FASER Tracking & Emulsion Stations Alignment

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FASER Collaboration

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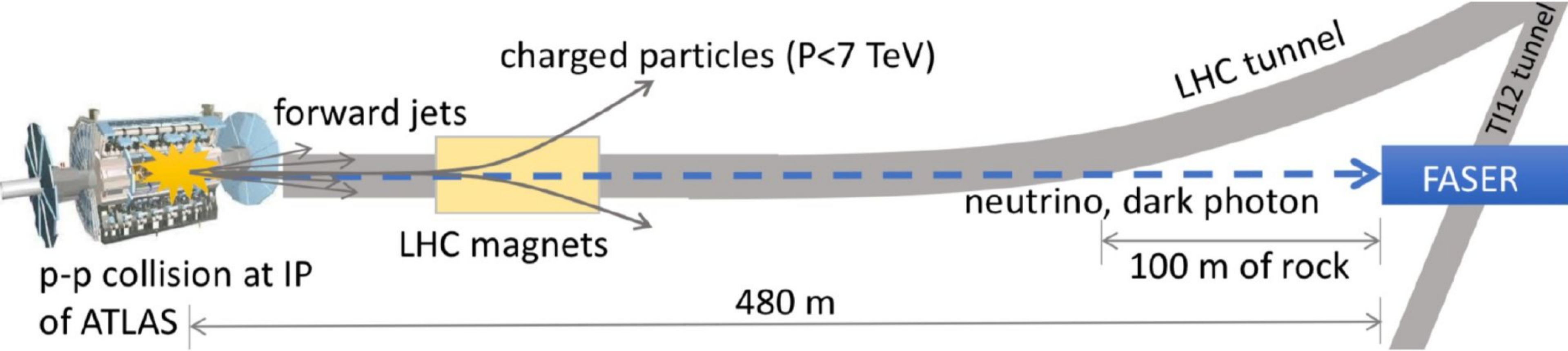
OUTLINE

- Introduction to FASER detector.
- Brief review of tracking
- Tracking station alignment
- Recent physics results
- Review to Emulsion-IFT matching

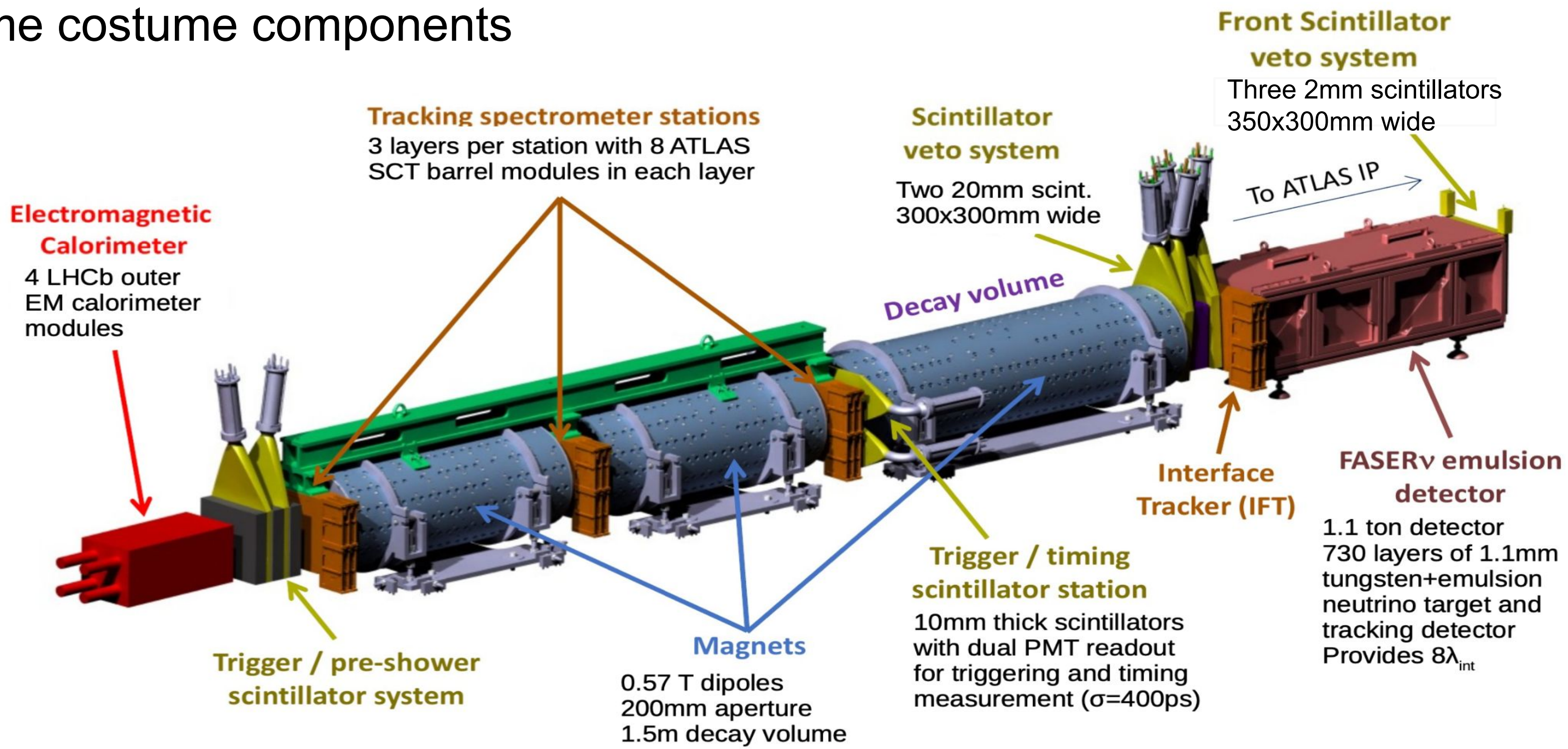
ForwArd Search ExpeRiment (FASER) At The LHC

