Tracker Alignment Emulsion-IFT matching

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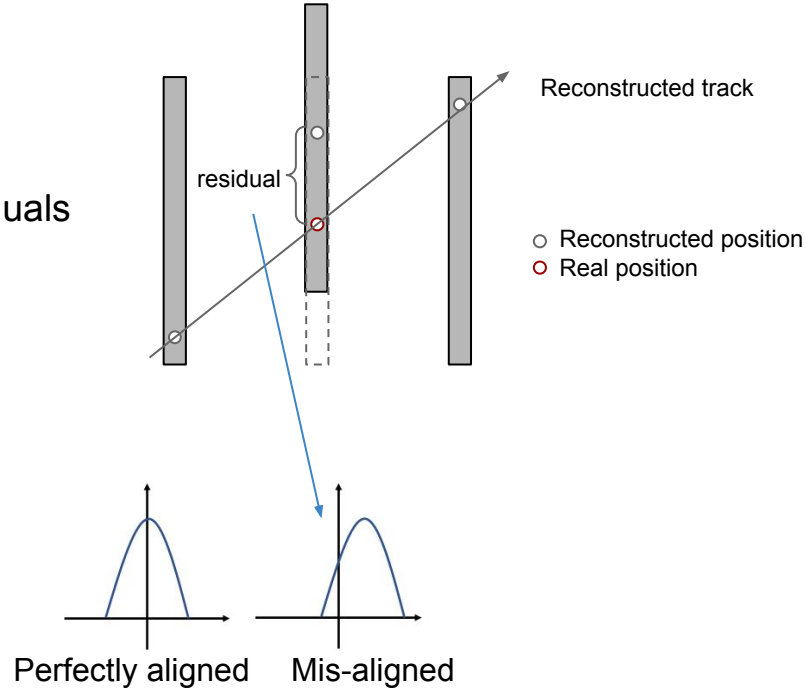
Alignment

Purpose:
Calibrate the geometry

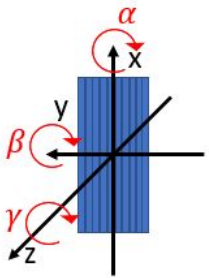
Method:
Minimize the chi2 defined with residuals

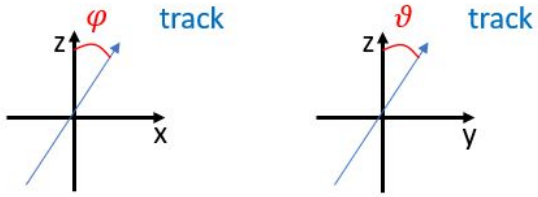
Two approaches in FASER
- Global chi2
- Iterative local chi2



Coordinate systems

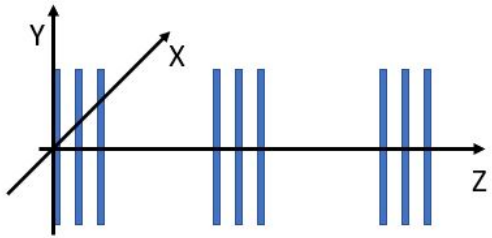
- Local (module)





Same with ATLAS

- Global



Origin point is defined by the center of magnets

- Local frame is used for module level alignment
- Global frame is used for layer/station level alignment
- Please be noted the local/global is different to that in millepede-II

Alignment

- 6 alignment parameters per module (X/Y/Z shift and rotations)
- Residual is defined as: $\vec{r} = \vec{f}(\vec{a}, \vec{\pi}) - \vec{m}$
- Define the total chi2 from all the tracks as:

$$\chi^2 = \sum_{tracks} \vec{r}_i{}^T \cdot V_i^{-1} \cdot \vec{r}_i$$

- Minimize the chi2

$$\frac{d\chi^2(\vec{a})}{d\vec{a}} = \vec{0}$$

$\vec{f}(\vec{a}, \vec{\pi})$: Prediction from track fitting

$\vec{m}$: Measurements

V_i^{-1} : Covariance matrix of residuals measurements

$$\Delta\vec{a} = -\left(\sum_{tracks}\left(\frac{d\vec{r}_i(\vec{a})}{d\vec{a}_0}\right) \cdot V_i^{-1} \cdot \left(\frac{d\vec{r}_i(\vec{a})}{d\vec{a}_0}\right)^T\right)^{-1} \cdot \left(\sum_{tracks}\left(\frac{d\vec{r}_i(\vec{a})}{d\vec{a}_0}\right) \cdot V_i^{-1} \cdot \vec{r}_i(\vec{a}_0)\right)$$

