Measurements of Quarkonium production at CMS

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for the CMS Collaboration

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Why Quarkonium?
— brief history

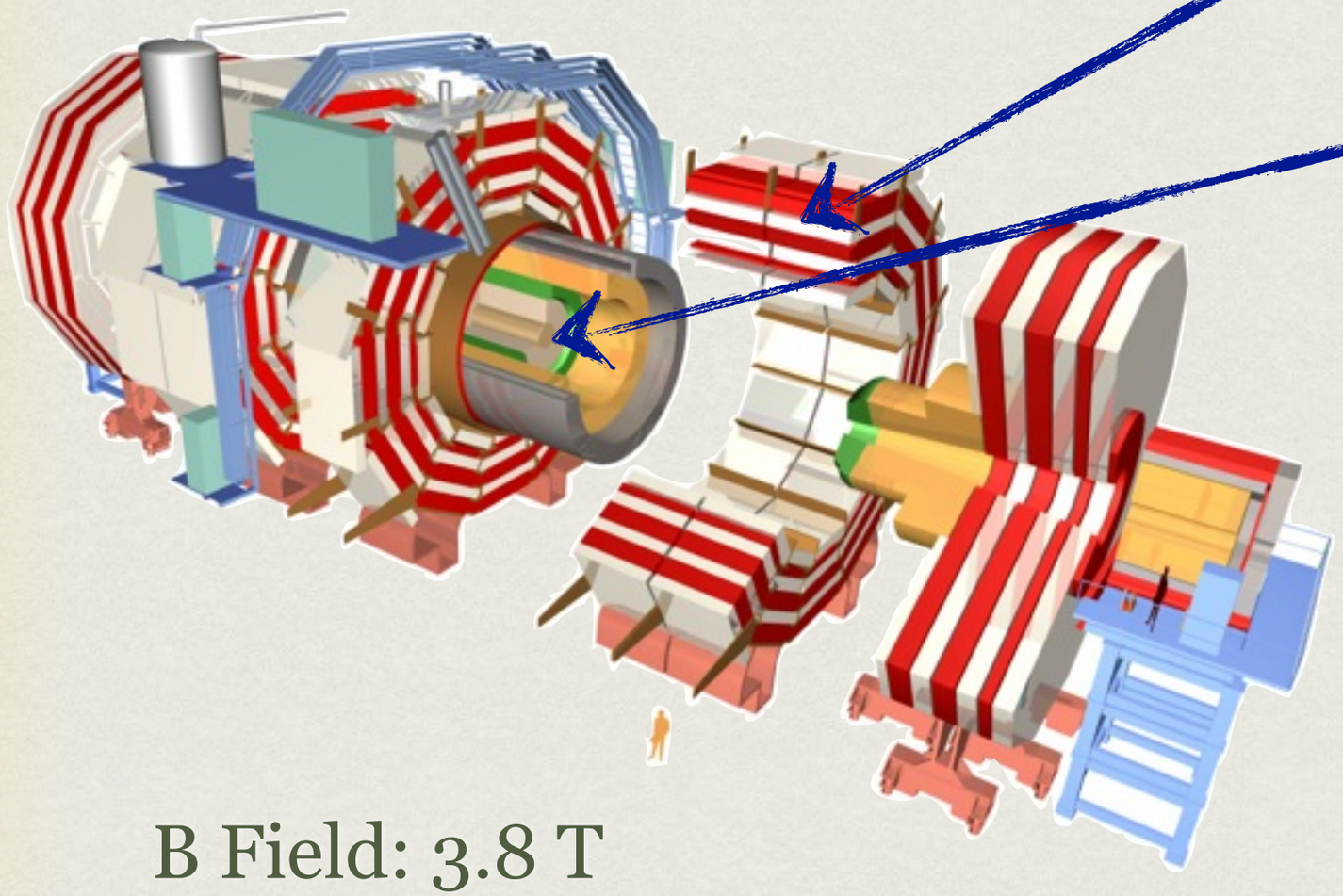
- With the contribution of Tevatron, J/ψ production cross section was found to be higher by a factor of ~30 compared to the color singlet prediction.

- Color octet model born as a fix, which describes differential cross section well.

- NRQCD predicts that S-wave quarkonium should be transversely polarized at high p_T. However, small longitudinal polarization was measured by CDF.

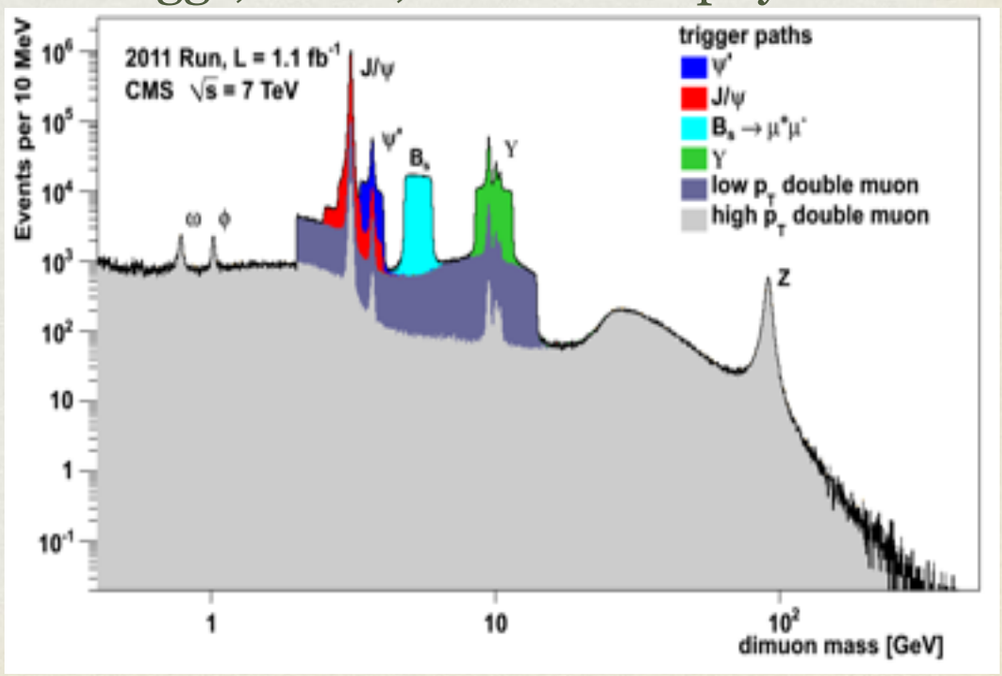
- More experimental inputs are needed!

CMS in Quarkonium studies



B Field: 3.8 T

- Muon tracking system consist of muon chamber and silicon tracker covers wide rapidity and p_T regions.
- Thanks to the highly sensitive tracker, even low energy photons can be measured accurately using conversions.
- Flexible trigger strategy provides a wide variety of study scopes including Higgs, SUSY, and even b-physics.



