Quarkonium Production with CMS Experiment

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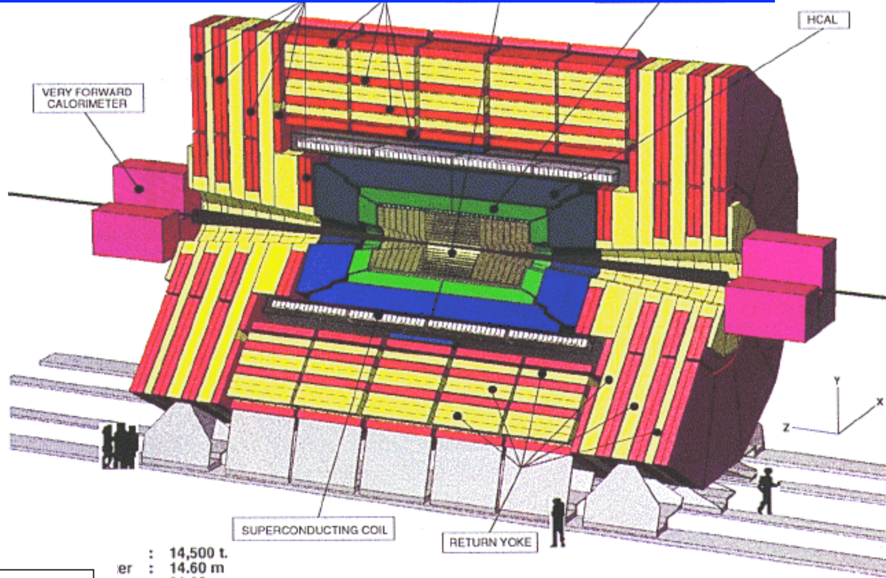
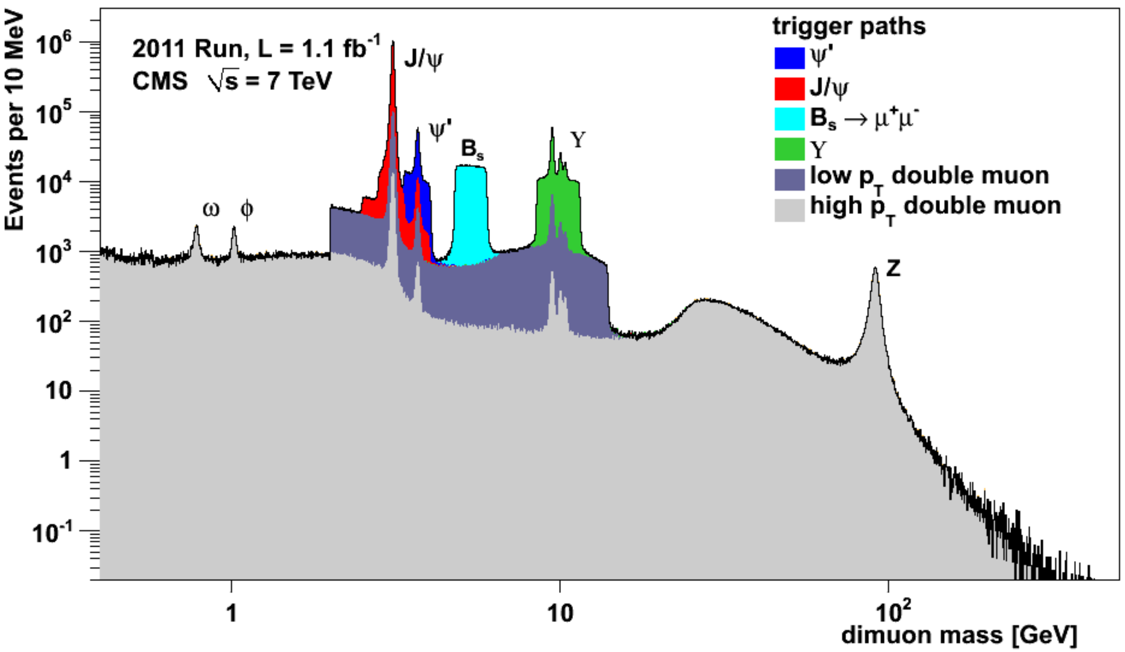
Outline

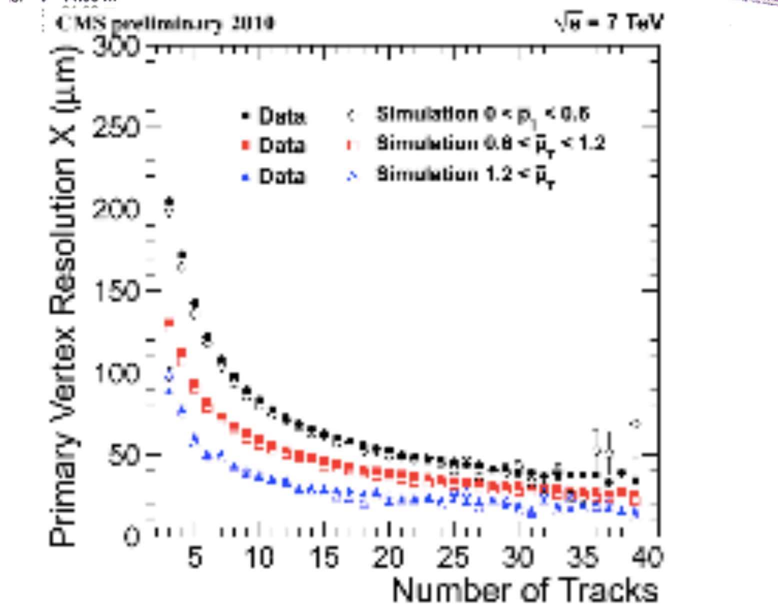
- The CMS detector and Muon Trigger
- χ_{c2}/χ_{c1} Cross Section Ratio (BPH-11-010)
- Υ(ns) Production Cross Section (BPH-11-001) NEW
- Observation of $B_c \rightarrow J/\Psi\pi^+$ & $J/\Psi\pi^+\pi^-\pi^+$ (BPH-11-003) NEW
- Conclusion

CMS Detector

- High muon reconstruction efficiency
- Good muon momentum resolution
- Good vertexing
- High purity and low rate B and quarkonium triggers from dimuons







