Dependence of the Spatial and Energy Resolution of BCAL on Segmentation

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Abstract: The spatial and energy resolution of the Barrel Calorimeter was investigated for different segmentations using HDGEANT and the BCAL reconstruction code. Single photons and neutral pions at random angles were considered with momenta ranging from 100 MeV/c to 2 GeV/c.

1. Outline

The spatial (in Z and rφ) and energy resolution of BCAL was investigated for different number of layers and sectors of each module, using HDGEANT and the BCAL reconstruction code integrated in DANA. Five different energies (100 MeV, 200 MeV, 500 MeV, 1 GeV and 2 GeV) for single photons, and five different momenta (100 MeV/c, 200 MeV/c, 500 MeV/c, 1 GeV/c and 2 GeV/c) for neutral pions were used, and neither physics nor accidental background was considered.

The layer and sector numbers were varied from 2 to 10 for both gamma and π^0 events were simulated and analyzed. Energy smearing according to the standalone BCAL Monte Carlo data was applied, and time smearing according to the expected one and based on the preliminary results from the TRIUMF beam test. Attenuation was also applied. All particles were generated with uniform random angles.

2. Spatial Resolution for Single Photons

The Z resolution dependence on the number of layers (in the first 10 cm depth of the BCAL modules) and on the number of sectors (again the first 10 cm depth) is shown in Fig. 1 and Fig. 2, respectively. The segmentation of the outer layers of the modules was kept constant during all calculations (4 layers and 3 sectors). The Z resolution dependence on the number of layers is more pronounced (as was expected) and changes in the range of 25-30% for the different incident energies, while the dependence on the sector number varies about less than 10%. Since the Z resolution is directly connected with the time resolution of BCAL, it may be useful to use up to five or six layers, as the variation above those is less pronounced (of the order of 15%).

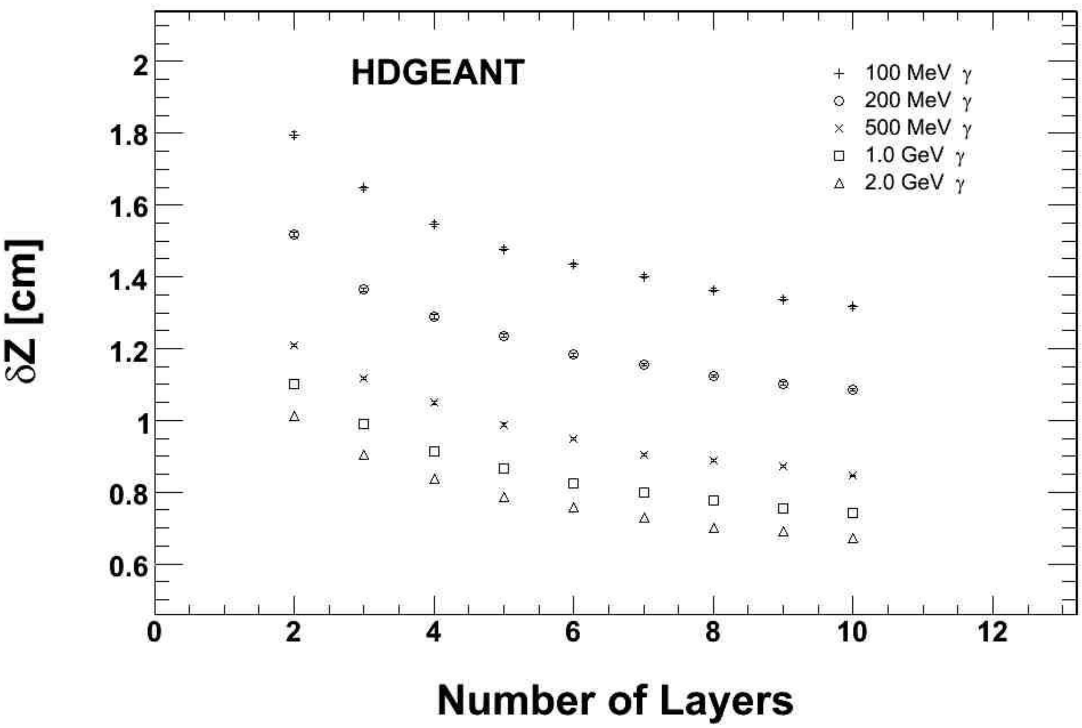

Fig. 1 Dependence of the Z resolution on the number of layers for gamma.

