The CLAS12 Central Vertex Tracker Reconstruction Efficiency

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About Jefferson Lab and CLAS12

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab is used to investigate the quark-gluon structure of the nucleon and nucleus. The accelerator (shown in *Fig. 1*) forms a racetrack-like shape capable of accelerating a beam up to 12GeV using two anti-parallel linear accelerators connected to recirculating arcs. The beam is delivered to experimental halls A, B, C, and D. The CLAS12 Spectrometer found in Hall B (see *Fig. 2*) consists of two separate detectors used to study multi-particle, exclusive reactions. The Forward Detector, surrounded by a six-coil superconducting toroidal magnetic field, measures particles scattered at polar angles between $5^\circ - 35^\circ$. The Central Detector, located within a cylindrical, 5T solenoid magnet (labelled in *Fig. 2* 2), measures particles scattered at large polar angles between $35^\circ - 125^\circ$ and can cover the full 360° azimuthal range. This work is focused on the Central Detector.

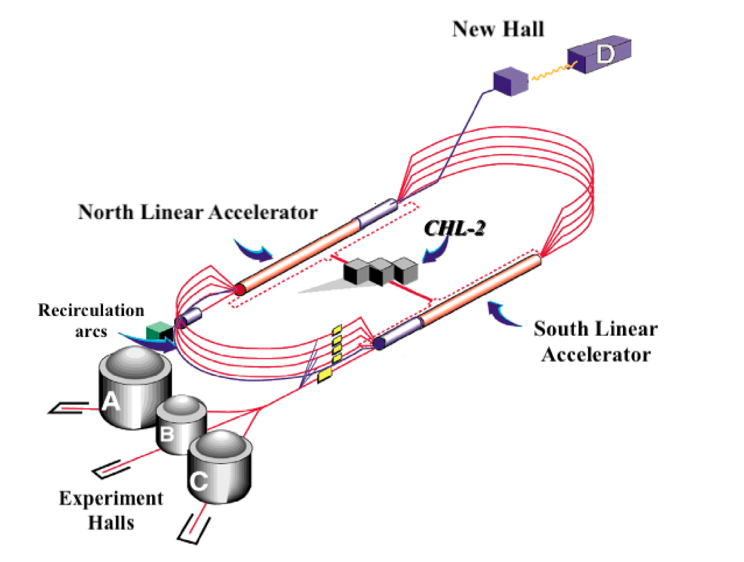

Figure 1: Diagram of CEBAF accelerator with main facilities labelled

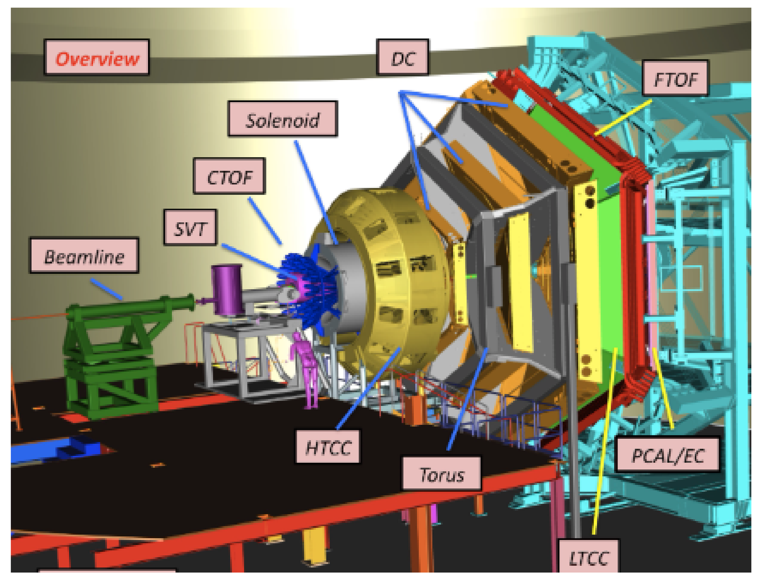

Figure 2: Overview of CLAS12 Spectrometer with detector subsystems labelled

The Central Vertex Tracker

CLAS12 has more than 100,000 readout channels that collect data from each detector subsystem at a rate of up to 15kHz. Data from the multiple layers of detector subsystems are processed in the CLAS12 reconstruction software to extract the interaction vertex and 4-momentum of particles scattered in the Forward and Central Detectors. Typically, particles detected in the Central Detector are of lower momentum ($0.35 - 2GeV$)

