MENU 2007
11th International Conference
on Meson-Nucleon Physics and
the Structure of the Nucleon
September10-14, 2007
IKP, Forschungzentrum Jülich, Germany

EXCLUSIVE PRODUCTION OF QUARKONIA IN pp AND $p\bar{p}$ COLLISIONS FAR FROM THE THRESHOLD

A. Szczurek
Institute of Nuclear Physics
PL-31-342 Kraków, ul. Radzikowskiego 152,
Rzeszów University, PL-35-959 Rzeszów, ul Rejtana 16A

Abstract

I discuss exclusive production of the η', J/ψ, and $\chi_c(0^+)$ mesons in pp and $p\bar{p}$ collisions at high energies. QCD diffractive mechanisms as well as non-diffractive mechanisms are discussed. Different unintegrated gluon distribution functions (UGDF) are used. Some differential distributions are shown and discussed.

1 Introduction

The search for Higgs boson is the primary task for the LHC collider being now constructed at CERN. Although the predicted cross section is not small it may not be easy to discover Higgs in inclusive reaction due to large background in each of the final channel considered. An alternative way is to search for Higgs in exclusive or semi-exclusive reactions with large rapidity gaps. Kaidalov, Khoze, Martin and Ryskin proposed to calculate diffractive double elastic (both protons survive the collision) production of Higgs boson in terms of UGDFs [1]. Here I shall present some application of this formalism to the production of η' and $\chi_c(0^+)$ mesons. More details can be found in Refs. [2, 3].

At present, there is ongoing investigations at Tevatron aiming at measuring the exclusive production of both vector and scalar quarkonia, but no result is yet publicly available.

Recently the J/ψ exclusive production in proton-proton and proton-antiproton collisions was suggested as a candidate in searches for odderon exchange [4]. In order to identify the odderon exchange one has to consider all other possible processes leading to the same final channel. One of such processes, probably dominant, is pomeron-photon or photon-pomeron fusion [5].

2 Diffractive production of mesons

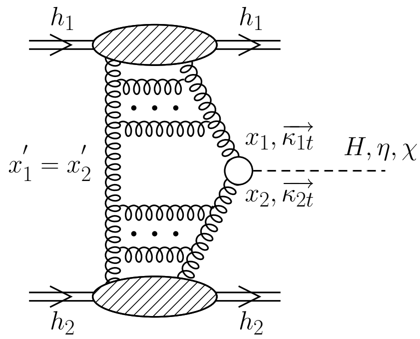

Figure 1: The sketch of the bare QCD mechanism. The kinematical variables are shown in addition.

Following the formalism for the diffractive double-elastic production of the Higgs boson one can write the amplitude from Fig.1 as

$$\mathcal{M}^{g^*g^* \to M}_{pp \to pMp} = \\ i\,\pi^2 \int d^2k_{0,t} V(k_1, k_2, P_M) \frac{f^{off}_{g,1}(x_1, x_1', k^2_{0,t}, k^2_{1,t}, t_1) f^{off}_{g,2}(x_2, x_2', k^2_{0,t}, k^2_{2,t}, t_2)}{k^2_{0,t}\, k^2_{1,t}\, k^2_{2,t}} , \tag{1}$$

where $f's$ are skewed unintegrated gluon distributions. For more details see [2].

As an example in Fig. 2 I show the results of calculations obtained for $M = \eta'$ with several models of UGDF (for details see [2]) for relatively low energy W = 29.1 GeV. For comparison I show also the contribution of the $\gamma^*\gamma^*$ fusion mechanism. The contribution of the last mechanism is much smaller than the contribution of the diffractive QCD mechanism.

In Fig.3 I show rapidity distribution of scalar $\chi_c(0^+)$ meson for different UGDFs. Similarly as for the η' production a strong dependence on UGDFs can be observed. [1] A slightly less dependence on UGDFs can be expected for diffractive Higgs produciton.

