# Aligning the CLAS12 CVT using a Kalman Alignment Algorithm

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CEBAF Large Acceptance Spectrometer

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- Awaiting feedback from second round of journal review

arXiv > physics > arXiv:2208.05054

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*[Submitted on 9 Aug 2022]*

## Alignment of the CLAS12 central hybrid tracker with a Kalman Filter

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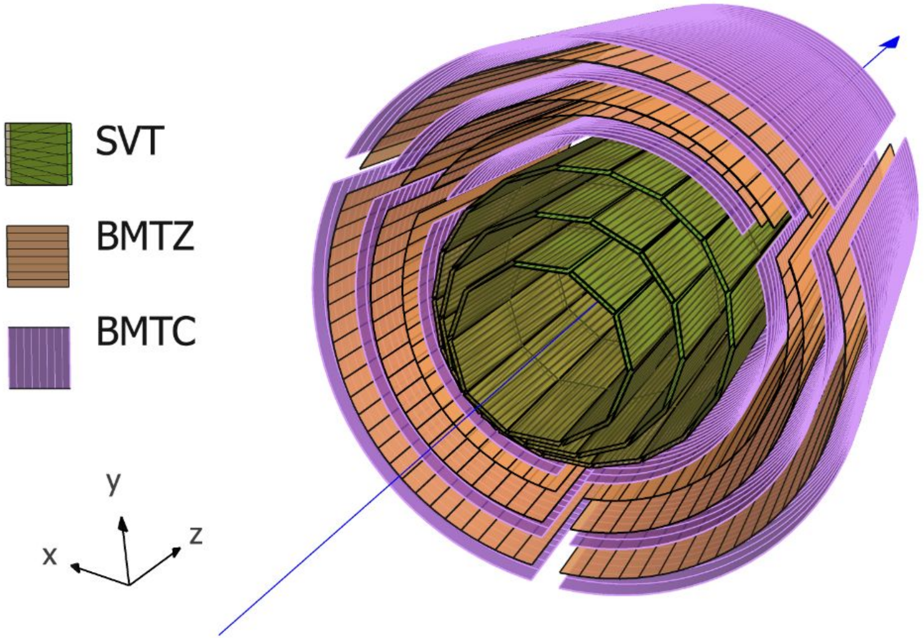
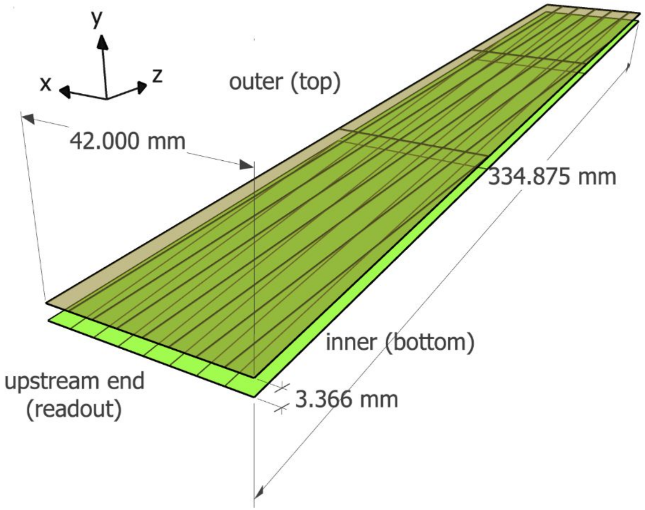
# The CLAS12 Central Vertex Tracker

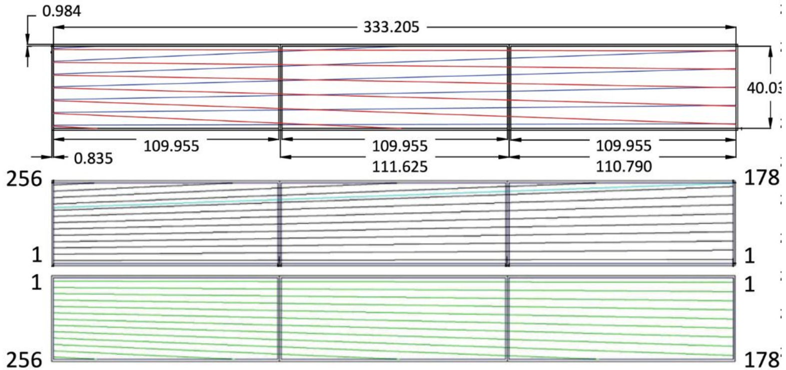
- 35°<θ<135° coverage
- Consists of silicon vertex tracker (SVT) and barrel micromegas tracker (BMT)
- BMT has layers with longitudinally oriented strips (Z) and circular arc strip (C)



# SVT module geometry

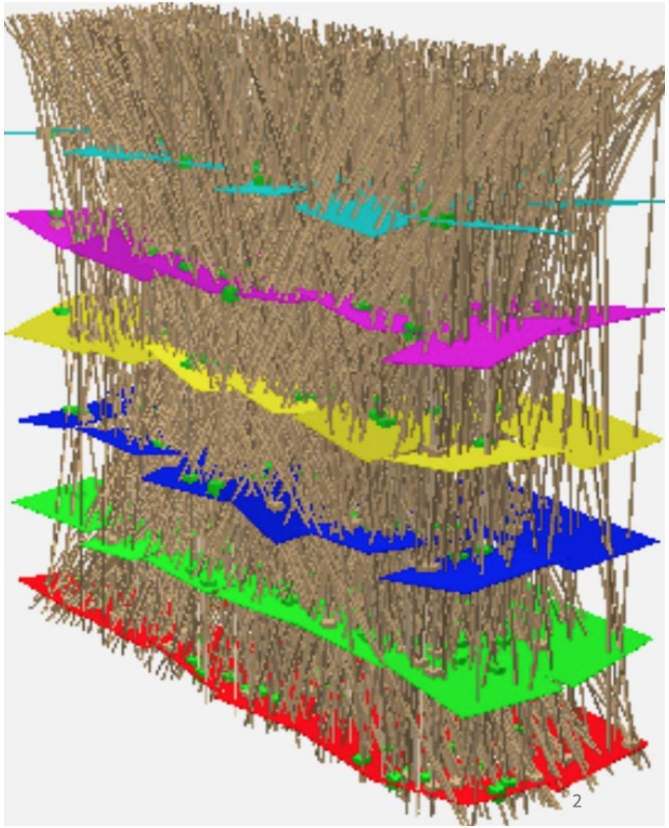
- Two sensors back-to-back with one another
- Strip pitch is 156 μm at upstream end (readout), and 224 μm at downstream due to “fanning out” layout of stereo sensors



