$

was measured as a function of m (see Fig. 7) for selected mixtures at different $\triangle V$ values. Here n_i is the number of events with pick-up strip multiplicity i. Good agreement with the charge distributions behaviour is observed. The universal behaviour of P(m) for different TFE based mixtures is seen in the avalanche region for the whole range of multiplicities which reflects the observed universality of charge distributions. In the plateau region the behaviour of P(m) is the same for m up to 4. The tail of high multiplicities (streamer fraction) becomes larger and larger with increasing of $\triangle V$ for the binary TFE/IB mixture and increases moderately for mixtures containing SF_6. The proper SF_6 admixture gives roughly one order of magnitude suppression for the tail of high multiplicity in comparison with the binary TFE/IB mixture.

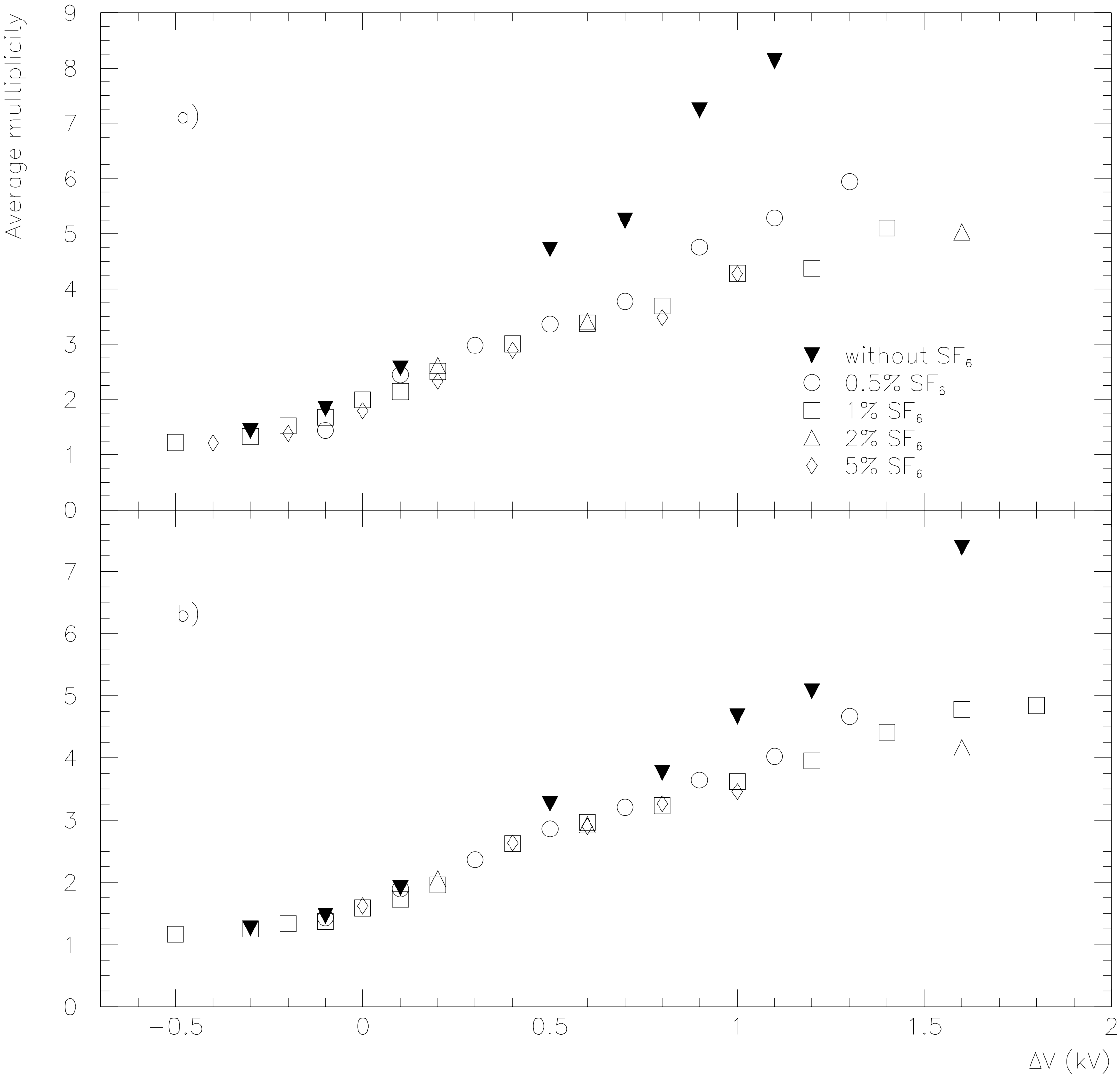

Fig. 8. Cumulative pick-up strip multiplicity distributions for low (0.5 mV) threshold at different $\triangle V$ for TFE/IB/SF_6 mixtures with 3% of IB and different SF_6 concentrations.

Fig. 8 shows the average pick-up strip multiplicity as a function of the $\triangle V$ for selected mixtures for low (0.5 mV) and high (1.0 mV) FEE thresholds. As one can see the behaviour of these averages reflects expectations which were drawn for P(m) cumulative distributions. It is important to note for practical use that the high FEE threshold is favourable for the "saturated avalanche" mode of the RPC operation. It allows one to reduce an average cluster size by 0.5 unit for the plateau region.

Fig. 9 shows the arrival time distributions for induced signal from the main strip for selected mixtures at different $\triangle V$ values. Decrease of the time delay as a function of $\triangle V$ is about 2 nsec/1 kV at the plateau region for all mixtures. Time resolutions for our RPC for all the mixtures are at a level of 1 nsec. Thus, in addition to significant improvement of the charge and multiplicity characteristics of the RPC performance, the SF_6 addition does not worsen its time properties.

