Quarkonium production at the Tevatron and the LHC

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NRQCD factorization

The cross section for inclusive quarkonium production is expressed as a sum of products of short-distance coefficients and long-distance matrix elements

$$\sigma[\mathcal{Q}] = \sum_n \hat{\sigma}_\Lambda[Q\bar{Q}(n)]\,\langle \mathcal{O}^{\mathcal{Q}}(n)\rangle_\Lambda$$

SD coefficients
many recent works have been devoted to improving their accuracy, i.e. by computing higher-order corrections in α_s

LD matrix elements
for the color-octet, no theoretical tool to constrain the LDME's other than the power counting rules in v

Direct production vs feed-down

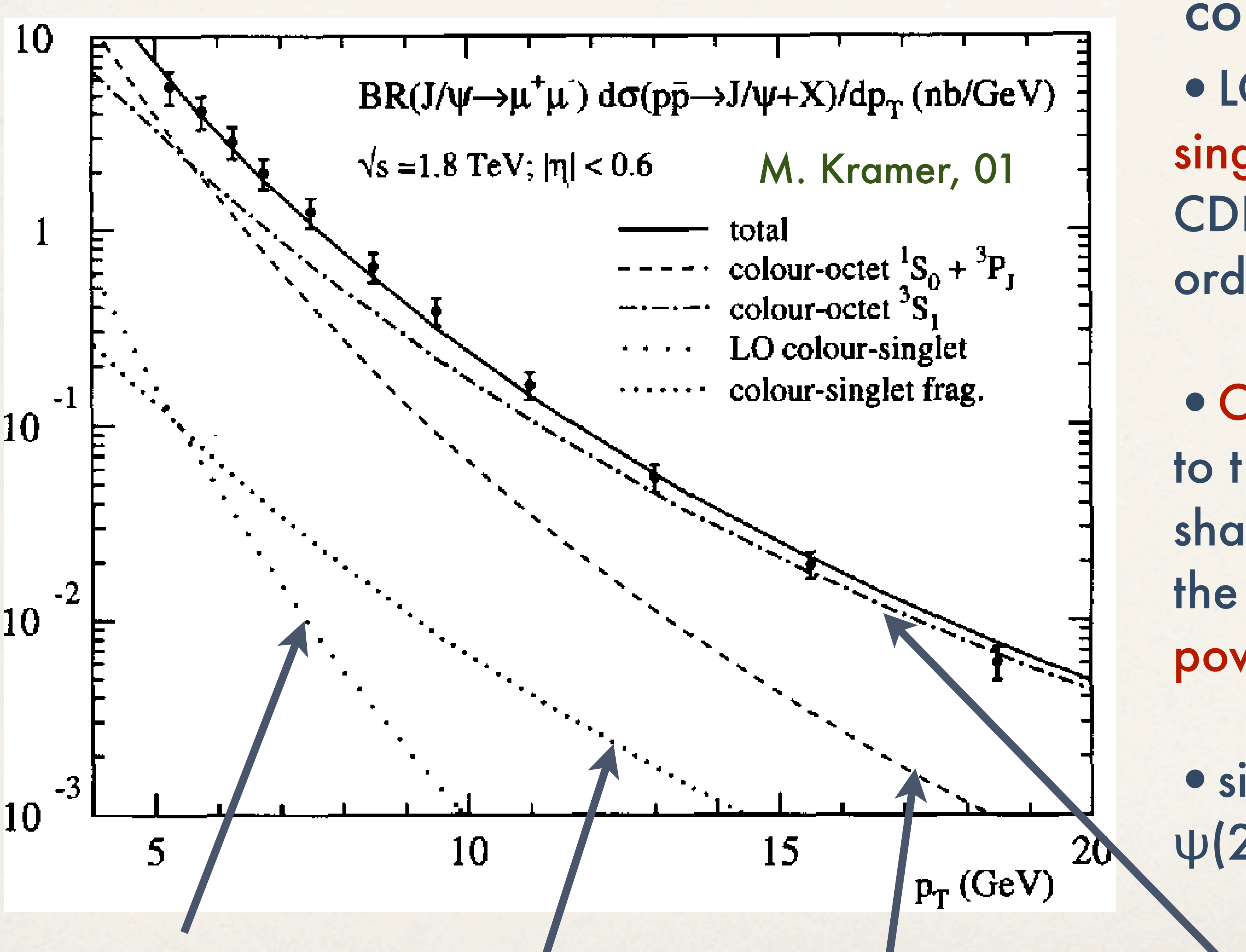
- Quarkonium production can also proceed via the decay of heavier hadrons (feed-down)