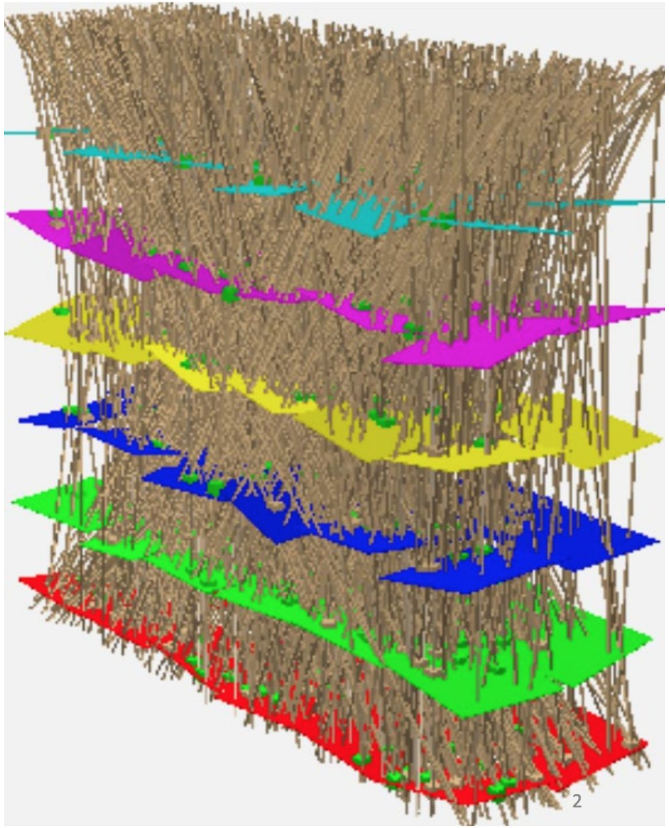
# Kalman Alignment Algorithm

- Developed for CMS as a general-use alignment algorithm (2010)
- Code was unused and unmaintained for about 10 years
- We revived the code, and adapted it for CLAS12



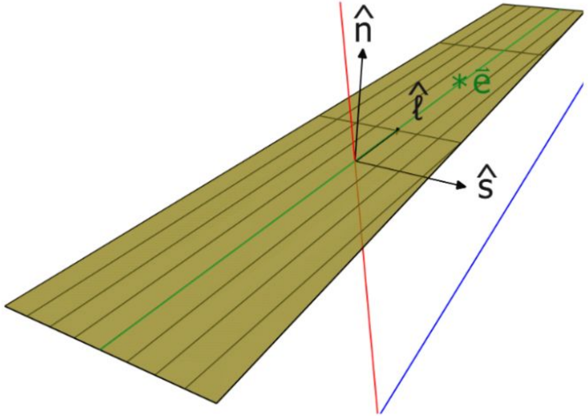
# Kalman Alignment Algorithm

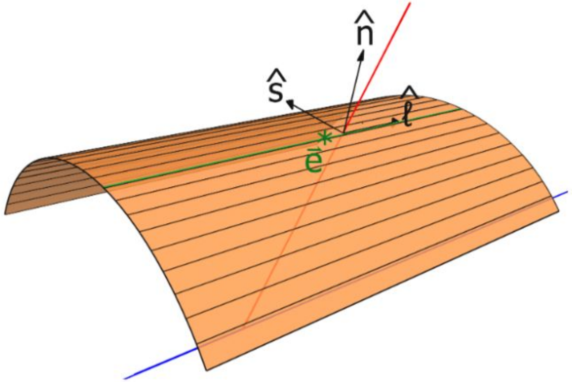
- Inputs
  - Reconstructed event sample
  - Initial estimate of alignment parameters $\mathbf{d}_0$
  - Initial covariance matrix $\mathbf{D}_0$ of the alignment parameters
- Algorithm
  - Reads in a reconstructed track from sample
  - MATH
  - Update **d** and **D**
  - Repeat for all tracks in sample
- Output:
  - Final values of **d** and **D.**

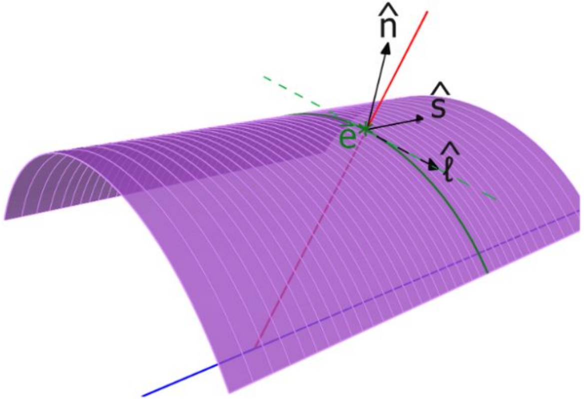


# Measurements

- One measurement for each cluster
- Residual $r_i$ is distance between struck strip and extrapolated position of track to the sensor
- A coordinate system is defined relative to the struck strip on the sensor
- Diagonals of the matrix **V** represent the squared resolution of the measurement for each cluster







