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Wire chamber as a fast, high efficiency and low mass trigger in high magnetic fields.

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Abstract

The efficiency and time jitter measurement results are presented for proportional and drift chambers with 2 mm half gap and CF_4:iC_4H_{10}(80:20) gas mixture in the presence of magnetic field. Data were taken on M15 beam line at TRIUMF for positrons with momentum 35 MeV/c. It is demonstrated that two layers of PCs when combined have better than 99.995% efficiency of positron detection in magnetic fields up to 6 T. The time jitter (RMS) of the sum signal from three layers of PCs does not exceed 2.3, 2.9 and 3.9 ns at $B = 0, 3, 6$ T respectively. The time shift of this signal does not exceed 2.0, 2.25 and 4.4 ns at $B = 0, 3, 6$ T respectively for the positron's incident angle (with respect to PC plane normal) range from 0 to 60°. Such PCs will serve as zero time trigger for PDC chambers with *DME* gas in TRIUMF Experiment 614 [1].

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1. Introduction

The "surface" muon beam with momentum 29.8 MeV/c from the M13 beam line at TRIUMF will be used in the Experiment 614 spectrometer as a source of muons with polarization > 0.9999 opposite to muon momentum. The experimental apparatus will consist of a superconducting solenoid with the maximum magnetic field 3 T collinear to muon beam direction [2]. Surface muons will stop inside a thin 75 μ m planar aluminum target in the centre of the magnet. Positrons from μ^+ decay going upstream or downstream will be detected by one of two planar drift chamber assemblies (PDCs) located symmetrically with respect to the stopped target. Each PDC assembly will consist of 20 planes $(10X + 10Y)$ perpendicular to the magnetic field direction. Positron spectrum $d^2\Gamma/dEd(\cos\Theta)$ will be analyzed in the energy range 20 MeV$< E <$ 53 MeV and angular range $0.5 < |\cos\Theta| < 0.985$, where Θ is the angle between muon spin direction and positron momentum. Three layers of planar proportional chambers (PCs) will be installed on the both sides of the aluminum-stopped target between the aluminum target and PDCs. PCs signals will provide the detection of μ^+ stops inside target and also give a zero time reference for drift times from positron helix in PDCs. As it follows from Monte Carlo simulations [2], this trigger must meet the following requirements:

(a) The amount of matter must be smaller than that of 20 planes of PDCs (about 40mg/cm^2). Otherwise, positron's backscattering will become essential. It would complicate the task of positron helix reconstruction, having in mind that we will need to accumulate and analyze the statistics of 10^9 $\mu \to e$ decays.

(b) The trigger's time jitter must be $2 \div 3$ ns(RMS). Otherwise, it will deteriorate the space resolution of PDCs with *DME* gas, especially for small distances between a positron track and a sense wire.

(c) The efficiency of the trigger must be better than 99.99%. Otherwise, we shall have more than 10^5 positron helices detected in PDCs only and not in PCs. And for each of these positrons one would have to find a proper zero time using χ^2 method. Obviously, it would slow down and complicate a reconstruction.

Requirement (a) excludes the possibility of using a scintillator counter as a zero time trigger. That is why we have chosen a wire chamber. For our study we selected CF_4:iC_4H_{10}(80:20) gas mixture. This mixture has high primary ionization cluster density (41 clusters/cm at 760 torr) and gas gain more than 10^4 [3]. Time jitter in PCs and PDCs with this gas mixture was measured at $B = 0$ T and $\theta = 0$ [3],[4]. In [5] it was shown that electron transit time in straw tube with CF_4:iC_4H_{10}(80:20) increases slightly at $B = 3$ T compared to $B = 0$ T. We have chosen the 4 mm gap to get inefficiency about 3×10^{-4} for the registration threshold 2e and the number of clusters about 16 [3]. Sense wire spacing was chosen to be 2 mm to minimize the amount of matter in our zero time trigger.

2. Setup

For our measurements we made PC and PDC assemblies. Basic parameters of the assemblies are presented in Table 1. In our calculation of the amount of matter in a chamber we have replaced all sense and field wires by a thin tungsten foil with the same weight. The base for each chamber is a glass frame with thickness 2.000 ± 0.002 mm. Sense and field wires were wound using a method suggested in [6]. The positions of all wires in each plane were measured with MITUTOYO Profile Projector PJ-300 with accuracy ± 0.001 mm.

