Threshold charm production

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Abstract

The energy upgrade proposed for CEBAF opens possibilities for studying near threshold charm production. In this talk I review some of the underlying physics issues.

1. Introduction

Remarkably threshold charm production data is essentially nonexistent. In photoproduction some of the relevant photon lab energies, E_γ are, $E_\gamma = 7.7$ GeV for $\gamma p \to \eta_c p$, 8.2 GeV for $\gamma p \to J/\psi p$, and 8.7 GeV for $\gamma p \to \bar{D}\Lambda_c$. With exception of the SLAC and Cornell photoproduction measurements [1], in the past twenty years all charm production experiments were performed at much higher energies. The lower energy, $E_\gamma \sim 10$ GeV Cornell data is rather poor and hardly exhibit characteristic threshold behavior. The few data points from SLAC analysis taken at the photon energy, $E_\gamma \sim 20$ GeV give $\sigma_{\gamma p} \sim 3$ nb. The experimental situation is far from being satisfactory. Even though there has not been much quantitative theoretical work done in this area there is a number of interesting phenomena to be explored [2, 3]. Charm production has proven to be a sensitive probe of production mechanisms. Since charmonium production requires the $c\bar{c}$ to be produced in a state determined by the quantum numbers of the final hadron, it is not yet being understood how the soft physics should be separated from the hard production region. Thus in absence of rigorous factorization theorem charmonium production has become a valuable tool for testing models of soft QCD. Charmonium phenomenology is interesting on its own since it is determined by interactions intermediate to the soft, confinement and hard, Coulomb potential dominated regions of the heavy quark potential. Finally, charmonium decays are expected to be gluon rich and therefore give a possibility for studying direct gluonic effects in production and final state interactions.

In the following I will briefly summarize the main features of the existing

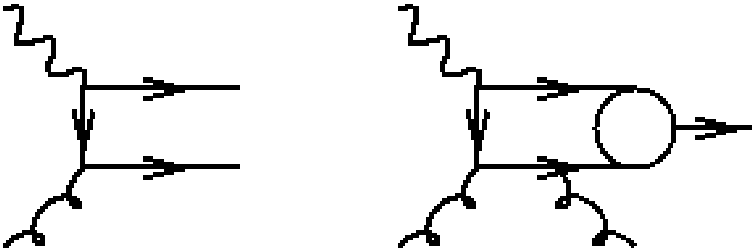

Figure 1: Basic contribution to J/ψ photoproduction from γg fusion, in the color evaporation model (left) and color singlet model (right)

models for high energy $c\bar{c}$ production and indicate possible differences near the threshold region.

2. Charm production

Since, as discussed above, restrictions imposed on $c\bar{c}$ production by the quantum numbers of the soft final state would in particular require taking into account soft gluons, in a popular approach, referred to as the color evaporation model (CEM), color interactions are treated in a simple way by averaging over possible final states below the open charm threshold [4]. More precisely the cross section for, say J/ψ production, corresponding to the diagram in Fig. 1a is parameterized as

$$\sigma(\gamma N \to J/\psi N) = f_\psi \int_{4m_c^2}^{4m_D^2} \frac{dM^2}{s} G(x = \frac{M^2}{s}) \sigma_{\gamma g \to c\bar{c}}(M^2). \tag{1}$$

Here G is the gluon structure function, and f_ϕ is a normalization constant that should depend only on the properties of the $Jpsi$.

Despite its simplicity, CEM has been quite successful in describing a variety of data. In hadroproduction it explains luck of significant polarization effects and an enhancement in $\sigma(\bar{p}A \to J/\psi X)/\sigma(pA \to J/\psi X)$ at low c.m. energies due to dominance of $\sigma(\bar{q}q \to gg \to J/\psi)$ (which is absent in other models). In photoproduction CEM describes the data over a wide range of photon energies although its significance near threshold and at very high energies is questionable.

An alternative approach is to include as many hard gluons as needed to fully implement the restrictions imposed by the final state [5]. This approach is known as the color singlet model or CSM. It has been successfully applied to J/ψ photoproduction, however it fails to reproduce the absolute normalization and large p_T dependence in hadroproduction. Strong, high p_T suppression comes in CSM from the hard propagators shown in Fig. 1b. It has been noted that CSM typically fails when extra gluons are required to satisfy quantum number constraints [3]. Thus, for example, it works in hadroproduction of χ_{c2} which proceeds via $gg \to \chi_{c2}$ or in $\gamma g \to J/\psi g$ where the extra gluon in the final state is only needed because of the momentum flow, but it fails in J/ψ hadroproduction where $gg \to J/\psi$ is forbidden by C-parity. Thus it seems necessary to have to incorporate effects of soft gluons from the final state. This is typically done within the framework of the so called color octet mechanism [6] which takes into account color octet $c\bar{c}$ configurations. In photoproduction, however, inclusion of color octet contributions tends to overestimate the cross section and furthermore there are large uncertainties in the values of the relevant color octet matrix elements.

