Track Efficiency and Corrections for the 2015 HPS Engineering Run

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Abstract

This note will discuss the methods used to estimate the charged track efficiency in data an Monte Carlo and to correct the Monte Carlo track efficiency to better match what is observed in data. This note uses "2-prong" events, where electron and positron candidates are selected from ECal clusters and a tag-and-probe method is used to obtain the efficiencies in data and Monte Carlo. The ratio of data:MC efficiencies is used to correct the MC for proper tracking efficiency.

1 Introduction

There are numerous reasons why a charge particle going through the HPS detector does not get reconstructed as a track: geometric acceptance, SVT hit reconstruction inefficiencies, large angle scattering (leading to poor track fits), etc. Differences in the geometry, SVT hit simulation, particle occupancies, etc between MC and real data can lead to a mis-estimate of the track finding efficiency and make data:MC comparisons difficult. In this note, we will describe how we estimate the track finding efficiency and what we do to correct the MC for the data:MC differences that we observe. Ideally, we would like to understand the cause of any differences and fix the MC so that they are as small as possible. We will discuss a few possible sources of these discrepancies and things we can do to address them.

2 Overview of Track Finding

Currently the HPS tracking algorithms require that a track includes at least 5 layers of 3d hits (stereo+axial pairs) with a maximum d0 and z0 at the minimum d0 [2] less than 15mm, a minimum momentum of >100 MeV (for 1.05 GeV beam energy), and a total χ^2 <100 (which is very loose).

The track finding procedure, briefly, is:

- Seeding: use 3 layers of 3d hits to make a seed track. Require the seed track meets the d0, z0, momentum and χ^2 requirements else, the seed track is discarded

- Confirm: add a hit from a designated confirmation layer, again requiring the new track meets all requirements and that the added hit does not increase the χ^2 by more than 10 units. If no confirm hit meeting requirements is found, seed track is discarded.

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[2] d0=$\sqrt{x0^2+y0^2}$ and z0 are defined in the HPS tracking frame; the equivalent in the detector frame is d0=$\sqrt{z0^2+x0^2}$ and z0=y0

- Extend: extend the track to designated extend layers, again requiring the new track meets all requirements and that the added hit does not increase the χ^2 by more than 10 units. If an extend hit does not meet these requirement, just discard the hit but keep the seed track.
- Verify: make sure final track contains at least 5 hits and the RMS of the hit times is $<$8 ns
- GBL: refit the track using "Generalized Broken Lines" fitter to get the best track parameters (no tracks are rejected at this stage)

There are additional cuts we put on tracks after this procedure for this track efficiency analysis which will be described in the next sections.

The HPS track efficiency has a complicated dependency on the track momentum and the initial direction of the track. We can miss a track for a variety of reasons, including:

- Lose a 3d hit because of geometry: the track does not intersect both the axial and stereo layers of a module, precluding the possibility of finding a 3d hit. Since we require 5-out-of-6 layers hit, another layer must be missing for some reason as well
- Lose a 3d hit because of hit inefficiency: the track does intersect both axial and stereo layers, but one of the hits fails to pass the SVT hit-making criteria
- Lose a 3d hit because of stereo hit making inefficiency: the track does intersect both axial and stereo layers and make good 1d hits, but the stereo hit maker rejects the hit for some reasons (e.g. Δt requirements)
- Reject a track due to track finding cuts: as listed above, almost each step of track finding has a requirement that can reject good tracks before the full picture is drawn

We use the MC to estimate the acceptance, tracking and reconstruction efficiency. However, the MC can get this efficiency wrong for various reasons: mis-matching the detector geometry, poor modeling of the SVT hit efficiency or timing, incorrect modeling or handling of multiple scattering, among others. The goal of this exercise is to find corrections to the MC efficiency, as a function of the track kinematics, using data.

