**Rate Dependence of the HMS Tracking Efficiency**

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**Abstract**

The experimental cross sections are determined from the efficiency corrected experimental yields. One of the larger corrections is the HMS tracking efficiency. A good understanding of this correction is thus important for any data analysis.

The electron tracking efficiency in the HMS drift chambers (DCs) has been observed to fall off linearly with rate, and discrepancies in the normalized yields have been observed at high rates. In this study, a basic explanation of the linear dependence and the contribution of multiple-track events to the tracking efficiency are presented.

## I. INTRODUCTION

The experimental cross section is extracted from the normalized yield. In forming the normalized yield, one must apply corrections for inefficiencies like track reconstruction and data acquisition deadtime. The total efficiency, $\epsilon_{tot}$, is applied to the total experimental yield as follows:

$$Y_{exp} = \frac{N}{\epsilon_{tot}\ Q_{tot}} \tag{1}$$

where N is the total number of events, $\epsilon_{tot}$ is the efficiency correction factor (all efficiencies combined) and $Q_{tot}$ is the total accumulated charge in mC.

One of the larger inefficiencies is the tracking effciciency. It is defined as the ratio of events where a particle passed through the drift chambers, and the number of events that produced a valid track. The latter are defined by requirements like the number of hits in a fiducial area of the scintillators. The resulting efficiency depends on both the drift chamber efficiency and the tracking algorithm finding a track.

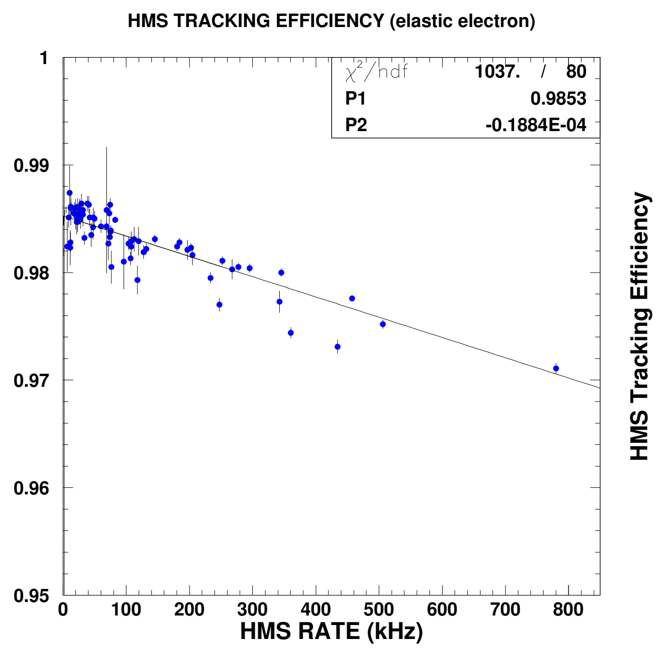


FIG. 1: *The HMS tracking efficiency versus rate for Fpi2. The zero-rate tracking efficiency is 98.8 %.*

Experimental data from Hall C have shown that the efficiency for tracking electrons in the HMS drift chambers falls off linearly with rate (see Figure 1). This behavior can be described by a simple model that takes into account contributions from multiple tracks.

At high rates there is a nonzero probability for more than one particle passing through the chambers within the TDC window used in the analysis (e.g., 250 ns during Fpi2). The tracking algorithm, however, keeps only one good track for each event. The loss of additional tracks from multiple-track events is taken into account by deadtime corrections. The electronic deadtime corrects for additional tracks, which are blocked from producing another trigger, and the computer deadtime corrects for tracks lost passing through the drift chamber after the track that gave a valid trigger and is read out by the data acquisition. In the coincidence configuration, a coincidence lost in the event that a single trigger is not recorded due to prescaling, is taken into account by the coincidence blocking correction. However, even after correcting for various deadtimes, the reconstruction efficiency for one good track for a given trigger remains dependent on the presence of multiple tracks in the drift chambers.

