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Photons and π^0 discrimination in the electromagnetic calorimeter (EMCal) of the ALICE experiment.

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Abstract

The ALICE experiment at the LHC identifies photons, electrons and neutral mesons with the electromagnetic calorimeters PHOS and EMCal. At high transverse momentum the π^0 decays into two photons with a small aperture angle in the lab system, what makes difficult their identification as separated photons in the calorimeters. One of the proposed methods to discriminate between photons and high momentum π^0s is to study the shape of the shower produced in the calorimeters. In this note we present our results for shower shape MC studies using EMCAL. The photons can be identified with an efficiency higher than the 80% with energies in the range 10-25 GeV.

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1 Introduction

High Energy Physics is dedicated to the study and description of the elementary components of matter and the interactions that govern it. In particular, heavy ion physics is interested in collective phenomena of elementary particles when they are under high pressure and temperature, as it is supposed to exist in the early universe, shortly after the Big Bang. When these conditions are met, the strong interaction theory predicts that nuclear matter is composed of free quarks and gluons, a new state of matter called quark-gluon plasma or QGP [1].

Similar conditions can be achieved in heavy ion collisions at ultrarelativistic energies. Study the QGP was among the objectives of the experiments at SPS (Super Proton Synchrotron) in CERN (Conseil Europen pour la Recherche Nuclaire) [2] and at RHIC (Relativistic Heavy Ion Collider) in BNL (Brookhaven National Laboratory) [3]. In particular at RHIC it was observed a decrease of particles with high momentum (jet quenching) and a modification of the structure of the jet [4]. The ALICE experiment (A Large Ion Collider Experiment) [5,6] at CERN is designed to study, among others, the creation of QGP, by detecting the particles produced in pp collisions at $\sqrt{s}$ = 14 TeV and $PbPb$ collisions at $\sqrt{s_{NN}}$ = 5.5 TeV, which is 30 times higher than at RHIC.

ALICE consist in an array of detectors that allow the detection of hadrons, leptons and photons. Specifically the electromagnetic calorimeter EMCal detects electrons and photons of high energies, improving the ALICE capabilities to find jets, to measure their energy and to study their quenching when the QGP is created [7,8].

In those strong interactions where a photon and a parton are produced in opposite directions, the detection of the photon is very important because it gives a measurement of the energy of the opposite parton that originated the jet. However, detection of these photons is highly contaminated by the decay into two photons of the neutral meson π^0, whose production is predicted to be high in both pp and $PbPb$ collisions [9]. To discriminate whether the signal is produced due to the π^0 photons decay or other source of direct photons [9], there is the method ”Shower Shape Analysis” (SSA) [10], which is based on the probability of forming one or two separated clusters, depending on the opening angle of the two-photon decay (Figure 1).

This paper presents a study of this method and the best parameters used to discriminate effectively between these particles in the detector EMCal.

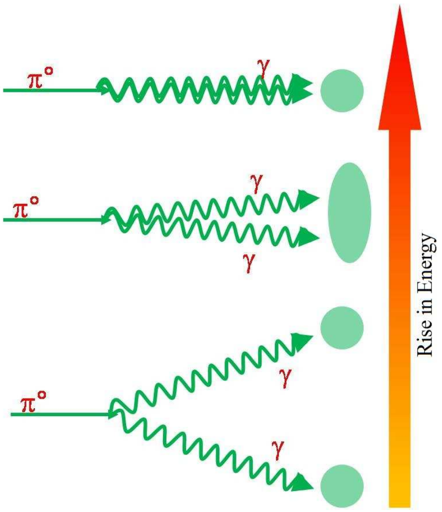

Figure 1: Signal in EMCal for different π^0 energies.

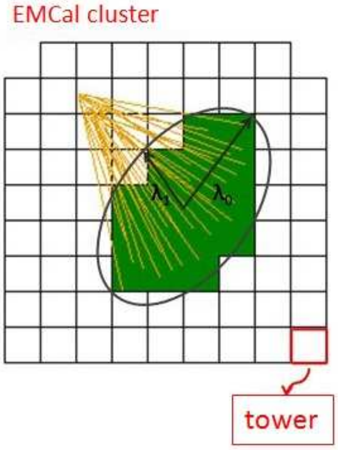

Figure 2: Shower in EMCal.

