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CERN Summer Student Program Report

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Summary

This report describes what I have done in the summer student program at CERN. I worked in the ForwArd Search ExpeRiment (FASER) group during the program and mainly focused on the alignment of the trackers in FASER Detector. The alignment of trackers is important in the analysis of FASER because it affect the determination of charge and momentum of particles in events. So far, the methods for the alignment was almost built up, but found some issues. I tried to resolve the issues. And I also worked on the anaysis of test beam data and improvement of Calibration Display.

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1 ForwArD Search ExpeRiment (FASER)

1.1 Physics in FASER

The standard model was proposed in the second half of the 20th century, and it is consistent with most of the experiment results. However, it is believed that there are still undiscovered particles to explain mysteries such as dark matter, dark energy, the matter-antimatter asymmetry problem, and so on. These particles are searched with some ways by various experiment. One of the regions is called "Energy frontier". ATLAS and CMS experiments are searching for new particle models in the energy frontier. It is one of the most worth looking places, but, new particles as a candidate for dark matter is not found so far. Another possibility is the "intensity frontier". FASER experiment search new particles in this intensity region. The target of the FASER experiments is new, light, and weakly-interacting particles such as a dark photon and axion. The investigation of interactions of high-energy neutrinos is also a target of FASER.

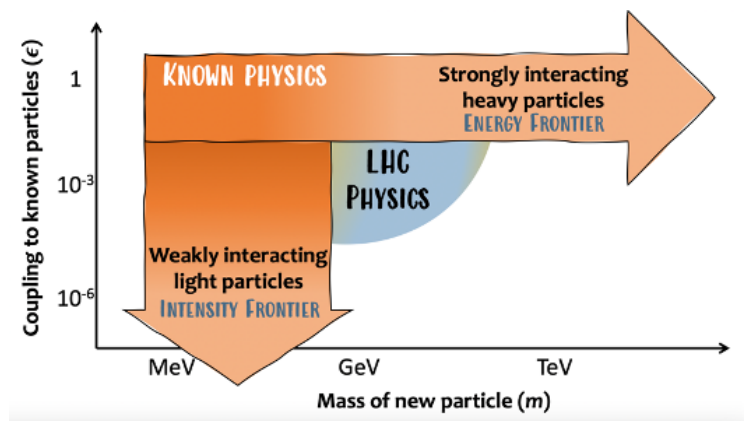


Figure 1: the Frontier Region [5]

1.2 FASER Detector

The detector of the FASER experiment is located in downstream 480m from ATLAS Interaction point. FASER detector is consist of scintillators, magnets,trackers, calorimeters and FASER ν emulsion detector. Scintillators are used to get timing, trigger of events, and veto for background rejection. Magnets work as a decay volume and separate oppositely charged particle by bending the track of charged particles. Trackers detect the tracks of particles. From the track, we can identify the charge of particle and measure momentum. Calorimeter detects shower and measures the energy of particles. FASER ν detector is arranged in the most front part of the FASER detector. It has high positioning resolution and is used to identify a flavor of neutrino and also to measure the momentum of charged leptons.



Figure 2: the Location of FASER Detector [1]

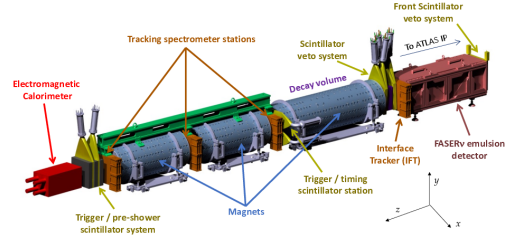


Figure 3: FASER tracker [1]

2 Tracker Alignment in FASER

2.1 Tracker

4 trackers are placed in FASER detector. The tracker in front, where is immediately after FASER ν detector, is called Interface Tracker, or IFT. IFT is important to connect the track in trackers and the track in the emulsion detector. This connection allows us to separate neutrino and anti-neutrino by being sensitive to a particle charge. Other trackers are called Station 1, 2 and 3. Each station, including IFT, has 3 layers, and each layer contains 8 silicon micro-strip sensor modules. Each module has 2 sides, front side and back side, and each side has 768 strips at a constant pitch of $80\ \mu\text{m}$. There are 6 chips to readout for each side and each chip read the signal from 128 strips. The Strip sensor has resolution only for one direction, which is perpendicular to the strip. However, the sides in each module differ by $40\ \text{mrad}$, so the tracker has resolution for 2 dimensions. The magnets bend the track of charged particles along to y-axis, so, we arrange the modules to that the tracker has a high resolution for the y-axis.