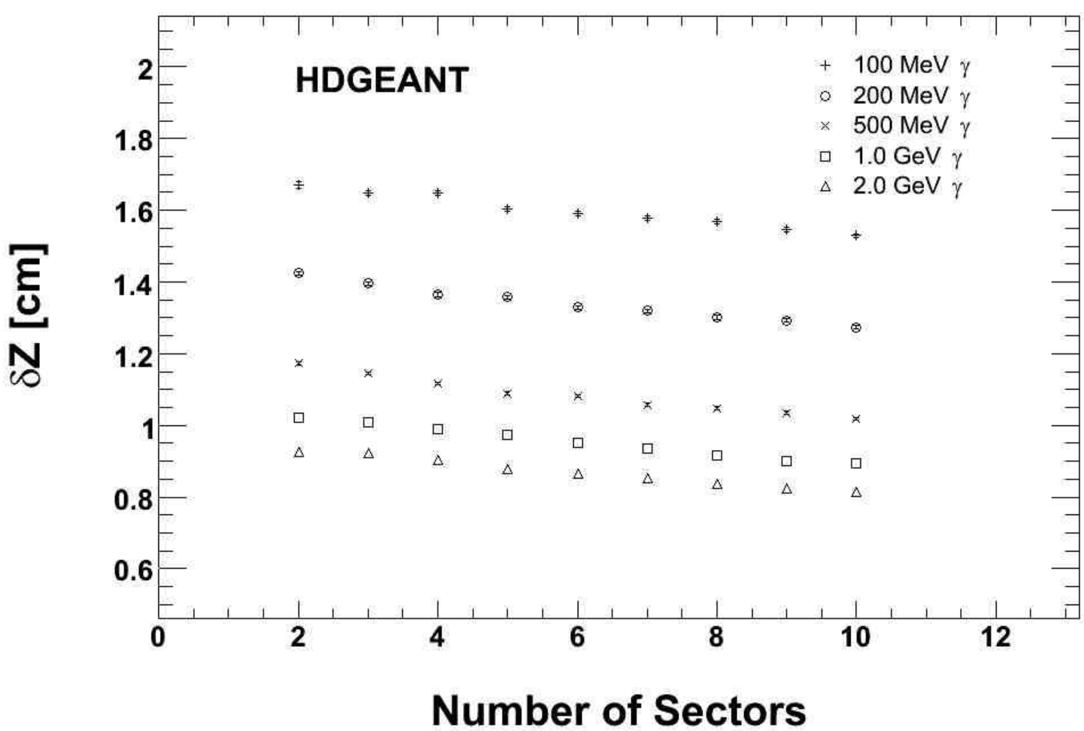

Fig. 2 Dependence of the Z resolution on the number of sectors for gamma.

The dependence of the rφ resolution on the number of layers and the number of sectors is shown in Fig. 3 and Fig. 4, respectively. This resolution does not depend on the number of layers, but varies with the number of sectors from about 20-25% (for 2 GeV gamma) up to 30-50% for the lowest tested incident energies. This significantly improves for sector numbers four and especially five (for sector numbers from 5 to 10 the resolution only changes 12-15% for the various energies), so this seems to be a reasonable number to use.

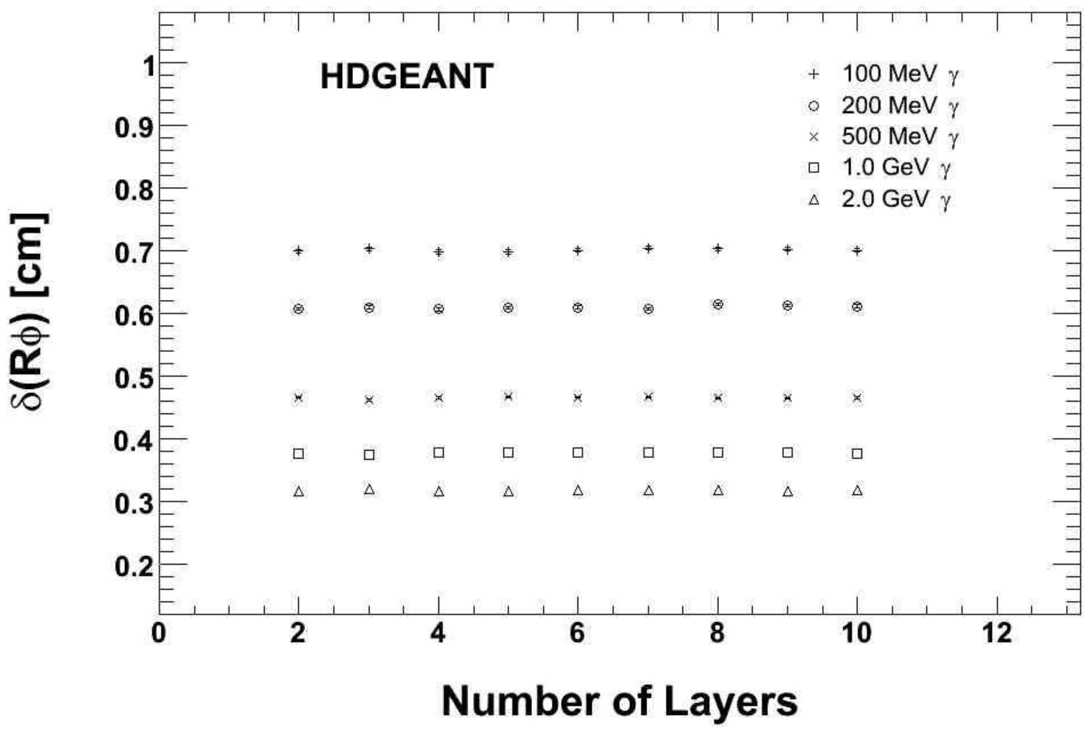

Fig. 3 Dependence of the rφ resolution on the number of layers for gamma.