PCs were mounted into an assembly shown on Fig. 1. Only the parameters of planes *Y2, Y3, Y4* were studied. Sense wire positions along Y-axis in planes *Y2* and *Y3* were identical. Sense wires in *Y4* plane were shifted by 1 mm along Y-axis with respect to *Y2* and *Y3*. Signals from *X1*, *Y1*, *Y5* and *X2* planes were used as a trigger indicating that particles had passed through these planes. Relative positions of wires in PDC assembly were similar to those of PC ones, i.e. *Y4* PDC plane was shifted along Y-axis by 2 mm with respect to planes *Y2* and *Y3*. Measurements were done in *HELIOS* superconducting magnet of TRIUMF μSR facility in magnetic fields up to 6 T. The beam from M15 beam line of TRIUMF at $p = 35$ MeV/c had about 98% positrons and about 2% positive muons. Beam diameter was more than 10 mm(FWHM) so that its distribution density within any 2 mm size PC cell was practically flat. Positrons were detected by Čherenkov counter (see Fig. 1). It was possible to rotate the chamber assembly in YZ plane to the angle $\theta \leq 60°$ as shown by a dashed line contour on Fig. 1.

Signals from wire chambers were amplified by the preamplifiers with input impedance 110Ω, impulse gain 1.5 mV/fC, impulse rise time 6 ns and fall time 18 ns, input noise was about 3200 electrons [7]. Preamps were mounted directly on the chambers assembly. Output signals from preamps were fed to inputs of discriminators via 4 m long 50Ω cables. Discriminator threshold was set to 9 mV (about 6 fC). Further on, standard LeCroy logic modules 429A, 821, 622 were used. Pulse duration of signals from sense wires was set to 500 ns. The signal from Čherenkov counter $\hat{C}$ was formed by ORTEC CFD 934 and delayed by 450 ns. A coincidence signal $X1 \times Y1 \times Y5 \times X2 \times \hat{C}$ was a common start for the LeCroy TDC 2228A. Stops for TDC were delayed signals from individual sense wires, sum signals from all sense wires of one plane and sum signals from several planes. Notation used throughout the paper is the following. *Y3(2)*, for example, denotes a signal from the second sense wire of *Y3* plane, *Y3* stands for a sum signal from all sense wires in *Y3* plane. *Y2+Y3* stands for the sum signal of *Y2* and *Y3* planes. Signal delays between individual wires and also between different planes were set equal with accuracy ± 0.2 ns. Four sense wires from each of *X1* and *X2* planes and three sense wires from each of *Y1* and *Y5* plane were sources of the coincidence signal. Different sets of sense wire triplets from *Y1* and *Y5* planes were selected when the assembly was rotated to maximize the counting rate from the wires. Eight neighbouring wires in each of the tested planes *Y2, Y3, Y4* were used. Their actual wire indexes also varied at different angles θ. The wire numbering scheme was chosen so that for every angle the centre of positron beam profile was approximately between 4^{th} and 5^{th} sense wires of the selected eight.

3. Results

3.1. *Drift time spectrum from PCs*

The measured drift time spectra at several magnetic field settings are presented on Fig. 2 for a signal from individual sense wire (a) and sum signals from planes: (b), (c) and (d). RMS and centre of gravity of the drift time spectra were calculated. They are presented on Fig. 3 and 4 as functions of B and θ. Fig. 5 shows the time jitter RMS and centre of gravity position for *Y3+Y4* planes sum signal as a function of high voltage at $B = 0$ and $\theta = 0°$.

3.2. *Efficiency of PCs*

We define efficiency in the following way. Let, for example, $N(Y3)$ be the number of TDC stops from *Y3* plane. Then the efficiency of *Y3* plane is defined as $\varepsilon(Y3) = N(Y3)/N_{starts}$ and inefficiency — as $\bar{\varepsilon}(Y3) \equiv 1 - \varepsilon(Y3)$, where N_{starts} is the total counts of the coincidence signal $X1 \times Y1 \times Y5 \times X2 \times \hat{C}$ (common start signal for TDC). Inefficiencies of *Y3*, *Y4*, and *Y3+Y4* as functions of the PC's high voltage at $\theta = 0°$ and $B = 0$, 3 and 6 T are presented on Fig. 6.

