PROCEEDINGS OF SCIENCE

Light neutral mesons in ALICE

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Light neutral mesons, like π^0, η and $\omega(782)$, will be produced abundantly in the first LHC run in pp collisions. These mesons will be detected by the PHOS detector via their decay channels $\pi^0 \to \gamma\gamma$, $\eta \to \gamma\gamma$ and $\omega \to \pi^0\gamma$. The physics motivation to study neutral meson production in pp and AA collissions will be discussed in this paper. Acceptances, reconstruction methods, as well as expected p_T limits of measured spectra, are presented.

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1. Introduction

The cross section of inclusive hadron production at large transverse momentum in proton-proton and nuclear collisions can be calculated within perturbative quantum chromodynamics (pQCD), because they are produced in fragmentation processes of quarks and gluons issuing from hard parton scattering. As long as an inclusive hadron cross section is calculated in pQCD with the use of the parton density functions of the colliding particles, fragmentation functions and QCD matrix elements, the experimental measurements of hadron production at high p_T is a valuable tool for pQCD validation. Therefore, high-p_T hadron, along with prompt photons and jets, are considered as sensitive probes for QCD processes at initial stage of hadronic collisions. Hadrons production at high p_T in nuclear collisions is sensitive to the properties of strongly interacting matter.

2. Experimental setup

Neutral mesons in photonic decay channels will be detected by the ALICE experiment with the use of the photon spectrometer PHOS which is a high-resolution electromagnetic calorimeter made of lead tungstate crystals. The lead tungstate, $PbWO_4$ is one of the heaviest inorganic scintillators with a Moliere radius $R_M = 2$ cm which defines a tiny lateral granularity and a high spatial resolution of the PHOS detector. The PHOS will consist of 5 modules, each including 56×64 crystals with a transverse size of 2.2×2.2 cm^2. The energy and the coordinate resolutions of the PHOS for photons and electrons is

$$\frac{\sigma(E)}{E} = \sqrt{\left(\frac{1.3}{E}\right)^2 + \frac{3.3^2}{E} + 1.1^2}, \quad \sigma(x) = \sqrt{\frac{3.26^2}{E} + 0.44^2}\ \text{mm}.$$

The azimuthal coverage of the PHOS detector will be $220^\circ < \varphi < 320^\circ$ for 5 modules. The partial PHOS geometry available for the first LHC run in 2009 includes 3 modules covering $226^\circ < \varphi < 320^\circ$. The PHOS acceptance in pseudorapidity will be $|\eta| < 0.12$.

3. Cross sections

Invariant cross section of π^0 meson production in pp collisions can be calculated in the next-to-leading order perturbative QCD (NLO pQCD). This cross section has been calculated using the program INCNLO v1.5 [1]. A parton distribution function set was chosen to be CTEQ5M, the fragmentation function was KKP [2] and a QCD scale $\mu = p_T$. The π^0 cross sections in pp collisions at $\sqrt{s} = 0.9, 5.5, 10$ and 14 TeV are shown in Fig.1.

Cross sections of η and $\omega(782)$ meson productions can be calculated only in the leading order pQCD, because their fragmentation functions are not known. These cross sections in pp collisions at $\sqrt{s} = 0.9, 10$ and 14 TeV were obtained in Pythia 6.214 [3] and are shown in Fig.2.

