Using HPS ECal Information to Determine the Opening Angle of a Particle from the Target

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18 Feb 2015

1 Motivation

December 2014 HPS running successfully commissioned the ECal and collected data despite not having additional readout information from the SVT. If one is to reconstruct the invariant mass of an e+e- pair from this run, it is necessary to obtain some angular information about the constituent particles. It has been shown previously [1] that an explicit relationship exists between a particle's angle at the target and its location, energy and charge at the ECal.

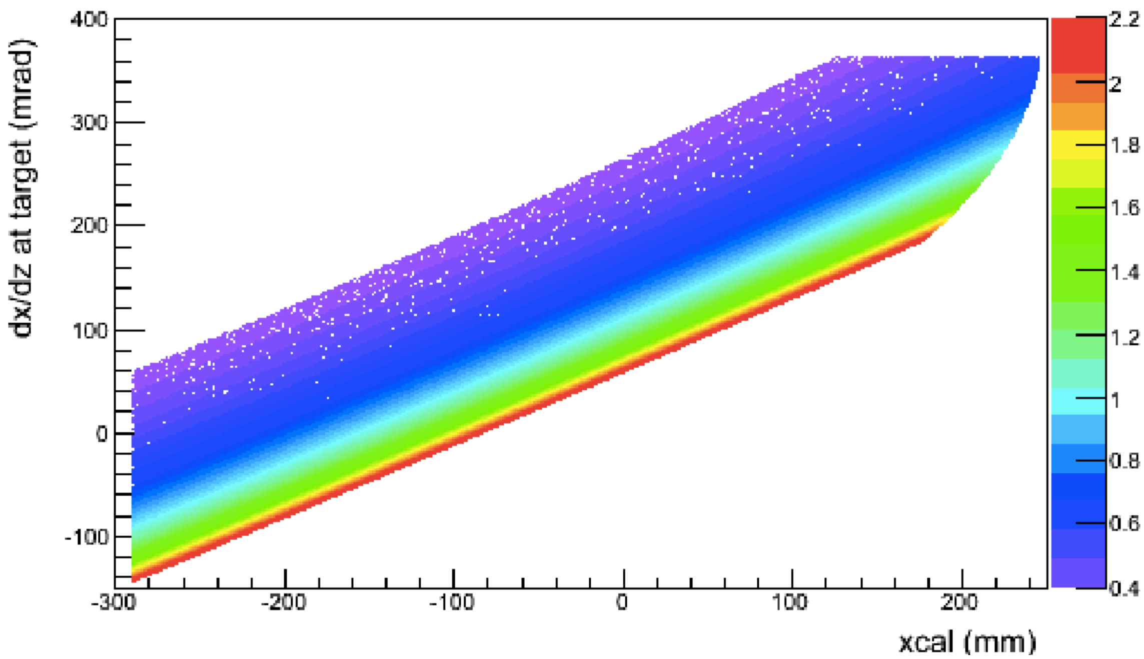


Figure 1: Horizontal angle at the target vs hit position at the ECal, for different color-coded energies in GeV [1].

This analysis will utilize simulation to develop these parameterizations for use in offline data analysis independent of SVT information.

2 Simulation/Method

The development of the parameterizations between the opening angle of a particle at the target and the particle's position at the ECal, energy, and charge is strongly dependent on magnetic field. This analysis utilizes full 2D field mappings including tails of the magnetic field distributions with the run conditions of December 2014. Simulations were performed in GEMC using a pair spectrometer current setting of 503A and a frascati magnet setting of 241.93A (each).

Electrons and positrons were generated from the target uniformly across the full range of acceptance at the ECal at discrete energies of 0.5, 0.75, 1.0, 1.25, 1.5, 2.5 and 5.0 GeV (higher energies inaccessible to HPS during running are used to for parameterizations). The positions of the particles were read out at the position of the face of the ECal as reflected by survey positioning. The HPS coordinate system defines positive z as traveling downstream with the beam and the x,y origin at the target location. Each particle's opening angle was divided into two components. The horizontal component of the angle, phi, is defined as the arctan(px/pz) while the vertical component, theta, is equal to the arctan(py/pz). The momentum is described by projections along each Cartesian axis; px, py, pz.

Phi can be uniquely determined by knowing the x-position of the particle on the ECal and the energy and particle type/charge. Theta can be determined by knowing the y-position of the particle on the ECal alone due to the magnetic fields running parallel to the y-axis. The complete parameterizations was studied by dividing the face of the ECal into a 1 mm by 1mm grid and then finding the angles associated in these segments (this is smaller than our position resolution [1] so should not be susceptible to resolution effects).