- FASER is a relatively new detector designed to search for long lived BSM particles and neutrinos.
- Located 480m from ATLAS interaction point
  - including 100m of rock which shields most backgrounds



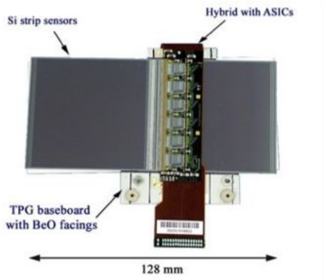
FASER Detector

- Low cost modular detectors built with both existing and some costume components

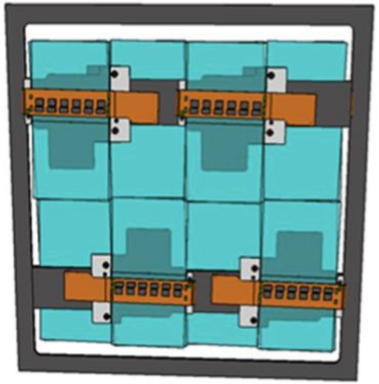


Silicon-Strip Tracker

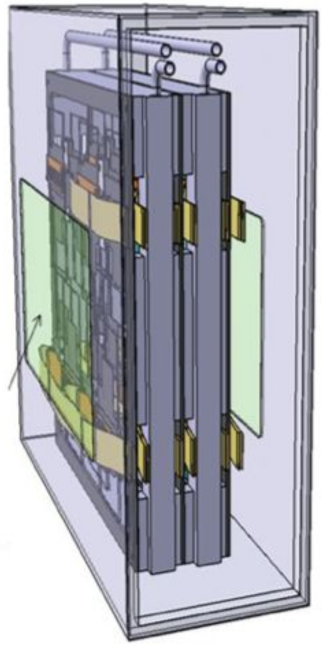
- There are four tracking stations
- Each made from 3 layers
- With each layer having 8 SCT modules
  - 80μm strip pitch, 40mrad stereo angle
- Same SCT modules as in ATLAS