3 Measuring the Track Efficiency in data and MC

If order to measure the track efficiency in data, we need to pre-select an event and region of phase space that is likely to contain a track without actually using the tracking or hits in the SVT at all. The method used in this note is to use the ECal to select events that look consistent with a 2-prong (e^+e^-) trident event and has at least one track pointing to a the cluster in the ECal. We use the track matched in the ECal to "tag" the event as a likely (e^+e^-) event and then use the other ECal cluster to "probe" the track efficiency on the other side. The track efficiency can be determined as a function of $E_{cluster}$, $X_{cluster}$, and $Y_{cluster}$ as:

$$\epsilon(E/X/Y) = \frac{N(matched\ probe\ track)}{N(tag\ events)} \tag{1}$$

A tag event is selected by requiring the event:

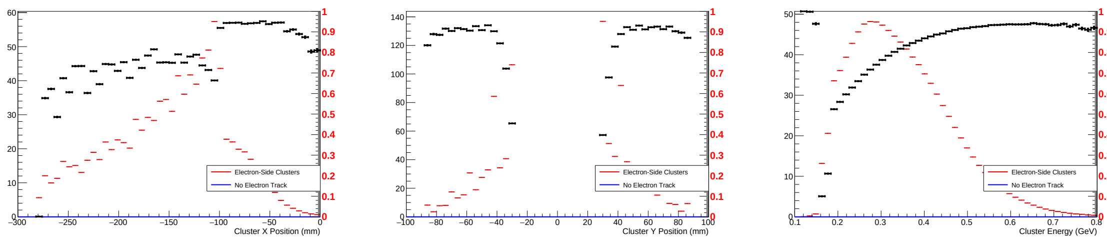

Figure 1: Electron efficiency from run 5772 as a function of (left to right) cluster X, Y, and energy. The red histogram shows distribution of all of the positron tagged events while the blue histogram shows events where there was not a matched electron found. The black histogram (using the right-hand axis) is the track efficiency.

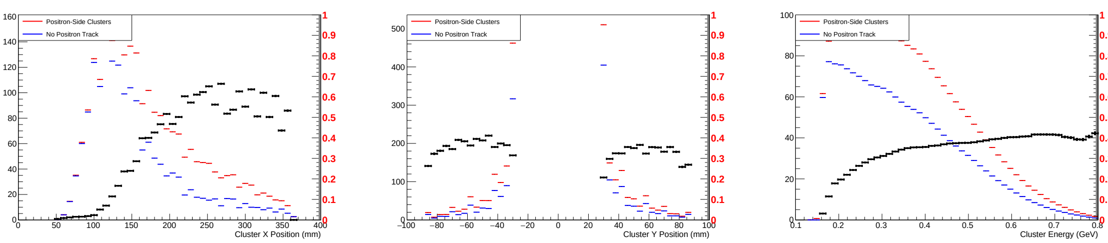

Figure 2: Positron efficiency from run 5772 as a function of (left to right) cluster X, Y, and energy. The red histogram shows distribution of all of the electron tagged events while the blue histogram shows events where there was not a matched positron found. The black histogram (using the right-hand axis) is the track efficiency.

- passed the pairs1 trigger
- a pair of ECal clusters, 1 top+1 bottom and 1 positron-side+1 electron side, with a relative Δt <10 ns
- one of the ECal clusters has a (correctly charged) track matched to it. If we are probing the electron side, the matched track should be on the positron side and vice versa.

When a tag event is found, we then ask whether the probe-side cluster has a track matched to it and at the we calculate the efficiency using Equation 1. The exact same procedure is done for data an MC.

The measured track efficiency for data and various MC samples versus $E_{cluster}$, $X_{cluster}$, and $Y_{cluster}$ is shown if Figure 1 for electrons (positron-tagged) and Figure 2 for positrons (electron-tagged). There is a clear drop-off in efficiency at low energy and high $|X|$, which are highly correlated, and at low $|Y|$.

One thing that sticks out comparing these two sets of plots is that the positron efficiency is much worse than the electron efficiency. The track efficiency peaks out at $\sim 93\%$ for electrons but only $\sim 40\%$ for positrons. This is not a real inefficiency for the positrons; there is a large contamination from wide-angle bremsstrahlung (WAB) events (γe^-) for the electron-tagged sample that's not present int he positron-tagged sample. Because of this contamination from WAB events, in order to correctly compare data and MC, we must use both trident and WAB

