Laboratori Nazionali di Frascati

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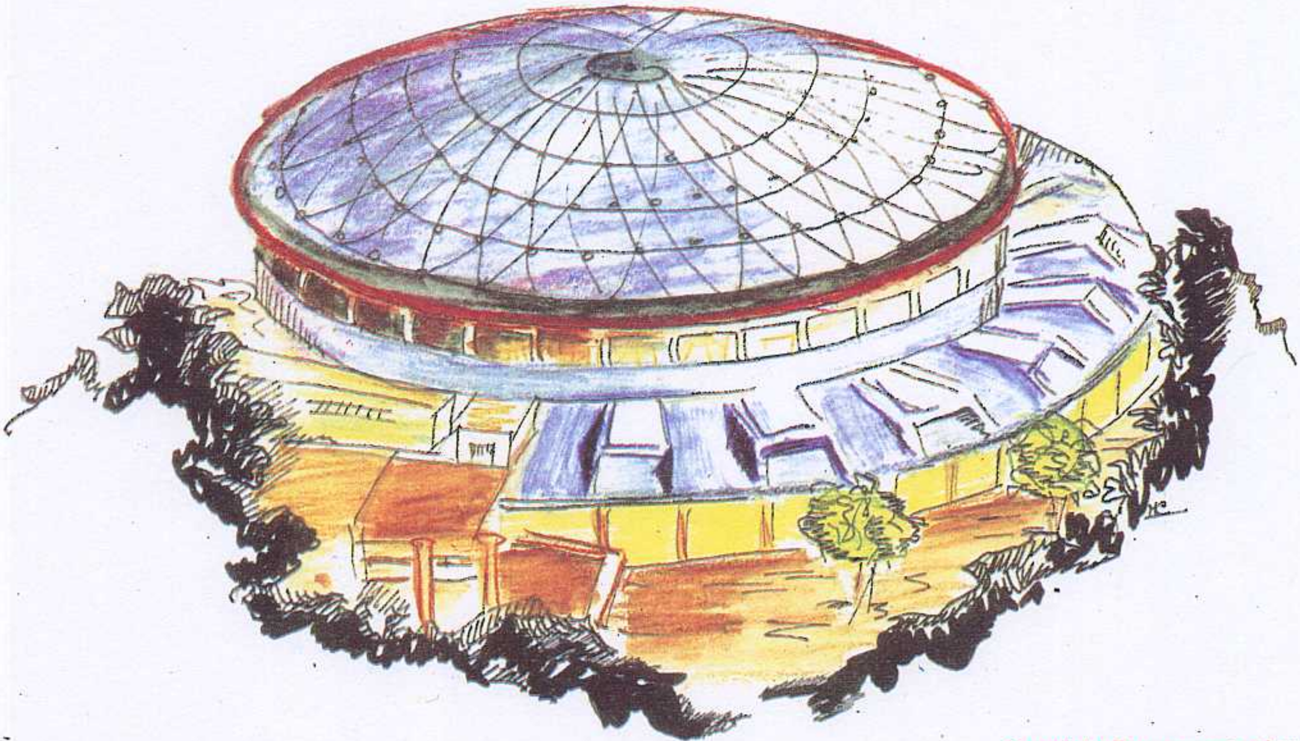
CLUSTER COUNTING IN A HELIUM BASED GAS MIXTURE



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CLUSTER COUNTING IN A HELIUM BASED GAS MIXTURE

G. Bencivenni, E. Carradori, G. Felici and F. Zecchinato
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In this paper the experimental results obtained irradiating with a collimated β–source a drift tube filled with an He(95%)/C_4H_{10}(5%) gas mixture are presented. An upper limit for primary ionization of 7.1 ± 0.3 i.p./cm has been measured. A cluster counting detection efficiency of at least 87% is achieved. The experimental data are compared with the results obtained with a MC simulation reproducing the experimental set–up and based on GARFIELD code.

1 - INTRODUCTION

The CP physics at DAΦNE (the Frascati Φ–factory machine) requires the detection and reconstruction of all the final states of the K_l, K_s decay modes. The main source of background for the $K^0_l \rightarrow \pi^+ \pi^-$ comes from the $K^0_l \rightarrow \pi^+ \pi^- \pi^0$ and the $K_{\mu 3}$ – K_{e3} decay modes. For these backgrounds rejection factors at 10^{-5} level are needed [1]. Kinematical cuts might provide a large fraction of the needed rejection power [2]. DE/Dx measurements, performed in the tracking device, can be useful in $K_{\mu 3}$ background rejection.

The tracking detector of KLOE consists of a cilindrical drift chamber filled with a low atomic number gas mixture, to reduce the multiple scattering over the momentum range of interest (p ≅ 200 MeV/c), and to minimize K^0 regeneration. An helium based gas mixture seems to fulfill these requirements (X_0(He) ≅ 5000 m). A small amount (5% – 10%) of organic gas (C_4H_{10}, CH_4, DME..) is added in order to obtain good and stable operation (good gas amplification, good efficiency and no breakdown). The radiation length of such gas mixtures must be maintained as large as possible (an X_0 ≅ 2000 m being acceptable).

Helium gas mixtures are characterized by low primary ionization density ($\lesssim$ 10 i.p./cm) and small drift velocity (≅ 100 ns/mm). Then an average time separation between two contiguous primary ionization clusters of few tens of nanoseconds is expected. So that in helium gas mixtures primary ionization cluster counting (PCC), rather than conventional total ionization loss (DE/Dx) measurement, should be possible. Because the PCC follows the Poisson statistics, this technique allows to avoid Landau fluctuations that affect conventional DE/Dx measurements. The PCC, proposed the first time by Walenta [3], is then a very powerful tool for particle identification.

The possibility of performing PCC in an He(95%)/C_4H_{10}(5%) gas mixture has been investigated using a square drift tube irradiated by an opportunely collimated β–source. The method used in PCC measurements, based on a simple pre–shaping plus a differential discrimination, will be discussed in the next paragraph. The results obtained on the specific primary ionization measurement of the gas mixture are reported. A comparison between the PCC results and a MC simulation, based on the GARFIELD code, is finally performed.

2 - EXPERIMENTAL SET–UP

2.1 – The experimental set–up is shown in Fig. 1. The drift tube is an aluminum square tube, 5.5 x 5.5 cm^2 cross section and 30 cm length, with a 100 μm diameter wire stretched on its axis. Mylar windows are made along the tube (on the top and bottom side) at different distances from the wire axis (impact parameter "d").

Two Pb–collimators (1 mm diameter, 1 cm thickness) are aligned for each measurement with the windows on the tube, in order to define a thin β–electron beam. The β source is a Sr^{90} – Y^{90} one , with a 2.44 MBq global activity. Typical β–electron energy spectrum of the source [4] is shown in Fig. 2.

