Measurements of the production of P-wave charmonium states through radiative decays at the ATLAS experiment

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Introduction

The $X_{cJ}(1P)$ states (with J = 0,1,2) are the only triplet of *P*-wave states below the open-charm threshold. The hyperfine mass splitting is small and the branching fractions are 1.3%, 34.4% and 19.5% respectively. The X_{cJ} may be produced directly in pp collisions or through the decay of higher mass quarkonium states (prompt); or through the decay chains of *b*-hadrons (non-prompt).
This analysis presents the measurement of the inclusive production of the X_{c1} and X_{c2} states in LHC pp collision at 7 TeV with the ATLAS detector.

Data and Monte Carlo Samples

The data sample corresponds to an integrated luminosity of 4.5 fb^{-1} collected during the 2011 LHC pp run at a $\sqrt{s}$ = 7 TeV.
Four Monte Carlo samples ($X_{c1} \rightarrow J/\psi \rightarrow \mu^+\mu^-\gamma$ and $X_{c2} \rightarrow J/\psi \rightarrow \mu^+\mu^-\gamma$ produced either directly or through the process $pp \rightarrow b\bar{b}X \rightarrow X_c$) are used to estimate the photon conversion reconstruction efficiency and to characterize the modeling of the X_c signal components. All samples are generated with PYTHIA6 and use the ATLAS 2011 MC underlying event and hadronization model tuning. The detector response is simulated using GEANT4.

Event and X_c Candidate Selection

Event selection $X_c \rightarrow J/\psi\,\gamma$:
Di-muon trigger: $p_T > 4$ GeV; $2.5 < m_{\mu\mu} < 4.0$ GeV; at least 1 pp collision vertex with at least 3 tracks with $p_T > 400$ MeV
J/ψ: $p_T^{\mu} > 4$ GeV; $|\eta^{\mu}| < 2.3$; $2.95 < m_{\mu\mu} < 3.25$ GeV; $|y^{J/\psi}| < 0.75$
Converted photon: oppositely charged track pairs $p_T > 400$ MeV; $|\eta| < 2.3$; $40 < r(\text{pair}) < 150$ mm; $p_T^{\gamma} > 1.5$ GeV; $|\eta^{\gamma}| < 2.0$
X_c: associate candidates J/ψ and γ; impact parameter of γ from di-muon vertex < 5 to remove combinatorial bkg.

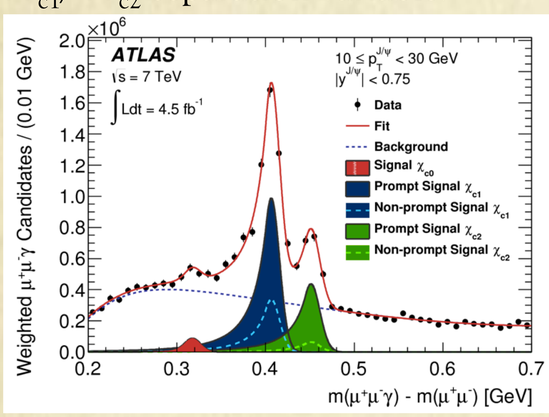
Cross-Section Determination

The differential X_{c1} and X_{c2} cross sections for prompt and non-prompt in a given bin of $p_T^{X_c}$

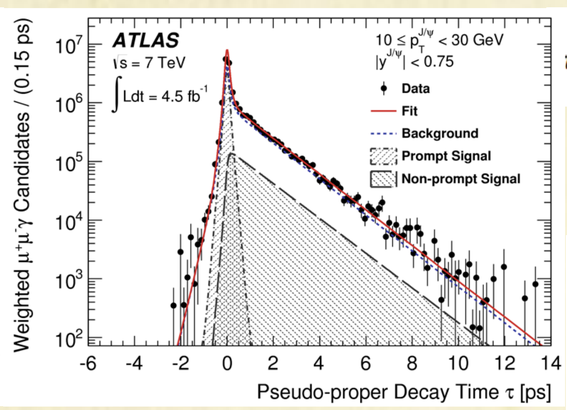
$$\frac{d\sigma(X_{cJ})}{dp_T^{X_c}} \cdot \mathcal{B}(X_{cJ} \rightarrow J/\psi\gamma) \cdot \mathcal{B}(J/\psi \rightarrow \mu^+\mu^-) = \frac{N_J}{\mathcal{L} \cdot \Delta p_T^{X_c}}$$

