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Abstract

The physical principle of discharge localization in Pestov spark counters is described. It was experimentally shown that Isoprene is one of the promising candidates to replace 1,3-Butadiene in the standard gas mixture. In the spark counter with the DME-Argon gas mixture and an aluminium nitrite cathode a discharge localization was obtained for the first time. This result is considered as the beginning of a new spark counter technology without conditioning.

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1. Introduction

The Pestov Counter version for ALICE [1] is a parallel plate gas counter operated in the streamer/spark mode with a gap size of 100 μm. The main feature of this spark counter is discharge localization, which provides good counting rate capability. The problem with discharge localization arises from UV-photons from sparks, which could hit the cathode, release secondary photoelectrons and finally a chain of secondary sparks could appear. A localization of the discharged area to 1-2 mm^2 is reached by the use of a highly resistive anode and a special gas mixture which absorbs UV-photons with an energy above the work function of the cathode.

However, the absorption efficiency of a special 4-component gas mixture used for the spark counter [2] is, as for most stable gases, very low in the vicinity of the work function of typical, e.g. aluminium or copper, cathode materials. The "gap" between the work function of the cathode material and the region where the photo absorption cross section is sufficiently high is closed during a process called conditioning: the counter is operated together with a γ-source in order to produce a thin polymeric layer on the surface of the cathode which shifts the work function to higher energies. After recording of $10^5 - 10^6$ sparks/cm^2 the counter characteristics stabilize in time.

This counter technology is already acceptable for ALICE from the ageing point of view [3]. However, a replacement in the standard gas mixture of 1,3-Butadiene by another gas could improve the gas mixture stability against polymerization i.e. increase the life time. Moreover, 1,3-Butadiene is now considered to pose a potential health hazard.

An alternative way to improve the spark counter is using a cathode material with a high work function to exclude conditioning with a gamma source completely. Measurements with spark counters using tungsten cathodes demonstrated good performance without conditioning [2] but the counter life-time with the standard gas mixture became worse due to the Malter effect. Therefore, both a new gas mixture with low polymerization as well as a cathode material with a high enough electron work function without the need of a polymeric layer is sought. A potential candidate is a mixture with DME which has low polymerization [4], in combination with an aluminum nitride cathode, which has a higher work function equal to $> 8eV$.

In the first part of the paper a possible replacement of 1,3-Butadiene is evaluated. In the second part the first observation of a discharge localization with gas mixture based on DME is demonstrated.

2. Isoprene-a candidate for 1,3-Butadiene replacement

Fig.1 shows the absorption spectrum of the standard gas mixture consisting of 0.07 (bar) $C_4H_6 + 0.3\,C_2H_4 + 2.4\,C_4H_{10} + 9\,Ar = 12$ bar. The pressure of each component of this gas mixture was optimized. The Isobutane pressure of 2.4 bar was chosen to

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gas	boiling point	vapor gas pressure at 15.4C
1,3-Butadiene (C_4H_6)	-4 °C	2 bar
Isoprene (C_5H_8)	34 °C	0.53 bar
Pentadiene (C_5H_8)	42 °C	0.41 bar
Biisopropenyl (C_6H_10)	68-78 °C	?

Table 1: Gas properties

get a better time resolution although just for discharge localization a much smaller Isobutane (C_4H_{10}) pressure would be enough. The quantity of Ethylene (C_2H_4) in this gas mixture was minimized to the value, which provides a stable counter performance. The quantity of 1,3-Butadiene (C_4H_6) was chosen for the ALICE application 4 times less than the optimal one in order to improve the counter live time proportionally.

Fig.2 shows the absorption spectrum of some candidates for 1,3-Butadiene replacement. The absorption intensity and the position of the absorption band on the photon energy scale are very similar for all gases presented. However, the Pentadiene and Isoprene (2-Methyl-1,3-Butadiene) absorption spectra look better because they extend further to the side of low energy photons as compared to the case of 1,3-Butadiene. The localization depends both on the absorption spectrum of the gas mixture as well as on the radiation spectrum of the sparks. In the proposed gas replacement the spark radiation spectrum cannot change dramatically because only 0.6% of the gas mixture would be changed. Important physical characteristics of the gases are shown in the Table 1. From Table 1 it is clear that both the Isoprene and Pentadiene vapor pressure are high enough for a replacement of 1,3-Butadiene.

The spark counter which was used in the experiments with different gas mixtures was conditioned with the standard gas mixture. Fig.3 shows the charge distribution at the ALICE high voltage value of 4.5 kV for two cases: a) the standard gas mixture and b) the gas mixture with 0.07 bar Isoprene instead of 1,3-Butadiene. A criterium for the quality of localization is the shape of the charge distribution: discharges with good localization result in narrow spectra, while, on the other hand, bad localization yields a tail to high amplitudes due to afterpulses. As can be seen the shape of the spectrum with Isoprene looks even steeper. To demonstrate the importance of the photon absorption in the low energy region Isoprene (as well as 1,3-Butadiene) was removed from the gas mixture. The problem with discharge localization immediately appears. Even at 3.9 kV the charge distribution is wide (Fig.3c). Fig.4 shows the RMS value of the charge distribution for the previous gas mixtures at different HV's.

