Setting Up and Investigating the M13 Beam-line Simulation in GEANT for TRIUMF Experiment E614

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1 Beam-Line Tune Plan

The purpose of this project is to find an accurate tune for the E614 GEANT simulation of the M13 beam-line. I began working on this project in May under the direction of Peter Gumplinger. The M13 beam-line consists of two dipoles, seven quadrapoles, two slits and the jaws. (When I refer to the first slit, I'm referring to the slit located after the jaws) The field-map of the detector solenoid, which can be implemented in the M13 GEANT simulation, is removed for the purposes of my investigations. Diagrams of just the effective fields alone and of the effective field with the associated fringe field regions can be found in Figures 1 and 2.

Peter and I tried a couple of different tuning techniques throughout the summer until we developed the following procedure. We first started with the settings that Jaap Doornbos developed with his RAYTRACE program. Then, we shot individual rays from a point source through the batch version of GEANT. The program produced a log file of the results. For rays which made it to the end volume, ENDV, the final information was listed in the format below:

x_final: -8.6670816E-03	?_final: 6.0164940E-02
y_final: -1.6690351E-03	f _final: -3.909453E-05

The x_final and y_final values are the distance away from the central position in centimeters in both the x and y directions. The ?_final and f _final values are the angles the beams direction makes with the central axis in the x/z plane (?) and in the y/z plane (f) in milliradians. The ideal ray that begins with zero angle in both the x/z plane (?) and the y/z plane (f) follows a specific path called the central ray. It passes through the exact center of the slits and the quadrapoles. Ideally, a ray that follows this path produces zero for all four of the above parameters.

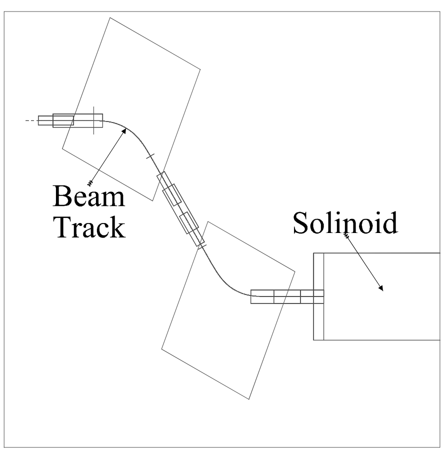

Figure 1 – Beam-line with solinoid and fringe fields

Jaap developed a strategy to optimize the tune in order to maximize the number of particles with highly polarized spins. It involves creating a ray that focused differently in the x/z plane compared to the y/z plane. In x/z we had three focal points, one in the center of the first slit, another in the center of the second slit and a final focus at the end of the beam-line. However, in the y/z plane we only have a focus in the second slit and the final focus. In the first slit the beam did not pass through the center. Jaap explained it to me using the following formulas:

$$x = R_{11}x_0 + R_{12}\theta_0 \qquad y = R_{33}y_0 + R_{34}\phi_0$$

$$\theta = R_{21}x_0 + R_{22}\theta_0 \qquad \phi = R_{43}y_0 + R_{44}\phi_0$$

Y_o and x_o are both zero so the first term of each equation goes to zero. Usually, the second terms are also made to go to zero as well. However, for this new tune R_{34} was 0.038 cm/mrad, a value Jaap obtained from his Transport program. This meant that at the first slit, for every milliradian in f that the initial ray starts with, the resulting ray is an additional 0.038 cm from the focus at the first slit. Since this required the distance versus angle relationship to be very linear, we had to concentrate on focusing rays with very small angles no more then ±5 mrads. So, for example, at the second slit an initial ray with 5 mrads in f would be a distance of 0.19 cm in y from the center of the first slit.

So, in order to optimize the GEANT simulation, I needed to adjust the strengths of the dipole and quadrapole elements until the beam behaved as required by Jaap's tune. It involved a lot of playing back and forth since adjusting any one element effected the tuning of the elements adjacent to it.

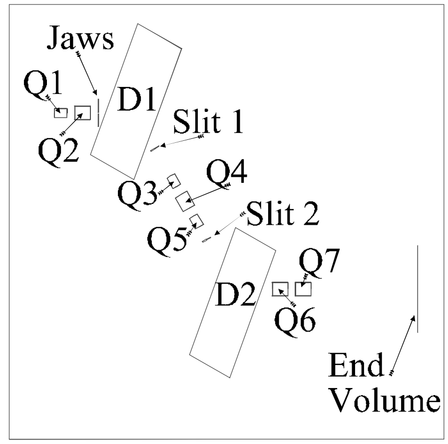

Figure 2 – Beam-line without the fringe fields

2 Beam-Line Tune Results

Since only the dipoles can influence the zero ray, it is impossible to get it to travel through each focus both centered in the slit and aimed perfectly down the beam-line. Even though adjusting the dipole will get the zero angle rays to travel through the center of the slit, its direction in ? isn't necessarily zeroed. This is why we needed to add something called shift cards before the first slit and after the second slit. We used them to move the position of the ray in the x-direction. They were placed just in front of the first dipole and just after the second dipole. When used in tandem with the dipoles, we were able to get both the position and angle of the zero rays to go to zero at the slits. The equivalence of the 'shift cards' in the real beam-line is small adjustment coils which are used to deflect the beam back on axis.

Another problem we found was that the initial angle vs. position at the focus was not linear for higher angles. The higher order effects of the magnets can only be corrected by sextupoles and octapoles in the beam-line, which are not present in M13. In order to stay mostly in the linear region, we only looked at small angles, ±5 mrads in f and ?, where the higher order effects are small.

We also found was that the central ray traveling through the second section was off axis by the time it reached the second slit. This could not be due to the quadrapoles since they can't bend anything travelling down the axis. By looking at a picture of the beam-line that included the fringe fields, the problem became apparent. The positions of both slits are significantly inside the fringe fields of the dipoles. What had happened was that we adjusted the magnets so that the zero ray passed through the center of the first slit but then the dipole fringe field continues to bend it off axis. Once the zero ray is no longer passing through the center of the quadrapoles, they to affected the beam. Before the beam reaches the second slit, it crosses the edge of the second dipole fringe field which bends it even more. The effect is small; 0.04mm off axis in x with a direction of 0.5 mrads in ?.

3 Muons created on the jaws

Using this new tune, I determined if muons created on the surface of the jaws will make it through the M13 beam-line. These muons result when pions from the original source at the beginning of the beam-line, travel down the beam-line, collide with the jaws, stop and decay.

At first, we simulated a uniform square emittance at the beginning of the beam-line. It had a square area of 1cm in x by 1cm in y. The second simulation had muons originate on the rim of the opening of the jaws. Both simulations had jaws of the same dimensions of ±3.0cm in x by ±1.6cm in y. As a first approximation, this his rim source had only a 0.5mm thickness away from the opening of the aperture. Both jobs were run for 50000 events and at an emittance of ±30 mrads in ? by ±50 mrads in f. The transmission probability of both was:

Created on the jaws rim	->	1.26%
Created from the uniform square emittance	->	19.29%

So even if a muon is created on the rim with the same emittance, it is about 15 times less likely to make it to the end of the beam-line as compared to one created at the production target.