Examinination of the events with two more more tracks reveals that the additional inefficiency is the result of having too many "hits" in the drift chambers. Figure 2 shows an example of an event with multiple tracks that are too close to each other to be disentangled by the tracking algorithm.

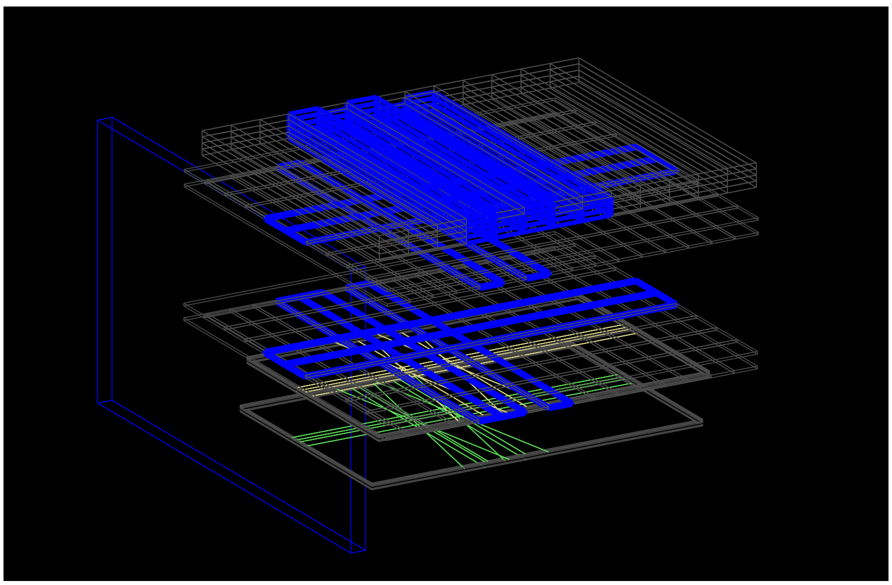

FIG. 2: *The one-event display for an electron trigger in the HMS. Intersecting lines in the drift chambers (the first two planes) denote "hit" wires. This is an event for which the separation between tracks was below the minimum required to disentangle the tracks.*

## II. RATE DEPENDENCE MODEL

A simple model was introduced in order to test the rate dependence of the tracking efficiency calculation in the presence of multiple tracks. The tracking efficiency is calculated from the single and multiple track efficiencies weighted by their contribution to the data sample. The present tracking efficiency study is limited to electrons, and does not include contributions from particle decay. Taking into account multiple track events, the total tracking efficiency can be expressed as,

$$\epsilon_{tr} = P_1 \cdot \epsilon_1 + P_2 \cdot \epsilon_2, \tag{2}$$

where $\epsilon_{tr}$ is the total HMS tracking efficiency, $P_1$ is the probability for a single electron passing

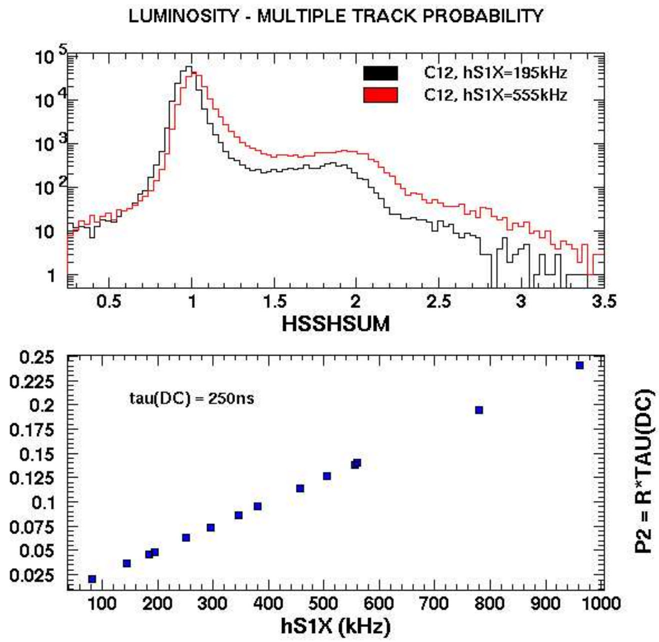


FIG. 3: *The probability of multiple track events. The upper panel shows the normalized electron energy deposition in the HMS calorimeter. The main peak centered around unity corresponds to single electron events. The second peak at higher energy corresponds to multiple track events. The lower panel shows the probability for multiple track events assuming Poisson statistics.*

