ALICE-PHOS: acceptance and efficiency correction factors $p - p \rightarrow \pi^0 + X$ at 10 TeV

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Abstract In ultra-relativistic Heavy-Ion Collisions (HIC), the properties of the quark gluon plasma (QGP) can be explored, in particular, via measurements of neutral pions. The π^0 is an important probe for both proton and heavy ion physics. In the former case, π^0 production provides an important mean of testing pQCD as well as useful data to constrain current and future theoretical models. In the latter case, π^0 measurements will serve as a baseline for exploring the nature of the HIC hard scattering. In the ALICE experiment, π^0 mesons are identified as they decay into two photons ($\pi^0 \rightarrow \gamma\gamma$) using the high-resolution photon spectrometer (PHOS). PHOS will measure π^0 transverse momentum over a wide range, from hundreds of MeV/c to several tens of GeV/c. An estimation of π^0 production cross-section in proton–proton collisions is calculated in a next-to-leading order (NLO) approximation and first presented. The π^0 geometrical acceptance and the identification efficiency along with the analysis on the invariant mass are the two important correction factors for obtaining a realistic π^0 spectrum discussed in this paper.

1 Introduction

Among the main RHIC discoveries is the suppression of hadrons with large transverse momentum in central nucleus–nucleus ($A - A$) collisions at $\sqrt{s} = 200$ GeV. The nuclear modification factor $R_{AA}(p_T)$, which compares the production yield in $A - A$ collisions with respect to proton–proton ($p - p$) ones, shows almost no change for photons from peripheral to central $A - A$ collisions, within errors [1]. However, high- p_T neutral pions are strongly suppressed ($R_{AA} \sim 0.2$) for a p_T larger than 6 GeV/c in central $A - A$ collisions [2]. The strong suppression of neutral pions, and

the differences in p_T dependence and centrality between photons and pions support the notion that scattered partons lose energy by gluon emission in the hot and dense medium produced in these collisions. High- p_T hadron production in $p - p$ and Pb – Pb collisions at the LHC will therefore be crucial in determining the properties of hot QCD matter (e.g. gluon density, transport coefficient parameter, etc.) at the highest energies ever studied.

In this report, we briefly describe the PHOS detector [3], which allows to identify and measure neutral pions decaying into photons. We also discuss the feasibility of π^0 measurement (in terms of statistics) for the first proton–proton run conditions at the LHC ($\sqrt{s} = 10$ TeV). Finally, we describe a Monte Carlo based method used to estimate the π^0 geometrical acceptance and reconstruction efficiency, where we account for the effect of bad channels.

2 ALICE PHOTon spectrometer PHOS

The ALICE¹ photon spectrometer: PHOS [3].

PHOS is optimized to measure photons and neutral mesons decaying into photons with excellent energy and spatial resolution. Photons are identified over a wide range of momentum, from a few hundreds of MeV/c up to several tens of GeV/c.

As a calorimeter, PHOS gives access to global observables of interest for event characterization, such as electromagnetic transverse energy and particle multiplicity at mid-rapidity. PHOS consists of 5 modules, each containing 64×56 PbWO₄ scintillator crystals, with orientations parallel and perpendicular to the beam direction. Each crystal is a 18 cm long parallelepiped, equivalent to 20 radiation lengths ($X_0^{\text{PbWO}_4} = 0.89$ cm). The surface area of each

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¹ A Large Ion Collider Experiment.

Fig. 1 (Color online) The Photon Spectrometer PHOS (green) and the ALICE detector

crystal is $(22 \times 22) \text{ mm}^2$, or 90% of the Molière radius ($r_M^{\text{PbWO}_4} = 20 \text{ mm}$).

