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QCD PREDICTIONS FOR BEAUTY PRODUCTION IN
 πp AND $\bar{p}p$ COLLISIONS

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ABSTRACT

The total cross-sections for beauty production in πp , pp and $\bar{p}p$ collisions are calculated within perturbative QCD. It turns out that the cross-sections are around several nanobarns at present available energy. For the future $\bar{p}p$ collider, the total cross-section reaches several millibarns.

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Recently a bump at $M \sim 5.3$ GeV has been observed in the $\psi K\pi$ channel in a $\pi^- p$ collision experiment at CERN¹⁾. We may seek to identify this bump as the B meson. But the result is not conclusive and needs further confirmation.

Hadronic production of heavy flavours within QCD has been discussed by many authors²⁾⁻⁶⁾. It seems that up to now there is no careful discussion for beauty production in πp and $\bar{p}p$ collisions, although there has been similar discussion of charm production. Fritzsche and Streng⁵⁾ have suggested a mechanism for the hadronic production of heavy flavours, namely, a gluon from incoming π , p or $\bar{p}$ firstly hadronize into a $b\bar{b}$ pair and then interact with a proton target, (see (a) of Fig. 1). This mechanism is similar to photoproduction in the vector meson dominance approximation (see (b) of Fig. 1). If the mechanism is correct, the cross-section of beauty production in πp collision are about 50nb not far from 200nb which was estimated in Ref. 1). Also, according to this mechanism the cross-sections of beauty production in πp and pp should be of the same order at ≥ 400 GeV⁷⁾. The cross-section for beauty production in pp collision predicted by the above mechanism at $E_{\text{Lab}} \sim 400$ GeV is $\sim 0.85\mu\text{b}$ but a recent experiment using 400 GeV proton beam and observing direct muons and neutrinos performed at FNAL⁸⁾ set an upper limit $\sim 40\text{nb}$ for beauty production. So the experimental status for beauty production is still quite obscure. On the other hand, the gluon has colour and the $b\bar{b}$ pair in (a) of Fig. 1 is not a colour singlet while that in (b) of Fig. 1 is a colour singlet. So, the $b\bar{b}$ pair in (a) of Fig. 1 might be a coloured bound state with very big mass or even not a bound state. Therefore the similarity between (a) and (b) of Fig. 1 is also questionable.

In this short article we shall examine other more conventional mechanisms and calculate the total cross-sections for beauty production in πp , $\bar{p}p$ collisions in the lowest order approximation of perturbative QCD.

BEAUTY PRODUCTION IN πp COLLISIONS

The Feynman diagrams contributing to beauty production processes are illustrated in Fig. 2. The energy of the pion beams at present machine (SPS and FNAL) is around several hundred GeV. Momentum conservation gives

$$xyS \gtrsim 4m_b^2 \quad (1)$$

where x, y are the Feynman variables of the interacting partons, $m_b \sim 4.8$ GeV is the b quark mass, S is the total energy squared of πp in their c.m. system. For $E_\pi \sim 150$ GeV, x, y must be larger than 0.3 according to Eq. (1). So, the contribution of the diagrams (b) - (d) will be seriously suppressed and the valence $q\bar{q}$ annihilation mechanism (a) will dominate. Actually, the contribution of (a) in Fig. 2 is

$$\hat{\sigma}_{\text{tot}}^{q\bar{q} \rightarrow b\bar{b}}(\pi^- p \rightarrow B\bar{B}X) = \iint_{xyS \geq 4m_b^2} dx dy \hat{\sigma}_{q\bar{q} \rightarrow b\bar{b}}(xyS) \frac{1}{xy} \left[x u_V^p(x, Q^2) \cdot y \bar{u}_V^{\pi^-}(y, Q^2) \right] \quad (2)$$

where

$$\hat{\sigma}_{q\bar{q} \rightarrow b\bar{b}}(xyS) = \frac{8\pi\alpha_s^2(Q^2)}{27(xyS)^3} \left[xyS(xyS - 4m_b^2) \right]^{1/2} (xyS + 2m_b^2) \quad (3)$$

