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Uncertainty Analysis of the NOvA Test Beam Wire Chambers

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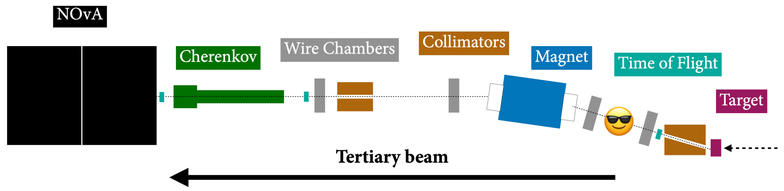
Introduction

The Fermilab Test Beam is a beam designed for R&D for a variety of experiments taking place at Fermilab, for instance the NOvA experiment. An essential component of the NOvA Test Beam is four wire chambers which measure the transverse position of particles travelling along the beamline. Occasionally, a particle will not produce a hit in one of the four wire chambers resulting in a "3 hit track" instead of the usual "4 hit track". In our research, we explored the possibility of including these 3 hit tracks into analysis, and how they impact relevant statistics.



Test Beam Top-Down View – NOvA DocDB 51270

Methodology

Our primary method was to use a "wire chamber hit reconstruction algorithm" to convert 3 hit tracks into 4 hit tracks with an estimated default 4th hit. Using this algorithm, we compare relevant observables such as position, momentum, and energy distributions between "true" 4 hit tracks and "reconstructed" 4 hit tracks, in order to assess if there is a noticeable difference in particle properties and statistics.

The wire chamber hit reconstruction algorithm works by creating estimated default hits at a midpoint between a different wire chamber hit, and the known position of a beamline element (magnet, target, etc.)

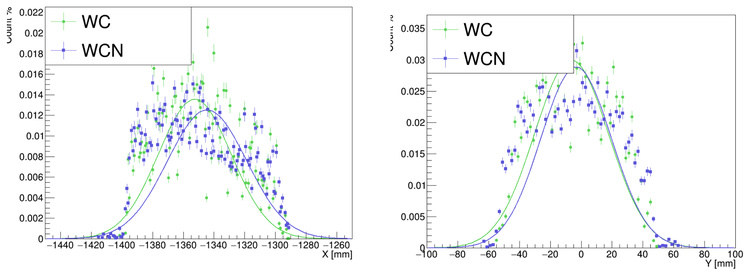
$$m_{21} = \frac{z_2 - z_1}{x_2 - x_t} \qquad m_{43} = \frac{z_4 - z_3}{x_4 - x_m}$$

$$\downarrow \qquad \downarrow$$

$$m'_{21} = \frac{z_2 - z_1}{x_2 - x_t} \qquad m'_{43} = \frac{z_4 - z_3}{x_4 - x_m}$$

Results

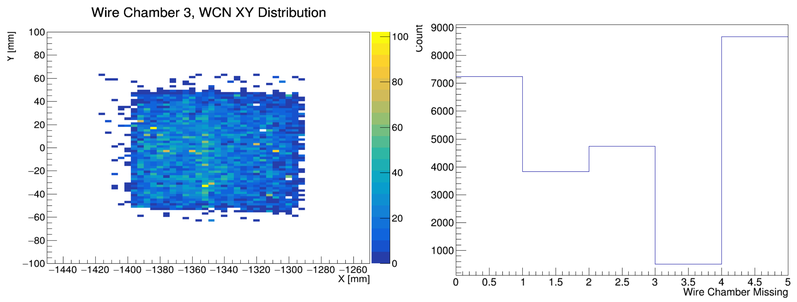
In our analysis, we found that the Wire Chamber hit reconstruction algorithm is effective at reproducing data similar to 4 hit tracks. Across variables of position, momentum, and energy the differences between the reconstructed and true 4 hit tracks were not qualitatively significant. For gaussian curves fit to each distribution, the difference in means with respect to the standard deviations was small, indicating that the distributions are statistically and functionally similar.



Distributions of X and Y for hits in Wire chamber 3, for old and new Wire Chamber Track Algorithms

Conclusions

From this analysis, we determined that three-hit tracks with an estimated default fourth hit are indistinguishable from four hit tracks, meaning the 3 hit tracks, which had previously been wasted data, can now be included into analyses with proper error. This will increase the sample size of future analyses by about 40% and will inform the R&D of the Test Beam, such as if all 4 wire chambers are needed.



(Left) XY Hits on Wire chamber 3 using Reconstruction algorithm
(Right) Count of Wire chamber misses across

There remains work to be done. For one, the quantity of misses across the 4 wire-chambers is not equal, and the error contributions from each chamber should be quantified. Furthermore, our statistical tests assumed the particle distributions were approximately Gaussian. This is not always a good assumption for the physical geometry of the beam and wire chambers.

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