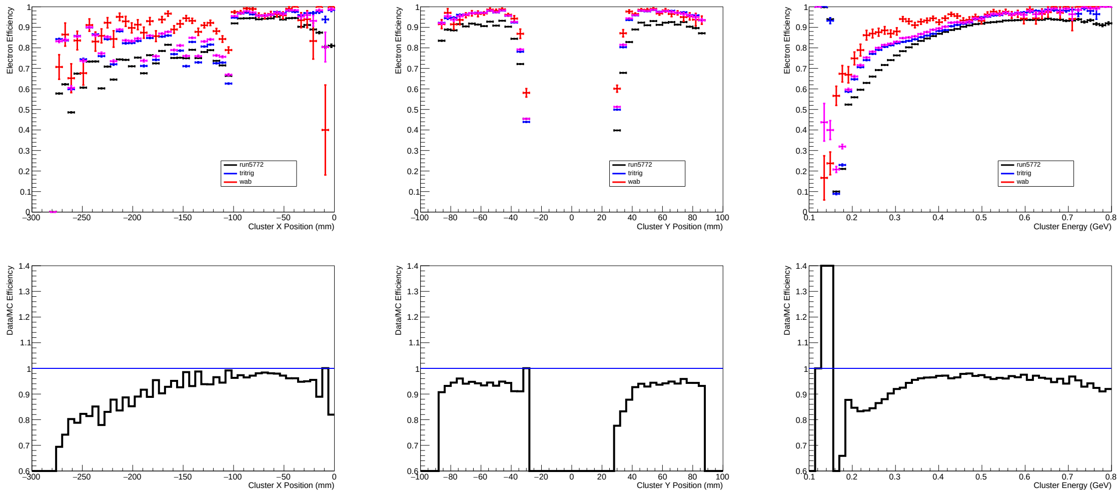

Figure 3: Top Plots: Electron track efficiency from run 5772 (black), trident MC (blue), WAB MC (red), and the cross-section weighted sum of trident+WAB (purple) as a function of (left to right) cluster X, Y, and energy. Bottom Plots: The ratio of data-to-trident+WAB efficiencies.

MC weighted in the appropriate ratios. The efficiencies for these MC samples, the weighted sum, and data are shown in Figure 3 for the electron probe and 4 for the positron probe.

Comparing MC and data for the electron-side efficiencies (Figure 3), the MC efficiency is generally higher and there is a clear mis-match in the efficiency around cluster energy 200-300 MeV (reflected in cluster X). On the positron side, the picture is less clear; it appears that a similar low-energy Data/MC efficiency deficit appears after accounting for WAB events, but in addition, there is a high-energy deficit which seems to be due to increased high-energy detection efficiency of WAB events in MC (which could correspond to higher WAB conversion probably for these events).

If the efficiencies in cluster X,Y, and energy were completely correlated to each other we could simply use any single distribution to correct the MC efficiency; conversely if they were completely uncorrelated, we could use each 1d ratio as the correction (multiplying the ratio from each bin for each event). Unfortunately, of course, reality is somewhere in the middle and ideally we'd use a 3d distribution of data/MC ratios for the correction. This is fairly data-intensive, however, and, since the cluster E and X are quite highly correlated, we use only a 2d data/MC distribution in cluster E and Y for corrections.

The data and MC efficiencies, as well as the ratio of the two, in cluster E vs cluster Y is shown in Figure 5 for electrons and Figure 6 for positrons. Again, the WAB contamination makes he efficiency for positions trickier to interpret but for electrons you clearly see the low energy and low angle inefficiencies and how data and MC don't quite match.

We correct the Monte Carlo track efficiency to more accurately match what's seen in data by using the electron data/MC ratio as a function of cluster Y and energy. We perform this correction by weighing each track by the data/MC ratio in the Y/energy bin of the matched cluster. These weights can then be used to, for example, project into histograms or integrating cross-sections. Figures 7 and 8 show the same efficiency plots as above but after correcting the MC for the data:MC differences. These plots use the electron correction for both electrons

