Quarkonium Production with the CMS experiment

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on behalf of the CMS collaboration

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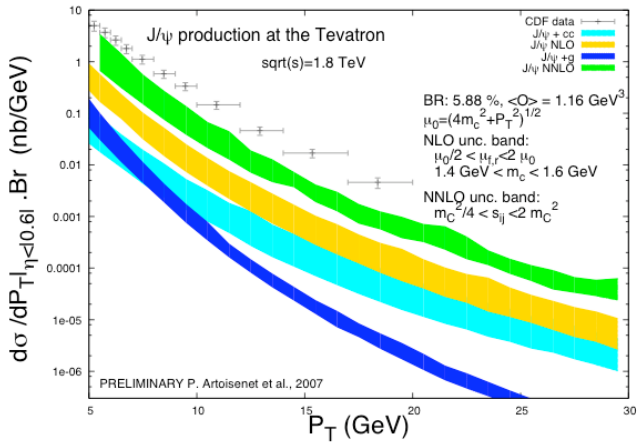
Outline

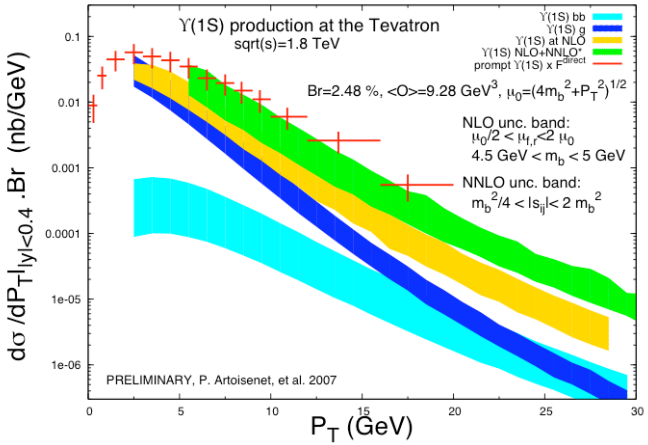
- Why Study Quarkonium at the LHC?
- The CMS Detector
- Quarkonium Cross Section Measurements
- Υ(nS) Polarizations
- χ_{c2}/χ_{c1} Cross Section Ratio
- Ratio of X(3872) and Ψ(2S) Cross Sections
- Observation of Structures in the $J/\Psi\Phi$ Mass Spectrum
- Summary

Motivation

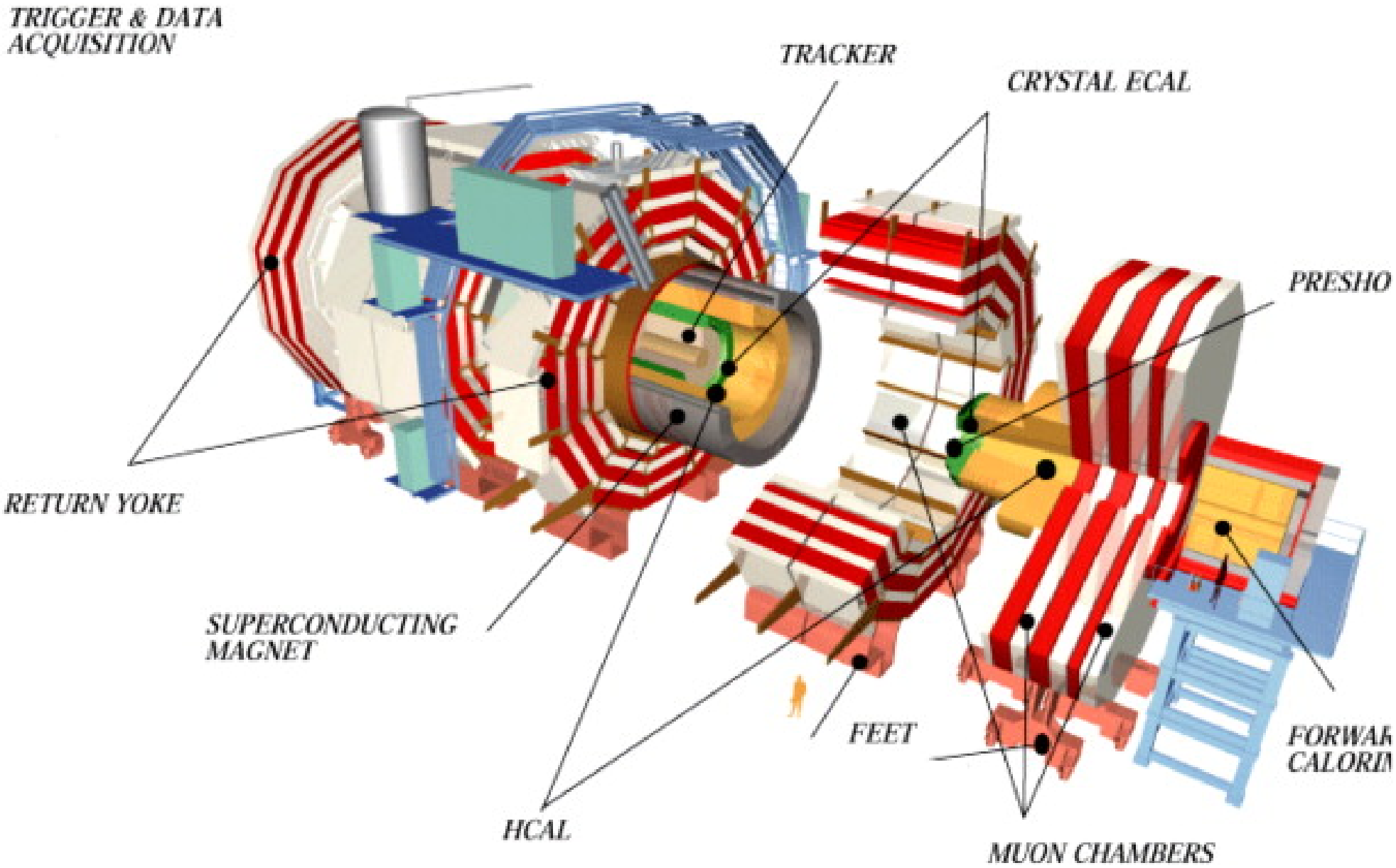
- Theoretical Motivation
  - no theory has simultaneously explained experimental measurements of both production cross section and polarization

- LHC provides:
  - New energy scale
  - Large p_T reach
- CMS provides:
  - excellent dimuon mass resolution
  - good photon reconstruction resolution, which allows to study P-wave quarkonium states through radiative decays



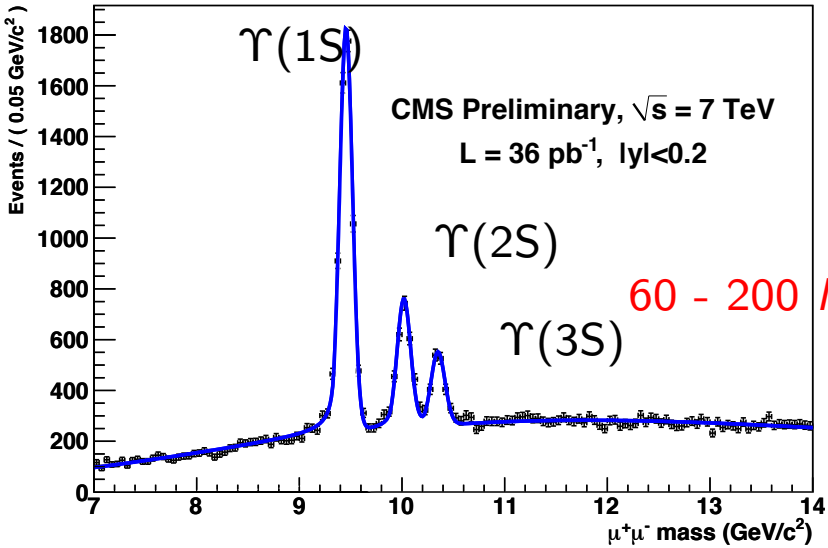


The CMS Detector

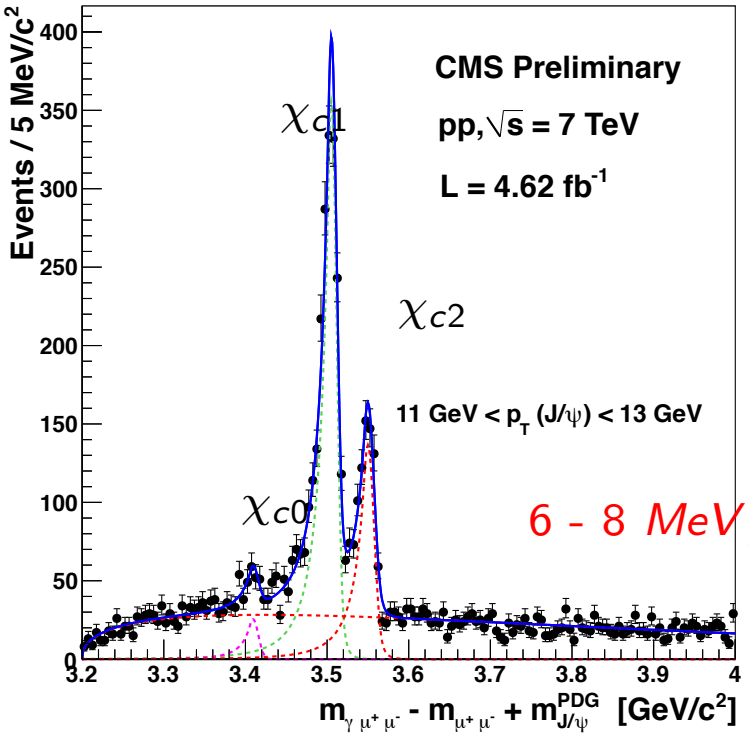


Mass Fits and Yields ($N_{Q\overline{Q}}$)

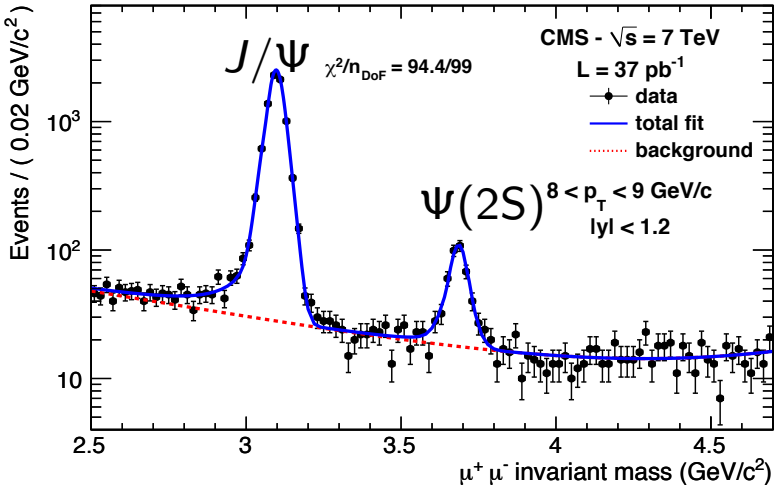
- Unbinned Maximum Likelihood fit
- signal: Crystal Ball, Background: Exponentials or exponential and error function product
- Mass differences fixed to PDG values, common resolution value scaled by mass



60 - 200 MeV/c^2



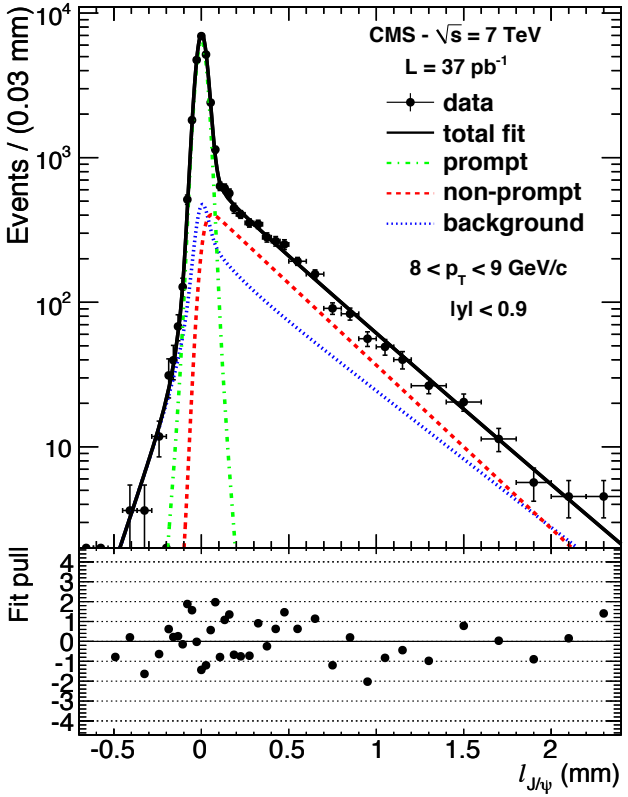
6 - 8 MeV/c^2



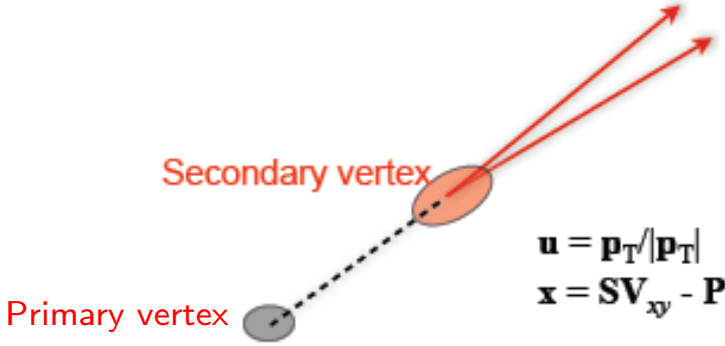
20 - 50 MeV/c^2

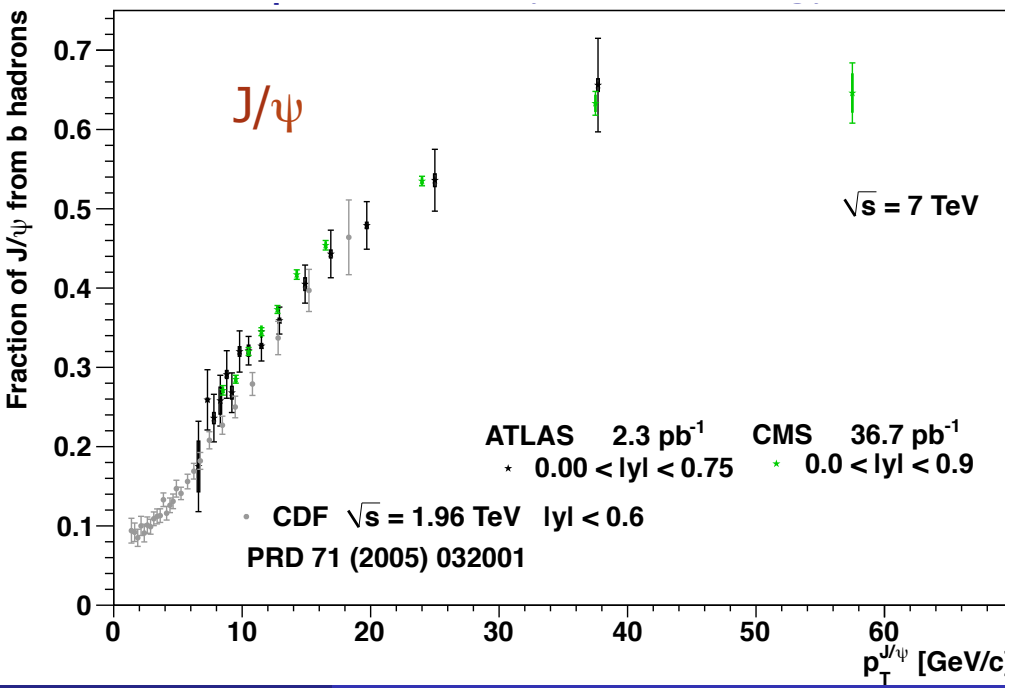
Disentangling Prompt and Non-prompt J/Ψ

- 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



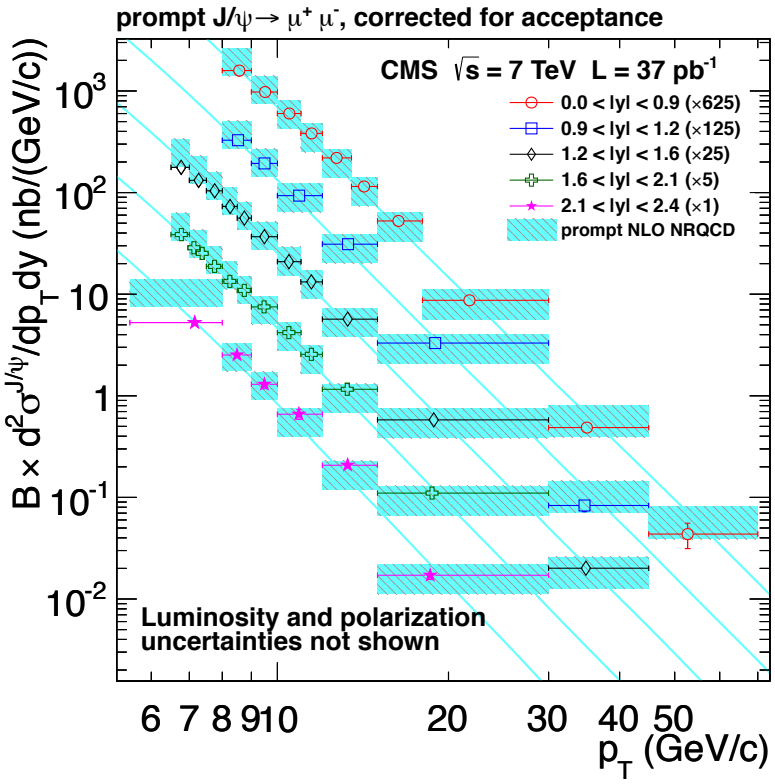
(JHEP 02 (2012) 011)

