Production of the B_c at Tevatron

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Outline

I. Introduction

II. α_s^4 full QCD calculation

III. fragmentation contribution

IV. nonfragmentation contribution

V. Summary

I. Introduction

CDF : (98)

$$\frac{\sigma(B_c)\cdot B_r(B_c \to J/\psi\, \ell \nu)}{\sigma(B)\cdot B_r(B \to J/\psi\, K)} = 0.132 \underbrace{{}^{+0.041}_{-0.037}}_{\text{stat.}} \underbrace{\pm 0.031}_{\text{syst.}} \underbrace{{}^{+0.032}_{-0.020}}_{\text{lifetime}}$$

3 lepton events

$$B_c \to J/\psi + \ell\, \nu$$
$$\hookrightarrow \mu^+\mu^-$$

LEP I Several candidates

Tevatron credible

Production of the B_c is essencial

In experments:

- sufficient B_c event number
  measure other decay channels,
- Monta Carlo simulation
  reduce background
  improve detection effecince

In theory

- small P_T dominated, factorization
- fragmentation
- non-fragmentation

6 possible color factors

$T^aT^bT^cT^c$ $\qquad$ $T^bT^aT^cT^c$

$T^bT^cT^aT^c$ $\qquad$ $T^aT^cT^bT^c$

$T^cT^aT^bT^c$ $\qquad$ $T^cT^bT^aT^c$

5 of the 6 are gauge indept. subsets

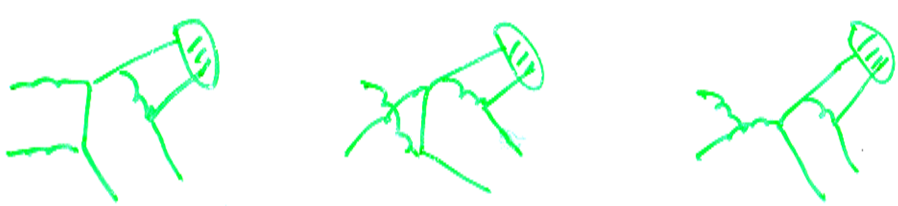
$$\sigma = \int_0^1 dx_1 \int_0^1 dx_2 \; g_1(x_1,\mu)\, g_2(x_2,\mu)\, \delta(\hat{s}-x_1x_2 s)\, \hat{\sigma}(\hat{s},\mu)$$

dominated by 2 subsets

$\hat{\sigma}$ in pb

$\sqrt{s}$ GeV		20	30	50	200
B_c	H2	5.4	8.8	8.5	1.90
	full	6.4	9.0	8.3	1.86

Including diagrams



frag.

+ ....

recombination

Numerical result

- P_T distribution

  Peak at $P_T \sim m_{B_c}$

  decrease very fast

	B_c	B_c^*	
$\sigma_{P_T>0}$	2	4.5	nb
$P_T>5\,GeV$	0.8	2	nb

μ-dependence

  tree level result, ℓ

Comments:

- calculation

  complicated

  straitforward

  $|M|^2$ lengthy

  all α_s^4 included

  higher order correction impossible

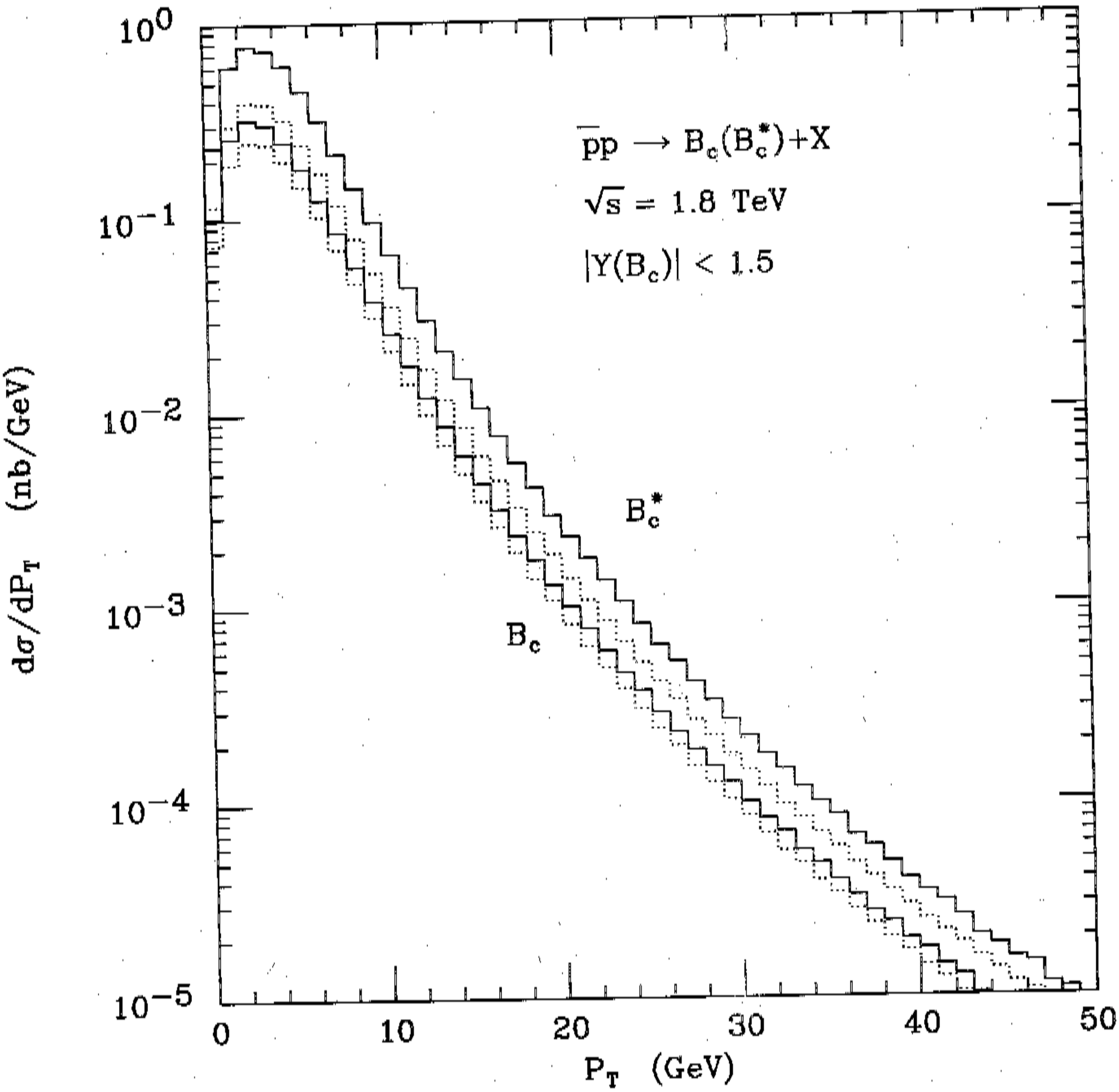

$\bar{p}p \longrightarrow B_c(B_c^*)+X$
$\sqrt{s} = 1.8$ TeV
$|Y(B_c)| < 1.5$
B_c^*
B_c
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
10
20
30
40
50
$d\sigma/dP_T$ (nb/GeV)
P_T (GeV)