A 3 cm thick, 1 cm width plastic scintillator is placed on the bottom of the tube in order to provide the trigger coincidence for the electrons passing through the collimators. In addition, by means suitable cuts on the deposited energy in the scintillator only the minimum ionizing energy electrons are selected. The fast scintillator signal is also used as reference for time measurements.

2.2 – The cluster counting method is based on the possibility of the detector to recognize signals that are close in time. Because in a gas proportional counter [5] a large fraction of the charge signal is collected in a short time (few T_0), while the current continues for a long time (hundreds of μs), in order to perform cluster counting we need to cut the long tail out. Obviously due to the limitation in the minimum signal time width at the baseline, because the electronic noise, the shortening filter must be optimized in order to have a good signal to noise ratio.

The configuration used in the head amplifier (Fig. 3) is the resistive feedback (current sensitive) one. In the working conditions the head amplifier is characterized by a transresistence gain of 10mV/μA and a rise time of about four ns. This stage is followed by a shaping circuit ($\tau \cong 15$ ns) to cut–off the tail due to the ionic motion toward the cathode. The output signal from the shaping circuit is discriminated using a differential discriminator with a delay connected between the two inputs. With this configuration by adjusting the delay and the threshold we can optimize the shaping for the selected detector working condition. In our case the parameters have been adjusted to obtain a final shaping time of about 10 ns.

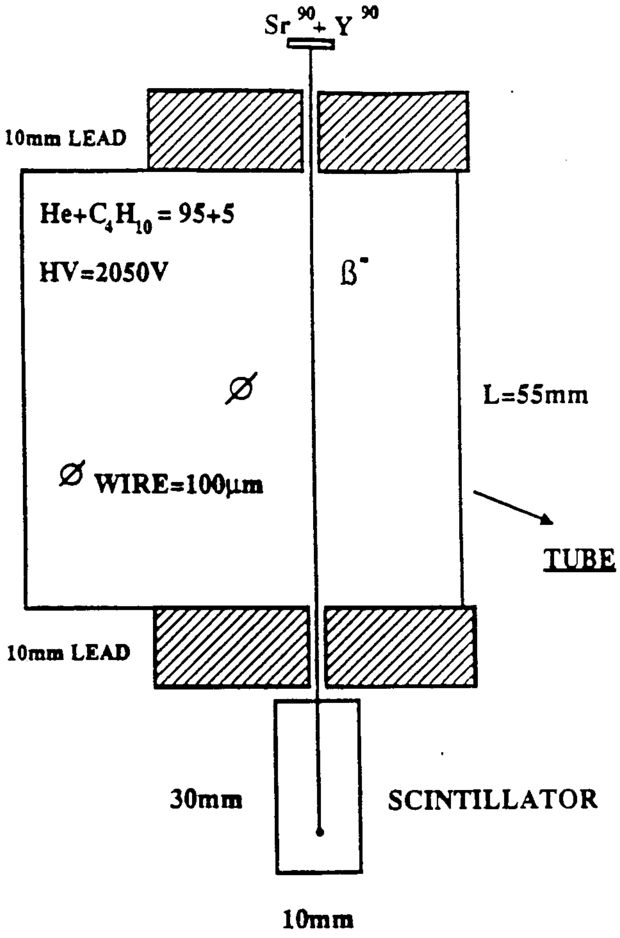


FIG. 1 – Experimental set–up.

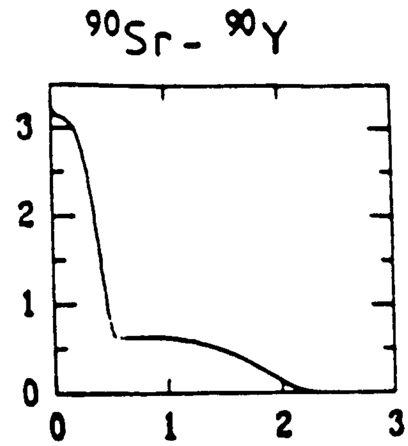


FIG. 2 – Beta electron energy spectrum of the 2.44 MBq Sr^{90}–Y^{90} source used in our measurements [4].

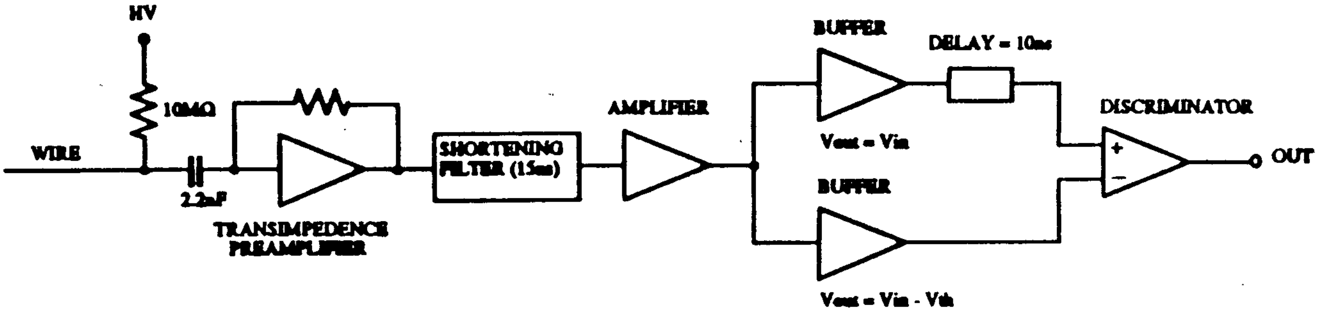


FIG. 3 – Schematic diagram of the electronic chain used in our measurements.

3 - SPECIFIC PRIMARY IONIZATION MEASUREMENTS

The specific primary ionization in gases have been measured by means the inefficiency method with low pressure gas chambers. Typical values for helium and isobutane are respectively 5.9 i.p./cm and 46 i.p./cm [5], giving a value of about 8 i.p./cm for a He(95%)/C_4H_{10}(5%) gas mixture.

The estimate of the specific ionization (N_0 i.p./cm) of our gas mixture has been done performing the measurement of the first cluster arrival time for tracks with an impact parameter $d \equiv 0$ mm. The arrival time distribution should be an exponential one. The knowledge of the space–time relation of our gas mixture, shown in Fig. 4 [6] allows the translation of the arrival time distribution in the spatial one: $f(x) = \lambda^{-1} \cdot \exp(-x/\lambda)$, where x is the distance of the first cluster position from the wire and λ its average ($\lambda^{-1} = 2 \cdot N_0$).

The main limitations on the measurement of λ are the collimator size (± 0.5 mm) and the multiple scattering of the β–electrons inside the gas volume. In both cases the effect is that, in average, the real impact parameter will be not exactly equal to zero. Then the evaluation of the λ parameter from the fit of the experimental data with a simple exponential function represents an upper limit of the real value.

