Charmonium from B decays

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Workshop: New results on Charmonium production and decays
The 6th-8th March 2013 at LAL Orsay

Charmonium production at hadron machines

- The first measurement of direct J/ψ and ψ' production at CDF in '97: striking discrepancy from theoretical expectation

  CDF, PRL79 ('97)

- NRQCD: double expansion in terms of α_s and v (velocity): an addition of "colour-octet" term was proposed.

  Bodwin, Braaten, Lepage, PRD51 ('95)

- Tremendous efforts have been made to obtain more precise theoretical prediction for the charmonium production at hadron machines (computation of the higher order corrections, extracting the matrix element of NRQCD, Color-singlet approach etc). ➡ after many debates, still the situation is unclear!

More investigation is needed!

New observables to help the situation ???

So far, the study has been limited to J/ψ, ψ', χ_{Jc}

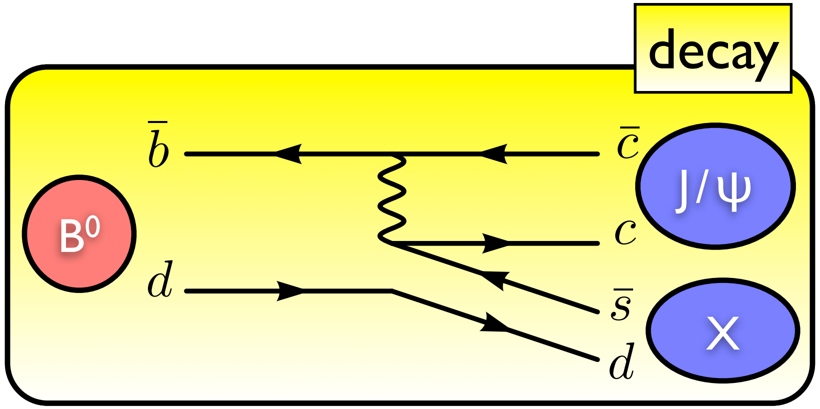
- Prompt/secondary production of charmonium states such as η_c or h_c have never been done at hadron machines although they could be useful for clarify some issues (using spin symmetry)!

Charmonium from B decays to extract the matrix elements?

- Secondary charmonium production is experimentally cleaner than the prompt production. Theoretically, it is less clean (e.g. issues in the NLO estimate of the singlet contribution) but can't we still learn something?

<--- Universality of matrix elements!

Revisiting the NRQCD computation of inclusive B decaying into charmonium



Beneke, Maltoni, Rothstein PRD59 ('99)

$$H_{eff} = \frac{G_F}{\sqrt{2}} \sum_{q=s,d} \left\{ V_{cb}^* V_{cq} \left[\frac{1}{3} C_{[1]}(\mu) \mathcal{O}_1(\mu) + C_{[8]}(\mu) \mathcal{O}_8(\mu) \right] - V_{tb}^* V_{tq} \sum_{i=3}^{6} C_i(\mu) \mathcal{O}_i(\mu) \right\}$$

$$\mathcal{O}_1 = [\bar{c}\gamma_\mu(1-\gamma_5)c]\,[\bar{b}\gamma^\mu(1-\gamma_5)q]$$

$$\mathcal{O}_8 = [\bar{c}\,T^A\gamma_\mu(1-\gamma_5)c]\,[\bar{b}\,T^A\gamma^\mu(1-\gamma_5)q]$$

It has been pointed out by several authors that the singlet term is too small to explain the experimental data.

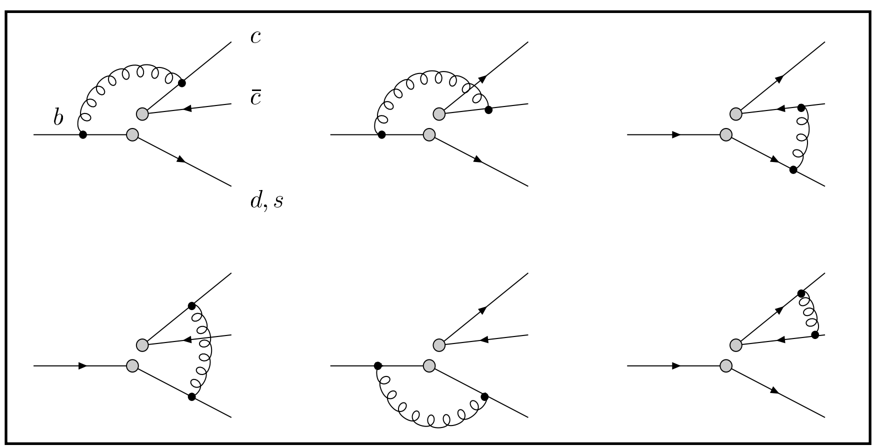
Revisiting the NRQCD computation of inclusive B decaying into charmonium