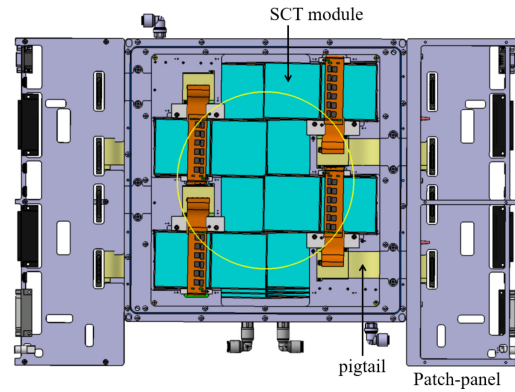
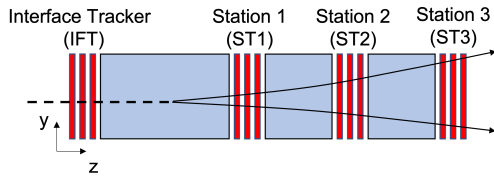


Figure 4: trackers in FASER Detector Figure 5: the layer of FASER tracker [2]

2.2 Alignment

For each module, there is some misalignment, which means the difference between the ideal position and real position. And, we have to know the length of misalignment for precise

measurement which is necessary to match the track in trackers with the track of the emulsion detector.) More precisely speaking, if the length of misalignment is enough smaller than the positional resolution of detector, we can ignore the effect of misalignment. However, the typical length of misalignment is around hundred micrometer and the resolution for y-axis is around 20 micrometers, so, we have to reduce the residual to this order by alignment.

There are 6 alignment parameters for each module, parallel translation for x,y,z, and rotation around the x,y, z axis. There are 96 modules over all trackers, so 576 parameters in total. We calculate the alignment parameters to minimize the sum of the chi2 value over all tracks. In this point, chi2 is a value that represents how much differ the measured points from the fitted track.

2.3 Methods

Currently, Tracker Alignment is conducted in the following method.

First, for each event, we can know about the strips which emit signal above the threshold. We start alignment with clustering. In clustering, we bundle the signaled strips at each layer and each side. The bundled strips is called a cluster. Secondly, in each station, we fit the clusters by line. This is called segment and we use this as a seed of track. After that, we fit the whole clusters in each event by track. In this track, we consider the effect of magnetic field, so the track becomes curved. By this fit, we can get residuals as the distance from the fitted track to locations of clusters. Finally, we calculate alignment parameters to minimize the sum of the chi2 value over all tracks. But it is not the end. By reflecting the calculated alignment parameter, the coordinates of signaled strips are changed, so, we have to refit the segments and tracks, and we have to repeat this process. After some iteration, typically around 5 times, we get the final alignment parameters.

2.4 Current Status

So far, we succeeded in alignment of station 1,2,3 with the clusters in 3 tracker stations. In this analysis, we ignore the clusters in IFT.

However, we have not succeeded in alignment with the clusters in all 4 stations yet. Fig.6 shows the result for 4 stations. The black one represents the chi2 distribution before the alignment. The red one and green one represents the chi2 distribution after 1 iteration and 5 iterations. The distribution is improving by iteration. But, the improvement almost stopped at 5 iterations and could not reach the ideal distribution. This means that something went wrong, so we have to check the alignment method and find the reason.

I was working on solving this issue.

3 Alignment for IFT

3.1 Observations

First, I checked the tracks and clusters concretely and tried to find the curious behavior seen only in IFT. In some events, the fitting is likely to be failed. One example is shown in the Fig.7. The blue point is the measured point and the orange polyline is the fitted track.

