Geometry Calibration of the SVT in the CLAS12 Detector

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Introduction

The Continuous Electron Beam Accelerator Facility's (CEBAF) Large Acceptance Spectrometer (CLAS) at Jefferson Lab is being upgraded for the 12 GeV electron beam. It is effectively a very large microscope that will be used to probe nucleons and nuclei to learn how the quarks and gluons are distributed inside. [Fig. 1]

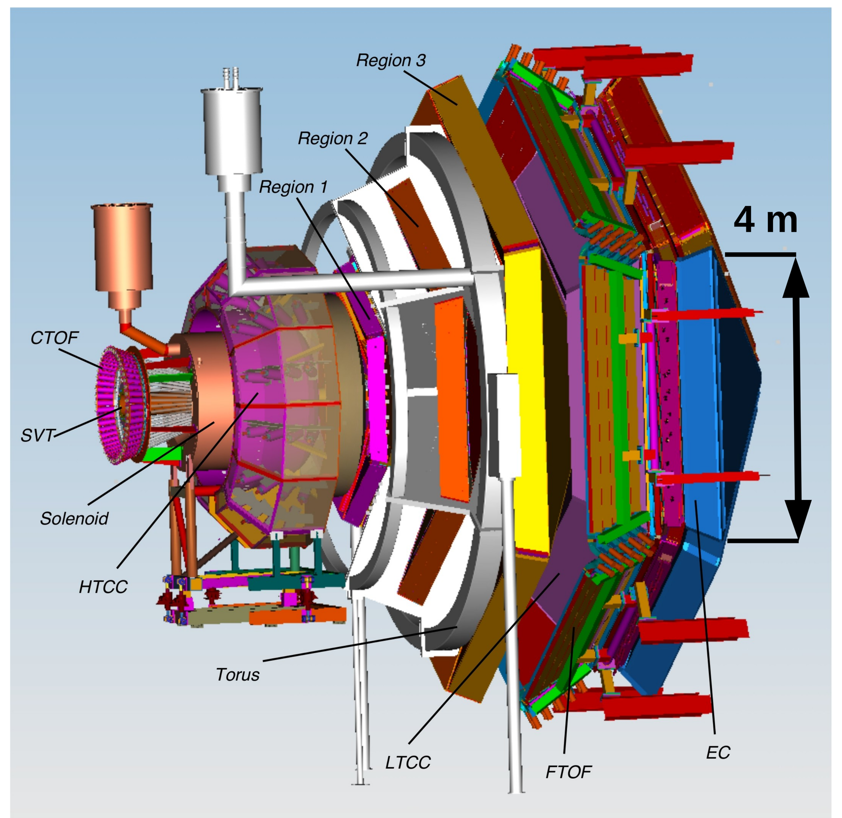


Figure 1: The CLAS12 detector.

The Silicon Vertex Tracker (SVT) is one of the subsystems designed to measure the trajectory of charged particles as they are emitted from the target at large angles (35°-125°) in a 5T solenoid magnetic field. The information gathered is used to reconstruct the path of an identified particle and calculate its 4-momentum at the target position.

The SVT is the smallest detector in CLAS12, boasting 33,792 readout channels at 512 channels per module. It is designed for a beam luminosity of 10^{35} cm^{-2} s^{-1}.

The sensors of the SVT consist of long, narrow strips of p-type silicon with aluminium electrodes on n-type, bulk silicon substrate. There are 256 strips in a sensor, with a readout pitch of 156 µm, and a stereo angle of 0-3 degrees. [Fig. 2]

The location of the sensor strips must be known to a precision of a few microns in order to accurately reconstruct particle tracks with the required position resolution of 60 µm.