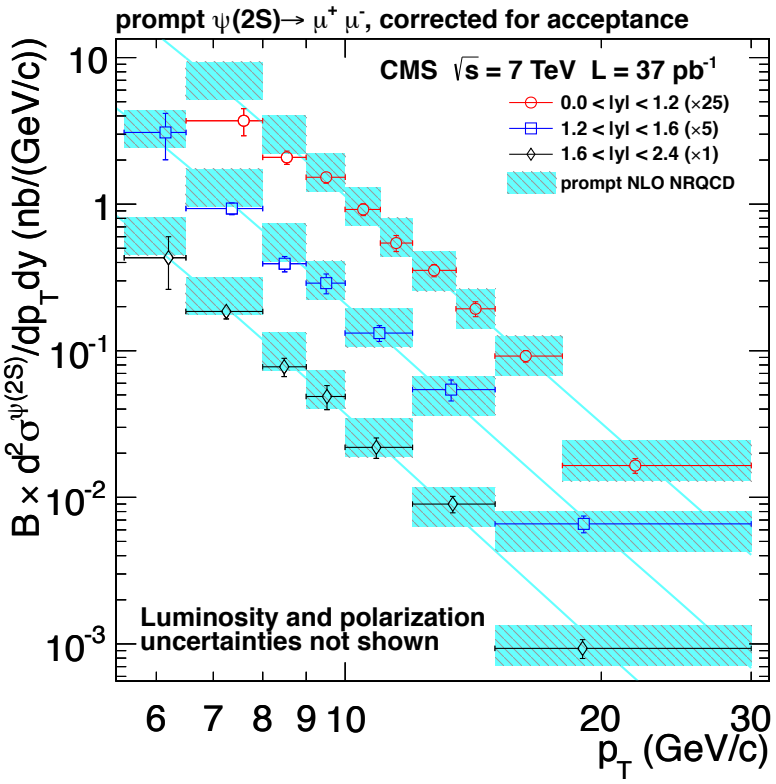




Results: Prompt J/Ψ and Ψ(2S) Differential X-section

J/Ψ $\Psi(2S)$



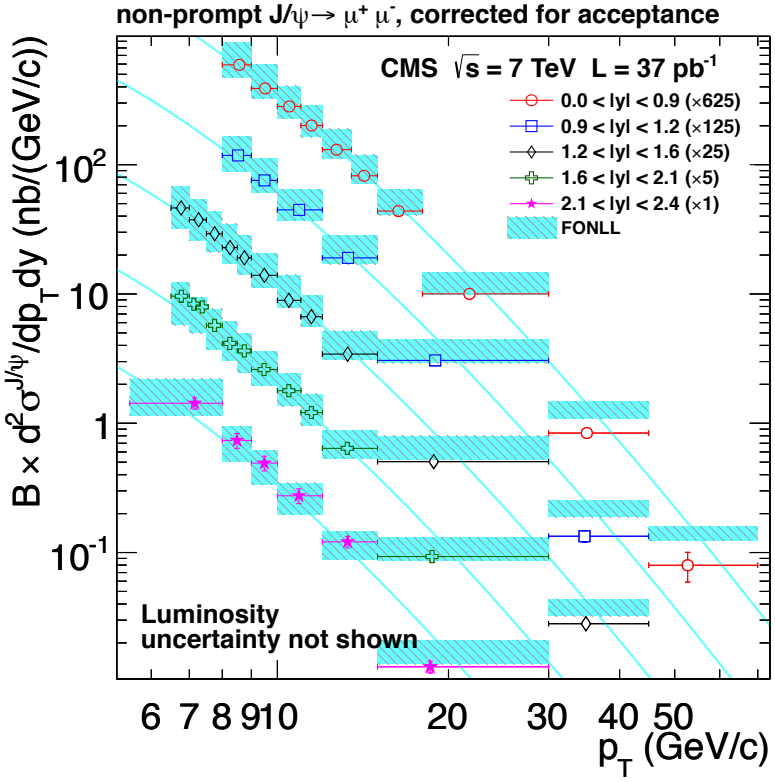


- Excellent agreement with NLO NRQCD predictions.

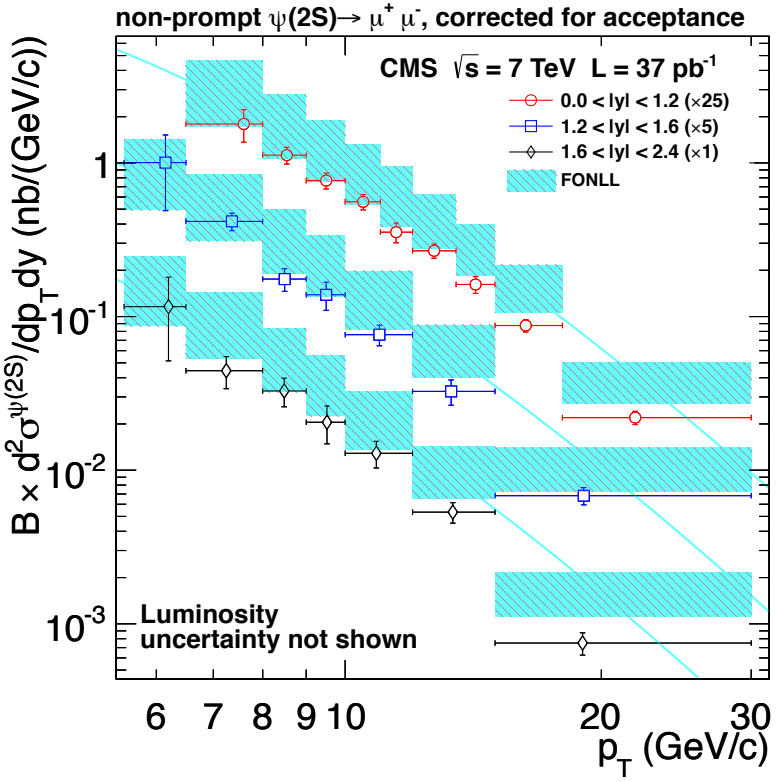
(JHEP 02 (2012) 011)

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

J/Ψ



$\Psi(2S)$

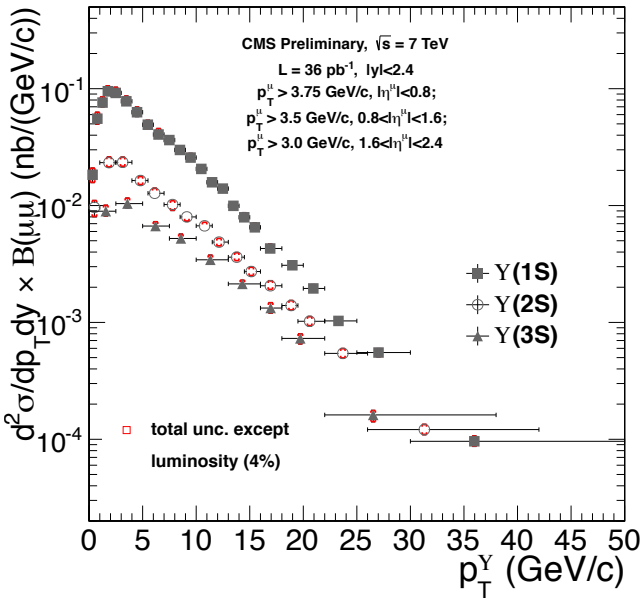


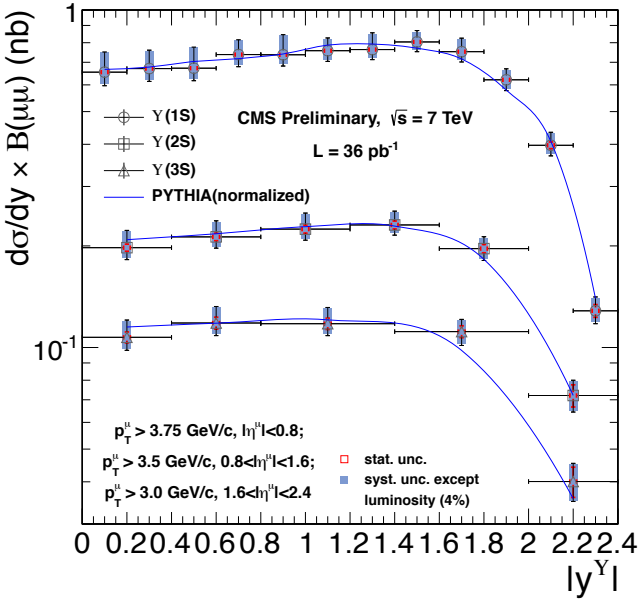
- Good agreement with FONLL predictions:
  - Overall shift in the $\Psi(2S)$ case
  - Spectra fall more rapidly than predictions at high p_T

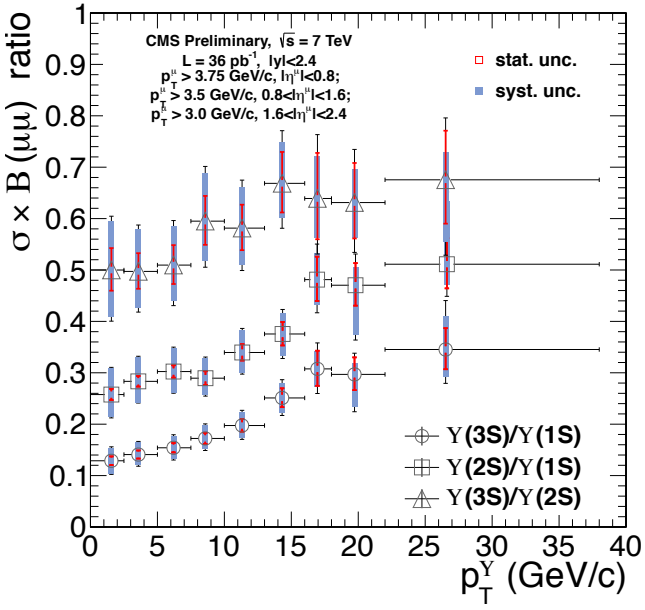
(JHEP 02 (2012) 011)

Υ(nS) Differential Fiducial X-section (36 pb^{-1})

- Acceptance is a strong function of production polarization
- The fiducial cross section results are not corrected for acceptance.







78K Υ(1S), 24K Υ(2S), 12K Υ(3S)

BPH-11-001,
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11001

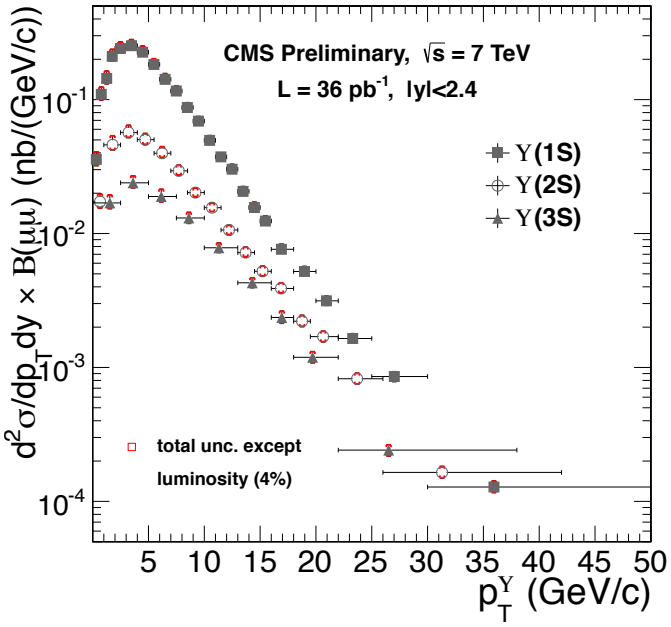
Differential Υ(nS) Cross Section of p_T and $|y|$ (36 pb^{-1})

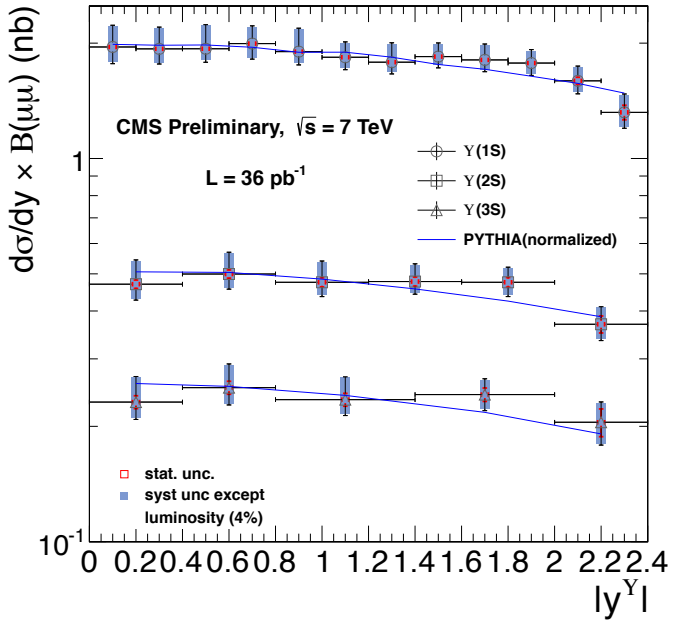
BPH-11-001, https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11001

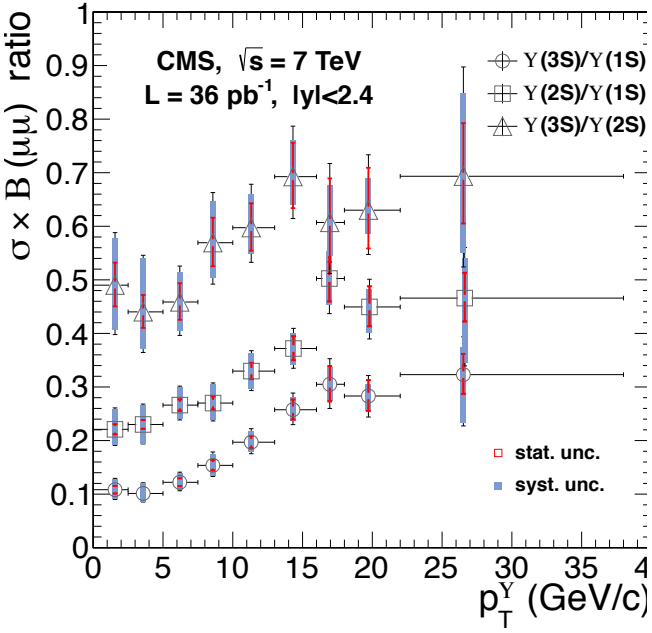
$$\sigma(pp \to \Upsilon(1S)X) \cdot \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) = (8.55 \pm 0.05(\text{stat.})^{+0.88}_{-0.78}(\text{syst.}) \pm 0.34(\text{lumi.}))\ \text{nb}\,,$$

$$\sigma(pp \to \Upsilon(2S)X) \cdot \mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) = (2.21 \pm 0.03(\text{stat.})^{+0.24}_{-0.21}(\text{syst.}) \pm 0.09(\text{lumi.}))\ \text{nb}\,,$$

$$\sigma(pp \to \Upsilon(3S)X) \cdot \mathcal{B}(\Upsilon(3S) \to \mu^+\mu^-) = (1.11 \pm 0.01(\text{stat.})^{+0.13}_{-0.12}(\text{syst.}) \pm 0.04(\text{lumi.}))\ \text{nb}\,.$$

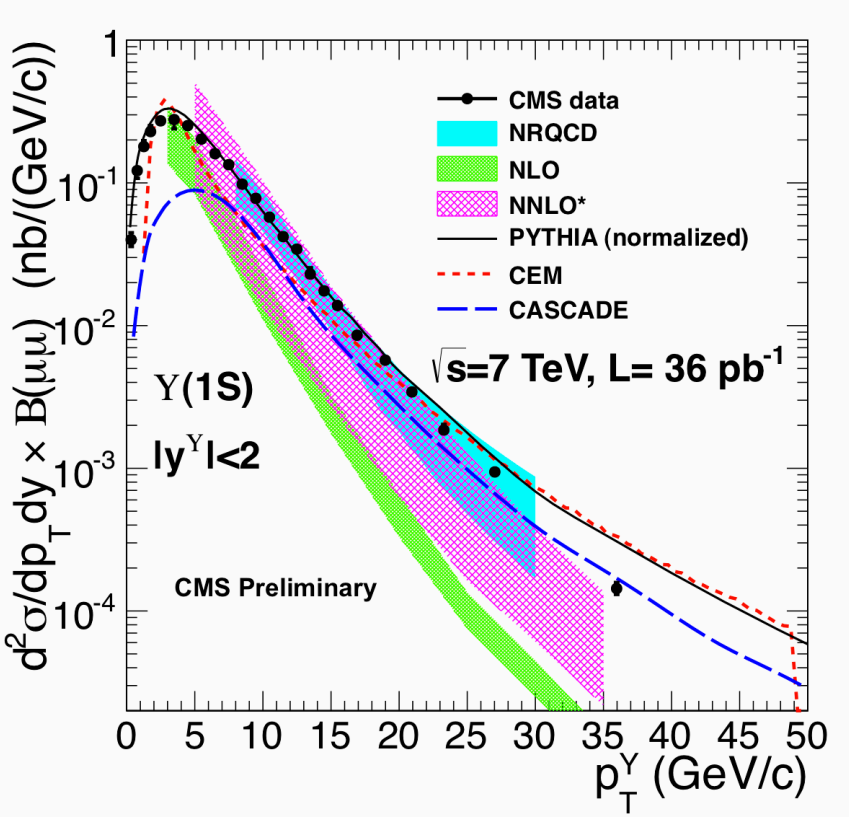


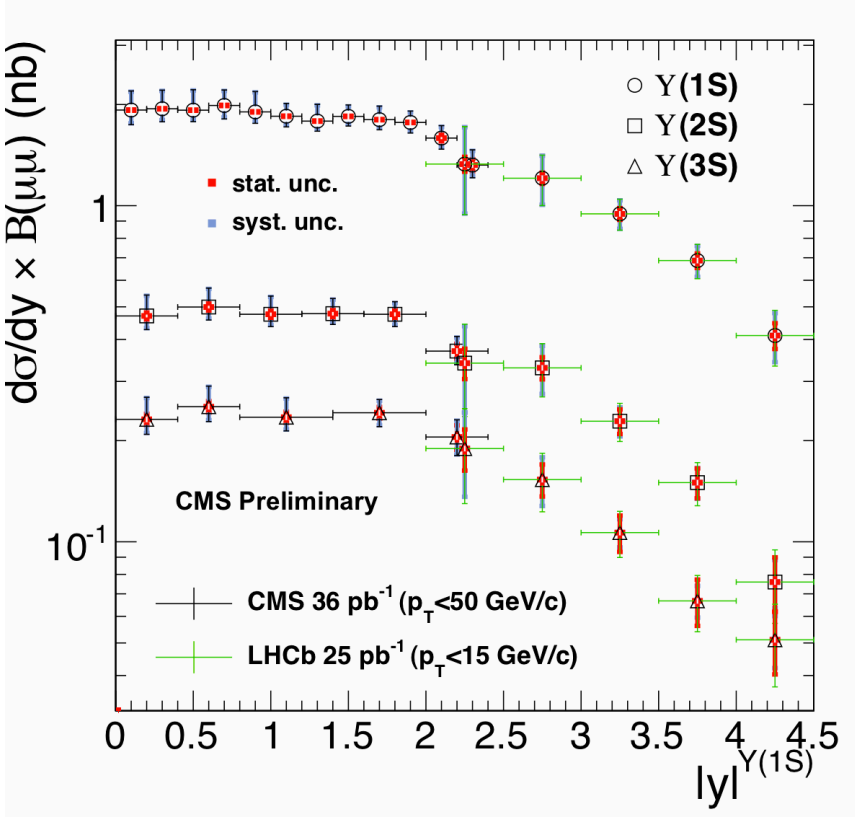




- Updated analysis using 36 pb^{-1} data, extending kinematic reach: $p_T < 20GeV \to 50GeV$, $|y| < 2 \to 2.4$
- Acceptance corrections for unpolarized assumption, down to zero p_T
- The dominant systematic is from the calculation of the efficiencies.

