Hadroproduction of J/ψ and Υ in association with a heavy-quark pair

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in collaboration with P. Artoisenet and F. Maltoni

Outline

- A few words on double-charm production at B-factories
- Double heavy-quark-pair hadroproduction as a new observable
- Brief reminder on the Colour-Singlet Model
- $\mathcal{Q} + Q\bar{Q}$: Testing the quark-fragmentation approximation
- $\mathcal{Q} + Q\bar{Q}$: Results
- $\mathcal{Q} + Q\bar{Q}$: CSM vs. COM
- $\mathcal{Q} + Q\bar{Q}$: Polarisation
- Conclusions

Double-charm production at B-factories

➪ **Exclusive production** e.g. $\sigma\,(e^+e^- \to J/\psi + \eta_c)$

➞ Belle $\sigma\,(e^+e^- \to J/\psi + \eta_c) = 25.6 \pm 2.8 \pm 3.4$ fb **PRD70, 071102,2004**

➞ BaBar $\sigma\,(e^+e^- \to J/\psi + \eta_c) = 17.6 \pm 2.8^{+.15}_{-2.1}$ fb **PRD72:031101,2005.**

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- ➞ LO NRQCD $\sigma_0 = 3 - 5.5$fb — **Liu,He, Chao, PLB557:45,2003**; **Braaten, Lee, PRD67:054007,2003**
- ➞ LCWF $\sigma_{LCWF} \sim 30$ fb — **Bondar,Chernyak,PLB612:215,2005**
- ➞ NRQCD "relativistic" correction:

$$\sigma\,(e^+e^- \to J/\psi + \eta_c) = \sigma_0(1 + 1.95\langle v^2_{J/\psi}\rangle + 2.37\langle v^2_{\eta_c}\rangle)$$

Braaten, Lee, PRD67: 054007 (2003),...

- ➞ NLO QCD corrections: $\sigma_{NLO} \simeq 1.96 \times \sigma_{LO}$ — **Zhang *et al.*,PRL96:092001,2006**
- ➞ Combining all corrrections: possible agreement:

$$\sigma\,(e^+e^- \to J/\psi + \eta_c) = 17.5 \pm 5.7 \text{ fb}$$

Double-charm production at B-factories

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- → Belle (2001) $\sigma\,(e^+e^- \to J/\psi + X) = 1.47 \pm 0.10 \pm 0.11$ pb
- → BaBar (2001) $\sigma\,(e^+e^- \to J/\psi + X) = 2.52 \pm 0.21 \pm 0.21$ pb
- → Belle (2002) $\sigma\,(e^+e^- \to J/\psi + c\bar{c}) = 0.87^{+0.21}_{-0.19} \pm 0.17$ pb
- → Belle (2003): Model-independent extraction of the ratio

$$\frac{\sigma\,(e^+e^- \to J/\psi + c\bar{c})}{\sigma\,(e^+e^- \to J/\psi + X)} = 0.82 \pm 0.15 \pm 0.14 > 0.48 \text{ at } 95\% \text{ CL}$$

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- → Small (and negative) NRQCD "relativistic" correction

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- → NLO QCD corrections: $\sigma_{NLO} \simeq 1.8 \times \sigma_{LO}$

Zhang, Chao,PRL98:092003,2007

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- **Irrespective of what would be the theoretical explanations, associated J/ψ production is a dominant channel**
- **We invite experimentalists to study it at pp and ep colliders.**

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double charm HADRO-production is a new valuable observable

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➞ NRQCD factorisation ?

See J.W. Qiu's talk

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One supposes **factorisation** between the hard part and the soft part

➪ The *hard part* consists in the **creation of two quarks Q and $\bar{Q}$ BUT**

- ➞ on-shell ($\times$)
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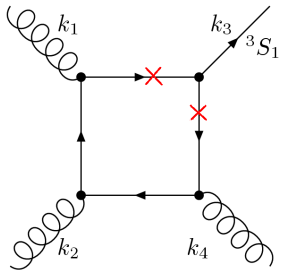
- ➞ in a $^3S_1$ state (for J/ψ, ψ' and Υ)



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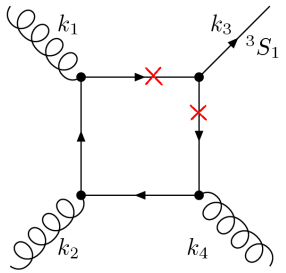

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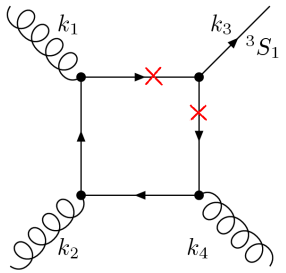

