Possible solution of the J/ψ Production Puzzle

Joint Meeting Heidelberg-Liège-Paris-Wroclaw 2008

Spa, Belgium, March 6-8, 2008

Jean-Philippe LANSBERG

Institut für Theoretische Physik, Heidelberg U.

based on works with J.R. Cudell, H.Haberzettl, Yu.L Kalinovsky

Before you leave Spa !

- The proceedings will be published in AIP
- We need 90% of the contributions

  (3 missings at most !)
- Deadline for you to send us your contribution: MAY 15

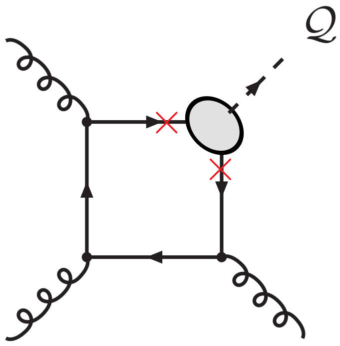
  (not MAY 31 as on the poster)
- Everyone has 10 pages
- Instruction will be posted next week on the net
- It'll be "camera-ready" submission,

  so please observe the sample file
- Please send us your pictures taken here

  we may include them

  especially if I'm on them

Naive pQCD approach: Colour Singlet Model (CSM)



- **Perturbative creation of two quarks Q and $\bar{Q}$ BUT**
  - on-shell ($\times$)
  - in a colour singlet state (we want a physical state thereafter)
  - with a vanishing relative momentum
  - in a $^3S_1$ state (for J/ψ, ψ' and Υ)

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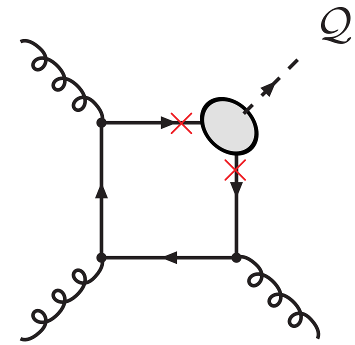

LO

$\alpha_s^3 \frac{(2m_Q)^4}{P_T^8}$

➩ **Non-perturbative binding of quarks**

Schrödinger wave function

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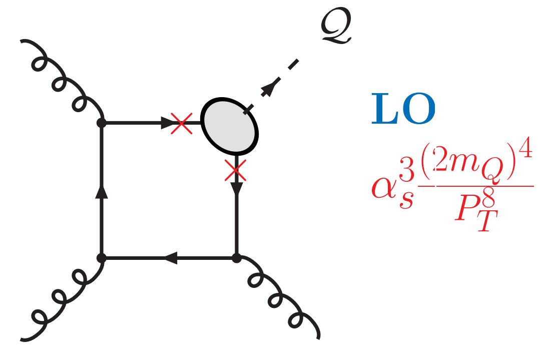

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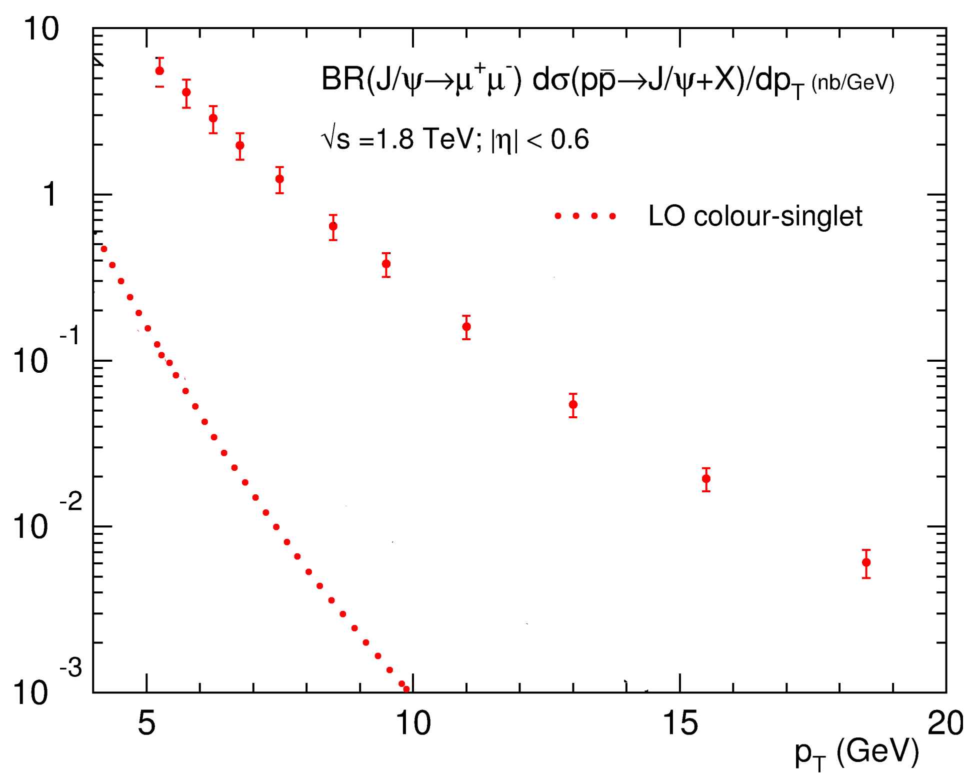

Colour Singlet Model: why does it fail ?

