

Fragmentation contributions to hadroproduction of prompt J/ψ , χ_{cJ} , and $\psi(2S)$ states



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GTB, HSC, URK, JL, PRL113, 022001 (2014); PRD92, 074042 (2015); GTB, HSC, URK, JL, YQM, KTC, PRD93, 034041 (2016)

Inclusive J/ψ production in NRQCD

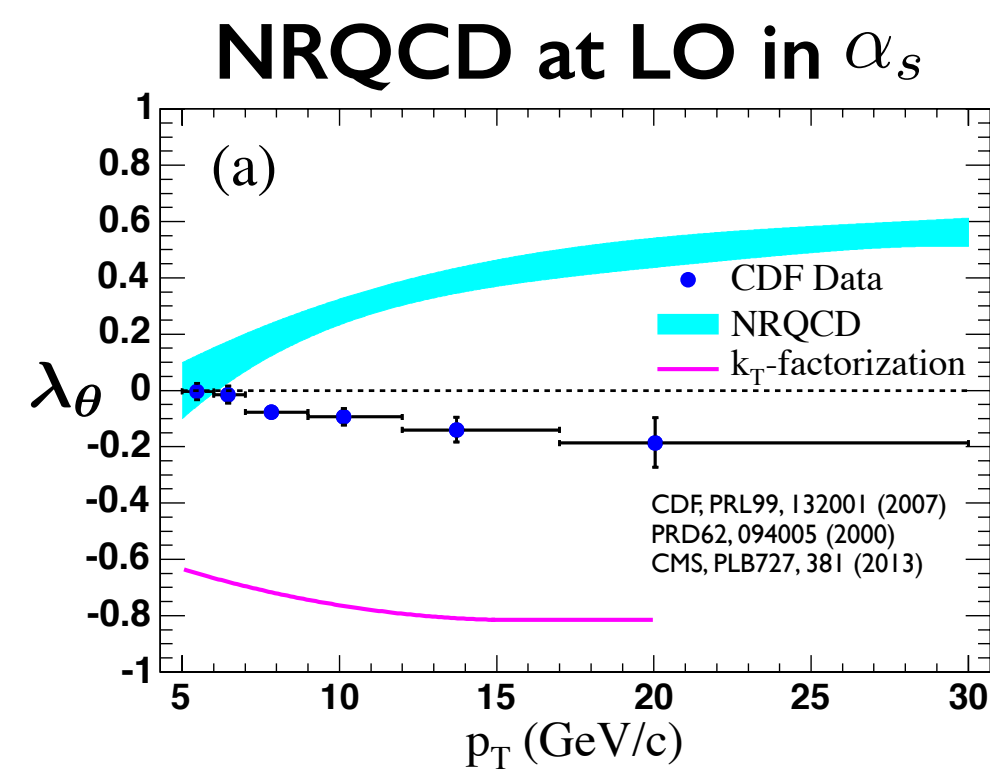
- NRQCD factorization conjecture for production of H is given by Bodwin, Braaten, and Lepage, PRD51, 1125 (1995)

$$d\sigma_{A+B \rightarrow H+X} = \sum_n d\sigma_{A+B \rightarrow Q\bar{Q}(n)+X} \langle \mathcal{O}^H(n) \rangle$$

