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OPERATION OF LIMITED STREAMER TUBES WITH THE GAS MIXTURE Ar + CO_2 + n–PENTANE

G. Bagliesi [3], R. Baldini-Celio[2], G. Batignani[3], G. Bencivenni[2], G.F. Bologna[2], F. Bossi[2], U. Bottigli [3], C. Bradaschia[3], P. Campana[2], G. Capon[2], M. G. Catanesi[1], V. Chiarella[2], G. De Ninno[2], M. de Palma[1], B. D'Ettorre Piazzoli[2-4], M. Dreucci[2], G. Felici[2], L. Foà[2], A. Giassi[3], G. Iaselli[1], P. Laurelli[2], G. Maggi[1], G. Mannocchi[2-4], G. P. Murtas[2], G. Nicoletti[2], S. Nuzzo[1], P. Picchi[2], A. Ranieri[1], G. Raso[1], H. Rigoni[5], F. Romano[1], F. Ruggieri[1], S. Scapellato[3], G. Selvaggi[2], R. Tenchini[3], G. Zito[1].

1. INTRODUCTION

The active detectors of the ALEPH hadron calorimeter al LEP consist of plastic streamer tubes developed in Frascati.The use of al large system of streamer tubes for gas sampling calorimetry was achieved for the first time in the NUSEX proton decay experiment at Mt. Blanc [1], running now since June 1982. The standard gas mixture for the operation of such devices is Argon-Isobutane (30/70). However in underground experiments, for safety reasons, one has to reduce the hydrocarbon content. Therefore ternary mixtures Ar/CO_2/Isobutane and Ar/CO_2/n-Pentane have also been tested. The first one allows stable operation only for Isobutane concentrations greater than 45%. In order to further decrease the hydrocarbon content one has to use more complex paraffin hydrocarbons which, due to the higher U.V. absorption cross section, are more effective in controlling the streamer propagation mechanism.

An Ar/CO_2/n-Pentane mixture was successfully used in the NUSEX experiment in the percentage 21/42/37 by volume obtained by flowing an $Ar+CO_2$ mixture in liquid n-Pentane kept at 10° C (n-Pentane (C_5H_{12}) is liquid at room temperature, the boiling point being at 36.1° C). In such a way a reduction of a factor two in hydrocarbon content has been obtained, the perfomances (plateau width and pulse amplitude) being equivalent to those obtained with the standard mixture. From the experience gained in operating the NUSEX detector, the same solution was envisaged for the ALEPH experiment. The vapour pressure of n-Pentane at 0° C corresponds to a concentration of about 25%, which satisfies the safety requirements at LEP.

A systematic study of the behaviour of streamer tubes operated with the Ar/CO_2/n-Pentane mixture has been performed. The influence of gas composition on efficiency, charge distribution and stability of operation has been investigated, and the results of these tests are presented.

2. THE EXPERIMENTAL SET-UP

The measurements have been performed with the set-up shown schematically in Fig. 1. A,B,C, D are four 1 m long ALEPH streamer tubes shielded on three sides by a Pb box 5 cm thick, in order to cut out most of the cosmic ray soft component.

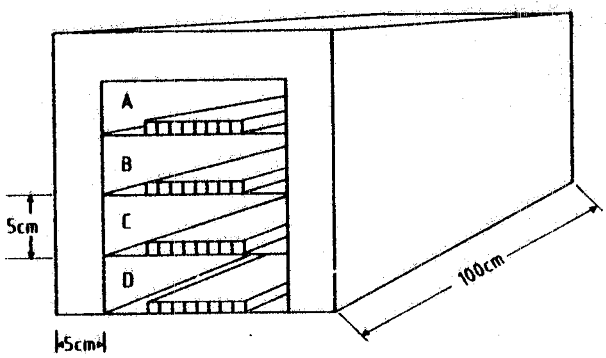


FIG. 1 - Schematic sketch of the experimental set-up. A, B, C, D are 1m long ALEPH streamer tubes shielded on three sides by a Pb box 5 cm thick.

