Experimental review of η_c, χ_c and χ_b production in $p\bar{p}^{(-)}$ collisions

Ilse Krätschmer* (HEPHY Vienna)

New Observables in Quarkonium Production
29. February 2016

*Supported by Austrian Science Fund (FWF):
P 28411-N36

HEPHY
INSTITUT FÜR HOCHENERGIEPHYSIK

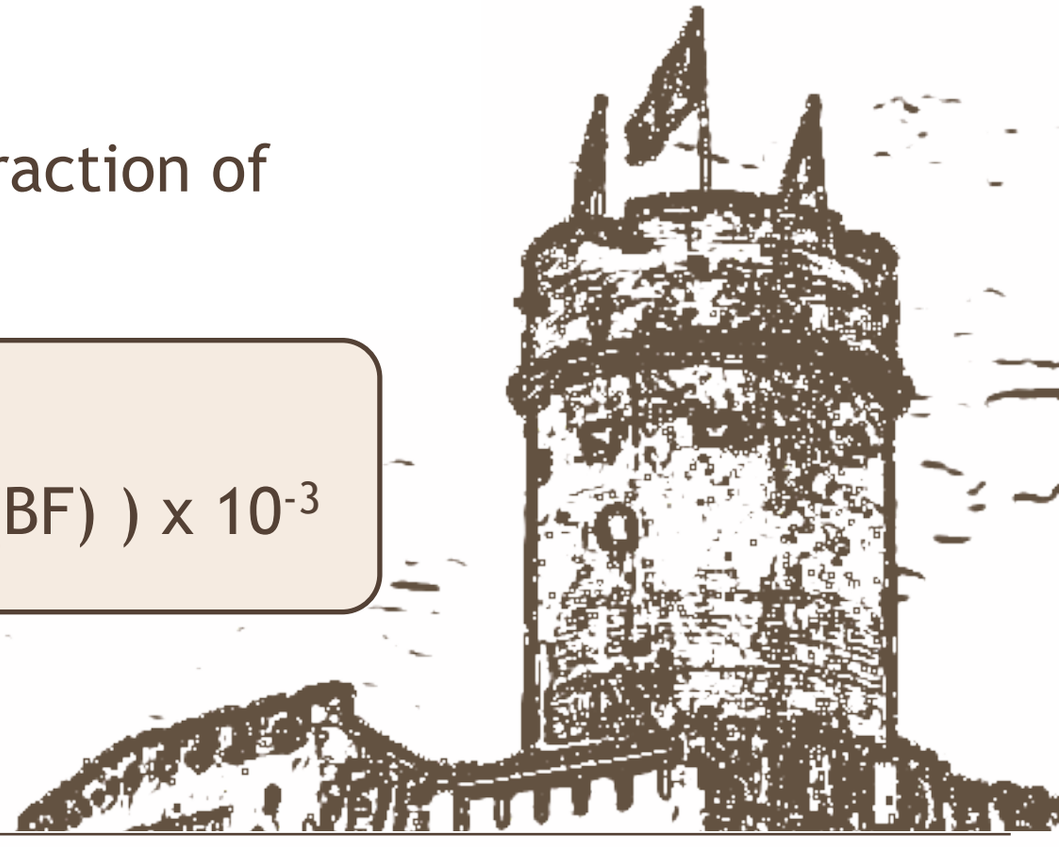
η_c cross section at LHCb

- $\eta_c(1S)$ and J/ψ are detected via their decay to $p\bar{p}$
- Prompt $\eta_c(1S)$ to J/ψ cross section ratio for $p_T > 6.5$ GeV

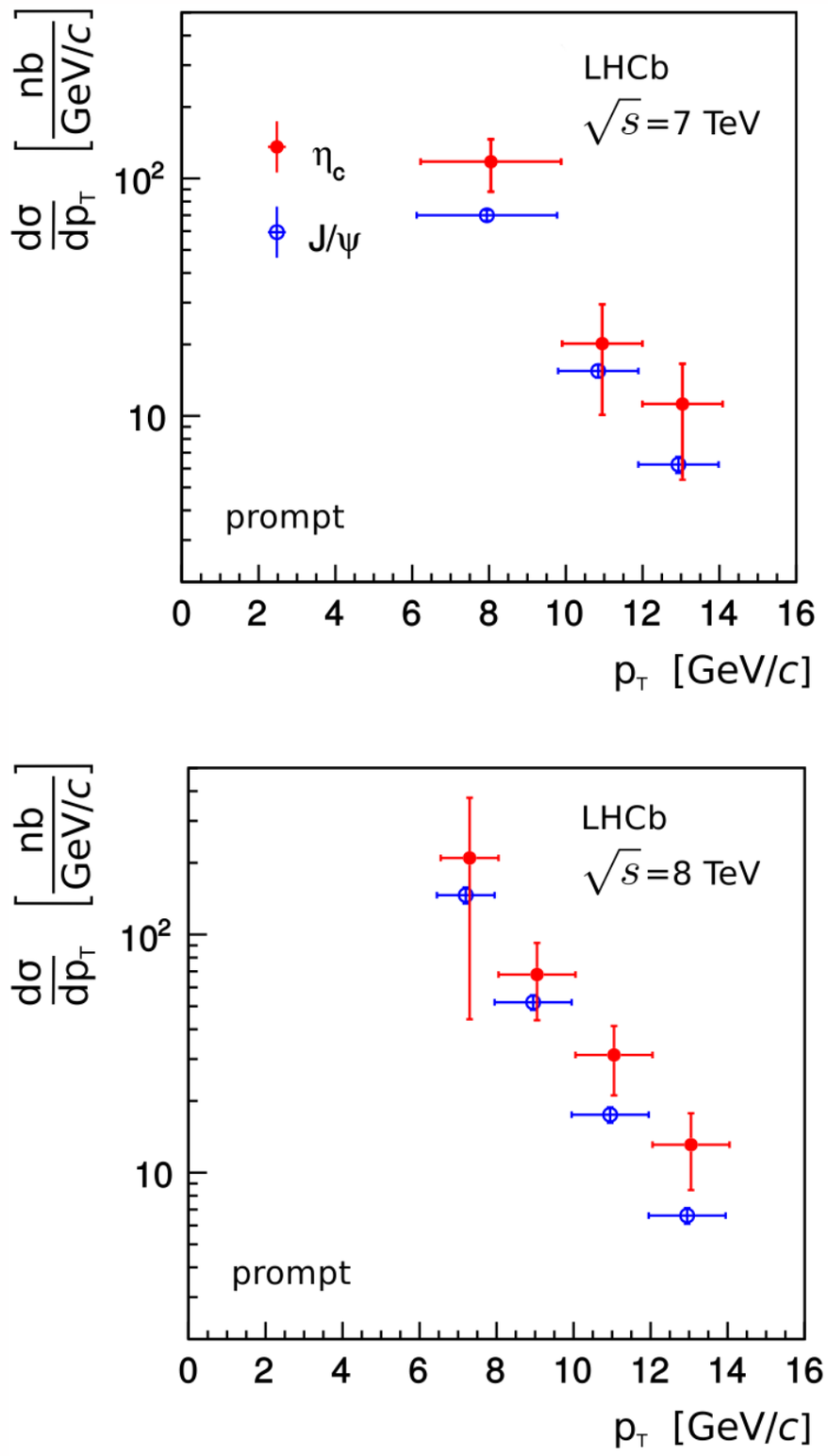
$$\sigma(\eta_c(1S))/\sigma(J/\psi)$$
$$= 1.74 \pm 0.29 \text{ (stat.)} \pm 0.28 \text{ (syst.)} \pm 0.18 \text{ (BF)} \quad (\sqrt{s} = 7 \text{ TeV})$$
$$= 1.60 \pm 0.29 \text{ (stat.)} \pm 0.25 \text{ (syst.)} \pm 0.17 \text{ (BF)} \quad (\sqrt{s} = 8 \text{ TeV})$$

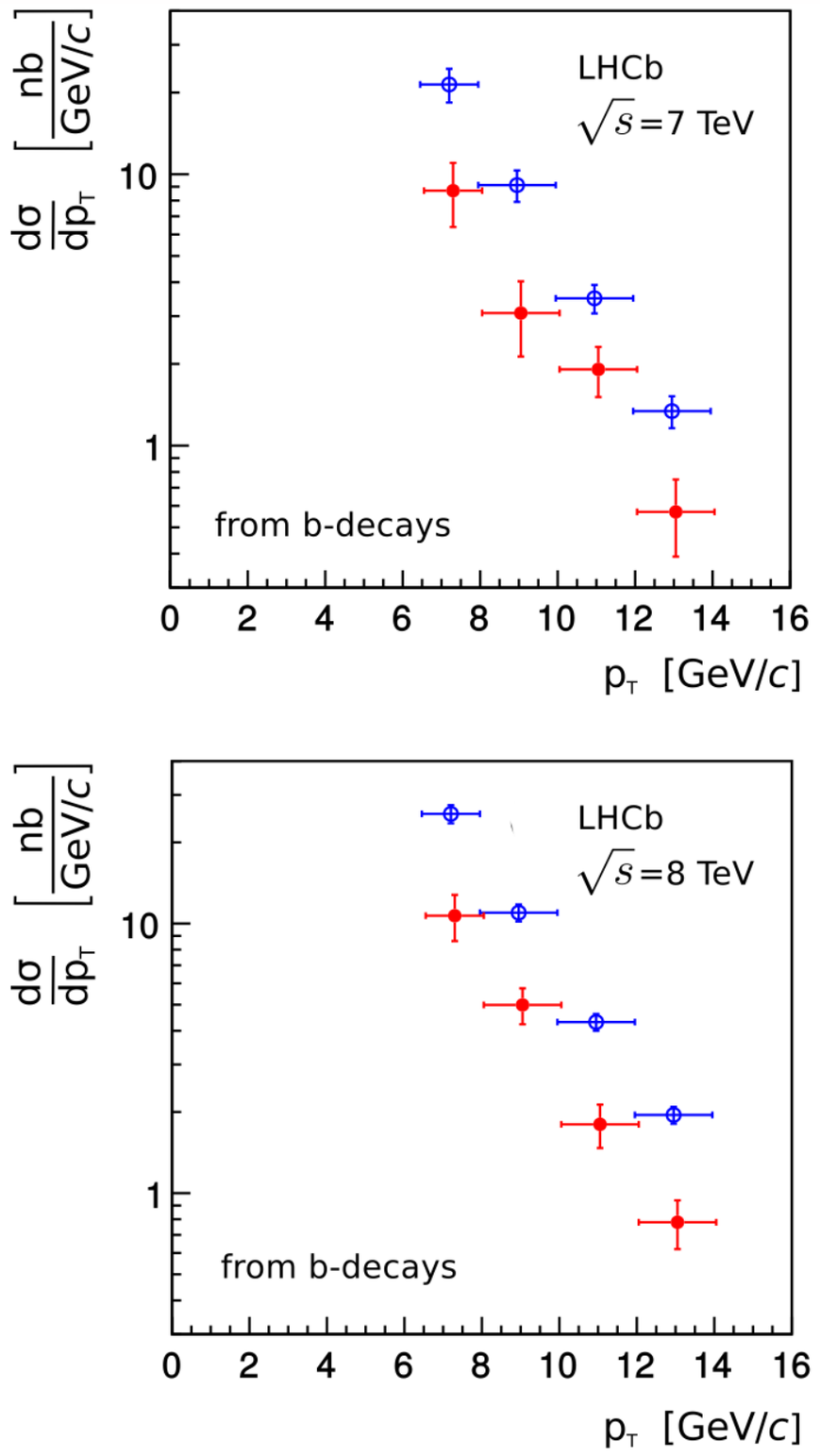
- First measurement of inclusive branching fraction of b-hadrons into $\eta_c(1S)$ mesons

$$BR(b \rightarrow \eta_c(1S)X) =$$
$$(4.88 \pm 0.64 \text{ (stat.)} \pm 0.29 \text{ (syst.)} \pm 0.67(BF)\ ) \times 10^{-3}$$



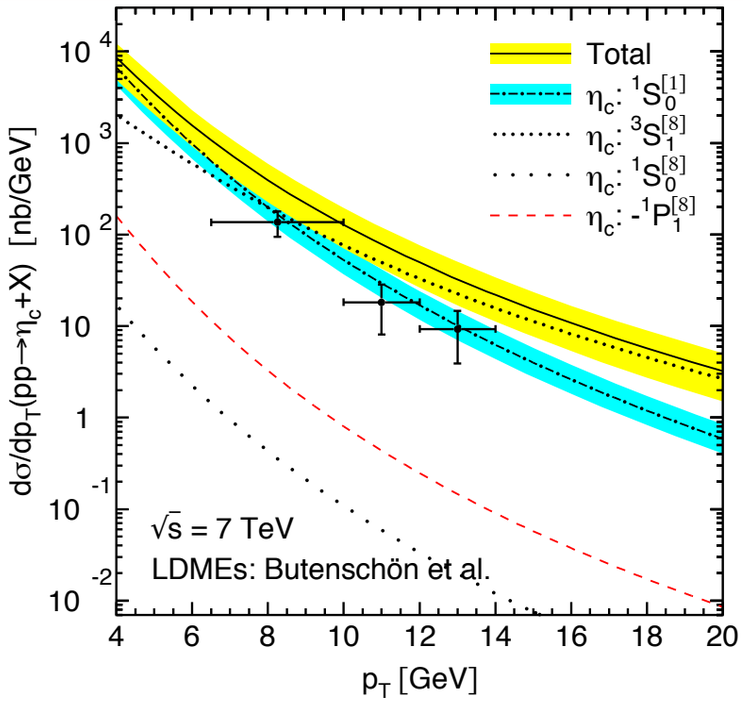
η_c cross section at LHCb

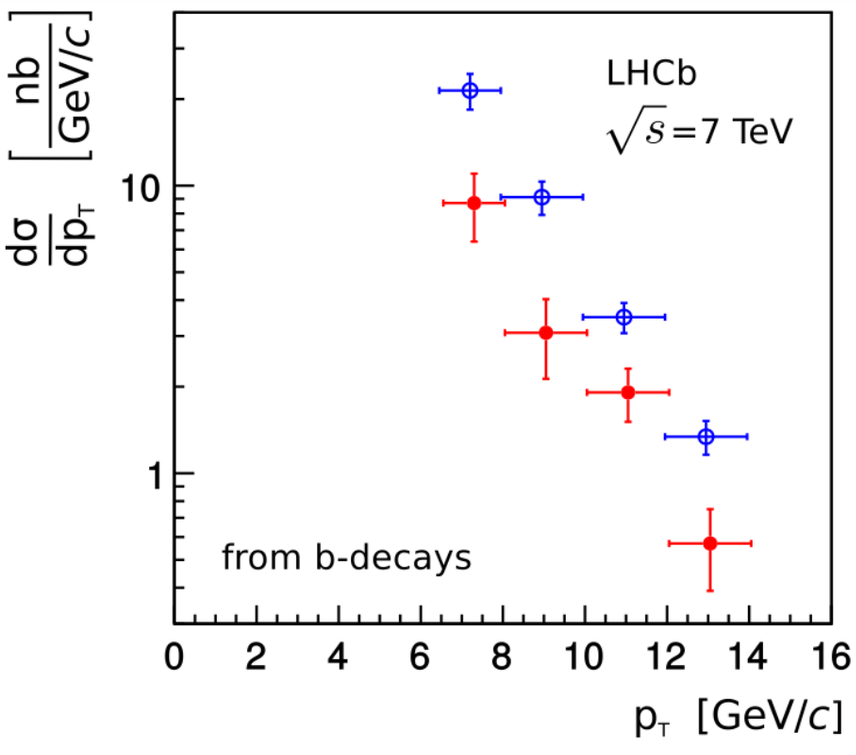




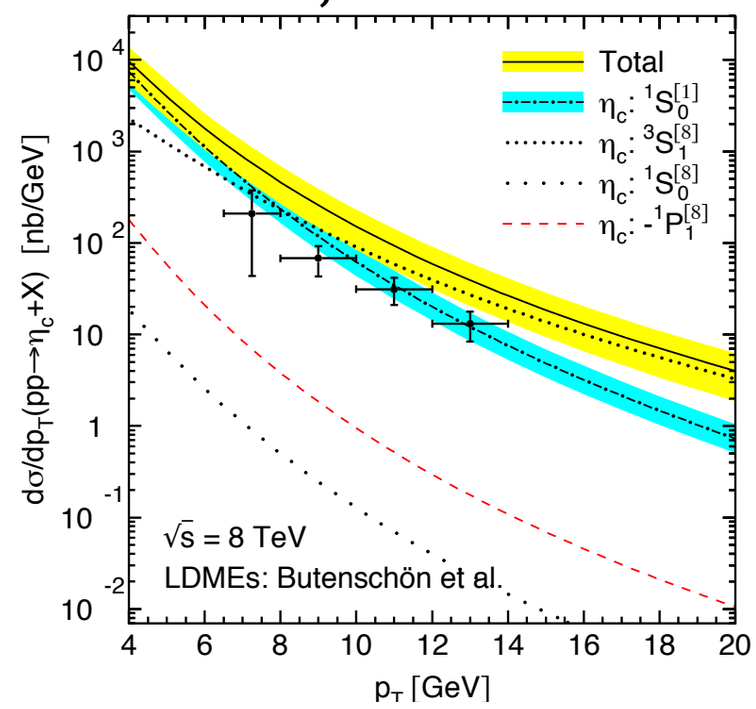
η_c cross section at LHCb

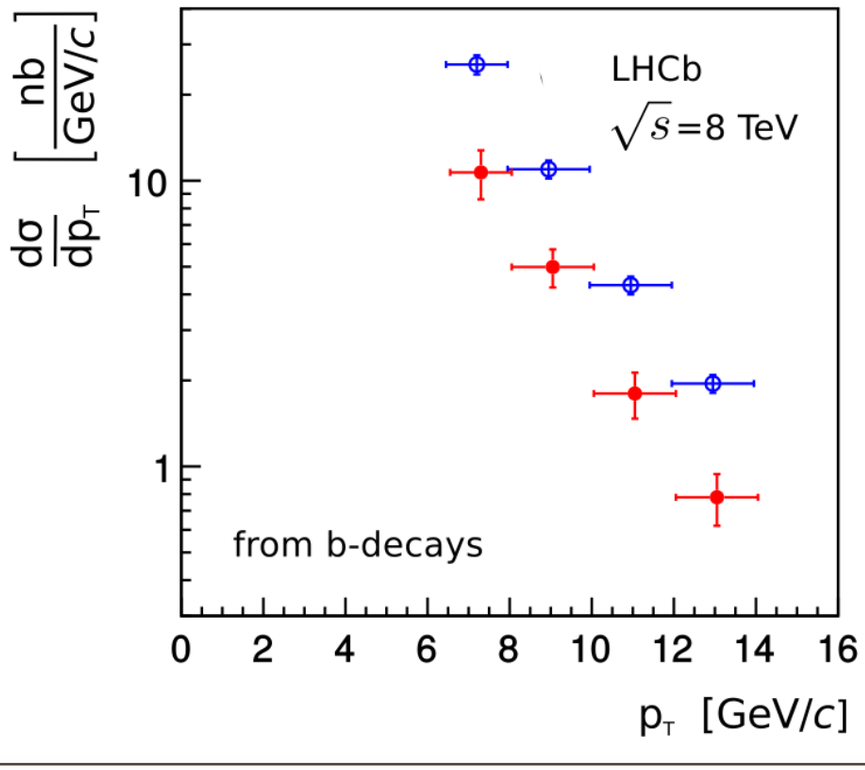
- Full NLO NRQCD predictions overshoot data
- Color singlet (CS) contribution alone seems to describe cross section





