ANL-HEP-CP-85-111

NOV 21 1985

ANL-HEP-CP--85-111

DE86 003044

HEAVY MESON DECAYS AND $p\bar{p}$ COLLISIONS

E.L. Berger
Argonne National Laboratory, Argonne, IL 60439

P.H. Damgaard
CERN, CH-1211 Geneve 23

K. Tsokos
University of Maryland, College Park, MD 20742

ABSTRACT

We use the formalism of exclusive processes at high momentum transfer, to give predictions for the decay of the 2^{++}chi state into a $p\bar{p}$ pair and the production cross section for chi in $p\bar{p}$ collisions.

INTRODUCTION

In this talk I will describe our work on the exclusive decays of the χ_2 state into baryons. The details of the calculation, which involve the application of the QCD formalism of exclusive processes[1] at high momentum transfer, have appeared elsewhere.[2,3,4]

We must first establish that the decay of a heavy meson is a process that can be treated in perturbation theory. When the mass M, of the decaying meson is sufficiently larger than a "typical hadronic scale" (of about 1 Gev) the decay amplitude is indeed calculable. The precise property of QCD that makes this analysis possible is factorization: the full decay amplitude can be expressed as a convolution of a hard decay amplitude, T_H and a distribution amplitude $\phi(x,Q^2)$ for each bound state in the final state. $T_H(x,Q^2)$ is specific to the process under investigation but since it is dominated by large momenta (see below) it is calculable from Feynman diagrams; the distribution amplitudes, by contrast, are universal and in general incalculable. They contain all the nonperturbative, low energy information of the binding. Their form can be extracted from some other experiment and then used again in a different one. As we will see shortly in our study of $\chi\to pp$ we shall use the process[5] $\psi\to p\bar{p}$ from which to extract suitable distribution amplitudes. (In general, if one compares distribution amplitudes from two processes at different momentum scales one must take care to account for the

---

*Work supported by the U.S. Department of Energy, Division of High Energy Physics, Contract W-31-109-ENG-38.

logarithmic ϕ variation with scale. This scale dependence is controlled by evolution equations[1] which have been extensively discussed in the literature. In our case, there is no significant Q^2 variation as ψ and χ have roughly the same mass).

THE DECAY $\chi \to p\bar{p}$

We work in light cone gauge ($A^+=0$) and $p^{\pm}=p^0 \pm p^3$, $p_T=(p^1,p^2)$. If a proton is assigned momentum $P=(P^+, P^-, P_T)$ its constituents carry longitudinal momentum fractions $x^i=k^+/P^+$ and $k_T{}^i$. The proton wavefunction is denoted by $\psi(x_i,k_T)$ and the distribution amplitude is defined in terms of ψ as follows:

$$\phi(x_i,Q^2) = (\log(Q/\Lambda)^2)^{-3\gamma/2\beta} \int^{Q^2} [d^2k_T]\ \psi(x_i,k_T) \qquad (1)$$

where γ and β are the anomalous dimension of the quark field and the coefficient of the beta function respectively. The decay amplitude has the general form shown in Fig.1(a). We treat the heavy chi state in the nonrelativistic approximation; we see that a large momentum ($Q^2 \sim M^2$) flows through the diagram from the left; if this momentum is allowed to enter either of the proton wavefunctions in the final state, the entire amplitude will be suppressed since a wavefunction is very small when evaluated at large momenta. The large momentum is thus contrained to flow through T_H. All internal lines in T_H are pulled off-shell by an amount of order Q^2 thus making a perturbative analysis possible as shown in Fig.1(b). The graphs which contribute to T_H are shown in Fig.2; there are 24 such graphs.

Renormalizing all lines and vertices in Fig.1(b), and performing the implied integrations turns the proton anti-proton wavefunctions into distribution amplitudes so that finally the factorization analysis yields the following expression for the full decay amplitude of $\chi \to p\bar{p}$:

$$T=-iM^{-11/2}\sqrt{(\tfrac{3}{8\pi})}R_P'(0)\epsilon_\alpha^* \epsilon^{\alpha\beta} g^{3\beta} \int dx dy \phi^*(y) T_H(x,y)\phi(x) \qquad (2)$$

Here, T_H is the hard scattering amplitude computed from the graphs of Fig.2 and is given by

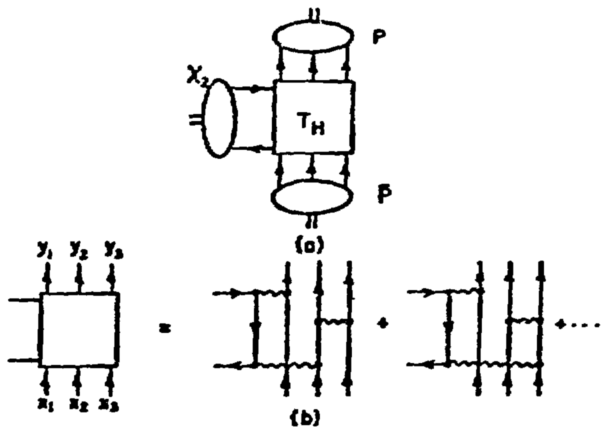

Fig.1: (a) Exclusive decay of the chi; (b) Short distance expansion of the scattering amplitude.