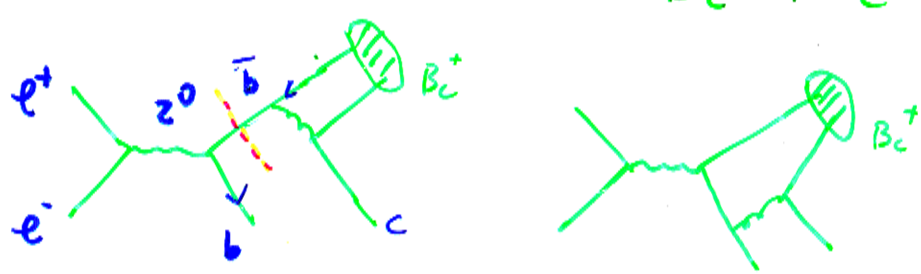
FIGURE 2

3. B_c production via fragmentation

$$\bar{b} \to B_c^+ + \bar{c}$$
$$c \to B_c^+ + b$$

fragmentation function

$$e^+e^- \to Z^0 \to b\bar{b}$$
$$\hookrightarrow B_c^+ + \bar{c}$$



in the limit of $m_Z/m_b \to \infty$

fragmentation dominated

$$z \equiv \frac{2E_{B_c}}{m_Z} \qquad (0 < z < 1)$$

$$\frac{d\sigma}{dz} = \sigma(e^+e^- \to Z^0 \to b\bar{b}) \cdot F_{\bar{b}\to B_c^+}(z) + \sigma(e^+e^- \to Z^0 \to c\bar{c}) \cdot F_{c\to B_c}(z)$$

$F_{\bar{b}\to B_c}(z)$, $F_{c\to B_c}(z)$ fragmentation function

process indept.

$F_{\bar{b}\to B_c^{(*)}}(z)$ perturbatively calculable

Chang & Chen
Braaten, Cheung, Yuan

$$F_{\bar{b}\to B_c}(z) = \frac{2\alpha_s^2(\mu)|R(0)|^2}{81\pi m_c^3}\frac{\alpha_1 z(1-z)^2}{(1-\alpha_2 z)^6}\Big[6-18(1-2\alpha_1)z + (21-74\alpha_1+68\alpha_1^2)z^2 - 2\alpha_2(6-19\alpha_1+18\alpha_1^2)z^3 + 3\alpha_2^2(1-2\alpha_1+2\alpha_1^2)z^4\Big]$$

$$F_{\bar{b}\to B_c^*}(z) = \frac{2\alpha_s^2(\mu)|R(0)|^2}{27\pi m_c^3}\frac{r z(1-z)^2}{(1-\alpha_2 z)^6}\Big[2-2(3-2\alpha_1)z + 3(3-2\alpha_1+4\alpha_1^2)z^2 - 2\alpha_2(4-\alpha_1+2\alpha_1^2)z^3 + \alpha_2^2(3-2\alpha_1+2\alpha_1^2)z^4\Big]$$

Fragmentation proporbility $\quad \alpha_1 = \frac{m_b}{m_{B_c}},\ \alpha_2 = 1-\alpha_1$

$$W_{\bar{b}\to B_c} \equiv \int_0^1 dz\, F_{\bar{b}\to B_c}(z) \doteq 2.2\times 10^{-4}$$

$$W_{\bar{b}\to B_c^*} \equiv \int_0^1 dz\, F_{\bar{b}\to B_c^*}(z) \doteq 3.1\times 10^{-4}$$

evalution of the fragmentation function

A–P equation

• B_c production in hadron collision via fragmentation

Cheung

$F_{b \to B_c}(z)$ $F_{c \to B_c}(z)$ universal

$g + g \longrightarrow B_c^+ + b + \bar{c}$

$$\frac{d\hat{\sigma}}{dz} = \hat{\sigma}(gg \to b\bar{b})\, F_{b \to B_c}(z) + \hat{\sigma}(gg \to c\bar{c})\, F_{c \to B_c}(z)$$

calculation is much simpler !

prediction :

$$\frac{\sigma(p\bar{p} \to B_c)}{\sigma(p\bar{p} \to b\bar{b})} \sim W_{\bar{b} \to B_c} \sim 10^{-3}$$

Compatible with α_s^4 calculation

Does fragmentation work well ?