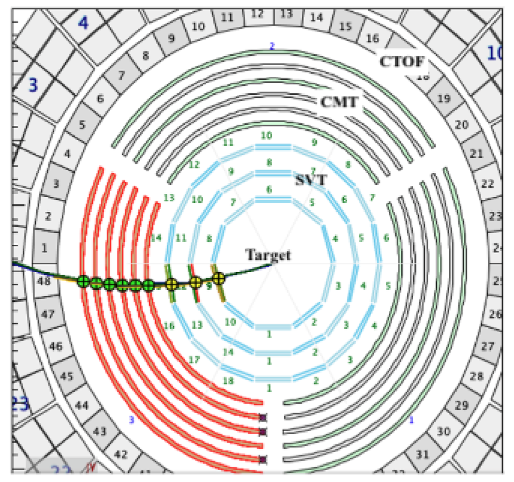

Figure 3: Viewed in the plane perpendicular to the beam direction, this is an example of a proton scattered in the Central Detector with its trajectory being determined by hit points in the CVT.

- In the Central Detector the particle 3-momentum is found using the Central Vertex Tracker comprised of the Silicon Vertex Tracker (SVT in *Fig. 3*) and the Barrel Micromegas Tracker (BMT in *Fig. 3*) by measuring the trajectory of charged particles bent in the solenoid field. The solenoid field is parallel to the beam axis.
- The Central Time of Flight scintillators (CTOF in *Fig. 3*) measure the time of flight for charged particle identification.
- Each of the three detector regions of the SVT consist of multiple back-to-back pairs of silicon modules. Each module contains 256 angled and nonparallel semiconductor strips that fire when a charged particle passes near a strip. Crosses are formed from the intersection of two pairs of strips when a "hit" is registered on that module (see *Fig. 4*).
- The BMT detector consists of 6 concentric layers, half of which provide information on the azimuthal angle with strips parallel to the beam axis. The other 3 layers consist of angled strips that improve the resolution of the z-vertex information obtained from the SVT. Raw hits in the SVT are formed into contiguous clusters. Pairs in adjacent SVT modules are formed and a cross is calculated.

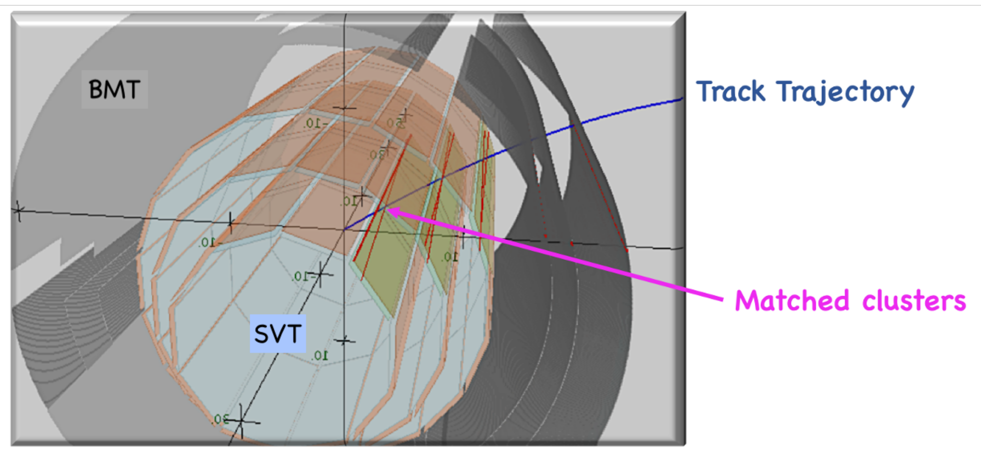

Figure 4: 3D Graphic of the three SVT regions and the first three BMT layers. The trajectory of a scattered particle is shown passing through or close to the hit clusters and the matched strips that fired used to form the track. Beam enters into the graphic diagonally and along the axis drawn

- Clusters and crosses are collected into track candidates using pattern recognition. The particle trajectory in the solenoid is a helix consisting of a circle transverse to the beam and a straight line in the *r-z* plane. The BMT components are extracted and combined into candidate tracks. A line is fit to the BMT hits and the SVT clusters. The Distance-of-Closest-Approach (DOCA) - the shortest distance between the trajectory and the SVT strips is a measure of track quality [1].