Isoprene is thus a promising candidate to replace 1,3-Butadiene. The short term ageing properties are satisfactory. However, for a final conclusion the long term ageing test must be done. The timing properties of the gas mixture with Isoprene have yet to be verified, but due to the well known detector properties and the small difference in the gas composition no change is expected. Based on the knowledge of the principle of a discharge localization in the spark counter it could be predicted

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that Pentadiene would also be a good candidate for the 1,3-Butadiene replacement.

3. Localization with DME

A dramatic improvement of the spark counter technology and characteristics could be achieved by employing a gas mixture with low polymerization potential and a cathode material with a high enough electron work function for the chosen gas mixture. A potential candidate for a new quencher in the gas mixture is DME, which demonstrated extremely low polymerization in applications with proportional and microstrip chambers [4]. Fig. 5 shows an absorbtion spectrum of a gas mixture consisting of 4(bar)DME + 8(bar)Ar=12bar. The right side of the absorbtion band of DME corresponds to the photon energy about 6.7eV. Therefore, the cathode material for this gas mixture should have a work function higher than this value. One possible cathode material could be aluminum nitride (AlN). The work function of AlN estimated from the measurement of the photoelectric emission threshold [5] is equal to 8.7eV. AlN is a direct gap material with a large forbitten gap of 6.2eV. The bulk resistivity of undoped AlN single crystals is $10^{11} - 10^{13} \Omega cm$, which is too high for the ALICE application because of counting rate limitations. However, doped (Al$_2$OC) single p-type crystals of AlN have an acceptable resistivity of $10^3 - 10^5 \Omega cm$ [6].

3.1 Localization with DME/N$_2$ and an Al cathode

The experiment described in this paragraph has the goal to obtain for the first time the discharge localization in the spark counter with a gas mixture based on a DME quencher. To exclude possible problems with a too high value of resistivity it was aimed to produce a very thin layer of AlN on the surface of an Al cathode during the operation with a gamma source in the presence of Nitrogen in the gas composition. Therefore, a mechanically polished bulk aluminum cathode was used in combination with a gas mixture consisting of 2.9 bar DME, 5.1 bar Ar and 4 bar N$_2$. The counter was irradiated with a ^{60}Co γ-source. Localization of the sparks is related to the width of the charge distribution. If a primary spark causes a secondary spark, the charge of the pulse will be higher.

Fig.6(a,b) shows the charge distribution at the beginning and after 13 days of operation, respectively. An improvement of the localization is visible. Fig.7 shows the rate during the irradiation with the ^{60}Co γ-source as a function of the applied high voltage. The maximum voltage was 1.22 times the threshold voltage. Afterwards the counter was refilled with a gas mixture without Nitrogen (4 bar DME and 8 bar Ar). Deterioration of the localization was observed. Fig.8(a,b) shows the charge distribution after the refilling and after 3 days of operation. In the following operation with the mixture including Nitrogen (2.9 bar DME, 5.1 bar Ar and 4 bar N$_2$) the localization was restored, which is shown in Fig.9(a,b).

This experiment confirmed our assumption about the mechanisms of discharge

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localization. The spark counter could not work with an Al cathode and with DME as quencher alone due to the low work function of the Al cathode. We came to the conclusion that the previous observation of the localization during the conditioning is related to the presence of nitrogen and could result from an increase of the cathode work function. The decreasing of the localization without N_2 in the gas mixture is explained by a process which removes the previous coating by the discharges. The experiment described at this paragraph demonstrated for the first time discharge localization with a gas mixture based on DME as a quencher.

3.2 First results with DME and an AlN cathode

In a second experiment an aluminum cathode with an aluminum nitride layer on the surface, produced by chemical vapor deposition technology was used. Unfortunately the AlN film quality was not good: the film thickness varied along the cathode surface between 0-0.3 μm and a measured bulk resistivity of AlN film was rather high- $10^{11} - 10^{12}\Omega cm$. The spark counter was operated with a gas mixture without Nitrogen (4 bar DME and 8 bar Ar) to obtain the localization with aluminum nitride. Fig.10 shows the charge distribution at the relative high value of HV of 4.7kV. This measurement showed that it is possible to get localization with the AlN cathode, which was not possible for a counter with an aluminum cathode in the DME-argon gas mixture. Due to the bad quality of AlN layer at this experiment the counter was noisy. A new cathode with a good quality AlN layer is presently being manufactured.

4. Conclusion

In summary, the investigation of possible new gas compositions for the spark counter gave the following results:

1) The experiments confirmed our understanding of the physical principles of a discharge localization in the spark counter;

2) It was shown that Isoprene is a candidate to replace the Butadiene in the standard gas mixture;

3) A drastic improvement of the spark counter technology and characteristics could be achieved using DME as a gas quencher in combination with a cathode from aluminium nitride. A localization property of this spark counter was demonstrated.

However, additional investigations of the new gas compositions like long term behaviour, the obtainable time resolution, efficiency etc. have to be carried out to ensure the applicability in experiments.