N_J = acceptance and efficiency corrected yield

X_{c1}/X_{c2} separation variable:



Prompt/non prompt separation variable:



$$\tau = \frac{L_{xy} \cdot m_{J/\psi}}{|\vec{p_T}|}$$

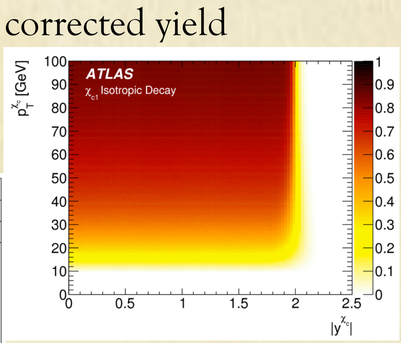
Corrected yields are extracted by performing a simultaneous fit to the mass difference and pseudo-proper time distributions of weighted X_c candidates. Probability Distribution Function used:

$$F(\Delta m, \tau, \delta\tau) = f_{\text{Sig}} \cdot F_{\text{Sig}}(\Delta m, \tau, \delta\tau) + (1 - f_{\text{Sig}}) \cdot F_{\text{Bkgd}}(\Delta m, \tau, \delta\tau)$$

Correction weight: $w^{-1} = \mathcal{A} \cdot \epsilon_{\text{trig}} \cdot \epsilon_{\text{di-muon}} \cdot \epsilon_{\text{conv}}$

Binning: $p_T^{J/\psi}$	Fractional Uncertainty [%]			
	Prompt		Non-prompt	
	χ_{c1}	χ_{c2}	χ_{c1}	χ_{c2}
Muon reco. efficiency	1	1	1	1
Trigger efficiency	4	4	4	4
Converted-photon reco. efficiency	11	11	11	11
Conversion probability	4	4	4	4
Acceptance	4	4	5	8
Fit model	2	3	3	9
Total systematic	13	13	13	17
Spin-alignment envelope (upper)	34	36	32	36
Spin-alignment envelope (lower)	13	23	13	23

Binning: $p_T^{X_c}$	Fractional Uncertainty [%]			
	Prompt		Non-prompt	
	χ_{c1}	χ_{c2}	χ_{c1}	χ_{c2}
Muon reco. efficiency	1	1	1	1
Trigger efficiency	3	4	4	4
Converted-photon reco. efficiency	11	11	11	11
Conversion probability	4	4	4	4
Acceptance	2	2	2	2
Fit model	2	3	3	8
Total systematic	12	12	12	14
Spin-alignment envelope (upper)	29	31	29	31
Spin-alignment envelope (lower)	11	20	11	20