Comparisons of Cross Section to Theory and Other Experiments



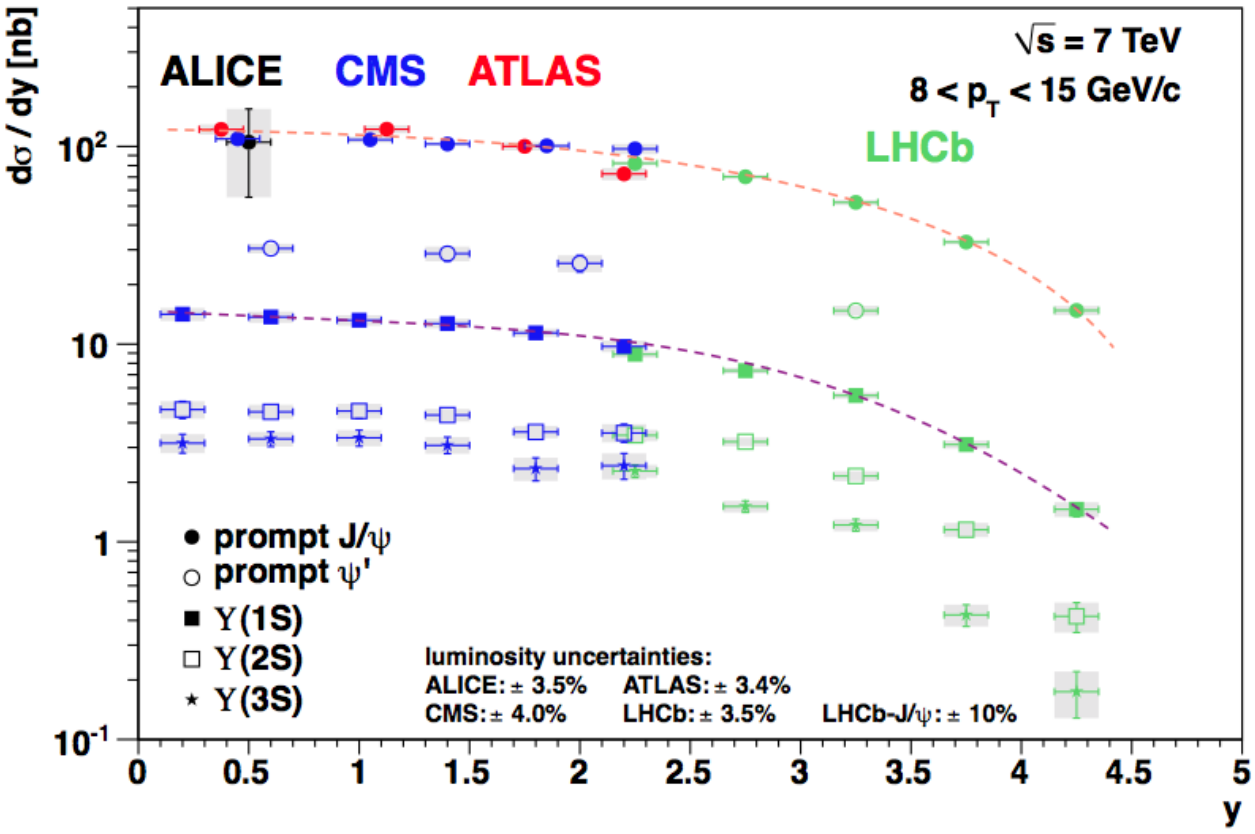


- NRQCD seems to give the best agreement

  BPH-11-001

- Complementary to LHCb and consistent in the region of overlap

Summary of Quarkonium Cross Sections and Comparisons to the other experiments at the LHC



ALICE : 5.6 nb^{-1}
ATLAS : 2.2 pb^{-1}
CMS : 37, 36 pb^{-1}
LHCb : 5.2, 36, 25 pb^{-1}

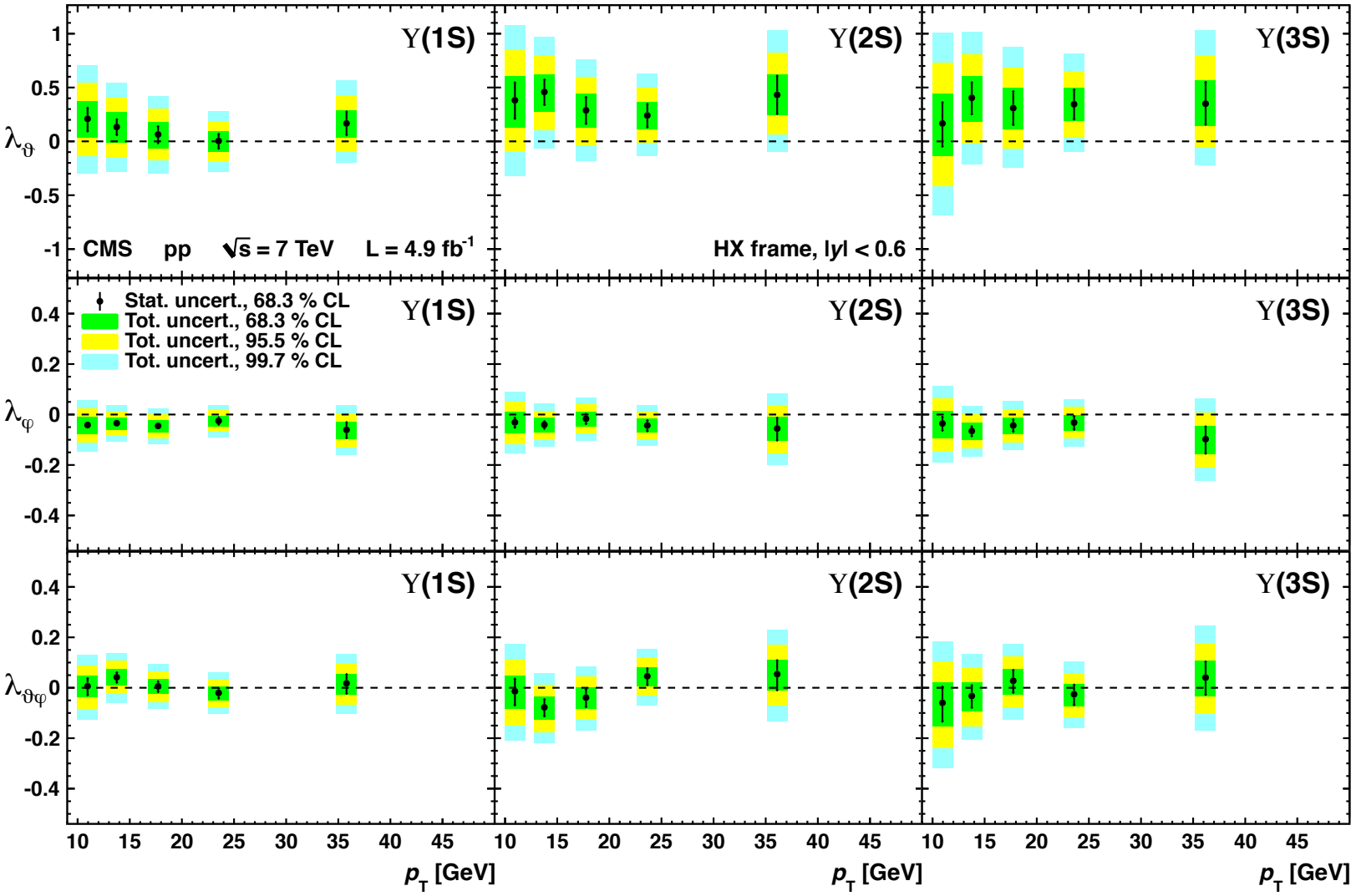
Compilation by H. K. Wöhri, presented in LHC Days in Split

- Prompt J/Ψ production has been measured by four LHC experiments with 2010 data
- CMS and LHCb trends can also be compared for prompt Ψ's and for the three Υ states
- Much larger data sets from 2011 and 2012 should provide even more accurate results

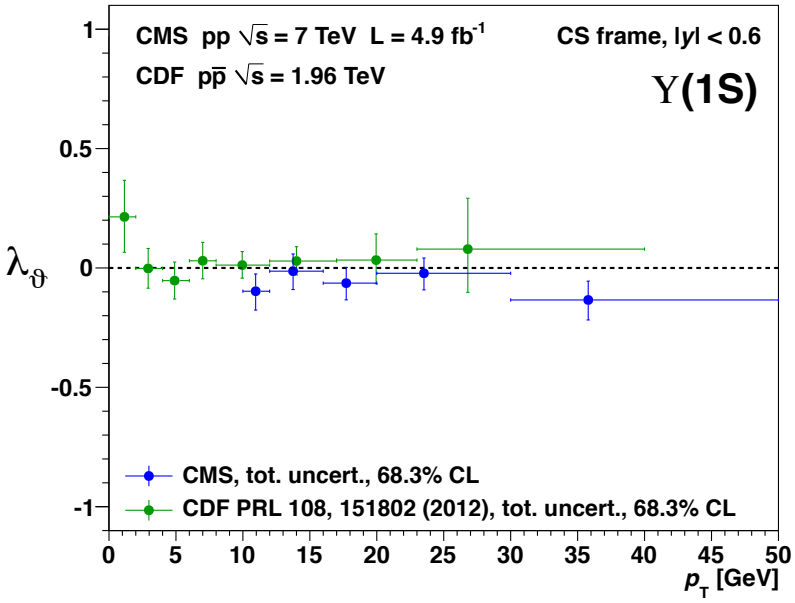
Υ(nS) Polarization Measurement

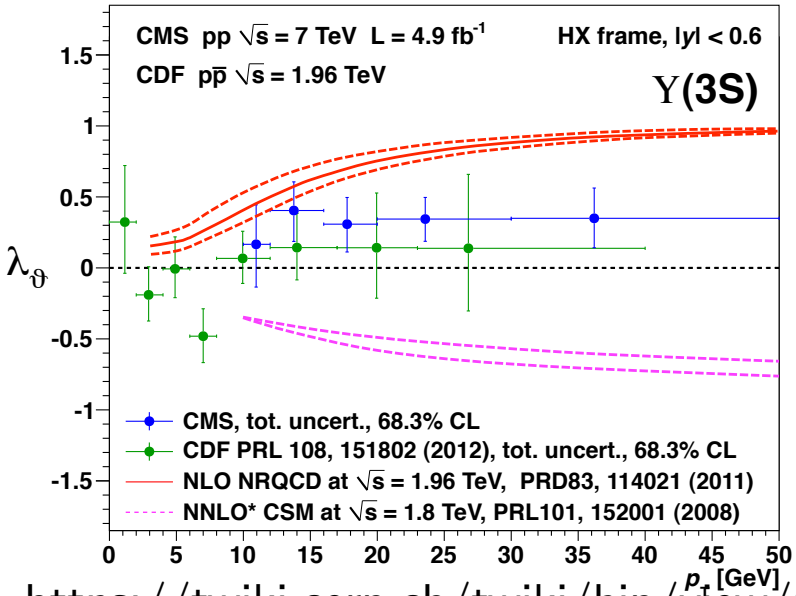
- The polarization parameters λ_θ, λ_ϕ, $\lambda_{\theta\phi}$ and $\tilde{\lambda}$ are measured in three frames (HX, CS, PX), in two rapidity regions, $|y| < 0.6$ and $0.6 < |y| < 1.2$

arXiv:1209.2922, accepted by PRL



Comparisons with CDF and theory





- CMS extends the measurements beyond the p_{T} and rapidity ranges probed by CDF at the Tevatron
- Theory is more reliable at high p_{T}
- Measurements do not show strong polarizations

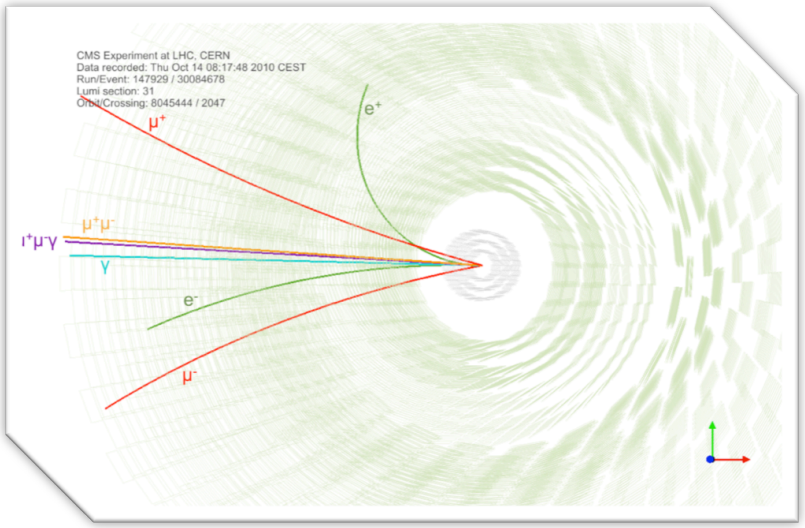
arXiv:1209.2922, accepted by PRL

- Υ(1S) suffers from large χ_b feed-down contribution, with unknown polarization
- Υ(3S) is almost free from feed-down $\rightarrow$ more robust comparison to calculations
- Theory predictions needed for λ_ϕ and $\lambda_{\theta\phi}$, and in the CS and PX frames

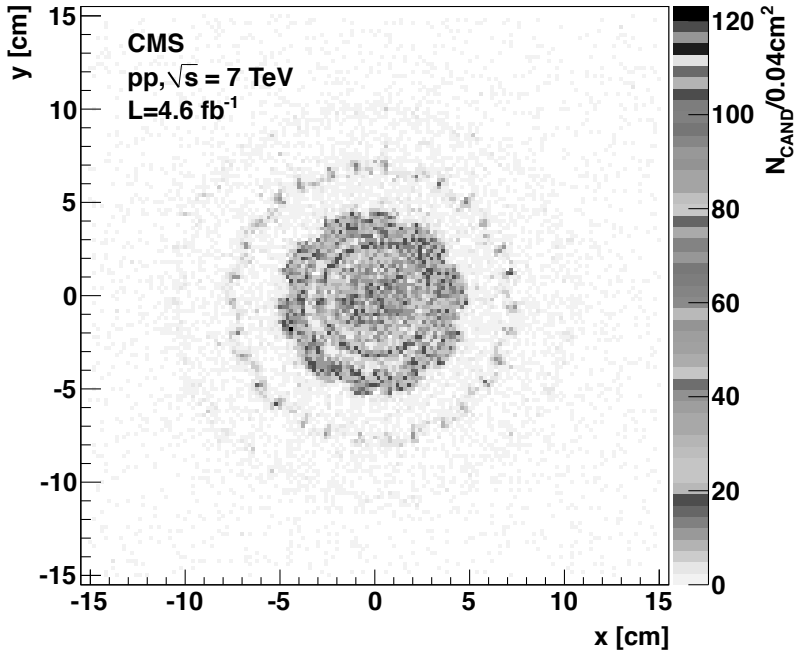
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11023

