FDC Alignment Studies

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Algorithm using straight-line fitting adapted from

R. Fruehwirth,T. Todorov, and M. Winkler, “Estimation of Alignment Parameters, using the Kalman Filter with annealing”, CMS Note 2002/008

Alignment algorithm

- Use **Kalman Filter** formalism: update state vector S and covariance matrix C with each measurement but use current result for alignment vector a (covariance matrix E)
  - Measurement vector M = f(S,a)+ε
  - Measurement covariance matrix V
  - Update state vector:

$$H = \frac{\partial f}{\partial \vec{S}}, G = \frac{\partial f}{\partial \vec{a}}$$

$$\vec{S}_1 = \vec{S}_0 + C_0 H^T W (M - f(\vec{a}_0, \vec{S}_0))$$

$$C_1 = C_0 - C_0 H^T W H C_0$$

  - Weight matrix:

$$W = (V + HCH^T + GEG^T)^{-1}$$

- Update alignment vector during smoothing stage

$$\vec{a}_1 = \vec{a}_0 + E_0 G^T W (M - f(\vec{a}_0, \vec{S}_0))$$

$$E_1 = E_0 - E_0 G^T W G E_0$$

State and alignment vectors

- State vector S={x, y, t_x=dx/dz, t_y=dy/dz}
- Alignment vector: offsets in x,y and rotation about z-axis for each wire plane

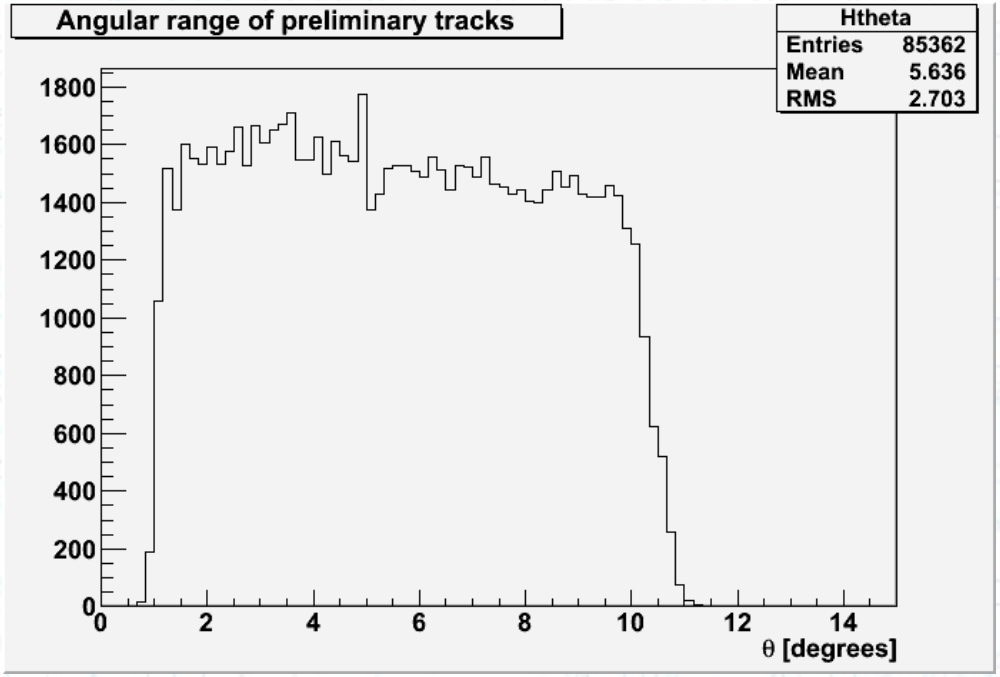
$$\vec{a} = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta\phi \end{bmatrix}, \begin{bmatrix} \Delta X \\ \Delta Y \end{bmatrix} = R(\Delta\phi) \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$$

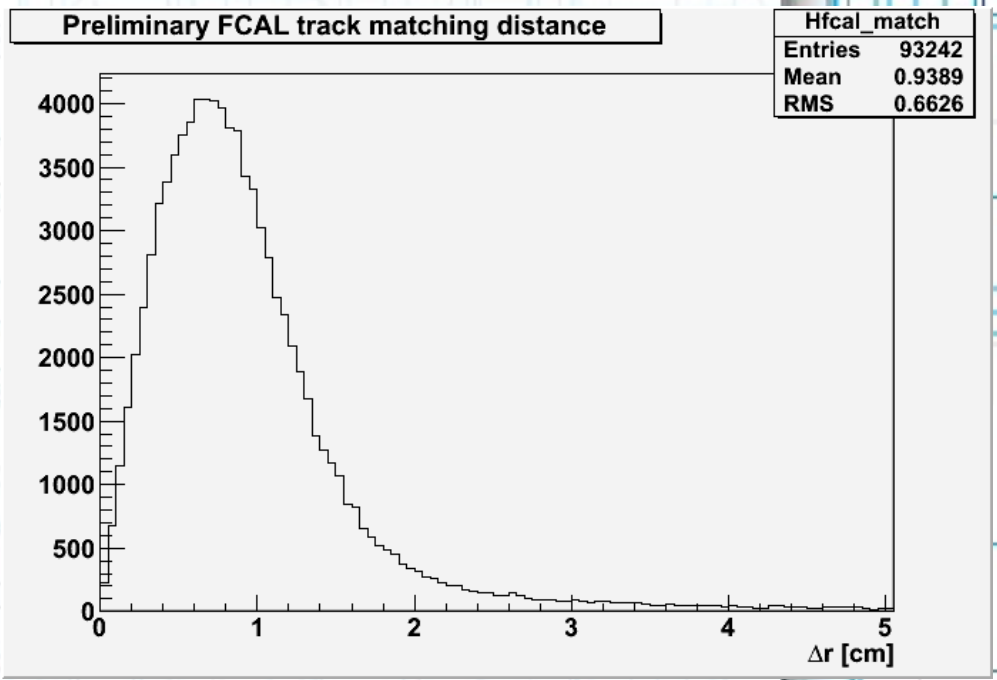
$$R(\Delta\phi) = \begin{bmatrix} \cos\Delta\phi & \sin\Delta\phi \\ -\sin\Delta\phi & \cos\Delta\phi \end{bmatrix}$$