4. Non-fragmentation contribution

condition for fragmentation

1) $\sqrt{\hat{s}} \gg 2(m_b+m_c) \sim 13$ GeV

2) no collinear singularities

1) + 2) $\Longrightarrow$ $P_T^{B_c}$ is large

- $\dfrac{d\sigma}{dP_T}$ decreases very fast

  $P_T \sim m_{B_c}$

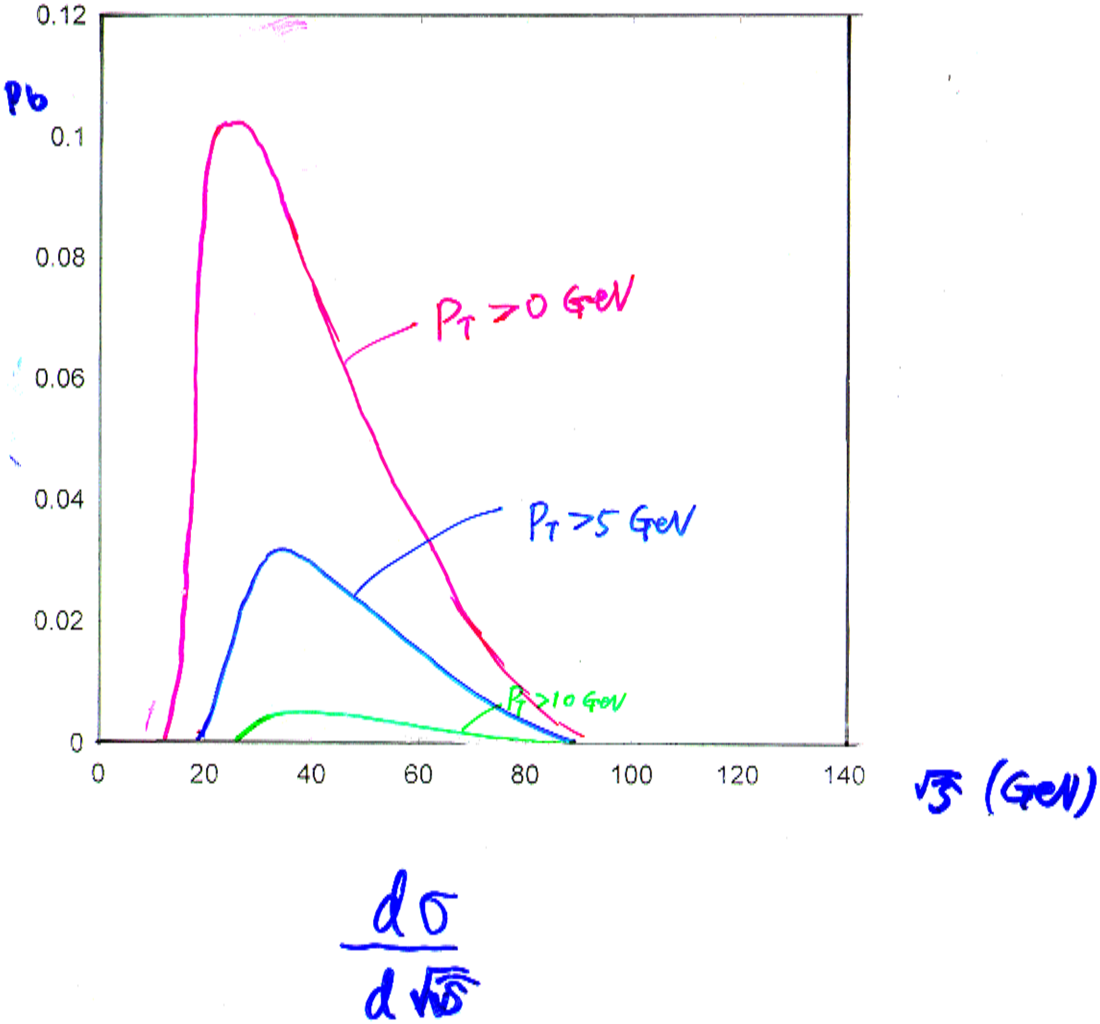
- $\sqrt{\hat{s}}$ not very large

  $\sqrt{\hat{s}} \sim$ threshold energy

expect

frag. approxi. not so good

nonfrag contri. important


Pb
0.12
0.1
0.08
0.06
0.04