SCT module



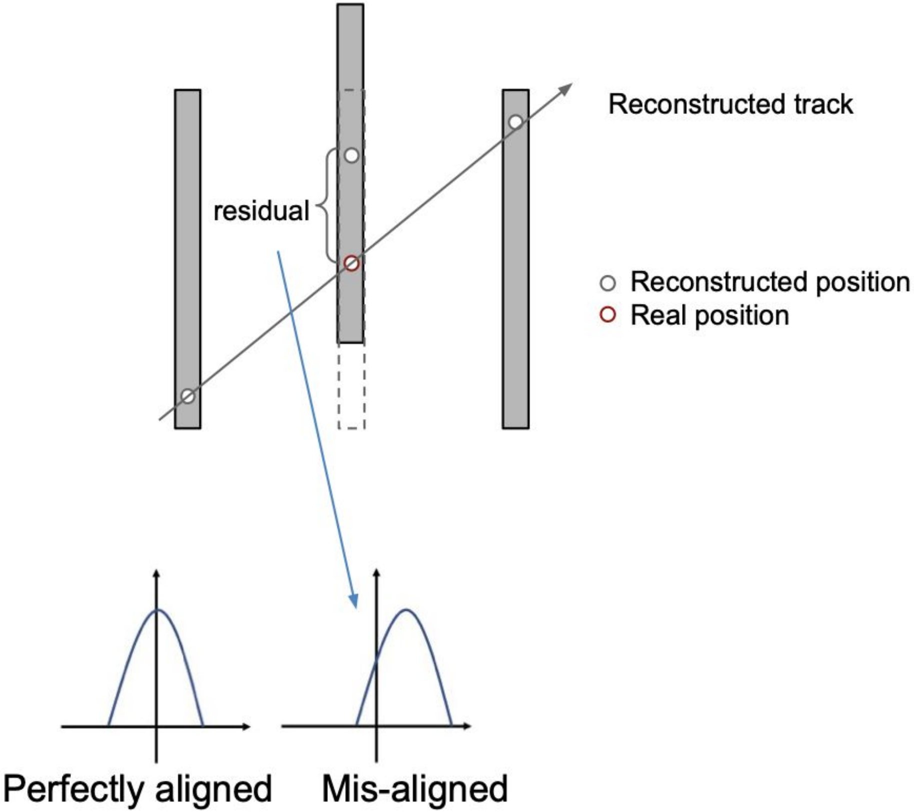
Tracking layer



Tracking station

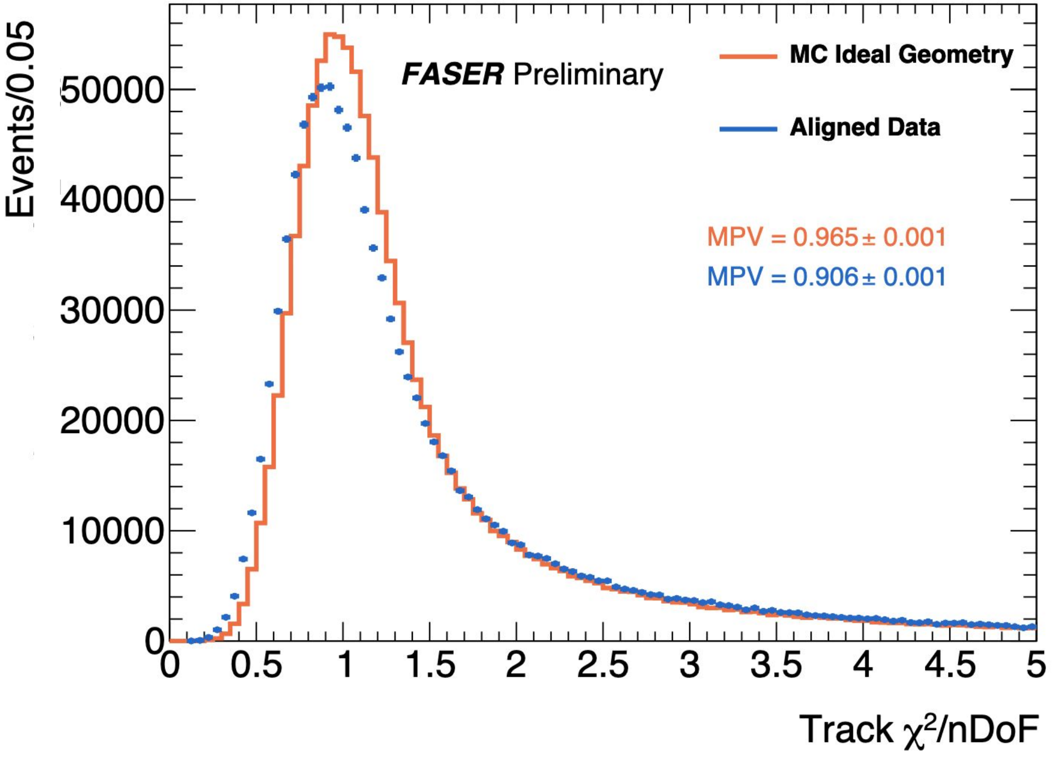
Tracking Stations Alignment

- Want to correct the tracking geometry
- Using global χ^2 method with Millepede II
- clusters of strips on 1 side of a module
  - to align the spectrometer (stations 1/2/3) at layer and module level.
- Construct space points which are 3D points formed from clusters of strips on both sides of a module, assuming that the track is perpendicular to the module.
  - IFT alignment at station and layer level. This is to align the large shift in the IFT.
- Use clusters to alignment all four station at layer and module level. This is for fine tuning the alignment.