3 Photoproduction of J/ψ

The basic mechanisms leading to the exclusive production of J/ψ are shown in Fig.4. The amplitude for the corresponding $2 \to 3$ process can be written

[1]In Ref. [3] we discuss many more uncertainties in theoretical predictions of exclusive diffractive production.

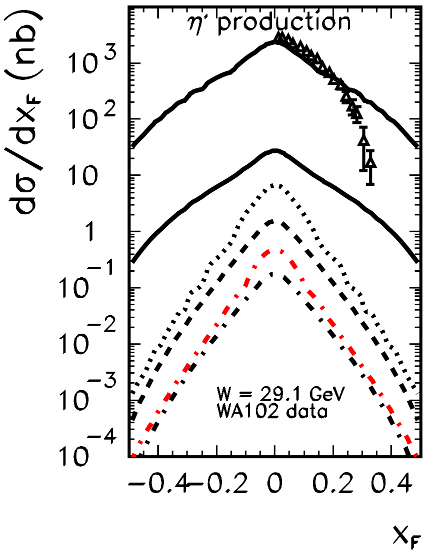

Figure 2: $d\sigma/dx_F$ as a function of Feynman x_F for W = 29.1 GeV and for different UGDFs. The $\gamma^*\gamma^*$ fusion contribution is shown by the dash-dotted (red) line (second from the bottom). The experimental data of the WA102 collaboration [6] are shown for comparison. The dashed line corresponds to the KL distribution, dotted line to the GBW distribution and the dash-dotted to the BFKL distribution. The two solid lines correspond to the Gaussian distribution with details explained in the original paper. No absorption corrections were included here.

as

$$
\begin{aligned}
&\mathcal{M}_{h_1 h_2 \to h_1 h_2 V}^{\lambda_1 \lambda_2 \to \lambda_1' \lambda_2' \lambda_V}(s, s_1, s_2, t_1, t_2) \\
&\qquad = \mathcal{M}_{\gamma IP} + \mathcal{M}_{IP\gamma} \\
&\qquad = \langle p_1', \lambda_1' | \, J_\mu \, | p_1, \lambda_1 \rangle \, \epsilon_\mu^*(q_1, \lambda_V) \frac{\sqrt{4\pi\alpha_{em}}}{t_1} \mathcal{M}_{\gamma^* h_2 \to V h_2}^{\lambda_{\gamma^*} \lambda_2 \to \lambda_V \lambda_2}(s_2, t_2, Q_1^2) \\
&\qquad + \langle p_2', \lambda_2' | \, J_\mu \, | p_2, \lambda_2 \rangle \, \epsilon_\mu^*(q_2, \lambda_V) \frac{\sqrt{4\pi\alpha_{em}}}{t_2} \mathcal{M}_{\gamma^* h_1 \to V h_1}^{\lambda_{\gamma^*} \lambda_1 \to \lambda_V \lambda_1}(s_1, t_1, Q_2^2) \, . \qquad (2)
\end{aligned}
$$

The amplitude of the $\gamma^* p \to J/\psi p$ was parametrized to describe data measured recently at HERA [7,8].

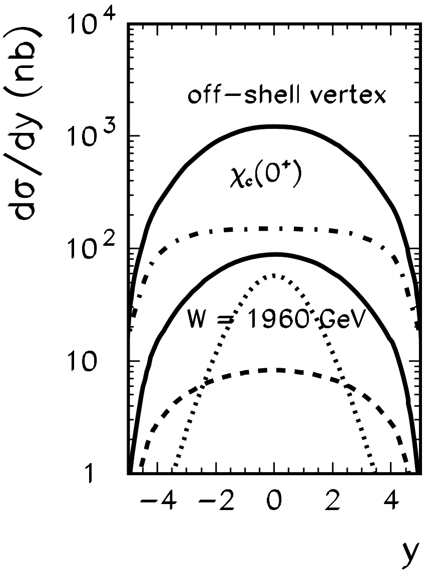

Figure 3: $d\sigma/dy$ as a function of rapidity for W = 1960 GeV and for different UGDFs. The dashed line corresponds to the KL distribution, dotted line to the GBW distribution and the dash-dotted to the BFKL distribution. The two solid lines correspond to the KMR distributions with details explained in the original paper. No absorption corrections were included here.

