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).

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 through 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 calculated 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^+.

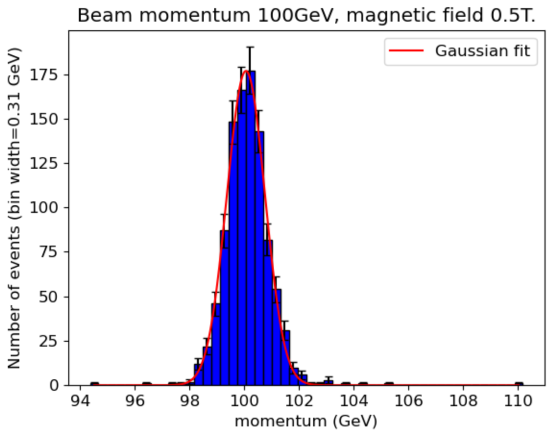

Figure 1: Momentum distribution for part 1

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

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

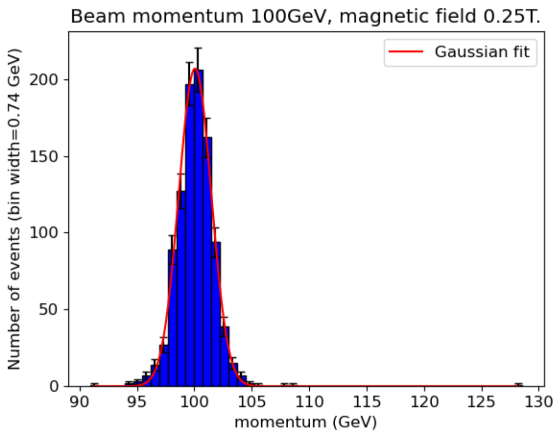

Figure 2: Momentum distribution for part 2a.

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

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

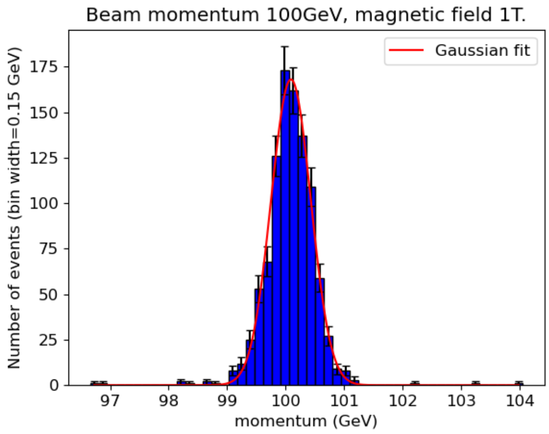

Figure 3: Momentum distribution for part 2b.

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.

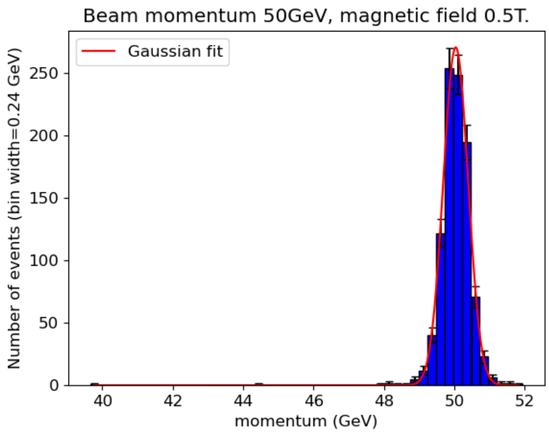

Figure 4: Momentum distribution for part 3a.

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.

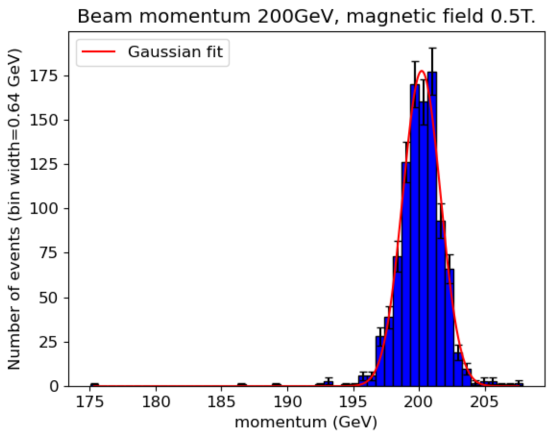

Figure 5: Momentum distribution for part 3b.

