第31卷第1期　　原 子 核 物 理 评 论　　Vol. 31, No. 1
2014年3月　　Nuclear Physics Review　　Mar., 2014

Article ID: 1007-4627(2014) 01-0014-05

Photoproduction of High-$p_{\rm T}$ Kaon and Pion in pp and PbPb Collisions

CAI Yanbing, YU Gongming, LI Yunde

(*Department of Physics, Yunnan University, Kunming 650091, China*)

Abstract: By taking into account the effects of shadowing and jet quenching, the production of high-p_T kaon and pion originating from photoproduction processes in pp and PbPb collisions is calculated based on perturbative quantum chromodynamics(pQCD). The enhancement of K^+/π^+ is found in photoproduction processes. The numerical results indicate that the photoproduction processes considering in our calculation are a good modification for kaon and pion production.

Key words: photoproduction; strangeness; K/π ratio; heavy ion collision

CLC number: O571.6　　**Document code:** A　　**DOI:** 10.11804/NuclPhysRev.31.01.014

1 Introduction

The study of strange hadron production always played a special role in the investigation of QCD matter. In particular, K/π ratios are often used to study strangeness production enhancement in heavy ion collisions[1]. In recent years, the enhancement of K^+ production per π^+ is observed by PHENIX, as compared to pp collisions at this energy[2], similar to the NA49[3], NA44[4] observations. These data call for theoretical efforts to overcome the challenges presented by the high-energy of nuclear collision.

To explain the strangeness enhancement, some people consider the recent observation of enhanced K/π ratios may be interpreted as the possible production of the quark gluon plasma with enhanced content of strange quarks and antiquarks[5–7]. Furthermore, K^+/π^+ ratios are found to be most sensitive to the density of the QGP[8]. However, there are alternative explanations in terms of hadronic scenarios[9−10] or double strings[11]. Such as the microscopic approach RQMD[12] and UrQMD[13] can be employed to study the strangeness production. These models are also able to account for some of the strangeness enhancement.

In the present work, we extend the photoproduction mechanism[14−15] to the kaon and pion production at the early stage of pp and PbPb collisions at LHC. Jet quenching was an powerful tool to investigate properties of the dense medium[16], it led to a suppression of single-particle inclusive spectra[17]. If the partons traverse dense medium they can loose energy[18−19]. Energy loss of the parton before fragmenting into hadrons will modify fragmentation[16, 20]. In our work, the high energy photon emitted by a charged incident nucleus can interact with the parton of another incident nucleon through the interaction of $\gamma q\to\gamma q$, $\gamma q\to qg$, $\gamma g\to q\bar{q}$, $\gamma g\to gg$, then the quark or gluon fragment into kaon and pion.

In this paper, we study the photoproduction of high-$p_{\rm T}$ kaon and pion in pp and PbPb collisions. In Sec. 2 we present the invariant cross section of large-$p_{\rm T}$ hadrons in pp and PbPb collisions respectively. The numerical results of K^+/π^+ ratios at $\sqrt{s}=2.76$ TeV and $\sqrt{s}=7$ TeV are presented. Sec. 3 is the summary.

Received date: 10 Jun. 2013; **Revised date:** 18 Jul. 2013
Foundation item: National Natural Science Foundation of China (10665003, 11065010)
Biography: CAI Yanbing(1989–), male, Kunming, Yunnan, Master, working on the field of nuclear and particle physics; E-mail:myparticle@163.com
Corresponding author: LI Yunde, E-mail:yndxlyd@163.com.

2 Formalism

At LHC energies, the medium effects will reduce the running coupling constant $\alpha_s \sim 0.3$ [21–23]. Hence we can use perturbative quantum chromodynamics (pQCD) to study the production of large-p_T kaon and pion. The inclusive cross section is given in terms of the constituent differential cross section with fragmentation functions(FFs) of the quarks and gluons into the outgoing hadrons. The FFs set of kaon and pion are generated by experimental progress and can be utilized in pQCD calculation[24].