χ_{c2}/χ_{c1} Cross Section Ratio

- The charmonium puzzle—"anomalous" production of charmonium at CDF (M. Mangano, Moriond QCD, 1994 and reference therein), ~50X higher J/Ψ production cross section than predicted
  - Color octet was the main solution to the puzzle
  - Also imply feed down from higher states, including hybrid states proposal (PLB 342, 369, 1995)

- Quarkonium production theoretically not well understood. Excited quarkonium states (χ_{cJ}) account for sizeable fraction of J/Ψ production. χ_{c2}/χ_{c1} prompt ratio provides useful information for J/Ψ cross section calculation

- Study $\chi_{cJ} \rightarrow J/\psi + \gamma$ (conversion), $\gamma \rightarrow e^+e^-$, excellent mass resolution (~6 MeV)

- Strategy for studying prompt χ_{c2}/χ_{c1} Prompt production:
  - Rejecting the displaced dimuons to reduce feed-down from B decays.
  - Reject π^0 candidates to reduce background
  - Photon efficiency almost cancels for cross section ratio

The Signal Extraction method

- Use un-binned likelihood fit to extract signal event yields

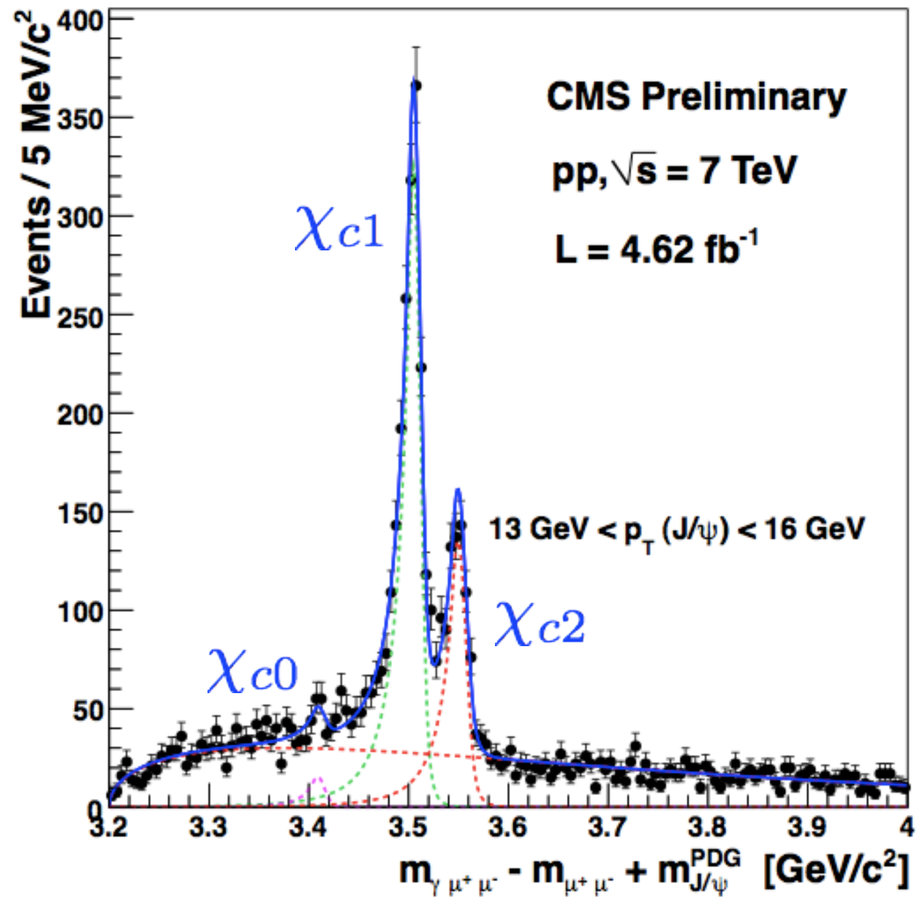
- Signal: double (χ_{c1} , χ_{c2}) or single (χ_{c0}) crystal balls (parameters fixed to MC)

- χ_{cJ} states clearly resolved, given the 6 MeV mass resolution

- Background: empirical function

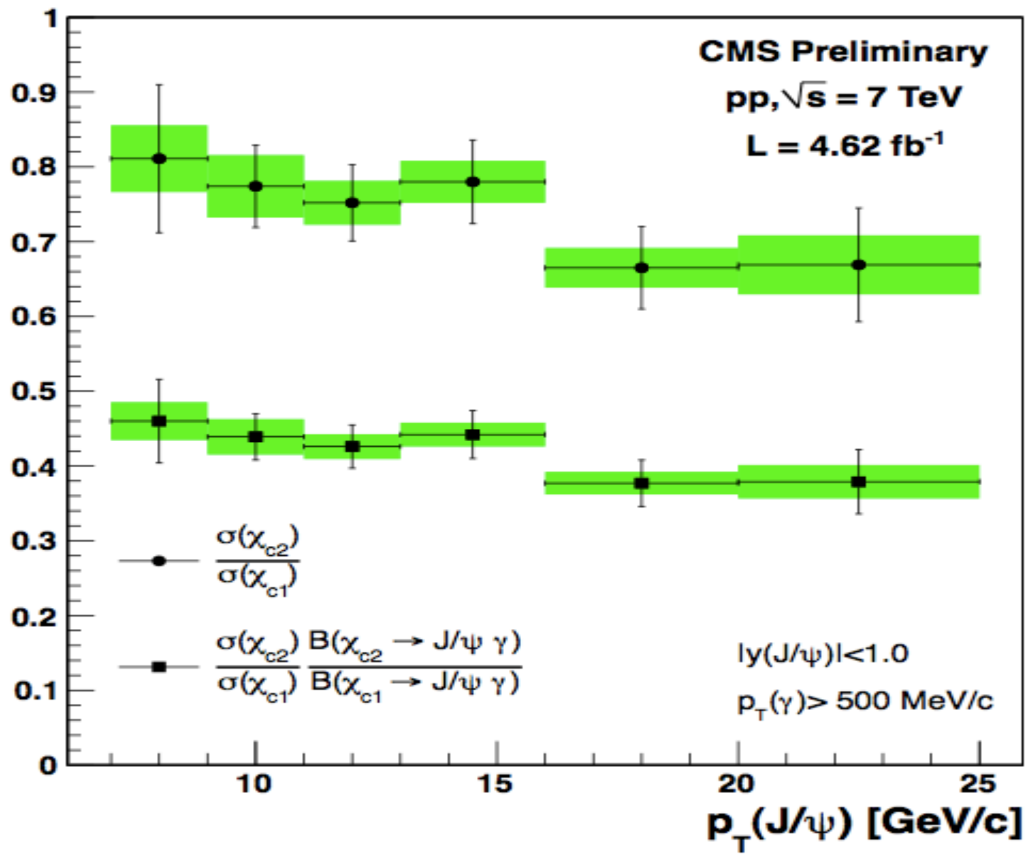
$$N_{bkg} = (Q - q_0)^{\alpha_1} \cdot e^{(Q-q_0)\cdot\beta_1}$$