0.02
0
0
20
40
60
80
100
120
140
$\sqrt{s}$ (GeV)
$P_T > 0$ GeV
$P_T > 5$ GeV
$P_T > 10$ GeV
$\frac{d\sigma}{d\sqrt{s}}$

Insight into the nonfrag. contribution

- subprocess with $\sqrt{s} = 200\ \text{GeV} \gg 2 m_{B_c}$

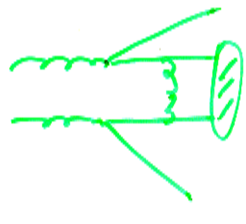
  p_T distribution

  two components

  $p_T \sim m_{B_c}$ nonfragmentation dominated

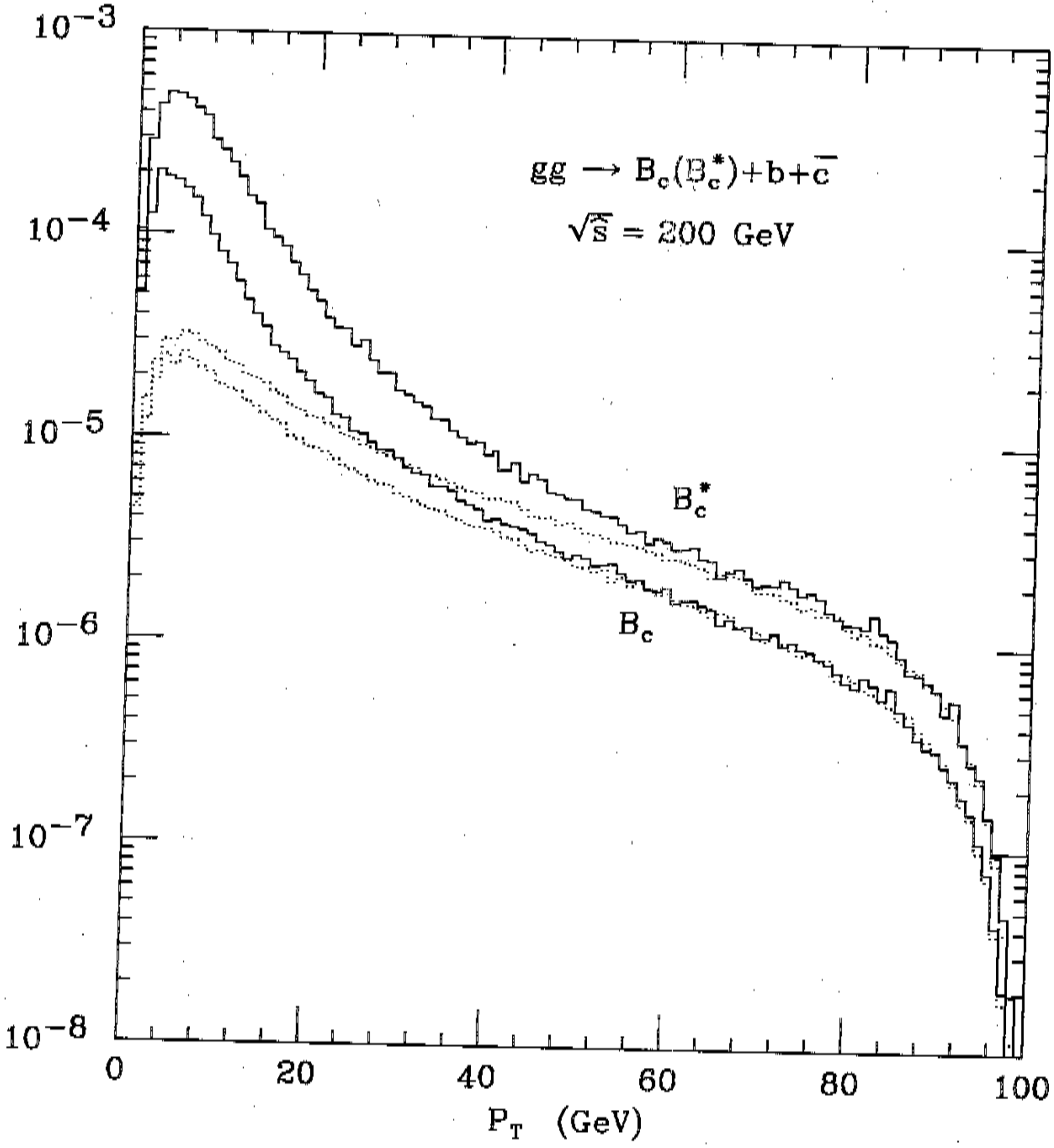
$$\frac{d\hat{\sigma}}{dp_T^2} \sim \frac{1}{p_T^4} \frac{f_{B_c}^2}{\hat{s}}$$