➫ Specifically large QCD-corrections ? Why so ?

hint: P_T scaling of fragmentation channels

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→ Should the pair be produced in a colour singlet ? Can't it evolve ?

Colour Octet Mechanism

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Colour Octet Mechanism

→ Can't the quarks be produced off-shell ? with relative momentum $\neq 0$?

s-channel cut contribution

Fragmentation via Colour Octets

Many solutions were proposed to solve this problem:

For a recent review, see J.P.L. IJMPA 21 3857-3915 (2006)

the most used solution: the Color Octet Mechanism (NRQCD):

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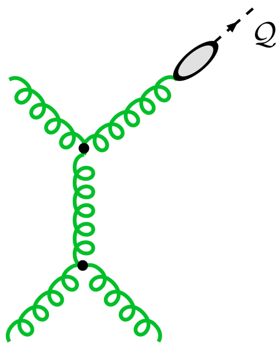

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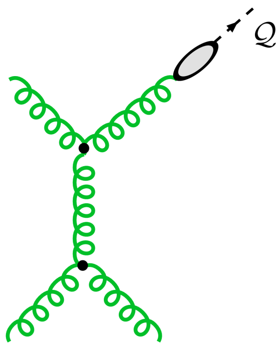

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- NRQCD spin symmetry: $\mathcal{Q}$ has the same polarisation as the gluon
- Experimentally, one can study α such that:

$$\alpha = +1 \Leftrightarrow \text{Transverse} \quad \alpha = 0 \Leftrightarrow \text{Unpolarised} \quad \alpha = -1 \Leftrightarrow \text{Longitudinal}$$

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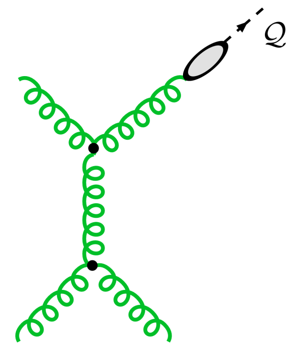