In photoproduction processes, the large-p_T photon from the nucleus A can interact with the parton from nucleus B. Fig. 1 shows the photoproduction of hadrons via the fragmentation of quark or gluon.

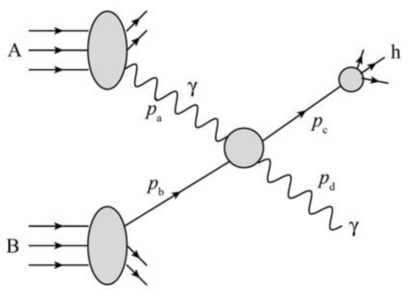

Fig. 1 The photoproduction processes of large-p_T hadrons via the fragmentation of quark or gluon.

In semielastic photoproduction processes, the invariant cross section of large-p_T hadrons in the process A+B →h+X in a pp collision can be written as[25]

$$E_h \frac{d\sigma}{d^3p}(A+B\to h+X; s, p_T) = \frac{2}{\pi}\int dx_a dx_b f_{\gamma/p}(x_a) f_{b/p}(x_b, Q^2)\times \frac{d\hat{\sigma}}{d\hat{t}}(ab\to cd; \hat{s}, \hat{t})\frac{1}{z_c}D_c^h(z_c, \hat{Q}^2)\ , \quad (1)$$

where $d\hat{\sigma}/d\hat{t}$ is the hard scattering cross section of the subprocess ab→cd.

The photon spectrum function from the charged proton is given by[26−27]

$$f_{\gamma/p}(x_a) = \frac{\alpha}{2\pi(x_a)}\left[1+(1-x_a)^2\right]\times \left(\ln A - \frac{11}{6} + \frac{3}{A} - \frac{3}{2A^2} + \frac{1}{3A^3}\right)\ , \quad (2)$$

where $A = 1+0.71/Q^2_{\min}$. At high energies $Q^2_{\min}$ is given by $m_p^2 x_a^2/(1-x_a)$.

$f_{b/p}(x_b, Q^2)$ is the parton distribution functions(PDF) for the colliding partons b carrying fractional momentum x_b in the interacting protons.

$D_c^h(z_c, \hat{Q}^2)$ is the FFs. The value of $D_c^h(z_c, \hat{Q}^2)$ corresponds to the probability for the parton c produced at short distance $\sim 1/\hat{Q}$ to form a jet that includes the hadron h carrying the fraction z_c of the longitudinal momentum of parton c. In the factorization theorem, $D_c^h(z_c, \hat{Q}^2)$ functions are independent of the process in which they have been determined, and generated by experimental progress[28–30]. Here we use the leading order set of FFs[30−31]. The momentum scales are $Q = 2p_T$ and $\hat{Q} = Q/z_c$.

The results for our numerical calculation of photoproduction processes of pp collisions in the minimum bias case are plotted in Figs. 2 and 3. The total point has been shifted slightly to the top for better visibility.

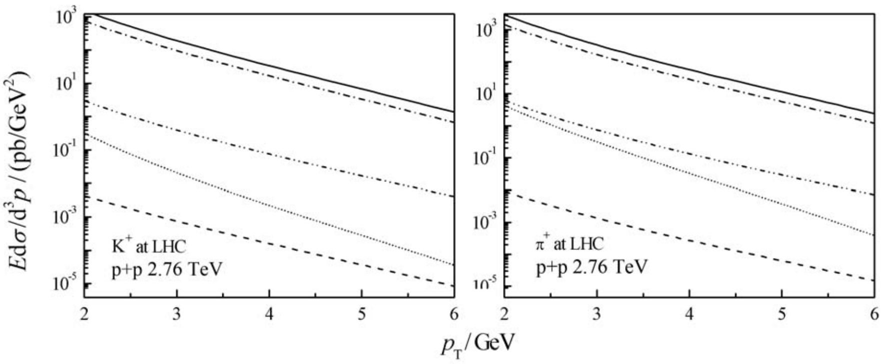

Fig. 2 Differential cross section of charged kaon and pion for $y = 0$ in pp collisions at LHC $\sqrt{s} = 2.76$ TeV (the contribution of photoproduction).
The dashed line corresponds to γq→γq, the short dotted line to γg→gg, the dash dotted line to γg→q$\bar{q}$, the dash dot dotted line to γq→qg, and the solid line to the total results.

