

J/ψ differential cross sections in pp collisions at 7TeV measurement with the CMS experiment

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and Related Subjects
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Motivations

- Important test of QCD
- J/ψ produced in 3 ways:
 - prompt, direct
 - prompt, indirect
 - non-prompt
- Quarkonium measurement at LHC: differential cross section at wider rapidity ranges and higher p_T than previous possible
- Polarization:
 - test of theory frameworks
 - affecting cross-section determination
- Non-prompt production:
 - related to b -hadron production
 - measurement of b -hadron cross-section



Event selection & simulation

Data sample

- $\sqrt{s} = 7\text{TeV}$; $\mathcal{L} = 314 \pm 34\text{nb}^{-1}$ (full 2010 data analysis coming soon)
- $J/\psi \rightarrow \mu^+ \mu^-$ decay channel

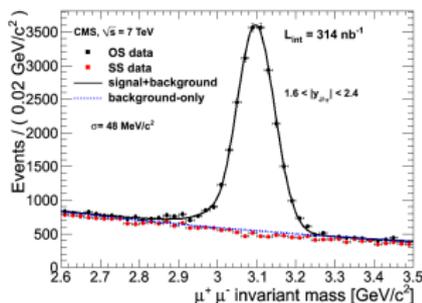
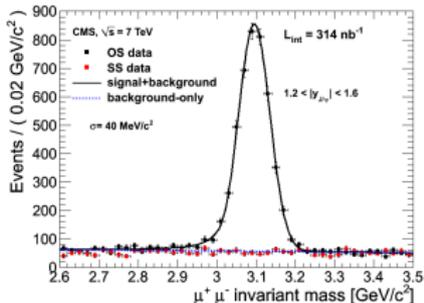
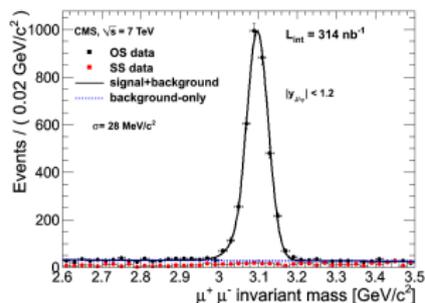
Simulation (mainly to compute acceptance and efficiencies)

- events generated with Pythia 6.421 (LO singlet & octet + NRQCD)
- b -hadron to J/ψ inclusive decay simulated with EvtGen
- detector simulation with GEANT-4 including trigger and finite precision of alignment and calibration



J/ψ reconstruction

- Muons reconstructed by matching tracker & muon chambers signal
- Opposite-charge muon pairs selected, vertex fit
- Muon p_T corrected by fitting invariant mass (Crystal-Ball function + exponential)



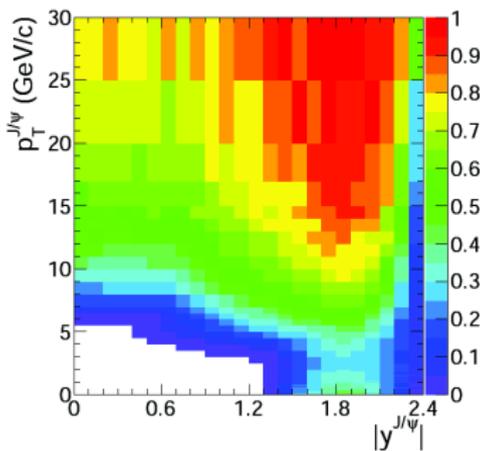
$$p_T^{corr} = (1 + a_1 + a_2 \eta^2) p_T^{meas}$$

$$a_1 = (3.8 \pm 1.9) \cdot 10^{-4} \quad ; \quad a_2 = (3.0 \pm 0.7) \cdot 10^{-4}$$