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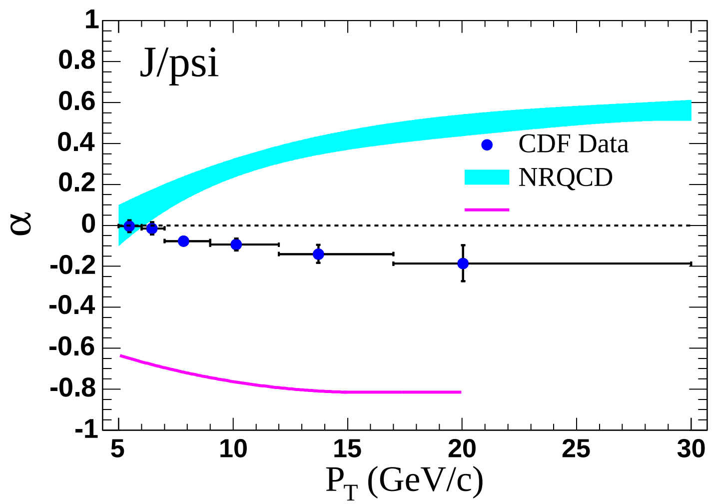
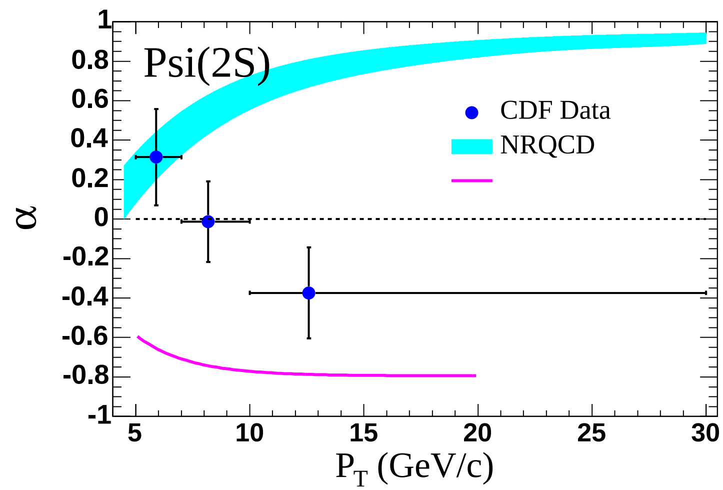
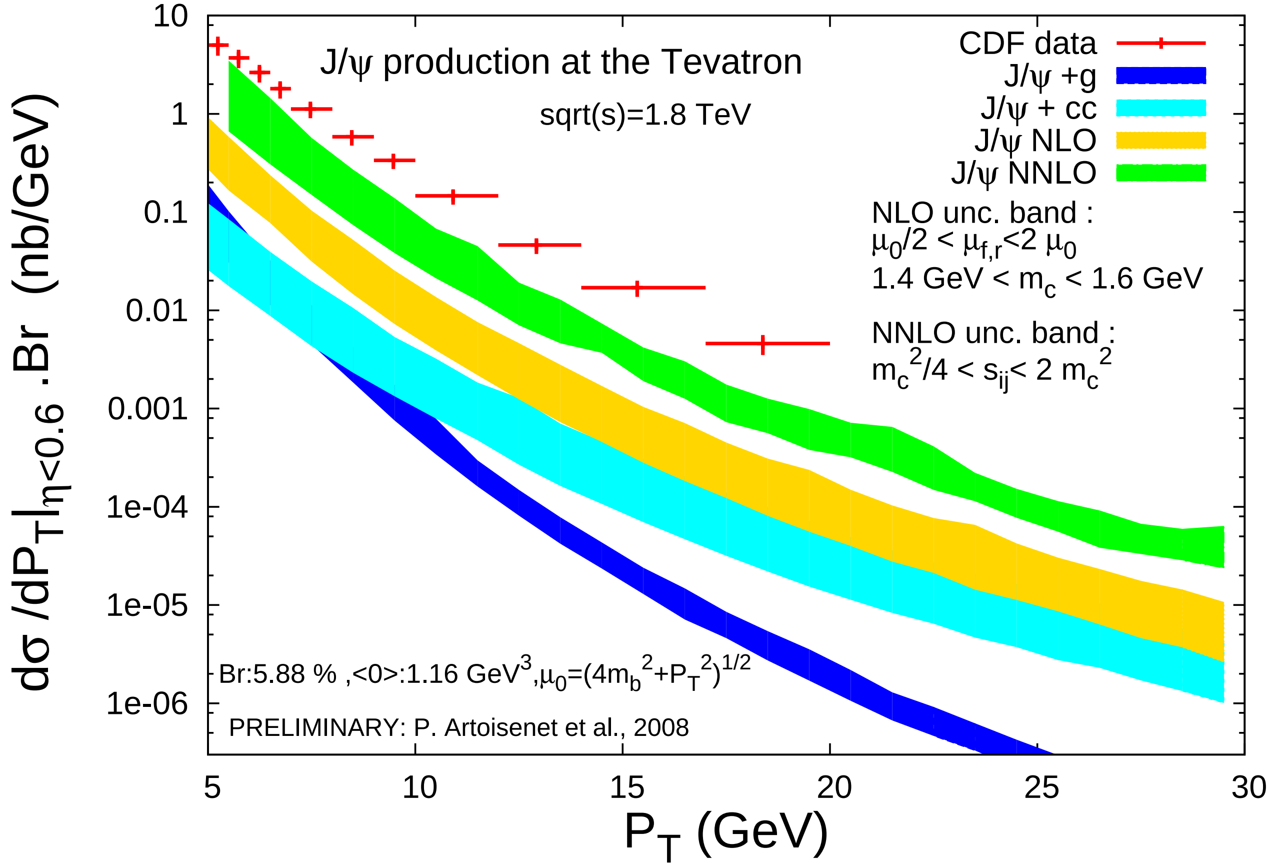




QCD-corrections

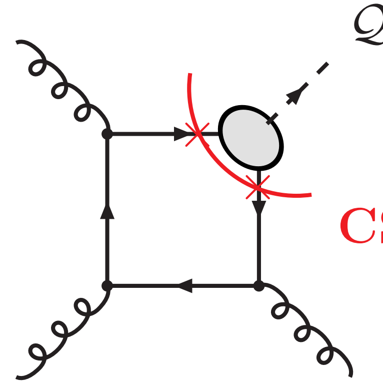
P. Artoisenet *et al.*, in progress



→ **Much closer, but still not enough. . .**

s-channel cut contribution

J.P.L., J.R. Cudell, Yu.L. Kalinovsky,PLB 633, 301,2006



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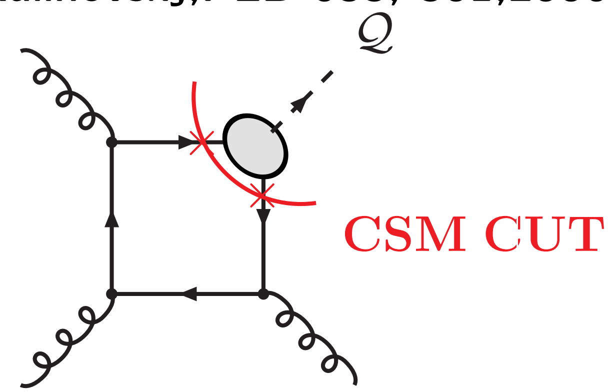
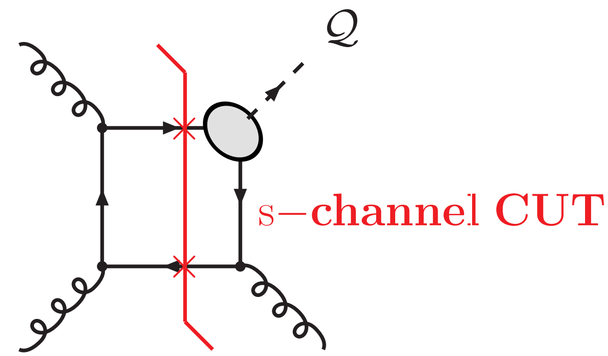


