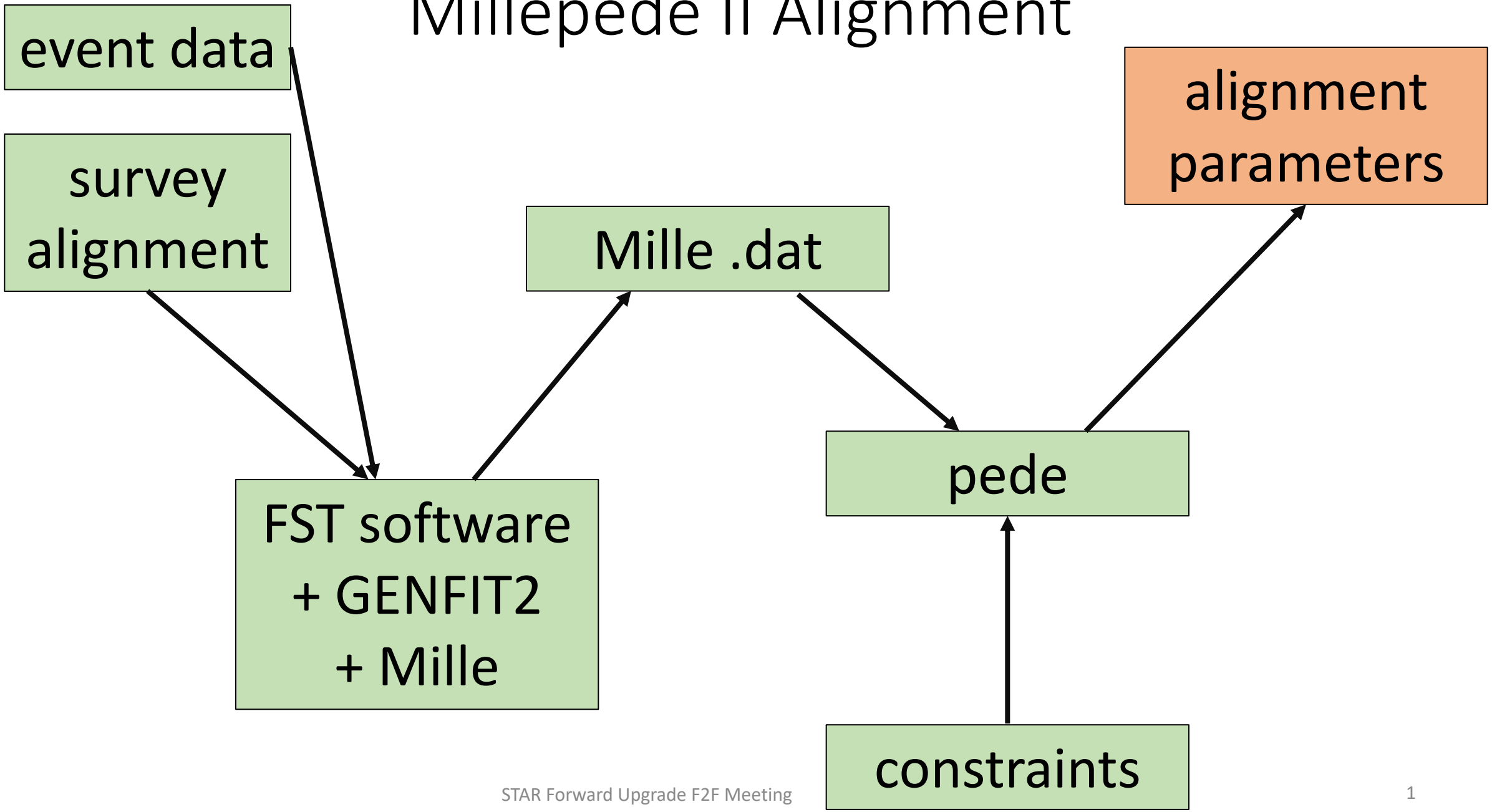
Millepede II Alignment



Millepede-II with GBL

- Track parameterized by $\boldsymbol{q} = (\boldsymbol{u_i}, \ldots, \boldsymbol{u_{\#planes}})$, where $\boldsymbol{u_i}$ vectors are offsets at FST or sTGC plane.
- Minimize the following function, where **p** are the alignment parameters and $\mathbf{q_j}$ are the track parameters.

$$\chi^2(\mathbf{p}, \mathbf{q}) = \sum_{j}^{\text{tracks}} \sum_{i}^{\text{measurements}} \left(\frac{m_{ij} - f_{ij}(\mathbf{p}, \mathbf{q}_j)}{\sigma_{ij}} \right)^2$$

- Data necessary to run Millepede-II:

# of local parameters
# of global parameters
residuals = $m_{ij} - f_{ij}(\boldsymbol{p}, \boldsymbol{q}_j)$
σ = standard deviation of the measurement

array: $\left(\frac{\partial f}{\partial q_j}\right)$
array: $\left(\frac{\partial f}{\partial p_l}\right)$
label array, l

https://www.desy.de/~kleinwrt/MP2/doc/html/draftman_page.html

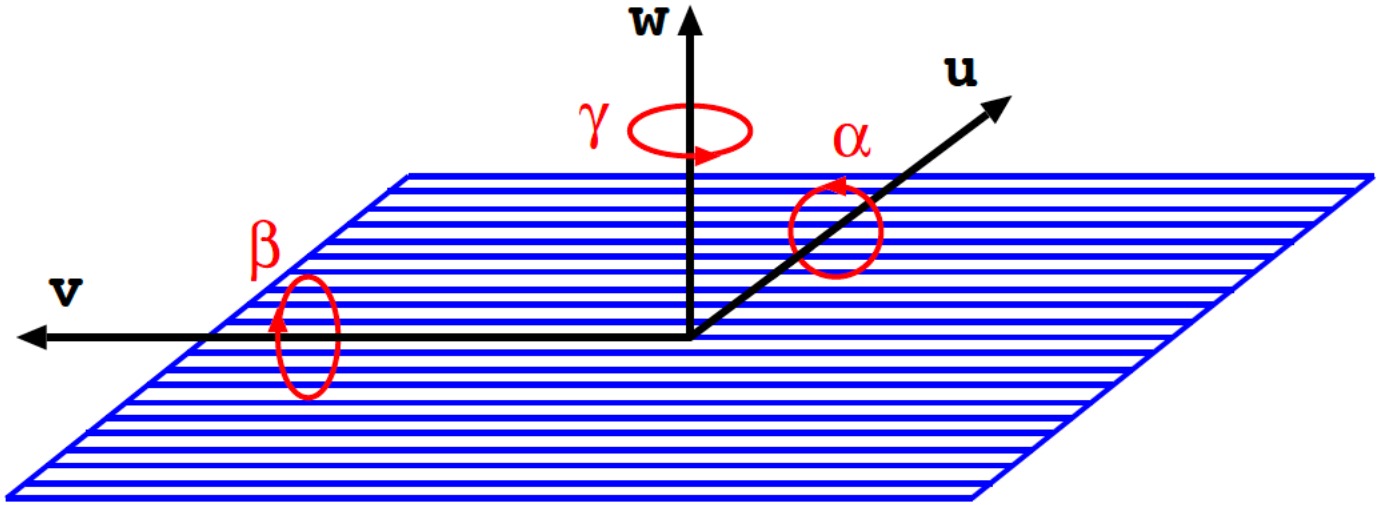
Alignment (global) Parameters

FST

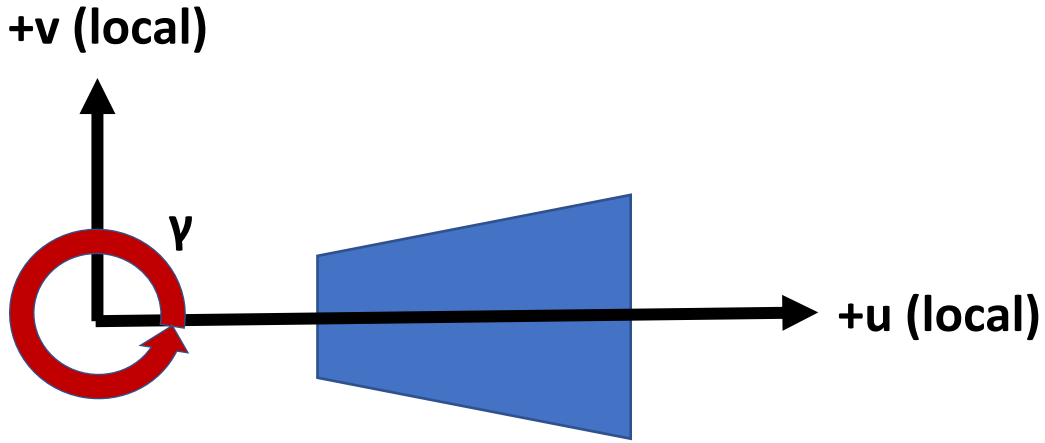
Translations: Δ*u*, Δ*v*, Δ*w*

Rotations: Δα, Δβ, Δγ

- 3 alignment parameters for a sensor (108 sensors).
  - Δ*w*, Δα, Δβ = 0, since we assume they lie flat on the wedge.
- 6 per wedge (36 wedges).
- 6 per FST half (2 halves).
- 6 for FST.
- 558 alignment parameters.



