\( \pi^0 \) measurement with ALICE electromagnetic calorimeters in p+p collisions at LHC

Renzhuo WAN \(^{1,2}\) for the ALICE collaboration

\(^{1}\)Key Laboratory of Quark & Lepton Physics (Huazhong Normal University), Ministry of Education, Wuhan, China
\(^{2}\)Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Strasbourg, France

E-mail: wanrz@iopp.ccnu.edu.cn

Abstract.

The electromagnetic calorimeters, PHOS (PHOton Spectrometer) and EMCAL (Electro-Magnetic CALorimeter) have been designed for photon detection and jet measurement in ALICE experiment at LHC. We discuss the strategy adopted for calorimetric \( \pi^0 \) measurements via the \( \pi^0 \rightarrow 2\gamma \) channel in ALICE and present the two-photon invariant mass spectra obtained in p+p collisions at \( \sqrt{s_{NN}} = 7 \) TeV.

1. Introduction

The goal of heavy-ion physics at ultra high energy is to explore the QCD phase diagram and probe the nature of QCD matter at extreme temperature and energy density. At LHC energies, the initial state temperature is expected to be well above the deconfinement transition temperature at which the Quark Gluon Plasma (QGP) is expected to be formed. Photon detection is one of the most promising methods to study the medium properties at the earliest phase of the collision thanks to electromagnetic calorimetry. Through the measurement of inclusive photon \( p_T \) spectra it is essential for the achievement of \( \gamma \)\text{direct}, \( \pi^0 \), \( \eta \) and \( \omega(782) \) distributions. All together, these measurements provide tests of perturbative QCD, investigation of \( m_T \) and \( x_T \) scaling and studies of the interaction of partons with the medium. In addition, \( \gamma \) and \( \pi^0 \) triggered jet measurements are sensitive tomographic probes of the hot and dense medium formed in heavy-ion collisions. Among this program of measurements, the light neutral meson \( \pi^0 \) measurement over a wide momentum range will play an important role in ALICE at the LHC.

2. ALICE electromagnetic calorimeters: PHOS and EMCAL

The ALICE experiment at LHC [1, 2] was specifically designed to cope with the high multiplicity environment in heavy-ion collisions at \( \sqrt{s_{NN}} = 5.5 \) TeV. PHOS [3] is a high resolution photon calorimeter designed to measure photons over a large momentum range from 0.5 GeV/c to 100 GeV/c. It is placed at 4.6 m from the interaction point and covers \( \Delta\phi = [220^\circ, 320^\circ] \) in azimuthal angle and \( |\Delta y| < 0.12 \) in rapidity. It is made of \( PbWO_4 \) [4] crystals with a fine granularity of \( \Delta\phi \times \Delta\eta = 4.8 \times 10^{-3} \times 4.3 \times 10^{-3} \) to allow precise identification and measurement of electromagnetic showers in a high multiplicity environment. The PHOS beam test measured an energy resolution of \( \frac{3\%}{\sqrt{E}} \oplus 1.1\% \). EMCAL [5], a lead-scintillator sampling electromagnetic
calorimeter, covers a much larger acceptance over $\Delta \phi = [80^\circ, 190^\circ]$ and $|\Delta y| < 0.7$ with a granularity of $\Delta \phi \times \Delta y = 14 \times 10^{-3} \times 14 \times 10^{-3}$ and allows precise jet measurements in addition to those of electrons and photons. The beam test of EMCAL module prototype has shown that the energy resolution corresponds to $11% \sqrt{E} + 1.7%$ [6]. These two different calorimeter designs offer complementary methods to cross-check measurements and better estimate systematic uncertainties.

3. Event reconstruction

The raw data taken with the ALICE experiment are reconstructed by using the ALICE offline software package AliRoot [7]. They are then decoded to provide energy and timing information. An electromagnetic cluster is defined as the total energy deposition in adjacent cells fired by a same incident particle. However, several clusters may overlap in high multiplicity context induced by heavy-ion collisions. The details of the cluster finding and unfolding algorithm can be found in [3, 5]. After the clustering procedure, the position and energy of the incident particles can be obtained with additional parameters related to the shower topology. To minimize charged particle contamination of the photon spectra, track matching in the (x, z) plane of the calorimeters is employed, using information from the central tracking detectors. By combining information from particle time of flight, track position matching and the shower shape parameters, particle identification can be performed as studied in simulation [8]. We also employ the Bayesian method which assigns a PID weight on an event-by-event basis for each reconstructed particle in order to improve the particle identification efficiency in the pp and AA environments (see detailed study in [9]).