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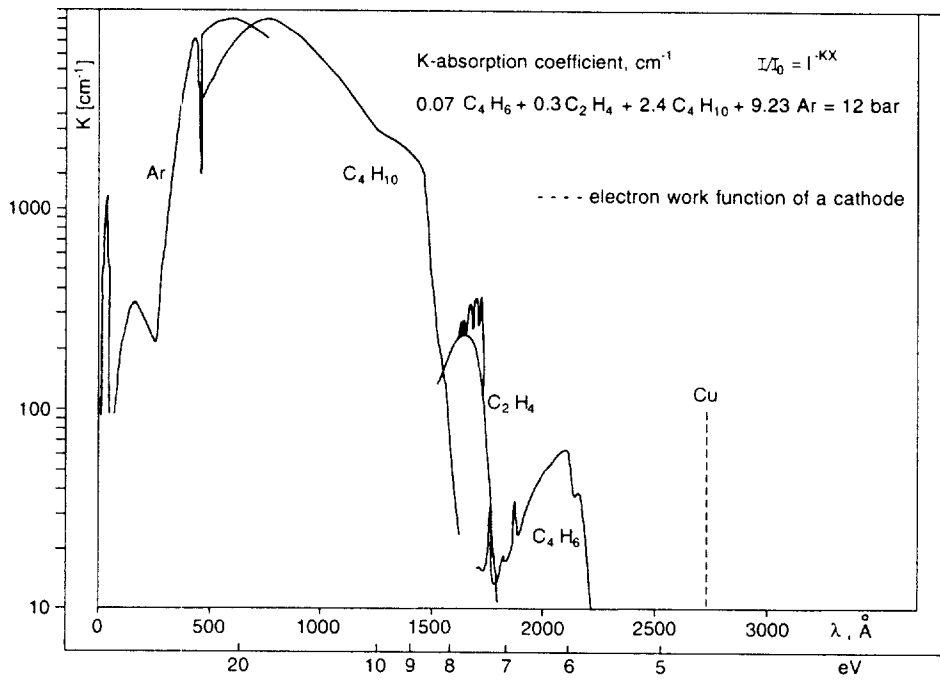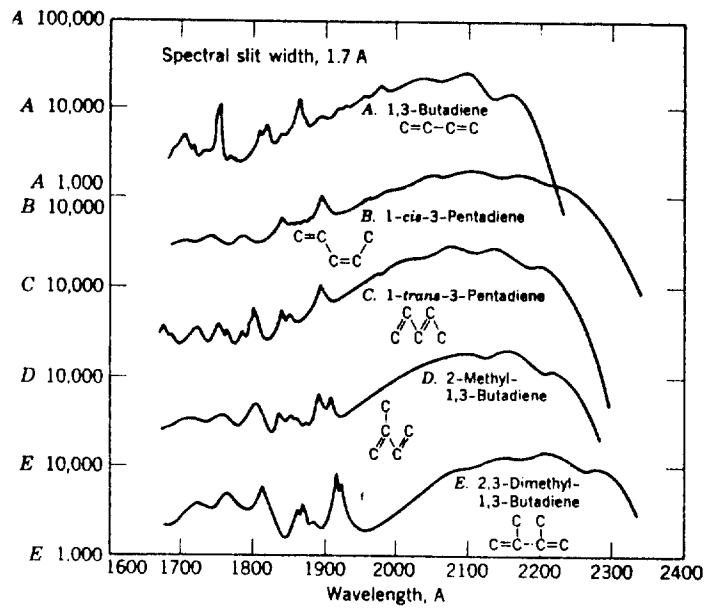
Figure 1: Absorption spectra of the standard gas mixture

Figure 2: Absorption spectra of some candidates for 1,3-Butadien replacement

4.5 kV

ID	2304
Entries	10000
Mean	22.07
RMS	8.522

(a)

sum adc counter : 4

4.5 kV, I

ID	2304
Entries	10000
Mean	19.59
RMS	6.956

(b)

sum adc counter : 4

3.9 kV no D

05/02/98 10.12

ID	2304
Entries	10000
Mean	28.41
RMS	24.20

(c)

