Estimate of Low Energy Neutron Rates in CKM

R. Tschirhart*

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Abstract

Data from the KTeV-E799 experiment is used to estimate the fluence of low energy neutrons that the CKM photon veto systems will have to contend with. The estimate is determined from the non-prompt fraction of plastic scintillator activity measured in the high intensity environment of E799. The fluence estimates conclude that low energy neutron fluence is probably tolerable, assuming the VVS can achieve the expected time resolution.

*Email address: tsch@fnal.gov

1 Introduction

Our estimates of rates and consequent deadtime in the CKM detector have been based on a full GEANT3 simulation of the beamline and detector. This is a complete procedure for the physical processes that are simulated in the GEANT3 package. Notable on the list of processes not treated by GEANT3 are low energy neutrons produced at the primary beam dump, the π^+ beam plug, and the K^+ beam dump. The experience of low energy kaon experiments that must operate near the primary beam dump has shown that low energy neutrons (less than 5 MeV) can be a serious rate problem. Plastic scinitllator is particulary vulnerable to these neutrons due to the high fraction of hydrogen in the active material. The reaction

$$p^+ + n^0 \rightarrow d_2^+ + \gamma(2.2\ MeV)$$

has a high cross section for low energy neutrons, and can be a copious source of 2.2 MeV photons. These 2.2 MeV photons and other reaction products are asynchronous with the K^+ beam since the parent neutrons are slow ($\beta(5MeV) = 0.1$) and quickly become decoherent with the beam. A reasonable model of these low-energy dump neutrons then is:

- The intensity falls of as $1/r^2$ from the dump location (point source model).
- The neutron fluence is asynchronous with the high energy proton or K^+ beam.
- The lowest end of the spectrum (< 1 MeV) has a diffusive/thermal component that can percolate through channels and spread the effective size of the originating dump source.

The CKM Vacuum Veto System (VVS) which is composed of $20m^3$ of distributed scintillator operating with a visible energy threshold of 1-2 MeV will be very sensitive to the low energy neutron fluence. Hence it is important to understand what data and simulation tools exist to estimate the vulnerability of the VVS to this fluence. In this note the KTeV E799 rare decay data set is employed to establish a limit on the magnitude of the low energy neutron fluence.

2 The KTeV Rate Environment.

The layout of the KTeV detector is shown in Figure 1. The KTeV vacuum decay volume begins 100 meters from the primary target station and dump. In the E799 rare-decay configuration two neutral parallel beams enter the vacuum decay volume. These beams have a neutron/kaon ratio of $\sim \times 4$ with a total rate of about 80 MHz, (KTeV Beamline Design, Fermilab TM-2046). The neutron and kaon energy spectra are broad, with mean energies of 150 GeV and 50 GeV respectively. The two neutral beams pass through the spectrometer and holes in the CsI calorimeter, and terminate in a muon filter steel dump 6 meters downstream from the front face of the CsI calorimeter. Two thin (3 mm thick) small ($15cm \times 15cm$) scintillator counters exist in each beam 3 meters upstream of the filter steel dump. The counters are fully efficient for traversing minimum ionizing particles, and the hit threshold corresponds to about 0.2 MeV of deposited visible energy.

The time distribution of hits in the beam counters with respect to an in-time kaon decay is shown in figure 2 on a linear scale and figure 3 on a log scale. The 53 MHz (19 nsec) bucket structure of the beam is clearly seen, with the in-time trigger bucket time set at zero. The clocked nature of the beam can be exploited to limit the magnitude of non-prompt hits in the scintillator that would arise from asynchronous low energy neutron fluence from the primary and secondary beam dumps. From figure 2 and figure 3 it is evident that prompt in-time hits vastly dominate the rate, even *in* the neutral beam with a low threshold and close to the neutral beam dump. From figure 3 one can see that the non-prompt fraction of hits between buckets prior to the trigger bucket is $\sim 1\%$.

In order to estimate the rate of non-prompt activity in bulk scintillator the trigger hodoscope 8 meters upstream of the neutral beam dump will be used. This hodoscope is a $2m \times 2m$ array of 24 $1m$ long scintillator counters $0.5cm$ thick with a hit threshold of 0.2 MeV visible energy. The hodoscope has two ($15cm \times 15cm$) holes to pass the neutral beam, and the total scintillator bank volume is $20,000\ cm^3$. The time distribution of hits with respect to an in-time kaon decay is shown in figures 3 and figures 4 for the four quadrants of this trigger hodoscope. Similar to the beam counters, the rate is dominated by in-time hits, although the in-time peaks are smeared by transit time within the long counters. Using tracks projected to the trigger counters and correcting for the transit time, the in-time peaks become quite narrow and Gaussian with a $\sigma = 600\ psec$. Since this is a rate analysis and the location of the raw hits are ussually not known, it is not possible to remove the geometric time slewing from the in-time peak.