The π^0 production in heavy ion collisions was estimated from that in pp collisions using a binary scaling following the approach [4]:

$$\sigma(AA \to \pi^0) = \langle N_{\text{coll}} \rangle_{C_1-C_2} \frac{\sigma_{AA}^{\text{geo}}}{\sigma_{NN}} \sigma(NN \to \pi^0),$$

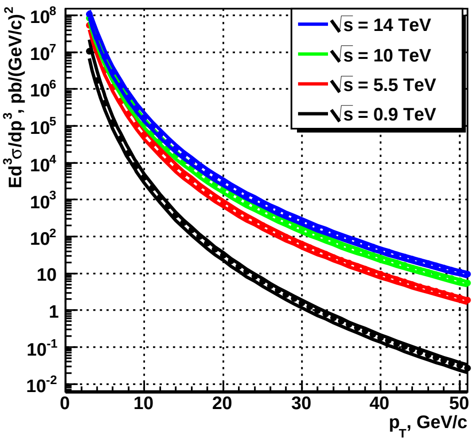


Figure 1: Invariant cross sections of π^0 production in pp collisions at 0.9, 5.5, 10 and 14 TeV.

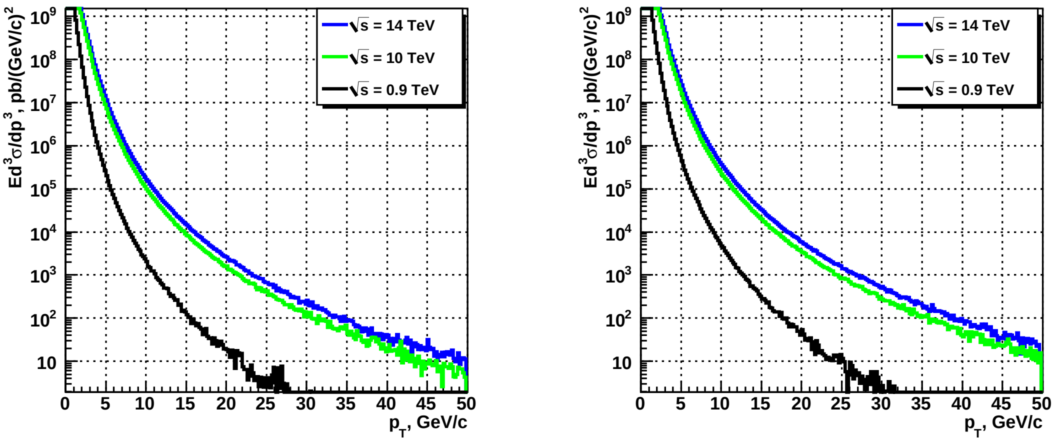


Figure 2: Production cross sections of η (left) and $\omega(782)$ (right) in pp collisions at 0.9, 10 and 14 TeV.

where $\langle N_{\rm coll}\rangle_{C_1-C_2}$ is the average number of binary nucleus collisions in colliding nuclei at centrality C_1-C_2, $\sigma_{AA}^{\rm geo}$ is a geometrical cross section of the nuclei AA, σ_{NN} is the total cross section of nucleons, and $\sigma(NN\to\pi^0)$ is a cross section of π^0 hard production in a nucleon-nucleon collision. For $Pb-Pb$ collisions and centrality class $0-10\%$ these values are equal to (see [4], Appendix 1):

$$\langle N_{\rm coll}\rangle_{0-10\%} = 1670, \quad \sigma_{AA}^{\rm geo} = 7745 \text{ mb}, \quad \sigma(NN\to\pi^0) = 72 \text{ mb}.$$

The hadron production will be highly suppressed in central heavy ion collisions, and we assume that the nuclear modification factor R_{AA} at the LHC energies will be similar to that at RHIC [5], $R_{AA}\sim 0.2$. The invariant cross section of π^0 production in $Pb-Pb$ collisions at 5.5 TeV/nucleon and centrality class $0-10\%$ is shown in Fig.3.

