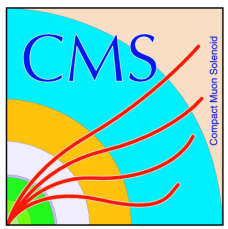
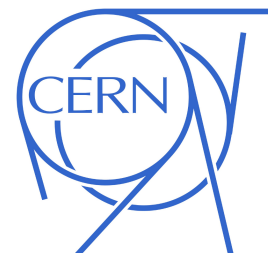
Quarkonium production and polarization in pp collisions with the CMS detector

Alessandro Degano for the CMS collaboration

Meson 2014 - May 30th 2014 Krakow





Overview

Quarkonium production puzzle

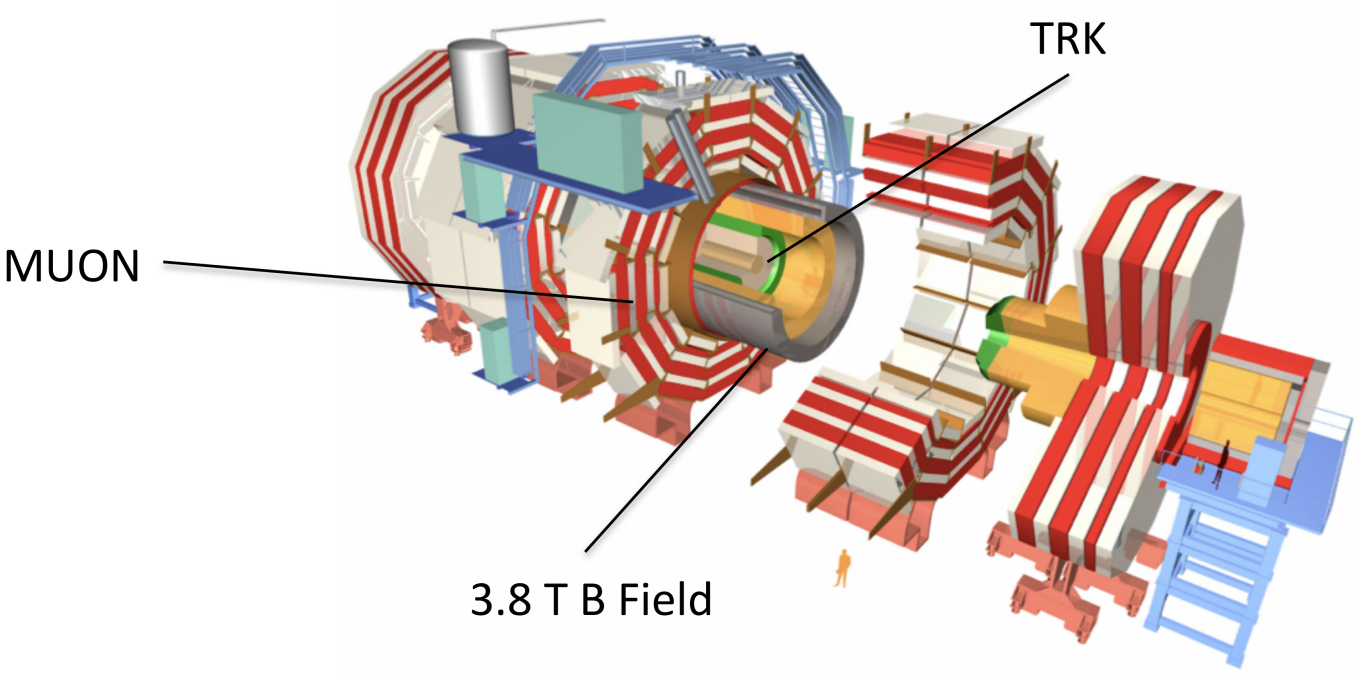
Recent CMS Measurement

- Y(1S,2S,3S) production
- Studies of P-wave quarkonia
- $Q\bar{Q}$(nS) polarization

The puzzle

- In the late 90' CDF found J/*Psi* production significantly higher than prediction
- NRQCD was born: factorizing short-distance and long-distance contribution allows precise prediction of polarization and production
- The LDME, however, needs to be evaluated from experimental data
- Since then a continuous comparison of experimental results and theoretical calculation started, producing several interesting works

CMS



- High precision measurement of muons
- Excellent resolution of tracker-converted low energy photons
- Flexible High Level Trigger ensure high statistics in the dimuon channel

Υ production CMS-PAS-BPH-12-006

- First measurements on 2010 data ~0.36 fb^{-1} up to 50 GeV p_T
- New measurements on 2011 data 4.9 fb^{-1} extends to 100 GeV p_T

Procedure:

- Data binned in increasing p_T ranges (10 to 100 GeV)
- Lineshape determined from data
- Fit to the efficiency weighted mass distribution

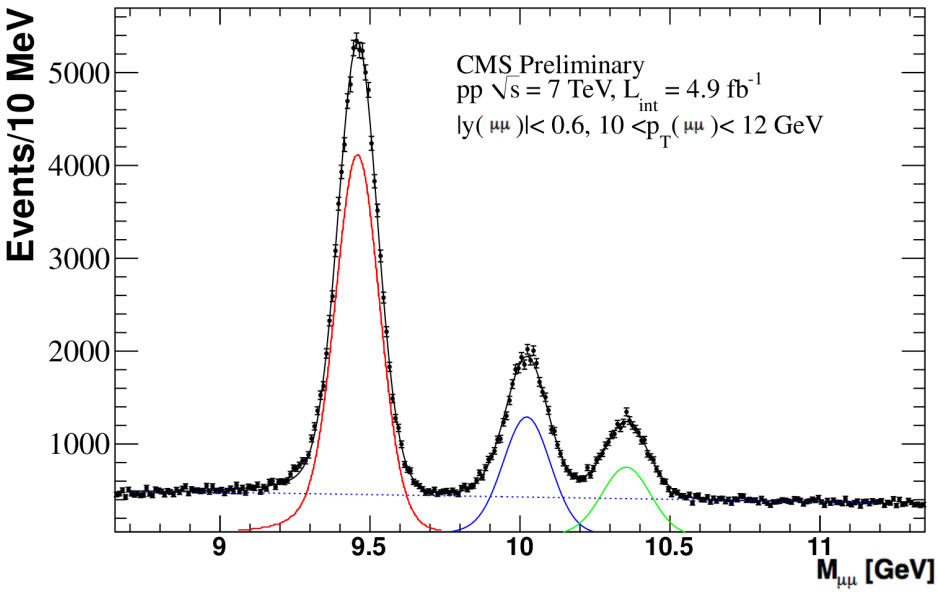
The differential x-section:

