Performance Study of MPD-ECAL

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Abstract:

It has always been a challenging task to investigate the hot and dense baryonic matter in modern physics. As a part of the Nuclotron-based Ion Collider fAcility (NICA) program, the Milti-purpose Detector (MPD) is of much significant. In this article, we will talk about the performance of the electromagnetic calorimeter in MPD (MPD-ECAL).

By simulating with mpdroot, I have got the information of performance of ECAL. Then I have tried to reconstructed π^0, which is a probe to QGP. Although I still can't get good results in real situation, the works I have done about this field are still useful. And the results I get in this practice have verified the results I get in China. As a foundation of future work, these works can play an important role.

1. Introduction to MPD-ECAL

1.1 The Nuclotron-based Ion Collider fAcility (NICA) program

It has always been a challenging task to investigate the hot and dense baryonic matter in modern physics. It provides information on the in-medium properties of hadrons and nuclear matter equation of state so that we can take a look into the deconfinement and chiral symmetry restoration, phase transition, mixed phase and critical end point, which have a lot to do with the origin of the early universe and the formation of the neutron stars [1].

From 1980s, getting hot and dense matter from the collisions of heavy-ions gradually became reality [2]. Many well-known laboratories have taken effort in this field, including Brookhaven National Laboratory (BNL) and European Organization for Nuclear Research (CERN).

The Nuclotron-based Ion Collider fAcility (NICA) program in Joint Institute for Nuclear Research (JINR) is aimed to research in this field with collisions of heavy-ions within a broad range of centre-of-mass energy from 4GeV to 11GeV [3]. The accelerator is being building in Dubna, Russia, which is planned to be finished in 2023. We hope there will be impressing discoveries about strong interaction and QCD phase transition after the accelerator is put to use.

1.2 MPD-ECAL

Multi-purpose Detector (MPD) is a detector in one of the collision point in collider. There are three sub-detectors: time projection chamber (TPC), time of flight detector (TOF) and electromagnetic calorimeter (ECAL) distributed from inside to outside [14]. The detailed structure of MPD is showed in Picture 1. If a charged particle enters the detector, we can get the charge, energy loss (dE/dx) and momentum from the TPC and square of mass from TOF. This information is enough for us to identify which kind particle has entered the detector. However, TPC and TOF can't have effective response for neutral particles like photons so that we should use electromagnetic calorimeter for the identification of photons.

The photons released from the decay of π^0 mesons is very important in this experiment as π^0 mesons are probes to the question we are interested in. The electromagnetic calorimeter in MPD is designed for this aim. We can get two photons with the same momentum in center-of-mass frame. Then we can reconstruct the primary π^0 with the help of these two photons.

In consideration of the cost and the goal we hope to achieve, the shashlyk electromagnetic calorimeter has been designed.

Shashlyk electromagnetic calorimeter has been developed for years [4, 5] in many high energy physics experiment, including SoLID [6], COMPASS-II [7], PHENIX [8], LHCb [9], ALICE [10], KOPIO [11] and JLab real compton scattering experiment [12]. There are several kinds of electromagnetic calorimeter. According to the difference in structure, they are divided to sampling and total absorption electromagnetic calorimeter. A shashlyk electromagnetic calorimeter is a kind of sampling electromagnetic calorimeter [13].

The MPD electromagnetic calorimeter module is proposed to be built of nine towers as basic building elements ($4cm^2$ each tower). Each tower consists of 220 alternating tiles of Pb (0.3mm) and plastic scintillator (1.5mm). Each scintillator tile is optically isolated from the neighbor tiles. Lead layer is common for all nine tiles of one layer. The module with a 12 radiation length thickness will be approximately 40cm long [1].

2. Performance of MPD-ECAL

As we know, only a part of the energy of incident particles can be deposited in the electromagnetic calorimeter. Therefore, the ratio of energy deposited and total energy is of great significance. The performance study of MPD-ECAL starts from this.

This ratio can be different when the incident particles have different energy and different pseudo-rapidity so that it is an important task to figure out whether this ratio has dependency of these two parameters.

2.1 Dependency of Energy

I have done some simulation works about this issue. There are totally 100000 gammas generated from BOX model. The launching angel ranges from 40-140 degree and energy is a uniform distribution within 0-2 GeV. I get the signals from ECAL and then reconstructed the energy deposited in ECAL.