3 Parameterizations

For each milli-meter in x and in y, the mean angle of this distribution was plotted versus the position. This yields a linear relationship between the angle and the position for both phi and x and theta and y.

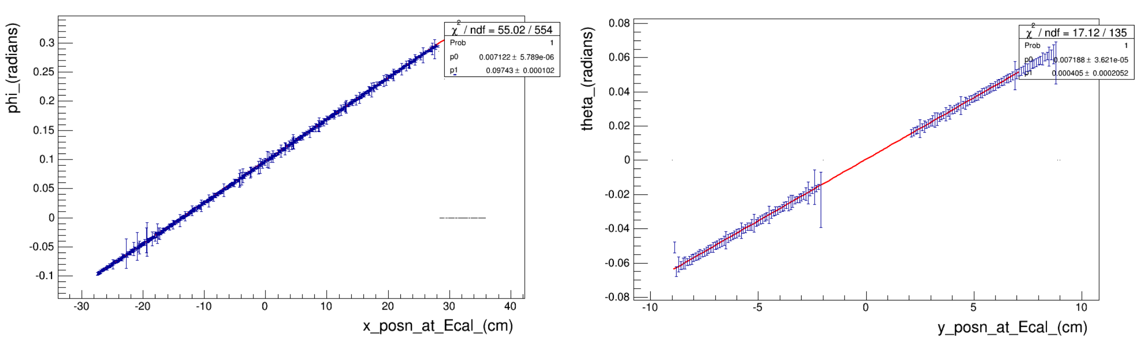


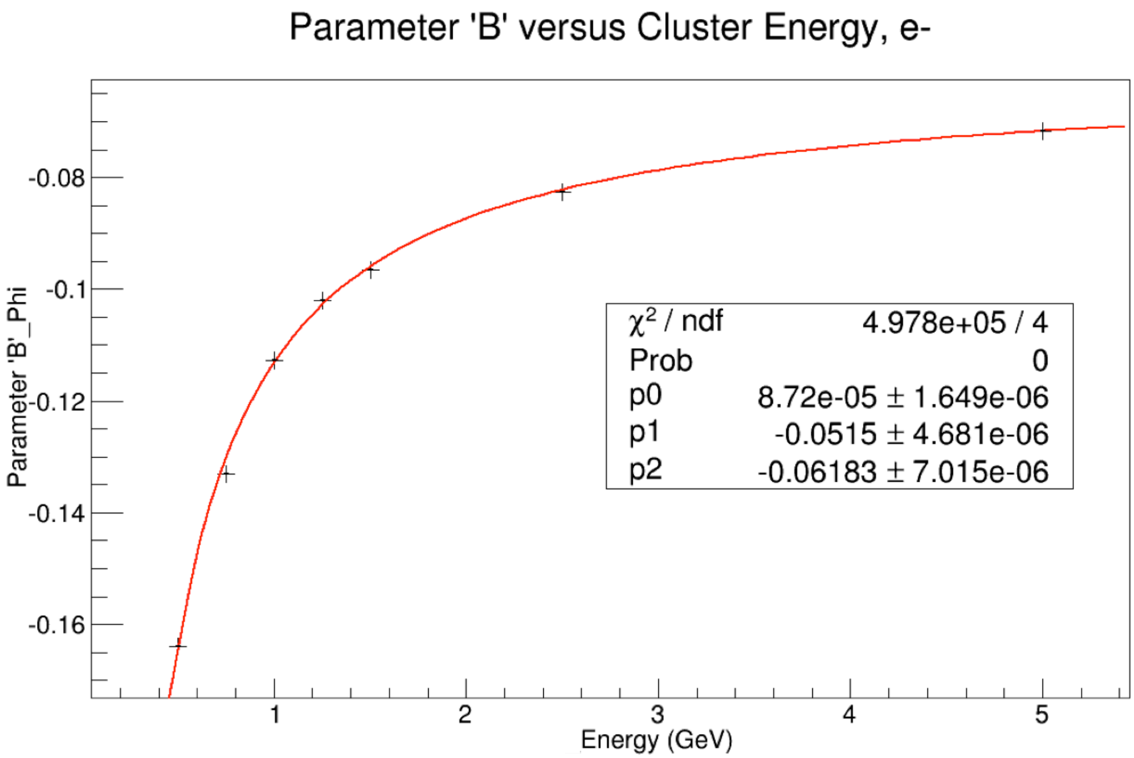
Figure 2: Opening angle components versus position at the ECal for 1 GeV electrons.