- For J/ψ production at the Tevatron:
  - b-hadron decays:
    EXP: Tevatron II, $b \to J/\psi + X$ accounts for 10% of the inclusive production rate at p_T=1.5 GeV (increasing to 45% at p_T=20 GeV) [CDF collaboration, 04]
    TH: FONLL scheme [Cacciari, Greco, Nason], good agreement between th. and exp.
  - feed-down from charmonium states:
    EXP: Tevatron I, $\psi(2S) \to J/\psi\pi\pi$ and $\chi_c \to J/\psi\gamma$ accounts for 35% of the prompt production rate [CDF collaboration, 97]
    TH: NRQCD calculation recently extended at NLO [Ma, Wang, Chao]

In this talk: focus on direct J/ψ or $\psi(2S)$ hadroproduction

J/ψ direct production

Th. status of direct J/ψ production at the Tevatron I: 9 years ago



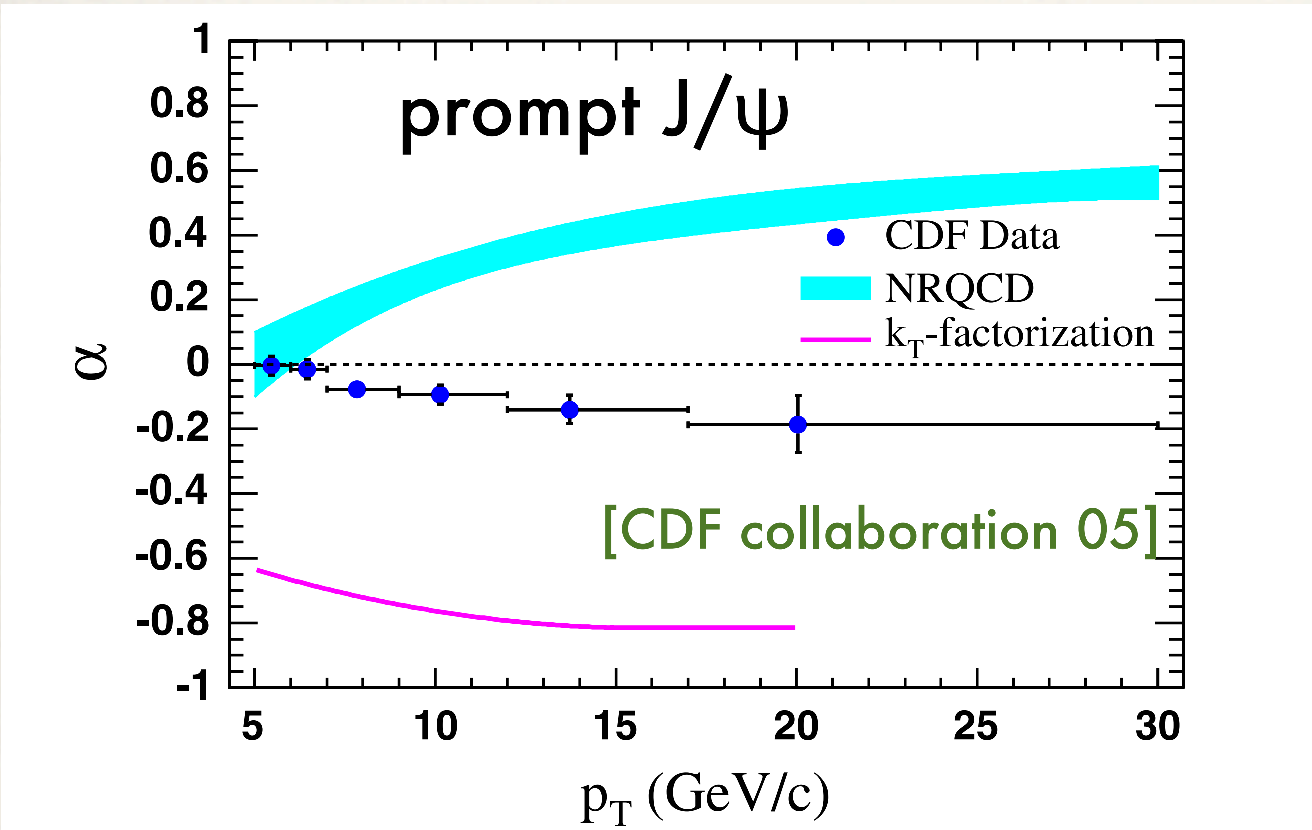
$^3S_1[1]$ $^3S_1[1]$, frag approx $^1S_0[8]+^3P_J[8]$ $^3S_1[8]$