$$q_0 = 3.2\ GeV$$

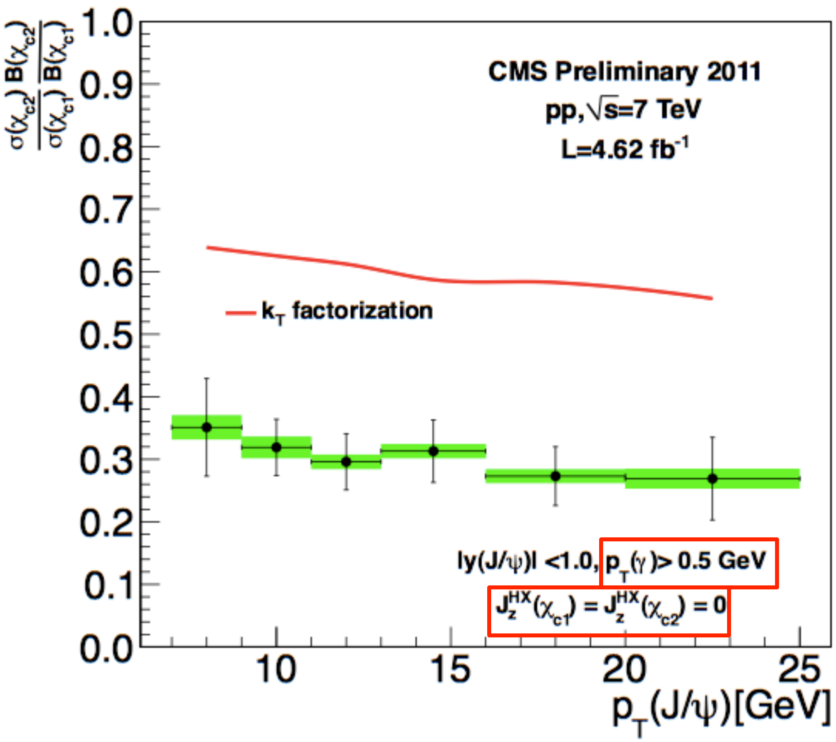


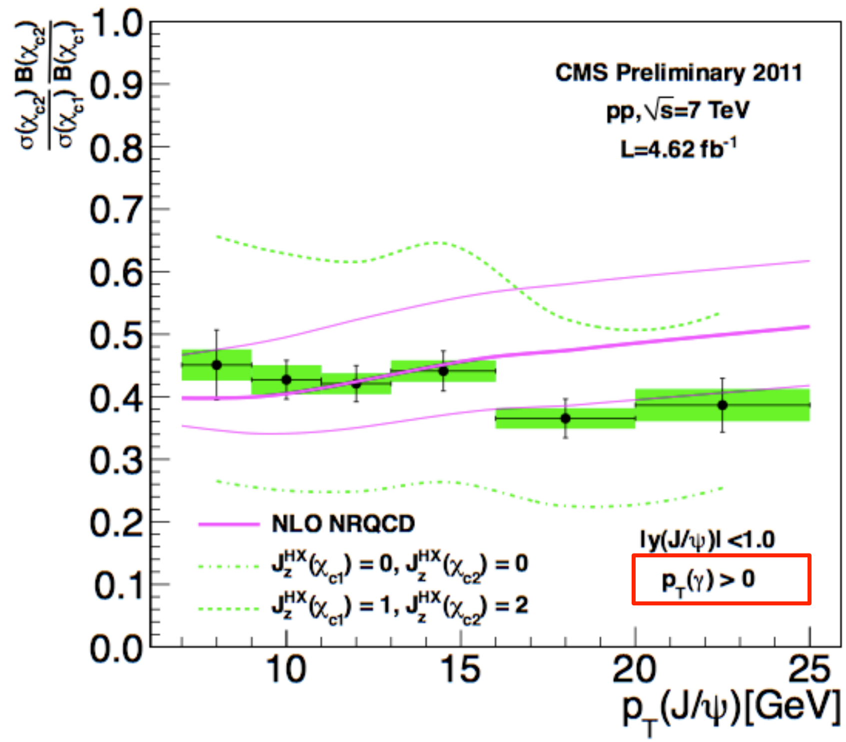
The results

- The χ_{c2}/χ_{c1} cross section ratio has been measured vs p_T
- Up to p_T = 25 GeV with small uncertainties, measurement indicates slight decrease vs. p_T
- Large uncertainty due to unknown polarization (up to 25%)



Comparison to theory





k_T factorization predicts both states in $Jz^{HX} = 0$, CMS result reported here with $Jz^{HX} = 0$ for comparison

The naive spin counting argument gives a ratio of 5/3, which was already excluded by CDF's measurement