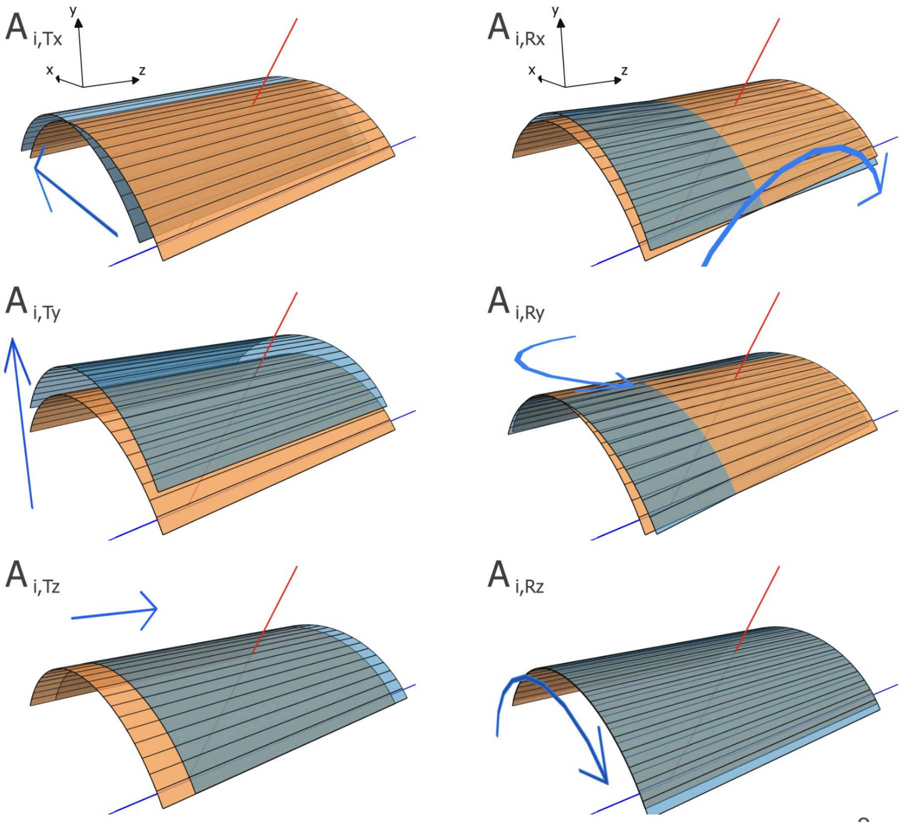
# Alignment parameters

- Dependence of residuals on alignment parameters encoded in matrix **A**

$$A_{ij} = \frac{\partial r_i}{\partial d_j},$$

$$A_{i,\vec{T}} = \vec{s}\,'$$

$$A_{i,\vec{R}} = -\vec{s}\,' \times \left( \vec{x}_{\mathrm{ref}} + \left( \frac{\vec{n} \cdot (\vec{e} - \vec{x}_{\mathrm{ref}})}{\hat{u} \cdot \hat{n}} \right) \hat{u} \right)$$



# Track parameters

- Dependence of residuals on track parameters encoded in matrix **B**

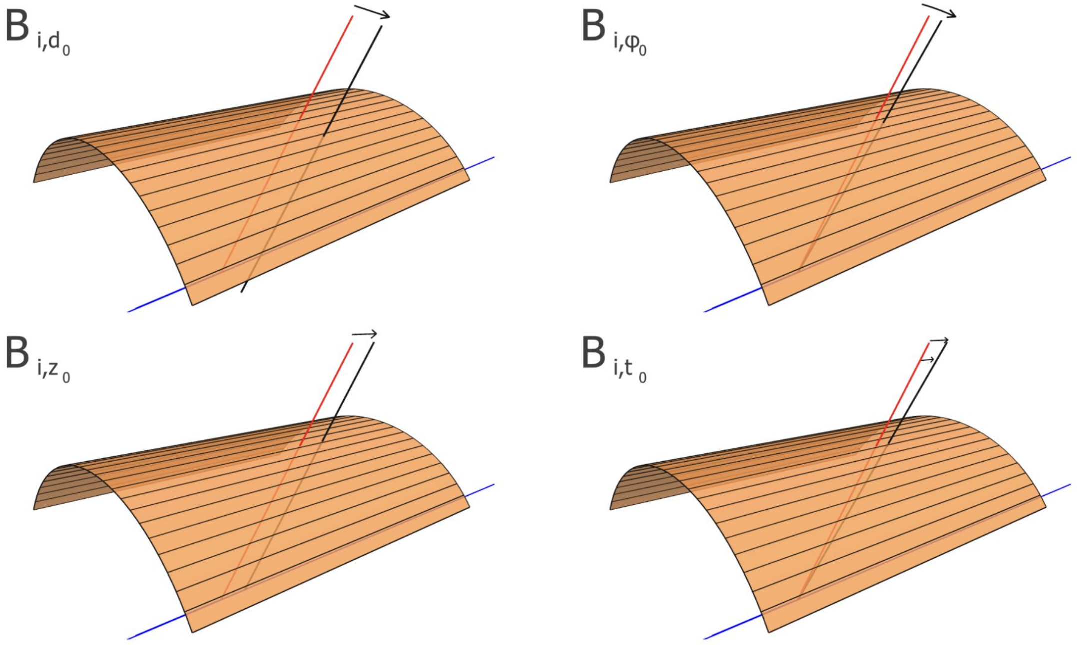
$$B_{ij} = \frac{\partial r_i}{\partial t_j},$$

$$B_{i,d_0} = -\vec{s}\,' \cdot (-\sin\phi_0,\ \cos\phi_0,\ 0)$$

$$B_{i,\phi_0} = -\vec{s}\,' \cdot \left( \frac{\hat{n} \cdot (\vec{e} - \vec{x}_{\text{ref}})}{\hat{u} \cdot \hat{n} \sqrt{1 + t_0^2}} (-\sin\phi_0,\ \cos\phi_0,\ 0) \right.$$
$$\left. - d_0(\cos\phi_0,\ \sin\phi_0,\ 0) \right)$$