- Start with a={0,0,0}, E(ΔX,ΔX)=E(ΔY,ΔY)=E(Δϕ,Δϕ)=1

Procedure

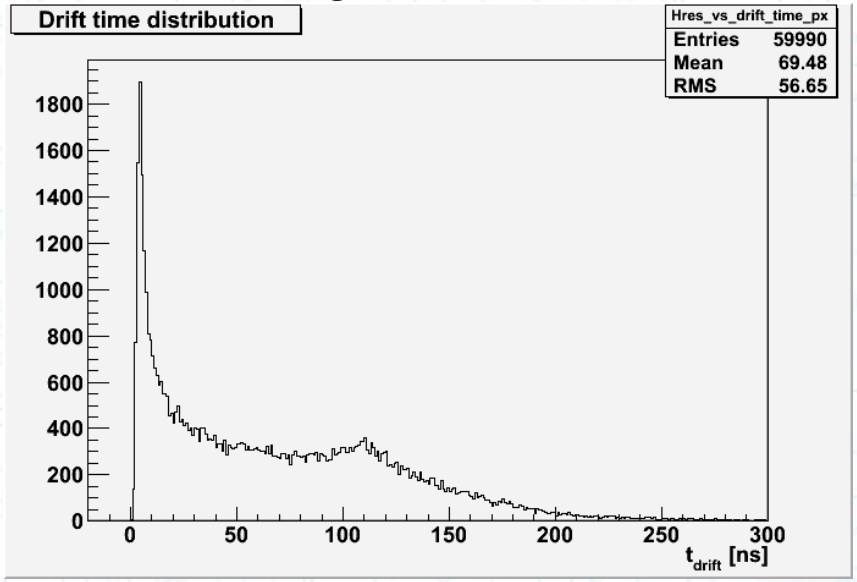
- Generate 200,000 e^- tracks from center of target
  - p = 2 GeV/c, $\theta < 10°$
- Analyze with JANA plug-in
  - Require at least one hit in FCAL
  - Preliminary line fit using wire position and coordinate along wire
    - Match to FCAL $\rightarrow \Delta r<2$ cm
  - Time-based fit allowing alignment parameters to change from event to event