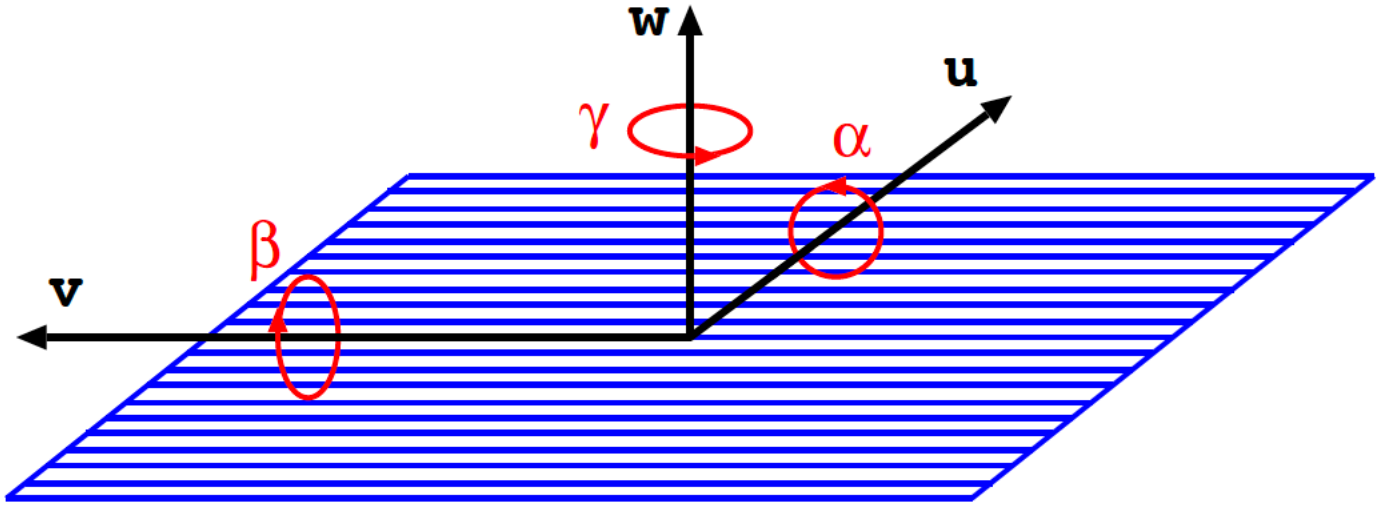
CMS, doi:10.1088/1748-0221/9/06/P06009.



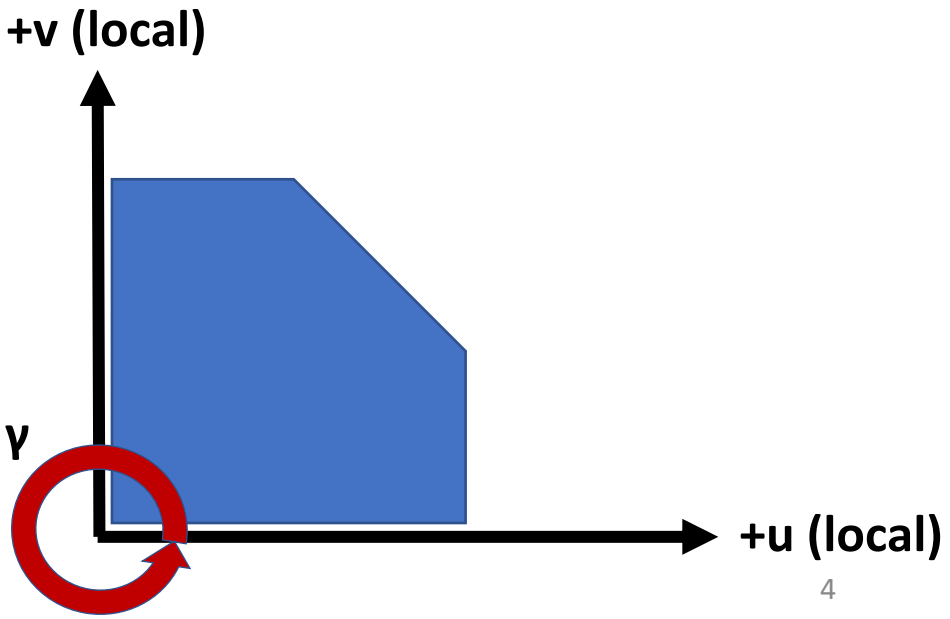
Alignment (global) Parameters

FTT (sTGC)

- 6 alignment parameters per pentagon (16 pentagons).
- 6 per plane (4 planes).
- 6 for sTGC.
- 126 alignment parameters.



CMS, doi:10.1088/1748-0221/9/06/P06009.



Hierarchy of Alignment Parameters

- Each track prediction for a sensor relies on the larger structures it is contained within.
  - Sensor on wedge, wedge on FST half, half on Full FST, full on TPC.
- We can calculate the all the global derivatives using chain rule

$$\frac{\mathrm{d}f_{u/v}}{\mathrm{d}\boldsymbol{\Delta p}_l} = \frac{\mathrm{d}\boldsymbol{\Delta p}_s}{\mathrm{d}\boldsymbol{\Delta p}_l} \cdot \frac{\mathrm{d}f_{u/v}}{\mathrm{d}\boldsymbol{\Delta p}_s},$$

$f_{u/v}$ = track prediction
$\mathrm{d}\Delta\mathbf{p}_s$ = change in sensor global parameter
$\mathrm{d}\Delta\mathbf{p}_l$ = change in containing structure global parameter

- The sum of all sensors global parameters pertaining to a larger substructure are constrained to zero to prevent shift of overall structure by the sub-components.
- Constraints added by .txt file input to pede.

CMS, doi:10.1088/1748-0221/9/06/P06009.

Multiple Scattering in GBL

- Multiple scattering covariance from the previous measurement plane accounted for at the current measurement plane in the GBL trajectory.
- The covariance matrix of scattering angle (w.r.t track direction) is calculated using:

$$\sigma_\theta = \frac{0.0136}{p}\sqrt{x/\chi_0}[1 + 0.038ln(x/\chi_0)].$$

$$V_k = \begin{pmatrix} \sigma_\theta^2 & 0 \\ 0 & \sigma_\theta^2 \end{pmatrix}.$$

- Where x is track length within the sensor, χ_0 is the radiation length of the material and p is the magnitude of momentum.
- Kalman filter can treat material as continuous, while GBL uses discrete scatters.

