Vertical Drift Chambers analysis for E94010.

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Contents

1 Introduction

Both Jefferson Lab Hight Resolution Spectrometers (HRS) rely on two Vertical Drift Chambers packages for particle tracking. In this note wire chamber basics principles and HRSs VDCs particular features will be shortly presented

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before the detailed results and a summary of the Wire Chamber analysis for the experiment E94-010.

2 Wire Chamber Principle

This section relies mostly ref [2]. See also ref [5]

Wire Chambers purpose is to provide a fine trajectory measurement of a traveling particle (tracking). Their informations are used to reconstruct the event vertex on the target. If the particle has traveled trough magnetic fields prior to reach the wire chambers, tracking information will provide an accurate relative[1] momentum measurement.

Wire chambers are composed of several wire planes enclosed in a gaseous medium. Each plane is closed by a frame at negative high voltage while the wires are either grounded or at positive high voltage. As a result the electric field lines between the frame and the wires will be parallel near the frame to gather on the wires as illustrated on *Fig. 2.1.* For VDC analysis, a good approximation of field lines is shown on *Fig. 2.2.* Usually "shaping wires" intercalated between the detection wires are used to optimized the field line pattern ([2]p 75).

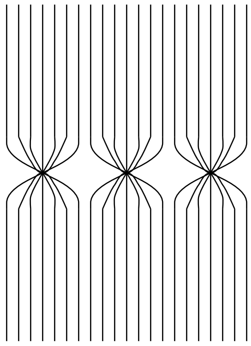
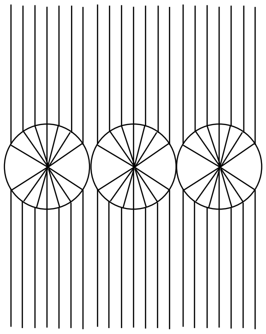


Fig. 2.1. Electric field lines between the frame and the wires.



[1] Relative to the magnet central momentum setting.

Fig. 2.2 Field lines modeled with two regions. A parallel one and a radial one where the field dependence is $1/r^2$.

A charged particle coming through a chamber will ionized the gas. In the parallel region, the electrons resulting from the gas ionization will drift toward the wires. In the radial region, accelerated by the stronger electric field, they will gain enough energy in their mean free path to ionized other atoms inducing an *avalanche* process ([2]p 41). Ions are drifting toward the negative charged frame while the electrons drift toward the detection wires inducing a negative signal. Knowing when this signal is induced, when the particle is crossing the wire plane and the avalanche drift velocity allow to compute the particle crossing point.

A Wire Chamber consists of different wire planes to provide an angle trajectory determination. Since a particle crosses the wire planes with an angle and since the wire are close to each other (a few mm to a few cm) several wires will get a signal. The requirement to have several firing wires avoids noisy wire problems. Another source of noise come from the low energy photons resulting for example from ion-electron recombination ([2]p 46). As they can induce ionization far from the crossing point that make its determination more difficult, a small quantity of quencher gas is added. This gas has the property to absorb these photons.

To track particles the drift velocity in the gas has to be well known as well as the timing of the processes. Time information is given by a Time to Digital Converter (TDC) which is basically a clock delivering a signal suitable for the acquisition. The TDC begins to count when the first wire signal arrives and is stopped by a signal coming from the scintillator trigger. Consequently high TDC channel represents a short drift time and *vice versa.* A typical TDC spectrum is shown in *fig* 2.3.

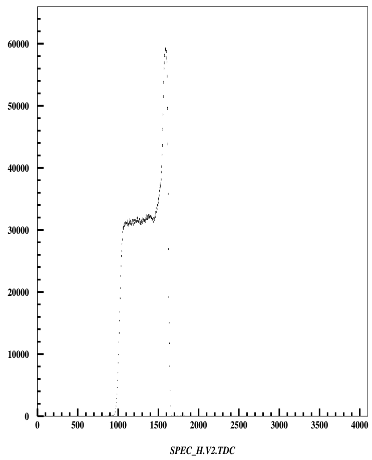


Fig. 2.3. TDC spectrum. The horizontal axis is the TDC channel. The small

drop just before the large TDC chanel peak comes from the lack of shapping wires of the Hall A VDCs (see section 3)