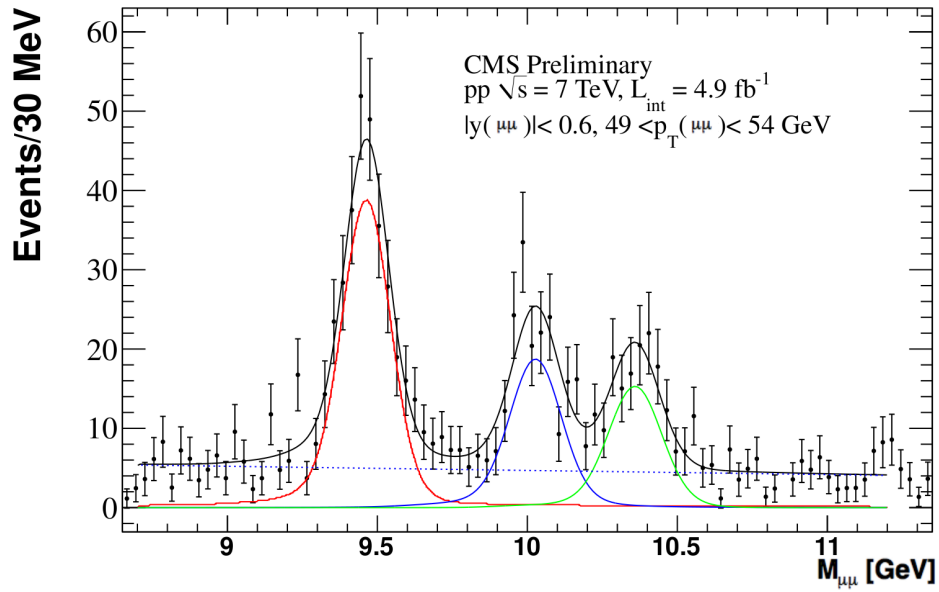
$$\frac{d\sigma(pp \to \Upsilon(nS))}{dp_T}_{|y|<0.6} \times Br = \frac{N^{\Upsilon(nS)}(p_T)}{\mathcal{L}\ \Delta p_T\ \epsilon_{\mu\mu}(p_T)\ A(p_T)}$$

Binned fit CMS-PAS-BPH-12-006

Efficiency obtained: $\epsilon_{\mu\mu}(p_T) = \epsilon_1(p_T, \eta)\ \epsilon_2(p_T, \eta)\ \rho(p_T)$

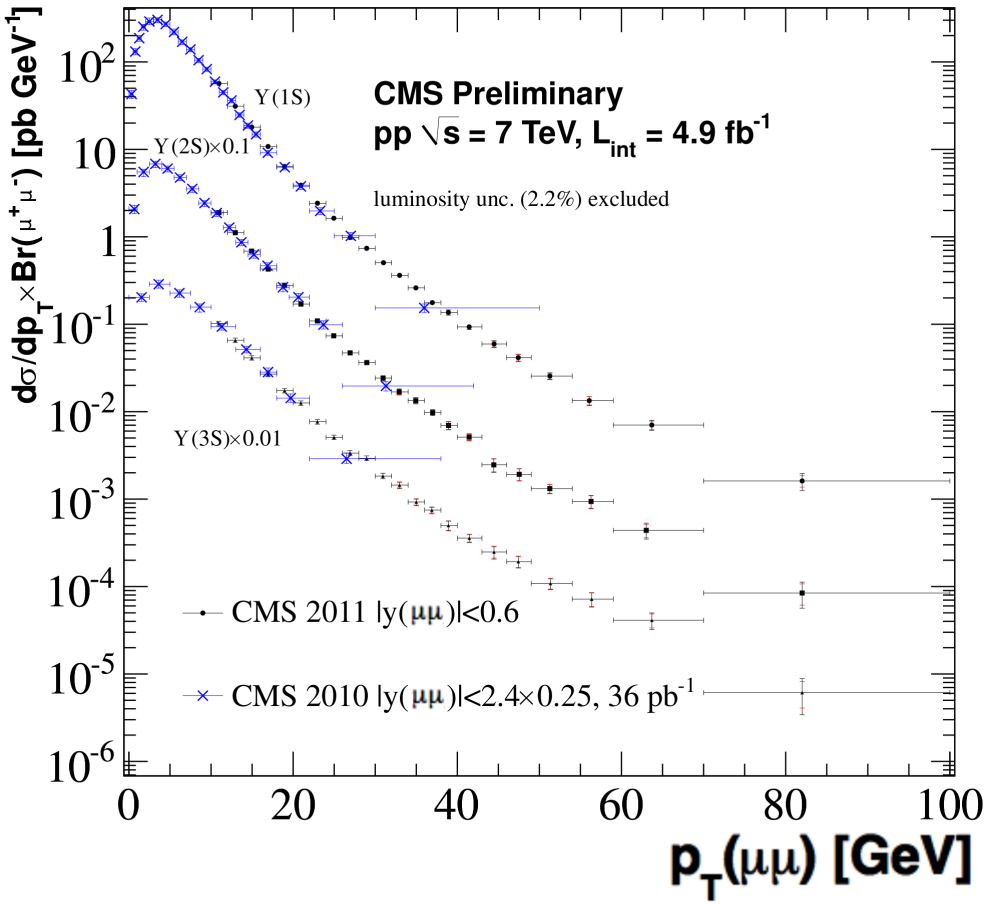
Invariant mass weighted to the inverse of the efficiency:

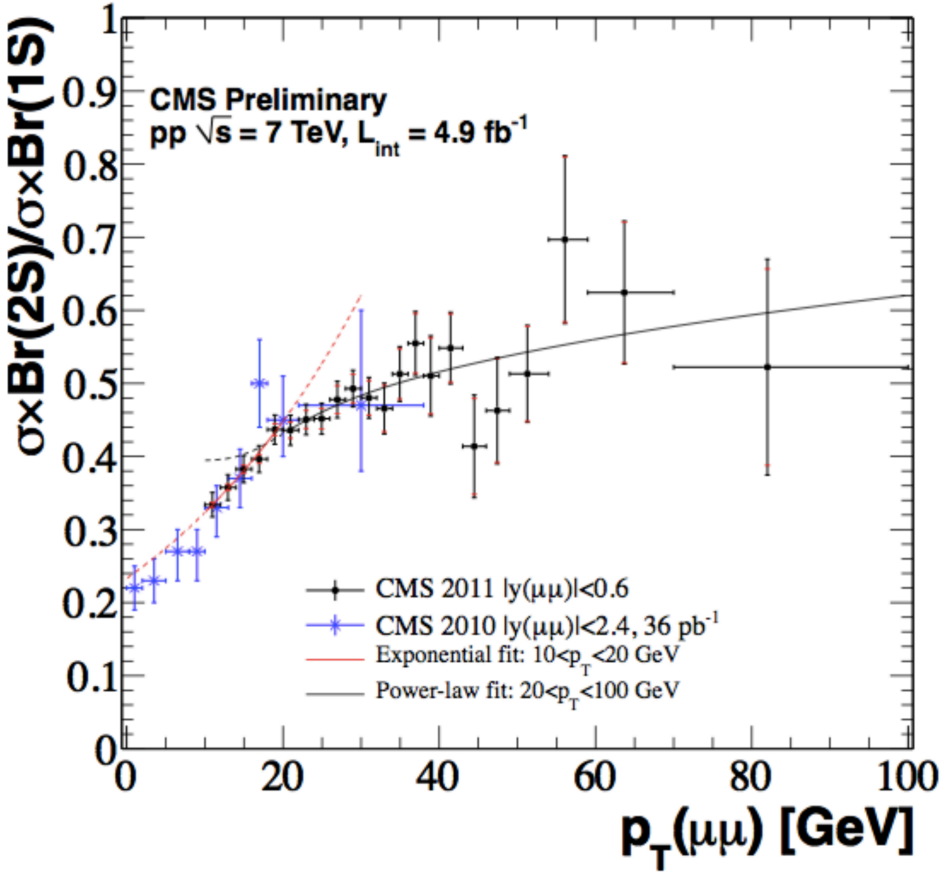




Example of the fit in two different p_T regions (10-12 GeV and 49-54 GeV)

Results CMS-PAS-BPH-12-006

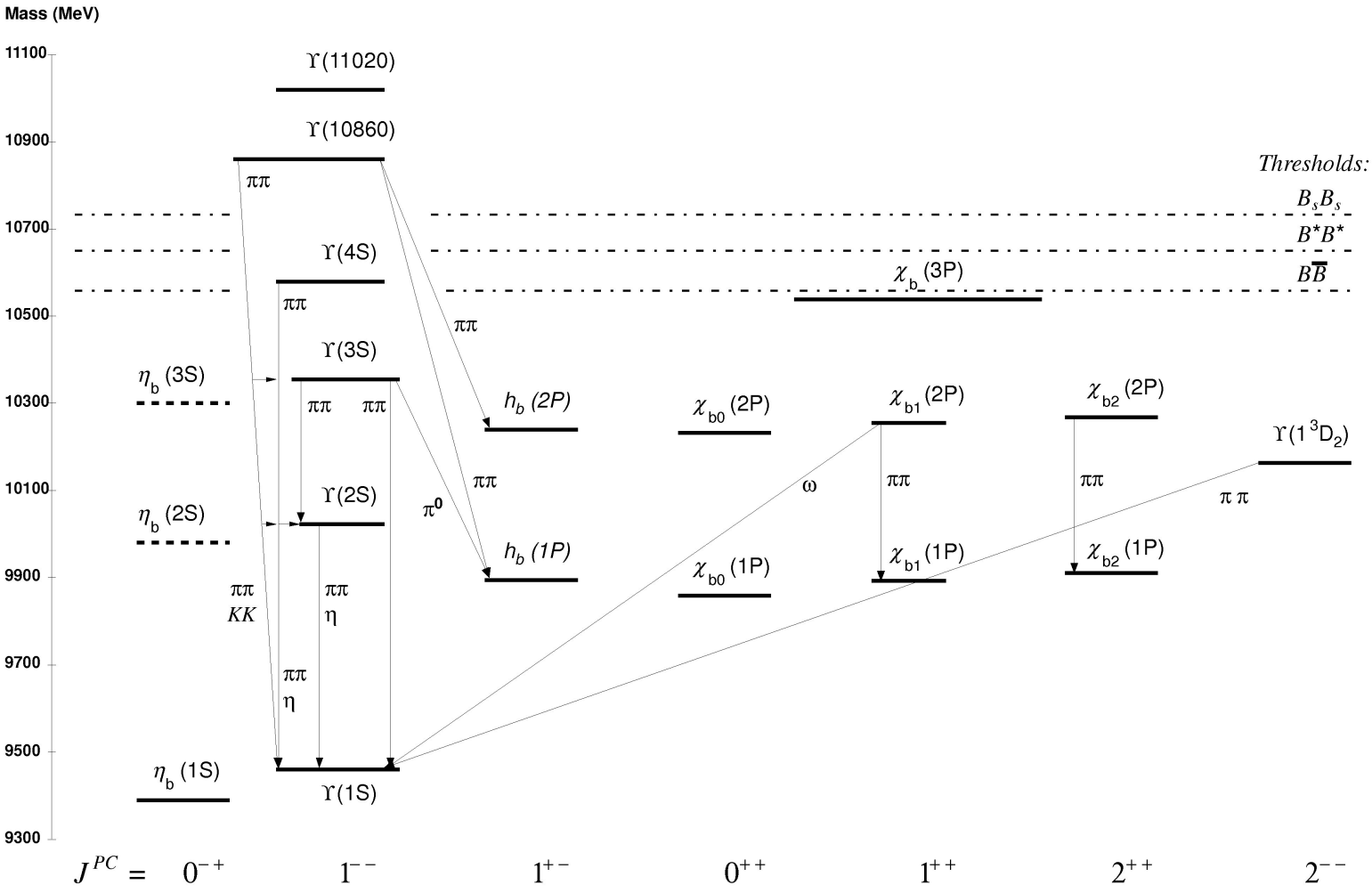




- Extend p_T covered
- Perfect agreement with previous CMS measurement

X-section ratio of P-wave states CMS-PAS-BPH-13-005

- P-wave states production offer great insight to NRQCD
- Feed-down of P-wave into S-wave must be considered
- X-section ratios allows for precise measurements