4. Trigger and run scenario

The ALICE can operate with different triggers. If the minimum bias trigger partition includes

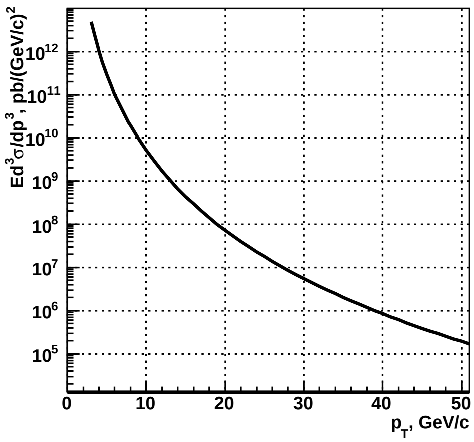


Figure 3: Invariant cross sections of π^0 production in $Pb-Pb$ collisions at 5.5 TeV/nucleon and centrality class $0-10\%$.

slower detectors (e.g. TPC), the rate of data taking will be determined by the dead time of these detectors, rather than by the collision rate. The TPC detector is limited by the data taking rate of 200 Hz, which, having in mind a cross section of events detected by the ALICE trigger detectors of 40 mb, corresponds to the effective luminosity $\mathscr{L}^{\rm eff} = 5\cdot 10^{27}$ cm^{-2}s^{-1}.

The PHOS detector can provide its own L0 trigger defined by the energy deposited in any patch of adjacent 2×2 crystals above a threshold. At the low enough threshold, $200-500$ MeV, the rate of events triggered by the PHOS L0 trigger becomes rather low, at the level of a $100-200$ Hz which is below the PHOS intrinsic data taking rate. If the PHOS is operating in a standalone trigger partition, the data taking rate is solely determined by the beam luminosity.

The first LHC run with proton-proton collisions is expected at the energy $\sqrt{s} = 10$ TeV and a lower luminosity $\mathscr{L} = 5\cdot 10^{28}$ cm^{-2}s^{-1} (see, e.g. [6]). The nominal luminosity for the ALICE experiment is $\mathscr{L} = 3\cdot 10^{30}$ cm^{-2}s^{-1}. The run time can vary from weeks to months with some duty factor. To have more definitive predictions, we calculate integrated luminosity for several periods of data taking: 3 day, 30 days and 3 months which are collected in Table 1. Keeping in mind

T	$\mathscr{L}$, cm^{-2}s^{-1}		
	$5\cdot 10^{27}$	$5\cdot 10^{28}$	$3\cdot 10^{30}$
3 days	1.3	13	780
30 days	13	130	7800
3 months	39	390	$2.2\cdot 10^4$

Table 1: Integrated luminosity $\int \mathscr{L} dT$ in nb^{-1} for different LHC luminosities $\mathscr{L}$ and different data taking times T.

the aforementioned run scenarios, we estimate the detection rate of light mesons for integrated luminosities $\int \mathscr{L} dT = 10, 100$ and 300 nb^{-1}.

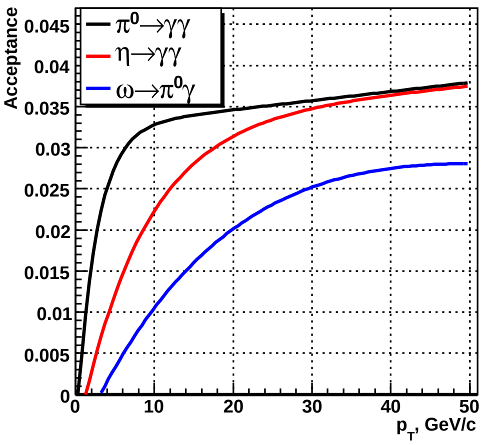
The heavy ion run will have the $Pb-Pb$ collision energy 5.5 TeV/nucleon and the luminosity $\mathscr{L} = 5\cdot 10^{26}$ cm^{-2}s^{-1}. Expected duration of the heavy ion run is about 10^6 s, which will give the integrated luminosity $\int \mathscr{L} dT = 0.5\ \text{nb}^{-1}$.