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.

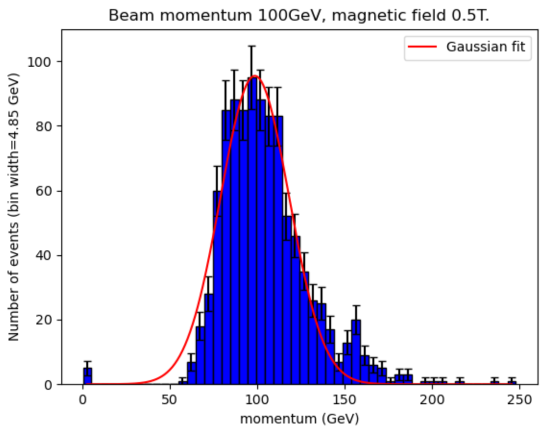

Figure 6: Momentum distribution for part 4, Here two blocks of lead with thickness 5cm are placed before and after the magnet. Events in the bin close to zero are ones with rather poor tracking, so momentum calculations fail.

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 energy in the EM calorimeter, while the other half deposits a large fraction 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.

3.1 Reconstruction

Reconstruction is required to account for energy leakage or any energy not deposited into the calorimeter. To do so corrections are calculated using the existing deposited energy, where they are modified using empirical models whose parameters are related to the detector material and geometry. The goal it to retrieve an average energy equal to the average predicted energies seen in figures 9 and 11. This predicted energy is done simply using the calculated momenta distributions and the mass of the particle i.e.

$$E_p = \sqrt{m^2 + p^2} \tag{8}$$

which is in natural units. For the EM calorimeter, the detector is too short to collect all the energy deposited in the shower so the correction calculated was the energy it should have collected if it was the correct length. This correction uses the exponential decay of the deposited energy over the distance i.e.

$$E = E_0 e^{-\frac{x}{X_0}} \tag{9}$$

where X_0 is the radiation length. This function was integrated to give the total energy deposited over a certain distance and implemented in the function **EMCalCorrection** in the file Calorimetry.py. the total length of the shower $t_{95}X_0$ and the length of the detector are used to calculate a factor which is multiplies to the critical energy (i.e. the energy at which bremsstrahlung and ionisation are equal) to estimate the energy leakage.

For the hadron calorimeter two corrections are made, one which multiplies the existing deposited energy by the ratio of the active to passive layers of the detector(set to 20) and a factor which attempts to estimate the energy lost due to ionisation. For the ratio, the depth of the whole detector is divided by the depth of a single scintillator in the H-Cal. For the ionisation correction, the number of hits with energies less than the hadronic interaction cutoff energy is taken as the number of ionisations occurring per event and so the energy lost to ionisation is equal to $n_{ion}E_h$ where E_h is the hadronic cutoff energy, which for lead is 1.3 GeV.

Looking a the plots the various models affect the data in an appropriate way i.e. for the positron the EM correction is the most significant and for the proton, the hadronic contribution is the most significant. Looking at figure 9 the hadronic contribtuion increases the total mean energy by around 1GeV and decreases the resolution by around 0.3GeV which is interesting. The EM correction increases the mean total deposited energy by 16GeV and the resolution increases slightly. In all cases the Gaussian function is a less accurate fit as there is a tail towards the lower end of the distributions so a more appropriate function may be a Landau distribution.

Looking at figure 11 the energy without reconstruction is rather low with a huge spread due to the energy deposited in the EM calorimeter. The EM correction is rather insignificant however, the hadronic correction massively improves the distribution, with the mean energy centering around 90GeV and increasing the resolution by a factor of 9. For the proton data, the EM correction is more significant than the hadronic contribution was in the positron data which may be expected as the proton is positively charge so interacts with the material via the electromagnetic force. Perhaps a better particle to study the hadronic corrections would be a neutron as it has no electromagnetic charge. Despite the massive corrections made, the energy falls short of the predicted average so it is likely the hadronic corrections is not sufficient to correctly estimate the energy.

