Front. Phys. China, 2010, 5(2): 215–218
DOI 10.1007/s11467-010-0026-6
RESEARCH ARTICLE

$K^{\pm}p$ elastic scattering in the QCD inspired eikonalized model

Ji-huan PAN (潘继环)[1,†], Li-juan ZHOU (周丽娟)[2], Wei-xing MA (马维兴)[3,*]

[1] *Department of Physics and Electronic Engineering, Hechi University, Yichou 546300, Guangxi, China*
[2] *Collaboration Group of Hadron Physics and Non-perturbative QCD Study, Guangxi University of Technology, Liuzhou 545006, China*
[3] *Institute of High Energy Physics, Chinese Academy of Sciences, P. O. Box 918, Beijing 100049, China*
*E-mail: †panjihuan@163.com, *mawx@ihep.ac.cn*

Received April 14, 2010; accepted April 28, 2010

Based on our previous study of the QCD inspired eikonalized model for describing vector meson photoproduction, pp, and $\bar{p}p$ elastic scattering at high energies, we apply the mode to high energy $K^{\pm}p$ elastic scattering. The total cross section $\sigma_{\rm tot}(s)$, differential cross section $d\sigma/dt$, the ratio of the real part to imaginary part of the forward scattering amplitude $\rho(s)$, and nuclear slope parameter function $\beta(s)$ are calculated in the model. Our results show that the theoretical prediction for $\sigma_{\rm tot}(s)$ is in a good agreement with the experimental data within error bars of the data. For the other theoretical predictions there are no data to test the predictive power of the model. We need the corresponding experimental data to examine the validity of our QCD inspired eikonalized model. However, our calculations clearly show that the Odderon exchange in the process makes a significant contribution to the observable of $\rho(s)$ and $\beta(s)$. Therefore, we may conclude that there is a good opportunity to find the QCD Odderon in the $K^{\pm}p$ elastic scattering at high energies.

Keywords $K^{\pm}p$ scattering, QCD inspired eikonalized model, non-perturbative QCD

PACS numbers 13.60.Le, 13.85.-t, 12.38.Cy

1 Introduction

A microscopic understanding of hadron–hadron scattering remains an elusive goal of hadron physics, and quark gluon contents of the nucleon. Two experiments at the ZEUS [1] and H1 [2] have measured the high energy hadron–proton differential cross section. In recent years many more data have been obtained in HERA experiments, with high accuracy and statistics, and their comparison with theoretical calculations provides many opportunities to understand and describe important general feature of the dynamics governing these processes. We can learn quark gluon structure of hadron from these processes. It also offers an opportunity to search for new physics and new particles such as H-particle, Higgs, Glueball and Odderon which has been predicted by QCD and Color Glass Condensate model [3, 4].

It is well known, within Quantum Chromo Dynamics (QCD), hadrons contain quarks, anti-quarks and gluons. Meson is supposed to consist of quark and antiquark pair. At the same time, we know that the photon can fluctuate into a quark and antiquark pair according to the QCD generalized vector meson dominance model. The mediators of interactions between projectiles (the quark and antiquark pair) and the hadron target (two quarks or three quark system) are the tensor Glueball and Odderon instead of the conventional hadron–hadron or photon hadron interaction such as the Reggeon and Pomeron exchange. This theory is named QCD inspired model for mesons or baryon interactions. In this paper, we use the QCD inspired model and eikonalized formulism which is initially proposed by Block [5, 6] in the two-dimensional transverse impact parameter space to study $K^{\pm}p$ elastic scattering at high energies.

This paper consists of four parts. In Section 2, we briefly introduce the QCD inspired model and eikonalized formulism. Theoretical prediction and comparisons to experimental data are given in Section 3. Finally the summary and conclusions is given in Section 4.