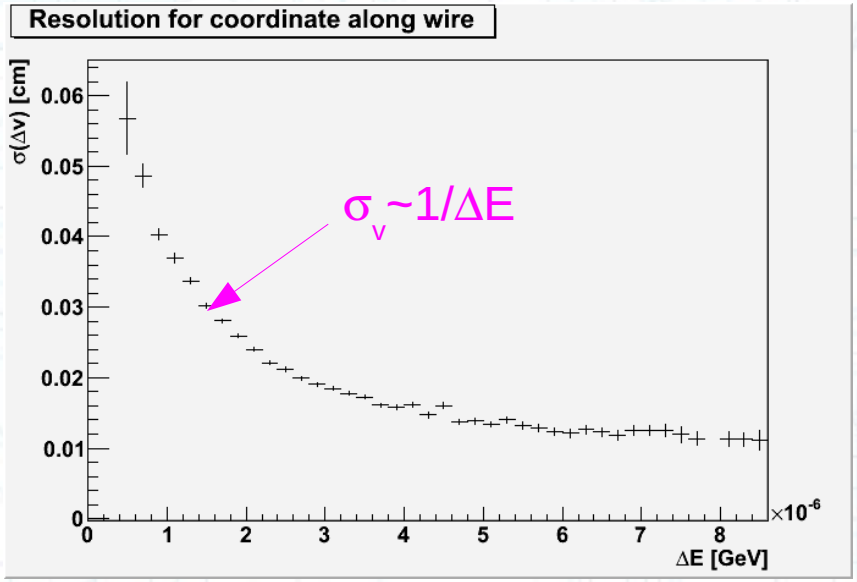


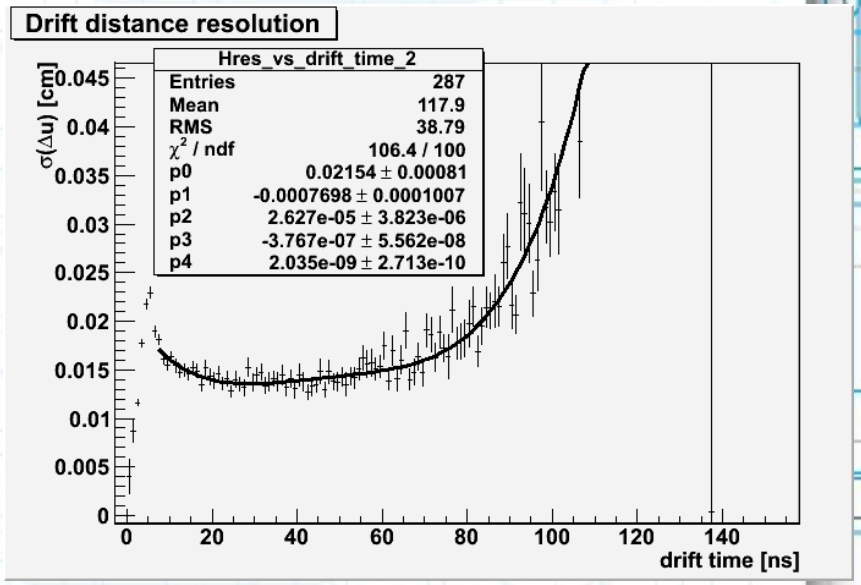


Benchmark: no alignment procedure, no offsets

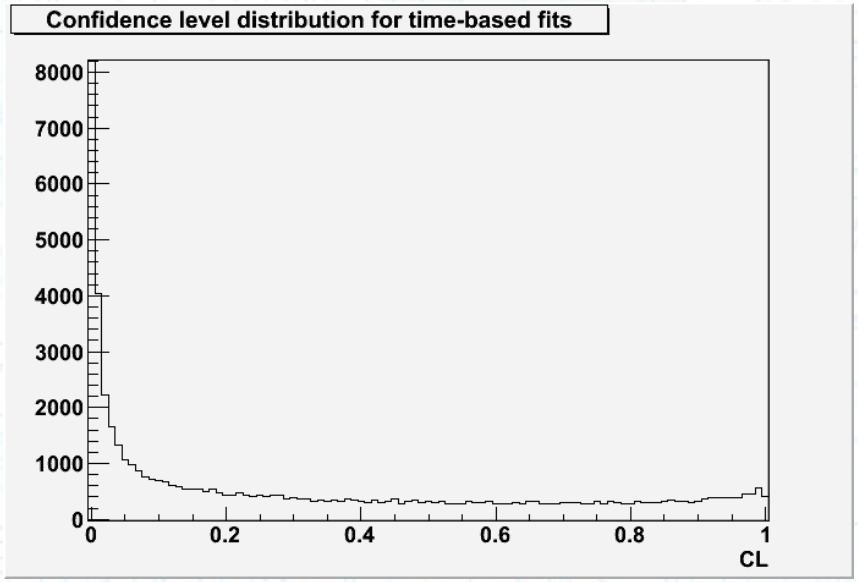
- Determine measurement errors for coordinate v along wire and drift time
- Determine time offset for reading drift time from table in *calib/FDC*