In summary, the corrections overestimate the positron energies, suggesting the EM corrections are too strong, and the corrections underestimate the proton energies implying the hadronic contribution is not strong enough. Regardless both corrections are crude estimates and the calculations used are not based on any physical models used in most energy reconstruction methods, other than the parameters. So a major improvement would be to spend more time understanding and implementing more commonly used reconstruction techniques. On top of this, modifications could be made to the simulation to output more data such as raw ADC signal which can be used along side more realistic reconstruction techniques (such as determining the hadron EM shower fractions).

3.2 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).

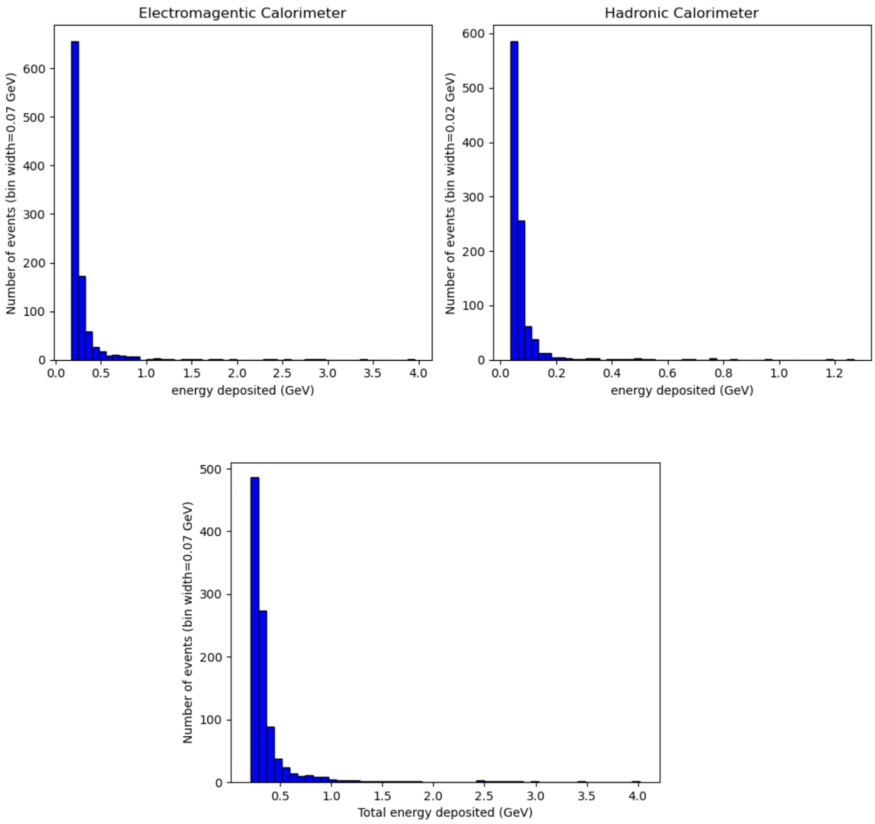

Figure 7: Shows plots of the total energy deposited (no reconstruction) in both calorimeters (seperately and together) for the antimuon events.