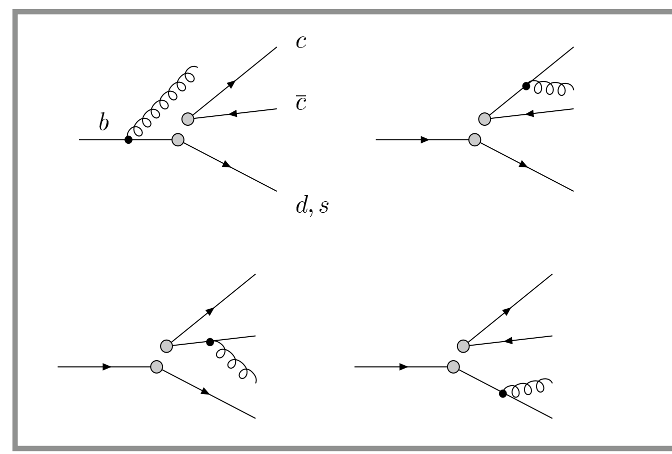
NLO computation

Beneke, Maltoni, Rothstein PRD59 ('99)

$$\Gamma[n] = \Gamma_0 \Big[C^2_{[1,8]} f[n](\eta) \left(1 + \delta_P[n]\right)$$

$$+ \frac{\alpha_s(\mu)}{4\pi} \Big(C^2_{[1]} g_1[n](\eta) + 2 C_{[1]} C_{[8]} g_2[n](\eta) + C^2_{[8]} g_3[n](\eta) \Big) \Big] \langle \mathcal{O}^H[n] \rangle,$$





The singlet term has a large renormalization running effect which makes it large negative (unphysical) at mb scale.

Revisiting the NRQCD computation of inclusive B decaying into charmonium

Beneke, Maltoni, Rothstein PRD59 ('99)

Improved NLO result

$$Br(B \to J/\psi X) =$$
$$0.0754 \times 10^{-2} \langle \mathcal{O}_1^{\psi}(^3S_1)\rangle + 0.195 \langle \mathcal{O}_8^{\psi}(^3S_1)\rangle + 0.342 \underbrace{\left[\langle \mathcal{O}_8^{\psi}(^1S_0)\rangle + 3.1/m_c^2 \langle \mathcal{O}_8^{\psi}(^3P_0)\rangle\right]}_{\mathcal{M}^{\psi}_{1,k}(^1S_0^{(8)},{}^3P_0^{(8)})}$$

$$Br(B \to \eta_c X) =$$
$$0.250 \times 10^{-2} \langle \mathcal{O}_1^{\eta_c}(^1S_0)\rangle + 0.342 \langle \mathcal{O}_8^{\eta_c}(^1S_0)\rangle + 0.195 \underbrace{\left[\langle \mathcal{O}_8^{\eta_c}(^3S_1)\rangle - 0.24/m_c^2 \langle \mathcal{O}_8^{\eta_c}(^1P_1)\rangle\right]}_{\mathcal{M}^{\eta_c}_{1,0.24}(^3S_1^{(8)},{}^1P_1^{(8)})}$$

Caveat:
A large uncertainty
(factor two?)

Revisiting the NRQCD computation of inclusive B decaying into charmonium

Beneke, Maltoni, Rothstein
PRD59 ('99)

Improved NLO result

$Br(B \to J/\psi X) =$ **exp. (1.094±0.032)x10^{-2}**

$$0.0754 \times 10^{-2} \langle \mathcal{O}_1^{\psi}(^3S_1)\rangle + 0.195 \langle \mathcal{O}_8^{\psi}(^3S_1)\rangle + 0.342 \underbrace{\left[\langle \mathcal{O}_8^{\psi}(^1S_0)\rangle + 3.1/m_c^2 \langle \mathcal{O}_8^{\psi}(^3P_0)\rangle\right]}_{\mathcal{M}^{\psi}_{1,k}(^1S_0^{(8)},{}^3P_0^{(8)})}$$

$Br(B \to \eta_c X) =$ **exp. < 0.9x10^{-2} <- update from LHCb?**

$$0.250 \times 10^{-2} \langle \mathcal{O}_1^{\eta_c}(^1S_0)\rangle + 0.342 \langle \mathcal{O}_8^{\eta_c}(^1S_0)\rangle + 0.195 \underbrace{\left[\langle \mathcal{O}_8^{\eta_c}(^3S_1)\rangle - 0.24/m_c^2 \langle \mathcal{O}_8^{\eta_c}(^1P_1)\rangle\right]}_{\mathcal{M}^{\eta_c}_{1,0.24}(^3S_1^{(8)},{}^1P_1^{(8)})}$$