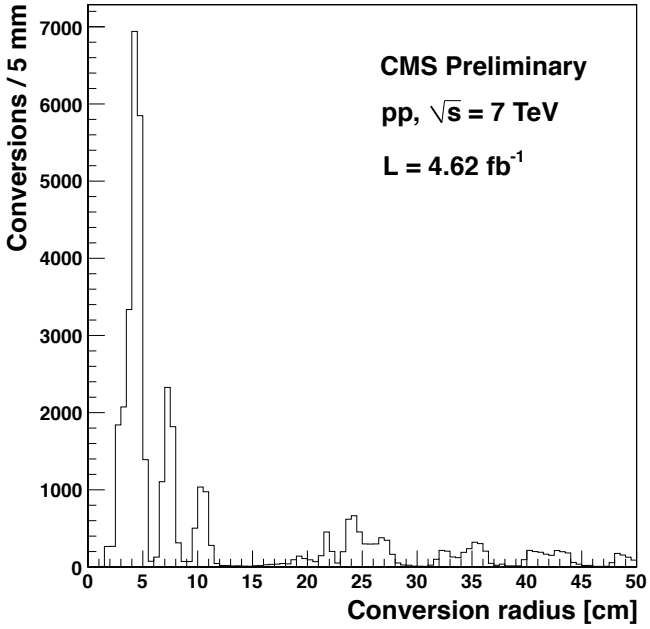
Measurement of the prompt χ_{c1}/χ_{c2} production cross-section ratio

- P-wave quarkonium states present complementary information to S-wave state production.
- Production of χ_c mesons studied via $\chi_c \to J/\Psi + \gamma$ decays, with tracker-only γ conversions to e^+e^-
- High purity γ Conversions



arXiv:1210.0875, accepted by EPJC

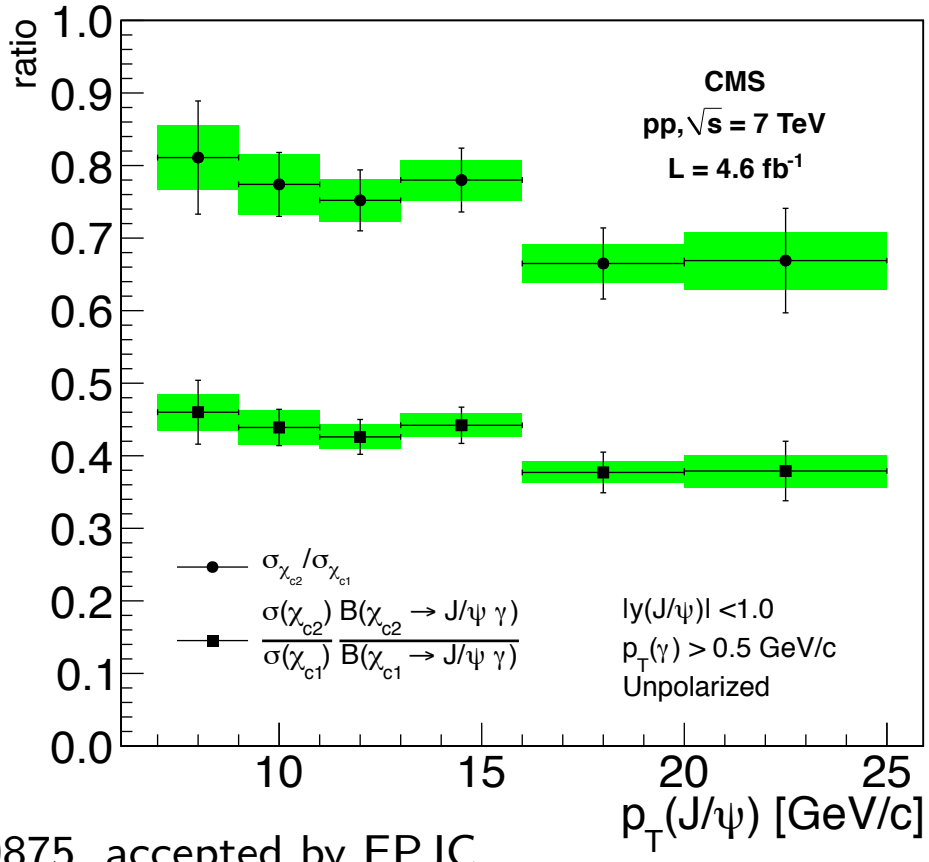




https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11010

The Results

- The prompt χ_{c2}/χ_{c1} cross-section ratio has been measured vs. p_T
- Systematic uncertainties dominated by fit to mass distribution. Also include efficiencies statistical uncertainty.



arXiv:1210.0875, accepted by EPJC

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Comparisons to Theories

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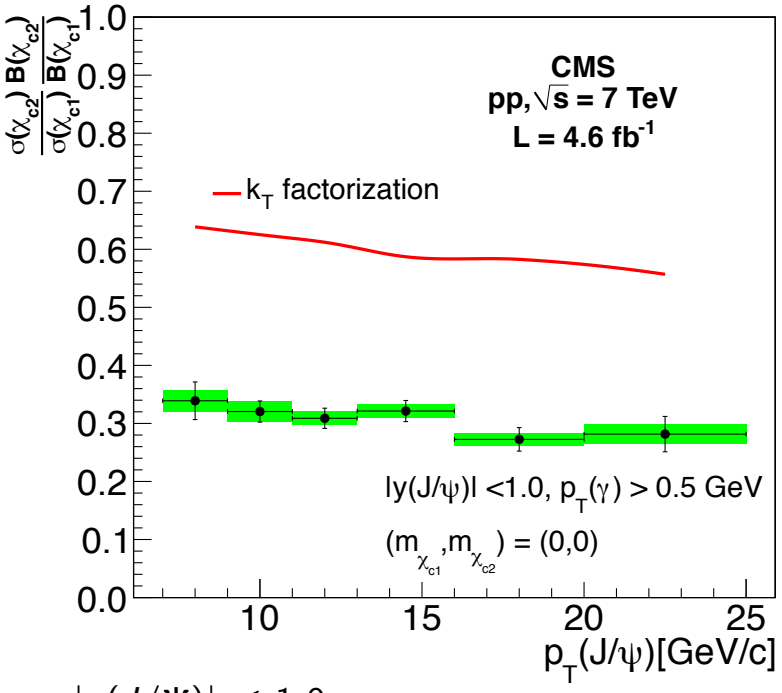
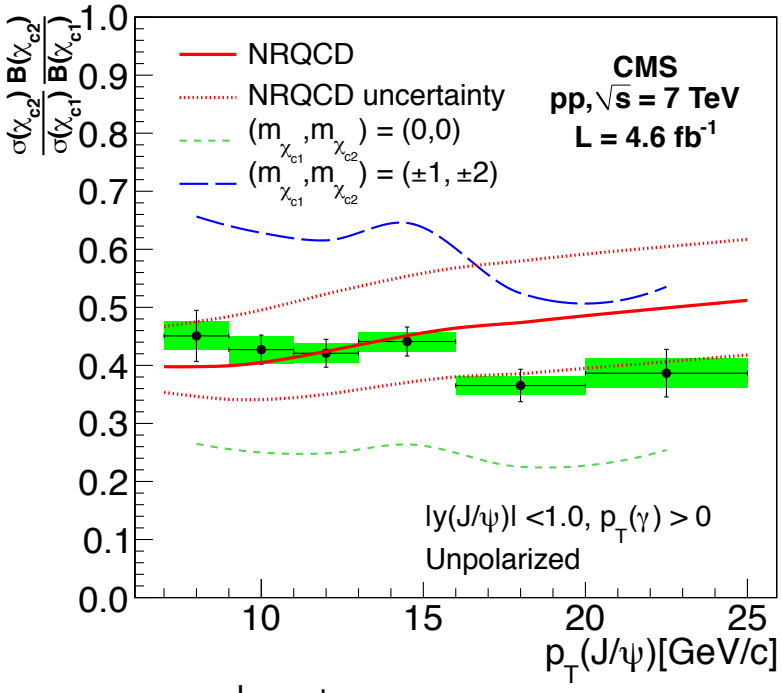


$|y(J/\Psi)| < 1.0$,
$p_T(\gamma) > 500 MeV/c$

- The k_T factorization model predicts the χ_{c1} and χ_{c2} states in a $J_z^{HX} = 0$ state. For a proper comparison, the acceptance was recalculated under this assumption.

arXiv:1210.0875, accepted by EPJC



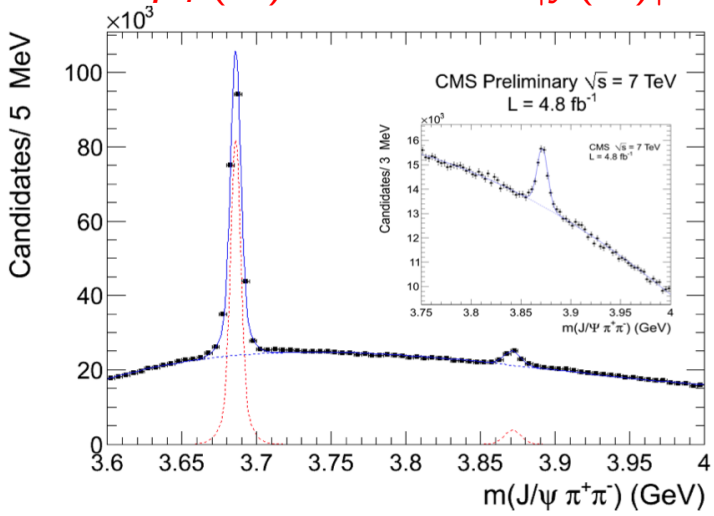
down to zero p_T

- The NLO NRQCD predictions were made without a cut on the photon transverse momentum.
- Extrapolated down to zero photon p_T.
- The measurements assuming two different extreme polarization scenarios are shown by the long-dashed blue and short-dashed green lines.

Ratio of X(3872) and Ψ(2S) cross sections

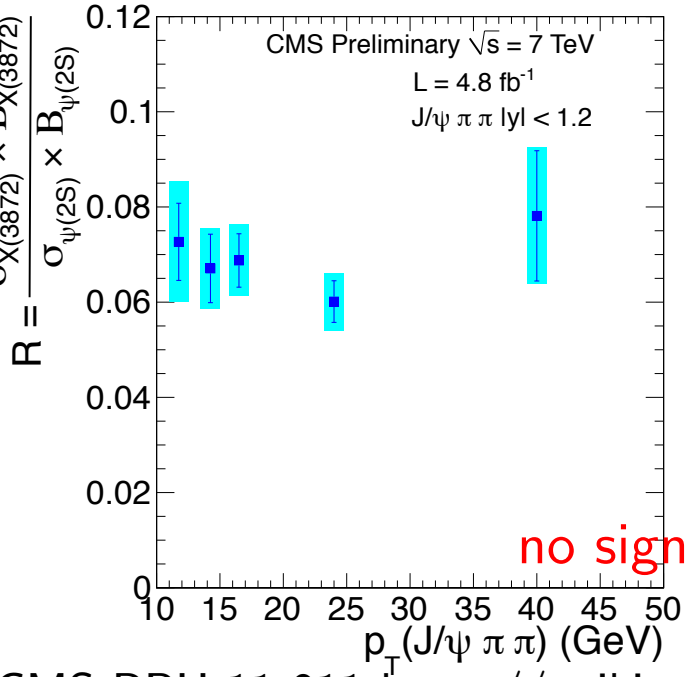
- X(3872): $c\bar{c}$, $D^*\bar{D}^0$ molecule, tetra-quark state
- Both X(3872) and Ψ(2S) include prompt and non-prompt components from B decays
- The non-prompt fraction is determined using the decay lifetime spectrum

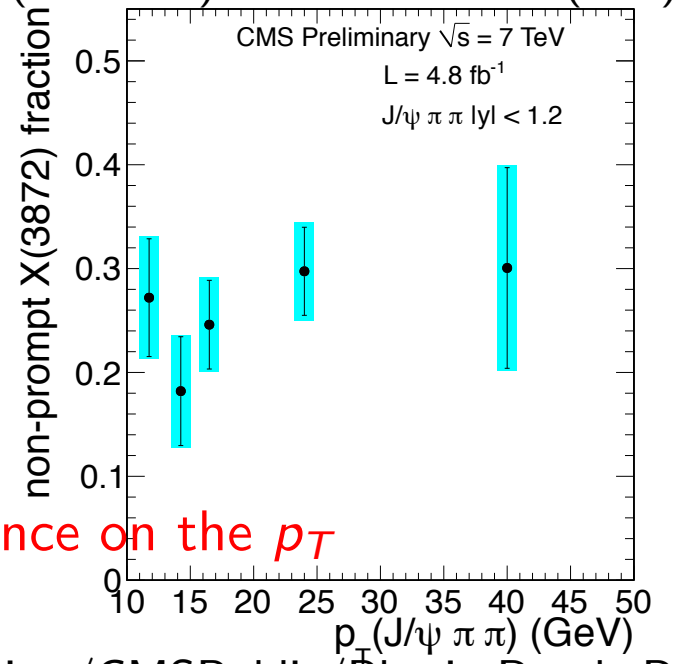
$10 < p_T(X) < 50$ GeV, $|y(X)| < 1.2$



$R = 0.0662 \pm 0.0038(\text{stat}) \pm 0.0064(\text{syst})$

$N(\text{B-enriched})/N(\text{inclusive}) = 0.259 \pm 0.029(\text{stat}) \pm 0.016(\text{sys})$



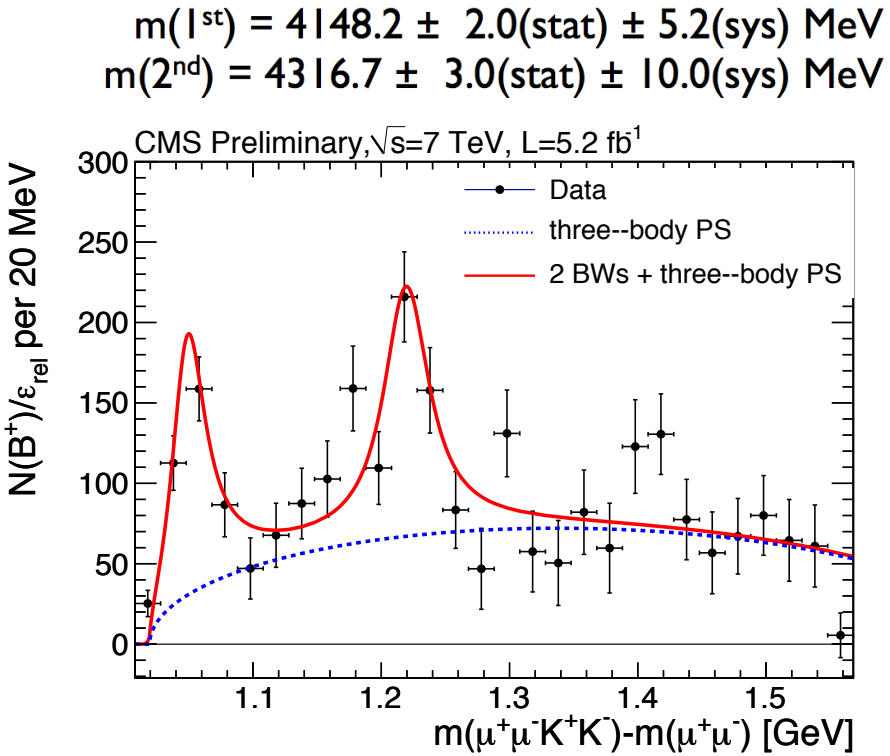


no significant dependence on the p_T

CMS-BPH-11-011 https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11011

Observation of Structures in the $J/\Psi\Phi$ Mass Spectrum

- CDF observed the Y(4140) structure with a significance greater than 5σ.
- CMS confirmed a structure at 4148 MeV with a significance greater than 5σ and saw an evidence for the second structure in the same mass spectrum.



CMS-BPH-11-026 https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11026

Summary

- J/Ψ, $\Psi(2S)$, $\Upsilon(nS)$ differential cross-sections measured with typical uncertainties (statistical + systematic) of 5%, 20%, 10%
  - p_T ranging from 0 to 70 GeV/c for the J/Ψ, 0 to 50 GeV/c for the Υs
  - 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
- $\chi_c \rightarrow J/\Psi + \gamma$ assessed through photon conversion
  - Excellent signal-to-background ratio, good separation of the three states: χ_{c0}, χ_{c1} and χ_{c2}
  - The χ_{c2}/χ_{c1} cross-section ratio measured up to p_T values extending beyond previous measurements
  - The most precise measurement currently!
- The exotic state X(3872) was observed at the new energy region with statistics 2 times as large as CDF; the p_{T} differential cross section has been measured
- Two structures were found in the $J/\Psi\Phi$ mass spectrum.