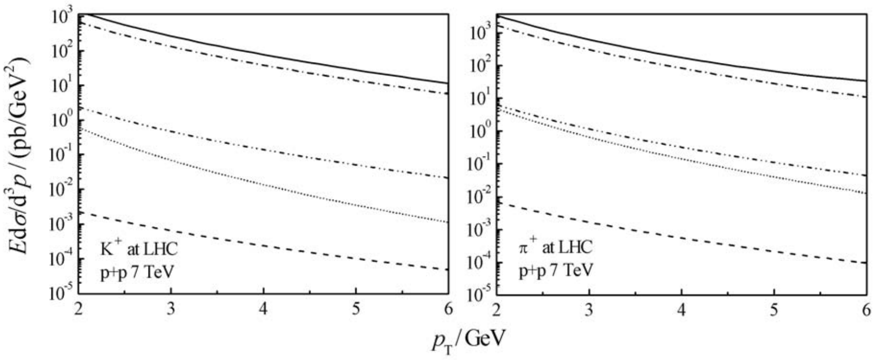

Fig. 3　Differential cross section of charged kaon and pion for $y=0$ in pp collisions at LHC $\sqrt{s}=7$ TeV (the contribution of photoproduction).
The dashed line corresponds to $\gamma q\to\gamma q$, the short dotted line to $\gamma g\to gg$, the dash dotted line to $\gamma g\to q\bar{q}$, the dash dot dotted line to $\gamma q\to qg$, and the solid line to the total results.

For PbPb collisions at LHC energy, the inclusive production cross section of single high-p_T hadrons is given by

$$E_h\frac{d\sigma}{d^3p}(A+B\to h+X;s,p_T) = \frac{2}{\pi}\int dx_a dx_b f_{\gamma/A}(x_a)G_{b/B}(x_b,Q^2)\times \frac{d\hat{\sigma}}{d\hat{t}}(ab\to cd;\hat{s},\hat{t})\frac{1}{z_c}D_c^h(z_c,\hat{Q}^2)\ . \tag{3}$$

In PbPb collisions at LHC energy jet quenching reduces the energy of the high momenta of quarks and gluons produced from the photoproduction before fragmentation. We include this effect and apply the energy loss spectrum to calculate the spectrum of hadrons by modifying the mean energy loss pQCD formulas. The inclusive production cross section of single high-p_T hadrons in PbPb collisions is given by[8, 32]

$$E_h\frac{d\sigma}{d^3p}(A+B\to h+X;s,p_T)= \frac{2}{\pi}\int dx_a dx_b f_{\gamma/A}(x_a)G_{b/B}(x_b,Q^2)\times \frac{d\hat{\sigma}}{d\hat{t}}(ab\to cd;\hat{s},\hat{t})\frac{z_c^*}{z_c}\frac{D_{h/c}(z_c^*,\hat{Q}^2)}{z_c}\ , \tag{4}$$

where $z_c^*=z_c/(1-\Delta E/p_c)$, $\hat{Q}=Q/z_c^*$. The factor z_c^*/z_c appears because of the in-medium modification of the FF[33].

The photon spectrum function from the charged nucleus is given by[34−35]

$$f_{\gamma/A}(x_a)=\frac{2Z^2\alpha}{\pi\omega}\ln(\frac{\gamma\delta}{\omega R})\ , \tag{5}$$

where $\delta=1.7$, $R=b_{\min}$(is the cut-off of impact), $w=x_aE$ is the energy of photon, E is the incident energy per nucleon, Z is charged nucleon number and γ is relativistic factor.