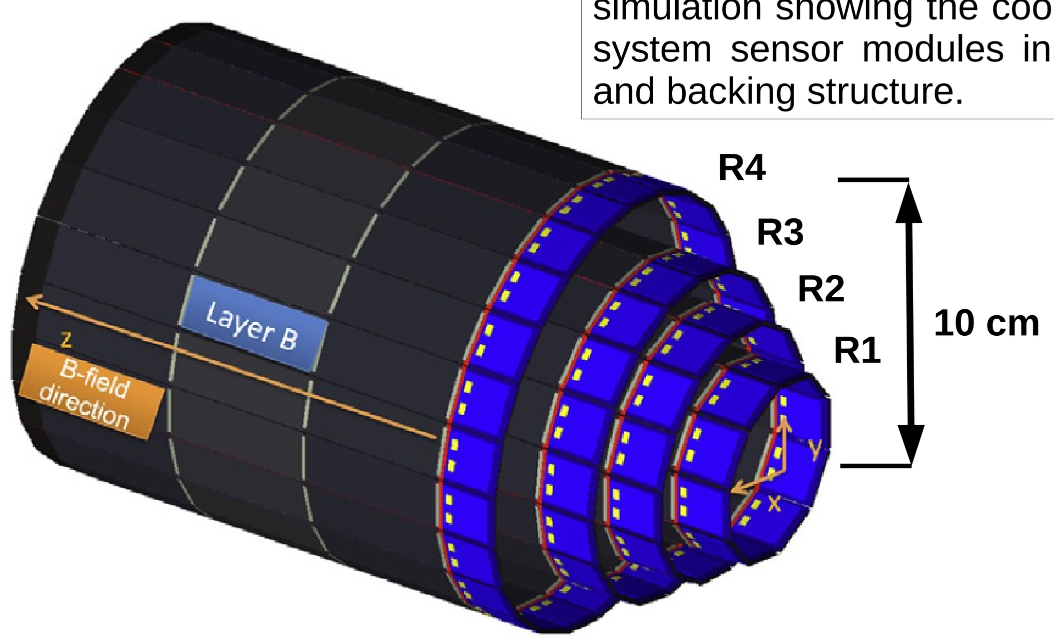


Figure 2: Screenshot of the simulation showing the coordinate system sensor modules in black, and backing structure.

Ideal Geometry

Two sensors are paired with opposite stereo-angle orientation in a module. [Fig. 3] The pairs of sensors are arranged into sectors in four circular regions, centred on the target. [Fig. 2, 4]

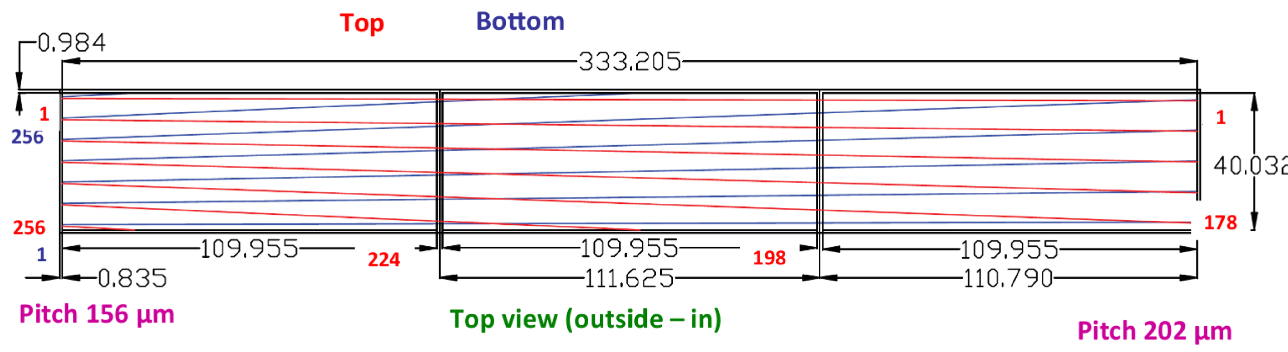


Figure 3: Diagram showing how the sensor strips are arranged in a module.

