sTGC Alignment

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Δv = 200μm ~0.5M tracks

Parameter	Input	Output	Error	Global Corr.
Δu (μm)	0.0	-11.5	21.3	0.672
Δv (μm)	200	160.5	23.1	0.715
Δγ (mrad)	0.0	-0.072	0.110	0.816

Δv = 200μm ~5M tracks

Parameter	Input	Output	Error	Global Corr.
Δu (μm)	0.0	-11.4	6.49	0.672
Δv (μm)	200	163.8	7.03	0.714
Δγ (mrad)	0.0	-0.054	0.034	0.816

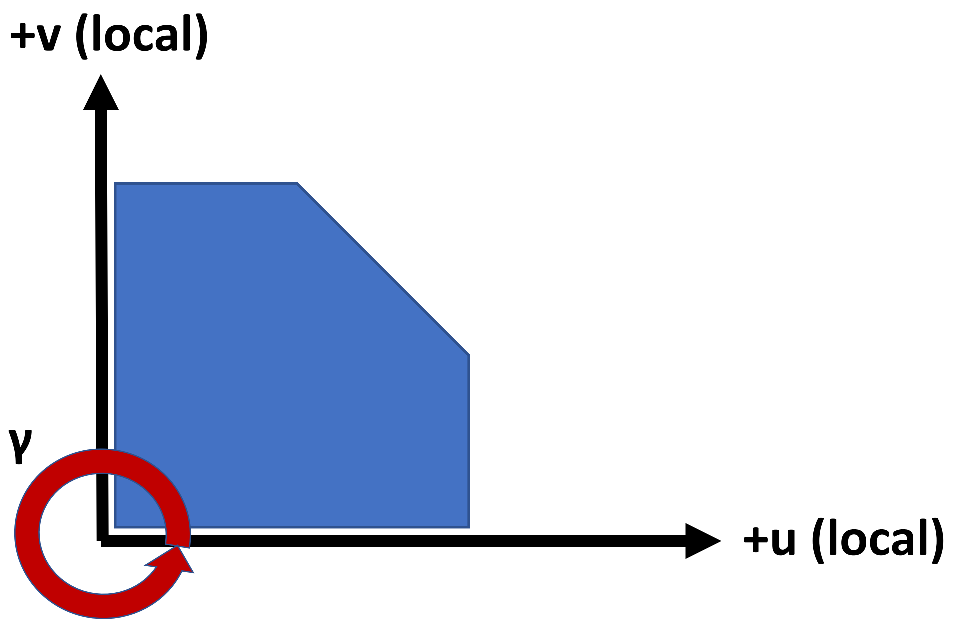
Δv has a significant negative shift after increasing statistics.

BACKUP

Alignment (global) Parameters

FTT (sTGC)

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



Single Pentagon Alignment

- Misalign 1 Pentagon (4) in sTGC simulated geometry. Located in +x,+y quadrant on plane second closest to IP.
- Throw mu+ with particle gun with following settings*:*
  - $0.2 < p_T < 2.0$ GeV/c
  - $2.3 < \eta < 4.4$
  - $0.0 < \phi < 1.83$ rad
  - B = 0 T
- Require hits on all sTGC and FST planes and pentagon module 4 (~450k tracks in our sample).
- Fit with GenFit Kalman filter and then refit with GenFit GBL.
- Output data to Mille.dat files. Mille.dat files are then fed to pede.
- Fix rotations about u-axis and v-axis, in addition to w translation all to 0.
- Matrix inversion used to solve for alignment parameters.

Testing Alignment

$\Delta\gamma$ = 2 mrad

Parameter	Input	Output	Error	Global Corr.
Δu (μm)	0.0	-21.4	21.2	0.671
Δv (μm)	0.0	-22.9	23.0	0.714
Δγ (mrad)	2.0	1.941	0.110	0.815

- Consistent within 2σ.
  - I would like to increase the statistics again to see if this holds.
- For the rotation of Δγ we rotate entire 2nd sTGC plane to prevent geometry overlaps for the time being.

Δu = 200μm

Parameter	Input	Output	Error	Global Corr.
Δu (μm)	200	185.1	21.3	0.673
Δv (μm)	0.0	-31.9	23.0	0.714
Δγ (mrad)	0.0	-0.042	0.110	0.817

Δv = 200μm

Parameter	Input	Output	Error	Global Corr.
Δu (μm)	0.0	-11.5	21.3	0.672
Δv (μm)	200	160.5	23.1	0.715
Δγ (mrad)	0.0	-0.072	0.110	0.816

Testing Alignment Software

No Misalignment

Parameter	Input	Output	Error	Global Corr.
Δu (μm)	0.0	-22.0	36.8	0.672
Δv (μm)	0.0	-37.2	39.8	0.714
Δγ (mrad)	0.0	0.0075	0.1899	0.816