$G_{b/B}(x_b,Q^2)$ is the parton distributions of nucleon[36−39]

$$G_{b/B}(x_b,Q^2)= R_{b/B}(x_b)\left[\frac{Z}{A}p(x_b,Q^2)+\frac{N}{A}n(x_b,Q^2)\right]\ , \tag{6}$$

where Z is the proton number, N is the neutron number and A is the nucleon number. $p(x_b,Q^2)$ and $n(x_b,Q^2)$ are the parton distributions of the protons and neutrons, respectively.

$R_{b/B}(x_b)$ is the nuclear modification factor[40−41]. We

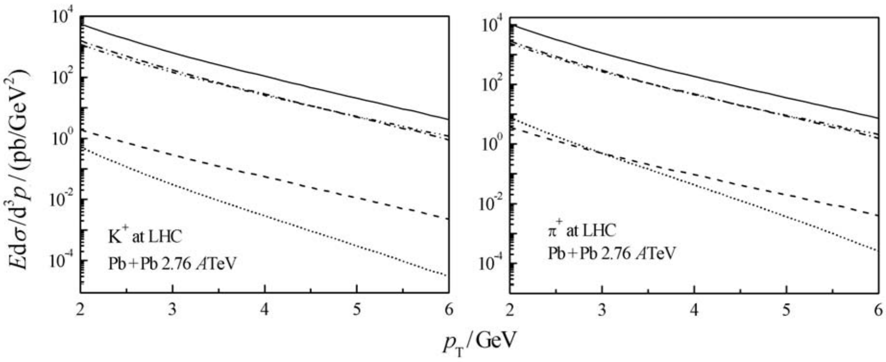

Fig. 4　Differential cross section of charged kaon and pion for $y=0$ in PbPb collision at LHC $\sqrt{s}=2.76$ TeV (the contribution of photoproduction).
The dashed line corresponds to $\gamma q\to\gamma q$, the short dotted line to $\gamma g\to gg$, the dash dotted line to $\gamma g\to q\bar{q}$, the dash dot dotted line to $\gamma q\to qg$, and the solid line to the total results.

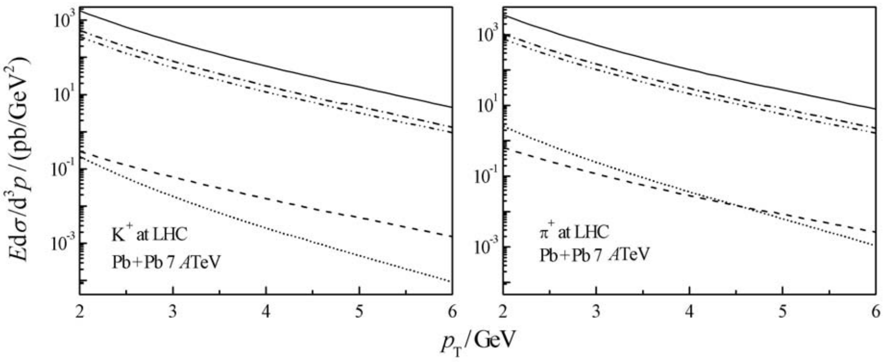

Fig. 5 Differential cross section of charged kaon and pion for $y = 0$ in PbPb collision at LHC $\sqrt{s} = 7$ TeV (the contribution of photoproduction).

The dashed line corresponds to $\gamma q \to \gamma q$, the short dotted line to $\gamma g \to gg$, the dash dotted line to $\gamma g \to q\bar{q}$, the dash dot dotted line to $\gamma q \to qg$, and the solid line to the total results.