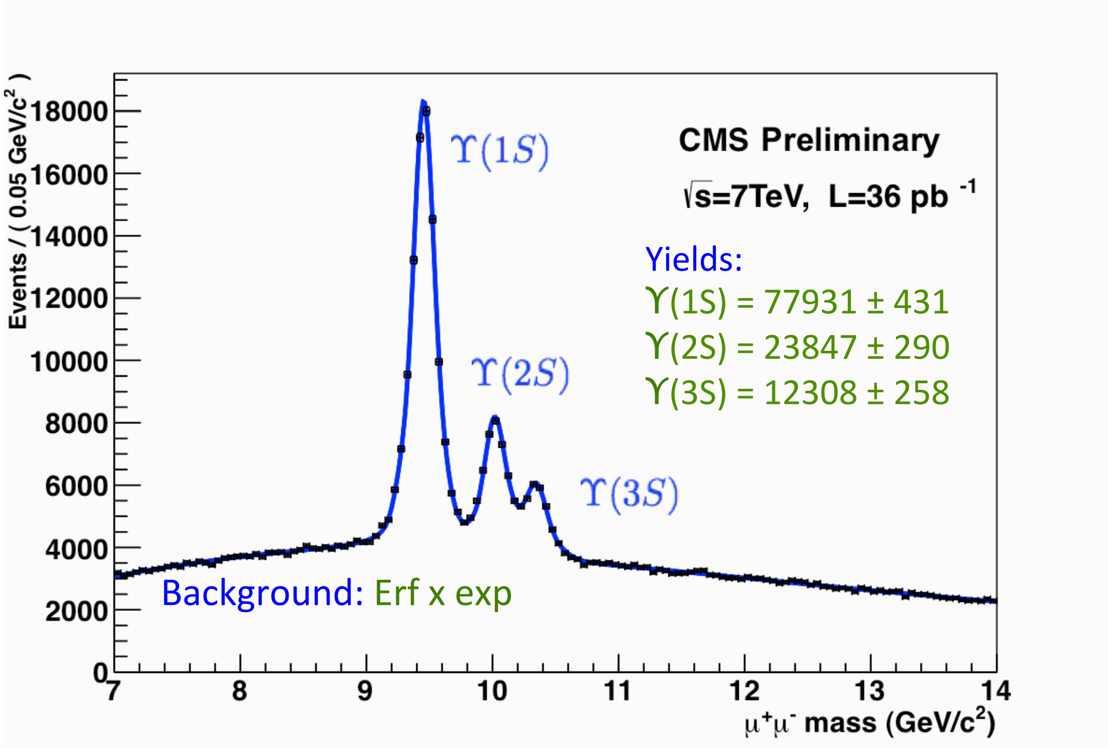
Measured ratio has been extrapolated down to zero photon p_T for the comparison with the NLO NRQCD prediction

NLO NRQCD does not predict the polarization; data show the full polarization uncertainties through the green bands

Υ(nS) Cross Section

- The J/ψ and Υ differential cross sections and polarizations still disagree with theory
- LHC (CMS, ATLAS, LHCb) provides a chance to study quarkonium production with:
  - higher center-of-mass energies; larger momentum range; wide rapidity range

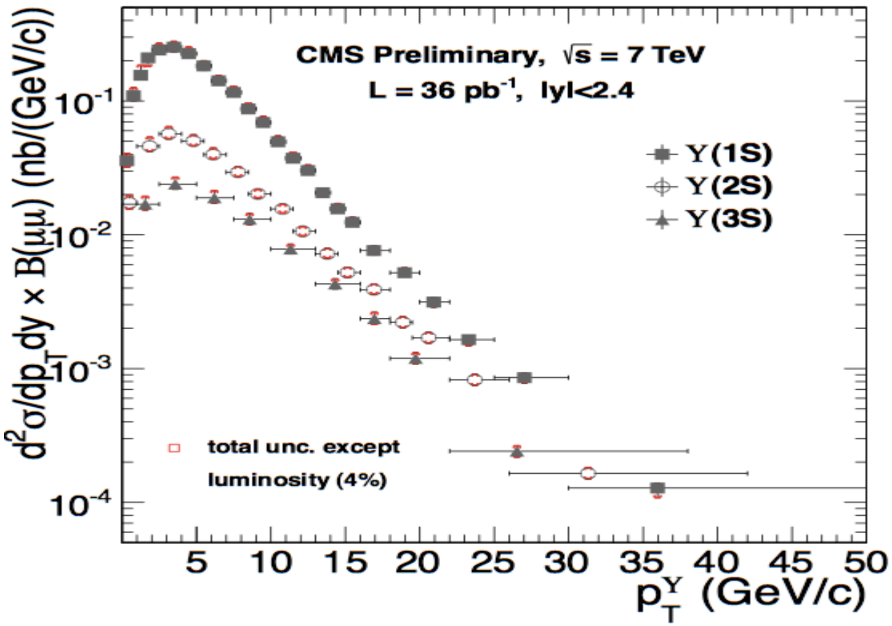
- Crystal ball function for signal PDF (MC)
- Data-driven (tag & probe) efficiencies
- Previous CMS result (3 pb-1): PRD 83:112004 (2011)

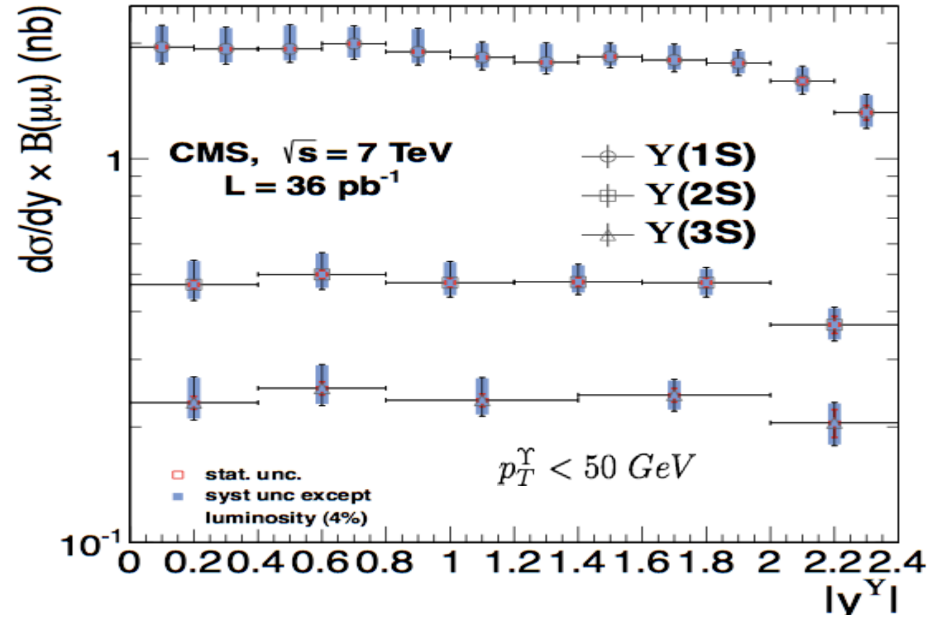


- The differential cross section is calculated as:

$$\frac{d\sigma(pp \to \Upsilon(nS))}{dp_T dy}\mathcal{B}(\Upsilon(nS) \to \mu^+\mu^-) = \frac{N^{corrected}_{\Upsilon(nS)}(p_T, y; \mathcal{A}, \epsilon)}{\mathcal{L} \cdot \Delta p_T \cdot \Delta y}$$