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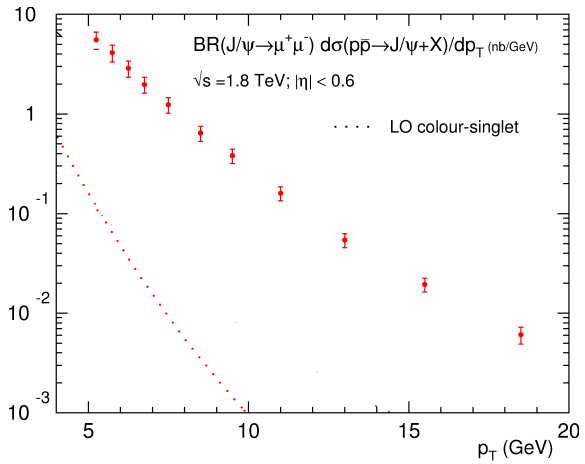
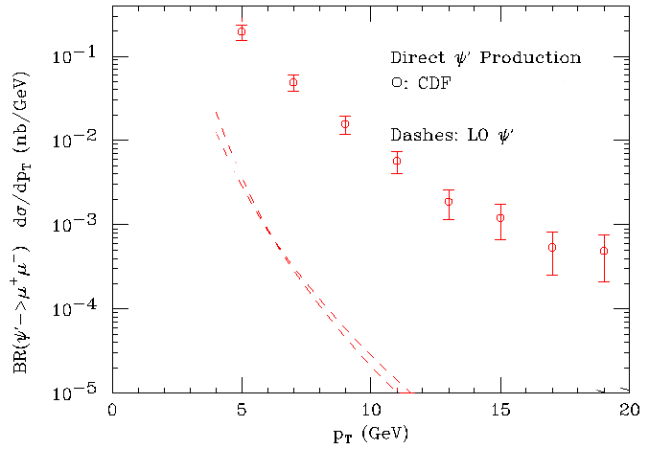
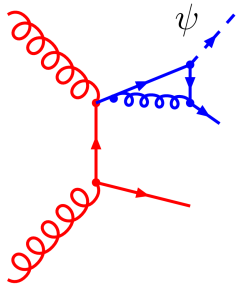




Brief reminder on the Colour Singlet Model (CSM) II

➪ Introduction of **quark and gluon fragmentation processes**:

➞ Effectively NLO (α_s^4 instead of α_s^3): this explains why not introduced before



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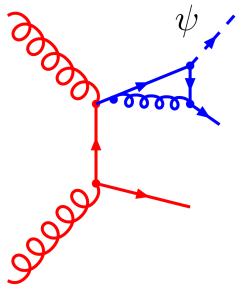

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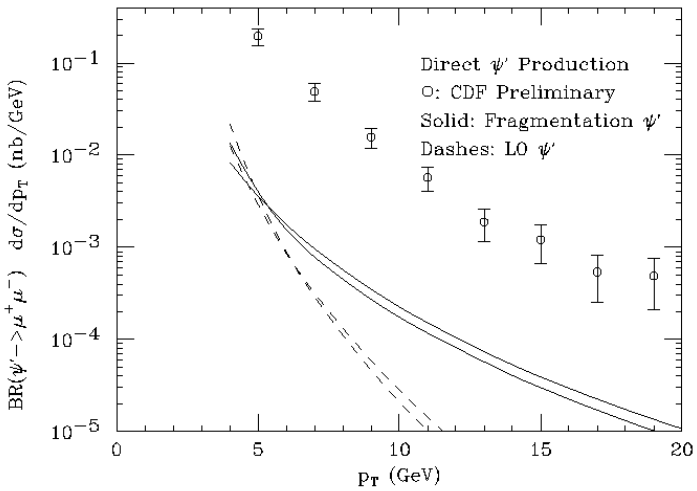
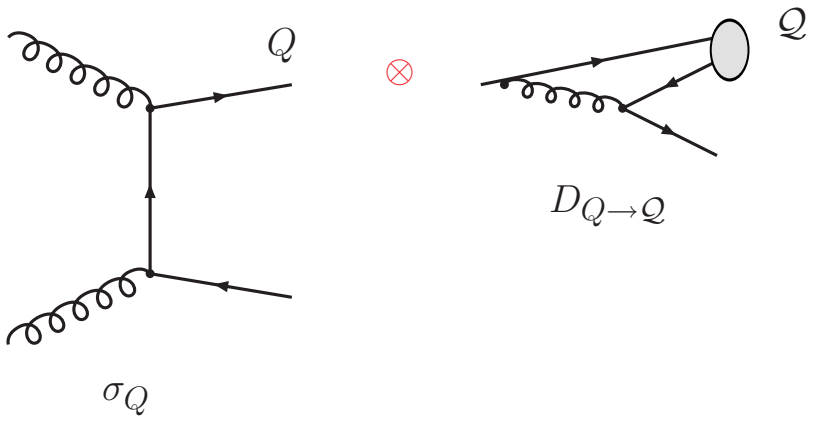
➞ Different p_T behaviour: $\frac{1}{P_T^4}$ vs. $\frac{1}{P_T^8}$.

➞ Illustration for the ψ'



The fragmentation approximation

$$d\sigma_{\mathcal{Q}}(P) \simeq \int_0^1 dz d\sigma_{Q_i}(P/z, \mu_{frag}) D_{Q_i \to \mathcal{Q}}(z, \mu_{frag})$$



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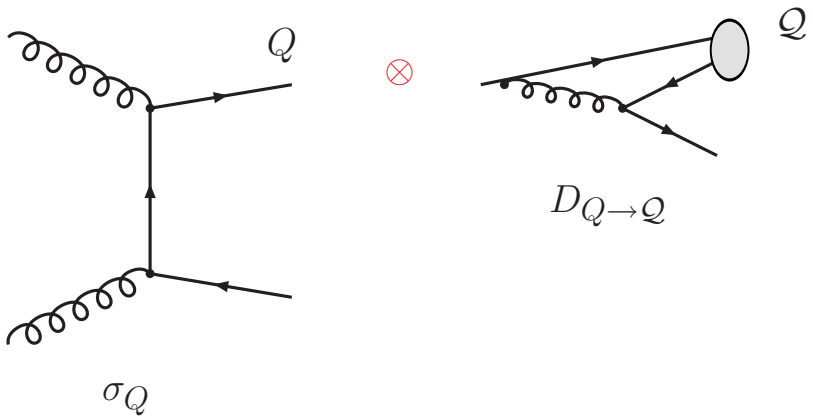