The contribution of (b)-(d) in Fig. 2 is

$$\hat{\sigma}_{\text{tot}}^{gg \rightarrow b\bar{b}}(\pi^- p \rightarrow B\bar{B}X) = \iint_{xyS \geq 4m_b^2} dx dy \hat{\sigma}_{gg \rightarrow b\bar{b}}(xyS) G_{\pi^-}^{\pi^-}(y, Q^2) G_p^p(x, Q^2) \quad (4)$$

where

$$\hat{\sigma}_{gg \rightarrow b\bar{b}}(xyS) = \frac{\pi\alpha_s^2(Q^2)}{3xyS} \left[\left(1 + 4\frac{m_b^2}{xyS} + \frac{m_b^4}{(xyS)^2} \right) \ln\left(\frac{1+\beta}{1-\beta}\right) - \left(\frac{7}{4} + \frac{33m_b^2}{4xyS} \right) \right] \quad (5)$$

$$\beta = \left(1 - \frac{4m_b^2}{xyS} \right)^{1/2} \quad (6)$$

In Eq. (2) we only include the contribution of the valence antiquark $\bar{u}$ in the π^- meson and neglect the sea quark contribution. For numerical calculations we use the proton structure functions given by Buras and Gaemers⁹⁾. For pion structure functions we use the results measured recently at FNAL and CERN^{10), 11)}. The data were taken in the range $\sim 16 \text{ GeV}^2 \leq Q^2 \leq \sim 80 \text{ GeV}^2$ which is quite near the range of Q^2 in beauty production ($Q^2 \geq 4m_b^2 \sim 100 \text{ GeV}^2$). We use the fit

$$v^{\pi^-}(y) = y \bar{u}^{\pi^-}(y, Q^2) \sim 0.9\sqrt{y} (1-y)^{1.27} \quad (7)$$

for FNAL data and

$$V^{\pi}(y) \sim 0.75 \sqrt{y} (1-y) \quad (8)$$

for CERN SPS data^{*)}.

For the gluon distribution of the proton, the only constraint is

$$\int x G^p(x) dx \sim 0.5 \quad (9)$$

For the gluon distribution of the pion, Field and Feynman¹²⁾ suggested that the total momentum fraction carried by gluons inside the pion is ~ 0.42 , but there is no reliable data to confirm it. So, for simplicity, we also take

$$\int x G^{\pi}(x) dx \sim 0.5 \quad (10)$$

For $G^p(x, Q^2)$ we use a Buras-Gaemers parametrization. According to Table 2 in Ref. 9)

$$\text{If } G^p(x, Q_0^2 \sim 1.8 \text{ GeV}^2) \sim 3 (1-x)^5/x, \text{ then } G^p(x, 4m_b^2) \sim 8.5 (1-x)^{16}/x \quad (11)$$

$$\text{If } G^p(x, Q_0^2 \sim 1.8 \text{ GeV}^2) \sim 5.5 (1-x)^{10}/x, \text{ then } G^p(x, 4m_b^2) \sim 11.5 (1-x)^{16}/x$$

where, we use the parametrization

$$G^p(x, Q^2) \sim \frac{n+1}{2} (1-x)^n/x \quad (12)$$

and n depends on Q^2 . For comparison, we also calculate the cross-sections for $n = 5$ and 10 .

For $G^{\pi}(y, Q^2)$, we use the same parametrization

$$G^{\pi}(y, Q^2) \sim \frac{n_{\pi}+1}{2} (1-y)^{n_{\pi}}/y \quad (13)$$

^{*)} The fit in Eq. (7) is taken from Ref. 10). The fit in Eq. (8) is provided by F. Martin. This fit is slightly different from the original fit $0.55 y^{0.4} \pm 0.06 (1-y)^{0.9} \pm 0.06$ but much simpler.

and speculate that

$$n_{\pi} \sim n-2 \quad (14)$$

by the naïve counting rule¹³⁾.

For the running coupling constant, we use

$$\alpha_s(Q^2) \sim 0.3 / \left[1 + 0.3 \frac{9}{4\pi} \ln(Q^2/4m_b^2) \right] \quad (15)$$

with $Q^2 \sim xyS$ *).

All the results are presented in Fig. 3. But we did not present the contribution of $gg \rightarrow b\bar{b}$ with $G^{\pi}(y, Q^2) \sim (1-y)^{20}/y$ and $G^p(x, Q^2) \sim (1-x)^{22}/x$ which is negligibly small. From Fig. 3 we can see that at present pion beam energies, the contribution of the mechanism $\bar{q}q \rightarrow b\bar{b}$ is dominant. At $E_{\pi} \sim 150-175$ GeV, $\sigma_{\text{tot}}(\pi^- p \rightarrow B\bar{B}x) \sim \ln b$ which is relatively small. Here the error induced by the uncertainty of beauty quark mass is small and not larger than a factor 2. The high order corrections are not very clear, but could not change the order of the cross-sections. Thus it seems difficult to search for beauty at such an energy range in $\pi^- p$ collisions. If it were not for the mechanism proposed by Fritzsche and Streng the present data¹⁾ would be questionable.

BEAUTY PRODUCTION IN $\bar{p}p$ COLLISIONS

The production mechanisms are the same as in πp collisions. The only differences are in the gluon and quark distributions.

