Report on Intrinsic time resolution (ITR) and Position Resolution of neutron Detector for E93-026

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Abstract

In JLab experiment E93-026 neutrons will be measured via the time of flight method. Thus we need the energy resolution of neutron detectors to optimize their place in the experiment E93-026. Constant Fraction Discriminator are used to improve the electronic configuration to obtain the time resolution and position resolution of neutron bars more precisely and more reliably thus obtaining the energy resolution more precisely. From the study we find that the average intrinsic time resolution observed for one end of detector (include PMT and neutron bar) is 199.5 ps. The position resolution is 49.7mm full width at half maximum.

1. Introduction

In Jlab experiment E93-026 neutrons will be measured via the time of flight method. To make sure the neutrons from different inelastic process can be discriminated without sacrificing much in the way of solid angle, we must optimize the place of neutron detectors according to the energy resolution. The fractional energy resolution ΔT/T of neutrons is given by[1]

$$\frac{\Delta T}{T} = \gamma(\gamma+1)[(\frac{\Delta x}{x})^2 + (\frac{\Delta t}{t})^2]^{1/2}$$

Δx is the uncertainty in the neutron flight path x due to the finite thickness of detector, and Δt is a quadrature combination of the intrinsic time dispersion of the detector and the time dispersion introduced by the reference time signal.

This study improves the test configuration, measures the ITR more precisely and more reliably. We have focused on the measurement of time dispersion of neutron detectors that will be used to determine the energy resolution of neutron detectors.

2. Setup of detectors

We tested two neutron bars as a group at a time. (See Fig1) Two neutron bars are placed one on top of another one. Cosmic ray muons are used to generate the events. We used the coincidence signal of two paddles as a reference signal. All other signals from 4PMTs are fed into a linear fan in/fan out module and then to a Constant Fraction

Discriminator and then to TDC as a stop signal. (See Fig2) From the analysis below we know that trigger signal just provides a reference point whose effect will be cancelled if we are only interested in the time difference between any two or four signals.

All modules we used are listed as following:

Table 1: electrical device

Device	Make	Model
Linear fan in/fan out	Lecroy	Model 428F
Linear fan in/fan out	Philips	Model 748
Coincidence	Lecroy	Model 622
ADC	Lecroy	Model 2249A
TDC	Lecroy	Model 2228A

3. Intrinsic time Resolution

Intrinsic Time Resolution includes contributions from both light collection and PMT. Of course the time dispersion we measured directly may include the contribution from the reference signal, paddle, TDC walk and uncertainty in the muon flight path that are related to the testing configuration. We will prove that our intrinsic time dispersion excludes the effect above by the trick of design and data analysis. For convenience and explicit we define the time dispersion of one end of neutron bar, σ, as the building block and the time dispersion of other quantity can be obtained from the error propagation.

Constant Fraction Discriminators are used in our test that provide a satisfying quality and avoid the problem of TDC walk. (See Fig3)

We measured the following value:

$$TDC_0 = T_0 + t_0$$
$$TDC_1 = T_1 + t_0$$
$$TDC_2 = T_2 + t_0$$
$$TDC_3 = T_3 + t_0$$

t_0 is the time offset from reference signal. TDC_i is the TDC value we measured and T_i is the transit time of produced light in the neutron bar.

If we build the following quantity the effect of trigger signal is cancelled by subtracting any two or four signals.

The time dispersion of ΔTDC_{top} can be obtained from the error propagation:

$$\sigma_{top\_\Delta} = \sqrt{\sigma_{T_0}{}^2 + \sigma_{T_1}{}^2}$$

If we build the time difference of mean time:

$$\Delta TDC_{mean} = \frac{1}{2}[TDC_0 + TDC_1 - TDC_2 - TDC_3]$$

We can get the time dispersion for ΔTDC_{mean}:

$$\sigma_{mean\_\Delta} = \frac{1}{2}\sqrt{\sigma_{T_0}^2 + \sigma_{T_1}^2 + \sigma_{T_2}^2 + \sigma_{T_3}^2}$$

At the same way we can obtain the time difference for mean time

$$TDC_{mean} = \frac{1}{2}[TDC_0 + TDC_1]$$

as

$$\sigma_{mean} = \sqrt{\sigma_{T_0}^2 + \sigma_{T_1}^2} / 2$$

Now we assume that all $\sigma_{T_i} = \sigma$ are the same we get:

$$\sigma_{top\_\Delta} = \sqrt{2}\sigma$$

$$\sigma_{mean\_\Delta} = \sigma$$

$$\sigma_{mean} = \sigma / \sqrt{2}$$

In the discuss above we did not consider the effect caused by the width of paddles. For the mean time difference the effect of the paddles will be cancelled. (See Fig4) Here we only consider:

a) Muons deposit energy along its full path;
b) The time for muon through the neutron bars(~0.5ns) are neglected with respect of fluorescence time of scintillator (~10ns).