3. Energy Resolution For Single Photons

The dependence of the energy resolution for single photons on the number of layers and the number of sectors is shown in Fig. 5 and Fig. 6, respectively. As is evident from the plots, the energy resolution depends at weakly (of the order of 5%) on the number of layers (excluding the number of layers = 2 case, which is obviously an insufficient number of layers) and even less on the number of sectors. Fig. 7 shows qualitatively the behavior of the energy resolution with the change in energy. This still does not include the electronics factors,

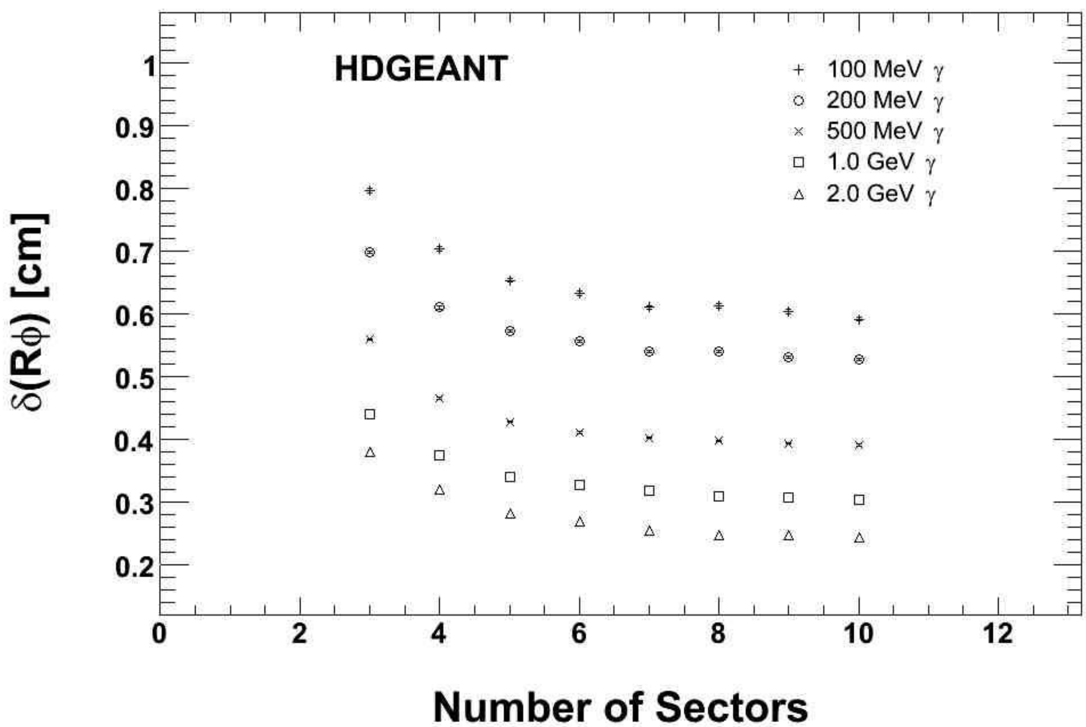

Fig. 4 Dependence of the rφ resolution on the number of sectors for gamma.

but, on the other hand, the effect of Monte Carlo fluctuations is higher. The dependence shown obeys:

$$\frac{\delta E}{E} = 1.2 + \frac{5.0}{\sqrt{E}}$$

The percentages should be taken more as "order of magnitude" numbers, as there are more factors to be taken into account. The result shows though that the energy resolution obeys the expected relationship with realistic coefficients.

4. Comparison between "Square" Configuration and Other Shapes

In an attempt to qualitatively test if the "square" segmentation of the inner half of the BCAL modules is optimal, three different configurations were tested (with the same number of "readout" elements – 36, meaning practically the same number of electronic channels and roughly the same price ultimately). The respective numbers for 100 MeV gamma are shown in Table 1 and for 1 GeV gamma in Table 2. The energy resolution is not very much affected, but the Z and rφ resolution show opposite tendencies (as expected). Of course the two spatial resolutions have different impact, and for example, if