J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012)

GENFIT2 Classes for GBL

GblPoint.h/cc: contains all data for 2D measurements (derivatives, residuals, covariance, etc.).

GblTrajectory.h/cc: holds all GblPoints, can be fit or used directly for Mille output.

MilleBinary.h/cc: Organizes the data from GblTrajectory into the exact format required for pede.

GFGbl.h/cc: GBL fitter class implementing Mille binary file output and data collection. Originally written for BELLE II alignment.

StFwdGbl.h/cc: Adapted version of GFGbl for use with the Forward Tracker Alignment.

Single Sensor Alignment

- Misalign 1 inner sensor (sensorIdx = 36) in FST simulated geometry.
- Throw mu+ with particle gun with following settings:
  - $0.2 < p_T < 2.0$ GeV/c
  - $2.8 < \eta < 4.5$
  - $0.9 < \phi < 1.7$ rad
  - B = 0 T
- Require hits on sensors: 0, 36, 72 (3 inner sensors, 3 different disks, all in same ϕ position.
- Fit with GenFit Kalman filter and then refit with GenFit GBL.
- Output all necessary data to Mille.dat files.

Single Sensor Alignment

- Mille.dat files are then fed to pede.
- Can specify initial values of alignment parameters and their pre-sigma (helps stabilize a poorly defined parameter).

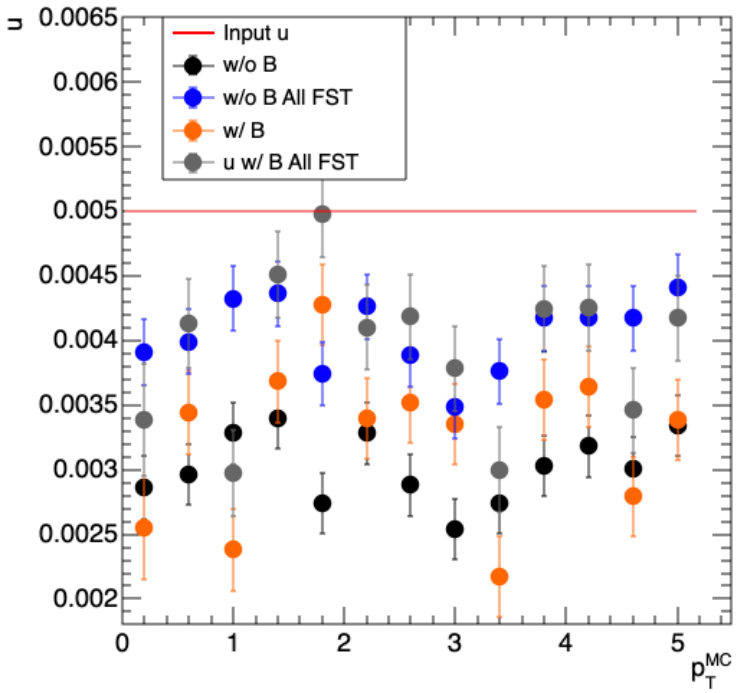
```
Parameter
label   initial_value   presigma
 ...
label   initial_value   presigma
```

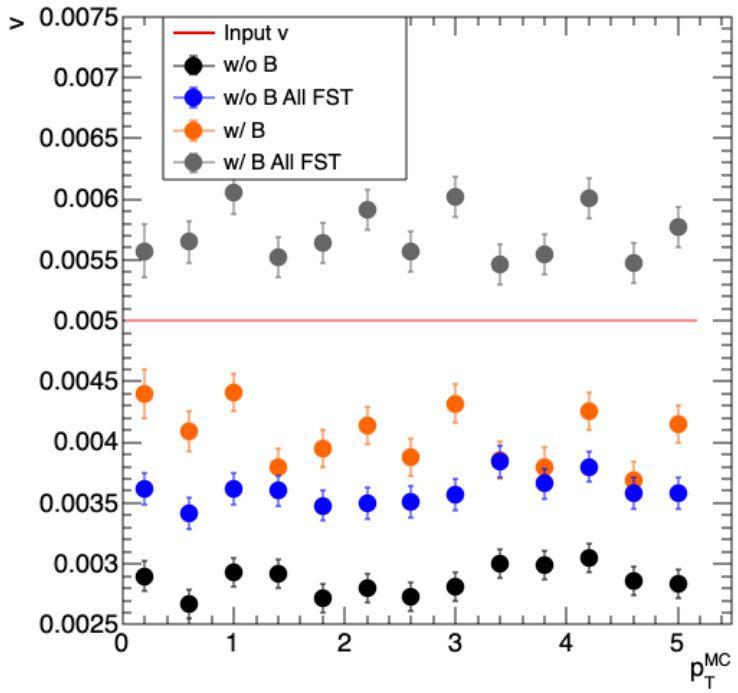
Example of pede parameter entries.