In this case the light produced at the left side trigger left TDC channel and the light produced at the right side trigger right TDC channel. So the effect of the paddle is the same for top and bottom mean time.

However the effect of the paddles apply to the time difference ΔTDC. At the point of this view we can get a method to extract the effect of the paddles. This will be discussed later. As a result we know that the contribution from the paddles is very small, up to 7% deviation.

4. The result of ITR

Here we list the TDC value and their time dispersion. σ_{Δ} represent the time dispersion we get from the quadrature of σ_{top_Δ} and σ_{bottom_Δ}. Comparing σ_{Δ} and σ_{mean_Δ}, we find the difference is averagely up to 7%.

By averaging all Intrinsic Time Resolution of mean time, σ_{mean_Δ}, we get the ITR for one end of single detector:

$$\sigma = 200 \pm 14ns$$

Table2: The result of ITR

Detector#	Paddle position(mm)	σ_{mean_Δ}	σ_{top_Δ}	$T_0 - T_1$	σ_{bottom_Δ}	$T_2 - T_3$	σ_Δ
#1-top	-464	219.2	197.3	-8.633	276.0	2.340	239.9
#2-	0	193.4	188.0	-2.473	210.4	8.372	199.5
bottom	566	197.4	192.1	5.076	236.4	16.22	215.4
#3-top	-489	181.2	203.6	-10.83	199.6	4.106	201.6
#4-	0	183.1	194.2	-4.441	203.5	10.37	198.9
bottom	499	185.8	211.3	2.213	194.5	17.08	203.0
#7-top	-474	208.7	229.7	-7.587	193.9	3.624	212.5
#8-	0	190.0	217.8	-1.253	180.6	9.771	200.1
bottom	568	193.5	214.6	6.495	210.7	17.60	212.7
#5-top	-504	226.1	197.2	-8.556	273.4	2.209	238.4
#2-	0	199.8	204.4	-1.827	224.5	8.825	214.7
bottom	525	216.2	203.9	5.331	237.4	1.605	221.3

Note: the unit for σ is ps and the unit for time difference is ns.

5. M.C. simulation

In our M.C. simulation program we consider the effect of paddle. From Fig5 we find that the time dispersion contributed by paddle does not follow the Gaussian distribution. The effect of the paddles is to spread the peak. We build:

$$2\sigma_p = \sigma_L - \sigma_R$$

Approximately we suppose that σ_p follow the Gaussian distribution so that we can numerically get the error contribution from paddle.

$$\sigma_p = \sqrt{\sigma_{top\_\Delta}^2 + \sigma_{bottom\_\Delta}^2 - 4 \times \sigma_{mean\_\Delta}} / 2$$

In the simulation we use the error contribution, except for paddles, σ_{mean_Δ}, as 2ch(slope is 0.1ns/ch). From the simulation we get the contribution of the paddles to be 0.98ch and from the test we get the contribution of paddle to be 0.86. Up to a small uncertainty we think that the two numbers are very close. This uncertainty may come from two reasons:

a) Actual width that contributes to the error is smaller than the width of paddle;

b) Muon flight path uncertainty contributes a little bit to the time dispersion.

At the point of this review we get a idea that we can extract the paddle contribution from above method and try to prove the time dispersion we obtained from mean time represent the intrinsic time resolution well which exclude the contribution from paddle.

From the M.C. simulation we also get a byproduct. The paddles contribution will limit to zero if the width of paddle is less than 3cm in the case of σ =200 ps. To obtain this result just run the appended program and set the parameter width of paddles to 3cm.

6. Position Resolution

Position resolution can be obtained from the relation between the time difference and position. (See fig6)

$$\Delta T = 2\frac{y}{u} + t_0$$

ΔT can be $T_0 - T_1$ or $T_2 - T_3$. Y is the change of position corresponding with ΔT. u is the transit velocity of light in the neutron bar.