PHOS is located inside the ALICE solenoid magnet (Fig. 1) at a distance of 4.6 m from the interaction point. The modules are centered with azimuthal angles of $\pm 40.7^\circ$, $\pm 20.3^\circ$ and 0° . Each module covers the pseudo-rapidity range $-0.12 < \eta < 0.12$ and covers 20° in azimuth. The granularity of PHOS is $(\Delta\phi, \Delta\eta) = (0.004, 0.004)$ and the energy resolution is

$$\frac{\Delta E}{E} = \sqrt{\frac{a^2}{E^2} + \frac{b^2}{E} + c^2} \quad (1)$$

where $a = 0.013 \pm 0.007 \text{ GeV}$ is the electromagnetic noise, $b = 0.036 \pm 0.002 \text{ GeV}^{1/2}$ is the stochastic term and $c = 0.0112 \pm 0.0003$ is the constant term [4]. The scintillation light is produced in the spectral region between visible and UV light. Photon detection is performed by the $5 \times 5 \text{ mm}^2$ Avalanche Photon Diode (APDs) coupled to low-noise pre-amplifiers. The detector is designed to operate at a temperature of -25°C to optimize the scintillation light output and to minimize noise from the APD. The electronics chain associated with each crystal produces two measurements, each with different amplification factors, (low- and high-gain) which are coincident in time. The first module of the ALICE photon spectrometer was installed in May 2008 and successfully recorded data from the first beam circulated at LHC in September 2008.

3 Production yield and cross section for π^0 measurement at NLO pQCD

Measurements of π^0 cross section from SPS, RHIC and the Tevatron, when compared to NLO (next-to-leading-order)

Fig. 2 Neutral pion cross section calculated with the next-to-leading order approach

pQCD calculations, show good agreement of data and theory. pQCD calculations describe inclusive photon production at many experiments, as presented in [5], and neutral pion production as presented in [6]. These pQCD calculations are used in this study to model the neutral pion cross section and counting rate, during the first $p-p$ collisions at LHC with the ALICE photon spectrometer. To compute the inclusive cross section for photon-hadron production in hadronic collisions, we use INCNLO² programs [7]. These data are purely inclusive. Figure 2 shows the neutral pion cross-section $E \frac{d^3\sigma}{dp^3}$ as a function of p_T . Although the first LHC collision energy is anticipated to be equal to 10 TeV, for completeness the cross sections were calculated for different possible LHC energies. Those predictions are made using the CTEQ5M parton density functions (PDF) and fragmentation functions KKP. These calculations have been performed using various factorization and renormalization scales: from $0.5p_T$ to $2p_T$ ($M = \mu = M_F = p_T$).

In order to predict the yield of neutral pions production in $p-p$ collisions at 10 TeV, we calculate the number of events per bin of p_T , $\frac{dN}{dp_T}$ using the counting rate formula

$$\frac{dN}{dp_T} = L_{int} \frac{d\sigma}{dp_T} A_{\gamma, \pi^0} \epsilon \quad (2)$$

where:

- $L_{int} = \int L dt$: integrated luminosity
- $\frac{d\sigma}{dp_T}$: π^0 differential cross section
- A_{γ, π^0} : PHOS geometrical acceptance
- ϵ : π^0 reconstruction efficiency.

The $\frac{d\sigma}{dp_T}$ has been calculated by means of the INCNLO program mentioned before over a p_T range of $[3-50] \text{ GeV}/c$.

We assume several scenarios of proton–proton collisions at the LHC. The collision energy of proton–proton beam

²INCLUSIVE Next-to-Leading Order Version 1.5.

Fig. 3 Estimation of neutral pion counting rate calculated for the first proton–proton collisions ($\sqrt{s} = 10$ TeV) at LHC

is chosen at 10 TeV. Accumulated statistics are expressed given integrated luminosities $\int LdT$ of 10 nb^{-1} , 100 nb^{-1} or 300 nb^{-1} , which can be achieved given instantaneous luminosity $L = 5 \times 10^{28} \text{ cm}^{-2} \text{ s}^{-1}$ and a run time of 3 days, 30 days or 3 months, respectively.