PRL 114, 092004



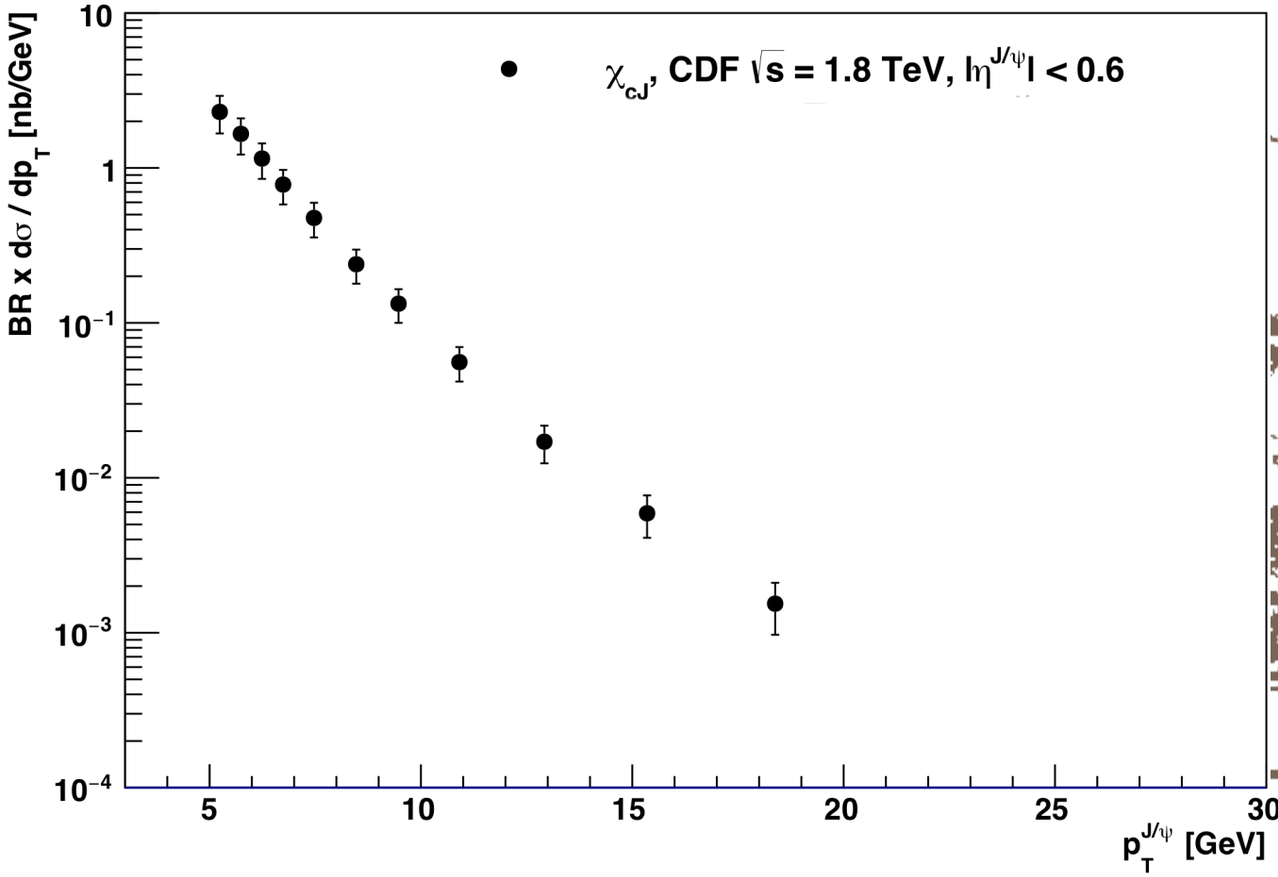


Prompt χ_c cross sections

- Prompt cross section of J/ψ's coming from χ_c decays (using converted photons)

$$\chi_c \rightarrow J/\psi\gamma \rightarrow \mu^+\mu^- (e^+e^-)$$

- CDF does not distinguish between χ_{cJ} states

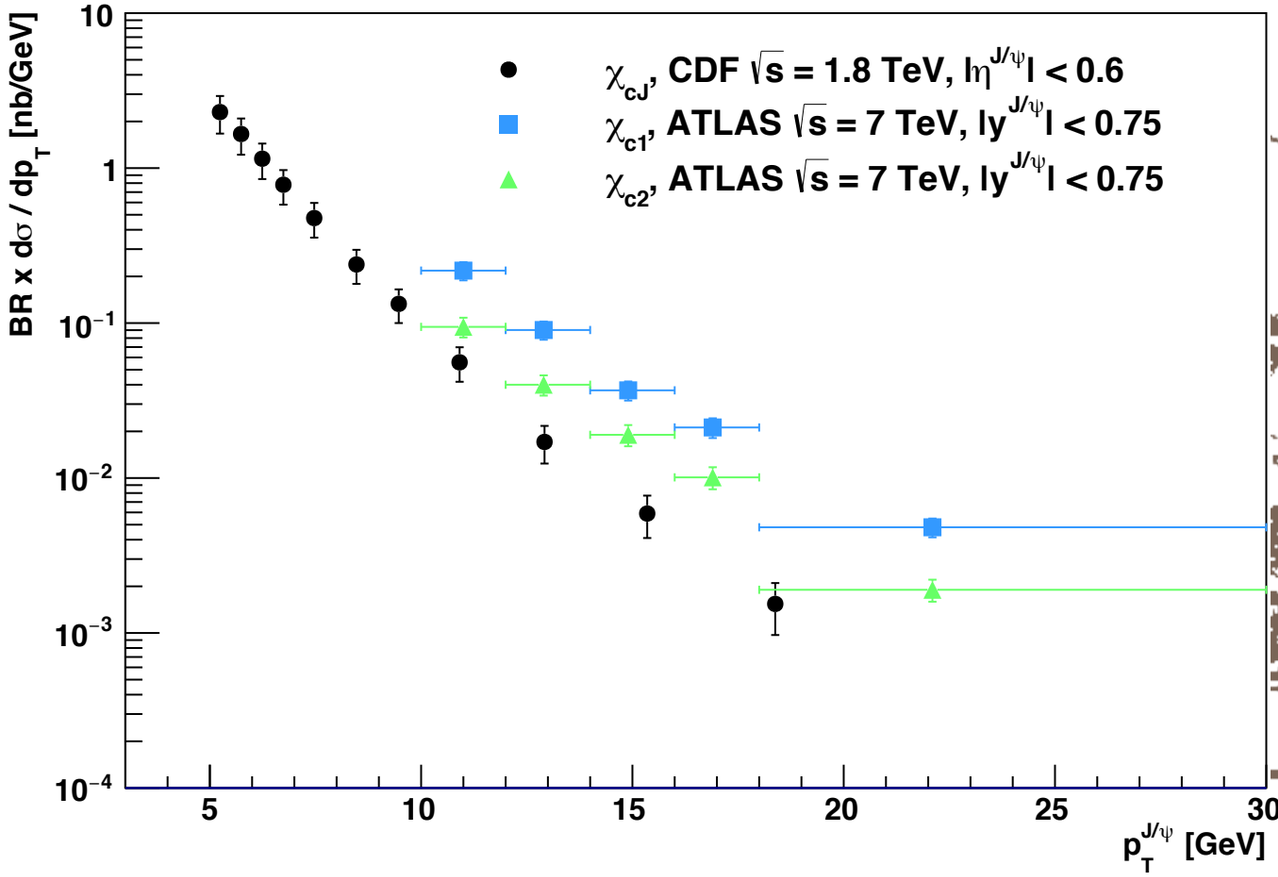


Prompt χ_c cross sections

- Prompt cross section of J/ψ's coming from χ_c decays (using converted photons)

$$\chi_c \rightarrow J/\psi\gamma \rightarrow \mu^+\mu^- (e^+e^-)$$

- CDF does not distinguish between χ_{cJ} states
- Different rapidity regions and energies for CDF and ATLAS measurements

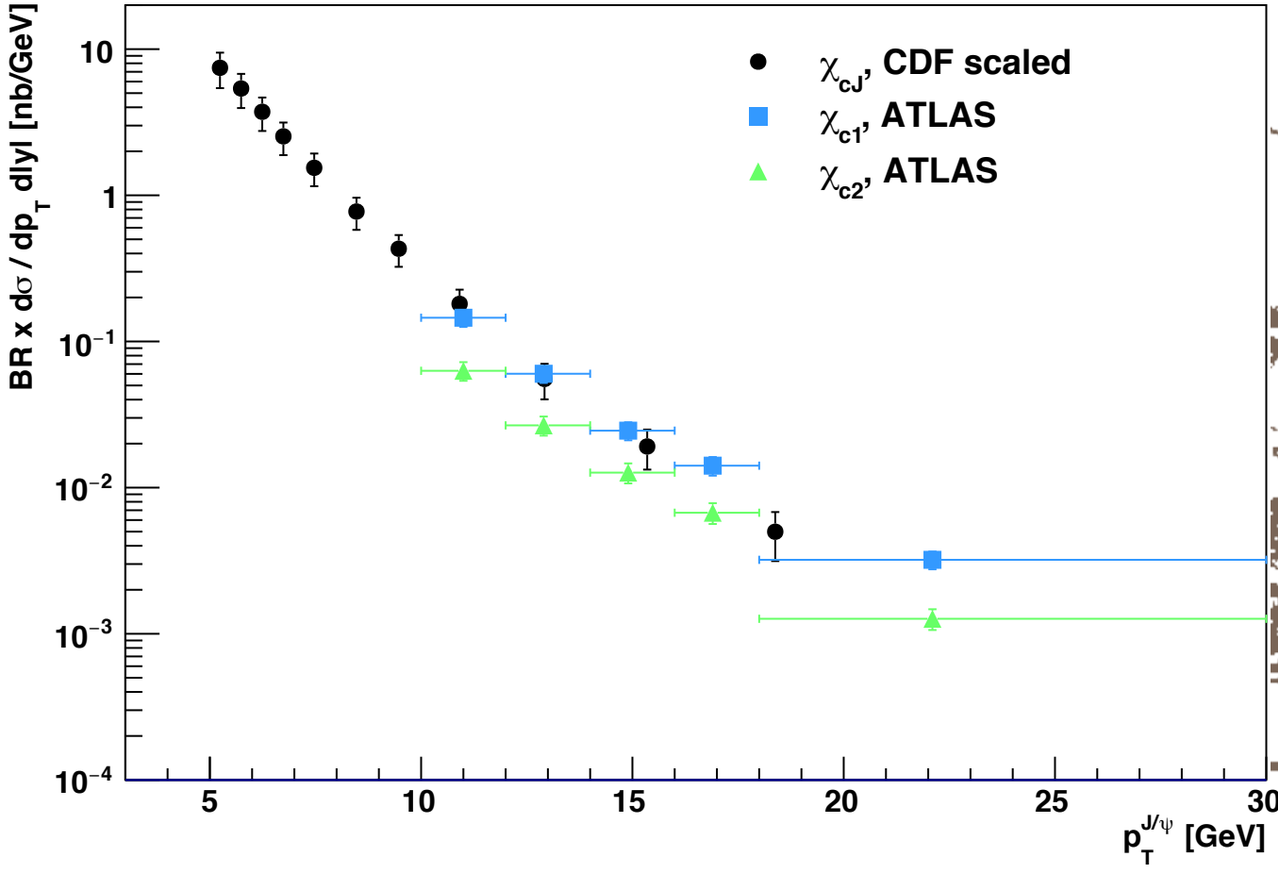


Prompt χ_c cross sections

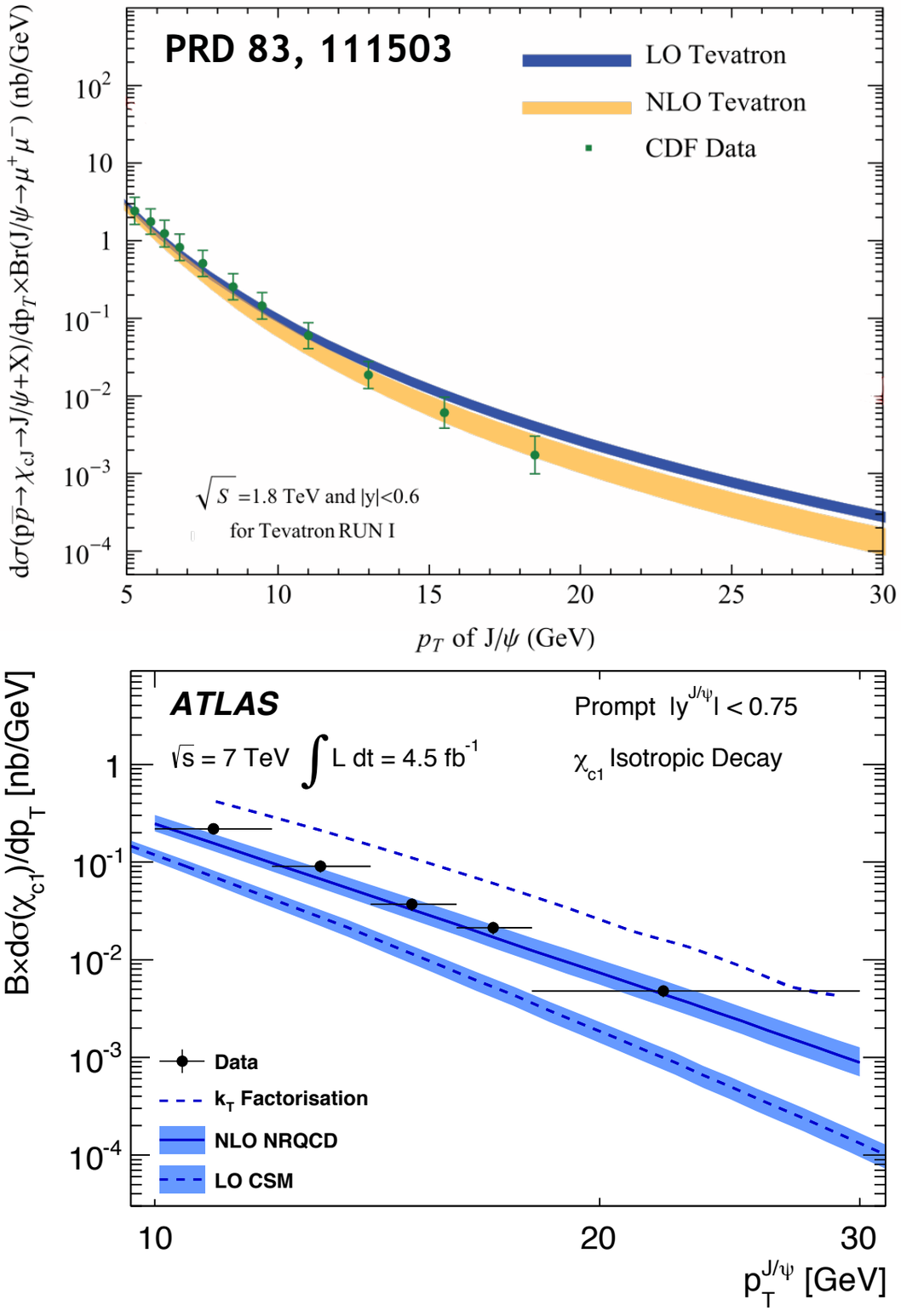
- Prompt cross section of J/ψ's coming from χ_c decays (using converted photons)

$$\chi_c \rightarrow J/\psi\gamma \rightarrow \mu^+\mu^- (e^+e^-)$$

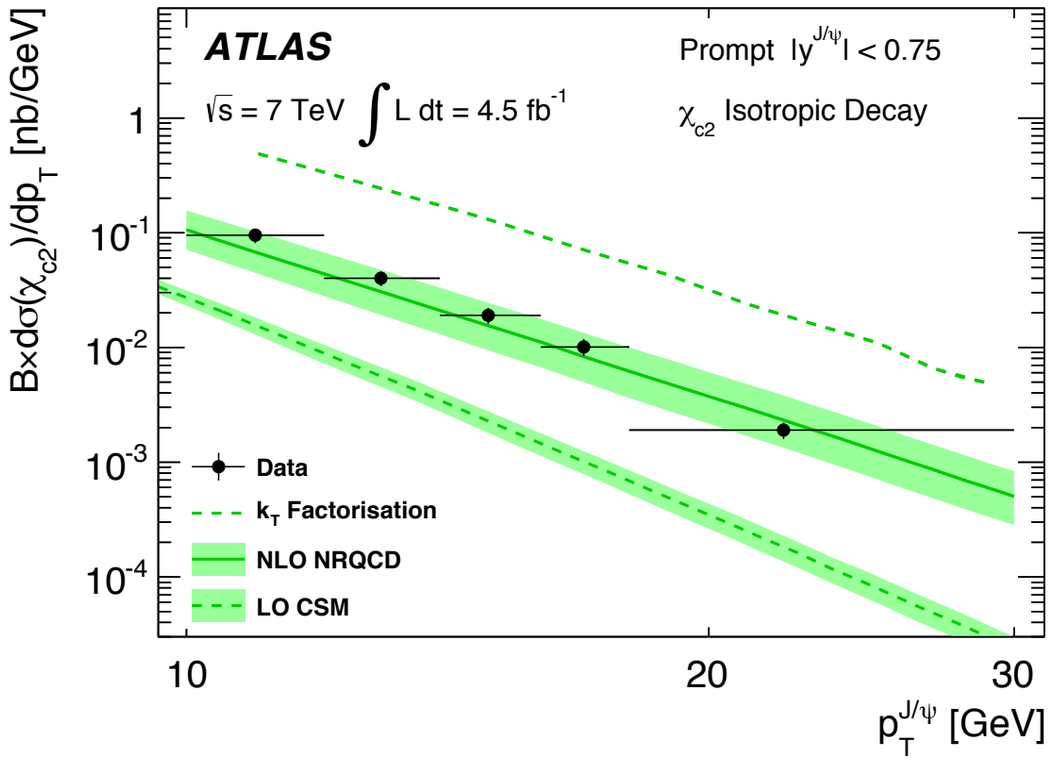
- CDF does not distinguish between χ_{cJ} states
- Different rapidity regions and energies for CDF and ATLAS measurements
- Scaled CDF and ATLAS measurements have similar p_T dependence