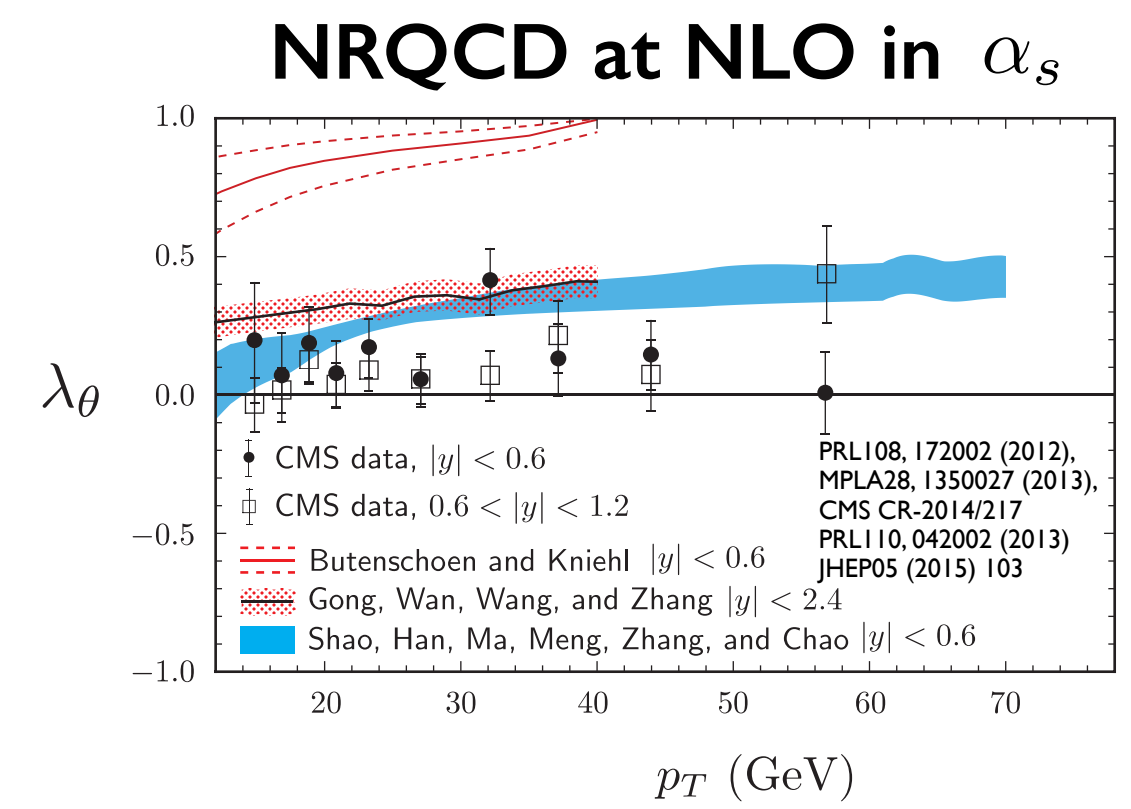
Short-distance cross section Long-distance matrix element (LDME)

- The sum is usually truncated at relative order v^4 : $^3S_1^{[8]}$, $^3P_J^{[8]}$, $^1S_0^{[8]}$, $^3S_1^{[1]}$ channels for J/ψ
- It is not known how to calculate nonperturbative color-octet (CO) LDMEs
- CO LDMEs are extracted from fits to measured cross sections

Prompt J/ψ polarization in NRQCD



NRQCD at LO in α_s predicts transverse polarization at large \rightarrow Disagrees with measurement



NLO corrections are large in the $^3S_1^{[8]}$ and $^3P_J^{[8]}$ channels \rightarrow NLO predictions vary

Leading-power fragmentation contributions

		Fragmentation functions			
		α_s	α_s^2	α_s^3	\dots
Parton production cross sections	$^3S_1^{[8]}$	LO	NLO	NNLO	
	$^3P_J^{[8]}$	NLO	NNLO		
	$^1S_0^{[8]}$	NNLO			
	\dots				
Parton production cross sections	$^3S_1^{[8]}$, $^3P_J^{[8]}$	α_s	α_s^2	α_s^3	\dots
	$^3S_1^{[8]}$	-	NLO	NNLO	
	$^3P_J^{[8]}$	-	NNLO		
	$^1S_0^{[8]}$	-			

Available Not yet available Leading logarithms only

- The leading power (LP) in p_T ($1/p_T^4$) is given by single-parton fragmentation Collins and Soper, NPB194, 445 (1982)
Nayak, Qiu, and Sterman, PRD72, 114012 (2005)

- Our strategy is to use LP fragmentation to supplement the fixed-order NLO calculation.