The unit is an 8-cell extruded PVC open profile. The single cell is 9x9 mm^2. 100 µm Be-Cu anode wires are soldered at both ends on printed circuit boards, where they are connected to a common high voltage bus. The wires are kept in place by PVC spacers. The tube walls are coated with graphite (50KΩ/□<R<1MΩ/□) and the whole system is inserted in an uncoated plastic container as shown in Fig. 2a. For this reason such tubes are called "cover-less". After the application of the high voltage, the drifting positive ions, produced by the streamer, charge-up the uncoated wall until the stable configuration of Fig. 2b is reached. The charge-up time depends on the radiation level and it is, in any case, quite fast. The operation of these tubes is similar to the

NUSEX ones, with a difference of 150 V shift towards higher voltages. Details of cover-less tube operation are given in [2].

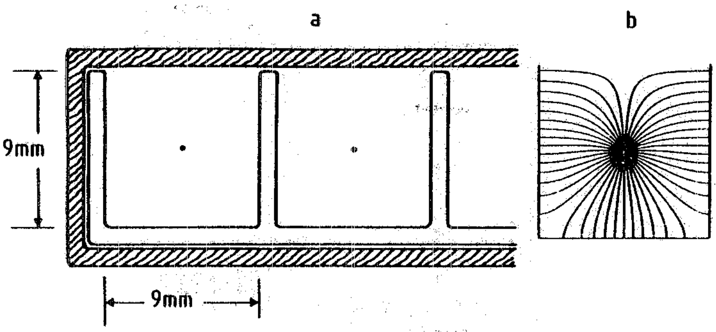


FIG. 2 - a) Geometrical structure of cover-less plastic streamer tubes.
b) Configuration of electric field lines for cover-less plastic streamer tubes.

Outputs from the 8 contiguous channels of each tube are OR-ed together. Pulses from A, B, D tubes are put in coincidence to select a cosmic ray beam crossing the test tube C. The output from this tube is split: one signal is fed directly into the input of a LeCroy 2249W ADC gated (1μs integration time) by the ABD coincidence, the other one is shaped to 1 μs by means of a non updating discriminator with 10 mV/50Ω threshold. Both are sent to a scaler to count the quadruple coincidence ABCD. In this way single counting rates, efficiency and charge spectra have been measured simultaneously as a function of the H.V. for different gas mixture compositions.

3. GAS CONTROL SYSTEM

Great care has been devoted to the control and monitoring of the gas composition. A gas handling system has been developed similar to the one installed in the NUSEX experiment, but with upgraded perfomances. Flow rates of Argon and CO_2 are controlled and measured by means of mass flowmeters with accuracy of ± 1% full scale and reproducibility of ± 0.2%. These gases pass through a mixing cell and the resulting mixture is sent to a two-stage system as shown in Fig. 3. In vessel B, filled with n-Pentane at room temperature, the gas saturates with hydrocarbon vapours at the temperature t_B. This mixture is then bubbled through vessel C filled with n-Pentane at controlled temperature $t_C < t_B$. Part of n-Pentane vapours are released as liquid phase in this bath whose level is kept constant by means of a syphon allowing the exceeding liquid to drop into vessel B. In such a configuration, the bath at controlled temperature works with a constant liquid level independently of the filling up operations which are performed when transferring the n-Pentane stocked in vessel A into vessel B.

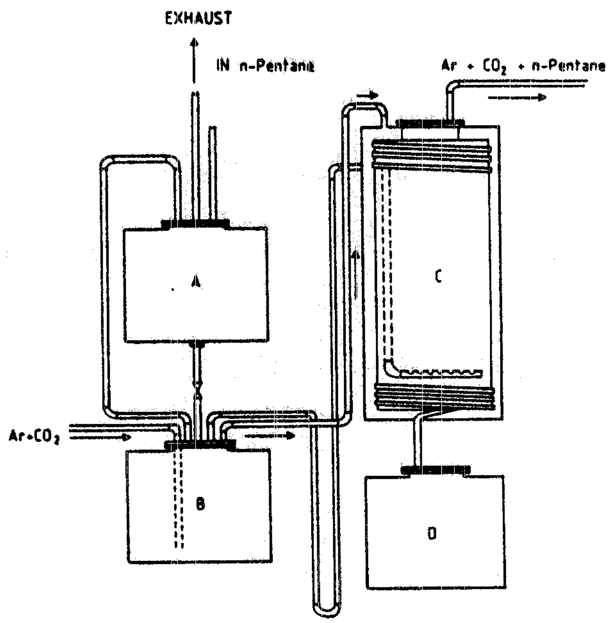


FIG. 3 - Schematic sketch of the gas handling system for the ternary mixture Ar/CO_2/n-Pentane.

