Measurement of Quarkonia production at 7 TeV with the CMS experiment

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on behalf of the CMS collaboration

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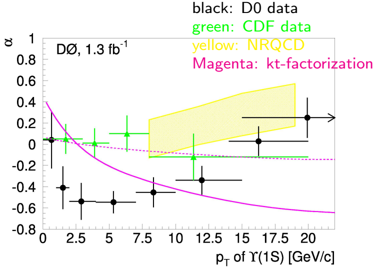
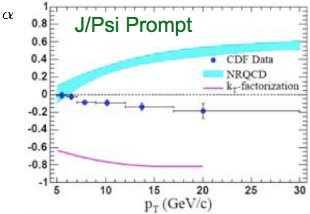
Outline

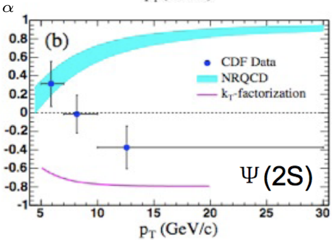
- Why study Quarkonia at the LHC?
- The CMS detector
- Quarkonia Cross Section Measurement
- Separation of X_{c1}/X_{c2} states
- $X(3872)/\Psi(2S)$ Cross Section Ratio
- Summary

Motivation

- Theoretical Motivation
  - no theory has simultaneously explained experimental measurements of both cross section and polarization

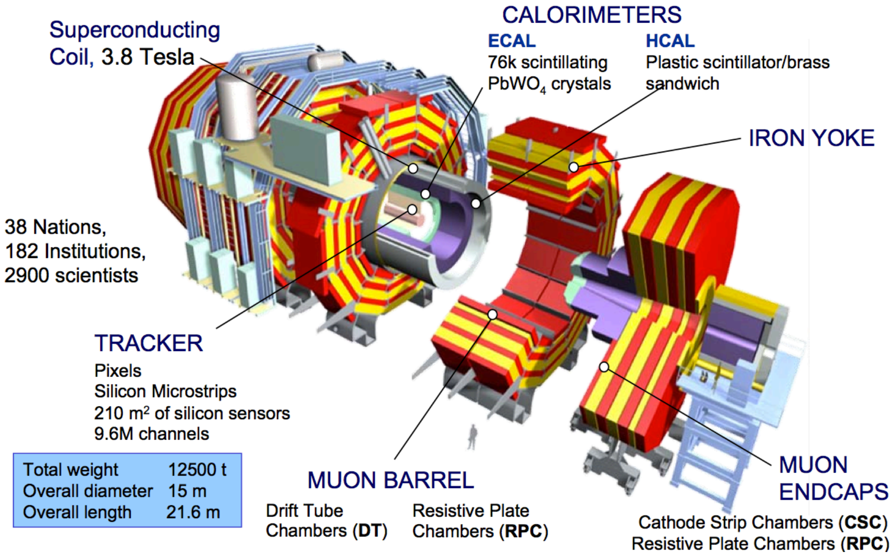






- LHC provides:
  - New energy scale
  - Large p_T reach
  - Early measurements
  - Detector Calibration

The CMS Detector



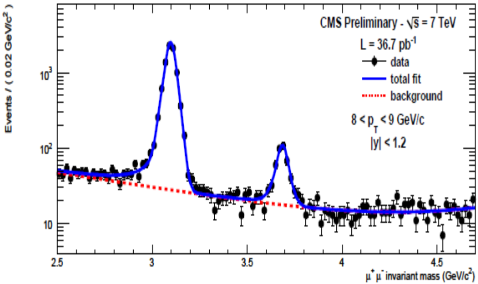
Total weight	12500 t
Overall diameter	15 m
Overall length	21.6 m

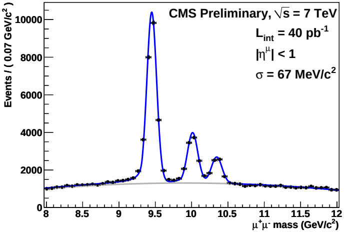
Cross Section Measurement Strategy

$$\frac{d^2\sigma\left(pp \to Q\overline{Q}\mathrm{X}\right)}{dp_T dy}\mathcal{B}\left(Q\overline{Q} \to \mu^+\mu^-\right) = \frac{N_{Q\overline{Q}}(\mathcal{A},\epsilon)}{\mathcal{L}\ \cdot \Delta p_T \cdot \Delta y},$$

- $N_{Q\overline{Q}}$: The $Q\overline{Q}$ yields, extracted via an extended unbinned maximum likelihood fit
- $\mathcal{A}$: Acceptance, obtained from Monte Carlo
- $\epsilon = \epsilon_{\mathrm{track}} \cdot \epsilon_{\mathrm{id}} \cdot \epsilon_{\mathrm{trig}}$
    - $\epsilon_{\mathrm{track}}$: Tracking efficiency
    - $\epsilon_{\mathrm{id}}, \epsilon_{\mathrm{trig}}$: Muon identification and trigger efficiency, determined with the tag-and-probe technique
- $\mathcal{L}$: The integrated luminosity of the dataset