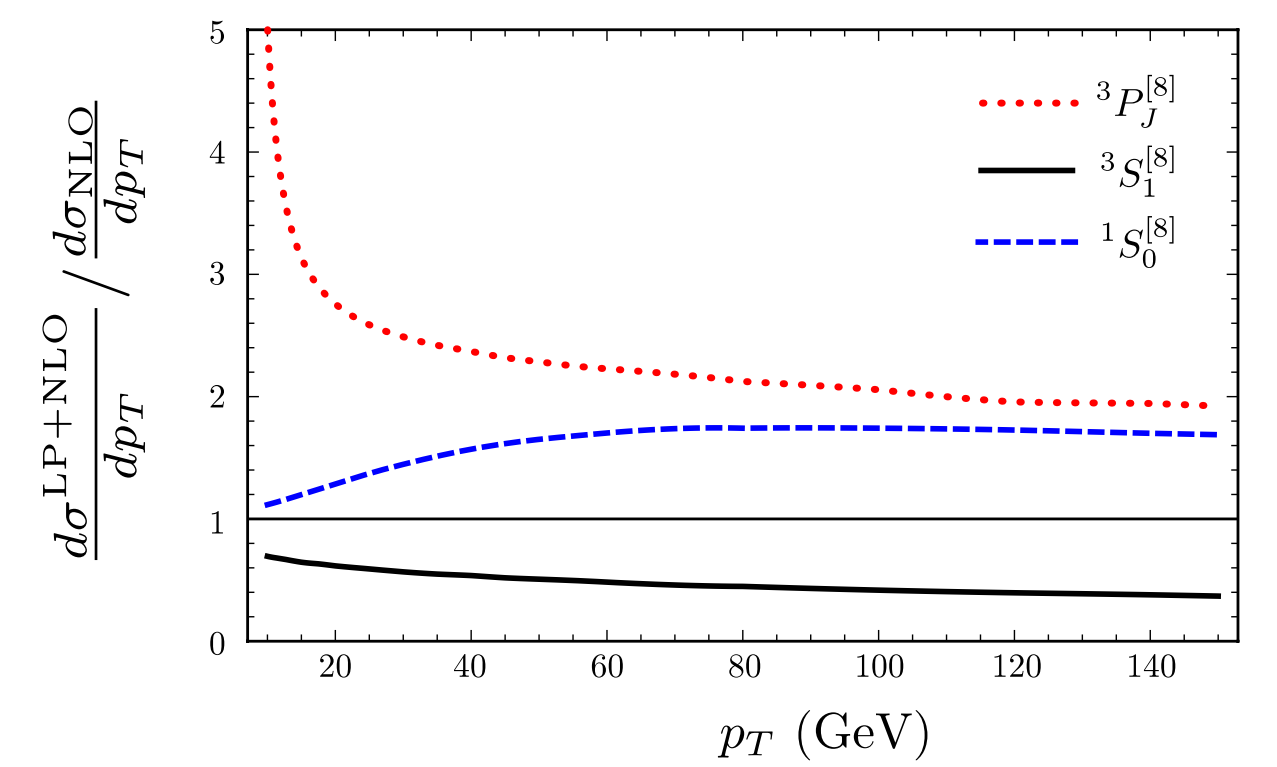
- We calculate

$$\frac{d\sigma^{\text{LP+NLO}}}{dp_T} = \frac{d\sigma^{\text{LP}}}{dp_T} + \frac{d\sigma^{\text{LP}}}{dp_T} \frac{d\sigma^{\text{LP}}}{dp_T} + \frac{d\sigma^{\text{NLO}}}{dp_T}$$