The VDC TDC spectrum width is related to the frame width: The last signals come from an avalanche developing near the frame. The peak at short drift time values is due to the radial field part (cf *Fig. 2.2*). It can be explain by the discriminator threshold set on the wires. If the particle crosses the VDC too close to the wire it will not ionize enough atoms to make the avalanches to induce a signal above the threshold. Statistically a minimal distance corresponding to the radial region is required. Tracks in the radial region will not generate signal until they leave this region (no very short TDC values at channel 1600 for example in *Fig. 2.3*). After to have left the radial region they produce signals in addition to the other tracks that will, or already have, passed near the radial region. This addition leads to the peak at short TDC values. This peak is the shift of the very short TDCs values toward higher values. *Fig. 2.4* shows a simulation reproducing this effect.

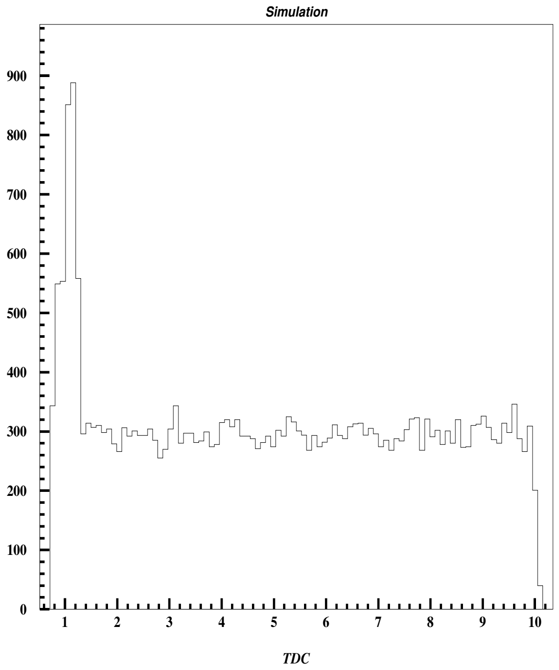


Fig. 2.4 Simulation of a TDC spectrum (TDC values on the horizontal axis have arbitrary unit). The nominal radial region limit is set with a discriminator threshold requiring 10 avalanches. The actual limit of the radial region is randomly shifted for each signal to reproduce the statistical process of ionization.

Another effect contributes to the peak: the number of count per time unit is directly proportional to the electric field intensity.[2] As we can see in *Fig. 2.2* the field intensity increases in the radial region as we move closer to the detection wire, contributing to the short TDC values peak. In the particular case of HRSs VDCs the discriminator threshold is low (one avalanche is enough to pass the threshold). The second contribution is dominant.

3 Jefferson Lab Hall A Vertical Drift Chambers

This section describes the particular features of an HRS VDC package. It consists of two identical VDCs spaced by 50 cm (*Fig. 3.1*). Each VDCs contains 2 wire planes spaced by 2.6 cm. Each plane consists of 400 gold plated wires of 20 μm diameter. 368 wires are dedicated to detection while the 16 first and 16 last wires shape the electric field. The frame is at negative high voltage (-4 kV) and 400 wires are grounded. Wires are separated by 4.243 mm and the frame width is 2.6 cm. This makes a particle crossing with the nominal 45^o trajectory to fire five wires (*Fig. 3.2*). A minimum of 3 firing wires is required to validate a good cluster in order to limit noise troubles and to avoid the left-rigth ambiguity[3]. The wire positions careful survey allows a 225 μm precision on the crossing point between particle and wire plane [3] and [4]. With the VDCs spaced by 50 cm we reach an angular precision of 0.3 mR. HRSs VDCs do not have shaping wires. This leads to a larger detection area around each wire. Thus higher signals are induced on wires allowing VDC operations at lower High Voltage to minimize the VDC trips [4]. The small drop in *Fig. 2.3* just before the large TDC chanel peak comes also from the lack of shapping wires.

A 65% argon gas (ionization gas) and 35% ethane gas (quencher) mixture is used to operate the VDCs.