5. Detection of neutral mesons in PHOS

The geometrical acceptance for reactions $\pi^0 \to \gamma\gamma$, $\eta \to \gamma\gamma$ and $\omega(782) \to \pi^0\gamma \to 3\gamma$ was calculated in Monte Carlo simulations for 3 adjacent PHOS modules corresponding the PHOS configuration available for the first LHC run. The parameterization of the acceptance $A(p_T)$ as a function of the meson's transverse momentum p_T normalized to the unit rapidity $|y| < 0.5$ and to the full azimuth angle $\Delta\phi = 2\pi$ can be expressed by the formula

$$A(p_T) = (a + bp_T)\left(1 - \exp\frac{c - p_T}{d}\right)$$

and shown in Fig.4 (left) with parameters given in the table (right).



Reaction	a	b	c	d
$\pi^0 \to \gamma\gamma$	0.032	$1.1 \cdot 10^{-4}$	0.355	2.51
$\eta \to \gamma\gamma$	0.033	$9.1 \cdot 10^{-5}$	1.33	8.10
$\omega \to \pi^0\gamma$	0.183	$2.0 \cdot 10^{-3}$	2.37	120

Figure 4: Acceptance parameterization for π^0, η and $\omega(782)$ in 3 PHOS modules.

Reconstruction of neutral mesons in PHOS is performed using the invariant mass spectrum of 2 reconstructed clusters for 2-photon decay channels of π^0 and η or of 3 reconstructed clusters for $\omega \to \pi^0\gamma$. Due to a low detector occupancy in pp collisions, the π^0 peak reveals itself without applying any particle identification criteria for reconstructed clusters. The invariant mass spectrum of cluster pairs in the mass range around π^0 is illustrated in Fig.5 for two p_T bins, $0 - 1$ GeV/c (left) and $3 - 4$ GeV/c (right). These spectra were obtained in the full Monte Carlo simulations of 4 million Pythia minimum bias events in the ALICE setup. The invariant mass spectra are fitted by the sum of the Gaussian and the polynomial of the first order, represented by the red curve. The number of reconstructed π^0 can be extracted from the invariant mass spectra by integrating the Gaussian part of the fitting function. The raw p_T spectrum of reconstructed π^0 per one pp collisions as a function of p_T is shown in Fig.6 (left). The ratio of the number of reconstructed π^0 to the combinatorial background is given in Fig.6 (right). The available simulated statistics is not enough to reconstruct $\eta \to \gamma\gamma$ and $\omega \to \pi^0\gamma$, but the reconstruction techniques should be similar to that of π^0. The obtained raw spectrum should be converted to the production cross section via

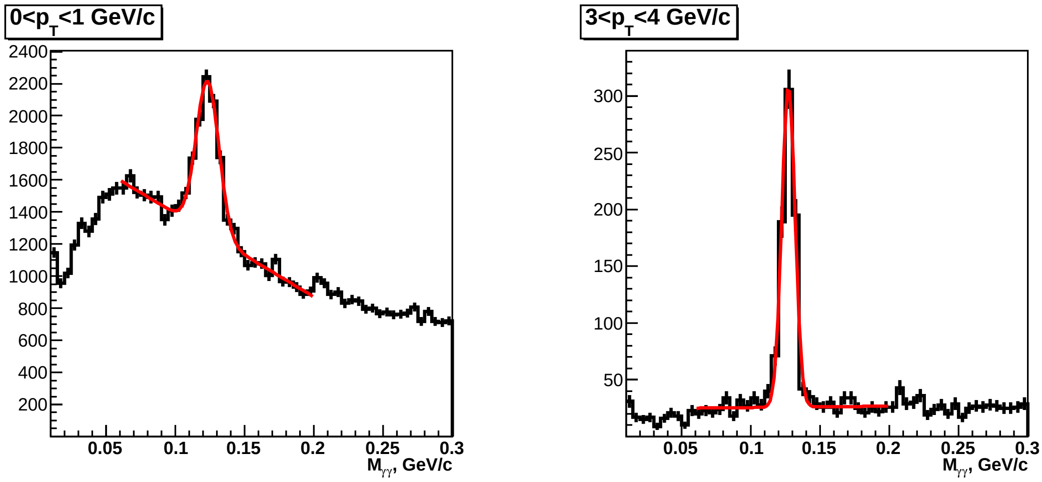


Figure 5: Invariant mass spectrum of cluster pairs reconstructed in PHOS in pp collisions at $\sqrt{s} = 10$ TeV at different p_T.