2 Materials and Methods

The EMCal detector, Figure 3, covers a region in pseudo-rapidity from η = -0.7 to η = 0.7, and an azimuthal acceptance of $\Delta\Phi$= 100°, and consists of a set of 11 520 towers (Figure 2). Each tower has a size of $\Delta\eta$ x $\Delta\Phi$ = 0.0143 x 0.0143 and is compound of alternate layers of lead and scintillating, traversed longitudinally by optical fibers providing the light collection [7]. The electromagnetic particles passing through the detector produce electromagnetic cascades and deposit their energy in a set of adjacent towers in the calorimeter. The reconstruction process is necessary to find the cluster signal that has been produced by a particle, get its position and calculate the energy of the cascade as the sum of the energy deposited in each tower of the cluster, as well as other parameters characterizing the shape of the electromagnetic cascade [10,11], among which is the shower shape. This is defined by the intersection of the cone that contains the frontal plane of the calorimeter (Figure 2) and can be expressed in terms of the covariant matrix

$$S = \left(\begin{smallmatrix} s_{xx} & s_{zx} \\ s_{xz} & s_{zz} \end{smallmatrix}\right) \tag{1}$$

where,

$$s_{xx} = \left\langle (x-\bar{x})^2 \right\rangle = \frac{\sum w_i x_i^2}{\sum w_i} - \left(\frac{\sum w_i x_i}{\sum w_i}\right)^2 \tag{2}$$

The sum is done over all the cluster towers and the w$_i$ values represent the logarithmic weight of the deposited energy in the tower i defined as:

$$w_i = max\left[0, p + log\left(\frac{e_i}{E}\right)\right] \tag{3}$$

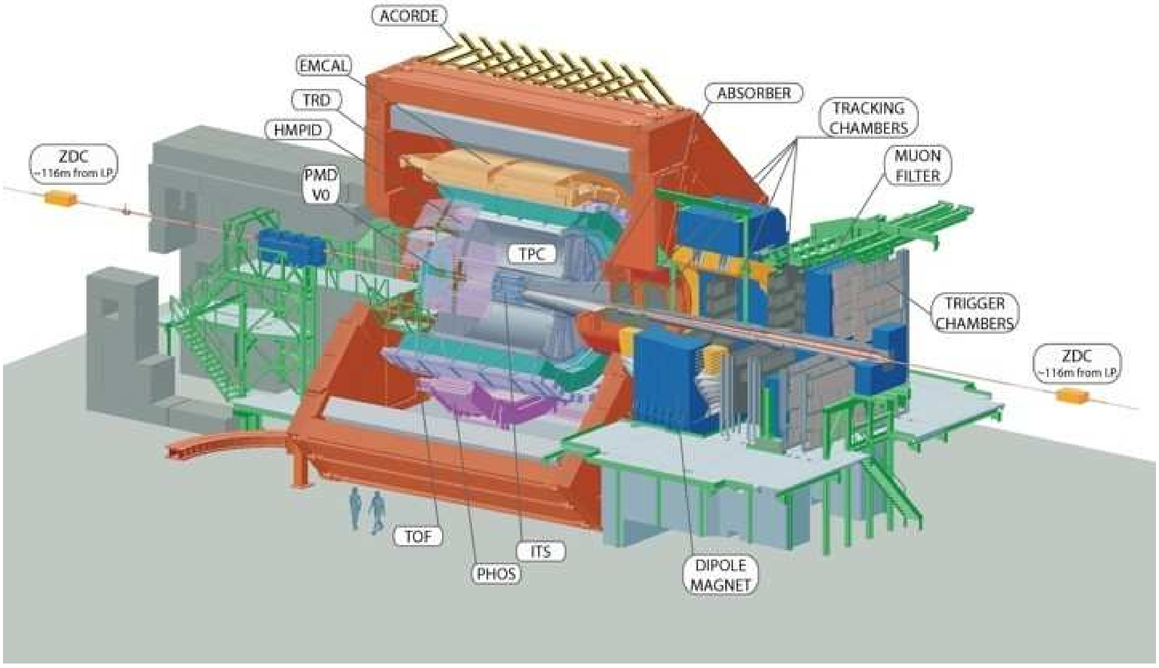

Figure 3: EMCal within the ALICE configuration.

where e$_i$ is the energy deposited in the tower i and p is a parameter whose value is determined empirically as 4.5 [10]. Similar definitions for s_{zz}, s_{xz} and s_{zx}.

The eigenvalues λ_0 and λ_1 of the matrix (1) are dimensionless parameters that define the main axes of the electromagnetic cascade, as shown in Figure 2.

The cascades produced by different particles can be identified by comparing the distribution of the above parameters for each particle. By studying the behavior of these parameters it was found that the most discriminative parameter to differentiate between these particles is the square of the largest eigenvalue of the covariant matrix (1) [11]. Thus the study of λ_0^2 allows to obtain the probability that a particle is of one or another kind.