When we use the information got from ECAL to reconstructed the signal, we calculate the sum of energy collected by several neighboring towers which has a signal larger than a given threshold. The threshold in my reconstruction procedure is 5 MeV. Figure 1 has shown the results.

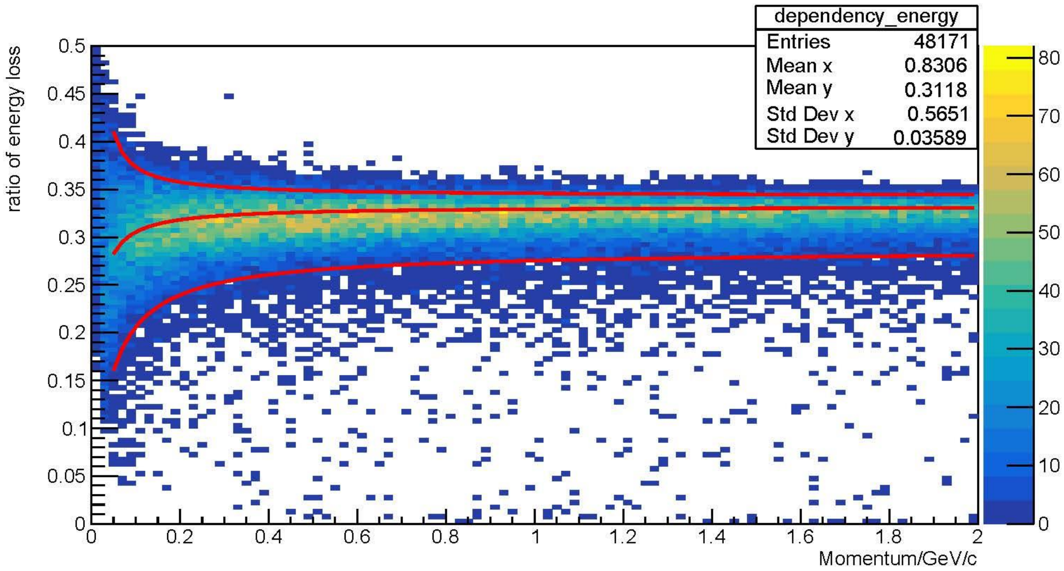

Fig. 1 Dependency of energy

We can find that this ratio is about 32% when the total energy is higher than 0.2 GeV. However, this ratio decreases fast when energy is lower than 0.2 GeV. Obviously, this ratio has dependency of energy so that we need a function of energy in order to get precise energy when we have a signal from ECAL.

We can see that there are three red lines in the picture. The upper one and the lower one is the profile of the area. In principle, there is a possibility of 90% for gammas to fall in this area. The middle line is the curve fit with the maximum of every bin in X-axis, which should be the function we need to get.

Before fitting the curve, we need to figure out the form of the function. We assume that when we reconstruct the signal of ECAL, we have lost the energy deposited in the towers whose signals are lower than the threshold. Therefore, the real signal should be

$$E_{dep} = E_{sig} + n \cdot E_{th}$$

E_{dep} is the total energy deposited in the towers. E_{sig} is the signal got from reconstruction procedure. E_{th} is the threshold energy and n is the number of towers not included in the calculation due to the threshold energy. We assume that the total energy of incident particles (E_{total}) is k times E_{dep} so that we can get the expression of E_{total}:

$$E_{total} = \mathrm{k} \cdot (E_{sig} + n \cdot E_{th})$$

Therefore, the ratio should have the following form:

$$\frac{E_{sig}}{\mathrm{k} \cdot (E_{sig} + n \cdot E_{th})} = \frac{1}{k(1 + \frac{n \cdot E_{th}}{E_{sig}})} = \frac{1}{k} - \frac{n \cdot E_{th}}{E_{total}}$$

As we can see, there are two parameters k and n to be fit. The threshold energy has a great impact on the parameter so that I have got the parameters when threshold is 3 MeV, 4 MeV and 5 MeV. The results are shown in the following table:

Threshold/MeV	k	$n \cdot E_{th}$
3	3.01074	0.00877876
4	3.03525	0.0170763

5	3.08094	0.016596

Table 1. the value of k and n

Except for this fit curve, we now have a look at the profile in the picture (the upper and lower red lines). We can find that the distance between these two lines increases quickly when the energy decreases, which states that the energy resolution get bad when the energy is low, especially lower than 100 MeV.