Comparison to theory

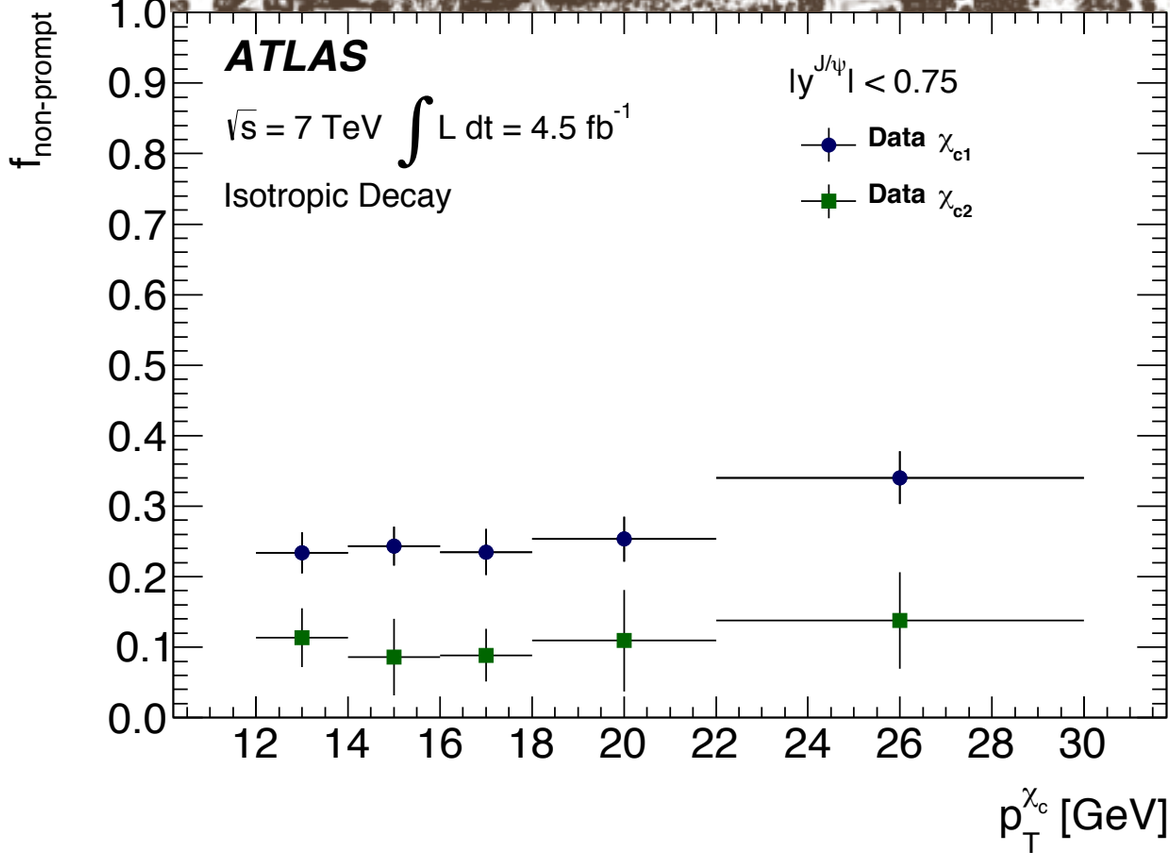


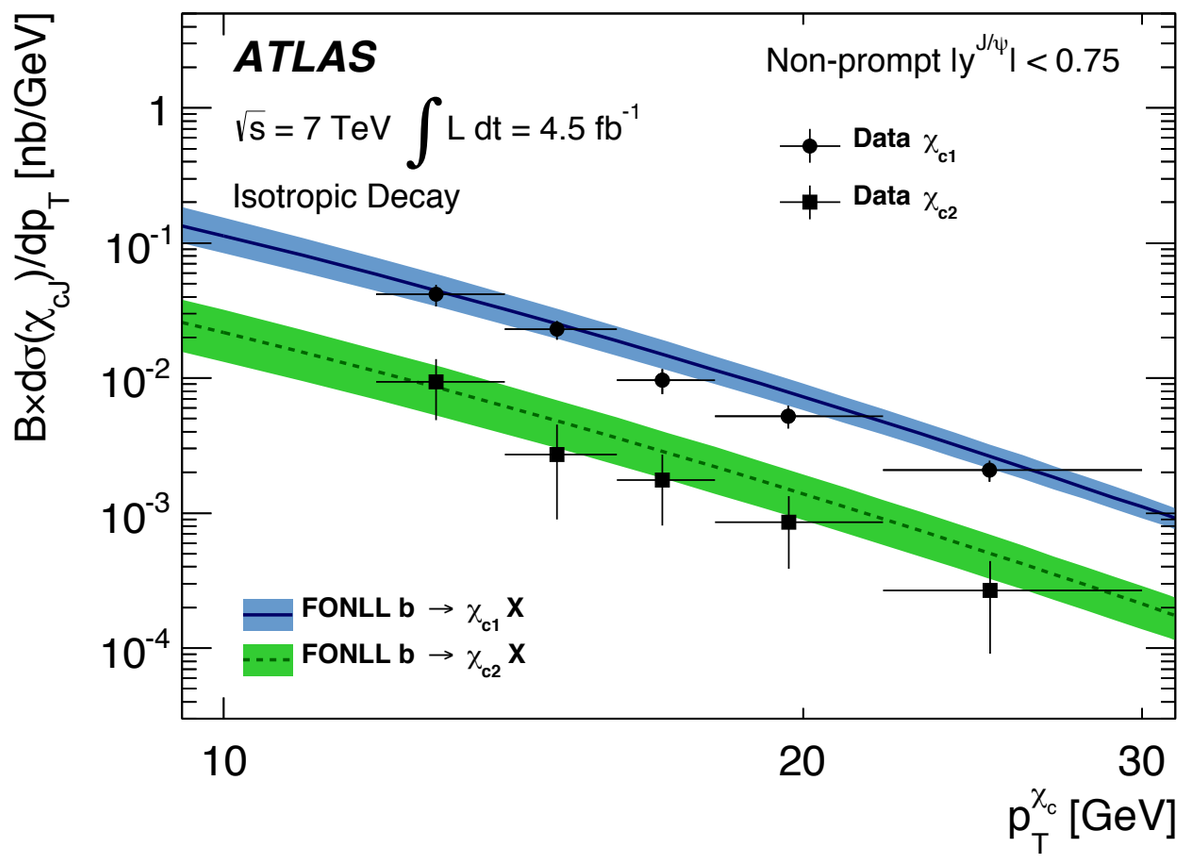
- NLO NRQCD calculations describe ATLAS and CDF data



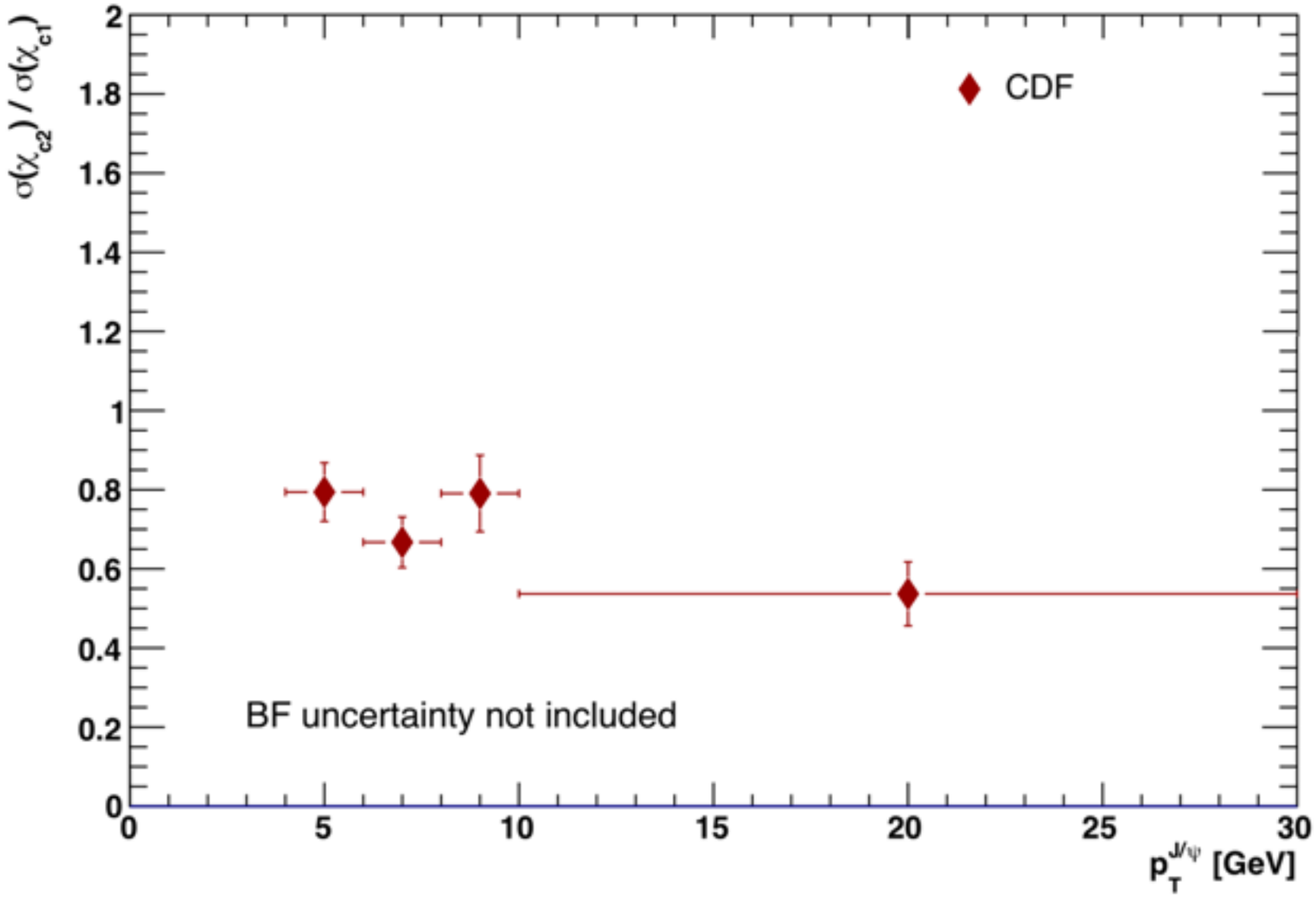
Non-prompt χ_{c1} and χ_{c2} cross sections at ATLAS

- Non-prompt fractions are around 25% for the χ_{c1} and 10% for the χ_{c2}
- Non-prompt cross sections are in agreement with FONLL predictions

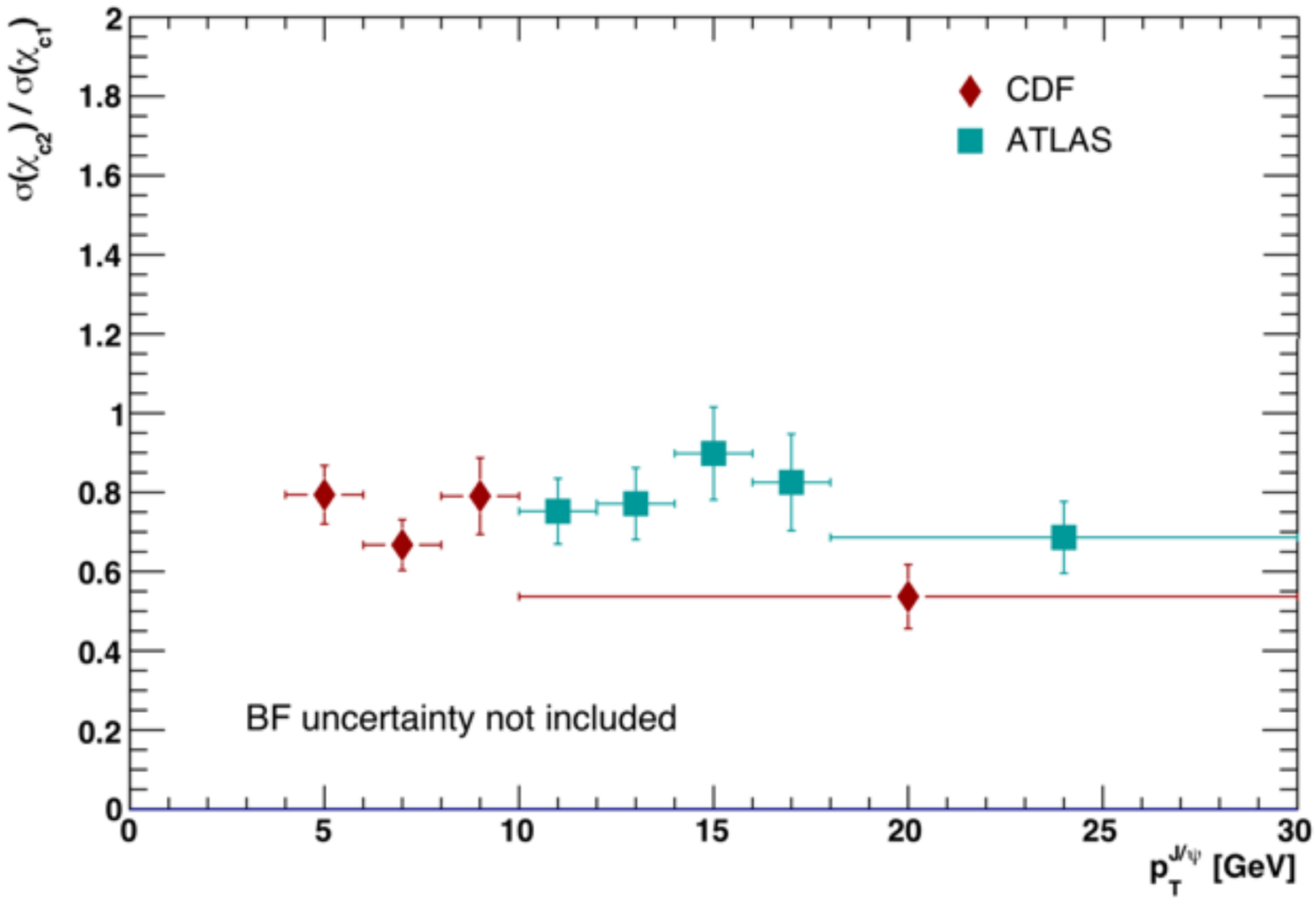




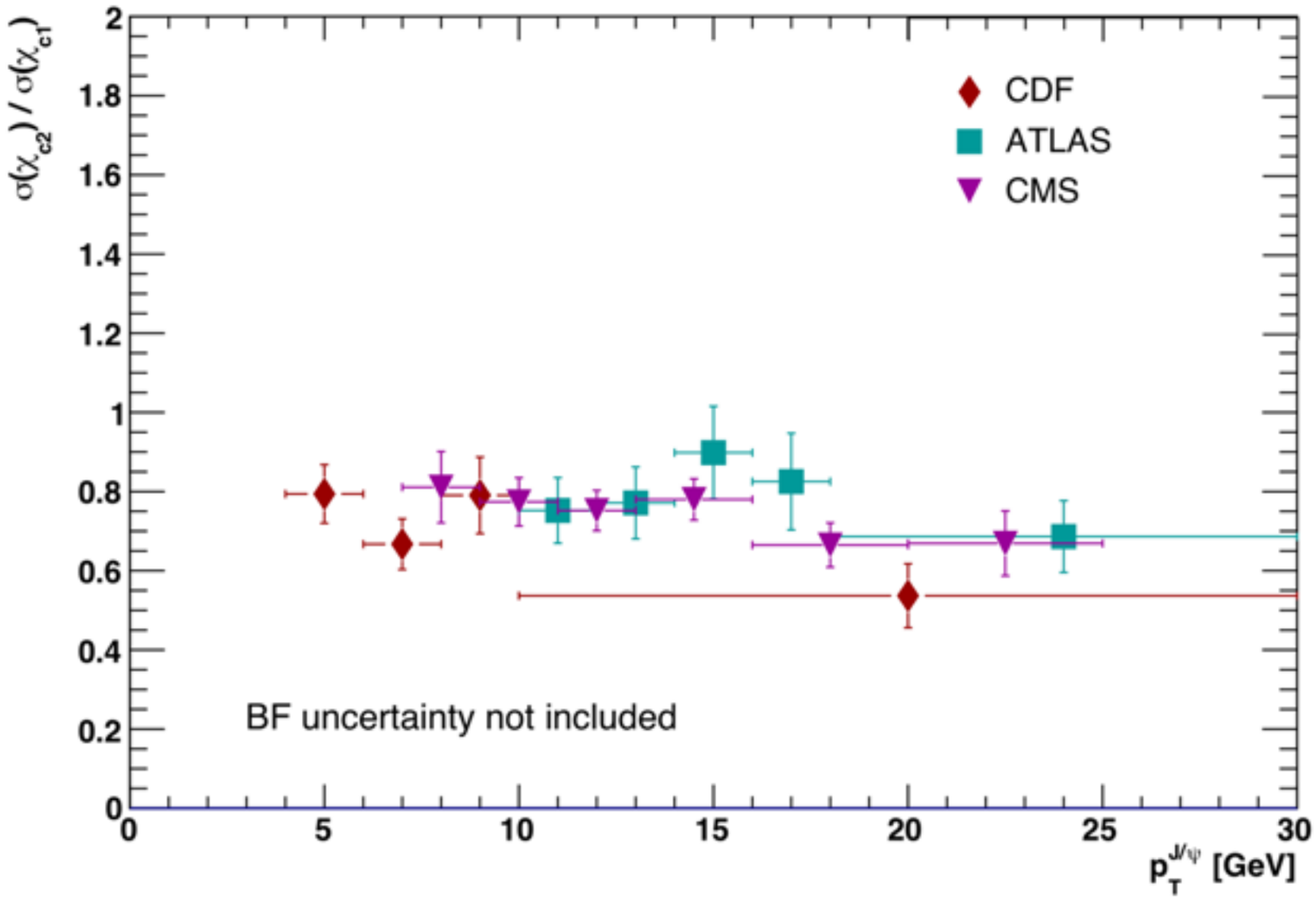
Relative prompt χ_{c2} to χ_{c1} cross section ratio