From the fitting we get the transit velocity to be:

$$u = 1.50\ (1 \pm 0.01) \times 10^8 m/s^2$$

From the error propagation we get the position resolution to be:

$$\sigma_y = \frac{u}{2} \times \sigma_\Delta = \frac{u}{2} \times \sqrt{2}\sigma = \frac{u\sigma}{\sqrt{2}}$$

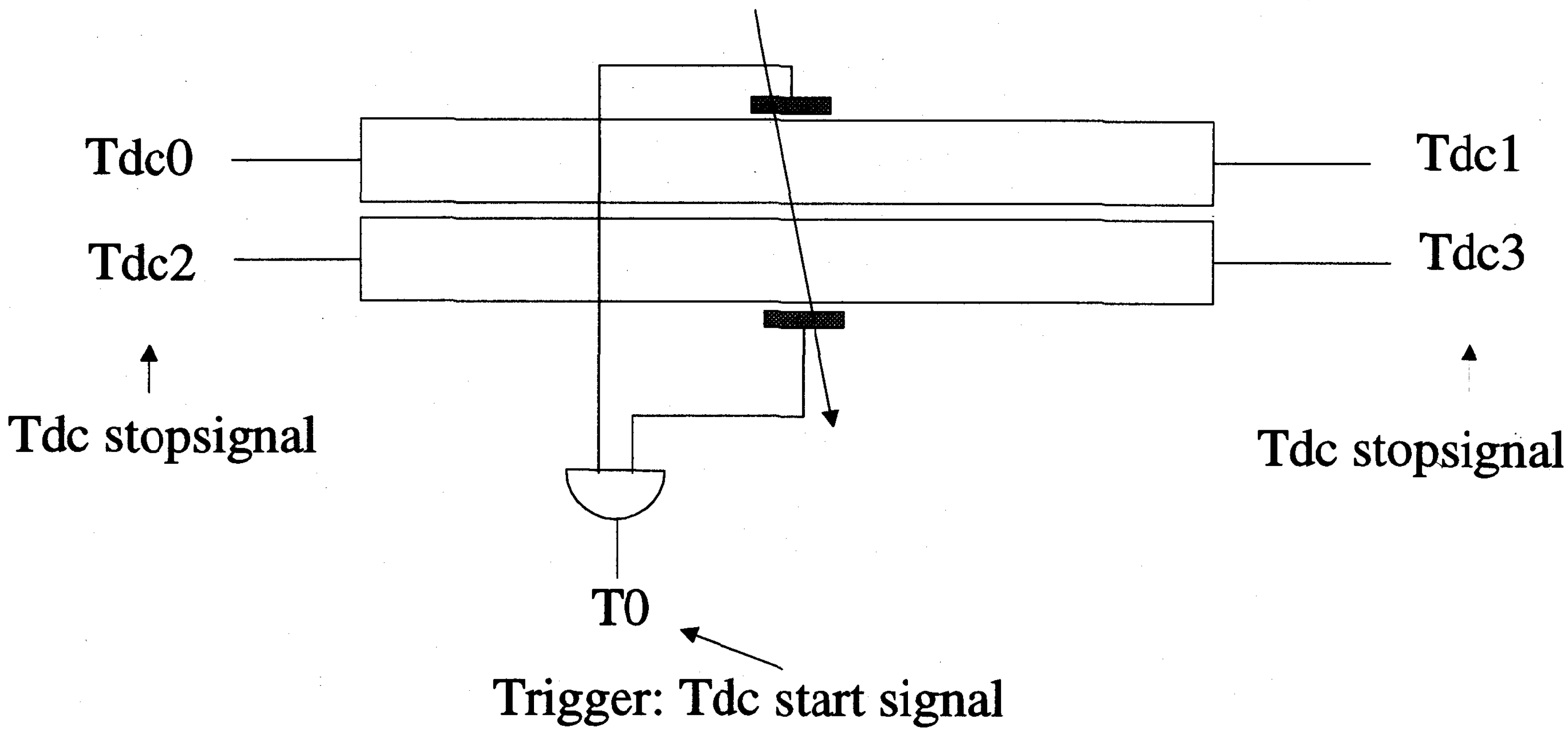
FWHM=2.35 σ_y

Therefore we obtain the position resolution to be 49.7mm.

7. Conclusion

From this study the Intrinsic Time Resolution of the neutron Detector is 199.5ps and position resolution is 49.7mm. This measurement excludes the effect of reference signal, paddle, TDC walk and the uncertainty in the muon flight path.