➡ What about those ?
(*i.e.* the usual contributions to $Im(\mathcal{M})$)



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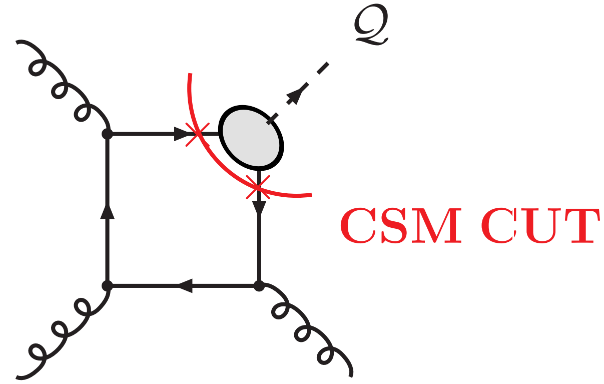

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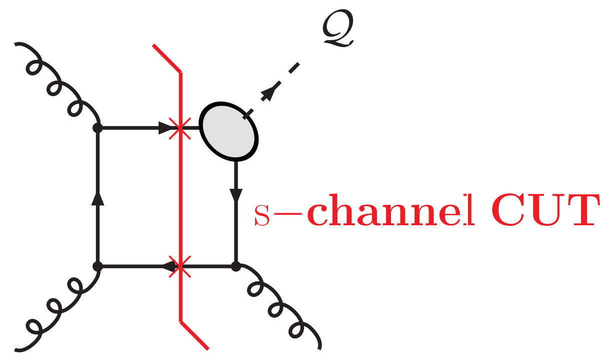

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(*i.e.* the usual contributions to $Im(\mathcal{M})$)

➯ A bit challenging:

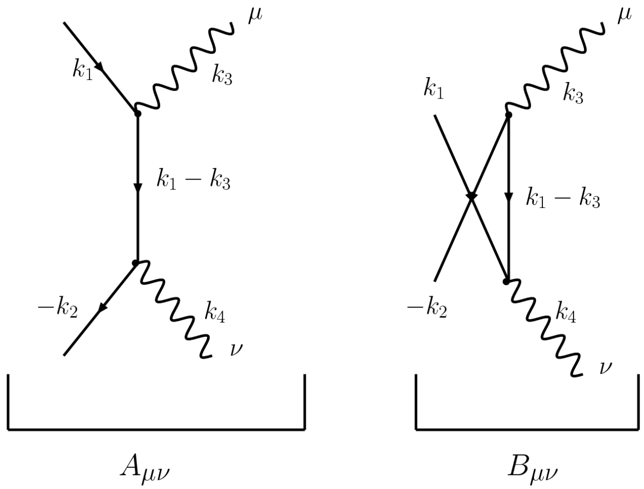
→ Quark relative momentum not fixed to zero; 2 more integrals

→ $Q - \bar{Q} - \mathcal{Q}$ vertex has one leg off-shell

Introduction of a 4-point function to preserve gauge-invariance

Problem with gauge invariance

➯ To change gauge amounts to the shift: $\varepsilon^\nu(k) \to \varepsilon^\nu(k) + \lambda k^\nu$
➯ Gauge **invariance** states that this cannot affect the final result: OK if $\mathcal{A}_\nu k^\nu = 0$
➯ Let us consider $Q\bar{Q} \to \gamma\gamma$:



Gauge invariance: $A_{\mu\nu}k_4^\nu + B_{\mu\nu}k_4^\nu = 0$

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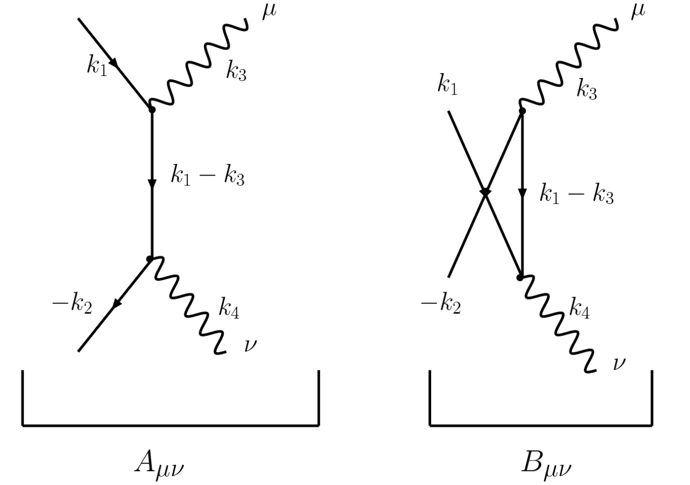