Relative prompt χ_{c2} to χ_{c1} cross section ratio

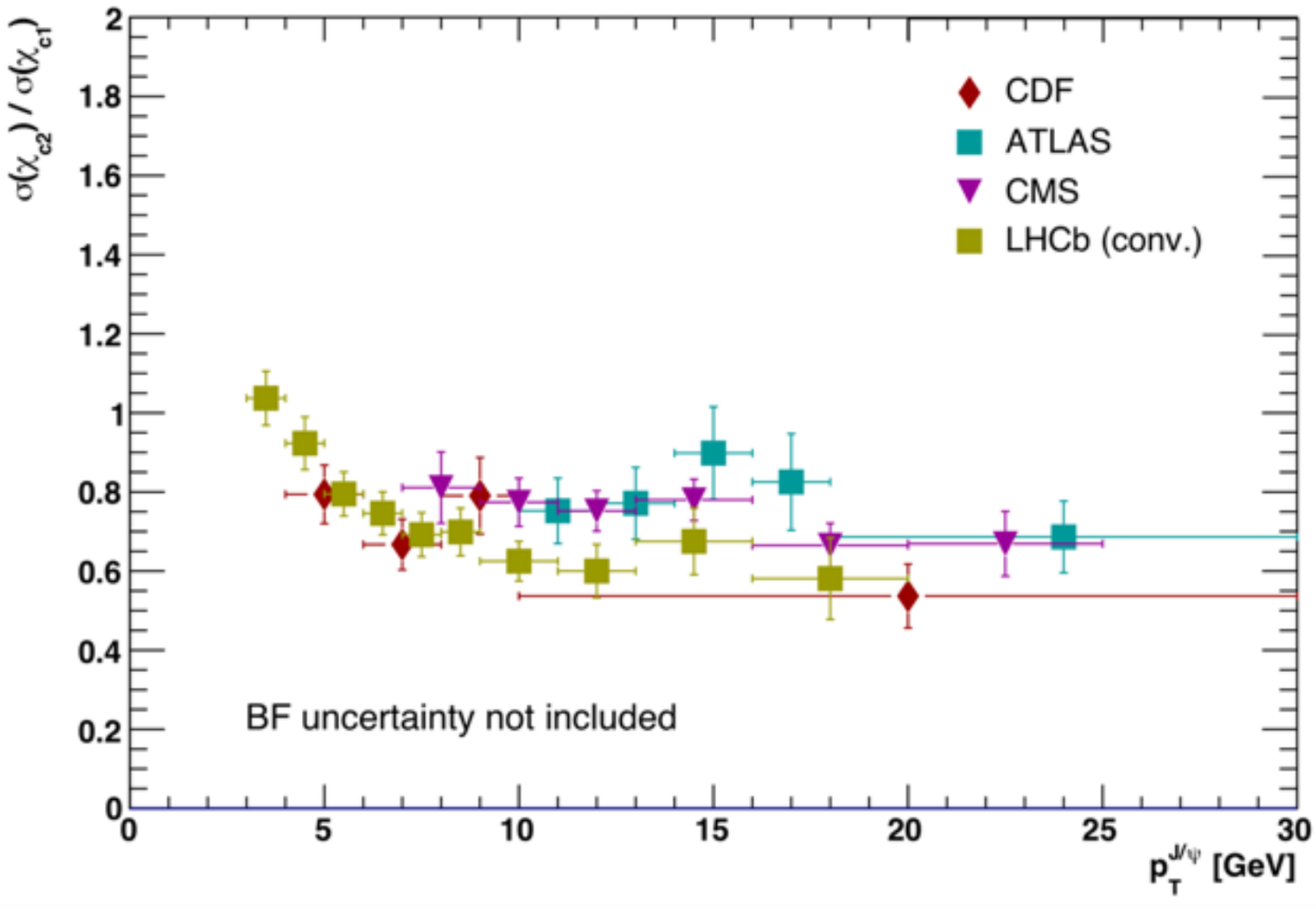


Relative prompt χ_{c2} to χ_{c1} cross section ratio



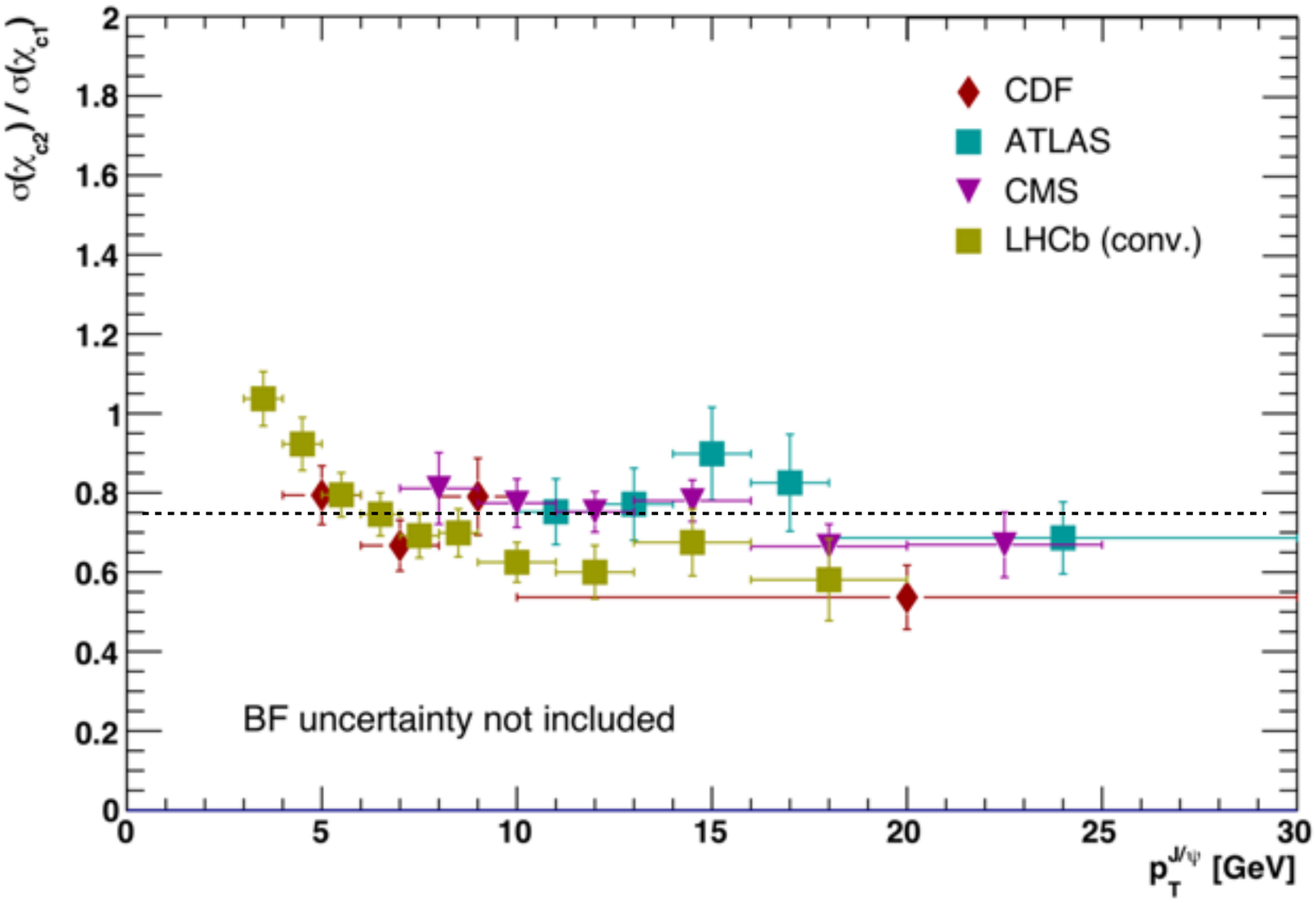
Relative prompt χ_{c2} to χ_{c1} cross section ratio

- Measurements using conversions are consistent



Relative prompt χ_{c2} to χ_{c1} cross section ratio

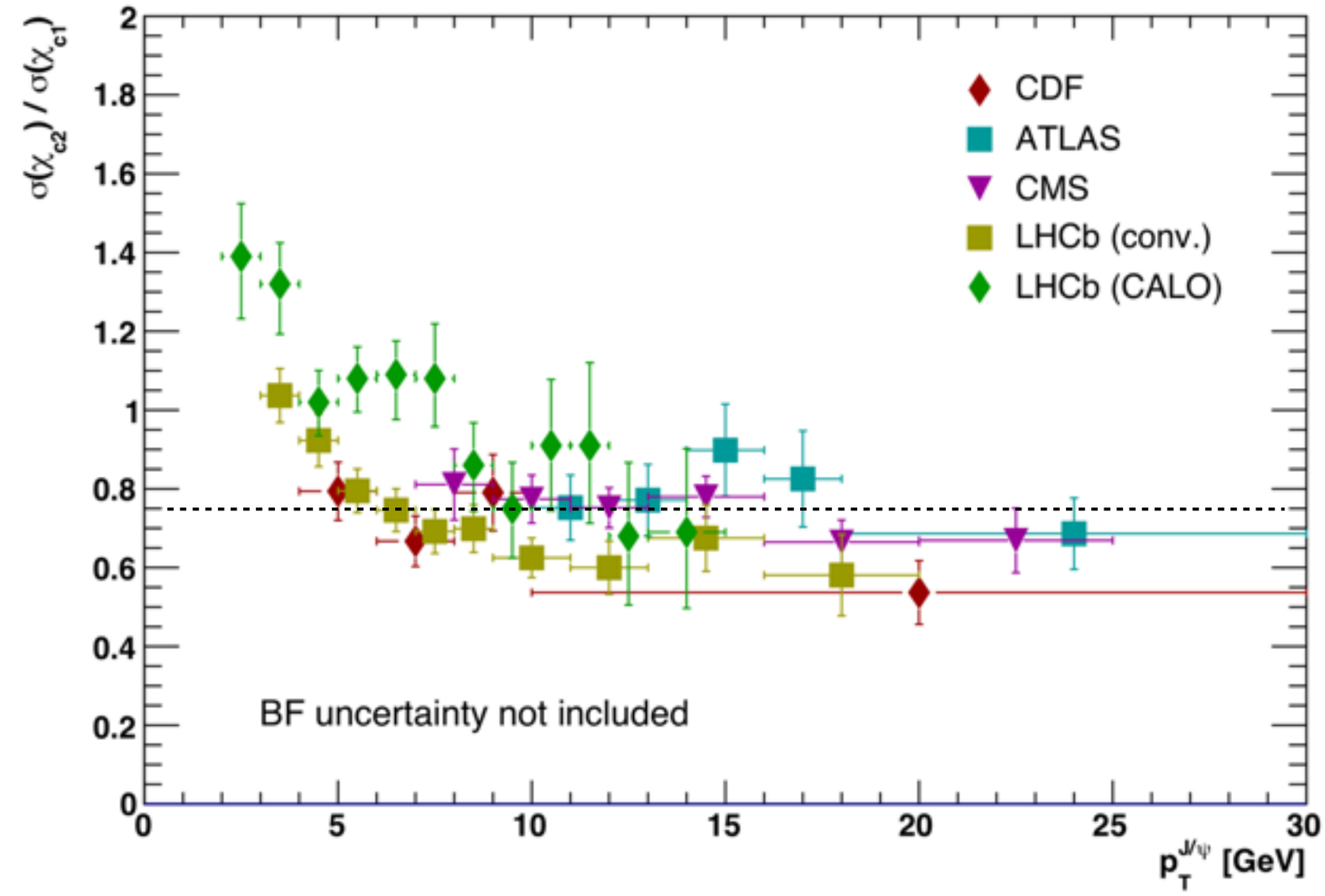
- Measurements using conversions are consistent



Ratio is essentially flat at ~0.75 for $p_T > 5$ GeV for unpolarized χ_c mesons

Relative prompt χ_{c2} to χ_{c1} cross section ratio

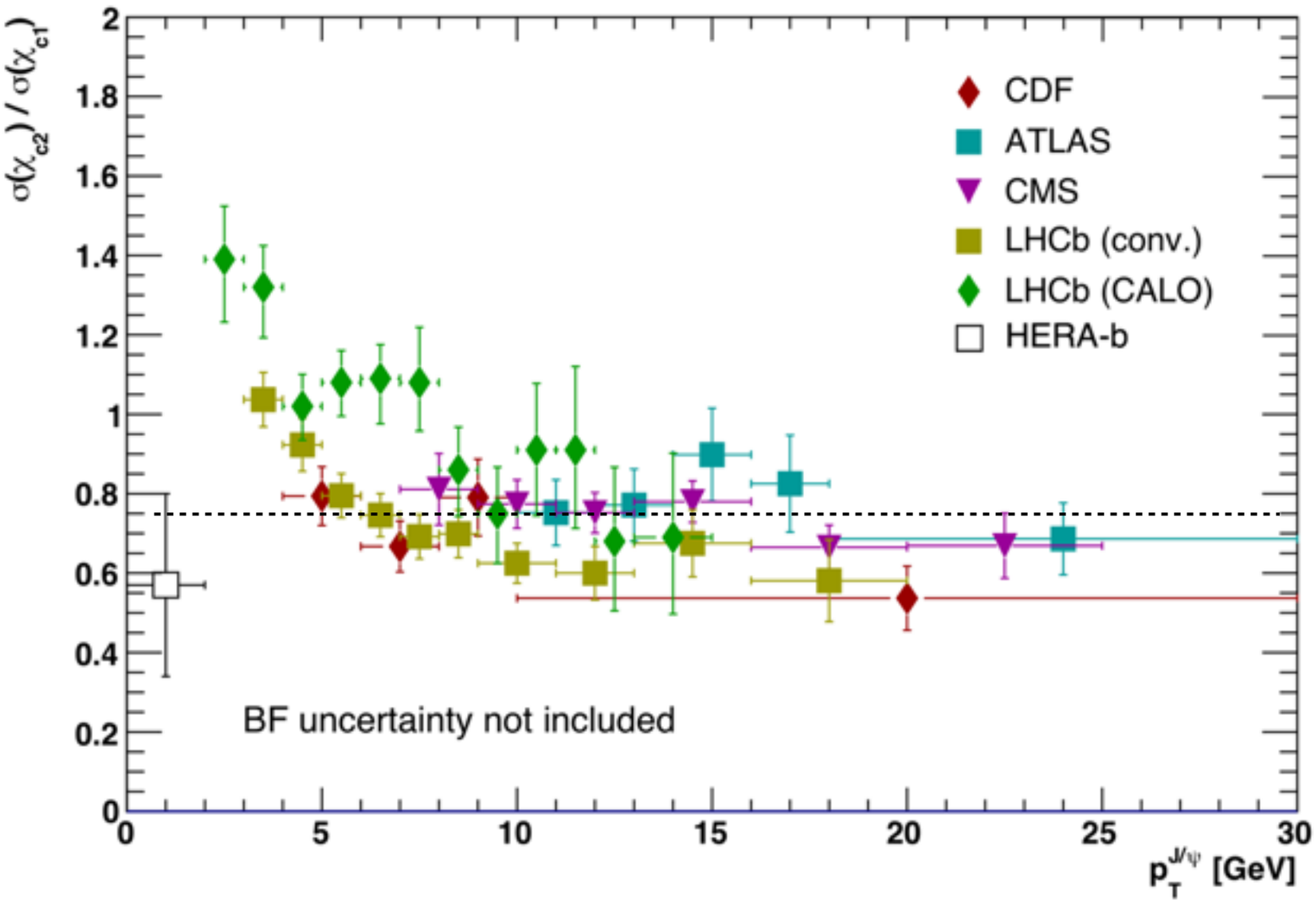
- Measurements using conversions are consistent
- LHCb results are different using different photon detection methods



Ratio is essentially flat at ~0.75 for p_T > 5 GeV for unpolarized χ_c mesons

Relative prompt χ_{c2} to χ_{c1} cross section ratio

- Measurements using conversions are consistent
- LHCb results are different using different photon detection methods

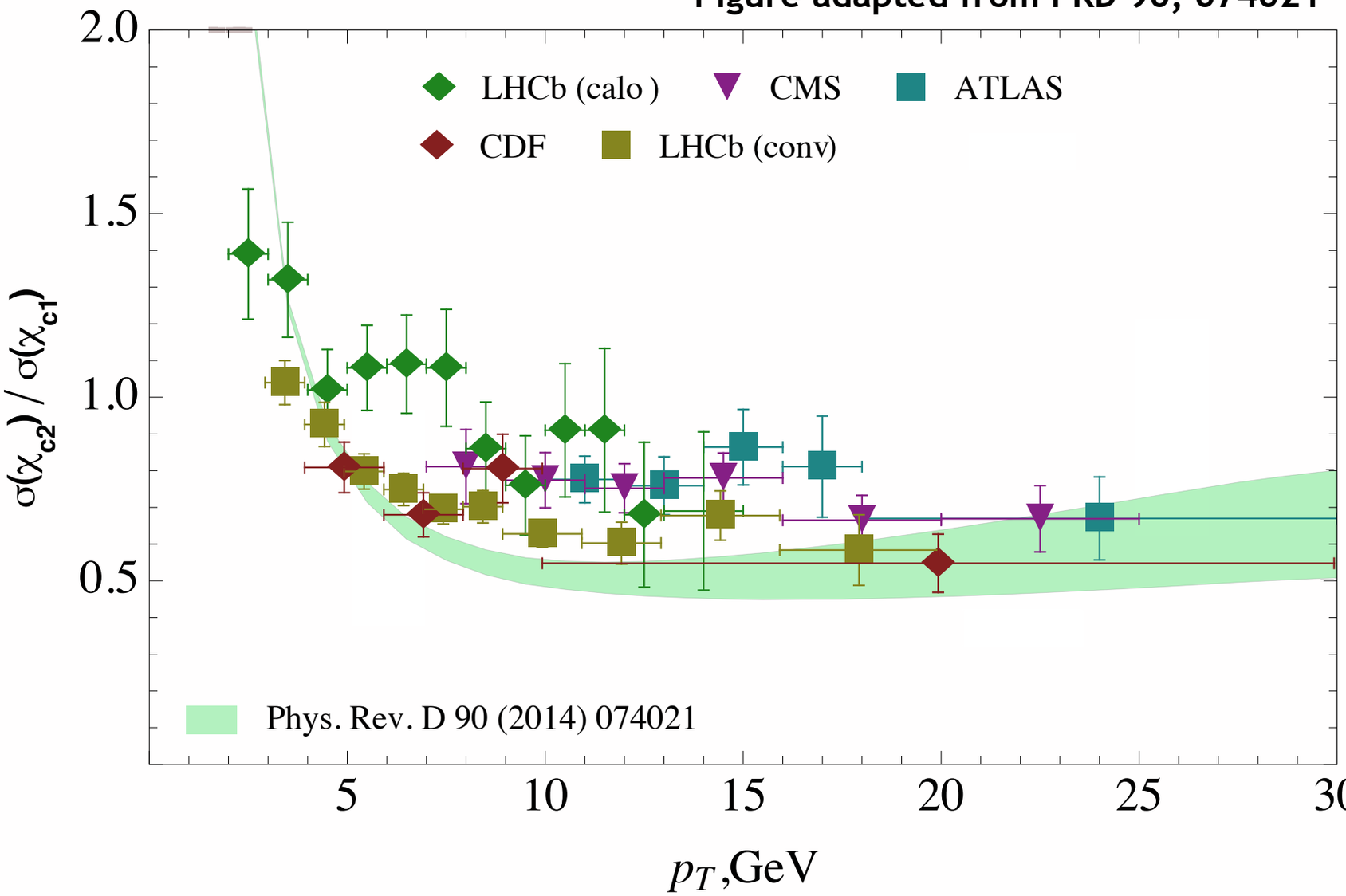


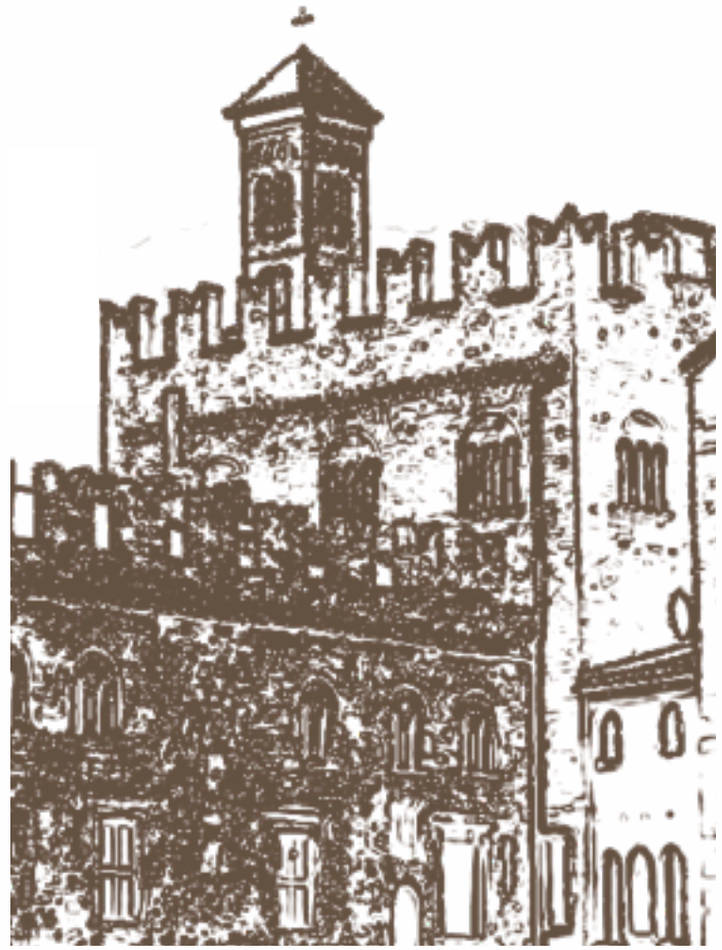
Ratio is essentially flat at ~0.75 for $p_T > 5$ GeV for unpolarized χ_c mesons