4. Strategy of $\pi^0$ spectra measurement

To measure the $\pi^0$ $p_T$ spectra to hundred GeV/c, we employ a multi-component method based on invariant mass analysis at low $p_T$, shower shape analysis at intermediate $p_T$ and an isolation cut method at high $p_T$ to enhance the extraction of the $\pi^0$ signal and suppress the background for direct photon measurement.

4.1. Invariant mass analysis

$\pi^0$ are identified via the $\pi^0 \rightarrow 2\gamma$ channel with a branching ratio of 98.8%. We assume that the two decay photons come from the collision point. At low $p_T$, $< 20$ GeV/c for PHOS and $< 8$ GeV/c for EMCAL, the two decay photons are well separated and thus can be reconstructed using the invariant mass formula

$$m_{\gamma\gamma} = \sqrt{p_1^2 + p_2^2} = \sqrt{2E_1E_2(1 - \cos \phi_{12})},$$

where $(p_1, E_1)$ and $(p_2, E_2)$ are the momentum and energy of the two photon candidates, $\phi_{12}$ is the opening angle in the laboratory frame. The uncorrelated photon pairs, which are not originating from a parent $\pi^0$, will produce a combinatorial background that we will subtract via an event mixing technique. The energy asymmetry cut $\alpha_{\gamma\gamma} = |E_1 - E_2|/(E_1 + E_2)$ and distance cut $\Delta R = \sqrt{(\phi_1 - \phi_2)^2 + (\eta_1 - \eta_2)^2}$ could be used to improve the signal-to-background ratio especially in heavy-ion collisions. For more technical details, refer to some of the RHIC publications [10, 11, 12].

4.2. Shower shape analysis

Going to higher $p_T$, $> 20$ GeV/c for PHOS and $> 8$ GeV/c for EMCAL, the two decay photons start to overlap. A cluster unfolding algorithm becomes thus essential to separate the two clusters. With such overlapping clusters, the shower eccentricity becomes measurable evolving
Figure 1. Two-photon invariant mass distributions with PHOS (left) at \( p_T > 3.0 \) GeV/c and EMCAL (right) with \( p_T \) bins of [3.0, 8.0] GeV/c from p+p collisions at \( \sqrt{s_{NN}} = 7 \) TeV.

from a circular shape when a single photon presents to an elliptic shape when a \( \pi^0 \) is produced. Measurement of shower eccentricity enables us to extend \( \pi^0 \) PID capability to 50 GeV/c for PHOS and 30 GeV/c for EMCAL.

4.3. Isolation cut method
However, when going to higher \( p_T \), the two photons from \( \pi^0 \) decay are completely overlapped to a single cluster and this becomes a challenge for \( \pi^0 \) identification. The isolation cut method [13, 14] originates from topology consideration induced by the initial hard processes at leading order of Compton scattering (\( q(\bar{q}) + g \rightarrow \gamma + g \)) and annihilation (\( q + \bar{q} \rightarrow \gamma + g \)) for direct photon identification. We thus can extract high \( p_T \) \( \pi^0 \) by subtracting the direct photon contribution from the inclusive photon spectrum. Although the next-to-leading order processes will spoil the isolation in both p+p and heavy-ion collisions, the starting point is to study the hadron and photon kinematics within a cone of the photon candidate \( R = \sqrt{(\phi - \phi_\gamma)^2 + (\eta - \eta_\gamma)^2} \) and its surrounding. The combination of the isolation cut method and shower shape analysis simultaneously allows us to enhance the \( \gamma/\pi^0 \) separation at high \( p_T \) [15].