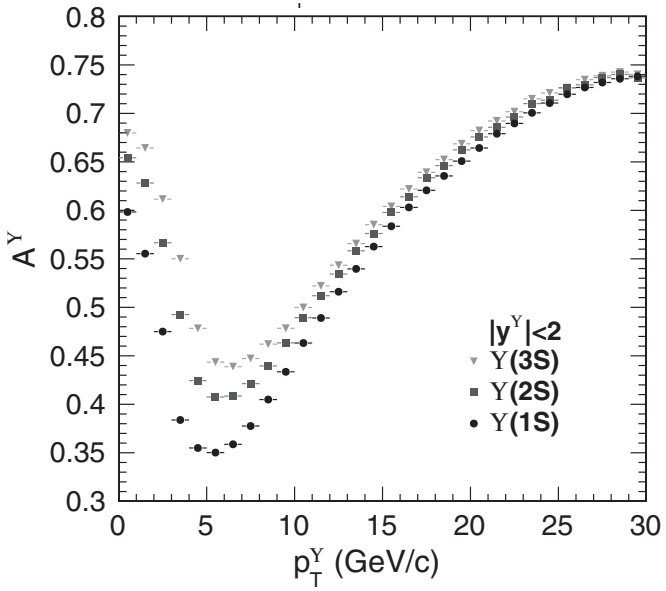
Back Up

Quarkonium Production Cross Section Measurements

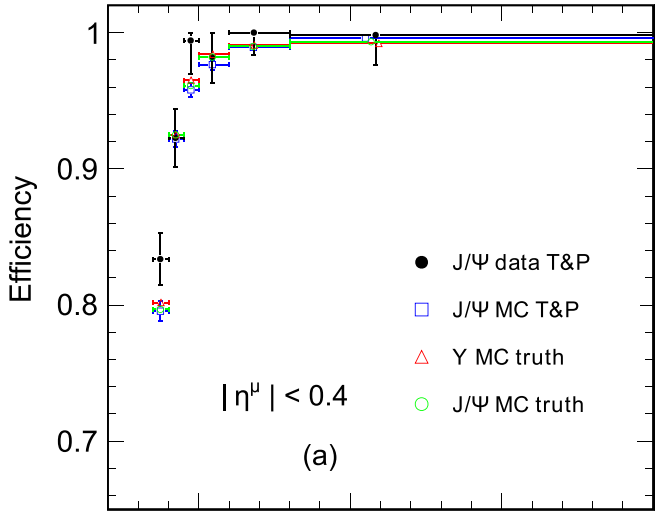
$$\frac{d^2\sigma(Q\overline{Q})}{dp_T dy}\mathcal{B}\left(Q\overline{Q}\to\mu^+\mu^-\right)=\frac{N_{fit}(Q\overline{Q})}{\mathcal{L}\ \cdot\mathcal{A}\cdot\epsilon\cdot\Delta p_T\cdot\Delta y},$$

- $\mathcal{A}$: Acceptance
- $\epsilon=\epsilon_{\rm track}\cdot\epsilon_{\rm id}\cdot\epsilon_{\rm trig}$
  - $\epsilon_{\rm track}$: Tracking efficiency
  - $\epsilon_{\rm id},\epsilon_{\rm trig}$: Muon identification and trigger efficiency
- $N_{fit}(Q\overline{Q})$: The $Q\overline{Q}$ yields, extracted via an extended unbinned maximum likelihood fit
- $\mathcal{L}$: The integrated luminosity of the dataset

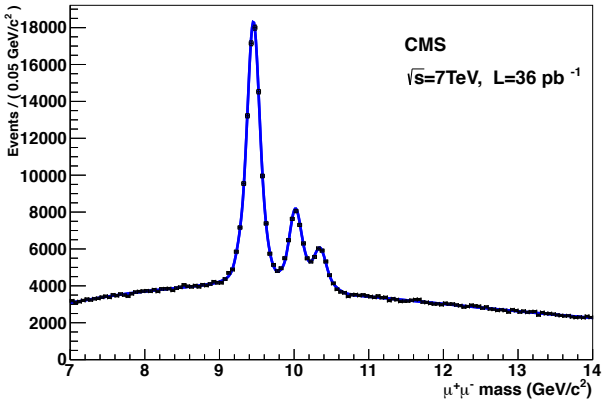
Acceptance ($\mathcal{A}$)



Efficiencies (ϵ)



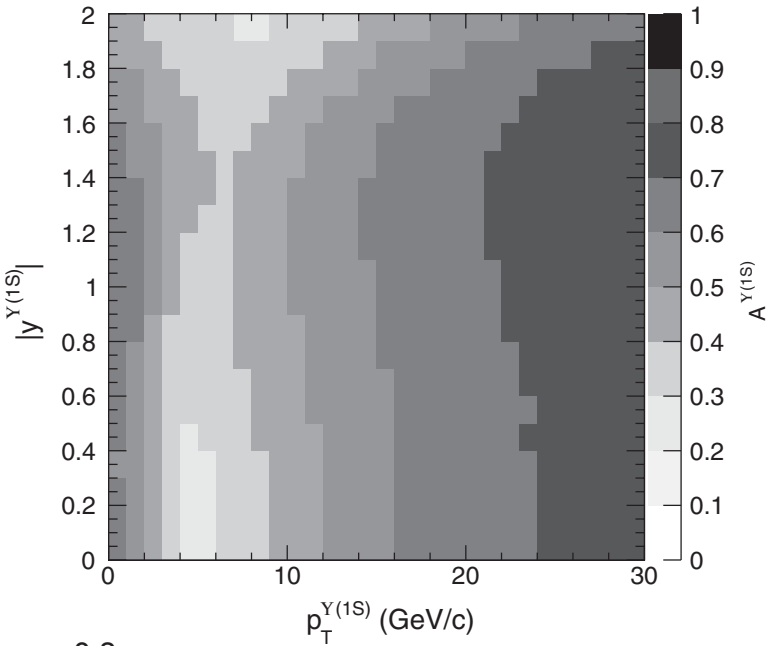
Mass Fit($N_{fit}(Q\overline{Q})$)



Acceptance ($\mathcal{A}$)

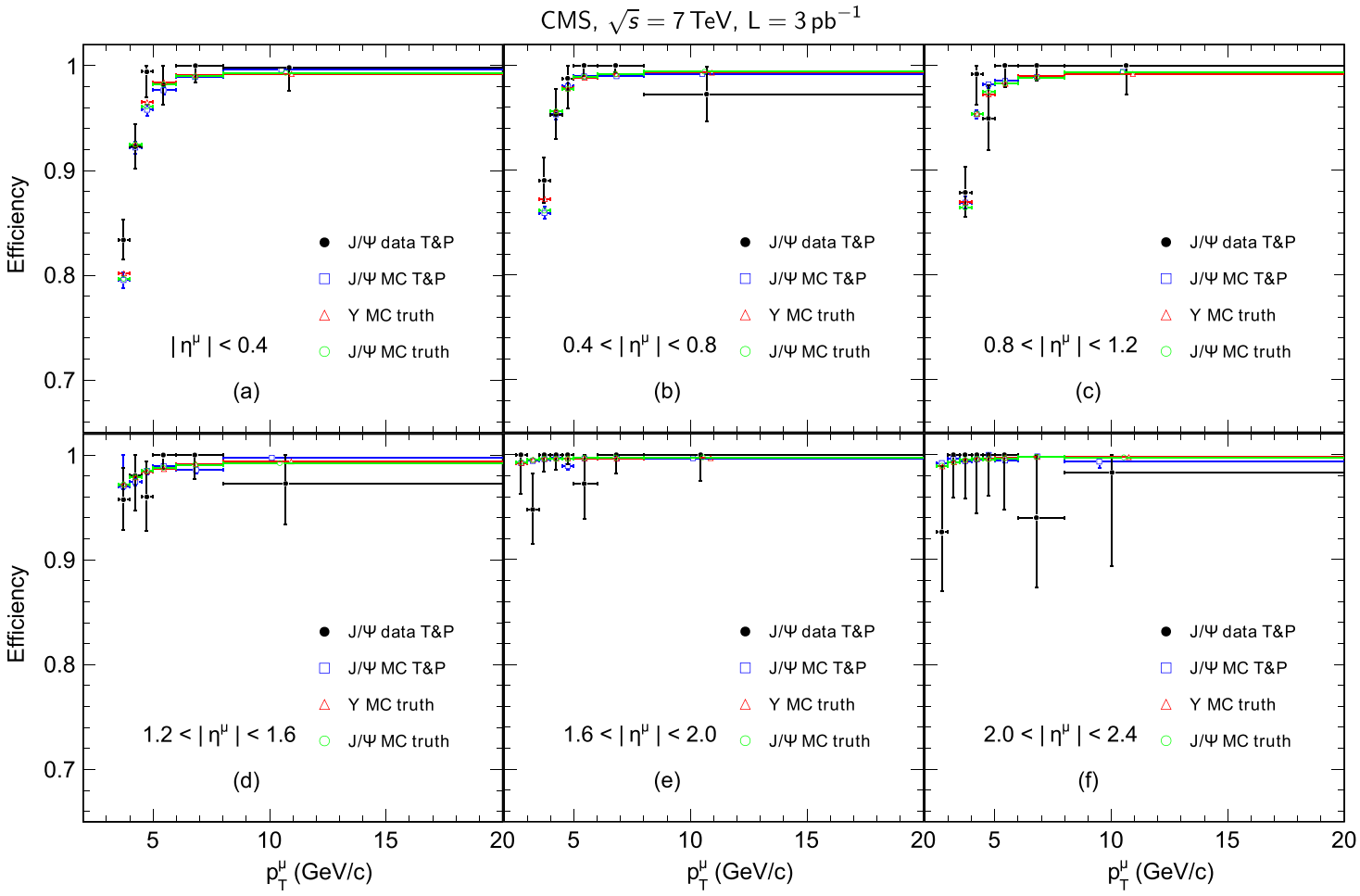
$$\mathcal{A}\left(p_T^{\Upsilon}, y^{\Upsilon}\right) = \frac{N^{\mathrm{reco}}\left(p_T^{\Upsilon}, y^{\Upsilon} \middle| \text{SiTRK track pair satisfies fiducial cuts}\right)}{N^{\mathrm{gen}}\left(p'^{\Upsilon}_T, y'^{\Upsilon}\right)}, \tag{1}$$

- Geometric and kinematic
- High-Statistics Υ(nS) Gun samples, generated flat in Υp_T
- Different acceptance maps for 1S, 2S and 3S



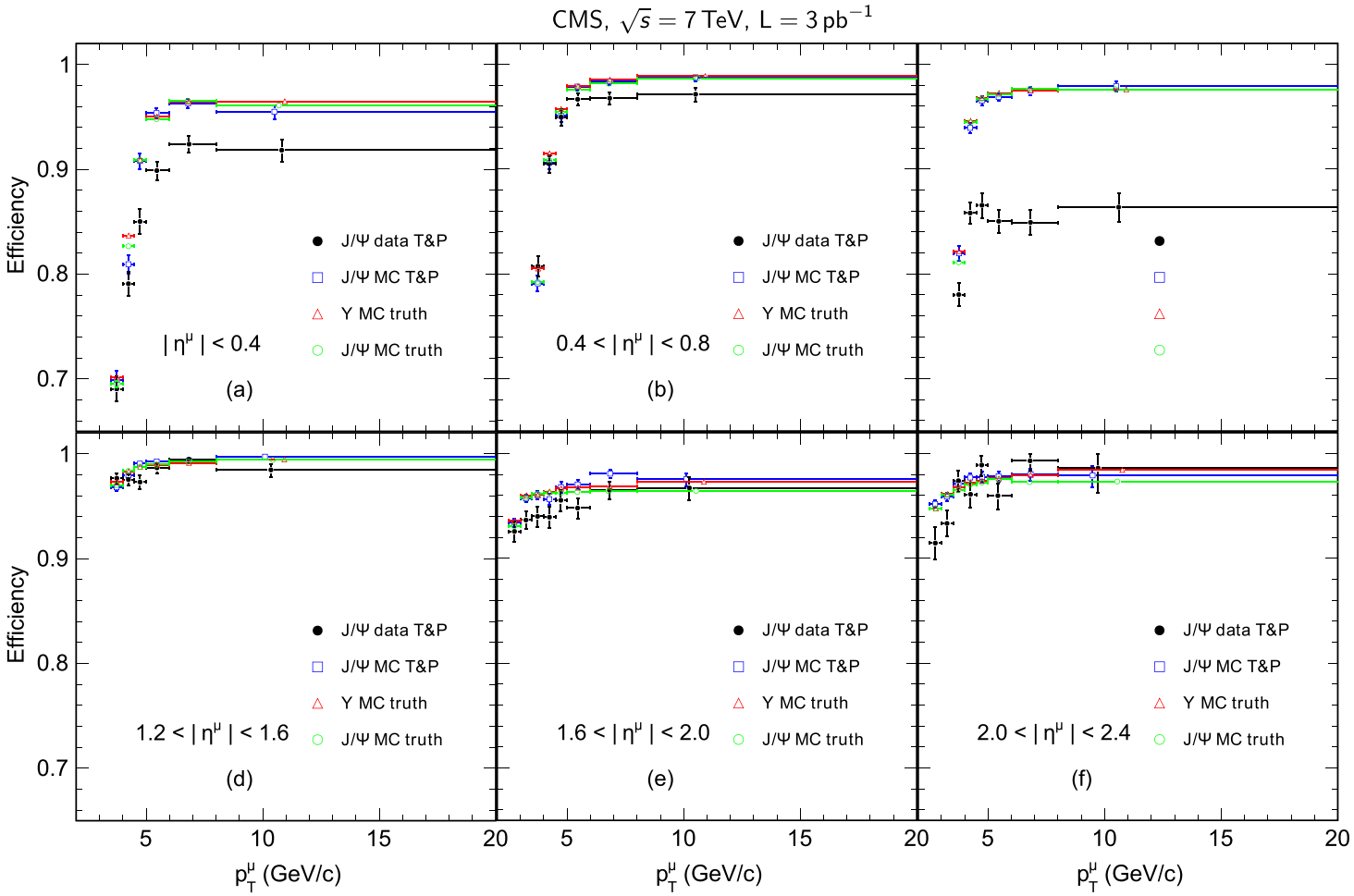
Phys. Rev. D 83, 112004 (2011)

MuonID Efficiencies (ϵ_{id})



Phys. Rev. D 83, 112004 (2011)

Trigger Efficiencies (ϵ_{trig})



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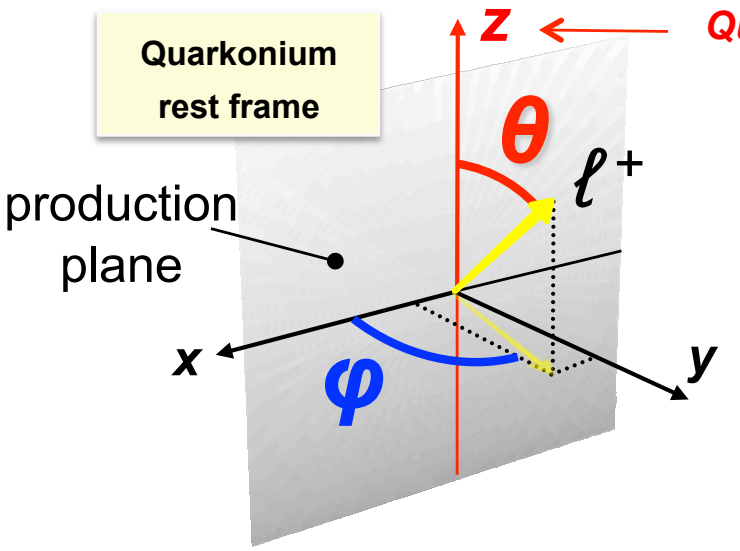
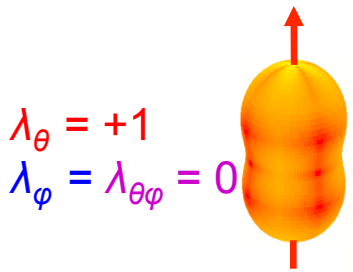
Definition of observables for polarization measurement



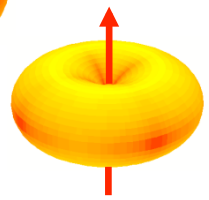
Most general observable angular decay distribution:

$$\frac{dN}{d\Omega} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta \cos 2\varphi + \lambda_{\theta\varphi} \sin 2\theta \cos\varphi$$



$\lambda_\theta = +1$
$\lambda_\varphi = \lambda_{\theta\varphi} = 0$

$J_z = \pm 1 \rightarrow \lambda_\theta = +1$: **"transverse"** polarization

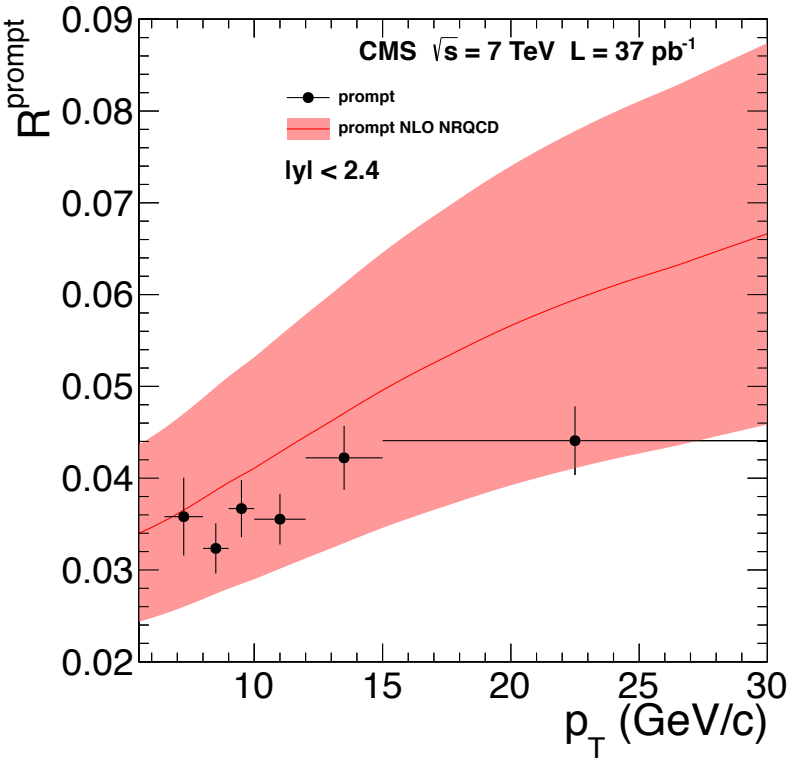


$\lambda_\theta = -1$
$\lambda_\varphi = \lambda_{\theta\varphi} = 0$

$J_z = 0 \rightarrow \lambda_\theta = -1$: **"longitudinal"** pol.