Acceptance

J/ψ acceptance (from MC) = function of dimuon p_T and y :

$$A(p_T, y; \lambda_\theta) = \frac{N_{det}(p_T, y; \lambda_\theta)}{N_{gen}(p_T, y; \lambda_\theta)} \quad \lambda_\theta = \begin{cases} 0 & \text{(unpolarized)} \\ -1 & \text{(longitudinal)} \\ +1 & \text{(transverse)} \end{cases} \begin{matrix} \text{CS/HX} \\ \text{frames} \end{matrix}$$



Systematic errors ((1.0-4.5)%):

- FSR: p_T, y from $\mu\mu$ or J/ψ at generation
- J/ψ spectra (Pythia vs. CASCADE)
- b fraction (from this analysis) & polarization (MC vs. BaBar)
- p_T calibration & resolution (sim. μ momenta smeared)



Efficiency

- Single muon efficiency estimated in data, by a “Tag and Probe” method, correlation from MC
- J/ψ efficiency dependent on single muon efficiency and vertex efficiency

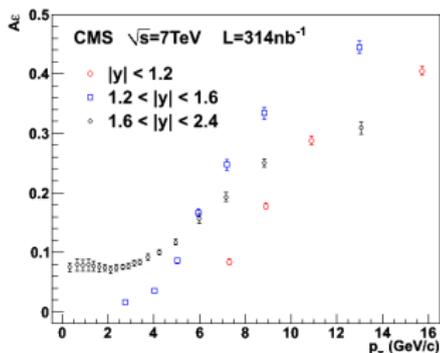
$$\epsilon(J/\psi) = \epsilon(\mu^+) \cdot \epsilon(\mu^-) \cdot (1 + \rho) \cdot \epsilon_{vertex}$$

$$-0.19 < \rho < +0.30, \text{ typically } |\rho| < 0.1$$

$$\epsilon_{vertex} = (98.35 \pm 0.16)\%$$

Systematic errors ((2.0-14.6)%):

- ρ : (J/ψ spectrum varied according to various models)
- single muon efficiency stat. error



Inclusive cross section

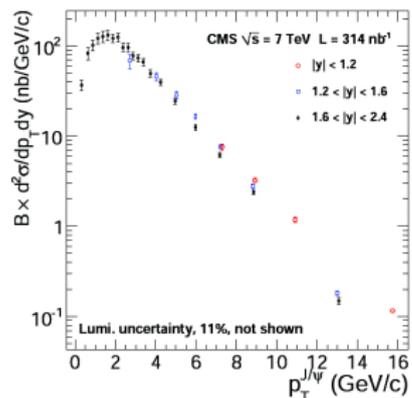
$$\frac{d^2\sigma(J/\psi)}{dp_T dy} \cdot Br(J/\psi \rightarrow \mu^+ \mu^-) = \frac{N_{corr}(J/\psi)}{\mathcal{L} \cdot \Delta p_T \cdot \Delta y}$$

$N_{corr}(J/\psi)$ from:

- invariant mass fit
- acceptance and efficiency

Systematic errors:

- fit function ((0.6-8.8)%)
- int. lumi. error (11%, not shown)