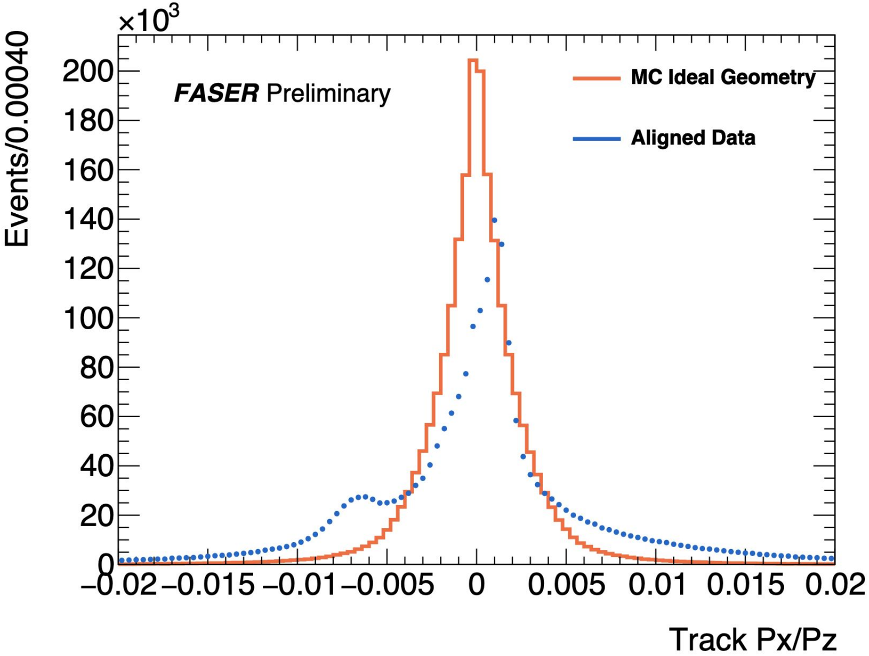


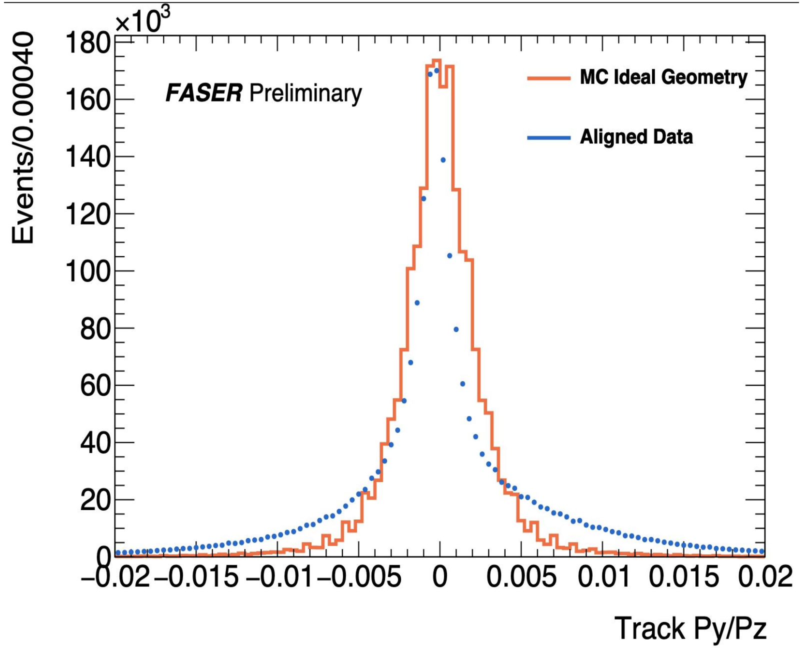
Four Station Alignment

- Alignment procedure was validated with MC
- Spectrometer alignment is performed in 20 iterations
- Then the space point and final cluster alignment are done in 6 iterations each.
- Track χ^2 shown. Shows good agreement with MC.