Additional fragmentation contributions fixed-order calculation to NLO

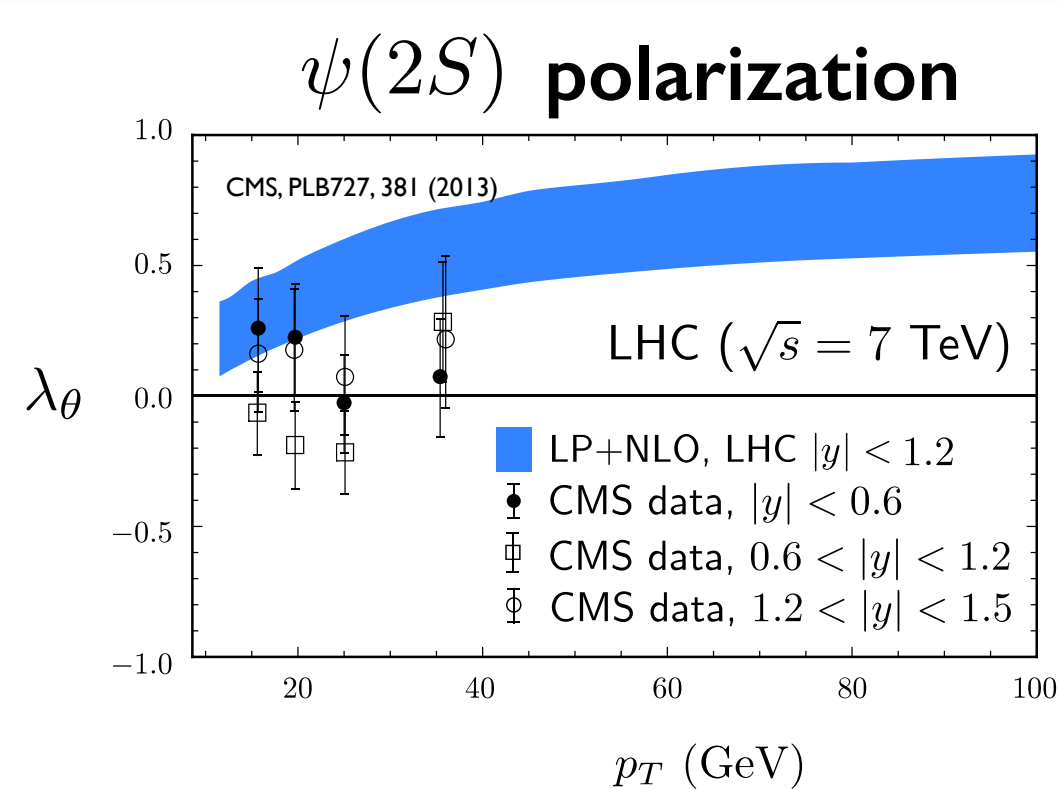
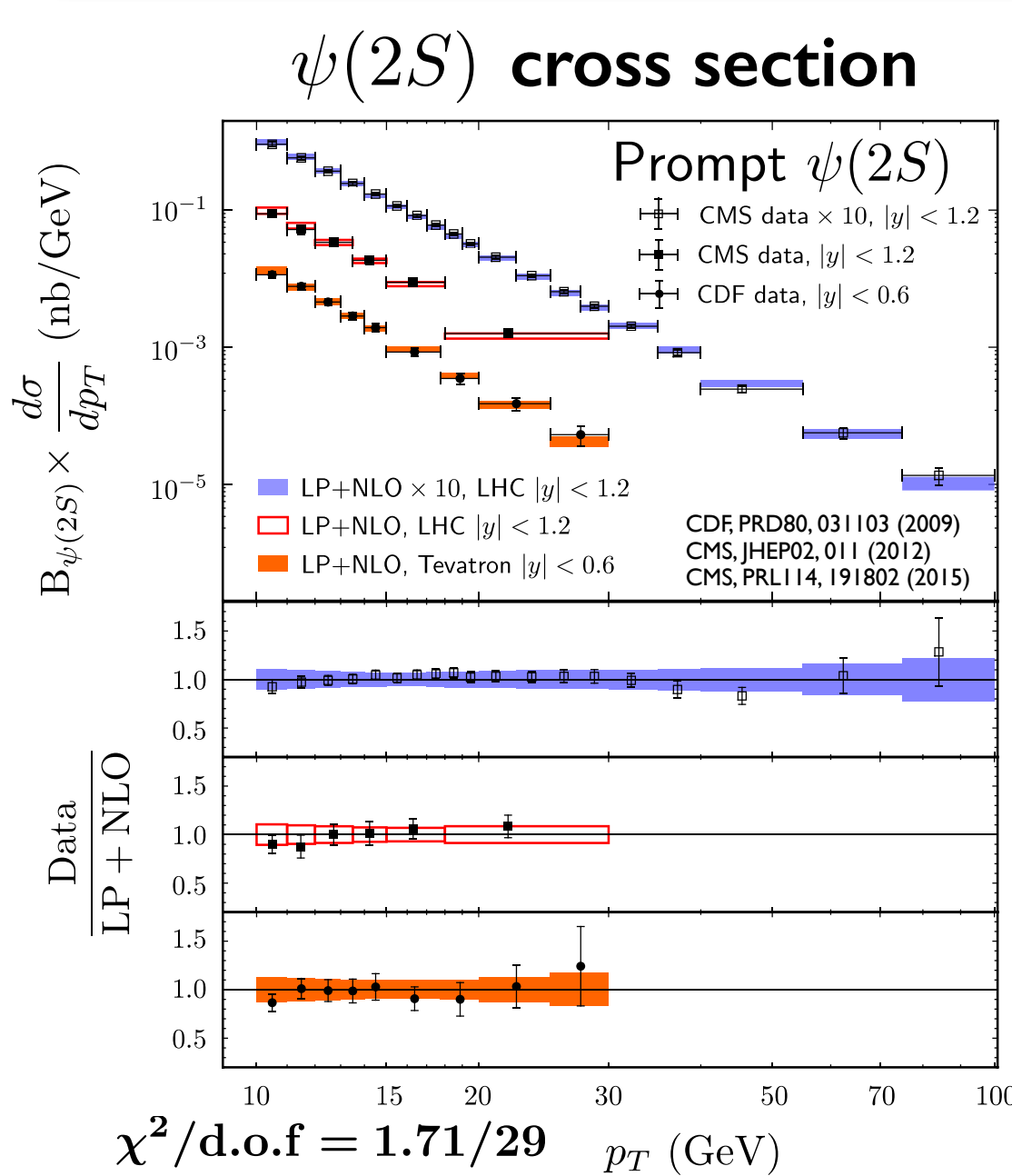
- We take $p_T > 3 \times m_{\text{quarkonium}}$ in order to suppress possible non-factorizing contributions