Recent CMS measurements

New Relative production rate of $\chi_{b2}(1P)$ and $\chi_{b1}(1P)$
CMS BPH-13-005

Covered

Prompt J/ψ and ψ(2S) polarizations
arXiv:1307.6070

Covered

Differential cross section measurements for Y(1S), Y(2S), and Y(3S)
arXiv:1303.5900, PLB 727 (2013) 101-125

Covered

Relative prompt production rate of χ_{c2} and χ_{c1}
arXiv:1210.0875, EPJC 72 (2012) 2251

Measurement of Y(1S), Y(2S), Y(3S) polarizations
arXiv:1209.2922, PRL 110 (2013) 081802

J/ψ and ψ(2S) production
arXiv:1111.1557, JHEP 02 (2012) 011

$\chi_b(1P)$ production ratio

- P-wave states play as an essential piece in solving the puzzle, and $\sigma(pp \to \chi_{b2}+X)/\sigma(pp \to \chi_{b1}+X)$ is a nice test of QCD!

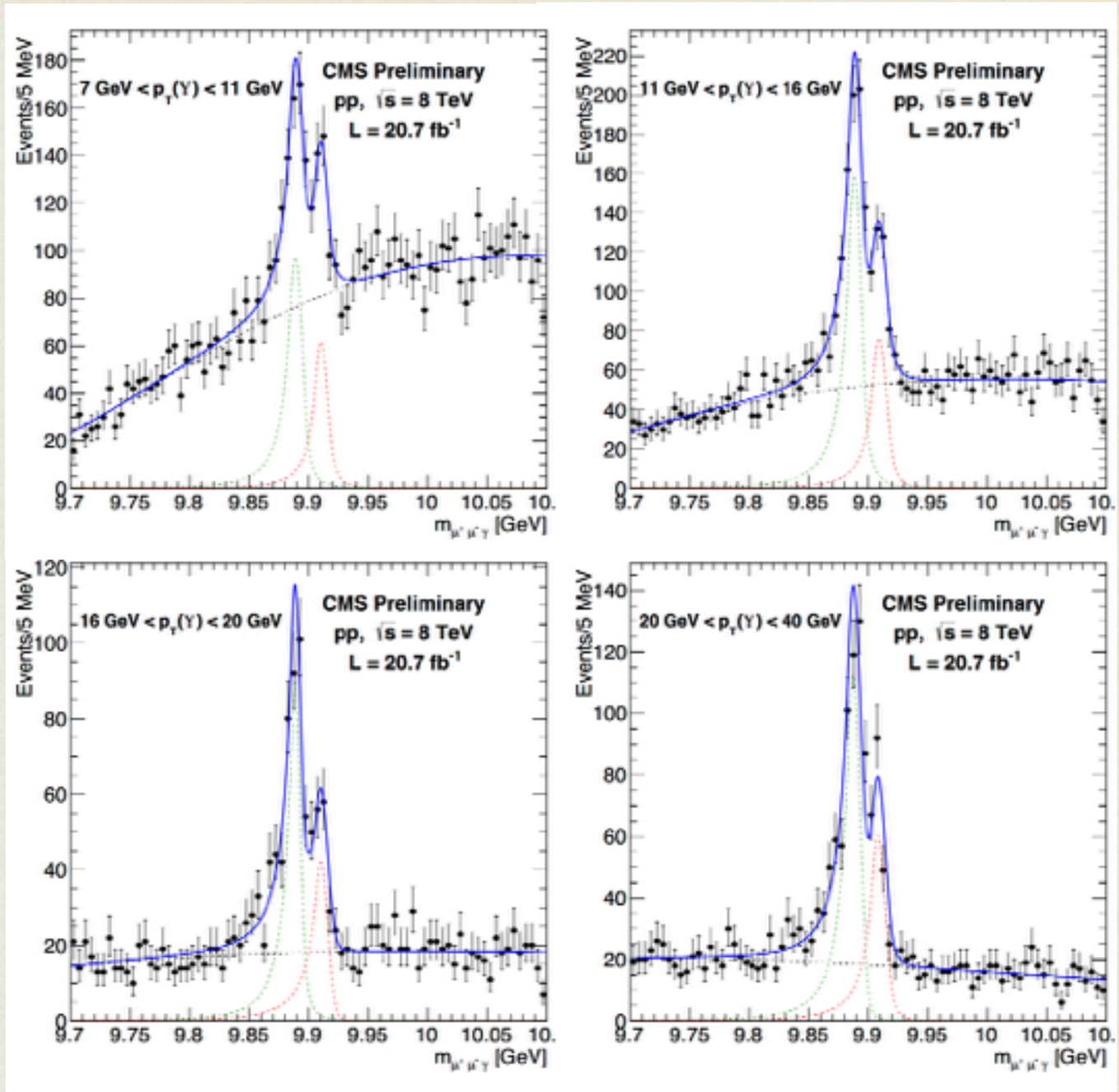
- The charmonium equivalent is measured by CMS, ATLAS and LHCb, the results doesn't fit naive spin counting expectations.

- First measurement of this ratio in hadron collision.

- Challenging due to small mass difference (~19 MeV).

χ_b Mass spectrum

- See $\chi_b \rightarrow \Upsilon(1S)\gamma \rightarrow \mu^+\mu^-\gamma$ channel.
- Using converted photons.
- $|y^{\Upsilon}| < 1.5$
  $|y^{\gamma}| < 1.$
  $7 < p_T < 40$ GeV
- Cuts are optimized for the best photon resolution.



Cross section ratio

$$\mathcal{R} = \frac{\sigma(pp \to \chi_{b2} + X)}{\sigma(pp \to \chi_{b1} + X)} = \frac{N_{\chi_{b2}}}{N_{\chi_{b1}}} \cdot \frac{\epsilon_1}{\epsilon_2} \cdot \frac{\mathcal{B}(\chi_{b1}(1\mathrm{P}) \to \Upsilon(1S)\gamma)}{\mathcal{B}(\chi_{b2}(1\mathrm{P}) \to \Upsilon(1S)\gamma)}$$