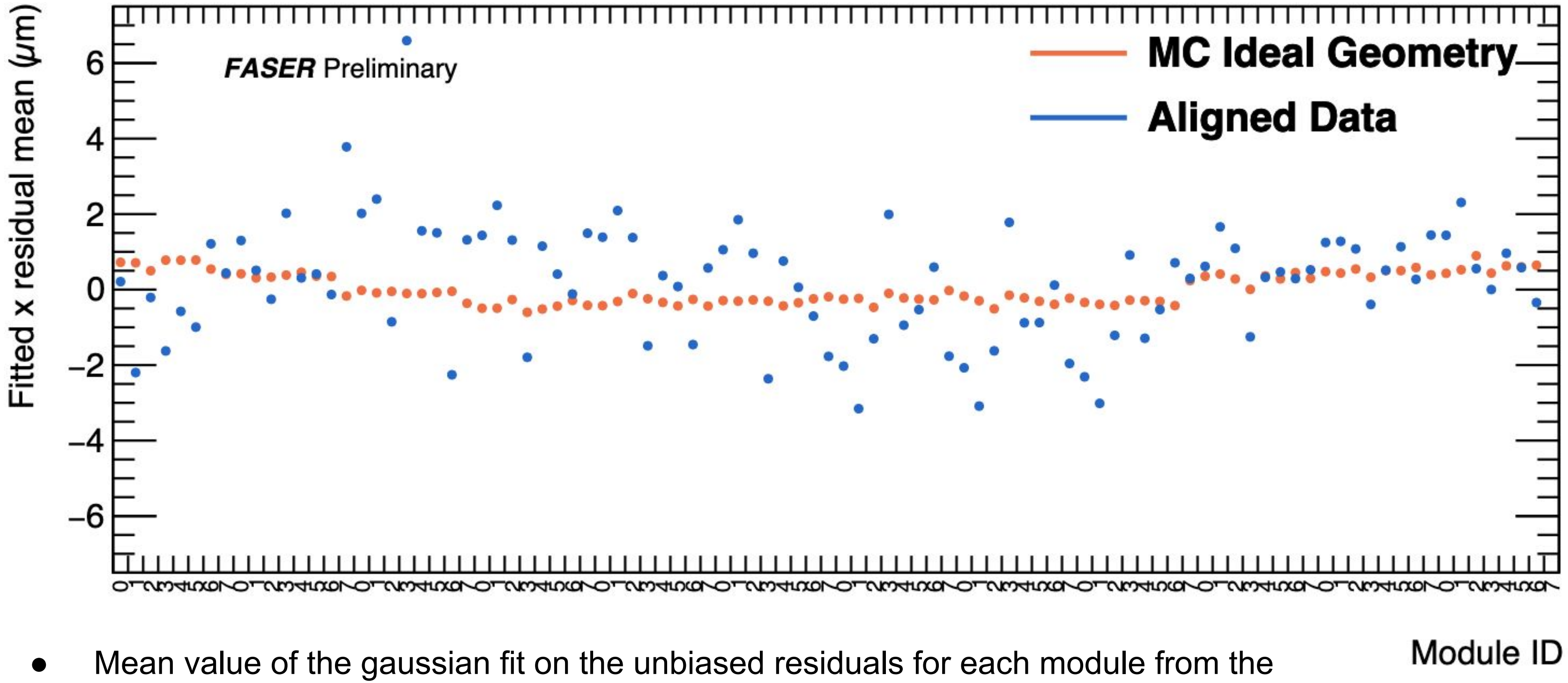
Track Parameters





- MC samples are muons produced upstream of FASERν with FLUKA energy spectrum. They do not simulate LHC conditions.
- In the px/pz distribution there is a smaller peak to the left of the main peak at zero in data which is due to background coming from the LHC arc.