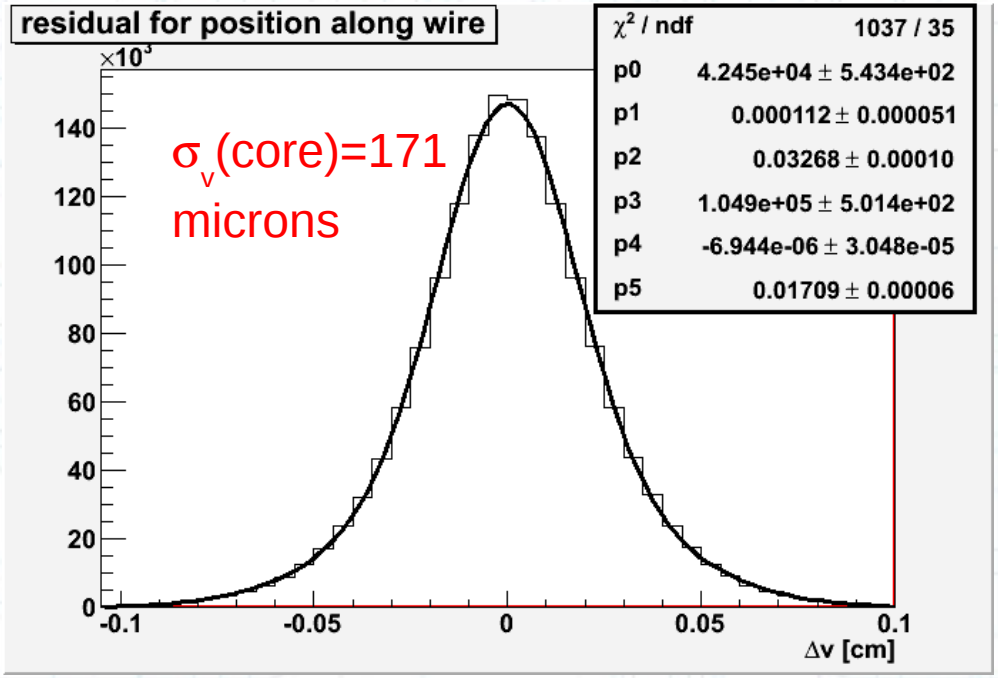


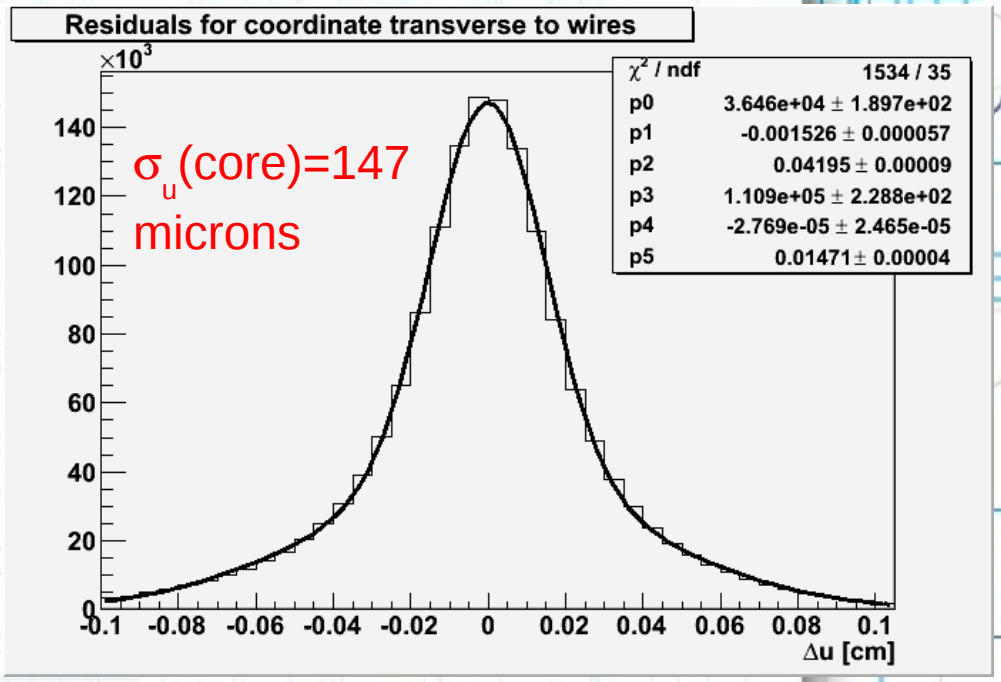




Benchmark: no alignment procedure, no offsets







Alignment: No scaling

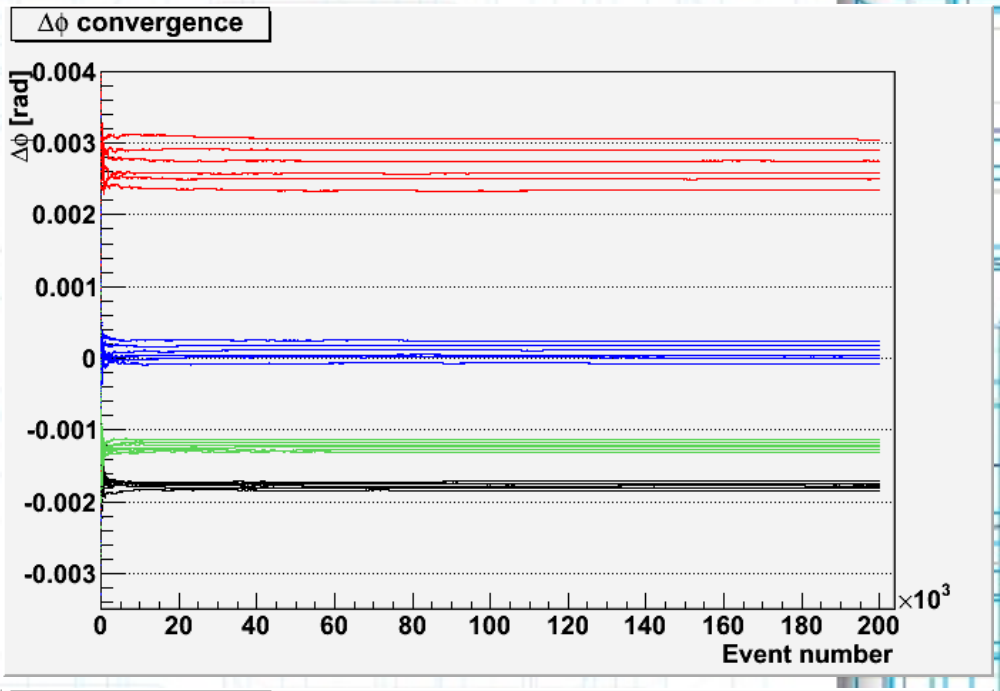
