Report on Track Based Alignment Procedure for CBM Silicon Tracking Detector

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Overview

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- Strategies on Alignment
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    - Introduction of GBL & its advantages
    - Test Setup for result extraction
    - GBL refit results
    - Toy misalignment scenario
- Realignment results
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Motivation

The purpose of the Alignment of a detector is to determine the accurate space coordinates and orientations of all of its components.

Mechanical Engineer

Me

Preparation of Inputs for MillePede

For a Global Alignment procedure the following inputs are needed at each measurement,

n_{lc} = number of local parameters (q) array : $\frac{\partial h}{\partial q_j}$

n_{gl} = number of global parameters (p) array : $\frac{\partial h}{\partial p}$; array level 1

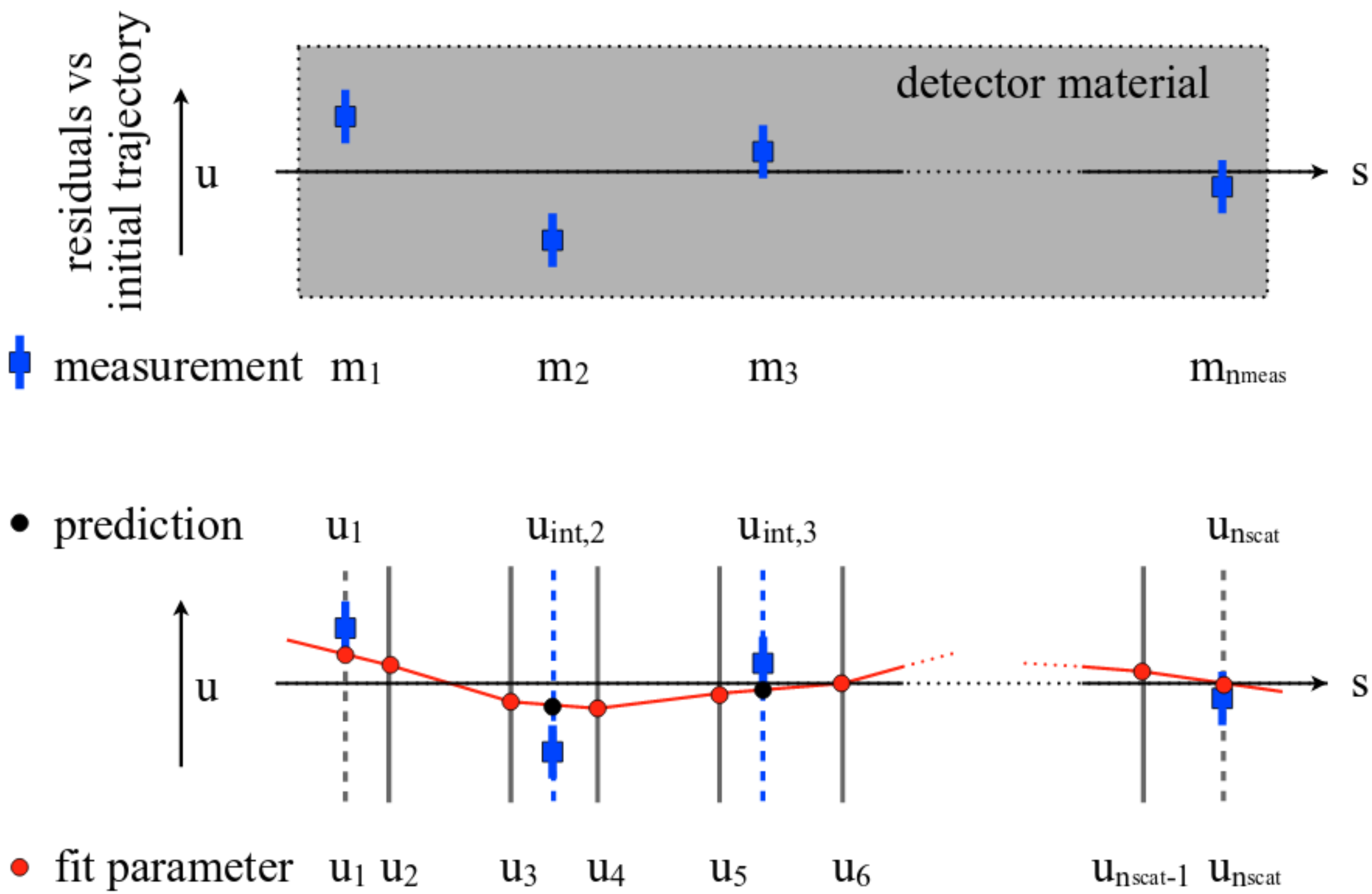
