Particle-Techniques

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1 Assignment 1 (Computer Issues)

1.1 Revised Method

Using the the hits from the drift chamber and the fact the geometry of the magnet is a cube, a revised method for calculating the momentum was done. (see the code Tracker.py for details).

- First, the direction vector of the particle exiting drift chamber 1 and entering drift chamber 2 are found by using the hits in the drift chamber to trace a line through the points, and then the direction vector is found by normalising the vector.
- The entry and exit points of the particle is found by extrapolating the direction vector of the hits of drift chambers 1 and 2 (1 for the entry point and 2 for the exit point), using the real distance between the drift chambers and the magnet. As a result the direction vector of the entry and exit points are the same as the direction vectors of the tracks.
- The deflection angle θ is found by seeing how much the direction vector of the particle changes as it exits the magnetic field. This is done by calculating the angle of the direction vectors of the particle entry and exit points and taking the difference.
- The distance between the entry and exit point of the magnet d is found using $d^2 = h^2 + l^2$, where l is the length of the magnet along z and h is the difference in the x position for the particle entry and exit points of the magnet.
- The bending radius r is found using the equation $d/\arcsin(\theta)$.
- Calculate the momentum using $p = qBr$ (need to switch to relativistic equation).

mean (GeV): 100.0948 +- 0.0005 standard deviation (GeV): 1.41 +- 0.0005 Amplitude: 900.0 +- 100.0 Average momentum resolution (GeV): 19.0+-2.0

mean (GeV): 100.09236 +- 3e-05 standard deviation (GeV): 0.33947 +- 3e-05 Amplitude: 143.0 +- 4.0 Average momentum resolution (GeV): 7.0+-5.0

mean (GeV): 50.03878 +- 3e-05 standard deviation (GeV): 0.35178 +- 3e-05 Amplitude: 239.0 +- 9.0 Average momentum resolution (GeV): 3.0+-4.0 50 GeV has significantly more outliers than the rest

mean (GeV): 200.211 +- 0.001 standard deviation (GeV): 1.433 +- 0.001 Amplitude: 600.0 +- 200.0 Average momentum resolution (GeV): 38.0+-4.0

2 Theory/Discussion

Beam Momentum is 100 GeV and the magnetic field is set to 0.5T. The beam angle (also all other parts) is zero. 1000 events are generated (same for subsequent parts). x precision is 10^{-4}m and y precision is 10^{-2}m.

Momentum is estimated using the deflection of the charged particle as it travels through the magnetic field. the equation for the momentum of a charged particle travelling through a magnetic field is

$$p = qBr, \tag{1}$$

where q is the charge, B is the Field strength and r is the radius of deflection. The radius can be determined by seeing ho much the direction vector of the particle changes as it passes through the magnetic field. Particles in this experiment will be moving considerably fast, so the amount the trajectory bends is very small. Hence we can approximate the arc length as the length of the magnet, hence

$$r = \frac{L}{\Delta\theta} \tag{2}$$

where L is the magnet length.

The resolution (I think) is dependant on how well the deflection radius can be calculated, so its relative uncertainty scales proportionally:

$$\frac{\sigma_r}{r} = \frac{\sigma_p}{p}. \tag{3}$$

To determine σ_r, propagation of uncertainties in the tracking is done. The trajectories before and after the magnetic field are $\vec{r_1}$ and $\vec{r_2}$ respectively. $\Delta\theta$ found using the trajectories:

$$\Delta\theta = \frac{x_2}{r_2} - \frac{x_1}{r_1} \tag{4}$$

so the uncertainty in $\Delta\theta$ is

$$\sigma_\theta = \sigma_x \sqrt{\frac{1}{r_2} + \frac{1}{r_2}}. \tag{5}$$

From equation 2 σ_r is given by:

$$\sigma_r = \frac{r}{\Delta\theta}\sigma_\theta \tag{6}$$

so the momentum resolution is:

$$\sigma_p = \frac{p\sigma_x}{\Delta\theta}\sqrt{\frac{1}{r_2} + \frac{1}{r_2}}. \tag{7}$$

Here, σ_x is the uncertainty in x which I take as the precision in x i.e. 10^{-4}m. Note it is the only uncertainty in the equation because all other parameters are dependant on the x precision (z is assumed to be perfectly known as it is part of the detector geometry).

These methods were implemented in python to generate the momentum distribution, the average momentum and the momentum resolution.