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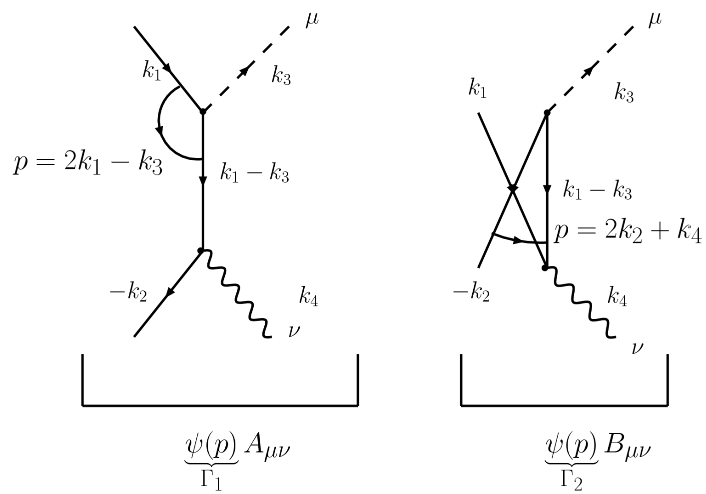
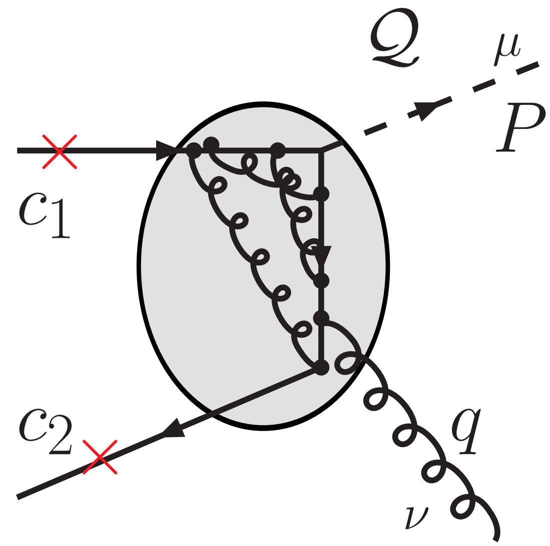
- and now $Q\bar{Q} \to \mathcal{Q}\gamma$:



Gauge invariance: $\Gamma_1 A_{\mu\nu} k_4^\nu + \Gamma_2 B_{\mu\nu} k_4^\nu = (\Gamma_1 - \Gamma_2) A_{\mu\nu} k_4^\nu \neq 0$

4-point function I



→ Accounts for such contributions

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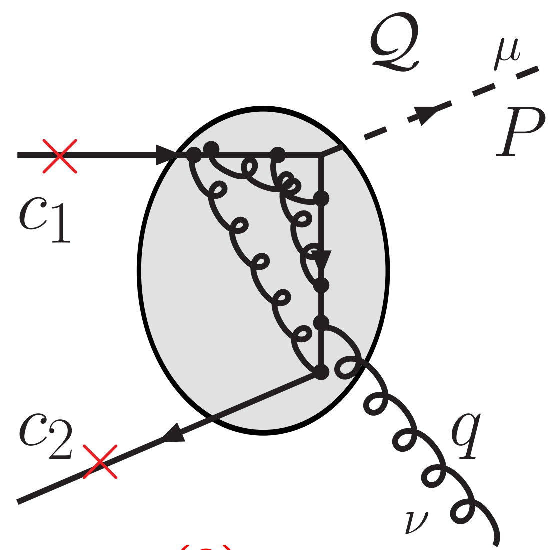

→ Accounts for such contributions

→ Cannot be uniquely derived from the $Q - \bar{Q} - \mathcal{Q}$ vertex $\Gamma^{(3)}$

→ Yet, constrained by gauge-invariance

$$(\Gamma^{(4)}(c_1, c_2, q))^{\mu\nu} = \left(\frac{(2c_2 + q)^\nu}{(c_2 + q)^2 - m_Q^2} (\Gamma_1^{(3)} - F) + \frac{(2c_1' - q)^\nu}{(c_1 + q)^2 - m_Q^2} (\Gamma_2^{(3)} - F) \right) \gamma^\mu$$

with $F(c_1, c_2) = \Gamma_0 - h(c_1, c_2) \dfrac{(\Gamma_0 - \Gamma_1(c_1, c_2))(\Gamma_0 - \Gamma_2(c_1, c_2))}{\Gamma_0}$