through the chambers, $P_2$ is the probability for multiple electrons traversing the drift chambers on a time scale, $\tau$, and $\epsilon_1$ and $\epsilon_2$ denote the tracking efficiency for single electrons events and multiple electrons events respectively. The efficiencies, $\epsilon_1$ and $\epsilon_2$, are assumed to be rate independent and the origin of the rate dependence is assumed to be attributable solely to the probability of multiple track pile-up within the allowed drift chamber gate width, $\tau$. Using Poisson statistics, the probability for arbitrary multiple-track events in the drift chambers, independent of particle identification, is,

$$P_2 = 1. - e^{(-R\tau)} \approx R\tau, \tag{3}$$

where $R$ is the drift chamber rate and $\tau$ denotes the drift chamber gate width used in the analysis. Substituting equation 2 into equation 3 allows for expressing the total tracking efficiency in terms of the multiple track probability and the single and multiple electron efficiencies,

$$\epsilon_{tr} = \epsilon_1 - R\tau \cdot (\epsilon_1 - \epsilon_2). \tag{4}$$

The validity of equation 4 can be tested using the following methods:

1. **TDC Windows Study**: At fixed rate the tracking efficiency should scale linearly with the relevant time window, $\tau$. This can be tested by varying the DC tdc window used to define 'good' hits and plotting the calculated $\epsilon_{tr}$ versus the window width.

2. **Multiple Track Efficiency**: $\epsilon_2$ can be determined from data by isolating 2-electron events using the energy deposition in the calorimeter and determining the tracking efficiency for these events. Figure 3 shows a representative example of an electron calorimeter spectrum. The contribution of multiple tracks increases significantly as the rate increases. The extracted multiple-track tracking efficiency should be rate independent.

## III. DRIFT CHAMBER TDC WINDOW STUDY

A study of the tracking efficiency with varying widths of the HMS drift chamber TDC window was performed for data taken during Spring 2003 with scintillator rates (hS1) up to 900 kHz. This particular study uses run 45283 with tracking efficiency close to the fit value and moderately high rate. As shown in Figure 4, the efficiency is linear with respect to the TDC window width. The efficiency corrected yield is plotted versus efficiency in Figure 5, and is largely independent of the TDC window width.

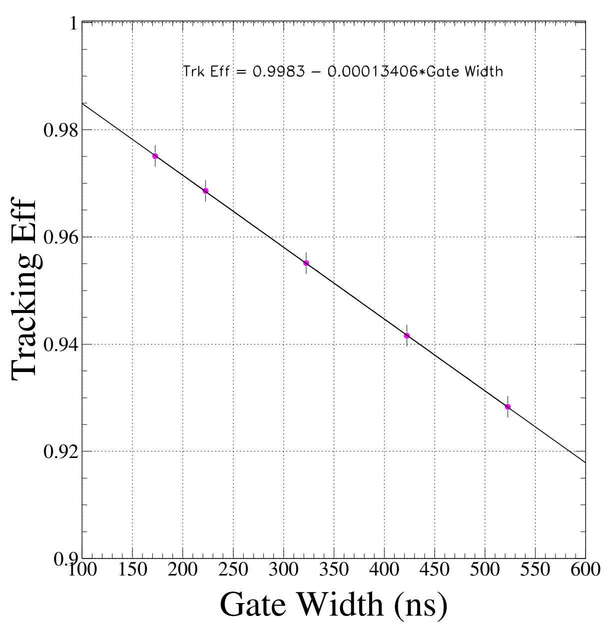


FIG. 4: *The tracking efficiency versus TDC window width for run 45283 with a scintillator rate of R=558 kHz. Approximate uncertainties in the tracking efficiency are shown.*