Spin symmetry

$$\langle \mathcal{O}_8^{\eta_c}(^1S_0)\rangle = \frac{1}{3} \langle \mathcal{O}_8^{J/\psi}(^3S_1)\rangle,$$
$$\langle \mathcal{O}_8^{\eta_c}(^3S_1)\rangle = \langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle,$$
$$\langle \mathcal{O}_8^{\eta_c}(^1P_1)\rangle = 3 \langle \mathcal{O}_8^{J/\psi}(^3P_0)\rangle.$$

Can we use this result to extract some information on the octet matrix elements?

Revisiting the NRQCD computation of inclusive B decaying into charmonium

Momentum dependence of B-> J/psi X

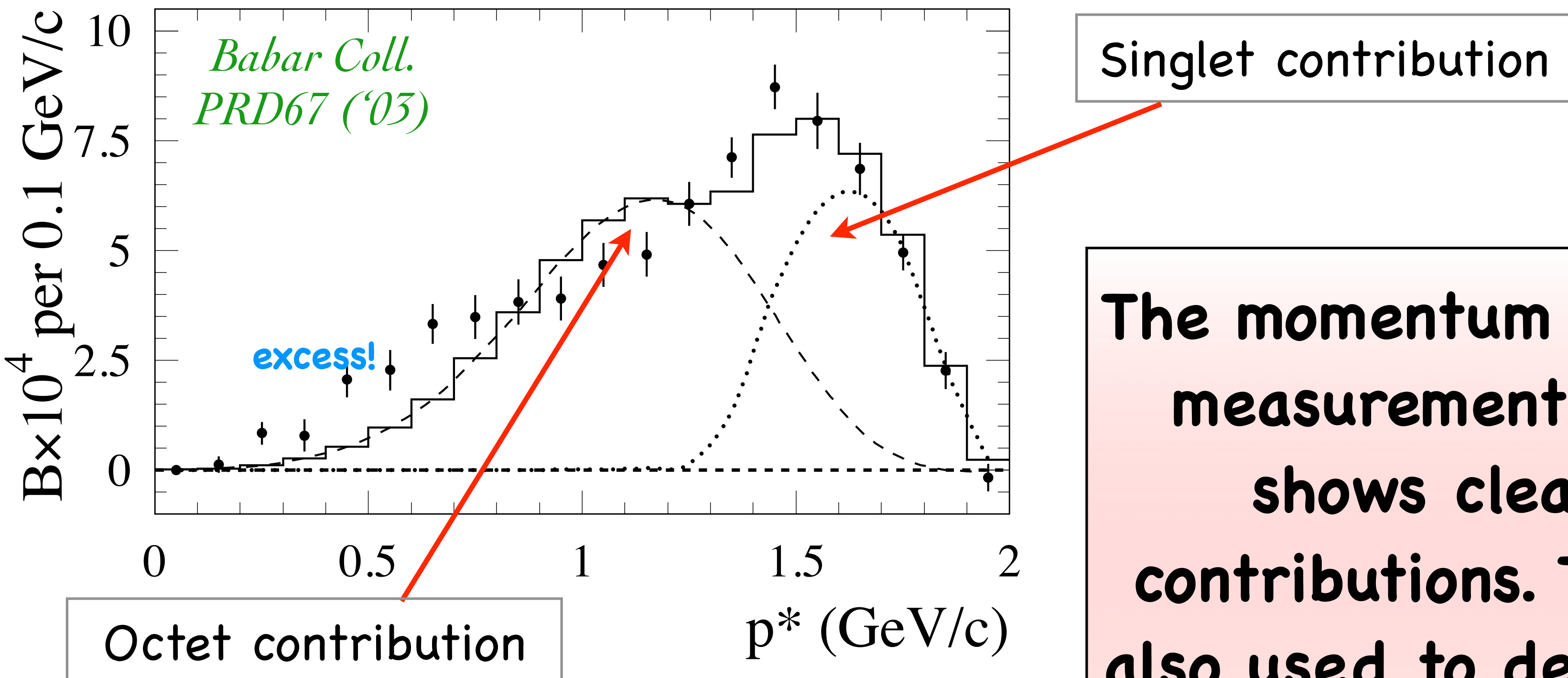


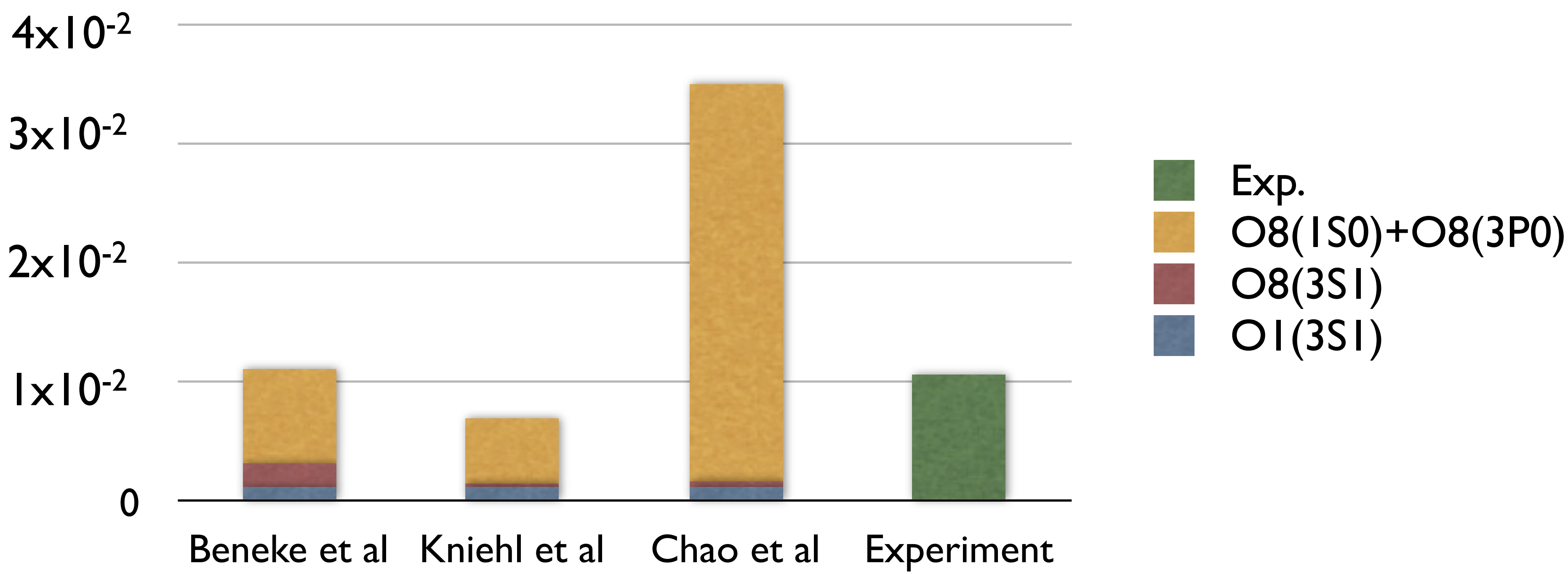
FIG. 10: p^* of J/ψ mesons produced directly in B decays (points). The histogram is the sum of the color-octet component from a recent NRQCD calculation [20] (dashed line) and the color-singlet $J/\psi\, K^{(*)}$ component from simulation (dotted line).

Beneke, Scgykerm Wolf, PRD62 ('00)

The momentum dependence measurement by Babar shows clear octet contributions. This can be also used to determine the octet matrix elements?

Prediction of Br(B-> J/psi X) with the fitted matrix elements

	$\langle\mathcal{O}_1^\psi(^3S_1)\rangle$	$\langle\mathcal{O}_8^\psi(^3S_1)\rangle$ x10^{-2}	$\langle\mathcal{O}_8^\psi(^1S_0)\rangle$ x10^{-2}	$\langle\mathcal{O}_8^\psi(^3P_0)\rangle$ x10^{-2}	$\mathcal{M}_{0,k}^\psi$
Beneke et al	1.16	1.06			2.0-2.7x10^{-2}
Ma et al	1.16	small?	~M_{0k}^{psi}	small?	7.4 x10^{-2}
Chao et al	1.16	0.30±0.12	8.9±0.98	0.56±0.21	9.8x10^{-2}
Kniehl et al	1.32	0.17±0.05	3.04±0.35	-0.91±0.16	1.6x10^{-2}