2 QCD inspired eikonalized model

According to the eikonal approximation, we can write scattering amplitude [7] in the center of mass system within the framework of eikonalized formulism as:

$$F(s,t)=\frac{k}{\pi}\int \mathrm{e}^{\mathrm{i}\boldsymbol{q}\boldsymbol{b}}a(s,b)\mathrm{d}^2\boldsymbol{b} \tag{1}$$

which ensures unitarity in the two-dimensional transverse impact parameter space $\boldsymbol{b}$, where $a(b,s)$ is the scattering amplitude in impact parameter frame with $a(b,s)=\langle\psi_i \mid \prod_{i=1}^{A}[1-\Gamma_i(b-s_i)] \mid \psi_i\rangle$ where Γ_i is profile function described two body interaction. $\mathrm{d}^2\boldsymbol{b}=2\pi b\mathrm{d}b$ and $\boldsymbol{q}$ is a two dimensional vector in the impact parameter space $\boldsymbol{b}$ and $q^2=-t$ with t being momentum transfer.

As it has been pointed out [6, 7] that the scattering amplitude of hadron–hadron scattering in QCD inspired model is given by $F(s,t)=F_+(s,t)+F_-(s,t)$, where $F_+(s,t)$ is the crossing even amplitude and $F_-(s,t)$ is the crossing odd amplitude of the interacting process. The quark–quark, gluon–gluon interactions and quark–gluon interference term contribute to the crossing even amplitude $F_+(s,t)$ and the QCD Odderon contribution is responsible for the crossing odd amplitude $F_-(s,t)$. For photoproduction process off the proton, the interaction between the incoming photon and the target hadron is treated as a strong interaction of a quark–antiquark pair, produced by photon, with the target proton in the quark model of hadron [8] according to the assumption of QCD generalized vector meson dominance model. For hadron–hadron interacting system, the quark gluon degrees of freedom naturally are involved. In both cases, the mediators of the interacting force are the tensor glueball [8], which is constructed by two Reggeinized gluons with mass of 2.23 GeV, decay width $\Gamma\approx 100$ MeV and quantum numbers $I^G, J^{P,C}=0^+, 2^{+,+}$, and the QCD Odderon is consisted of three Reggeinized gluons with charge conjugation number $C=-1$. For $K^{\pm}p$ elastic scattering, the mechanism of scattering is similar to pp elastic scattering [7, 8]. The diagrammatic representation of the interacting mechanism can be seen in Refs. [7, 8].

Assuming $F(s,t)$ is scattering amplitude in general, then the total cross sections $\sigma_{\text{tot}}(s)$, ratio of the real part to the imaginary part of the forward scattering amplitude $\rho(s)$, and the nuclear slope parameter function $\beta(s)$ are normalized in such a way that [9, 10]

$$\sigma_{\text{tot}}(s)=\frac{1}{s}\mathrm{Im}F(s,t=0) \tag{2}$$

$$\rho(s)=\frac{\mathrm{Re}F(s,t=0)}{\mathrm{Im}F(s,t=0)} \tag{3}$$

$$\beta(s)=\frac{\mathrm{d}}{\mathrm{d}t}\Big[\ln\frac{\mathrm{d}\sigma(s,t)}{\mathrm{d}t}\Big]_{t=0} \tag{4}$$

with $\mathrm{d}\sigma(s,t)/\mathrm{d}t$ in Eq. (4) being the differential cross sections of the process under study which is determined by $F(s,t)$ and normalized such that

$$\frac{\mathrm{d}\sigma(s,t)}{\mathrm{d}t}=\frac{1}{16\pi s^2}|F(s,t)|^2 \tag{5}$$