[2] If $\frac{dN}{dt}$ is the number of counts per time units we can write $\frac{dN}{dt} = \frac{dN}{dy}\frac{dl}{dt} = kv_d$ were v_d is the drift velocity and k the number of count per distance unit. Even in the case of an elastic kinematic the area near the considered wire is broadly uniformly covered by the scattered particles i.e. k is constant: The number of counts per time unit is proportional to the drift velocity i.e. to the electric field intensity.

[3] When a particle fires a wire, the only information is the TDC and one is unable to know if it crossed on the left or the right of the wire.

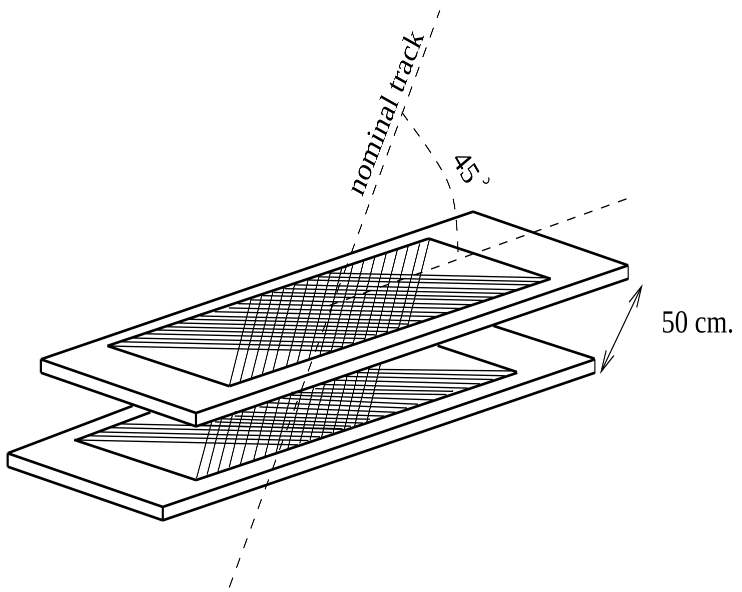


Fig. 3.1 A VDC detector package

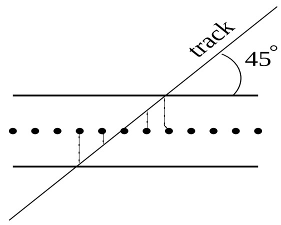


Fig. 3.2. A particle going through a wire plane with the nominal 45° track fires five wires.

4 Analysis

4.1 Timing Management

To reconstruct a track we need to know the time taken by the electrons to reach the wire. Each firing wire triggers a TDC. Then the particle triggers S2. After a 900 ns delay The signal from the S2 right paddle stops the TDC. A typical VDC TDC plot is shown in *Fig. 2-3*. *Fig. 4.1* shows the VDC TDC control.

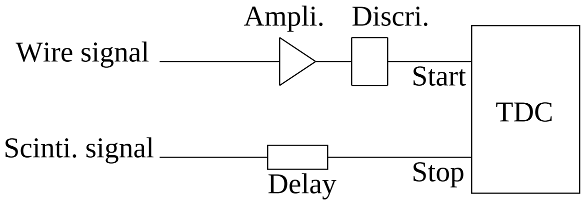


Fig. 4.1 VDC TDC control (Common Stop from the Scintillator paddles).

As the delay between the VDC TDC starting time and the stopping time is fixed, the S2 TDCs define the time reference for the VDCs TDCs. The TDC maximum channel defines the time T_0 (around 900 ns). It corresponds to the beginning of the signal collection. Since T_0 depends on the cable length between the VDC wires and S2 right scintillators, it is different for each wire and needs to be optimized for each new experiment or after each hardware change on the VDC (see subsection 4.1.1).

Knowing the electron drift velocity (about 4.4 10^4 m/s)[4]we can compute using the TDC drift time the position where the particle crossed the wire plane and reconstruct the track.

4.1.1 T_0 Optimization

T_0 had to be optimized once for all for the experiment. However this optimization was performed for several runs covering the whole experiment in case of hardware modifications. The online analysis was done with a none optimized database. It was found between 4% to 10% of 0 track events (depending on kinematics). Among them 3 % were good events (good shower and preshower, Cerenkov signal, good scintillator pattern, ...) albeit the VDC hardware efficiency was expected to be close to 100 % (see 4.4). ESPACE, the Hall A analyzer software, has cut 3% of the reconstructed tracks because of wrong T_0 values. To optimize the T_0s ESPACE needs to take the averaged value of the TDC maximum channel for each wire. To do so it simply takes the largest negative derivative value and assumes a linear behavior until to cross the abscissa. The crossing defines the optimized T_0.