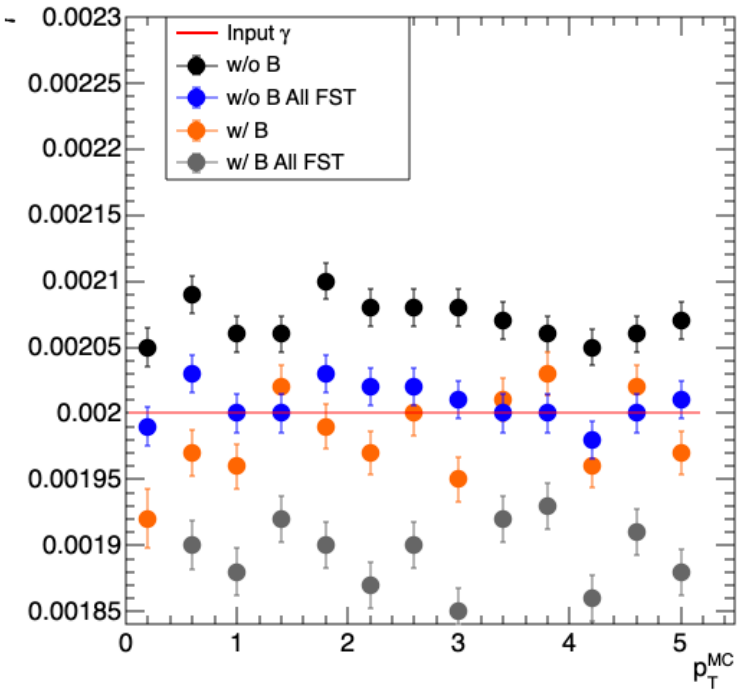
- Fix rotations about u-axis and v-axis, in addition to w translation by setting pre-sigma < 0.0.
- Matrix inversion used to solve for alignment parameters.
- ~50k tracks used for each trial.

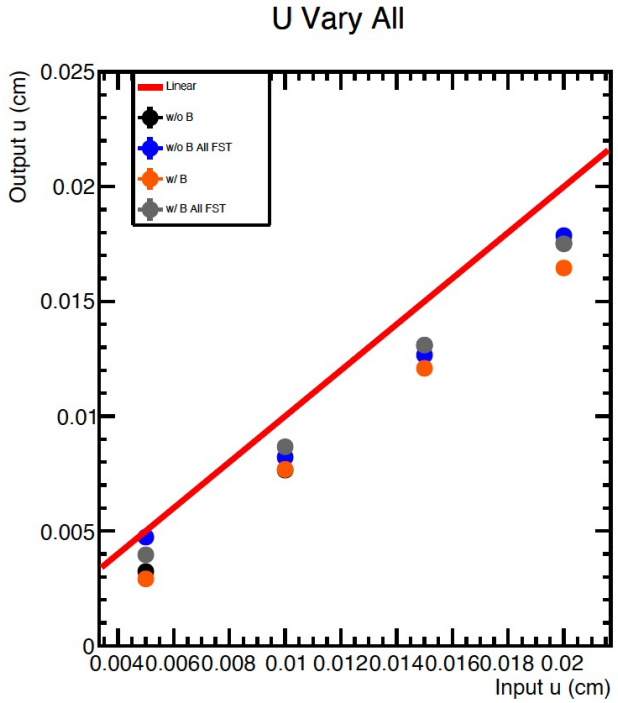
MC pT Study

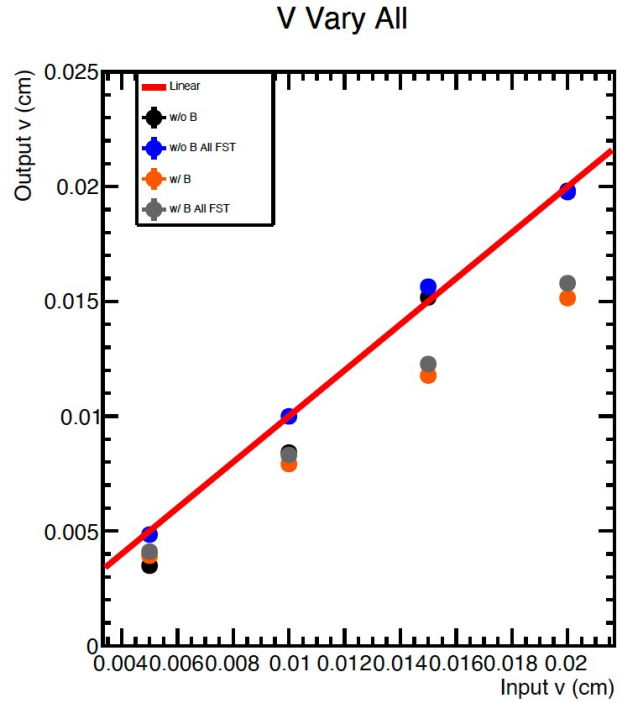
- Inner sensor 36 (middle FST plane) is misaligned.
- Alignment input
  - Δγ = 2mad, Δu = Δv = 50 μm

