Coming Soon

NEW RESULTS FOR UPSILON

Adam K Leibovich

Work being done with: Eric Braaten
Sean Fleming

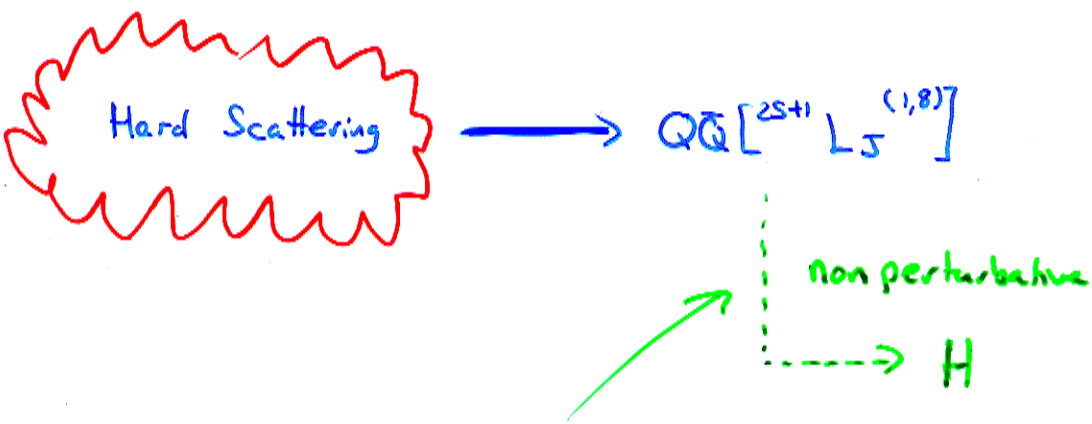
New Extraction of $b\bar{b}$ NRQCD Matrix Elements

NRQCD Review

Effective Field Theory

Handle multiple scales : $M_Q \gg M_Q v \gg M_Q v^2$; Λ_{QCD}

Quarkonia Production in NRQCD



Strength? NRQCD Matrix Elements

$$\langle 0 | \mathcal{O}^H_{(1,8)}[^{2S+1}L_J] | 0 \rangle$$

Size of matrix elements?

- Estimate with Counting Rules
- Color Singlet $\Rightarrow$ wavefunctions
- Extract from data.

Why bother?

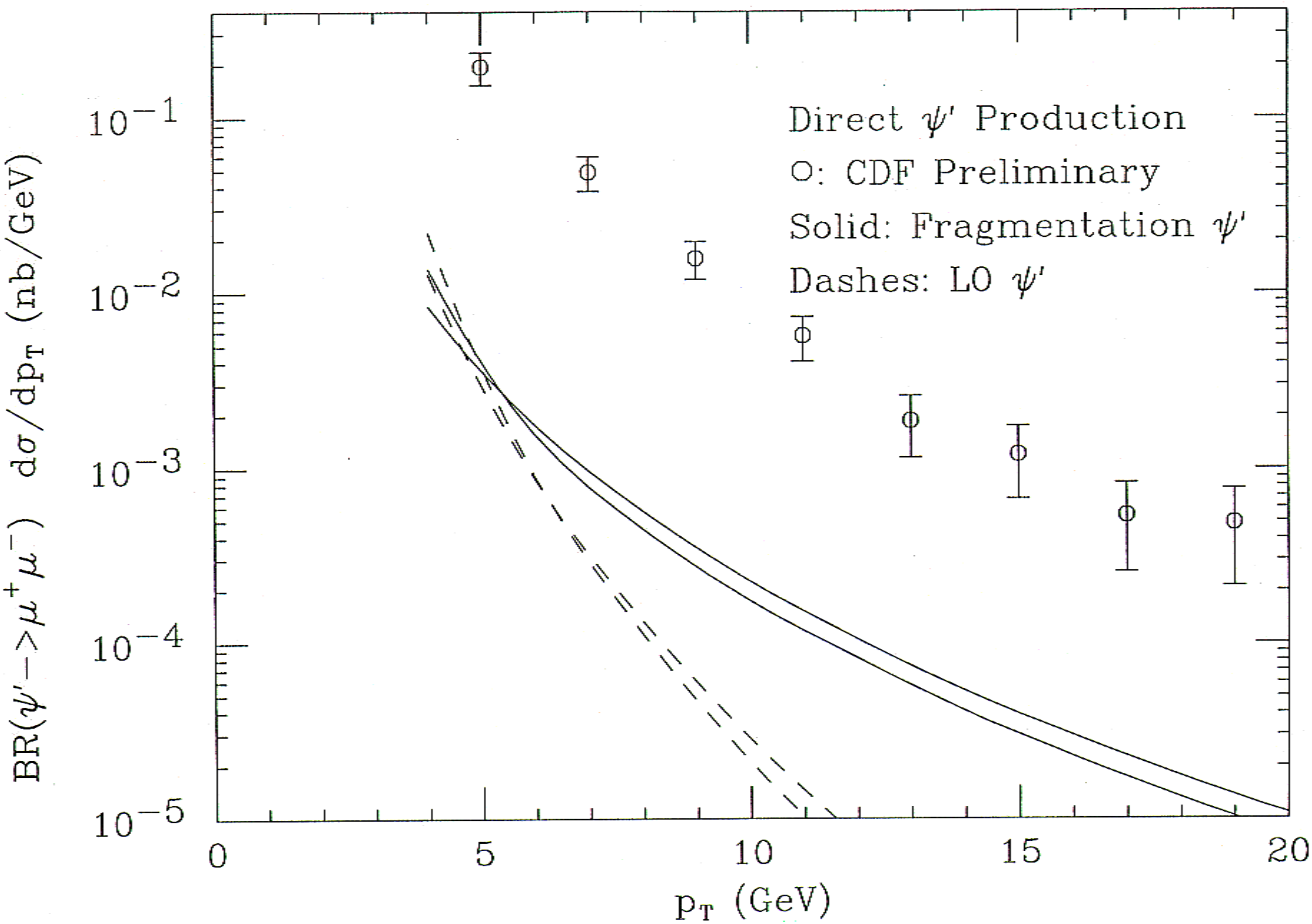
- Υ as probe for new physics
  - Associated $W^{\pm} + \Upsilon$ and $Z^0 + \Upsilon$