4.2 Beta Optimization

This section owns a lot to Marat Rvachev.

4.2.1 Goal

The triggering particle (e^- or π^-) travels almost at light speed ($\beta \simeq 1$) . This fact provides a way to define a common time basis for all the TDCs. It is also a criteria for a good VDC track reconstruction.

[4]Homogeneous field (for the parallel region of *Fig. 2.1*) leads to convenient linear time space relationship.

4.2.2 Principle

define β=v/c and v=d/t where d is the distance covered by the particle between the two scintillator planes and t the time needed to cover it. d is given by the detector package geometry and the track reconstruction (that's why β is criteria for a good track). To compare the TDCs of the different scintillators we have to put them on the same time basis. To achieve this we correct each TDC from its time delays. The time correction looks like:

$t_{tdc} - \frac{e}{c_1} - D - k(ADC - pedpos)$

where:

- e is the distance between the particle crossing point on the paddle and the scintillator phototube (given by tracking).
- c_1 is the light speed in the scintillator. It is computed during the β optimization.
- D is the cable length correction (values in the database).
- $k.ADC$ is the timewalk correction. The timewalk effect is due to the fact that signals have different amplitudes (i.e different widths if the shape remains the same). To avoid noise the TDC signals need to pass a threshold before to trigger. Consequently large signals trigger the TDCs before small signals. Timewalk correction is approximated to be linear with the signal amplitude (ADC). k is the proportionality coefficient.
- Pedpos is a correction to the hardware pedestal suppression done for the ADC optimization [1].

The β optimization is done by plotting the TDC difference between the right and left scintillator side vs the crossing point of the particle given by the tracking. The linearly fitted result gives the speed of light in the scintillator (slope) and the cable length difference between the right and left TDCs (abscissa crossing). As we need to compare TDCs of every paddle we have to do this operation for the two opposite S1 and S2 paddles, then for the paddle of plane S1 and the neighbor of the opposite paddle on plane S2 and so on. At the end of the operation all the TDCs are in the same time basis.

4.3 Wire (hardware) efficiency.

A way to check the wire efficiencies is to look at a none firing wire inside a cluster. Both neighbors having collected a signal, its silence betrays its inefficiency. It is commonly expected to have more than 90% efficiency for each wire. The Hall A VDC design being a five cell design, the tracking hardware efficiency should be almost 100%[5]. Wire efficiency was checked online and was alway close to 100%.

[5] We assume the conservative value of 90 % efficiency for a wire. 3 Firing wires are required to reconstruct a track. The probability that only 0,1 or 2 wires on the 5 wires supposed to be

Comparison between the number of good events (Cerenkov signal+good total shower) and the number of good events with good track yields a tracking efficiency of 99.92 % for Electron arm and 99.7 % for "Hadron" Arm.

The VDC hardware inefficiency is low enough to be neglected in the analysis.

4.4 Software Efficiency.

By software efficiency I mean the loss of good events due to bad tracking reconstruction. During the production run analysis we apply standard cuts on physical reconstructed quantities, for example cuts on target length to remove the events coming from the target window. However if these quantities are not reconstructed properly or not at all (0 track events) some good events will be rejected.

4.4.1 Track Number

At each event is associated a number of tracks. ESPACE takes care of events with up to 4 tracks. *Fig. 4-2* shows the event distribution according to the track number. Both arms look similar.