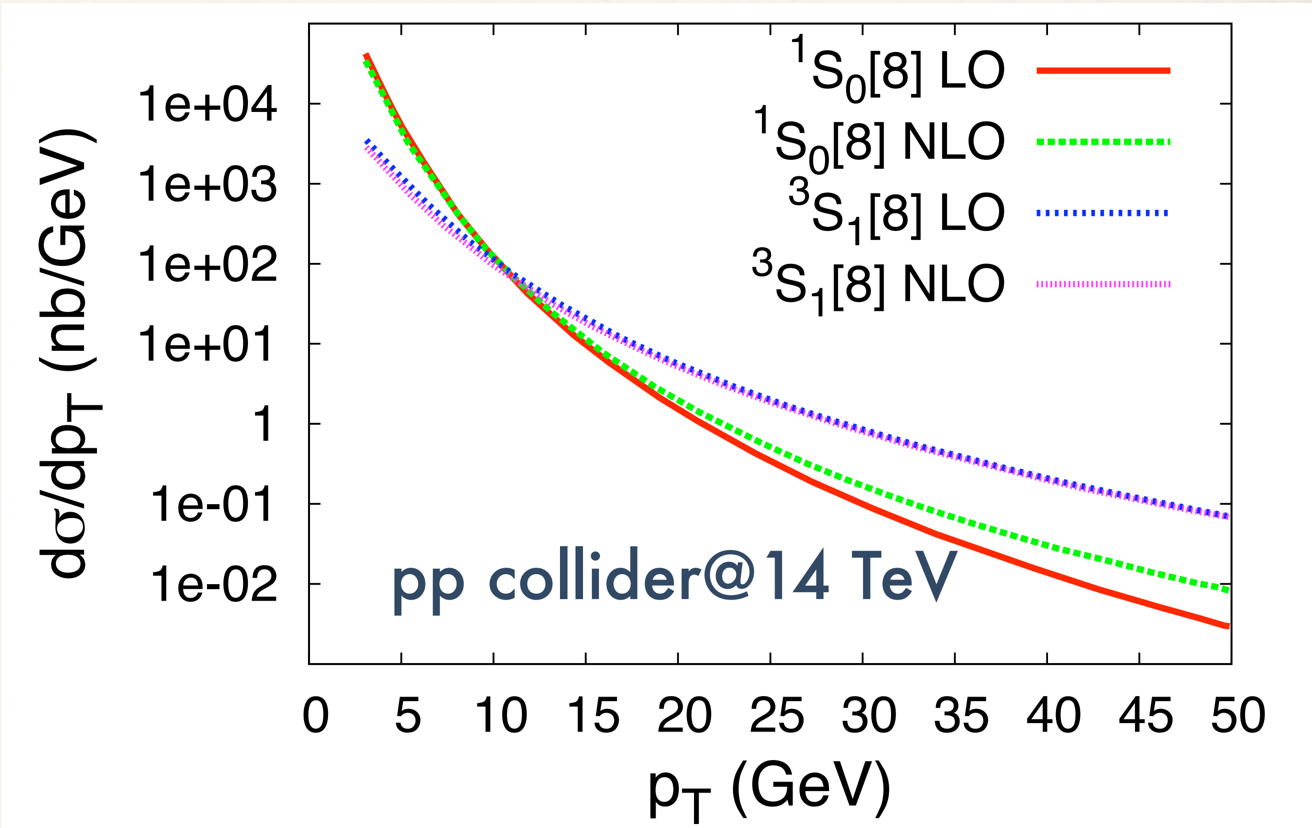
color-octet dominance:

- LO + fragmentation color-singlet channels undershoot the CDF data by more than an order of magnitude.
- Color-octet contributions fitted to the data describe well the shape in p_T, and the values of the CO LDME's agree with the power counting rules in v.
- similar situation for prompt ψ(2S) production

Color-octet channels: th. vs exp. (update)

- More recent results have challenged the previous picture





Gong, Li, Wang; 08:

At large p_T, the production is dominated by $g^* \to {}^3S_1^{[8]}$, which leads to transverse polarization in the c.m. helicity frame. This prediction may be affected by perturbative and non-perturbative corrections