2.2 Dependency of pseudo-rapidity

Now we have got the dependency of energy. Then we will consider the dependency of pseudo-rapidity. The way I study this issue is the same. Now we can see Figure 2.

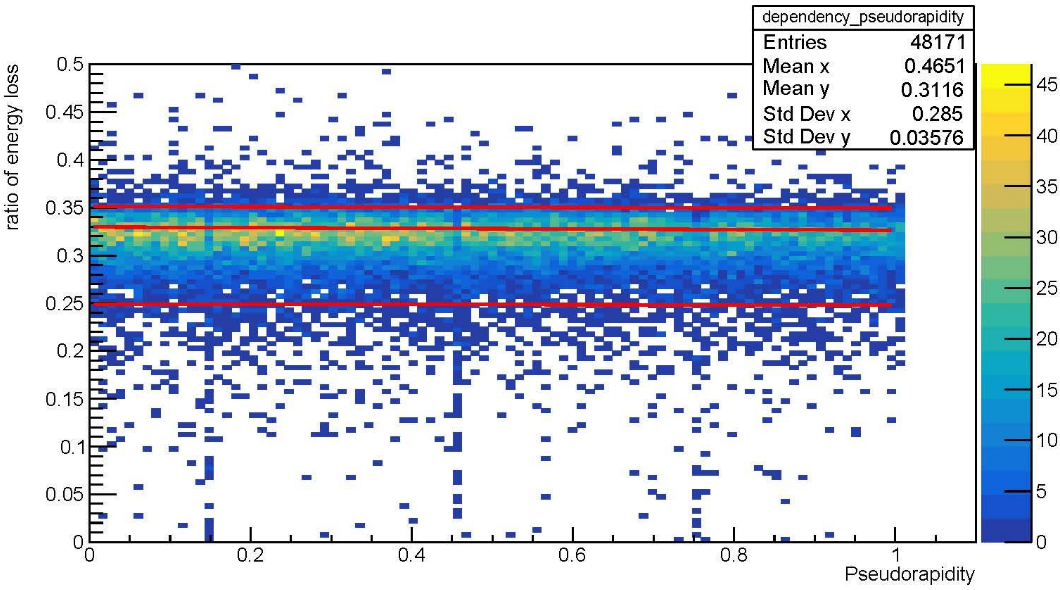

Fig. 2. Dependency of pseudo-rapidity

As we can see in the picture, the ratio has no dependency of pseudo-rapidity, which meets our expectation. Therefore, the ratio is a single value function of energy.

However, the ratio become a little strange when the absolute value of pseudo-rapidity is close to 0.15, 0.46 and 0.75. I zoom in the area of this picture and get the following result:

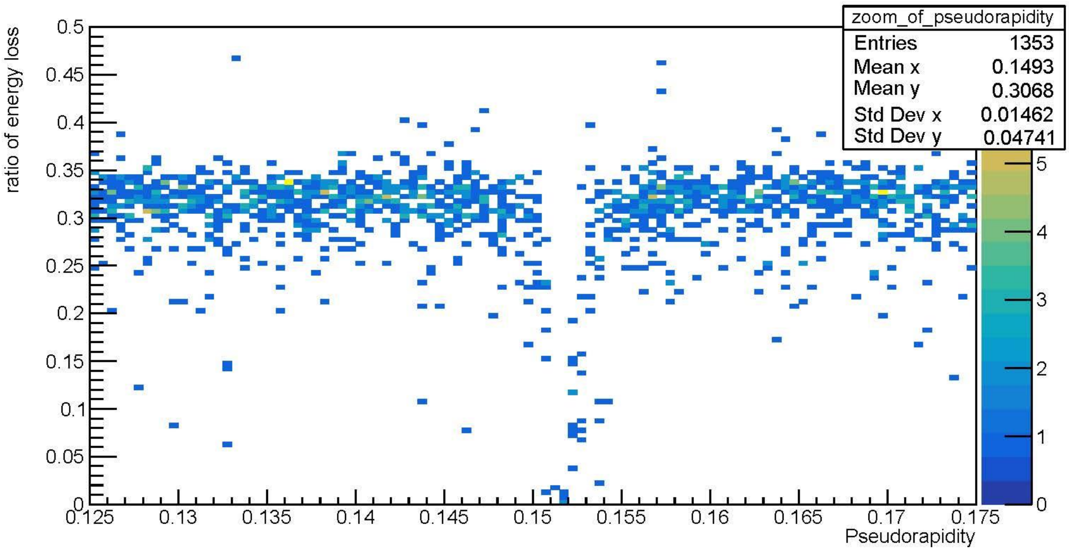

Fig.3 Dependency of pseudo-rapidity

We can see that there is a small range where no signal falls. After some discussion, we know that is due to some gaps in the geometry.