For the momentum distribution plots, the average momentum is within the expected beam momenta, though for figure 6 the momentum resolution calculated from the fit is very wide. This is due to the lead blocks placed around the magnet which will cause the muons to loss energy and multiple scatter through the material. As a result the points where the particle enters or exits the magnet is known to a lower accuracy. in addition, the material is quite dense so the muons loose some energy as they pass thorugh the material which may explain why the mean is slightly different to the expected beam momentum, though considering the momentum resolution from the fit or the propagated uncertainty, it is within range. The poorer tracking results in a wider spread in the momentum and thus the resolution, and there appears to be an overestimation of the momentum for many particles resulting in a skewed Gaussian.

A field too weak or too strong leads to a wider momentum distribution. If it is too weak the particle trajectory bends less in the field so the bending radius becomes more difficult to calculate where a field that is too strong will not work well with the small angle approximation and the calculation becomes less accurate as a result.

For the 50GeV momentum run, the spread is smaller than the 100GeV or 200GeV run, and it seems the resolution is somewhat proportional to the magnitude of the beam momentum. The resolution calcualted from uncertainty propagation is much higher for a higher beam energy, which may indicative of the the particle trajectory bending less in the magnetic field as previously discussed.

If the trajectory is perfectly known, σ_x will be zero, so following equation 7, σ_p will be zero so you can perfectly determine the resolution if calculated using this method (not sure?).

2.1 Results(Momentum)

All plots have around 1000 events (outliers excluded). Particles are μ^+.

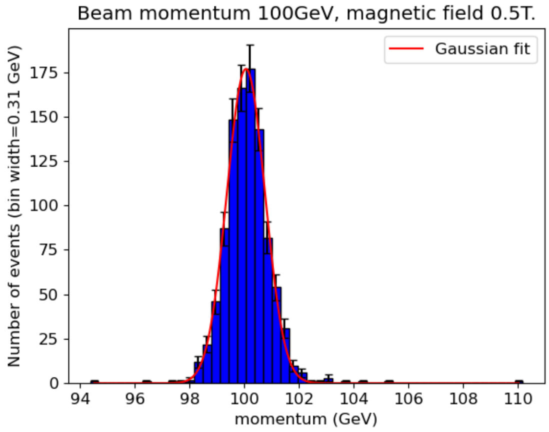

Figure 1: Momentum distribution for part 1

Mean (GeV)	100.06215 ± 8e-05
Standard deviation (GeV)	0.69766 ± 8e-05
Amplitude	310.0 ± 10.0
Average momentum resolution (GeV)	9.5 ± 0.5

Table 1: Table of fitted Gaussian parameters for figure 1.

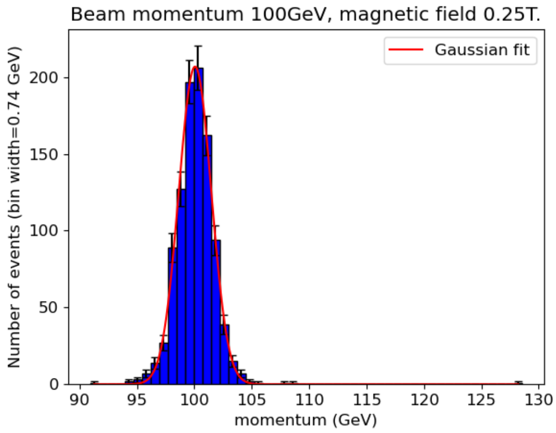

Figure 2: Momentum distribution for part 2a.

Mean (GeV)	100.0948 ± 0.0005
Standard deviation (GeV)	1.41 ± 0.0005
Amplitude	900.0 ± 100.0
Average momentum resolution (GeV)	19.0 ± 2.0

Table 2: Table of fitted Gaussian parameters for figure 2.

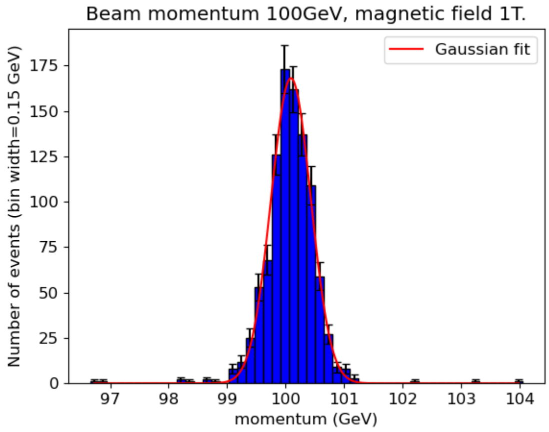

Figure 3: Momentum distribution for part 2b.