sum adc counter : 4
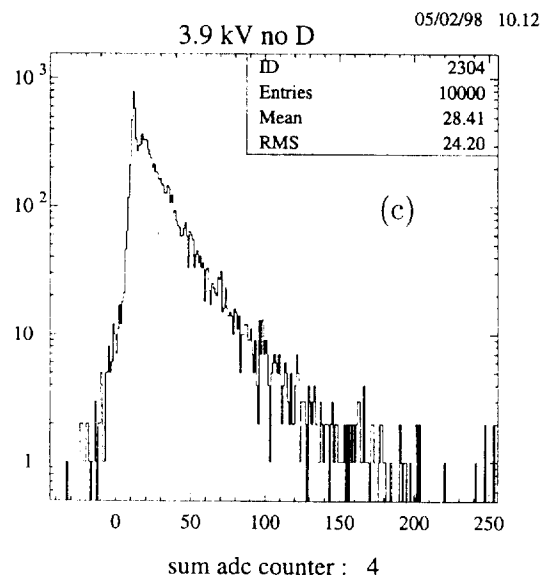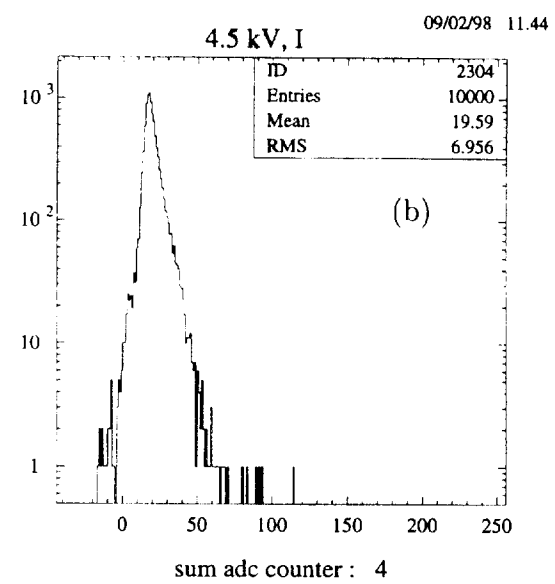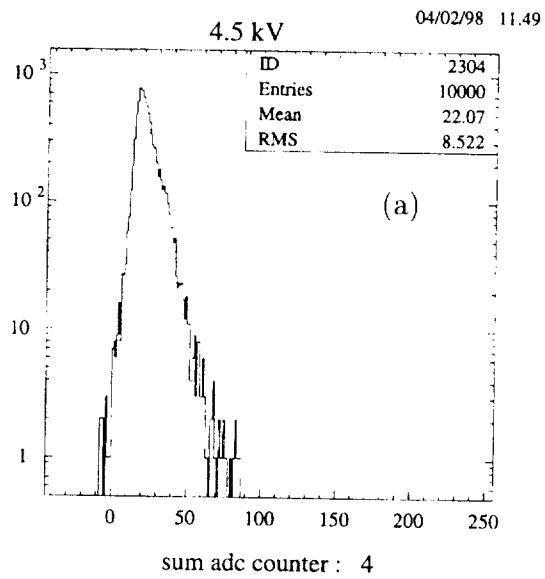
Figure 3: Charge distribution for the standard gas mixture with a) 1,3-Butadien, b) Isoprene and c) none of them
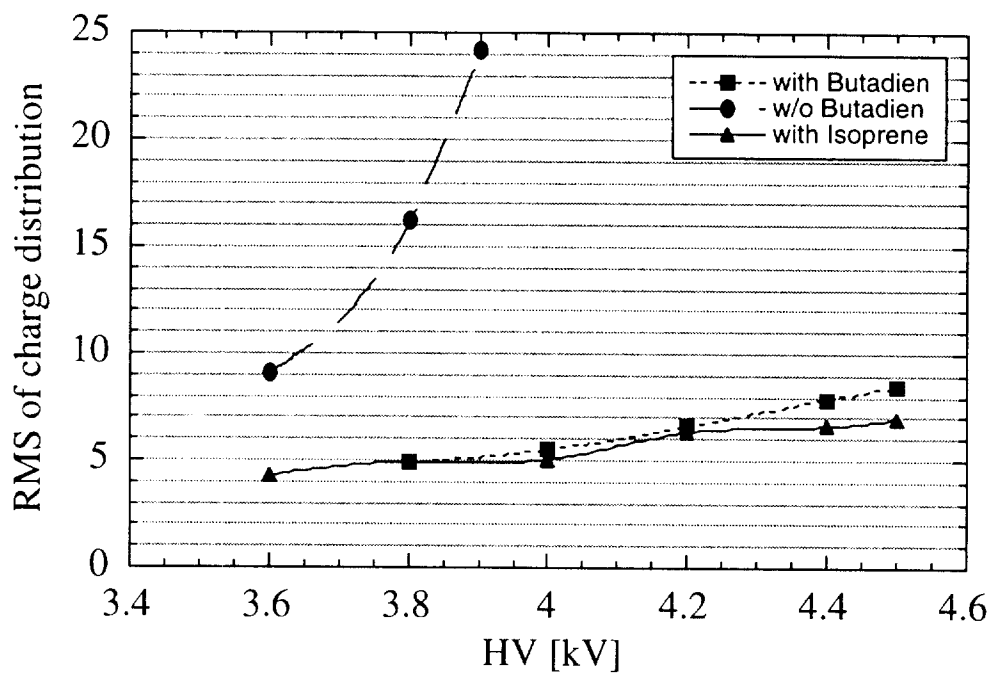
Figure 4: RMS of the charge spectra for different gases
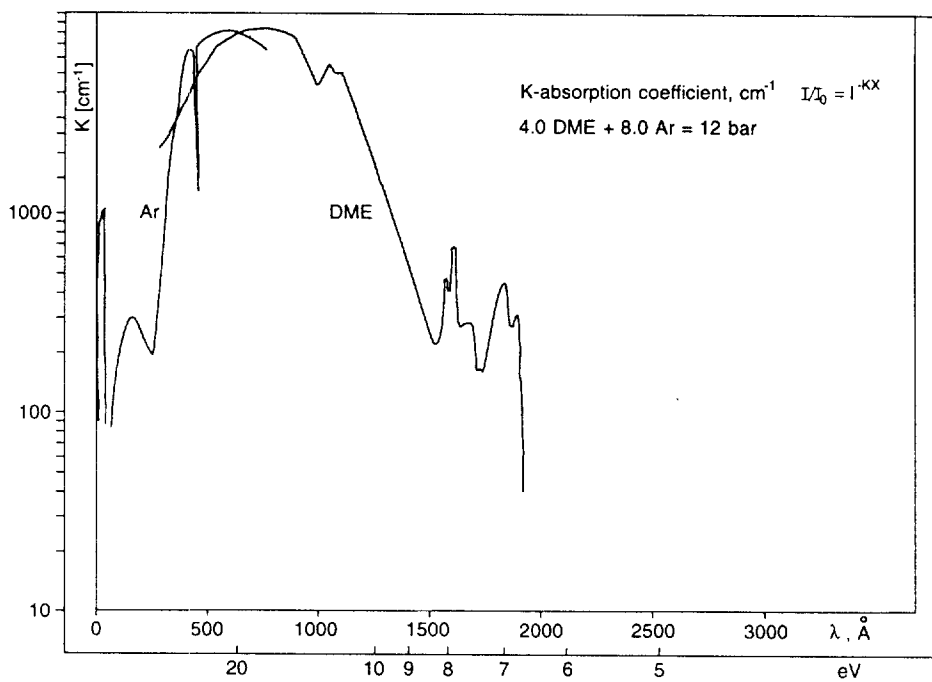
Figure 5: Absorption spectra for the new mixture with DME