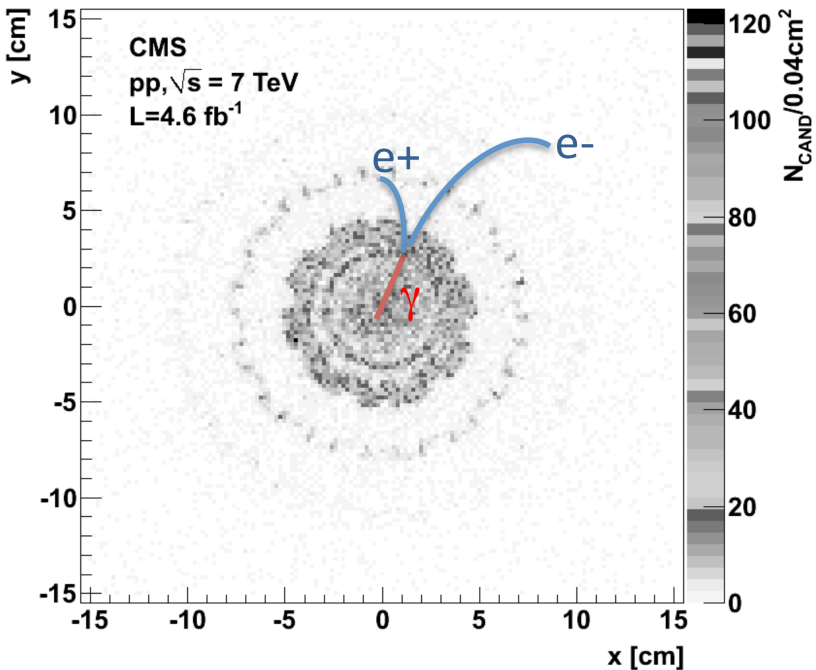


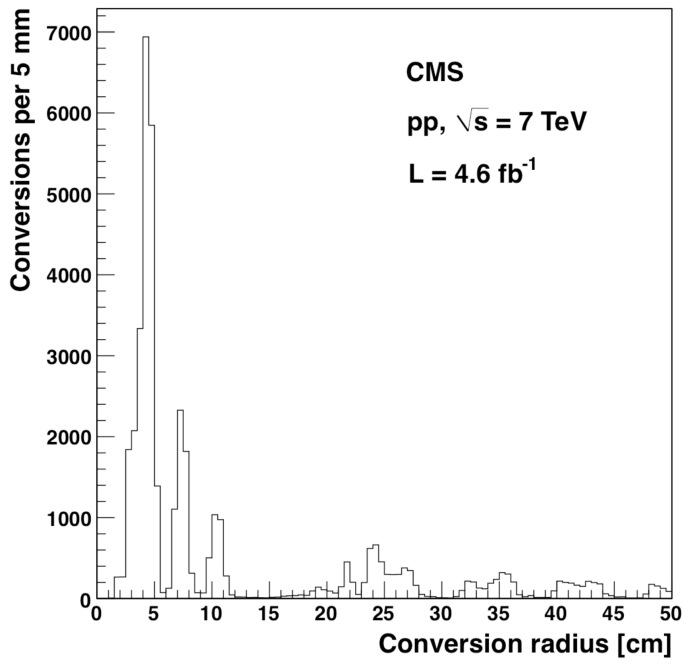
P-wave quarkonia in CMS

Best channel $\longrightarrow$ radiative decays:

$$\chi_{c1,2} \longrightarrow J/\Psi + \gamma$$
$$\chi_{b1,2}(nP) \longrightarrow \Upsilon(nS) + \gamma$$
$$J/\Psi \ / \ \Upsilon(nS) \longrightarrow \mu^+\mu^-$$

CMS ECAL has low resolution at this energy
($\sigma \simeq 41$ MeV @ 1 GeV γ)
Use photons converted in the silicon tracker $\longrightarrow$ $\sim$ 5-6 MeV resolution

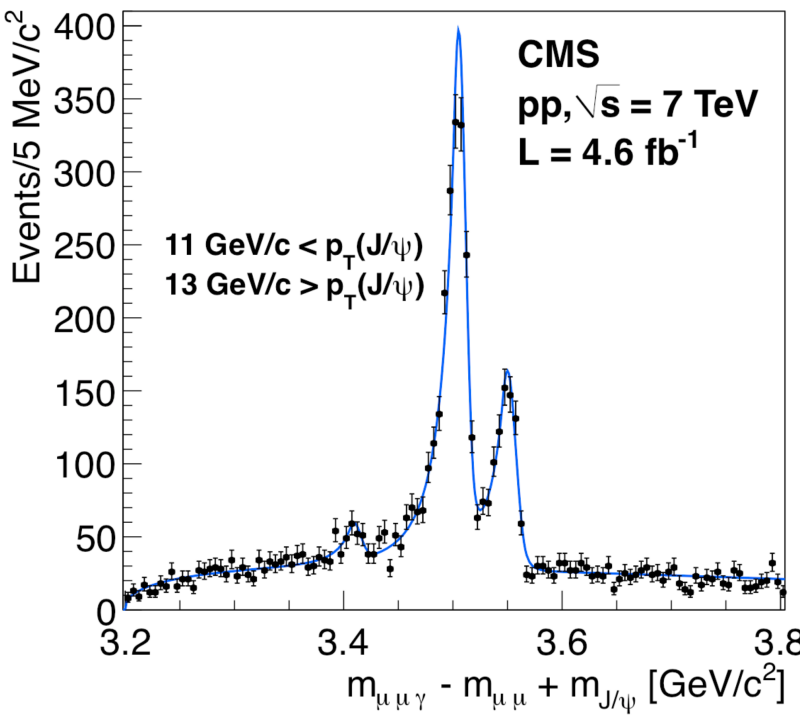




χ_{c2}/χ_{c1} X-section ratio

$$R_p \equiv \frac{\sigma(pp \to \chi_{c2} + X) Br(\chi_{c2} \to J/\Psi + \gamma)}{\sigma(pp \to \chi_{c1} + X) Br(\chi_{c1} \to J/\Psi + \gamma)} = \frac{N_{\chi_{c2}}}{N_{\chi_{c1}}} \cdot \frac{\epsilon_1}{\epsilon_2}$$