The contribution of (a) in Fig. 2 is

$$\sigma_{\text{tot}}^{\bar{q}\bar{q} \rightarrow b\bar{b}}(\bar{p}p \rightarrow B\bar{B}x) = \int \int_{xyS \geq 4m_b^2} dx dy \hat{\sigma}_{\bar{q}\bar{q} \rightarrow b\bar{b}}(xyS) \frac{1}{xy} \left[x u_V^p(x, Q^2) y u_V^p(y, Q^2) + x d_V^p(x, Q^2) y d_V^p(y, Q^2) \right] \quad (16)$$

where, $\hat{\sigma}_{\bar{q}\bar{q} \rightarrow b\bar{b}}(xys)$ is given in Eq. (3) and $u_V^p(x, Q^2)$, $d_V^p(x, Q^2)$ are given in Ref. 9).

The contribution of (b)-(d) in Fig. 2) is

*) There are also some other possible choices such as $Q^2 \sim \sqrt{s} \hat{s} \hat{t} \hat{u}$, $-\hat{t}$, $-\hat{u}$, etc., which are equivalent to leading order in $\alpha_s(Q^2)$.

$$\sigma_{tot}^{gg \rightarrow b\bar{b}}(\bar{p}p \rightarrow B\bar{B}x) = \iint_{xyS \geq 4m_b^2} dx dy \hat{\sigma}_{gg \rightarrow b\bar{b}}(xyS) G^p(y, Q^2) \cdot G^p(x, Q^2) \quad (17)$$

where $\hat{\sigma}_{gg \rightarrow b\bar{b}}(xys)$, β , $G^p(x, Q^2)$, $\alpha_s(Q^2)$ are given in Eqs (5), (6), (9) and (12) respectively.

All the results are presented in Figs 4 and 5. Note that because there are no valence antiquarks inside proton, we should have

$$\sigma_{tot}(pp \rightarrow B\bar{B}x) \sim \sigma_{tot}^{gg \rightarrow b\bar{b}}(pp \rightarrow B\bar{B}x) = \sigma_{tot}^{gg \rightarrow b\bar{b}}(\bar{p}p \rightarrow B\bar{B}x) \quad (18)$$

From Fig. 5 we can see that for a 400 GeV proton beam on a stationary proton target $\sqrt{S} \sim 28$ GeV, the $\sigma_{tot}(pp \rightarrow B\bar{B}x) < 2\text{nb}$ for $n = 5-22$. We should emphasize that $n = 5$ is not the favourite gluon distribution in the proton at such a large $Q^2 \sim 4m_b^2 \sim 100 \text{ GeV}^2$. For $n = 10, 16, 22$, $\sigma_{tot}(pp \rightarrow B\bar{B}x)$ is negligibly small at $\sqrt{S} \sim 28$ GeV.

For $\bar{p}p \rightarrow B\bar{B}x$, when $\sqrt{S} < 70$ GeV, the $q\bar{q} \rightarrow b\bar{b}$ mechanism is dominate. When $\sqrt{S} > 200$ GeV, the $gg \rightarrow b\bar{b}$ mechanism is dominate and the contribution of $q\bar{q} \rightarrow b\bar{b}$ can be neglected.

For the forthcoming $\bar{p}p$ experiment at ISR, $\sqrt{S} \sim 20-60$ GeV, $\sigma_{tot}(\bar{p}p \rightarrow B\bar{B}x) \sim 20-50 \text{ nb}$. But the luminosity is much smaller than with a stationary target and it seems not easy to look for beauty in a ISR $\bar{p}p$ experiment.

For the future $\bar{p}p$ collider, $\sqrt{S} \sim 400-800$ GeV, $\sigma_{tot}(\bar{p}p \rightarrow B\bar{B}x) \sim 8-10\text{mb}$ (see Fig. 5). It should be relatively easy to search for beauty at such an energy. In that case the contribution of $q\bar{q} \rightarrow b\bar{b}$ can be neglected.

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FIGURE CAPTIONS

- Fig. 1 : (a) Mechanism for the hadronic production of beauty suggested by Fritzsche and Streng.
- (b) Photoproduction of beauty in the vector meson dominance approximation.
- Fig. 2 : Feynman diagrams contributing to beauty production in πp and $\bar{p}p$ collisions.
- Fig. 3 : Total cross-sections for beauty production in πp collisions; E_π is the pion beam energy in the Lab system.
- Fig. 4 : Total cross-section for beauty production in $\bar{p}p$ collisions at $20 \leq \sqrt{s} \leq 70$ GeV, where $\sqrt{s}$ is the total energy in the c.m. system.
- Fig. 5 : Total cross-section for beauty production in $\bar{p}p$ collisions at $70 \leq \sqrt{s} \leq 420$ GeV.

FIG. 1

FIG. 2

FIG.3

FIG. 4

FIG.5