Figure 1: Neutron Bar Setup for Intrinsic Time Resolution

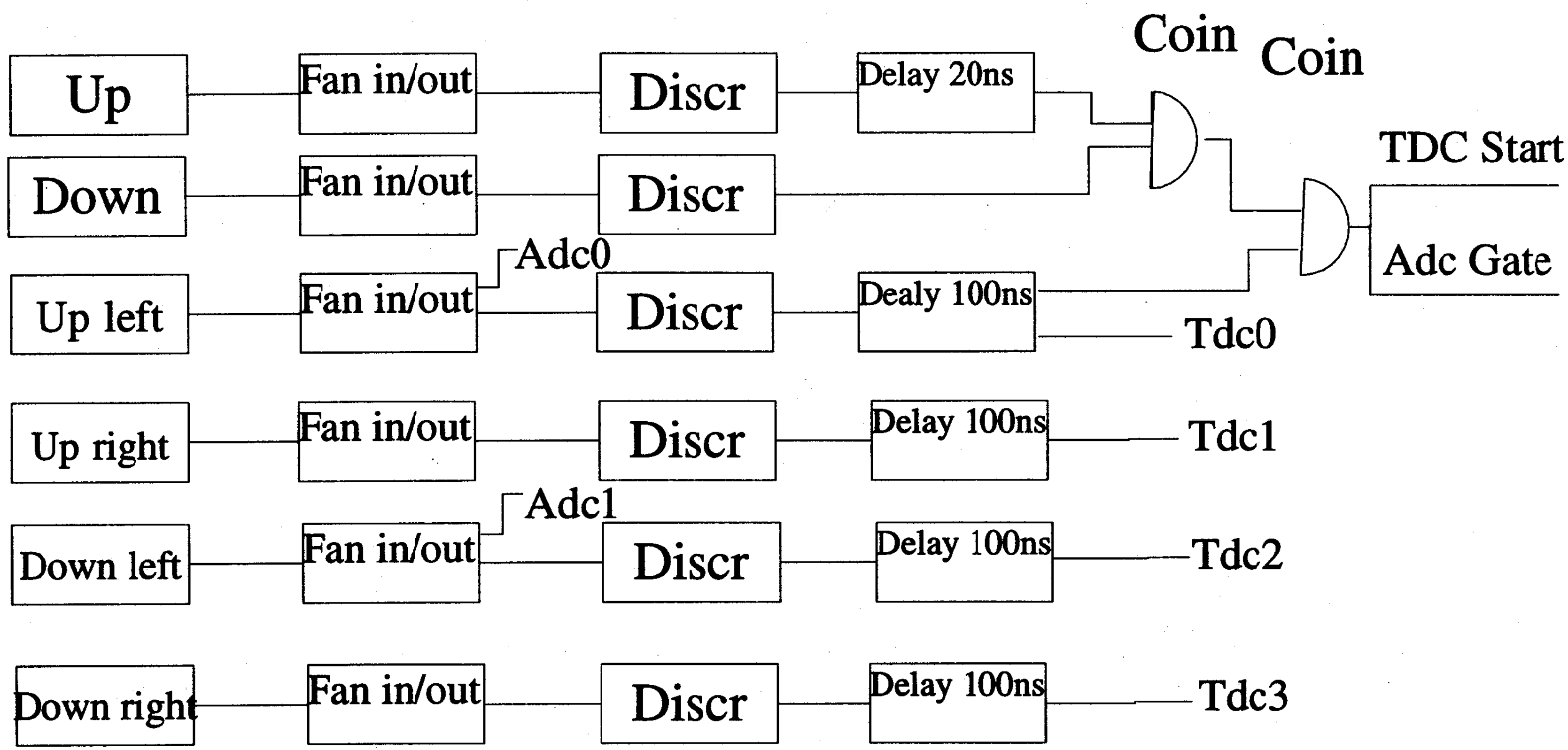


Note: t0 is zero point, which is not measured but indicates the time of TDC Start signal.

Tdc0–T0 ⟶ Tdc0 Tdc1–T0 ⟶ Tdc1

Tdc2–T0 ⟶ Tdc2 Tdc3–T0 ⟶ Tdc3

Figure2: Neutron Dector Electronics for Intrinsic Time Resolution



*All discriminator widths are 100ns.
*All discriminator thresholds are 80 mv
*All coincidence widths are 100ns.