In this study, we consider the π^0 geometrical acceptance A_{γ,π^0} as a function of p_T , which saturates at 0.06 for pions with momenta above 10 GeV/c for 5 PHOS modules [8]. The efficiency of photon detection is $\epsilon(\gamma) = 0.9$ in ideal conditions [8]. For neutral pions, the efficiency is $\epsilon(\pi^0) = 0.9 \times 0.9$, assuming that all pions decay into $\gamma\gamma$ pairs. We conclude that the first LHC run with $p-p$ collisions at $\sqrt{s} = 10$ TeV will produce enough data to measure the inclusive neutral pion spectrum. Depending on LHC run scenarios, this spectrum can be measured for $p_T < 20$ –50 GeV/c with 3 PHOS modules (see Fig. 3).

4 Correction factor

In order to experimentally obtain the final p_T -differential pion invariant cross-section, the total number of pions in each p_T bin has to be measured and various corrections have to be applied to account for the “inefficiencies” of the measurement. Correction factors C_{MC} estimated using Monte Carlo (MC) simulations are applied to the yield spectrum 3.

$$E \frac{d^3\sigma}{d^3p_T} = \frac{1}{2\pi p_T dp_T d\eta} C_{MC} N_{measured}^{\pi^0} \quad (3)$$

The overall correction factor includes many contributions. Here we focus on the dominant corrections, mainly corrections for geometrical acceptance and reconstruction efficiency.³

³Other corrections such as off-vertex pions, photon conversion losses, or trigger efficiency, etc. are of minor importance.

Fig. 4 Geometrical acceptance correction factor for neutral pions as a function of the π^0 energy for the ALICE photon spectrometer PHOS

4.1 Geometrical acceptance

The photon acceptance is defined as the probability that a photon, radiated from the interaction point within one unit of rapidity ($-0.5 < y < 0.5$) and full azimuthal angle ($\phi = 2\pi$), will be detected. The acceptance factor for neutral pions in the $\gamma\gamma$ decay channel is defined as the probability that both photons are within the fiducial volume of the PHOS spectrometer, for mesons which originate from the primary interaction point and are within one unit of rapidity ($|y| < 0.5$ and $\phi = 2\pi$). This acceptance has been computed from single pion event simulation and is presented in Fig. 4. As shown on the figure, the acceptance depends strongly on E_{π^0} , due to the varying opening angle between the two decay photons as a function of the pion boost. We can perform a fit of the acceptance as a function of the generated neutral pion energy:

$$C_{geo.ac.}(E_{\pi^0}) = p_0(p_1 + p_2 E_{\pi^0}) \left(1 - \exp \frac{p_3 - E_{\pi^0}}{p_4} \right) \quad (4)$$

Above $E_{\pi^0} \sim 10$ GeV, the π^0 acceptance of PHOS flattens out about 1% (Fig. 4).

4.2 Reconstruction efficiency

The reconstruction efficiency $C_{efficiency.rec.}$ can be estimated after analysis of the π^0 invariant mass spectrum. This includes background subtraction where the signal is fit to a Gaussian function and the background modeled by a 2nd degree polynomial function. $C_{efficiency.rec.}$ is defined as the number of reconstructed pions around 2- and 3- σ , where σ is the width of the Gaussian function fit to the invariant mass distribution of the neutral pions within in the PHOS acceptance discussed above. The reconstruction efficiency correction increases with π^0 energy, and reaches 85% (for 2σ) for pions with $E_{\pi^0} > 10$ GeV (see Fig. 5).