For each energy and particle type, the relationship between the angle and position coordinate were fit with a linear straight line fit.

$$\varphi = A(E)x + B(E)$$
$$\theta = A(E)y + B(E)$$

Equation 1.

The variables from Equation 1 for the slope, A, and the intercept, B, were then plotted as a function of energy to locate any energy dependence. A strong energy correlation with the energy was found for the variable phi's intercept. While the slope of the fit for phi was unaffected by energy, the relationship of the intercept variable (B) was dependent on the energy of the particle. The parameterizations for phi's shift variable are shown in Figure 3.



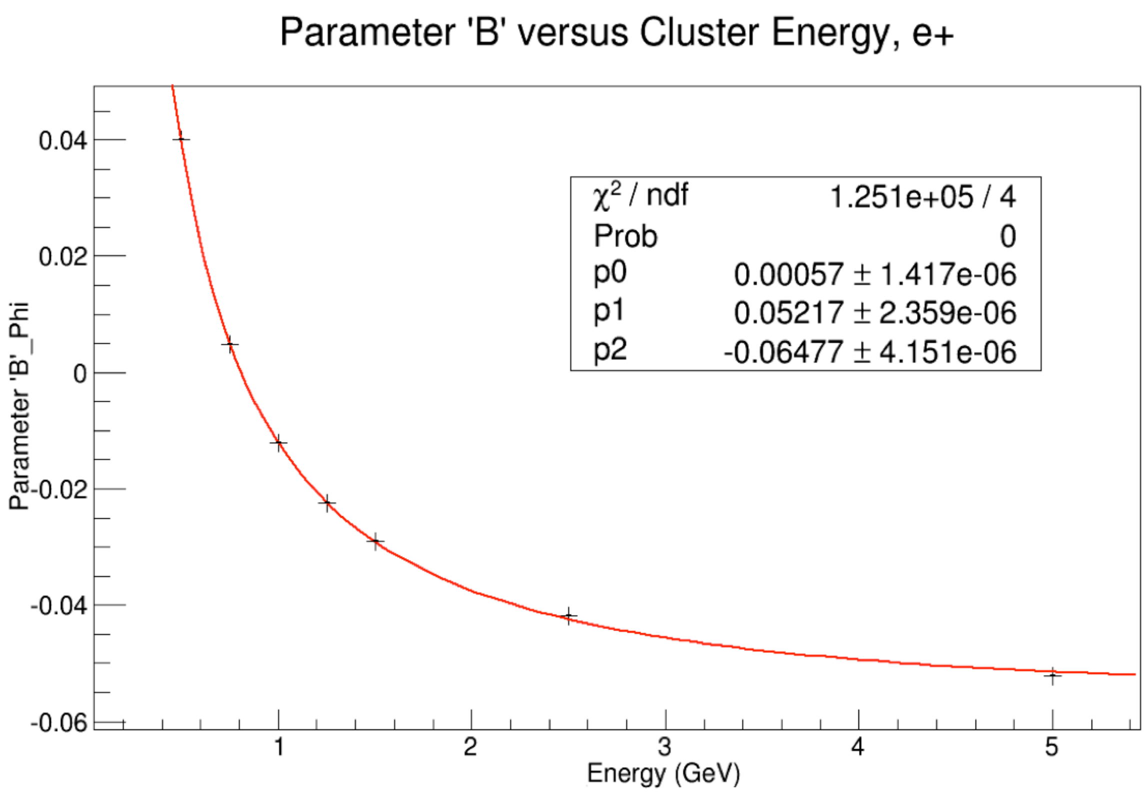


Figure 3: Intercept parameter "B" versus the generated particle energy for phi for both electrons and positrons.

The energy dependence of the intercept variable for phi was fit with Equation 2 where E is the full energy of the generated Monte Carlo particle, and p represents various fit parameters.

$$B(E) = p_0 E + \frac{p_1}{E} + p_2$$

Equation 2.

The final results of all parameterizations are summarized in Table 1.