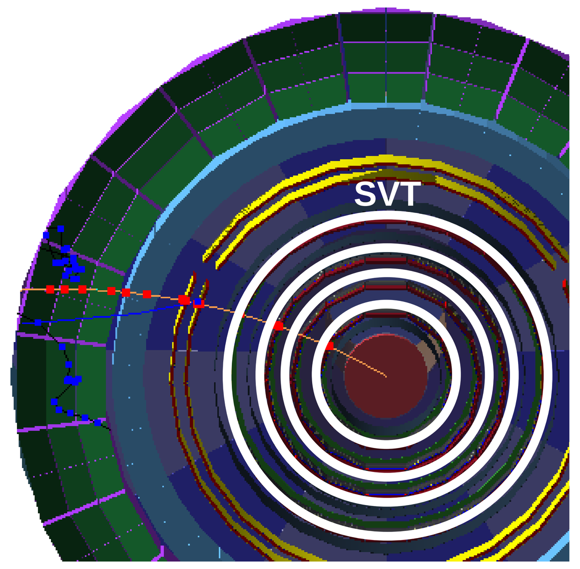


Figure 4: Downstream view (beam into page) of a simulated low momentum proton. The 5 T solenoid field causes the track to curve as the proton moves outwards from the target in the centre.

Orange: Generated track
Red: Points where the proton triggers a hit
White: Silicon vertex Tracker (SVT)
Yellow: Barrel Micromegas Tracker (BMT)
Green: Central Neutron Detector (CND)
Blue: Central Time of Flight (CTOF)

The first step toward calibrating the geometry was to compare an early version of simulated geometry to the technical design drawings. [Fig. 5] Several inconsistencies were discovered. The location of the sensor layers was not the same for the simulation and the reconstruction, and the backing structure did not match.

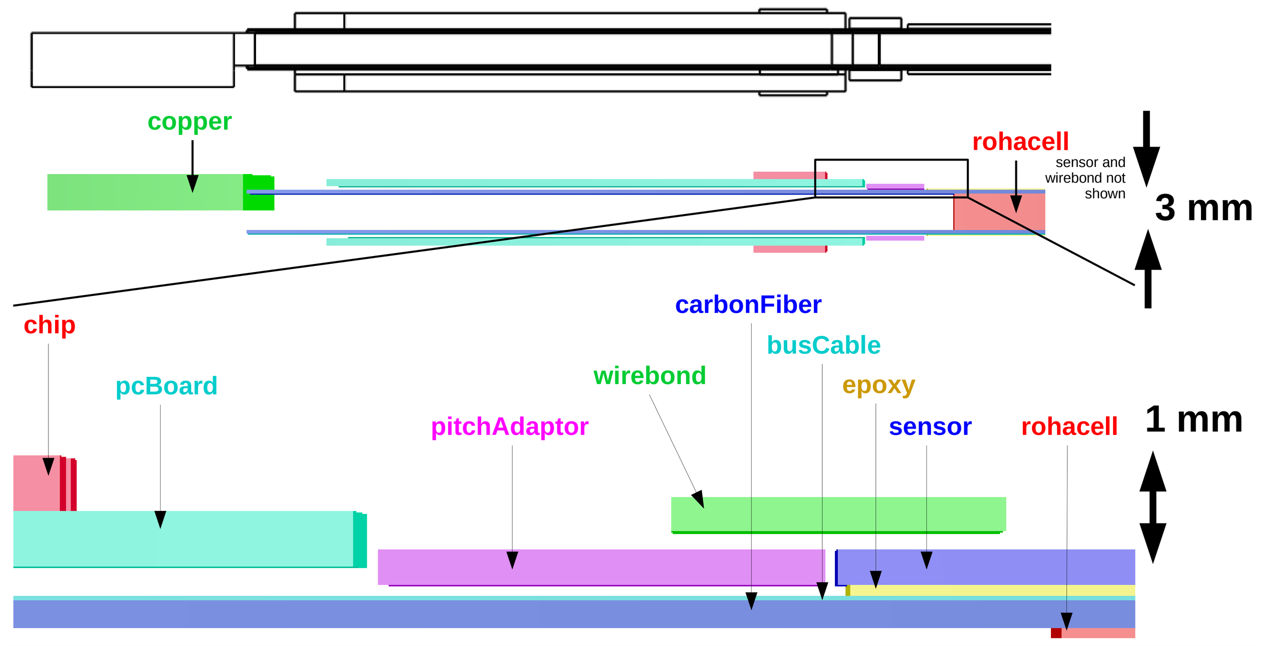
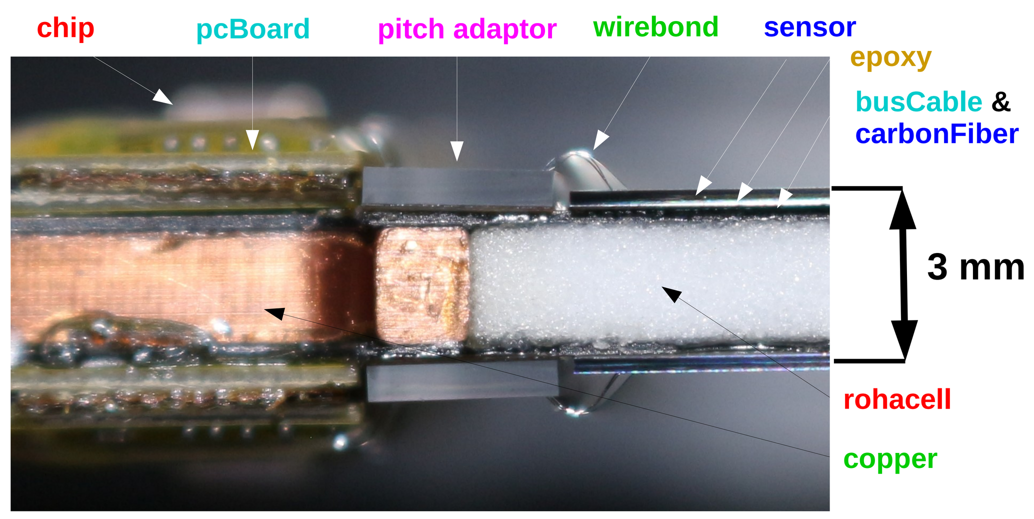


