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Reconstruction of π^0 at STAR in the Monte Carlo simulations

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1 Introduction

In this note, we provide the estimates how well the STAR Barrel Electromagnetic Calorimeter (EMC) with the gaseous Shower Maximum Detector (SMD) can reconstruct π^0-decays. The STAR is one of the two large RHIC's detectors which, along with its rich capabilities for heavy ion physics, will also carry out practically the entire spin program with polarized protons colliding at RHIC. A feasibility to reconstruct π^0-decays is important for both heavy ion and spin physics at STAR. As it has been suggested in the RHIC Spin Proposal [1], the information on spin-dependent gluon structure functions will be obtained by measuring the asymmetries of direct photons at $P_T \geq 10$ GeV/c. The main background for direct photon production will be π^0-decays. It's important to reconstruct them and then delete to decrease background for direct gammas.

Single photons and dileptons are also regarded as the "penetrating" probes for quark-gluon plasma (QGP) because they are produced at the early stage of the collision and are not affected by the subsequent hadronization of the system [2]. The region of interest here is $P_T \simeq$ 1–7 GeV/c compared to polarized proton collisions. As it has been suggested in Ref. [3], the recognition of direct photons at $P_T \geq$ 7–10 GeV/c is also interesting for the exploration of Jet Quenching mechanism in heavy ion collisions.

It is important to know whether it is possible to see a π^0-peak and use π^0 for absolute calibration of the EMC.

Monte-Carlo events were generated and written on tapes during the Mock Data Challenge-2 (MDC-2) procedure about an year ago. The EMC and the SMD information was there as well. As we understand, nobody has seen π^0-peaks in the EMC so far. The goal of our work was to analyze the Monte Carlo data to look for π^0 in the Calorimeter.

2 The Geometry of the Electromagnetic Calorimeter and Shower Maximum Detector

In the simulations presented in this note the EMC consisted of three main parts [4]:

1. **EMC lead-scintillator sampling calorimeter.**

   The calorimeter module consisted of 20 sandwich type layers of the thickness approximately equal to 0.9 of radiation length each. In turn, each layer consisted of 5 mm thick scintillator tile plus 5 mm thick Pb plate. It covers $\mid \eta \mid < 1.0$ and 2π in φ with granularity $\delta\eta \times \delta\varphi = 0.05 \times 0.05$ (4800 towers).

2. **Shower Maximum Detector.**

   It is the multi-wire proportional chamber with two gaseous planes and read out from strips in η and φ direction. A granularity of the SMD towers is $\delta\eta \times \delta\varphi = 0.1 \times 0.1$. Each module consists of ten towers. There are 15 strips of fixed width in φ direction ($15 \times 1.494\ cm$) in each tower. Altogether 10 towers consist of 150 strips in η ($75 \times 1.537\ cm\ +\ 75 \times 1.961\ cm$).

3. **Preshower.**

   The first two planes in the EMC have independent read out, which can be used as a preshower.

3 π^0 at STAR

A π^0 identification algorithm consisted of three main parts:

- An EMC cluster finder;
- a γ-identification in EMC and SMD;
- a π^0-reconstruction in EMC and SMD.

3.1 EMC cluster finder

The EMC cluster finder looked for a cluster in the EMC towers and used the tables *emc_energy* which was created by module *emc_egrid.F* (see STAR EMC software page).

This cluster finder proceeded through the following steps:

- to each cell in the $\eta - \varphi$ grid, an energy vector whose magnitude was given by the neutral energy deposited in the cell was assigned;

- all the cells with an energy greater than a threshold value were ordered by their energy deposited values;
- the cell with the highest energy deposit initiated the first cluster;
- energy deposits from adjacent cells which were within a distance R_0 ($R_0 = 0.055$) in $\eta - \varphi$ space from the center of a cone at the cell with the highest energy were added;
- η, φ of the cluster and it's width were found, the correction function (S-curve) was used;
- for $R_0 = 0.055$ usually about 2 to 20% of energy flowed away outside this radius. To take into account an energy leakage the correction factor as a function of η, φ, and energy was used;
- an isolation parameter was calculated.