Results: $\Psi(2S)$ to J/Ψ X-section Ratios

Prompt Ratio



- No $|y|$ dependence observed
  Results as a function of p_T

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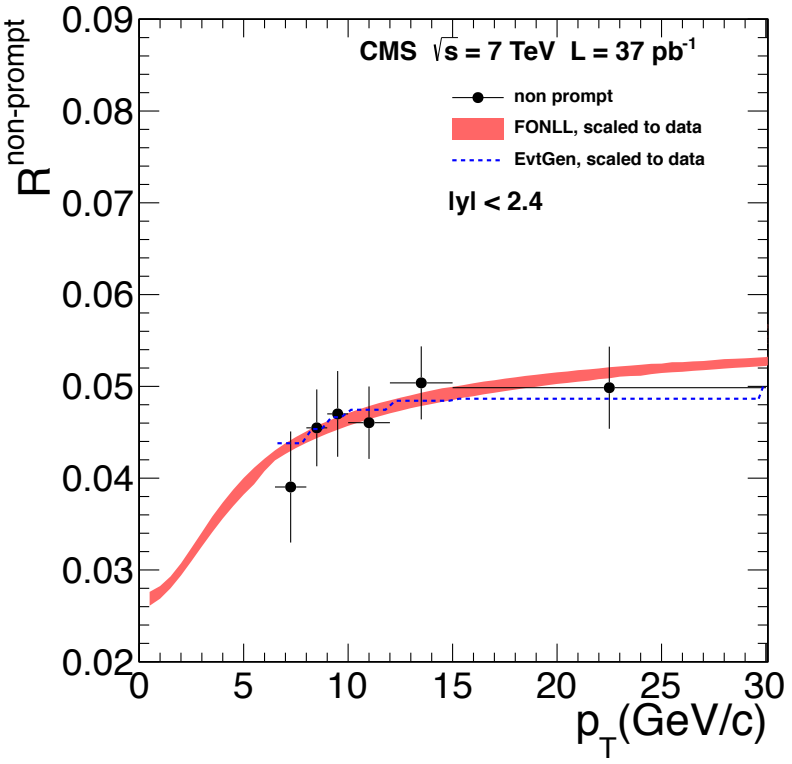
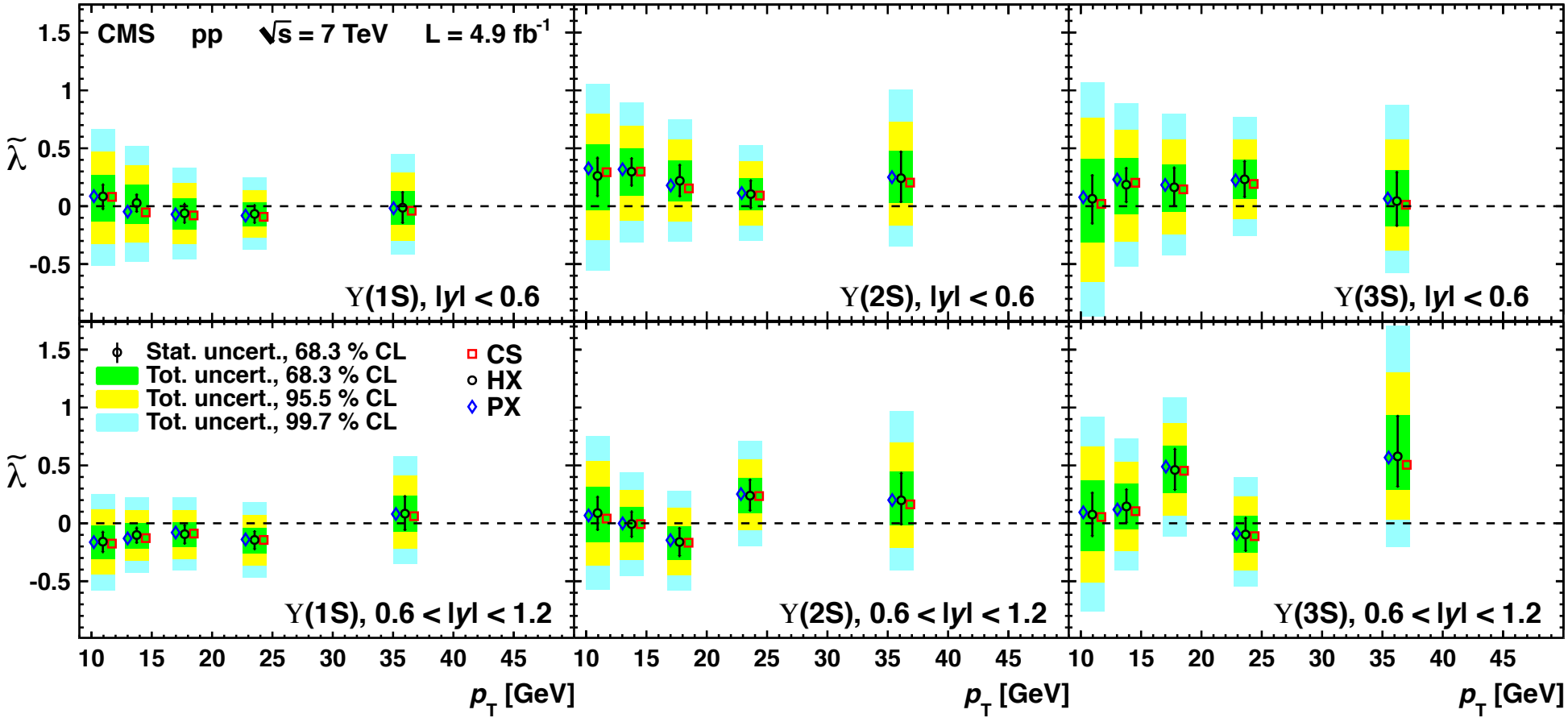
Non-prompt Ratio



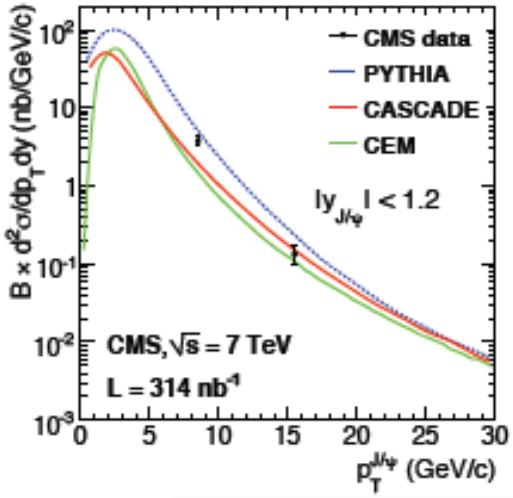
$\mathcal{B}(\mathrm{B} \to \Psi(2\mathrm{S})\mathrm{X}) = (3.08 \pm 0.12(\mathrm{stat.} + \mathrm{syst.}) \pm 0.13(\mathrm{theor.}) \pm 0.42(\mathcal{B}_{\mathrm{PDG}}))$
In agreement with world average
$(4.8 \pm 2.4) \cdot 10^{-3}$

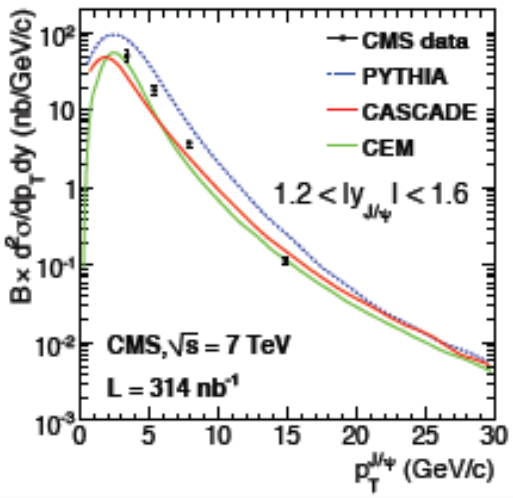
more precise by a factor of 2.5!

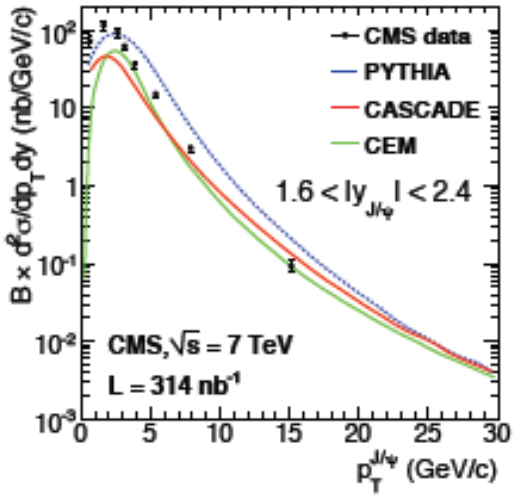
Υ(nS) Polarization frame-invariant parameter



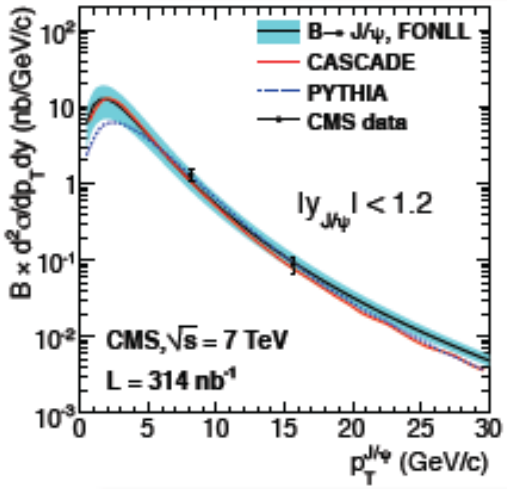
First CMS paper on J/ψ

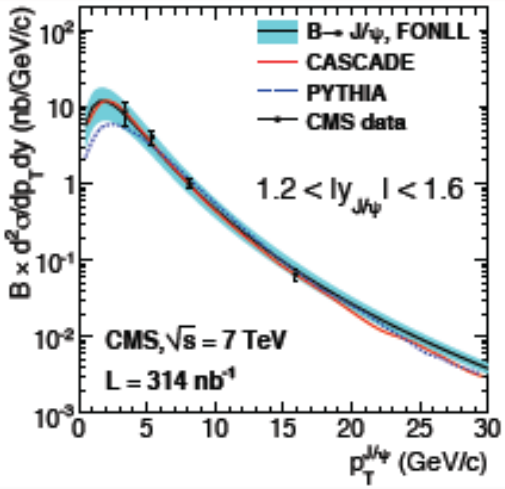


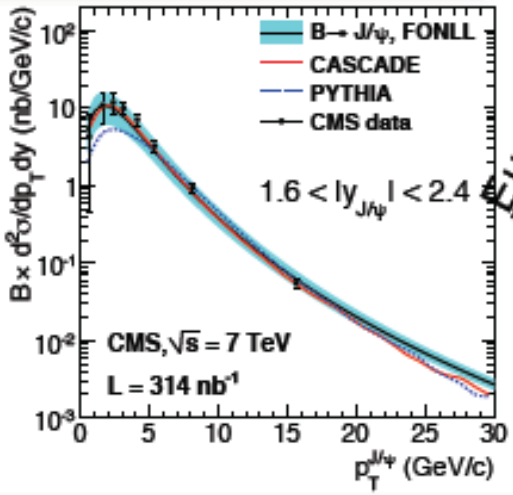




$$\sigma(pp \to J/\psi + X) \cdot \mathrm{BR}(J/\psi \to \mu^+\mu^-) = 70.9 \pm 2.1(\mathrm{stat}) \pm 3.0(\mathrm{syst}) \pm 7.8(\mathrm{luminosity})\ \mathrm{nb}$$







$$\sigma(\mathrm{pp} \to bX \to J/\psi X) \cdot \mathrm{BR}(J/\psi \to \mu^+\mu^-) = 26.0 \pm 1.4\,(\mathrm{stat}) \pm 1.6\,(\mathrm{syst}) \pm 2.9\,(\mathrm{luminosity})\ \mathrm{nb}$$

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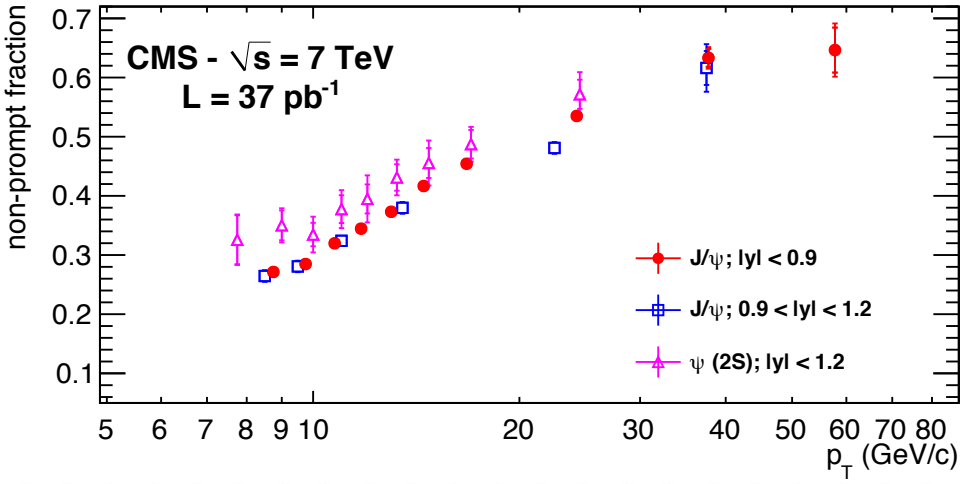
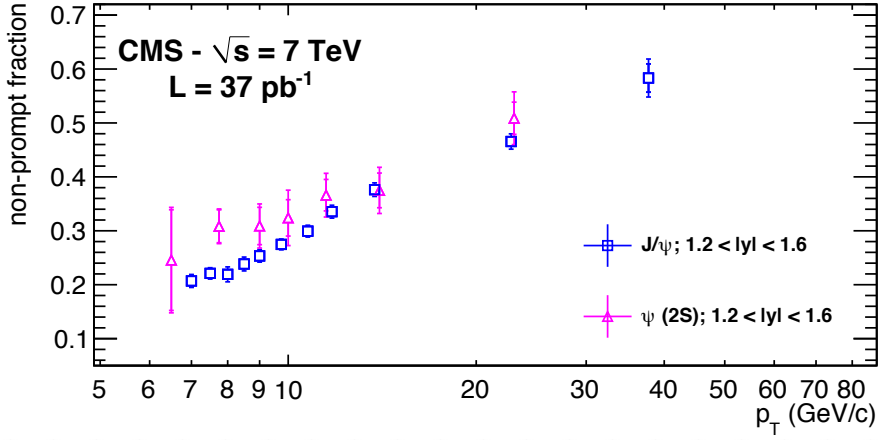
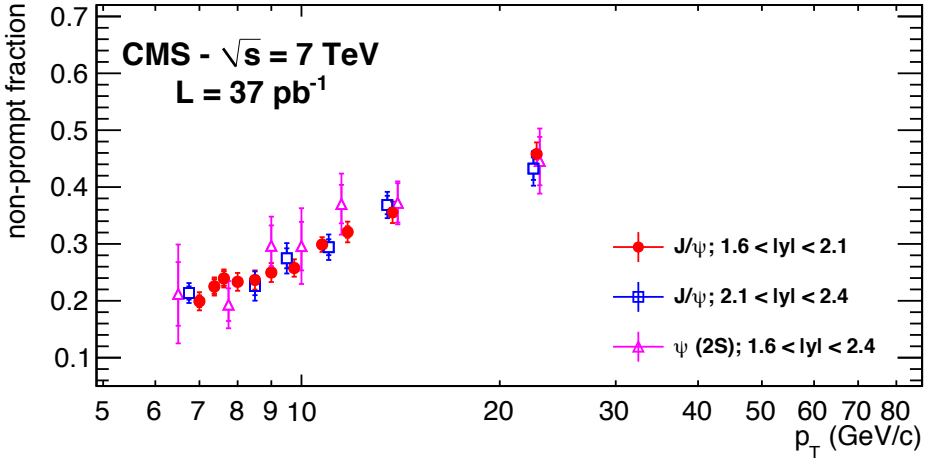
B fraction results

- Above p_T ≈20 GeV, more than 50% of the J/ψ and ψ(2S) mesons result from B decays







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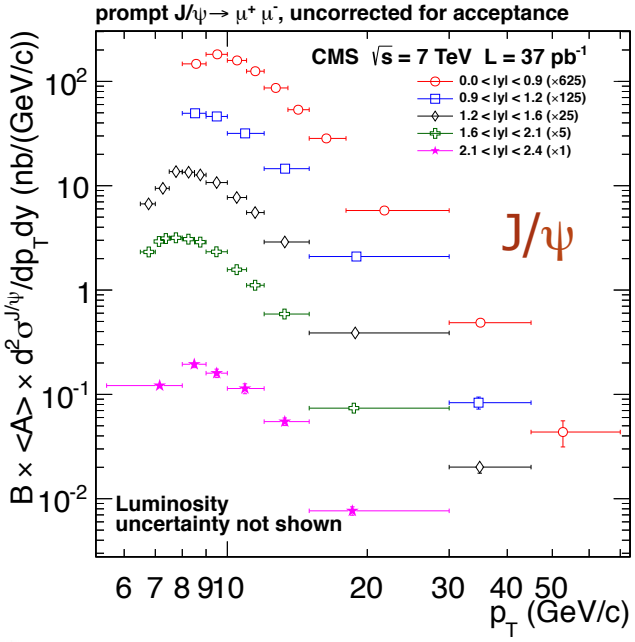
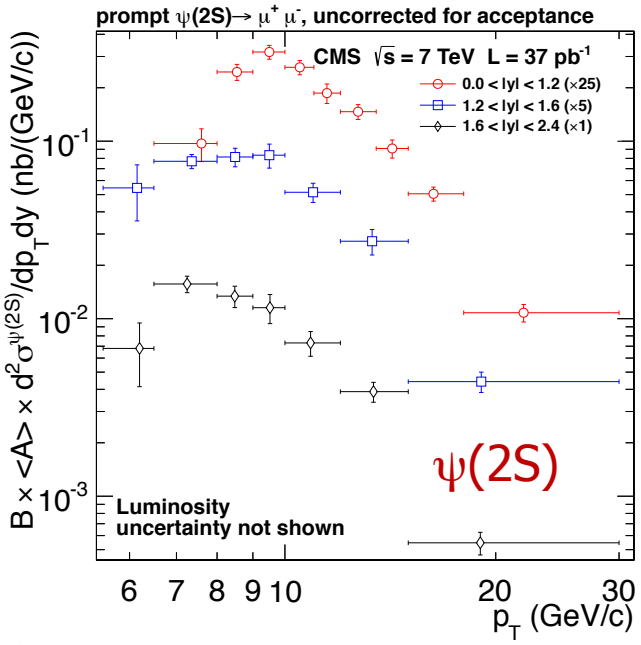
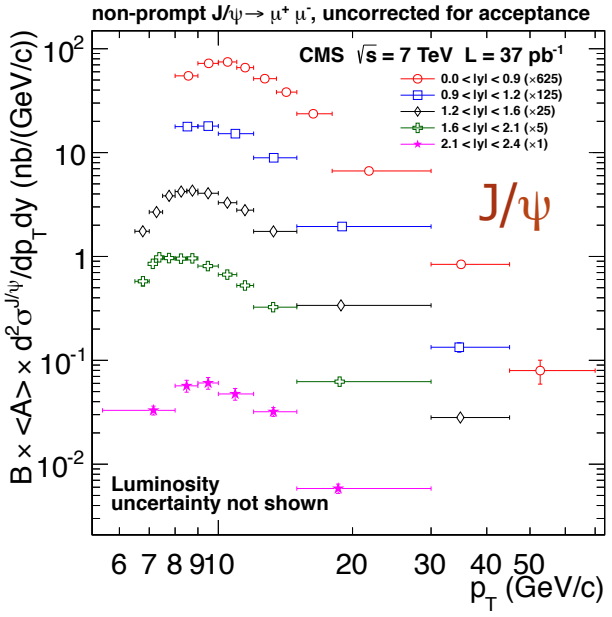
ψ(nS) Cross Sections