Eqs. (2)–(5) are the fundamental formulae of our present study of the $K^{\pm}p$ elastic scattering at high energies. Now, the task to reach our goal is to work out the amplitude $F(s,t)$ in QCD inspired eikonalized model. According to Glauber multiple scattering theory [11], the scattering amplitude is given by

$$F(q)=\frac{\mathrm{i}k}{2\pi}\int \mathrm{e}^{\mathrm{i}q\boldsymbol{b}}[1-\mathrm{e}^{\mathrm{i}\chi(s,b)}]\mathrm{d}^2\boldsymbol{b} \tag{6}$$

and the eikonal phase transition function $\chi(s,\boldsymbol{b})$ is defined by

$$\chi(s,\boldsymbol{b})=-\frac{2m}{k}\int_0^{\infty}V(\sqrt{b^2+z^2})\mathrm{d}z \tag{7}$$

with $V(\sqrt{b^2+z^2})$ being interaction, and $\boldsymbol{b}$ is the impact vector in colliding plane. The amplitude $F(s,t)$ can be simply expressed by $\chi(s,\boldsymbol{b})$. Therefore, calculating amplitude becomes a task to calculate χ. In the QCD inspired eikonalized model

$$\begin{aligned}\chi(s,\boldsymbol{b})&=\chi_{\text{even}}(s,\boldsymbol{b})+\chi_{\text{odd}}(s,\boldsymbol{b})=\chi_{qq}(s,\boldsymbol{b})\\&\quad+\chi_{gg}(s,\boldsymbol{b})+\chi_{qg}(s,\boldsymbol{b})+\chi_{\text{odd}}(s,\boldsymbol{b})\end{aligned} \tag{8}$$

where χ_{even} is responsible for the crossing even amplitude $F_+(s,t)$ and χ_{odd} corresponds to the crossing odd amplitude $F_-(s,t)$. For $K^{\pm}p$ scattering in the QCD inspired eikonalized model, the scattering amplitudes can be obtained by substitution $\sigma_{ij}\rightarrow\frac{2}{3}\sigma_{ij}$ and $\mu_{ij}\rightarrow\sqrt{\frac{3}{2}}\mu_{ij}$ in the even and odd eikonal functions of the $K^{\pm}$-proton scattering according to additive quark model because we use the formula derived for pp scattering [7] but K meson consists of two quarks and the proton is made up of three quarks. Therefore, the χ_{even} and χ_{odd} can be written as:

$$\begin{aligned}\chi_{\text{even}}^{Kp}&=\chi_{qq}^{Kp}(s,b)+\chi_{gg}^{Kp}(s,b)+\chi_{qg}^{Kp}(s,b)\\&=\mathrm{i}\Big[\frac{2}{3}\sigma_{qq}(s)W(b;\sqrt{\frac{3}{2}}\mu_{qq})\\&\quad+\frac{2}{3}\sigma_{gg}(s)W(b;\sqrt{\frac{3}{2}}\mu_{gg})\\&\quad+\frac{2}{3}\sigma_{qg}(s)W(b;\sqrt{\frac{3}{2}}\sqrt{\mu_{qq}\mu_{gg}})\Big]\end{aligned} \tag{9}$$

and

$$\begin{aligned}\chi_{\text{odd}}^{Kp}&=\frac{2}{3}\sigma_{\text{odd}}(s)W(b;\sqrt{\frac{3}{2}}\mu_{\text{odd}})\\&=\frac{2}{3}C_{\text{odd}}\Sigma_{gg}\frac{m_0}{\sqrt{s}}W(b;\sqrt{\frac{3}{2}}\mu_{\text{odd}})\end{aligned} \tag{10}$$

Here χ is complex function $\chi(b,s)=\chi_R(b,s)+\chi_I(b,s)$ and depends on the energy s and impact parameter $\boldsymbol{b}$. The $W(b,\mu)$ stands for the probability distribution function of partons (quarks and gluons) in hadron. Using the above discussions and formulism, the $\sigma_{\text{tot}}(s)$, $\mathrm{d}\sigma/\mathrm{d}t$, $\rho(s)$ and $\beta(s)$ of $K^{\pm}$ scattering off the proton, can be expressed by

$$\sigma_{\rm tot}^{Kp}(s) = 2\int\Big[1-{\rm e}^{-\chi_I^{Kp}(b,s)}\cos(\chi_R^{hp}(b,s))\Big]{\rm d}^2\boldsymbol{b} \quad (11)$$