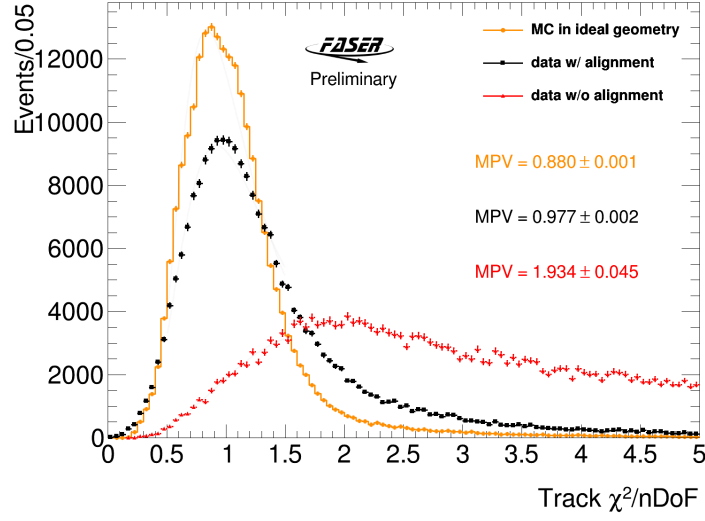


Figure 6: Chi2 distributions of 2023 data with IFT [3]

To show the track, I only connected the points that has the same z coordinate as measured points by line, so, it is not strange that the orange polyline is not smooth.

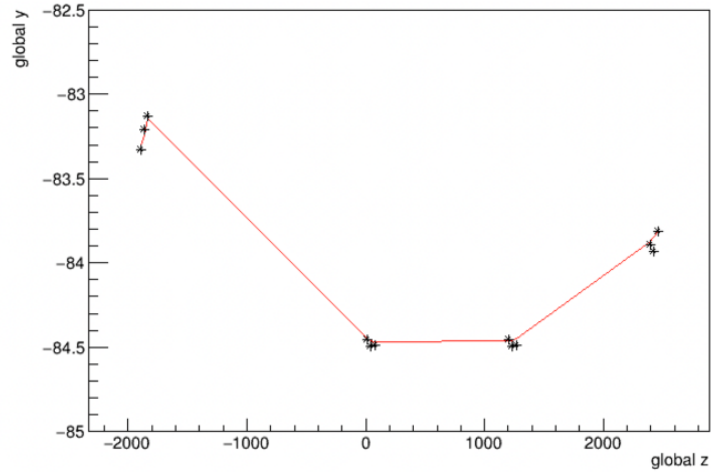


Figure 7: an Example of Strange Track

The remarkable point is that the slope of the track in IFT is positive. When we see all measured points, the track look like concave up and the slope of the track in IFT should be negative. When we see only the measured points in IFT, it looks like the slope is positive. But it will be due to misalignment of IFT. So, it is strange that the slope of the fitted track in IFT is positive. In other words, I suspect that the fitting algorithm may be fitted to the wrong track due to a too-large misalignment of IFT.

3.2 Methods

From the previous observation, I suggested that set initial alignment parameters for IFT. When I assume that the magnetic field is uniform and the direction is parallel to global x-axis, the projection to yz-plane of the track becomes a part of circle. So, I proposed the following method.

1. Align 3 stations except for IFT
2. Fit aligned clusters in ST 1,2,3 by circle and set the mean value of residual as a initial value
3. Align IFT with fixing 3 stations

For the first step, I used the alignment parameter for 3 stations which was derived by Ke in the past analysis [4]. For the second step, I used the clusters in the middle layer of ST 1,2,3 and took circumscribed circle as a track. Finally, I iterated alignment process with initial alignment parameter which was derived in the previous step.

3.3 Results

There is no time to iterate enough, but the chi2 distribution was comparable to the analysis so far. This will mean that the method is working well and worth iterating for comparing the results with the results so far. The standard deviation of the residual was around $20 - 30\mu\text{m}$ in the most of modules. It is corresponding to the ideal value which was calculated from MC simulation [4]. But, in some module, the standard deviation of the residual was around $40\mu\text{m}$, so there will be a room for improvement.

This will be help for determining what is happening in alignment and improving for more precisely alignment.

