Diffractive χ Production at the Tevatron and the LHC*

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We show predictions for cross sections based on the Bialas-Landshoff formalism for the diffractive production of χ mesons in the central rapidity region. We make use of the DPEMC Monte-Carlo simulation with the appropriate kinematics for small-mass diffractive production. We compare generator-level results with a CDF measurement for exclusive χ production, and study background and other scenarios including the contribution of inclusive χ production. We show that the results agree with the Tevatron data we extrapolate them, highlighting the exclusive χ_{c_0} production at LHC energies. We also investigate a possible measurement at the Tevatron using the DØ forward proton detectors.

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1. Introduction

Exclusive and inclusive central diffractive production of heavy states have been studied previously in the double Pomeron exchange formalism (DPE) [1, 2, 3, 4], and experimental results have been presented [5], attracting theoretical attention. One motivation for this search is that the Higgs boson could be produced in such a mode, allowing for a good mass determination for this elusive particle.

One way to address this problem is looking for a similar production mechanism with lighter particles like the χ mesons [6], which gives rise to high enough cross sections to check the dynamical mechanisms. Exclusive production of χ_c has been reported by the CDF collaboration [7] with an upper limit for the cross section of

$$\sigma_{exc}(p\bar{p} \to p + J/\psi + \gamma + \bar{p}) < 49 \pm 18(stat) \pm 39(sys)\ pb\ . \tag{1}$$

One generally considers two types of DPE topologies for the production of a heavy state: exclusive DPE [1, 2, 3]

$$hh \to h + \text{heavy object} + h\ , \tag{2}$$

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and inclusive DPE, where the colliding Pomerons are resolved (very much like ordinary hadrons), accompanying the central object with Pomeron "remnants" (X,Y):

$$hh \rightarrow h + X + \text{heavy object} + Y + h \ . \tag{3}$$

in both cases h represents the colliding hadrons. The formulae of the Bialas-Landshoff cross sections is taken as in Ref. [4] and includes the full kinematics valid for small masses.

2. Full kinematics for exclusive production

Exclusive events have the property that the full energy available in the center-of-mass is used to produce the diffractive object mass, usually approximate as $M^2_{diff} \approx s\xi_1\xi_2$. This approximation is no longer true for low mass states such as χ mesons, and we had to modify the method to generate events in this case. We had to start from 4-momentum conservation and not assume that $|t|$ is much smaller than M^2_{diff}. The equation, using the full kinematics is

$$M^2_{diff} = s \times \left(1 + \frac{(1-\xi_1)(1-\xi_2)}{2cos\theta_1 cos\theta_2}(1-\Omega) - \left(\frac{1-\xi_1}{cos\theta_1} + \frac{1-\xi_2}{cos\theta_2} \right) \right) \ , \tag{4}$$

where $\Omega = -cos\theta_1 cos\theta_2 + sin\theta_1 sin\theta_2 (cos\varphi_1 cos\varphi_2 + sin\varphi_1 sin\varphi_2)$, θ is the scattering angle and φ the polar angle. It is important to notice that this formula depends not only on ξ_1 and ξ_2 but also on the angles of the hadrons θ_1, φ_1 and θ_2, φ_2. t and θ are related by the following formula:

$$\sin^2\theta_{1,2} \sim \theta^2_{1,2} = \frac{|t_{1,2}|}{(1-\xi_{1,2})(s/4)}. \tag{5}$$

3. Exclusive and inclusive χ_{c_0}, χ_{b_0} production cross sections

Table (1) presents our results for the cross section predictions at the Tevatron and the LHC. The gap survival probability (the probability of the gaps not to be populated) S^2_{gap} is taken to be 0.1 at the Tevatron and 0.03 at the LHC (cf. A.B. Kaidalov et al in [8]). We note that our model does not contain Sudakov factors on contrary to Ref. [2, 6]. The effect of the Sudakov suppression is however supposed to be small at small masses.