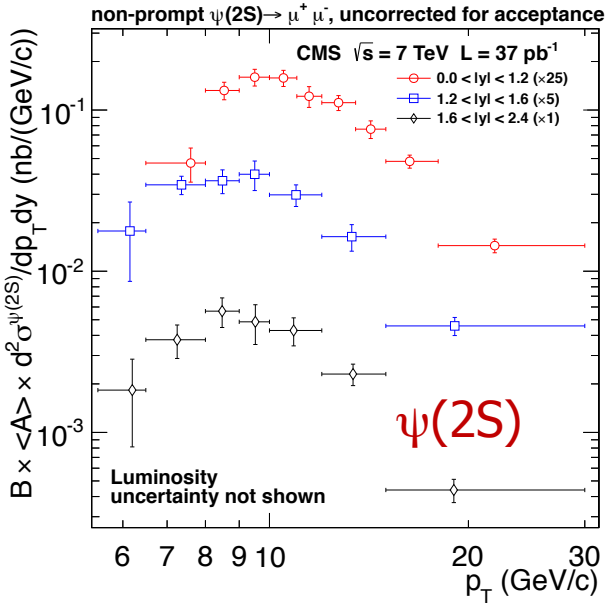
uncorrected for acceptance





Prompt





Non-Prompt

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J/Ψ Systematics

$\lvert y\rvert$ range		$0-0.9$	$0.9-1.2$	$1.2-1.6$	$1.6-2.1$	$2.1-2.4$
Quantity affected	Source	Relative uncertainty (in %)				
		All cross sections				
$m_{\mu\mu}$ fits	Statistical	$1.2-8.9$	$1.5-7.1$	$1.6-8.4$	$1.2-3.2$	$2.3-3.9$
$\ell_{J/\psi}$ fits	Statistical	$1.0-5.9$	$1.4-4.7$	$1.4-7.6$	$2.1-8.3$	$4.4-7.1$
Efficiency	Single-muon efficiency	$0.3-0.9$	$0.2-1.6$	$0.1-1.4$	$0.2-1.0$	$0.6-1.4$
	ρ factor	$1.9-23.2$	$1.2-7.6$	$0.7-5.7$	$0.8-5.4$	$3.7-6.8$
Yields	Fit functions	$0.6-3.4$	$0.4-2.8$	$0.5-2.8$	$0.8-2.2$	$1.0-4.2$
Luminosity	Luminosity	4.0	4.0	4.0	4.0	4.0
Non-prompt fraction	Tracker misalignment	$0.1-2.1$	$0.1-0.8$	$0.0-1.5$	$0.2-3.2$	$0.2-5.1$
	b-lifetime model	$0.1-3.0$	$0.1-3.4$	$0.1-3.7$	$0.2-2.6$	$0.2-6.6$
	Vertex estimation	$0.1-0.7$	$0.7-3.0$	$0.4-3.7$	$1.5-4.6$	$2.3-5.0$
	Background fit	$0.0-0.2$	$0.1-1.4$	$0.1-1.0$	$0.0-2.5$	$0.1-1.2$
	Resolution model	$0.2-3.5$	$0.0-4.2$	$0.8-3.5$	$1.1-5.0$	$1.1-4.4$
	Efficiency	$0.4-2.1$	$0.9-3.3$	$0.5-9.9$	$0.3-3.3$	$1.6-10.5$
		Only acceptance-corrected cross sections				
Acceptance	FSR	$0.0-1.5$	$0.0-2.5$	$0.0-4.2$	$0.7-8.0$	$0.5-3.5$
	p_T calibration	$0.0-0.6$	$0.0-0.6$	$0.0-0.8$	$0.1-0.6$	$0.0-0.8$
	Kinematic spectra	$0.0-0.3$	$0.0-0.7$	$0.0-0.7$	$0.7-3.8$	$0.4-5.3$
	B polarization	$0.0-0.5$	$0.0-0.4$	$0.0-0.5$	$0.1-0.8$	$0.3-1.3$

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$\Psi(2S)$ Systematics

$\lvert y\rvert$ range		$0-1.2$	$1.2-1.6$	$1.6-2.4$
Quantity affected	Source	Relative uncertainty (in %)		
	All cross sections			
$m_{\mu\mu}$ fits	Statistical	$5.6-14.8$	$7.5-31.7$	$7.3-24.1$
$\ell_{\psi(2S)}$ fits	Statistical	$4.3-12.7$	$5.9-38.0$	$9.1-26.4$
Efficiency	Single-muon efficiency	$0.1-0.5$	$0.1-0.6$	$0.2-0.9$
	ρ factor	$0.7-13.1$	$2.1-6.6$	$2.3-9.8$
Yields	Fit functions	$1.2-3.7$	$0.6-12.1$	$3.1-10.0$
Luminosity	Luminosity	4.0	4.0	4.0
Non-prompt fraction	Tracker misalignment	$0.3-2.6$	$1.5-7.1$	$1.8-11.1$
	b-lifetime model	$0.0-2.5$	$0.4-7.6$	$0.0-2.9$
	Vertex estimation	$0.0-1.7$	$0.2-3.5$	$1.2-4.2$
	Background fit	$1.0-6.8$	$2.2-10.0$	$2.5-15.3$
	Resolution model	$0.5-3.5$	$0.1-4.6$	$0.9-24.9$
	Efficiency	$0.5-7.8$	$0.9-6.3$	$0.5-13.8$
	Only acceptance-corrected cross sections			
Acceptance	FSR	$0.0-3.9$	$0.5-3.4$	$0.3-4.1$
	p_{T} calibration	$0.2-0.5$	$0.3-0.5$	$0.3-0.5$
	Kinematic spectra	$0.1-1.2$	$0.0-0.9$	$0.7-2.0$
	B polarization	$0.1-0.8$	$0.0-0.6$	$0.2-1.7$

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ϒ Systematic Uncertainties

$|y^{\Upsilon}| < 2.4$

Υ(1S)

p_T	A	S_p	A_{p_T}	A_{fsr}	$\varepsilon_{trig,id}$	ε_ρ	ε_{func}	ε_{trk}	PDF_{CB}	PDF_{bkgd}	M_{scale}
0.0 – 50.0	1.8 (1.7)	1.0 (1.0)	1.7	0.5	7.1 (5.4)	6.8	1.8	0.4 (0.3)	1.7	0.7	0.0 (0.0)
0.0 – 0.5	1.3 (1.2)	0.1 (0.1)	0.3	0.8	10.1 (7.9)	7.5	0.4	0.4 (0.3)	2.0	0.7	0.1 (0.1)
0.5 – 1.0	1.3 (1.3)	0.1 (0.1)	0.3	0.8	9.5 (7.6)	8.2	0.7	0.3 (0.4)	1.8	1.3	0.0 (0.4)
1.0 – 1.5	1.4 (1.3)	0.9 (0.9)	1.5	0.5	8.4 (6.8)	7.1	3.6	0.4 (0.4)	2.1	0.5	0.0 (0.0)
1.5 – 2.0	1.4 (1.4)	1.8 (1.8)	1.5	0.4	8.9 (7.0)	8.1	3.4	0.4 (0.4)	1.3	2.8	0.1 (0.0)
2.0 – 3.0	1.7 (1.6)	0.2 (0.0)	0.7	0.7	8.5 (6.6)	7.2	2.6	0.4 (0.3)	1.7	2.4	0.0 (0.0)
3.0 – 4.0	1.9 (1.9)	0.8 (0.8)	1.0	0.6	7.7 (5.6)	7.2	1.9	0.3 (0.4)	2.0	1.2	0.1 (0.1)
4.0 – 5.0	1.8 (1.9)	0.3 (0.3)	0.1	0.8	7.2 (5.3)	7.4	2.6	0.4 (0.6)	1.5	0.4	0.0 (0.2)
5.0 – 6.0	2.1 (2.1)	1.8 (1.8)	2.3	0.3	6.7 (5.0)	6.7	2.2	0.3 (0.4)	1.3	1.8	0.2 (0.2)
6.0 – 7.0	2.2 (1.9)	1.2 (1.2)	2.0	0.4	6.7 (4.7)	6.9	1.9	0.4 (0.2)	1.3	0.6	0.3 (0.3)
7.0 – 8.0	2.0 (1.9)	1.5 (1.5)	2.6	0.3	6.2 (4.6)	5.2	1.4	0.4 (0.4)	1.5	0.9	0.2 (0.2)
8.0 – 9.0	1.8 (1.8)	1.1 (1.1)	2.2	0.3	5.9 (4.3)	4.4	1.2	0.4 (0.4)	1.3	0.9	0.0 (0.0)
9.0 – 10.0	1.8 (1.7)	1.9 (1.9)	3.3	0.2	5.9 (4.4)	3.9	0.1	0.4 (0.4)	1.2	1.3	0.2 (0.1)
10.0 – 11.0	1.5 (1.5)	1.8 (1.8)	3.3	0.2	5.4 (4.1)	5.0	0.4	0.4 (0.3)	1.2	1.2	0.2 (0.0)
11.0 – 12.0	1.7 (1.6)	1.4 (1.4)	2.8	0.1	5.5 (4.2)	1.8	0.5	0.4 (0.4)	0.7	2.3	0.2 (0.2)
12.0 – 13.0	1.5 (1.4)	2.4 (2.4)	3.9	0.0	5.4 (4.2)	5.1	0.4	0.4 (0.4)	1.2	1.0	0.6 (0.6)
13.0 – 14.0	1.4 (1.4)	2.0 (2.0)	3.6	0.0	5.2 (4.0)	5.2	0.2	0.4 (0.3)	1.3	0.1	0.1 (1.0)
14.0 – 15.0	1.3 (1.3)	2.5 (2.5)	4.1	0.1	5.3 (4.2)	6.4	0.7	0.4 (0.3)	1.3	0.1	1.2 (0.4)
15.0 – 16.0	1.3 (1.2)	2.0 (2.0)	3.7	0.0	5.1 (4.1)	5.8	1.3	0.4 (0.3)	1.2	0.1	0.8 (0.1)
16.0 – 18.0	1.1 (1.1)	2.2 (2.2)	3.9	0.1	4.8 (3.9)	6.1	1.5	0.4 (0.4)	1.2	0.7	0.1 (0.4)
18.0 – 20.0	1.1 (1.1)	2.2 (2.2)	4.1	0.1	4.8 (3.8)	5.6	1.4	0.4 (0.4)	1.4	0.2	0.2 (0.2)
20.0 – 22.0	1.0 (1.0)	2.4 (2.4)	4.1	0.0	4.8 (3.9)	3.0	2.2	0.4 (0.3)	0.9	0.6	0.0 (0.0)
22.0 – 25.0	1.0 (1.0)	1.8 (1.8)	4.3	0.0	4.7 (3.9)	2.7	2.1	0.4 (0.4)	1.5	1.3	0.4 (0.4)
25.0 – 30.0	1.1 (1.1)	1.1 (1.1)	4.4	0.7	4.9 (4.2)	1.1	2.3	0.4 (0.4)	1.3	0.6	0.3 (0.2)
30.0 – 50.0	0.6 (0.6)	2.1 (2.1)	3.5	0.3	4.5 (3.8)	4.7	2.1	0.3 (0.3)	1.3	4.0	0.1 (1.0)

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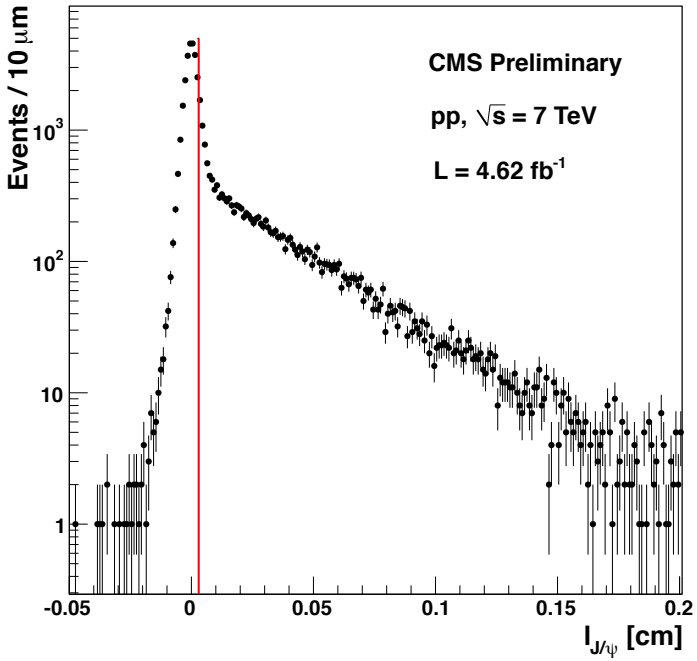
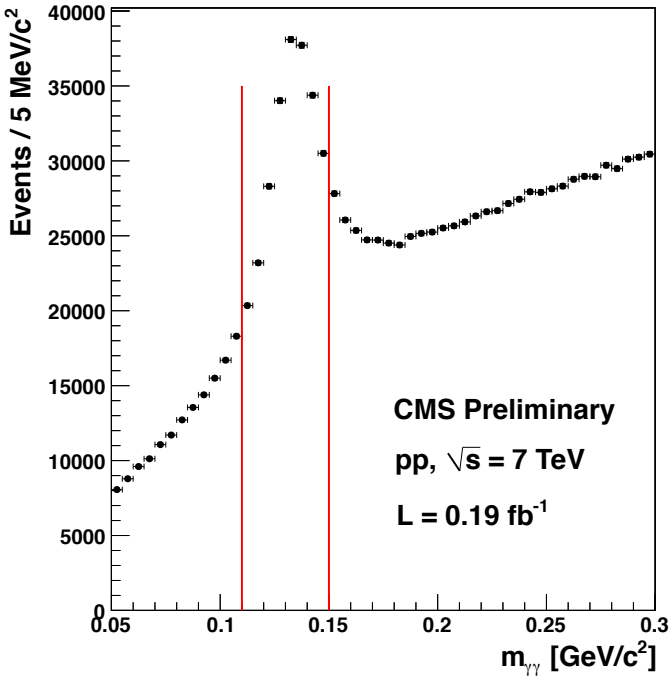
χ_c Background Rejection

- To study χ_c prompt production, we minimize feed-down from B decays by rejecting the displaced dimuons.



arXiv:1210.0875

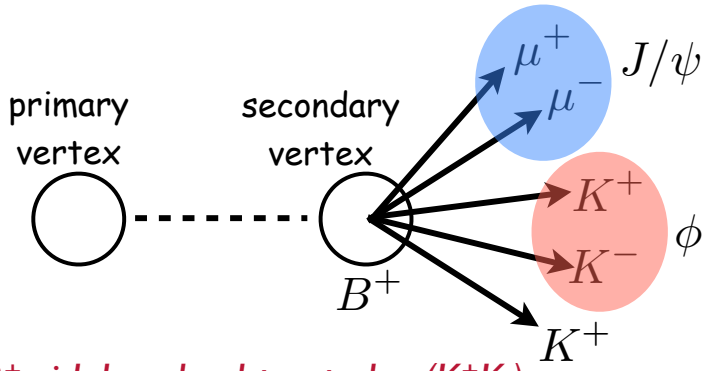
- To minimize the photon background from π^0 decays, we reject photons that, combined with other photons in the event, give the π^0 mass



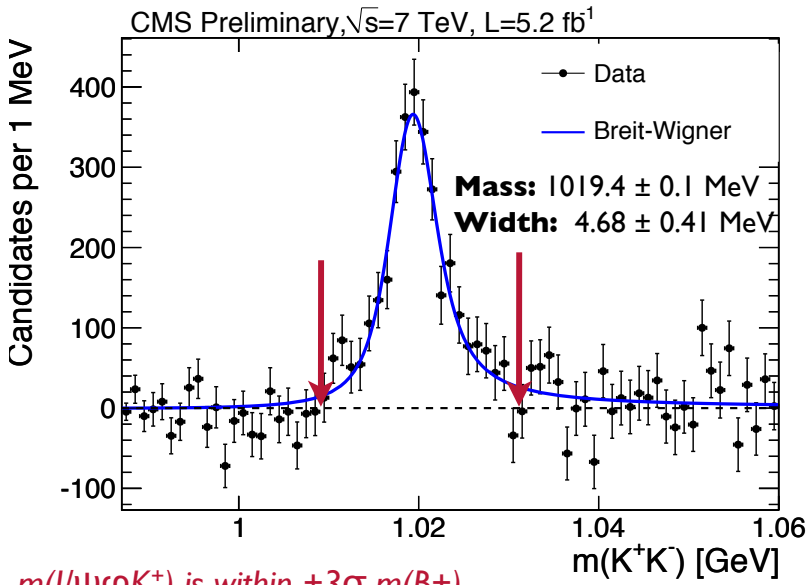
Observation of Structures in the J/ψϕ Mass Spectrum