Fit

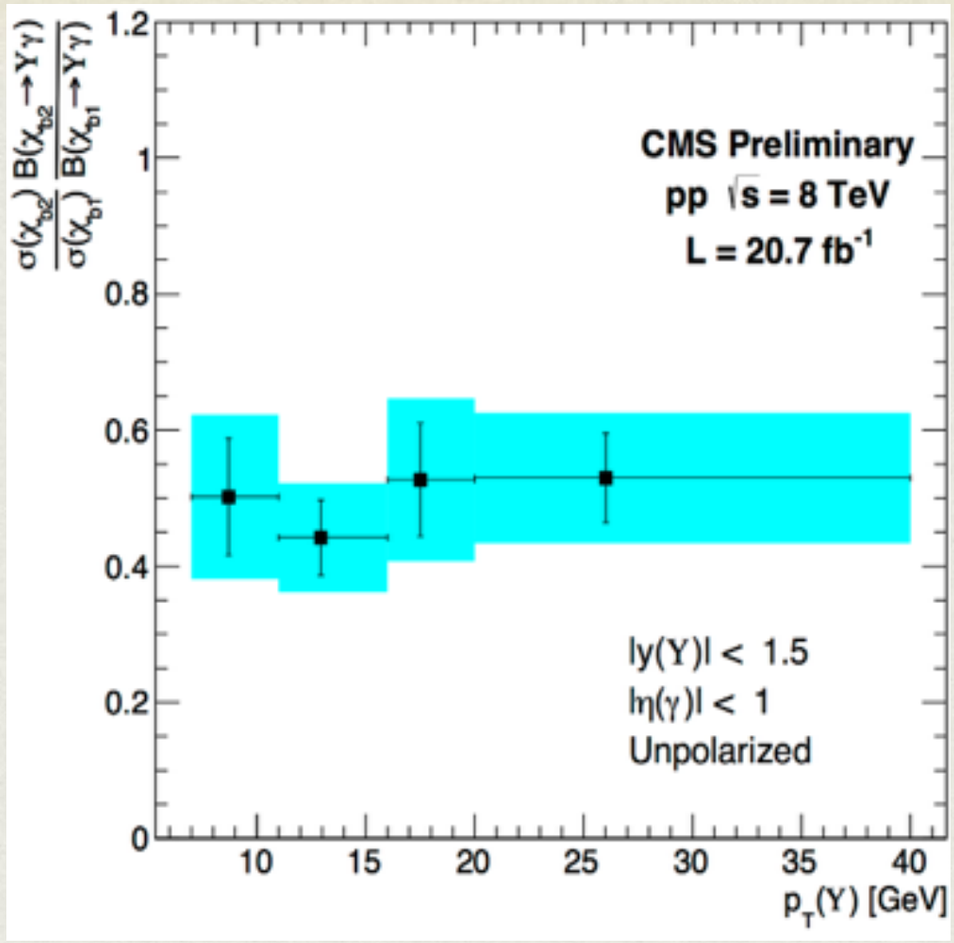
PDG value

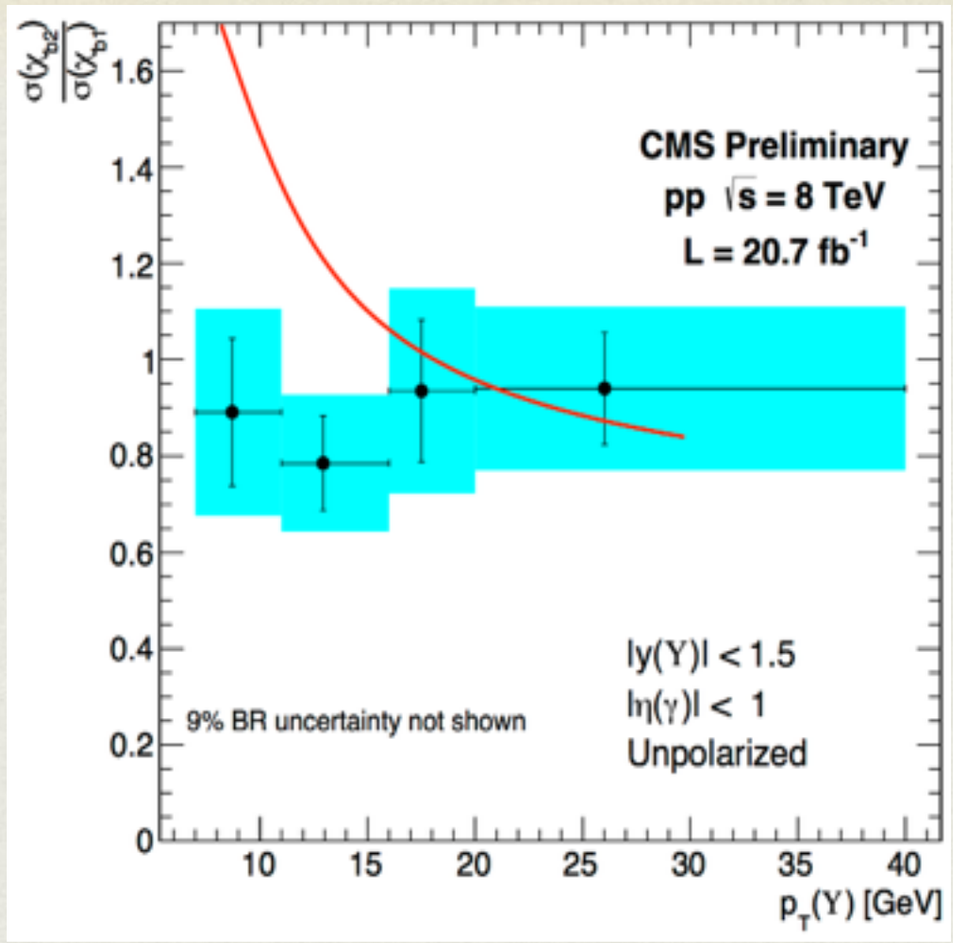
- Efficiency ratio is needed and derived from MC.

- Assuming the same p_T distribution as Y(2S).
  Other p_T distribution possibilities are considered as uncertainty.

- Apply unpolarized assumption.
  Unknown polarizations are taken as systematic uncertainty and compared in various frames since polarization in one frame may appear as zero in another.

Result





Error bars show statistical uncertainty; cyan bands show total uncertainty.

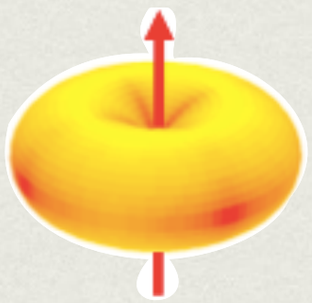
Red curve is a recent theoretical prediction. [Phys. Rev. D 86, 074027 (2012)]
The increase of the ratio at low p_T is not observed.

Prompt J/ψ and ψ(2S) polarizations

- The S-wave quarkonia produced at high p_T is predicted to be transversely polarized.

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

- CDF measured small longitudinal polarization of J/ψ, however, mixed with P-wave feed-down factors — remain ambiguous.



Longitudinal

$J_z = 0$

$\lambda_\theta = -1$

- ψ(2S) is unaffected by feed-down from heavier P-wave charmonium.