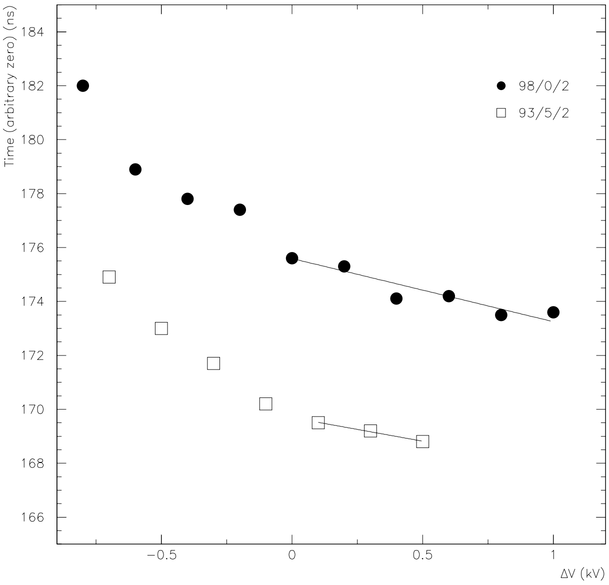

Fig. 9. Average arrival time as a function of $\triangle V$ for TFE/IB/SF_6 mixtures with 2% SF_6 and different IB concentrations. Lines on the figure show fit of the data by straight line in the range above the knee. The slopes of the lines equal 2.1 and 1.8 ns/kV for the upper and lower lines, respectively, with un error of about 0.1 ns/kV (including systematic ones).

Conclusions

Addition of the electro-negative gas SF_6 to the ordinary TFE/IB mixture allows one to achieve good approach for the "saturated avalanche" mode of the RPC operation, i.e. allows for the 1 kV wide plateau region

— to decrease the average fast charge;

— to decrease the high pick-up strip multiplicity by an order of magnitude

in comparison with the binary TFE/IB mixture.

Our conclusions are in agreement with results reported in papers [4,5].

The work in the "saturated avalanche" mode is suitable to apply the high FEE threshold ($\sim$ 1 mV which is favourable for the FEE performance.

No distinguished influence of the small amount of the IB on the charge properties of the 2% SF_6 mixtures was observed. Therefore, the IB can be excluded from the SF_6 mixtures thus leaving the integral charge properties unchanged.

The universal behaviour of the charge distributions for all different TFE based mixtures as a function of $\triangle V$ is observed in the avalanche region (below the knee). Thus, the addition of SF_6

does not change, in general, the process of the avalanche development except for the increase of the applied voltage.

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