Mass Fits and Yields ($N_{Q\overline{Q}}$)



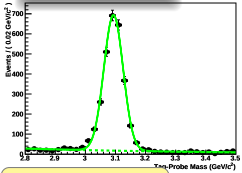


- signal: Crystal Ball, Background: Exponentials or 2nd order Polynomial
- Mass differences fixed to precise PDG values
- Some shape parameters in common when fitting multiple peaks
- Mass resolution: 20-50 MeV for J/Ψ, $\Psi(2S)$, 100 MeV for Υ

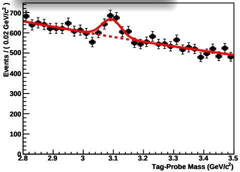
Efficiencies ($\epsilon = \epsilon_{\rm track} \cdot \epsilon_{\rm id} \cdot \epsilon_{\rm trig}$)

- calculated from data, using track embedding + tag and probe on J/Ψ sample
- tracking efficiency ($\epsilon_{\rm track}$): 98%, constant in p_T, η
- muon ID($\epsilon_{\rm id}$) and trigger($\epsilon_{\rm trig}$) efficiency: unbinned maximum likelihood fit to passing and failing tag-probe mass distributions

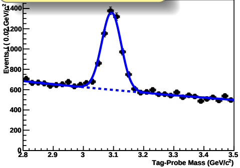
Passing probes



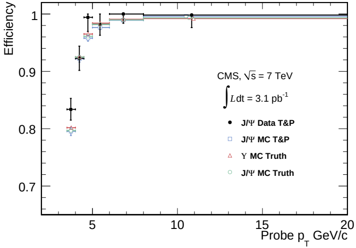
Failing probes



All probes



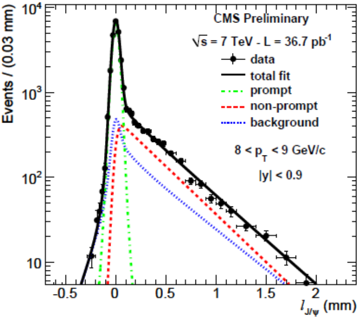
efficiency = 0.89 ± 0.02
lf = -0.419 ± 0.04
lp = -1.59 ± 0.2
mean = 3.0933 ± 0.0007
numBackgroundFail = 19933 ± 155
numBackgroundPass = 592 ± 30
numSignalAll = 3056 ± 86
sigma = 0.0320 ± 0.0006



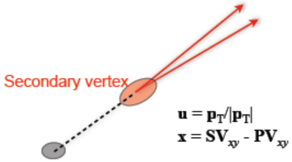
Muon ID, $|\eta| < 0.4$

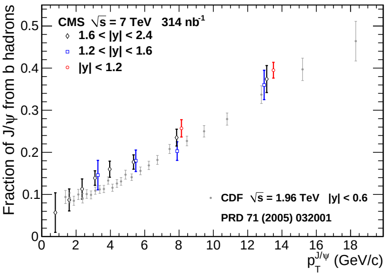
Disentangling Prompt and Non-prompt J/Ψ

- Based on pseudo-proper decay length $\ell_{xy} = \frac{L_{xy}^{J/\Psi} M_{J/\Psi}}{p_T^{J/\Psi}}$, $L_{xy}^{J/\Psi} = \frac{u^T \sigma^{-1} x}{u^T \sigma^{-1} u}$
- Prompt and non-prompt components determined from simultaneous likelihood fit to M and ℓ_{xy} in each p_T and $|y|$bin

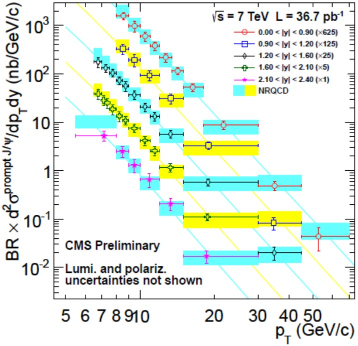


(CMS PAS BPH-10-014 (2011))
(Eur. Phys. J C71, 1575 (2011))

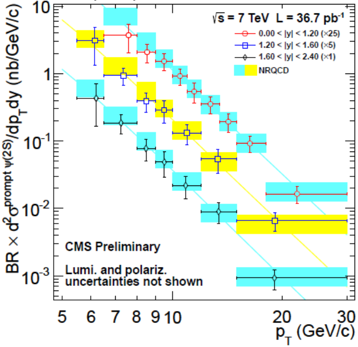




J/Ψ



$\Psi(2S)$

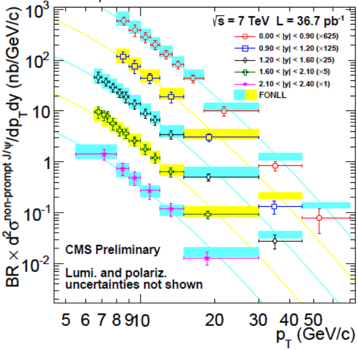


- Excellent agreement with NRQCD predictions.