Z = residual = $m_i - h(q,p)$

σ = standard deviation of the measurement

Goal is to minimise the χ^2 ensemble of all the track χ_t^2 with respect to both the local and global parameters and to extract the alignment offsets.

Where, $\chi^2 = \sum_t \chi_t^2$ and $\chi_t^2 = z_t^T V_t^{-1} z_t$

General Broken Line Track Fit



Advantages of Using GBL

The fit parameters $\mathbf{q} = (\Delta\kappa, u_1, \ldots, u_{nscat})$ are determined by minimising,

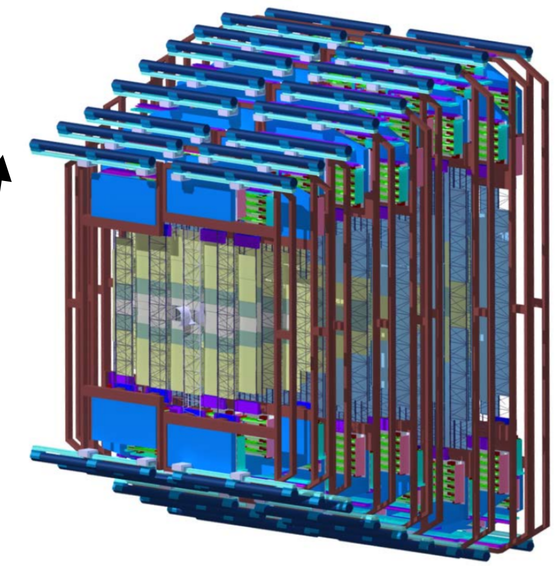
$$\chi^2(\mathbf{q}) = \sum_{i=2}^{n_{\text{scat}}-1} \boldsymbol{\beta}_i(\mathbf{q})^T \mathbf{V}_{\beta,i}^{-1} \boldsymbol{\beta}_i(\mathbf{q}) + \sum_{i=1}^{n_{\text{meas}}} (\mathbf{m}_i - \mathbf{P}_i \mathbf{u}_{\text{int},i}(\mathbf{q}))^T \mathbf{V}_{\text{meas},i}^{-1} (\mathbf{m}_i - \mathbf{P}_i \mathbf{u}_{\text{int},i}(\mathbf{q}))$$

- ☑ KF already provides the necessary input for GBL.
- ☑ Uses linear least square method for track fitting, writes binary input for Millepede.

