# 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 $2mm$ 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 $35MeV/c$. It is demonstrated that two layers of $PC$s when combined have better than 99.995% efficiency of positron detection in magnetic field up to $6T$. The time jitter (RMS) of the sum signal from three layers of $PC$s does not exceed $2.3, 2.9$ and $3.9ns$ at $B = 0, 3, 6T$ respectively. The time shift of this signal does not exceed $2.0, 2.25$ and $4.4ns$ at $B = 0, 3, 6T$ respectively for the positron's incident angle (with respect to $PC$ plane normal) range from 0 to $60°$. Such $PC$s 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 M13 beam line at TRIUMF will be used in E614 spectrometer as a source of muons with polarization $> 0.9999$ opposite to muon momentum. The experimental apparatus will consist of superconducting solenoid with the maximum magnetic field $3T$ collinear to muon beam direction [2]. Surface muons will stop inside a thin $75\mu m$ planar aluminum target in the centre of the magnet. Positrons from $\mu^+$ decay going upstream or downstream will be detected by one of two planar drift chamber assemblies ($PDC$s) 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 $20MeV < E < 53MeV$ and angular range $0.5 < |\cos\Theta| < 0.985$ , where $\Theta$ is the angle between muon spin direction and positron momentum. Three layers of planar proportional chambers ($PC$s) will be installed on the both sides of the aluminum stopped target between the aluminum target and $PDC$s. $PC$s signals will provide the detection of $\mu^+$ stops inside target and also give a zero time reference for drift times from positron helix in $PDC$s. 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 $PDC$s (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 $10^9$ $\mu \rightarrow e$ decays.

(b) The trigger's time jitter must be $2 \div 3ns$(RMS). Otherwise, it will deteriorate the space resolution of $PDC$s 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 $PDC$s only and not in $PC$s. And for each of these positrons one would have to find a proper zero time using $\chi^2$ 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 $PC$s and $PDC$s with this gas mixture was measured at $B = 0T$ 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 $B = 3T$ compared to $B = 0T$. We have chosen the $4mm$ gap to get inefficiency about $3 \cdot 10^{-4}$ for the registration threshold $2e$ and the number of clusters about 16 [3]. Sense wire spacing was chosen to be $2mm$ 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 $2.000 \pm 0.002mm$. Sense and field wires were winded using a method suggested in [6]. The positions of all wires in each plane were measured with MITUTOYO Profile Projector PJ-300 with accuracy $\pm 0.001mm$.

$PC$s 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 $1mm$ along Y-axis with respect to *Y2* and *Y3*. Signals from *X1, Y1, Y5* and *X2* planes were used as a trigger indicating that particle 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 $2mm$ with respect to planes *Y2* and *Y3*. Measurements were done in *HELIOS* superconducting magnet of TRIUMF $\mu$SR Facility in magnetic field up to $6T$. The beam from M15 beam line of TRIUMF at $p = 35MeV/c$ had about 98% positrons and about 2% positive muons. Beam diameter was more than $10mm$(FWHM) so that its distribution density within any $2mm$ size $PC$ cell was practically flat. Positrons were detected by Cherenkov counter (see Fig. 1). It was possible to rotate 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 $110\Omega$ , impulse gain $1.5mV/fC$, impulse rise time $6ns$ and fall time $18ns$, input noise was about 3200 electrons [7]. Preamps were mounted directly on the chambers assembly. Output signals from preamps were feeded to inputs of discriminators via $4m$ long $50\Omega$ cables. Discriminator threshold was set to $9mV$ (about $6fC$). Further on, standard Le Croy logic modules 429A, 821, 622 were used. Pulse duration of signals from sense wires was set to $500ns$. Signal from Cherenkov counter $\hat{C}$ was formed by ORTEC CFD 934 and delayed by $450ns$. A coincidence signal $X1 \times Y1 \times Y5 \times X2 \times \hat{C}$ was a common start for the Le Croy 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 $\pm 0.2ns$. 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 neighboring wires in each of the tested planes *Y2, Y3, Y4* were used. Their actual wire indexes also varied at different angles $\theta$. The wire numbering scheme was chosen so that for every angle the center of positron beam profile was approximately between $4th$ and $5th$ sense wires of selected 8.

# 3 Results

## 3.1 Drift time spectrum from $PC$s

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 center of gravity of the drift time spectra were calculated. They are presented on Fig. 3 and 4 as functions of $B$ and $\theta$. Fig. 5 shows the time jitter RMS and center 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 $PC$s.

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 $6T$ are presented on Fig. 6.

### 3.3 Efficiency of $PDC$s.

Inefficiency of *Y3* $PDC$ plane versus high voltage at $B = 0$ and $B = 3T$ is shown on Fig. 7. This 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 $PDC$s.

