Perspectives for quarkonium production at the LHC

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Outline

What we understand:

1. why QCD corrections do matter at mid- and high-$P_T$

What we seem to understand:

2. The CSM predictions account correctly for the yield
3. Colour Octet Dominance is challenged at low/mid $P_T$ in pp
4. QCD corrections do matter for the polarisation

What we do not understand:

5. $\psi$ production at very large $P_T$

What we expect from the LHC

6. More observables!
Part I

What we understand
QCD corrections for \( \Upsilon \) at the Tevatron
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P. Artoisenet, J. P. L, F. Maltoni, PLB 653:60, 2007

Quarkonium production at the LHC
July 22, 2010
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$\Upsilon (1S)$ prompt data $\times F^{\text{direct}}$

LO
NLO

$\psi$ or $\Upsilon$

$\alpha_3 S P^{-8}$

$\alpha_4 S P^{-6}$

Yet, the impact of double $t$-channel gluon exchange at $\alpha_5 S$ is unsure
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QCD corrections for $J/\psi$ at RHIC

PHENIX data with $F_{J/\psi}^{\text{direct}} = 59 \pm 10\%$

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$\alpha_{S}^{5} P_{T}^{-4}$
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Part II

What we seem to understand
the CSM predictions account correctly for the yield \( \frac{d\sigma}{dy} \)

S. J. Brodsky and JPL, PRD 81 051502 (R), 2010
The CSM predictions account correctly for the yield \( \frac{d\sigma}{dy} \)

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LO: \( gg \rightarrow J/\psi g \) (nothing new !, back to 1981 !)
The CSM predictions account correctly for the yield $(\frac{d\sigma}{dy})$

S. J. Brodsky and JPL, PRD 81 051502 (R), 2010

LO: $gg \rightarrow J/\psi, gg \rightarrow J/\psi gq, \ldots$

using the matrix elements from J.Campbell, F. Maltoni, F. Tramontano, PRL 98:252002, 2007
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\[ d\sigma / dy \times Br (nb) \]

\[ F_{\text{direct}}^{J/\psi} = 59\pm10\% \]

\[ \text{PHENIX (PRL 09 232002)} \]
\[ \text{PHENIX (2009; Prelim.)} \]

NLO\(^{+}\): adding one new LO contribution \(cg \rightarrow J/\psi c\)

Could be studied via azimuthal correlation \(J/\psi + e, \mu\); 10-40% of the direct signal

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- **Constraints from the $P_T$ dependence in $pp$**
  - Computation at NLO for CO channel: CO predictions overshoot data at low $P_T$

![Graph showing the $P_T$ dependence](image)

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  - $e^+e^- \rightarrow J/\psi gg \text{ CO at NLO: } 0.9-1.0 \text{ pb using universality from the Tevatron (Academical) reduction by a factor of } 3 \text{ of the LDMEs, if one ignores the CSM}$
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- Actually, the reduction is much stronger and the CS channel dominates over CO at low/mid $P_T$ in $pp$
\[ \Upsilon \ \& \ \psi \ \text{polarisation in hadroproduction at } O(\alpha_s^4) \ \& \ O(\alpha_s^5) \]

JPL, EPJC 61, 693, 2009.
QCD corrections do matter for the polarisation

$\Upsilon$ & $\psi$ polarisation in hadroproduction at $\mathcal{O}(\alpha_s^4)$ & $\mathcal{O}(\alpha_s^5)$


JPL, EPJC 61, 693, 2009.


$\alpha = (\sigma_T - 2\sigma_L) / (\sigma_T + 2\sigma_L)$

$P_T (\text{GeV})$ helicity frame ($|y| < 0.35$)

LO from $gg$

NLO from $gq+gg$

Direct $\psi(2S)$ CDF data at $s^{1/2} = 1.96$ TeV

LO

NLO

NNLO

© Complete modification of the polarisation at NLO (also at NNLO $^\star$)

© Yield from $k_T$ factorisation is also longitudinal (in the helicity frame)

© This is not yet explained by simple arguments (although reasonable)
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Part III

what we do not understand
Could simply be the colour octets \( (^3S^1_1) \)
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What about the polarisation measurement, then?

Could be the data …

Let’s wait for the LHC data for prompt \(\psi(2S)\) or direct \(J/\psi\)
Part IV

what we expect from the LHC:
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what we expect from the LHC: new measurements
New observables

- $J/\psi+$ hadron azimuthal correlations


PYTHIA might not be reliable (Color Singlet at LO: $gg \rightarrow J/\psi g$)

Need for updates with NLO and NNLO

$J/\psi+$ or $J/\psi+$ lepton: peak at $\Delta \phi = \pi$ in the yield integrated over $P_T$. J. S. Brodsky and JPL, PRD 81 051502 (R), 2010

Besides, the rapidity dependence gives info on $c(x)$ plot for RHIC kinematics.
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- $J/\psi + \gamma$

CS rate at NLO $\simeq$ conservative (high) expectation from CO

R.Li and J.X. Wang, PLB 672:51, 2009

A priori, no real new info on the relative importance of CS vs CO

But...

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![Graph showing differential cross-section as a function of $p_T$ for $J/\psi + \gamma$.]
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see C. Yu’s talk during the first session
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  - allow to study $h_c$ as well as $\psi$
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- Quarkonium studies via \( p\bar{p} \) decay
  - planned by LHC-b
  - allow to study \( h_c \) as well as \( \psi \)
  - maybe different acceptances, nice cross check
Part V

Conclusions and Outlooks
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- **LO pQCD (CSM) fails as far as \( d\sigma/dP_T \) is concerned**

- The LO (and NLO) CSM reproduces the yield relevant for heavy-ion studies.
- Agrees with the strong reduction of CO contributions at low/mid-\( P_T \) expected from \( e^+e^- \) analyses.
- Moreover, QCD-corrections bring agreements for \( d\sigma/dP_T \) in \( \gamma p \) for \( J/\psi \).
- JPL, EPJC 61:693, 2009

Drawback: large theoretical uncertainties.

The time has come for another look with new observables at the LHC or elsewhere!
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  - $\gamma p$ for $J/\psi$
  - $pp$ for $\Upsilon$ (Tevatron)
  - $pp$ for $\psi$ (RHIC, Tevatron) (gap at large $P_T$)
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