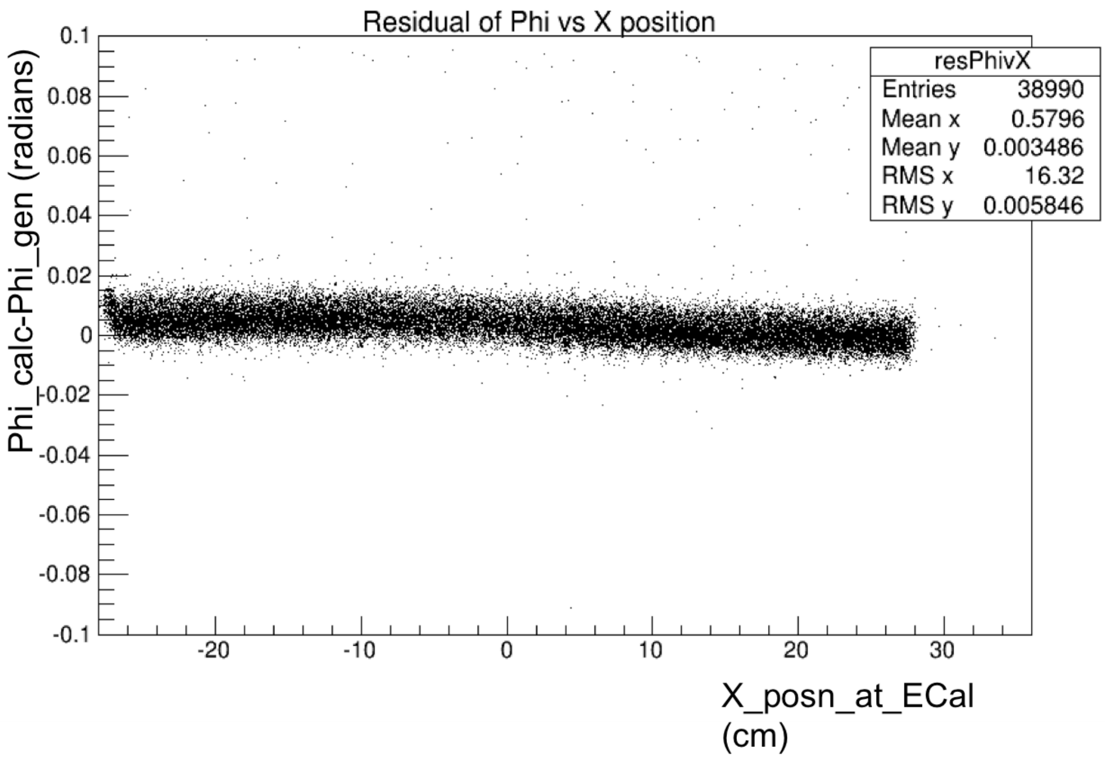
e-	**theta**	0.00072 y
	phi	0.00072 x + 0.0000872 E - 0.0515/E - 0.06183
e+	**theta**	0.0072 y
	phi	0.0007 x + 0.00057 E + 0.05217/E -0.06477

Table 1: Summary of parameterizations using particle energy (E), type, and position (x/y) to obtain the opening angle components.

These values were found using full energy generated particles and position information at the face of the ECal. In reality, there will be position corrections and energy corrections that will need to be applied to a cluster in order to apply these parameterizations and extract the opening angle.

4 Resolution

The angular resolution was studied after applying cluster position corrections and cluster energy corrections. Events were chosen when the cluster carried greater than 80% of the incident particle energy. The residual difference between the calculated angle at the target and the generated angle at the target were checked for various dependencies on position and angle. Since the residual for the angle versus its position is the same as the residual versus the generated angle, the position dependencies are shown in Figure 4.