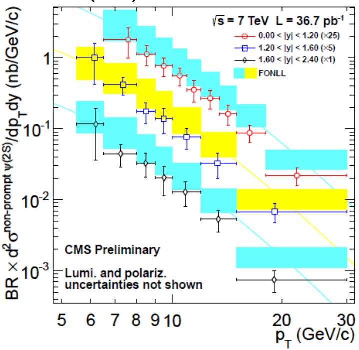
(CMS PAS BPH-10-014 (2011))
(Eur. Phys. J C71, 1575 (2011))

Results: Non-Prompt J/Ψ and $\Psi(2S)$ Differential X-section

J/Ψ



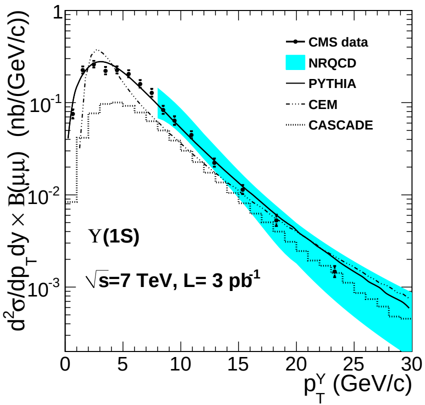
$\Psi(2S)$

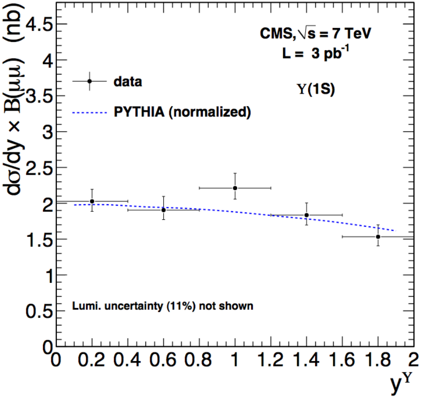


- Good agreement with FONLL predictions:
  - Overall shift in the $\Psi(2S)$ case
  - Spectra fall more rapidly than predictions at high p_T

(CMS PAS BPH-10-014 (2011))
(Eur. Phys. J C71, 1575 (2011))

$\Upsilon(nS)$ Differential X-section (I)



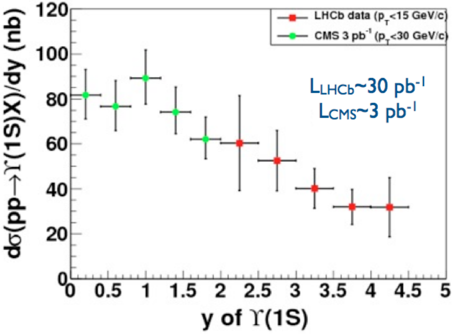


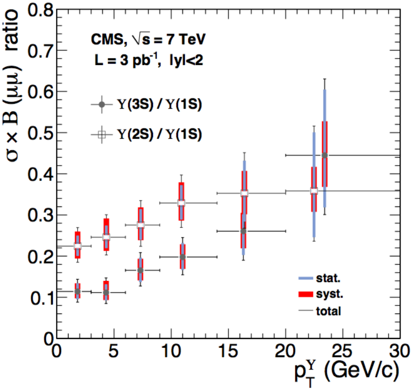
- The normalized p_T-spectrum prediction from Pythia is consistent with the measurements

Phys. Rev. D83, 112004 (2011)

- The cross section shows a slight decline towards $|y| = 2$, consistent with the expectation from Pythia.

$\Upsilon(nS)$ Differential X-section Results (II)





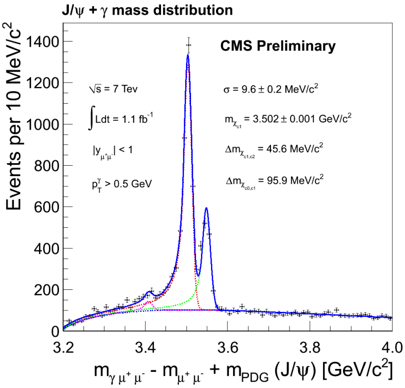
- complementary rapidity regions probed by the two experiments
- results are in good agreement

- Ratios of excited wrt. ground states increase with p_T.