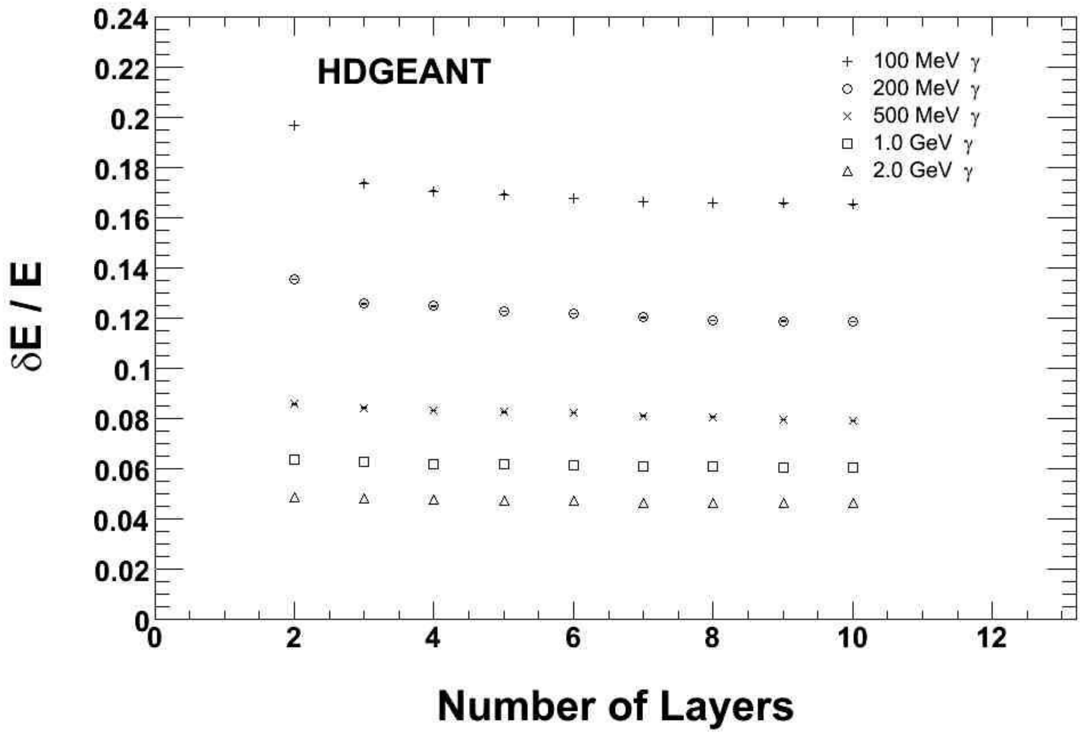

Fig. 5 Dependence of the energy resolution on the number of layers for gamma.

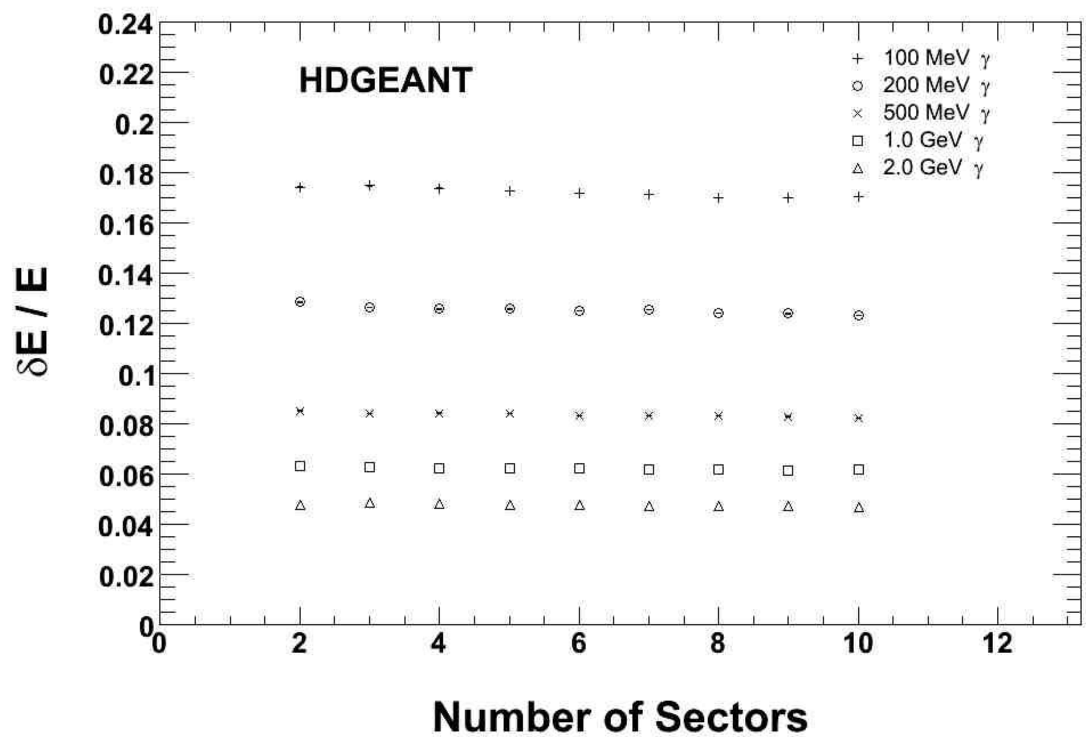

Fig. 6 Dependence of the energy resolution on the number of sectors for gamma.