While the scintillator rate is expected to be larger than the DC rate due to the larger active area of the scintillators, the effective time window, $\tau$, is expected to be smaller than the DC tdc window, $\tau_{DC}$. This is due to an intrinsic biasing in the tracking efficiency algorithm. In order to reduce the effect of chamber noise and junk events (such as in-scattering) at low rates, events with multiple (separated) scintillator paddles firing in a single plane are discarded from the efficiency calculation. This specifically excludes multiple particle events which come within some $\Delta\tau$ of each other, and which have an intrinsically smaller tracking efficiency. If the second particle comes later than $\Delta\tau$ after the electron which produced the trigger, then only the scintillators associated with the first track will be recorded as having fired. This type of multi-particle event will be included in the tracking efficiency calculation. This give rise to an effective time scale of $\tau = \tau_{DC} - \Delta\tau$.

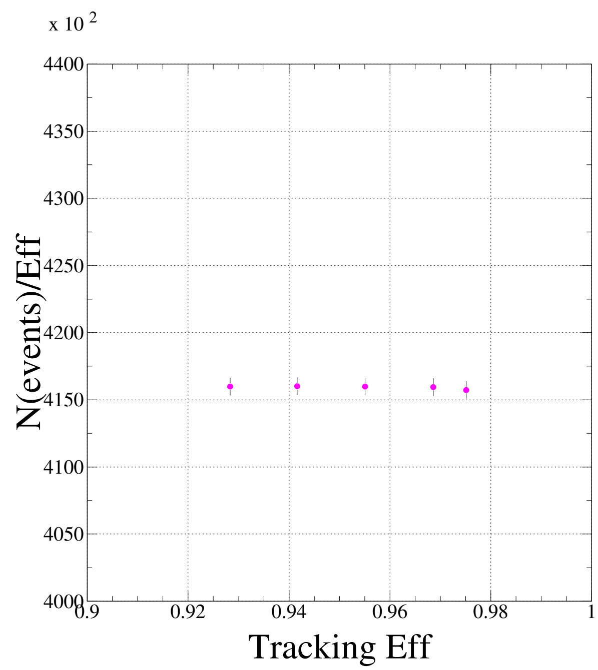


FIG. 5: *The efficiency corrected yield versus efficiency. The yield is independent of the tracking efficiency.*

The HMS single-track tracking efficiency ($\epsilon_1$) of 0.9983, given by the intercept in Figure 4, is significantly larger than the zero-rate efficiency of 98.8 % determined from the intercept in Figure 1. Assuming that this difference is due to the difference between $\tau$ and $\tau_{DC}$, $\Delta\tau$ can be extracted,

$$\Delta\tau = \frac{0.9983 - 0.988}{0.000134 \text{ ns}^{-1}} = 77 \text{ ns}. \quad (5)$$

## IV. MULTIPLE TRACK EFFICIENCY

The multiple track efficiency, $\epsilon_2$, was determined by isolating multiple track events via the energy deposition in the calorimeter and determining the tracking efficiency for these events. This efficiency is rate independent. The single track efficiency is obtained in a similar fashion, and is generally higher by more than 25% relative to the intrinsic multiple track efficiency of 71% (see Figure 6). The values for single and multiple track efficiencies for the Fpi2 luminosity data are in good agreement with the results from Spring 2003 data.