Figure 5: Top: Technical drawing showing side view of the copper support and Hybrid Flex Circuit Board (pcBoard) components of a sector module. Middle: Early version of the simulated geometry showing inconsistencies. Bottom: Close-up of the readout components. Below: A photograph of the same area on a test module.



Geometry Validation Results

There were three fiducial points on each sector module for surveying purposes, two on the upstream copper support (Cu+ and Cu-), and one on the downstream peek support (Pk). [Fig. 6]

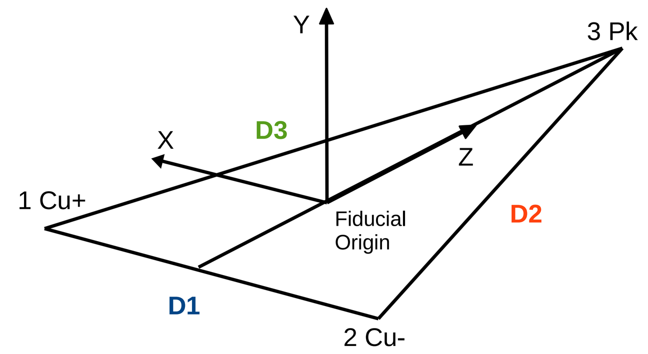


Figure 6: Triangle formed of three fiducial points, Cu+, Cu-, and Pk. The distances between them are labelled D1, D2, and D3.

One set of fiducial points was computed from the core parameters that describe the SVT, such as the radius and position along the beam of the regions. Another set of fiducial points were read from a Computer Aided Design (CAD) model based on the technical drawings. The latter was used to verify the former, and the ideal geometry is now well defined within 2 µm resolution of the design specification. [Fig. 7]