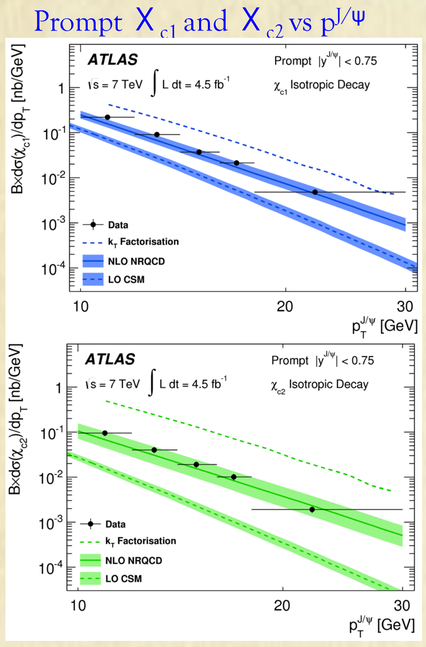


Acceptance vs p_T and $|y|$

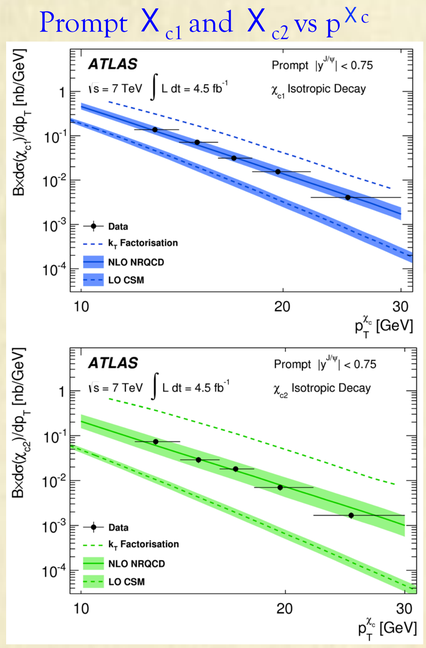
Contributions to the total uncertainty on the cross section measurements binned in $p^{J/\psi}$ (p^{X_c}) averaged across all $p^{J/\psi}$ (p^{X_c}) bins. Contributions of integrated luminosity (1.8%) and track reconstruction (1%) are not shown. The average variation in acceptance corresponding to all possible polarization scenarios is also shown.

Differential Cross Sections

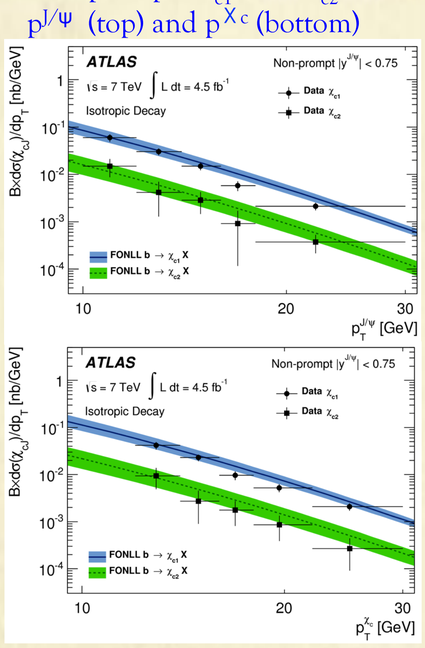
Prompt X_{c1} and X_{c2} vs $p^{J/\psi}$



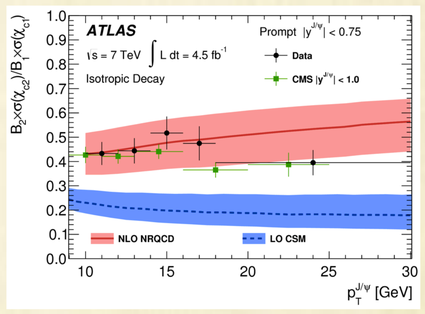
Prompt X_{c1} and X_{c2} vs p^{X_c}



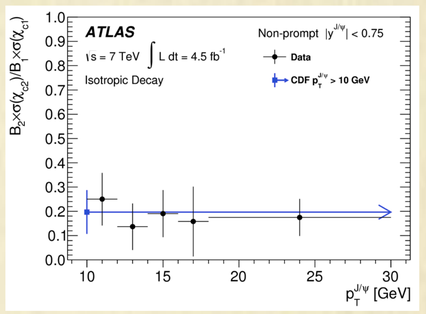
Non prompt X_{c1} and X_{c2} vs $p^{J/\psi}$ (top) and p^{X_c} (bottom)



Cross Section Ratios

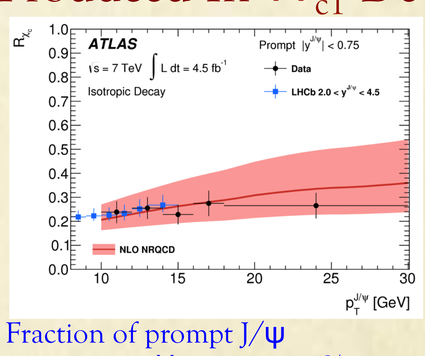


Production cross section of prompt X_{c2} relative to prompt X_{c1} vs $p^{J/\psi}$