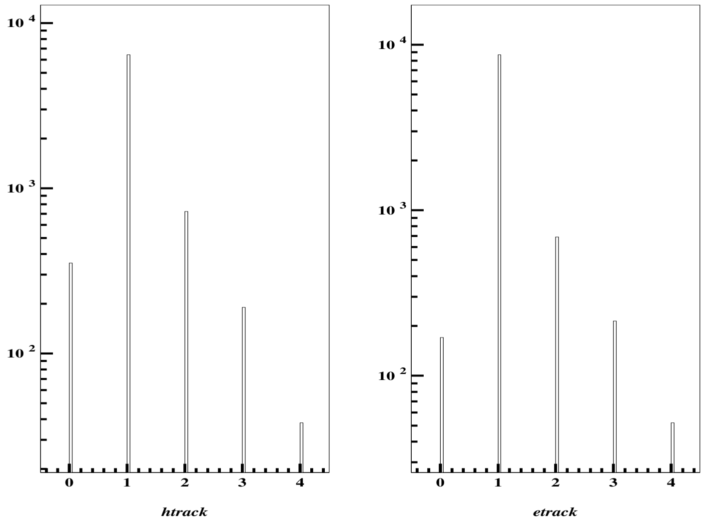


Fig. 4-2. Event distribution according to track number for "Hadron" (left) and Electron (right) arms.

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hit do not fire is:

$$\sum_{n=0}^{2} C_5^n (1-0.9)^{5-n}(0.9)^n = 1.5 \times 10^{-4} = 0.015\%$$

Zero Track Events 6 % of the total number of events have no track. With cuts on Cerenkov and Shower almost all these events disappear. These events are believed to be particles going through the scintillators but not the VDCs. The VDC solid angle is smaller than the one defined by the scintillator plans. It sees the full target length but if a particle rebounds on a collimator or on a magnet pole it can trigger the scintillators without going through the VDCs. Elastic runs at 1.72 GeV are rich of these events and have more zero track events (see section 4-4-4). *Fig. 4-3* shows only 0.08 % of good events after proper cuts on Shower and Cerenkov. Zero track events can be safely cut away in the analysis.

One Track Events After proper cuts to remove neutral particles and noise, 99 % of events are one track events.

Two Track Events 1 % of the good events have two tracks. 2 electrons coming from the target in the same time is unlikely as shows a naive estimate: The scintillator deadtime is about 400 ns. The maximum acquisition rate of CODA is 2 kHz. That makes the probability of an electron to come in the 400 ns time window to be 0.08 %. Assuming a random event time distribution we have 0.0064 % chance of two electrons coming in the same time window. A simulation taking care of the fact that the time window is open with a first event (To illustrate this fact: during 1 second we have not 1/400 10^9windows but only 2000 for a 2 kHz rate) increases the probability to 0.012 % which is still negligible. Cosmic events coming in the time window is even less probable since they have a few Hz rate.

We conclude that these two tracks events are due to electron knock out. In the two particles giving two track only one is a good event.

Three and Four Track Events Three and four track events represent less than 0.1 % of the good events and are neglected.

Fig. 4-3 shows the event distribution with the number of track after good electron cuts.

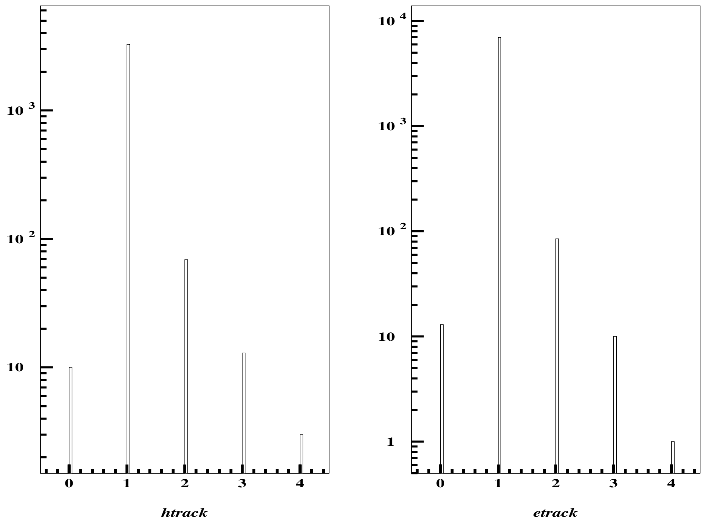

Fig. 4-3. Event distribution with track number for "Hadron" (left) and Electron (right) arms after "good electron" cuts.

4.4.2 Track Selection Algorithm

For multitrack events, ESPACE, chooses the best track between the possibilities. As a first criteria, the different candidates should be consistent with the two scintillators (plane S1 and S2) that fired (This was not implemented during the experiment E94-010).