Reconstruction Efficiency Studies

The CLAS12 reconstruction for central tracking consists of pattern recognition to identify track candidates and subsequent track fitting based on a Kalman filter algorithm. The Reconstruction Efficiency, E_R, is a measure of how well the software is able to reproduce the trajectory of a real particle scattered in the Central Detector:

$$E_R = N_S/N_T$$

where N_s is the number tracks successfully reconstructed by the software and N_T is the total number of real tracks present in the Central Detector.

Motivation

- High luminosity experiments (high rate of electrons hitting the target) are necessary for rare reactions to be detected. This leads to more background in all detector subsystems.
- It is difficult to find the hit signals that belong to a real track due to the high levels of background and the presence of "ghost" tracks (see *Fig. 5*).
  - One way of reducing the number of noise tracks is to impose constraints to remove tracks with large DOCAs (described in CVT section)
  - The effect of DOCA cuts on the reconstruction efficiency can be measured by simulating or taking low luminosity (5nA) events where the background is low (compare *Fig. 3 and 5*) and merging them with realistic background events. We then measure the effect of background on the reconstruction.
  - Finally, by varying the size of the DOCA cut, we find which configuration yields the highest efficiency.

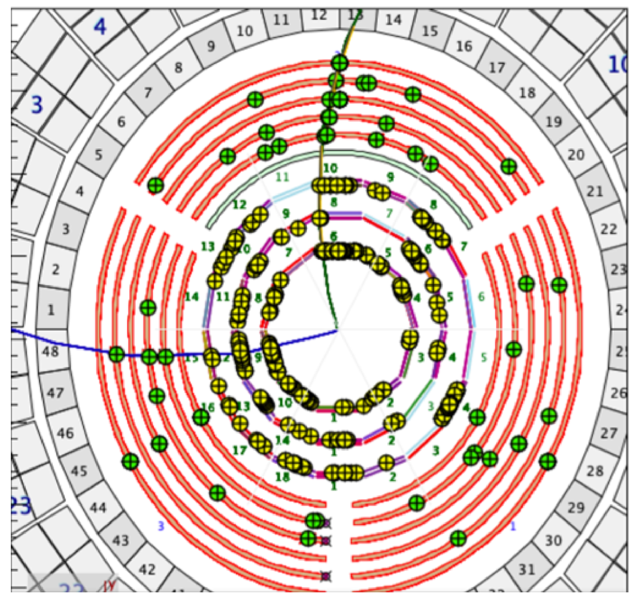

Figure 5: Same event as in *Fig. 3* but merged with 50nA background noise. The reconstruction software finds the real track but generates a ghost track constructed out of background hits.

Method

1. Prepare a data file consisting of low-momentum (0.6-1.4GeV) protons taken from a real 5nA (low background noise) experiment. Make a copy of the 5nA file and merge with 50nA background from a data experiment.
2. We define a DOCA "sum" cut consisting of the sum of the individual DOCAs from each SVT cross. Reconstruct the 5nA file for a range of DOCA sum cuts and select the optimal 5nA DOCA sum cut configuration that has the most tracks matched to the CTOF detector by extrapolating the track. Order optimal 5nA event file by event number ID.
3. Next, we reconstruct the background merged file for a range of different DOCA sum cut sizes and order the event files by event number ID.
4. Run hit-matching algorithm that compares tracks event-by-event from the merged background files to 5nA file and scans each reconstructed track for similar hit signals.
5. Sort reconstructed tracks according to the following Figures of Merit (FOM):
   - Fully Matched: Tracks in background merged file share 100% of hits with tracks in 5nA file.
   - Partially Matched: Tracks in background merged file share 80% or more of hits with tracks in 5nA file.
   - Matched by cuts: Tracks in background merged file with momentum, polar angle, and azimuthal angle that were within 3σ (as determined by system resolution specifications) of tracks from the same event.
6. Calculate reconstruction efficiency, E_R, according to success criteria from FOMs for the DOCA sum cut range of the merged background files.