Phys. Rev. D83, 112004 (2011)

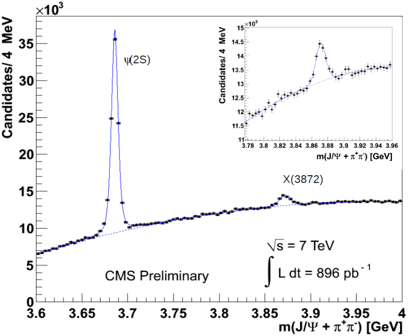
Separation of χ_{c1}/χ_{c2} states

- Full 2011 sample (1.1 fb-1)
- Combine a prompt J/Ψ candidate with a photon converted to e^+e^- in the silicon tracker
- γ Conversion selection based on:
    - High Purity Conversions:
        - Vertexing probability
        - Large conversion radius
    - $p_T > 0.5 GeV$
    - π^0 Rejection: combining candidates with photons in the ECAL



First measurement of the X(3872) / $\Psi(2S)$ Ratio

- Both reconstructed in the J/Ψ $\pi^+\pi^-$ channel
- Background reduction using:
  - 4-track vertex
  - Di-pion p_T
  - Di-pion / J/Ψ angular separation



With the data sample of 40 pb^{-1}, $R = 0.087 \pm 0.017(stat) \pm 0.009(syst)$

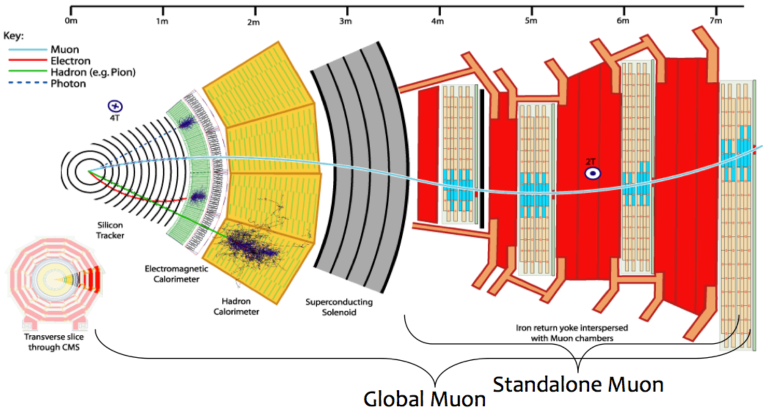
CMS PAS BPH-10-018 (2011)

Summary

- J/Ψ, $\Psi(2S)$, $\Upsilon(nS)$ differential cross-sections measured with typical uncertainties (statistical + systematic) of 5% 20% 15%
  - p_T ranging from 0 to 70 GeV/c for the J/Ψ
  - For charmonium, prompt and non-prompt separation achieved using decay length information
  - Good agreement with NLO NRQCD predictions at 7 TeV
  - B$\rightarrow J/\Psi$, $\Psi(2S)$ in reasonable agreement with FONLL predictions, except for the very high p_T region and for the total $B \rightarrow \Psi(2S)$ rate
- χ_c states separation in the J/Ψ plus converted photon channel
  - Excellent signal-to-background ratio, good separation of the three states: χ_{c0}, χ_{c1} and χ_{c2}
- First CMS measurements in the field of "exotic" quarkonia X(3872) to $\psi(2S)$ [cross-section x BR] ratio

Back Up

Muon Reconstruction



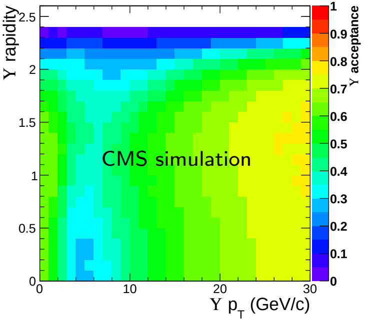
Low p_T muons might not traverse more than one instrumented muon layer because of the B-field (mid-rapidity) or material thickness (forward).

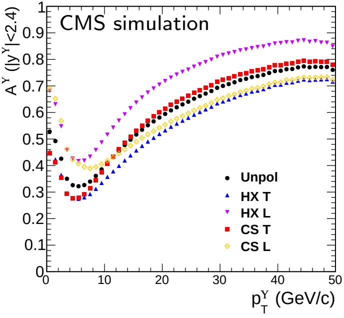
Tracker muon reconstruction starts from a silicon track and search for a compatible muon signal (even in one instrumented layer.) Tight quality cuts are applied on the track-segment match.

Acceptance ($\mathcal{A}$)

- Geometric and kinematic
- MC for each signal component
- Strong function of production polarization
- Quote five cross sections for discrete polarization values

unpolarized





HXT: Helicity frame, transversely polarized HXL: Helicity frame, longitudinally polarized CST: Collins-Soper frame, longitudinally polarized CSL: Collins-Soper frame, transversely polarized