In Fig. 5 the spatial distribution of the first cluster position, obtained at 2050 V, is shown. From the fit of the tail a λ of 704 ± 26 μm is obtained. The results corresponding to different HV supplies are reported in Fig. 6. An average specific primary ionization of 7.1 ± 0.3 i.p./cm is obtained, giving, for our geometry, about 39 clusters.

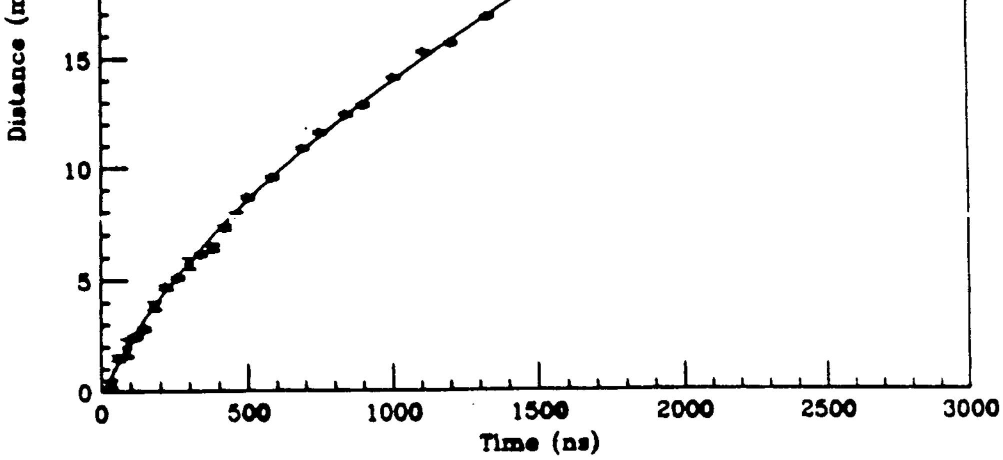


FIG. 4 – Space time relation for a helium/isobutane = 95%/5% gas mixture obtained at 2050 Volt, [6].

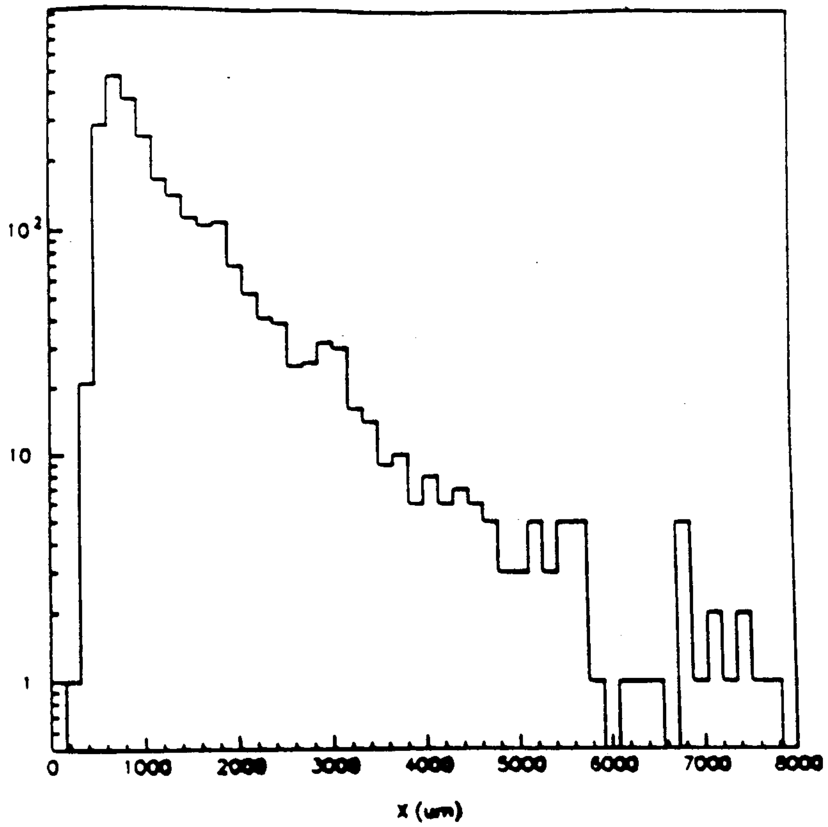


FIG. 5 – Spatial distribution of the first cluster distance respect to the wire.

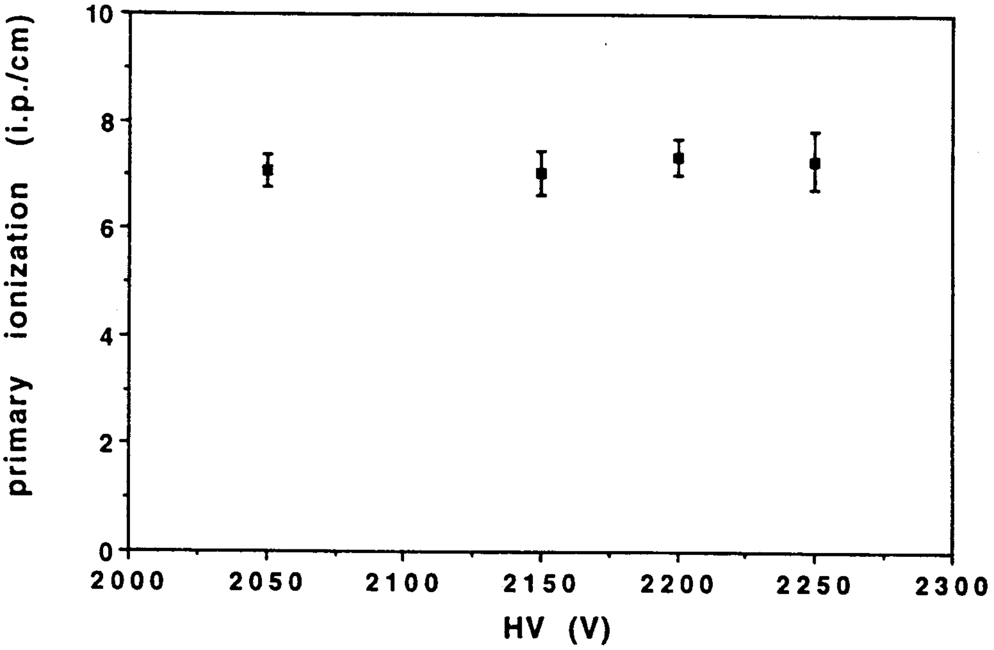


FIG. 6 – Specific primary ionization at different high voltage supplies.

