Experiment 787
Technical Note No. 349
Range Stack TDC Feasibility Study

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1 Introduction

It has been proposed that the range stack be instrumented with TDC's, and that the TD window be decreased from it's end-of-1997 run value of 6.6 μs after prompt (7.1 μs total) to perhaps 0.5 μs after prompt (1 μs total). The TD's would be used to record prompt and muon-time hits, and the TDC's would be used to record prompt, muon- and electron-time hits. The potential benefits of this TD + TDC scenario are:

- The TD readout time is currently the limiting readout time in DAQ. Reducing this readout time would therefore decrease the online deadtime.
- The time window for TDC's on the range stack could be made longer than the current TD window in order to increase the acceptance of electrons from $\pi^+ \rightarrow \mu^+ \rightarrow e^+$.
- TDC thresholds could be made significantly smaller than current TD thresholds in order to improve the rejection of rate-dependent backgrounds (low thresholds and narrow time windows are known to work best for the offline photon veto).
- 0.5 ns TDC's would provide better pulse and flag time resolution than is currently available from the TD's.
- The overall data size is reduced $\rightarrow$ fewer data tapes.

The questions addressed here are:

1. Can the electron-finding routines operate adequately without detailed pulse shape information?
2. What is the potential gain in online deadtime?
3. What is the potential gain in electron acceptance?
4. Can a range stack TDC system be incorporated into DAQ?

2 Electron Search Using TDC Data

2.1 Study Method

The electron-finding routine is $KOFIA_USER/ev5. This routine examines all hits in the range stack (as found by $KOFIA_TD/pulsate, which requires pulse height.ge.5 counts over pedestal), constructs coincidences out of the "local" hits (where local is defined by ± 1 sector, ± 2 layers around the stopping counter), and prepares a list of electron candidates out of the coincidences which occur after muon time. If the ev5 routine is called with the argument imode = 0, then electron candidates are evaluated based on their energy and z position. If ev5 is called with imode = 1, then in addition to energy and z position, electron candidates are required to have a certain "pattern"; that is, they must have a hit in the stopping sector, and a hit in a layer within ± 1 of the stopping layer.

In order to study the performance of the electron-finding, a second version of ev5 was written (ev5fill) that has looser time requirements and local area definition, and saves the times and pulse heights, widths, areas, pedestals, and maxima of hits associated with the resulting electron candidates in an ntuple. This information is also saved for accidental electron candidates which are found on the opposite side of the range stack (i.e., around the same layer but opposite sector to the stopping counter). These ntuple variables are read into a COMIS (PAW fortran) routine which is a reproduction of the ev5 algorithm. In addition, this COMIS routine can manipulate ntuple variables and be modified on the fly in order to optimize parameters, and to convert TD data and cuts into TDC data and cuts.

The data sample used to measure the rejection of electron-finding is the "opposite-side" electron candidates (described above) from the 1995 TRIUMF skim2 pass1.5 output. These electron candidates define a clean sample of TD electron-time accidental background. The data sample used to measure the acceptance of electron-finding is the 1995 TRIUMF skim3 pass1.5 output, with pscut1 inverted (select piscats), tmuav1.ge.15 (remove TD tail fluctuation background), and abs(dt1).le.2 (remove muon-time accidental background).

The TRIUMF 1995 analysis ran ev5 with imode = 0. Using the above ev5fill routine and data samples to measure rejection (R) and acceptance (A), we find $R = 8.44$, $A = 0.7968$. The Princeton 1995 analysis ran ev5 with imode = 1, for which $R = 18.60$, $A = 0.7723$. A rejection of 8.44 was found to be adequate in the TRIUMF analysis, because the TD background was not limited by electron-time background, but rather by muon-time background. Also, if TDC data is to be used to find electrons, then pattern recognition is the major tool by which electrons are identified, and ev5 would certainly be run in imode = 1. Therefore, the goal of the TDC study is to remove energy cuts (which require TD data) and to design additional pattern recognition cuts such that an acceptance of 0.7723 is maintained and a rejection of at least 8.44 is obtained. Note that TDC data provides information on pulse widths, so a pulse width energy cut can also be applied.