The individual quadrant non-prompt fractions evident in figure 4 are about 4%. The correlated non-prompt fraction for the entire bank is about 6%, and the nominal single-hit rate of the full bank is 3 MHz from the 80 MHz neutral beams. The non-prompt fractions are stable over a wide range of intensity, indicating that the source is beam related. At nominal E799 intensity the beam related non-prompt rate is 180 kHz for this volume of $20,000\ cm^3$ of scintillator that samples a large solid angle in the experiment. This rate is an upper limit on the neutron induced rate, since the non-prompt fraction has other contributions from calorimeter splash-back and the tail of the prompt peak.

3 Neutron Rate Estimates for CKM

This non-prompt rate of 180 kHz in the E799 trigger hodoscope can be used to construct an estimate of the neutron fluence in CKM assuming that the rate originates from a point source at the downstream K^+ beam dump and the upstream π^+ beam plug where the separated beam originates. Assuming $1/r^2$ scaling from the dump location the normalized rate is:

$$Dump\ Rate = (7.2\times 10^{-6}\ m^2/cm^3/hadron.)\times Vol(cm^3)\times 1/(r(m))^2\times Beam(Hz).$$

As seen in CKM apparatus in figure 5, the VVS which is comprised of $2\times 10^7 cm^3$ of plastic scintillator is located between $40m$ and $65m$ from the K^+ beam dump. The dump is illuminated with 40 MHz of undecayed 22 GeV/c hadron beam, which corresponds to a *Dump rate* = 3.6 MHz assuming all of the VVS volume is $40m$ from the K^+ dump. Given the complexity of the downstream detector mass near the K^+ dump, $1/r$ scaling should be considered as well. Assuming $1/r$ scaling, this rate rises to 18 MHz. As discussed in the proposal, a VVS time resolution of $\pm 3nsec$ (6 nsec window) is plausible, which would correspond to a *Dump rate* dead time of (2-10)%.

The upstream beam plug that terminates (Tom K., personal communication) $\sim$ 2000 MHz of unseparated beam is located $85m$ upstream of the VVS. The $(1/r^2)$ *Dump rate* from the beam plug is 40 MHz, which corresponds to a VVS dead time of 25%.

4 Summary

These estimates bound the VVS slow neutron deadtime to less than 10% from the kaon beam dump, and less than 25% from the upstream π^+ beam plug. These bounds are quite conservative, and the deadtime associated with low energy neutron fluence will likely be far less for the following reasons:

- The average energy of the KTeV hadron beam is about $\times 5$ that of CKM. Hence the neutron fluence/hadron in the CKM beam will be less.

- The visible energy threshold on the KTeV scintillator trigger hodoscope used in these estimates is 0.2 MeV, which is below most energy deposits of low energy neutron induced reactions. Consequently the KTeV trigger hodoscope efficiently samples the local neutron fluence. In contrast the lowest visible energy fraction considered for the CKM VVS is 1 MeV, which corresponds to incident photon energies greater than 3 MeV on average. The $n + p \rightarrow d + \gamma(2.2MeV)$ reaction discussed previously will ussually deposit visible energy less than 1 MeV.

- The amount and geometry of the shielding between the CKM K^+ beam dump and the VVS is similar to the material between the KTeV neutral beam dump and the KTeV trigger hodoscope. The extrapolated neutron fluence limit from the upstream beam plug however ignores the large amount of integrated shielding between this upstream CKM beam element and the VVS. Hence the neutron fluence from the beam plug will likely be far below the upper limit determined from downstream detector elements of KTeV.

These estimates and simple arguments suggest that the VVS singles rate will not be swamped by low energy neutrons. These estimates do however underscore the importance of shielding of upstream beam elements. Experience at BNL and other low energy kaon beam facilities has shown that low energy neutron fluence can be significantly reduced with careful dump design and the use of neutron absorbers. Our next round of investigations should include simulation codes designed specifically for low energy hadron and neutron transport such as MARS and PICA.