LP+NLO/NLO



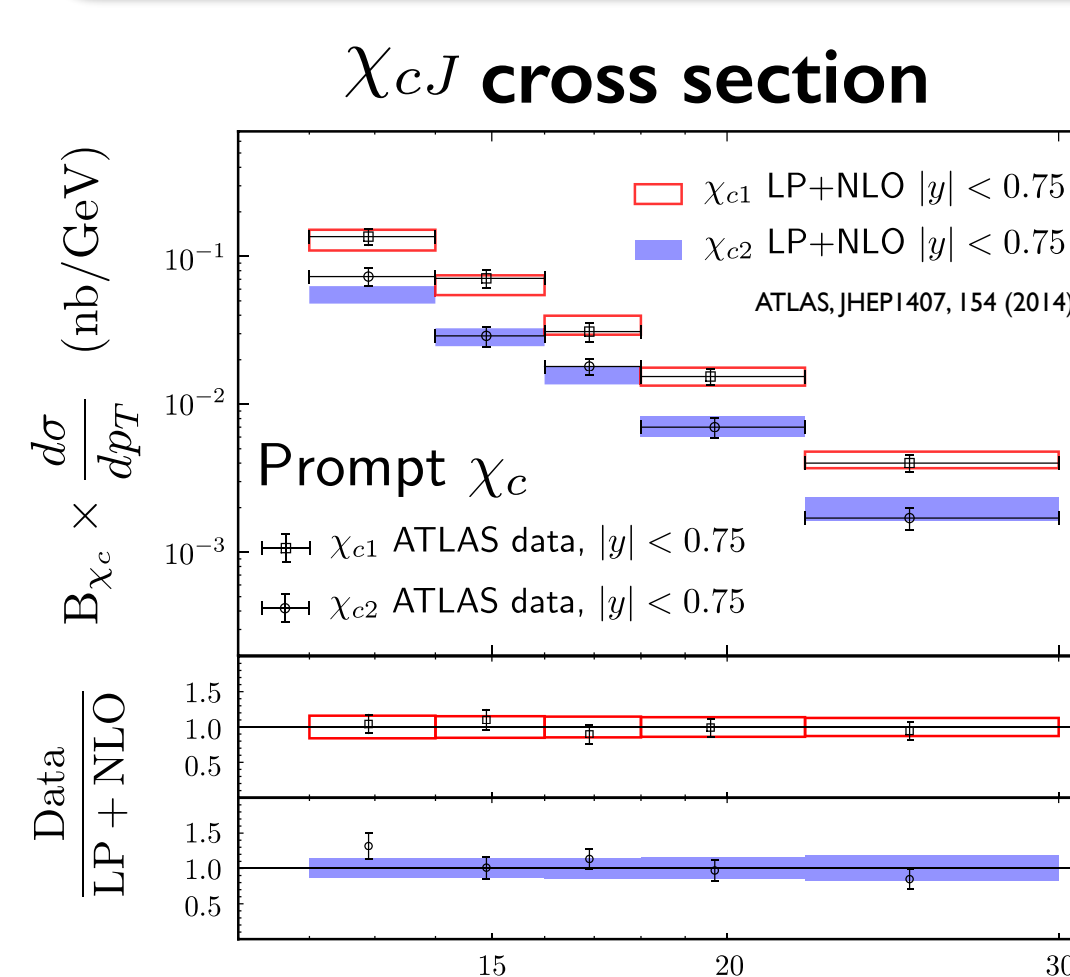
- The additional fragmentation contributions have important effects on the shapes in the $^3P_J^{[8]}$ channel
- Large corrections to the shape of the $^3P_J^{[8]}$ channel because the LO and NLO contributions cancel at about $p_T \approx 7.5$ GeV