2.2 Pattern Recognition and Pulse Width Energy Cuts

The pattern recognition cuts (in addition to imode = 1) that are found to be effective in identifying electrons are:

1. totlhit – a cut on the total number of hit counters in a local area around the stopping counter, where local is defined as a counter from any layer within ± 2 sectors of the stopping sector. An electron must have totlhit.le.9.

2. (maxlay - minlay) – a cut on the range (in layers) of the local area hits. An electron must have (maxlay - minlay).le.9.

Furthermore, when using these pattern recognition cuts, the time window which defines a counter-to-counter coincidence is narrowed from the nominal ev5 value of 5.0 ns to 2.5 ns. Also, as

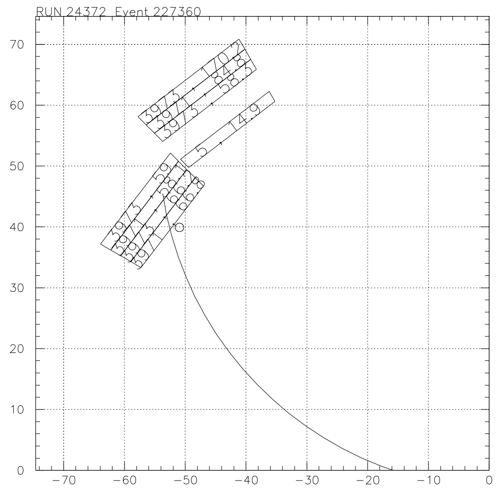

Figure 1: Photon splash in the range stack which, without energy information, mimics an electron. Each counter is labelled by the average time and geometric mean pulse height of upstream and downstream pulses. Summing the pulse height geometric means which occur at electron time (3971-3 ns), this splash has an energy of 563.4 counts / 6 counts/MeV $\sim$ 94 MeV, which is well above the electron endpoint of $\sim$ 55 MeV.

explained is section 2.3, the pulsate TD times are converted into TDC times with a TDC threshold of 2 counts over pedestal (0.3 MeV for a pulse at $z = 0$).

Cut (1) is used to distinguish electrons from accidental charged tracks and photon splashes. Cut (2) is designed to distinguish electrons from charged tracks and from non-contiguous photons which Compton-scatter before pair-producing. Note that acceptance loss in cut (2) can come from electrons which emit bremsstrahlung photons, which subsequently Compton scatter and/or pair-produce some distance away from the electron.

The types of non-electron events that can still pass the cuts above are small-area accidentals similar to the photon splash shown in figure 1. While this photon splash can be identified by its energy, many electron-time accidentals have only 2 or 3 hit counters, and can not be rejected by pattern recognition or energy cuts, at least not without a substantial loss in acceptance. It is these types of accidentals which limit the electron-time background rejection.

TDC widths can potentially be used to distinguish high energy accidentals from electrons. The pulse width energy spectrum, where the widths are those returned from pulsate and corrected to an absolute threshold of 2 counts over pedestal, is shown in figure 2, along with the pulse height and pulse area energy spectra for comparison. (The current ev5 algorithim uses a TD pulse height as opposed to area energy cut, because heights are less sensitive to accidentals.) Note that for small TDC thresholds, the pulse width energy spectrum may not be as clean as that shown in figure 2 due to fluctuations in the pulse tails.

Electrons were defined to lie in the region between 20 and 450 on the pulse width energy spectrum. The rejection and acceptance of the electron-finding using pattern recognition and pulse width energy cuts is shown in table 1. Based on the criteria of maintaining an acceptance of 0.7723 and obtaining a rejection of at least 8.44 (see section 2.1), electron-finding can be performed sufficiently well with TDC data in place of TD data.