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→ $\sigma_{Q_i}(\frac{P}{z}, \mu_{frag})$: quark on-shell

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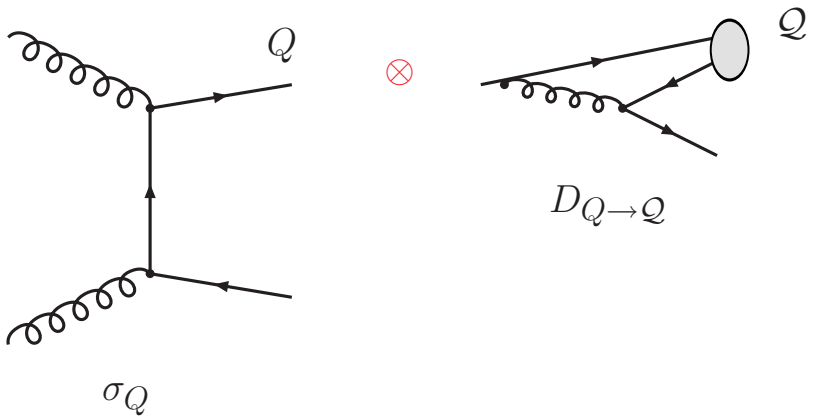

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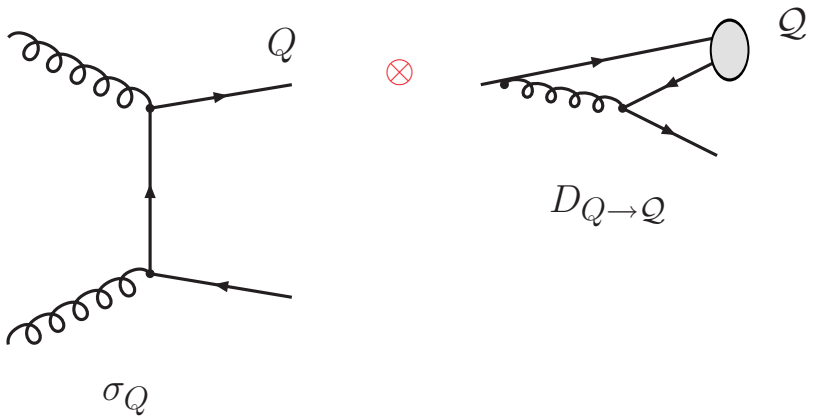

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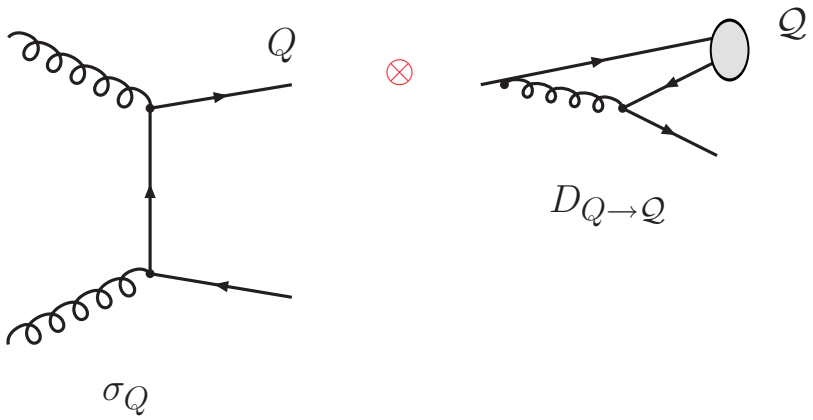

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- → Dominate the CSM inclusive & –thus– the associated production

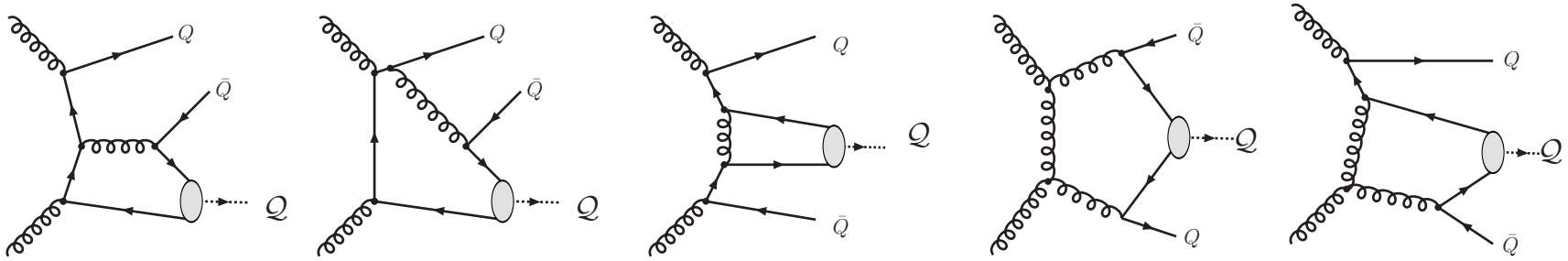
Braaten *et al.*

$\mathcal{Q} + Q\bar{Q}$: testing the quark-fragmentation approximation

→ *A priori* $\sigma(\mathcal{Q} + Q\bar{Q})$ *could be approximated by the fragmentation approx*

leading P_T behaviour

→ We would *just* miss some (sub-dominant) topologies like:



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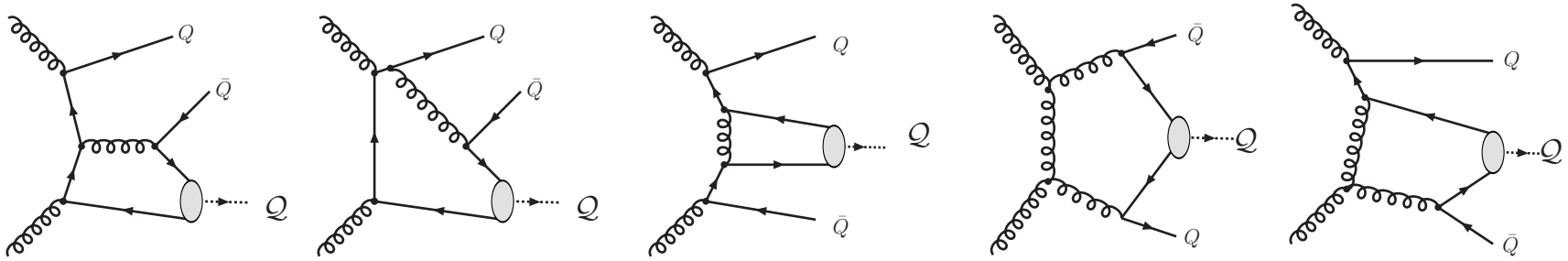
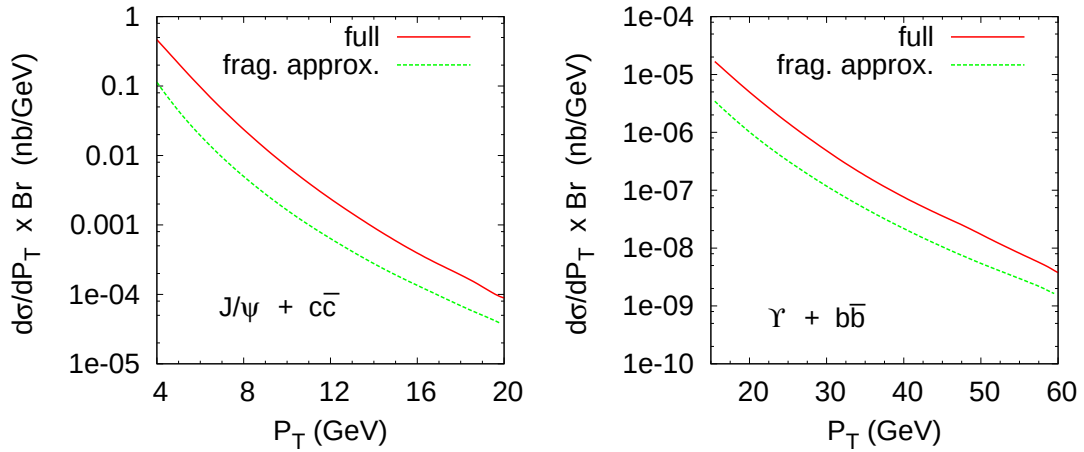
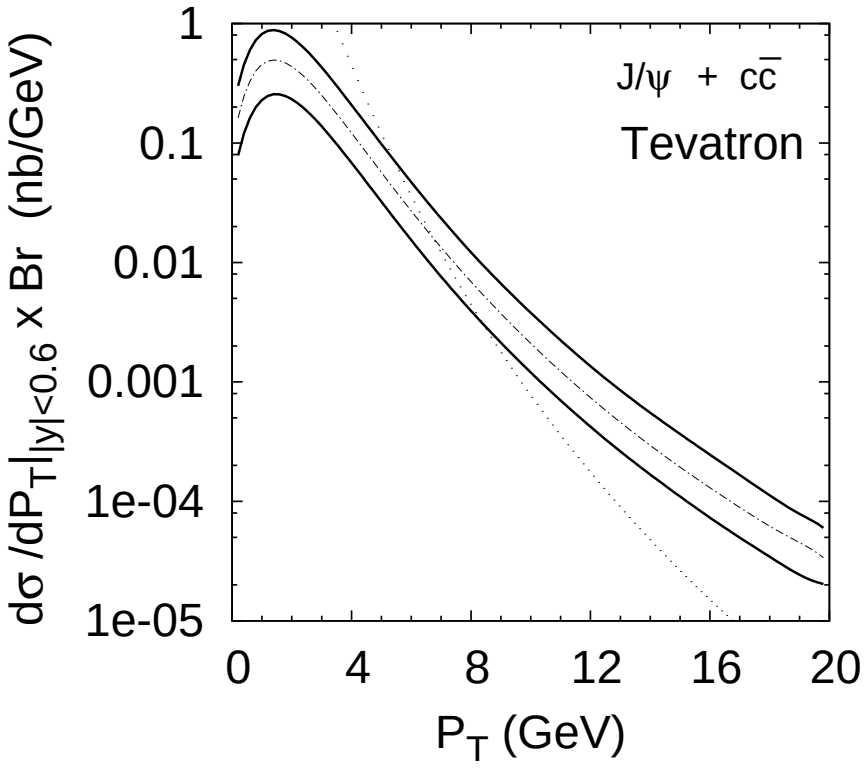