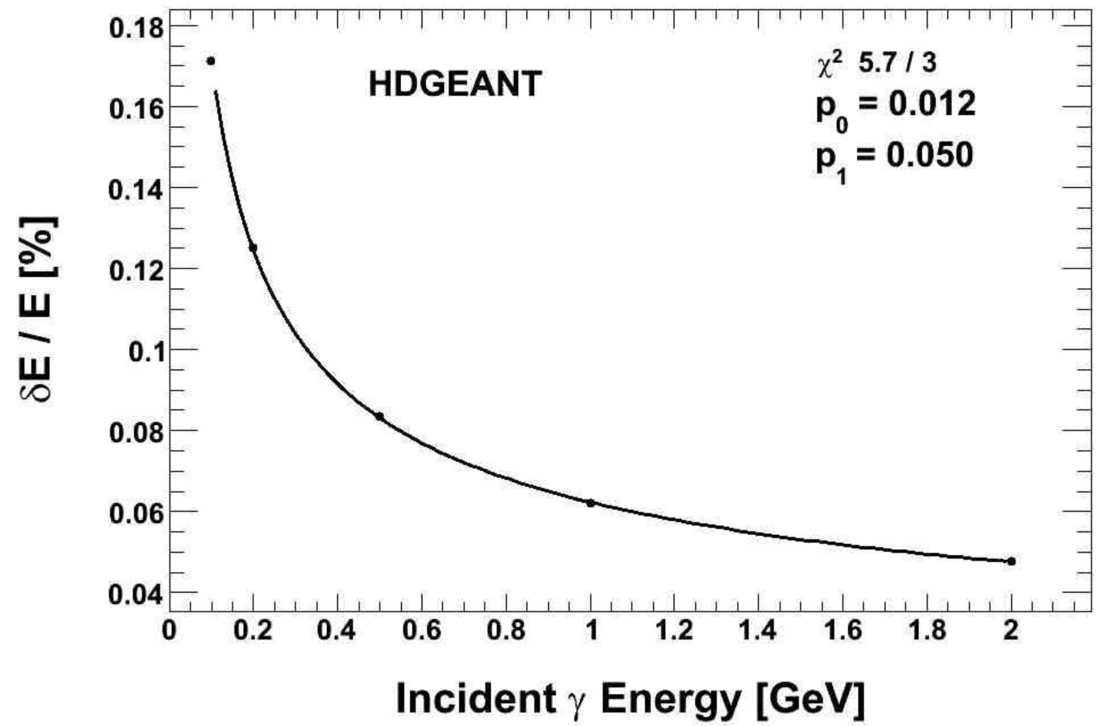

Fig. 7 Dependence of the energy resolution on the incident gamma energy.

Layers × Sectors	rφ resolution, cm	Z resolution, cm	Energy Resolution, MeV
9 × 4	0.703 ± 0.003	1.337 ± 0.005	16.6 ± 0.1
6 × 6	0.632 ± 0.003	1.41 ± 0.01	16.9 ± 0.1
4 × 9	0.603 ± 0.003	1.451 ± 0.005	16.9 ± 0.1

Table 1 Resolutions for equal number of readout elements but different layer and sector number for 100 MeV photons.

Layers × Sectors	rφ resolution, cm	Z resolution, cm	Energy Resolution, MeV
9 × 4	0.379 ± 0.001	0.754 ± 0.003	60.8 ± 0.2
6 × 6	0.325 ± 0.001	0.807 ± 0.003	60.7 ± 0.2
4 × 9	0.304 ± 0.001	0.844 ± 0.003	61.1 ± 0.2

Table 2 Resolutions for equal number of readout elements but different layer and sector number for 1 GeV photons.

higher Z resolution must be achieved, a higher number of layers at the expense of lower number of sectors may be more appropriate.

5. Invariant Mass for π^0

The invariant mass of neutral pions was reconstructed (when both photons produced by their decay are detected in the barrel calorimeter) and its dependence on the number of layers was investigated. Two sample plots of the reconstructed invariant mass are shown in Fig. 8 and Fig. 9, for 2 GeV pions and 200 MeV pions, respectively. The quality of the fits was reasonable for all energies and segmentations. The results for the fitted parameters of the resolution of the invariant mass and the invariant mass itself are shown in Fig. 10 and Fig. 11, respectively. The directions for the momentum used to calculate the invariant mass were calculated by using the entry point of the gamma into the BCAL and the Monte Carlo vertex (under the assumption that the vertex will be known from charged tracks and the spatial resolution of the BCAL will carry most of the uncertainty in the momentum).

The invariant mass shows steady decrease with the number of layers. Since the particles' incident angles are random, a correction function (of the dependence of the reconstructed energy on the entry point Z) may be applied to improve the reconstructed energy [1]. Determining such a function would require a more detailed study with fixed directions of the incident particles.

The resolution of the reconstructed invariant mass varies from 10% for the highest energy pions up to about 20% for the lowest energy ones. The variation with the number of layers is 5 to 8%. A number of layers of five or more produces a resolution that varies only within about 5%.

There is no discernible dependence (within the estimated error) of the resolution of the reconstructed invariant mass on the number of sectors (Fig. 12). The absolute values of the resolution for the different energies studied are similar to those with varying number of layers. The pion mass peak (Fig. 13) shows the same dependence on the sector number (the invariant mass decreases when the number of sectors increases). This can be again improved by careful corrections.

As a speculation, the decrease in the pion mass may be due to energy cutoffs (in more sectors more energy is likely to fall under the cutoff), despite the fact that the invariant mass is not directly proportional to the energy, but is a more complicated function of the energies and momenta of the two gamma particles. This then becomes a pure calibration issue and can be corrected.

