Inclusive production of $\pi^0$ in $pp$ collisions at 0.9 and 7 TeV and perspectives for heavy-ion measurements with the ALICE calorimeters

Yuri Kharlov for the ALICE collaboration

Institute for High Energy Physics, Protvino, 142281 Russia

Abstract

The inclusive spectrum of $\pi^0$ production has been measured in $pp$ collisions at $\sqrt{s} = 900$ GeV and 7 TeV with the ALICE experiment. The preliminary results of these measurements are presented, and perspectives for $\pi^0$ measurements with heavy ions are discussed.

Key words: Hadron production, differential cross section, experimental data analysis

PACS: 13.85.Ni, 13.20.Cz

1. Introduction

Hadron production measurements in proton-proton collisions at the LHC energies open up a new kinematic regime for testing and validating the predictive power of quantum chromodynamics, and to impose new constraints on models and their parameters. Quantitative description of hard processes is provided by perturbative QCD (pQCD). However, a significant fraction of hadrons are produced in $pp$ collisions at high energies via soft parton interactions, and thus they cannot be well described within the framework of pQCD. Many advanced event generators have to appeal to phenomenological models, along with the pQCD calculations, in order to describe hadron production adequately. Evidently, such phenomenological models are tuned to available experimental data, and have been validated using data delivered by lower-energy colliders, like RHIC, SPS and Tevatron. Extrapolation of these models to LHC energies cannot be valid a priori, because the increase in the collision energy is very large. Even the validity of the pQCD predictions cannot be guaranteed at the LHC, since the parton density functions (PDF) are not well determined at such a high energy.

Hadron spectra measured in heavy ion collisions shed light onto the parton energy loss in hot quark-gluon matter, via comparison with the spectra measured in $pp$ collisions.
Suppression of the hadron yield, defined as the ratio of the hadron production spectra in central heavy ion and \( pp \) collisions, normalized per nucleon-nucleon collision, is referred to as the nuclear modification factor \( R_{AA} \). It was measured in Au-Au collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \) by PHENIX [1] and STAR [2] at RHIC. The LHC brings the Pb-Pb collisions to almost 10 times higher energy, \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \), and thus the measurements of \( R_{AA} \) becomes important for understanding the properties of the quark matter produced in these high-energy nuclear collisions. Suppression of charged particle production at large \( p_T \) in central Pb-Pb collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \) has been already observed by ALICE [3].

The ALICE experiment [4] performs measurements of the neutral pion production in \( pp \) collisions at the collision energies \( \sqrt{s} = 7 \text{ TeV} \) and 900 GeV, and in Pb-Pb collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \) at mid-rapidity in a wide range of the transverse momenta \( p_T \). Conventionally, the \( 
\pi^0 \) meson is detected via its two-photon decay in the electromagnetic calorimeters, PHOS and EMCAL. The PHOS detector [5] covers the acceptance of \( 260^\circ < \phi < 320^\circ \) in azimuth angle and \( |\eta| < 0.13 \) in pseudorapidity. The EMCAL [6] acceptance is \( 80^\circ < \phi < 120^\circ \) and \( |\eta| < 0.7 \). The decay \( \pi^0 \rightarrow \gamma \gamma \) was also measured by ALICE via identifying the conversion photons produced in the material of the ALICE inner tracking system, \( \gamma \rightarrow e^+e^- \), described elsewhere [7,8].

2. Analysis

The proton-proton collision data used for the measurements of the \( \pi^0 \) spectrum were collected by the ALICE detector in 2010 with the minimum bias trigger [9]. This trigger required a hit in the Silicon Pixel Detector (SPD) or in either one of the two scintillator hodoscopes V0A and V0C surrounding the interaction point at large rapidities. The integrated luminosities of the event samples are \( \int LdT = 5.5 \text{ nb}^{-1} \) at \( \sqrt{s} = 7 \text{ TeV} \) and \( \int LdT = 0.14 \text{ nb}^{-1} \) at \( \sqrt{s} = 900 \text{ GeV} \).

Reconstruction of the \( \pi^0 \) mesons in the ALICE calorimeters, PHOS and EMCAL, was performed by invariant mass analysis. To minimize a possible bias by the photon identification, rather loose cuts on the photon candidates were imposed. To suppress a major part of hadronic background, the lower cut on the cluster energy was set to a value just above the minimum ionizing energy, \( E > 0.3 \text{ GeV} \). An additional cut on the number of cells in a cluster was set in PHOS — all clusters containing at least 3 cells were
considered as candidates for photons. Due to the low occupancy of both calorimeters by the secondary particles in $pp$ collisions, the background under the $\pi^0$ peak is not very large and allows easily to extract the number of $\pi^0$'s. Examples of the invariant mass distributions in PHOS and EMCAL are shown in Fig.1. The number of reconstructed $\pi^0$'s was found in each $p_T$ bin from the invariant mass distributions by fitting and extracting the number of events under the $\pi^0$ peak. The raw spectrum obtained was corrected for the reconstruction efficiency calculated in Monte Carlo simulations tuned to reproduce the real-data characteristics.