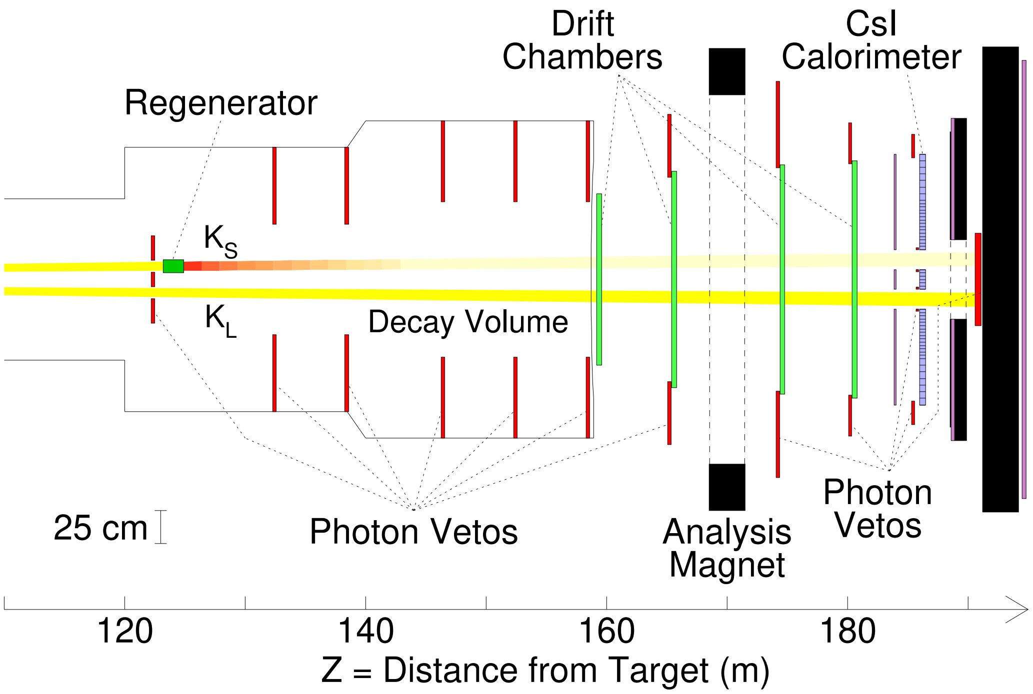

Figure 1: Plan View of the KTeV detector. E832 configuration shown.