    Braaten, Lee + Fleming hep-ph/9812505
  - $t \to c\Upsilon$ Handoko + Qiao hep-ph/9907375

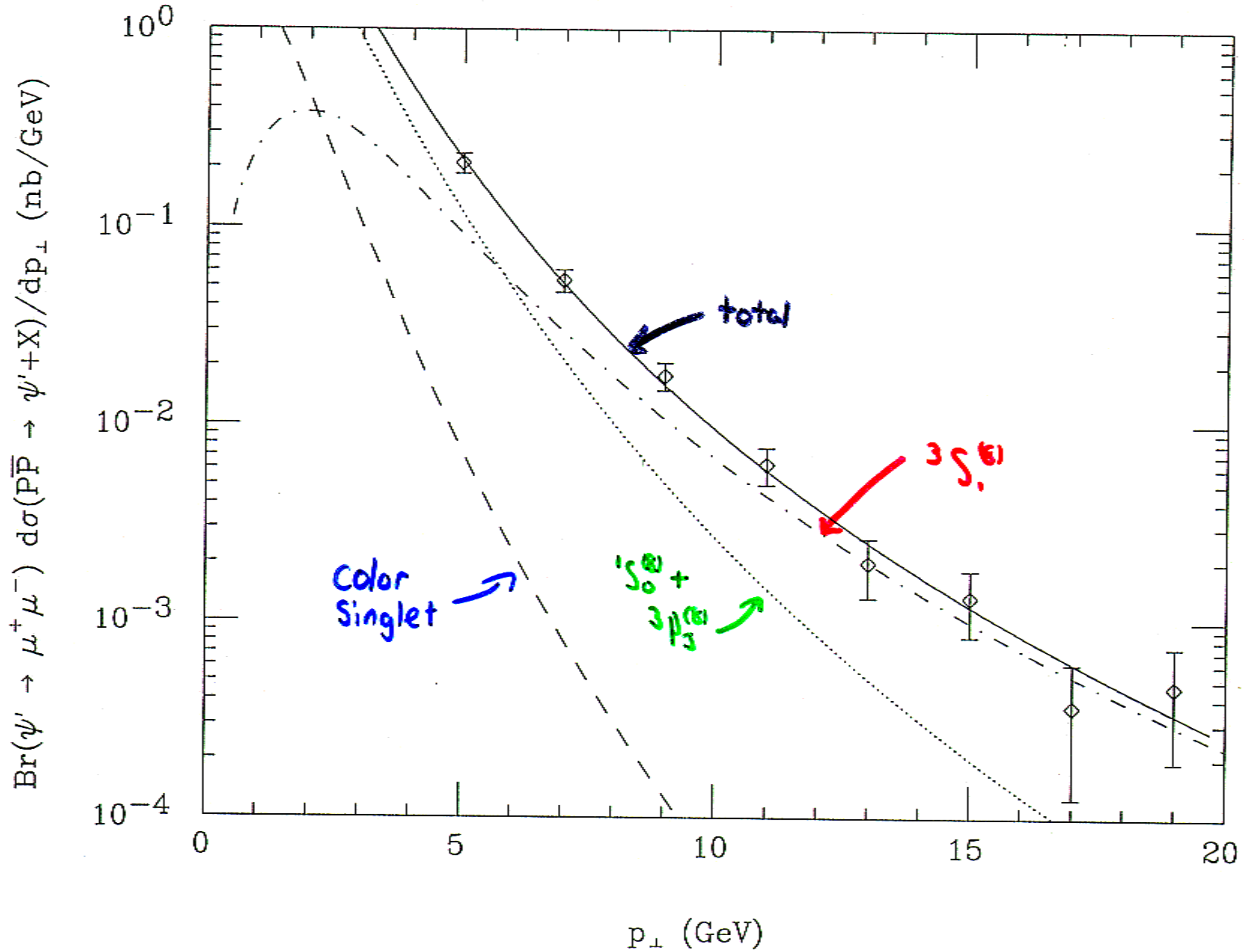
- Test NRQCD
  - $v_b^2 \sim 0.1$ ($v_c^2 \sim 0.24$)
  - Counting rules same?
  - Is it necessary?