The EMC cluster finder created and filled out the table *emc_cluster*, which was used for γ identification.

3.2 γ identification

The table *emc_cluster* was used to find this cluster or several clusters in the SMD.

At first stage of a gamma identification procedure we analyzed each plane of the SMD separately. For each cluster in η and φ plane we defined the next values:

- a coordinate of the "logarithmic weighted center of shower" in the SMD [5];
- a transverse width of a shower;
- a χ^2 of the transverse shower shape.

Two exponential functions for a fraction of energy in the SMD channel was used for approximation of the shower shape and χ^2 is defined as

$$\chi^2 = \sum_i \frac{(Y_i - T_i)^2}{\sigma_i^2}, \tag{1}$$

where Y_i is a relative energy deposited in i-th strip, T_i is a relative energy deposited for "frozen" shower, σ_i-fluctuation in the i-th channel. The relative transverse shower shape is practically independent on energy of the shower.

The shower width and χ^2 were analyzed, and if these values did not correspond to the values for a single gamma, and a second maximum was found close to the first one, the following function was used to separate them:

$$\sum \frac{(E_1 P(x_m - x_i) + E_2 P(y_x - y_i) - E_i)^2}{\sigma_i^2(x_m) + \sigma_i^2(y_m)} = min, \tag{2}$$

where E_1 and E_2 were energies of gammas, x_m, y_m were strips with the maximum deposited energy, P was a theoretical relative transverse shower profile, E_i was a energy deposited in i-th strip.

After such analysis in each η and φ plane in the SMD, showers in different planes were matched on energy. A program which solved the so-called *Assignment problem* was used [6].

If there were more than one cluster in the SMD, the energies of gammas E_i were found from the equation:

$$\sum \frac{(E_i - E_i^*)^2}{\sigma_i^2} + \frac{(\sum E_i - E_{emc}^*)^2}{\sigma_{emc}^2} = min, \tag{3}$$

where E_i^* was the energy deposited in SMD, E_{emc}^* was the energy deposited in EMC.

We removed those candidate from the gamma list in which we had "good" charged track in the global track table (*dst_track*) with the coordinates projected to the SMD plane within R_{int} from the ones defined in the SMD. R_{int} was the parameter in the table *emc_gamma_par* and was equal to 0.5 cm in our case. In this procedure charge hadrons and electrons were removed from gamma table.

An information about the gamma energy, coordinates, and the uncertainties was written out in the table *emc_gamma*.

3.3 π^0 reconstruction

The table *emc_gamma* was used for a π^0 reconstruction and filled out the table *emc_pizero*.

A typical π^0 mass spectrum for single π^0 is presented in Fig. 1 for different P_T of π^0. The resolution of mass of π^0 ("sigma" of the Gaussian fit of the mass spectra) and the efficiency of reconstruction are presented in Fig. 2. We have defined the reconstruction efficiency as a ratio of a number of the reconstructed two gammas with a mass $0.75 < M_{\gamma\gamma} < 1.97\,GeV/c^2$ to a number of all two gamma pairs which were generated within $\mid \eta \mid < 1.0$ region.

We see that the efficiency is less than 50%. The reason of it is as follows. The STAR EMC is not hermetic. There are cracks in φ-direction between two adjacent modules. In the analysis we removed the region close to a boundary, where γ-quanta were reconstructed poorly. In other words, we sort of increased the cracks in the analysis from real 1.5 cm up to 3 cm. Moreover, at P_T of π^0 less than 3 GeV/c part of gamma were below the energy threshold for one gamma (500 MeV). At P_T above 5 GeV/c two showers from π^0 started to overlap significantly, and we reconstructed some of them as one γ. Both these factors decreased the reconstruction efficiency for π^0.