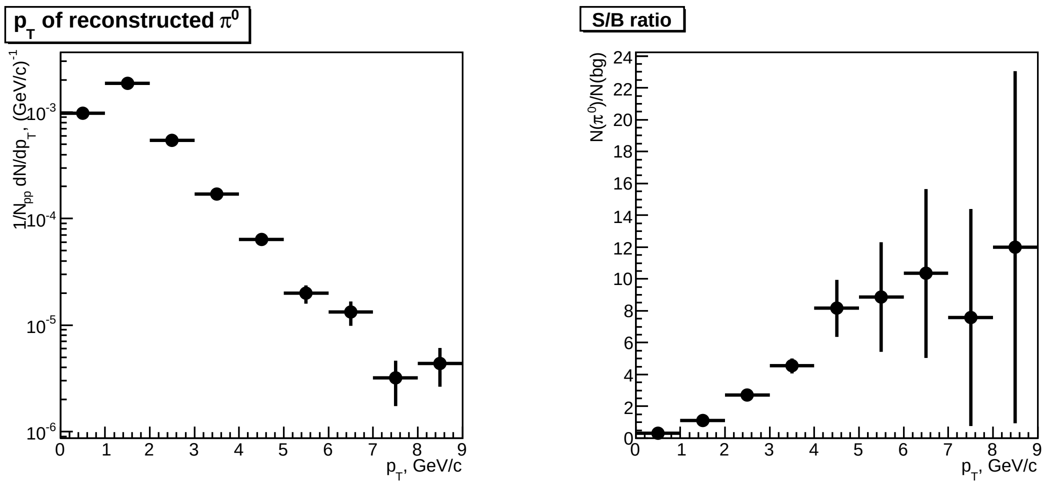


Figure 6: The raw p_T spectrum of reconstructed π^0 in pp collisions (left) and a ratio of signal to background (right).

correcting it by the acceptance A (Fig.4), the reconstruction and trigger efficiencies ε, and by the off-vertex background c_{offvtx}:

$$\frac{d\sigma}{dp_T} = \frac{dN}{dp_T}\frac{1}{\mathscr{L}\cdot T\cdot A\cdot\varepsilon\cdot c_{\text{offvtx}}}. \tag{5.1}$$

The reconstruction efficiency of one photon is $\varepsilon_\gamma = 0.85$ [7], and for N-photon final states it is estimated as ε_γ^N. The off-vertex background was estimated at the level less then 0.1%.

Detection rate can be estimated from the predicted cross sections (Figs.1 and 2) by applying the inverse relation between the cross section and event rate (5.1). Detection rate of π^0 in pp collisions at $\sqrt{s} = 10$ TeV and for three integrated luminosities $\int \mathscr{L} dT = 10, 100$ and 300 nb^{-1} is shown in Fig.7 (left). The number of detected π^0 in the central $Pb-Pb$ collision at $\sqrt{s} = 5.5$ TeV/nucleon at centrality class $0-10\%$ and for the integrated luminosity $\int \mathscr{L} dT = 0.5$ nb^{-1} is presented in Fig.7

(right). The number of detected η and ω mesons in the photonic decay channels was calculated for