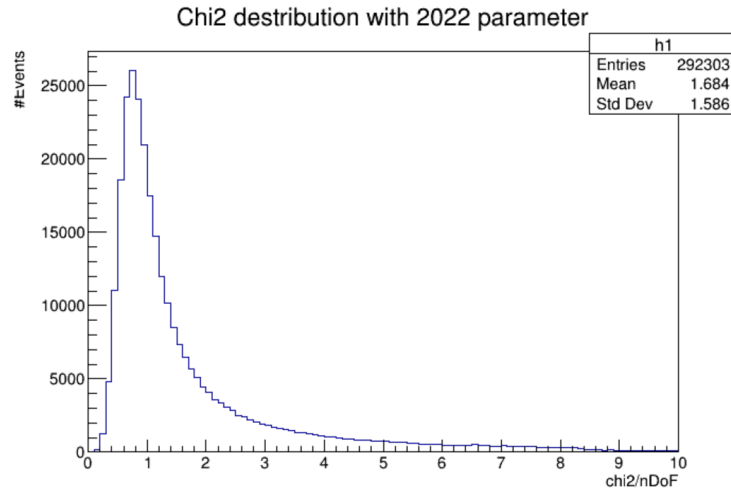


Figure 8: Chi2 distributions of 2023 data by new method

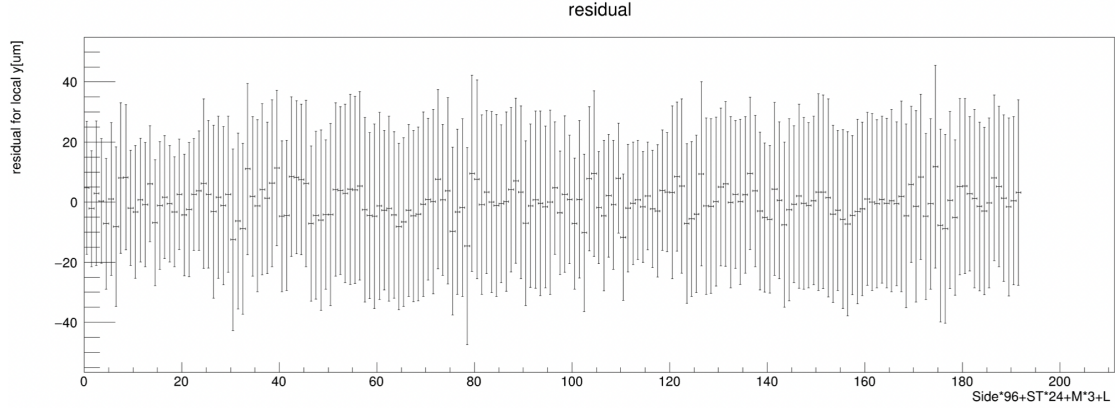


Figure 9: Residual distributions of 2023 data by new method

4 Alignment by test beam Data

Test beam for FASER was conducted in 2021. In the test beam, only one tracker, IFT was located. The alignment method is essentially the same as the original one for real data. But, in this situation, there is only one station and the magnet between trackers does not exist. So, the track becomes line regardless the momentum of charged particle, and complicated fitting algorithm are not needed. I was working in implement of the codes for alignment by test beam data.

I implemented the codes as a way of embedding the codes in the existing software for the real data rather than implemented independent codes to software. By using this way, the other people who use software can understand what the code do easily though the codes may be more complicated and difficult to implement than necessary.

First, I prepare the framework to compile the part for test beam data. I prepared configure file, set flag, and so on. After that, I started to implement the codes for fitting and alignment. This is almost done so far, and will complete after debug and check by using the real data.

5 Calibration Display

To check the change of the trackers in FASER detector and to make sure the trackers are working properly, the calibration is carried out regularly. The result of the calibration is recorded in database and can see the visualized plot in the page called "Calibration Display" on the CERN server. Calibration Display has mainly two page. One page is main page. By choosing the calibration type and module, the display shows the results of the module per chip in the module. Another page is dashboard page. However, this page did not work well. I was working in the improvement of Calibration Display.