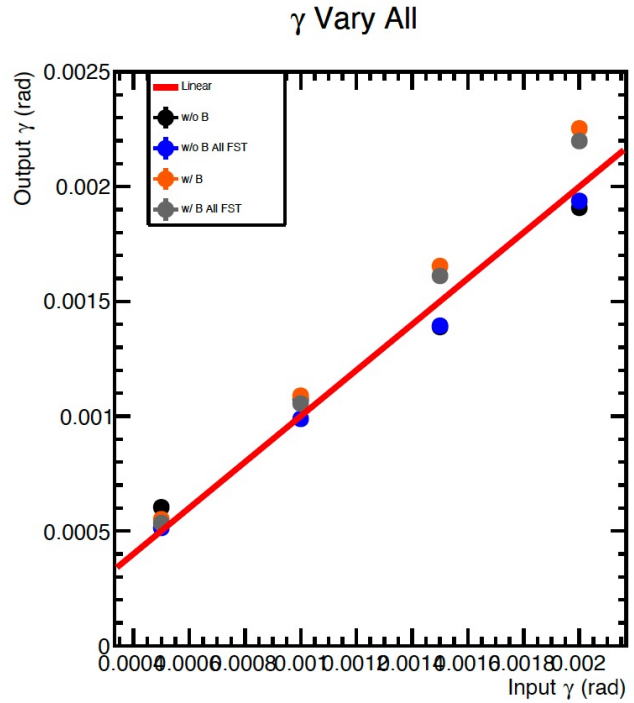


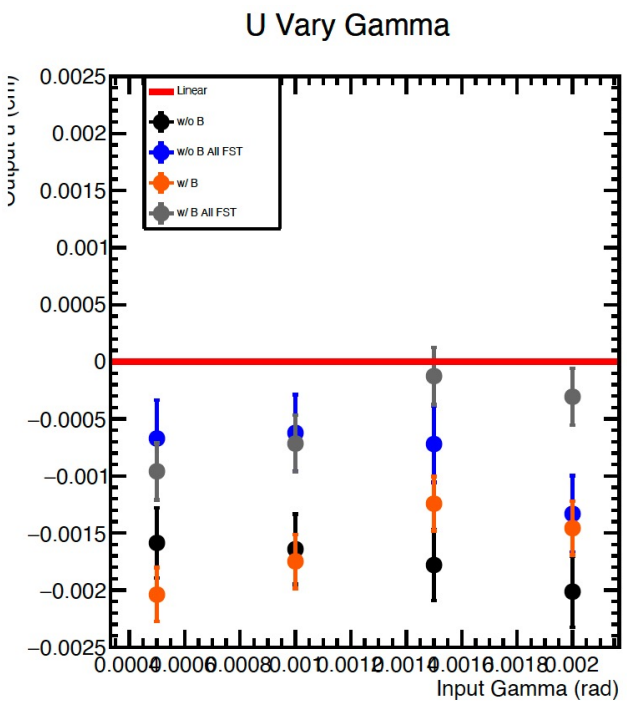


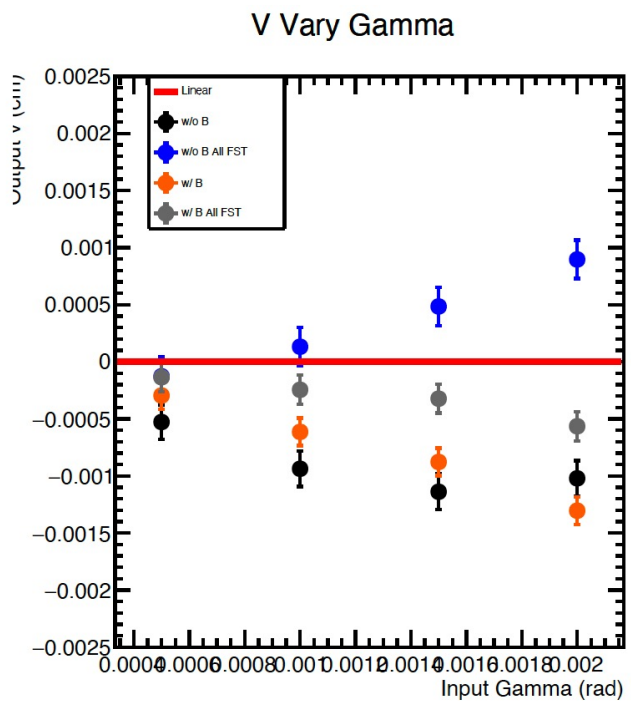


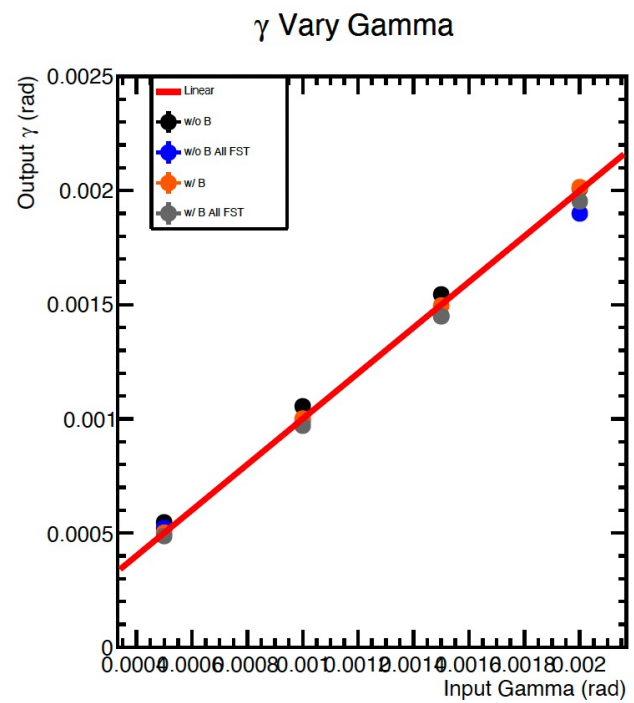

U Vary All
Linear
w/o B
w/o B All FST
w/ B
w/ B All FST
Output u (cm)
Input u (cm)