3. Reconstruction of π^0

We have several expectations for MPD-ECAL and one of them is to get some information of π^0, which is a probe to QGP. However, it is never an easy task for us. Except gammas, charged particles can also have signals in ECAL and the gammas released from decays of π^0 have low energy, most of which are lower than 200 MeV, where energy resolution of ECAL is not very good. However, if the performance of MPD-ECAL is good, we can get some glues of π^0.

3.1 First step of my attempt

As the results may get bad when charged particles and gammas are mixed up, I use only π^0 to do my simulation in the first step.

In this simulation, there are 100000 π^0 and 100 π^0 in each events. The energy of π^0 ranges from 0 to 3 GeV. In order to get the cut conditions for gammas, I draw the distribution of gammas released from the decays of π^0.

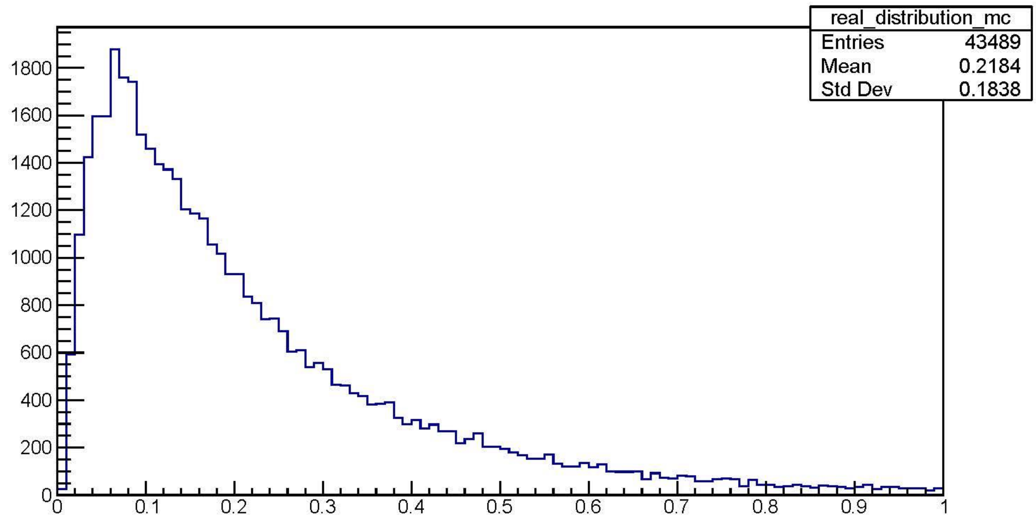

Fig.4. Distribution of gammas released from decays of π^0

We can find that only a few gammas have very low energy. As the energy resolution of ECAL is bad when energy is low, I use three conditions for cutting. I remove gammas whose energy is lower than 50 MeV, 60 MeV and 70 MeV and decide which condition is the best one.

The method for reconstruction of π^0 is not very complicated. As is known to us, π^0 has an invariant mass about 135 MeV. When we get a signal in ECAL, we can know the energy of the incident particle. And, we can get the vertex in the reconstruction information, use the positions of ECAL tower and vertex, we can get the launching angel of gammas. Then we can get the momentum of gammas by the angel and the energy. After that, the invariant mass can be calculated by the following equation:

$$M = \sqrt{(E_1 + E_2)^2 - |\overrightarrow{P_1} + \overrightarrow{P_2}|^2}$$

One π^0 can release two gammas. However, there should be 200 gammas in one event so that there should be many possible combinations of two gammas in one event and we can't know which combination is the correct one.