Comparison to theory

- LHC and Tevatron data agree with theory calculations
- Theory predicts that CS contribution is dominating

Figure adapted from PRD 90, 074021

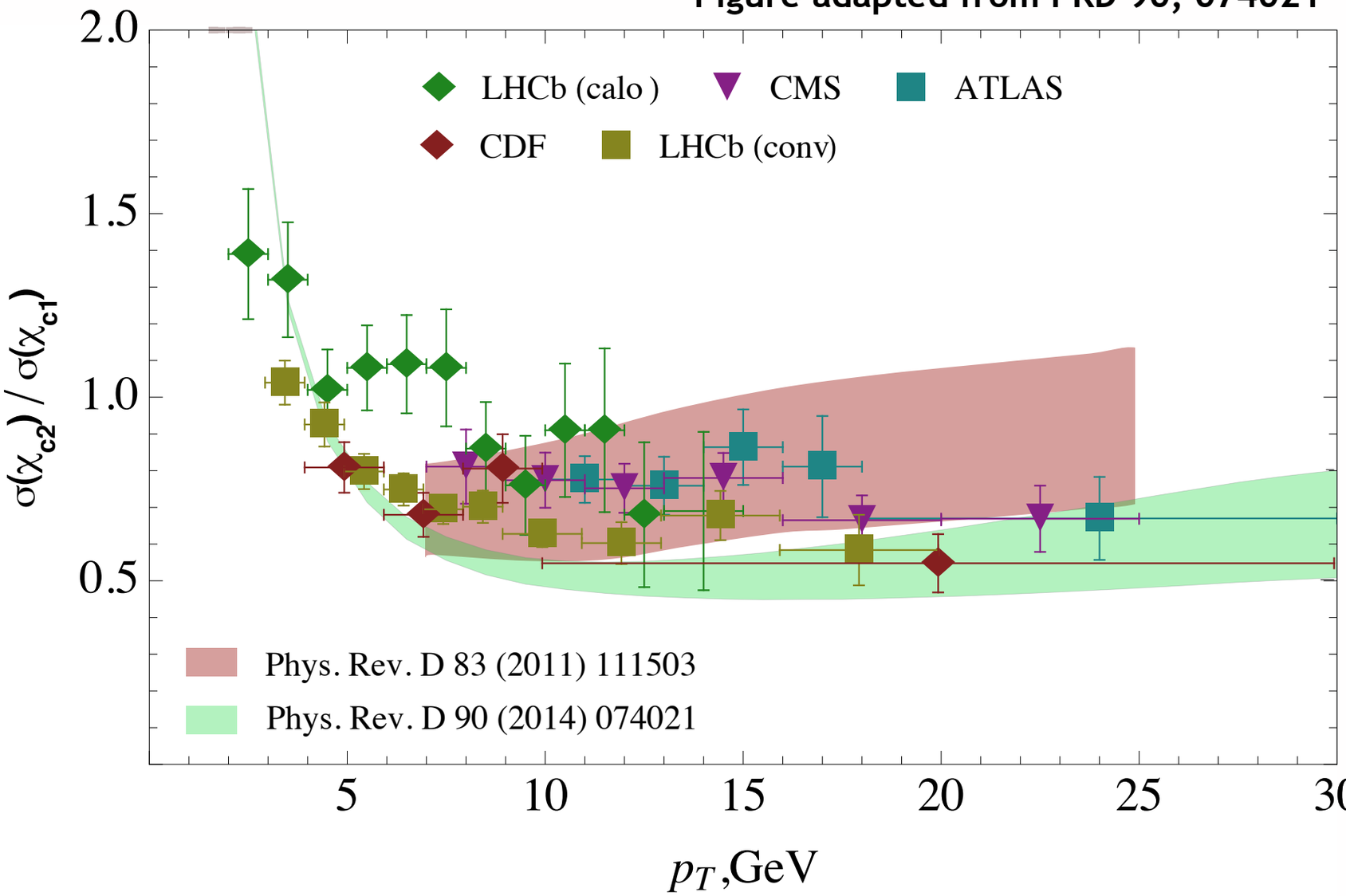


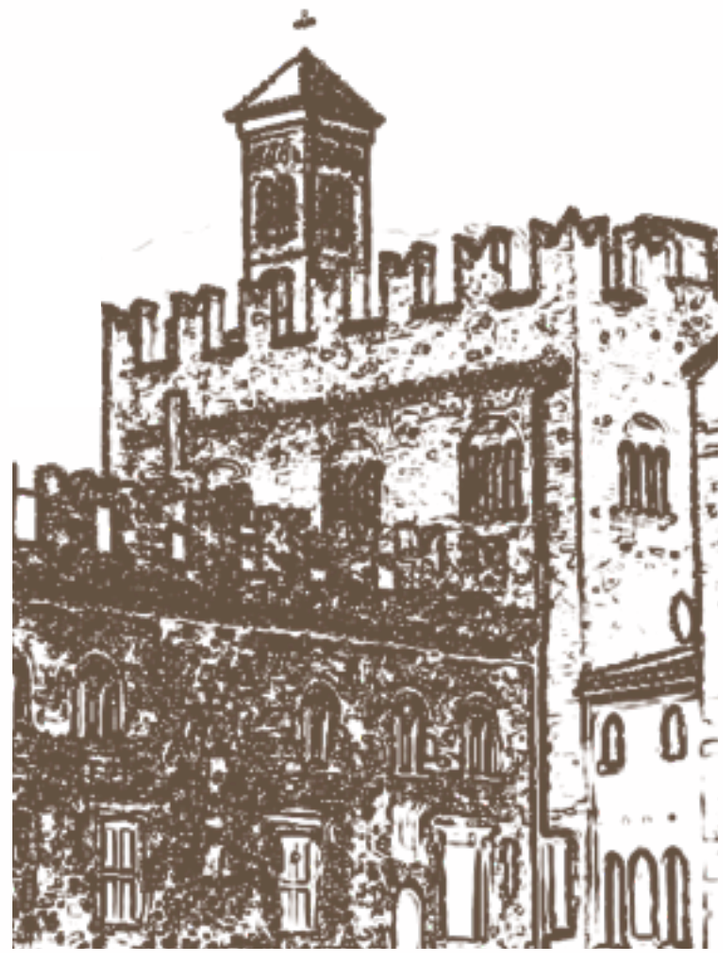


Comparison to theory

- LHC and Tevatron data agree with theory calculations
- Theory predicts that CS contribution is dominating

Figure adapted from PRD 90, 074021

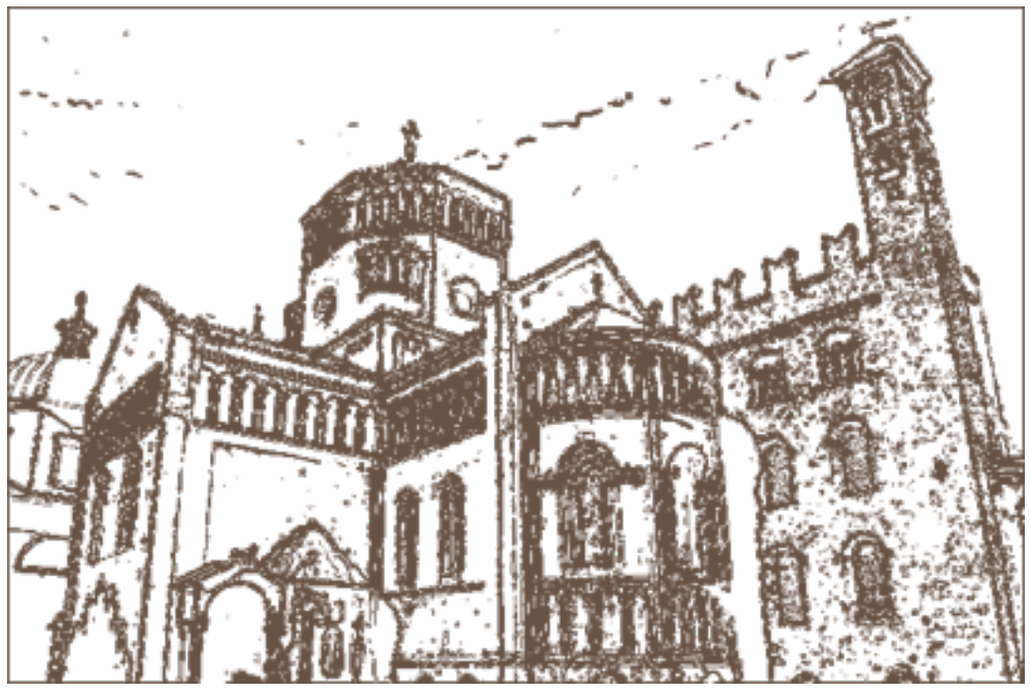


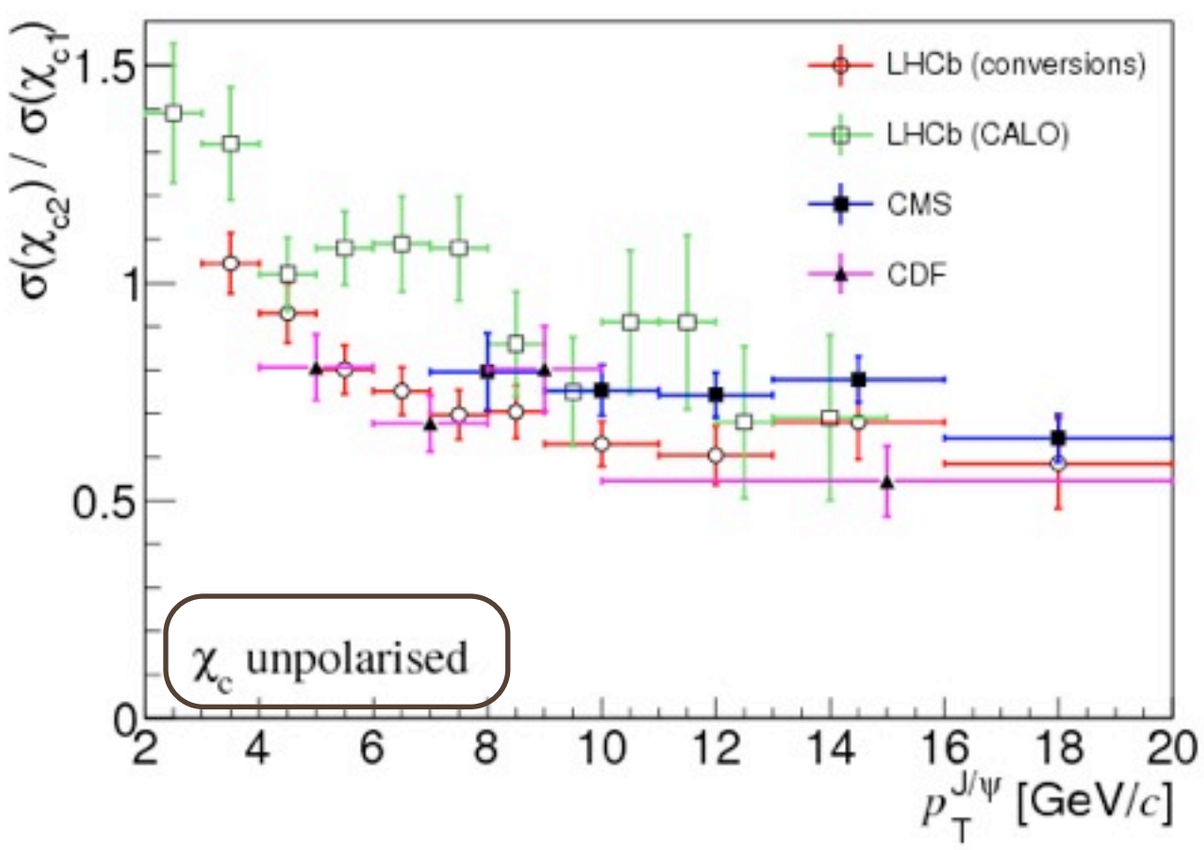


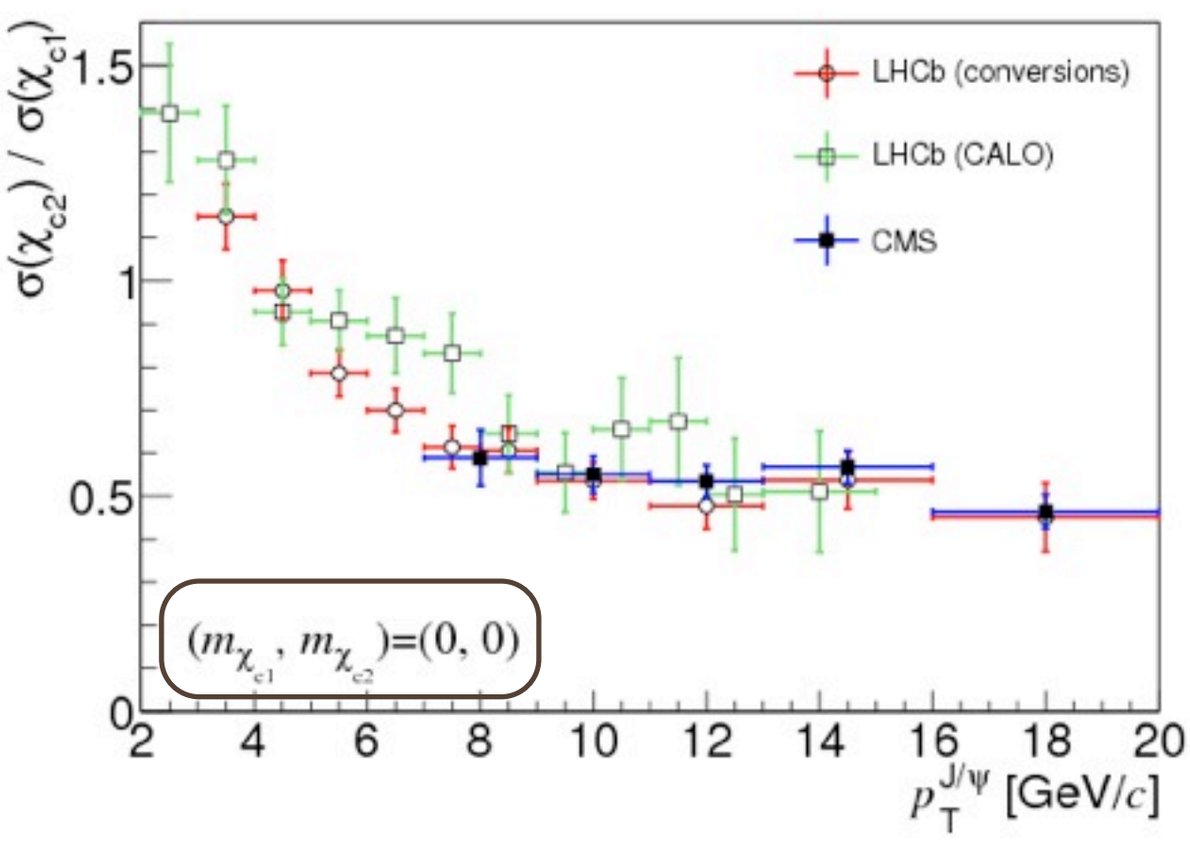
Relative prompt χ_{c2} to χ_{c1} cross section ratio

- Results depend on the polarizations assumed for the two states
- If both states have helicity 0, the LHCb results agree