4 - CLUSTER COUNTING MEASUREMENTS AND MC RESULTS

When a particle crosses a gas thickness L, along its trajectory, an average number $N=N_0 \cdot L$ of primary ionization clusters is produced.The average distance between two clusters will be $\Delta x = N^{-1}$. considering an $N_0=8$ i.p./cm (as given in literature, [5]) an average spatial separation of about 1.25 mm is expected. Taking into account that clusters arrive on the wire both from the top and bottom side of the tube cell, an average arrival separation time between clusters of the order of 50 ns is expected (for about 100 ns/mm drift velocity). Following this very simple scheme an electronic dead time τ of the order of 10 ns should be adequate to perform cluster counting measurements with a good efficiency. Obviously clusters separated in time less than τ will be counted as one, and then only with a zero dead time all clusters should be detected.

A more realistic approach must take into account also the effects due to the secondary ionization processes and diffusion. The secondary ionization processes are responsible of the presence of clusters with more than one electron. Average cluster size of the order of $1.5 \div 1.6$ electrons [7] per cluster is expected in our gas mixture. In addition, during the drift toward the wire, because the diffusion, the clusters blow-up and then an electron separation time smaller than the quoted 50 ns is expected. In this case with a $\tau = 0$ dead time a measurement of the total ionization rather than of the primary one is obtained. Then in order to take into account diffusion processes the overall dead time must be opportunely tuned.

In order to simulate the cluster counting response of the set-up a MC simulation based on the GARFIELD code [8] has been performed. The square tube perimeter has been simulated by means a dense structure of wires put very close one to each other. The other MC inputs are:

i) the HV supply (2050 V);
ii) the specific primary ionization (8 i.p./cm);
iii) the mean cluster size (1.55);
iv) the space-time relation (Fig. 4);
v) the diffusion, calculated by Sauli et al [9] in the range $0 < E < 3$ kV/cm at $p = 1$ atm and extrapolated according to the $\sigma(E/P) = \exp(A + B \cdot (E/P))$, ($A = -3.19$, $B = -4.94 \cdot 10^6$ atm cm/V).

In the simulation the possible space charge effects, that could mask a not negligible fraction of the generated clusters, are not considered.

The distribution of the time interval between two successive clusters for a $d \cong 0$ mm track impact parameter, without diffusion, is shown in Fig.7a; an average of about 50 ns is obtained. When diffusion is considered, as previously discussed, one must speaks of single electron time rather than cluster time. In Fig.7b the corresponding distribution for single electron is shown. In this case an average electron time separation of about 33 ns is observed. As shown in Fig.8a,b and 9a,b, increasing the impact parameter both the cluster and the electron average time separation decrease. In Fig.10, for d = 0 mm, 10 mm and 20 mm the expected cluster distributions (without diffusion) and the reconstructed ones (taking into account the diffusion) as a function of different electronic dead time values (5 ns, 10 ns, 15 ns) are reported. A $\tau \cong 10$ ns is largely adequate to reconstruct the right number of clusters, even at track-wire distances up to 20 mm. It must be noticed that, in agreement with the results obtained by Lapique and Puiz [10], the distributions show a poissonian shape.

A typical signal, at the preamplifier output, for a β ray crossing the tube at d = 0 mm is shown in Fig. 11a. The observed multipeak structure is a clear evidence of the signal clusterization. A subsequent differentiation, removing the characteristic long tail of the ionic induced signals, allows a better discrimination between contiguous clusters. In Fig.11b the signal, after a shaping of about 15 ns, is shown; the choice of the shaping time constant coming from a compromise between the need to discriminate close clusters and to have a good signal to noise ratio. In Fig. 12 the average cluster counts as a function of the differential discriminator threshold are reported; a working range around 40 mV is found.

The cluster distribution obtained at d ≅ 0 mm with an electronic dead time of about 10 ns, reported in Fig. 13, shows an average number of clusters <n> = 34.4 ± 0.1 and an r.m.s. = 5.40 ± 0.06. This means that a fraction of at least 87% of the total generated clusters (i.e. 39) are detected. An explanation of the possible losses might be found in the relatively large value of the electronic dead time used in our measurements, the not completely full detection efficiency of single electron clusters (because the very large fluctuations of the avalanche size, [11]) and the possible space charge effects. In addition, as shown in Fig. 14, the average number of clusters slightly depends on the track impact parameter. This result, in agreement with the MC calculations, is a clear evidence that the diffusion effects are dominant.