3.35 kV, after 0 days

2.9 bar DME + 5.1 bar Ar + 4 bar N2   (a)

4.1 kV, after 13 days

2.9 bar DME + 5.1 bar Ar + 4 bar N2   (b)
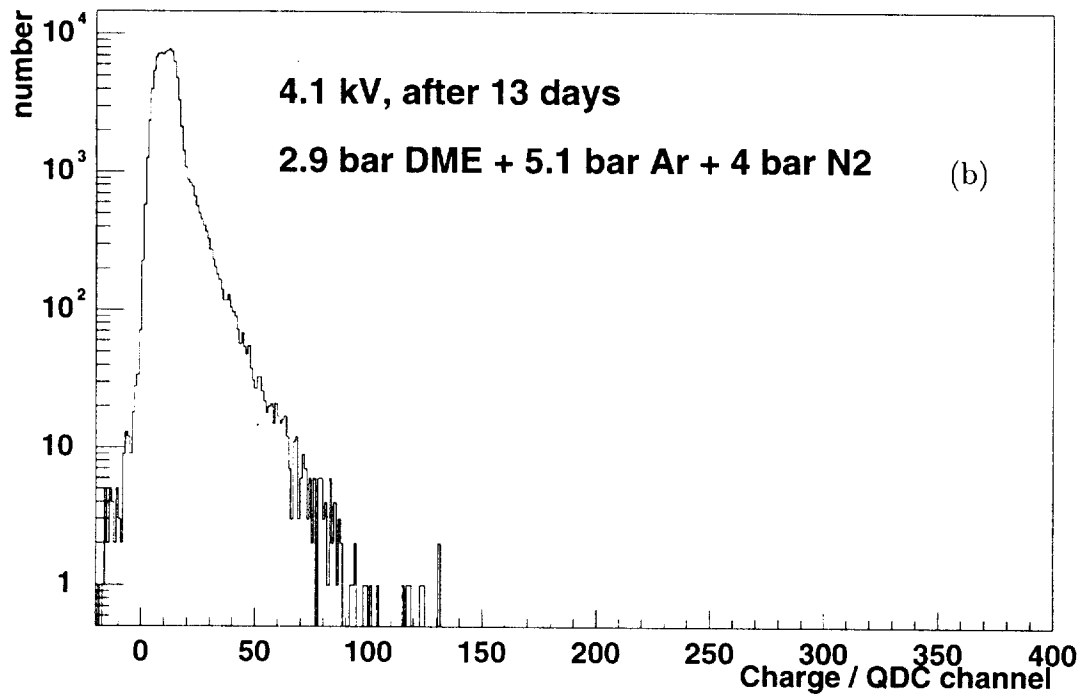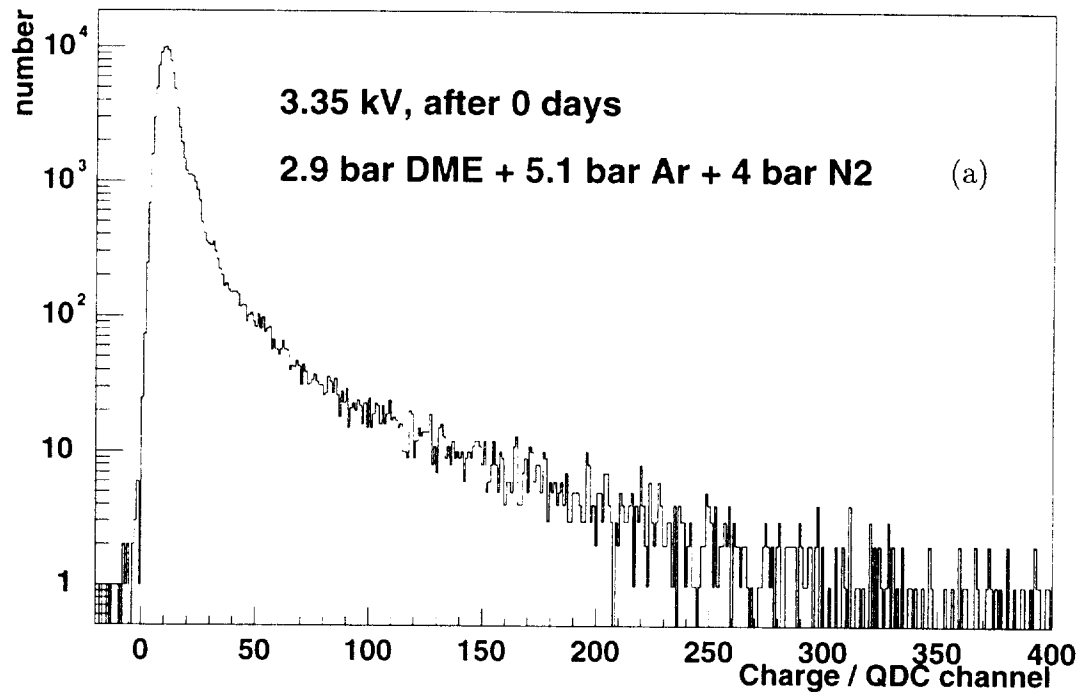