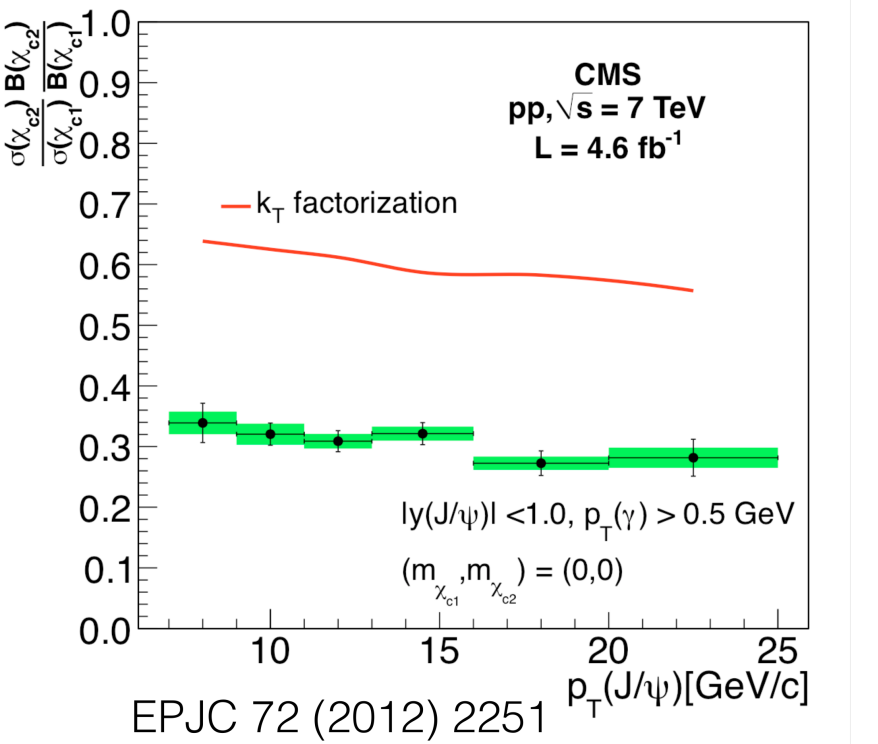
- $N_{\chi_{c2}}$ and $N_{\chi_{c1}}$ obtained with unbinned log-likelihood minimization
- Line shape determined from simulation
- Efficiency ratio determined from simulation



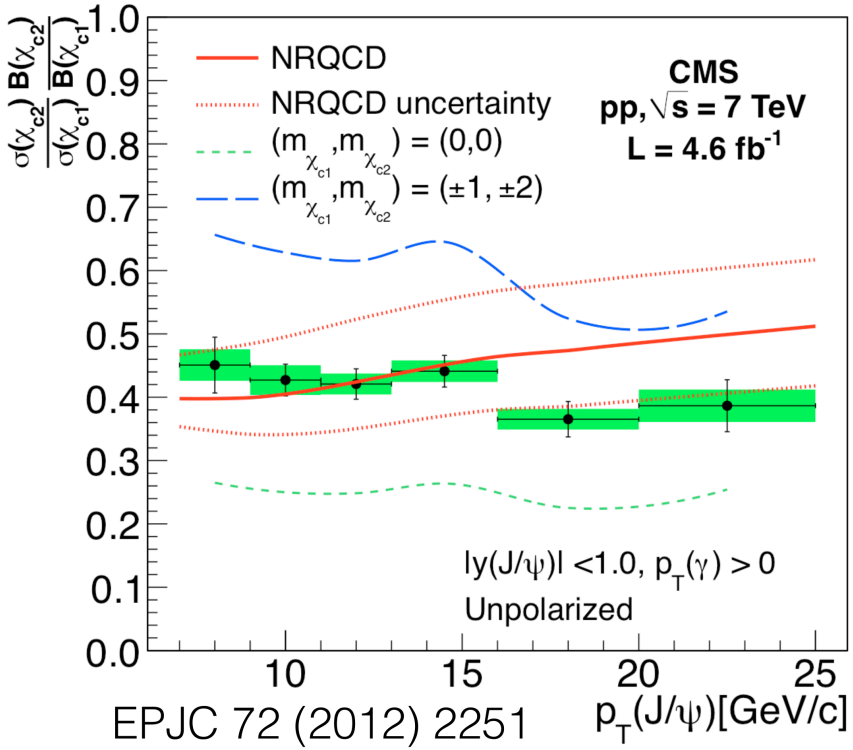
Systematic uncertainties:

- Signal parametrization
- Ratio of efficiencies

χ_{c2}/χ_{c1} X-section ratio



EPJC 72 (2012) 2251
Baranov et al., PRD 83 (2011) 034085



EPJC 72 (2012) 2251
Ma et al., PRD 83 (2011) 111503

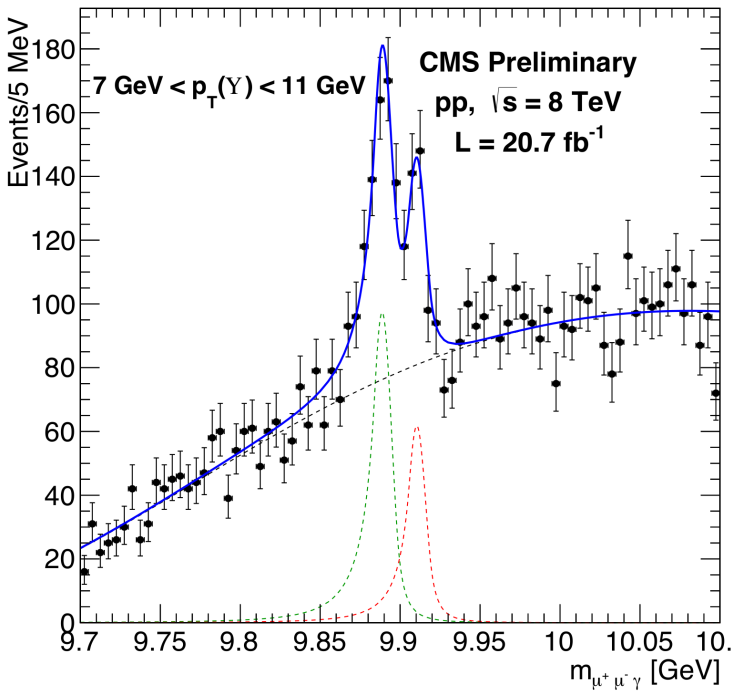
Comparison of CMS results with two theoretical predictions