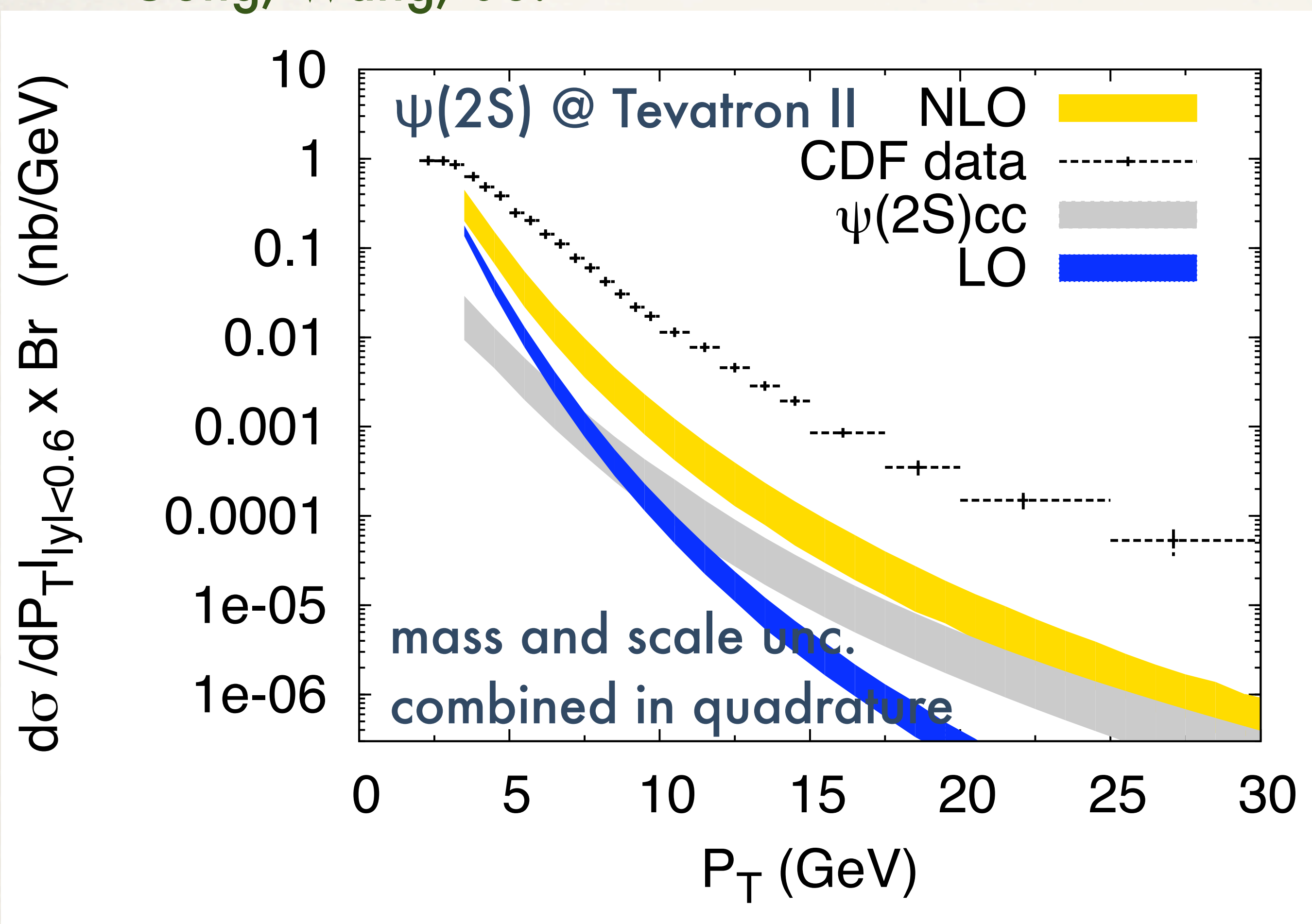
NLO correction has little impact on the pheno

very small correction to the polarization [also investigated in the frag. approx: Ma 95, Beneke & Rothstein 96, Braaten & Lee, 00].

Color-singlet channel: th. vs exp. (update)

- NLO correction:

  Campbell, Maltoni, Tramontano, 07
  Artoisenet, Lansberg, Maltoni, 07
  Gong, Wang, 08:



- huge enhancement at large p_T.
- large th. unc., mainly from variations of the scales →size of higher-order corrections ?

  (see talk by J.-P. Lansberg)

- Fragmentation approach at large p_T:
  - leading p_T component:

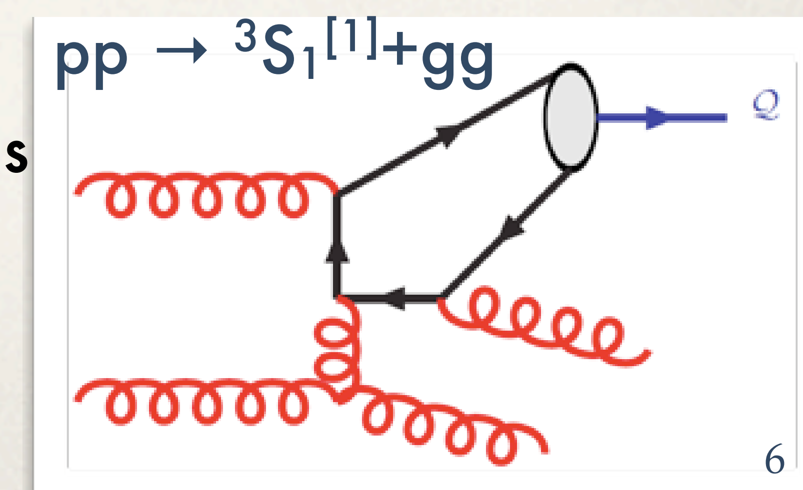
    ⬌ single-parton fragmentation

    [Braaten, Yuan, 93]
  - next-to-leading p_T component

    ⬌ charm-quark pair fragmentation

    [Kang, Qiu, Sterman, in preparation]

New channels at α_s^4:



What can we learn from the first LHC data ?