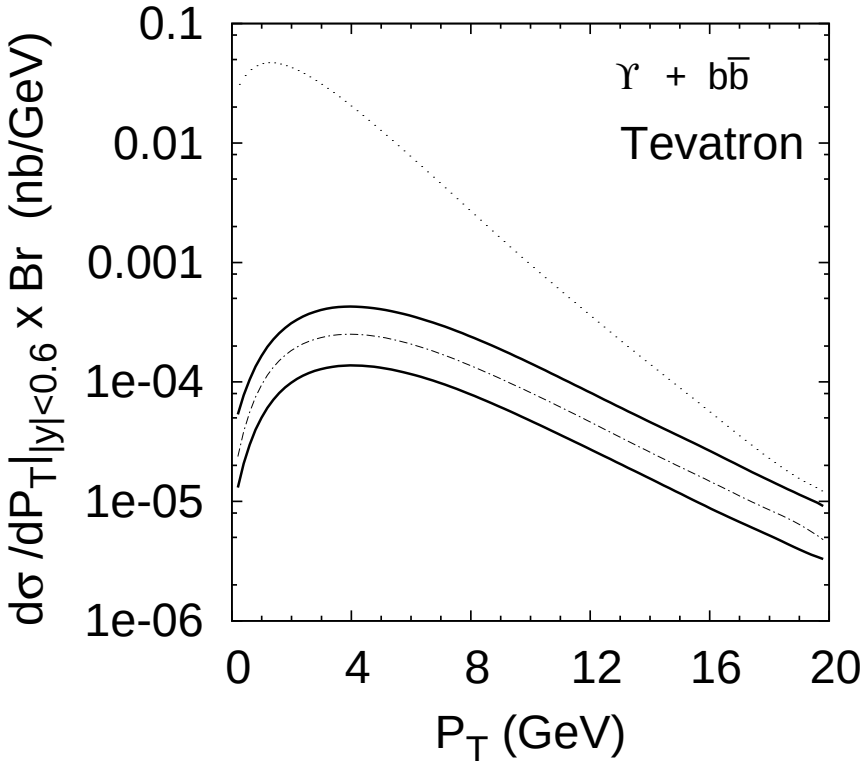
→ However, the comparison with the full LO CSM for $pp \to \mathcal{Q} + Q\bar{Q}$ shows

no ambiguity: The fragmentation approximation does not work !



$\mathcal{Q} + Q\bar{Q}$: Results





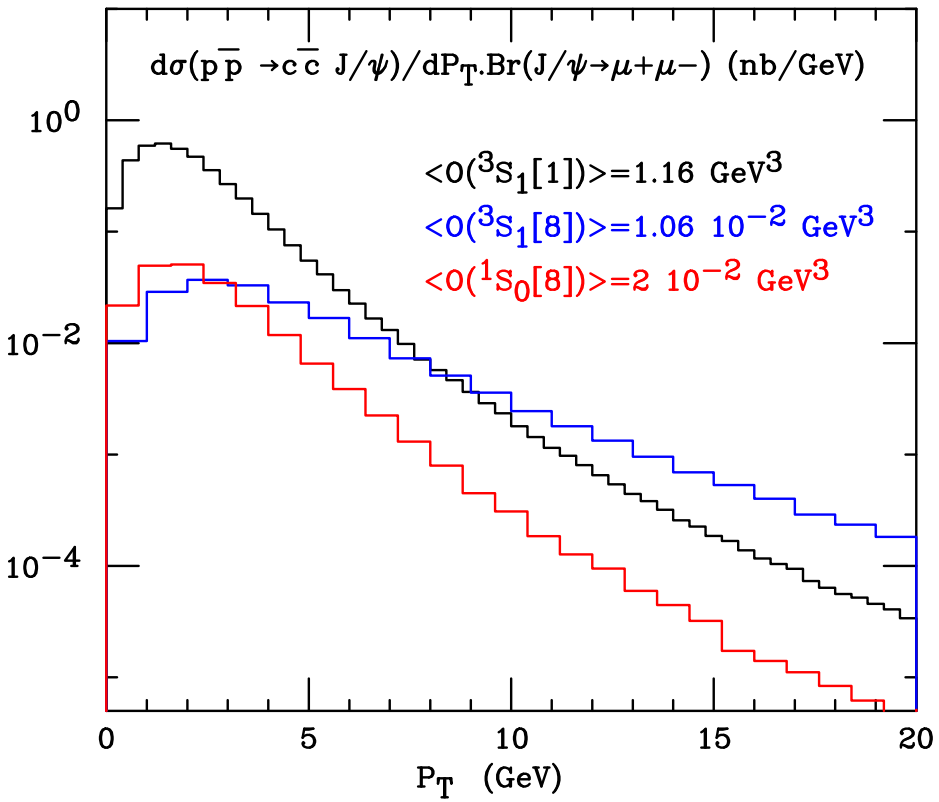
- **Larger than $pp \to \mathcal{Q}g$ at large P_T:**