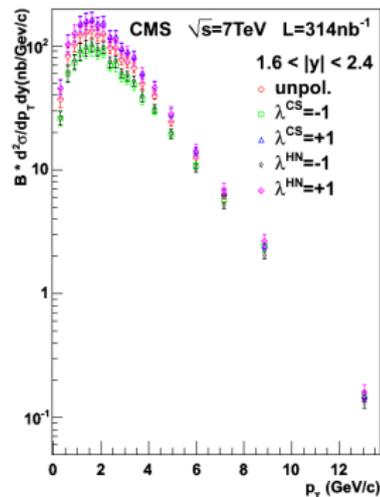
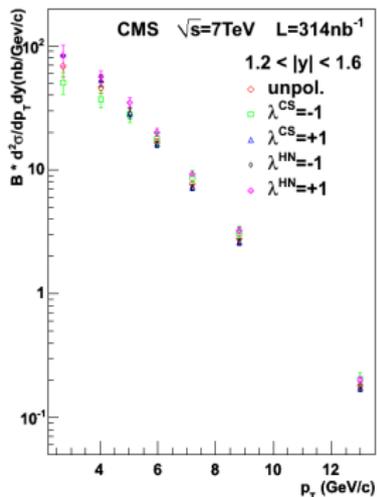
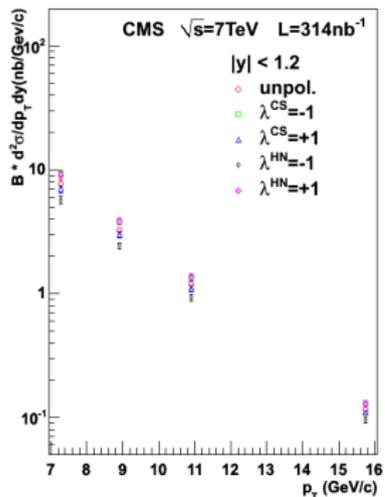
Unpolarized scenario

$$6.5 \text{ GeV}/c < p_T < 30 \text{ GeV}/c \quad ; \quad |y| < 2.4$$

$$\sigma(pp \rightarrow J/\psi + X) \cdot Br(J/\psi \rightarrow \mu^+ \mu^-) = 97.5 \pm 1.5(\text{stat}) \pm 3.4(\text{sist}) \pm 10.7(\text{lumi}) \text{ nb}$$

Different polarization scenarios

Polarization of prompt J/ψ not well known:
differential cross-section computed for each scenario



luminosity uncertainty 11% not shown



Prompt / non-prompt separation

Discrimination of J/ψ produced away from pp collision vertex:

- primary vertex built excluding the 2 muons
- pile-up ambiguity resolved by choosing the vertex closest in z coordinate
- b -hadron proper decay length computed from transverse decay-length:

$$\ell_{J/\psi} = L_{xy} \cdot m_{J/\psi} / p_T$$

- dimuon mass and proper decay length simultaneously fitted in each p_T , y bin:

$$\ln L = \sum_{i=1}^N \ln F(\ell_{J/\psi}, m_{\mu\mu})$$

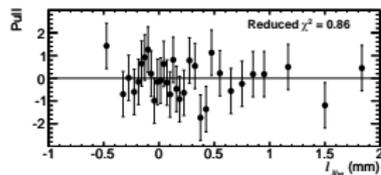
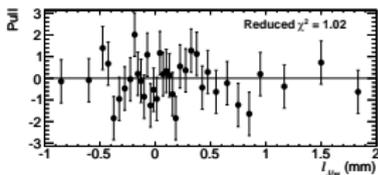
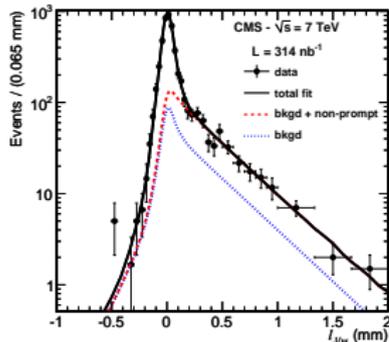
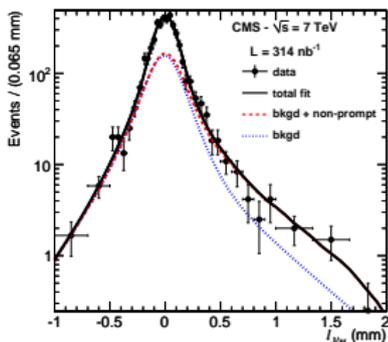
- likelihood function: sum of signal-prompt, signal-non-prompt and background components, each scaled with the corresponding fraction