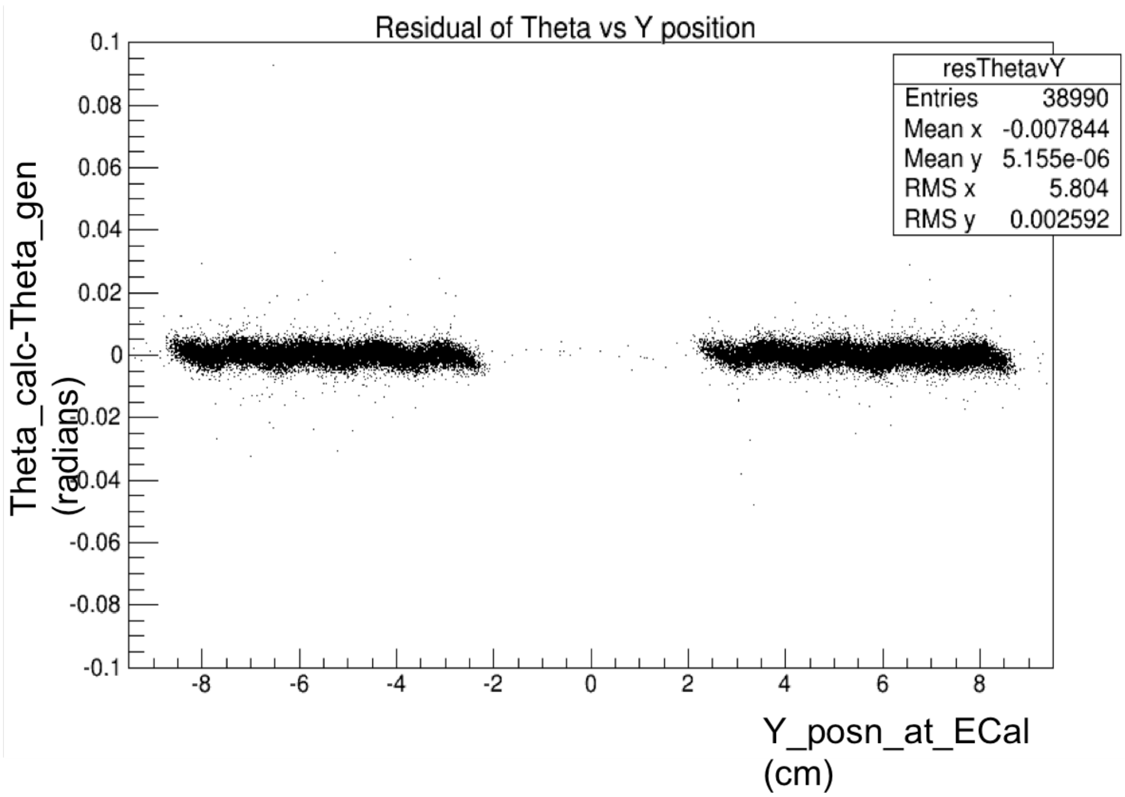
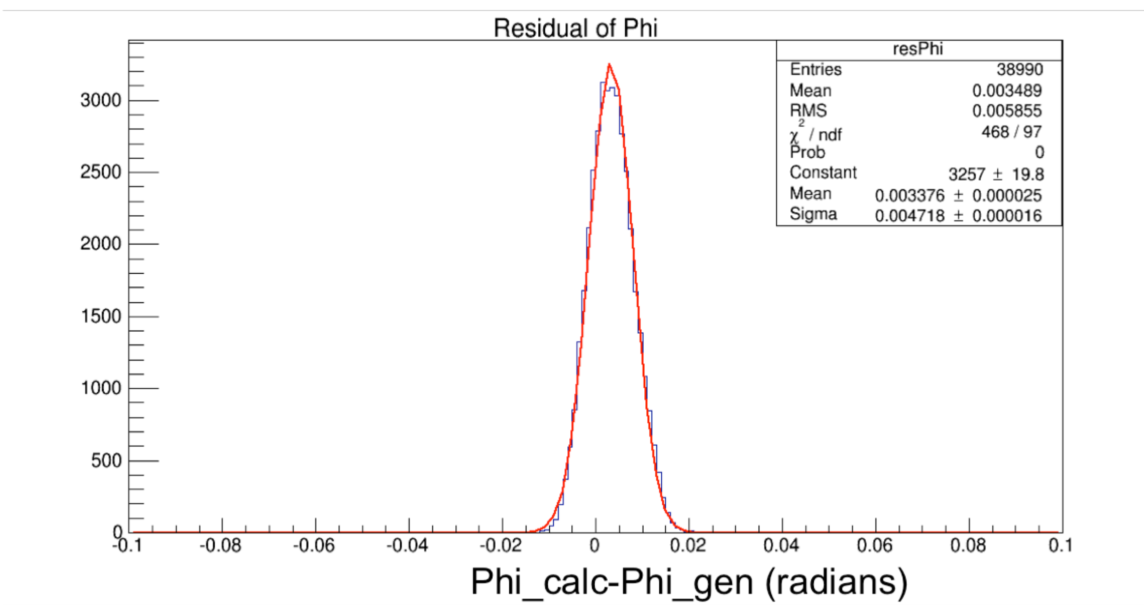


Figure 4: Residuals of phi and theta versus position along the face of the ECal for 1GeV electrons. Results are comparable for positrons.

Additionally, the residuals of each angle phi and theta were found as a function of energy.