We can calculate the invariant mass of each possible combination in one event. The real combination must be included in all these invariant masses. So there should be a peak at about 135 MeV in the background distribution. However, we need to get the background distribution if we want to get the integral of the peak. If the two gammas in one combination are from different event, this combination must be a fault combination so that we can get the background distribution. This method to get background distribution is called "Mixed events". And, if we use the mirror-symmetric momentum of one gammas to get the combination, this combination must be a fault one, either, which is called "Reflect momentum". Both of these two method have been tried, I get the similar background distribution. As the second one can be calculated faster, I use the second one at last.

After getting these two distributions, I normalize them and do subtracting. Then I get the distribution of the invariant mass peak. Before using reconstruction information, I use the Monte Calo information to do a test in order to check if my method is correct. The result is shown in Fig.5

and Fig.6.

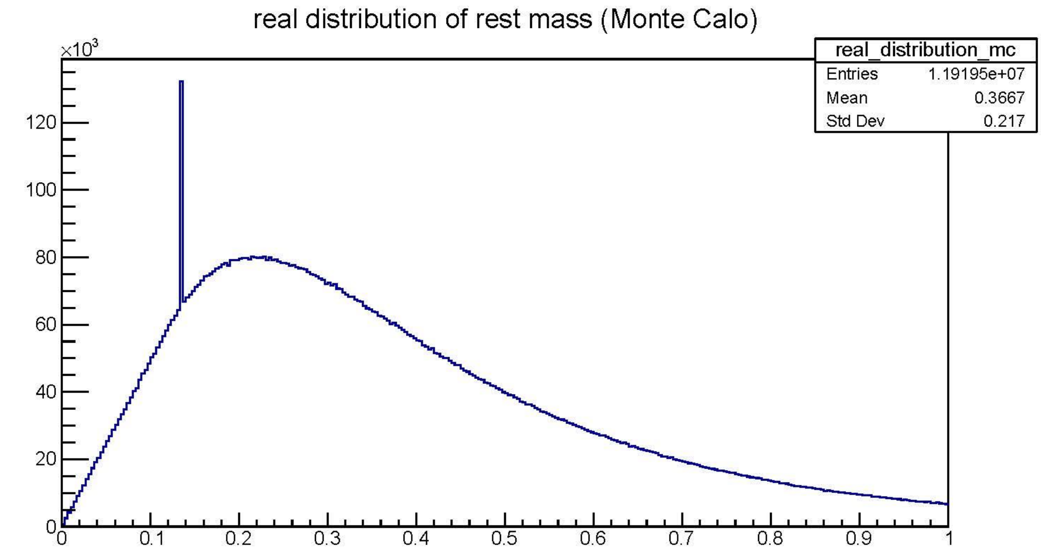

Fig.5 Real distribution of invariant mass (Monte Calo)

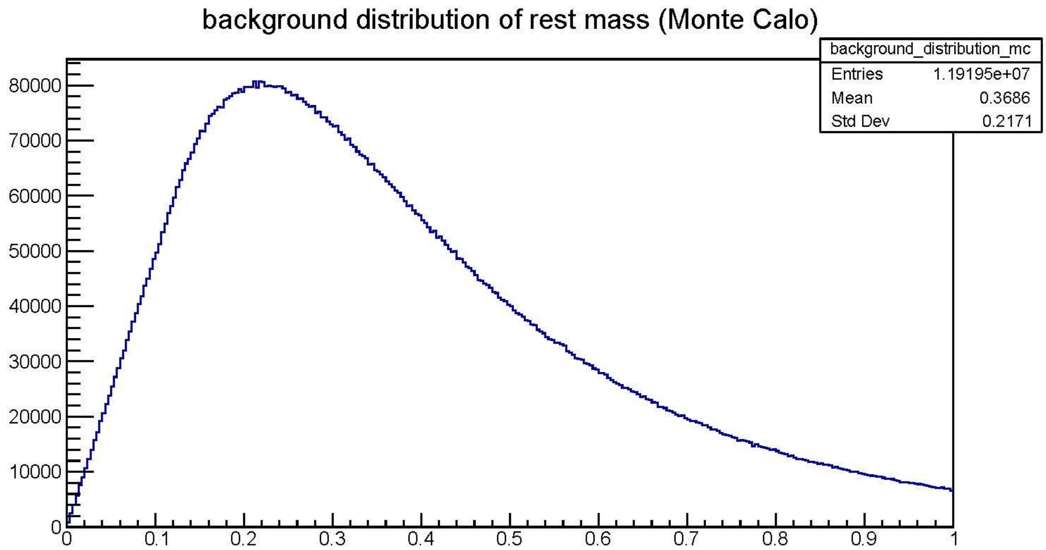

Fig.6 Background distribution of invariant mass (Monte Calo)

After this test, I use the reconstruction information to have a try, and the results are shown in Fig.7, Fig.8 and Fig.9.