The temperature in vessel C is monitored by a platinum resistor probe (accuracy better than 0.1° C) placed in the center of the bath.When the n-Pentane temperature rises above an upper limit $t_C + \delta t_C$, a pump is automatically switched-on and glycol at a temperature about 1° - 2° C lower than t_C is sent from vessel D in a coil surrounding vessel C. The uniformity of the temperature in the liquid is ensured by the mixing action of the gas itself bubbling in the whole liquid volume. For this reason the gas outlet in vessel C is accomplished through a drilled plate. This uniformity has been measured by moving the probe inside the whole volume. Temperature differences have been found not to exceed 0.1°C. The circulation of glycol is stopped when the temperature of the bath reaches the lower limit $t_C - \delta t_C$. As a result the liquid temperature cycles inside a fixed interval of ± .3°C. An appropriate tuning of the temperature ranges allows an uncritical, stable and well reproducible operation.

4. EXPERIMENTAL RESULTS

Results obtained at n-Pentane temperature of -0.5[±.3]°C , 4.5[±.3]°C , 8.5[±.3]°C corresponding to n-Pentane concentrations of 23.5% , 29.5% , 35.0% by volume are reported. Values in square brackets define the interval of temperature cycling as explained in sect. 3.

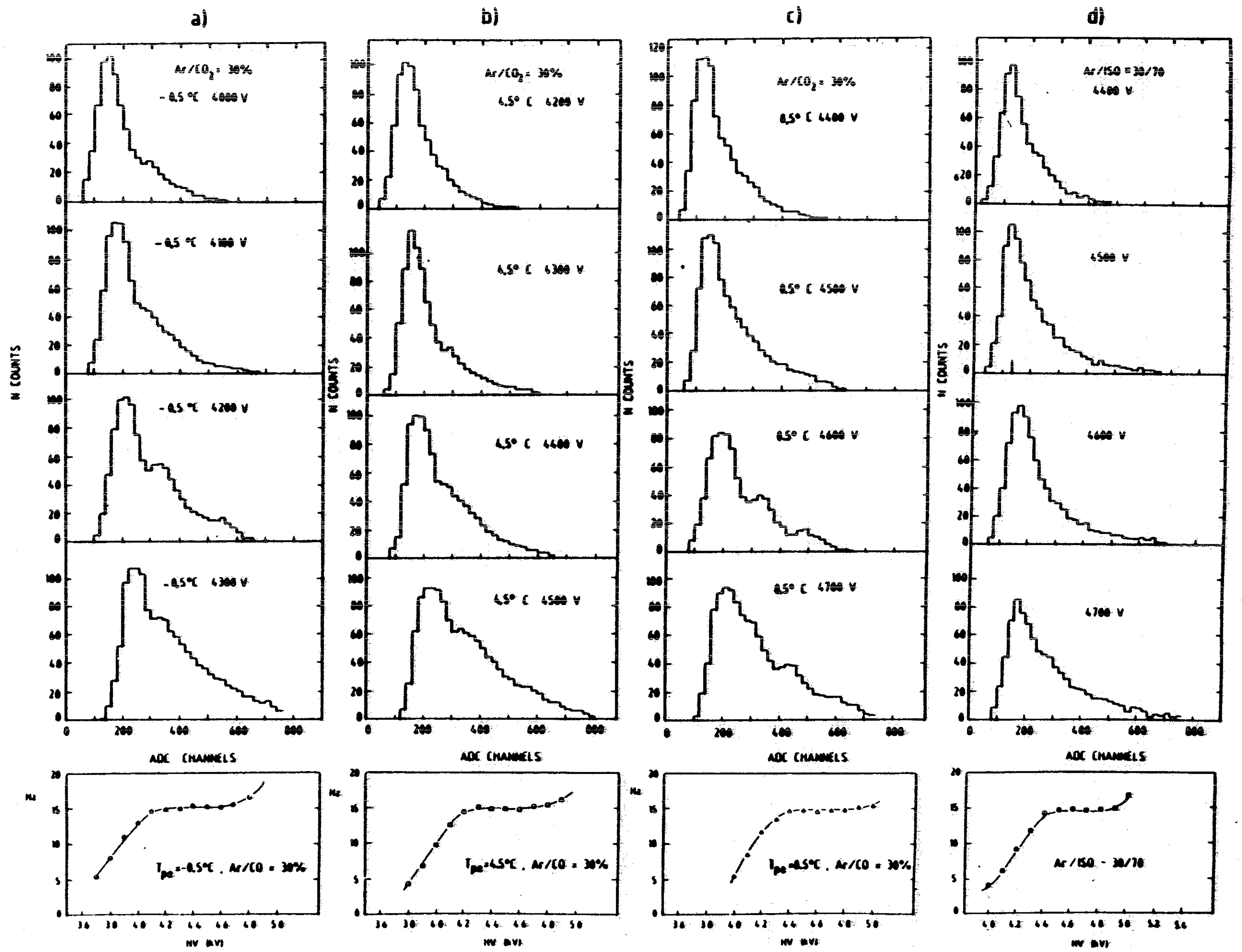


FIG. 4 - Sample of singles rate plateaux and charge distributions at different voltage for: a) Ar/CO_2 = 30% and Tpe=-0.5°C; b) Ar/CO_2 = 30% and Tpe= 4.5°C; c) Ar/CO_2 = 30% and Tpe= 8.5°C; d) Ar/Isobutane=30/70.

The estimated error on the temperature definition is about ±.1°C. This error is estimated from a comparison with three other calibrated platinum resistor probes. This correponds to an uncertainty of ~.5% on the n-Pentane total volume.

