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DIFFRACTIVE χ PRODUCTION AT THE TEVATRON AND THE LHC*

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We give the predictions for the diffractive production cross-sections of χ mesons based on the Bialas–Landshoff formalism in the central rapidity region. We 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 the background including the contribution of inclusive χ production. We show that the results agree with Tevatron data. We also highlight the exclusive χ_{c_0} production at LHC energies, and we 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) [1–4], 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 to look 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

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

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

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

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

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

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 and its mass is usually approximated as $M^2_{\rm diff} \approx s\xi_1\xi_2$. 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 $M^2_{\rm diff}$. The equation, using the full kinematics is

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

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 I 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) $S^2_{\rm gap}$ is taken to be 0.1 at the Tevatron and 0.03 at the LHC [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.

TABLE I

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

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

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: $p_{\rm T}(\mu^\pm) \geq 1.5$ (GeV), $|\eta(\gamma)| \leq 3.5$ and $|\eta(\mu^\pm)| \leq 0.6$.

If we apply the CDF cuts at generator level, we predict $\sigma_{\rm exc}(p\bar{p} \to p + \chi_{c0}(\to J/\psi\gamma) + \bar{p}) = 61$ pb. CDF removes most of the inclusive background using a cut on the mass fraction, $\mathrm{F}_M > 0.85$. 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 II. 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

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

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	5.40	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 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.

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

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.

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: $((p_{\rm T}(\mu^+) \geq 2.0$ (GeV) or $p_{\rm T}(\mu^-) \geq 2.0$ (GeV)) and $|\eta(\mu^\pm)| \leq 2.0$ and $|\eta(\gamma)| \leq 3.0)$ (see Table III).

TABLE III

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.

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

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 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 $p_{\rm T}$ cut at low luminosity is on the order of $p_{\rm T} \geq 1.5$ (GeV) for $|\eta| \leq 2.4$. The predictions for exclusive and quasi-exclusive production at the LHC are shown in Tables IV and V. We note that the number of events can be dominated by exclusive production, independently on the uncertainties on the gluon distribution, if a high enough cut on the mass fraction can be made.

TABLE IV

Quasi-exclusive cross-section (in pb) at the LHC, after central activity cuts, using different mass fractions and gluon distributions, defined in Sec. 5.

Mass fraction cut	$\nu = 0$	$\nu = -1$	$\nu = -0.5$	$\nu = 0.5$	$\nu = 1$
≥ 0.9	1.35	138.11	17.88	0.34	0.17
≥ 0.95	0	13.83	1.18	0	0

TABLE V

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

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

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 parameters 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.

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