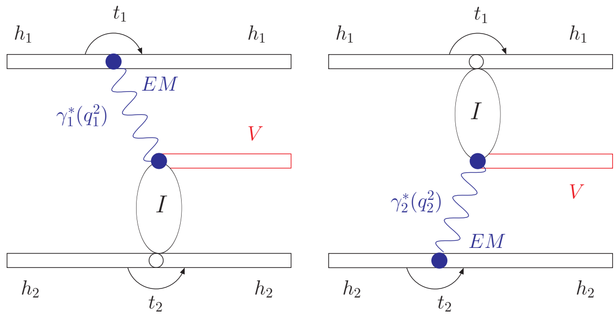

Figure 4: The sketch of the two mechanisms considered: photon-pomeron (left) and pomeron-photon (right). Some kinematical variables are shown in addition.

The differential cross section is calculated as

$$d\sigma = \frac{1}{512\pi^4 s^2} |\mathcal{M}|^2 \, dy dt_1 dt_2 d\phi \,, \tag{3}$$

where y is the rapidity of the vector meson, and ϕ is the angle between outgoing protons. Notice that the interference between the two mechanisms γIP and $IP\gamma$ is proportional to $e_1 e_2$ and introduces a charge asymmetry.

In Fig.5 I collect rapidity distributions for different energies relevant at RHIC, Tevatron and LHC. One observes an occurence of a small dip in the distribution at midrapidities at LHC energy. One should remember, however, that the distribution for the LHC energy is long-distance extrapolation of the $\gamma^* p \to J/\psi p$ amplitude (or cross section) to unexplored yet experimentally energies. Therefore a real experiment at Tevatron and LHC would help to constrain cross sections for $\gamma p \to J/\psi p$ process.

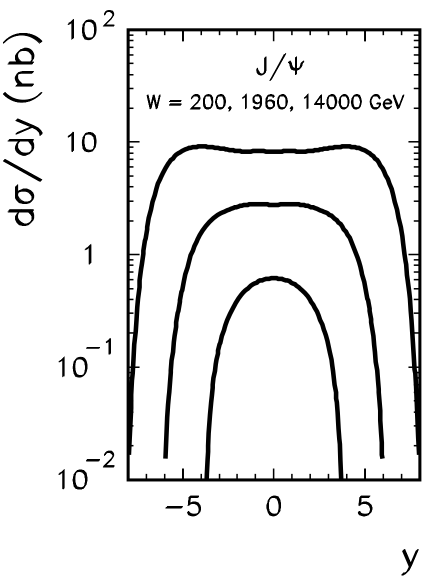

Figure 5: $d\sigma/dy$ for exclusive J/ψ production as a function of y for RHIC, Tevatron and LHC energies. No absorption corrections were included here.

The parametrization of the $\gamma^* p \to Vp$ amplitude which describes corresponding experimental data (see [5]) includes effectively absorption effects due to final state Vp interactions. In the $pp \to ppJ/\psi$ ($p\bar{p} \to p\bar{p}J/\psi$) reaction the situation is more complicated as here pp (or $p\bar{p}$) strong rescatterings occur in addition. In Ref. [5] we have included only elastic rescatterings shown schematically in Fig.6.