Figure 6: Charge distribution for the mixture with DME and N_2
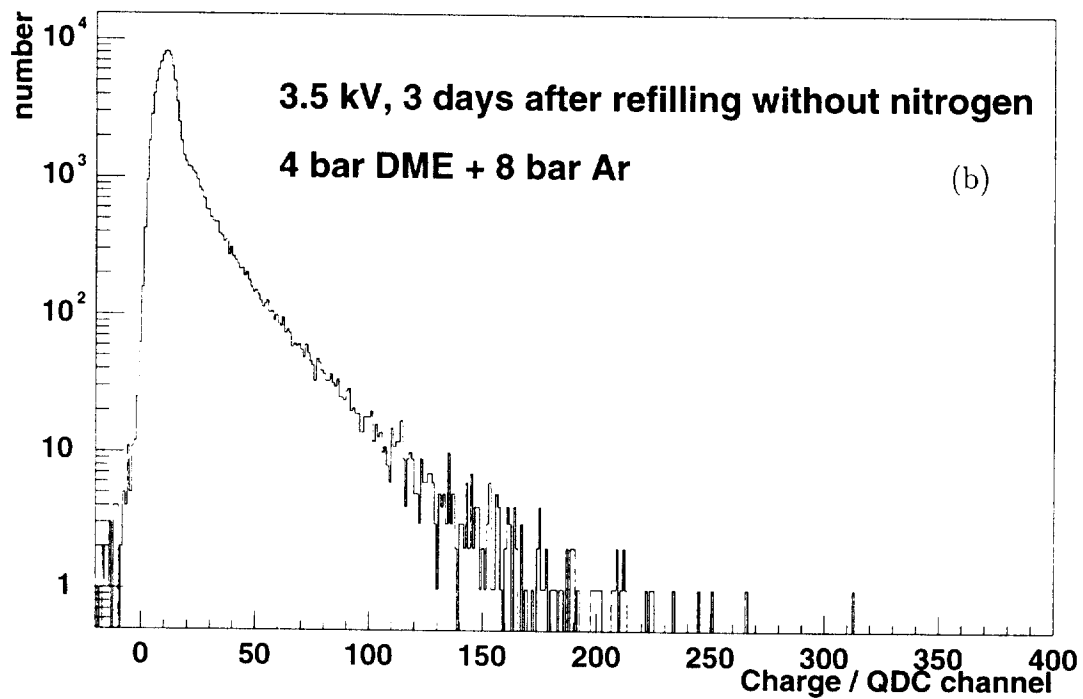
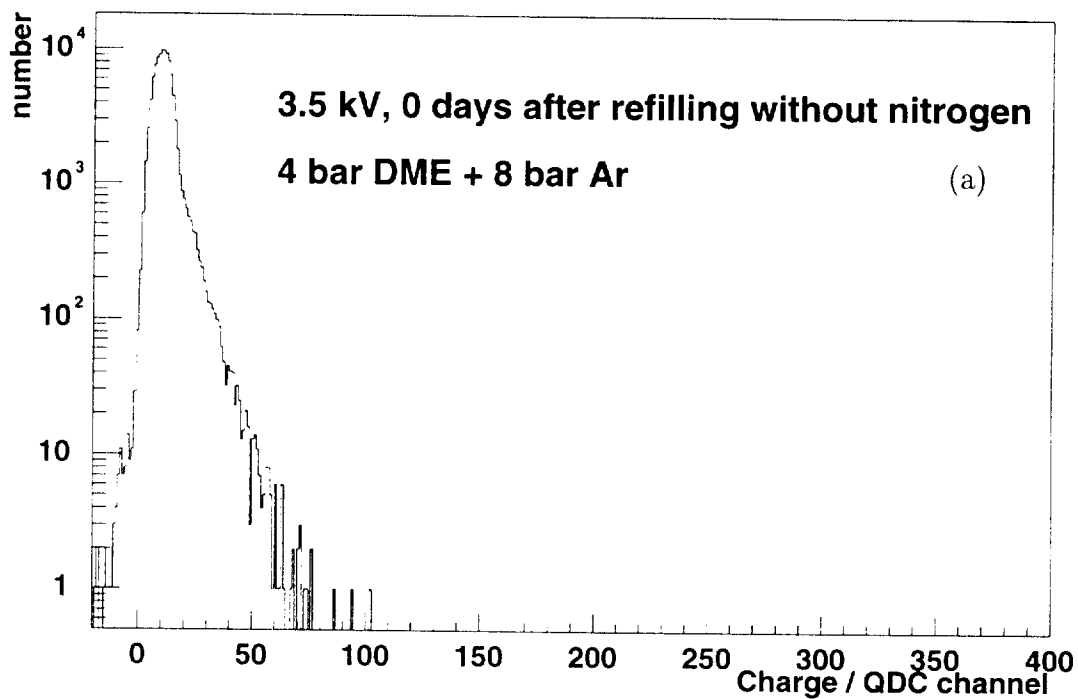10
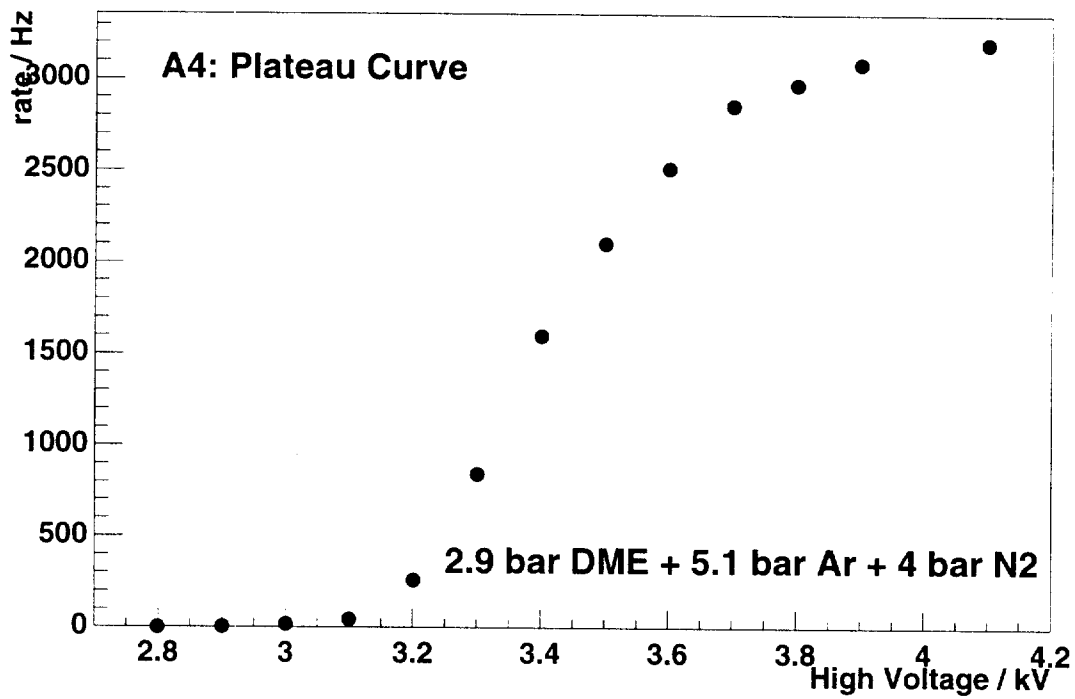