	TD data	TDC data	
		pattern cuts	pattern + pulse width energy cuts
R	18.60 ± 0.15	13.96 ± 0.10	17.96 ± 0.14
A	0.7723 ± 0.0012	0.7804 ± 0.0012	0.7579 ± 0.0012

Table 1: Rejection and acceptance of ev5 with imode = 1, using standard cuts involving TD data, as well as cuts designed for TDC data. The TRIUMF portion of the 1995 data was analyzed. All uncertainties are statistical.

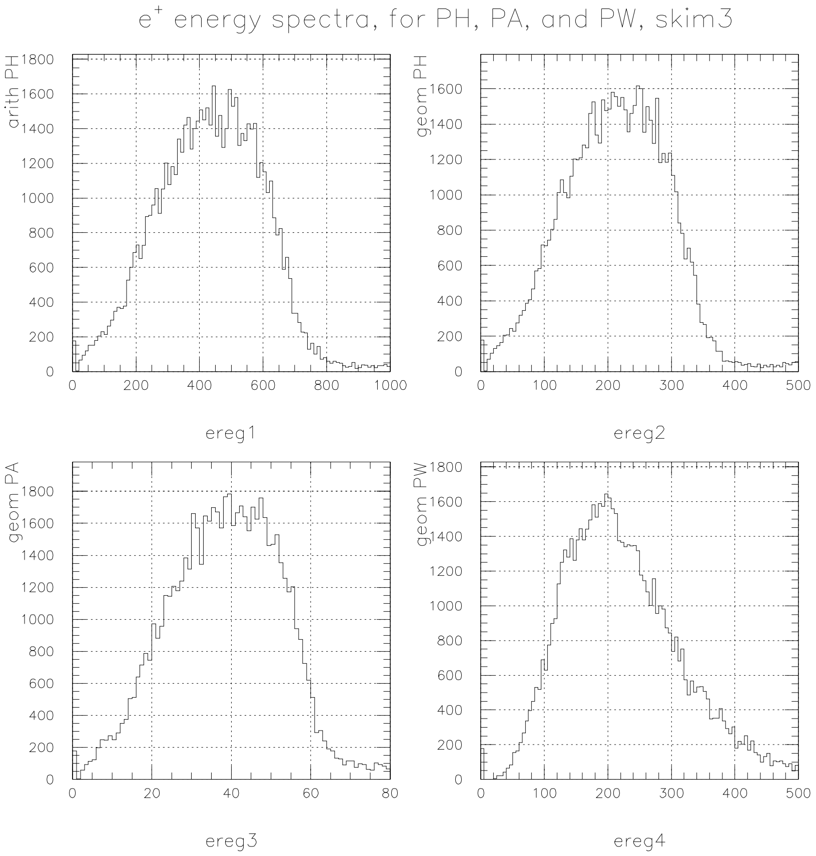

Figure 2: Electron energy spectra, where ereg1 = pulse height arithmetic sum, ereg2 = pulse height geometric mean, ereg3 = calibrated pulse area geometric mean, and ereg4 = pulse width geometric mean of upstream and downstream pulses summed over all electron hits.

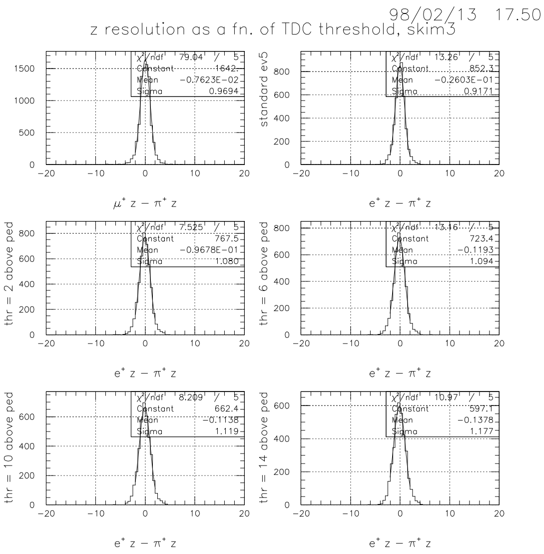

Figure 3: z resolution of electrons. The top left histogram is the muon z relative to the pion z (shown for comparison). The top right histogram is the electron z relative to pion z as found using TD data. The remaining 4 histograms are the electron z relative to pion z found using equivalent TDC data, for 4 different values of the TDC threshold. The electron z was calculated using only the electron hit in the stopping counter.