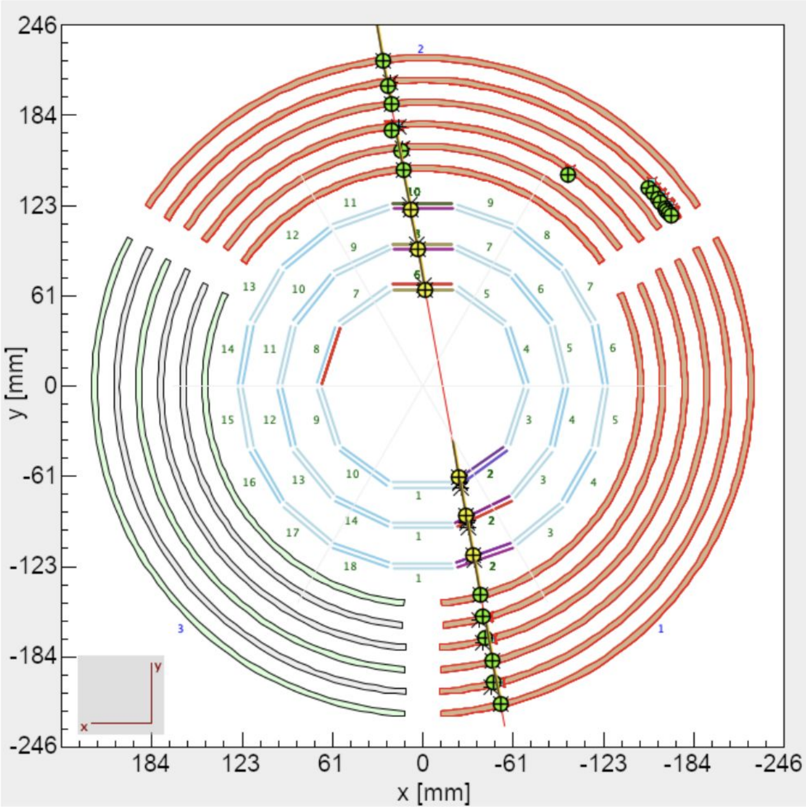
$$B_{i,z_0} = -s'_z$$

$$B_{i,t_0} = -s'_z \frac{\hat{n} \cdot (\vec{e} - \vec{x}_{\text{ref}})}{\hat{u} \cdot \hat{n}}.$$