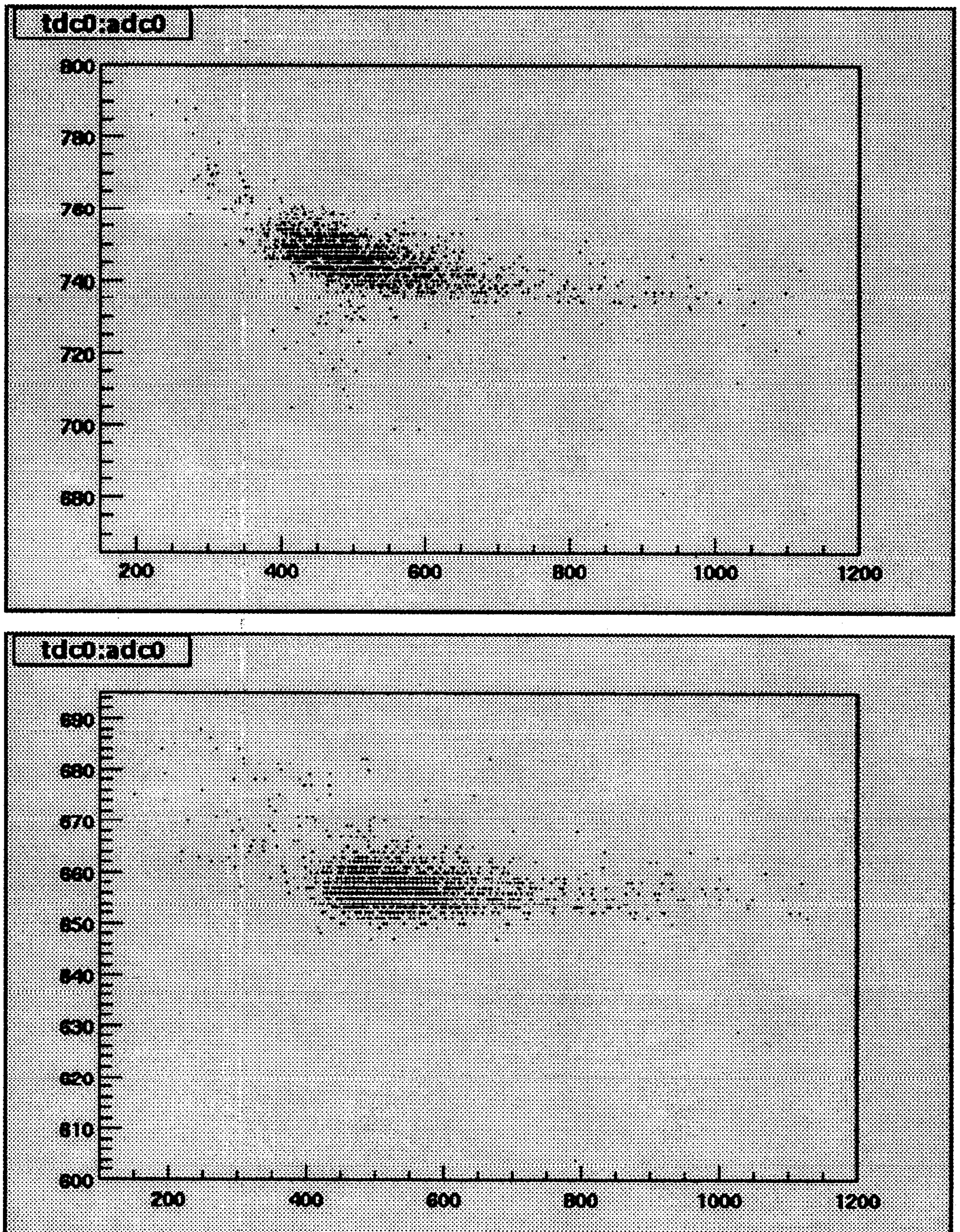