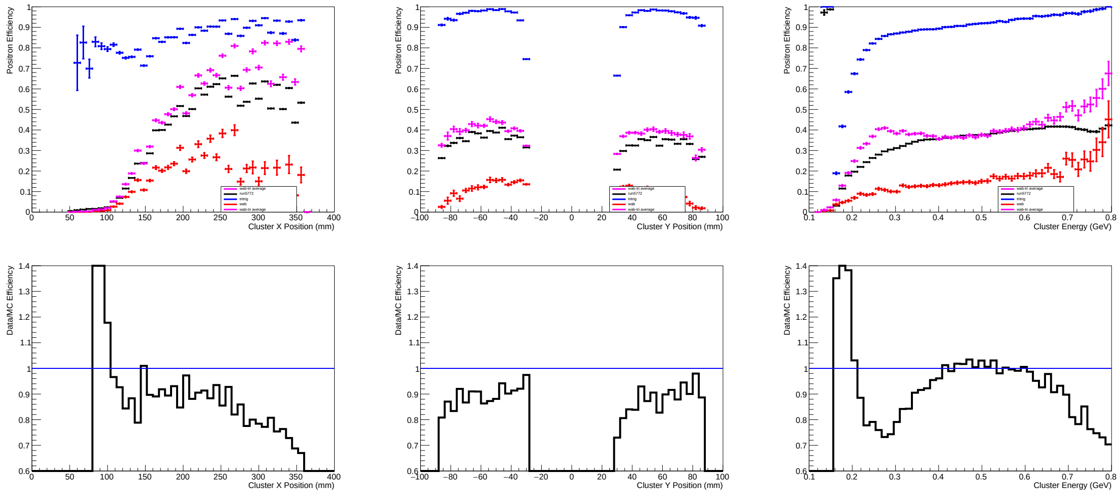

Figure 4: Top Plots: Positron track efficiency from run 5772 (black), trident MC (blue), WAB MC (red), and the cross-section weighted sum of trident+WAB (purple) as a function of (left to right) cluster X, Y, and energy. Bottom Plots: The ratio of data-to-trident+WAB efficiencies.

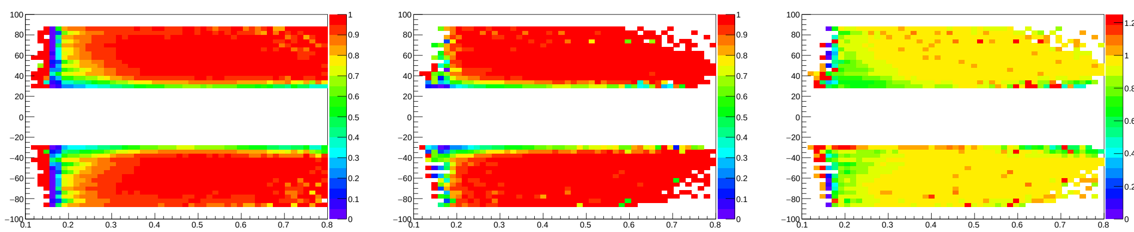

Figure 5: The electron track efficiency for run 5772 data (left) and trident+wab MC (middle) versus cluster Y and cluster energy. The right-hand plot shows the ratio of data:MC.

and positrons (i.e. the corrections from Figure 5. Using the positron correction (Figure 6) for positrons gives a very similar result.

4 Applying the Track Efficiency Correction to Your Data

The recommended recipe to apply these track efficiency correction to your MC data set are here: Track Efficiency Corrections. This web site will be kept up-to-date with the best efficiency correction method.

The current recipe (as of July 2017) uses the electron cluster Y vs cluster E corrections for both the electron and positron tracks. The difference between using the same correction as opposed to separate corrections for the two charges is minimal and the electron correction obtained from 2-prong events is considered much more reliable. In the future, we should try to use 3-prong events to obtain he positron corrections.

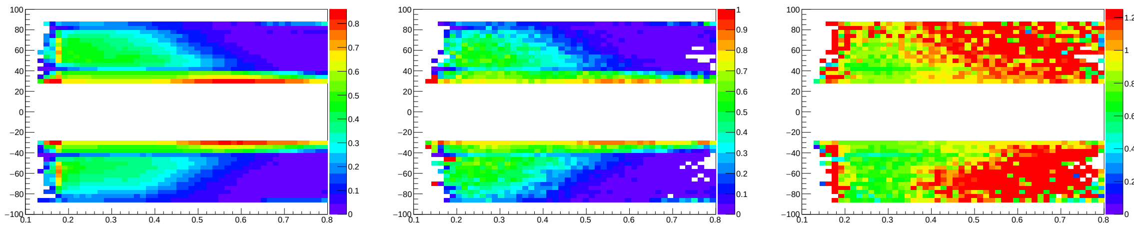

Figure 6: The positron track efficiency for run 5772 data (left) and trident+wab MC (middle) versus cluster Y and cluster energy. The right-hand plot shows the ratio of data:MC.