Figure 7: Plateau Curve with a ^{60}Co γ-source
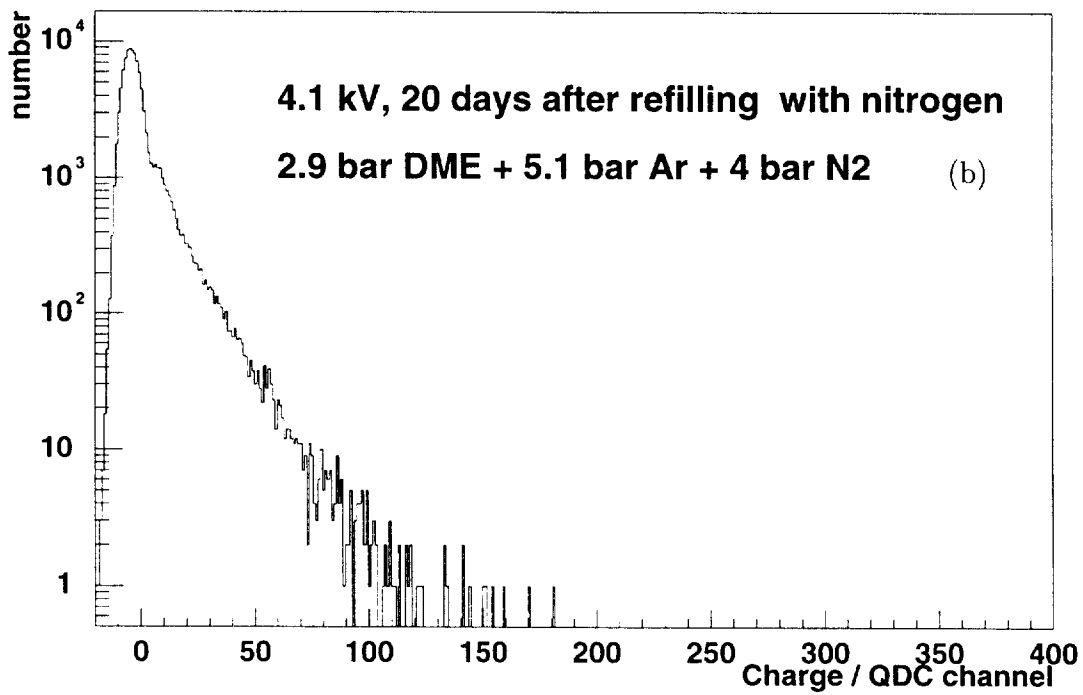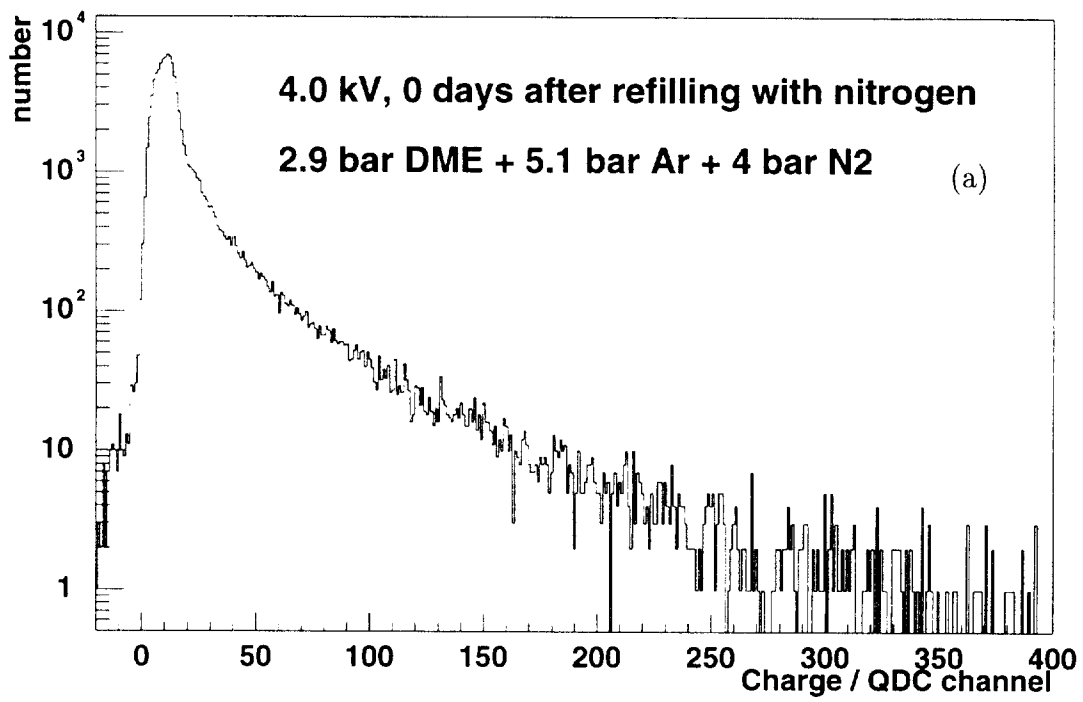
Figure 8: Charge distribution for the mixture without N_2