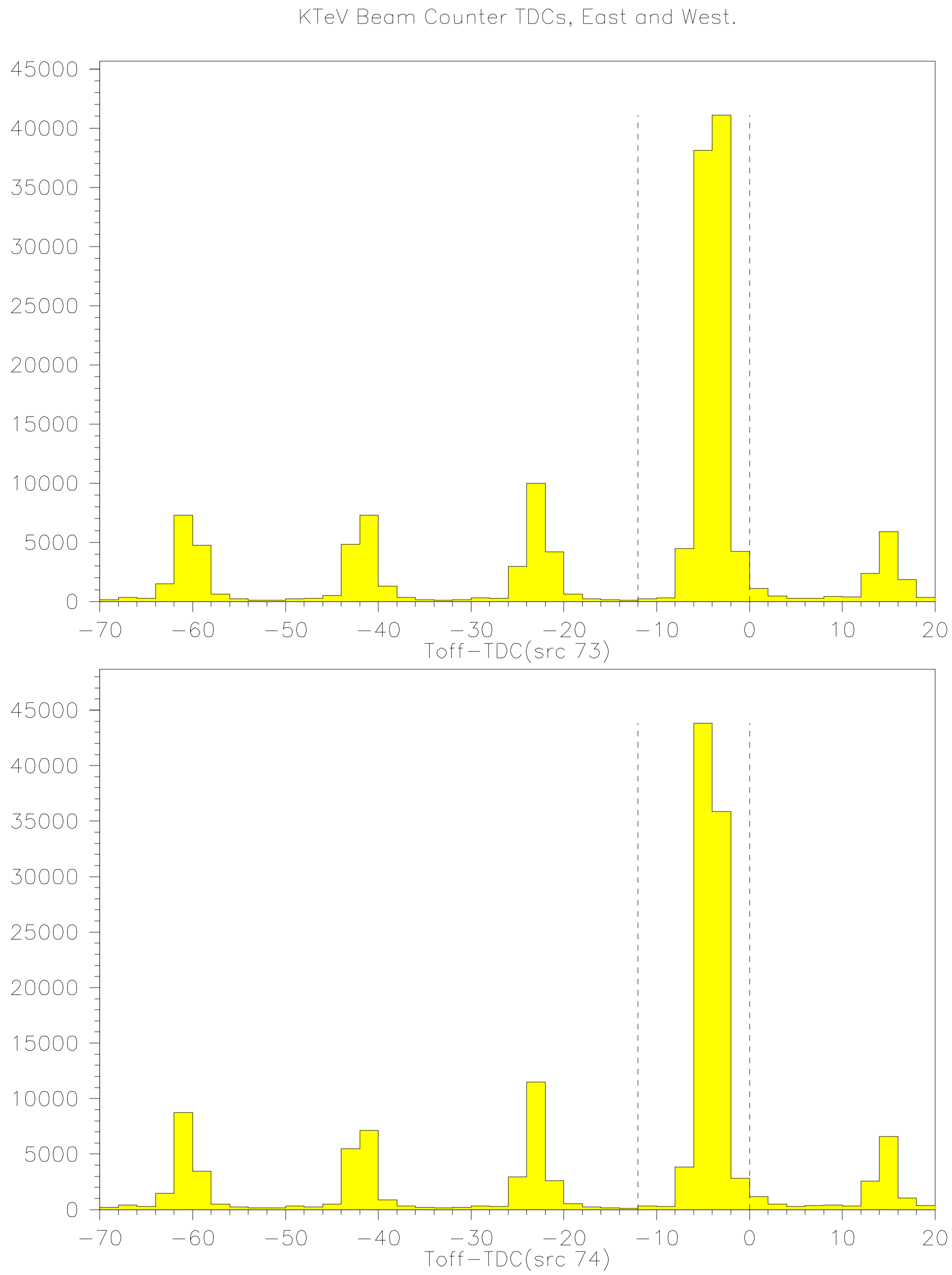

Figure 2: Linear scale: TDC distribution of the two small ($15cm \times 15cm$) counters present in the two neutral beams.