3 Results and discussion

In order to find the best parameters of discrimination, photons and π^0 were generated towards the EMCal detector with energies of 8, 10, 12, ... up to 40 GeV. In total 1 000 000 of photons and π^0 were generated and reconstructed. The transport of particles through the detector material is performed with the code GEANT 3.21 [12].

As an example, by studying the distribution of λ_0^2 for the reconstructed energy 8 GeV (Figure 4) it is shown that the photon distribution is sharp and centered around λ_0^2=0.2. In the case of the π^0 the shower shape distribution is much wider and centered at a higher value of λ_0^2=1.8. The small π^0 contribution bellow the single photon peak is because at these low energies the separation of the two photons decay of π^0 can still be large enough to form individual clusters (Figure 1) in which case the reconstruction of the π^0 is performed by the invariant mass method.

For this reason, during the analysis of the π^0, the values of λ_0^2 are taken only in those cases where the two photons generate a single cluster in the detector. Figure 5 shows the distributions of λ_0^2 for photons and π^0 for four values of reconstructed energy.

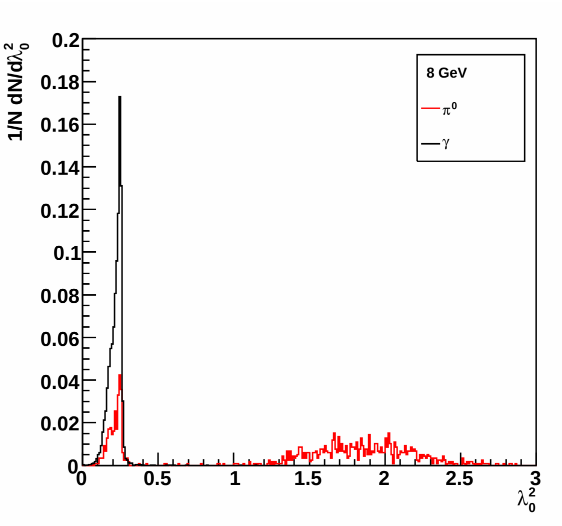

Figure 4: Distribution of λ_0^2 for photons (black) and π^0 (red) at $E = 8GeV$.

For energies below 16 GeV these distributions are well separated by a visible differentiation of photons respect to π^0. Thus, at these energies,a value of λ_0^2 (λ_{0-opt}^2) can be determined such as only photons has λ_0^2 smaller than this optimal value and an optimal value such that only π^0 have a larger value of λ_0^2.

As the energy increase, it occurs an overlap of these distributions. For this reason, to separate photons and π^0 whit merged clusters, the λ_{0-opt}^2 value is selected as the one that allows to obtain the largest number of correctly identified particles for each energy. In order to find it we look at each energy for the maximum of the reason:

In photons case:

$$\frac{No.\ of\ photons\ with\ \lambda_0^2 < \lambda_c}{No.\ of\ \pi^0\ with\ \lambda_0^2 < \lambda_c} \tag{4}$$

In π^0 case:

$$\frac{No.\ of\ \pi^0\ with\ \lambda_0^2 > \lambda_c}{No.\ of\ photons\ with\ \lambda_0^2 > \lambda_c} \tag{5}$$

In Figure 6 is shown this relation for 16 GeV photons. The λ_c, is studied for values between the maximum of the λ_0^2 distribution for photons up to the maximum for the π^0.

The optimal cutoff values obtained in terms of energy are represented in Figure 7. The lines represent a mathematical fit of these optimal cutoff values for photons and π^0.