The cluster finder as well as the γ and π^0 reconstruction algorithm described above have been used for minimum biased PP interaction Geant simulated data. The mass spectra for π^0 with $P_T > 1$ GeV/c is presented in Fig. 3.

4 π^0 at STAR (The second method)

In this section we describe the second independent method of π^0-reconstruction at STAR. The idea for these two independent algorithms was to compare the main result such as a π^0-reconstruction efficiency and a π^0-mass resolution to establish a robustness of an EMC data analysis.

In the second method the barrel EMC consisted of four independent detectors:

1) EMC towers;
2) EMC preshower;
3) SMD to measure η-coordinate;
4) SMD to measure φ-coordinate.

We need to point out that only one first tile of the EMC has been considered as the preshower as it was in the MDC2 data.

The code consisted of four modules.

4.1 The first module (Cluster Finder).

A Cluster Finder for all the four parts of the barrel EMC reconstruction algorithm mentioned above is described in this section. An input data were taken from the tables:

g2t_emc_hit and

g2t_smd_hit.

The algorithm was as follows:

1. The hits from different tracks with same coordinates, η and ϕ, were summed.

2. An energy detected by a preshower was added to an energy of a proper tower.

3. The obtained energy deposits were put in the order from the highest one down to the lowest one independently for all four detectors mentioned above.

4. A cluster forming started from the maximal energy deposit which is declared as a first cluster.

5. The second and the further energy deposits could be added to the existent clusters if they were at distances less than a threshold value:

a) the cluster maximum (a cluster size could not be more than 3×3 cells for the towers and the preshower) or b) any cell which has been included in the cluster (non-restricted size of the cluster).

These threshold distances were taken as follows:

	η-coord.	ϕ-coord
Tower	.06	.06
Preshower	.06	.06
SMD-η	.03	.11
SMD-ϕ	.11	.03

For each cluster the following sums were accumulated:

$$\Sigma E_i,\ \Sigma E_i\eta_i,\ \Sigma E_i\eta_i^2,\ \Sigma E_i sin\phi_i,\ \Sigma E_i cos\phi_i,\ \Sigma E_i sin^2\phi_i,\ \Sigma E_i cos^2\phi_i.$$

The energies, coordinates and cluster widths have been defined from these values.

The results for each out of the four detectors were written into the table *emc_cluster*. A history of hits combining into one cluster was written into the table *emc_cluster_index*

4.2 The second module (Matching EMC and SMD clusters)

The second module looked for a corresponding cluster in the preshower, smd-η and smd-ϕ for the clusters in the tower. The input table was *emc_cluster* a cluster energy was simply a tower energy. Initial coordinates were the centers of gravity of the towers. If there was one more corresponding cluster in the smd-η or smd-ϕ, the tower coordinate was substituted by the smd coordinate. If there were few (more than one) corresponding clusters among smd-η and smd-ϕ, then only two clusters with the highest energies were left for the each plane.

The cluster was divided into two clusters with energies proportional to the smd cluster energies.

The information about energies, coordinates, cluster widths, and about the numbers of defined smd clusters was in the table *emc_gamma*.

4.3 The third module (Mass spectra accumulation)

The input table was the *emc_gamma*. The module could apply different cuts to the input data and accumulate a mass spectrum of cluster pairs. The results are in miscellaneous histograms.

4.4 The fourth module (Test of the second method)

The fourth module was devoted to a test of the algorithm. It did not work for real physics events. Also the module was used to defined an efficiency of the proposed method. The module used the tables emc_gamma and *g2t*_track, where the data contain the information about particles created in physics interactions and also about particles produced in decays and in interactions with a set-up matter.

This module allowed us to compare the obtained values with the known ones. For example, one can find a portion of energy deposited in the active medium of the calorimeter, an accuracy of coordinate definition, energy and mass resolution, an efficiency to find π^0.

A typical π^0 mass spectrum is presented in Fig.4.

One can see coordinate resolutions in Fig.5. The efficiencies of π^0-reconstruction at different P_T are presented in Fig.6.