Alignment parameters

Global chi2 alignment

- Global chi2 alignment, solve the equation directly without any assumption

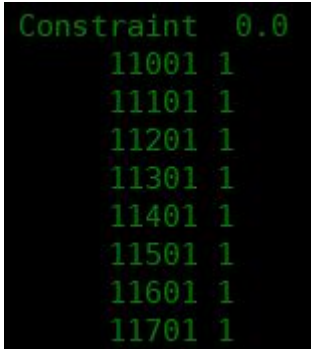
$$\delta a = \left(\sum_{tracks} \frac{\partial r^T}{\partial a_0} W \frac{\partial r}{\partial a_0}\right)^{-1} \cdot \left(\sum_{tracks} \frac{\partial r^T}{\partial a_0} W r(a_0, \pi_0)\right)$$

$$W = V^{-1} - V^{-1} \frac{\partial r}{\partial \pi_0} \left(\frac{\partial r^T}{\partial \pi_0} V^{-1} \frac{\partial r}{\partial \pi_0}\right) \frac{\partial r^T}{\partial \pi_0} V^{-1}$$

- In Faser, 6 freedom per module -> 576 freedoms, not too big
- Main problem is how to get the derivations $\frac{\partial r}{\partial a_0}$, $\frac{\partial r}{\partial \pi_0}$
  - Not easy to get them analytically
  - Calculate them numerically, i.e. change a and π by a small value, then calculate $\frac{\Delta r}{\Delta \pi / a}$
    - For each measurement and each alignment parameter
    - Change the module position by Δa, then recalculate the residual r
    - The module position is always defined by module side 0
      - For side 1, we will change the side 0 position

Millepede-II

- A library to perform the global chi2 alignment
  - Inputs are $\frac{\partial r}{\partial a_0}$, $\frac{\partial r}{\partial \pi_0}$ for each measurement (mille format)
  - Easy to add constraints
    - Fixed the average of the modules to be the layer center
    - 11001*1+11101*1+11201*1 …. =0
    - Label naming scheme:
      - Module: <stationID+1><layerID><moduleID><sideID><DoF id+1>
      - Layer: <stationID+1><layerID><DoF id+1>
  - Very fast, but not integrated into calypso yet
    - Need to do alignment manually
      - CKF output -> convert to mille format -> extract alignment corrections -> prepare new geometry -> CKF
      - Next todo: integrate the whole alignment into calypso



Task list (tracker alignment + Emulsion-IFT matching)

Task	Description	Priority	Responsible person	Status
1	Add more DoFs for layers/stations/modules	1	Ke, ?	Finalizing
2	Integrate millepede and alignment to calypso	2	Ke, ?	
3	New strategy of fixing layers as the reference for coordinate system	2	?	
4	Estimate the systematic uncertainty on track parameters	2	?	
5	Estimate the alignment corrections for all the datasets	3	?	
6	Align IFT w.r.t other tracker stations, need to validate the IFT geometry first	1	?	
7	Testbeam alignment, application to IFT alignment	2	?	
8	Test the survey/metrology data	2	?	
9	Matching strategy, definition of residuals and extraction of alignment corrections	1	Ali, Yuxiao, ?	
10	(optional) Reconstruct the emulsion track		?	
11	Extend the emulsion track to tracker and estimate the track charge	3	?	

Sundry items

- Weekly meeting for discussion
  - Tomohiro and I will coordinate the efforts
  - Everyone need to report the status and progress
- Mattermost or skype group channel ?
- For tracker alignment, additional experts, Pavel and Claus, are happy to help and discuss
- For emulsion-IFT matching, we need to keep closely discussion with FASERnv experts

All the tasks are super important for physics analysis !