The CDF Collaboration has presented preliminary results [7] for exclusive $J/\psi + \gamma$ production using the rapidity gap selection of diffractive events in Run II ($\sqrt{s}$ =1.96 TeV). The cuts used by CDF are the following: $p_T(\mu^{\pm}) \geq 1.5$ (GeV), $|\eta(\gamma)| \leq 3.5$ and $|\eta(\mu^{\pm})| \leq 0.6$.

$\sigma(nb)$	Tevatron $\sqrt{s} = 1.96$ TeV	LHC $\sqrt{s} = 14$ TeV
$\sigma_{exc}(\chi_{c_0})$	1.17×10^3	0.804×10^3
$\sigma_{exc}(\chi_{b_0})$	4.4	3.29
$\sigma_{inc}(\chi_{c_0})$	$1.8\ \times10^4$	$4.8\ \times10^4$
$\sigma_{inc}(\chi_{b_0})$	20	$1.8\ \times10^2$

Table 1. Cross sections (in nb) for exclusive and inclusive production at the Tevatron and the LHC.

If we apply the CDF cuts at generator level, we predict $\sigma_{exc}(p\bar{p} \to p + \chi_{c0}(\to J/\psi\gamma) + \bar{p}) = 61pb.$. CDF removes most of the inclusive background using a cut on the mass fraction, $F_M > 0.85$. Due to the fact that we are missing the smearing between detector and generator levels, we choose to investigate the effect on the cross section due to various mass-fraction cuts, as displayed in Table 2. We also consider the uncertainty of the gluon density in the Pomeron, which can be taken into account by multiplying the gluon density measured at HERA, by a factor $(1-\beta)^\nu$ where ν varies between -1.0 and 1.0 [10] [1]

Table II shows that the signal seen by the CDF collaboration could be explained by a combination of a higher gluon density at high β and some smearing effects due to the reconstruction of the mass fraction.

Mass Fraction Cut	$\nu = 0$	$\nu =$ -1	$\nu =$ -0.5	$\nu = 0.5$	$\nu = 1$
≥ 0.75	14.33	194.94	52.28	3.88	0.84
≥ 0.8	5.4	118.87	27.15	0.84	0.17
≥ 0.85	2.02	61.89	11.13	0.17	0
≥ 0.9	0.34	28.43	2.87	0	0
≥ 0.95	0.08	19.48	0.84	0	0

Table 2. Quasi-exclusive cross section (in pb) at the Tevatron, after CDF cuts, using different F_M and gluon distributions.

4. Possibility of a new measurement at DØ

We now examine the possibility of measuring the exclusive χ_{c_0} production at the Tevatron using the roman pot detectors in the DØ collaboration. The Forward Proton Detector (FPD) installed by the DØ collaboration consists of eight quadrupole spectrometers, four being located on the outgoing proton side, and the other four on the antiproton side.

[1] The QCD fits to the HERA data lead to the value of the $\nu = 0.0 \pm 0.6$.

The quadrupole detectors are sensitive to outgoing particles with $|t| > 0.6$ GeV^2 and $\xi < 3.10^{-2}$, with good acceptance for high mass objects produced diffractively in the DØ main detector. We use the following selection cuts: $((p_T(\mu^+) \geq 2.0$ (GeV) or $p_T(\mu^-) \geq 2.0$ (GeV)) and $|\eta(\mu^\pm)| \leq 2.0$ and $|\eta(\gamma)| \leq 3.0)$ (see Table 3).

Regular Tevatron Stores - L = 100pb^{-1}				
Scenario	A	B	C	D
0	1.2×10^8	2.6×10^6	4.8×10^6	2.9×10^5
DØ selection	1.8×10^2	2.7×10^1	3.0×10^1	1.5

Table 3. Number of exclusive χ_{c_0} events at the Tevatron (MC error $\sim 10\%$) for a regular Tevatron store. The scenario 0 represents all decay channels included without selection cuts. The columns represents the number of events: A - all (without p or $\bar{p}$ tagging); B - tagged in the p side quadrupole; C - tagged in the $\bar{p}$ side quadrupole and D - double tagged events in the quadrupoles.

We note that the number of events in double tagged configuration is quite small after applying the selection cuts. However, a single tag event with a rapidity gap on the other side yields a good number of events.