4.5 π^0 at STAR in the MDC2 data

To study a possibility to find π^0-peak at STAR, one file from the MDC2 Geant simulated data has been analyzed with the use of the reconstruction algorithm described above. It was a file with *pp*-interactions at 200 GeV.

The tower clusters were chosen only when they were corresponding to smd-η and smd-ϕ cluster to improve a coordinate resolution. It obviously decreased the π^0-s reconstruction efficiency. To suppress charged particles, the clusters with

$$0.02 < E_{pr}/E_{smd} < 0.06$$

were removed.

The mass spectra of π^0 for different energies are presented in Fig.7.

We can see that for pure π^0s a detection efficiency is over 70% for an energy region 2 to 3 GeV and about 40% for an energy region 5 to 10 GeV. A mass resolution is about (20-25) MeV/c^2 for the energy range from 0.5 to 5 GeV/c.

5 Conclusion

Two independent methods of a π^0-reconstruction are described in this note. Both methods have given the same result, that increases their robustness.

A π^0-reconstruction efficiency for isolated π^0's is over 50% at $0.5 < P_T < 3$ GeV/c, and is about 40% at $3 < P_T < 10$ GeV/c. A π^0-mass resolution is about $20\,MeV/c^2$ at P_T less than 5 GeV/c. A coordinate resolution is 4 mm.

The MDC2 pp-data have been analyzed, and clear π^0-peak has been seen for the first time in the STAR simulations study.

Acknowledgments
It's our pleasure to thank V. Perevozchikov for the useful discussions.

References

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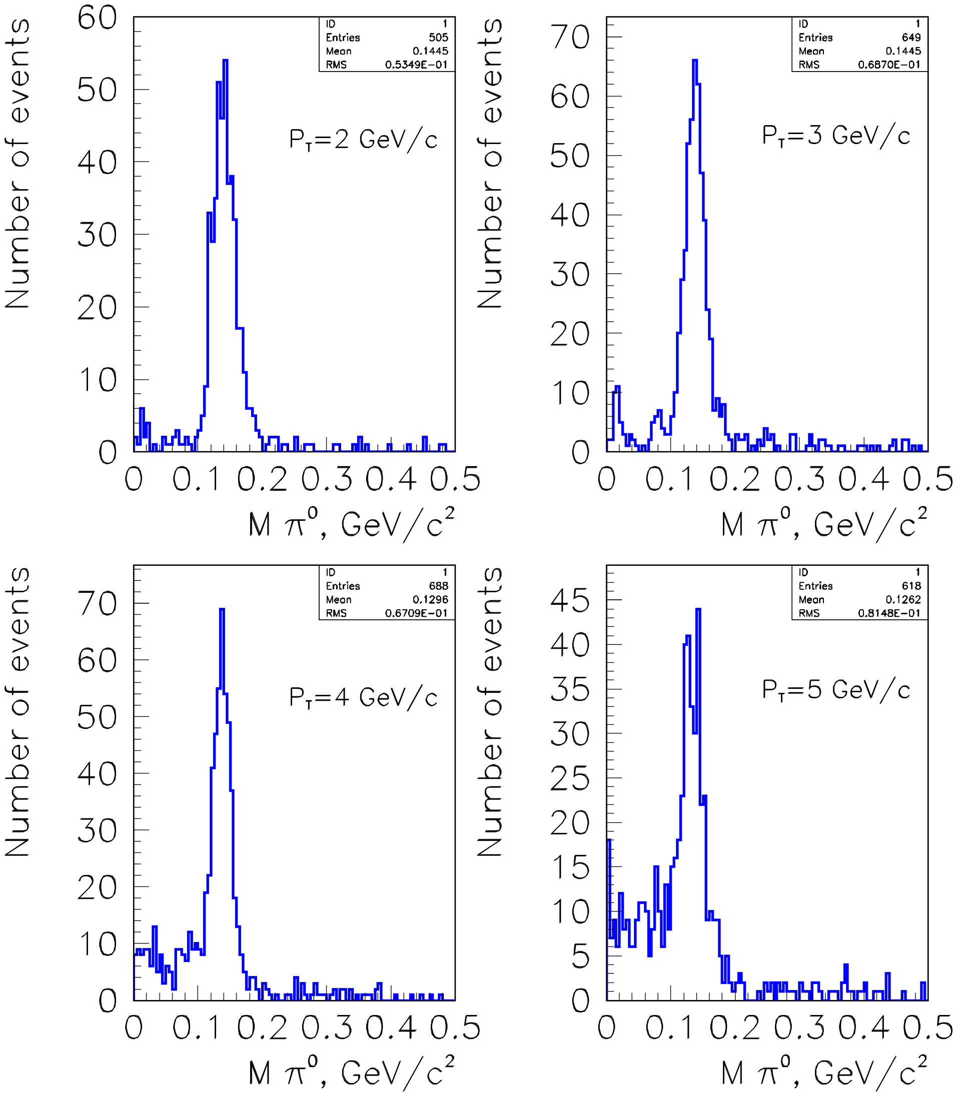