In particular, I made the following change.

- Adjusted the layout of Main page and Dashboard page
- Added the function that show the result of the layer per module (by averaging the

results for chips in the module) to the main page

- Displayed the list of the results for all calibration type in the latest 6 months per layer.

Especially, the last improvement enabled fast check of the recent calibration results and this page is using in the weekly meeting.

Dashboard

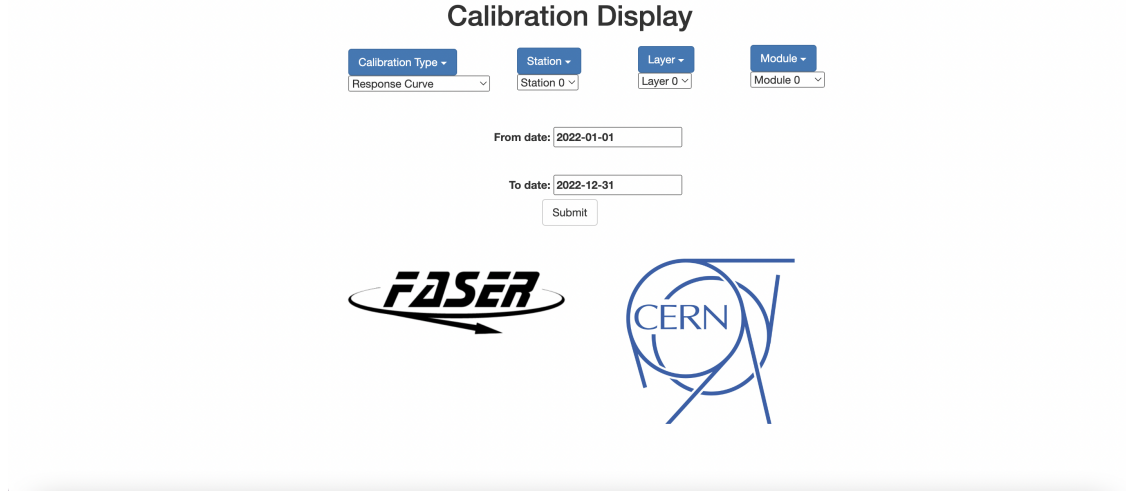


Figure 10: Main page of Calibration Display

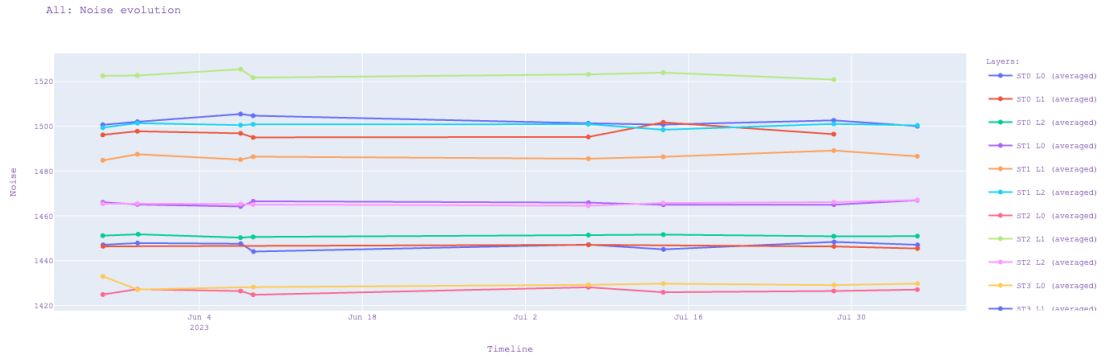


Figure 11: an plot in the Dashboard page of Calibration Display

6 Conclusion

I worked in three theme in this summer student program: The alignment with 4 stations, the alignment with test beam data, and Calibration Display. I proposed solution for the issue in 4 station alignment. And, I implemented the codes for the alignment with test beam data. Additionally, I improved the Calibration Display. The experience in the summer student program was interesting and valuable for me and I learned something new every day.



Figure 12: at the H4 beamline in EHN1,prévessin for the beam test

7 Acknowledgement

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Figure 13: with the FASER Detector