No offsets

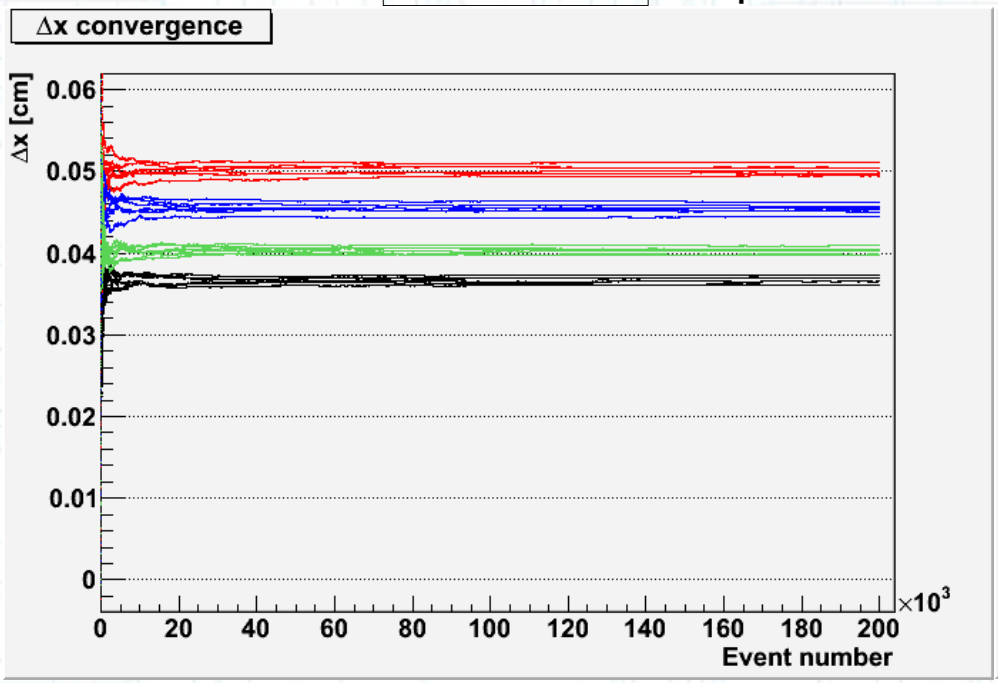
- Use measurement errors determined from previous step (scale factor S=1.0)
- Alignment procedure produces significant biases...