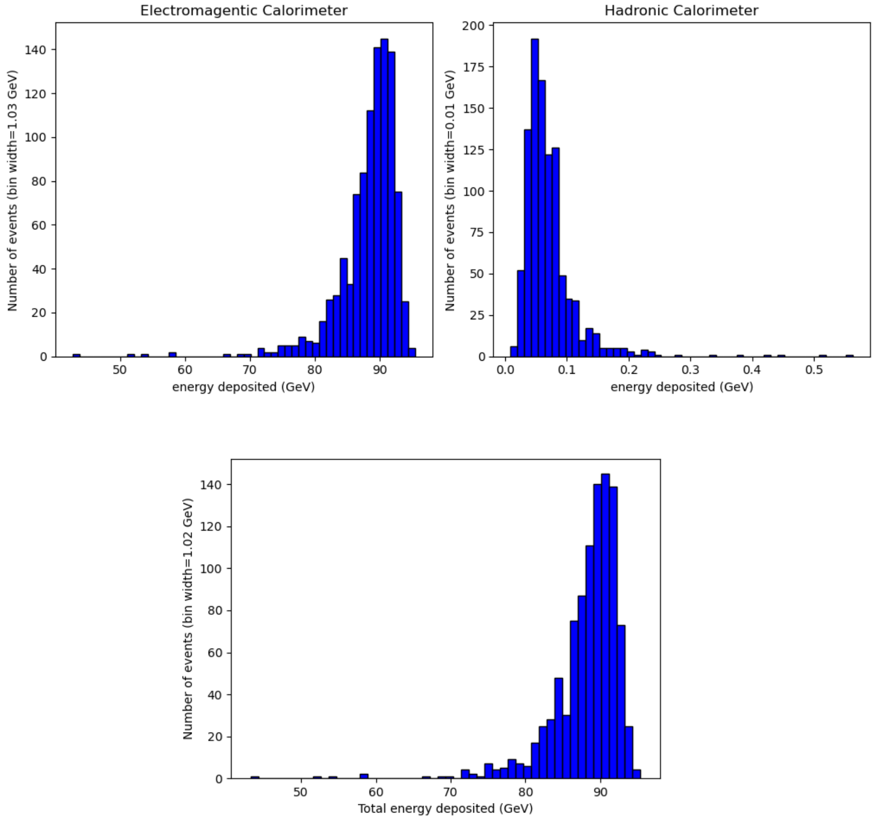

Figure 8: Shows plots of the total energy deposited (no reconstruction) in both calorimeters (seperately and together) for the positron events.

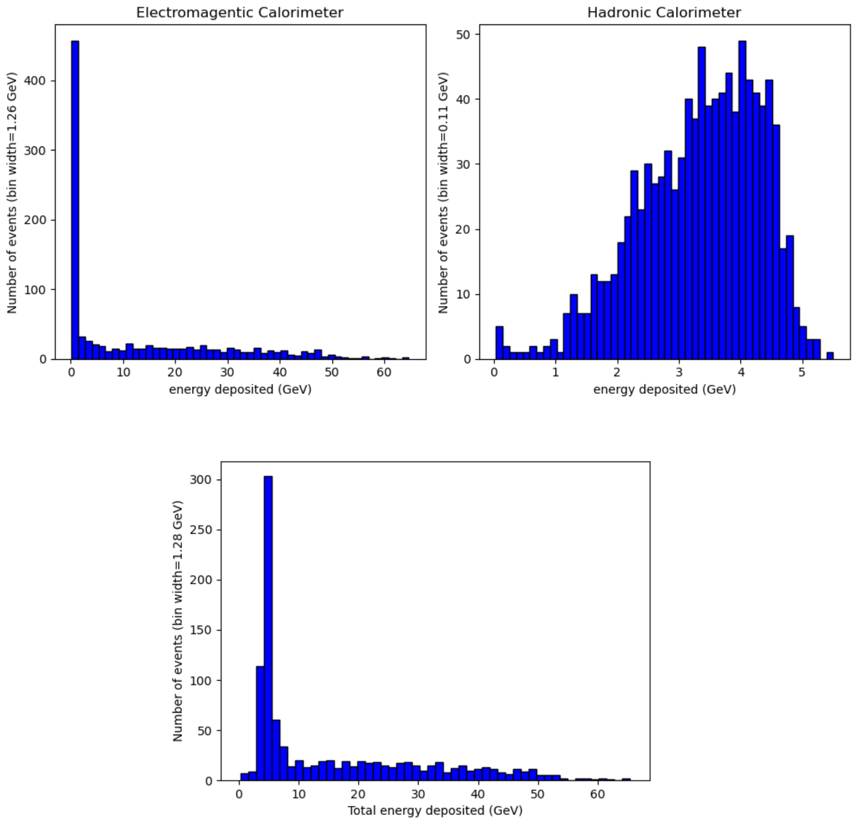

Figure 9: Shows plots of the total energy deposited (no reconstruction) in both calorimeters (seperately and together) for the proton events.