Test Setup

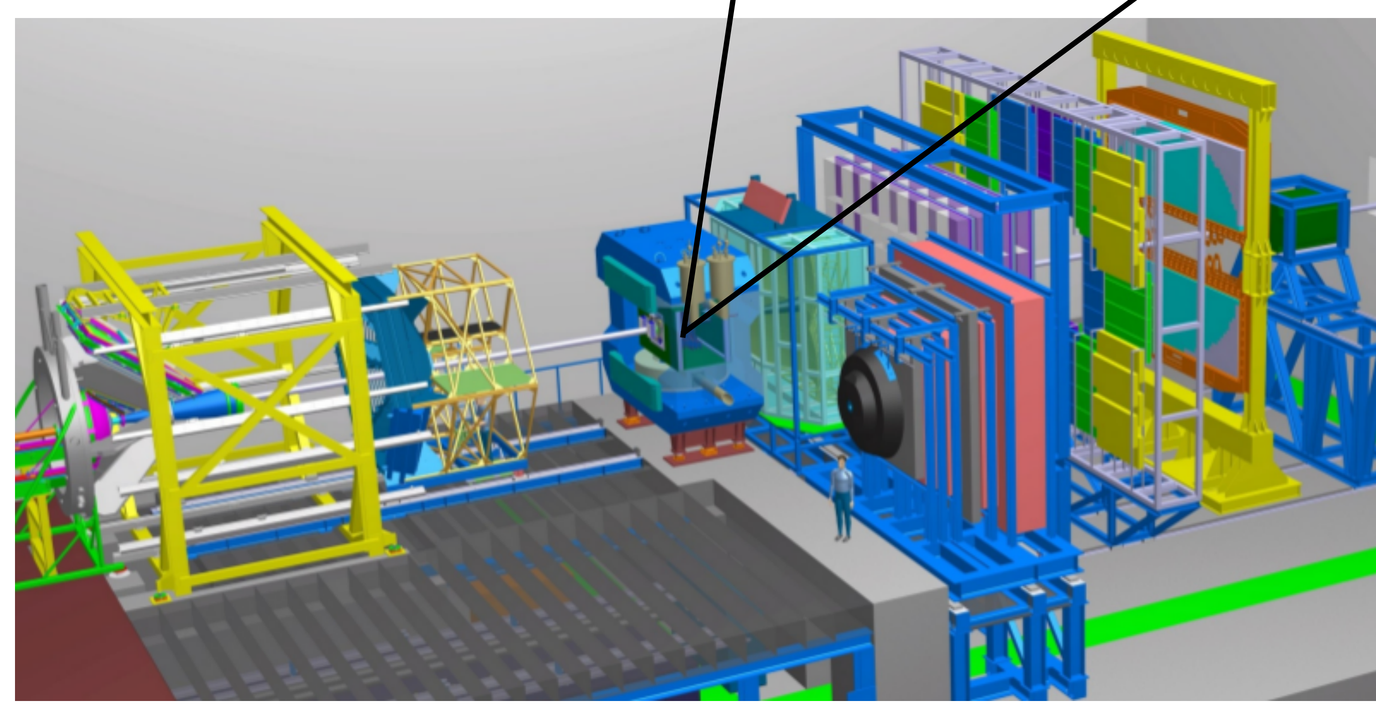
```
[INFO   ] STS: Elements in setup:
[INFO   ]      stations       8
[INFO   ]      ladders      106
[INFO   ]      halfladders  212
[INFO   ]      modules      900
[INFO   ]      sensors     1220
[INFO   ] STS: 9 sensor types in database
[INFO   ] STS: Set types for 1220 sensors
[INFO   ] ==========================================

[INFO   ] STS: Address map initialised with 1220 sensors.
```