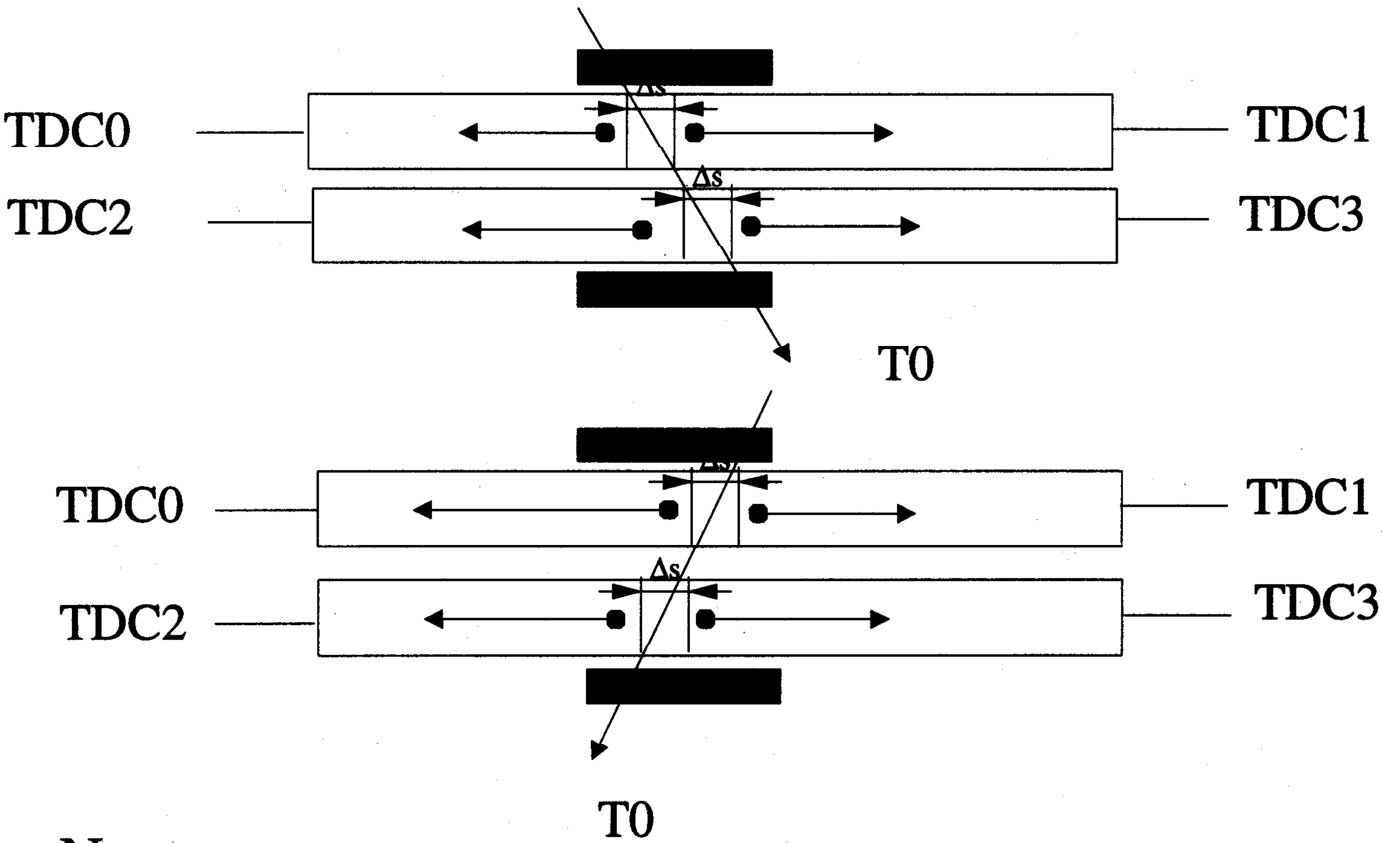