An analysis performed by CMS tries to solve the puzzle and confirm the results of one of the experiments

CMS

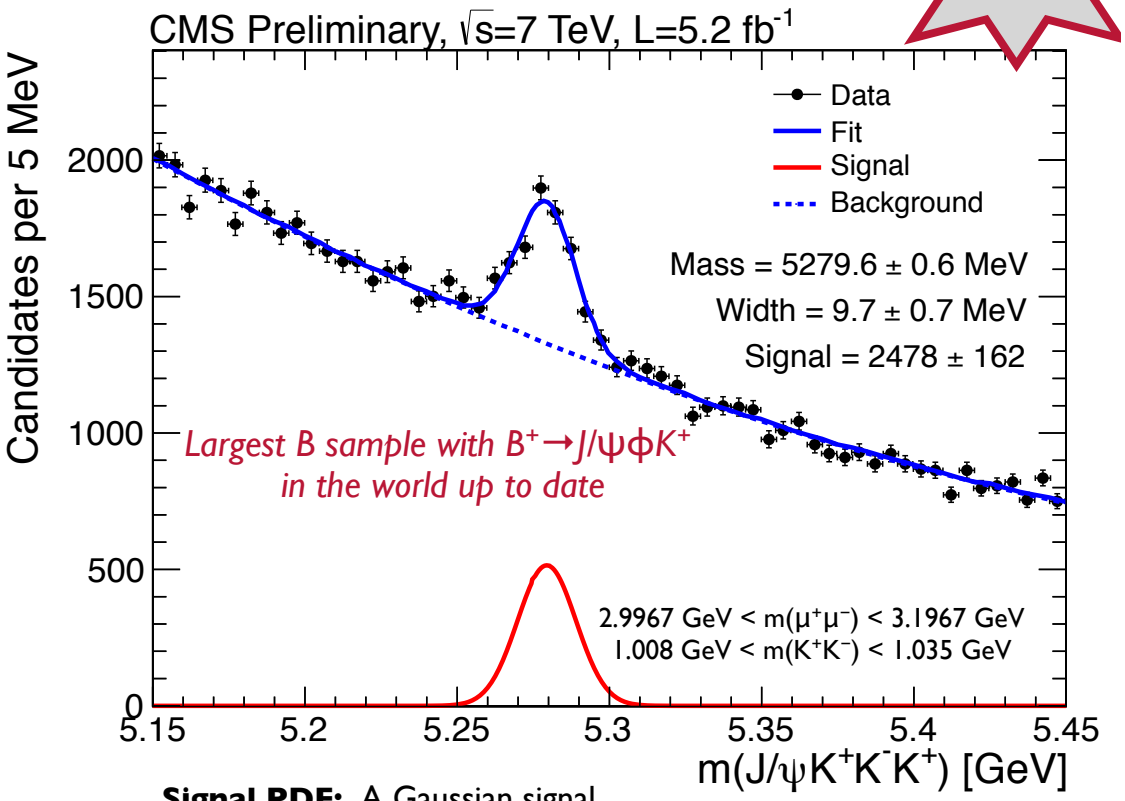


The B^+ sideband subtracted $m(K^+K^-)$



$m(J/\psi\varphi K^+)$ is within $\pm 3\sigma$ $m(B+)$

New



Signal PDF: A Gaussian signal

Background PDF: A second order Chebychev polynomial

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11026

Observation of Structures in the J/ψϕ Mass Spectrum

The $\Delta m = m(\mu^+\mu^-K^+K^-) - m(\mu^+\mu^-)$ is used to investigate the possible structures

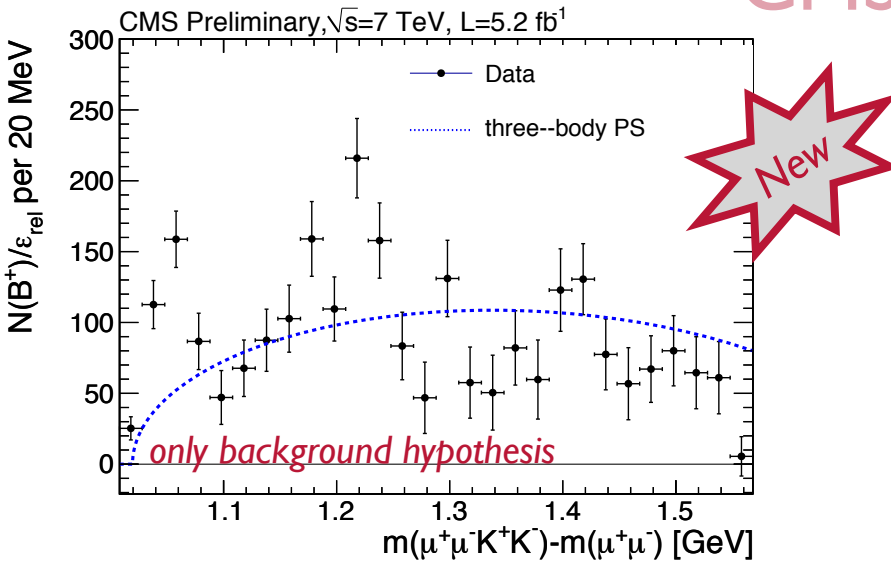
CMS

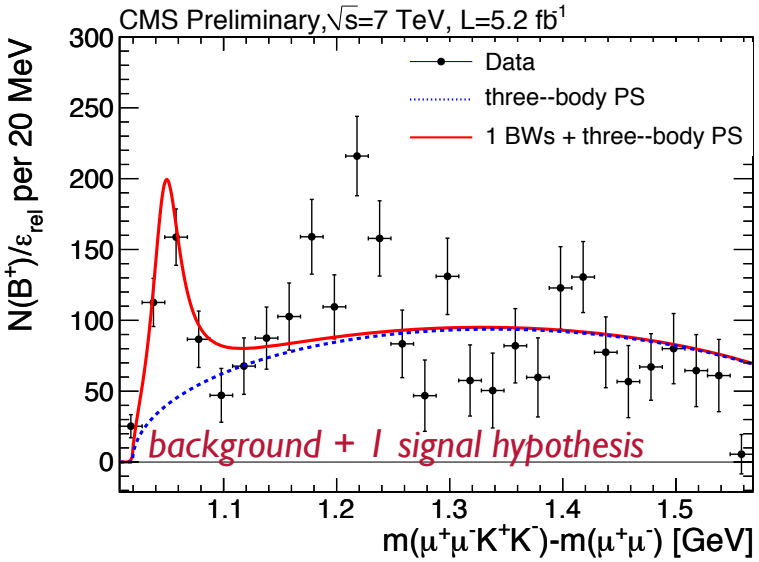
Extracting the Δm Spectrum

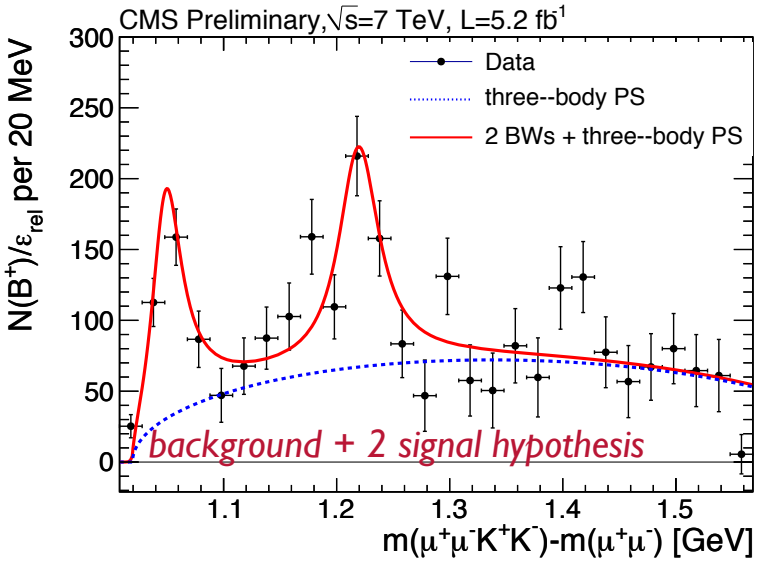
- Divide the dataset into the 20 MeV Δm bins
- Extract the number of B signal for each Δm by fitting the J/ψφK spectrum
  - Mean is fixed to the PDG value of B mass
  - RMS is fixed to the number predicted by signal MC
- Plot the B yield with uncertainty in each bin
- Correct the spectrum by relative efficiency

Background: *3-body phase space*

Signal*: S-wave relativistic Breit-Wigner functions convoluted with a Gaussian resolution function*







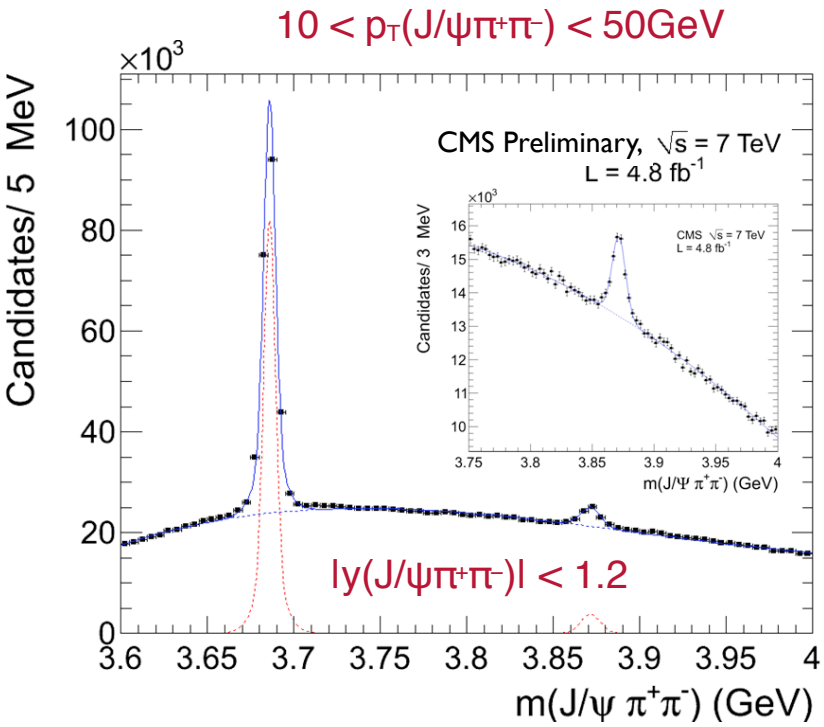
X(3872) production via decays to J/ψπ⁺π⁻

CMS studied
(1) Ratio of σxBr for X(3872) and ψ(2S)
(2) Fraction of X(3872) production from B decays
(3) The $\pi^+\pi^-$ mass spectrum from X(3872)→J/ψπ⁺π⁻

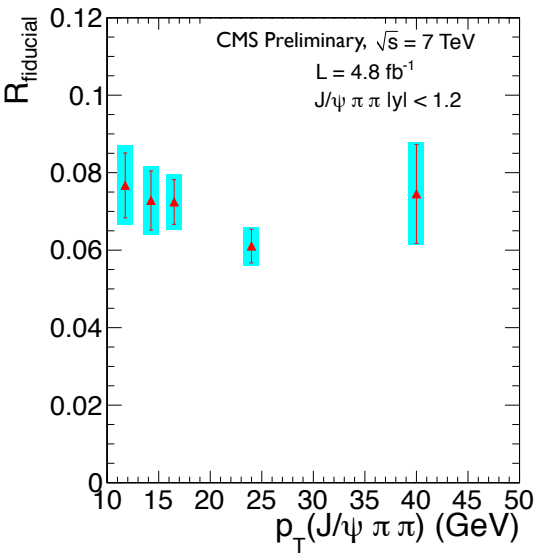
New

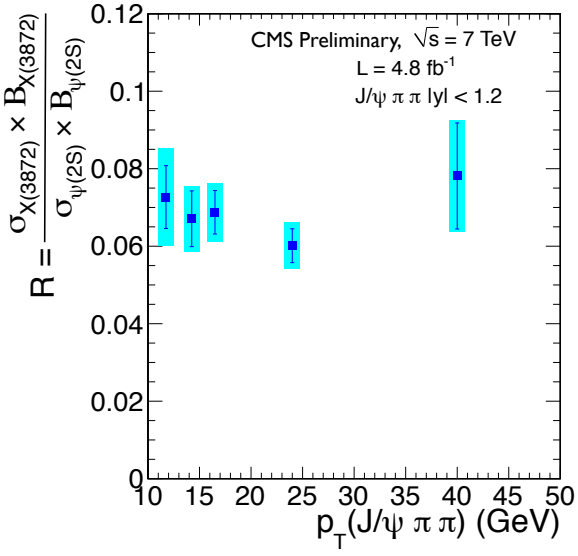
CMS

$$R = \frac{\sigma(pp \to X(3872) + \text{anything}) \times B(X(3872) \to J/\psi\pi^+\pi^-)}{\sigma(pp \to \psi(2S) + \text{anything}) \times B(\psi(2S) \to J/\psi\pi^+\pi^-)}$$



the $J/\psi\pi^+\pi^-$ invariant mass spectrum





no significance dependence on the p_T

$$R = 0.0662 \pm 0.0038(\text{stat}) \pm 0.0064(\text{syst})$$

$$R_{fiducial} = 0.0700 \pm 0.0038(\text{stat}) + 0.0038(\text{syst})$$

https://twiki.cern.ch/twiki/bin/viewauth/CMS/PhysicsResultsBPH1101

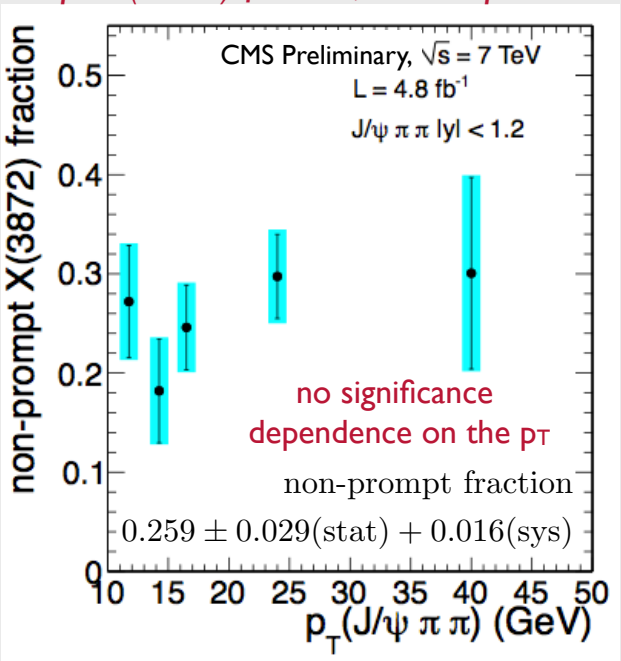
X(3872) production via decays to $J/\psi\pi^+\pi^-$

Measurement of the non-promt contribution

Measured within the CMS acceptance.

$$\text{non-promt fraction} = \frac{\text{Signal Yield (B hadron enriched sample)}}{\text{Signal Yield (whole sample)}}$$

non-prompt X(3872) fraction, no acceptance correction



New

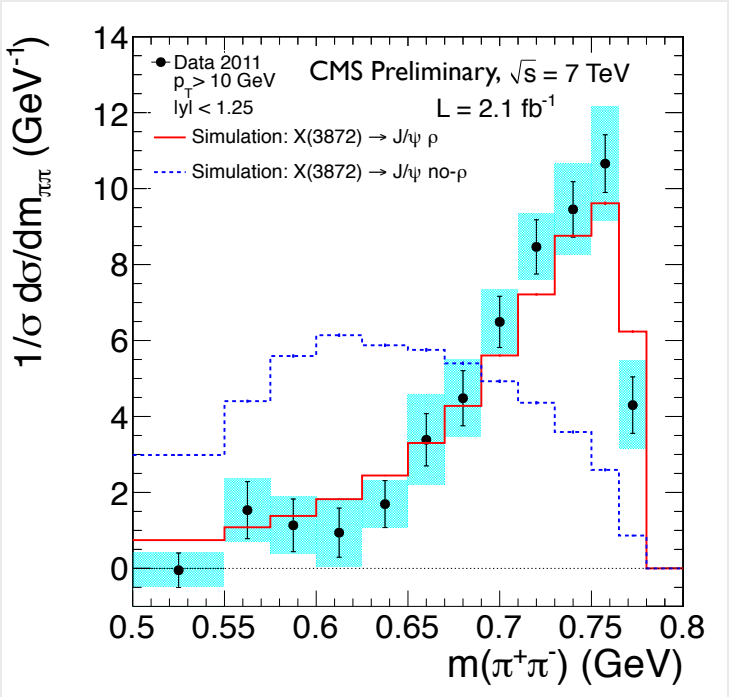
By using ratio R and previous CMS measurement for the cross section for prompt ψ(2S) (pT 10-30 GeV, |y|<1.2)

$$\sigma^{prompt}(pp \to X(3872) + \text{anything}) \times B(X(3872) \to J/\psi\pi^+\pi^-) = 1.03 \pm 0.11(\text{stat}) + 0.15(\text{sys})\ \text{nb}$$

Measurement of the dipion mass spectrum

The background subtracted pion pair invariant mass spectrum is extracted from likelihood fit to the $J/\psi\pi^+\pi^-$ invariant mass spectrum.

acceptance and efficiency corrected pion pair invariant mass



normalized to the total cross section in the interval 0.5 < mππ < 0.78 GeV