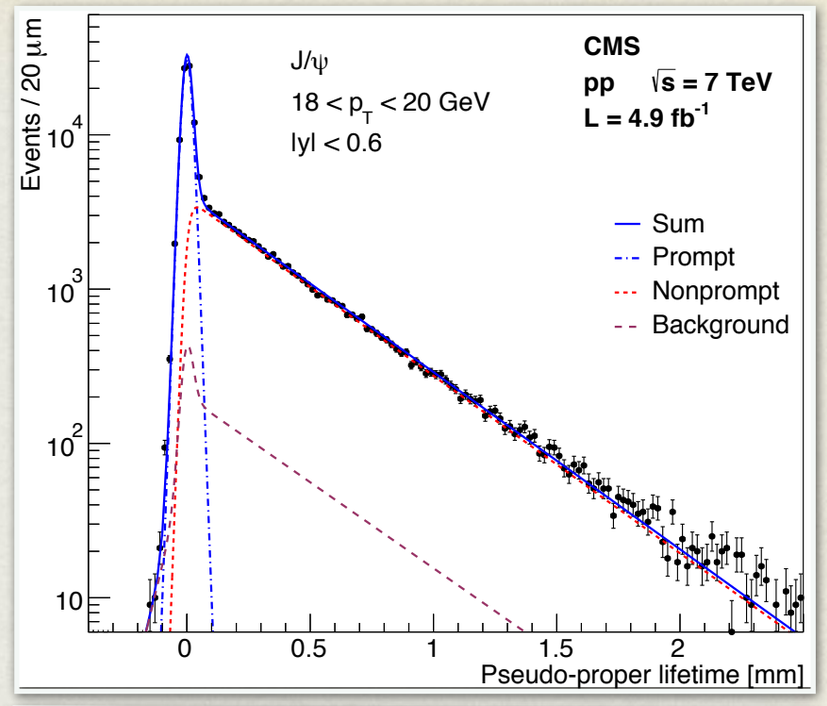
Transverse

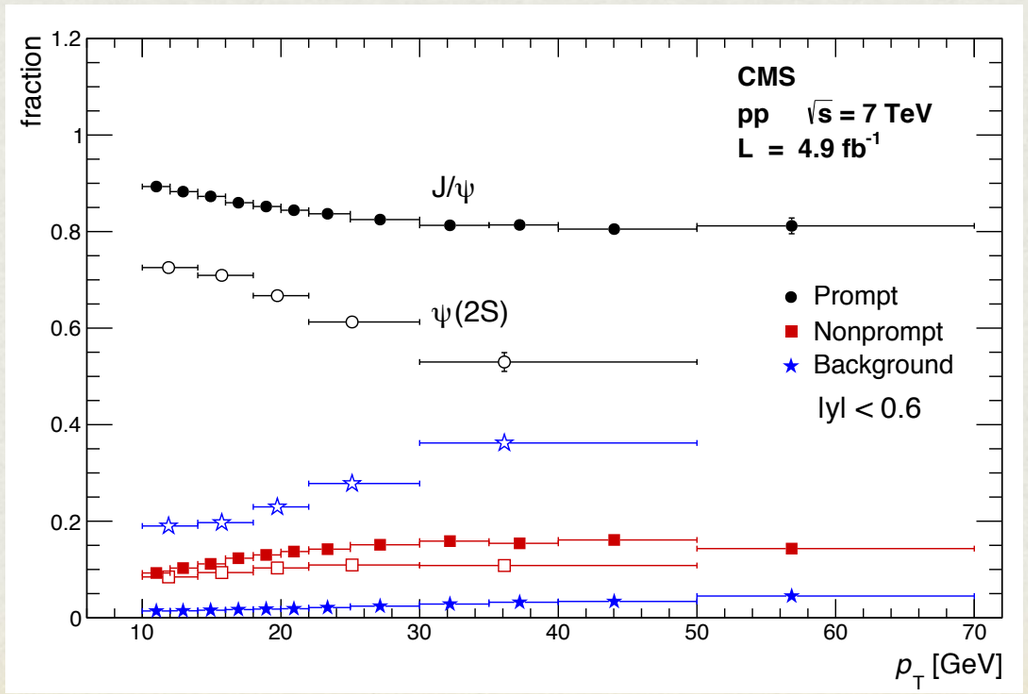
$J_z = \pm 1$

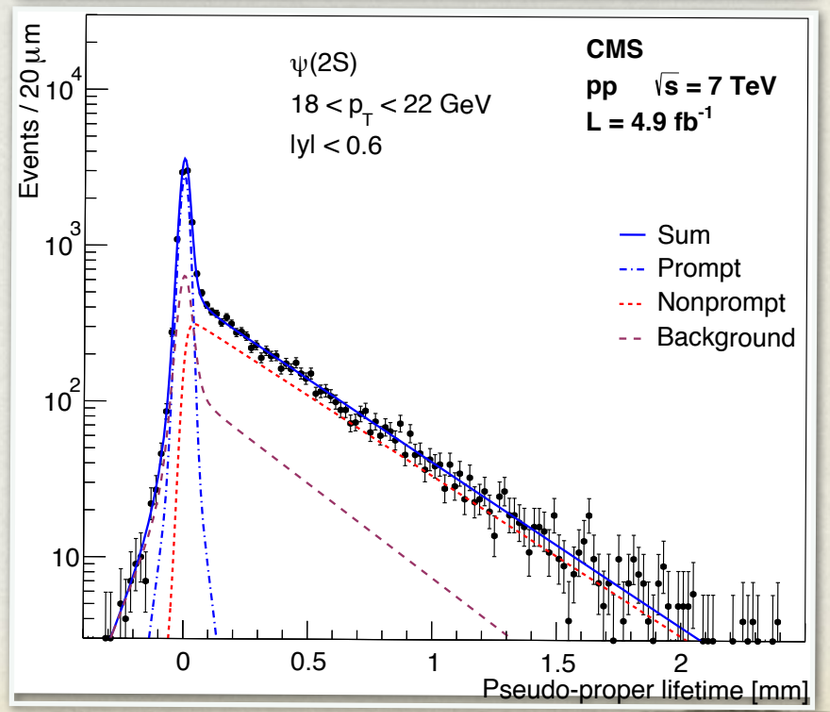
$\lambda_\theta = +1$

Extract prompt components

- Non-prompt factors (mainly contributes from B decays) should be removed.
- Fit to pseudo-proper lifetime, $l=L_{xy}*m_{\Psi(nS)}/p_T$, where L_{xy} is the most probable decay length at lab frame, distribution.
- Prompt region: $[-3\sigma_l, 3\sigma_l]$
  Non-prompt region: $[\ 3\sigma_l, \infty\ ]$
  Typical σ_l is 12-25μm, increasing with p_T.