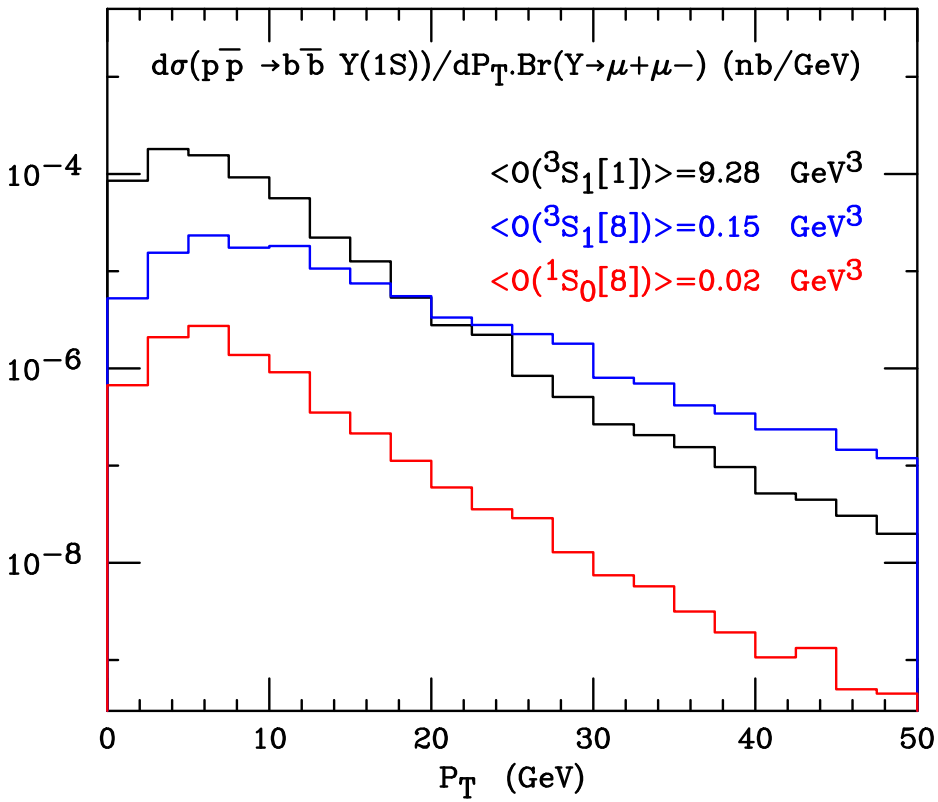
  points at large NLO (α_S^4) corrections

- **Predictions done for LHC as well**

$\mathcal{Q} + Q\bar{Q}$: CSM vs. COM

P.Artoisenet





- CSM contributions dominate at low P_T
- COM contributions dominate from $P_T \geq 15$ GeV