Figure 1: π^0 mass spectra for single π^0 at different P_T values.

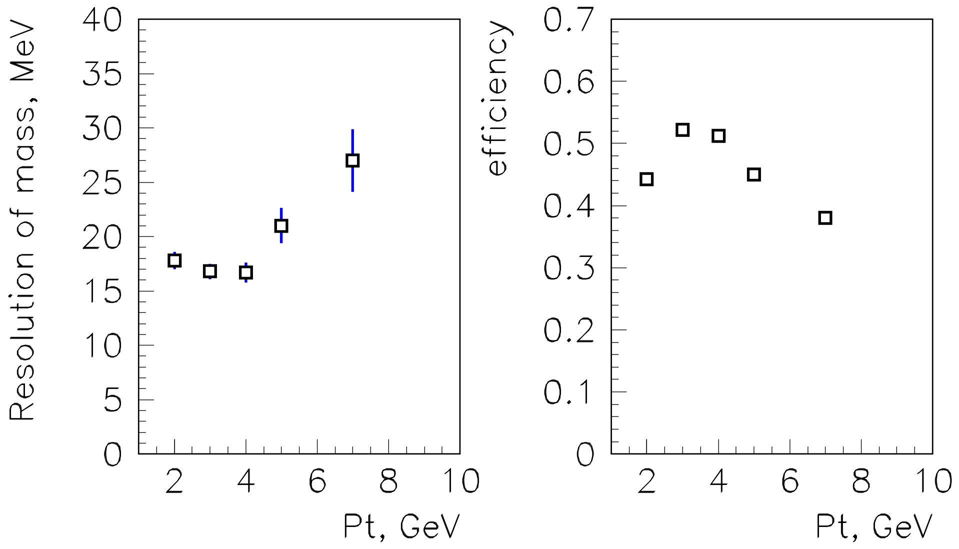

Figure 2: The resolution of mass of π^0 and efficiency of reconstruction.