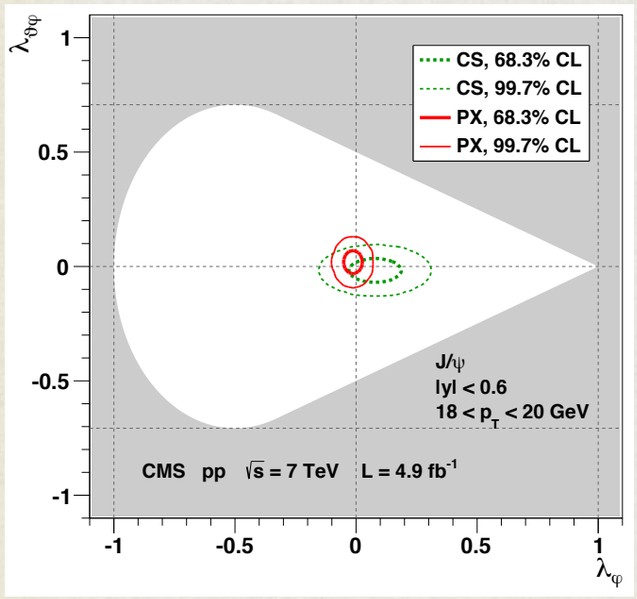


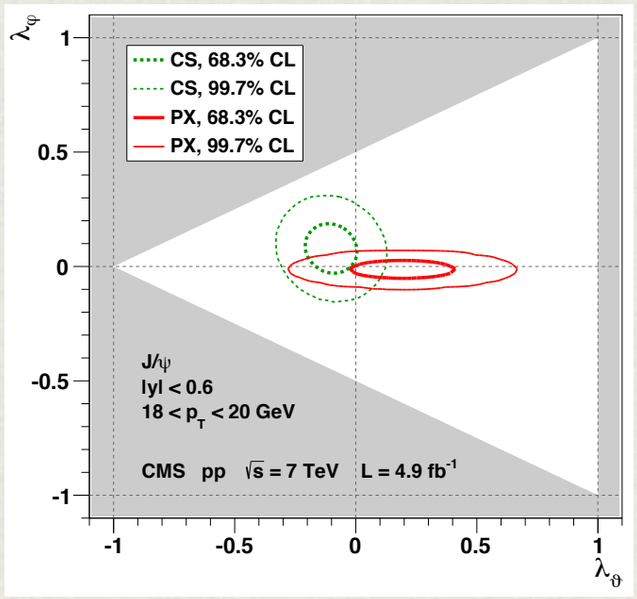


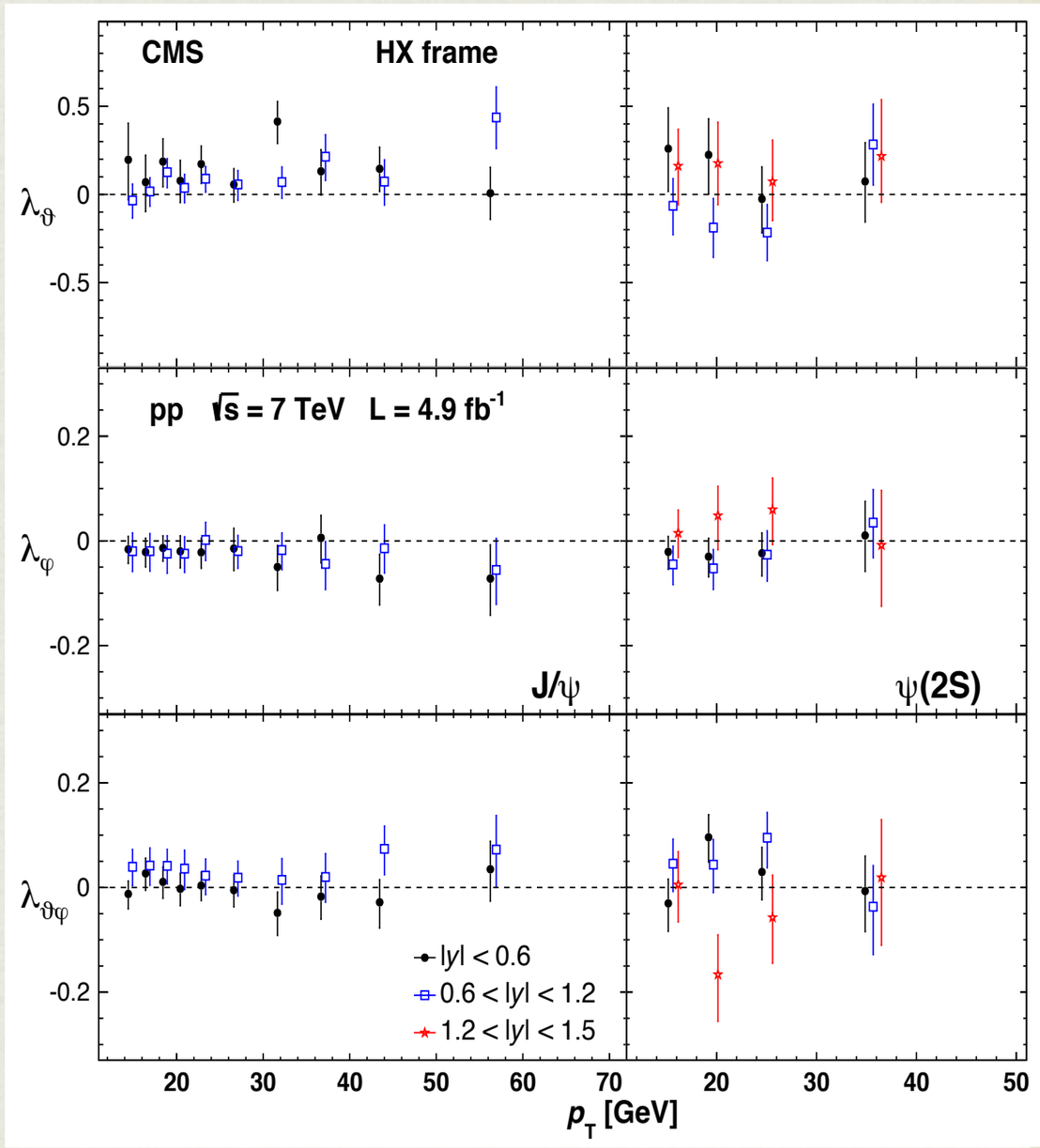


Results

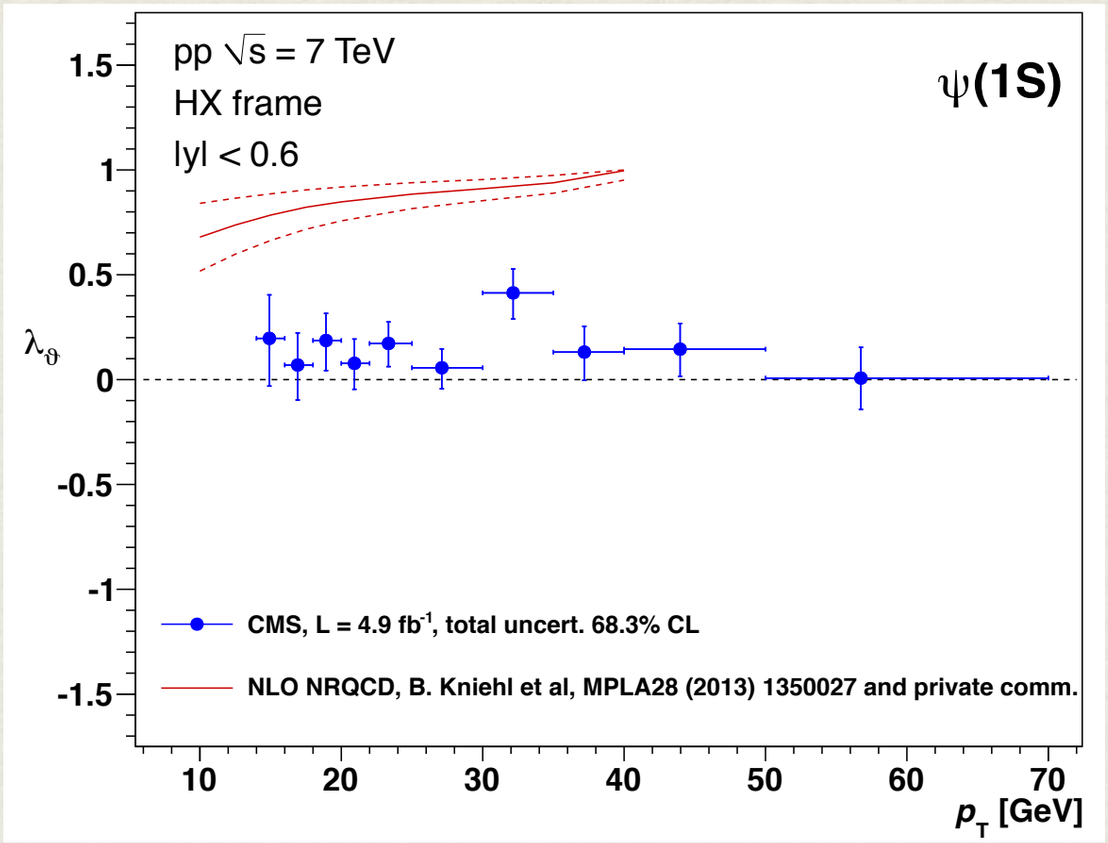
- No large longitudinal or transverse polarization is seen in various frames.
- Significant polarization could remain undetected because of smearing effect induced by different coordinates.