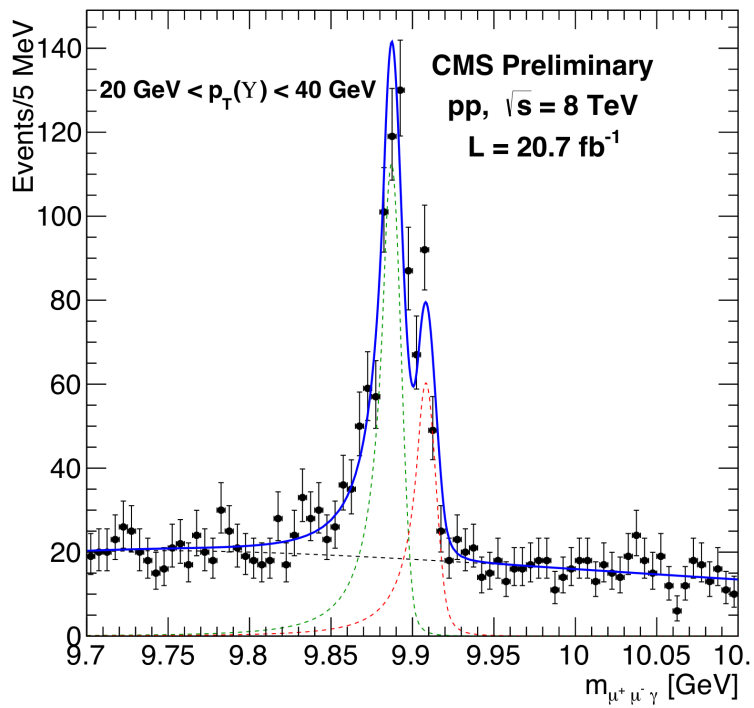
- k_t factorization predicts polarization states $m_{\chi_1}=m_{\chi_2}=0$
- NRQCD does not fix a polarization $\rightarrow$ different polarizations change the prediction significantly.

χ_{b2}/χ_{b1} X-section ratio CMS-PAS-BPH-13-005

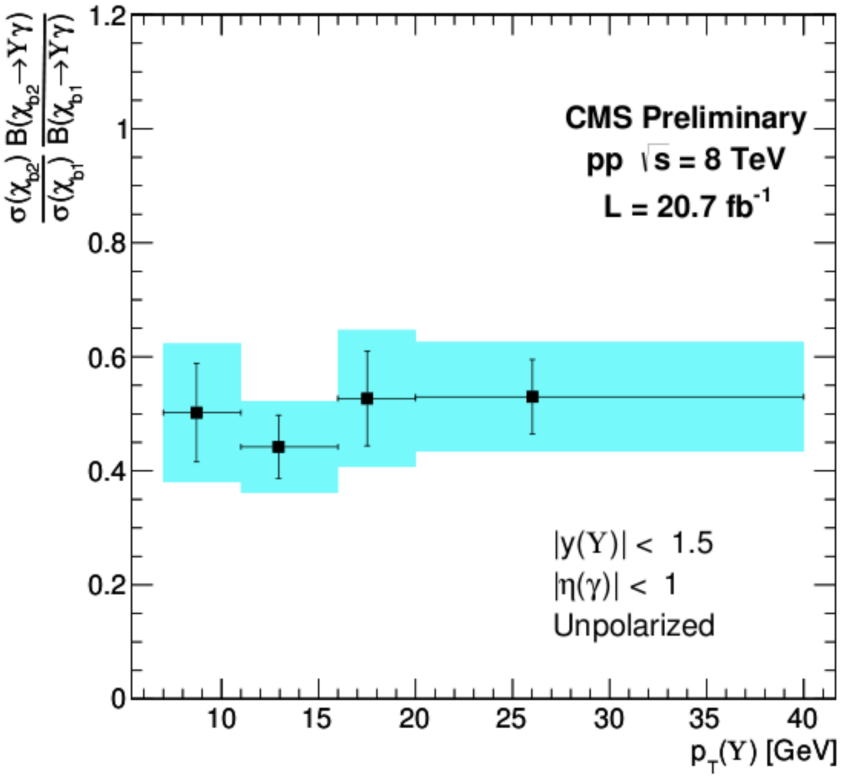
X-section ratio measurement repeated for Bottomonium:

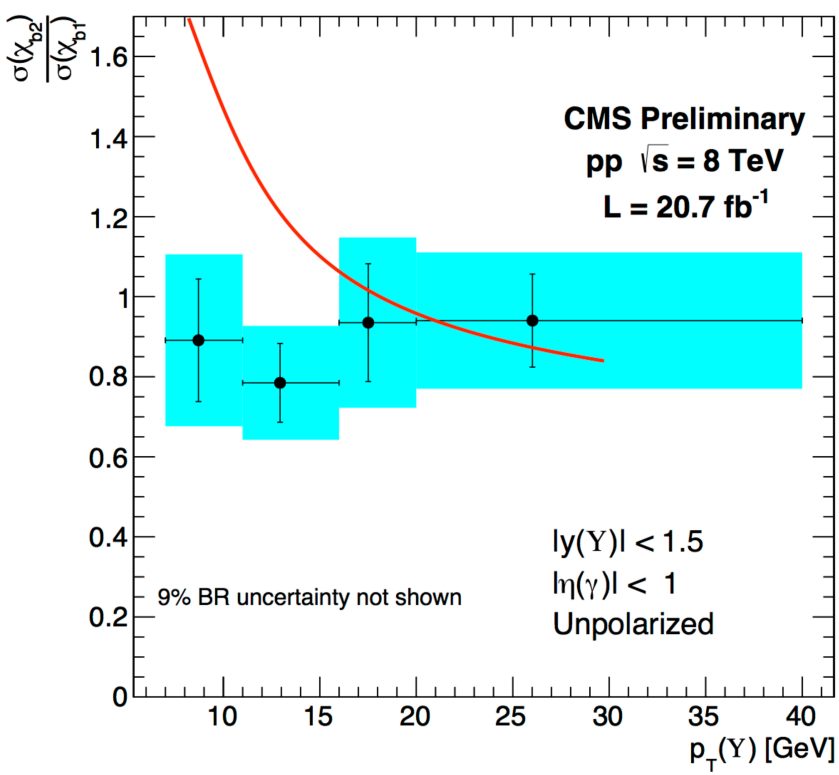
- $\sigma\chi_{b2}/\sigma\chi_{b1}$ on 2012 data (~ 20 fb^{-1}) in four p_T bins.
- Mass separation even smaller than charmonium case (~ 19 MeV)
- Cuts optimized for best photon energy resolution
- Kinematic re-fit to reconstruct $m_{\mu\mu\gamma}$





χ_{b2}/χ_{b1} X-section ratio CMS-PAS-BPH-13-005





Most recent theoretical work (PRD 86 (2012) 074027) predicts an increase at low p_T, not observed in this analysis.