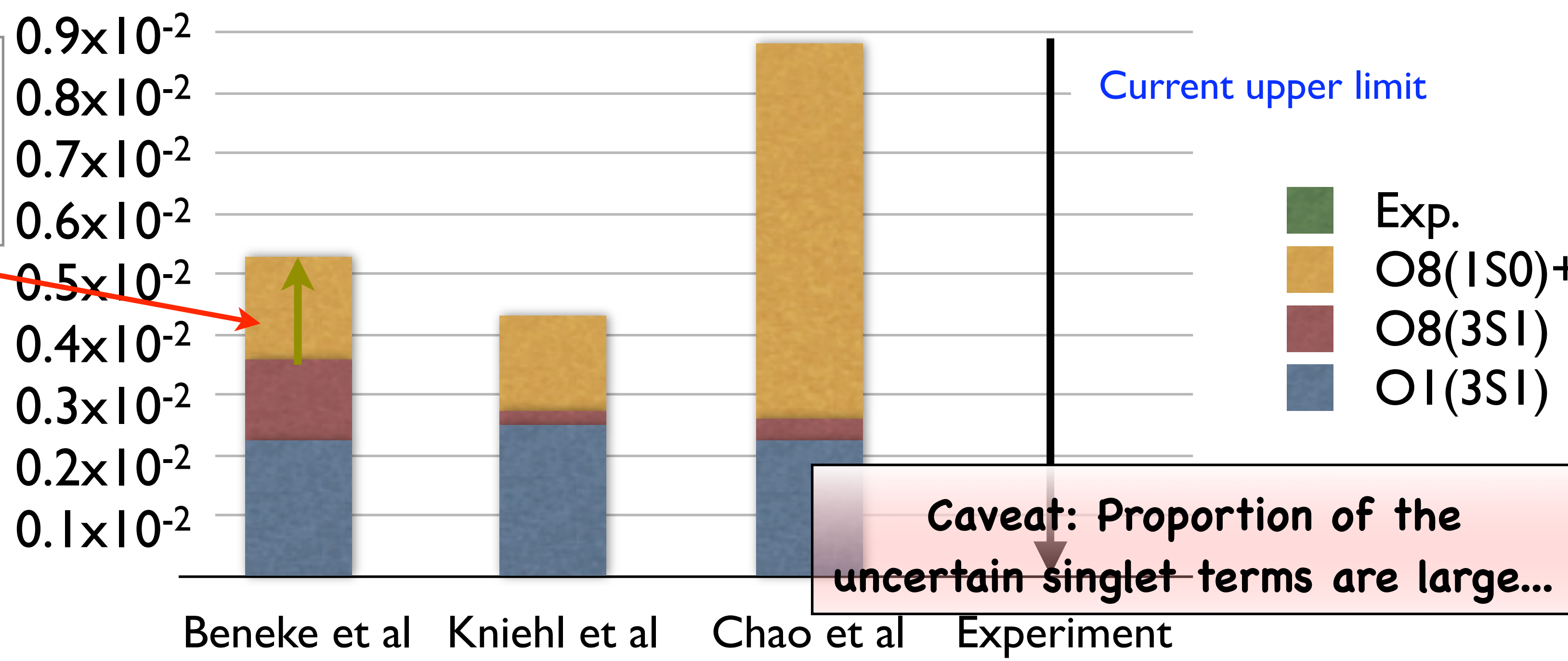


Prediction of Br(B-> etac X) with the fitted matrix elements

Assuming Spin symmetry...

	$\langle\mathcal{O}_1^{\psi}(^3S_1)\rangle$	$\langle\mathcal{O}_8^{\psi}(^3S_1)\rangle$ x10^{-2}	$\langle\mathcal{O}_8^{\psi}(^1S_0)\rangle$ x10^{-2}	$\langle\mathcal{O}_8^{\psi}(^3P_0)\rangle$ x10^{-2}	$\mathcal{M}_{1,k}^{\psi}$
Beneke et al	0.39	0.35			
Ma et al	0.39	small?	~M_{0k}^{psi}/3	small???	2.5 x10^{-2}
Chao et al	0.39	0.10±0.04	3.0±0.32	1.68±0.63	2.8x10^{-2}
Kniehl et al	0.44	0.06±0.02	1.01±0.12	-2.73±0.48	1.3x10^{-2}

Assuming, O8(1S0) for psi and O8(3S1) for etac is small...



Spin symmetry

$$\langle\mathcal{O}_8^{\eta_c}(^1S_0)\rangle = \frac{1}{3}\langle\mathcal{O}_8^{J/\psi}(^3S_1)\rangle,$$

$$\langle\mathcal{O}_8^{\eta_c}(^3S_1)\rangle = \langle\mathcal{O}_8^{J/\psi}(^1S_0)\rangle,$$

$$\langle\mathcal{O}_8^{\eta_c}(^1P_1)\rangle = 3\langle\mathcal{O}_8^{J/\psi}(^3P_0)\rangle.$$