Chapter 3. Data reduction

3.1 Hodoscope calibration

Hodoscope is a device to measure positions of the track trajectory and time of flight from the target. To get those informations, several steps of calibration are necessary. There are five steps of the hodoscope calibration called PASS1, PASS2, PASS3, PASS4 and PASS5.

In PASS1, ADC pedestals of all photomultiplier tube will be calibrated with non-hitted (no valid TDC signal) detector elements (slats) from each event. The fitted pedestal peak values will be saved as a calibration constant called 'PEDE'. The time of flight TOF peaks are calculated.

$$TOF = \frac{TDC(top) + TDC(bottom)}{2} - \frac{TDC(CX1) + TDC(CX2)}{2},$$

which is the time difference between the hodoscope and CX beam counter. The peak for each slat is fitted and saved as 'TOF1'. A velocity of scintillation light within the slat will be calibrated, a timing difference $TDF(i)$ between top and bottom photomultiplier tubes in one slat will be calculated for three different event groups requiring a hit of one of the three horizontal slats, called 'finger counters'.

$$TDF(i) = TDC(top) - TDC(bottom),$$

where i is 1,2 and 3 corresponding top, center and bottom finger counter, respectively. Timing difference of these three $TDF(i)$ and real Y position $Y(i)$ of those three finger counters give the Y position gain parameter Y_{GAIN} with the following formulas,

$$Y_{GAIN}(i,j) = \frac{Y(i) - Y(j)}{TDF(j) - TDF(i)},$$

$$Y_{GAIN} = \frac{Y_{GAIN}(1,2) + Y_{GAIN}(2,3)}{2},$$

which is proportional to the scintillation light velocity inside the slat, called 'TDIF' and 'YVEL' constants. This Y_{GAIN} calibration is done with special calibration run 'finger counter run' to get enough statistics of finger counter hitted events, where at least one hit of the finger counters will be required in on-line trigger to take the special calibration run. Because this Y_{GAIN} parameters are rather stable, this calibration is done once in one period of the beam time.

In PASS2, a pulse height dependence of the time of flight will be corrected, this correction is called as a slewing correction. Because the leading edge discriminator is used for timing information, the pulse height dependence of the time of flight is well known as the following formula,

$$TOF = A + \frac{B}{\sqrt{ADC}}.$$

This is an effect that smaller charged pulse firing the leading edge discriminator give more delaied output timing signal than larger charged pulse, because of a characteristic fixed rise time of the photomultiplier tube and a fixed threshold of the leading edge discriminator. Two dimensional histogram (TOF vs ADC) will be fitted with the formula to get the parameters A and B and saved as 'SLEW' constants.

In PASS3, the same previous 'slewing correction' will be done again, to tune the slewing parameters finely. Only one time of the slewing correction is sometimes not enough or over corrected, therefore this correction will be done twice. Then the reviced slewing correction factor 'SLEW' constants will be saved.

In PASS4, the corrected time of flight offset with the 'SLEW' constants will be fitted in order to move the fitted peak into $TOF = 0$. Normally, the highest peak will be fitted for pion triggered run, since the pions are normally major particle and will make the highest peak in every slats at each hodoscope. In case of kaon/proton triggered run with C1 and C2 on-line selection, the earlier or later peak in TOF spectrum can be chosen by an external flag to force the fitting of the peak of kaon or proton for the TOF offset correction. Because the ratio between the amounts of kaons and protons is closer compared with the amount of pions, and depends on the slat number on each hodoscope, which is corresponding the particle momentum and TOF separation between kaon and proton is large enough to fit the specified peak. In the following analysis, this ΔTOF which is the timing difference from the main (fitted) peak will be used to calculate mass square or identify particle species. This TOF offset is saved as 'TOFS' constants. To get Y position Y_{POS} from the hit of each element slat, Y_{GAIN} which has been calibrated at PASS1 and Y_{OFF} which is the Y position offset are necessary as the following,

$$Y_{POS} = Y_{GAIN} \times (TDF - Y_{OFF}).$$

Then Y_{POS} will be known for given TDF of each hit. By requiring a hit of the center finger counter, which is located at $Y = 0$, Y offset will be calculated,

$$Y_{OFF} = TDF(2 : \text{center finger counter}),$$

and saved as 'YOFF' constants. Main peak in ADC spectrum, where the pedestal is already subtracted with 'PEDE' constants made at PASS1, will be fitted to normalize the peak ADC channel into 1 for all slats in hodoscopes, and saved as 'GAIN' constants.