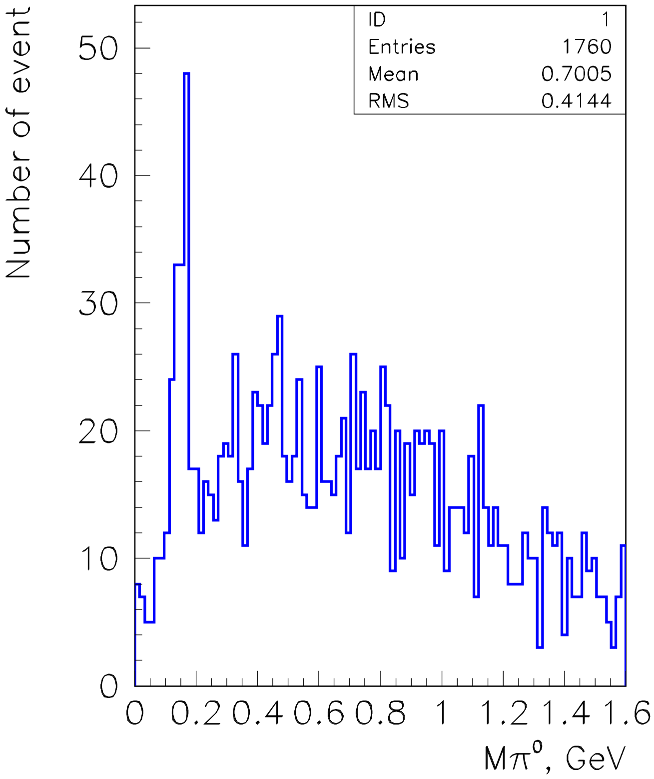

Figure 3: The mass spectra for π^0 with $P_T > 1\,\mathrm{GeV/c}$ for PP-interactions.