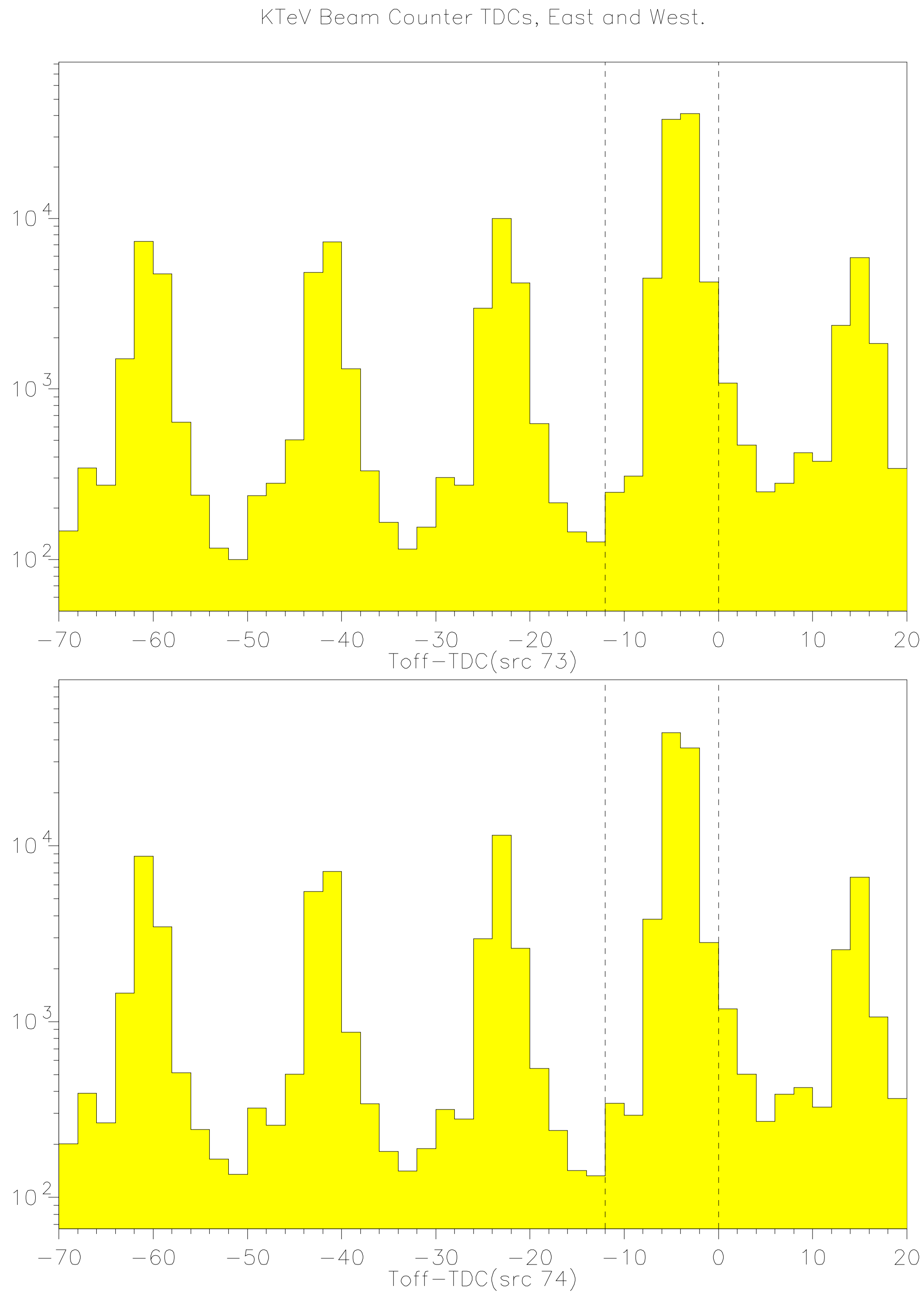

Figure 3: Log scale: TDC distribution of the two small ($15cm \times 15cm$) counters present in the two neutral beams.