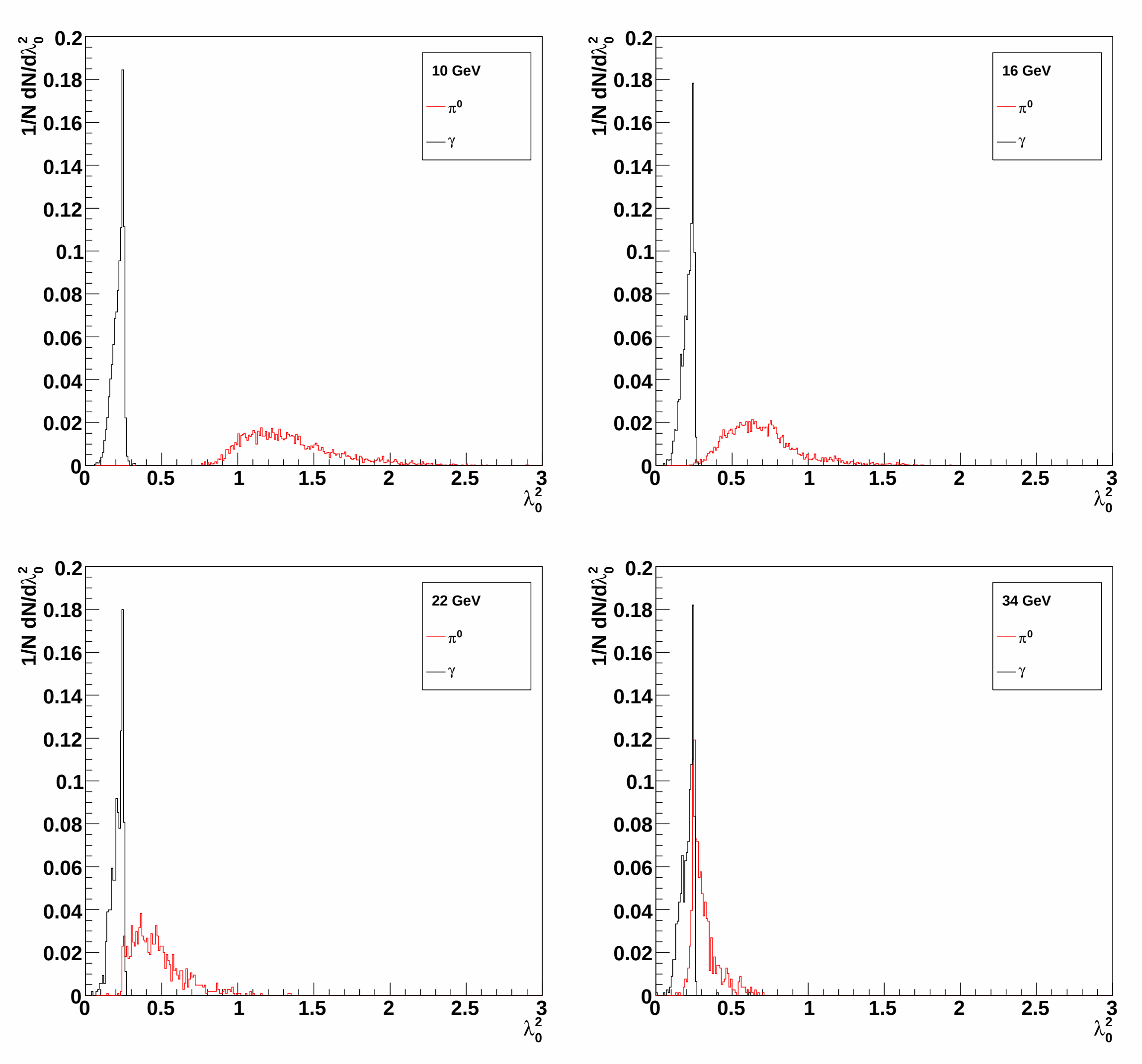

Figure 5: Distribution of λ_0^2 for photons (black) and π^0 (red) at 10, 16, 22 and 34 GeV.

In order to study the effectiveness of the method we study the identification and misidentification probabilities. Figure 8 shows the probability of correctly identifying photons, P (γ, γ), as the fraction of photons with $\lambda_0^2 < \lambda_{0-opt}^2$ (γ) of the total photons. This is over 90% over the whole energy range studied. Points of P (γ, π^0) take values close to zero and represent the probability of identifying photons as π^0 determining the fraction of photons that have $\lambda_0^2 > \lambda_{0-opt}^2$ (π^0) of the total photons.

Figure 9 shows the probability of correctly identifying π^0, P (π^0, π^0), as the fraction of π^0 with $\lambda_0^2 > \lambda_{0-opt}^2$ (π^0) of the total π^0, and reaches a maximum of 95% with values above 80% between 10 and 25 GeV. Below 10 GeV this probability decreases as the neutral pion photons decay produce separated clusters and are identified by this method

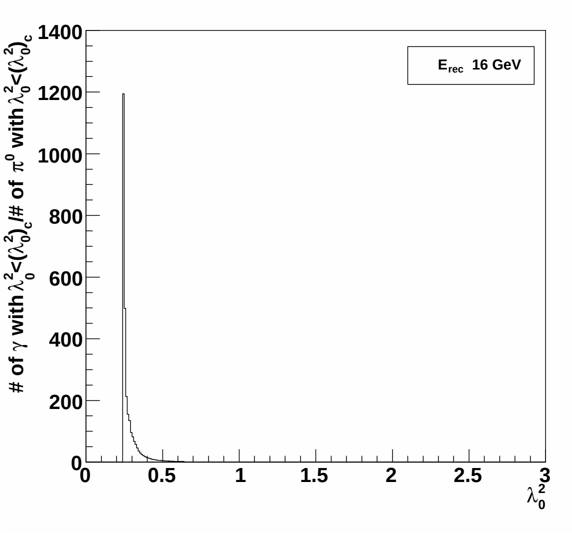

Figure 6: Study of λ_c for the determination of the optimal cut at $16GeV$.