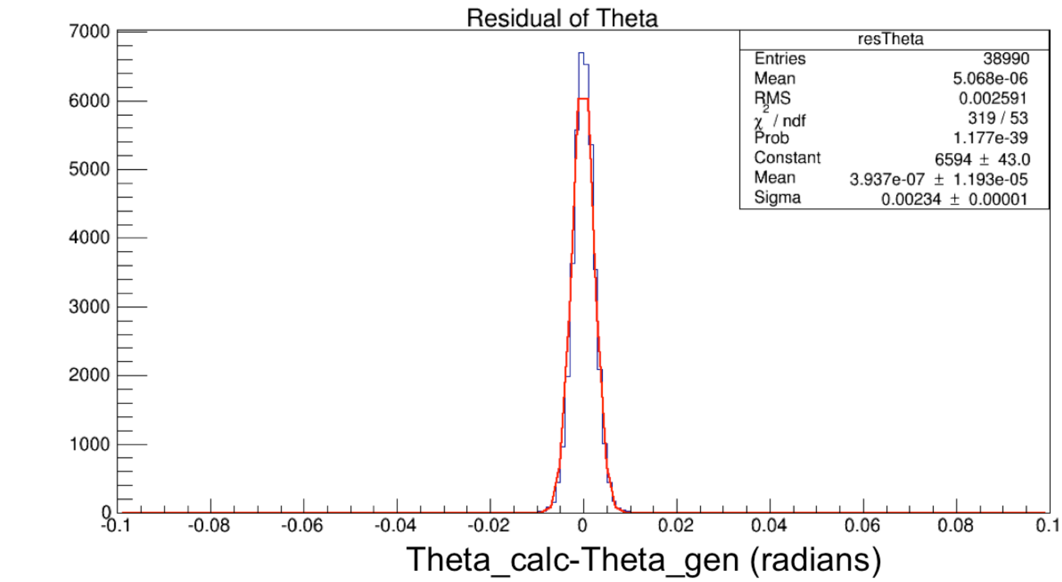
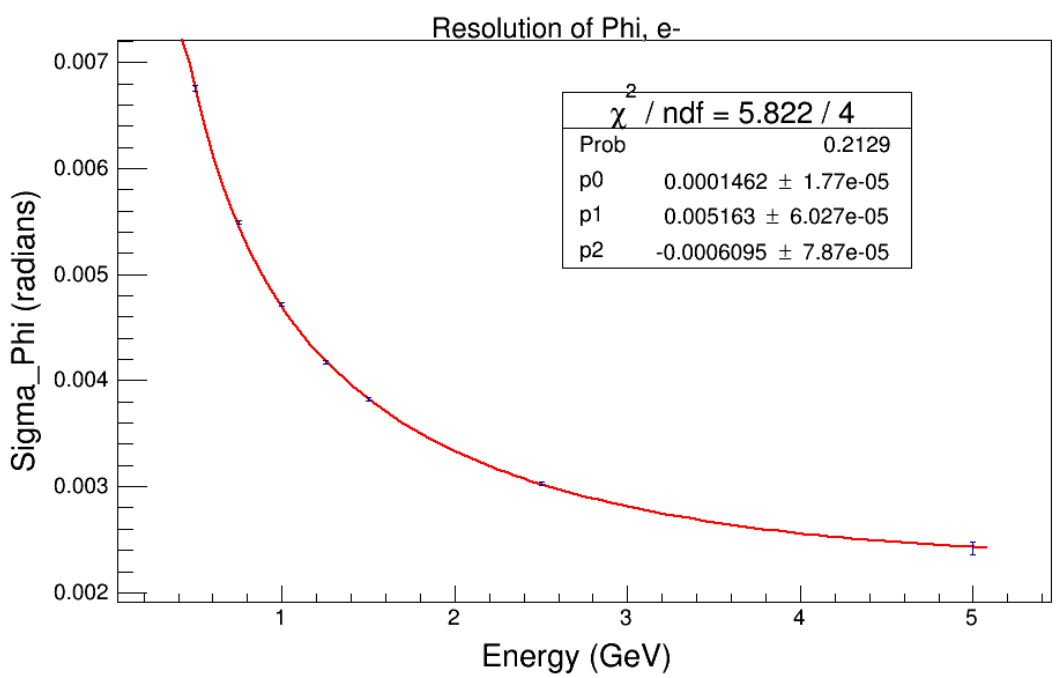