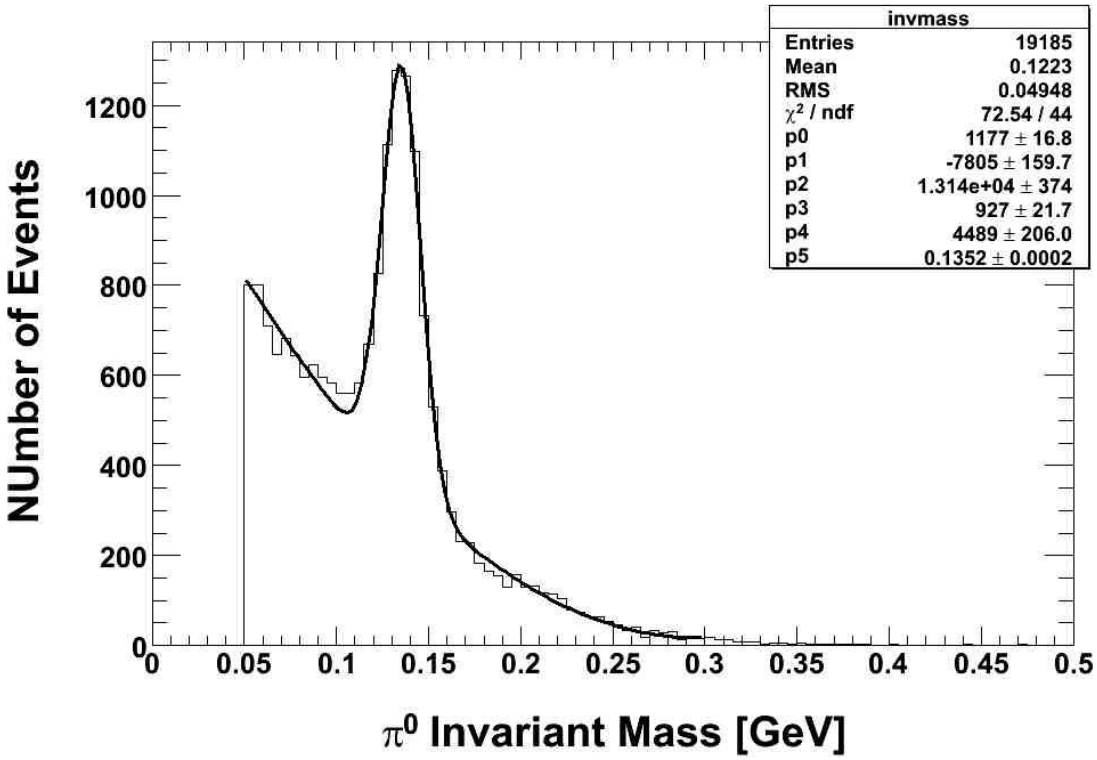

Fig. 8 Invariant mass reconstructed for 2 GeV/c neutral pions.

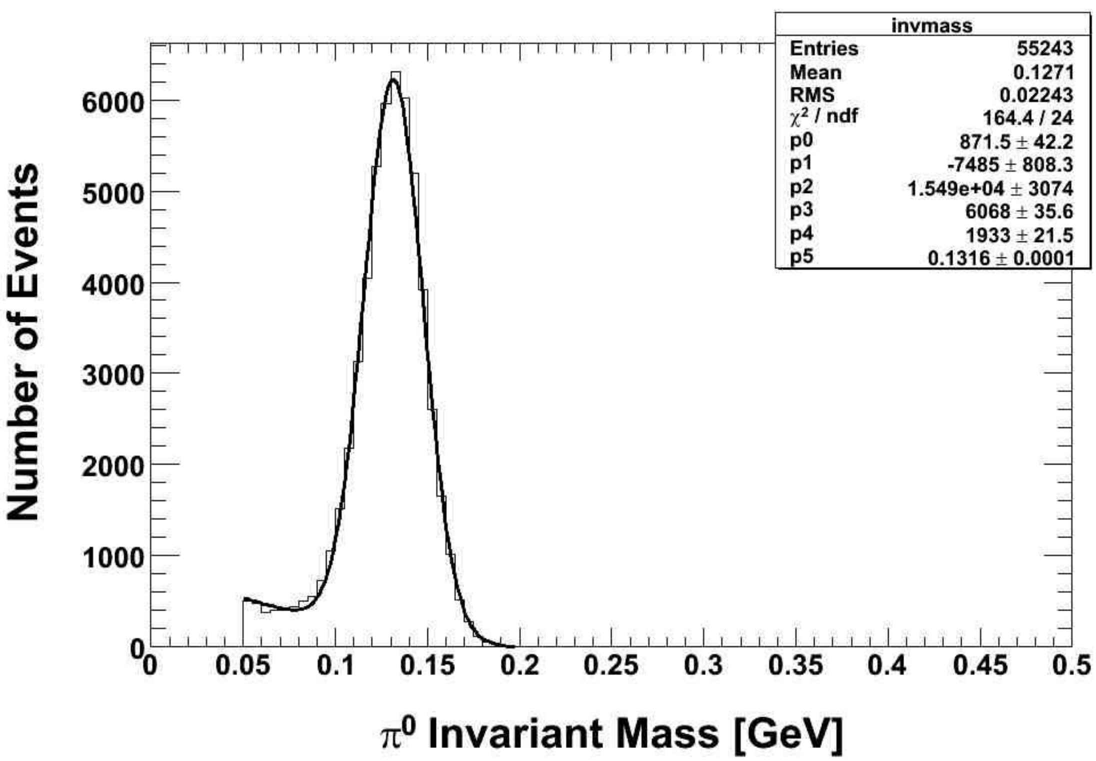

Fig. 9 Invariant mass reconstructed for 200 MeV/c neutral pions..