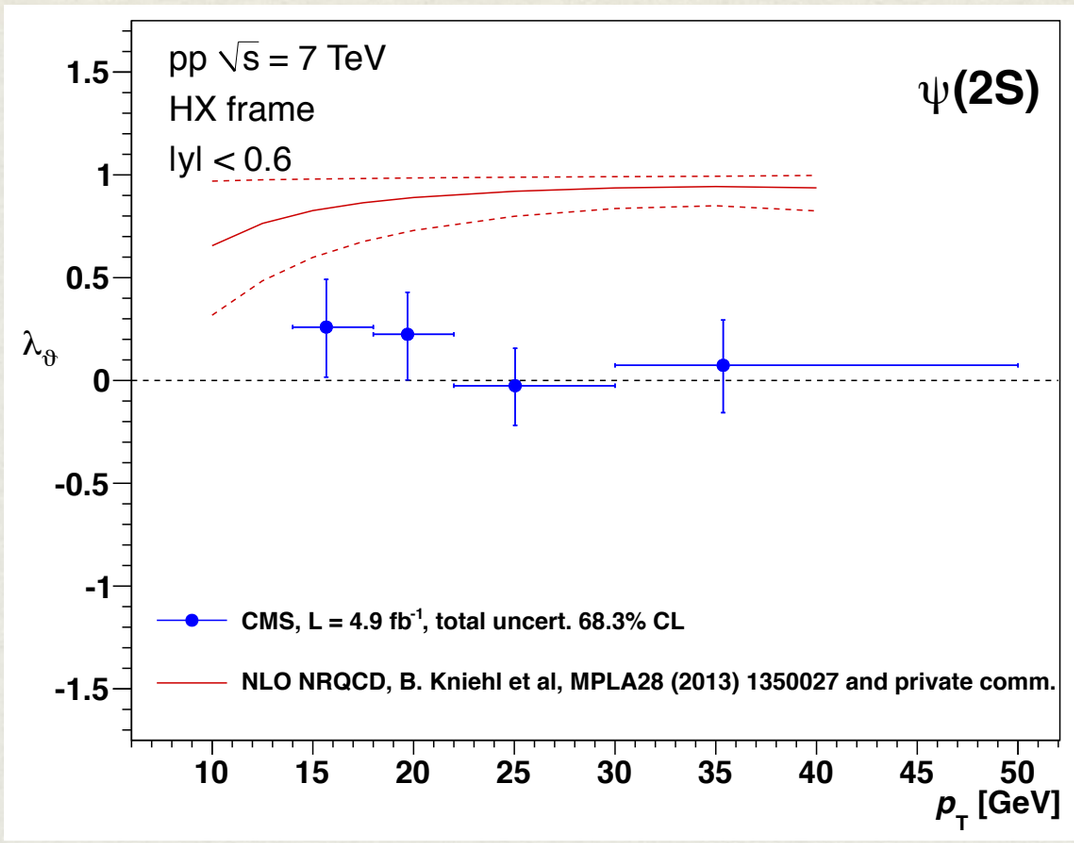






Compare with NLO NRQCD

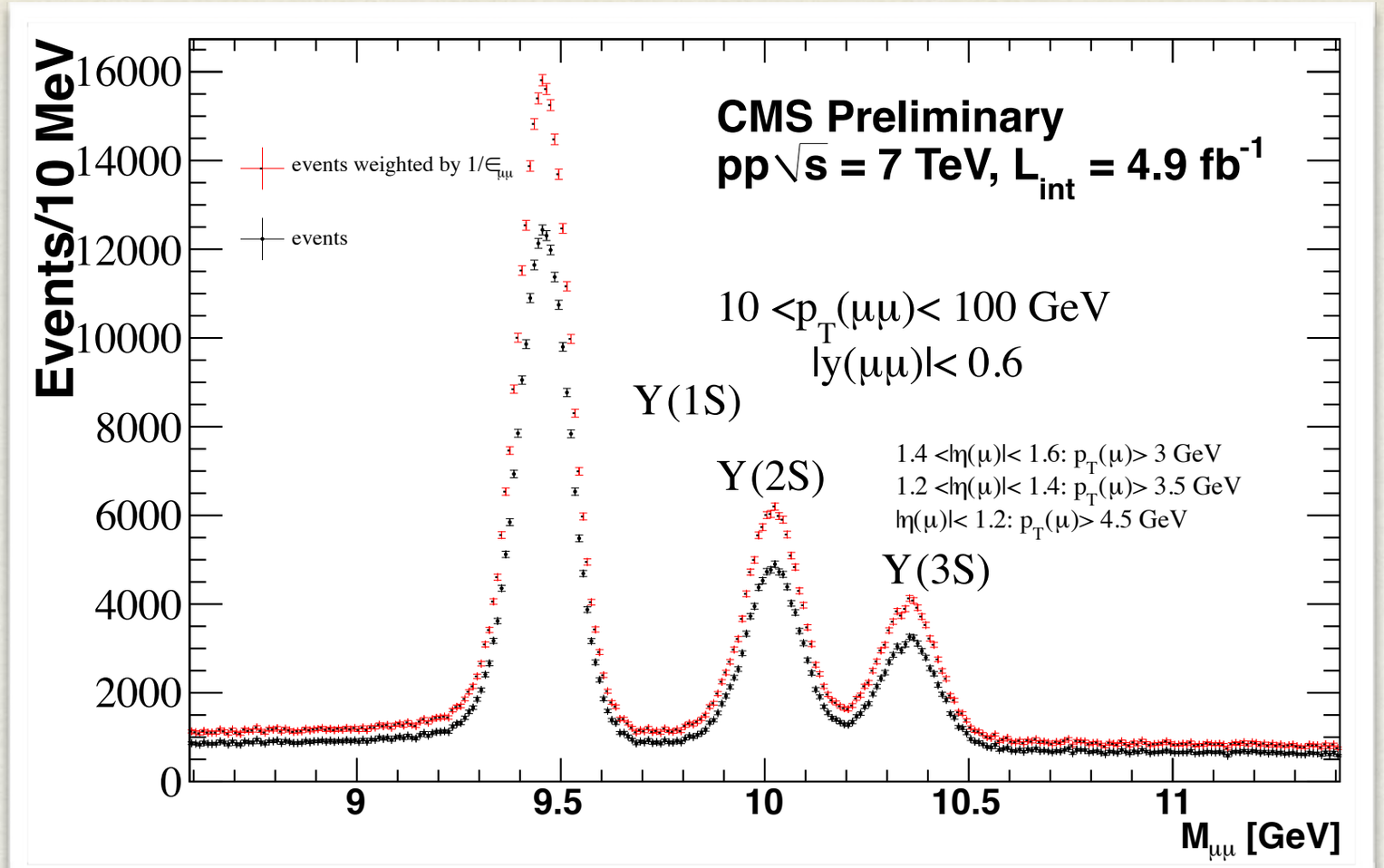




Compare with the prediction given by Butenshoen and Kniehl. [PRL 108 (2012) 172002]

Predicted transverse polarization is not observed!