$\mathcal{Q} + Q\bar{Q}$: CSM vs. COM

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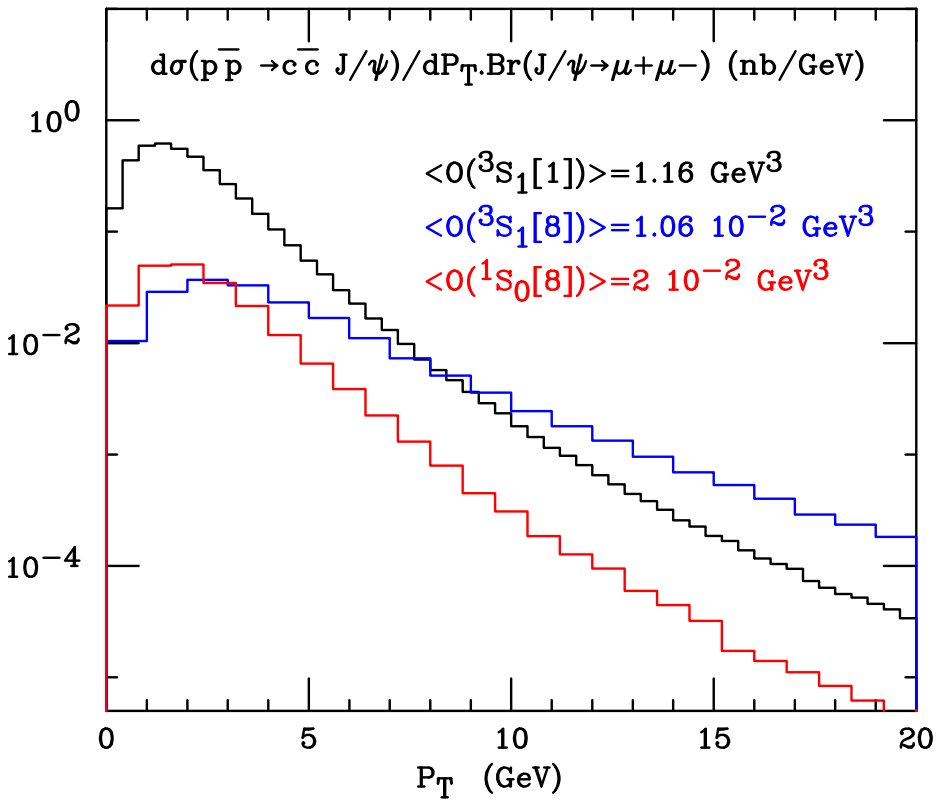
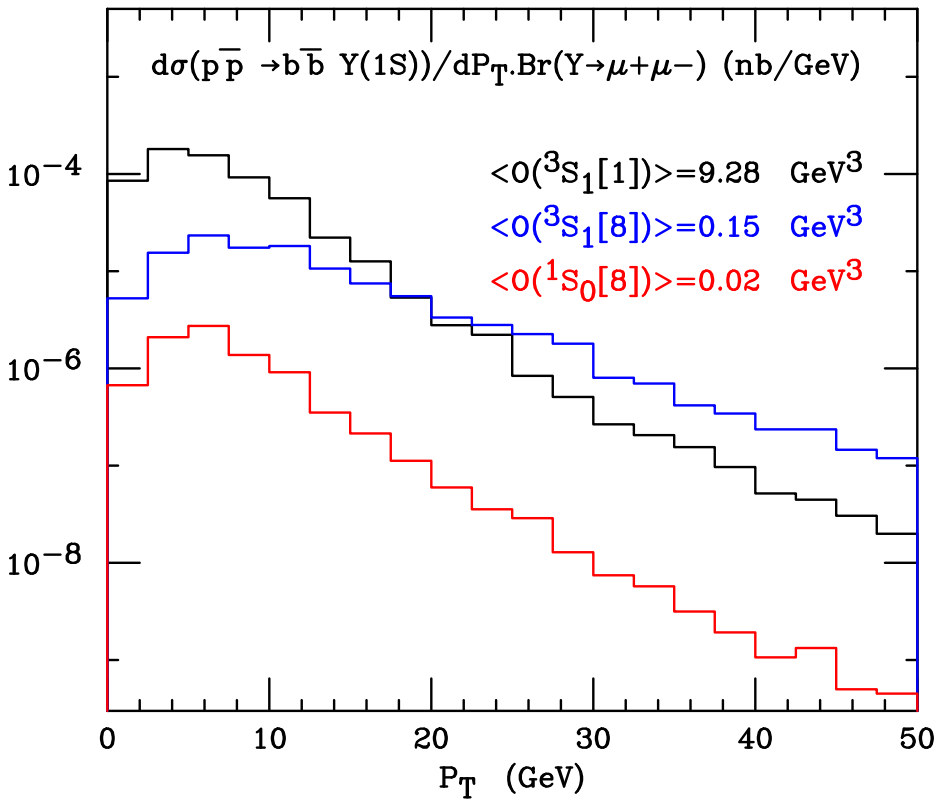
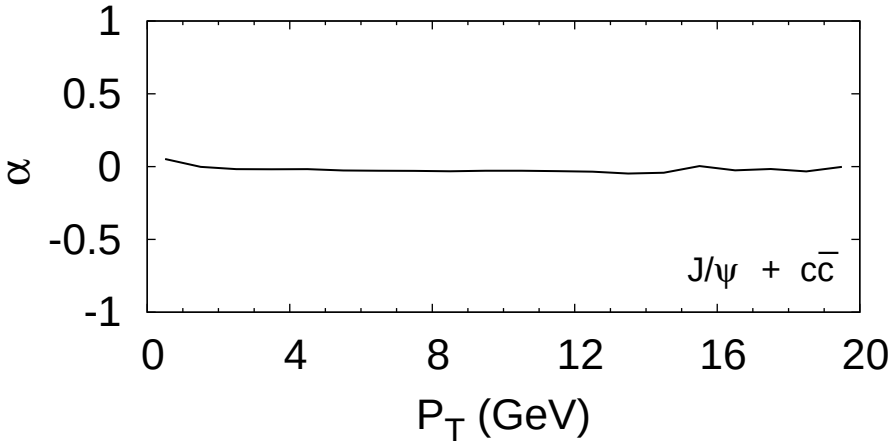
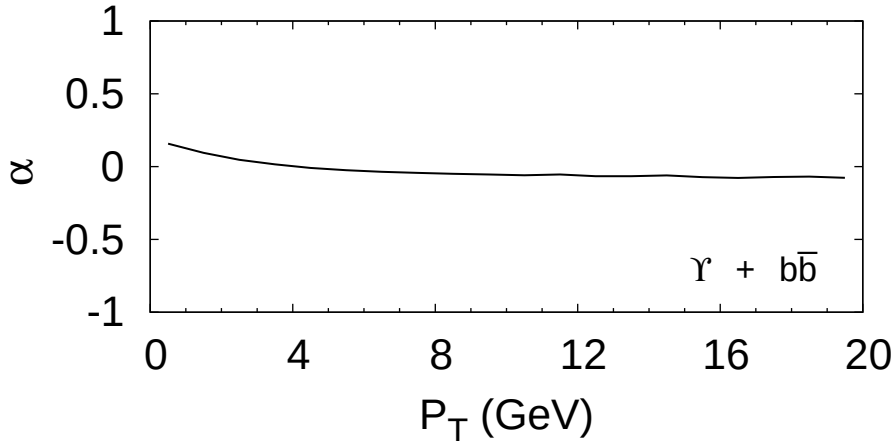




- CSM contributions dominate at low P_T
- COM contributions dominate from $P_T \geq 15$ GeV
- Integrated cross section largely dominated by CSM contributions
- Can rely on CSM predictions for α for $P_T \leq 15$ GeV