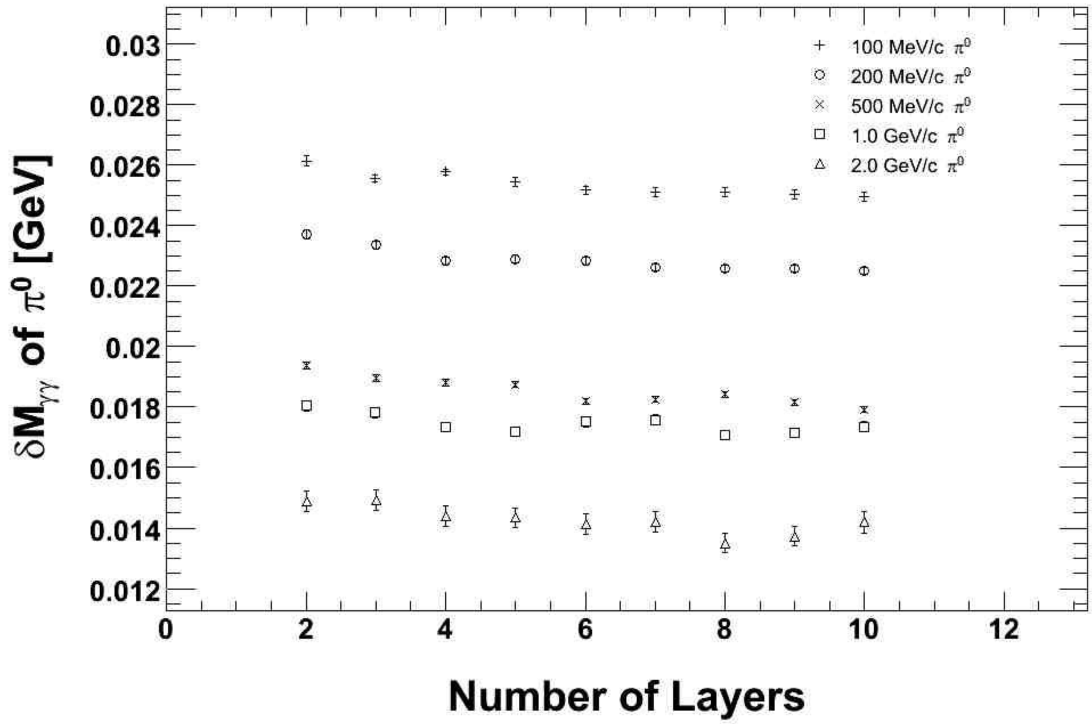

Fig. 10 Dependence of invariant mass resolution on the number of layers.

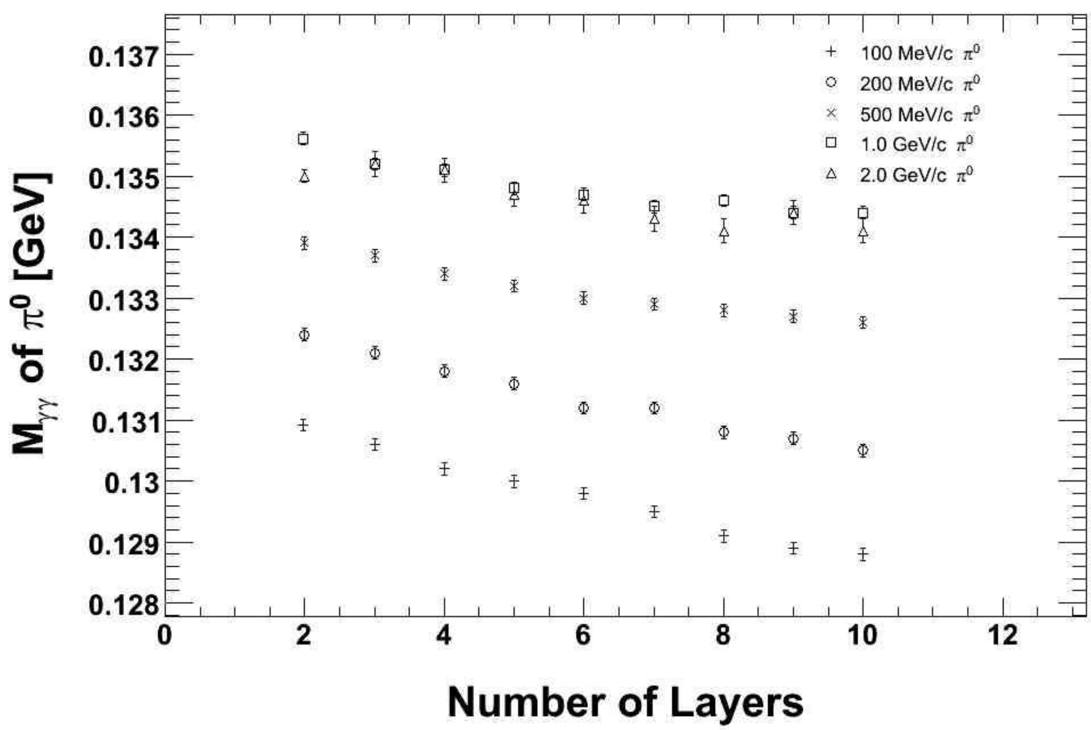

Fig. 11 Dependence of the peak position of the invariant mass on the number of layers.