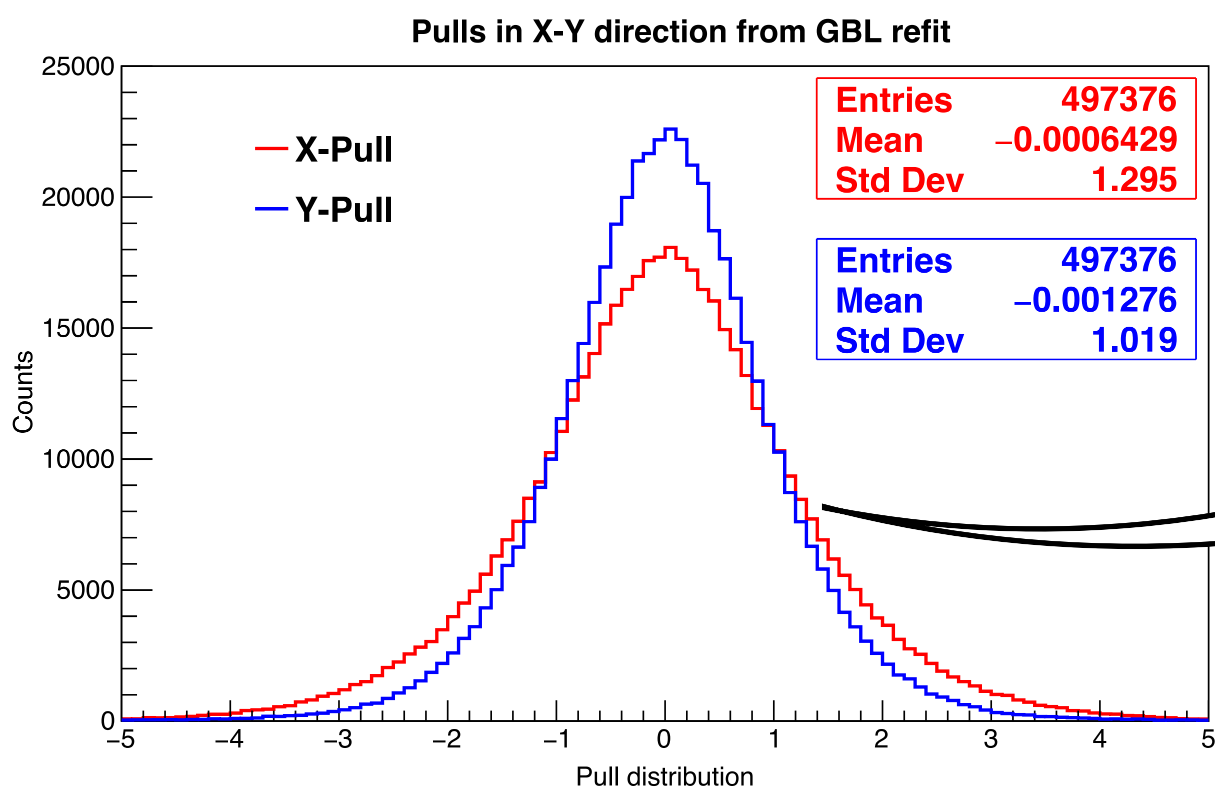


STS Geometry (V15b) with Stations

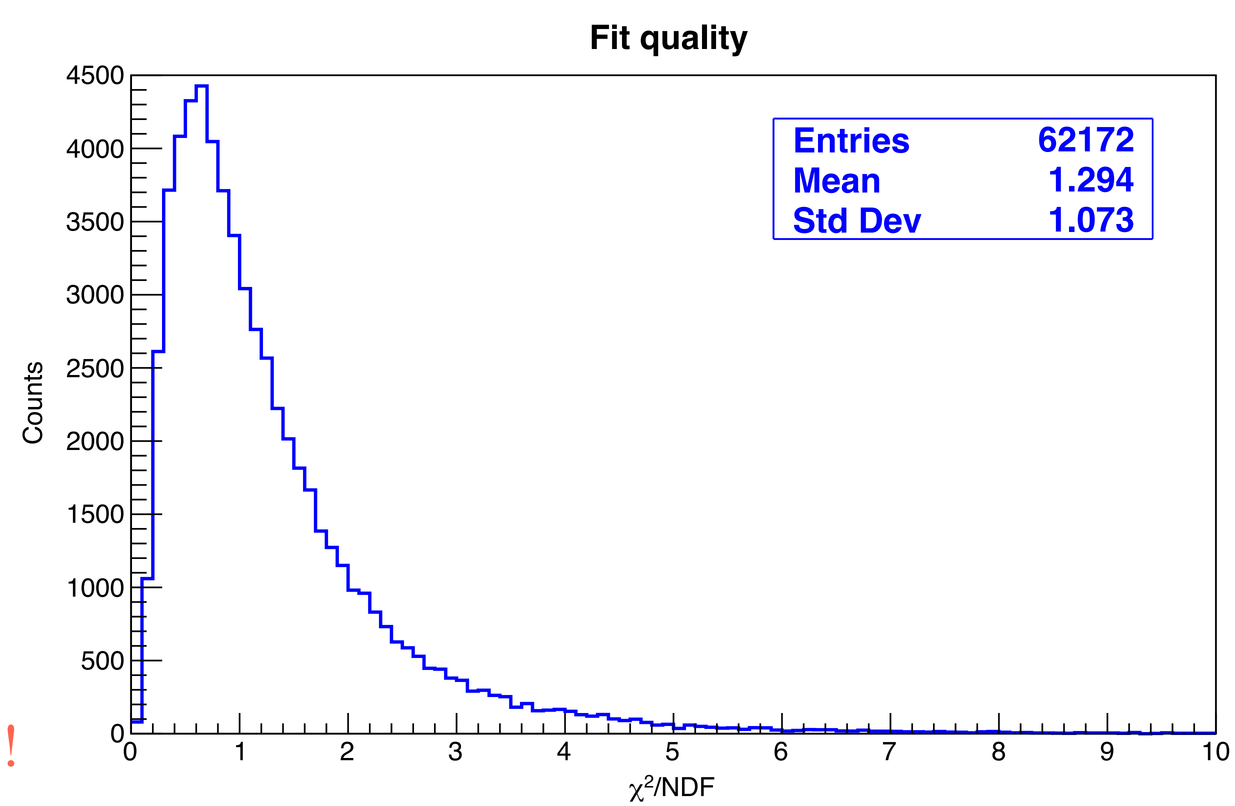
- 1000000 single Muon events in use
- No magnetic field
- 0-10 GeV/c momentum range
- Ideal track finder in use
- Only long tracks(8 hits) taken