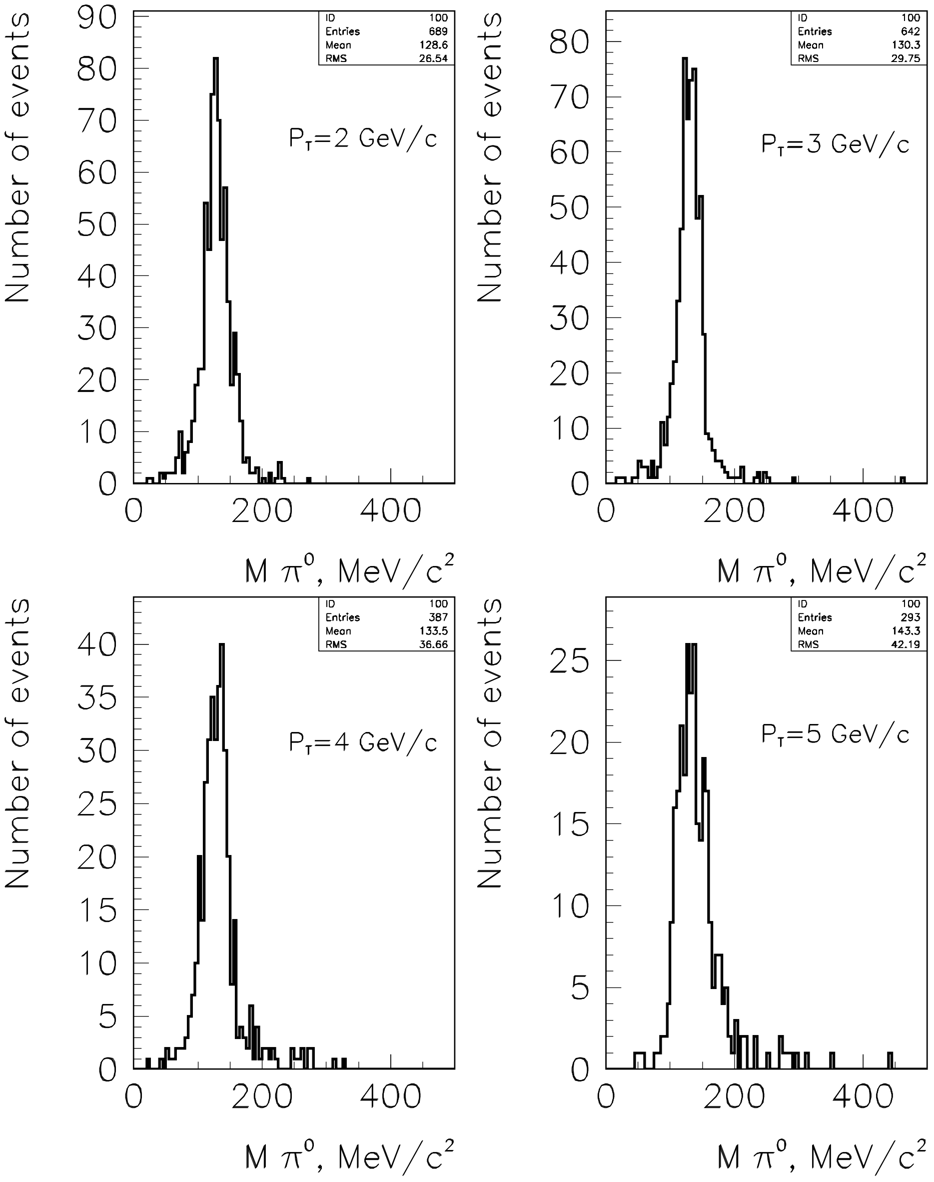

Figure 4: π^0 mass spectra for single π^0 at different P_T values.

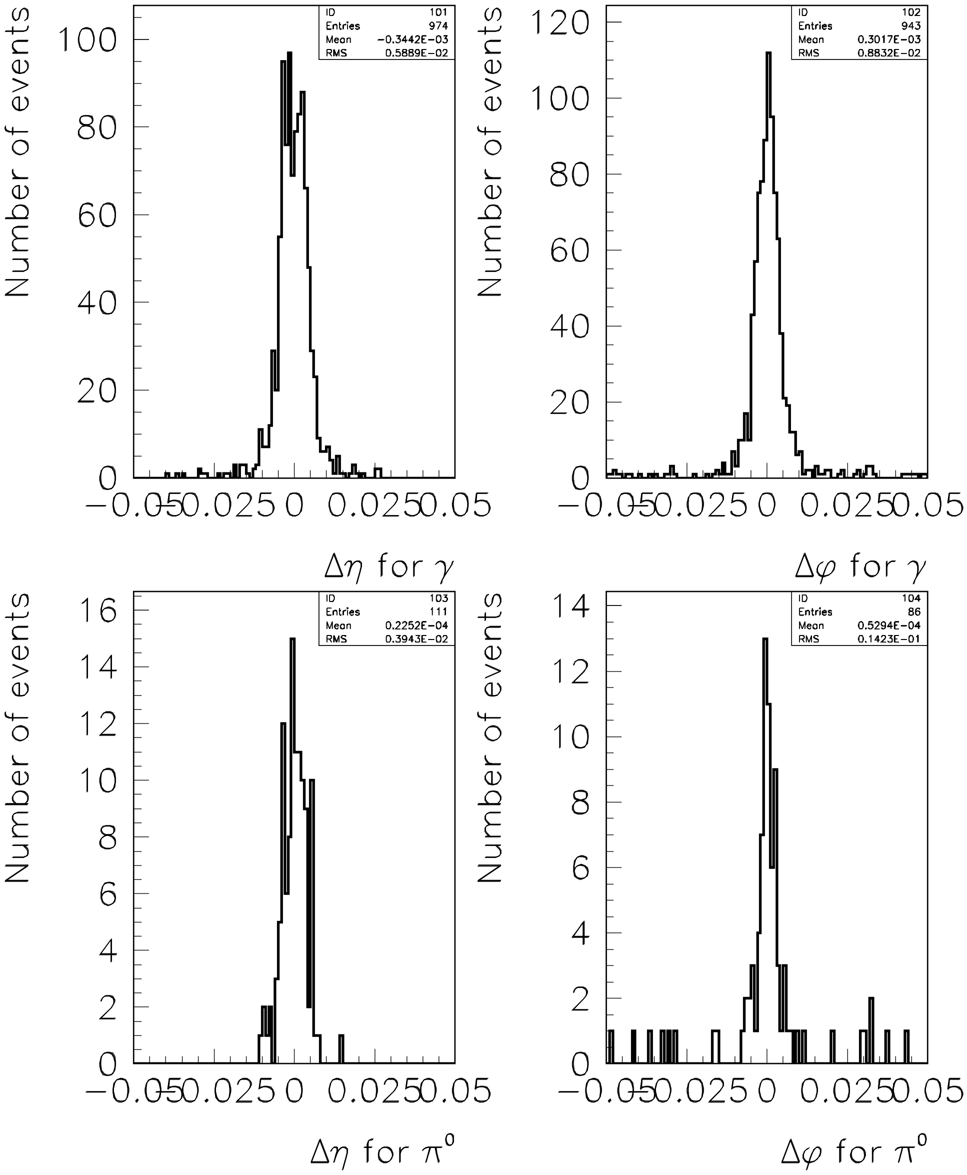

Figure 5: The coordinate resolution for γ and π^0.