Υ(1S,2S,3S) polarization CMS-PAS-BPH-11-023

Polarization of quarkonium states evalued from angular distribution of $\mu\mu$ pair.

$$\frac{dN}{d\Omega} \propto 1 + \lambda_\theta cos^2\theta + \lambda_\phi sin^2\theta cos2\phi + \lambda_{\theta\phi} sin2\theta cos\phi$$

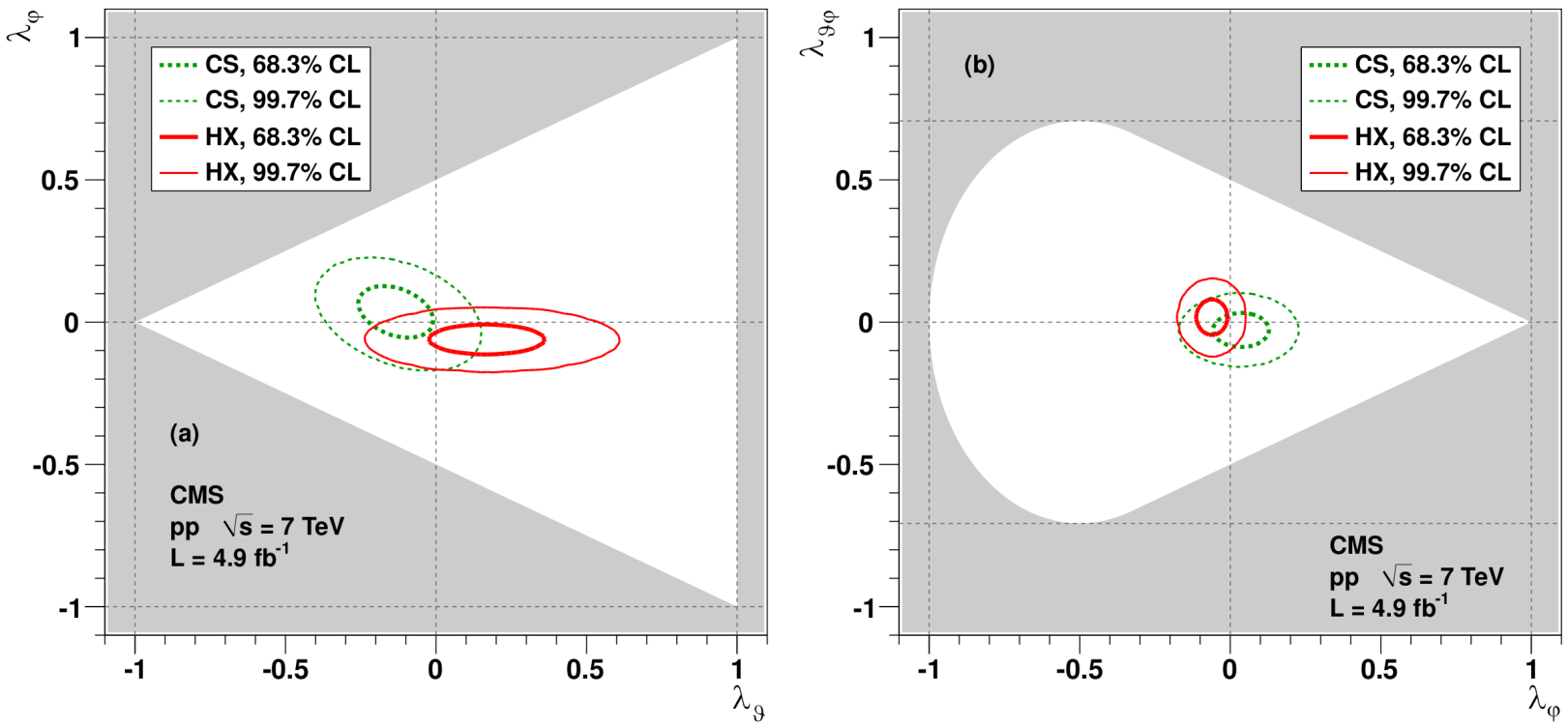
$$J_z = \pm 1 \Rightarrow \lambda_\theta = +1$$
$$J_z = 0 \Rightarrow \lambda_\theta = \text{-}1$$

Technique:

- Precise measurement of efficiency in p_T and η
- Evaluate all the angular distribution parameters $(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi})$
- Express the result in 3 different frames (HX, CS, PX)

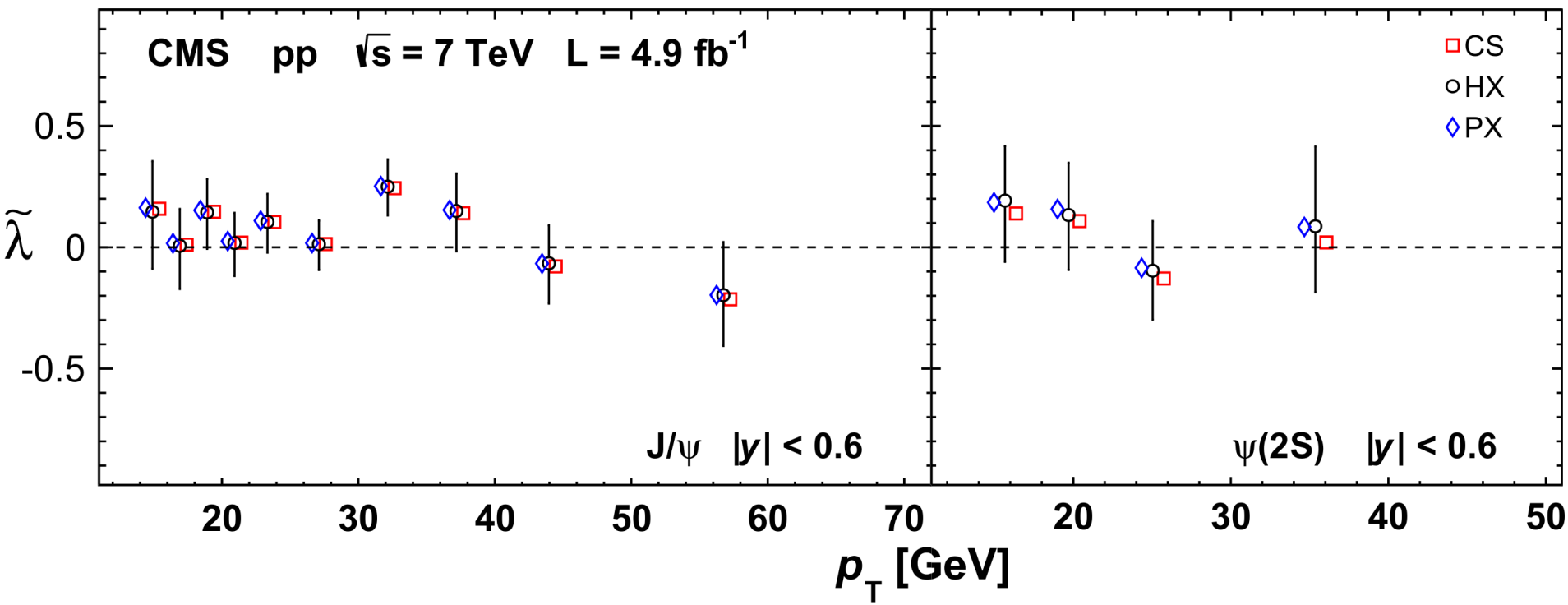
Υ(1S,2S,3S) polarization CMS-PAS-BPH-11-023