3.3. *Efficiency of PDCs*

Inefficiency of *Y3* PDC plane versus high voltage at $B = 0$ and $B = 3$ T is shown on Fig. 7. These data were taken for PDC assembly with CF_4:iC_4H_{10}(80:20) gas mixture, also. Fig. 8 gives the dependence of *Y3* plane inefficiency on positron beam intensity at $B = 0$ and $\theta = 0°$.

3.4. *Drift time spectrum from PDCs*

The measured drift time spectra for *Y3* plane of PDC are shown on Fig. 9. One can see that the time jitter of PDC is considerably greater than of PCs. We did not go into detailed study of PDC's time jitter.

4. Discussion

4.1. *Efficiency*

We would like to attract attention to the unusual dependence of inefficiency $\bar{\varepsilon}$ on high voltage. As seen from Fig. 6, the $\bar{\varepsilon}$ value drops sharply at $U > 1.8$ kV. Comparison of Fig. 6(a) and Fig. 6(c) shows that the left sharp edge of $\bar{\varepsilon}$ dependence at $B = 6$ T is shifted by +70 V with respect to $B = 0$ curve. A similar shift can be seen on Fig. 7(a,b). The easy explanation is that the value of Lorenz drift angle for electrons in CF_4:iC_4H_{10}(80:20) gas mixture is essential at $B = 1$ T [8]. Consequently, the time intervals between the arrival of individual clusters to a sense wire are increased. Thus, effectively, a peak amplitude of a sense wire signal is reduced. Since a front-end has always a certain amplitude threshold it results in a loss of gain though the total number of clusters does not get smaller. Note, that the effect of efficiency ε reduction would be observed even if the detection threshold is lower than the average single electron amplitude, because single electron pulse height spectra are flat in various gases [9]. Another reason for ε reduction can be the increase of electron attachment losses due to a longer drift time. This effect is known for pure CF_4 gas [3]. The latter effect was small in our measurements, since the efficiency of each plane gets even higher at $B = 6$ T compared to $B = 0$ T (see Fig. 6).

The next peculiarity of $\bar{\varepsilon}(U)$ dependences is that the expected obvious probability law $\bar{\varepsilon}_{Y3+Y4}(U) = \bar{\varepsilon}_{Y3}(U) \times \bar{\varepsilon}_{Y4}(U)$ is met only in a narrow interval $U = 1800 \div 1850$ V of high voltage (see Fig. 6). For $U = 1850 \div 2050$ V one sees $\bar{\varepsilon}_{Y3+Y4}(U) > \bar{\varepsilon}_{Y3}(U) \times \bar{\varepsilon}_{Y4}(U)$, and for $U > 2050$ V at $B = 0$ T (see Fig. 6(a)) $\bar{\varepsilon}_{Y3}(U) \approx \bar{\varepsilon}_{Y4}(U) \approx \bar{\varepsilon}_{Y3+Y4}(U)$. This can happen if the dead time of *Y3* and *Y4* planes or both grows simultaneously with high voltage. The possible reason for this can be a slow dissipation of positive ion cloud around a sense wire originating from the previous positron event, and, consequently, a long time of temporarily lower efficiency of the affected wire for next positron track. If this hypothesis is valid, then the inefficiency $\bar{\varepsilon}$ value must grow together with positron beam intensity. Fig. 8 demonstrates this efficiency deterioration when positron intensity grows from the working level of $I_{e^+} = 10^3 s^{-1}$ to $I_{e^+} = 8.5 \times 10^3 s^{-1}$. Lowering of a signal amplitude from a straw tube due to this effect with the increase of intensity was observed in [10].

Comparison of Fig. 6(a,b,c) also reveals that the high voltage range of high efficiency widens in higher magnetic field. It can be attributed to clusters being distributed over a longer length along sense wire due to a Lorentz drift, so that the density of positive ions is lower and causes a weaker field screening effect.

Note also, that under the same conditions the inefficiency of *Y3* PDC plane at $B = 0$ T (Fig. 7(a)) is approximately six times smaller than that of *Y3* PC plane (Fig. 6(a)). We have reached PDC inefficiency value 5×10^{-5} (see Fig. 7) which is limited by statistical fluctuations of the number of clusters $n = 16$ per 4 mm length in CF_4:iC_4H_{10}(80:20) gas mixture [3]. From this it is easy to calculate the threshold of our front-end. It amounts to about 1.6*e*. As it follows from Fig. 6(a,b,c) the inefficiency an individual PC plane is $\bar{\varepsilon} \approx 3 \times 10^{-4}$. Therefore, the threshold in this case was about 2*e*. We believe that a lower value of $\bar{\varepsilon}$ can be achieved using a front-end with a lower level of noise and threshold of discrimination than ours (noise 0.5 fC, discrimination threshold 6 fC). Perhaps, it is technically feasible with ASD-8 bipolar integrated circuit [11] or VTX-preamp [12], which have a noise about 0.2 fC(ENC) at capacity of our wire 5 pF.