Δu = 50μm

Parameter	Input	Output	Error	Global Corr.
Δu (μm)	50	34.6	37.0	0.671
Δv (μm)	0.0	-28.2	40.1	0.713
Δγ (mrad)	0.0	-0.0161	0.192	0.816

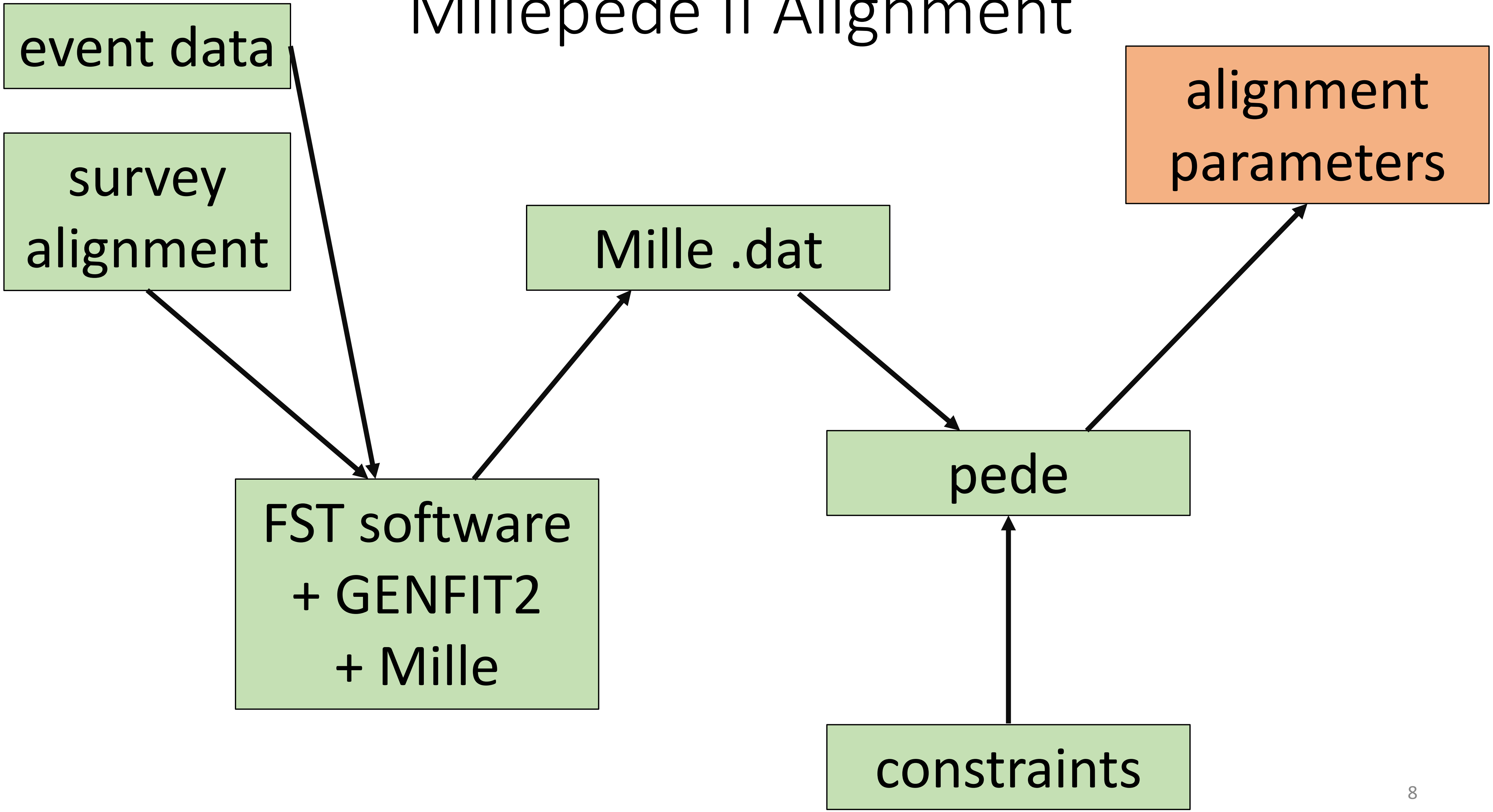
Δv = 50μm

Parameter	Input	Output	Error	Global Corr.
Δu (μm)	0.0	-13.6	36.7	0.672
Δv (μm)	50μm	37.2	39.8	0.714
Δγ (mrad)	0.0	-0.0353	0.191	0.816

Differences from FST

- We are testing a whole pentagon not just one inner or outer sensor with a similar number of tracks.
- Error is an order of magnitude higher for each parameter.
- Global correlation for Δu is larger.
- Global correlations for Δv and Δγ are smaller, which we would expect.

Millepede II Alignment



Millepede-II with GBL

- Track parameterized by $\boldsymbol{q} = (\boldsymbol{u_i}, \dots, \boldsymbol{u_{\#planes}})$, 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

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

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

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

- 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.