Fig3: Two-dimensional spectra of the coincidence TDC (0.1ns/ch) versus ADC (1mv/ch). The difference is that top one use leading edge discriminator and bottom one use constant fraction discriminator.

Fig4: How does the mean time work?



Note:

1. Mean time is defined as t=TDC0+TDC1,or t=TDC2+TDC3
2. Because of the width of paddle mean times fluctuate a little bit such as Δs.
3. From the figure we know the difference of mean time between the parallel neutron bars exclude the influence of the width of paddle because the fluctuations Δs are the same in the same event .
4. In fact any difference between measured time exclude the influence of trigger signal.
5. Above assume that constant fraction discriminator is used and no TDC walk influent the data.

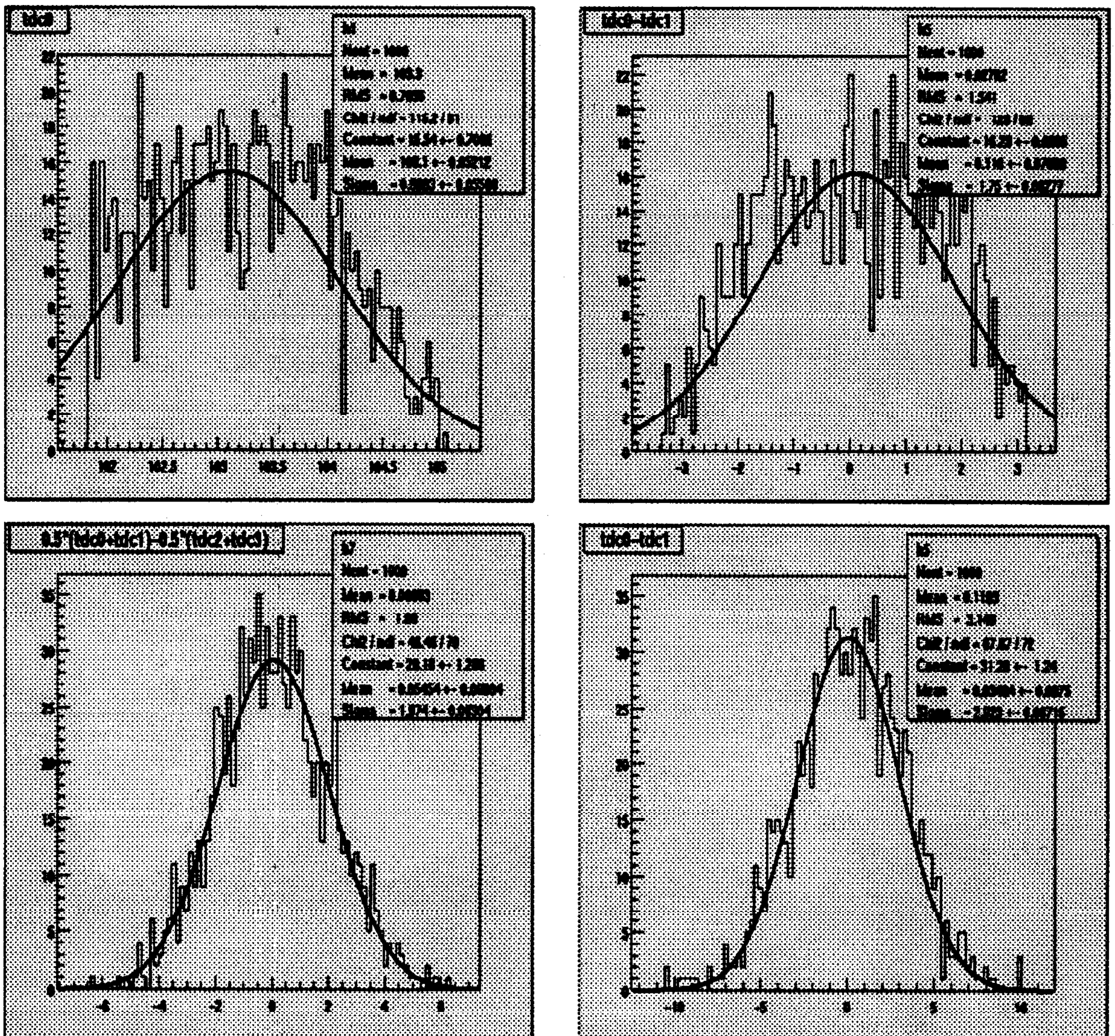
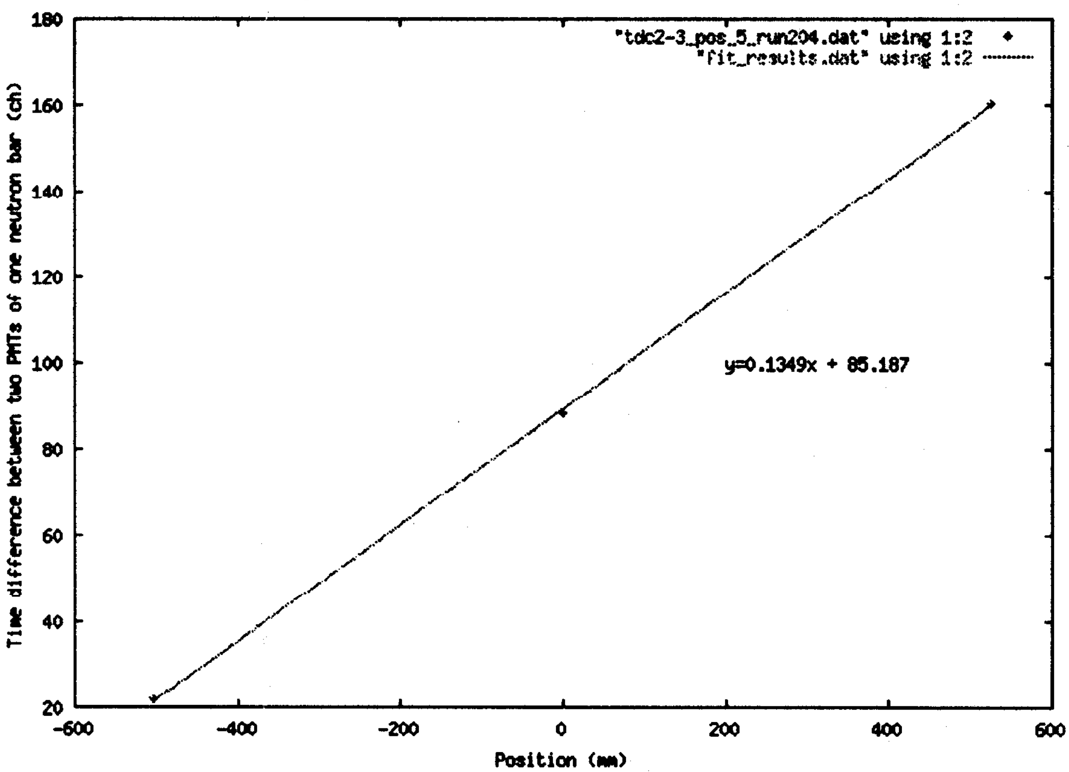