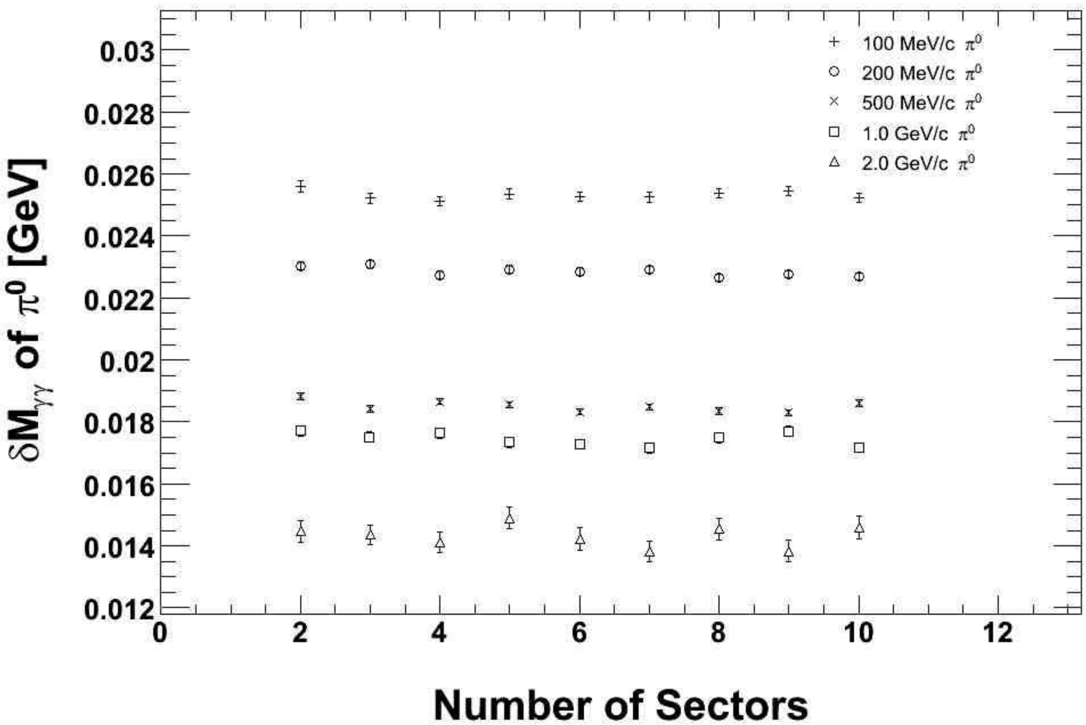

Fig. 12 Dependence of invariant mass resolution on the number of sectors.

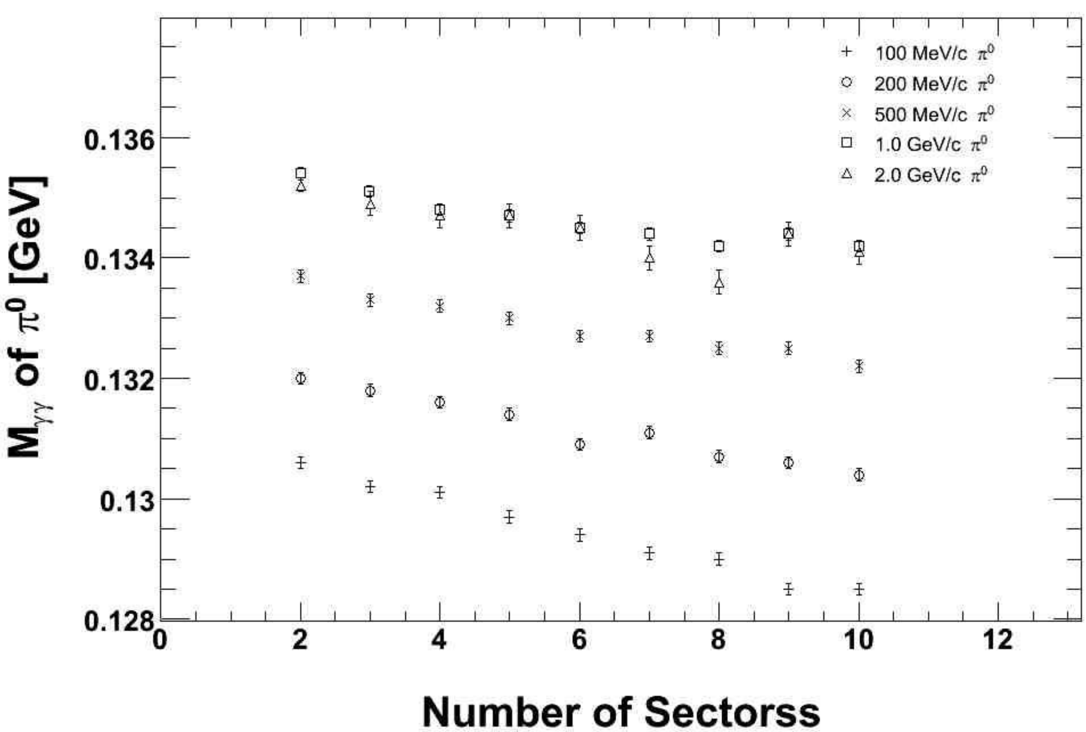

Fig. 13 Dependence of the peak position of the invariant mass on the number of sectors.

6. Conclusions and Suggestions for Further Studies

It was found that for single gamma events a reasonable number of layers and sectors would be 5-6 and 4-5, respectively. If the spatial resolution of one of the coordinates (say Z) is expected to be more important, it may prove useful to use an increased number of layers (for Z) at the expense of decreased number of sectors.

The energy resolution does not show a very strong dependence on the number of layers or sectors (unless they are unreasonably low). The dependence of the resolution on the energy of incident gamma agrees with the expectations.

Neutral pion invariant mass was reconstructed and the resolution estimated. Energy corrections may need to be applied to remove the tendency of the invariant mass to decrease with the number of layers. A number of layers of five or more gives a resolution within 5% variation.

As a further study the detailed Monte Carlo data can be used directly (this has already been started). Single photon events at fixed directions can be studied to extract correction functions for the positions and energy. The outer layers of the BCAL were kept fixed in number in this study, as well as the number of sectors in these layers. It may prove useful to investigate the influence of varying these numbers on the reconstructed parameters of the barrel calorimeter.

References

[1] David Lawrence, private communication.