3. Results and discussion

Data collected with the PHOS detector in the $pp$ run allowed to measure the $\pi^0$ spectra in the $p_T$ range from 0.6 to 25 GeV/c at the center-mass energy $\sqrt{s} = 7$ TeV and in the $p_T$ range from 0.6 to 7 GeV/c at $\sqrt{s} = 900$ GeV. The invariant $\pi^0$ production yields normalized per $pp$ minimum bias collision are shown for both collision energies in Fig.2. Besides the PHOS measurements, these plots show the results of the measurements in the central tracking system via photon conversion. The PHOS points were fitted by the Tsallis function $d^3N/p_d\, dp_d\, dy\, d\phi = C[1+(m_T-m)/nT]^{-n}$ and the ratio of the data points to the fitting function, shown at the bottom of the spectra, illustrates the stability of the measured points. These normalized spectra were converted to the invariant differential cross section of the $\pi^0$ production $Ed^3\sigma/ dp^3|_{y=0}$ with the assumption of the absolute cross section of $pp$ collisions. Within conservative uncertainty estimation, the $pp$ cross section was taken as $\sigma_{pp} = 67 \pm 10$ mb at $\sqrt{s} = 7$ TeV and $\sigma_{pp} = 50 \pm 10$ mb at $\sqrt{s} = 900$ GeV. The production cross sections obtained are shown in Fig.3. Next-to-Leading Order pQCD calculations with the parton density function CTEQ5M, fragmentation function KKP and different QCD scales $\mu$ [10] have been compared with the data. The ratio of the measured cross section to the NLO prediction is shown in the bottom panels. The uncertainty in the $pp$ cross section $\pm 10$ mb is represented by the pink box. At the collision energy of 900 GeV the NLO calculations at $\mu = p_T$ describe well the measured data, while at $\sqrt{s} = 7$ TeV the higher QCD scale ($\mu > 2p_T$) is required to reproduce better the data, although the discrepancy is still significant.

Data collected by the ALICE calorimeters in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV are sufficient to measure the $\pi^0$ spectrum at $1 < p_T < 15$ GeV/c. More sophisticated analysis
is ongoing now involving advanced methods of background subtraction and of reconstruction efficiency evaluation in a high-multiplicity environment. The nuclear modification factor $R_{AA}$ of the $\pi^0$ spectrum will be a complimentary measurement to the charged particle suppression [3] which will lead to better understanding of transport properties of hot QCD matter.

**Conclusion**

The ALICE experiment at the LHC has measured the production spectrum of neutral pions in proton-proton collisions at the energies $\sqrt{s} = 7$ TeV and 900 GeV, using two independent methods. The photons from the $\pi^0$ were detected by the calorimeters, as well as via photon conversion identified in the central tracking system. Deploying these techniques provided a cross check and allowed to reduce systematic uncertainties in the overlapping $p_T$ region and to extend the joint spectrum to a wide $p_T$ range. The production yield was measured at mid-rapidity at $0.4 < p_T < 25$ GeV/$c$ at $\sqrt{s} = 7$ TeV and at $0.6 < p_T < 7$ GeV/$c$ at $\sqrt{s} = 900$ GeV. These measurements allow a test of pQCD-based calculations and provide reference data to measure the nuclear modification factor $R_{AA}$ of the $\pi^0$ production in heavy ion collisions at the LHC.

This work was partially supported by the grants RFBR 08-02-91021 and 10-02-91052.

**References**

[1] A. Adare et al., PHENIX Collaboration. Phys.Rev.Lett. 101 (2008) 232301.
[2] J. Adams et al., STAR Collaboration, Phys. Rev. Lett. 91 (2003) 172302.
[3] K. Aamodt et al. ALICE collaboration. Phys. Lett. B 696 (2011) 30–39.
[4] K. Aamodt et al. ALICE collaboration. JINST. 2008, 3, S0800.
[5] ALICE collaboration. Photon Spectrometer PHOS, Technical Design Report. CERN/LHCC 99-4, 5 March 1999.
[6] ALICE collaboration. The electromagnetic calorimeter, Addendum to the Technical Proposal. CERN/LHCC 2006-014, 14 April 2006.
[7] K. Aamodt et al. In: 4th Hot Quarks Workshop, La Londe Les Maures, 21 June 2010.
[8] K. Koch et al. In: Conference Hard Probes 2010, Eilat, 6–10 October 2010. To appear in Nucl.Phys.A.
[9] K. Aamodt et al. ALICE collaboration. Phys.Lett. B 693 (2010) 53–68.
[10] P. Aurenche, et al., Eur. Phys. J. C 13,347 (2000)