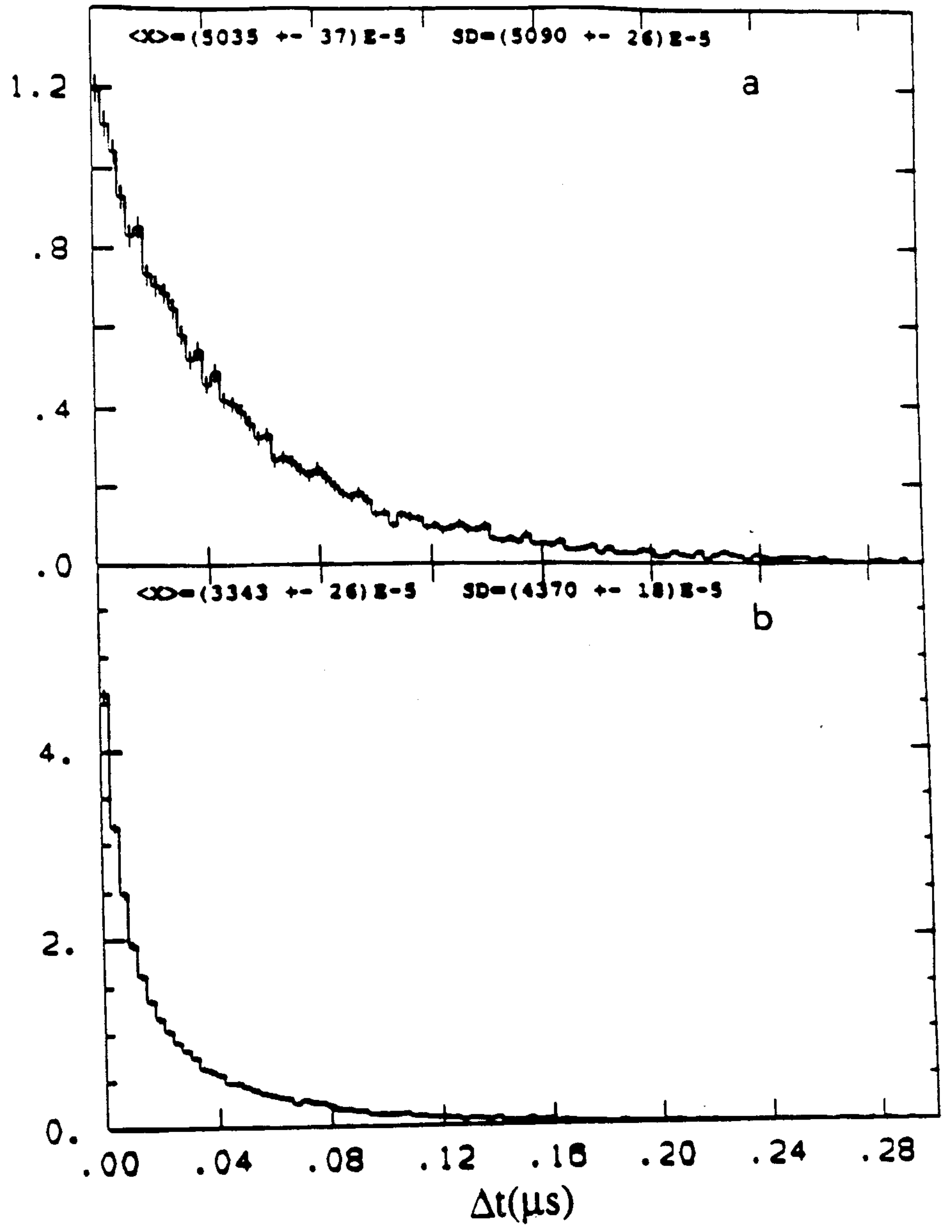


FIG. 7 – Simulated time interval distribution (for d=0 mm) between a) two successive clusters and b) two successive electrons.

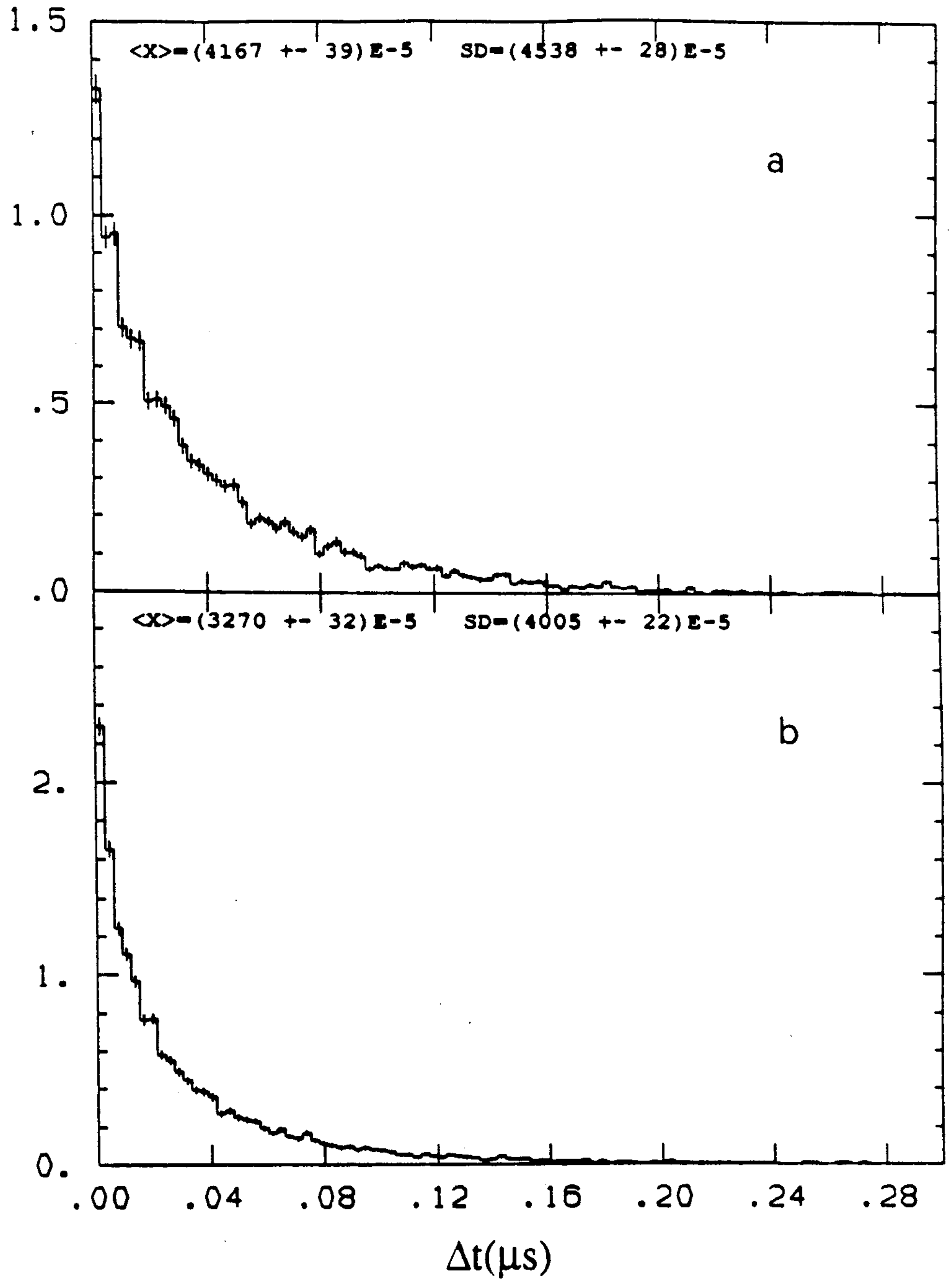


FIG. 8 – Simulated time interval distribution between two clusters for a) d=10 mm and b) d=20 mm.