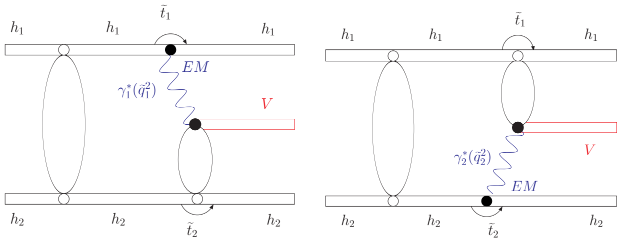

Figure 6: The sketch of the elastic rescattering amplitudes. Some kinematical variables are shown in addition.

4 Summary

In contrast to diffractive Higgs production, in the case of meson production the main contribution to the diffractive amplitude comes from the region of very small gluon transverse momenta and very small longitudinal momentum fractions. In this case application of Khoze-Martin-Ryskin UGDFs seems not justified and we have to rely on UGDFs constructed for this region.

The existing models of UGDFs predict cross section much smaller than the one obtained by the WA102 collaboration at the center-of-mass energy W = 29.1 GeV. This may signal presence of subleading reggeons at the energy of the WA102 experiment or suggest a modificaction of UGDFs in the nonperturbative region of very small transverse momenta.

The $\gamma^*\gamma^*$ fusion may be of some importance only at extremely small four-momentum transfers squared for the η' production and is practically negligible for the $\chi_c(0^+)$ production.

It was shown in [5] that at the Tevatron energy one can study the exclusive production of J/ψ at the photon-proton center-of-mass energies 70 GeV $< W_{\gamma p} <$ 1500 GeV, i.e. in the unmeasured region of energies, much larger than at HERA. At LHC this would be correspondingly 200 GeV $< W_{\gamma p} <$ 8000 GeV. At very forward/backward rapidities this is an order of magnitude more than possible with presently available machines.

An interesting azimuthal-angle correlation pattern has been obtained due to the interference of photon-pomeron and pomeron-photon helicity-preserving terms.

We have estimated also absorption effects. In some selected configurations the absorption effects may lead to the occurence of diffractive minima. The exact occurence of diffractive minima depends on the values of the model parameters. Such minima are washed out when integrated over the phase space or even its part.

5 Acknowledgements

I thank organizers of MENU2007 for very efficient organization of the conference and hospitality. The collaboration with Roman Pasechnik, Oleg Teryaev and Wolfgang Schäfer on the issues presented here is acknowledged. A partial support by the MEiN research grant 1 P03B 028 28 (2005-08).

References

[1] V.A. Khoze, A.D. Martin and M.G. Ryskin, Phys. Lett. B **401**, 330 (1997);
V.A. Khoze, A.D. Martin and M.G. Ryskin, Eur. Phys. J. C **23**, 311 (2002);
A.B. Kaidalov, V.A. Khoze, A.D. Martin and M.G. Ryskin, Eur. Phys. J. C **31**, 387 (2003) [arXiv:hep-ph/0307064];
A.B. Kaidalov, V.A. Khoze, A.D. Martin and M.G. Ryskin, Eur. Phys. J. C **33**, 261 (2004);
V.A. Khoze, A.D. Martin, M.G. Ryskin and W.J. Stirling, Eur. Phys. J. C **35**, 211 (2004).

[2] A. Szczurek, R. S. Pasechnik and O. V. Teryaev, Phys. Rev. D **75**, 054021 (2007) [arXiv:hep-ph/0608302].

[3] R. S. Pasechnik, A. Szczurek and O. V. Teryaev, [arXiv:0709.0857].

[4] A. Bzdak, L. Motyka, L. Szymanowski and J.-R. Cudell, arXiv: hep-ph/0702134.

[5] W. Schäfer and A. Szczurek, arXiv:0705.2887, Phys. Rev. **D76**, 094014.

[6] D. Barberis et al. (WA102 collaboration), Phys. Lett. **B422**, 399 (1998).

[7] S. Chekanov *et al.* [ZEUS Collaboration], Eur. Phys. J. C **24**, 345 (2002).

[8] A. Aktas *et al.* [H1 Collaboration], Eur. Phys. J. C **46**, 585 (2006).