Results from GBL Refit



X-Pull distribution is more wider than the Y-pull one

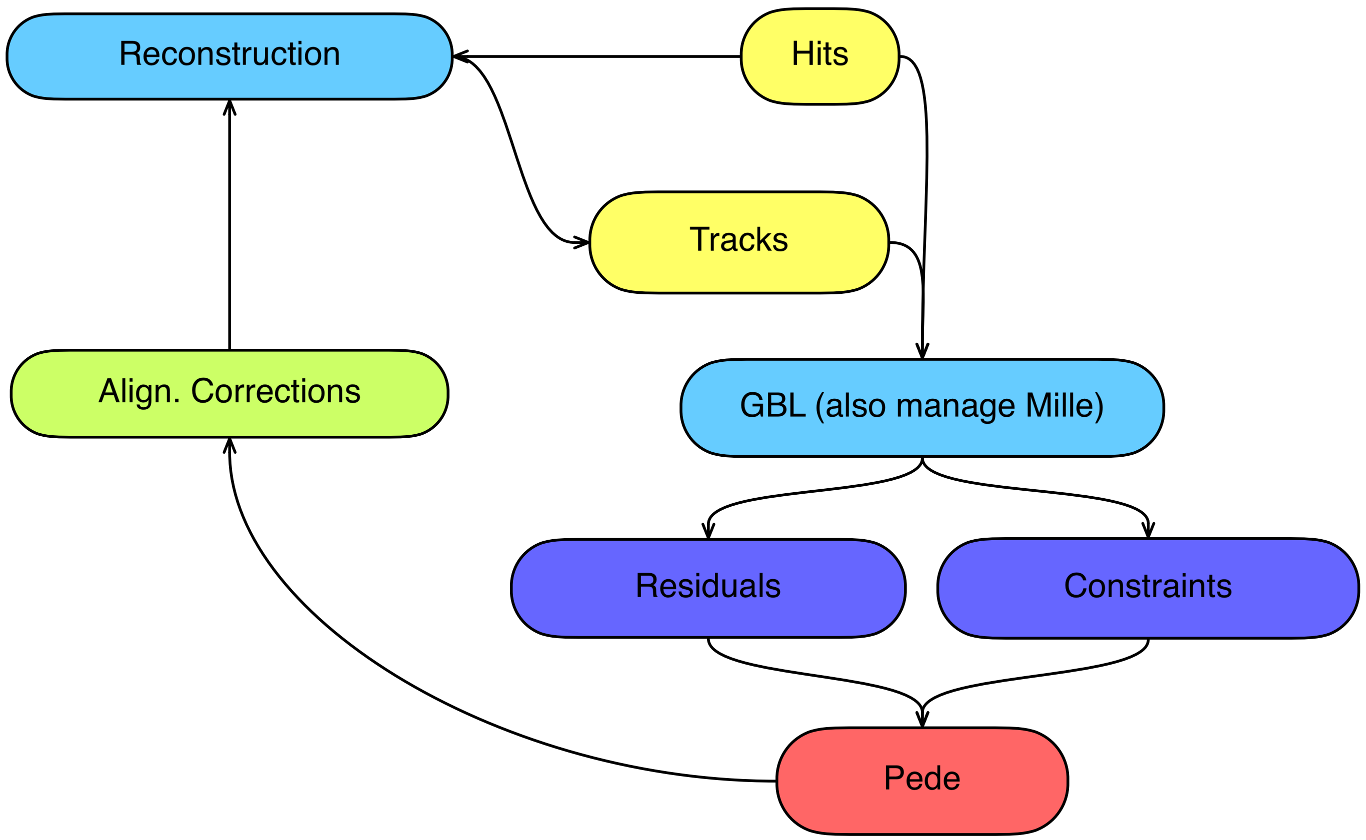


Possible Sources:

- Multiple scattering effect and its momentum dependency
- Better spatial resolution on X-direction compare to Y and its effect on measurements, measurement errors

Should be reviewed further!