Results





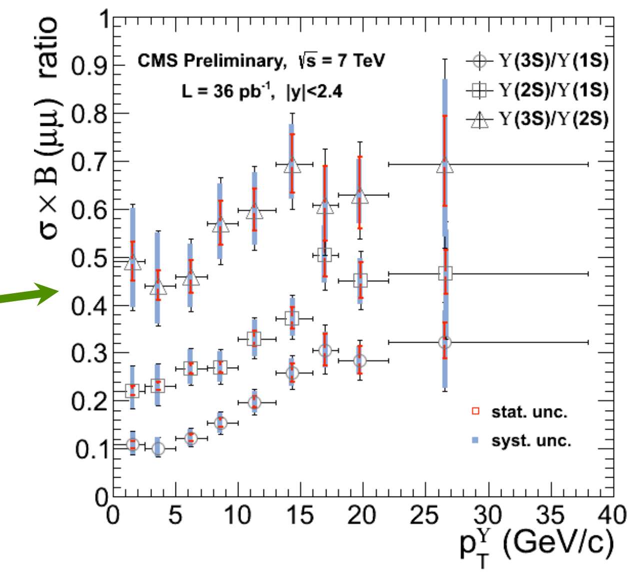
- Total cross section:

$$\sigma(pp \to \Upsilon(1S)X) \cdot \mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) = (8.55 \pm 0.05^{+0.88}_{-0.78} \pm 0.34)nb$$

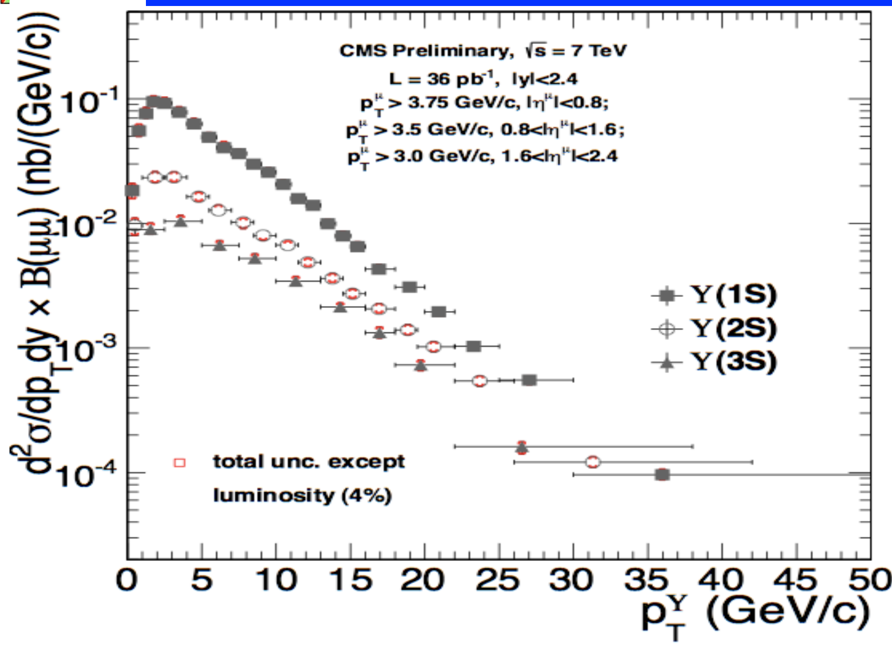
$$\sigma(pp \to \Upsilon(2S)X) \cdot \mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) = (2.21 \pm 0.03^{+0.24}_{-0.21} \pm 0.09)nb$$

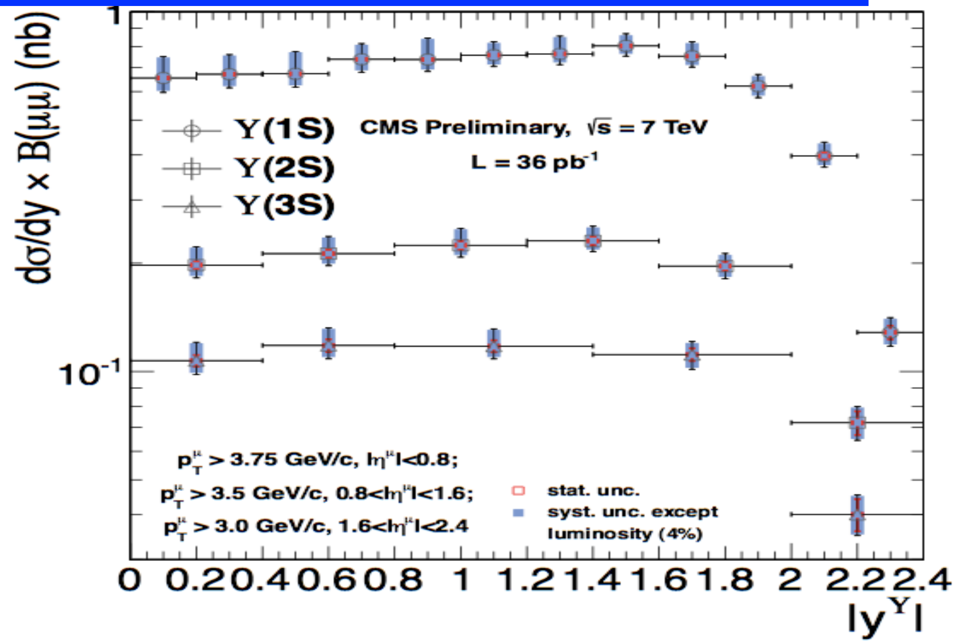
$$\sigma(pp \to \Upsilon(3S)X) \cdot \mathcal{B}(\Upsilon(3S) \to \mu^+\mu^-) = (1.11 \pm 0.02^{+0.13}_{-0.12} \pm 0.04)nb$$

- Cross-Section Ratios.
- Unknown polarization affects acceptance: up to 24% effects