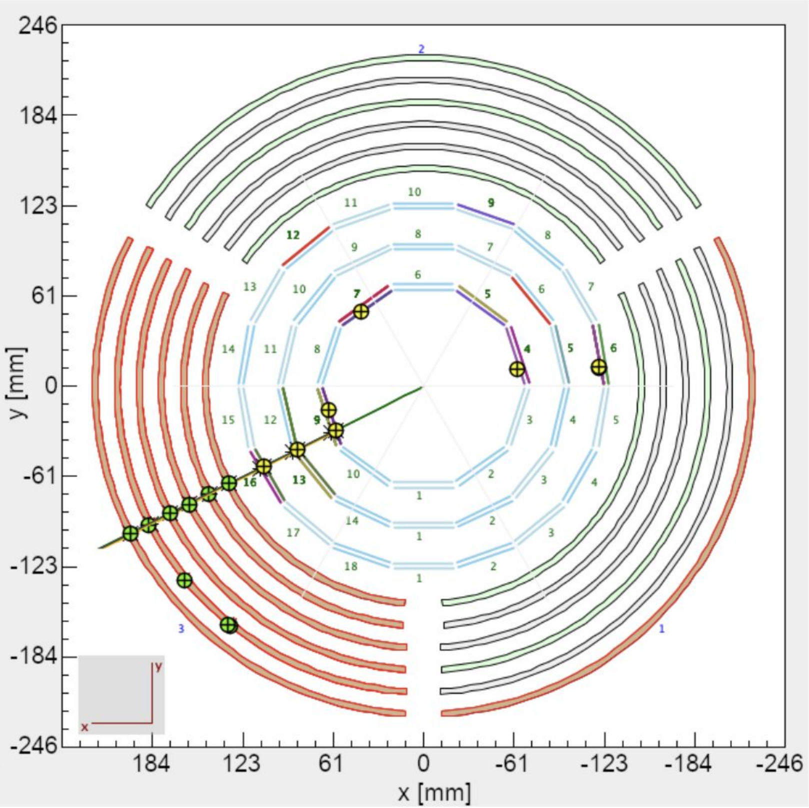


# Event topologies

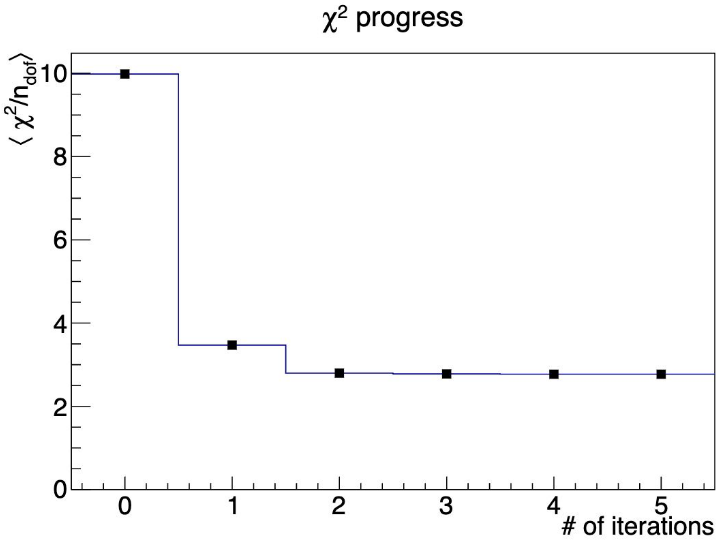
Cosmic Ray



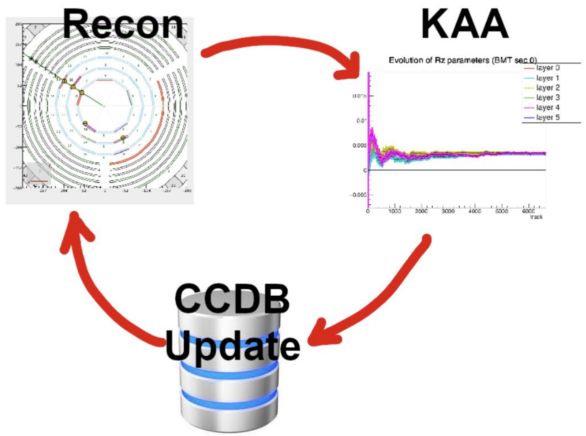

Field-off tracks from target



# Multi-iteration approach

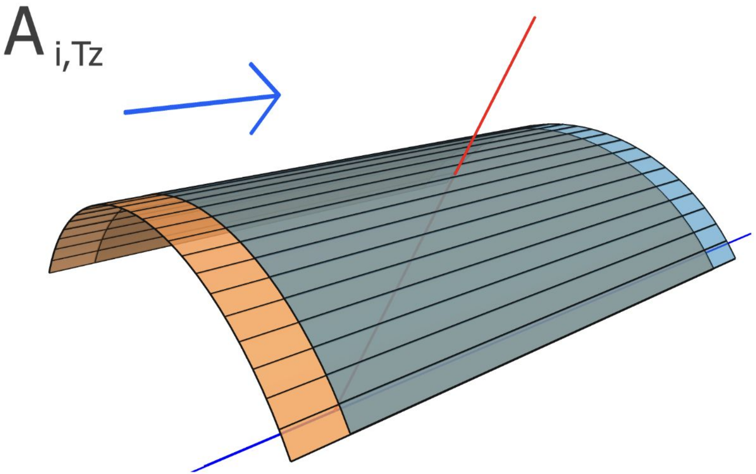


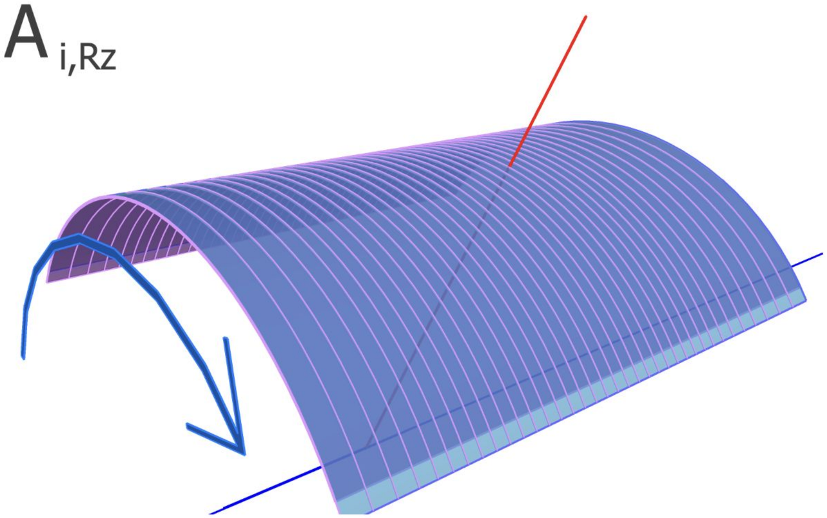

- fixes issues with nonlinear dependence of residuals on alignment and track parameters
    - Run KAA