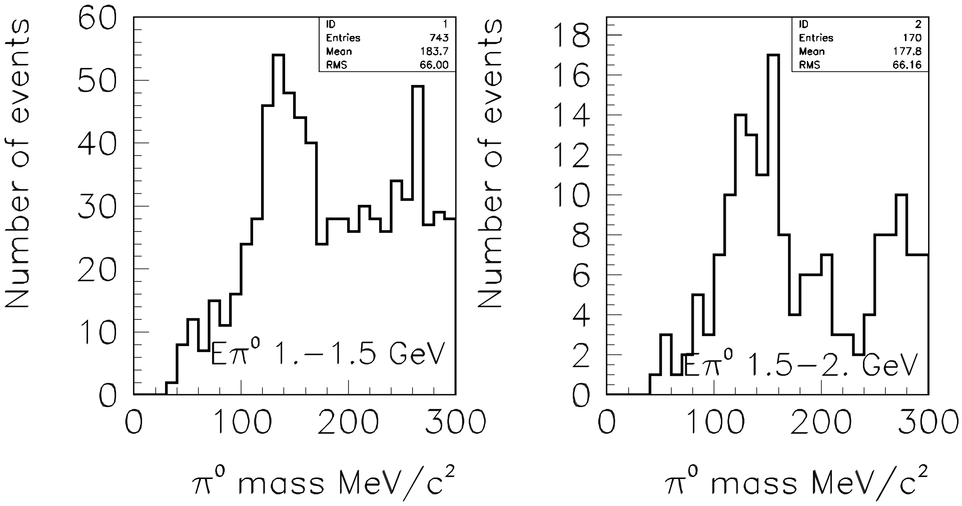

Figure 6: The mass spectra for π^0 for PP-interactions.

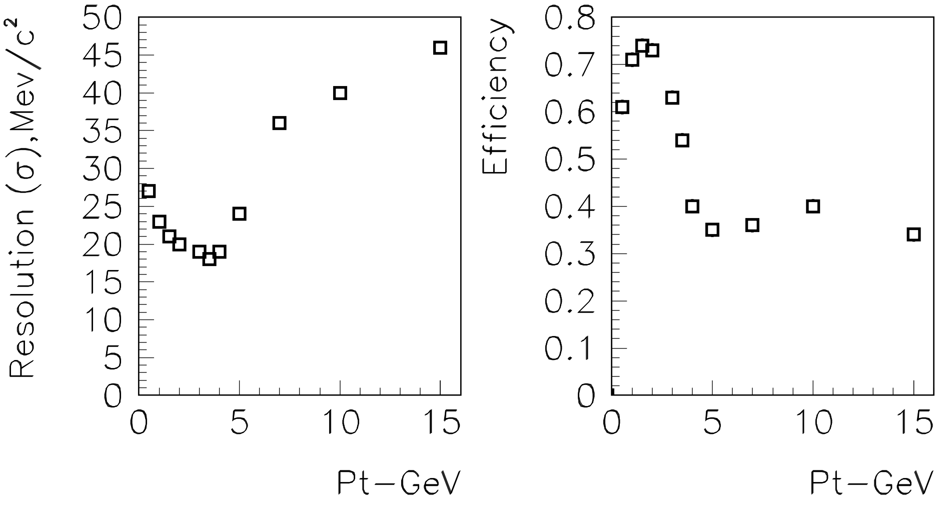

Figure 7: The resolution of mass of π^0 and efficiency of reconstruction.