$$\frac{{\rm d}\sigma^{Kp}(s,t)}{{\rm d}t} = \frac{1}{4\pi}\Big|\int J_0(qb)\Big[1-{\rm e}^{-\chi_I(b,s)+{\rm i}\chi_R(b,s)}\Big]{\rm d}^2\boldsymbol{b}\Big|^2 \quad (12)$$

$$\rho^{Kp}(s) = \frac{{\rm Re}\Big\{{\rm i}\int\Big[1-{\rm e}^{-\chi_I(b,s)+{\rm i}\chi_R(b,s)}{\rm d}^2\boldsymbol{b}\Big]\Big\}}{{\rm Im}\Big\{{\rm i}\int\Big[1-{\rm e}^{-\chi_I(b,s)+{\rm i}\chi_R(b,s)}{\rm d}^2\boldsymbol{b}\Big]\Big\}} \quad (13)$$

$$\beta^{Kp}(s) = \frac{1}{2}\frac{\int\Big[1-{\rm e}^{-\chi_I(b,s)+{\rm i}\chi_R(b,s)}\Big]b^2{\rm d}^2\boldsymbol{b}}{\int\Big[1-{\rm e}^{-\chi_I(b,s)+{\rm i}\chi_R(b,s)}\Big]{\rm d}^2\boldsymbol{b}} \quad (14)$$

3 Theoretical prediction and comparison to experimental data

As is known, the total even contribution is not yet analytic. For large s, the even amplitude in Eq. (9) can be made analytic by the substitution $s \to s{\rm e}^{-{\rm i}\pi/2}$. Therefore, the contributions to total cross section from quark–quark, gluon–gluon, quark–gluon interference can be rewritten as [7, 12]:

$$\sigma_{gg}(s) = 2\pi(\frac{\epsilon}{\mu_{gg}})^2(\log^2\frac{s}{s_0} - \frac{\pi^2}{4}) - {\rm i}\pi^2(\frac{\varepsilon}{\mu_{gg}})^2\log^2\frac{s}{s_0} \quad (15)$$

$$\sigma_{qq}(s) = \Sigma_{gg}(C + C_{Regge}^{even}\frac{m_0}{\sqrt{s}}\cos\frac{\pi}{4}) + {\rm i}\Sigma_{gg}C_{Regge}^{\rm even}\frac{m_0}{\sqrt{s}}\sin\frac{\pi}{4} \quad (16)$$

$$\sigma_{qg}(s) = \Sigma_{gg}C_{qg}^{\log}\log\frac{s}{s_0} - {\rm i}\Sigma_{gg}C_{qg}^{\log}\frac{\pi}{2} \quad (17)$$

The odd amplitude corresponding to Eq. (10) is not yet analytic too, but it can be made analytic in the same way as that for even amplitude, i.e., we replace the s by use of $s{\rm e}^{-{\rm i}\pi/2}$. In doing so, we arrive at

$$\sigma_{\rm odd}(s) = C_{\rm odd}\Sigma_{gg}\frac{m_0}{\sqrt{s}}\cos\frac{\pi}{4} + {\rm i}C_{\rm odd}\Sigma_{gg}\frac{m_0}{\sqrt{s}}\sin\frac{\pi}{4} \quad (18)$$

It should be emphasized that in the QCD inspired eikonalized model, the mediators of the force are tensor glueball and Odderon. This is very different from other calculations because the exchange mediators are glueball and Odderon, and in particular, it is completely different from the conventional treatment in hadronic level of high energy hadron–hadron scattering in which the quark and gluon degrees of freedom have not been taken into account.

Using the above discussions and the Eqs. (2)–(18), we can calculate the total cross sections $\sigma_{\rm tot}(s)$, differential cross section ${\rm d}\sigma/{\rm d}t$, ratio of the real part to imaginary part of the forward scattering amplitude $\rho(s)$, and nuclear slope parameter function $\beta(s)$ of the $K^{\pm}p$ elastic scattering in the QCD inspired eikonalized model.