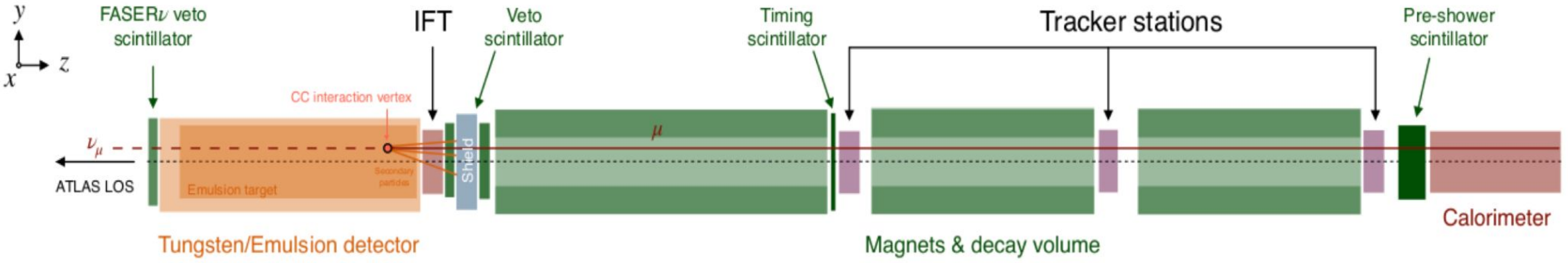
Residual vs Module ID



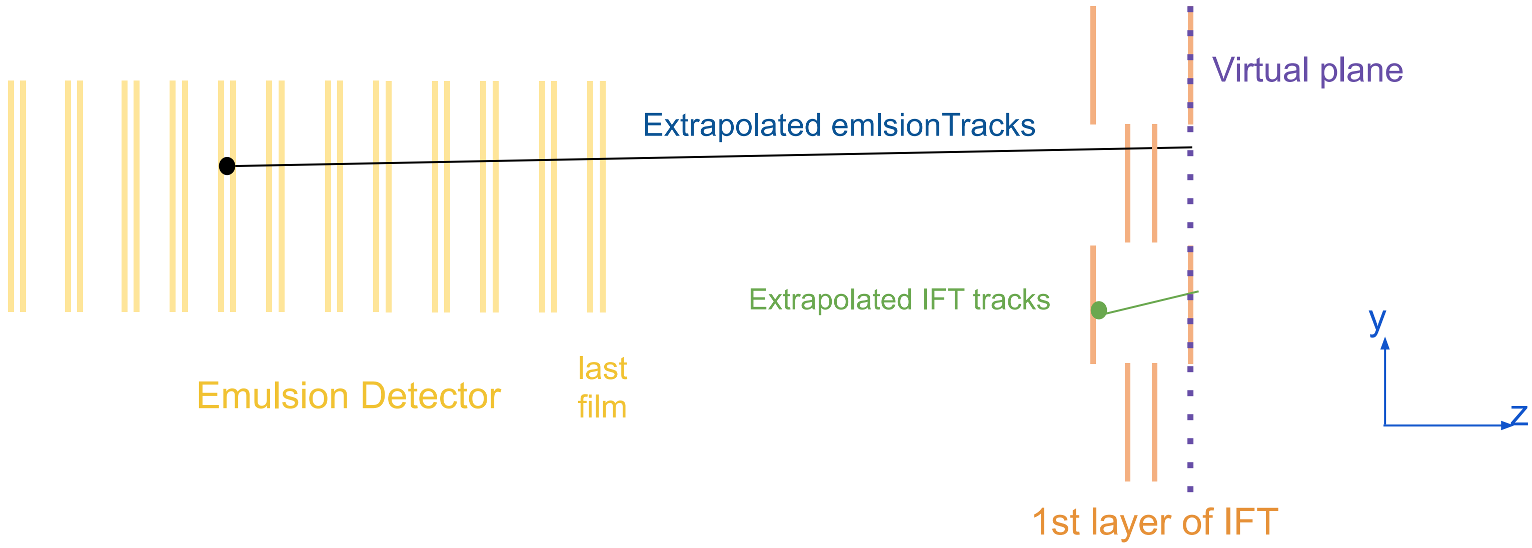
- Mean value of the gaussian fit on the unbiased residuals for each module from the tracks reconstructed from MC simulation in ideal geometry and from data in aligned geometry.
- Mean of residual after alignment a few microns from expectation in MC simulation

Recent Physics Results

- Search for Dark Photons with FASER (arXiv)
- First observation of collider neutrinos with FASER (arXiv)
  - With 153 events at 16 σ
- FASERν analyses are in progress for identifying neutrino candidates.
- We want to use FASERν neutrino candidates to match with tracks from IFT.
- Emulsion sub-detector is in place for about 2 months. Up to O(10^6) tracks/cm^2, with O(10^7) tracks in the spectrometer triggered while one emulsion detector is in place.