- observable: p_T spectrum associated with J/ψ production

  σ^{tot}: large th. uncertainties since dominated by low p_T
  polarization: measurements require sample with large statistics

- calculation scheme: NRQCD at leading order in α_s

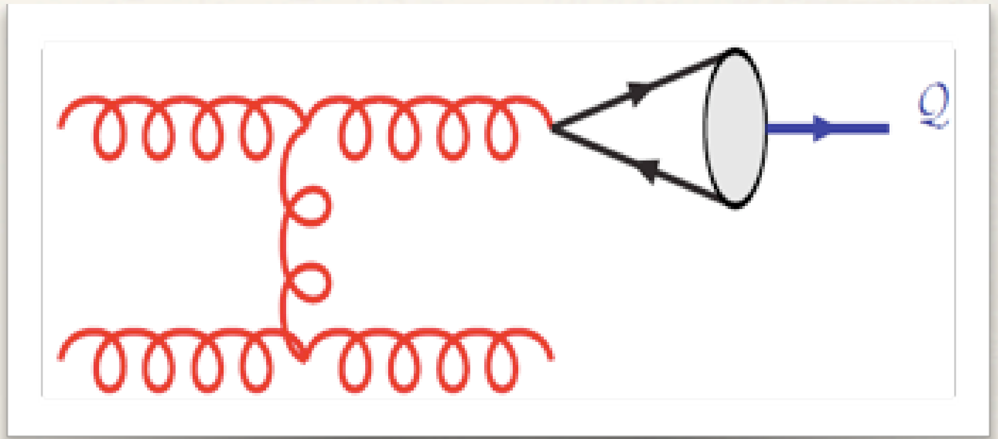
  - QCD correction to color-octet channels have negligible impact on the pheno (at least for the S-wave) [Gong, Wang, 08]

  - QCD corrections to the color-singlet yield might have a large impact on the phenomenology, but current th. uncertainties are very large

➡ This scheme provides a test of the color-octet dominance picture for a different collision energy and over a wider p_T range

Additional ingredient:

- resummation of $[\alpha_s \log(m_c/p_T)]^n$ to all order in α_s by solving the DGLAP equation for the evolution fragmentation function $d_{g\to c\bar{c}_8(^3S_1)}(z,\mu)$



based on a calculation by Maltoni & Petrelli

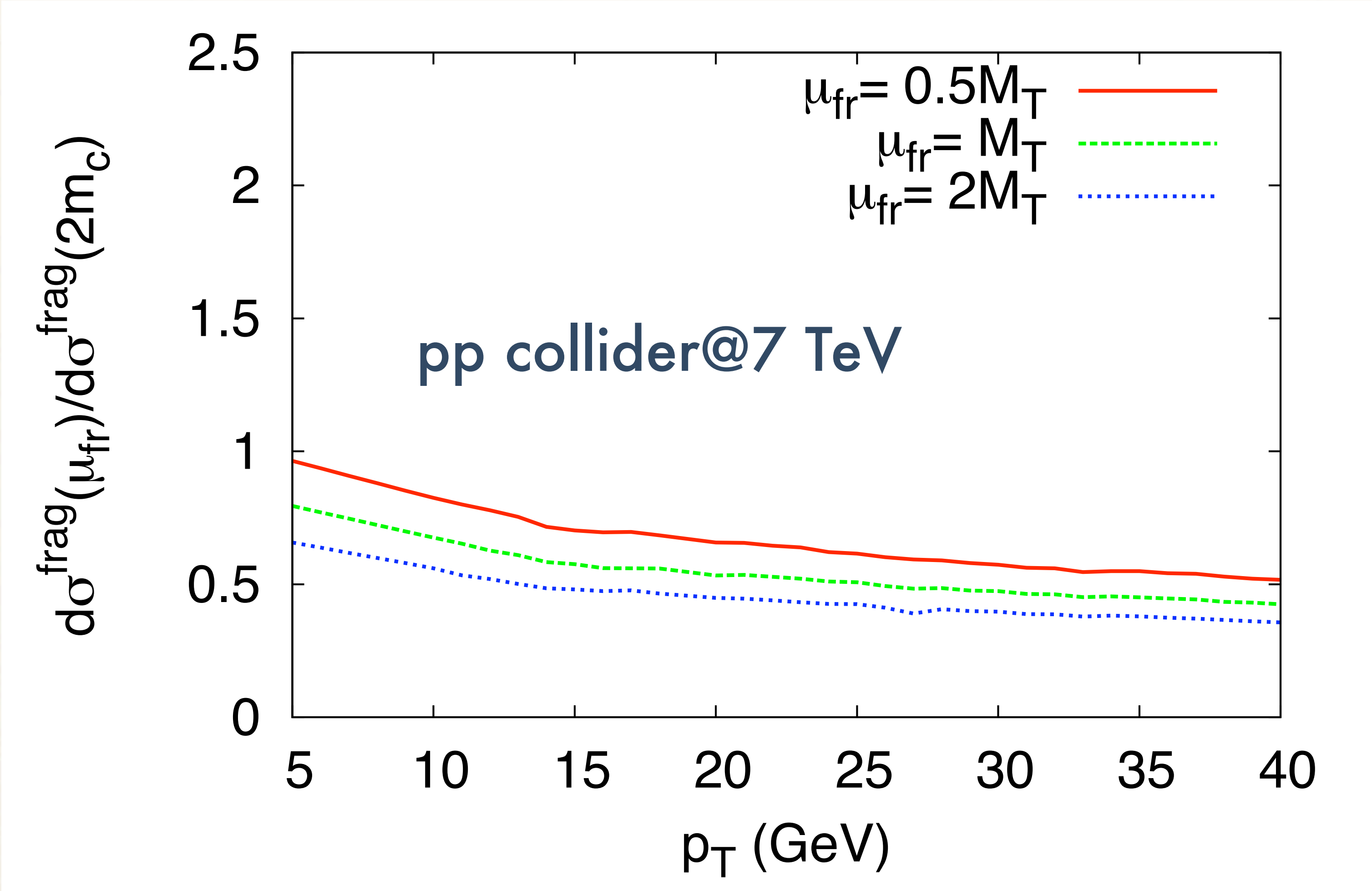
- The short-distance coefficient for the color-octet $^3S_1$ is expressed as