$\psi(2S)$ hadroproduction



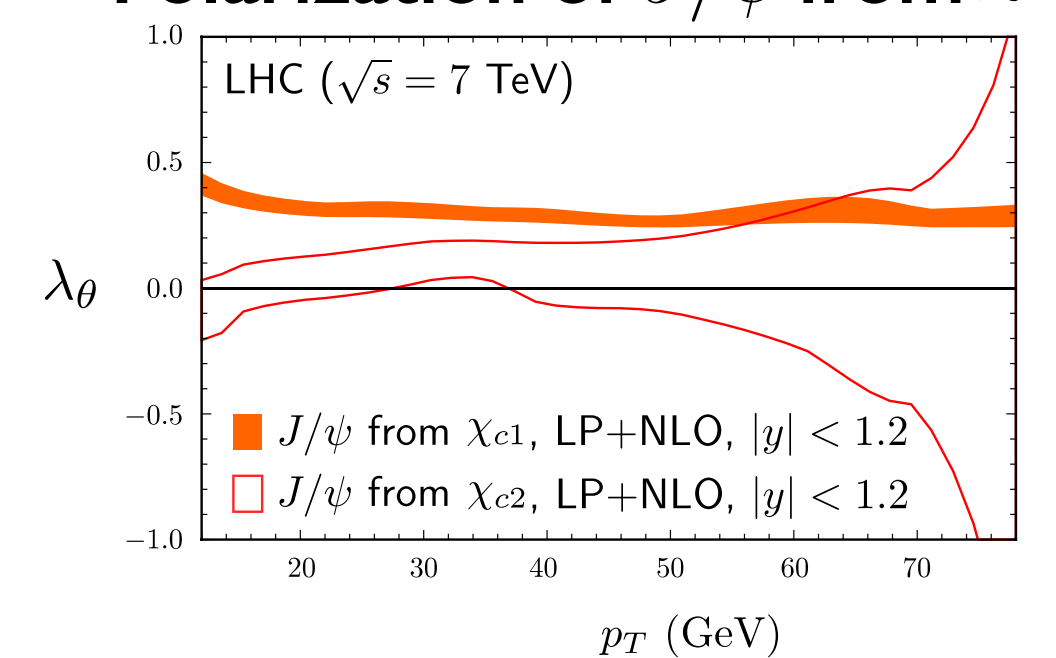
Using LDMEs from fit to CMS and CDF cross section data, we predict that the $\psi(2S)$ is slightly transverse at the LHC