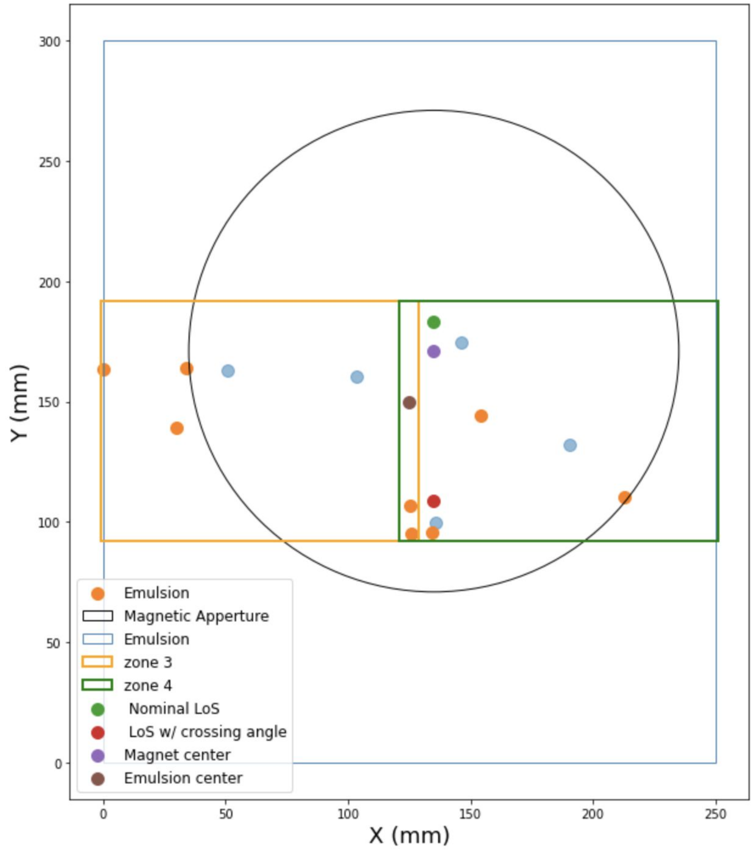


All Combinatorial Matching



- Using the extrapolated tracks calculate the residual between each IFT track and all given Emulsion tracks. call this the all combinatorial method.
  - Residual between X, Y, Px/Pz, Py/Pz.
- Use residuals in χ^2 like formula to find minimum and match tracks.

Emulsion-IFT Matching



- MC validation of matching emulsion and IFT tracks works well.
- Work in progress to apply this to data.
  - For now only see one possible match
  - Currently only sub-region of emulsion is processed hence why we are using the orange and green regions in data.
  - Using high quality neutrino candidates for matching. Plan to use lower quality for more statistics.

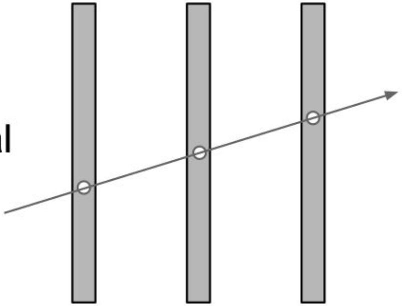
Summary

- FASER successfully took data in 2022 and 2023.
- Alignment of the spectrometer had been done and used for recent physics results.
- Preliminary results of global χ^2 alignment with all four stations
  - Improves Chi2 and residuals to similar level in perfect geometry MC
- All combinatorial Emulsion-IFT matching works well in MC. Work in progress on data.
- Future improvements:
  - Include all 6 parameters in alignment
  - Optimization can be done in alignment workflow
  - More neutrino candidates from emulsion detector