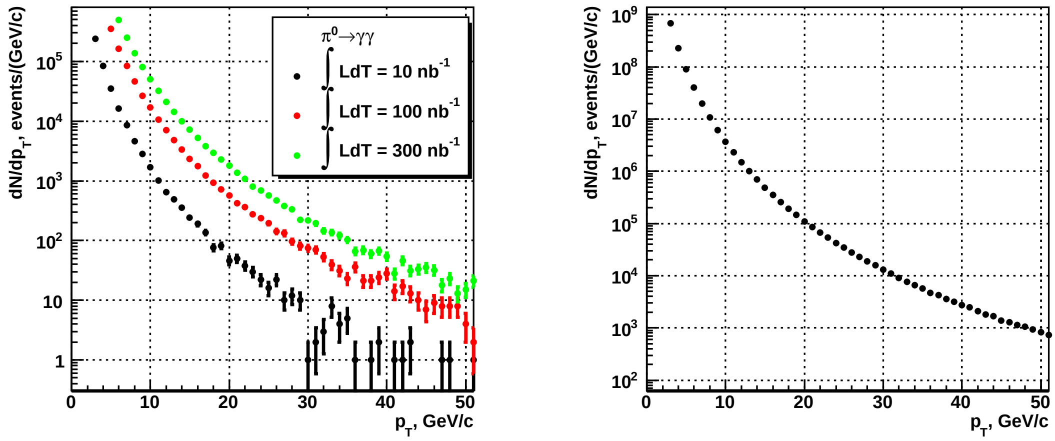


Figure 7: Detection rate of π^0 in 3 PHOS modules in pp collisions at $\sqrt{s} = 10$ TeV (left) and in central $Pb-Pb$ collisions at $\sqrt{s} = 5.5$ TeV/nucleon (right).

pp collisions only, because their detection in high-multiplicity environment in $Pb-Pb$ collisions seems to be a very challenging task. Detection rate of these mesons for three integrated luminosities are illustrated by Fig.8.

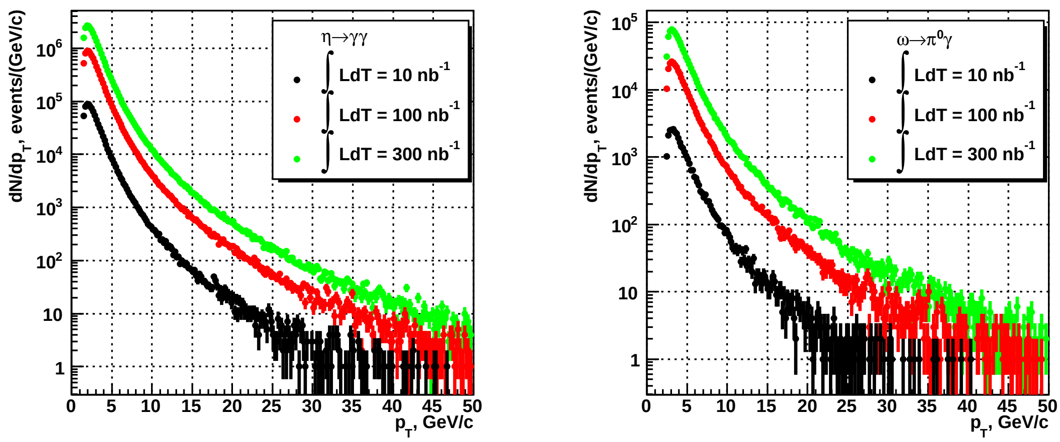


Figure 8: Detection rate of η (left) and $\omega(782)$ (right) in pp collisions at 10 TeV.

6. Summary

The ALICE experiment will measure inclusive spectra of light neutral mesons in pp and $Pb-Pb$ collisions in a wide transverse momentum range. The first data obtained from the pp run of LHC will provide enough statistics to measure spectra of π^0, η and $\omega(782)$ at transverse momenta up to $p_T = 30-50$ GeV/c. Precise measurement of these spectra can be used to validate the pQCD calculations. The detection of neutral mesons in $Pb-Pb$ collisions will give the nuclear modification factor R_{AA} and will help for interpretation of the parton energy loss models.

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