Mean (GeV)	100.09236 ± 3e-05
Standard deviation (GeV)	0.33947 ± 3e-05
Amplitude	143.0 ± 4.0
Average momentum resolution (GeV)	7.0 ± 5.0

Table 3: Table of fitted Gaussian parameters for figure 3.

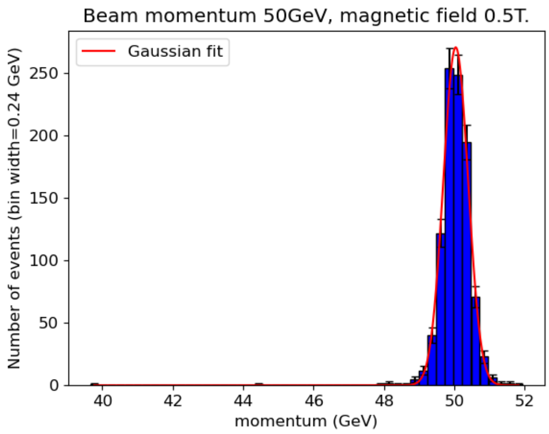

Figure 4: Momentum distribution for part 3a.

Mean (GeV)	50.03878 ± 3e-05
Standard deviation (GeV)	0.35178 ± 3e-05
Amplitude	239.0 ± 9.0
Average momentum resolution (GeV)	3.0 ± 4.0

Table 4: Table of fitted Gaussian parameters for figure 4.

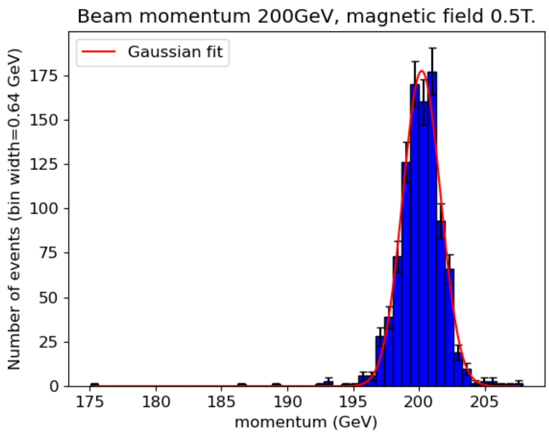

Figure 5: Momentum distribution for part 3b.

Mean (GeV)	200.211 ± 0.001
Standard deviation (GeV)	1.433 ± 0.001
Amplitude	600.0 ± 200.0
Average momentum resolution (GeV)	38.0 ± 4.0

Table 5: Table of fitted Gaussian parameters for figure 5.

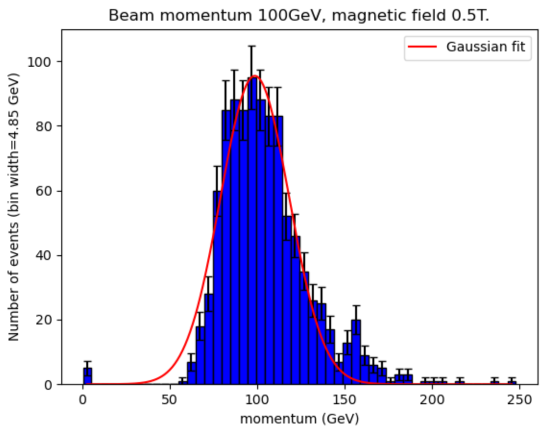

Figure 6: Momentum distribution for part 4, Here two blocks of lead with thickness 5cm are placed before and after the magnet. Events in the bin close to zero are ones with rather poor tracking, so momentum calculations fail.