Toy Misalignment Scenario and Realignment Results



Working Flowchart

Station	2	3	4	5	6	7
X-Shift	−50	50	−50	50	−50	50

Summary of applied misalignment* (in μm)

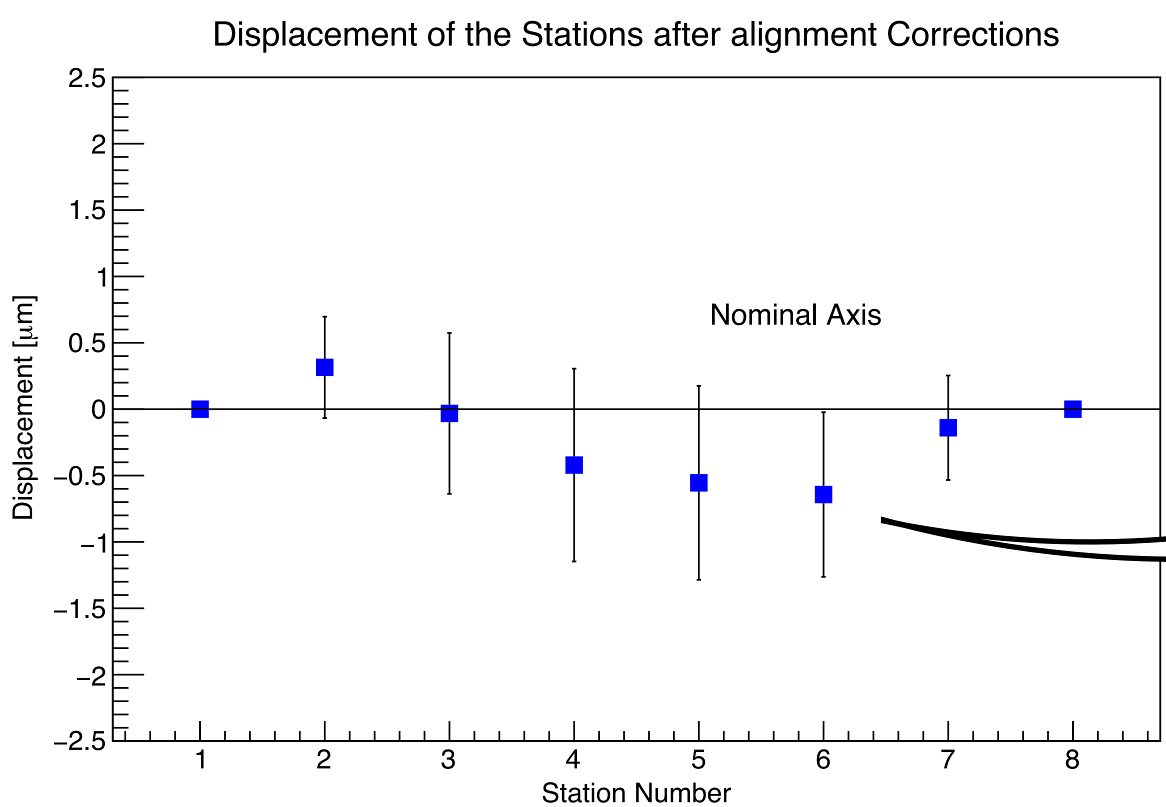
Station	X-Correction	Corr. Uncertainty
1	0	0
2	−50.315	±0.382
3	50.032	±0.606
4	−49.579	±0.726
5	50.555	±0.730
6	−49.357	±0.620
7	50.140	±0.394
8	0	0