In PASS5, no more constant will be made in this PASS, but a quality of the constants made in the previous calibration from PASS1 to PASS4 will be checked and shown, by looking at the several spectra and the distributions, in order to know the calibrations just made were acceptable for the coming further analysis. After the calibration, hit position and time of flight of each hit will be known for the following tracking and analysis procedures. In the figure 3-1, several output picture from PASS5 are shown. By looking at bottom two figures in the figure 3-1, one can see that the time of flight offsets are corrected for pion at zero for all slats and Y position with requiring the the hit of the finger counters shows clearly the image of the three finger counters.

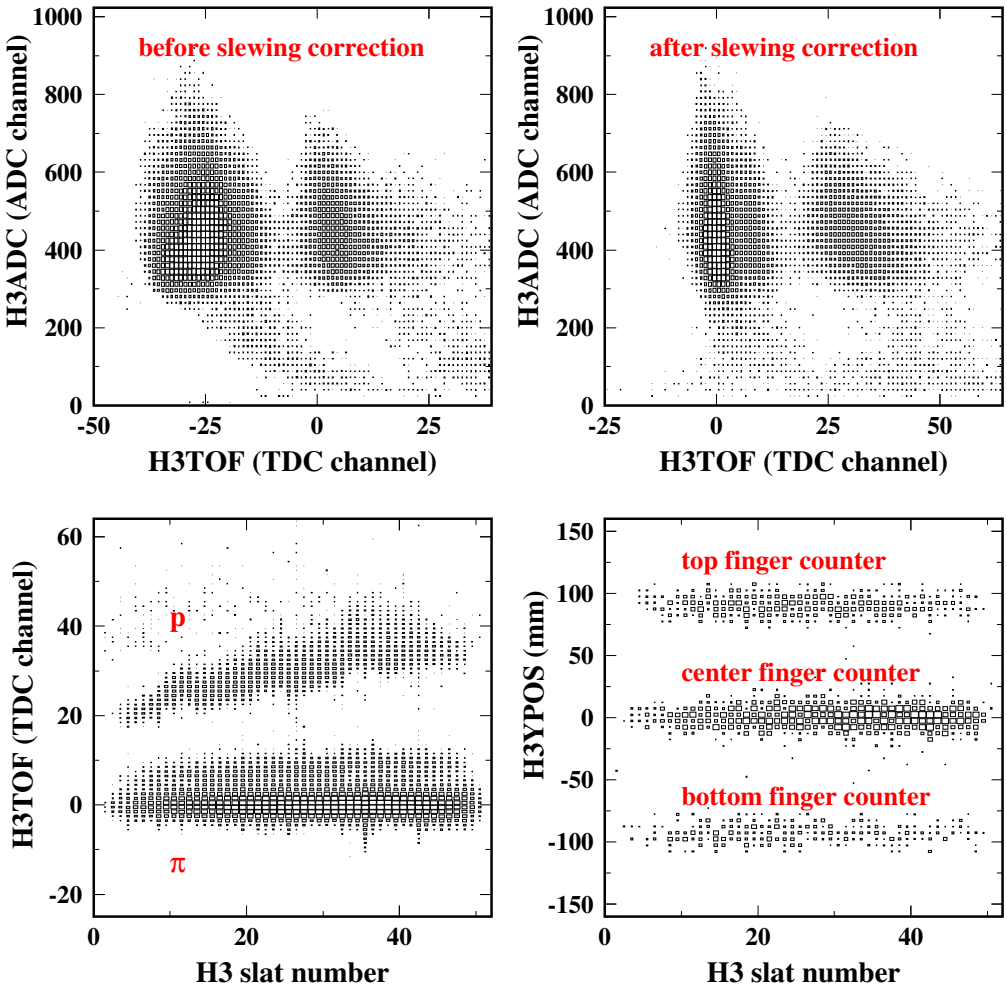

Figure 3-1: calibrated TOF and Y position

3.2 Tracking

In order to reconstruct the trajectories of the secondary particles measured by three hodoscopes, two different tracking algorithms are developed in order to check systematics and consistency. One is based on the chi-square minimizing method, another is based on look-up table.