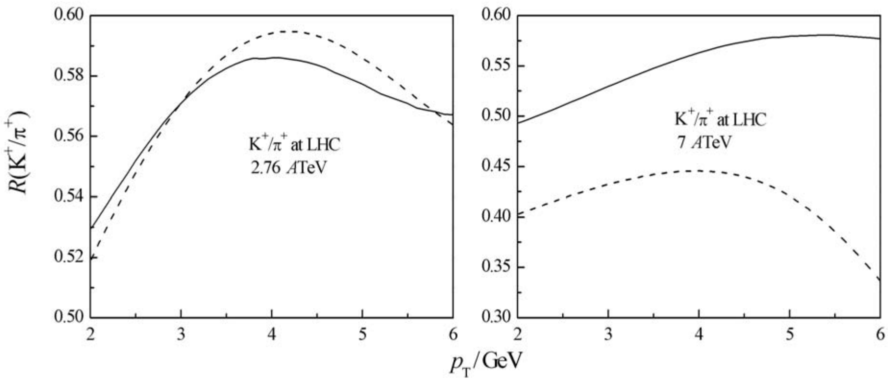

Fig. 6 K^+/π^+ ratios at $\sqrt{s} = 2.76$ TeV and $\sqrt{s} = 7$ TeV in pp and PbPb collisions.

The dashed line corresponds to pp collisions and the solid line to the PbPb collisions.

consider the shadowing effect of the nucleus and use the following parametrization in HIJING[42]

$$R_{b/B}(x_b) = 1 + 1.19\ln^{1/6} B\left[x_b^3 - 1.5(x_0 + x_L)x_b^2 + 3x_0 x_L x_b\right] - \left[\alpha_B - \frac{1.08(B^{1/3} - 1)}{\ln(B+1)}\sqrt{x_b}\right]\exp(-x_b^2/x_0^2) \,, \qquad (7)$$

where $\alpha_B = 0.1(B^{1/3} - 1)$, $x_0 = 0.1$ and $x_L = 0.7$.

The numerical calculation for photoproduction processes of PbPb collisions in the minimum bias case are plotted in Figs. 4 and 5. The K^+/π^+ ratios at $\sqrt{s} = 2.76$ TeV and $\sqrt{s} = 7$ TeV are shown in Fig. 6. We plot K^+/π^+ ratios in pp and PbPb in one figure for better comparisons.

3 Summary

In summary, we have investigated the photoproduction processes of high-p_T kaon, pion production and the K^+/π^+ ratios in relativistic pp and PbPb collisions at LHC. In photoproduction processes, the large-p_T photon from the nucleus A can interact with the parton from nucleus B via the QED Compton scattering. In PbPb collision we consider the effect of shadowing and jet quenching effect which can be described by replacing the vacuum FF. The numerical results show that the modification of photoproduction processes for kaon and pion production cannot be negligible in relativistic heavy ion collisions at LHC energies.

References:

[1] EGGERS H C, RAFELSKI J. Int J Mod Phys A, 1991, **6**: 1067.

[2] PHENIX Collaboration. ArXiv: nucl-ex/1304.3410, 2013.

[3] NA49 Collaboration. Phys Rev C, 2002, **66**: 054902.

[4] NA44 Collaboration. Phys Lett B, 1999, **471**: 6.

[5] RAFELSKI J. Nucl Phys A, 1992, **554**: 279.

[6] KOCH P, MULLER B, RAFELSKI J. Phy Rep, 1986, **142**: 167.

[7] RAFELSKI J, MULLER B. Phys Rev Lett, 1982, **48**: 1066.

[8] LEVAI P, PAPP G, FAI G, *et al.* Acta Phys Hung A, 2006, **27**: 459.

[9] KO C M, XIA L H. Nucl Phys A, 1989, **498**: 561.

[10] PANG Y, SCHLAGEL T J, KAHANA S H. Phys Rev Lett, 1992, **68**: 2743.

[11] WERNER K, AICHELIN J. Phys Lett B, 1993, **308**: 372.