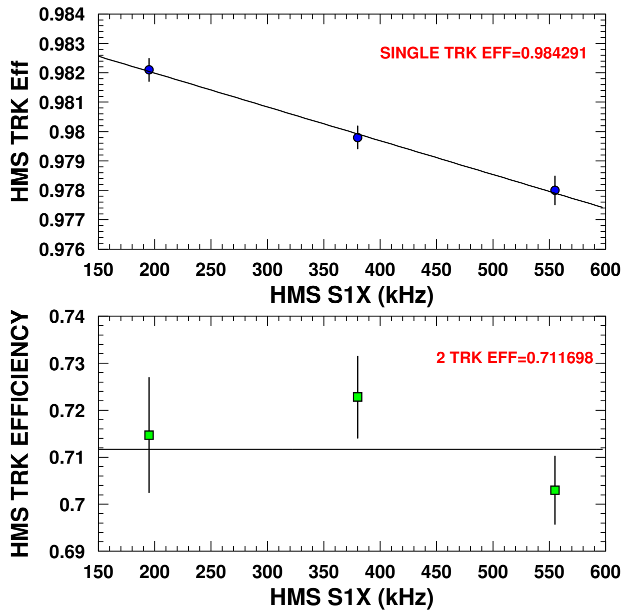


FIG. 6: *The tracking efficiency for single and multiple track events. The single track efficiency is 98.4 %, and the multiple track efficiency is 71.1 % (lower panel).*

The total particle rate in the drift chambers was estimated from the rate in the first scintillator layer (S1X) instead of using the pretrigger rate. This eliminated any dependence on the particular trigger configuration. The resulting efficiency prediction agrees to within 1 % at 1 MHz with the efficiency calculation including multiple track events used in the Hall C ENGINE (analyzer). The discrepancy observed at high rates can be attributed to the difference between drift chamber and scintillator rates used in the model prediction of the tracking efficiency.

Figure 7 illustrates the HMS tracking efficiency including multiple track events. The presence of multiple track events reduces the tracking efficiency for a given valid electron trigger, and can be attributed to the exclusion of multiple track events (that arrive within the allowed drift chamber gate) in the efficiency calculation. The intrinsic bias towards single track events is introduced in software by disallowing events with signals from multiple, separated scintillator paddles in a single plane. While this approach is desirable for a low signal to noise ratio, by reducing chamber noise due to, e.g., scraping in the magnetic elements, it results in an over-estimate of the tracking efficiency at high rates.

The difference of including multiple track events in the tracking calculation is on the order

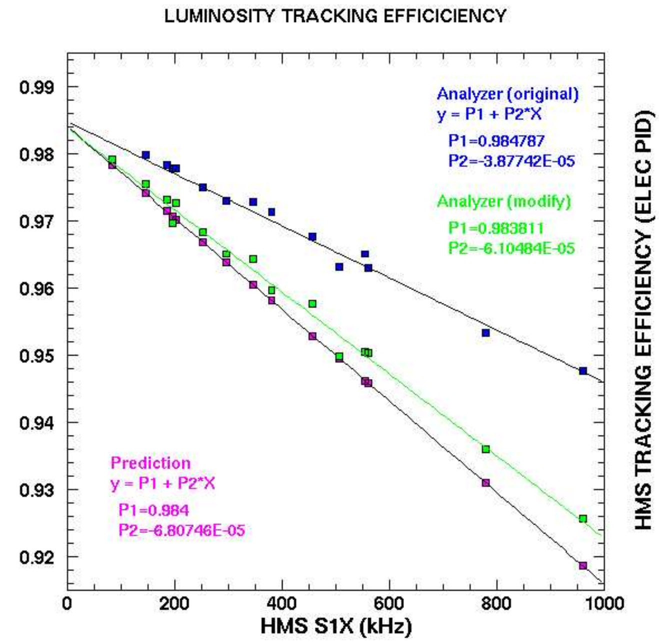


FIG. 7: *The HMS tracking efficiency calculated from equation 2 (magenta), and using the Hall C ENGINE with single track bias (blue) and taking into account multiple track events (green). The difference between the prediction and the corrected Hall C ENGINE calculation at high rates can be attributed to differences in the trigger gate widths and the larger active area of the scintillators.*

of 1 % at rates of 200 kHz, and 5 % at higher rates. It is thus a significant effect.

## V. SUMMARY

The HMS efficiency is one of the larger corrections in the determination of the experimental yield. Its understanding is therefore essential to the analysis of cross section data. Multiple track events contribute significantly to the tracking efficiency at high rates, and have to be taken into account. This requires a modification to the Hall C ENGINE tracking efficiency calculation. At low rates, the original ENGINE configuration can be used.