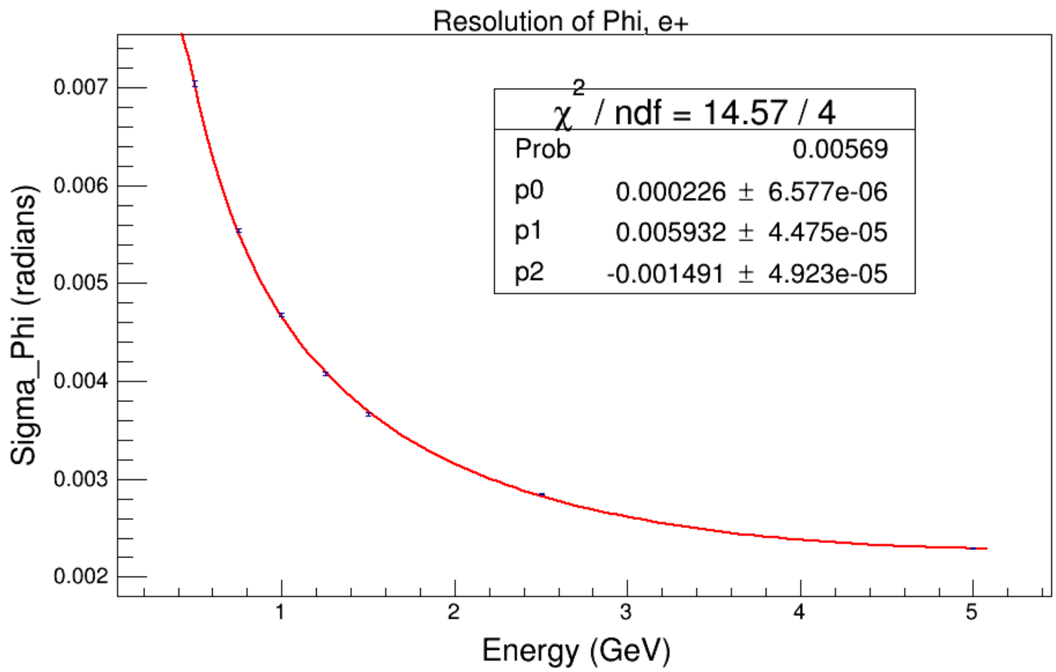
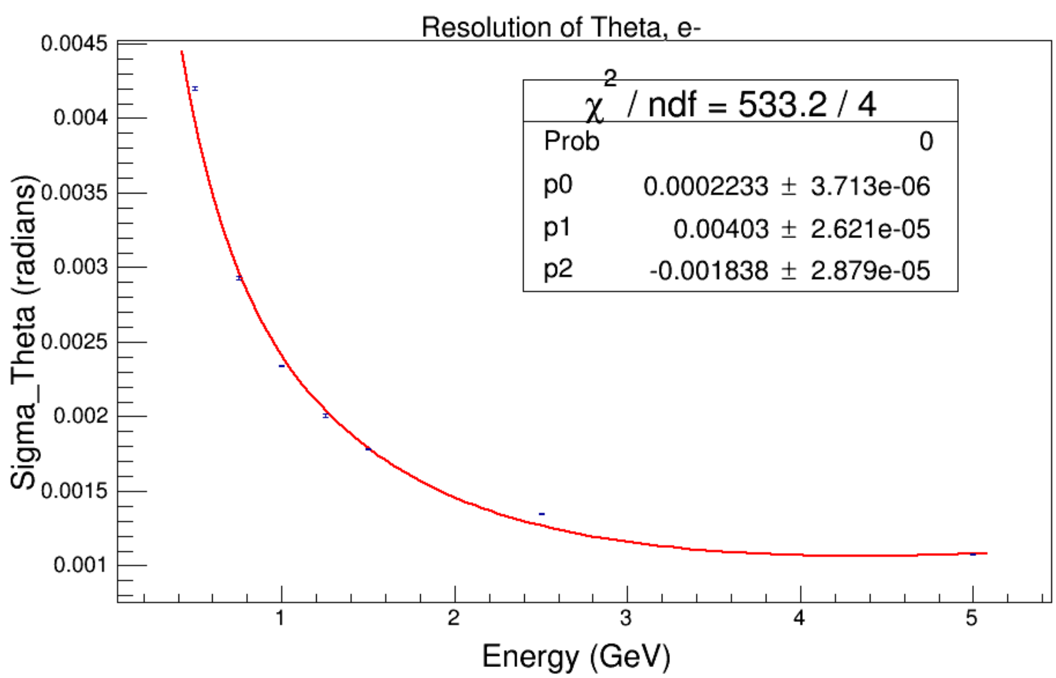