The algorithm will make a "tree". Each root of the tree corresponds to a cluster of the first VDC wire plan. All the combinations with the second plan define the branches. The same operation is done for the second VDC. The branches of the upper plan of the bottom VDC are then connected to the lower plan branches of the upper VDC. The algorithm then orders the possible tracks according to there χ^2 value.

4.4.3 Software efficiency.

The Selection Algorithm is not perfect and the track can be mischosen or misreconstructed. 30 % of the good 2 track events are removed by standard cuts on reconstructed quantities. With 1 % of 2 track events we are losing 0.3 % of the events.

Two track events can introduce errors on the reconstructed quantities using track informations (momentum, vertex coordinates,...). It can also modify the number of counts. In *Fig. 4.4* we see the reconstruction is less accurate in the case of 2 track events. Some events coming from the target window will be included and will bias the number of counts.

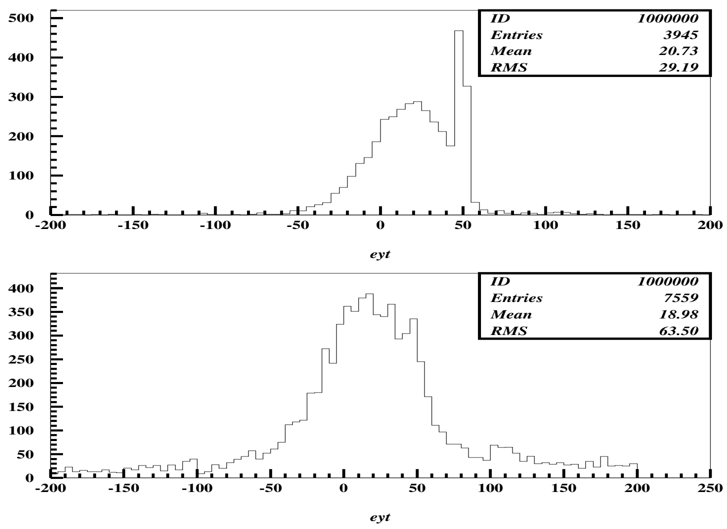

Fig 4.4 y_target reconstruction for one track events (up) and two tracks events (bottom).

To avoid this source of error we decide to cut the totality of the two tracks events and to treat them as a VDC “efficiency”. This method should not introduce systematic errors unless the two tracks event distributions (in respect to the quantity where the cut is applied) is not uniform.

4.4.4 Two Tracks events distribution.

The assumption that two tracks are uniformly distributed should introduce small errors if the number of two tracks events stays small. Electron arm has 1 % of two tracks events while the Hadron arm has 3 % (in the worst case of some elastic runs). This high number could not reflect true good two tracks events but a contamination coming from events deposing a low amount of energy in the shower. These events are particles rebounding on the collimators and have to be cut. Small energy cuts on shower to avoid contamination make the 3% to go to 1%. If these low energy events are real contamination we can safely treat the 1% as VDC efficiency like the electron arm. *Fig. 4.5* is a comparison between the Electron and “Hadron” arms for an inelastic run (top plot, run 2647) and an elastic run (bottom plot, run 1768). The ratio of two by one track events is plotted vs the energy (shower channel). The plain line is the ratio before 2D cut on shower and preshower. This cut is efficient to remove the “low energy events” but cannot be applied to hadron arm (no hadron arm preshower). The dash-doted line is the same ratio after 2D cut. The dashed line is the hadron arm ratio. We see a peak in the low energy region. This low energy deposit is (statistically) unexpected for electrons and we deduce this background is due to detector noises and/or pedestals. The tail of the peak for the hadron arm clearly extends in the "good energy" region especially in the case of the elastic run.