    In $c\bar{c}$ system had ψ' anomaly.

E. Braaten, M.A. Doncheski, S. Fleming and M.L. Mangano, Phys. Lett. B 333 (1994)



Dashed - lowest order color-singlet production
Solid - fragmentation (color-singlet)


Br(ψ' → μ⁺μ⁻) dσ(PP̄ → ψ'+X)/dp⊥ (nb/GeV)
10^0
10^−1
10^−2
10^−3
10^−4
0
5
10
15
20
p⊥ (GeV)
total
Color Singlet
¹S₀⁽⁸⁾ + ³P_J⁽⁸⁾
³S₁⁽⁸⁾

Sizes of Contributions

Lowest order color singlet

$$g + g \to Q\bar{Q}[{}^3S_1^{(1)}] + g \qquad \alpha_s^3 \frac{(4M_Q^2)^2}{p_\perp^8}$$

Color singlet fragmentation

$$g + g \to \{Q\bar{Q}[{}^3S_1^{(1)}] + g + g\} + g \qquad \alpha_s^5 \frac{1}{p_\perp^4}$$

Color octet fragmentation

$$g + g \to Q\bar{Q}[{}^3S_1^{(8)}] + g \qquad \alpha_s^3 v^4 \frac{1}{p_\perp^4}$$

$$\frac{\text{Color octet fragmentation}}{\text{Color singlet fragmentation}} \sim \frac{v^4}{(\alpha_s/\pi)^2}$$

For $c\bar{c}$ $\quad \frac{v_c^4}{(\alpha_s/\pi)^2} \sim 10$

$b\bar{b}$ $\quad \frac{v_b^4}{(\alpha_s/\pi)^2} \sim 3$

What has been done before?

One "extraction" of $b\bar{b}$ NRQCD matrix elements

(Cho + AKL - PRD 53 (1996) 6203)

$$\langle 0 | \mathcal{O}_8^{\Upsilon(1S)}(^3S_1) | 0 \rangle = (5.9 \pm 1.9) \times 10^{-3} \ \mathrm{GeV}^3$$

$$\langle 0 | \mathcal{O}_8^{\Upsilon(2S)}(^3S_1) | 0 \rangle = (4.1 \pm 0.9) \times 10^{-3} \ \mathrm{GeV}^3$$

$$\langle 0 | \mathcal{O}_8^{\chi_{b1}(1P)}(^3S_1) | 0 \rangle = (4.2 \pm 1.3) \times 10^{-3} \ \mathrm{GeV}^3$$

$$\langle 0 | \mathcal{O}_8^{\chi_{b1}(2P)}(^3S_1) | 0 \rangle = (3.2 \pm 1.9) \times 10^{-3} \ \mathrm{GeV}^3$$