Our theoretical predictions with the parameters given in Refs. [13, 14] are shown in Figs. (1)–(4). As is seen from Fig. 1, our prediction for total cross section fits the experimental data successfully. The present prediction of differential cross section ${\rm d}\sigma(s,t)/{\rm d}t$ is shown in Fig. 2. However, there is no data, so far, to prove this prediction. Figure 3 and Fig. 4 show the ratio of the real part to imaginary part of forward scattering amplitude $\rho(s)$ and the nuclear slope parameter function $\beta(s)$ respectively which are also required data to be proved. According to our present calculations, the Odderon exchange interaction makes a significant contribution to the observable of $\rho(s)$ and $\beta(s)$. But corresponding data are urgently demanded for testing our theoretical predictions.

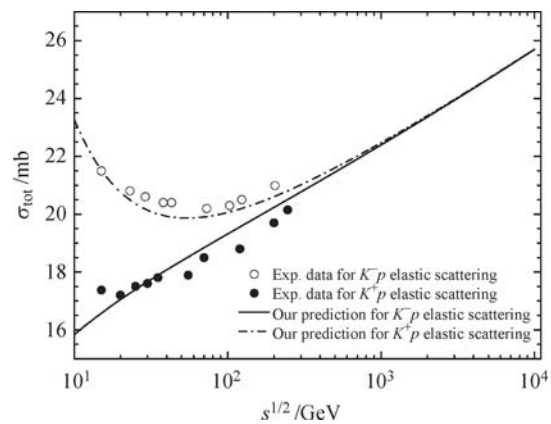

Fig. 1 $s^{1/2}$-dependence of total cross section $\sigma(s)$ of $K^{\pm}p$ elastic scattering at high energies.

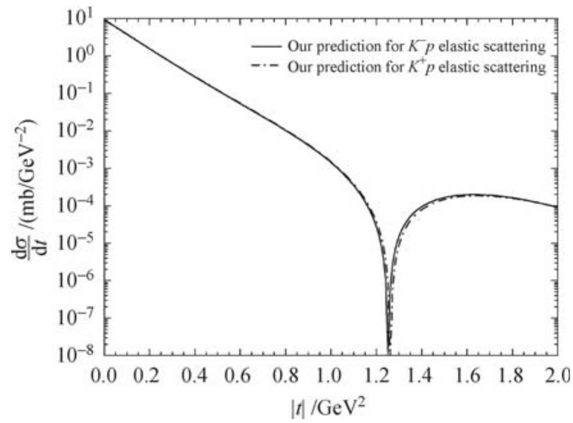

Fig. 2 $|t|$-dependence of differential cross section ${\rm d}\sigma(s,t)/{\rm d}t$ for $K^{\pm}p$ elastic scattering at the energy of $s^{1/2} = 80$ GeV.

4 Summary and conclusions.

Based on our previous investigation of pp, $\bar{p}p$ and vector meson photoproduction at high energies in the QCD inspired eikonalized model, we predict the total cross sec-

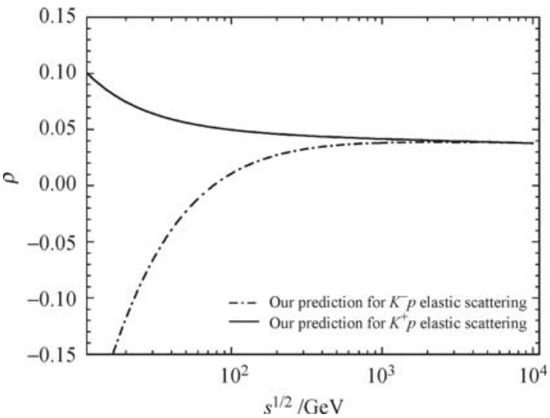

Fig. 3 $s^{1/2}$-dependence of the ratio of the real part to the imaginary part of forward scattering amplitude $\rho(s)$ for $K^{\pm}p$ elastic scattering.