4.2. Time jitter and shift

The values of time jitter (RMS) for several combinations of PC planes are presented in Table 2. The data in this table are the maximum values of time jitter from Fig. 3. Table 3 gives the maximum relative shift of the drift time spectrum centre of gravity with respect to its minimum value within the angular range $\theta = 0 \div 60°$ (see Fig. 4) at several fixed settings of magnetic field. The analysis of data in Tables 2 and 3 shows that the sum signal from *Y2+Y3+Y4* PC planes has the minimum value of time jitter over the range $B = 0 \div 6$ T and $\theta = 0 \div 60°$. The minimum value of the time shift for $B \leq 1.5$ T is obtained for *Y2+Y3* sum signal, while for $B \geq 2$ T *Y2+Y3+Y4* variant is better.

If a PC assembly is used in an experiment as a time master only, than it can be characterized by the maximum statistical (Table 2) and systematic errors (Table 3). Their average values, obviously, are smaller, especially for $B \geq 3$ T. In our Experiment 614 at TRIUMF, PC assemblies are planned to be used with a zero time trigger for drift time measurements in PDC assembly, which will further be used in track reconstruction. In this case PC's zero time shift can be later taken into account and corrected with adequate accuracy, making use of the data in Fig. 4.

5. Conclusion

To summarize our results:

(a) It is suggested to use a PC assembly with a fast gas as a fast, high efficiency, low mass zero time trigger for PDC assembly with a slow gas.

(b) We have measured characteristics of this trigger for the detection of relativistic positrons with momentum 35 MeV/c in the magnetic field range $0 \div 6$ T and angles $\theta = 0 \div 60°$. It is shown that when using the sum signal from two adjacent planes of PC assembly the inefficiency value is $< 5 \times 10^{-5}$ over a wide ($\Delta U > 120$ V) high voltage range in magnetic field $0 \div 6$ T. The decrease of efficiency is observed for both the sum signal of two planes and for a signal from an individual PC plane when high voltage is increased further. We explain this effect by the screening of electric field near sense wire by the ion cloud from a previous particle.

(c) It is shown that PCs with a fast drift gas can provide time resolution better than 5 ns (RMS) in the presence of a high magnetic field in spite of a large Lorentz drift angle. It is obtained using three planar PCs with a special choice of wire positions. The time jitter of a sum signal from three PCs at $B = 6$ T is 5.1 times smaller than that of one PC and 4.2 times smaller than that of two PCs (see Fig. 3). Note, that at $B =$ 0T this method gives only 1.5 times gain. Using three PCs also makes the systematic shift of a trigger signal at $B = 6$ T three times smaller (see Table 3). These results were obtained for CF_4:iC_4H_{10}((80:20) gas mixture. According to [5] using a CF_4:CO_2:iC_4H_{10}(60:20:20) gas mixture will allow further improvements in time resolution at $B = 6$ T.

(d) It is shown that the efficiency of one PDC plane is six times higher than of one PC plane.

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Table 1. Basic parameters of the PC and PDC assemblies.

SPECIFICATIONS		
	PC's assembly	PDC's assembly
Aperture diameter	80 mm	60 mm
Anode wire spacing	2.000 mm	4.000 mm
Measured deviations (RMS) of sense wire positions	±0.005 mm	±0.002 mm
Anode wire diameter	$12.7\,\mu$m, W(Au)	
Anode wire tension	15 g	
Half gap	2.000 ± 0.002 mm	
Field wire spacing	—	4.000 ± 0.002 mm
Field wire diameter	—	$30\,\mu$m, W(Au)
Field wire tension	—	80 g
Cathodes	$6\,\mu$m double-sided aluminized Mylar	
No. of sense wires in plane	36	15
No. of planes	7	12
Gas mixture	CF_4:iC_4H_{10}(80:20) at 760 torr	
Amount of matter in three planes	5.2 mg/cm^2	8.6 mg/cm^2

Table 2. Maximum time jitter (RMS) of the sum signal from different combinations of PC planes for $\theta = 0 \div 60^\circ$ at several settings of B.