recombination diagrams ...



  $p_T \gg m_{B_c}$ fragmentation dominated

$$\frac{d\hat{\sigma}}{dp_T^2} \sim \frac{1}{p_T^2} \frac{f_{B_c}^2}{m_b^2 \hat{s}}$$



$gg \longrightarrow B_c(B_c^*)+b+\bar{c}$
$\sqrt{s}$ = 200 GeV
B_c^*
B_c
$d\sigma/dP_T$ (nb/GeV)
P_T (GeV)

FIGURE 1

- $p\bar{p}$ collision

1) $\dfrac{d\sigma}{dz}$ $\qquad z \equiv \dfrac{2(k_1+k_2)\cdot p}{\hat{s}}$

$$\frac{d\sigma}{dz} = \int_0^1 dx_1 \int_0^1 dx_2 \; g(x_1,\mu)\, g(x_2,\mu)\, \delta(x_1 x_2 s - \hat{s}) \frac{d\hat{\sigma}(\hat{s},\mu)}{dz}$$

In fragmentation approximation

$$\frac{d\hat{\sigma}(\hat{s},\mu)}{dz} = \sum_i \hat{\sigma}_{gg\to Q_i\bar{Q}_i} \otimes D_{Q_i\to B_c}(z,\mu)$$

$$\frac{d\sigma}{dz} \propto D_{\bar{b}\to B_c}(z,\mu)$$

It's true when $P_T > 20\ \mathrm{GeV} \gg m_{B_c}$