Resolution Tests

Before finding the optimal DOCA sum cuts, we verified the dependence of the track parameters resolution on the DOCA cut value.

- We simulated events in the CLAS12 simulation software, GEMC (Geant4 Monte Carlo), at the expected momentum ranges for particles in the Central Detector and merged 50nA background data to the data file.
- The resolution of the track parameters, $\Delta p/p$, $\Delta\theta$, and $\Delta\phi$ of the tracks relative to the truth information of the simulation were extracted.
- The standard deviation of the track parameters were calculated as $\sigma = RMS/2$ where (RMS) is the root-mean-square. The standard deviations are plotted as a function of DOCA cuts.

Results

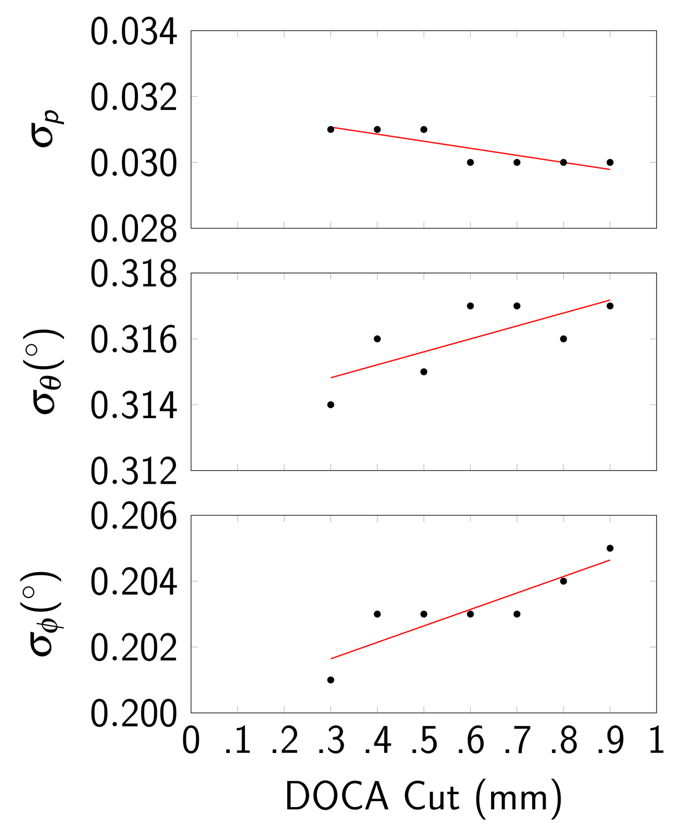

Figure 6: Resolution Results

- The results of the reconstruction resolutions are shown in *Fig. 6* for the track parameters. Each data point represents the standard deviation from $\Delta p/p$, $\Delta\theta$, and $\Delta\phi$ distributions obtained from a set of 3000 simulated protons reconstructed with 7 different individual DOCA cuts. No uncertainties are present due to reconstruction being run on the same data sample each time.
- In the top graph we observe a slight improvement in the momentum resolution, $\Delta p/p$, of the reconstructed tracks with increasing DOCA cut. The middle and bottom graphs show a steep degradation of the angular resolutions with increasing DOCA cut.
- A representative sample of the optimal DOCA sum cut results are shown in *Fig. 7*. We reconstructed 5000 events from both 5nA run and a 5nA+50nA luminosity background file and plotted the DOCA sum cut configurations that yielded the highest reconstruction efficiencies for each FOM.
- The efficiency for fully matched tracks (the most important FOM) begins to plateau when cutting tracks with a total sum of individual DOCAs greater than 1.0 mm from the strips and similarly for partially matched tracks.