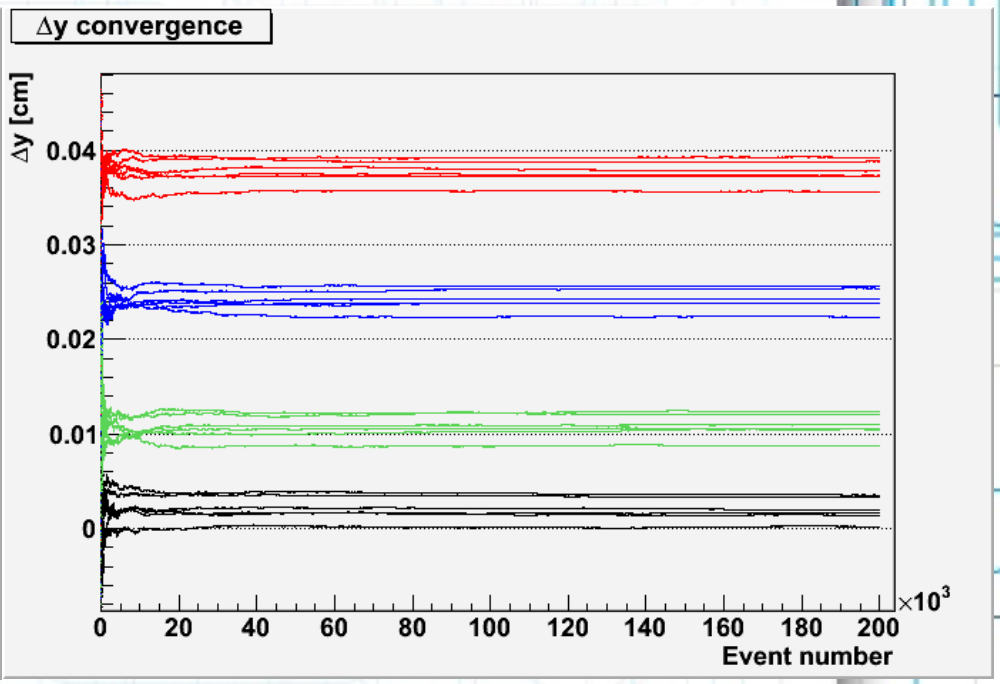
Package 4
Package 3
Package 2
Package 1

downstream

upstream





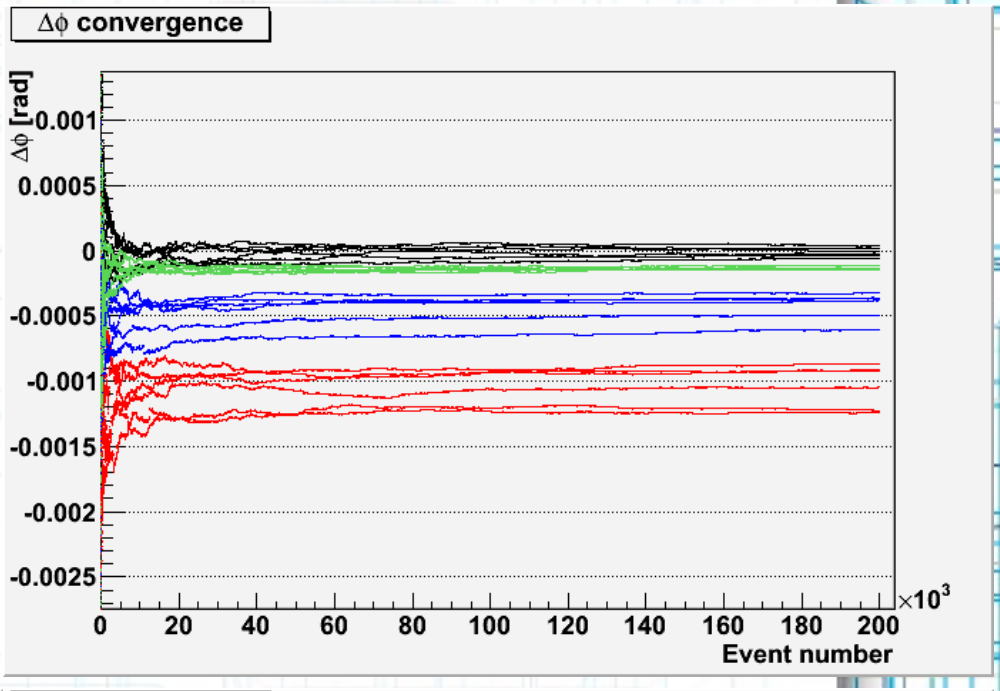


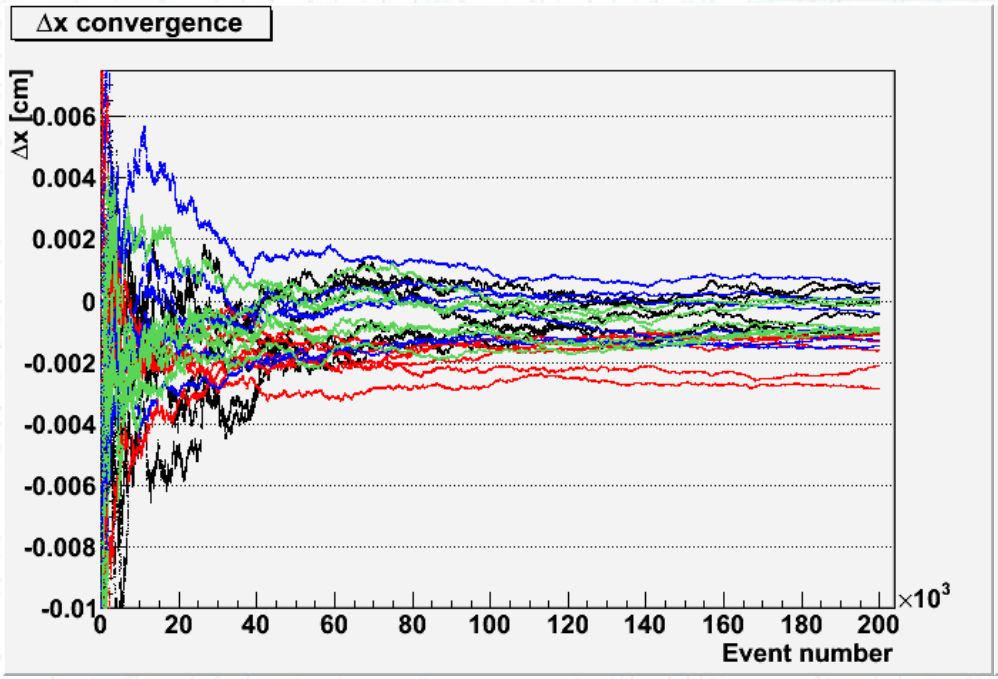
Alignment: Scale errors

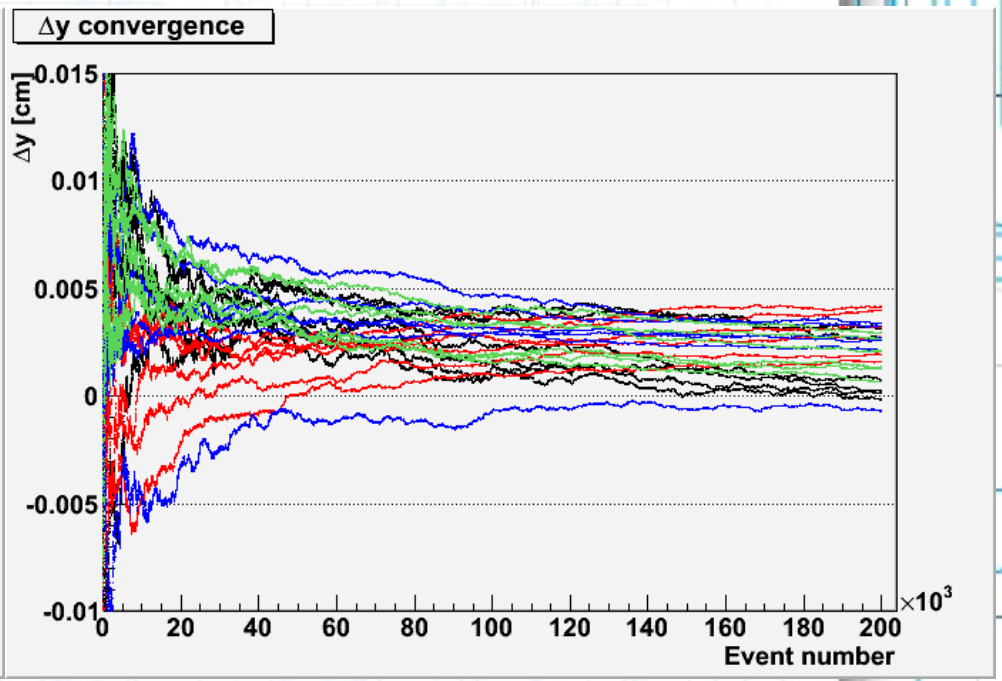
No offsets

- Scale factor S=50000.0 on V
- Biases greatly reduced...