2) $\dfrac{\sigma_{B_c^*}}{\sigma_{B_c}} \equiv R$

$R \doteq \dfrac{W_{b\to B_c^*}}{W_{b\to B_c}} \doteq 1.6$ fragmentation

$R =$	2.4	2.4	2.4	2.3	2.0
$P_{T\min}$	0	5	10	20	30

α_s^4 calculation

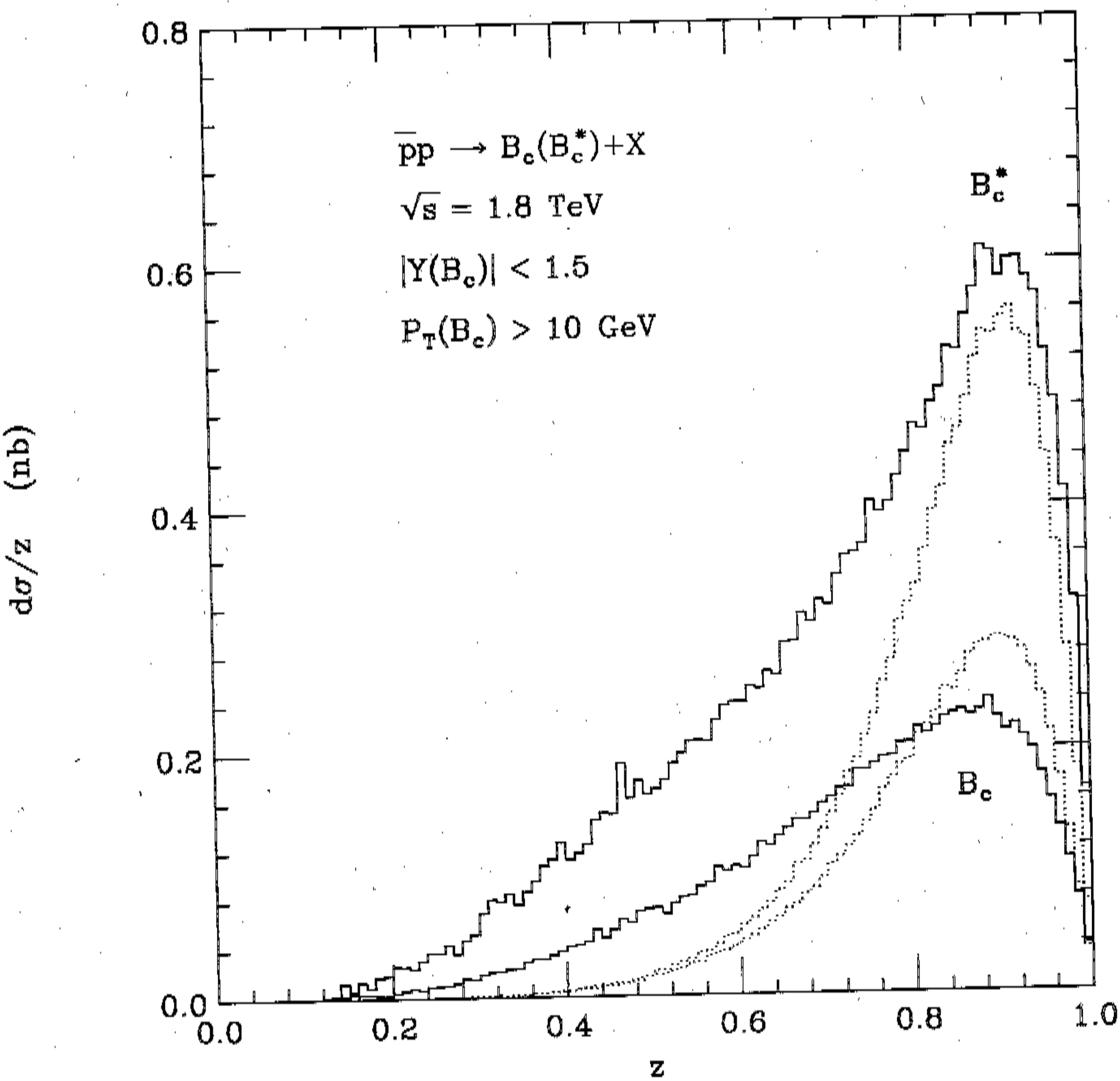

$\bar{p}p \longrightarrow B_c(B_c^*)+X$
$\sqrt{s} = 1.8$ TeV
$|Y(B_c)| < 1.5$
$P_T(B_c) > 10$ GeV
B_c^*
B_c
0.8
0.6
0.4
0.2
0.0
$d\sigma/z$ (nb)
0.0
0.2
0.4
0.6
0.8
1.0
z

FIGURE 3a

Summary

- α_s^4 calculation complicated, straightford
  higher order QCD correction hard
- fragmentation approximation
  valid when and only when $P_T \gg M_{B_c}$
- at smaller P_T, both fragmentation
  contribution and nonfragmentation
  are important
- testable by measuring $\dfrac{\sigma_{B_c^*}}{\sigma_{B_c}}$

question

How to get a compact form
for nonfragmentation contribution?