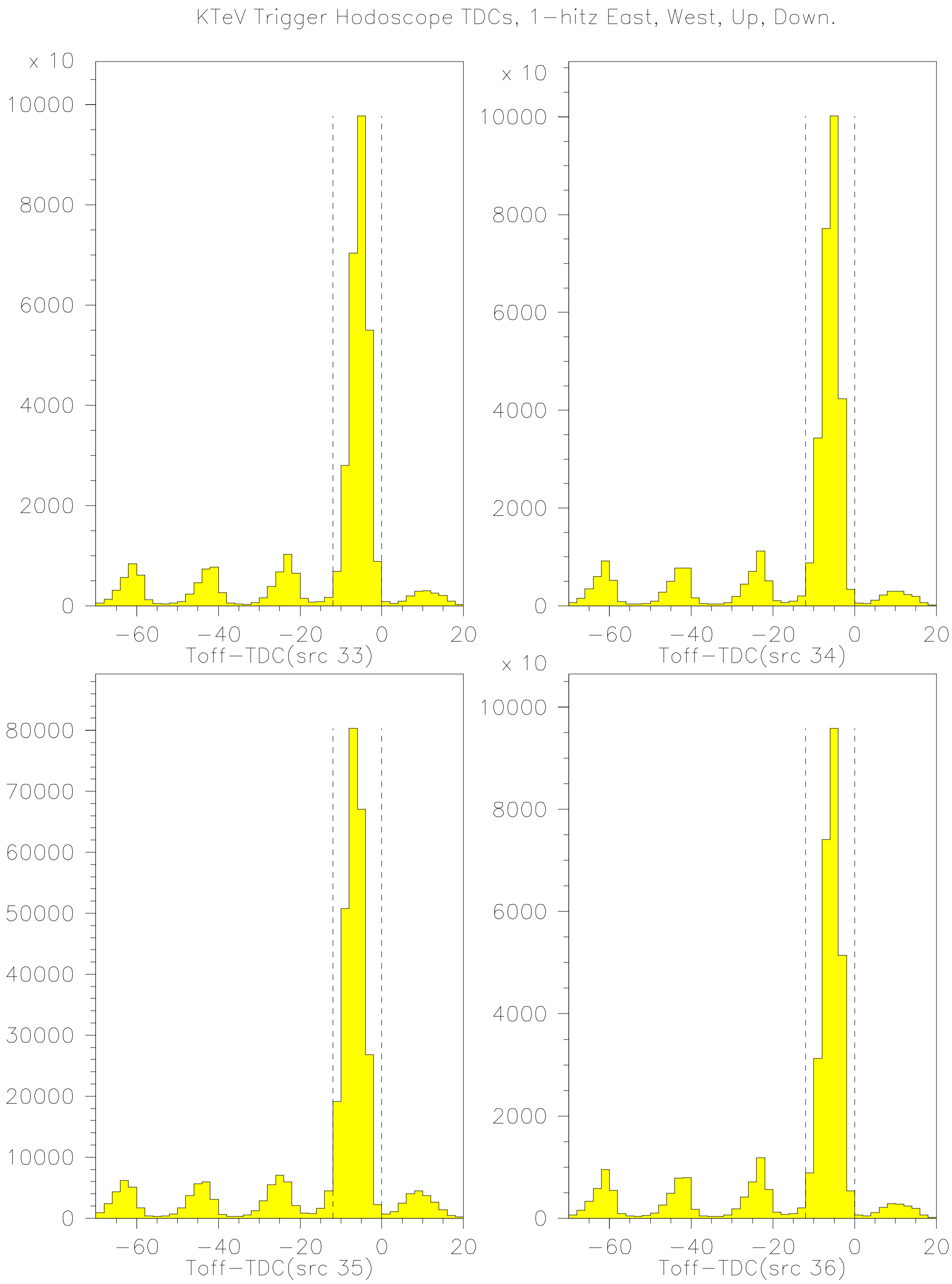

Figure 4: Linear scale: TDC distribution of the four quadrants (Up,Down,East,West) that compose the trigger $2m \times 2m$ trigger hodoscope.