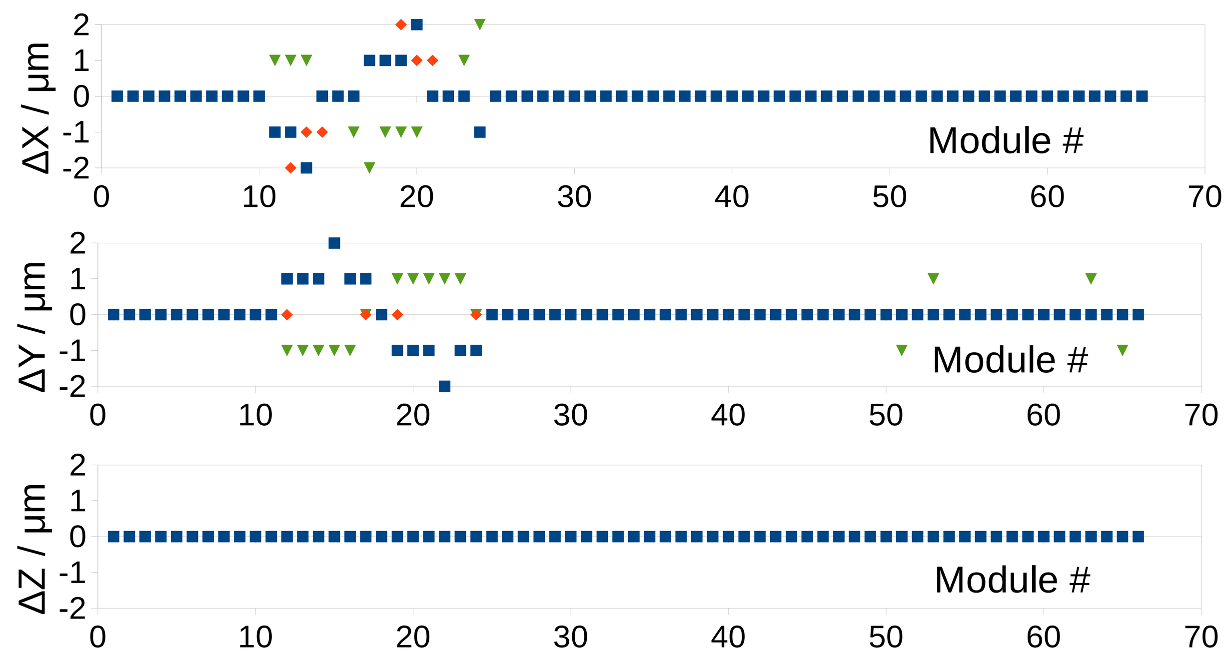


Figure 7: Comparison of fiducial points generated from core parameters and CAD software. The Module # is an index to iterate over all sectors and regions. The blue, red, and green points represent the Cu+, Cu-, and Pk fiducial points located on each module, respectively.

Module #	Region	Sector
1-10	1	1-10
11-24	2	1-14
25-42	3	1-18
43-66	4	1-24

Alignment Shifts

Software was developed to apply alignment shifts to the ideal design geometry from two sources:

- Survey of fiducial points on the structure that supports each pair of sensor modules.
- Analysis of reconstructed cosmic tracks using linear least-squares fitting with many parameters.

The fiducial points were used to form plane vectors that represented the data. The raw points from the survey were fit to three circles for each region to minimise the overall shift of each module.

References

1. M.A. Antonioli et al. "Performance of the CLAS12 Silicon Vertex Tracker modules", Nucl. Instr. and Meth., A732 (2013) 99-102.
2. V. Blobel "Millepede: Linear Least Squares Fits with a Large Number of Parameters", DESY, https://www.wiki.terascale.de/index.php/Millepede_II (2014).

Calibration Results

Computer code developed within the CLAS12 software framework was used to calibrate and align the SVT.

- A Geometry package generates the ideal geometry in formats suitable for the simulation and reconstruction software.
- A general Alignment package uses matrix algebra to compute the translation and rotation shifts between two given sets of plane vectors, and apply a given shift to a set of points or volumes.

The code was validated by generating track-based alignment shifts from the analysis of real (not simulated) Type-1 cosmic tracks. Type-1 tracks were selected for the analysis because they pass through all 8 horizontal layers.

A program called Millepede used a least squares approach to simultaneously fit straight lines to the cosmics ray tracks and shifts in the module positions. It used the partial derivatives of the distance of closest approach (DOCA) taken with respect to the track parameters and the SVT geometry. This approach accounts for correlated shifts among the geometry parameters.