- Results given in terms of Posterior Probability Densities (PPD)
- Systematic uncertainties from data and pseudo-experiments
- Results exclude large transverse or longitudinal polarization



J/Ψ, Ψ(2S) polarization PLB 727 (2013) 381

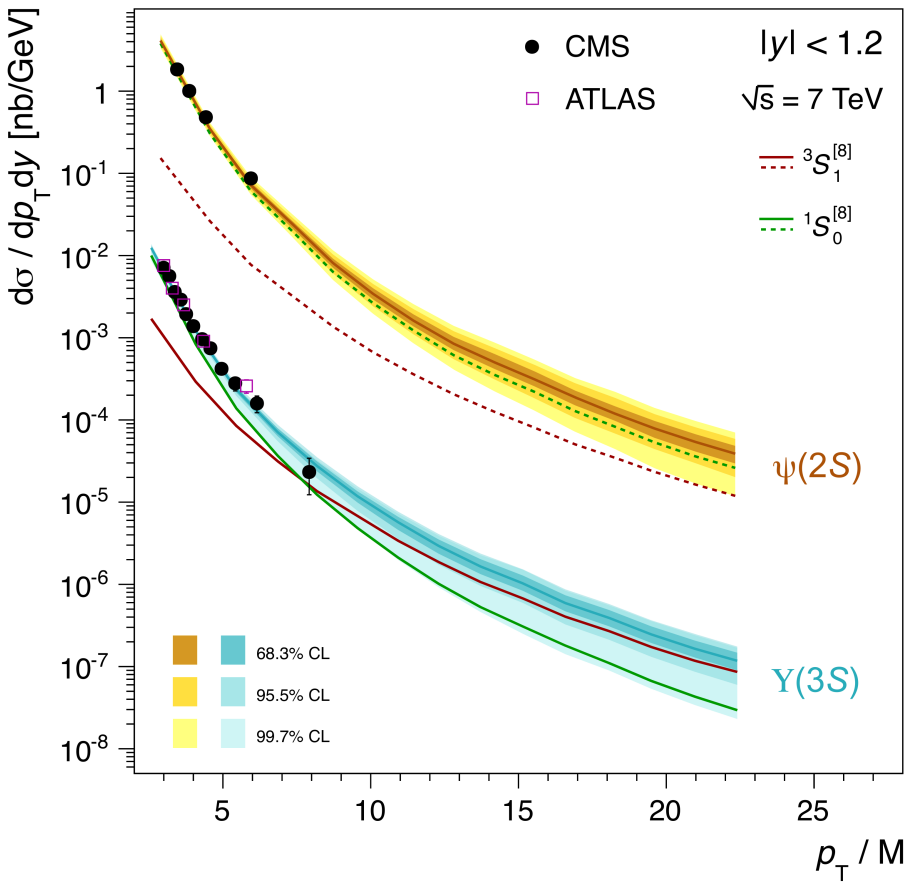
- Most recent polarization study from CMS
- No feed-down contributes to Ψ(2S)
- Results exclude large transverse or longitudinal polarization

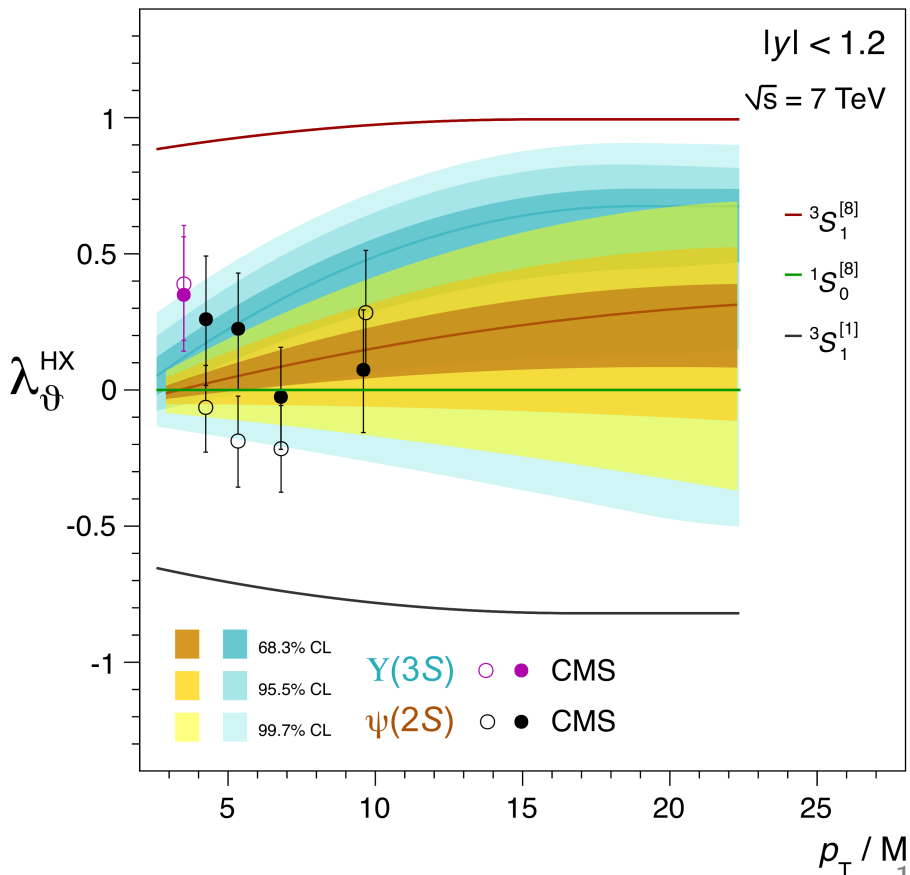


A polarized perspective to NRQCD arXiv:1403.3970 [hep-ph]

P. Faccioli et al. take a different perspective:

- Polarization data at the center of the study
- Search for the best kinematic domain for polarization and cross-section





Conclusions

- CMS has proven to be an excellent instrument to probe QCD through quarkonia studies
- An improved methodology to measure polarization opened new possibility to "global-fits" of quarkonium data
- Results so far gave good input to NRQCD but more are required:
  - Feed-down fractions
  - Polarization of P-wave states
  - Further x-section measurements
- New CMS results planned with Run 1 data