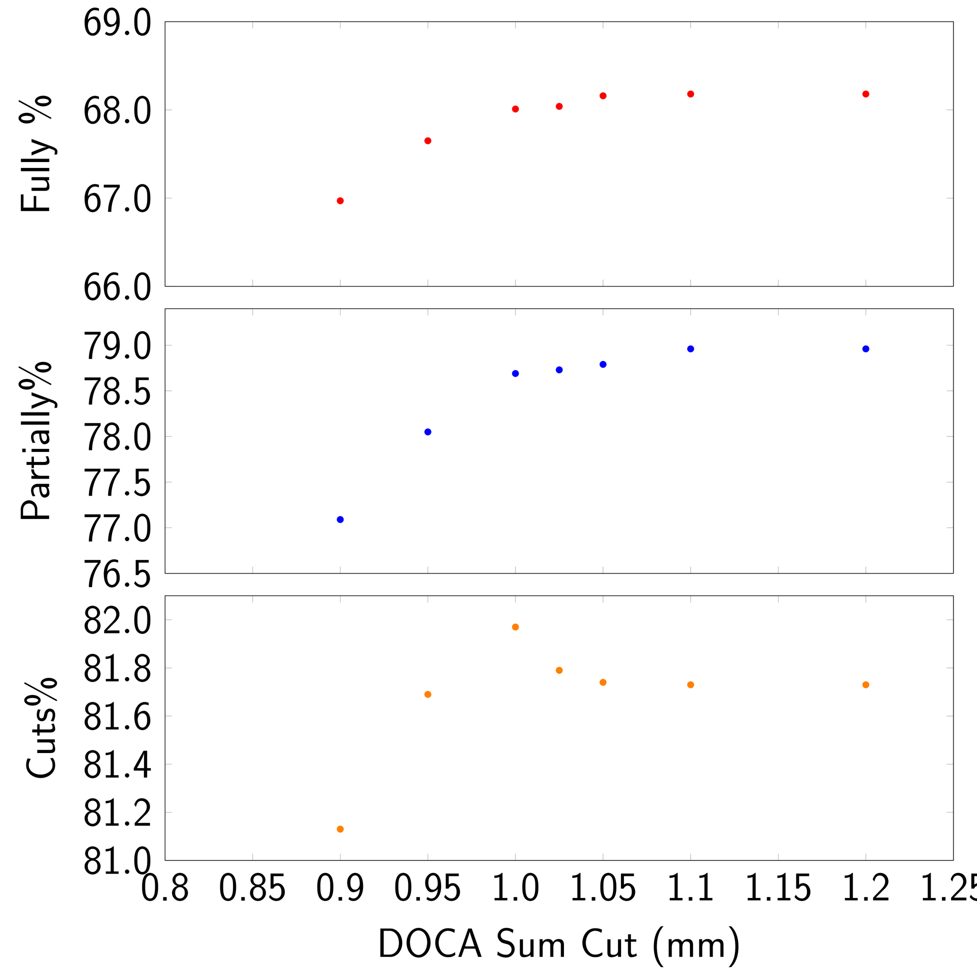

Figure 7: Optimal DOCA Sum cut results

- The efficiency for tracks matched by cuts reaches a maximum at 1mm DOCA cut before dropping back down abruptly. This is due to the degradation of angular resolutions with larger cuts, resulting in the tracks with θ and ϕ parameters that exceed the 3σ limit not being included in the sample.
- We additionally found the 1.0 mm DOCA sum cut to be the configuration that yielded the third highest number of single track events.
- Lastly, we observed that in events from the merged file where the number of tracks was greater than in the 5nA, the additional tracks were from reconstructing the trajectory of a real secondary electron (which is still a background effect).

Conclusions

- The implementation of constraints on track candidate parameters in the CVT is essential for the reduction of fake tracks and the improvement of the reconstruction efficiency in the Central Detector at high luminosities.
- The momentum resolution improves, while the angular resolutions of track candidates degrade with increasing DOCA cuts.
- Excluding tracks whose total sum of DOCA from their associated SVT hits exceed 1mm return a maximum reconstruction efficiency of 79% (using 80% or more hits matched in the CVT matching criteria). Due to recent developments in the reconstruction software, the reconstruction efficiency has been improved to 91% for a sample of π^- particles.

References

[1] V. Ziegler, N. A. Baltzell, F. Bossù, D. S. Carman, P. Chatagnon, M. Contalbrigo, R. De Vita, M. Defurne, G. Gavalian, G. P. Gilfoyle, D. I. Glazier, Y. Gotra, V. Gyurjyan, N. Harrison, D. Heddle, A. Hobart, S. Joosten, A. Kim, N. Markov, S. Mancilla, M. D. Mestayer, J. Newton, W. Phelps, S. Niccolai, D. Sokhan, and M. Ungaro, "The CLAS12 software framework and event reconstruction," *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 959, 4 2020.

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