PC planes combination	*Y2+Y3*	*Y3+Y4*	*Y2+Y3+Y4*
B(T)	Maximum time jitter (RMS) [ns]		
0	2.75	2.5	2.3
1.5	3.38	2.75	2.35
3.0	6.63	3.0	2.9
4.5	10.5	7.75	3.25
6.0	20.0	16.5	3.9

Table 3. Maximum time shift of the sum signal from different combinations of PC planes for $\theta = 0 \div 60^\circ$ at several settings of B.

PC planes combination	*Y2+Y3*	*Y3+Y4*	*Y2+Y3+Y4*
B(T)	Maximum time shift [ns]		
0	1.5	2.5	2.0
1.5	1.5	2.87	2.0
3.0	2.75	3.5	2.25
4.5	4.5	4.75	2.5
6.0	14.4	11.9	4.37

Figure captions

1. Schematic of the experimental setup. Sense wires in *Y4* plane are shifted by 1 mm along Y-axis with respect to all other *Y* planes. It was possible to rotate PC assembly in YZ plane in the range of angles $\theta = 0 \div 60^\circ$. The dashed line contour on the figure represents the PC assembly rotated by 10°.
2. Measured PC drift time spectra at U=1980 V for *Y3(3)* wire (a), *Y3* plane (b), *Y3+Y4* planes (c) and *Y2+Y3+Y4* planes (d). All spectra are normalized to equal total counts.
3. PC time jitter as a function of θ and B for *Y3* plane (a), *Y3+Y4* planes (b) and *Y2+Y3+Y4* planes (c).
4. The centre of gravity position of the measured PC drift time spectrum as a function of θ and B for *Y2+Y3* planes (a), *Y3+Y4* planes (b) and *Y2+Y3+Y4* planes (c).
5. The centre of gravity position (a) and time jitter (b) for *Y3+Y4* PC planes drift time spectrum as a function of high voltage at $B = 0$ and $\theta = 0$.
6. Inefficiency of *Y3*, *Y4* and *Y3+Y4* PC planes versus high voltage at $\theta = 0^\circ$ and $B = 0$ T (a), $B = 3$ T (b), $B = 6$ T (c).

7. Inefficiency of PDC's *Y3* plane versus high voltage at $\theta = 0°$ and $B = 0\,\mathrm{T}$ (a), $B = 3\,\mathrm{T}$ (b).

8. Dependence of PDC's *Y3* plane inefficiency at $\theta = 0°$ and $B = 0\,\mathrm{T}$ on positron beam intensity.

9. Measured drift time spectra of PDC's *Y3* plane at $\theta = 0°$ and several values of B. All curves are normalized to equal total counts.