For each temperature data have been collected as a function of the Ar/CO_2 relative concentration (i.e. Ar/CO_2 = 25% means that 1 volume of Ar and 4 volumes of CO_2 are mixed before being bubbled through the liquid). A Sample of singles rates and charge distribution are shown in Fig. 4 for a relative concentration Ar/CO_2 = 30% at the three n-Pentane temperatures. For comparison singles rate and charge distribution in the operation with the standard mixture (30/70) Argon/Isobutane are also shown. The efficiency was found to be about 92%, independent of the gas mixture and compatible with the geometrical one. These plots show that the shift of the knee of the singles rate plateau is a function of the quencher concentration, and also that secondary peaks, due to after-pulses, increase with voltage.

One must stress that the working conditions where after-pulses are produced, are a safe region of stable operation for digital readout purposes. Nevertheless an appreciable after-pulses generation can spoil charge resolution and linearity even if a broad efficiency plateau were available. Hence data have been analyzed in order to optimize the working conditions for simultaneous digital and analog operations.

a) Singles rate plateau and charge distribution

The onset of full efficiency of streamer generation depends on the Ar/CO_2 fraction as shown in Fig. 5. As expected, the knee of the plateau decreases with increasing Argon concentration, although with a rate depending on the quencher percentage. The operation at potentials as low as 4200 V is always possible, for a fixed n-Pentane temperature, by tuning the Ar/CO_2 relative concentration.

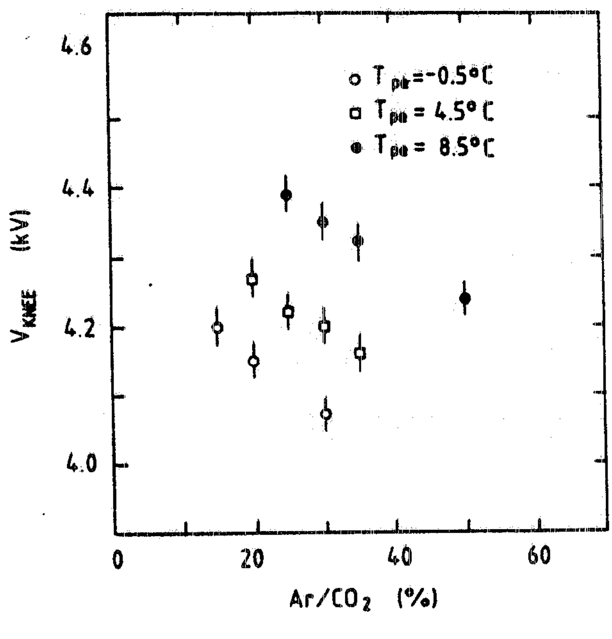


FIG. 5 - Knee of the singles rate plateau versus Ar/CO_2 relative concentration for the three n–Pentane temperature (Tpe =-0.5, 4.5°C, 8.5°C).