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 $PC$s. 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 $U > 1.8kV$. Comparison of Fig. 6(a) and Fig. 6(c) shows that the left sharp edge of $\bar{\varepsilon}$ dependence at $B = 6T$ is shifted by $+70V$ with respect to $B = 0$ curve. 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 $B = 1T$ [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

$\varepsilon$ 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 $\varepsilon$ 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 even gets higher at $B = 6T$ compared to $B = 0T$ (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 $U = 1800 \div 1850V$ of high voltage (see Fig. 6). For $U = 1850 \div 2050V$ one sees $\bar{\varepsilon}_{Y3+Y4}(U) > \bar{\varepsilon}_{Y3}(U) \times \bar{\varepsilon}_{Y4}(U)$ , and for $U > 2050V$ at $B = 0T$ (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 $I_{e^+} = 8.5 \cdot 10^3 s^{-1}$. 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 distrubuted 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 $B = 0T$ (Fig. 7(a)) is approximately six times smaller than that of *Y3 PC* plane (Fig. 6(a)). We have reached $PDC$ inefficiency value $5 \cdot 10^{-5}$ (see Fig. 7) which is limited by statistical fluctuations of the number of clusters $n = 16$ per $4mm$ 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 $1.6e$. As it follows from Fig. 6(a,b,c) the inefficiency an individual $PC$ plane is $\bar{\varepsilon} \approx 3 \cdot 10^{-4}$. Therefore, the threshold in this case was about $2e$. 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 $0.5fC$, discrimination threshold $6fC$). Perhaps, it is technically feasible with ASD-8 bipolar integrated circuit [11] or VTX-preamp [12], which have a noise about $0.2fC$(ENC) at capacity of our wire $5pF$.

### 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 center 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, 3 shows that the sum signal from *Y2+Y3+Y4* $PC$ planes has the minimum value of time jitter over the range $B = 0 \div 6T$ and $\theta = 0 \div 60°$. The minimum value of the time shift for $B \leq 1.5T$ is obtained for *Y2+Y3* sum signal, while for $B \geq 2T$ *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 $B \geq 3T$. In our experiment 614 at TRIUMF $PC$ assemblies are planned to be used 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) Using a $PC$ assembly with a fast gas as a fast, high efficiency, low mass zero time trigger for $PDC$ assembly with a slow gas is suggested.

(b) We have measured characteristics of this trigger for the detection of relativistic positrons with momentum $35MeV/c$ in the magnetic field range $0 \div 6T$ and angles $\theta = 0 \div 60°$ . It is shown that when using the sum signal from two adjuscent planes of $PC$ assembly the inefficiency value is $< 5 \cdot 10^{-5}$ over a wide ($\Delta U > 120V$) high voltage range in magnetic field $0 \div 6T$. 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 $PC$s with a fast drift gas can provide time resolution better than $5ns$ (RMS) in the presence of a high magnetic field in spite of a large Lorentz drift angle. It is obtained using three planar $PC$s with a special choice of wire positions. The time jitter of a sum signal from three $PC$s at $B = 6T$ is 5.1 times smaller than that of one $PC$ and 4.2 times smaller than that of two $PC$s (see Fig. 3). Note, that at $B = 0T$ this method gives only 1.5 times gain. Using three $PC$s also makes the systematic shift of a trigger signal at $B = 6T$ 3 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 to further improve time resolution at $B = 6T$.

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

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## Figure captions

Figure 1: Schematic of the experimental setup. Sense wires in *Y4* plane are shifted by $1mm$ 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 $\theta = 0 \div 60°$. The dashed line contour on the figure represents the $PC$ assembly rotated by $10°$.

Figure 2: Measured $PC$ drift time spectra at $U = 1980V$ 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.

Figure 3: $PC$ time jitter as a function of $\theta$ and $B$ for *Y3* plane (a), *Y3+Y4* planes (b) and *Y2+Y3+Y4* planes (c).

Figure 4: The center of gravity position of the measured $PC$ drift time spectrum as a function of $\theta$ and $B$ for *Y2+Y3* planes (a), *Y3+Y4* planes (b) and *Y2+Y3+Y4* planes (c).

Figure 5: The center 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 $\theta = 0$.

Figure 6: Inefficiency of *Y3*, *Y4* and *Y3+Y4* $PC$ planes versus high voltage at $\theta = 0°$ and $B = 0T$ (a), $B = 3T$ (b), $B = 6T$ (c).

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

Figure 8: Dependence of $PDC$'s $Y3$ plane inefficiency at $\theta = 0°$ and $B = 0T$ on positron beam intensity.

Figure 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.

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

| SPECIFICATIONS | | |
|---|---|---|
| | $PC$'s assembly | $PDC$'s assembly |
| Aperture diameter | $80mm$ | $60mm$ |
| Anode wire spacing | $2.000mm$ | $4.000mm$ |
| Measured deviations (RMS) of sense wire positions | $\pm 0.005mm$ | $\pm 0.002mm$ |
| Anode wire diameter | $12.7\mu m$, $W(Au)$ | |
| Anode wire tension | $15g$ | |
| Half gap | $2.000 \pm 0.002mm$ | |
| Field wire spacing | — | $4.000 \pm 0.002mm$ |
| Field wire diameter | — | $30\mu m$, $W(Au)$ |
| Field wire tension | — | $80g$ |
| 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 $760torr$ | |
| Amount of matter in three planes | $5.2mg/cm^2$ | $8.6mg/cm^2$ |

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 |