Fig. 5 Efficiency correction factor $C_{\text{efficiency.rec.}}$ calculated with invariant mass method for 2σ (respectively 3σ) cuts as a function of the π^0 energy

Fig. 6 Efficiency correction factor as a function of the π^0 energy for various percentages of bad channels (2%, 10%, 25%) for DTBC = 1 cell

4.3 Influence of bad channels on the reconstruction efficiency

Dead or noisy channels in the PHOS (hereafter called bad channels) will contribute to a decrease in the neutral pions reconstruction efficiency. In order to estimate the effect of bad channels on the π^0 reconstruction efficiency, we simulate random bad channel maps, each with a different fraction of bad channels. We describe three bad channel scenarios:

- a realistic scenario which corresponds to a total of 2% of bad channels
- an intermediate scenario with 10% bad channels
- a pessimistic scenario with 25% bad channels.

We calculate the reconstruction efficiency for each of the above cases and introduce a new parameter: the “distance to bad channel” (DTBC).

DTBC is thus the distance between the cluster reconstructed point and the center of the bad channel. This distance is used as a criterion for excluding clusters with bad

Fig. 7 Efficiency correction factor as a function of the π^0 energy for various percentages of bad channels (2%, 10%, 25%) for DTBC = 2 cells

Fig. 8 Efficiency correction factors a function of the π^0 energy for various percentages of bad channels (2%, 10%, 25%) for DTBC = 3 cells

channels. Figures 6 to 8 show how the neutral pion reconstruction efficiency varies as a function of the π^0 energy for DTBC = 1, 2, 3 cells. These figures clearly show the effect that the percentage of bad channels and the distance to bad channels (DTBC) have on the π^0 reconstruction efficiency. If the cut on DTBC is too strict (3 cells), the efficiency decreases from 65% to 45%.

5 Conclusions

According to the next-to-leading order pQCD calculations, we will be able to measure neutral pions up to 20 GeV/c in the first proton–proton collisions at the LHC. We have estimated the PHOS acceptance as a function of the neutral pion energy; this correction has been fitted using a simple analytic expression, and can be applied to extrapolate to 1 unit of rapidity and full azimuthal coverage of the experimental spectrum.

The efficiency correction factor of neutral pions is estimated with the invariant mass method; it reaches 85% for

a 3σ cut above 10 GeV. Bad channels are shown to have an important effect on the neutral pion reconstruction efficiency. In particular, the influence of the criterion on cluster selection ‘distance to bad channel’ is also significant. These studies will be useful for understanding the neutral pion spectrum in the first proton–proton collisions at the LHC.

References

1. T. Sakaguchi, Direct photons basis for characterizing heavy ion collisions. *J. Phys. G: Nucl. Part. Phys.* **35**(10), 104025 (2008)
2. D. d’Enterria, Quark-gluon matter. *J. Phys. G: Nucl. Part. Phys.* **34**, S53–S81 (2007)
3. ALICE Collaboration et al. ALICE Technical Design Report of the photon spectrometer (PHOS), CERN-LHCC-99-04 (1999)
4. G. Conesa, H. Delagrangé, J. Diaz, M. Ippolitov, Y. Kharlov, D. Peressounko, Y. Schutz, Performance of the ALICE photon spectrometer PHOS. *Nucl. Instrum. Methods Phys. Res. A* **537**, 363 (2005)
5. P. Aurenche, M. Fontannaz, J.Ph. Guillet, B. Kniehl, E. Pilon, M. Werlen, A critical phenomenological study of inclusive photon production in hadronic collisions. *Eur. Phys. J. C* **9**, 107–119 (1999)
6. P. Aurenche, M. Fontannaz, J.Ph. Guillet, B. Kniehl, M. Werlen, Large- p_T inclusive π^0 cross sections and next-to-leading-order QCD predictions. *Eur. Phys. J. C* **13**(2), 347–355 (2000)
7. P. Aurenche, M. Fontannaz, J.P. Guillet, B.A. Kniehl, M. Werlen, *Eur. Phys. J. C* **13**, 347 (2000). http://www.lapp.in2p3.fr/lapth/PHOX_FAMILY
8. ALICE Collaboration et al., *J. Phys. G: Nucl. Part. Phys.* **32**, 1295–2040 (2006)