The dependance of the peak of the charge distribution on the potential, follows the exponential behaviour $Q \sim e^{KV}$ usual in the proportional regime (Fig. 6), and at the knee of the plateau it varies between 30-40 pC. The value of K, in the range of the tested mixtures, is independent of the n-Pentane concentration. One finds

$K = (19\pm2) \cdot 10^{-4} V^{-1}$ $\quad T_{pe} = -0.5°C$

$K = (16\pm2) \cdot 10^{-4} V^{-1}$ $\quad T_{pe} = 4.5°C$

$K = (16\pm1) \cdot 10^{-4} V^{-1}$ $\quad T_{pe} = 8.5°C$

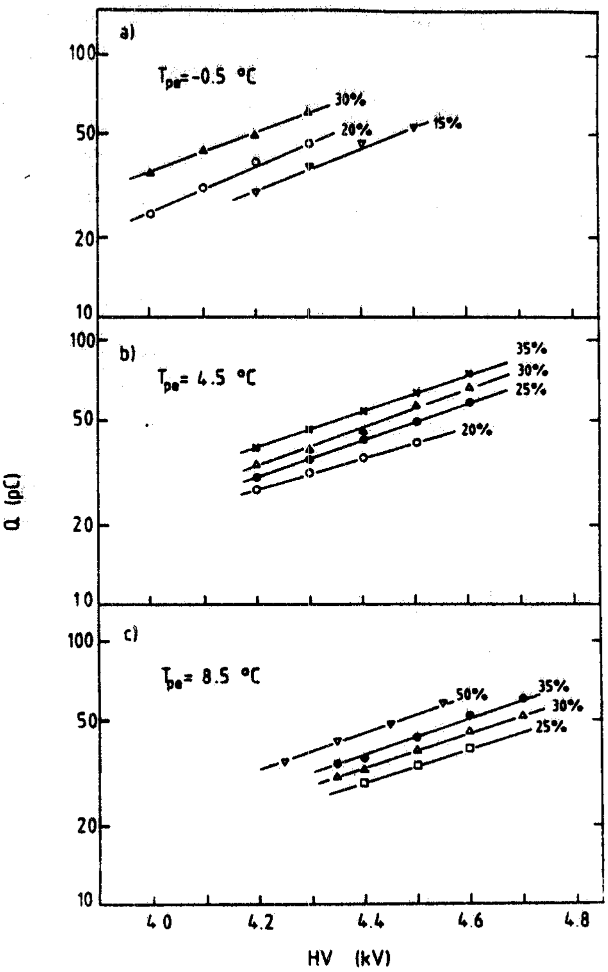


FIG. 6 - Peak of the charge distribution as a function of the voltage for: a) Tpe=-0.5°C, Ar/CO_2 = 15%, 20% 30%. b) Tpe=4.5°C, Ar/CO_2= 20%, 25%, 30%, 35%. c) Tpe=8.5°C, Ar/CO_2 = 25%, 30%, 35%, 50%.

showing that the collected charge changes typically of 17% for 100 V increasing potential.

The streamer process is expected to produce a charge distribution with a reduced Landau tail, because of the saturation of the multiplication mechanism. On the contrary, the experimental distribution shows a high amplitude tail, which can be attributed to multistreamers produced by particles crossing the chamber at small angles with respect to the wires, residual soft cosmic ray component and, to a minor extent, to δ rays produced in the material. At the same time, as the high voltage increases, the charge distributions develop multipeaks, generated by the emission of secondary electrons from the cathode. This emission is induced by ultraviolet photons produced in the first streamer process and not fully absorbed. This leads to pulses which have ~ 150 ns delay with respect to the primary pulse (after-pulses). This delay is the drift time of electrons over the cathode-wire distance.

A noticeable correlation between the peak charge (Q) and the charge resolution (FWHM/Q) has been found, as shown in Fig. 7a, b, c. In performing this analysis the results of the measurements have been put together, for each n-Pentane temperature, irrespective of the relative Ar/CO_2 concentration. Only spectra with a low (< 15%) fraction of after-pulses have been taken into account. The plots indicate clearly that the resolution slowly decreases from 90% to 70% as the charge increases from about 30 to 45 pC. This effect is more evident at low n-Pentane concentrations. Within the measurement errors it is not possible to show any dependence of the effect on the Ar/CO_2 concentration. Once after-pulses have been produced copiously, the charge distribution broadens and the resolution deteriorates. Similar results are obtained with Argon/Isobutane mixture (Q ~ 32 pC, K = $(18\pm1)\cdot10^{-4}V^{-1}$ FWHM/Q decreasing from ~87% to 77%).