Mean (GeV)	98.6 ± 0.5
Standard deviation (GeV)	19.6 ± 0.5
Amplitude	4696 ± 20000.0
Average momentum resolution (GeV)	11.0 ± 4.0

Table 6: Table of fitted Gaussian parameters for figure 6. The amplitude in the fit

3 Assignment 2

for the antimuon events, looking at figure 7, the energy deposited by the muon is very small as they do not interact with matter as strongly as other particles so the distribution makes sense. For the positron events, 8 shows that the majority of the energy is deposited in the EM calorimeter and a very small fraction into the hadron calorimeter. The total distribution appears as the EM energy deposited as the Hadronic contribution is minimal. Note the shape of the distribution is similar to a landau curve, though the expected mean energy should be centered around 100GeV, given the positron is very light so the approximation $E \simeq pc$ is true. This indicates there is some energy loss not yet accounted for (no reconstruction is done yet). For the Proton, about half the protons deposit almost no enery in the EM calorimeter, while the other half deposits a large fracion of their energy. The energy deposited in the hardon calorimeter is larger compared to that of the muon and the positrons, but not compared to the EM contribution as seen in figure 9. Also from this figure, the total energy distribution has a sharp peak near 4GeV, with a large spread of energy up to 60GeV. Again, reconstruction is needed to get the correct distribution, as the proton mass is small relative to the beam momentum, so the energy distribution should be centered around 100GeV.

(not sure how to do reconstruction)

3.1 Results

All results are for 1000 events, beam momentum of 100GeV and Magnetic field of 0.5T where the particle type is changed (antimuons, positrons and protons).

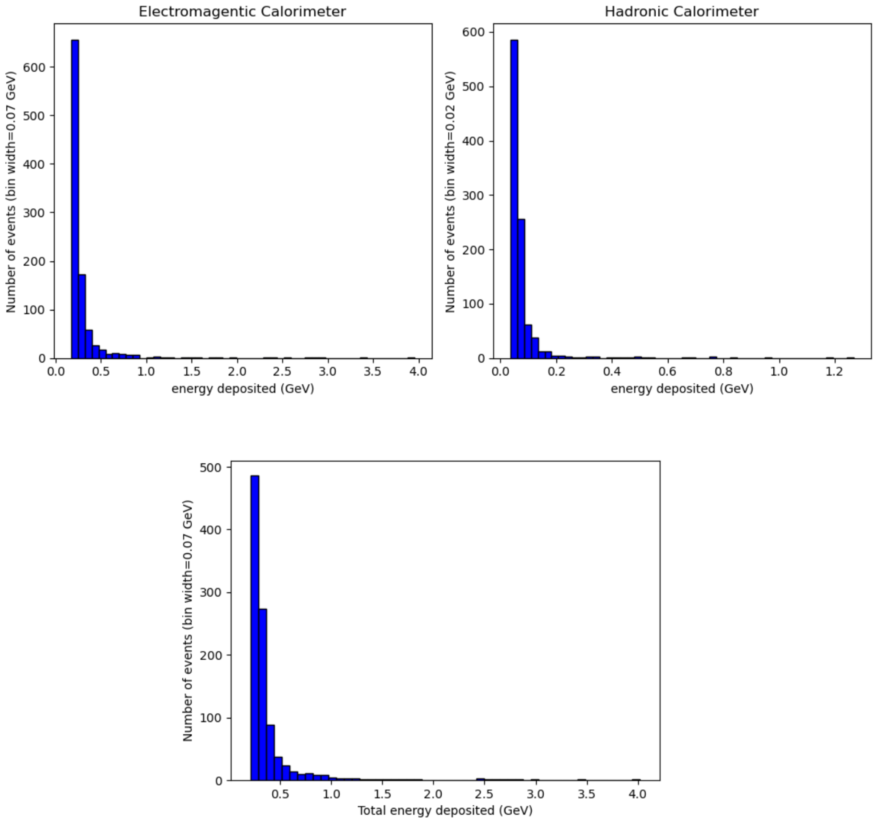

Figure 7: Shows plots of the total energy deposited (no reconstruction) in both calorimeters (seperately and together) for the antimuon events.