h being an **arbitrary** crossing symmetric function

H. Haberzettl, PRC56:2041,1997
H. Haberzettl *et al.* **,PRC58:40,1998**

4-point function II

→ **Limiting behaviour:**

× **low momentum: minimal substitution:**

Let's represent $\Gamma^{(3)}$ by an effective Lagrangian, the formal replacement

$$\partial^\mu \to \partial^\mu + iQA^\mu \qquad (Q\text{: charge; } A^\mu\text{: vector potential})$$

leads to $F = \Gamma_0$

S.D. Drell, T.D. Lee, PRD5:1738,1972

K. Ohta, PRC40:1335,1989

➾ Most natural choice for low momenta (low P_T), but

➾ In a toy model for $F_2^p(x)$ ($p \to p' X^0$), this leads to a logarithmic scaling-violation

➾ In our case, $\frac{d\sigma}{dP_T}$ has a wrong P_T scaling.

× **large momentum: scaling:** $h = 1$

S.D. Drell, T.D. Lee, PRD5:1738,1972

4-point function III

→ Limiting behaviour:

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→ Let's interpolate:

$$h(c_1.c_2) = 1 - a\frac{\kappa^2}{\kappa^2 - (c_1.c_2 + m_Q^2)}$$

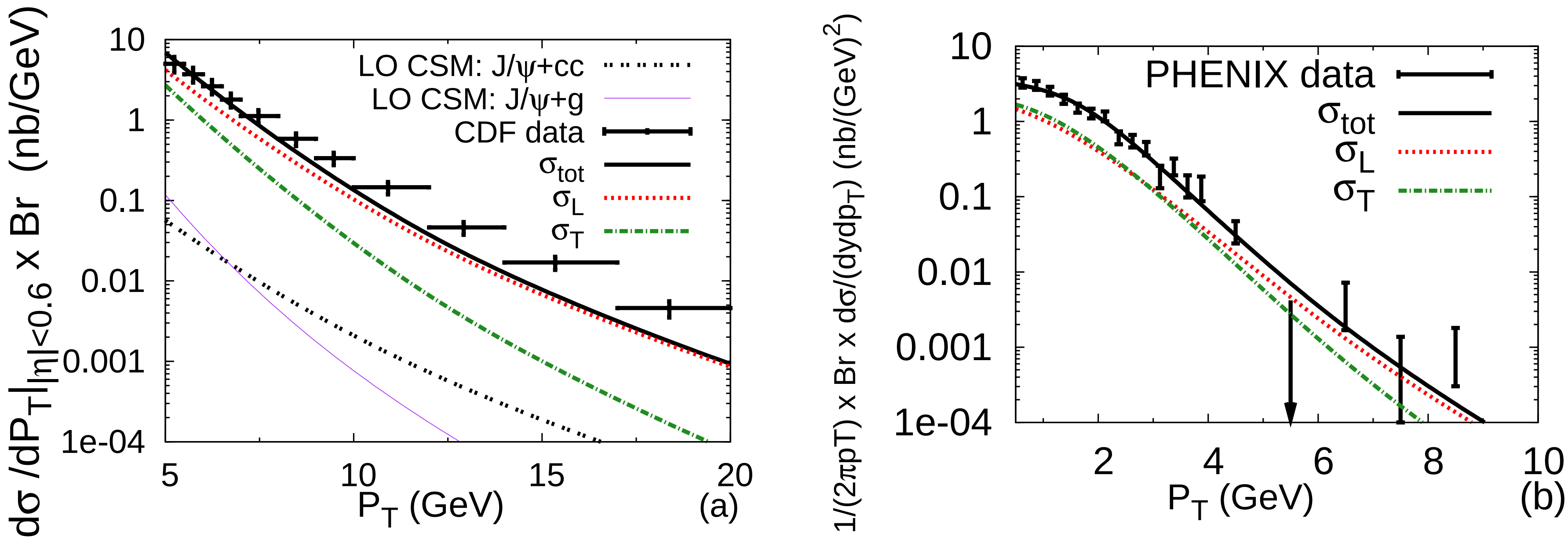
H. Haberzettl, J.P.L,Phys.Rev.Lett.:100,032006,2008

a and κ will be fixed by the data.

Does the s-cut matter ?