➡ Important to measure χ_c polarizations

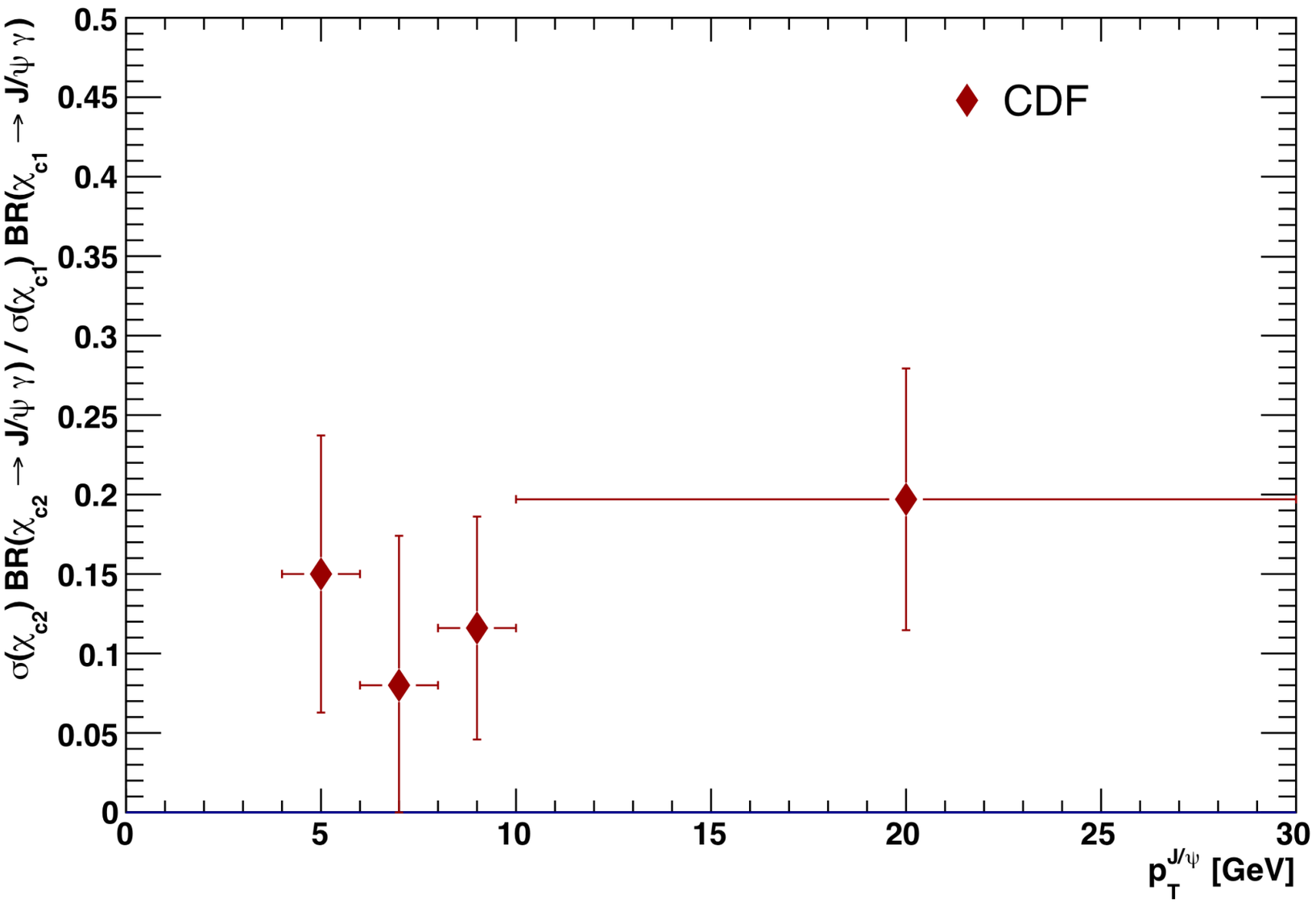






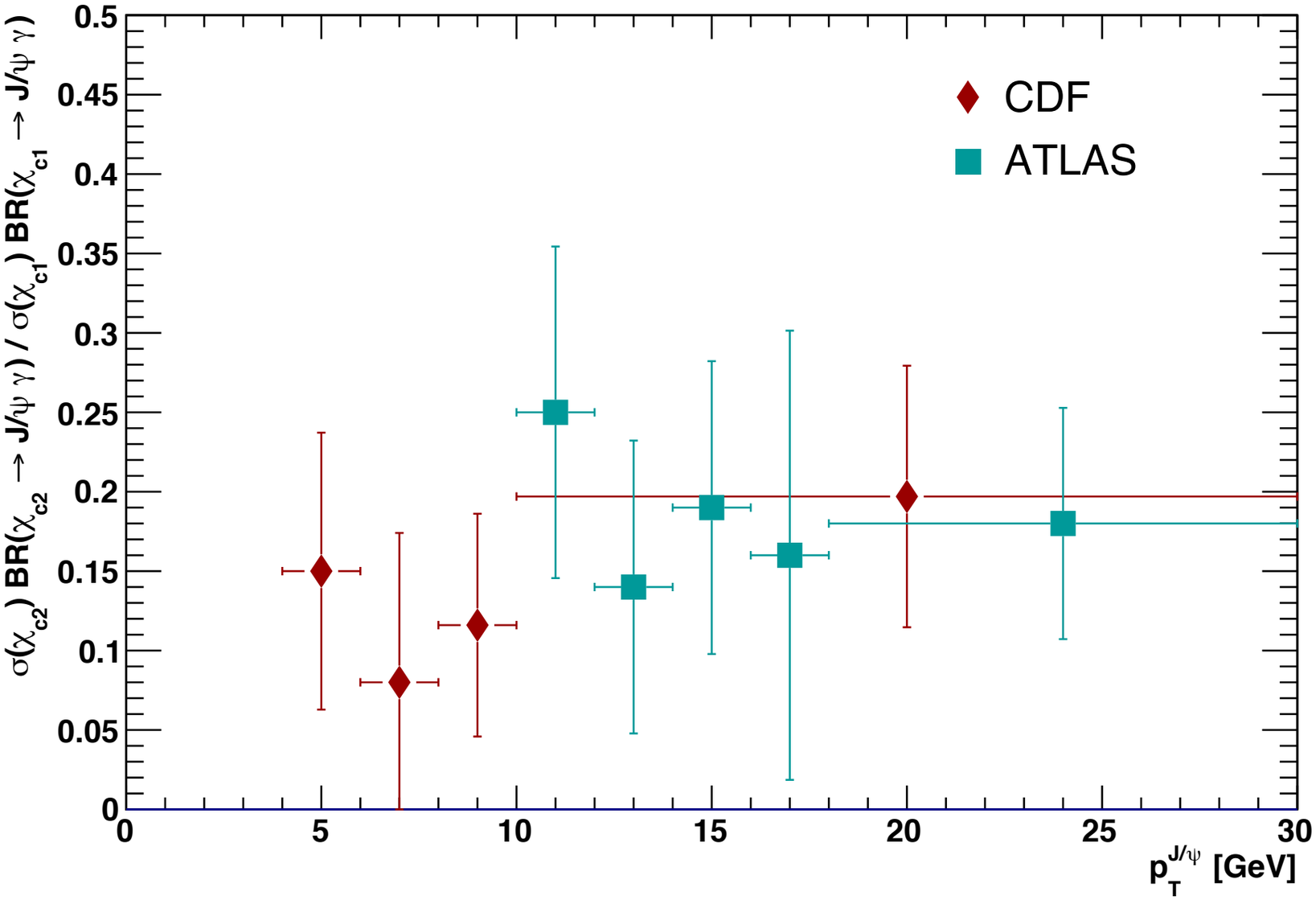
Relative non-prompt $\chi_{c2}(1P)$ to $\chi_{c1}(1P)$ cross section ratio

- Non-prompt ratio seems to be flat



Relative non-prompt $\chi_{c2}(1P)$ to $\chi_{c1}(1P)$ cross section ratio

- Non-prompt ratio seems to be flat
- CDF and ATLAS measurements are in agreement

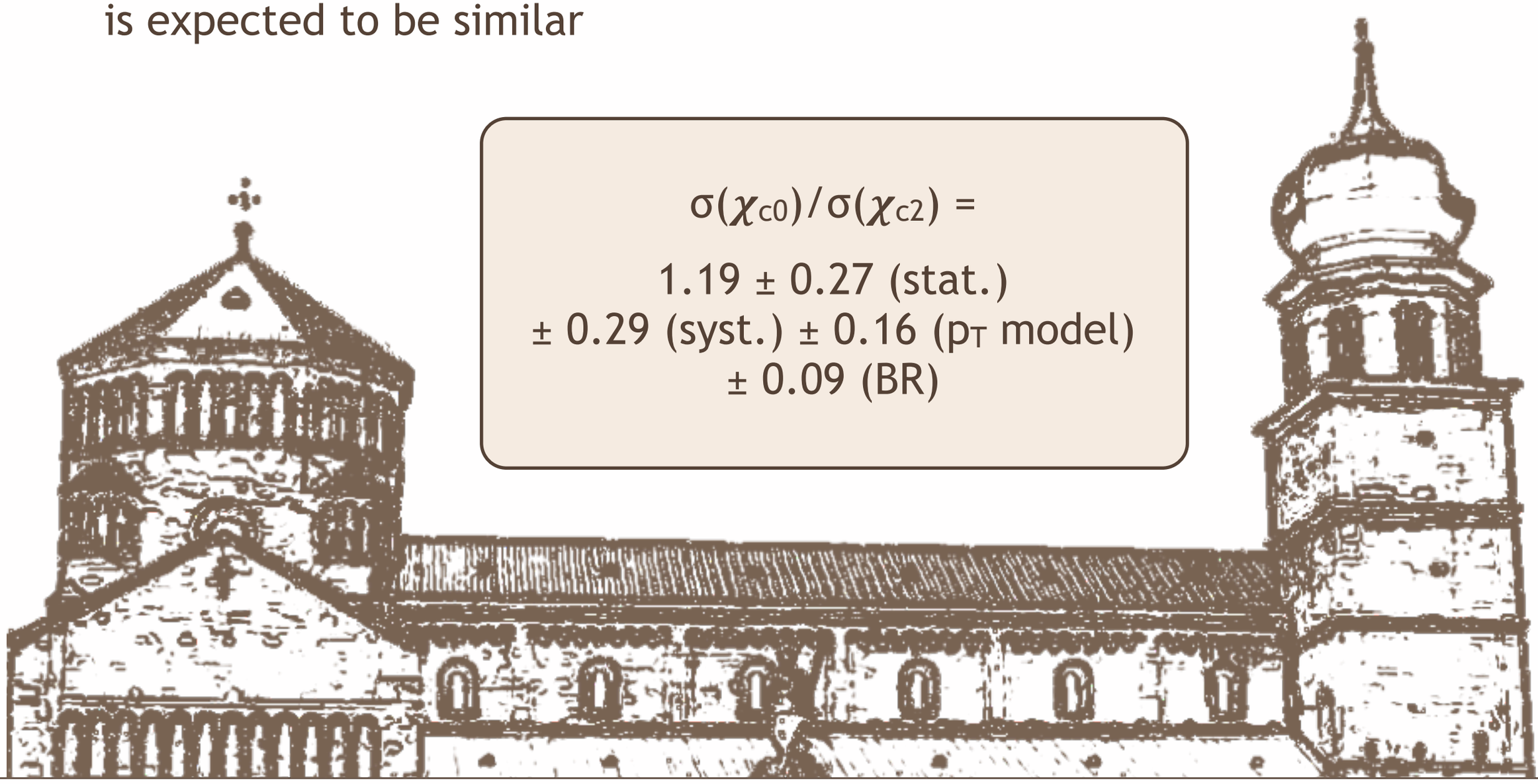


Relative prompt χ_{c0} to χ_{c2} cross section ratio at LHCb

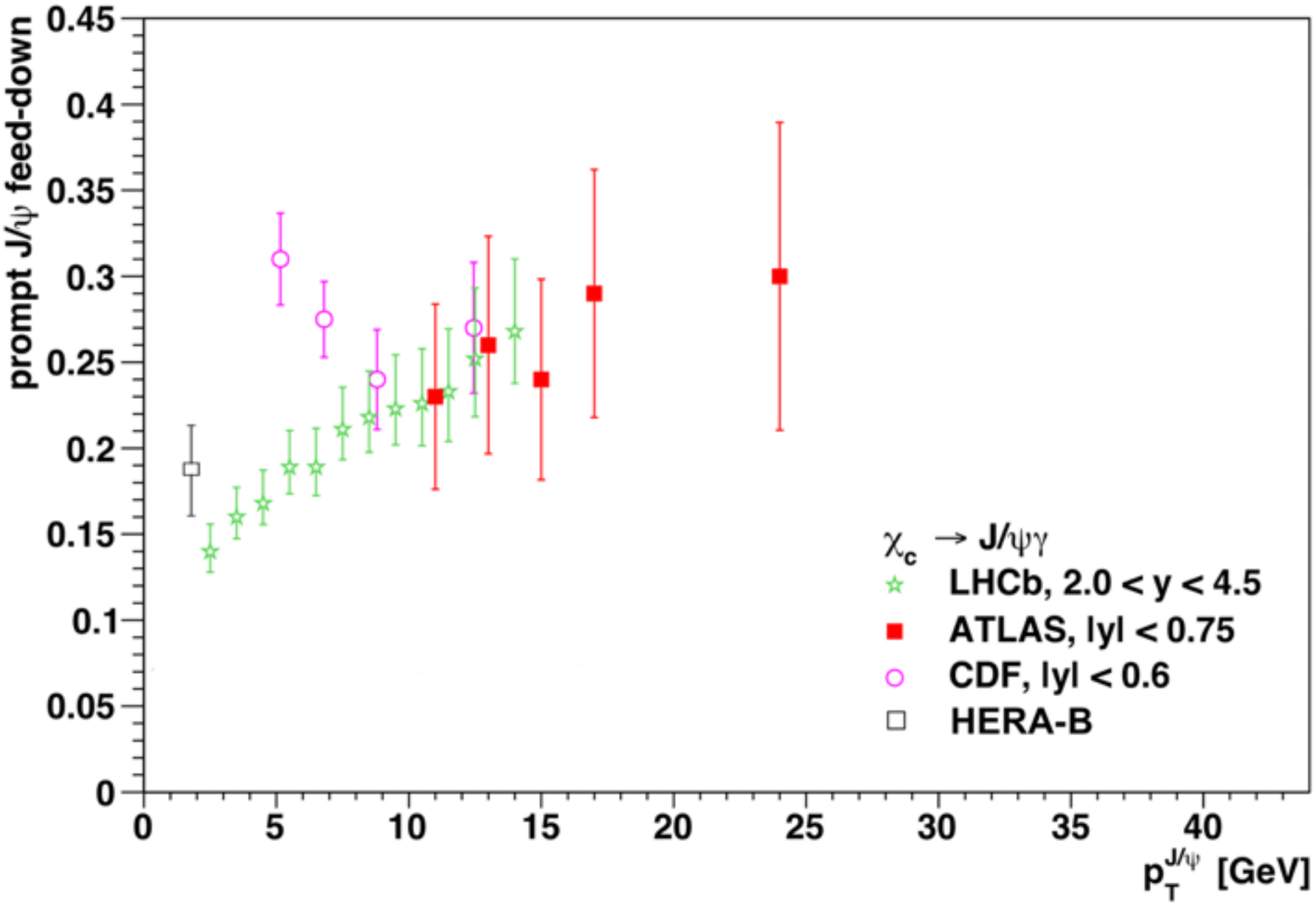
- χ_{c0} signal is observed at LHCb with a significance of 4.3σ
- 705 ± 163 χ_{c0} candidates for $4 < p_T(J/\psi) < 20$ GeV
- χ_{c0} cross section is measured relative to χ_{c2} because the p_T dependence is expected to be similar

$$\sigma(\chi_{c0})/\sigma(\chi_{c2}) =$$

$$1.19 \pm 0.27 \text{ (stat.)} \pm 0.29 \text{ (syst.)} \pm 0.16 \text{ (p_T model)} \pm 0.09 \text{ (BR)}$$