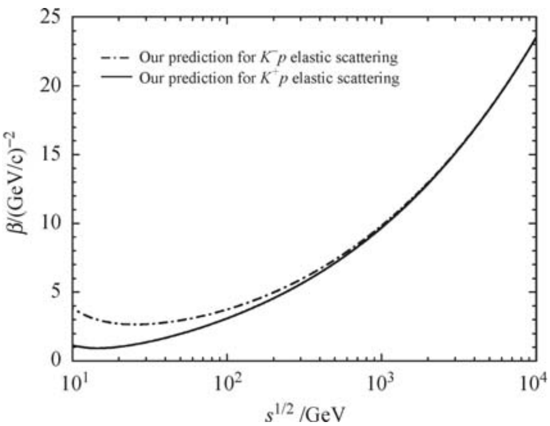

Fig. 4 $s^{1/2}$- dependence of slope parameter functions $\beta(s)$ for $K^{\pm}p$ elastic scattering.

tion $\sigma_{\text{tot}}(s)$, differential cross section $\mathrm{d}\sigma/\mathrm{d}t$, ratio of the real part to imaginary part of the forward scattering amplitude $\rho(s)$, and nuclear slope parameter function $\beta(s)$ of $K^{\pm}p$ elastic scattering at high energies. The numerical prediction of total cross section is successfully consistent with the experimental data. Although for our other theoretical predictions we urgently need experimental data to examine the validity of our QCD inspired eikonalized model, the agreement between theory and data for total cross section, together with our previous excellent fits to data of pp, $\bar{p}p$ and vector meson photoproduction off the proton, we may conclude that the QCD inspired eikonalized model has a strongly predictive power to hadron scattering at high energies.

We emphasize that the Odderon exchange term makes a significant contribution to the observable of $\rho(s)$ and $\beta(s)$. Therefore, we may claim that the $K^{\pm}p$ scattering can provide a good opportunity to search for existence of the Odderon. We will investigate this problem in our coming work.

Acknowledgements This work was supported in part by the National Natural Science Foundation of China (Grant No. 10647002), Guangxi Natural Science Foundation for young researchers (Grant No. 0991009) and Guangxi Education Department (Grant No. 200807MS112).

References

1. S. Chekanov, et al. (ZEUS Collaboration), Nucl. Phys. B, 2004, 695: 3
2. A. Aktas, et al. (H1 Collaboration), Eur. Phys. J. C, 2002, 24: 345
3. L. J. Zhou, B. R. Liu, and W. X. Ma, Commun. Theor. Phys., 2007, 48: 519
4. Y. Hatta, E. Iancu, K. Itakura and L. Mclerran, Nucl. Phys. A, 2005, 760: 172
5. M. M. Block and R. N. Cahn, Rev. Mod. Phys., 1985, 57: 563
6. M. M. Block and A. R. White, in: Proceedings of the 4th Blios Workshop, The International Conference on Elastic and Diffractive Scattering, Elba, Italy, 1991, edited by F. Cervelli and S. Zucchelli, Nucl. Phys. B (Proc. Suppl.)
7. J. Lu, W. X. Ma, and X. R. He, Commun. Theor. Phys., 2007, 47(4): 715
8. J. H. Pan, W. X. Ma, Y. T. Gu, and L. Z. Luo, Commun. Theor. Phys., 2009, 52(1): 108
9. L. J. Zhou, Q. Wu, W. X. Ma, and Y. T. Gu, Commun. Theor. Phys., 2006, 46: 287
10. J. Lu, W. X. Ma, and X. R. He, Commun. Theor. Phys., 2006, 45: 908
11. R. J. Glauber, Lectures in Theoretical Physics, edited by W. Brittin and L. G. Dunham, New York: Interscience, 1959, 1: 315
12. M. M. Block, E. M. Gregores, F. Halzen, and G. Pancheri, Phys. Rev. D, 1999, 60: 054024
13. J. H. Pan, L. J. Zhou, and W. X. Ma, Front. Phys. China, 2009, 4(4): 534
14. J. Lu, W. X. Ma, and X. R. He, Commun. Theor. Phys., 2008, 49(2): 456