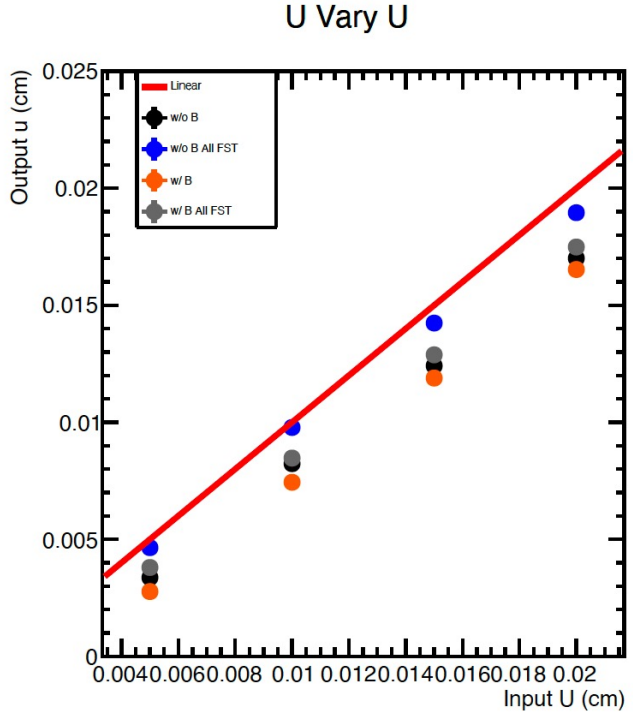

V Vary All
Linear
w/o B
w/o B All FST
w/ B
w/ B All FST
Output v (cm)
Input v (cm)

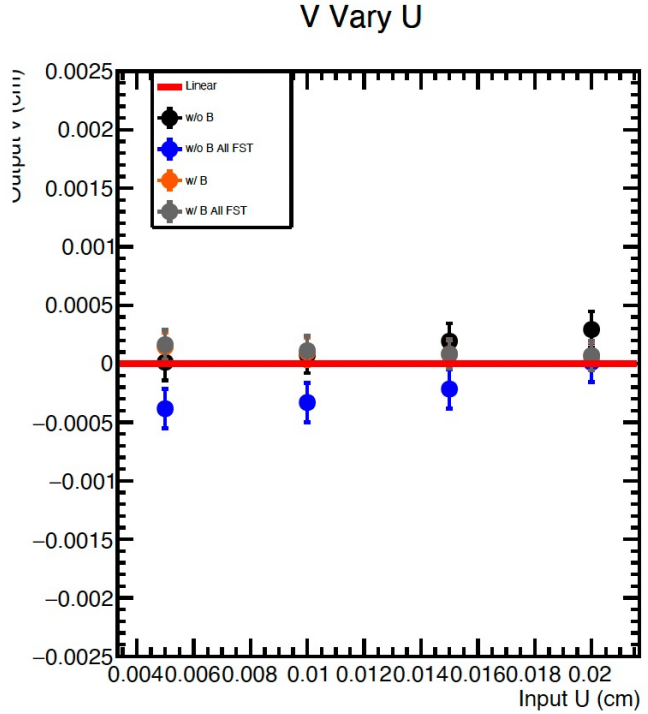

γ Vary All
Linear
w/o B
w/o B All FST
w/ B
w/ B All FST
Output γ (rad)
Input γ (rad)

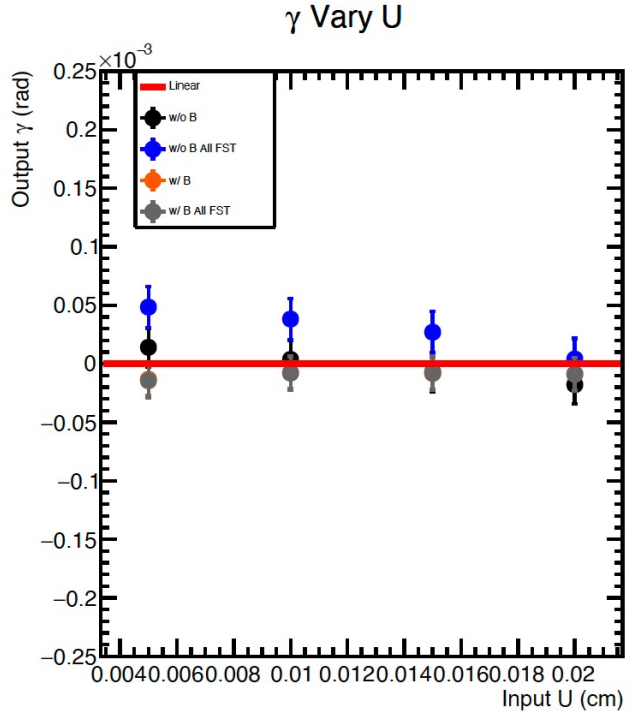

U Vary Gamma
Linear
w/o B
w/o B All FST
w/ B
w/ B All FST
Input Gamma (rad)