In the chi-square minimizing method, by using the positions from the hit lists of three hodoscopes, every combinations of hits from three hodoscopes will be tried and all track candidates will be sorted in the order of the calculated chi-square value from the straight line fitting in the free space, because those three hodoscopes are located after the magnetic spectrometer, described in the previous chapter. Track candidate having the smallest chi-square will be selected. By looking at the neighbouring slat hits and angle of this track, H1 ADC pulse height will be checked whether the total ADC pulse height is consistent to the single track having this angle. If this is satisfied, the selected track will be defined as a reconstructed track and the slats used by the reconstructed track will removed from the hit lists. Then the next smallest chi-square track will be used, until one of the three hit lists becomes empty. The hodoscope H1 is inclined 5 degrees respect to the detector axis, therefore the probability to hit neighbouring two slats on H1 is around 40% of the total number of track, this is the reason why H1 ADC pulse height is useful to separate single track and neighbouring two tracks on the hodoscope H1.

In the look-up table method, a clustering technique is used to determine single hit or double hits cluster, when there are more than one neighbouring hits cluster on each hodoscope. The hits lists of each hodoscope will be modified to the expected track hit list by taking into account total normalized ADC pulse height of each cluster. Then a track, which satisfies the three hodoscopes hit-combination found in the look-up table, is assigned as a track candidate. The look-up table is prepared by using Monte Carlo events in advance. Based on the last hodoscope (H3) hits, minimum chi-square track for each H3 hit will be normally found with avoiding the coincidental usage of the hits on the other hodoscopes (H1 and H2). But sometimes the hit combination of the maximum total chi-square for the event will be selected to maximize the total number of the reconstructed track depending on the number of the expected tracks from the raw hits and the number of the reconstructed tracks, and also avoiding the coincidental usage of the hits on each hodoscope.

Because of the difference of the treatment of close tracks between those two different tracking algorithms, tracking result is sometimes different, where the difference is around 10% of the total tracks. However, the global feature like physical spectra and momentum distributions are comparable. The figure 3-2 shows the example of the track reconstruction with three hodoscopes.