2.3 TDC Time Slewing

$KOFIA TD/pulsate puts the time of a pulse at the leading-edge half-max. However, the leading-edge time returned by a TDC is the time at some absolute threshold. The TDC time of a pulse therefore depends on the size of the pulse (assuming that the rise-time of the pulse is longer than the TDC time resolution). For example, for pulses which are small, such that the threshold is higher than the half-max of the pulse, the TDC time will be larger than the TD time. Conversely, for pulses that are big, such that the threshold is below the half-max, the TDC time will be smaller than the TD time. When calculating the end-to-end time difference of a pulse, T1 - T2, this effect cancels out for electrons that are at $z = 0$, because the end 1 and end 2 pulses are the same size and are therefore shifted in time by the same amount. However, for electrons which are at $-z$ (T1 - T2 < 0), the end 1 pulse is larger than the end 2 pulse (due to attenuation in scintillator). Therefore, T1 as found by a TDC is shifted “more negative” than T2, which makes T1 - T2 even smaller; that is, the electron is moved to smaller values of z (farther upstream). Similarly, pulses which are at $+z$ get moved to larger values of z (farther downstream). Therefore, one expects the TDC z distribution of electrons to be more “smeared-out” than the TD z distribution, and that this smearing should increase with increasing TDC threshold.

In order to simulate this effect, a representative TD pulse shape was taken from the TD_SHP calibration, and used to adjust the leading-edge half-max pulsate times to times found at some absolute number of counts over pedestal. These times were then put into 500 ps bins. The z resolution of electrons obtained using TD times is compared to that obtained using these TDC times for different thresholds in figure 3. The z resolution is indeed worse for TDC data, and worsens with increasing threshold, but the effect is small, even for large thresholds (threshold.ge.6 counts = 1 MeV for a pulse originating at $z = 0$). Furthermore, we can always use the muon z (from piscats) and/or the electron z (from early $K_{\mu 2}$ decays) as returned by the TD's and TDC's to calibrate out any time slewing effects.

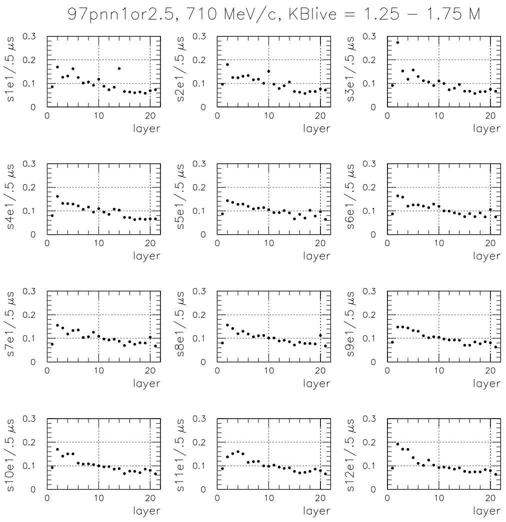

Figure 4: Accidental rate in sectors 1-12, end 1 of the range stack counters, in a 500 ns pre-prompt window.

3 Online Deadtime

The limiting readout time in DAQ currently comes from the TD system. So a gain in online deadtime can potentially be realized by reducing the width of the TD gate from the end-of-1997 value of $\sim 7\ \mu$s to, say, $\sim 1\ \mu$s. The activity in the range stack was measured in a 500 ns window before prompt using data from the 1997 pnn1or2.5 monitor tape. As shown in figure 4, the average rate in a range stack counter is ~ 0.1 pulses/500 ns. Therefore, in a 7 μs window, a TD channel will typically have 1 fiducial pulse + 0.1×14 accidental pulses + $\sim 1/24$ probability of prompt activity, giving ~ 2.4 pulses. In a 1 μs window, this number is reduced to ~ 1.2 pulses, leading to a data reduction factor of 2.