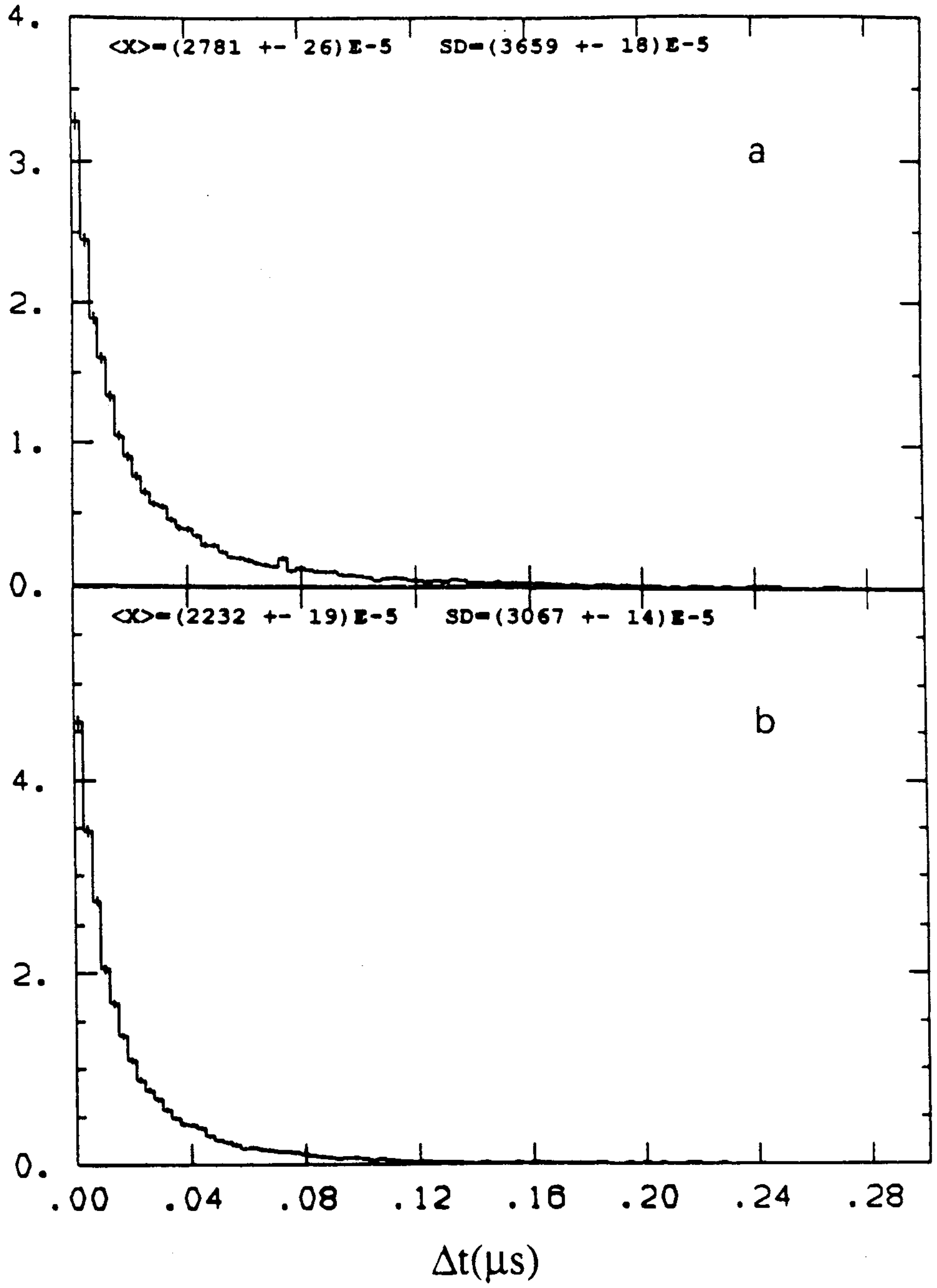


FIG. 9 – Simulated time interval distribution between adjacent electrons for a) d = 10 mm and b) d = 20 mm.

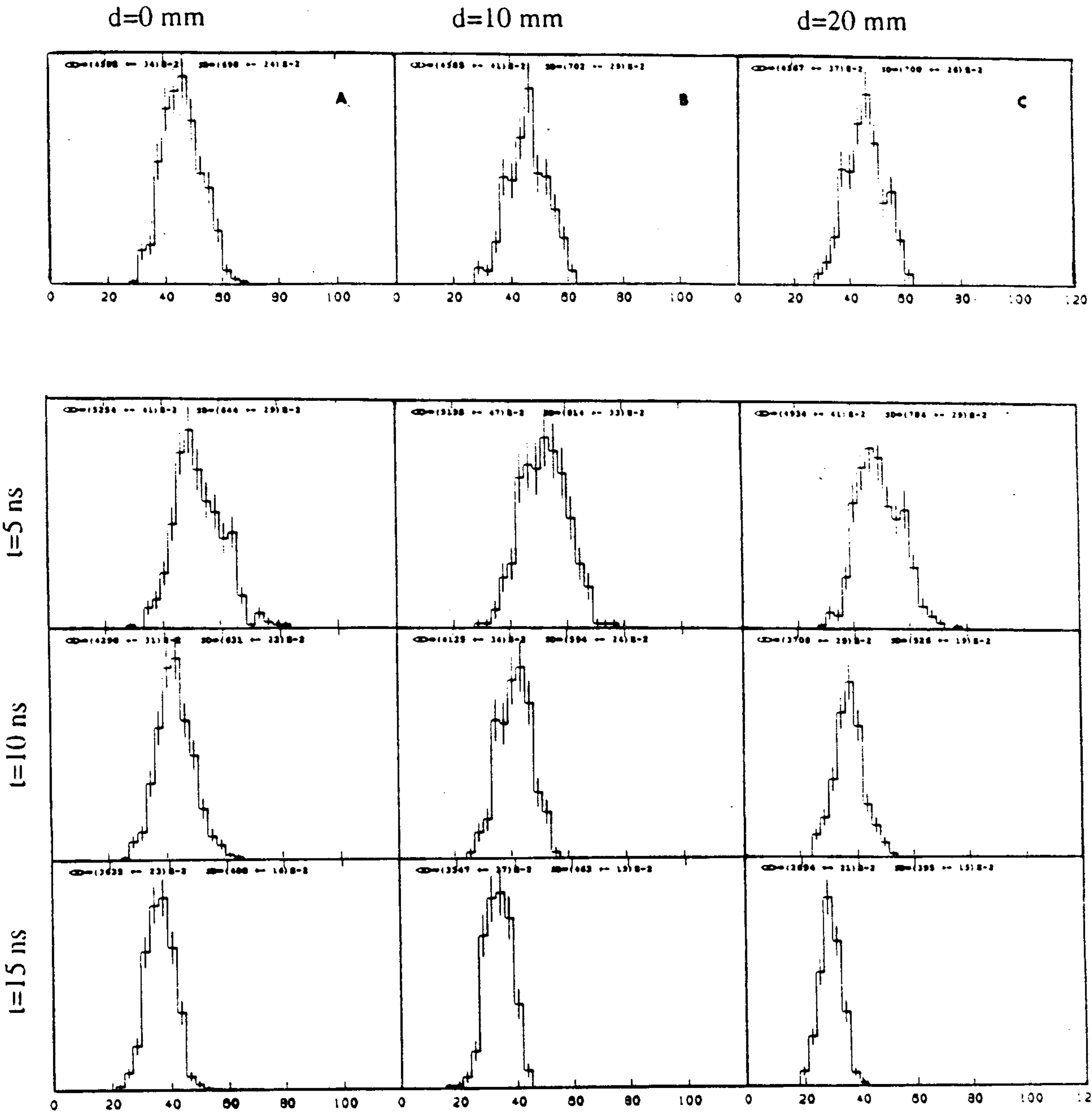
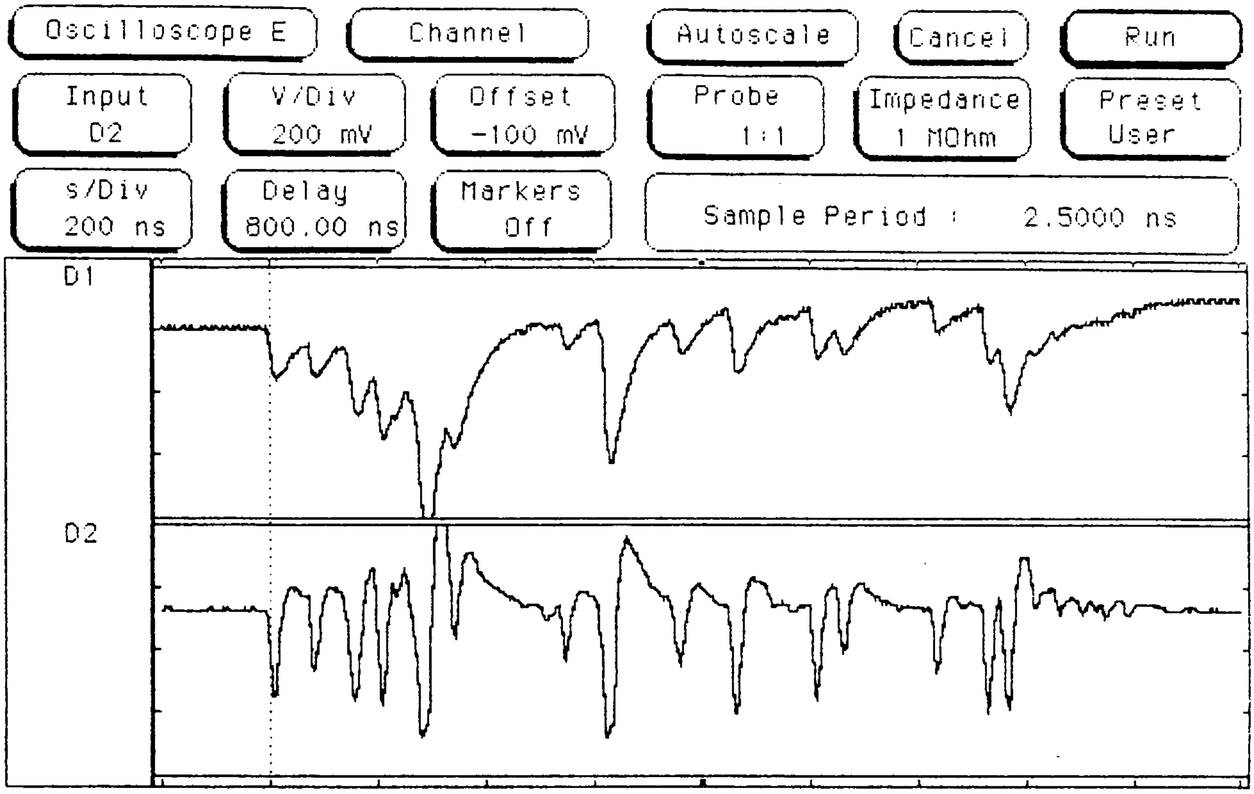