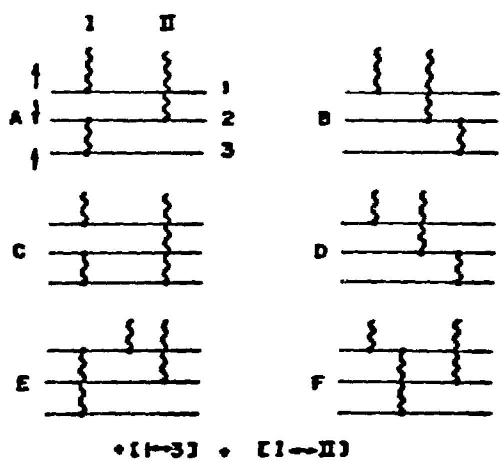

Fig.2: Graphs which contribute to to T_H

$$T_H = 2cg^6\left(\frac{1}{x_3y_3} + \frac{1}{x_2y_2}\right)\frac{x_1+y_1}{x_1y_1(1-x_1)(1-y_1)[x_1(1-y_1)+y_1(1-x_1)]^2} + (1\leftrightarrow 3) \quad (3)$$

$R'_p(0)$ is the derivative of the radial wavefunction at the origin of the chi state, $\varepsilon_{\mu\nu}$ the chi state's polarization tensor (we are only considering the 2^{++} chi state-see below) and $\varepsilon^{\mu}=g^{1\mu}+ig^{2\mu}$. The common color factor to all graphs is $c=2/3/27$. We parametrize ϕ by writing $\phi=K(x_1x_2x_3)^{\eta}$. (This form is suggested by the evolution equation obeyed by the distribution amplitude). The normalization constant K will be fixed by comparison with the process $\psi\to p\bar{p}$. (Note that there is an apparent dependence on η; however, the ratio of the amplitudes for ψ and χ decay is insensitive to the value of this parameter). With a value $\alpha_s(Q^2)=0.2$ we finally obtain

$$\left.\frac{\Gamma(\chi_2\to p\bar{p})}{\Gamma(\chi_2\to 2g)}\right|_{th.} = \begin{cases} 1.2\times10^{-4} & \eta=1 \\ 0.8\times10^{-4} & \eta=4 \end{cases} \quad (4)$$

This to be compared with the experimental value[6] (see also, E. Menishetti, this conference)

$$\left.\frac{\Gamma(\chi_2\to p\bar{p})}{\Gamma(\chi_2\to 2g)}\right|_{exp.} = .8^{+.25}_{-.23}\times10^{-4} \quad (5)$$

SUMMARY AND DISCUSSION

We have only been discussing the decay of the 2^{++} state: in the approximations we have been using (massless quarks in the protons and massless protons), the QCD helicity rules imply that $|\lambda-\bar{\lambda}|=1$ where $\lambda,\bar{\lambda}$ are the helicities of the produced $p\bar{p}$ pair. This rule suppresses the $^3P_0$ state. Also since $S=|\lambda-\bar{\lambda}|$, CP conservation rules out $^1P_1$. (The decay of the $^3P_1$ state suffers from collinear divergences and we do not discuss it here). Unfortunately the helicity rules are not a good guide here since experimentally the η_c has been observed to decay into $p\bar{p}$ with a rate comparable to that of the χ_2 state.[6] (See also the discussion of Martin, Olsson and Stirling[7] and Buchmuller[8]). This once again calls into question the applicability of perturbative QCD to decays of the ψ family of states and necessitates a closer look at the mass corrections ($\langle k^2\rangle/Q^2$, m^2/Q^2) to the naive approximations. This is perhaps not so surprising since $M(P)/M(\chi)=1/3$. Corrections of this type are expected to be much less significant for the heavier Υ family but unfortunately scaling laws make the branching ratios there extremely small. Simple dimensional analysis shows that as long as we compare branching ratios, all dependence on meson wavefunctions cancells so that, for example, $Br(\Upsilon\to p\bar{p})/Br(\chi_2\to p\bar{p}) = (M(c\bar{c})/M(b\bar{b}))^4 \sim 10^{-8}$.

Finally we note that knowledge of the decay rate we have computed enables us to use the Breit-Wigner formula

$$\sigma = \frac{4\pi(2J+1)}{4M_\chi^2}\,\frac{\Gamma^2_{p\bar{p}}}{(\sqrt{s}-M_\chi)^2+1/4\Gamma^2} \qquad (6)$$

to give predictions for the production cross section of chi states in $p\bar{p}$ collisions. Here $\Gamma=2.7$ Mev is the χ_2 total decay rate. With our values for $\Gamma_{p\bar{p}}$, and $M_\chi=3.5$ Gev our prediction is in rough agreement with what has been reported here today.

REFERENCES

1. S.J. Brodsky and G.P. Lepage, Phys.Rev.D22 (1980) 2157 and references therein.
2. A. Andrikopoulou, Z. Phys.C22 (1984) 63
3. V.L. Chernyak and A.R. Zhitnitsky, Physics Reports 112 (1984) 173
4. P.H. Damgaard, K. Tsokos and E.L. Berger, CERN report 4112/85
5. S.J. Brodsky and G.P. Lepage, Phys. Rev.D24 (1981) 2848
6. C. Baglin et. al., CERN report EP/84-145, and Como Workshop 1983, 327.
7. A.D. Martin, M.G. Olsson and W.J. Stirling, Phys.Lett.147B (1984) 203
8. W. Buchmuller, CERN report 4142/85