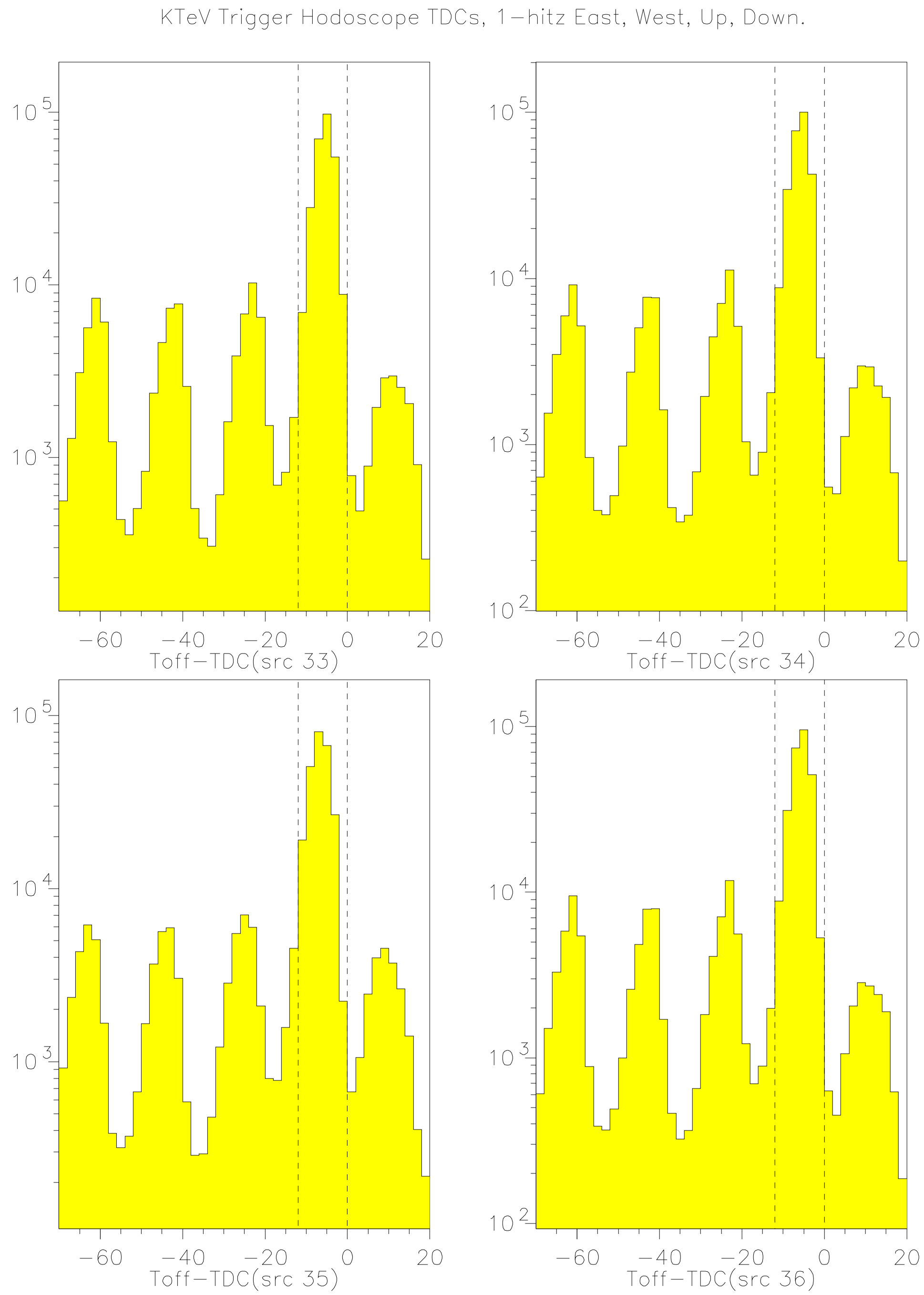

Figure 5: Log scale: TDC distribution of the four quadrants (Up,Down,East,West) that compose the trigger $2m \times 2m$ trigger hodoscope.

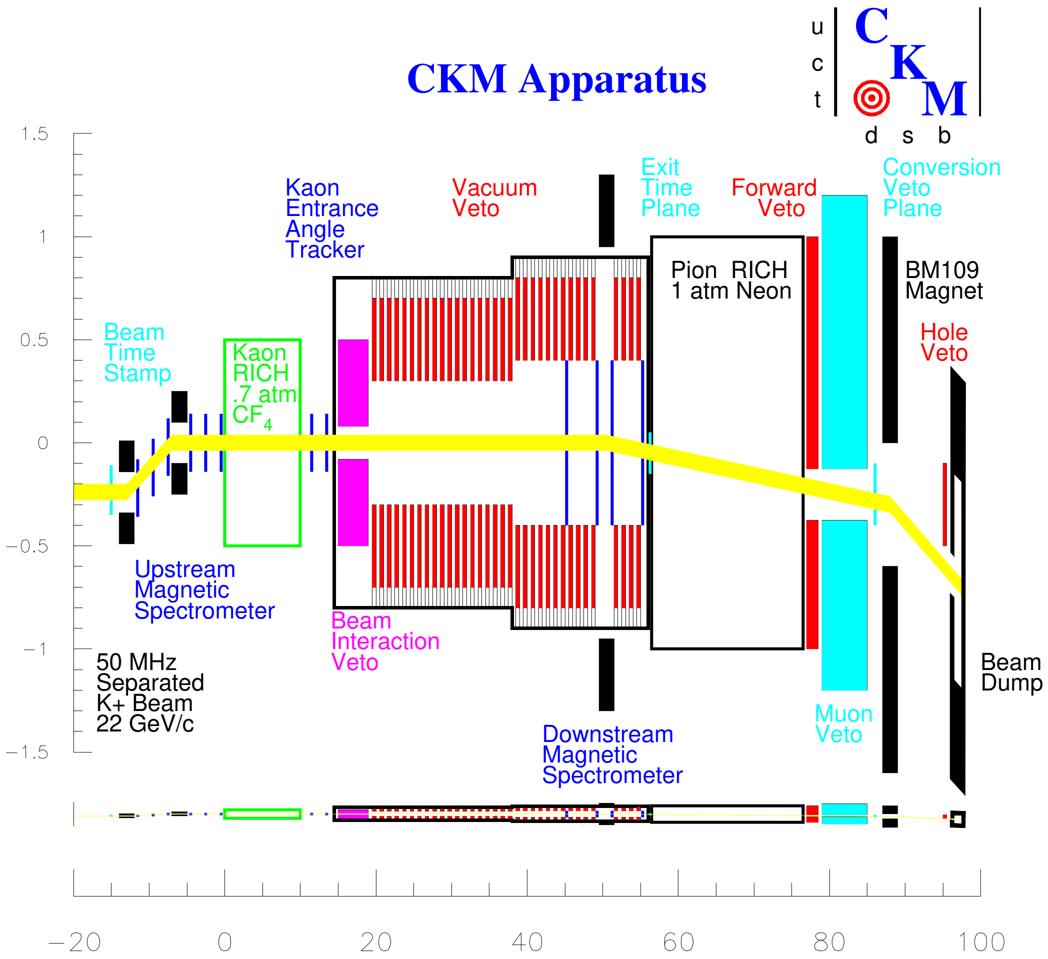

Figure 6: The CKM detector.