5. Exclusive χ_{c_0} Production at the LHC

We can also estimate the number of events accessible to the TOTEM/CMS detectors. The TOTEM acceptance for the high β^* optics and low ξ values is typically 90 %, for the range $0 < |t| < 1$ GeV^2. Then for 10 pb^{-1} of data, 5.3×10^6 double tagged events are predicted, with no requirement in the central detector activity. In this way, one might look for the χ_{c_0} in the reconstructed diffractive mass.

If central activity is required, the lowest possible muon p_T cut at low luminosity is on the order of $p_T \geq 1.5$ (GeV) for $|\eta| \leq 2.4$. The predictions for exclusive and quasi-exclusive production at the LHC are shown in tables 4 and 5. We note that the number of events can be dominated by exclusive production, independent of uncertainties in the gluon distribution, if a high enough cut on the mass fraction can be made.

6. CONCLUSION

We calculate the diffractive production cross section for χ mesons at the Tevatron and LHC using an extended version of the Bialas-Landshoff model, including the full kinematics needed for low mass states.

The results for exclusive production at the Tevatron agree with a recent CDF upper limit for the exclusive production of χ_{c_0}, with the default param-

Mass Fraction Cut	$\nu = 0$	$\nu =$ -1	$\nu =$ -0.5	$\nu =$ 0.5	$\nu =$ 1
$\geq$ 0.9	1.35	138.11	17.88	0.34	0.17
$\geq$ 0.95	0	13.83	1.18	0	0

Table 4. Quasi-exclusive cross section (in pb) at the LHC, after central activity cuts, using different mass fractions and gluon distributions, defined in section V.

Central cut	1	2	3	4
Total	3.74×10^3	1.43×10^3	3.64×10^2	1.27×10^2
After Totem Acceptance	3.03×10^3	1.16×10^3	2.95×10^2	1.03×10^2

Table 5. Exclusive cross section (in pb) $\sigma_{exc}(p\bar{p} \to p + \chi_{c_0}(\to J/\psi\gamma) + \bar{p})$ at the LHC energies for each central cut: 1 - one muon with $p_T \geq 1.5$; 2 - one muon with $p_T \geq 1.5$ and $|\eta| \leq 2.4$; 3 - two muons with $p_T \geq 1.5$; 4 - two muons with $p_T \geq 1.5$ and $|\eta| \leq 2.4$.

eters of the model. In the same conditions, the non-exclusive background can reach similar levels as the exclusive signal.

We showed a possibility of observing exclusive χ_{c_0} production at the Tevatron, using the DØ forward detector if a tight cut on the mass fraction can be performed successfully.

Exclusive production at the LHC, using the CMS/TOTEM detectors, is also investigated and appears promising with a high enough cut on the mass fraction.

REFERENCES

[1] A. Bialas and P.V. Landshoff, Phys. Lett. B **256**, 540 (1991).

[2] V.A. Khoze, A.D. Martin, M.G. Ryskin, *Eur. Phys. J.* **C24** (2002) 581.

[3] M. Boonekamp, R. Peschanski and C. Royon, Phys. Lett. B **598**, 243 (2004)

[4] M. Rangel, C. Royon, G. Alves, J. Barreto and R. Peschansk, Nucl. Phys. B **774**, 53 (2007)

[5] CDF Collaboration, T. Affolder *at al.*, Phys. Rev. Lett. **85**, 4215 (2000).

[6] V.A. Khoze, A.D. Martin, M.G. Ryskin, W. J. Stirling, *Eur.Phys.J.* **C35** (2004) 211.

[7] M. Gallinaro [On behalf of the CDF Collaboration], Acta Phys. Polon. B **35**, 465 (2004)

[8] A. B. Kaidalov, V. A. Khoze, A. D. Martin and M. G. Ryskin, *Eur. Phys. J.* **C21** (2001) 521;

[9] M.Boonekamp, T.Kucs, *Comput. Phys. Commun.* **167** (2005) 217;

[10] O. Kepka, C. Royon, Phys. Rev. D **76**, 034012 (2007)