$$\frac{\langle 0 | \mathcal{O}_8^{\Upsilon(1S)}(^3P_0) | 0 \rangle}{M_b^2} + \frac{\langle 0 | \mathcal{O}_8^{\Upsilon(1S)}(^1S_0) | 0 \rangle}{5} = (7.9 \pm 10.0) \times 10^{-3} \ \mathrm{GeV}^3$$

$$\frac{\langle 0 | \mathcal{O}_8^{\Upsilon(2S)}(^3P_0) | 0 \rangle}{M_b^2} + \frac{\langle 0 | \mathcal{O}_8^{\Upsilon(2S)}(^1S_0) | 0 \rangle}{5} = (9.1 \pm 7.2) \times 10^{-3} \ \mathrm{GeV}^3$$

Extracted from CDF data

Errors statistical

Extraction

- **Calculate Rate for Different Channels**

  - Color Singlet

    Υ produced directly $\qquad \langle 0 | \mathcal{O}_1^{\Upsilon}({}^3S_1) | 0 \rangle$

    Feeddown from χ_b $\qquad \langle 0 | \mathcal{O}_1^{\chi}({}^3P_J) | 0 \rangle$

    Matrix elements from potential models

  - Color Octet

    Υ directly $\qquad \langle 0 | \mathcal{O}_8^{\Upsilon}({}^3S_1) | 0 \rangle$

    $\langle 0 | \mathcal{O}_8^{\Upsilon}({}^1S_0) | 0 \rangle$

    $\langle 0 | \mathcal{O}_8^{\Upsilon}({}^3P_0) | 0 \rangle$

    Feeddown from χ_b $\qquad \langle 0 | \mathcal{O}_8^{\chi}({}^3S_1) | 0 \rangle$

- **Fit to data**

  - Problem #1: Shape of ${}^1S_0^{(8)}$ + ${}^3P_0^{(8)}$ same

    Fit linear combination of matrix elements

  - Problem #2: Shape of Υ ${}^3S_1^{(8)}$ + χ ${}^3S_1^{(8)}$ same

    Scale $\langle 0 | \mathcal{O}_8^{\Upsilon}({}^3S_1) | 0 \rangle = \frac{m_b^3 v_b^7}{m_c^3 v_c^7} \langle 0 | \mathcal{O}_8^{\psi}({}^3S_1) | 0 \rangle$

  - Problem #3: Not much data

    $\Upsilon(2S)$ – 3 usable data points

    $\Upsilon(3S)$ – 2 usable data points

    Deal

Usable data ?

- Initial gluon radiation
- Intrinsic transverse momentum
- Diverging rate

Cut off data

Ignoring ?

- Higher orders : v small
  α_s not so small
- Systematics : PDF
  Renormalization scale
  etc

Example : PDF and scale dependence for J/ψ

(Beneke + Krämer, PRD 55 (1997) 5269)

	CTEQ4L	GRV (1994) LO	MRS (R2)
$\langle 0 \vert \mathcal{O}_8^{J/\psi}({}^3S_1) \vert 0 \rangle$	$1.06 \pm 0.14 ^{+1.05}_{-0.59}$	$1.12 \pm 0.14 ^{+0.99}_{-0.56}$	$1.40 \pm 0.22 ^{+1.35}_{-0.79}$
$M_{3.5}^{J/\psi}({}^1S_0^{(8)}, {}^3P_0^{(8)})$	$4.38 \pm 1.15 ^{+1.52}_{-0.74}$	$3.90 \pm 1.14 ^{+1.46}_{-1.07}$	$10.9 \pm 2.07 ^{+2.79}_{-1.26}$

↑ linear combination

(in units 10^{-2} GeV^3)

Fixes

- More data, better data
  - Soon have χ_b separated out (at large $p_\perp$)

    Independent extractions of $\langle 0 | \mathcal{O}_8^{\Upsilon}(^3S_1) | 0 \rangle$

    $\langle 0 | \mathcal{O}_8^{\chi}(^3S_1) | 0 \rangle$

- Low $p_\perp$
  - Cut off data - Same as before
  - Phenomenological model - fit shape at small $p_\perp$ onto NRQCD
  - Smear with $k_\perp$ of partons - should be small
  - Resum soft gluons

- Systematics
  - Vary : PDF's

    Renormalization scale

    Quark mass

    Color-singlet matrix elements