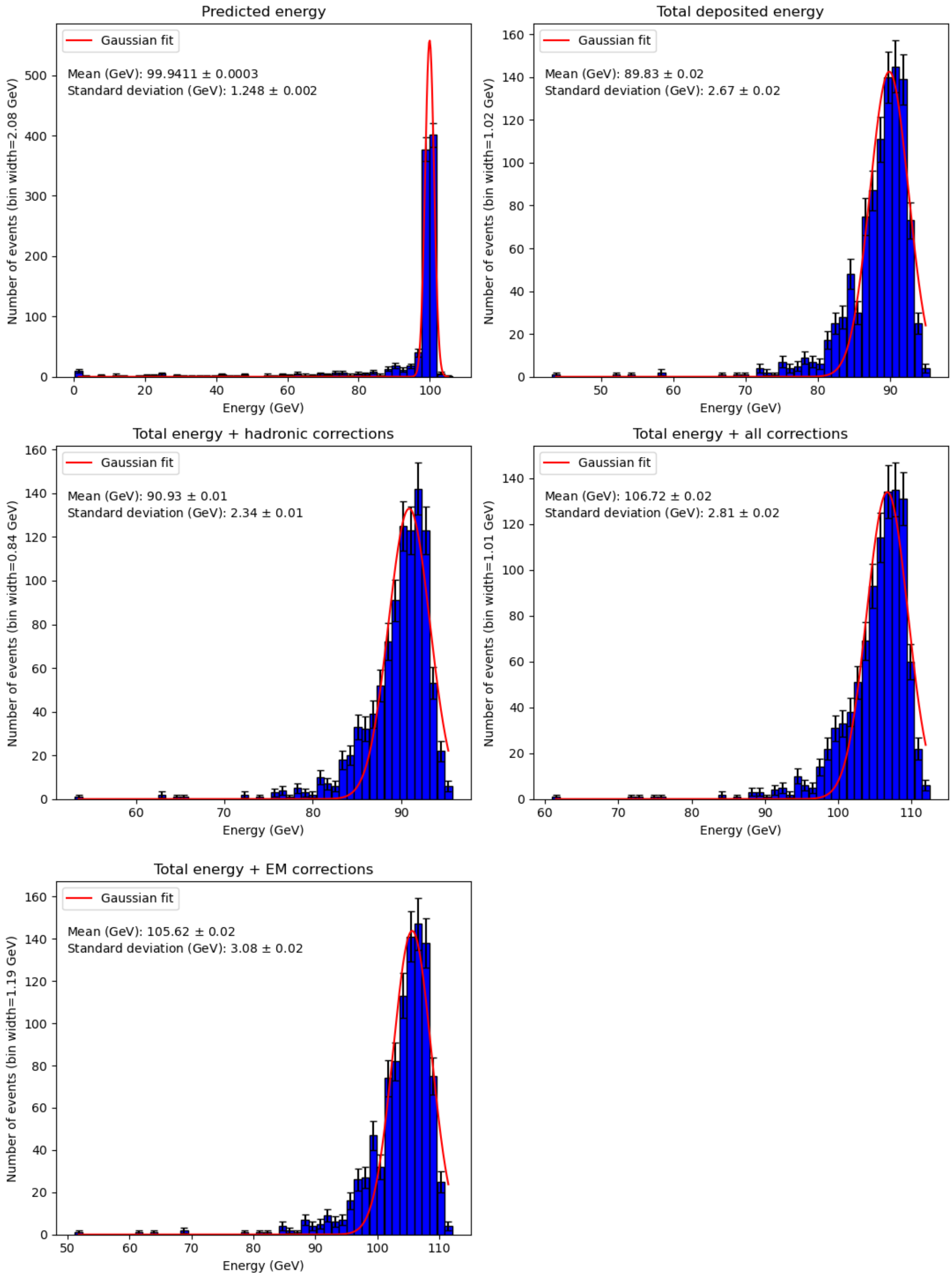

Figure 10: Shows plots of various energy distributions for the positron data, described by the titles above each plot. ALl plots a fitted with the Gaussian function used to fit the momentum distribution in order to get the resolution (standard deviation) and mean energy. These values are given on the plots.