FIG. 10 – Reconstructed cluster distributions with 5 ns, 10 ns and 15 ns electronic dead time are compared, for different impact parameter values, with the expected cluster distributions calculated without diffusion effects.



Input D2

V/Div 200 mV

Offset -100 mV

Probe 1 : 1

Impedance 1 MOhm

Preset User

s/Div 200 ns

Delay 800.00 ns

Markers Off

Sample Period : 2.5000 ns

FIG. 11 – Typical signal obtained with our set–up at a) the preamplifier output and b) the 15 ns shaping circuit output (time scale = 200 ns; vertical scale = 200 mV).

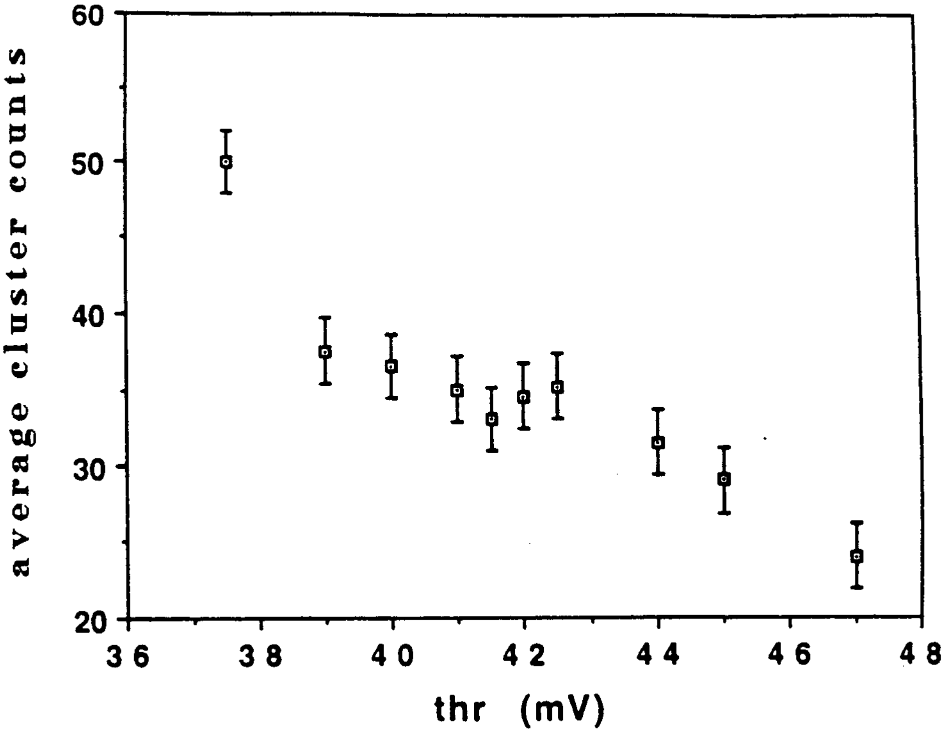


FIG. 12 – Average cluster counts as a function of the applied threshold.