5. \( \pi^0 \) extraction
The early LHC data runs beginning in Dec. 2009 with p+p collisions at 900 GeV, 2.36 TeV and 7 TeV will be used as reference data for the future pA and AA collisions. During these runs, the ALICE central barrel detectors ITS, TPC, TOF, 7/18 of TRD, 3/5 of PHOS (without CPV) and 4/10 EMCAL were installed. After several iterations made for data reconstruction using the OCDB (Offline Conditions Data Base) where the calibration, alignment and reconstruction parameters are stored, the raw data have been converted to the final physics data to be analyzed by different physics working groups. The two-photon invariant mass spectra have been then constructed. In each \( p_T \) bin, the combinatorial background in real events is subtracted using the mass spectra from mixed events. The \( \pi^0 \) signals are extracted on a statistical basis within its nominal mass window.

From the data with pp collisions at 7 TeV, clear peaks around the \( \pi^0 \) nominal mass (\( m_{\pi^0} = 0.135 \) GeV/c\(^2\)) have been observed up to 20 GeV/c. Fig. 1 shows the \( m_{\gamma\gamma} \) spectra for PHOS.
at $p_T > 3.0 \text{ GeV/c}$ and EMCAL for $p_T$ bins of [3.0, 8.0] GeV/c. The $\pi^0$ peaks are extracted by a fitting of Gaussian+Polynomial function. The mass resolutions of 4$\sim$7 $MeV/c^2$ for PHOS and 8$\sim$14 $MeV/c^2$ for EMCAL correspond to the expected detector performance. We are now at the stage of collecting additional data for analysis, while improving the calibration to a level allowing full use of the calorimeters. The goal of the first analysis is the invariant cross section measurement. It will also be essential to estimate the systematic uncertainties and compare the final spectra with the existing experimental data to cross-check.

6. Conclusion
The $\pi^0$ analysis plays an important role itself in QCD physics and also in photon and jet physics in the new TeV energy region at LHC. We have presented the $\pi^0$ analysis strategy in ALICE using PHOS and EMCAL calorimeters. These detectors joined the global data-taking and have collected $\sim 3 \times 10^8 M$ events for physics analysis through the end of August, 2010. The clear peaks around the $\pi^0$ nominal mass have been observed up to 20 GeV/c. The analysis is in a good progress moving toward the final physics results.

Acknowledgement
We thank the ALICE collaboration and the ALICE funding agencies (the same as the acknowledgement in [16]). The work is supported partly by the NSFC (10875051, 10635020, 10975061 and 11020101060), the Key Project of Chinese Ministry of Education (306022 and IRT0624), and the Program of Introducing Talents of Discipline to Universities of China: B08033 and CCNU09C01002 (Key Project) of China.

References
[1] ALICE Collaboration, J. Phys. G: Nucl. Part. Phys. 30 (2004)1517
[2] ALICE Collaboration, J. Phys. G: Nucl. Part. Phys. 32 (2006)1295
[3] ALICE Collaboration, CERN-LHCC-99-4
[4] Aleksandrov D. V. et al., Nucl. Instrum. Meth. A 550 (2005) 169
[5] ALICE Collaboration, CERN-LHCC-2008-014
[6] Allen J. et al., arXiv: 0912.2005
[7] http://aliweb.cern.ch/Offline/AliRoot/Releases.html
[8] Conesa G. et al., ALICE-INT-2005-053
[9] Conesa G. et al., ALICE-INT-2005-016
[10] Adler S. S. et al. PHENIX collaboration, Phys. Rev. C 76 (2007) 034904
[11] Abelev B. I. et al. STAR collaboration, Phys. Rev. C 80 (2009) 044905
[12] Abelev B. I., et al. STAR collaboration, arXiv: hep-ex/0912.3838v2
[13] Aaltonen T. et al. CDF collaboration, Phys. Rev. D 80 (2009) 111106
[14] Abezov V. M. et al. D0 collaboration, Phys. Lett. B 639 (2006) 151
[15] Conesa G., Nucl. Instrum. Meth. A 580 (2007) 1446
[16] K. Aamodt et. al ALICE collaboration, Eur. Phys. J. C 68 (2010) 89