Summary of alignment corrections* (in μm)

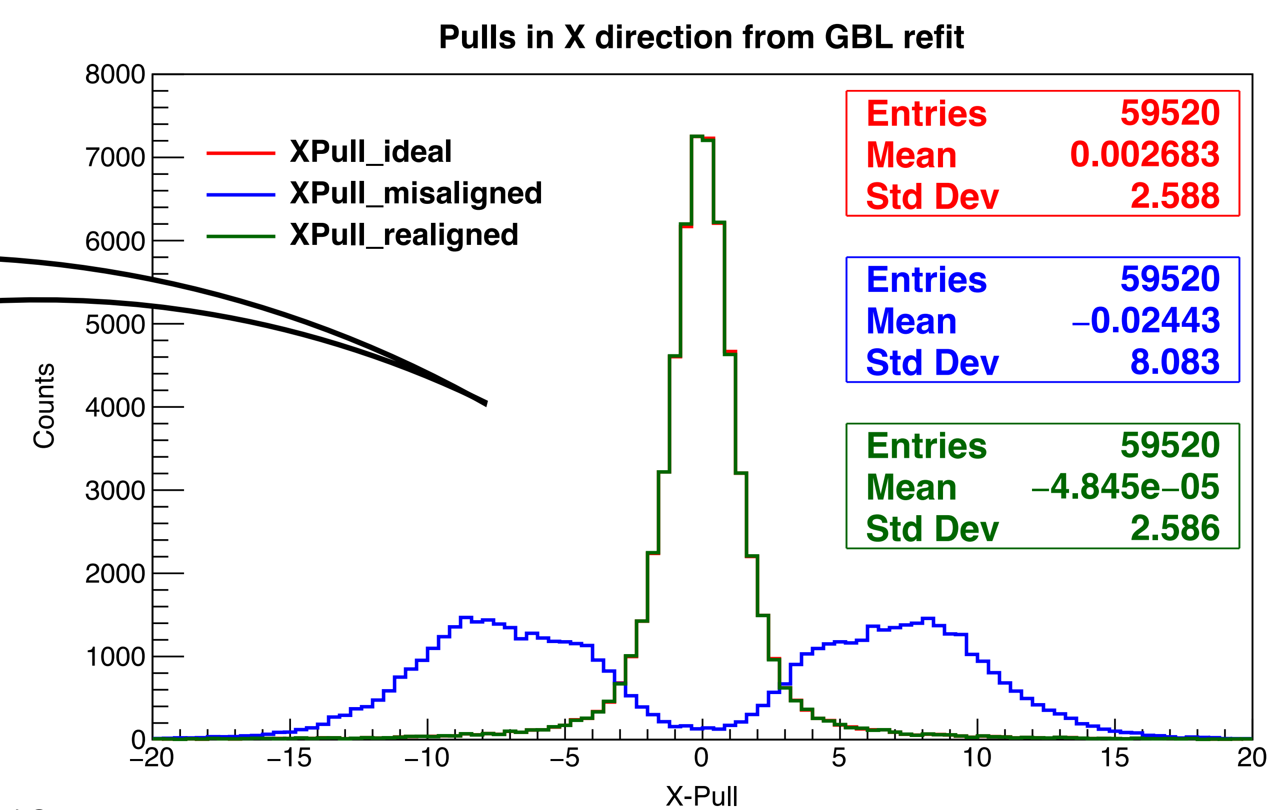
*10000 events been used

*Station 1 & 8 are fixed.

Realignment Quality



The maximum displacement uncertainty below 1 µm depicts pretty good performance of the alignment task.