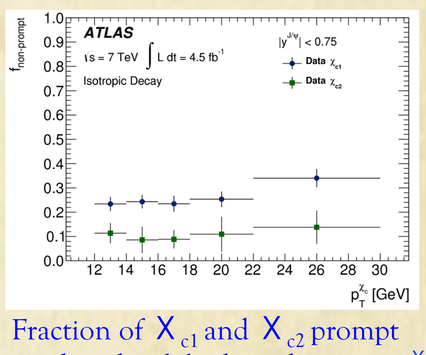
Production cross section of non-prompt X_{c2} relative to non-prompt X_{c1} vs $p^{J/\psi}$

Fraction of Prompt J/ψ Produced In X_{c1} Decays



Fraction of prompt J/ψ produced in X_c decays vs $p^{J/\psi}$

Non-Prompt Fractions



Fraction of X_{c1} and X_{c2} prompt produced in b-hadron decays vs p^{X_c}

Measurement of $Br(B^{\pm} \rightarrow X_{c1} K^{\pm})$

Relative measurement: $B^{\pm} \rightarrow J/\psi K^{\pm}$ used as reference channel (same final state excpt of the photon)

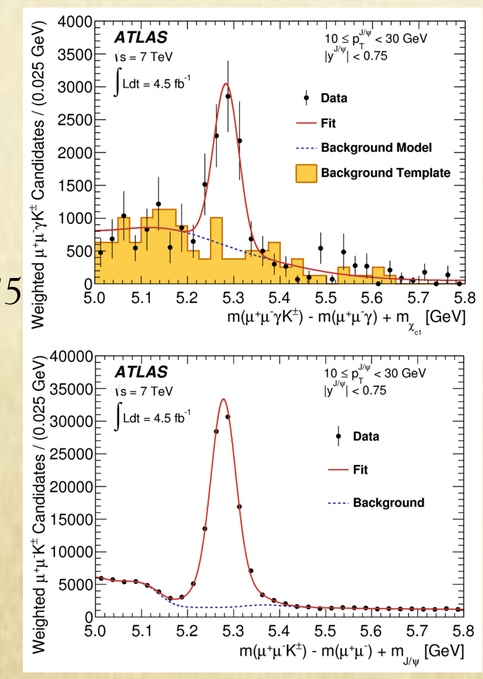
$$\mathcal{B}(B^{\pm} \rightarrow \chi_{c1} K^{\pm}) = \mathcal{A}_B \cdot \frac{N^B_{\chi_{c1}}}{N^B_{J/\psi}} \cdot \frac{\mathcal{B}(B^{\pm} \rightarrow J/\psi K^{\pm})}{\mathcal{B}(\chi_{c1} \rightarrow J/\psi\gamma)}$$

$Br(B^{\pm} \rightarrow J/\psi K^{\pm}) = (1.016 \pm 0.033) \times 10^{-3}$; $Br(X_{c1} \rightarrow J/\psi\gamma) = 0.344 \pm 0.015$
Decays reconstructed in $10 < p_T^{J/\psi} < 30$ GeV; $|y^{J/\psi}| < 0.75$
Same data sample, and selection as the X_c analysis

	Fractional Uncertainty [%]
Converted-photon reconstruction efficiency	10
Conversion probability	4
Muon reconstruction efficiency	1
Trigger efficiency	1
Acceptance	3
Fit model	6
Statistical	18
Systematic	13
Total	22

$Br(B^{\pm} \rightarrow X_{c1} K^{\pm}) = (4.8 \pm 0.6^{\text{stat}} \pm 0.6^{\text{syst}}) \times 10^{-4}$

Good agreement with PDG value $(4.9 \pm 0.23) \times 10^{-4}$



Conclusions

The cross sections for prompt and non-prompt X_{c1} and X_{c2} production have been measured in *pp* collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector at the LHC. Production rate of the X_{c2} state is measured relative to the X_{c1} state for both prompt and non-prompt production as a function of $p_T^{J/\psi}$. The fraction of prompt J/ψ produced in feed-down from X_c decays is also derived.
The fractions of X_{c1} and X_{c2} produced in the decays of *b*-hadrons are also presented as functions of $p_T^{X_c}$. Finally, the branching fraction $Br(B^{\pm} \rightarrow X_{c1} K^{\pm}) = (4.8 \pm 0.6^{\text{stat}} \pm 0.6^{\text{syst}}) \times 10^{-4}$ is measured with the same dataset and X_c event selection.