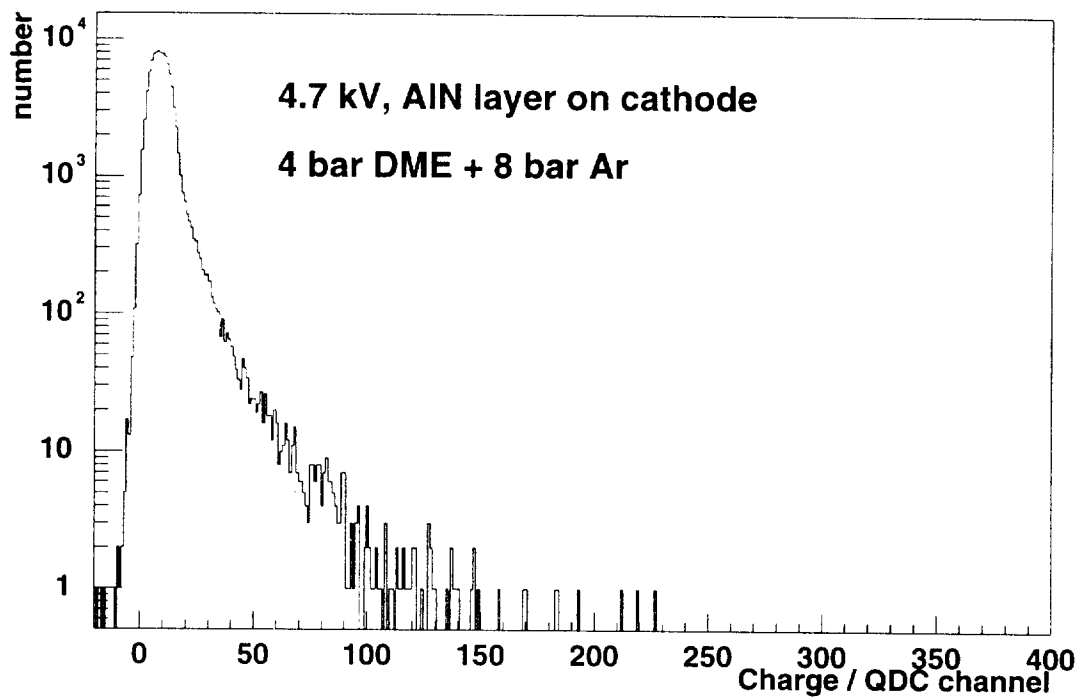Figure 9: Charge distribution for the mixture with N_2

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Figure 10: Charge distribution for the counter with the AlN cathode and a gas composition with DME but without N$_2$