This result is quiet expected as all the misaligned detector elements were brought back really close to the nominal axis with very small uncertainties again after the realignment.

Conclusion and Outlook

- GBL interface task is ready for performance check, with scatterers using proper material budget map.
- Still there are some issues with Pull distributions, mentioned before; soon to be reviewed.
- First toy misalignment scenario was tackled pretty well, with the track based alignment method.
- Soon, more realistic and adaptive misalignment scenarios will be introduced, and Millepede II will be used for alignment.
- For comparison and future stage, Kalman filter approach should be implemented in parallel.

References

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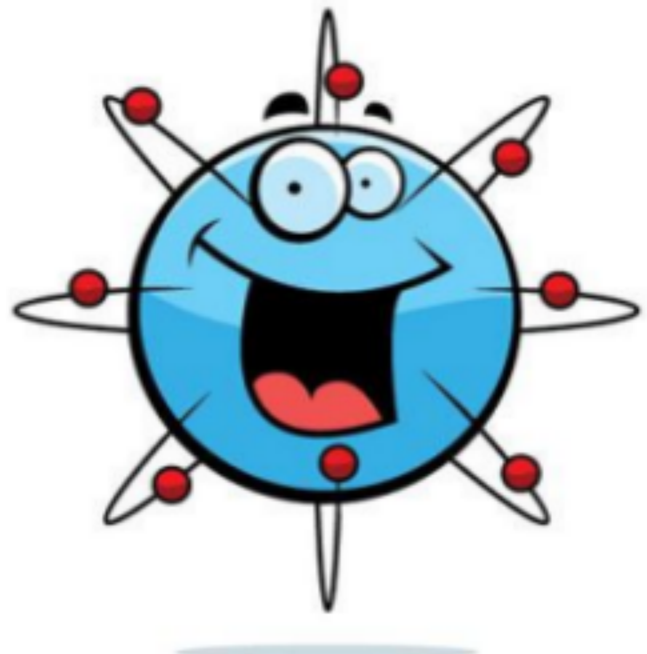

Thank You

Extra Slides

Limitation of Using KF for Global Alignment

In contrast to the global least square method, where $\vec{x}$ is a vector of, generally, 5 parameters and C is an 5×5 matrix, for KF $\vec{x}$ is now a vector of $5 \times N$ and C is an $N \times N$ matrix of 5×5 matrices, $i.e.$

$$\vec{x} = \begin{pmatrix} \vec{x}_1 & \vec{x}_2 & \vec{x}_3 & \dots & \vec{x}_N \end{pmatrix}$$

$$C = \begin{pmatrix} C_{11} & C_{12} & C_{13} & \cdots & C_{1N} \\ C_{21} & C_{22} & C_{23} & \cdots & C_{2N} \\ C_{31} & C_{32} & C_{33} & \cdots & C_{3N} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_{N1} & C_{N2} & C_{N3} & \cdots & C_{NN} \end{pmatrix}$$

- Off-diagonal elements (hold correlation in between residual) are not calculated during normal KF track fit.

Way Out from Limitation

The correlation between state x_i and the state x_j in the Kalman filter fit is given by,

$$C^n_{i-1,j} = A_{i-1} C^n_{i,j} \quad \text{For} \quad i \leq j$$

Where A is the smoother gain matrix.

The corrections to the alignment parameters, $\Delta\alpha = \alpha - \alpha_0$, that minimise the total χ^2 are calculated using the Newton-Raphson method. This leads to an expression of the final form,

$$\begin{aligned} \Delta\boldsymbol{\alpha} &= \left[\frac{d^2\chi^2}{d\boldsymbol{\alpha}^2}\right]^{-1} \left[\frac{d\chi^2}{d\boldsymbol{\alpha}}\right] \\ &= \left[\sum_t A^T V_t^{-1} \left(V_t - H_t C_t H_t^T\right) V_t^{-1} A\right]^{-1} \left[\sum_t \frac{\partial \boldsymbol{r}_t}{\partial \boldsymbol{\alpha}} V_t^{-1} \boldsymbol{r}_t\right], \end{aligned}$$