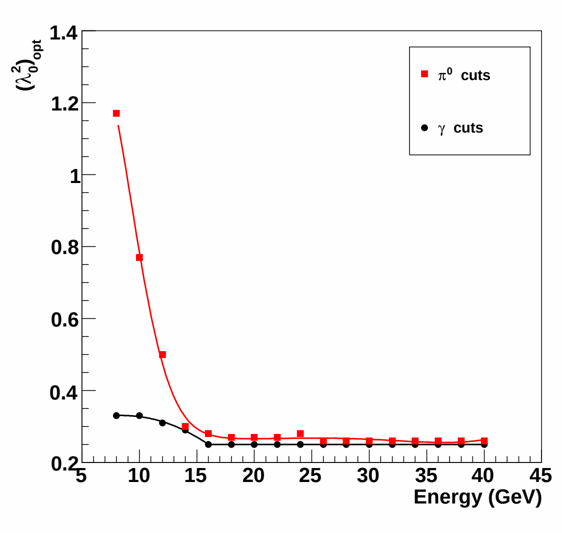

Figure 7: Optimal cuts as function of the reconstructed energy.

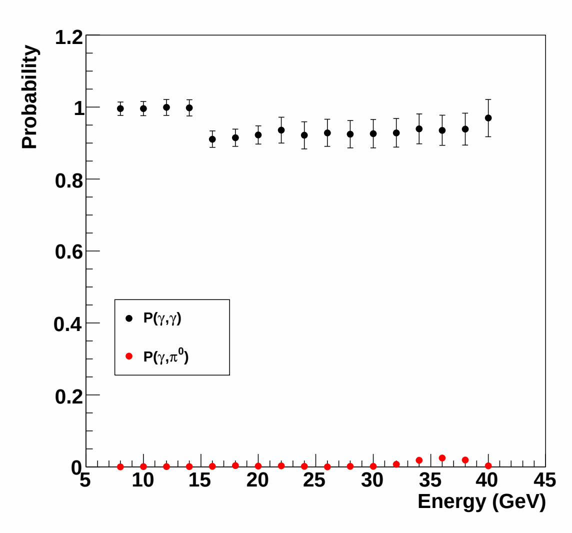

Figure 8: Probability of identification and misidentification of photons.

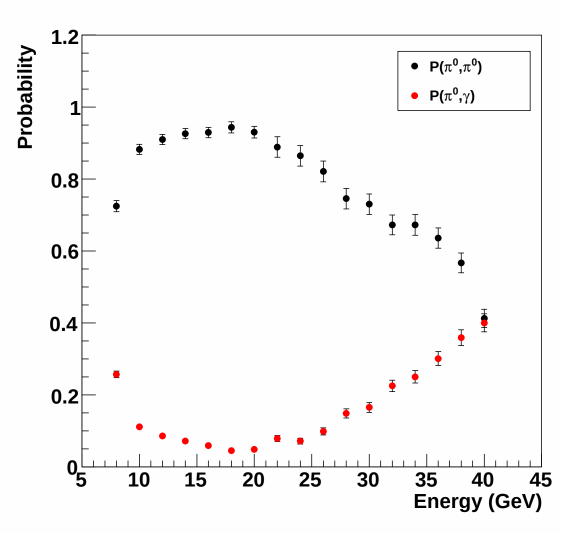

Figure 9: Probability of identification and misidentification of π^0.

as photons instead of π^0. In this case the invariant mass method can be better applied. For energies above 25 GeV it decreases as the cluster size generated by these features similar to the cluster formed by a single photon and is identified as such by this method. At these high energies the so called isolation cut method is better applied.

The probability of identifying π^0 as photons, P (π^0,γ) is determined by the fraction of π^0 with $\lambda_0^2 < \lambda_{0-opt}^2$ (γ) of the total of π^0.

4 Conclusion

We studied the shower shape method to discriminate efficiently the photons from the decay of π^0 from other sources of photons. It has been shown that the method can be applied in the energy range between 10 and 25GeV. This method will be implemented in further data analysis as an alternative method to the Bayesian approach [6].

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