CLAS12 Track-Based Alignment

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Outline:

- Statement of the problem
- CLAS12 Silicon Vertex Tracker (SVT) Alignment Studies
- What’s next for SVT?
- Other subsystem track-based alignment efforts
- Summary
Statement of the Problem - 1

- 'Good' Alignment necessary to reach CLAS12 design specs.
- Software designed initially for 'ideal' geometry.
- After construction and installation, detector geometry will be imperfect.
- Misalignments can lead to incorrect tracking results.
- Ambiguity in misalignments.

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Which layer is misaligned?
CLAS12 Silicon Vertex Tracker

- Needed to obtain few percent resolution for low-momentum, large-angle particles.
- Assembled, integrated, calibrated, and now being commissioned in the EEL.
- Cosmic ray data now being collected for validation and alignment.

SVT Cosmics →
SVT Cosmic Ray Studies

- Cosmic rays
  - Full SVT DAQ using CODA.
  - Standalone trigger, $\sim 10$ Hz.
  - One double hit in R1/R2, R3, and R4.

- Taking cosmics for weeks now - extensive validation studies.

- Initial alignment studies.
  - Select 'good' tracks - eight crosses.
  - Residuals show need for alignment.
  - Dependence on fit parameters

Results are summed over 8-cross topologies.

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Results are summed over 8-cross topologies.

$\sigma \sim 100 \, \mu m$
Isolate individual sectors and 'simple' tracks - type 1 tracks.

Select tracks

- Exactly eight crosses.
- Topology: R4S1+R3S1+R2S1+R1S1+R1S6+R2S8+R3S10+R4S13
- Reduced $\chi^2$ cut: $\chi^2/\nu < 20.$
SVT Cosmic Rays - Type 1 Track Residuals

Sectors Type 1 cosmic rays
R1 R2 R3 R4
6 8 10 13

Residual, sector 1 layer 1 (mm)
Residual, sector 1 layer 2 (mm)
Residual, sector 1 layer 3 (mm)
Residual, sector 1 layer 4 (mm)
Residual, sector 1 layer 5 (mm)
Residual, sector 1 layer 6 (mm)
Residual, sector 1 layer 7 (mm)
Residual, sector 1 layer 8 (mm)
Residual, sector 1 layer 9 (mm)
Residual, sector 1 layer 10 (mm)

Entries 412
Mean 0.3101
RMS 0.1922

Entries 409
Mean 0.2898
RMS 0.1905

Entries 413
Mean 0.2984
RMS 0.2121

Entries 360
Mean 0.2787
RMS 0.2065

Entries 405
Mean 0.1456
RMS 0.1727

Entries 403
Mean 0.1077
RMS 0.1150

Entries 397
Mean 0.1514
RMS 0.1348

Entries 415
Mean 0.2185
RMS 0.2538

Entries 412
Mean 0.0904
RMS 0.1237

Entries 398
Mean 0.1050
RMS 0.1174

Entries 413
Mean 0.2785
RMS 0.1884

Entries 360
Mean 0.2786
RMS 0.2226

Entries 404
Mean 0.0904
RMS 0.1074

Entries 404
Mean 0.0922
RMS 0.1074

Entries 415
Mean 0.0904
RMS 0.1218

Entries 400
Mean 0.2520
RMS 0.2188

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SVT Cosmic Rays - Type 1 Track Residuals and Differences

- Plot centroid and RMS as error bar to represent residual distribution.
- Take difference between residuals within each region (outer-inner).
- Misalignment between Region 4 and Regions 1-3?

![Type 1 tracks diagram]

Type 1 tracks.
Type 1 tracks.

SVT Cosmic Rays - Test Reconstruction with Simulation

Type 1 cosmic rays

Validates reconstruction code.

Expected resolution: 65 μm
Type 1 tracks.

Validates reconstruction code.
Resolving Alignment Ambiguities

- Recall relative shift in residual centroid for R4S13 and Regions 1-3.
- Regions 1-3 and Region 4 are on different supports.
- Take the same event set and reconstruct only using Regions 1-3.
Resolving Alignment Ambiguities

- Recall relative shift in residual centroid for R4S13 and Regions 1-3.
- Regions 1-3 and Region 4 are on different supports.
- Take the same event set and reconstruct only using Regions 1-3.
Survey data can complement/validate track-based alignment results.

All survey points on modules.

Displacements of fiducials from ideal values (color) in $x - y$ plane.
Type-1 track sectors are nominally horizontal so average the position to look for shifts.
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What’s Next for SVT?

- Incorporate these measurements into the reconstruction code to correct misalignments - SVT is test case for other subsystems.
- Fit the track data AND the geometry parameters simultaneously.
  - Let the residual be $z_i = y_i - f(\vec{p}, \vec{q}_i)$ where
    - $y_i$ - measured value
    - $\vec{p}$ - global parameters (geometry)
    - $\vec{q}_i$ - local parameters (the fit)
    - $f(\vec{p}, \vec{q}_i)$ - parameterization.
  - The sum of $z_i^2/\sigma_i^2$ is minimized in the $\chi^2$.
  - Typically the number of global parameters is large.
  - For the SVT: 66(no. of sectors) × 3(no. of fiducials) × 3 = 594!
  - Millepede is already being used for alignment in Hall D and HPS and is running on the JLab farm (M.Staib, CMU).
Other Subsystem Track-Based Alignment Efforts

- **FTOF**
  - Being used now with PCAL/EC to detect cosmic rays and study FTOF-PCAL-EC alignment.
  - Awaiting analysis of survey data.
  - More studies planned for the spring.

- **PCAL/EC**
  - Possible issues appearing in $\pi^0$ analysis of *gemc* data.
  - Will use cosmics to align strips with box.

- **DC**
  - Need to know chamber alignment accurately.
  - Used straight tracks ($\vec{B} = 0$) with empty target to measure alignment in CLAS6.

- **HTCC** - Use survey and laser measurements - no track-based.
The SVT is collecting cosmic ray data to validate the detector response and study its alignment.

Eight-cross tracks have resolution $\sigma \sim 100 \, \mu m$, little dependence on fit parameters, and average misalignments $\sim 200 \, \mu m$.

Type 1 tracks have similar properties for Regions 1-4.

Test of the reconstruction code with simulations validates the code.

Type 1 tracks reconstructed without Region 4 show improvement in accuracy and resolution.

Survey results are now available and being studied.

Program Millepede can simultaneously fit track parameters and the geometry.

Listed other track-based alignment efforts.