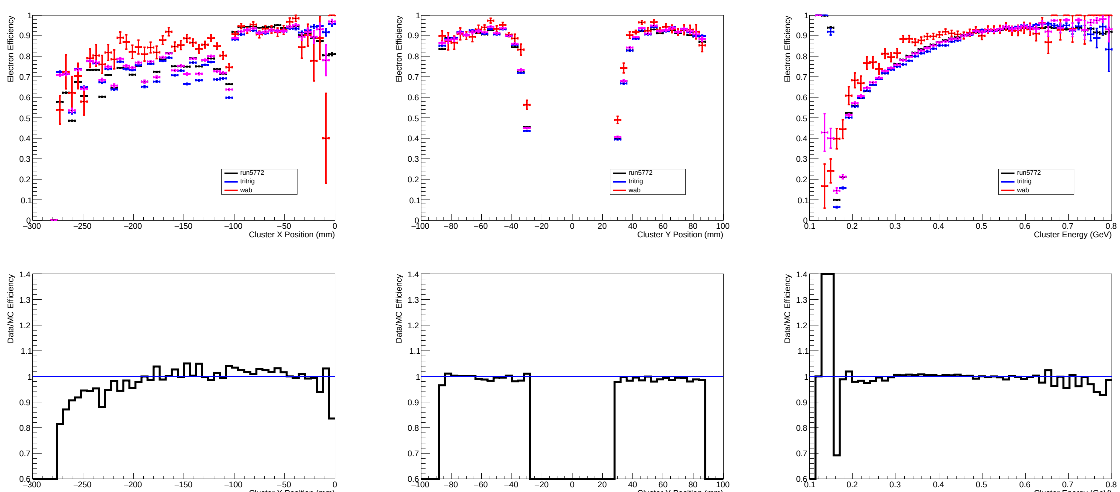

Figure 7: Top Plots: Electron track efficiency from run 5772 (black), trident MC (blue), WAB MC (red), and the cross-section weighted sum of trident+WAB (purple) as a function of (left to right) cluster X, Y, and energy. Bottom Plots: The ratio of data-to-trident+WAB efficiencies. These plots have used the electron cluster Y vs cluster E data:MC ratio-weighted corrections (Figure 6).

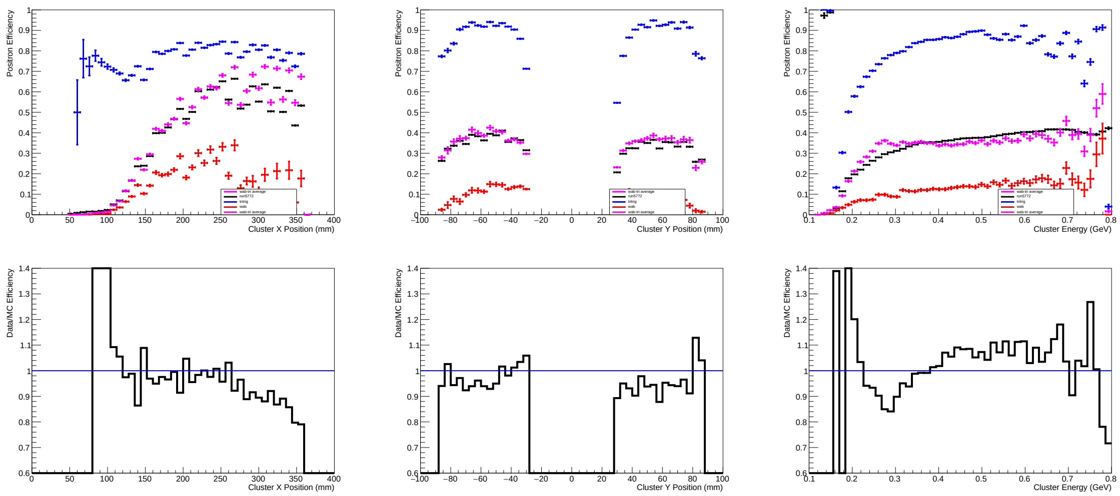

Figure 8: Top Plots: Positron track efficiency from run 5772 (black), trident MC (blue), WAB MC (red), and the cross-section weighted sum of trident+WAB (purple) as a function of (left to right) cluster X, Y, and energy. Bottom Plots: The ratio of data-to-trident+WAB efficiencies. These plots have used the electron cluster Y vs cluster E data:MC ratio-weighted corrections (Figure 6).