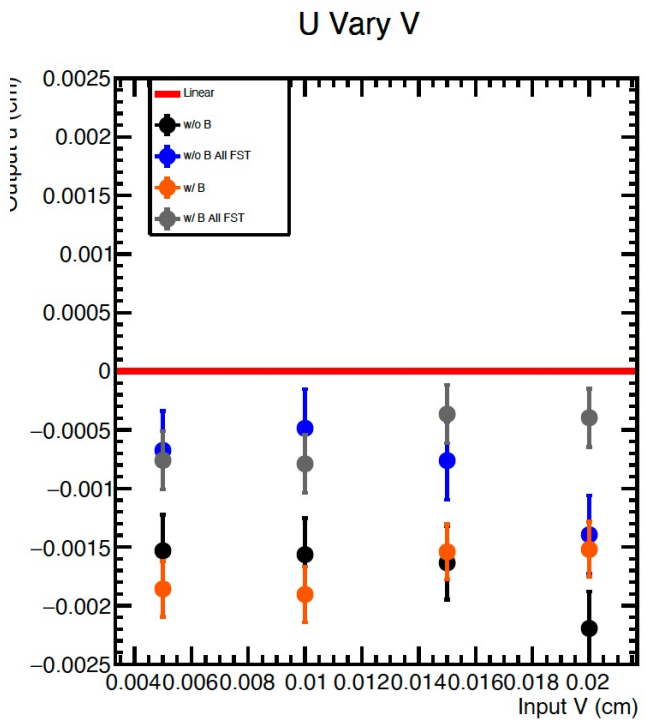

V Vary Gamma
Linear
w/o B
w/o B All FST
w/ B
w/ B All FST
Input Gamma (rad)

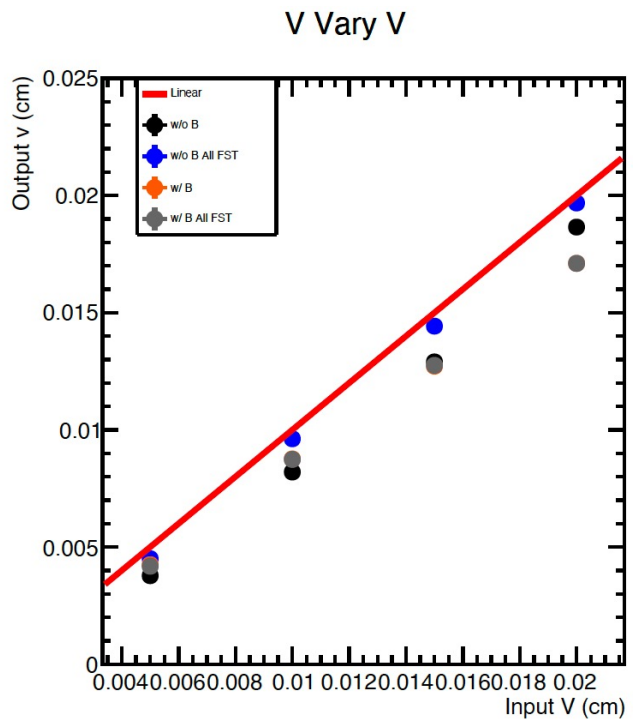

γ Vary Gamma
Linear
w/o B
w/o B All FST
w/ B
w/ B All FST
Output γ (rad)
Input Gamma (rad)

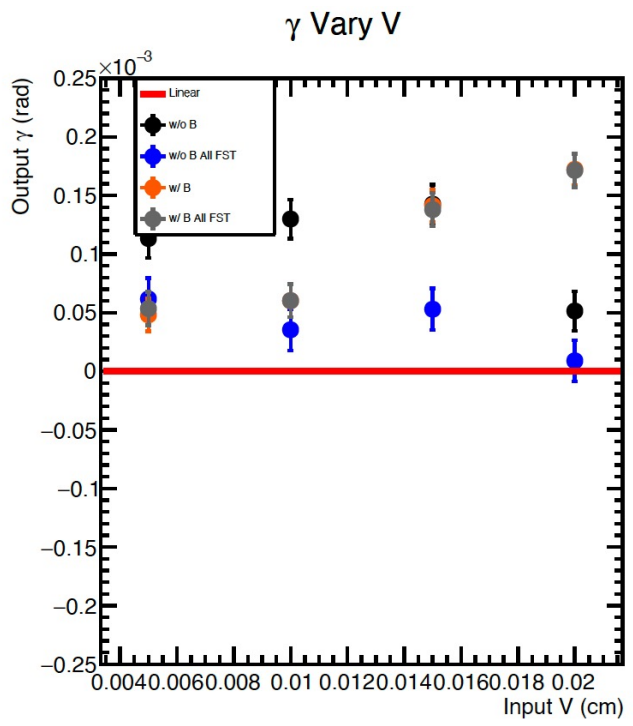

U Vary U
Linear
w/o B
w/o B All FST
w/ B
w/ B All FST
Output u (cm)
Input U (cm)


V Vary U
Linear
w/o B
w/o B All FST
w/ B
w/ B All FST
Input U (cm)


γ Vary U
Linear
w/o B
w/o B All FST
w/ B
w/ B All FST
Output γ (rad)
Input U (cm)


U Vary V
Linear
w/o B
w/o B All FST
w/ B
w/ B All FST
Input V (cm)


V Vary V
Linear
w/o B
w/o B All FST
w/ B
w/ B All FST
Output v (cm)
Input V (cm)


γ Vary V
Linear
w/o B
w/o B All FST
w/ B
w/ B All FST
Output γ (rad)
Input V (cm)