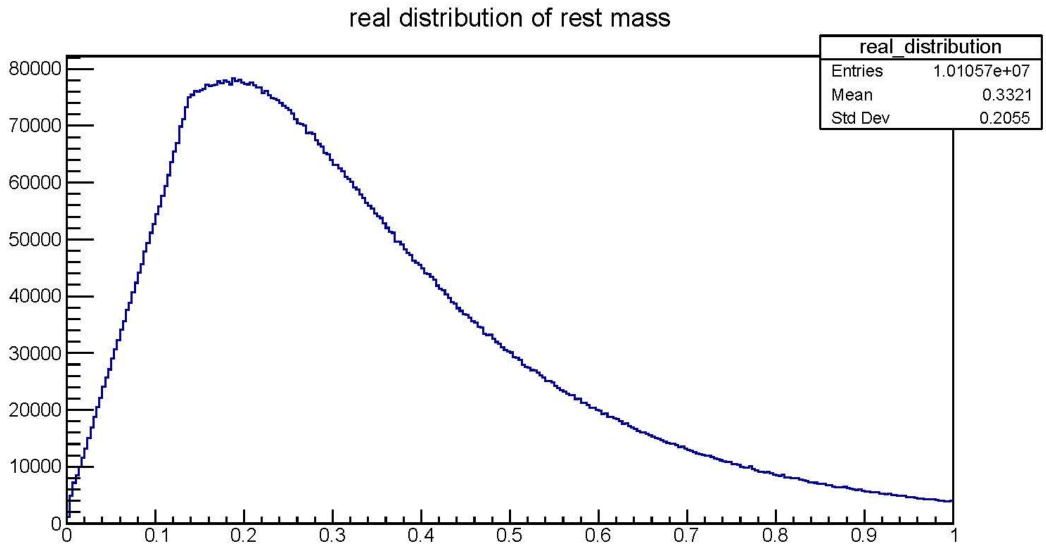

Fig.7 Real distribution of invariant mass (Reconstruction)

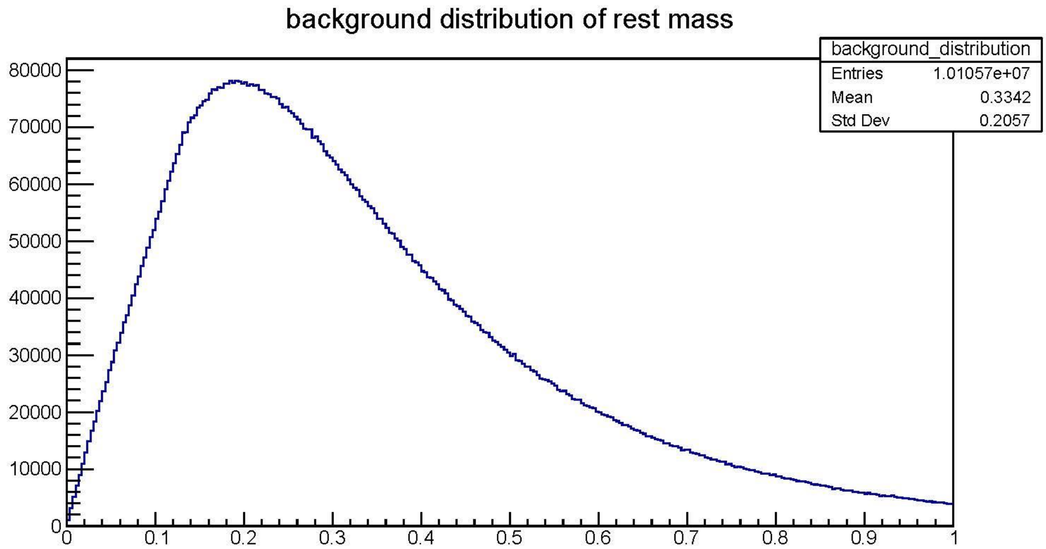

Fig.8 Background distribution of invariant mass (Reconstruction)