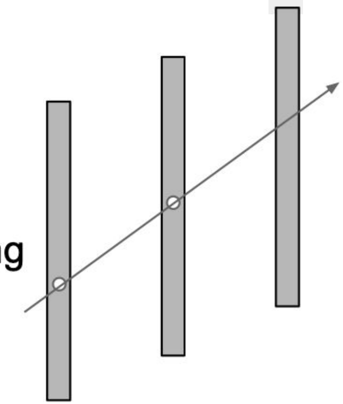
Backup Slides

Weak Modes in Alignment

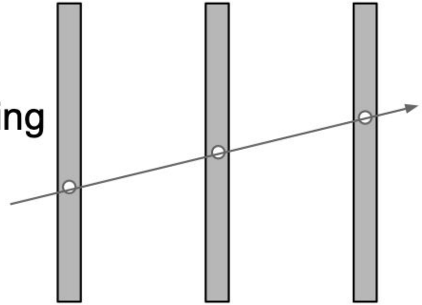
nominal



shearing

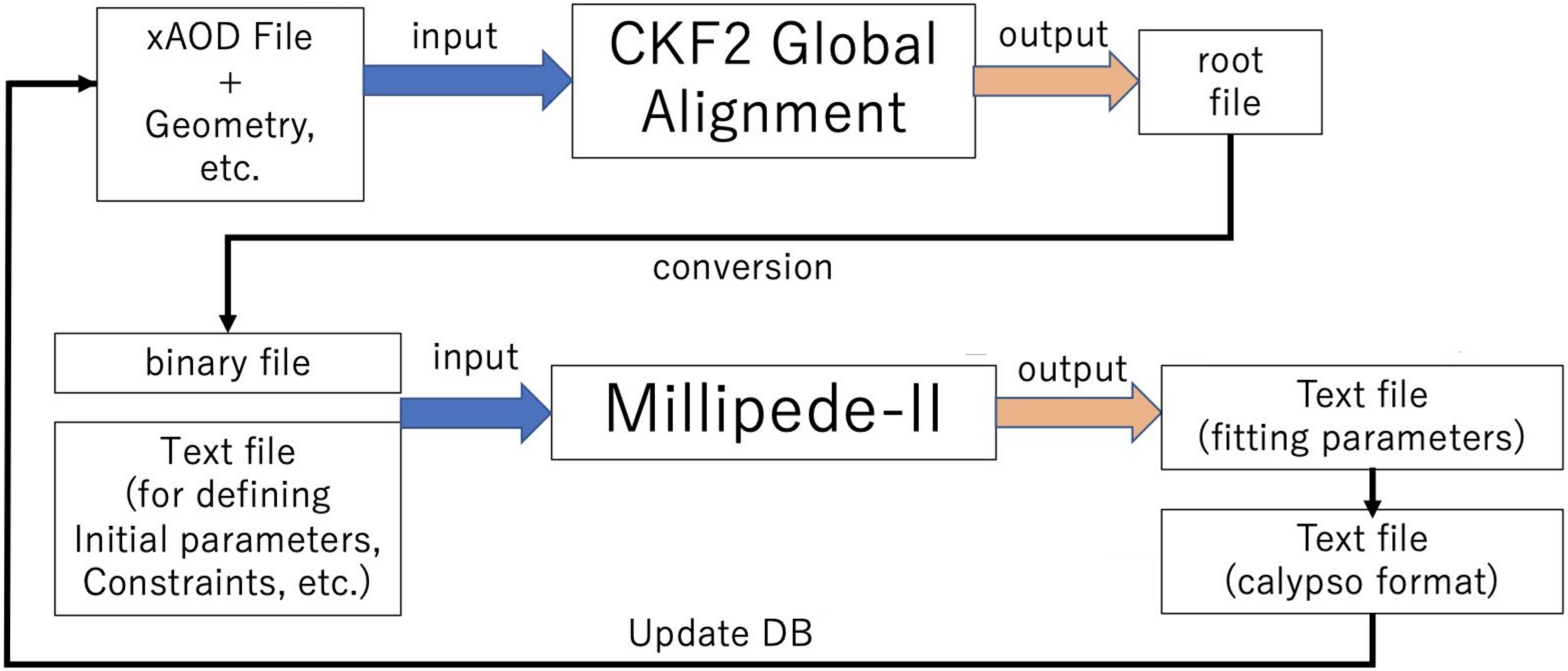


stretching



- The global chi2 keeps invariant in weak modes but track parameters will be affected
- Need extra constraints
    - In ATLAS/CMS, good constraints from J/psi or Z mass
- In FASER, fix two layers in order to avoid weak modes

Summary of Alignment Workflow



Chi2 Alignment

- 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