At high energies dominant contribution to photoproduction comes from the elastic, diffractive region. In this case one can show that the three subprocesses, corresponding to : photon dissociation into $c\bar{c}$ pair, $c\bar{c}$ scattering of the nucleon and formation of the bound charmonium, occur at very different time scales and thus factorize. In Ref. [7] it has been shown at at high energies the cross section grows with energy proportionally to $G^2(x = M^2_\psi/s)$ *i.e.* faster than predicted by CEM. It has also been shown that the diffractive amplitude is very sensitive to the Pomeron/two gluon coupling to the charmonium wave function.

The main difference between high energy, diffractive and threshold production has to do with the kinematics of the reaction products. In diffractive production $t \sim t_{min}$ *i.e.* the momentum of the outgoing nucleon is close to the incoming one. The momentum fraction, x carried by the reaction spectators is therefore close to unity and the process is sensitive to the small-x gluon momentum distribution. In contrast, in threshold kinematics, in the lab frame the final nucleon is nearly at rest, the net momentum fraction carried by the spectators is $x \sim 0$ and $c\bar{c}$ scattering probes the $(1 - x) \sim 1$ configuration of the target wave function. Furthermore, since near thresh-

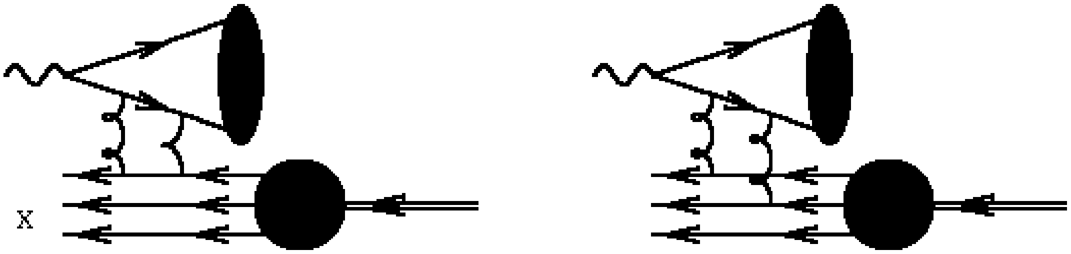

Figure 2: Charmonium photoproduction. The $c\bar{c}$ pair produced by the photon interacts with a quark from the target though Pomeron/gluon exchange (left). Contribution from the intrinsic charm component of proton wave function (right). The spectators carry fraction x of target momentum in the infinite momentum frame (or in the lab frame for high energy scattering).

old all of the kinamatical variables, $s \sim M_{c\bar{c}}^2$, $|t| \sim |u| \sim m_N M_{c\bar{c}}$ are large as compared to Λ_{QCD} it is possible that production mechanisms are dominated by short distance effects. To transfer the entire target momentum to a single quark, in leading twist, hard gluons have to be exchanged between all of the constituents. This mechanism leads to a familiar $(1-x)^{2n_s-1}$ behavior near $x \to 1$, where n_s is the number of spectators, known from DIS for Bjorken $x \to 1$. It has been argued however that there may be important subleading twist contributions coming from the intrinsic charm component of the target wave function associated with diagrams shown in Fig. 2b [8].

It is also possible to use open charm production to study these, extreme target wave function configurations [2].

There is also a lot of interest in charmonium interactions with nuclei. There are predictions that QCD Van der Waals force, could enhance threshold production. On a nuclear target taking $0.3-0.4$ GeV of Fermi momentum, the photon energy threshold could be as low as ~ 6.5 GeV. One could then use the A dependence to extract $\sigma_{\psi N}$ and to study $\sigma(\psi)/\sigma(D\bar{D})$ to look for information on charmonium formation and nuclear rescattering effects. Preliminary studies of subthreshold production at CEBAF has been already presented at this meeting [9].

Acknowledgments

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References

[1] U. Camerini *et al.*, Phys. Rev. Lett. **35**, 483 (1975); B. Gittelman *et al.*, Phys. Rev. Lett, **35**, 1616 (1975).

[2] S.J. Brodsky, in proceedings of *CEBAF Workshop on Electroproduction*, Newport News, Virginia, April 14-16, 1994, hep-ph/9407361.

[3] P. Hoyer, hep-ph/9703462.

[4] J.F. Amundson, O.J.P.Eboli, E.M. Gregores, F. Halzen, Phys. Lett. B **390**, 323 (1997).

[5] M.L. Mangano, in proceedings of the *Topical Workshop on Proton-Antiproton Collider Physics*, Batavia, IL, 1995, hep-ph/9507353.

[6] G.T. Boldwin, E. Braaten and G.P. Lepage, Phys. Rev. D **51**, 1125 (1995).

[7] L. Frankfurt, W. Koepf, and M. Strikman, Phys. Rev. D **57**, 512 (1998).

[8] S.J. Brodsky, P. Hoyer, C. Peterson, and N. Sakai, Phys. Lett. B **93**, 451 (1980); R. Vogt, S.J. Brodsky, and P. Hoyer, Nulc. Phys. B **360**, 67 (1991); S.J. Brodsky, C. Peterson, and N. Sakai, Phys. Rev. D **23**, 2745 (1981).

[9] J. Dunne, contribution to the pre-workshop.