χ_{cJ} hadroproduction



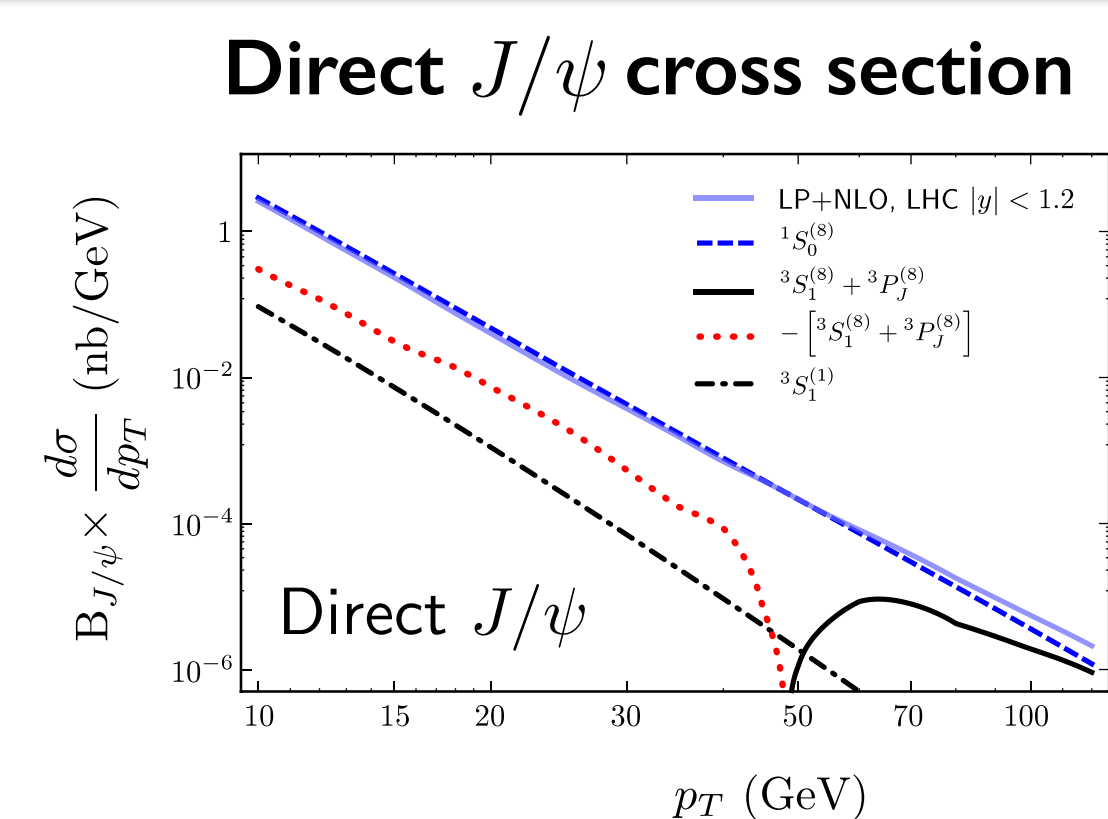
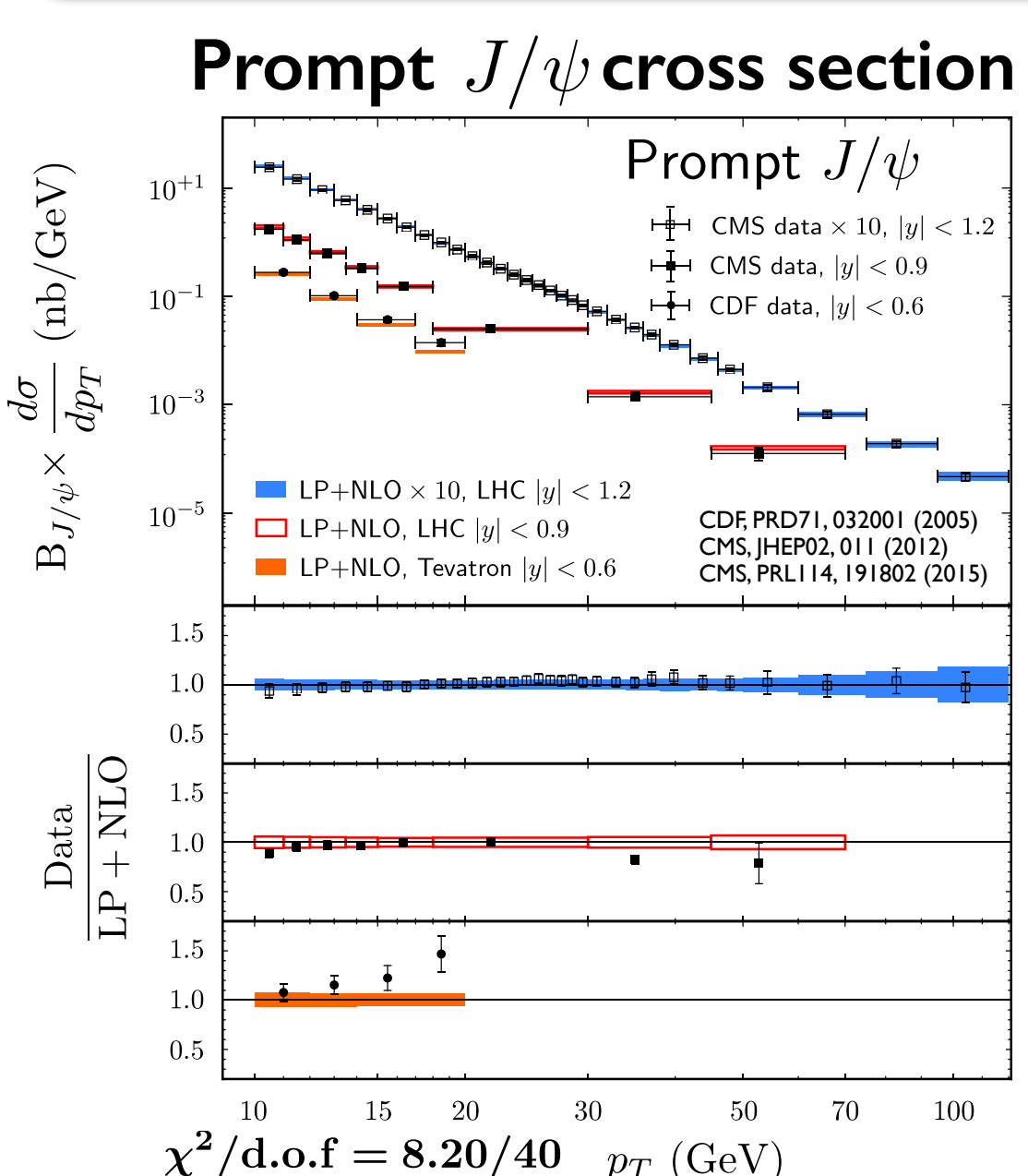
We assume E1 transition in $\chi_{cJ} \rightarrow J/\psi + \gamma$