Prompt $\chi_c \rightarrow J/\psi$ feed-down

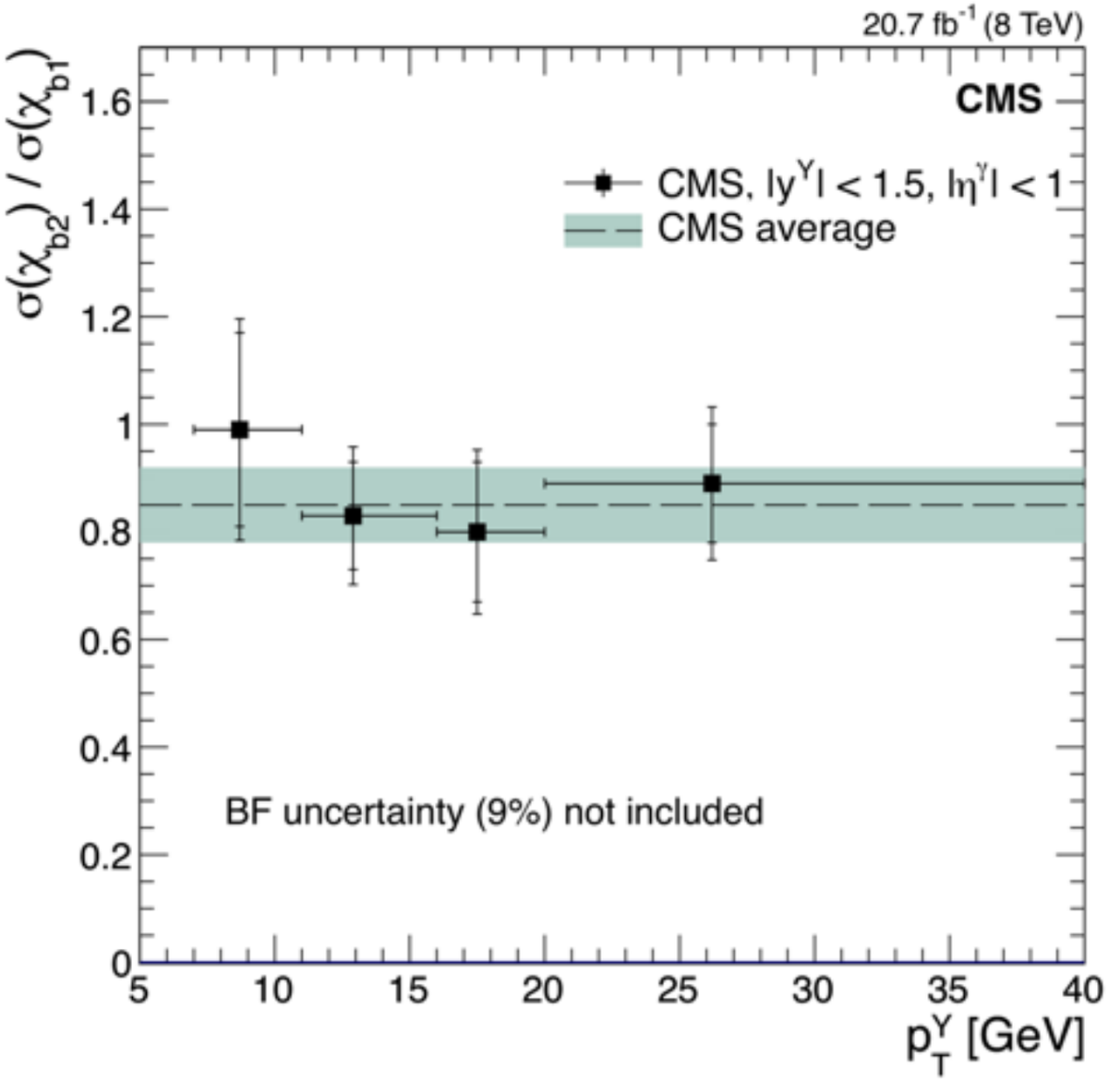


LHCb, ATLAS and higher p_T CDF points are well aligned

Relative $\chi_{b2}(1P)$ to $\chi_{b1}(1P)$ cross section ratio

- χ_b mesons are detected via their radiative decay using converted photons

$$\chi_b(1P) \rightarrow \Upsilon(1S)\gamma \rightarrow \mu^+\mu^- e^+e^-$$

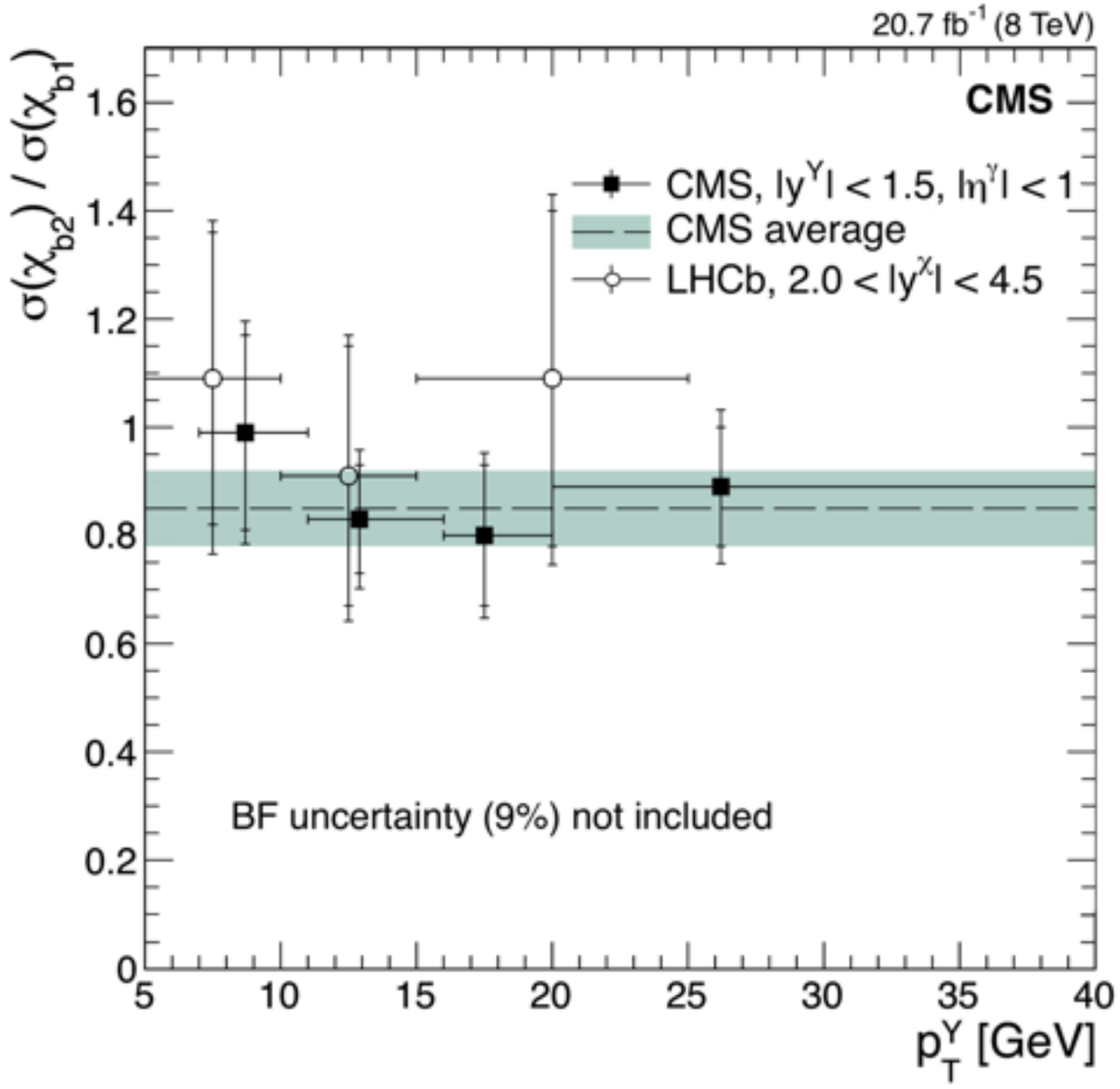


- Ratio is seemingly flat

Relative $\chi_{b2}(1P)$ to $\chi_{b1}(1P)$ cross section ratio

- χ_b mesons are detected via their radiative decay using converted photons

$$\chi_b(1P) \rightarrow \Upsilon(1S)\gamma \rightarrow \mu^+\mu^- e^+e^-$$

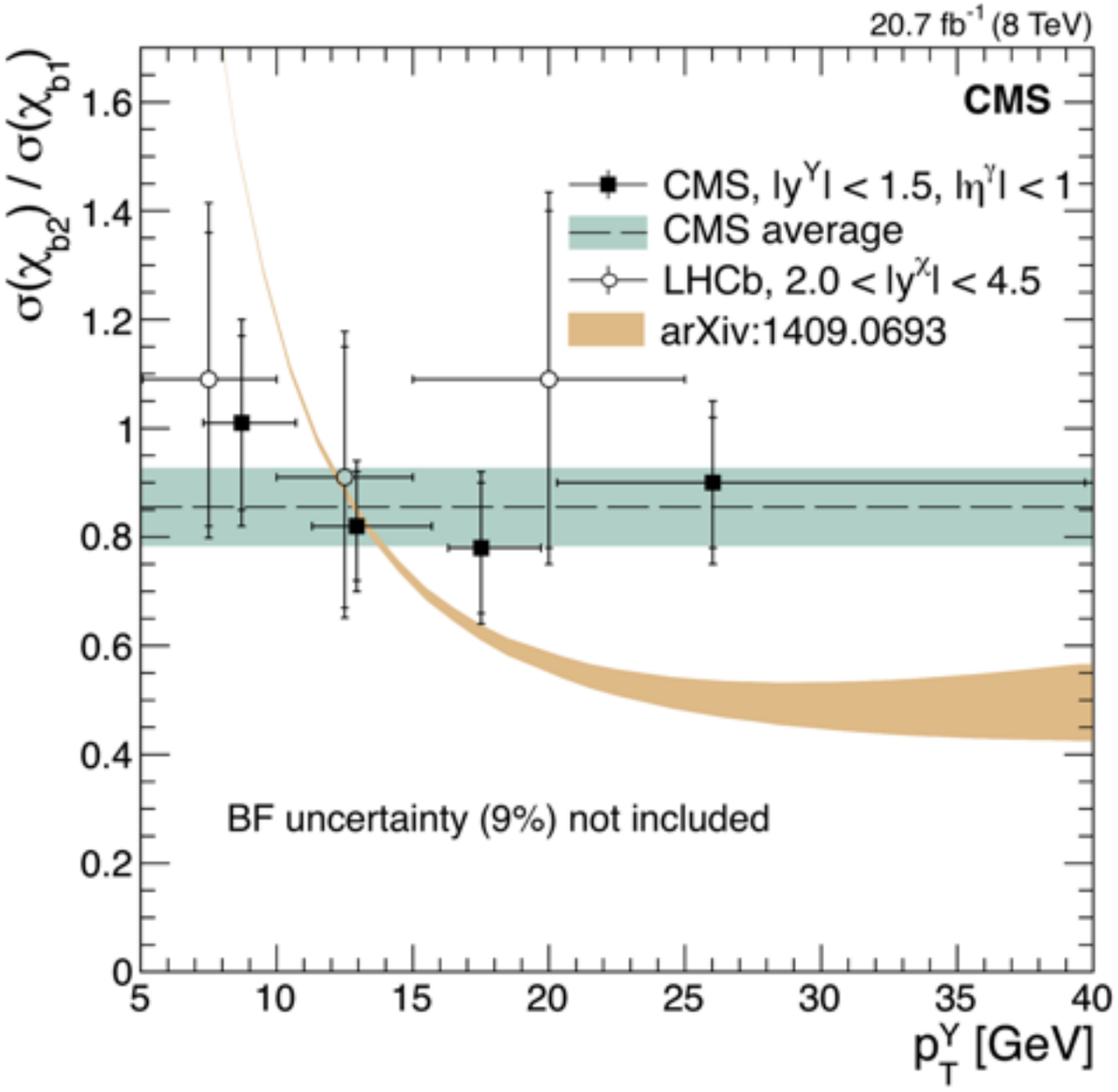


- Ratio is seemingly flat
- LHCb and CMS measurements are consistent within large uncertainties

Relative $\chi_{b2}(1P)$ to $\chi_{b1}(1P)$ cross section ratio

- χ_b mesons are detected via their radiative decay using converted photons

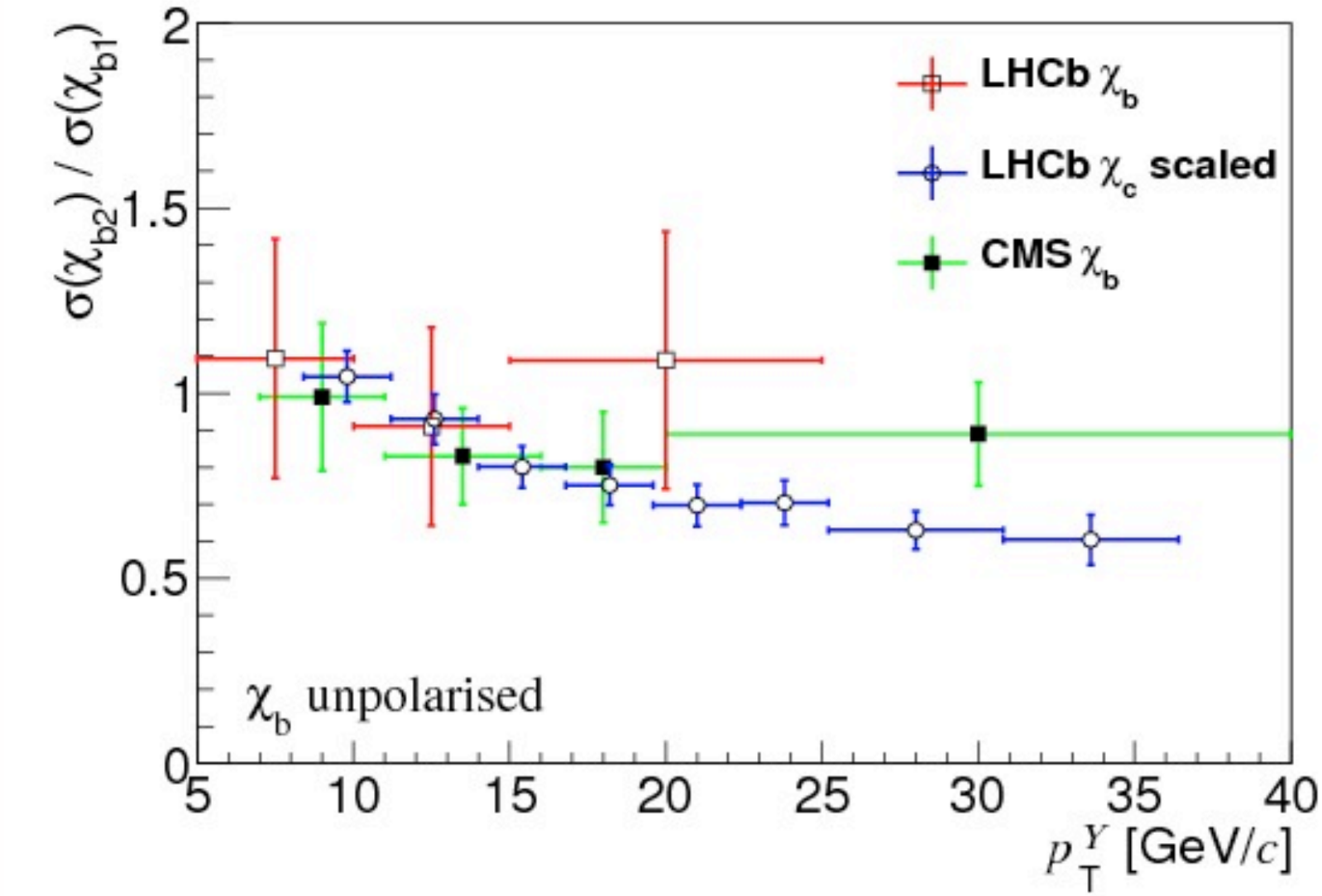
$$\chi_b(1P) \rightarrow \Upsilon(1S)\gamma \rightarrow \mu^+\mu^- e^+e^-$$



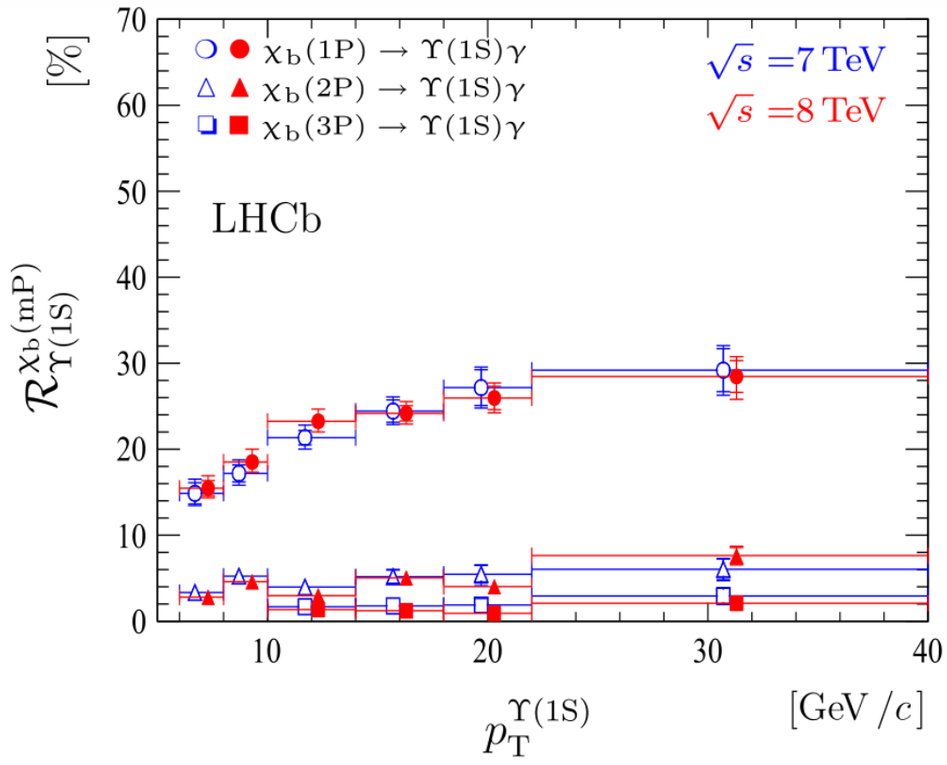
- Ratio is seemingly flat
- LHCb and CMS measurements are consistent within large uncertainties
- Experimental results are in disagreement with theory

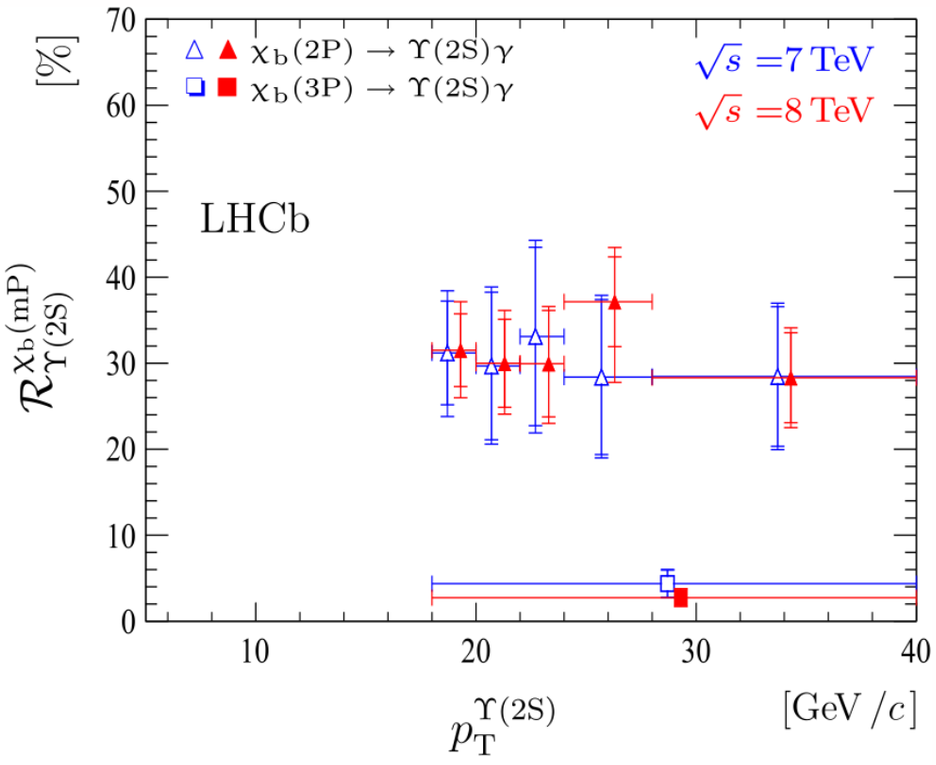
Relative $\chi_{b2}(1P)$ to $\chi_{b1}(1P)$ cross section ratio

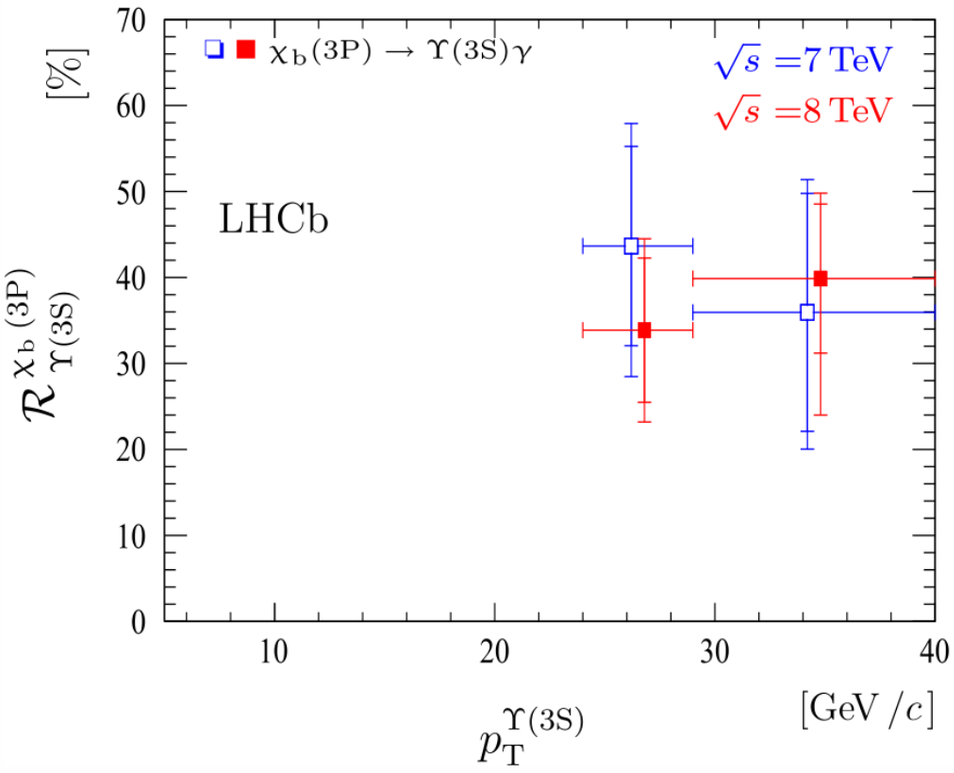
- Scaled LHCb χ_c cross section ratio is consistent with χ_b cross section ratio measurements