    - Get alignment parameters
    - Rerun reconstruction using new alignment parameters
    - Repeat



# Fixed parameters

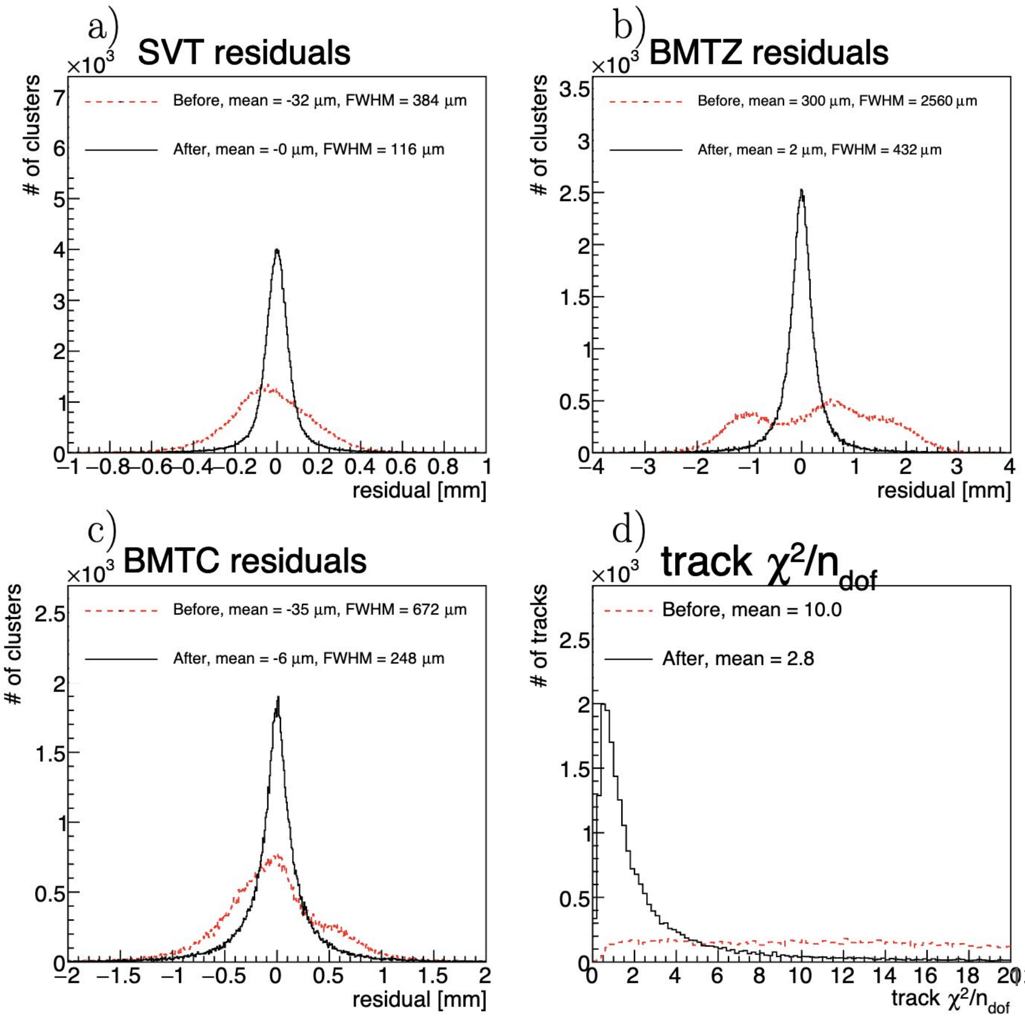
- Use tiny values for the corresponding values in $\mathbf{D}_0$
- Fix weak modes:
    - Translations in z for BMTZ
    - Rotations around z for BMTC
- Fix global degrees of freedom
    - Fix all DOFs  for one BMTZ tile
    - z translation for one BMTC tile