Y(1,2,3S) cross section measurements



First measurement published on 2010 data. PRD 83, 112004 (2011)

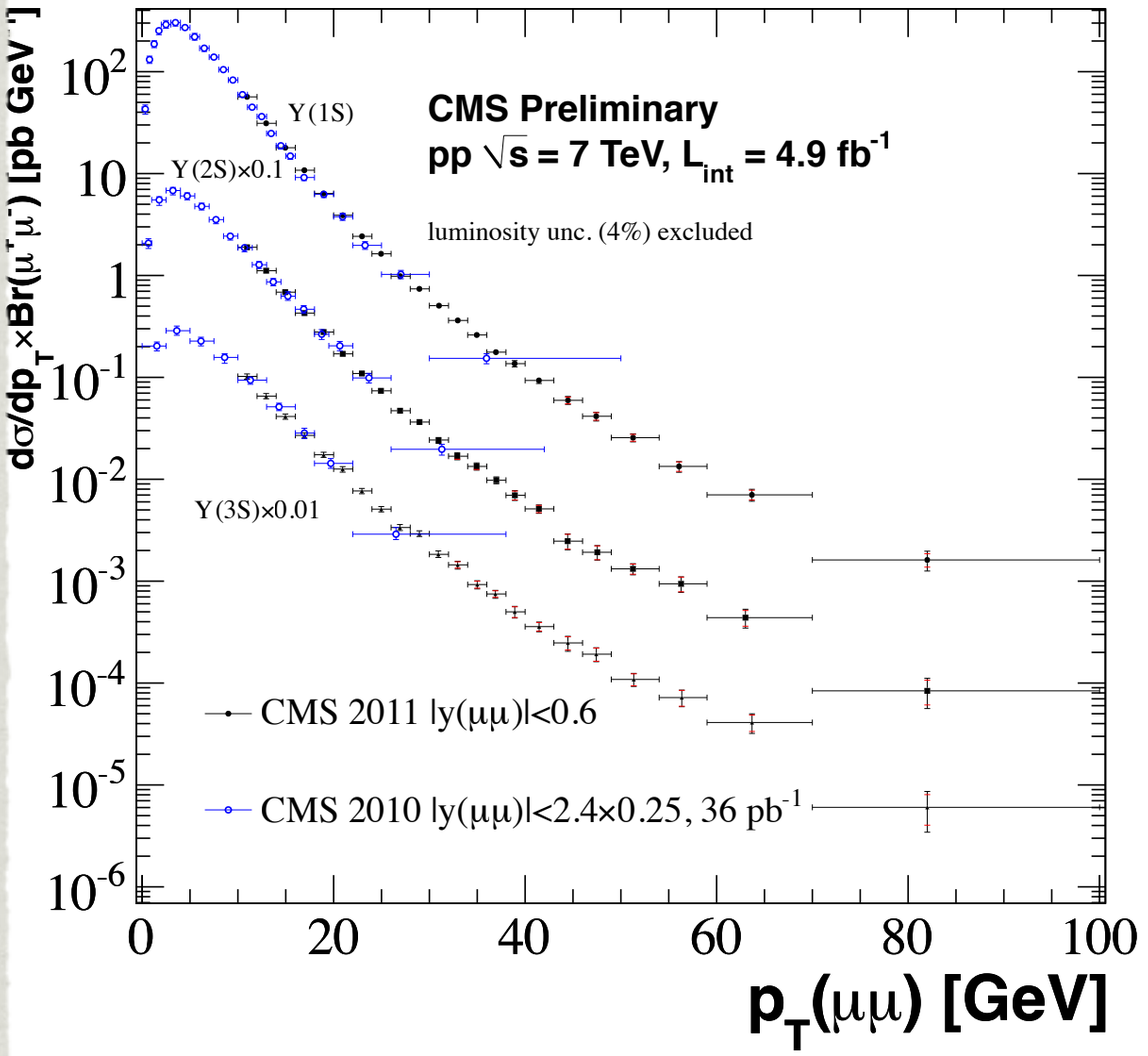
Update to 2011 data with a higher p_T upper bound of 100 GeV.

CMS measured Y polarization result is used in efficiency determination.