Fig5: Error contribution of paddle obtained from M.C. simulation. Top two show the error contribution of 5cm width paddle. Bottom two show the combination of paddle contribution and intrinsic time dispersion.

Fig6: The Relation between Time difference and Position



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2. A. Lewandowski, Report on Neutron Detector for G_E^n
3. D. Day, R. Ent, R. Lindgren etc., CEBAF proposal, an Experiment to Measure the Charge form factor of Neutron
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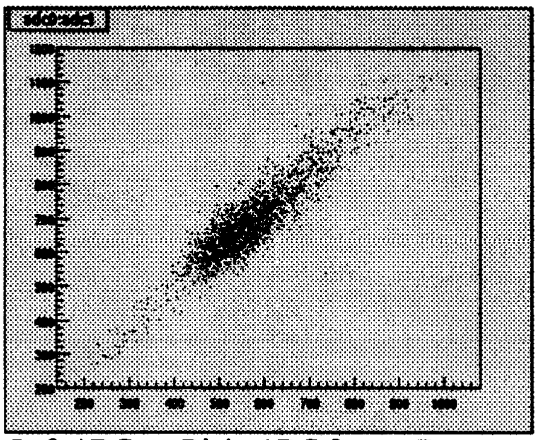
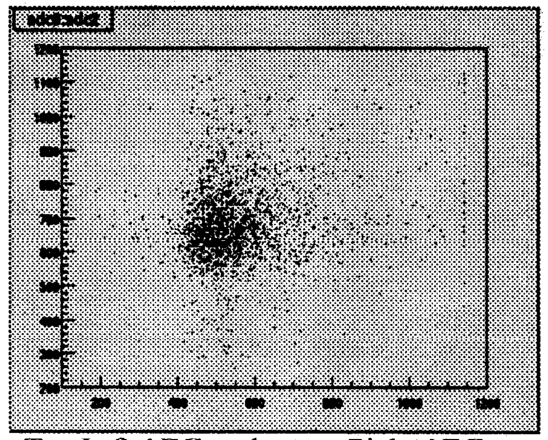
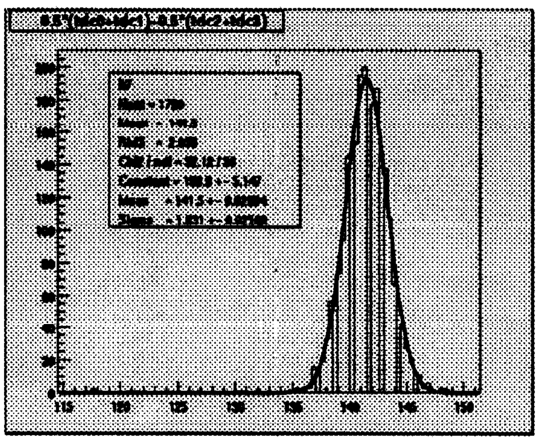


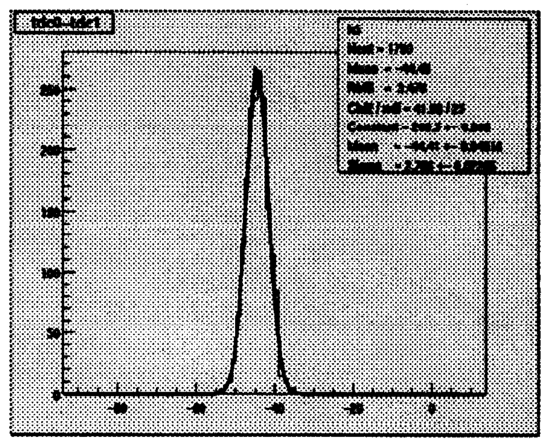
Left ADC vs. Right ADC for top Detector



Top Left ADC vs. bottom Right ADC



Fit of mean time difference



Fit of time difference for top neutron bar

Fig7. The plot of ADC correlation and TDC fit.