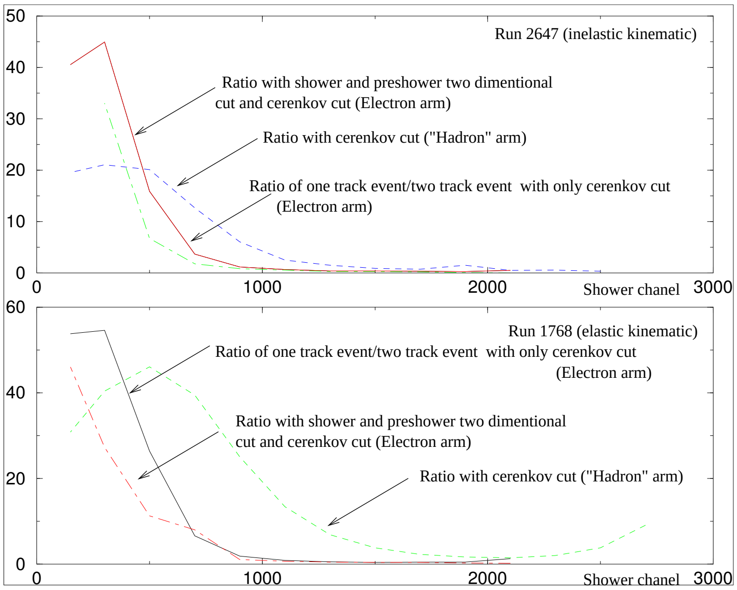

Fig. 4.5 ratio of two track events with one track event for inelastic run (top plot, run 2647) and elastic run (bottom plot, run 1768) plotted vs shower channel.

The low energy background contamination is confirmed by the plot of the 0 track events background. The 0 track background has also a shape extending in the our region of interest. This does add contamination since all the 0 track events are bad events.

Fig. 4.6 illustrates the fact that the two track distribution is not uniformly distributed in the region of interest. The two tracks are mainly due to knock out. In this process the electron losses some energy and the distribution is expected to decrease as the shower channel number increases in accordance to *Fig. 4*.6. However this dependence is small. In another hand some good track events can be due to two electrons coming in the same time. We can thus expect a increase of the ratio at high energy. However with 2 kHz data acquisition and short time window this process is not likely to happen and we don't see such increase in accordance to the estimate of section 4.5.1.

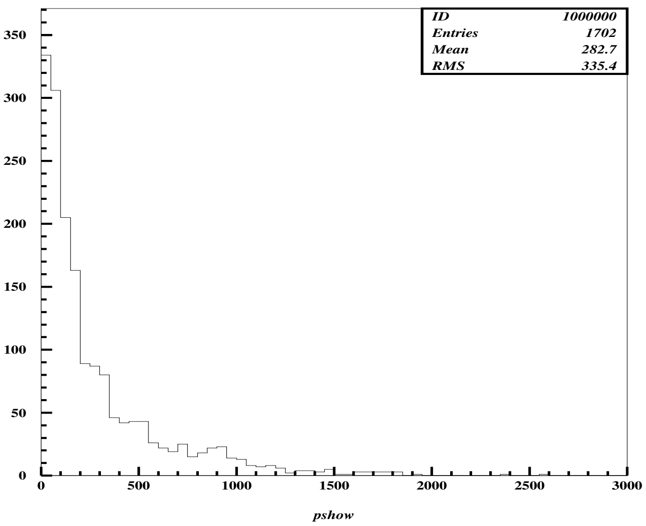

Fig. 4.6. Ratio of 2 track events with 1 track events plotted vs shower channel.

4.4.5 TDC corrections.

The TDC spectrum peak of *Fig. 2.3* is due to the radial field region. We need to know the straight distance between the wire and the crossing point. The TDC is corrected in this purpose. *Fig 4.7* shows a corrected TDC spectrum. A background appears during the correction. Selection and plots of reconstructed value such y_target or Q^2 using these TDC miscorrected events are reasonable. This miscorrection appears to not be a problem.

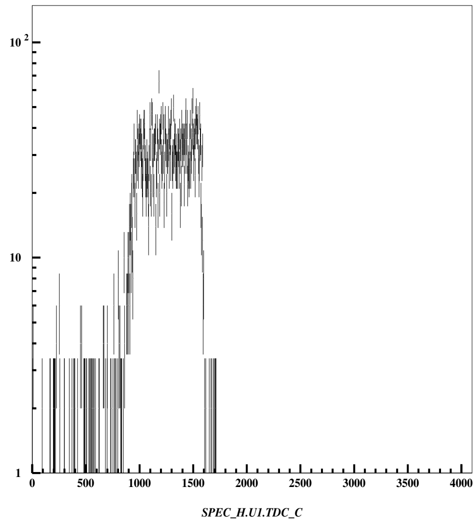

Fig. 4.7. TDC corrected spectrum. Horizontal axis is the TDC channel.