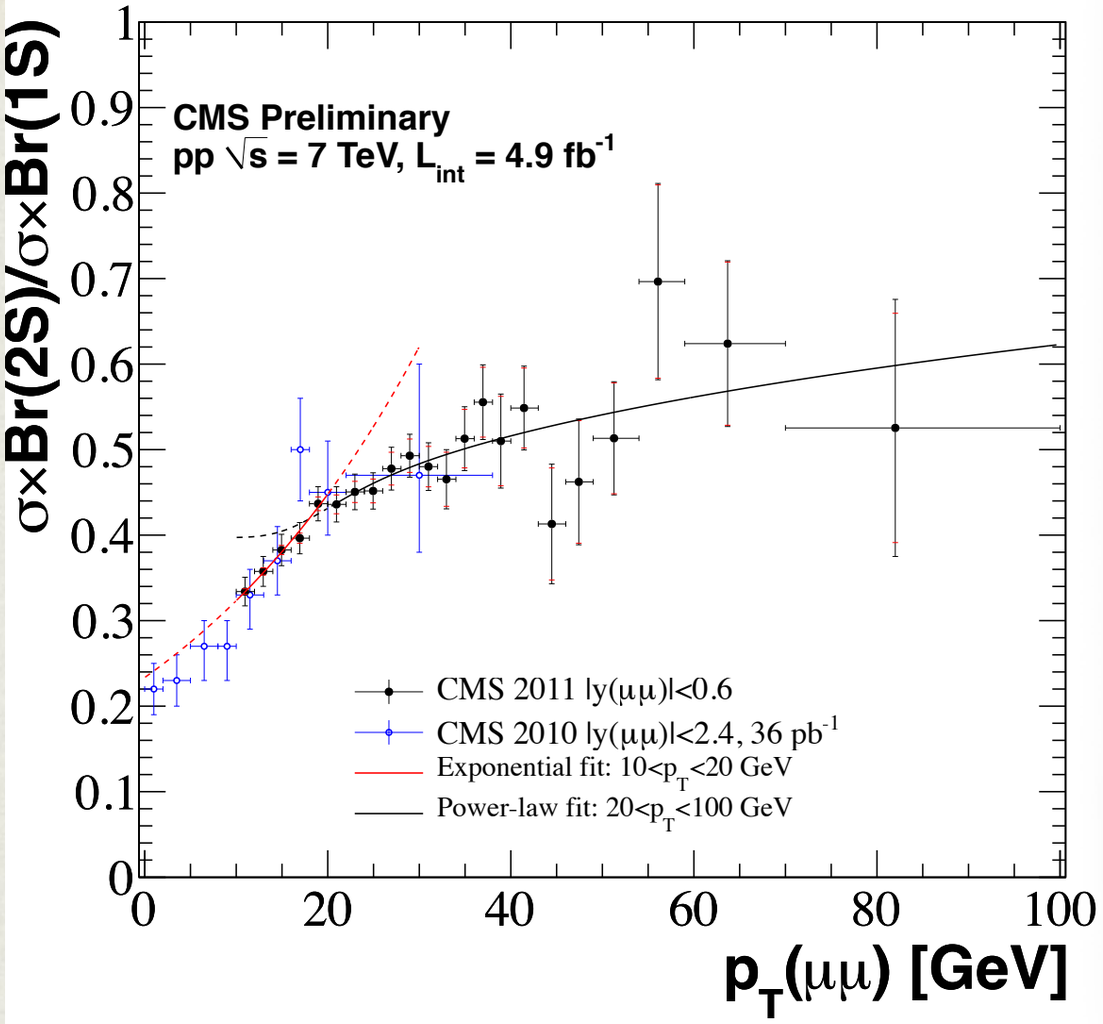
p_T dependencies

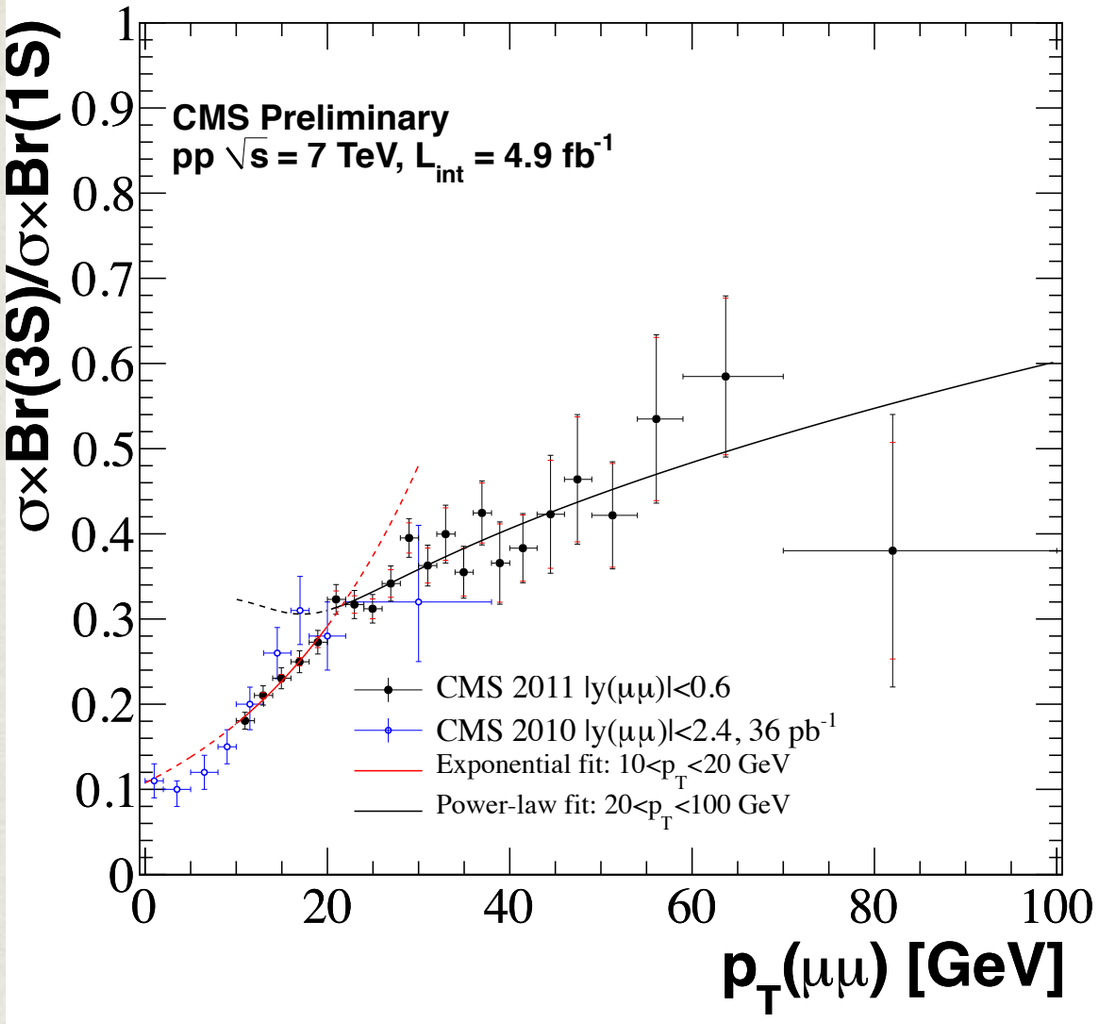
- Production rates peak near 4 GeV and fall roughly exponentially.

- Agrees well with previous (2010) measurement in low p_T region.



What's the ratio say?





Exponential fit in low p_T region.↔Power-law in high p_T region.

Summary

- CMS has conducted several measurements in quarkonium production and polarization.
- P-wave states play essential roles in solving the puzzle. More measurements such as feed-down fractions and polarization, are needed.
- Current NRQCD model cannot describe production rate and polarization at the same time.
- Looking forward to more new results.

THANK YOU

ENJOY TAIWAN!