Misalignments as large as 250 µm before alignment have been reduced to ~20 µm. The resolution of individual strips has been improved from an average of 93 µm to 80 µm. [Fig. 8]

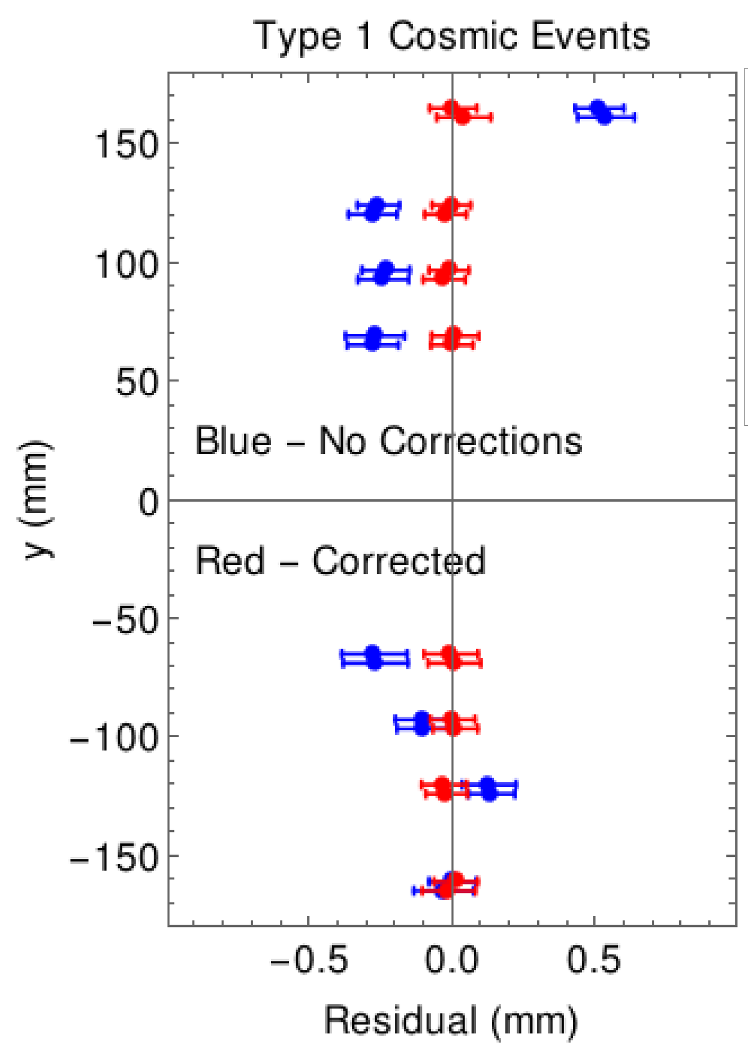
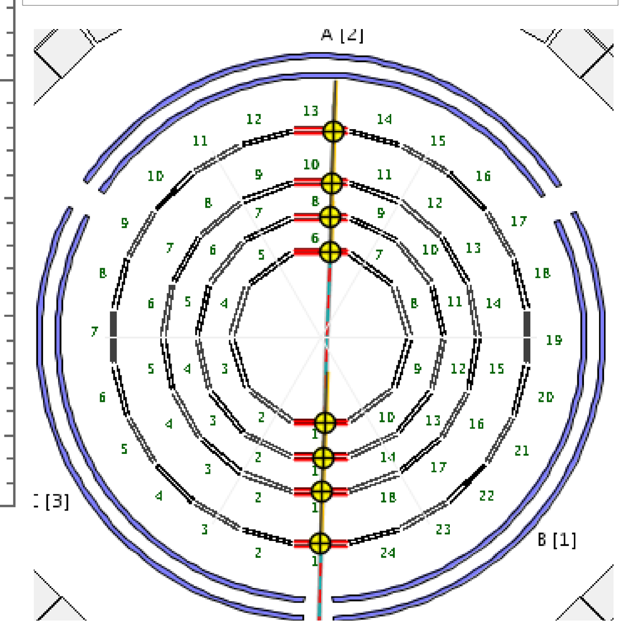


Figure 8:
Left: Results of the alignment shifts from millepede. The error bars show the uncertainty in the width of the gaussian fit instead of the uncertainty in the mean.

Below: A Type-1 track.



Conclusion

- Geometry has been well defined according to the design specification.
- Aligned the SVT using real cosmic data.
- The simulation and reconstruction software now receive the same geometry from one source.

Future work:

- Further alignment studies using non-Type-1 tracks.
- Processing the fitted fiducial survey data into alignment shifts.
- Testing the common geometry.