H. Haberzettl, J.P.L,Phys.Rev.Lett.:100,032006,2008

With $\kappa = 4.5$ GeV and $a = 4$, we get for the Tevatron and RHIC:



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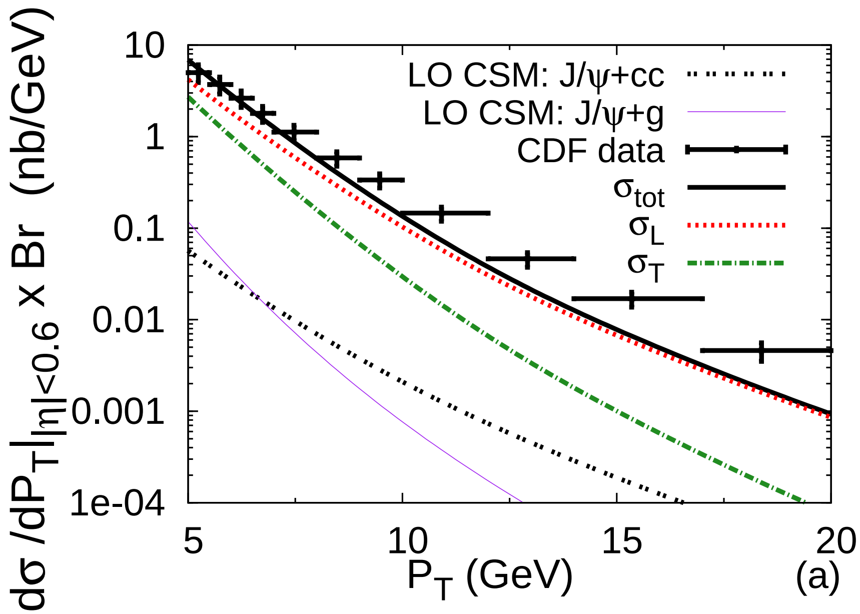
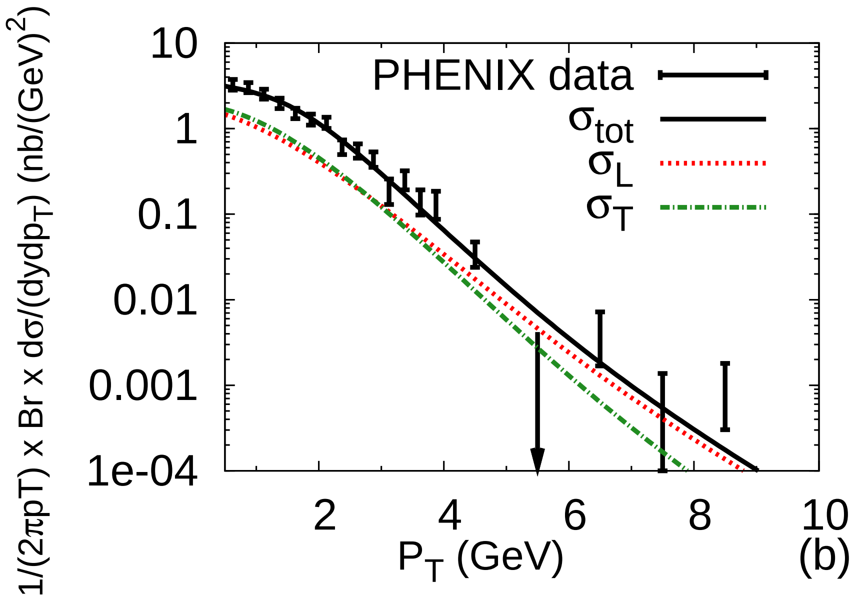
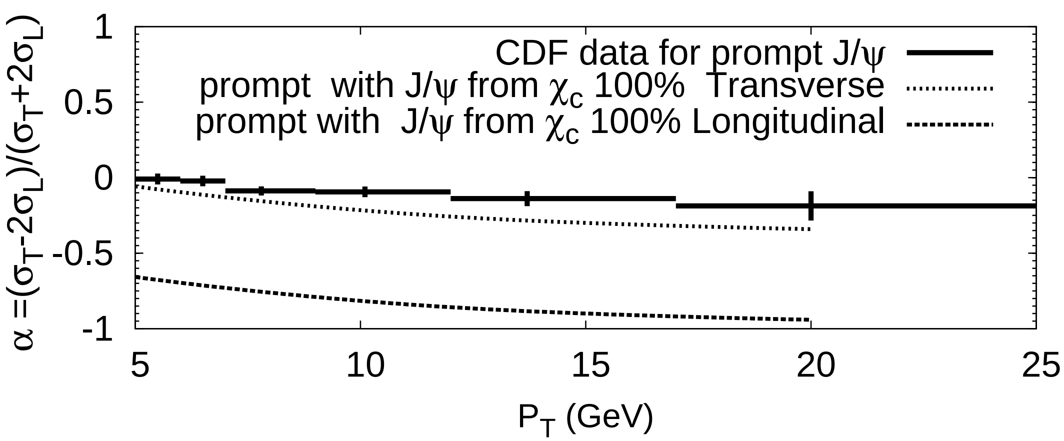
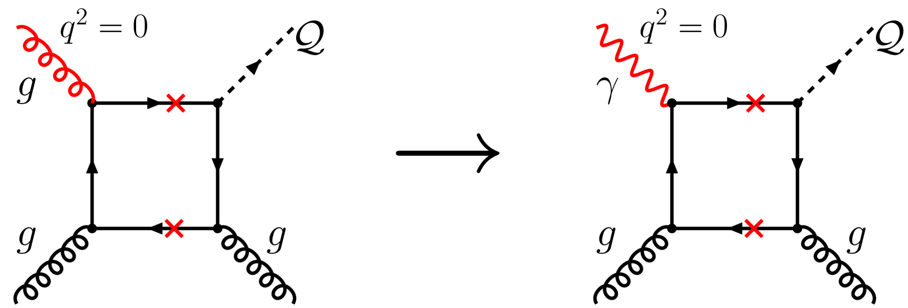