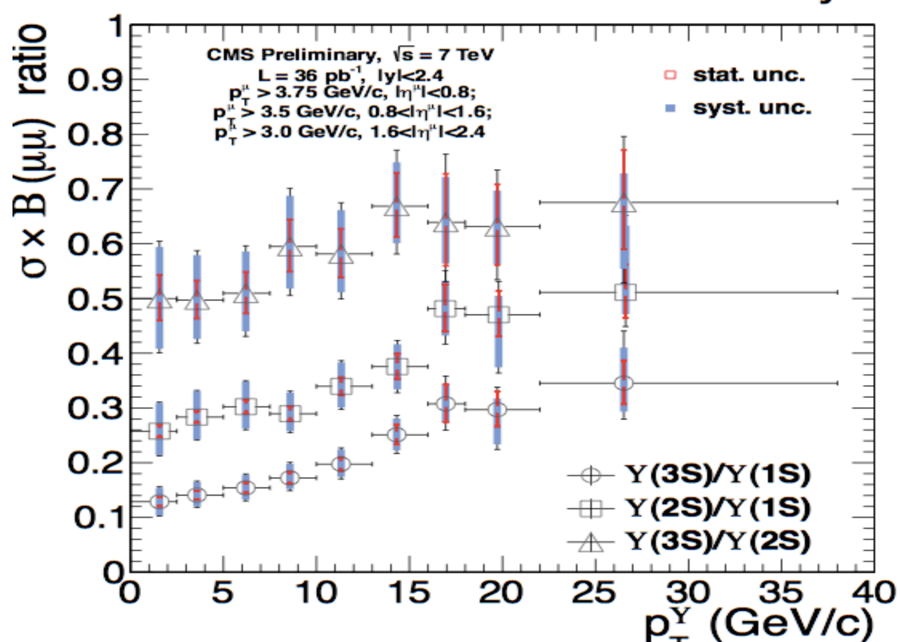
Fiducial Cross Section Results



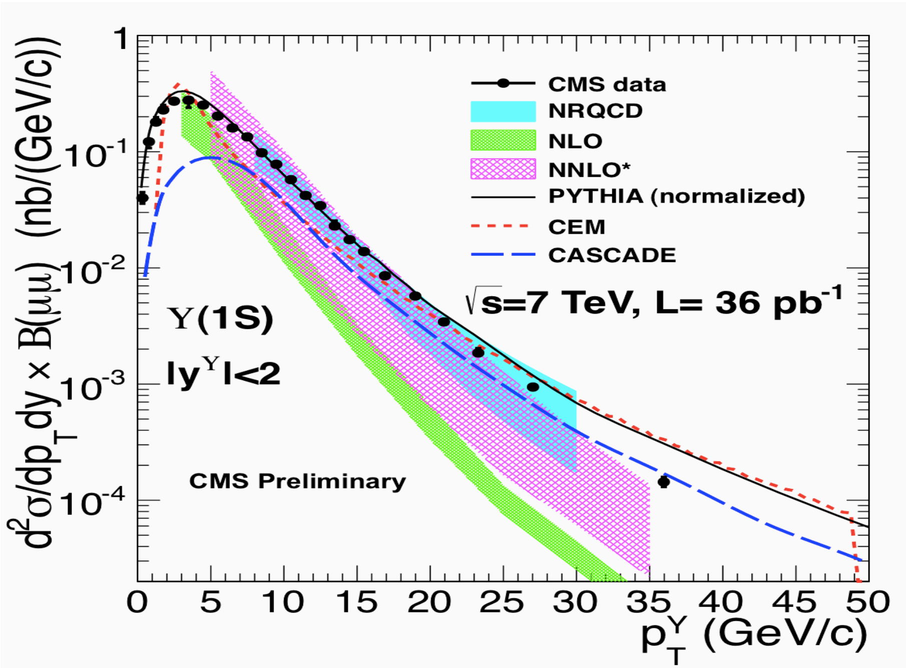


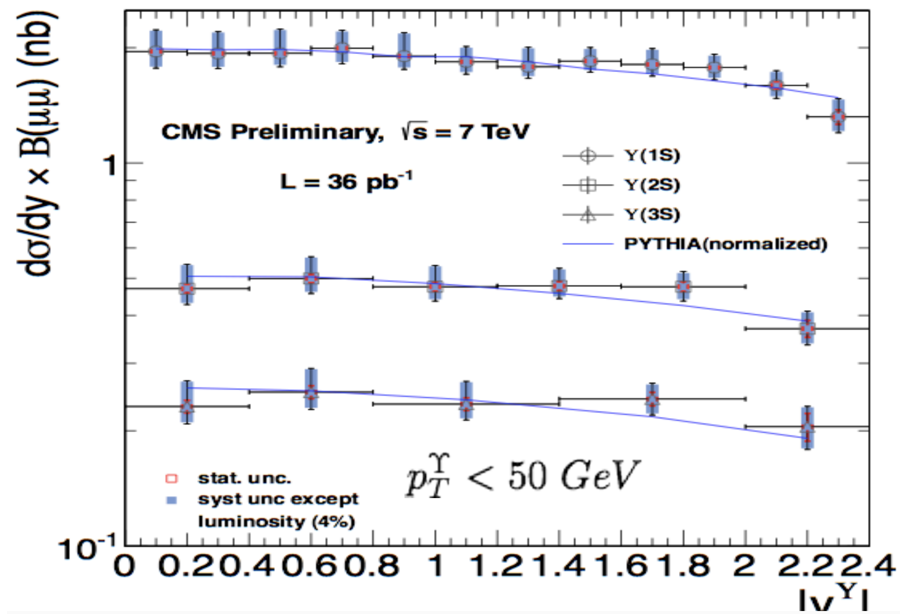
- Fiducial cross section not affected by acceptance & unknown polarization uncertainty