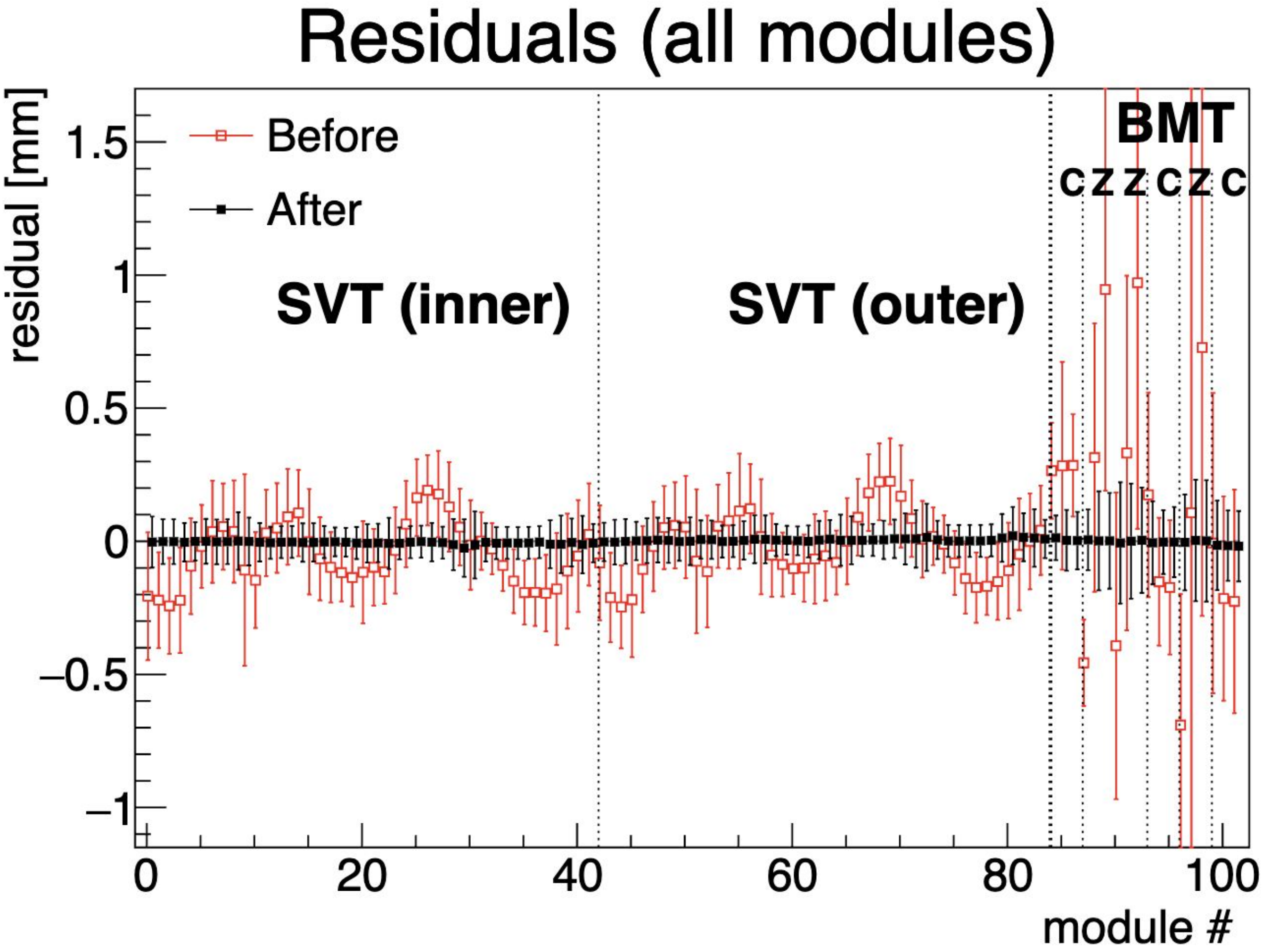


# Results

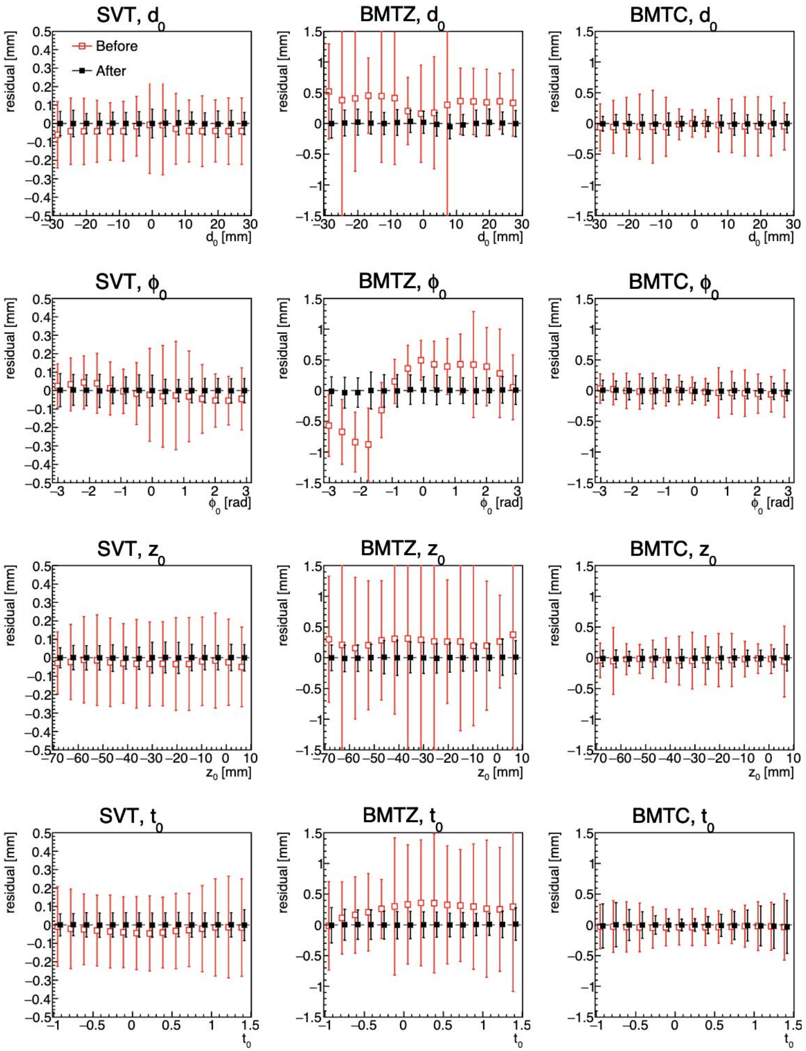
- Residual distributions get considerably narrower
- Track chi^2 considerably reduced




Residuals (all modules)
residual [mm]
1.5
1
0.5
0
−0.5
−1
Before
After
SVT (inner)
SVT (outer)
BMT
C Z Z C Z C
0
20
40
60
80
100
module #