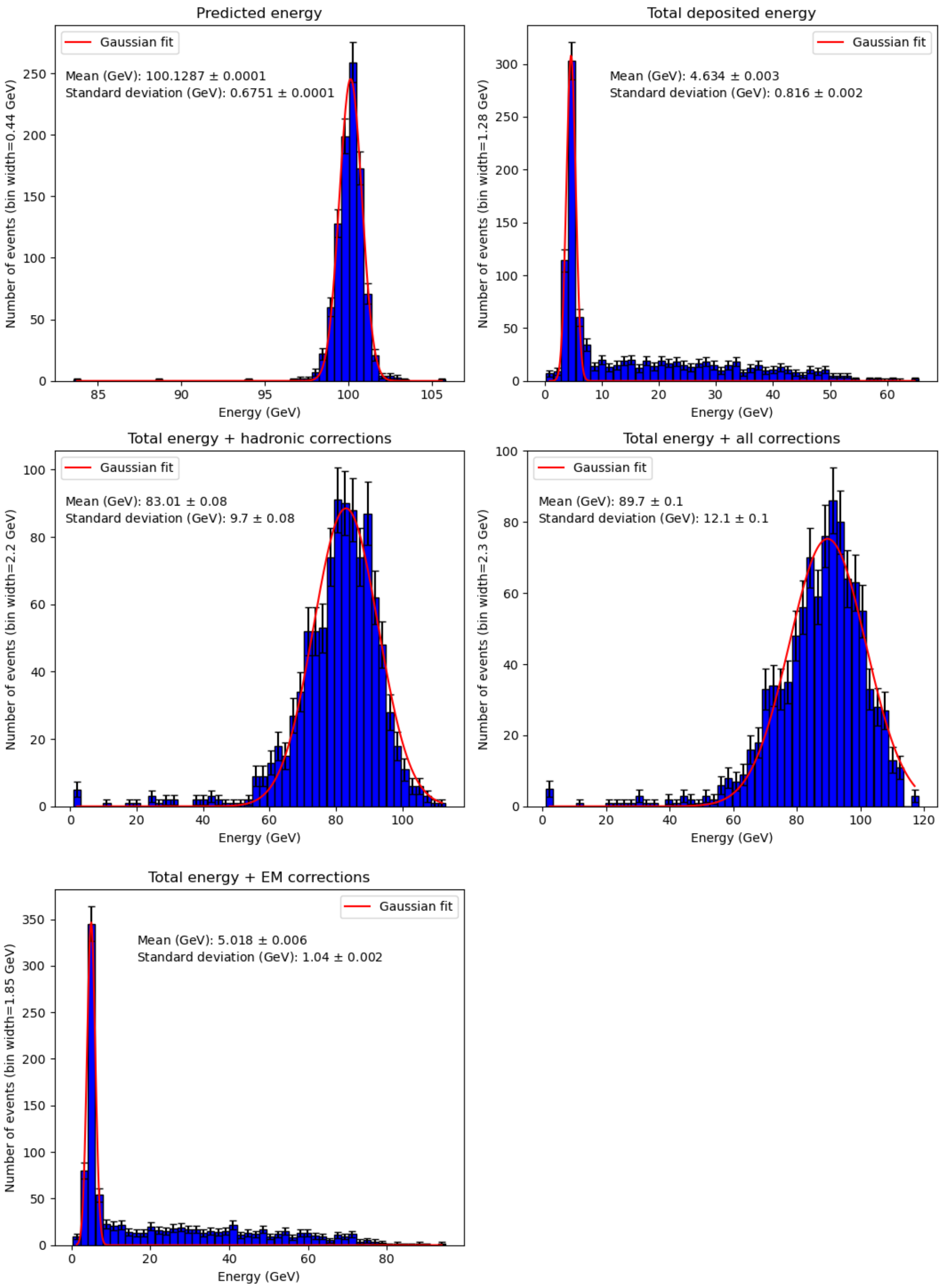

Figure 11: Shows plots of various energy distributions for the proton data, described by the titles above each plot. ALl plots a fitted with the Gaussian function used to fit the momentum distribution in order to get the resolution (standard deviation) and mean energy. These values are given on the plots.