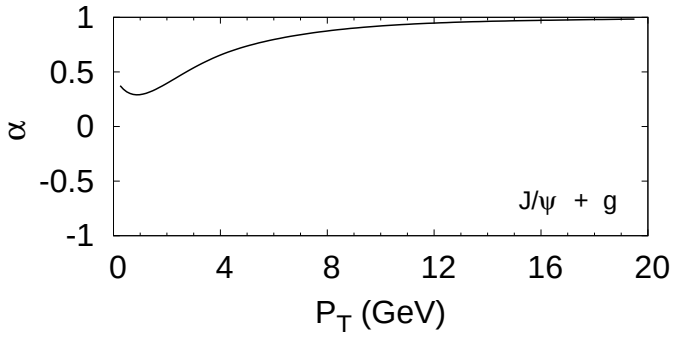
$\mathcal{Q} + Q\bar{Q}$: polarisation

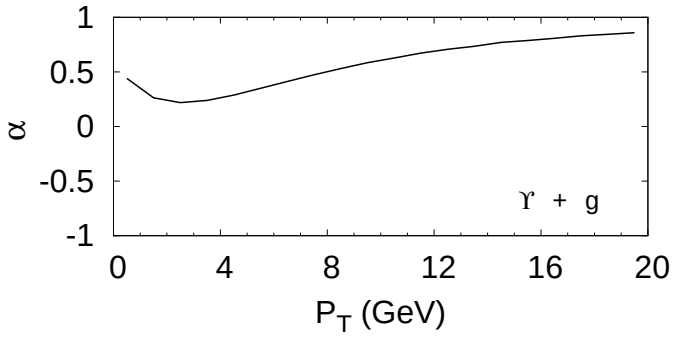




whereas the –unmeasurable– CSM polarisation for $gg \to \mathcal{Q}g$ was

(LO CSM for $p\bar{p} \to \mathcal{Q} + X$)





$\mathcal{Q} + Q\bar{Q}$: polarisation with COM included

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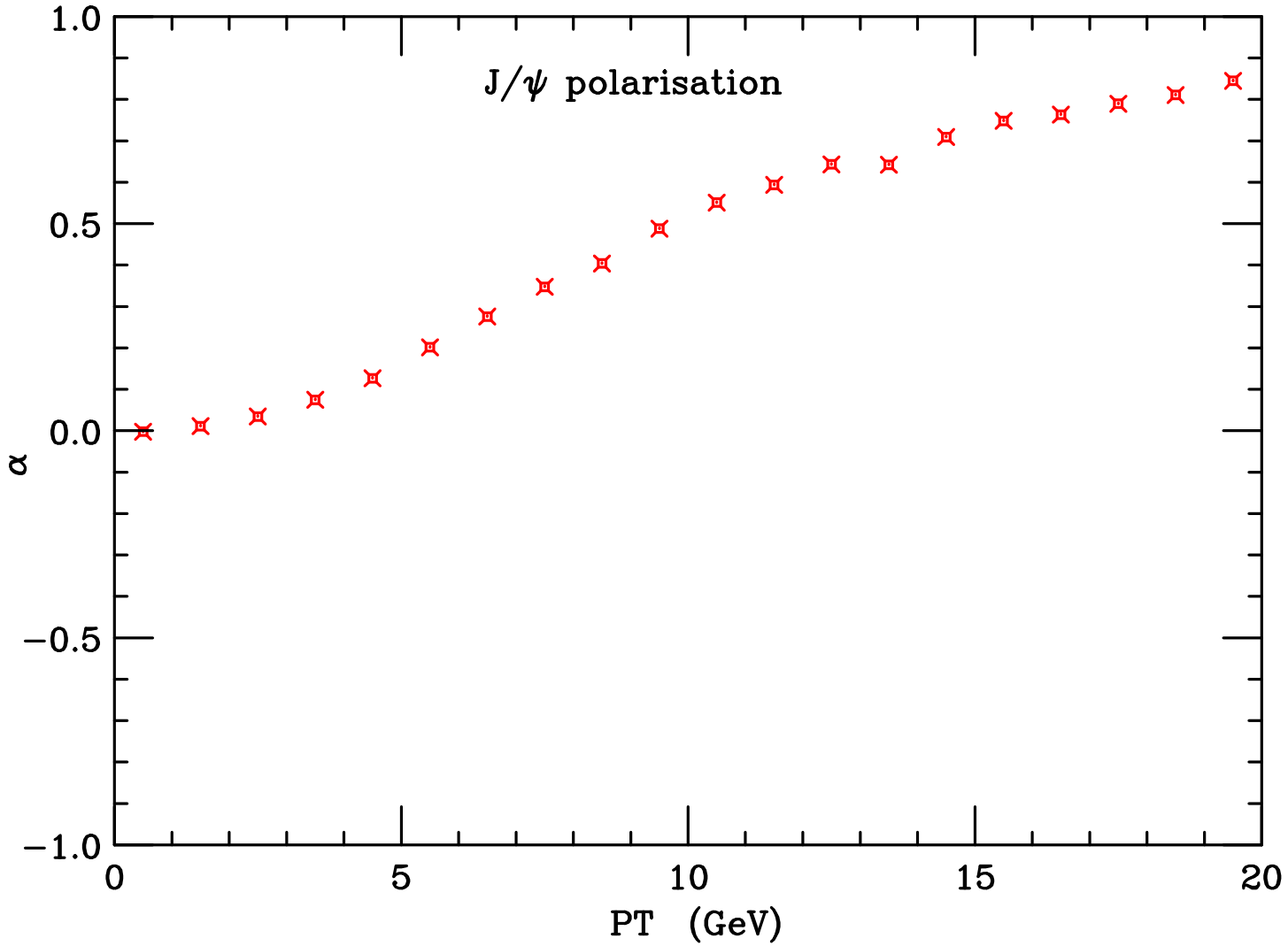

Conclusions

➪ **Reasons to measure associated hadro-production:**

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➪ **Further reasons why it was worth to fully compute such process:**

➞ We showed that quark-fragmentation approximation was not applicable

➞ We computed a significant part of the NLO corrections

➞ We confirmed that the NLO corrections are large