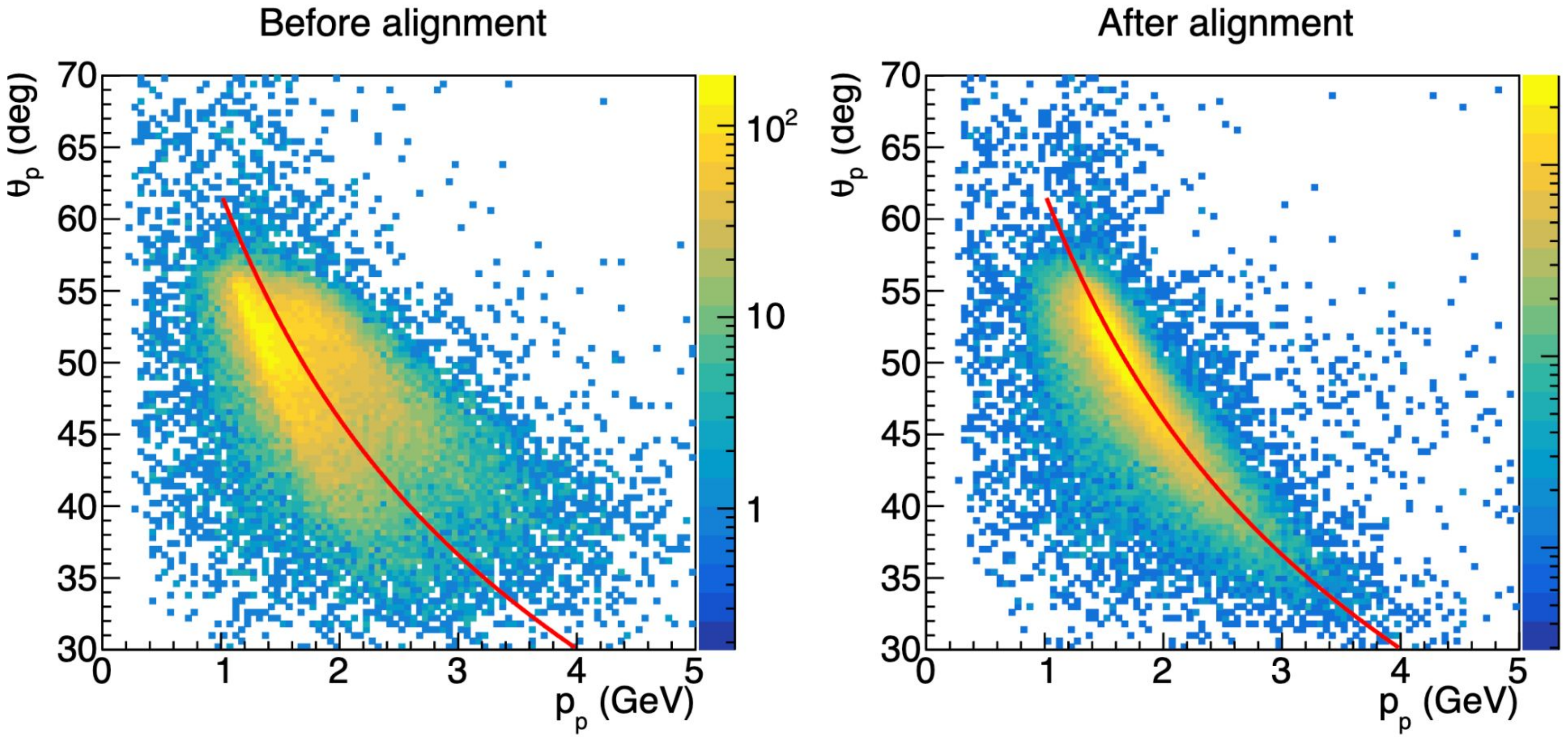
# Residual distributions

Improvement in the FWHM of the residuals over entire kinematic phasespace

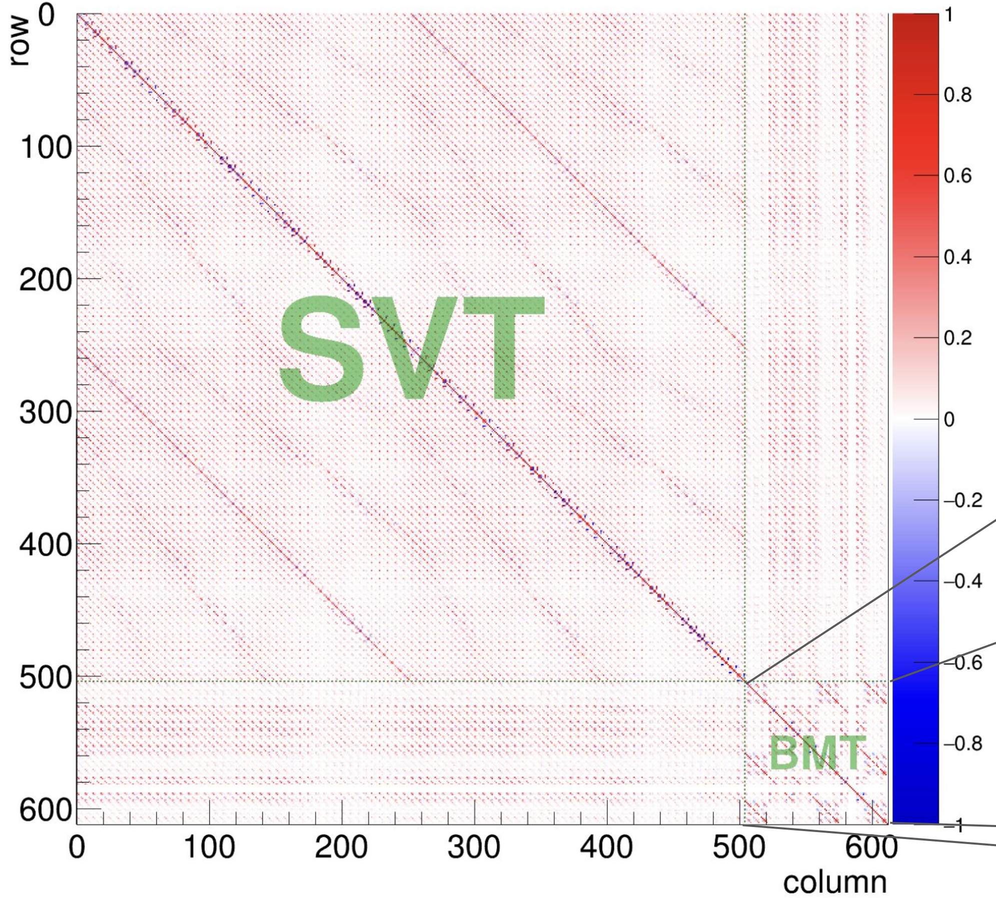


# Results: proton recoil from elastic *ep* scattering

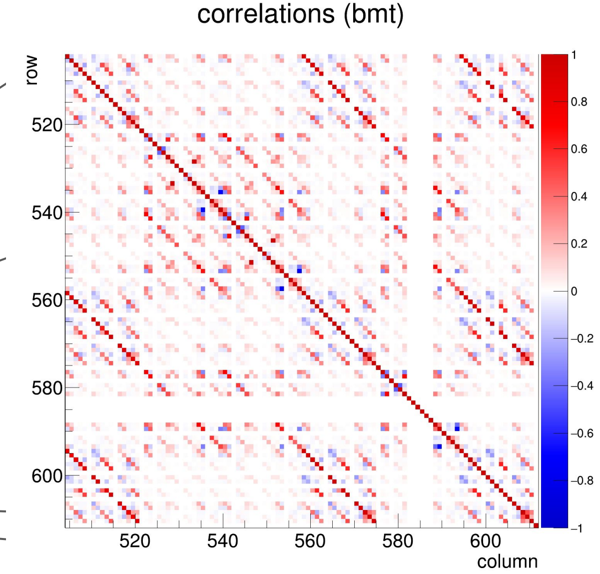
$$p_p = \frac{2E_b m_p (E_b + m_p)\cos\theta_p}{E_b^2 \sin^2\theta_p + 2E_b m_p + m_p^2},$$



# Correlation matrix




- Shows residual correlations between alignment parameters.
- $$C_{ij} = D_{ij}/\sqrt{D_{ii}D_{jj}},$$



# Conclusions

- We have performed alignment of the CVT using the KAA algorithm
  - Alignment procedure takes about an hour or less, even on a laptop.
  - The spacial-residual distributions are centered at zero, within 10 μm, for all channels
- Impact
  - Prior to this procedure, the CVT alignment was insufficient for use in many physics analyses
  - Greatly extends kinematic reach of CLAS12 tracking compared to DC alone
  - KAA can in principle be used for alignment of other detectors in CLAS12 or even at the future EIC