χ_b(nP) → Υ(nS) feed-down

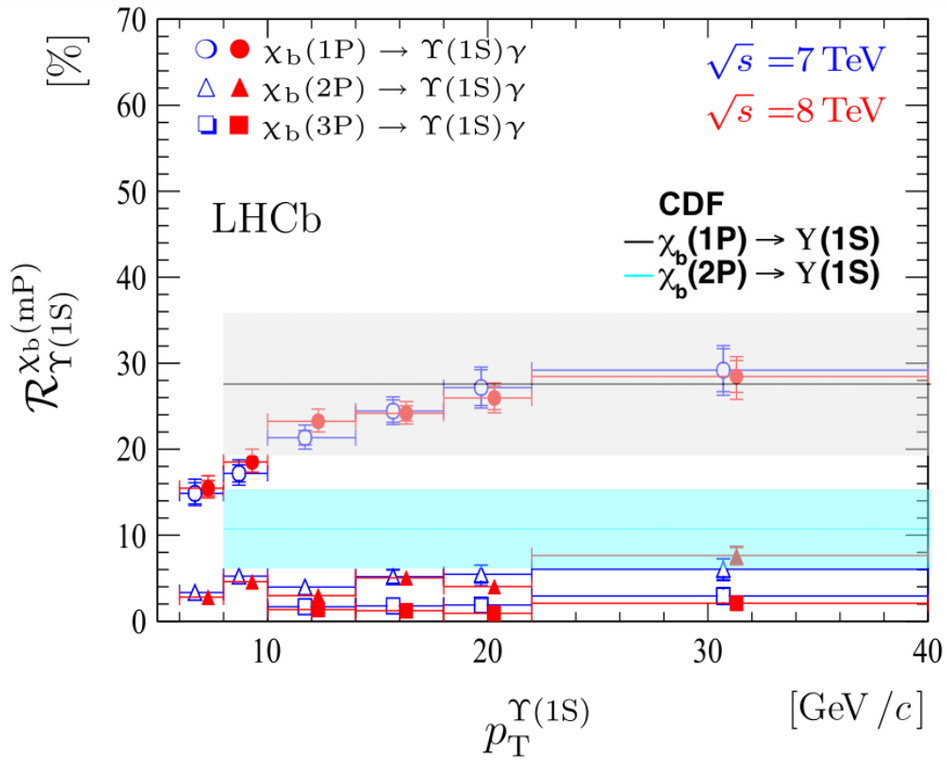


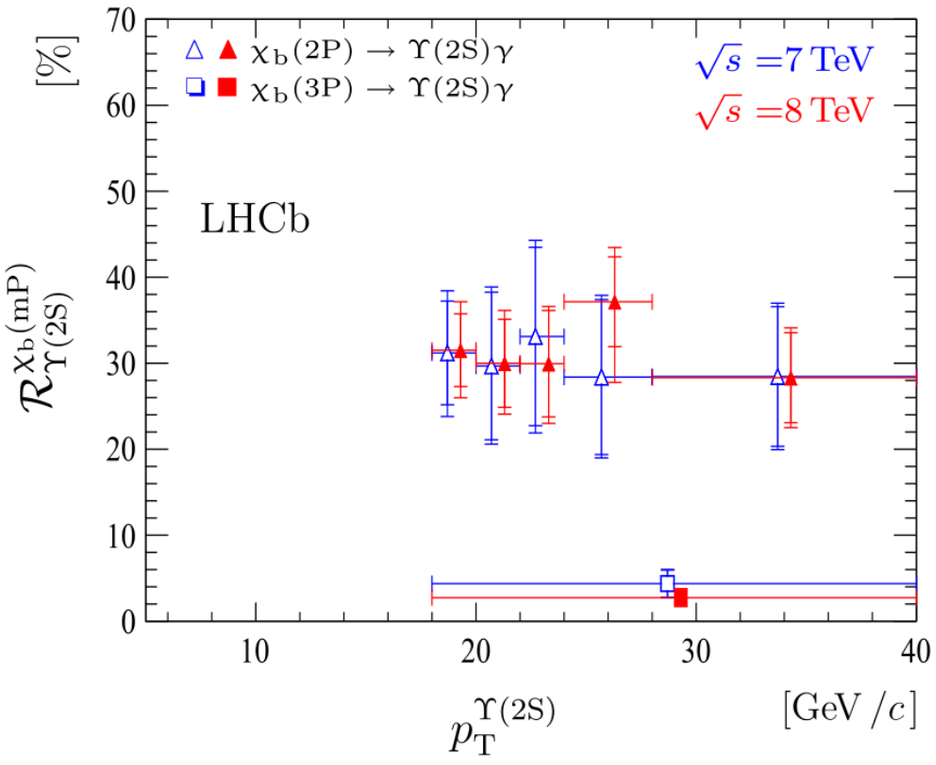


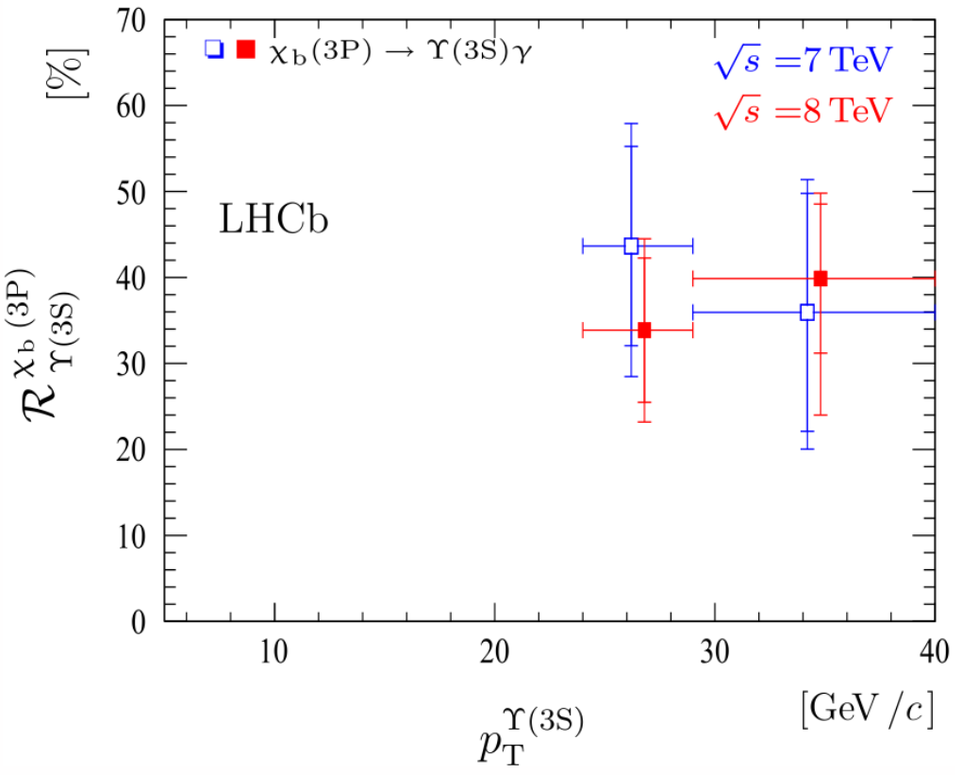


- Large χ_b(3P) → Υ(3S) feed-down fraction

χ_b(nP) → Υ(nS) feed-down







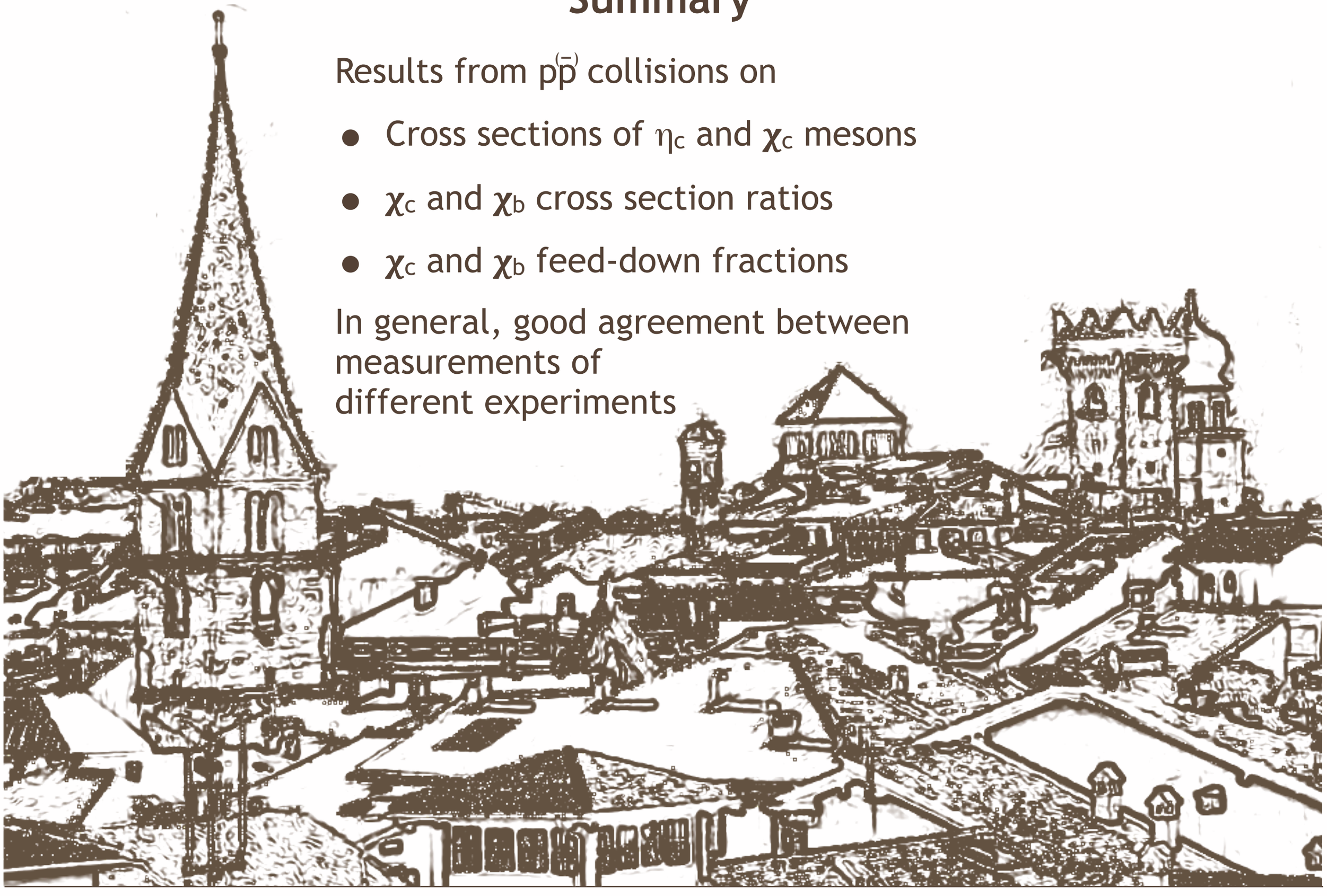
- Large χ_b(3P) → Υ(3S) feed-down fraction
- CDF χ_b(1P) → Υ(1S) feed-down is compatible with LHCb measurement
- CDF χ_b(2P) → Υ(1S) feed-down fraction is higher

Summary

Results from $p\bar{p}^{(-)}$ collisions on

- Cross sections of η_c and χ_c mesons
- χ_c and χ_b cross section ratios
- χ_c and χ_b feed-down fractions

In general, good agreement between measurements of different experiments



References

LHCb collaboration. Measurement of the $\eta_c(1S)$ production cross-section in proton–proton collisions via the decay $\eta_c(1S) \to p\bar{p}$. Eur. Phys. J. C (2015) 75:311

LHCb collaboration. Measurement of the cross-section ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ for prompt χ_c production at $\sqrt{s}$ = 7 TeV. Phys. Lett. B 714 (2012) 215–223

ATLAS collaboration. Measurement of χ_{c1} and χ_{c2} production with $\sqrt{s}$ = 7 TeV pp collisions at ATLAS. JHEP 07 (2014) 154

CMS collaboration. Measurement of the relative prompt production rate of χ_{c2} and χ_{c1} in pp collisions at $\sqrt{s}$ = 7 TeV. Eur. Phys. J. C (2012) 72:2251

LHCb collaboration. Measurement of the relative rate of prompt χ_{c0}, χ_{c1} and χ_{c2} production at $\sqrt{s}$ = 7 TeV. JHEP 10 (2013) 115

HERA-B collaboration. Production of the charmonium states χ_{c1} and χ_{c2} in proton nucleus interactions at $\sqrt{s}$ = 41.6 GeV. Phys. Rev. D 79, 012001 (2009)

CDF collaboration. Production of J/ψ Mesons from χ_c Meson Decays in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.8 TeV. Phys. Rev. Lett. 79, 578 (1997)

CDF collaboration. Measurement of $\sigma(\chi_{c2})$ BR($\chi_{c2} \to J/\psi\gamma$) / $\sigma\chi_{c1}$ BR($\chi_{c1} \to J/\psi\gamma$) in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.96TeV. Phys. Rev. Lett. 98, 232001 (2007)

LHCb collaboration. Measurement of the ratio of prompt χ_c to J/ψ production in pp collisions at $\sqrt{s}$ = 7 TeV. Phys. Lett. B 718 (2012) 431–440

LHCb collaboration. Measurement of the cross-section ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ for prompt χ_c production at $\sqrt{s}$ = 7 TeV. Phys. Lett. B 714 (2012) 215–223

References

CMS collaboration.Measurement of the production cross section ratio $\sigma(\chi_{b2}(1P))/\sigma(\chi_{b1}(1P))$ in pp collisions at $\sqrt{s}$ = 8 TeV. Phys. Lett. B 743 (2015) 383–402

LHCb collaboration.Study of χ_b meson production in pp collisions at $\sqrt{s}$ = 7 and 8 TeV and observation of the decay $\chi_b(3P) \rightarrow \Upsilon(3S)\gamma$. Eur. Phys. J. C (2014) 74:3092

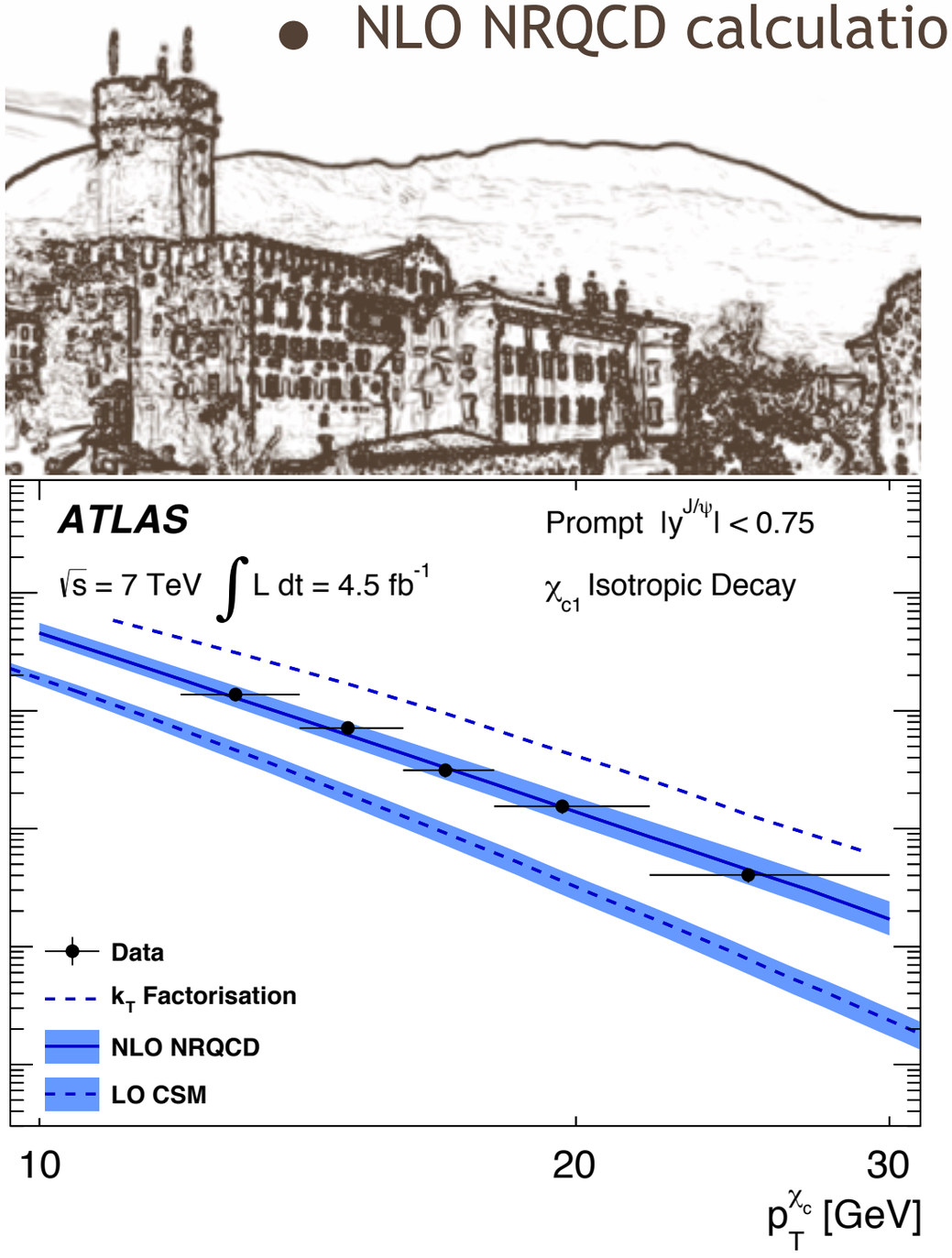
LHCb collaboration. Measurement of the $\chi_b(3P)$ mass and of the relative rate of $\chi_{b1}(1P)$ and $\chi_{b2}(1P)$ production. JHEP 10 (2014) 088

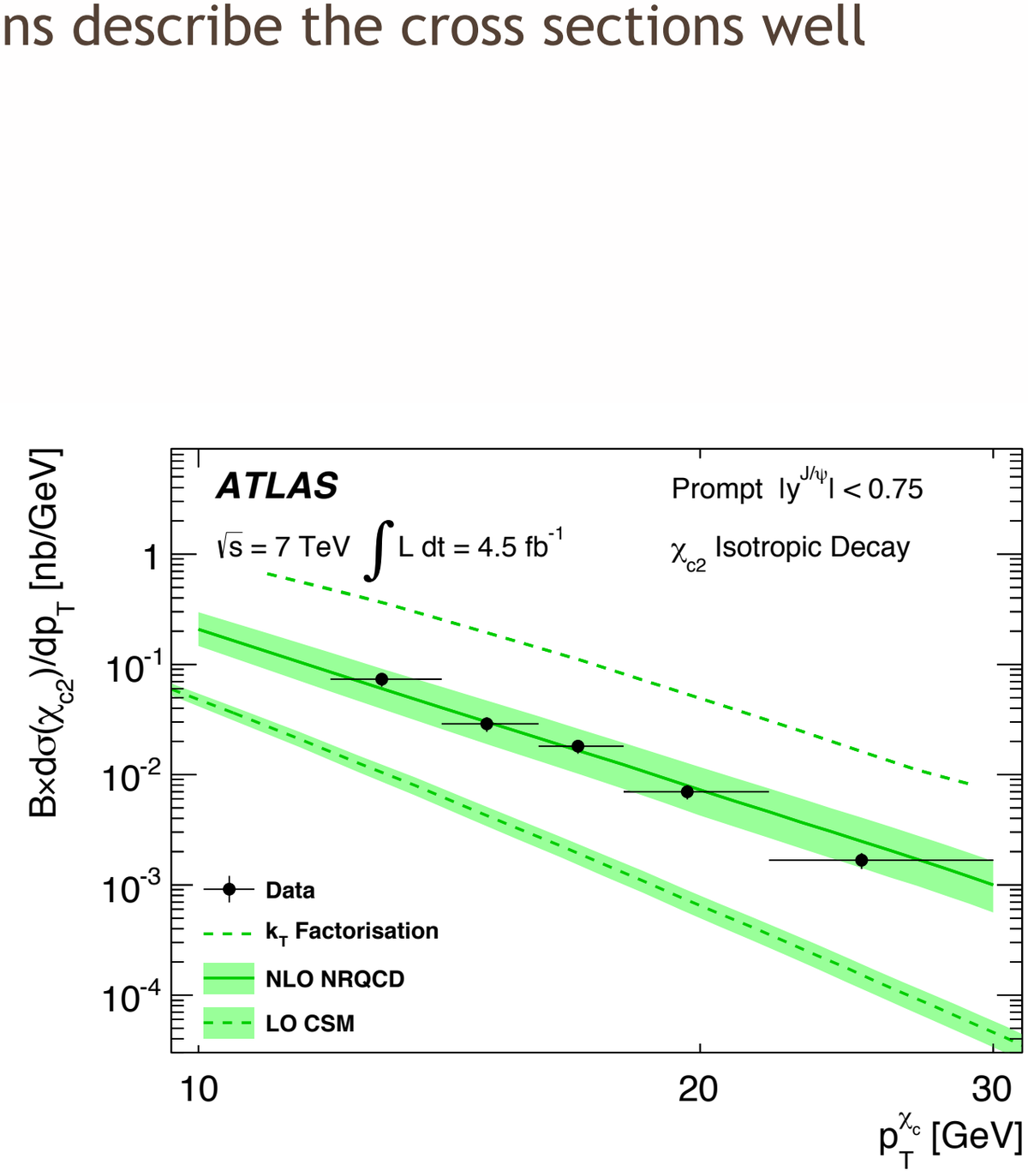
CDF collaboration. Production of Υ(1S) Mesons from χ_b Decays in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.8 TeV. Phys. Rev. Lett. 84 (2000) 2094

BACKUP

Prompt χ_{c1} and χ_{c2} cross sections at ATLAS

- ATLAS provides cross sections as function of J/ψ and χ_c p_T
- NLO NRQCD calculations describe the cross sections well





$\chi_c \rightarrow J/\psi$ feed-down at PHENIX

- No distinction between prompt and non-prompt χ_c mesons
- J/ψ detected through its decay to electrons
- Feed-down fraction is 32 ± 9 % for $|y| < 0.35$ in pp collisions at $\sqrt{s}$ = 200 GeV