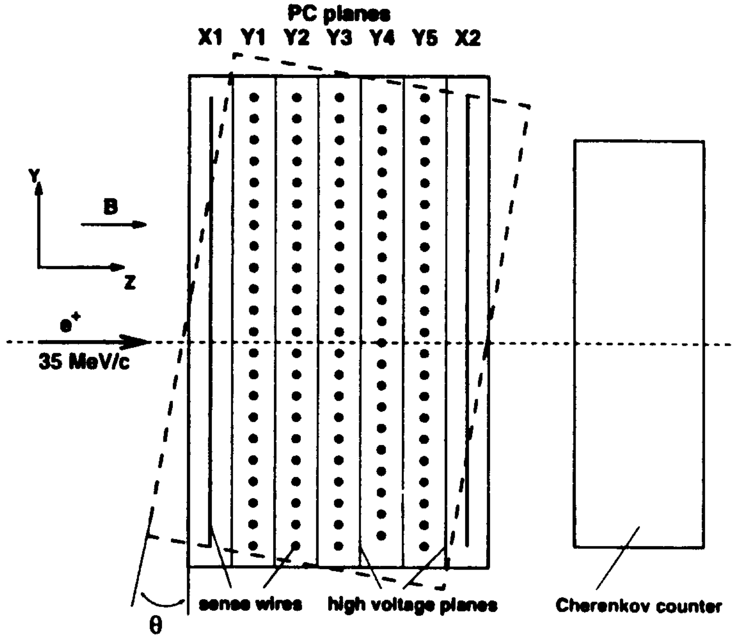

Fig. 1

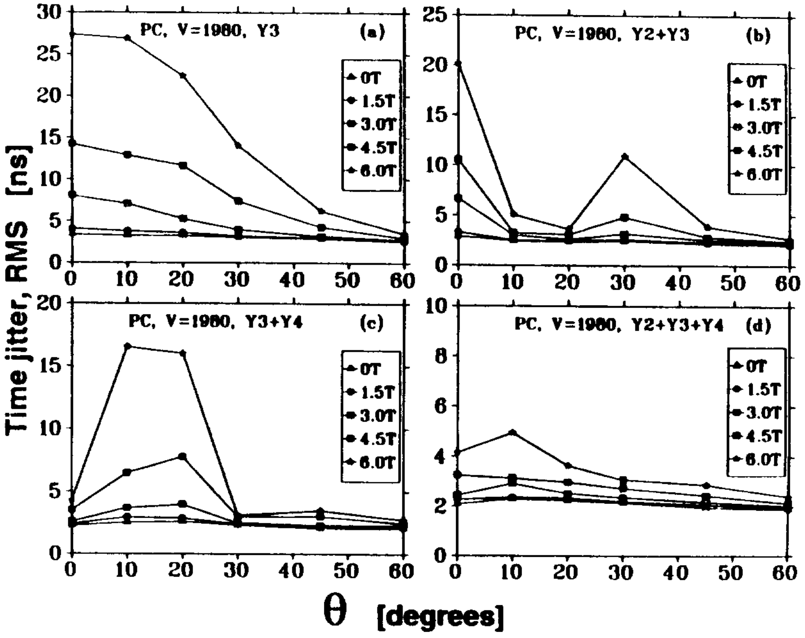

Fig. 2

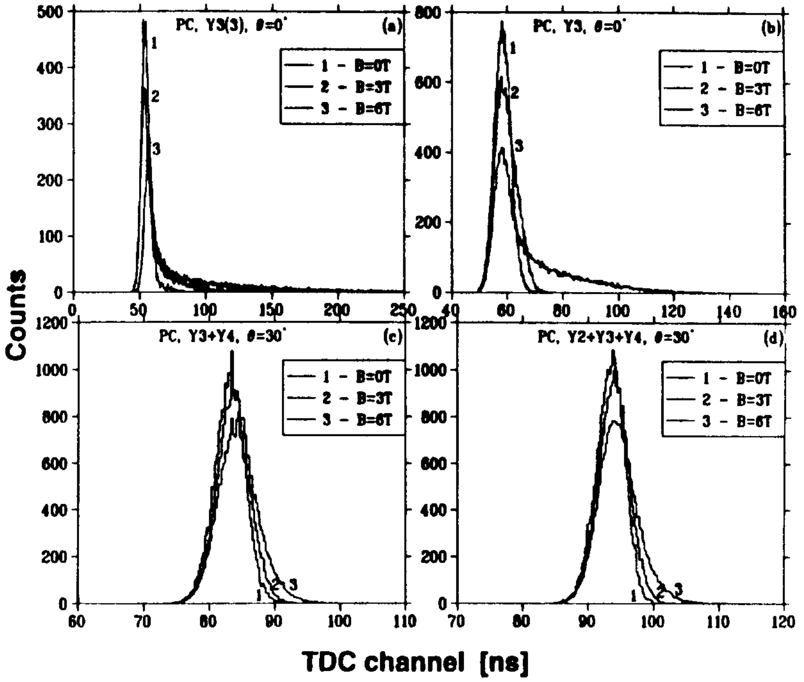

Fig. 3