$$d\hat{\sigma}_8\left({}^3S_1\right) = d\hat{\sigma}_8^{FO}\left({}^3S_1\right) \frac{d\hat{\sigma}^{\rm frac}_{g\to c\bar{c}_8(^3S_1)}(\mu_{\rm fr}=M_T)}{d\hat{\sigma}^{\rm frac}_{g\to c\bar{c}_8(^3S_1)}(\mu_{\rm fr}=2m_c)}$$

→ includes both the evolution and the effects from the finite mass of the charm quark

Impact of the evolution

- decrease of the differential rate by a factor 2 at p_T=25 GeV
- large uncertainties from the variations of μ_{fr}

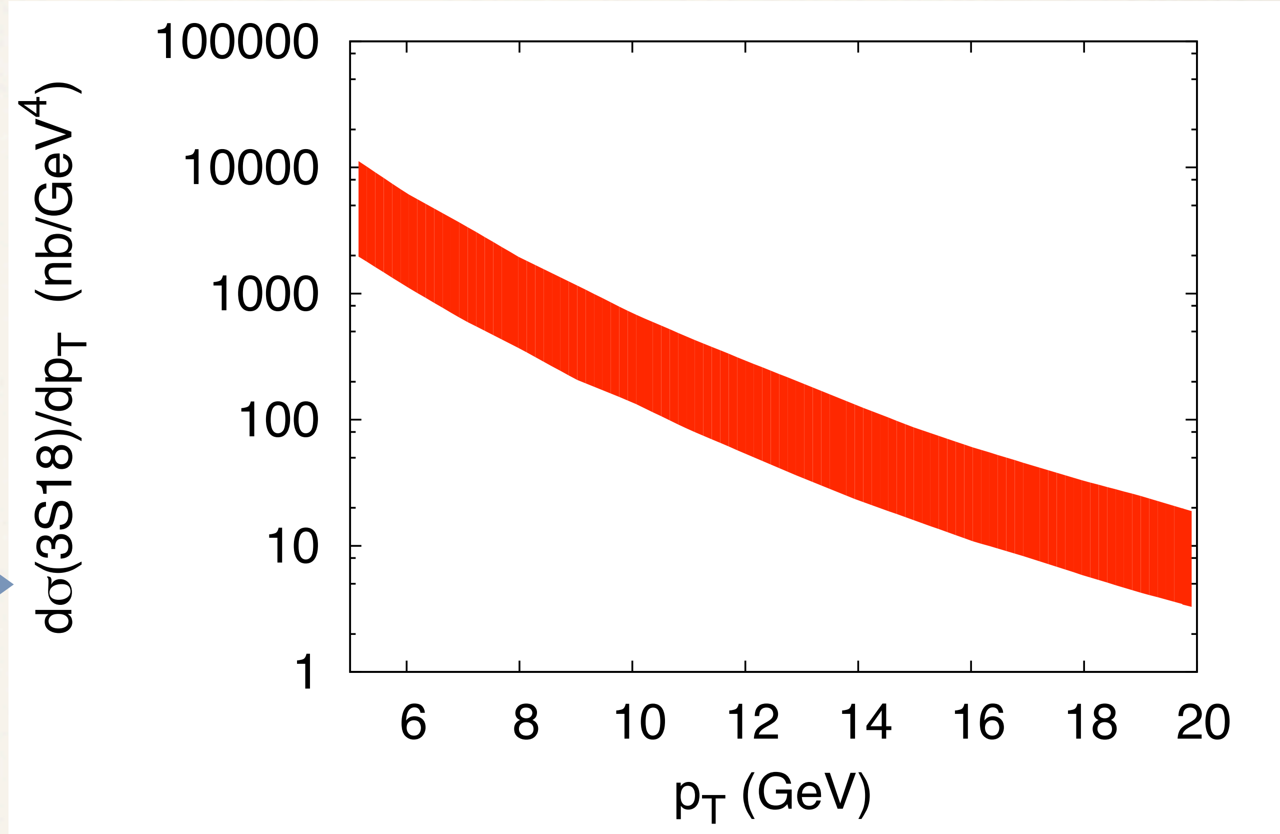


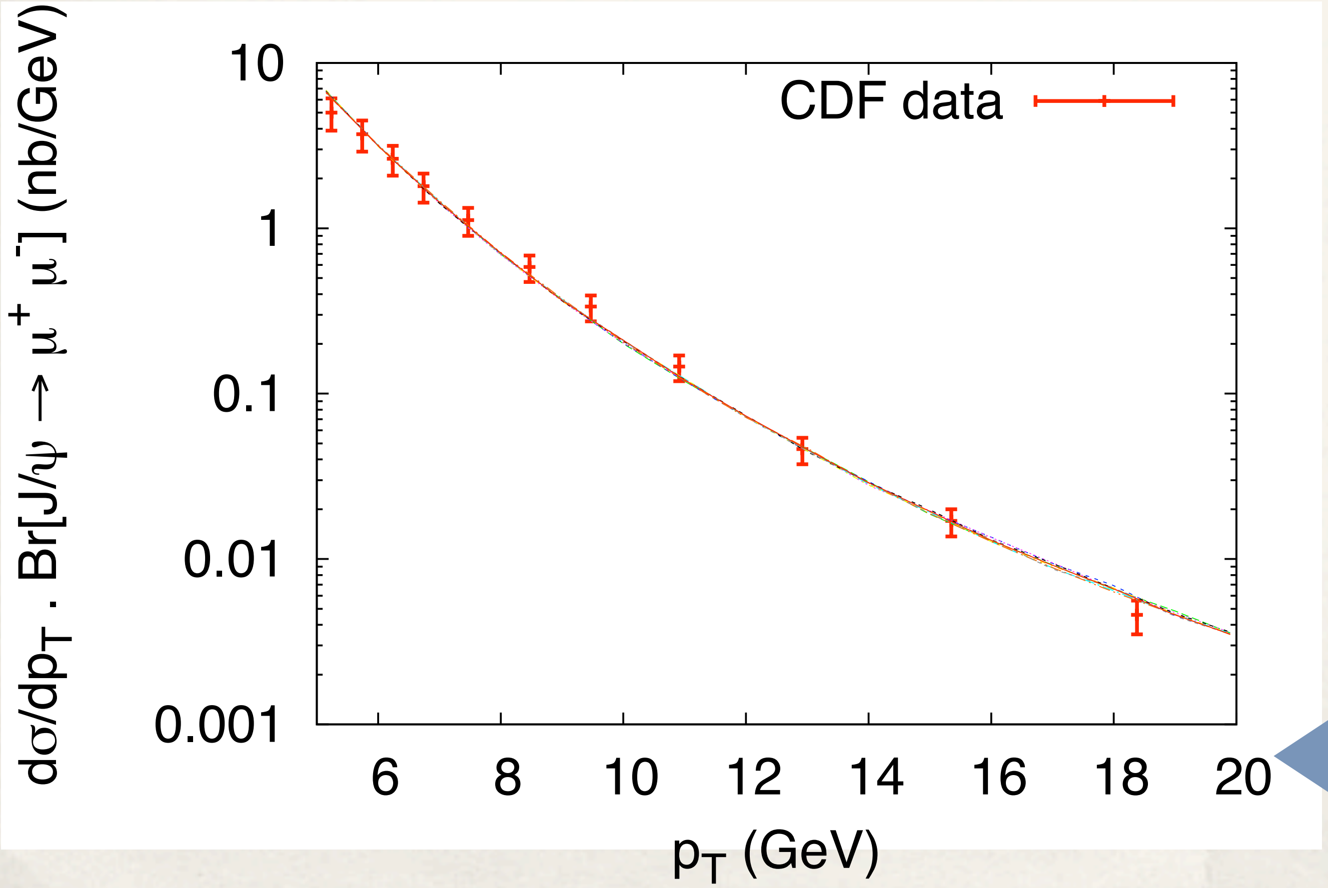
Theoretical uncertainties

- **scales:** $M_T/2 < \mu_r, \mu_f, \mu_{fr} < 2M_T$
- **charm-quark mass:**

$$m_c = 1.5 \pm 0.1 \text{ GeV}$$

→results in a large uncertainty on the normalization of the NRQCD short-distance coefficients