Polarization of J/ψ from χ_{cJ}

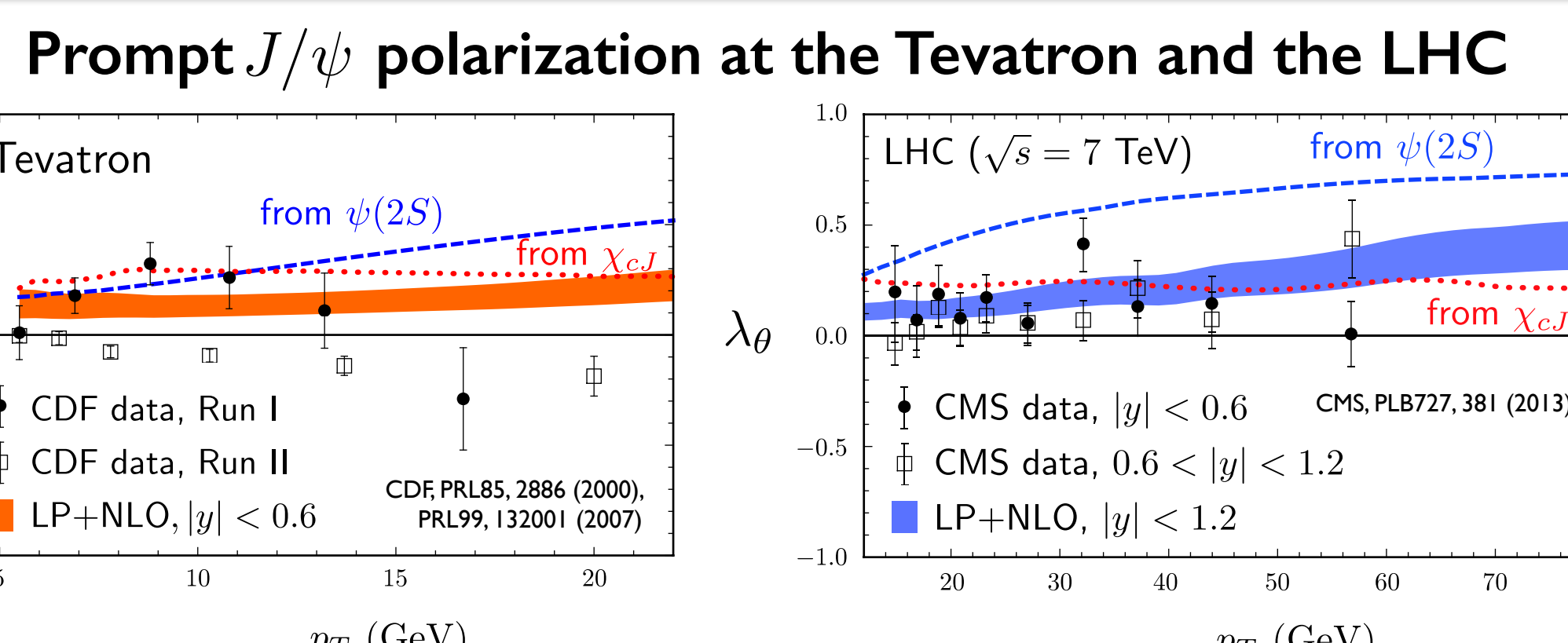


Using LDMEs from fit to ATLAS cross section data, we predict that the polarization of J/ψ from χ_{cJ} is slightly transverse at the LHC

J/ψ hadroproduction



- Including feeddown contributions, we obtain good fits to J/ψ cross section
- The fit constrains the $^3P_J^{[8]}$ and $^3S_1^{[8]}$ to cancel
- $^1S_0^{[8]}$ dominates the direct cross section



- Direct J/ψ and J/ψ from feeddown is slightly transverse
- PROMPT J/ψ HAS SMALL POLARIZATION**
- This is in *reasonably good agreement with CMS data*, but disagrees with CDF Run II data