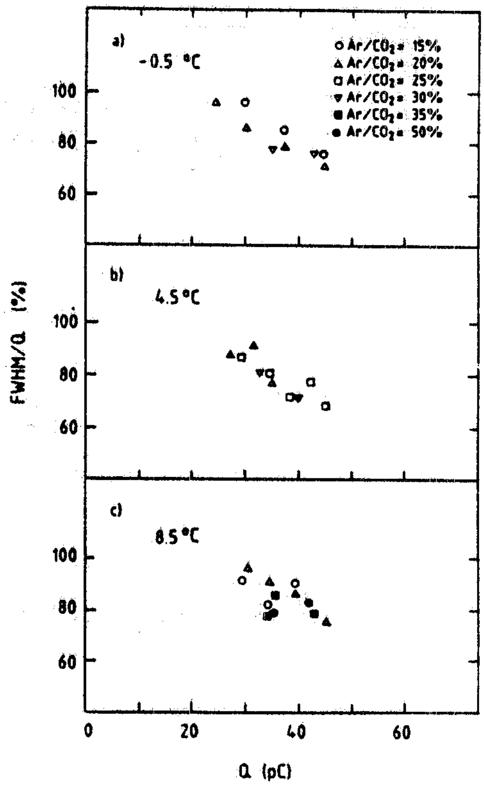


FIG. 7 - Charge resolution (FWHM/Q) versus peak charge at different Ar/CO2 relative concentrations for each n-Pentane temperature: a) Tpe=-0.5°c; b) Tpe=4.5°C; c)Tpe=8.5°C.

In conclusion, streamers develop in the ternary mixtures of Ar/CO_2/ n-Pentane in a similar way as in Argon/ Isobutane, showing that no change occurs in the basic generation mechanism. However our investigation shows that the three component gas mixture gives a streamer tube perfomance not completely equivalent to that of the Ar/Isobutane when a low (<15%) relative concentration Ar/CO_2 is used. In this case the approach to the full efficiency tends to be smoother and the plateau curve is not so flat as for Ar/Isobutane mixture. The first effect is clearly related to Argon being the primary source of UV radiation capable of ionizing the gases. The second effect is characterized by a rise in counting rate of up to 5% for a 100 V increase in operating voltage. The departure from flatness of the plateau has been found to be due to the presence of very delayed (> 50μs) spurious counts. After-pulses seen on μs timescales in proportional counters have been attributed to the neutralization of ions, or free radicals, impacting on the cathode and to subsequent secondary emission. This effect is more probable for triatomic gases, such as CO_2, than for heavier molecules which decompose promptly after neutralization. The electrons migrate to the sense wire producing after-pulses with a delay corresponding to the ion drift time of several microseconds. However it is worth remarking that, due to the particular time correlation of this phenomenon, the generation of these after pulses does not influence the charge resolution, only contributing to a slight increase of the noise.

b) Operating ranges

Use of streamer tubes in large detectors requires operation in a region which is stable and reproducibile. The correct definition of the working conditions becomes of primary importance when both digital and analog readout are implemented. A wide high voltage plateau is the main requirement for safe operation far from breakdown processes. Plateaux larger than 400 V can be achieved with a wide range of Ar/CO_2 relative concentrations. At low Argon concentrations the knee moves towards higher voltages, while high Argon concentrations forestall the onset of the discharge process, which in both cases results in a shortening of the plateau length. This effect is shown in Fig. 8 where the length of the plateau at T_{pe} = -0.5 °C is plotted as a function of the Ar/CO_2 ratio.

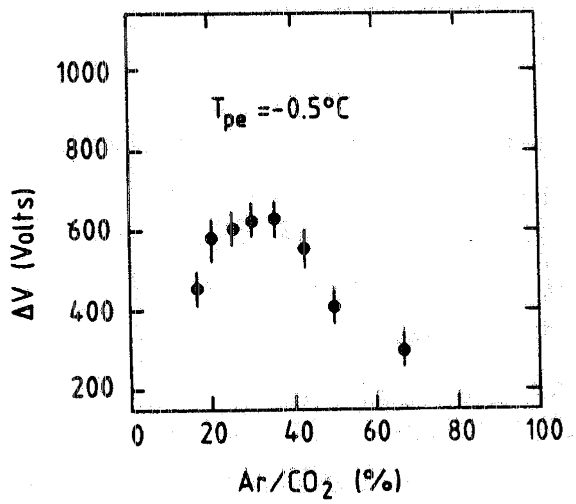


FIG. 8 - Plot showing the plateau legth at Tpe = −0.5°C as a function of the Ar/CO_2 relative concentration.