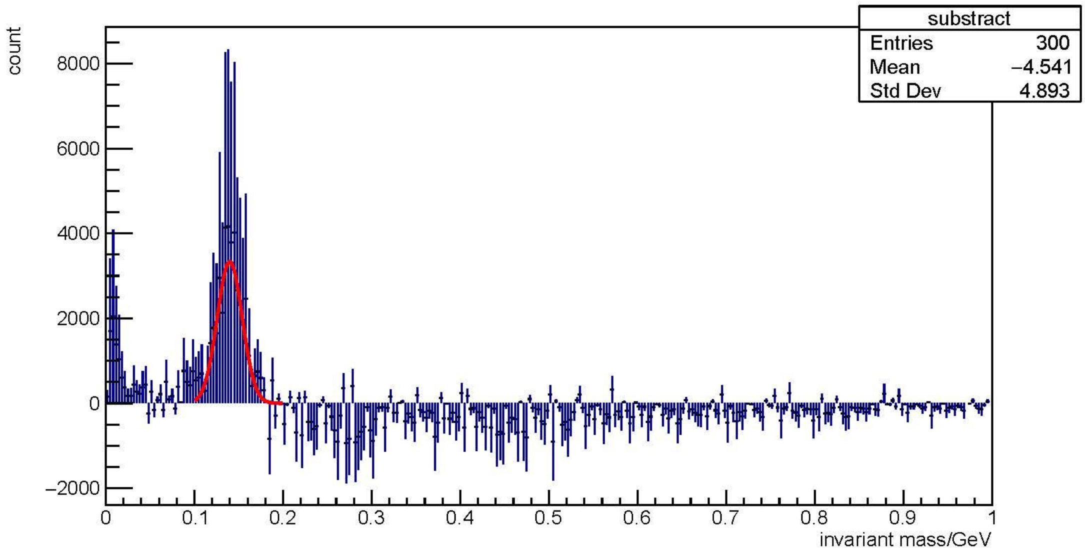

Fig.9 Subtracting of real distribution and background distribution (Reconstruction)

We can see that there is obviously a peak surrounding 135 MeV, which states that my attempt is successful.

Then I try to use UrQMD model to simulate the real situation of Au+Au collision.

3.2 The reconstruction of π^0 in real situation

When we consider the real situation, the largest difficulty is to select gammas from all the particles which enter ECAL. As we can get information from TPC, we can remove particles which leave signals in TPC. In general, gammas can't have signals in TPC, but charged particles can have obvious signal.

Now the difficulty is to match the tracks in TPC and the signals in ECAL. Luckily, we have had the class to do this task. However, the match is not a one-to-one correspondence, but a multiple correspondence. Therefore, we need to find the correct matches.

There are several cut conditions we use to find correct matches. First, the distance between tracks and signal in ECAL should be small enough. Then, the ratio of energy got from ECAL and momentum got from TPC should not be larger than a constant, which we now assume as 0.8. And we don't allow one signal in ECAL to match with several tracks in TPC. However, one track can at most match with two signal in ECAL. By this way, we can select the signals which is most likely created by gammas.

Even we have these cut conditions, we can't remove all the signals created by charged particles and some of the gammas can be removed in this procedure. Therefore, there must be much noise when we try to find the peak of π^0 invariant mass.

In summary, I have try to do this work but I haven't been able to finish this task. I still can't find the peak in my histogram. In consideration of the following work after my returning to China, this mission nay be finished in China. I believe that I can get a better result when the method and my code are improved a lot.

4. Conclusion

After this summer practice, I have got a lot of knowledge in field of detectors and high energy physics, which is of much significance for my work in China and our group's project. I have leant the main method to reconstruct π^0 meson. Although I haven't been able to finish my target here, but it has become possible to get good result of reconstruction of π^0 in real situation.

The performance study of MPD-ECAL is similar to the result I get in China, which verifies that our design of ECAL is very good. The dependency of energy can be used for our future reconstruction in experiments.

If the reconstruction of π^0 can be implemented well in our simulation framework, it will be very possible to get good results when we have real experiment statistics. Therefore, what I have done in JINR can be a test and verification to the method we use to deal with statistics. I hope this would be useful for future works.

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