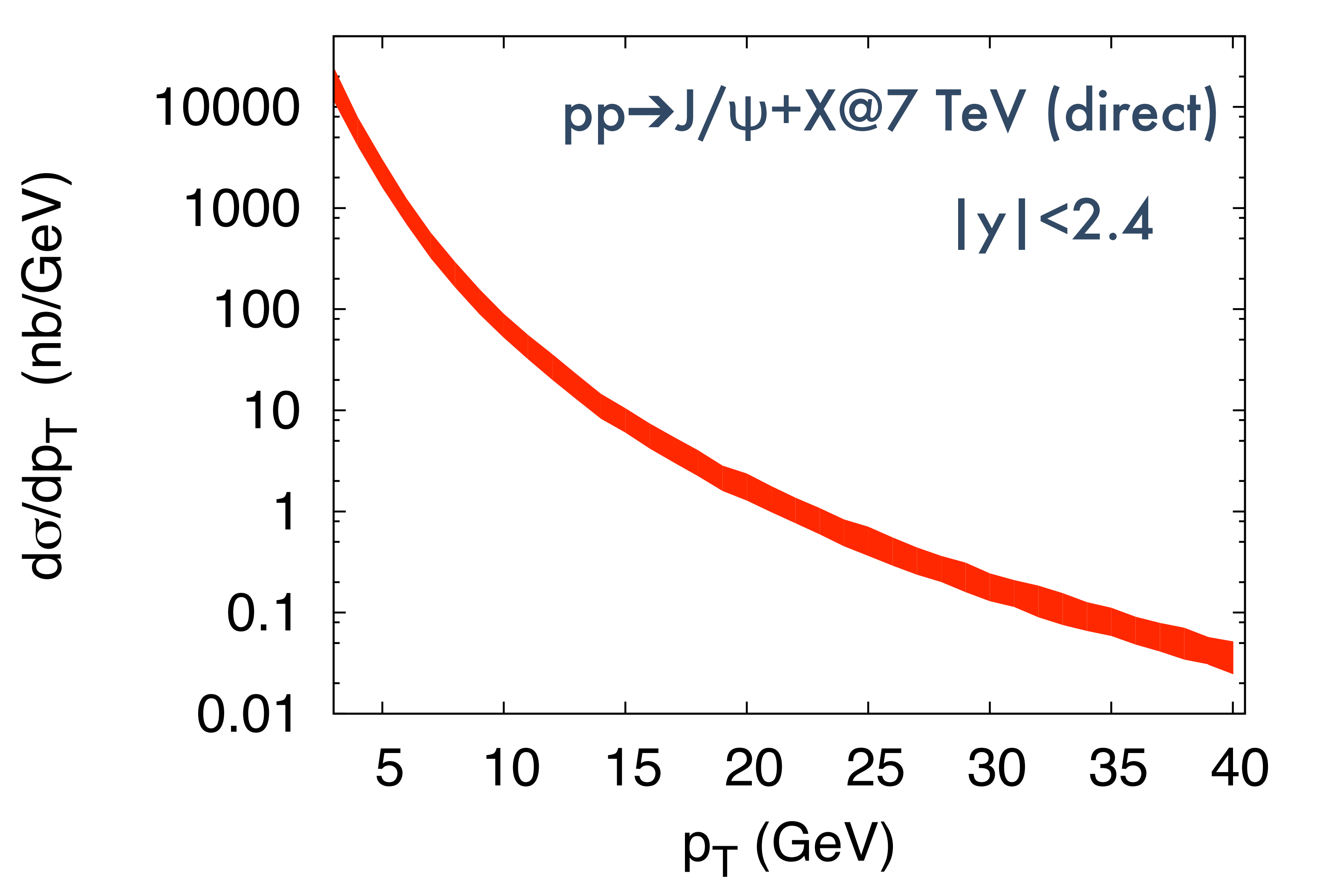




We repeat the fit to the CDF data for each set of input parameters (any change in the normalization of the SD coefficients is reabsorbed into the color-octet LDME's)

Predicted p_T spectrum at the LHC

- th. & exp. uncertainties combined in quadrature



- factor ≈2 of uncertainty in the normalization of the production rate
- analogous prediction for the forward region
- the p_T spectrum can be effectively described by a LO Monte Carlo generator such as Pythia or MadOnia with an appropriate choice of the LDME's

Conclusion

- I presented a prediction for direct J/ψ production rate at the LHC
- comparison with the data would provide a test of the color-octet dominance
- the same approach can be followed for the prompt production of $\psi(2S)$