Application to other processes

➪ **Inelastic photo-production**



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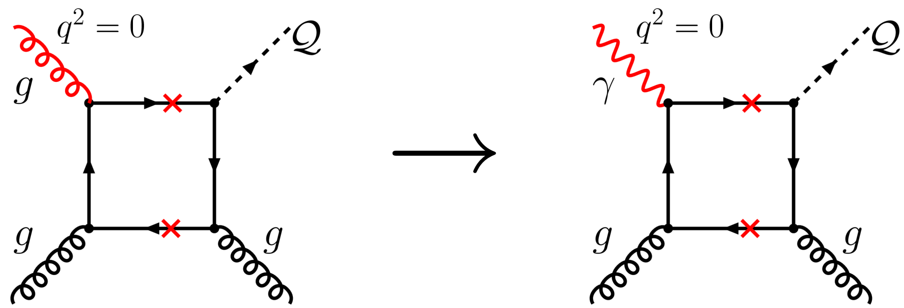

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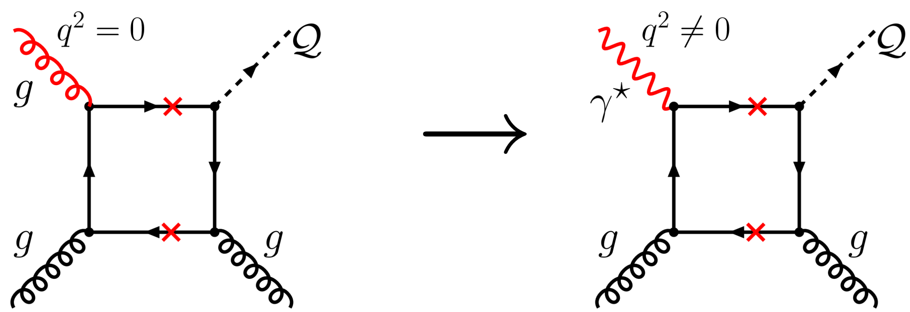

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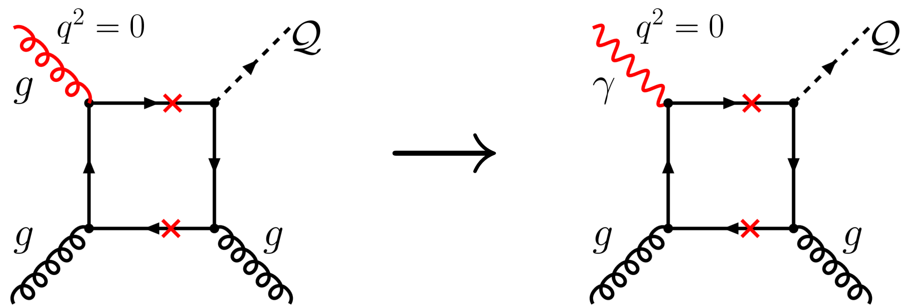

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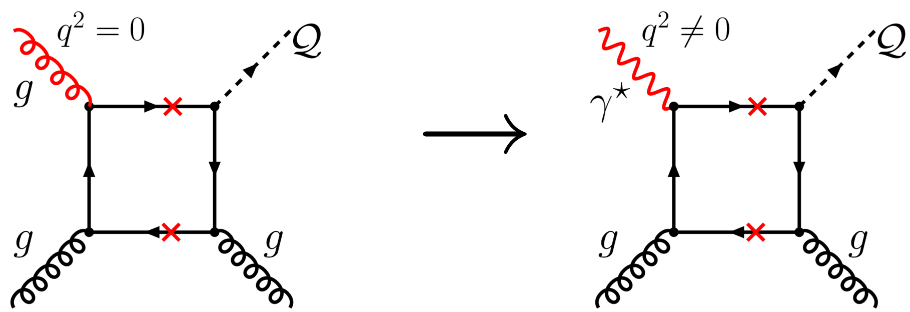

➯ **Other states than $^3S_1$:**

- ➠ change the vertex function
- ➠ consider the adequate diagrams

Conclusion and outlooks

➩ **Higher-order QCD corrections modify significantly the P_T scaling:**

→ For the Υ, they bring an **agreement with experiments** (at last !)

→ For the J/ψ and ψ', we still miss something . . .

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- **So far, s-channel cuts (as well as real contributions) were overlooked**
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➭ **(near) Future:**

→ Application to photo-production (check of the fit)

→ AA collisions **F. Fleuret, J.P.L, A. Rakotozafindrabe, in progress.**