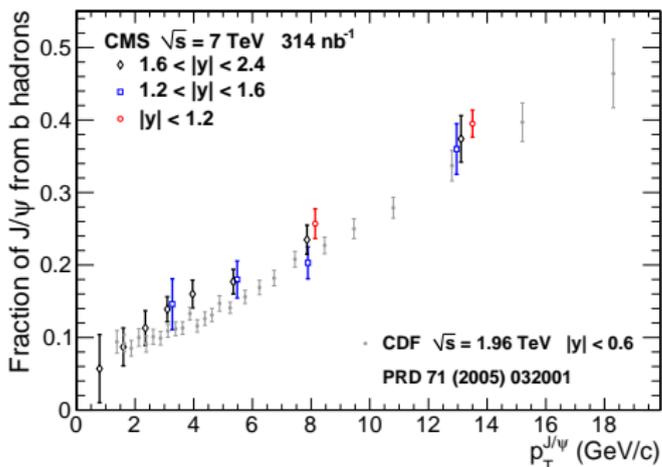
Decay-length fit

Fit performed in 3 $|y|$ bins and 2, 4, 8 p_T bins; e.g.:

$2.0 < p_T < 4.5 \text{ GeV}/c$ $6.5 < p_T < 10 \text{ GeV}/c$
 $1.2 < |y| < 1.6$ $1.6 < |y| < 2.4$



b -fraction



Main systematic errors:

- primary vertex:
beam-spot vs. fitted vertex
- resolution: two gauss. vs. three gauss.
- bkg: fit in sidebands with different boundaries

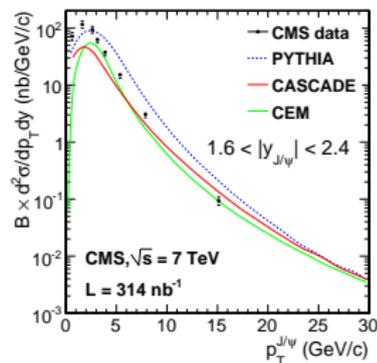
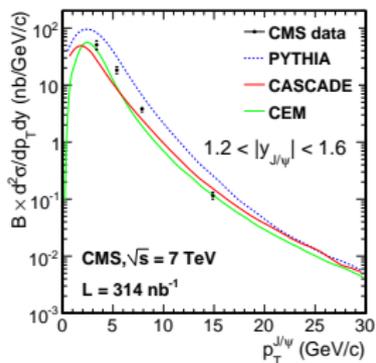
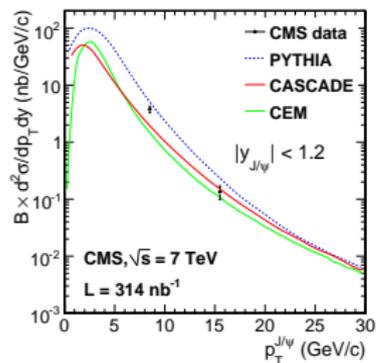
$$6.5 \text{ GeV}/c < p_T < 30 \text{ GeV}/c ; |y| < 2.4$$

$$\sigma(pp \rightarrow \text{prompt } J/\psi + X) \cdot Br(J/\psi \rightarrow \mu^+ \mu^-) = 70.9 \pm 2.1(\text{stat}) \pm 3.0(\text{sist}) \pm 7.8(\text{lumi}) \text{nb}$$

$$\sigma(pp \rightarrow b + X \rightarrow J/\psi + X) \cdot Br(J/\psi \rightarrow \mu^+ \mu^-) = 26.0 \pm 1.4(\text{stat}) \pm 1.6(\text{sist}) \pm 2.9(\text{lumi}) \text{nb}$$