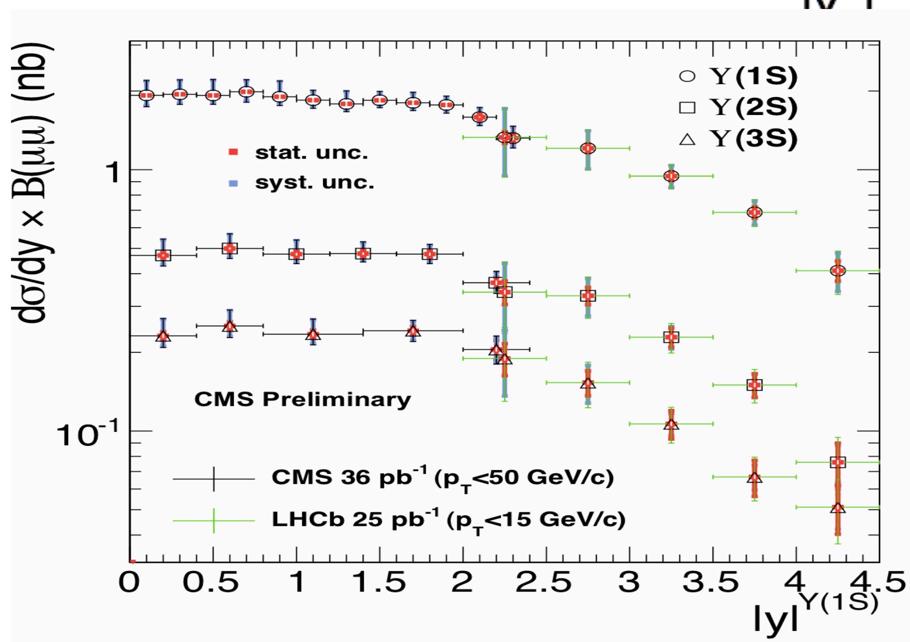
- Systematic uncertainty sources:
  - muon ID & trigger (4-10%).
  - Two muon efficiency correlation (4-10%)
  - Fit method, FSR.



Comparison to Theory and LHCb







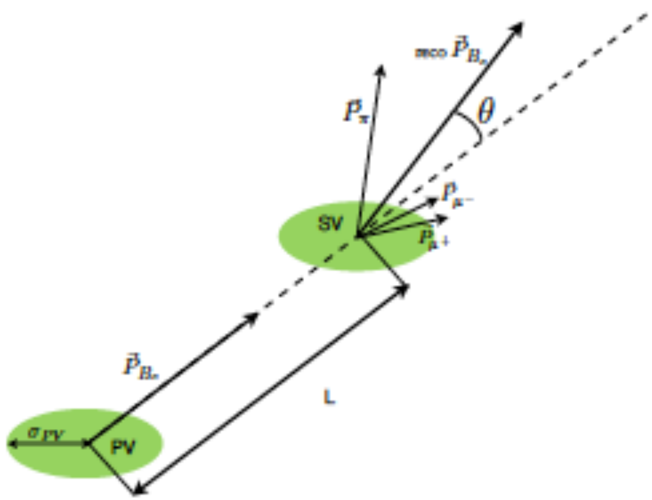
NRQCD gives best pT shape match to data

CMS and LHCb results complimentary in coverage and show good agreement in overlap

Observation of B_c via $J/\Psi\pi^+$ and $J/\Psi\pi^+\pi^-\pi^+$

- The "last" meson observed through its semileptonic decay at CDF
- The least understood meson due to
  - Low production rate
  - Short lifetime (naïve expectation—1/3 of B hadron)
- Properties not well measured—mass, lifetime
- A unique place to study heavy quark dynamics due to two different heavy quarks

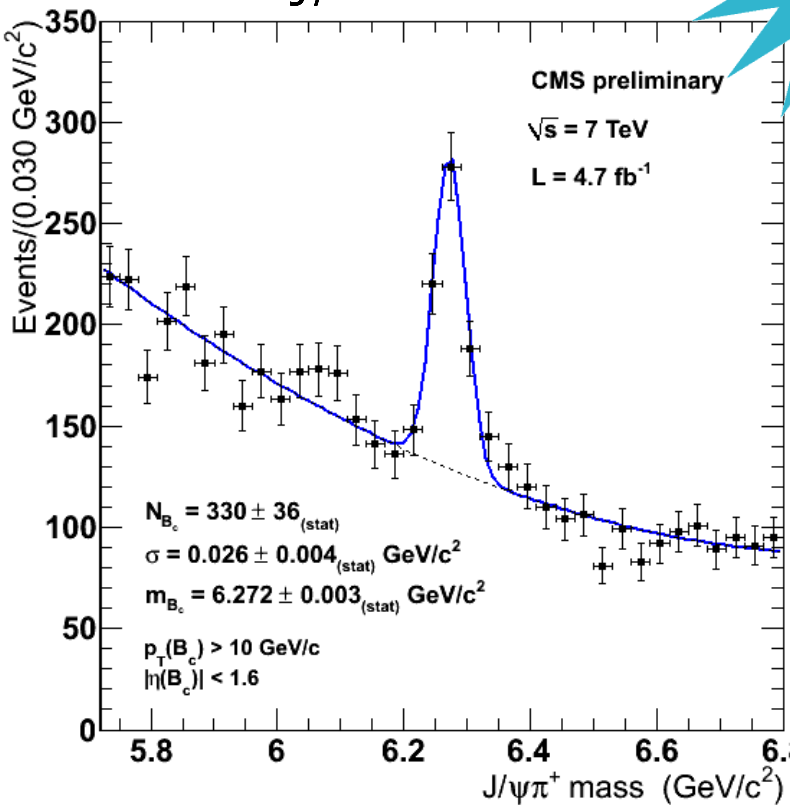
- Reconstructed channels: $J/\Psi\pi^+$, $J/\Psi\pi^+\pi^-\pi^+$
- Displaced J/Ψ trigger, constrain J/Ψ mass to its nominal mass