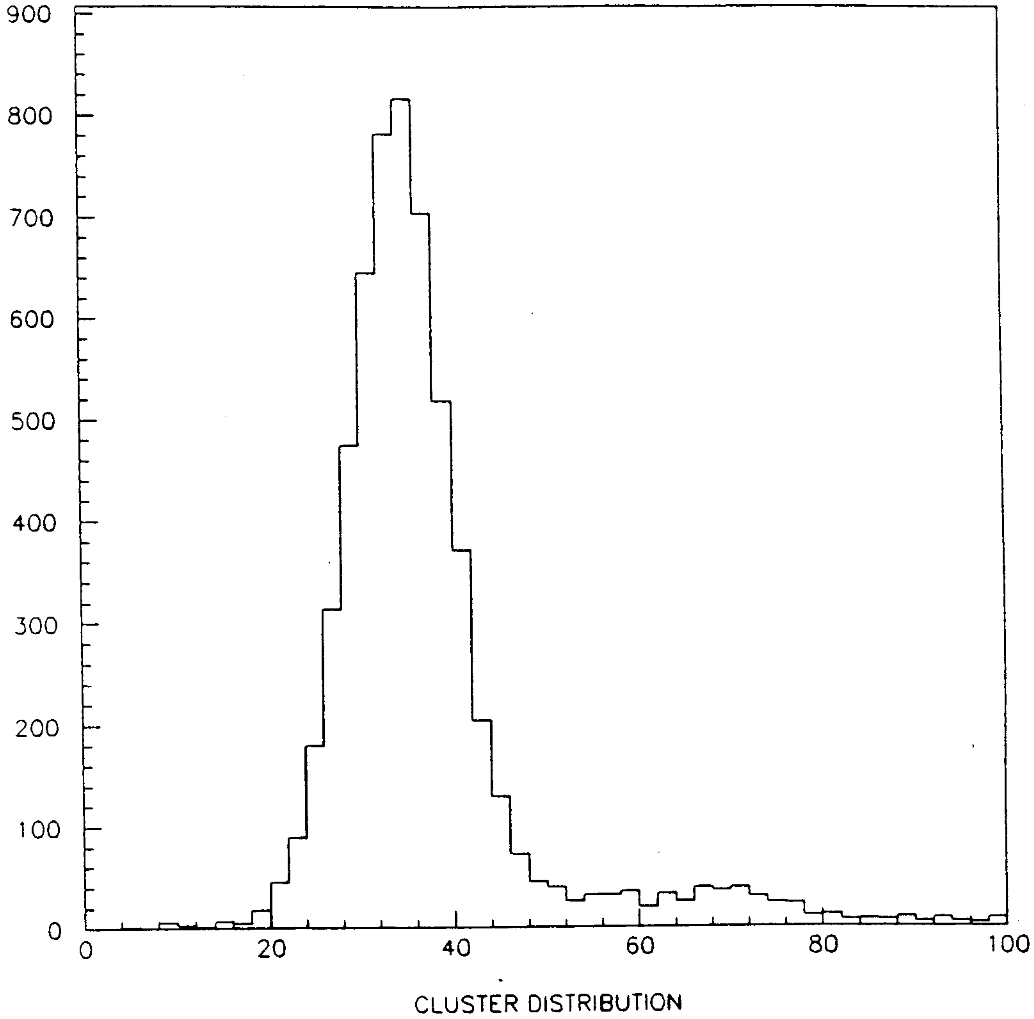


FIG. 13 – Experimental cluster distribution at d = 0 mm obtained with an electronic dead time of 10 ns.

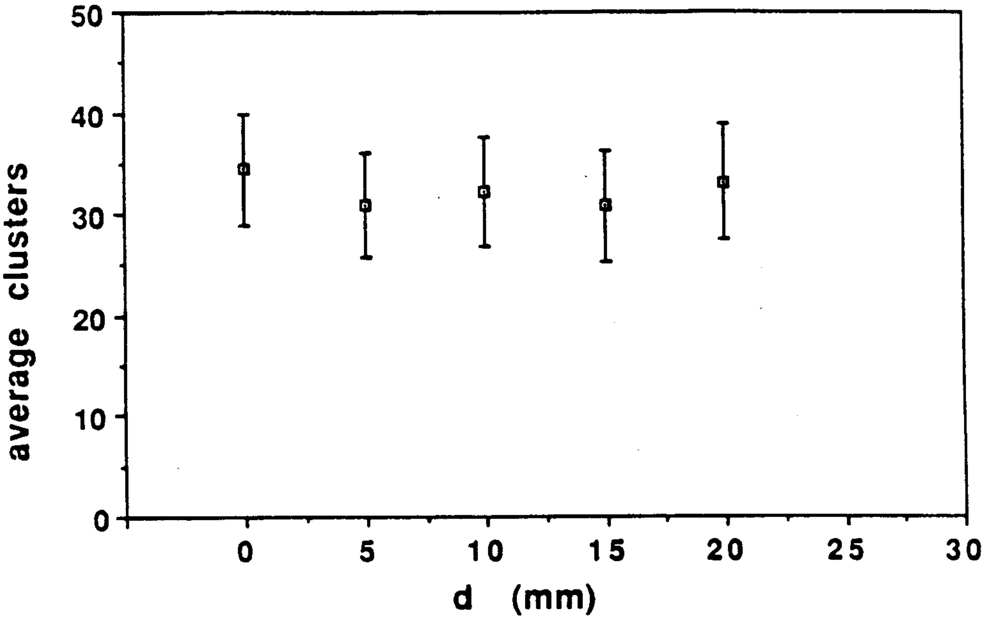


FIG. 14 – Average cluster number as a function of the track impact parameter (the error bars are the cluster distribution r.m.s.).

CONCLUSIONS

Our measurements demonstrate that it's possible to perform cluster counting in a 95% /5% helium/isobutane gas mixture by means simple and cheap electronics with a good cluster detection efficiency. In fact assuming a π/μ separation of the order of 15% at 200 MeV/c and taking into account the results of our measurements a discrimination power $\Delta N_{\pi,\ \mu}/\sigma \cong 3.5$ is obtained for 1 m track length.

A more accurate investigation about the causes of losses and the possibility of improving the cluster detection efficiency, is in progress. In addition helium/methane gas mixtures are under study.

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REFERENCES

[1] M. Piccolo, contribution to the Workshop on physics and detectors for DAΦNE, pag. 707, Frascati, April 9–12, 1991.
[2] F. Bossi and G. Capon, KLOE note 91–05, A. Farilla et al., KLOE note 91–13.
[3] A. H. Walenta, IEEE TRANS. NUCL. SCI., NS–26 vol 1 (1979) 73.
[4] W.G. Cross et al., Phys. Med. Biol., 1983, Vol 28, No 11, 1251.
[5] F. Sauli, Yellow Report CERN 77–09, 1977.
[6] M. Piccolo KLOE note 91–07.
[7] H. Fischle, Nucl. Instr. and Meth. A301(1991) 202.
[8] Rob Veenhof GARFIELD manual version 3.00 pool – W5050 (1991).
[9] F. Sauli, Yellow Report CERN 84–08, 1984.
[10] F. Lapique and F. Puiz, Nucl. Instr. and Meth. 175 (1980) 297.
[11] G. F. Knoll, RADIATION DETECTION AND MEASUREMENTS, 1989 John Wiley & Sons, Inc.