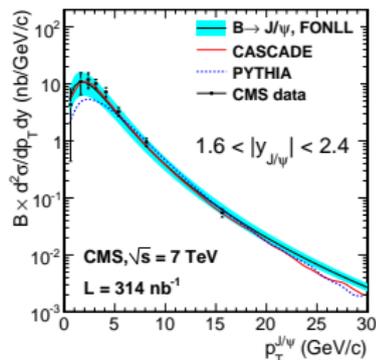
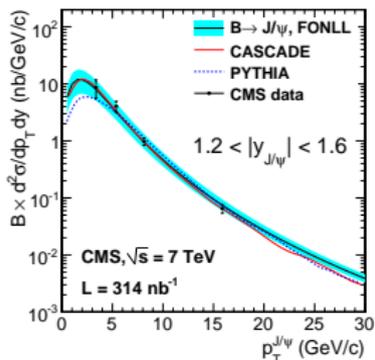
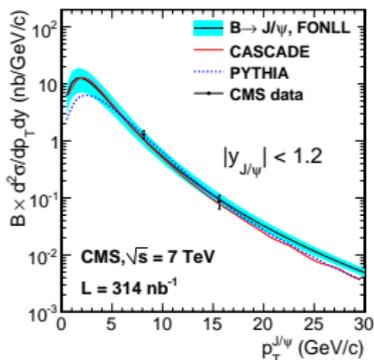
Prompt J/ψ cross section comparisons



- Calculations include contributions from heavier states decays (χ_c , $\psi(2S)$)
- Other models available only for direct J/ψ production, not comparable with this measurement



Non-prompt J/ψ cross section comparisons



Conclusions

- J/ψ production cross section at $\sqrt{s} = 7\text{TeV}$ in pp collisions measured by CMS with part of the collected data
- Inclusive p_T differential cross section in the dimuon channel measured in 3 rapidity bins
- Prompt and non-prompt components discriminated by mean of secondary vertex reconstruction
- Prompt and non-prompt cross sections measured
- Non-prompt cross section found in reasonable agreement with theory
- Prompt cross section exceeding expectations in the forward region at low p_T



BACKUP



Muon tag and probe

$$\epsilon(\mu) = \epsilon_{\text{track}} \cdot \epsilon_{\text{off|track}} \cdot \epsilon_{\text{trig|off}}$$

Muon pairs selected in the J/ψ mass region:

- Tag: one “tight” muon
- Probe: one “loose” muon
 - Reconstructed only with the muon detectors
→ tracking efficiency
 - Selected by calorimeters
→ μ -tag efficiency
 - Reconstructed offline
→ trigger efficiency
- Tag-probe bias corrected with MC

Single μ efficiency $\epsilon(\mu) > 10\%$ in the acceptance region

$$\begin{aligned} |\eta^\mu| < 1.3 &\Rightarrow p_T^\mu > 3.3\text{GeV} \\ 1.3 < |\eta^\mu| < 2.2 &\Rightarrow p_T^\mu > 2.9\text{GeV} \\ 2.2 < |\eta^\mu| < 2.4 &\Rightarrow p_T^\mu > 0.8\text{GeV} \end{aligned}$$



Decay length / dimuon mass likelihood function

$$F(\ell_{J/\psi}, m_{\mu\mu}) = f_{Sig} \cdot F_{Sig}(\ell_{J/\psi}) \cdot M_{Sig}(\mu\mu) + (1 - f_{Sig}) \cdot F_{Bkg}(\ell_{J/\psi}) \cdot M_{Bkg}(\mu\mu)$$

$$F_{Sig}(\ell_{J/\psi}) = f_B \cdot F_B(\ell_{J/\psi}) + (1 - f_B) \cdot F_p(\ell_{J/\psi})$$

- $F_p(\ell_{J/\psi})$: resolution function (double gaussian, free + single gaussian, fixed from MC, for primary vertex)
- $F_B(\ell_{J/\psi})$: true $\ell_{J/\psi}$ distribution (from MC) convoluted with resolution function
- F_{Bkg} : linear combination of 3 exponentials with positive/negative/symmetric decay lengths, convoluted with resolution