[12] MATTIELLO R, SORGE H, STOCKER H, *et al.* Phys Rev Lett, 1989, **63**: 1459.
[13] SOFF S, BASS S A, BLEICHER M, *et al.* Phys Lett B, 1999, **471**: 89.
[14] YU G M, LI Y D. Chin Phys Lett, 2013, **30**: 011201.
[15] FU Y P, LI Y D. Phys Rev C, 2011, **84**: 044906.
[16] GYULASSY M, VITEV I, WANG X N, *et al.* ArXiv: nucl-th/0302077, 2003.
[17] WANG X N, GYULASSY M. Phys Rev Lett, 1992, **68**: 1480.
[18] WANG E, WANG X N. Phys Rev Lett, 2001, **87**: 142301.
[19] ZHANG B W, WANG E, WANG X N. Phys Rev Lett, 2004, **93**: 072301.
[20] WANG E, WANG X N. Phys Rev Lett, 2002, **89**: 162301.
[21] CHEN Y B, ZHUANG P F. ArXiv: hep-ph/1204.4389, 2012.
[22] KARSHENBOIM S G, JENSCHURA U D, IVANOV V G, *et al.* Phys Lett B, 1988, **424**: 397.
[23] FAMELI N, BALZARINI D A. Phys Rev E, 2011, **72**: 056105.
[24] ZHANG Y. ArXiv: hep-ph/0401198, 2004.
[25] FEILD R D. Applications of Perturbative QCD[M]. Redwood City: Addison-Wesley Publishing Company, 1989: 270-274.
[26] DREES M, GODBOLE R M, NOWAKOWSKI M, *et al.* Phys Rev D, 1994, **50**: 2335.
[27] DREES M, ZOPPENFELD D. Phys Rev D, 1989, **39**: 2536.
[28] BINNEWIES J, KNIEHL B A, KRAMER G. Z Phys C, 1995, **65**: 471.
[29] BINNEWIES J, KNIEHL B A, KRAMER G. Phys Rev D, 1995, **52**: 4947.
[30] KNIEHL B A, KRAMER G, POTTER B. Nucl Phys B, 2001, **597**: 337.
[31] ZHANG Y, FAI G, PAPP G, *et al.* Phys Rev C, 2002, **65**: 034903.
[32] GYULASSY M, LEVAI P, VITEV I. ArXiv: nucl-th/0112071, 2001.
[33] WANG X N, HUANG Z. Phys Rev C, 1997, **55**, 3047.
[34] PAPAGEORGIU E. Phys Lett B, 1990, **250**: 155.
[35] JACKSON J D. Classical Electrodynamics[M]. New York: Wiley, 1962: 520-524.
[36] GLUCK M, REYA E, VOGT A. Z Phys C, 1992, **53**: 127.
[37] ZHU J Q, LI Y D. Chin Phys Lett, 2012, **29**: 081301.
[38] YIN Ruitao, FU Yongping, LI Yunde. Nucl Phys Rev, 2011, **28**: 168.
[39] FU Yongping, LI Yunde. Nucl Phys Rev, 2010, **27**: 16.
[40] ESKOLA K J, KOLHINEN V J, SALGADO C A. Eur Phys J C, 1999, **9**: 61.
[41] QIU J W. Nucl Phys B, 1987, **291**: 746.
[42] WANG X N, GYULASSY M. Phys Rev D, 1991, **44**: 3501.

pp 和 PbPb 碰撞中大横动量 K 和 π 的光生过程

蔡燕兵，余功明，李云德

（云南大学物理系，昆明 650091）

摘要： 基于微扰量子色动力学(pQCD)，计算了考虑核遮蔽效应和喷注淬火效应的pp和PbPb碰撞中大横动量K和π的光生过程的产额。在光生过程中可以看到K^+/π^+的增强。数值计算结果表明，所考虑的光生过程对K和π产生是一个很好的修正。

关键词： 光生过程；奇异性；K/π产率；重离子碰撞

收稿日期： 2013-06-10； **修改日期：** 2013-07-18
基金项目： 国家自然科学基金资助项目(10665003, 11065010)
通信作者： 李云德，E-mail: yndxlyd@163.com。