From a QOD printout of run 34928 (near the end of the 1997 run, with $p_{K^+} = 670$ MeV/c, TD gate = 6.6 μs after prompt), we have

KB/second = 0.76 M
events/spill = 80
TD readout time = 1.6 ms/event
total deadtime fraction = 0.16

(Note: we typically run at 1.0 KB/second = 1.6 KB/spill, so scaling these numbers up we get 100 events/spill and 20% deadtime.) Of the 1.6 ms/event TD readout time, 0.46 ms is overhead (e.g., word-size fetching) [1], so reduction of the TD data size by a factor of 2 would reduce the TD readout time to 1.6 - (1.6 - 0.46)/2 = 1.0 ms/event.

The total online deadtime = 0.16×1.6 s/spill / 80 events/spill = 3.2 ms/event. With 1.6 ms due to readout of the TD system, the other 1.6 ms is non-readout deadtime, e.g., level0 and level1.N trigger processing. Therefore, the total online deadtime could potentially be reduced by a factor of $(3.2 - (1.6 - 0.46)/2)/3.2 = 0.82$. For a typical total online deadtime of 20%, this means a reduction to 16%, which is a gain of 4%. However, this gain may be limited by the EC CCD system, which has a readout time of between 1 and 2 ms depending on the CCD pedestal level. If the EC CCD readout time can be kept below 1.0 ms, then the full 4% gain in online deadtime can be realized.

4 Electron Acceptance

At an accidental rate of 0.1 pulses/500 ns (see figure 4), it would be possible to use a TDC window of ~ 15 μs, and still only have 3 hits/TDC channel (well within the TDC limit of 8 hits/channel for LeCroy 1877 500 ps TDC's). With the current 1997 TD window of 6.6 μs after prompt (3 μ^+ lifetimes), the electron acceptance is $(1 - e^{-3}) = 95\%$. Using a TDC window of 7 μ^+ lifetimes, the acceptance increases to $(1 - e^{-7}) = 100\%$, for a gain of 5%. However, our acceptance for a 2 μ^+ lifetime TD window (1995) is 0.78 (see table 1), so we are killing roughly $0.78/(1 - e^{-2}) = 0.91$ of the real electrons. So we only expect to gain perhaps $0.91 \times 5\% = 4.5\%$ in electron acceptance. Furthermore, a wider time window will likely result in a loss in rejection, because the accidental background has a flat time distribution, whereas the electron signal exponentially decays with time. However, this may or may not be a problem because as mentionned in section 2.1, the limiting TD background is believed to be muon-time background, not electron-time background.

5 Range Stack TDC's in DAQ

As stated in section 4, each TDC channel can record a maximum of 8 hits. The accidental rate in the range stack is low enough to easily allow for a 7 μ^+ lifetime TDC window. The readout time for this 15 μs TDC window is 150 ns/word $\times 2$ words/hit $\times 3$ hits/channel $\times (24 \times 21 \times 2)$ channels = 0.91 ms, which is below the limiting readout time. The total TDC data size is 3 hits/channel/event $\times 2$ words/hit $\times 4$ bytes/word $\times (24 \times 21 \times 2)$ channels $\times 100$ events/spill = 2.4 Mbytes/spill. An SSP can take 8 Mb/spill, so a single SSP can handle the range stack TDC data, even if we go to a spill length longer by a factor of 3.

6 Conclusions

- electron-finding can be done sufficiently well with TDC data in place of TD data
- reduction of the TD gate from 7 μs to 1 μs could give a 4% gain in online deadtime
- use of 15 μs gate TDC's on the range stack could give a 4.5% gain in electron acceptance
- a 15 μs range stack TDC system can handle typical accidental rates and a long spill

References

[1] M. Kuriki, E787 Technical Note 348.