Analog readout by means of external pads is planned to measure shower energy. This requires more stringent operation conditions (gas and H. V.) than those quoted above, if after-pulse generation has not to affect the detector perfomance. Hence charge distributions have been analized to identify for each gas mixture the high voltage at which a significant production of after-pulses is induced. An operating range has been defined as the potential interval between the knee of the singles rate plateau and the voltage at which after-pulses follow the main streamer signal by more than 15% of the total counts. The result of this analysis is shown in Fig. 9. Operating ranges of the order of > 200 V for combined analog and digital readout can be achieved irrespective of the n-Pentane temperature even if operation at -0.5°C exhibits an enhanced dependence on Argon concentration. Limiting voltages defining the operating ranges has been superimposed on the curves showing the peak amplitude dependance on high voltage, and are presented in Fig. 10. These curves are an useful basis for making the appropriate choice of the working conditions (gas concentration and operating potential).

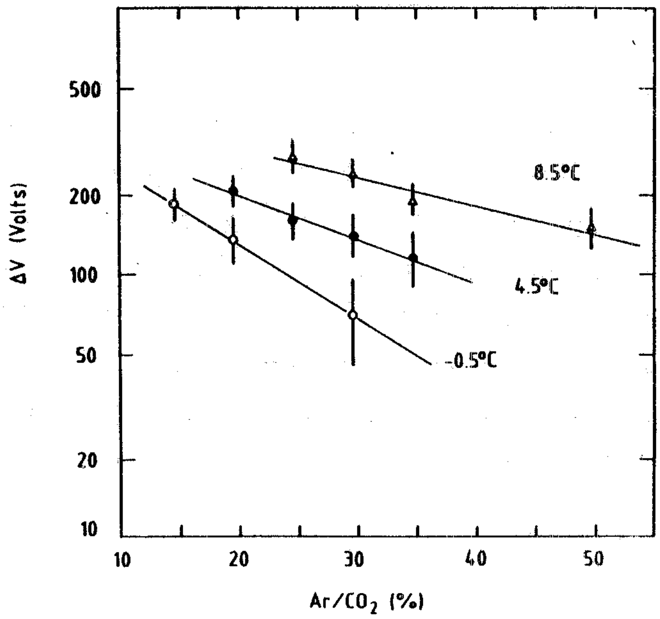


FIG. 9 - Operating ranges (ΔV) as a function of Ar/CO_2 ratio for the three n–Pentane temperatures.

c) Amplitude dependence on gas parameters

Knowledge of the dependence of the charge amplitude on gas parameters is of relevent importance when gas handling systems have to be designed. The relative stability and reproducibility of electronic mass flowmeters are claimed to be better than ±1% [3,4] . Relative variations in the amplitude response of streamer tubes are given by $\Delta Q/Q \sim K_r \, \Delta r$ where r is the Ar/CO_2 relative fraction. Values of K_r for each of the three n-Pentane temperatures are given in Table I showing that a relative stability better than 3% is easily obtained.

Dependence on n- Pentane temperature can be parametrized in a similar way $\Delta Q/Q \sim K_T \Delta_T$. Experimental values for K_T are reported in Table II showing that a 0.2°C uncertainty in temperature is equivalent to less than 2% in the collected charge.