4.4.6 Efficiency evolution.

The percentage of 0, 1 and 2 tracks versus the run number for all the runs taken at 1.72 GeV are plotted in *Fig. 4.8.* The plots on the left are without any good event cuts. The plots on the right are only for good events. The upper plots are for Electron Arm while the lower plots are for "Hadron" Arm. The wire chamber efficiency[6] is stable and close to 99 % (Electron arm) or 98 % ("Hadron" arm) but drops around the runs 1750 and 2250. These two periods correspond to the elastic kinematics. The elastic runs show more sensitivity to the "low energy events" contamination. A comparison between left and right plots shows the good efficiency of the "low energy events" cuts but the right plots still show a little contamination. The "Hadron" Arm seems to have a bad efficiency around runs 1500. This is due to the large prescale factor: This arm was not used during this time.

[6]This number include the cut of the good two track events. cf subsection 4.5.3

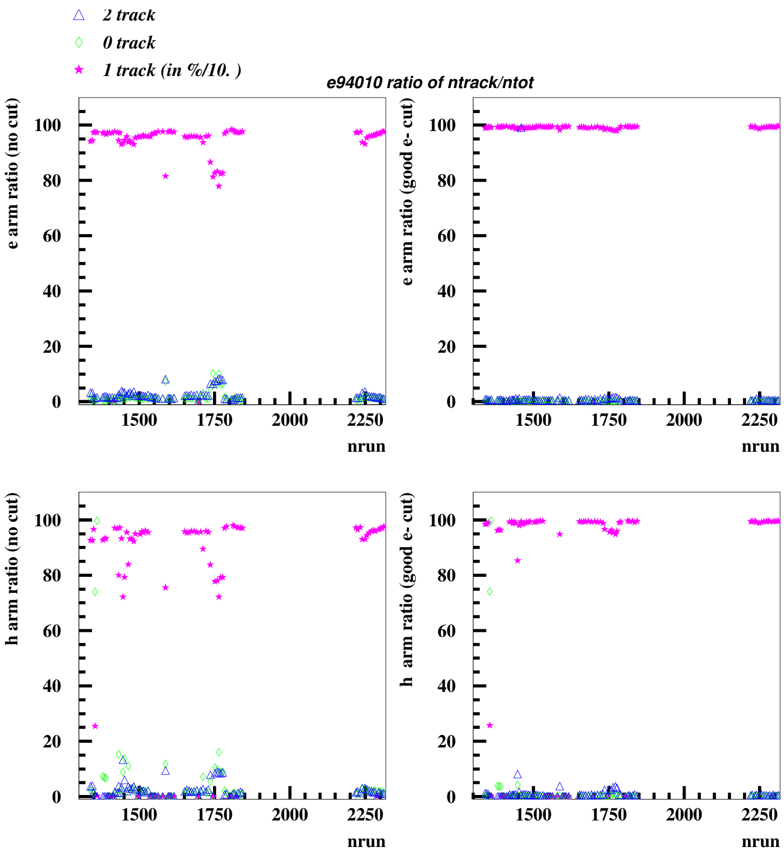

Fig. 4.8 Percentage of 0, 1 and 2 tracks versus the run number for the 1.72 GeV energy. The plots on the left are without "good electron cuts". The plots on the right are with "good electron cuts". The upper plots are for Electron Arm while the lower plots are for "Hadron" Arm.

5 Summary

VDCs have worked well during the experiment E94010. Hardware inefficiency is negligible. The software efficiency of the VDC is superior to 99 % for the inelastic runs. Elastic runs at 1.72 GeV have a lower efficiency due to "low energy events" contamination. With reasonable cuts on y_target, θ_target and φ_target these events mostly disappear and the VDC efficiency for elastic runs raise up to 99 %. Elastic data at 0.86 GeV does not show this contamination and has an efficiency close to 100 %.

References

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