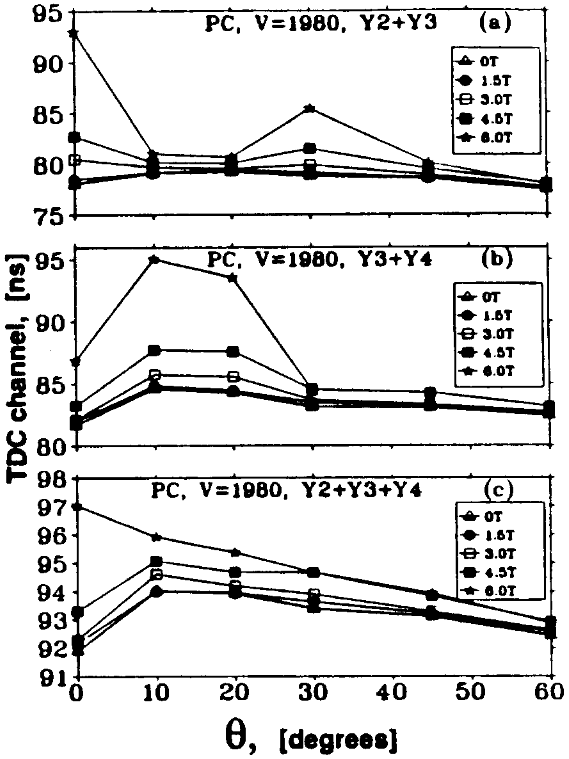

Fig. 4

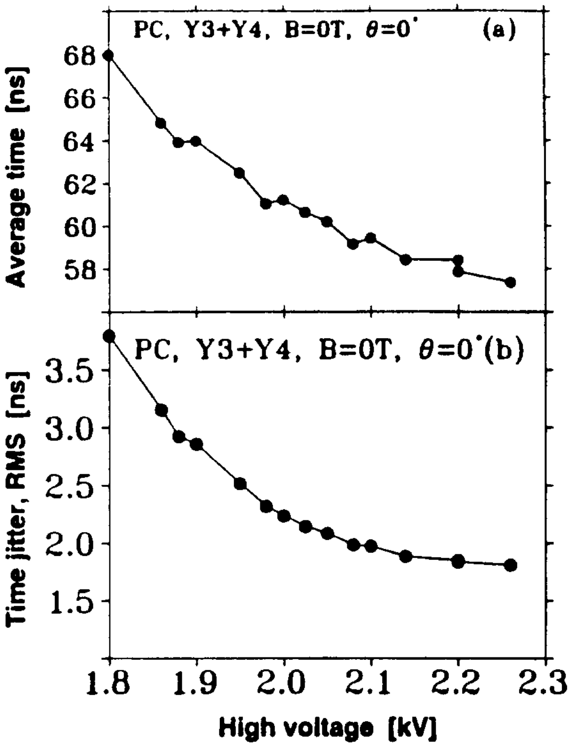

Fig. 5

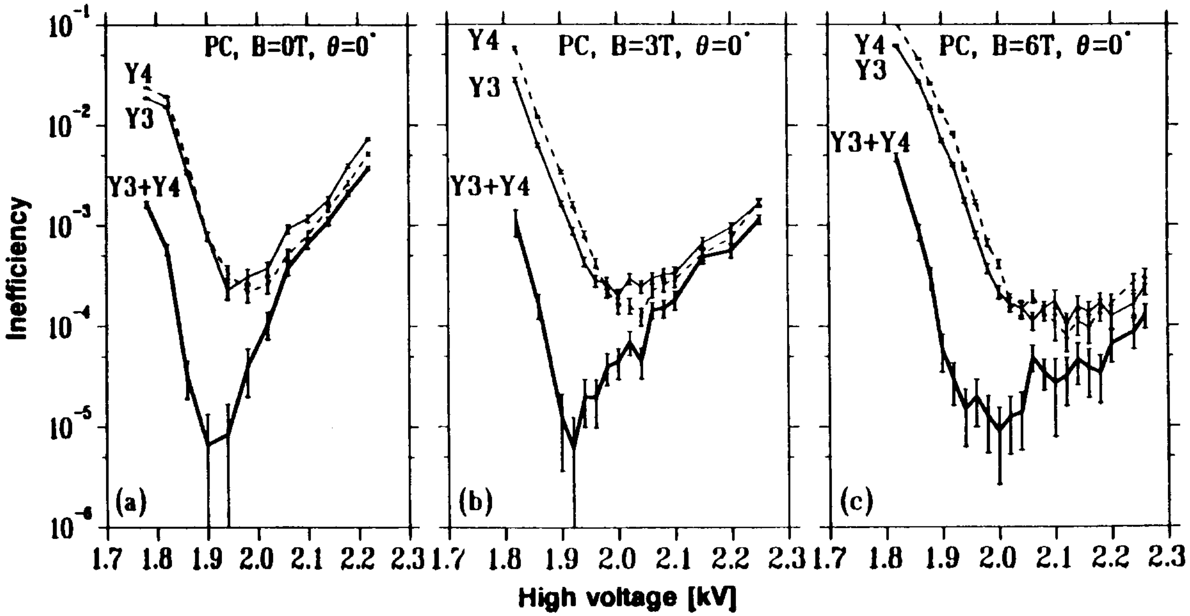

Fig. 6