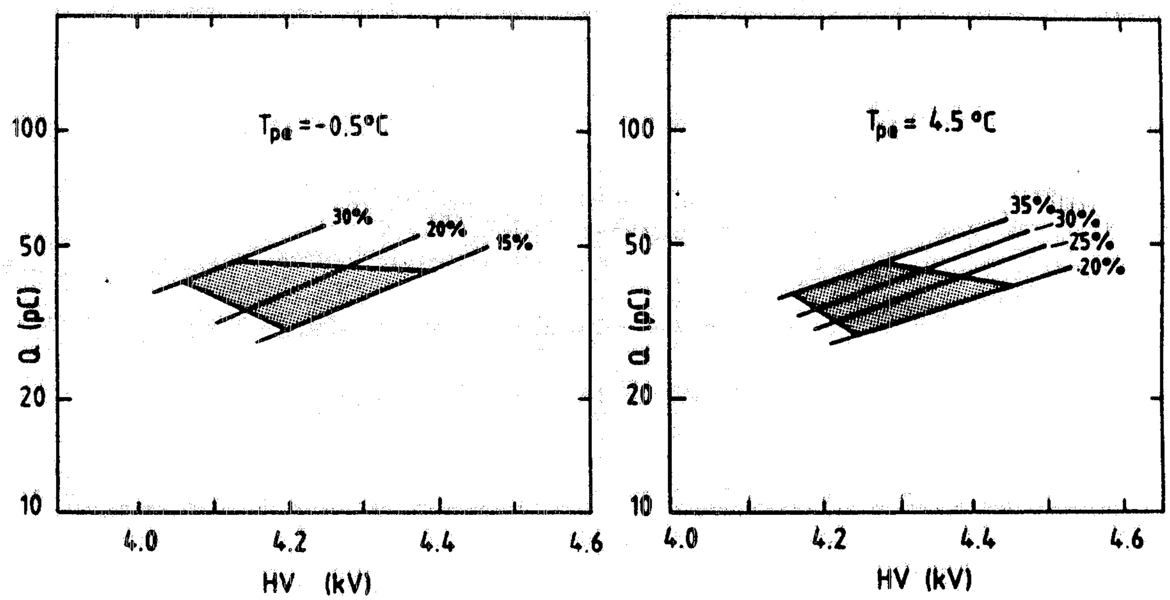
A charge stability better than 4% is thus obtained due to the precision in controlling the gas composition (Ar/CO_2) and the n-Pentane temperature.

TABLE I

T_{pe} (°C)	K_r
- 0.5	3.2 ± 0.2
4.5	2.6 ± 0.2
8.5	2.0 ± 0.2

TABLE II

T_{pe} (°C)	K_T (°C^{-1})
-0.5 ÷ 4.5	$(8 \pm 1) \cdot 10^{-2}$
4.5 ÷ 8.5	$(9 \pm 1) \cdot 10^{-2}$



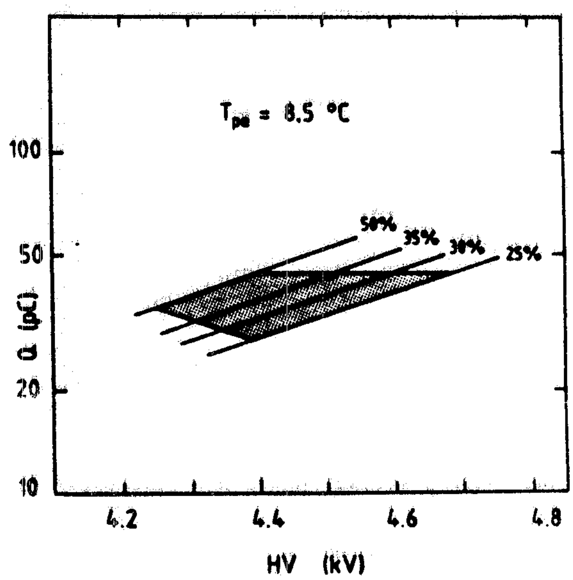


FIG. 10 - Operating ranges (dashed region) superimposed to the curves showing the charge peak amplitude versus high voltage for: a) Tpe= −0.5°C; b) Tpe= 4.5°C; c) Tpe= 8.5°C.

CONCLUSIONS

Our investigation on ternary mixtures of Ar/CO_2/n-Pentane demostrates that one can obtain performances which are practically equivalent to those of the the Ar/Isobutane mixture, by tuning the relative concentration of Ar/CO_2 and n-Pentane. The dependence on high voltage of the charge distribution and efficiency plateau has been measured for different gas concentrations. Hydrocarbon concentrations as low as 25% have been used successfully in stable tubes operation with both digital and analogic readout. Thus this ternary mixture is suitable for limited-streamer calorimetry in a large variety of relative gas compositions. A test module made of 23 iron plates 5 cm thick interleaved with 23 layers of cover-less plastic streamer tubes (in a similar but not equal design) has been operated successfully with Ar/CO_2/n-Pentane (15/60/25) [5]. Operating ranges for streamer tubes used in the ALEPH hadron calorimeter have been determined. Such an investigation could be extended to streamer tubes with different design.

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