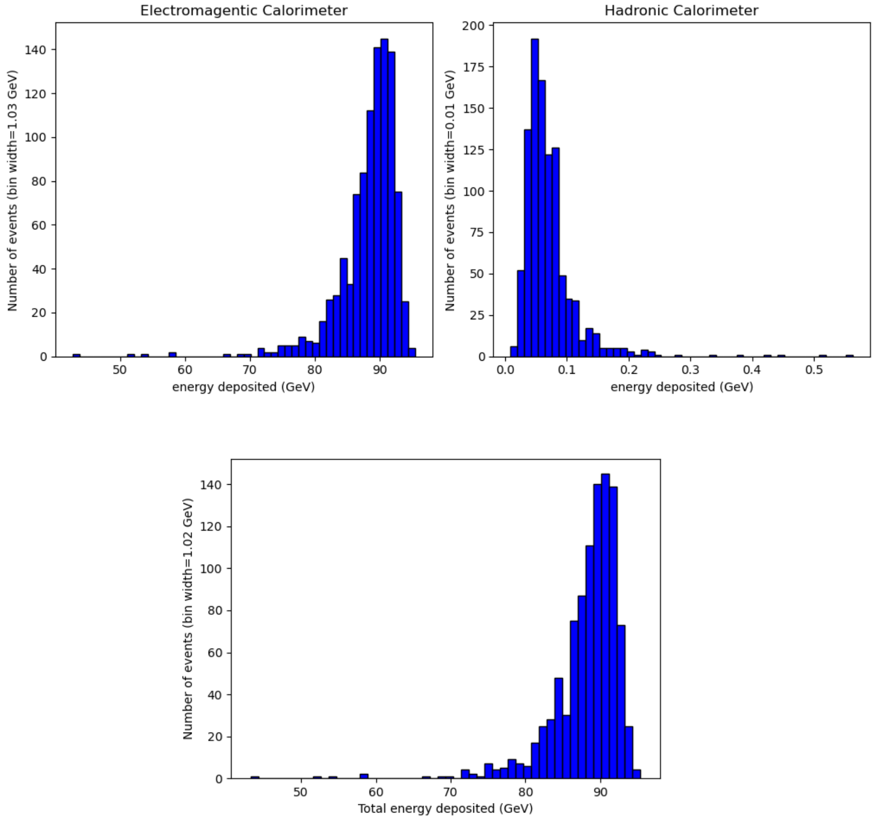

Figure 8: Shows plots of the total energy deposited (no reconstruction) in both calorimeters (seperately and together) for the positron events.

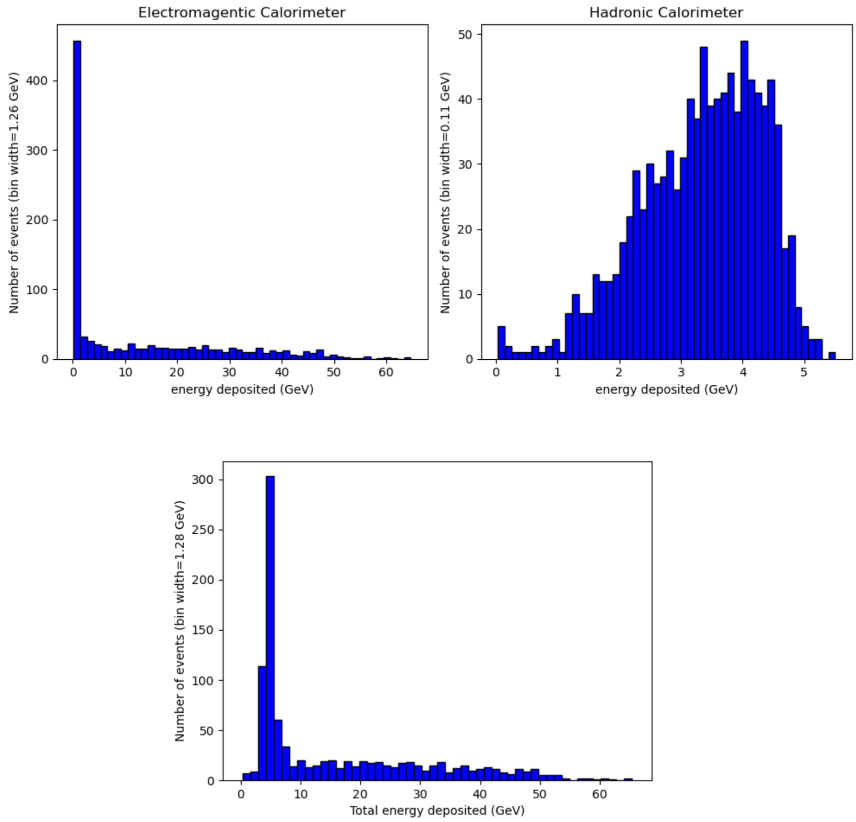

Figure 9: Shows plots of the total energy deposited (no reconstruction) in both calorimeters (seperately and together) for the proton events.