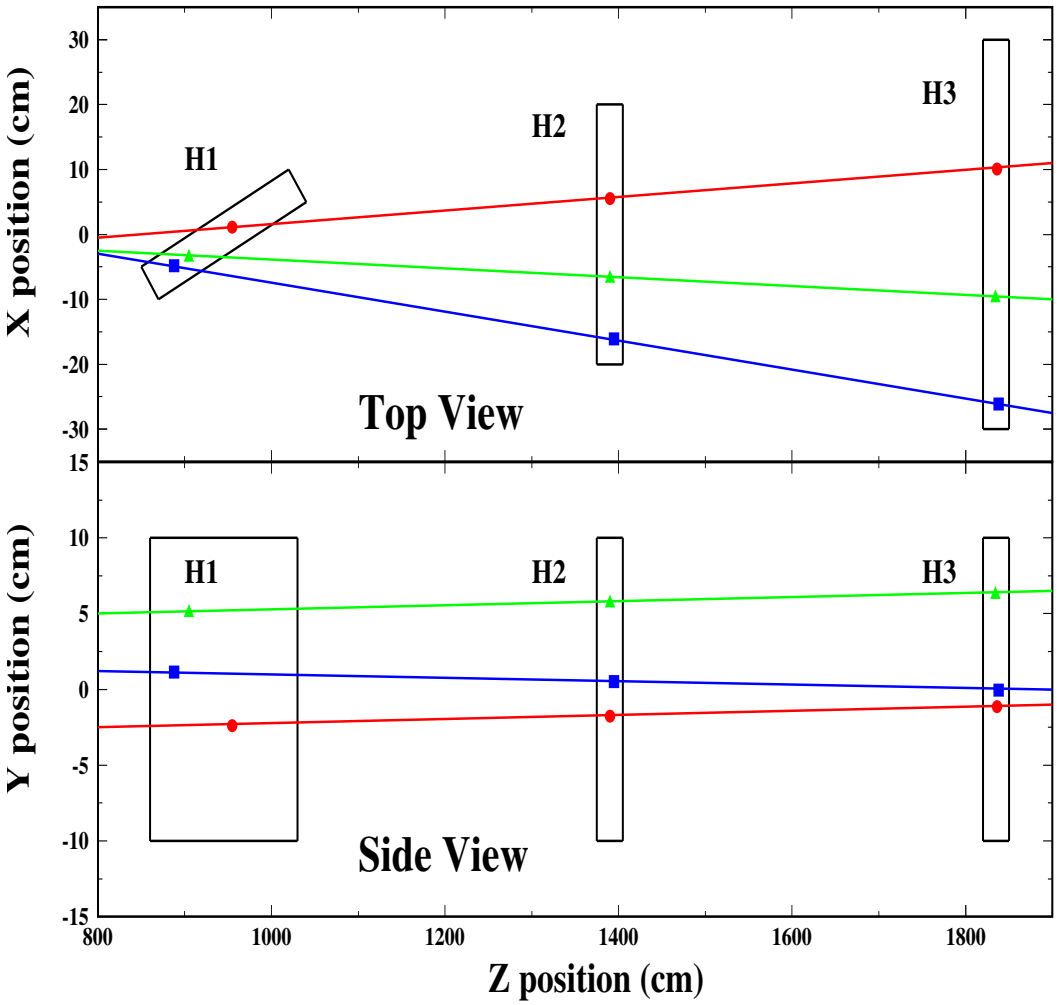

Figure 3-2: track reconstruction with three hodoscopes

3.3 Momentum reconstruction

Produced momentum at the target position for each track will be reconstructed with using the previous tracking informations. Tracking gives one position and vector at the free space after the magnetic spectrometer for each track, this position and vector will be extended backward into the magnetic spectrometer from the downstream to the upstream up to the target position in order to know the three momentum vector ($\mathbf{P}$) at the target position. Here again, two independent different momentum reconstruction algorithms are developed, one is based on a Runge Kutta method called 'ray-trace', another is based on a matrix calculation method called 'RC'.

In the Runge Kutta method, particle trajectory reconstructed by the previously discussed tracking methods will be traced back in the magnetic field map by solving a differential equation of mortion in each step until the target position. The first calculation will be done with the nominal momentum of the setting. This procedure will be iterated several times by changing the momentum until the traced back position is converged to be close enough to the real target position. Then the reconstructed momentum will be known from the final iteration. If the track does not converge onto the target, the track will be thrown away as a back-ground noise track, which does not come from the target. Track which does not go through inside the aperture of the last quadruple magnet will also be thrown away as a back-ground noise track.

In the matrix calculation method, a polynomial function approximation of the momentum as a function of the positions on the hodoscopes is first made by a look-up table of the simulated momentum and hitted positions on the hodoscopes. This look-up table is prepared with a program called DECAY TURTLE, where field matrixes of all magnets will be multiplied to the generated momentum and multiple scatterings and decaies are taken into account, in order to know the hitted slat of each hodoscope. The given polynomial function will calculate the reconstructed momentum from the hitted track positions of hodoscope H2 and H3. This method will give a fast and a good approximation.

The first methods for both tracking and momentum reconstruction are based on the experimental data, on the other hand, the second methods for both are based on the look-up table. There is a philosophical difference, the first one (chi-square based tracking and Runge Kutta based momentum reconstruction) is trying to define the noise or the back ground tracks positively to avoid the hits to be used in the other fake tracks, the second one (look-up table based tracking and matrix calculation based momentum reconstruction) is trying to neglect the noise or the back ground at the first step of the tracking to minimize the noise or the back ground hit contribution. In this case, because of low track multiplicity in the acceptance (typically one or two track in one event) and low back ground hit environment, those two approaches give almost comparable results.

3.4 data reduced file

After all processes mentioned in this chapter, compressed data file will be created for further physics analysis. There are several types of the data file, ascii or binary file having a bank structure for each process or n-tuple for a use in PAW program, which is one of CERN library, having a event and track structure will be normally used, where (1) raw ADC and TDC information for trigger devices which does not require any calibration, (2) calibrated hit positions and time of flight from hodoscopes, (3) reconstructed track informations and (4) reconstructed momentum informations will be saved into the data file.

Especially for the single particle distribution analysis, scaler informations are important to analyze an absolutely normalized cross section, therefore the scaler informations of beam and trigger devices will be recorded at the every end of burst, and those numbers are saved in the data file separately.

For the pair particle correlation analysis, further reduced file is normally prepared, after selecting good trigger or required centrality and two identical required particle species in the same event from the above data file. The new file only contains a momentums of two particle and each position of the tracking detectors to analyze two particles interferometry effect in order to analyze the large amount of the data sample efficiently. Because the positions on the tracking detector affect the analysis of the two particle interferometry, especially for pair events having small momentum difference which is corresponding to the close position on the tracking detector. This position information is used for further event selection and one needs to make the exactly same cut or selection for the fake pair event, which is created by mixing two particles from the different events.