Package 4
Package 3
Package 2
Package 1





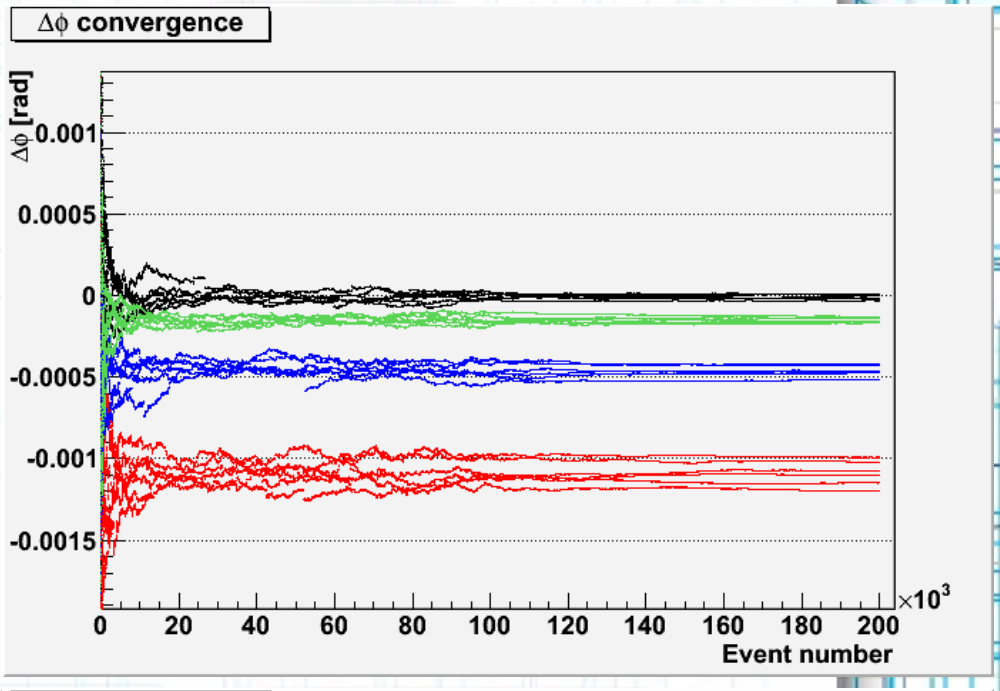


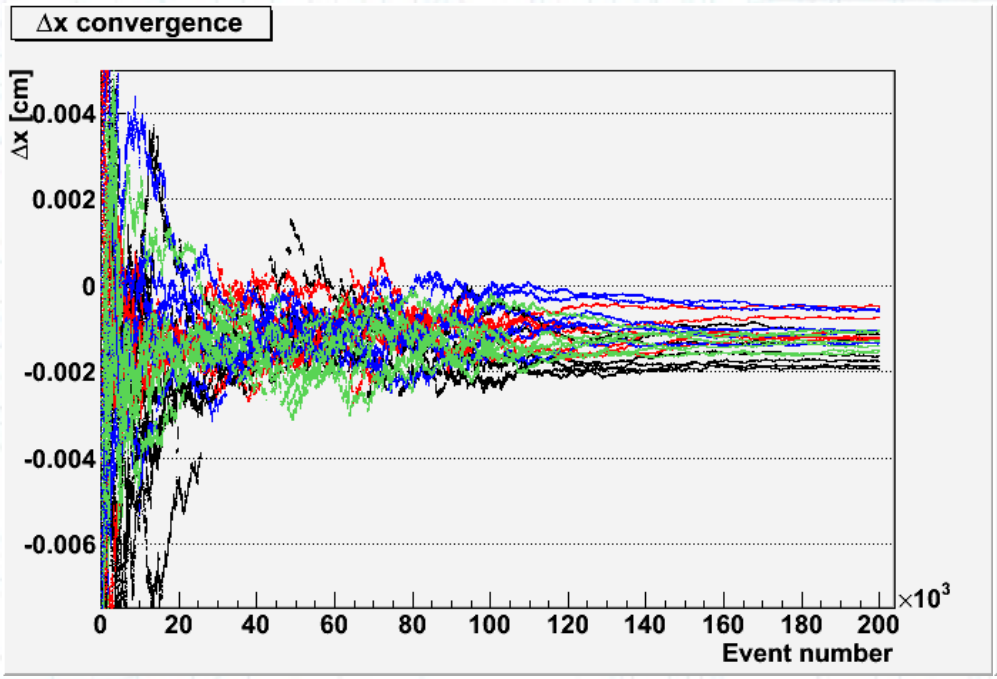
Alignment with annealing

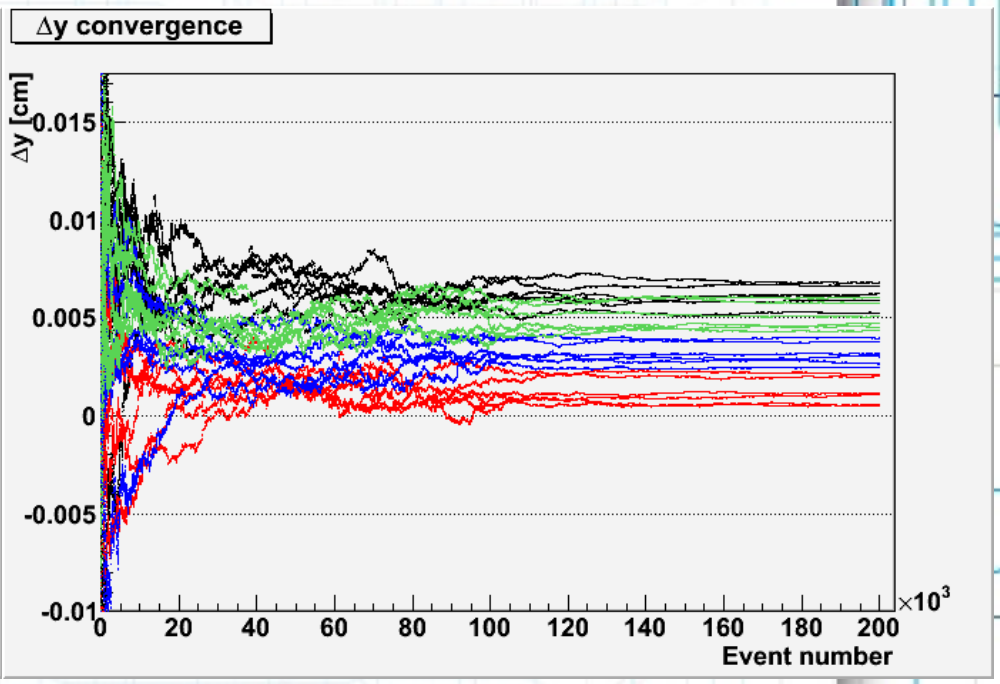
No offsets

- Scale factor $S=50000.0^{(100000-N)/99999}$, $N<100000$
- $S=1$, $N>=100000$

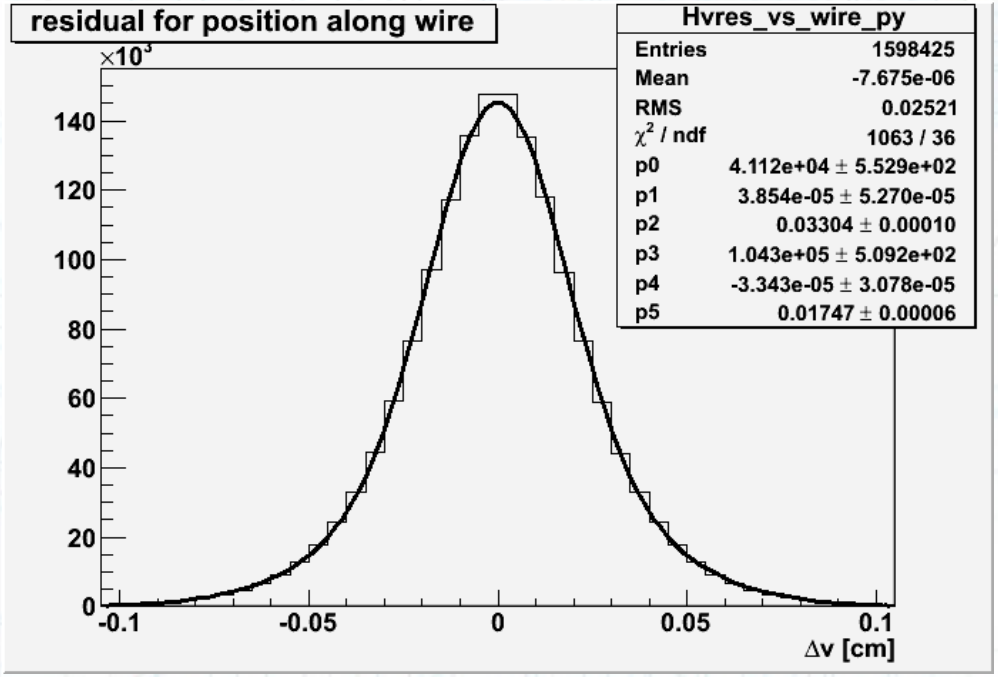
Package 4
Package 3
Package 2
Package 1

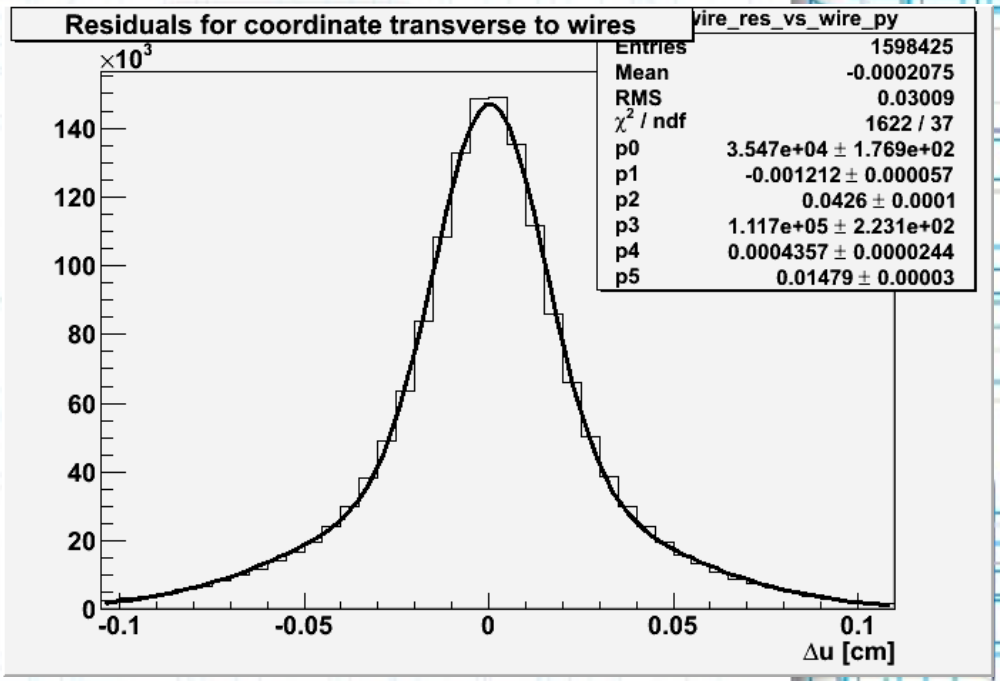






Residuals after alignment





No obvious difference from benchmark...

Summary

- Without scaling errors, convergence is fast, but biases are large (~few hundred microns in x and y)
- After annealing, biases are greatly reduced
  - Accuracy in Δx <~20 microns, Δy < ~70 microns
  - $\Delta\phi$ bias worst for package 1 = ~1.1 mrad = 0.06°
  - *Some sort of annealing/error scaling scheme seems to be necessary...*