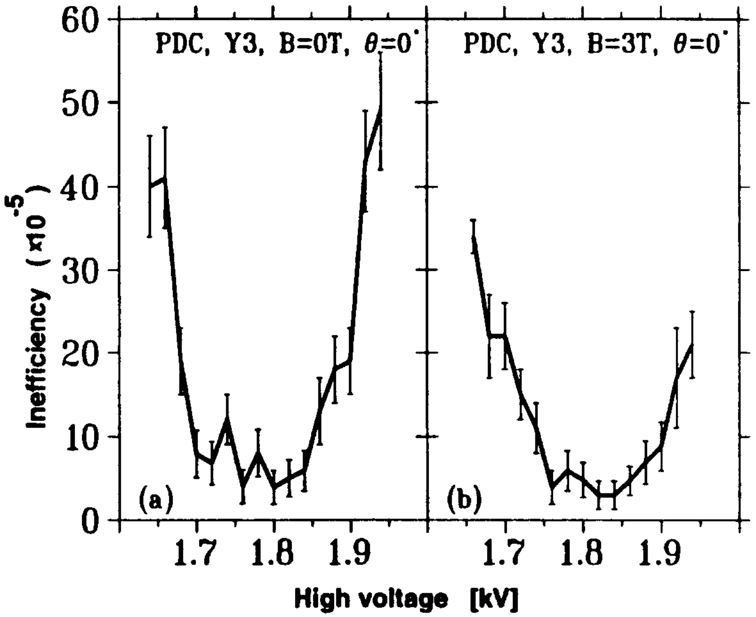

Fig. 7

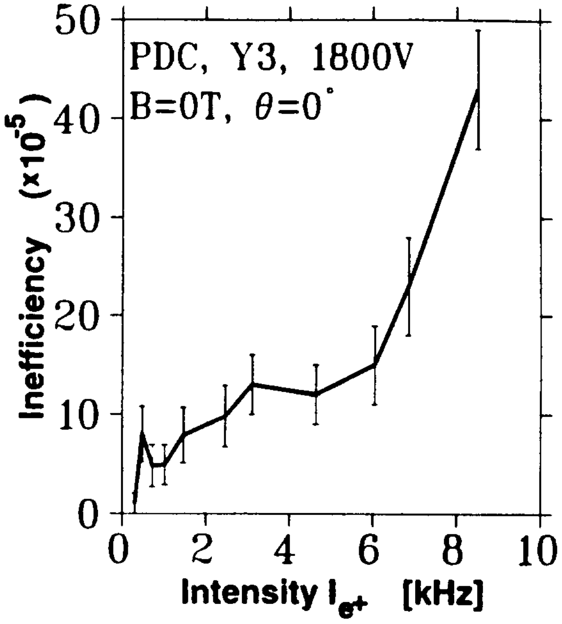

Fig. 8

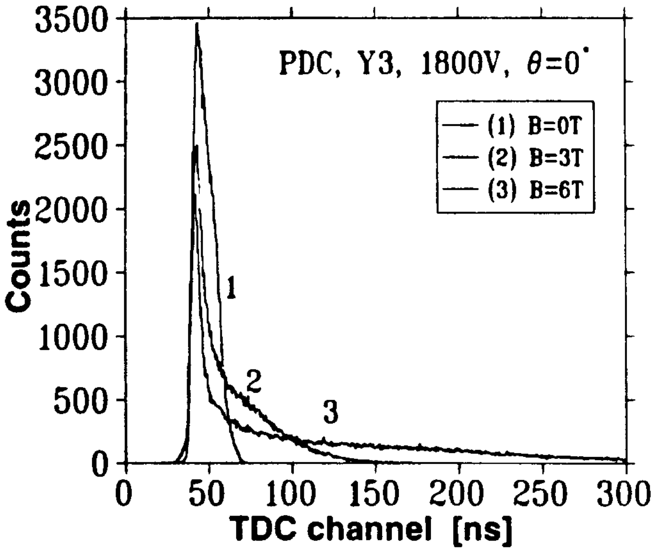

Fig. 9