Figure 5: Residuals of Phi and Theta for 1GeV electrons. Results are comparable for positrons.

Additionally, the residuals of each angular component were plotted versus the energy as in Figure 6. The energy dependence of the resolution was fit with a three-parameter fit as shown in Equation 3. As one can see from Figure 6, the resolution of the angular components improves with energy. This is a result of both improved energy and position resolution for higher energy clusters.




Resolution of Phi, e+
χ^2 / ndf = 14.57 / 4
Prob 0.00569
p0 0.000226 ± 6.577e-06
p1 0.005932 ± 4.475e-05
p2 -0.001491 ± 4.923e-05
Sigma_Phi (radians)
0.007
0.006
0.005
0.004
0.003
0.002
1
2
3
4
5
Energy (GeV)


Resolution of Theta, e-
χ^2 / ndf = 533.2 / 4
Prob 0
p0 0.0002233 ± 3.713e-06
p1 0.00403 ± 2.621e-05
p2 -0.001838 ± 2.879e-05
Sigma_Theta (radians)
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
1
2
3
4
5
Energy (GeV)

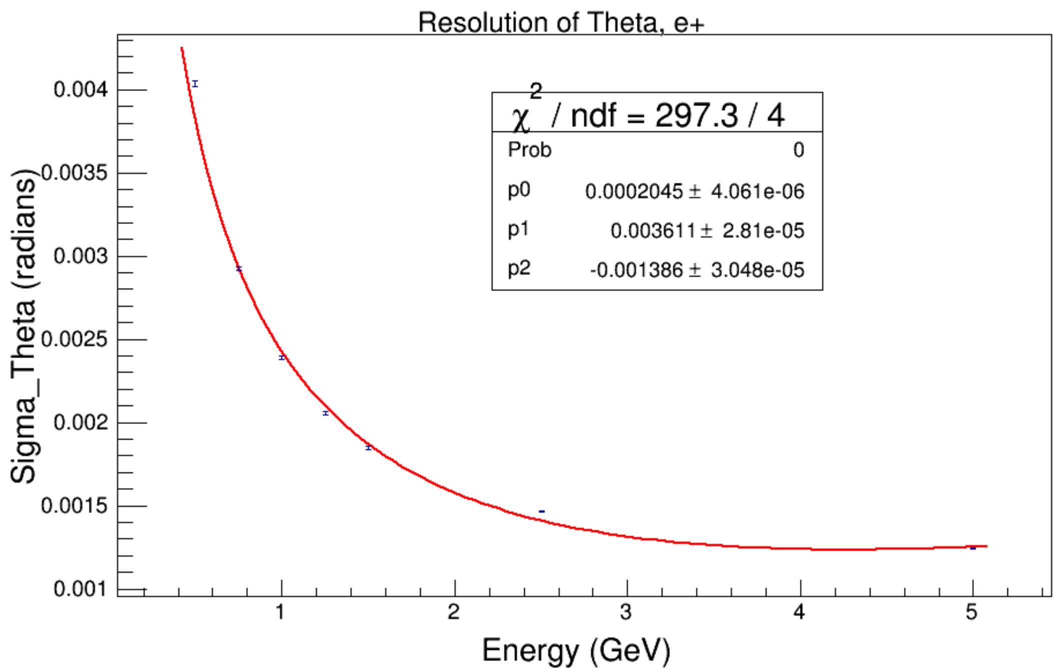


Figure 6: Energy dependent resolution of the angular components of theta and phi for both electrons and positrons.

$$\sigma_\theta = p_0 E + \frac{p_1}{\sqrt{E}} + p_2$$

Equation 3.

Phi, as expected due to the magnetic field, has a worse resolution than theta by an approximate factor of two. Using this relationship, the overall result on the invariant mass resolution can be calculated as previously discussed [1] with Equation 4.

$$\sigma_m \simeq 0.7 \frac{M(MeV)}{100} \times \frac{\sigma_E}{E}(\%) \oplus 1.2\sigma_\Theta(mrad)$$

Equation 4. [1]

Using the simulated ECal energy resolution of 3.6% at 1 GeV and a horizontal angular resolution of 6.3 mrad, the overall invariant mass resolution is 6.2 MeV for a 100 MeV mass using the ECal only. This can be compared to the resolution obtained by including ECal and SVT information in [1].

5 Conclusions

For the HPS commissioning run in December 2014, a precise parameterization of a particle's position at the ECal and energy can provide angular information about the particle at the location of the target. While the resultant invariant mass resolution is about a factor of two worse than could be obtained with the SVT, this parameterization can be used for data obtained using ECal information only as in the December 2014 run.

6 References

[1] H. Szumila-Vance and M. Garçon, HPS Note 2014-001