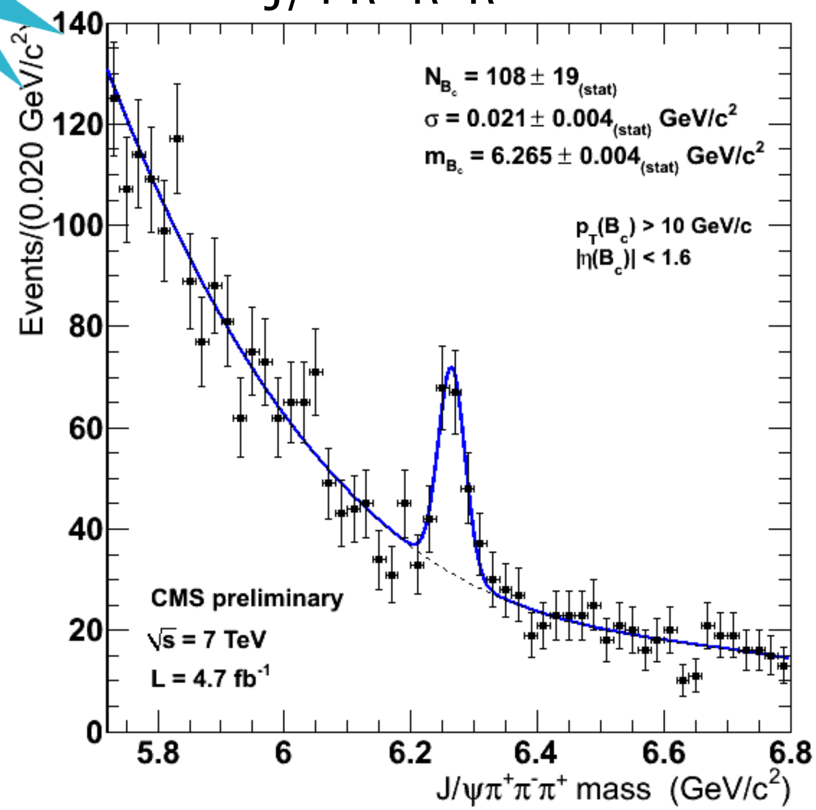
Observation of $B_c \rightarrow J/\Psi\pi^+$ and $J/\Psi\pi^+\pi^-\pi^+$

New!

$J/\Psi\pi^+$



$J/\Psi\pi^+\pi^-\pi^+$



Mass (B_c) = 6.272 ± 0.003(stat) GeV
N_{Bc}= 330 ± 36 (stat)
σ(Bc) = 26 ± 4 MeV

Mass (B_c) = 6.265 ± 0.004(stat) GeV
N_{Bc}= 108 ± 19 (stat)
σ(Bc) = 21 ± 4 MeV

Conclusions

- CMS is producing high quality results on heavy flavor physics.
- Presented results:
  - Measurement of the χ_{c2}/χ_{c1} production cross-section ratio up to unprecedented J/ψ p_T's with quite small uncertainties
  - Υ(ns) cross section measurement extended to p_T < 50 GeV
  - Observation of $B_c \rightarrow J/\Psi\pi^+$ and $J/\Psi\pi^+\pi^-\pi^+$

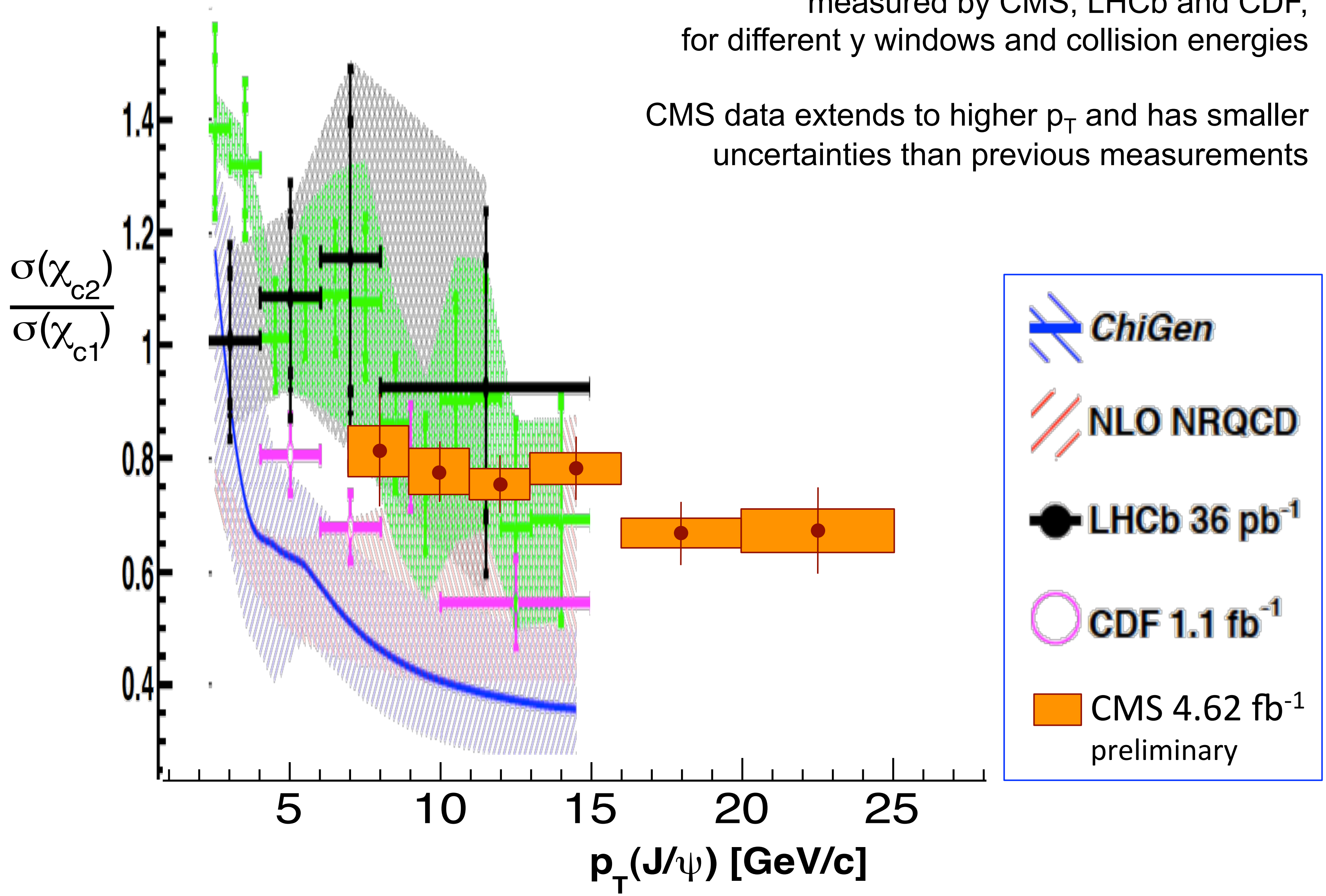
- More results to come from 2011 data. Analysis of 2012 data in progress. See other relevant CMS results at ICHEP 2012:
  - Valentin Knunz: Measurement of Υ(1S), Υ(2S) and Υ(3S) polarizations with the CMS experiment, 7 July, 14:30, TR6 - QCD, Jet, Parton Distribution
  - Keith Ulmer: Heavy Flavor Results from CMS, 6 July, 15:00, TR9+TR5+TR7

- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH

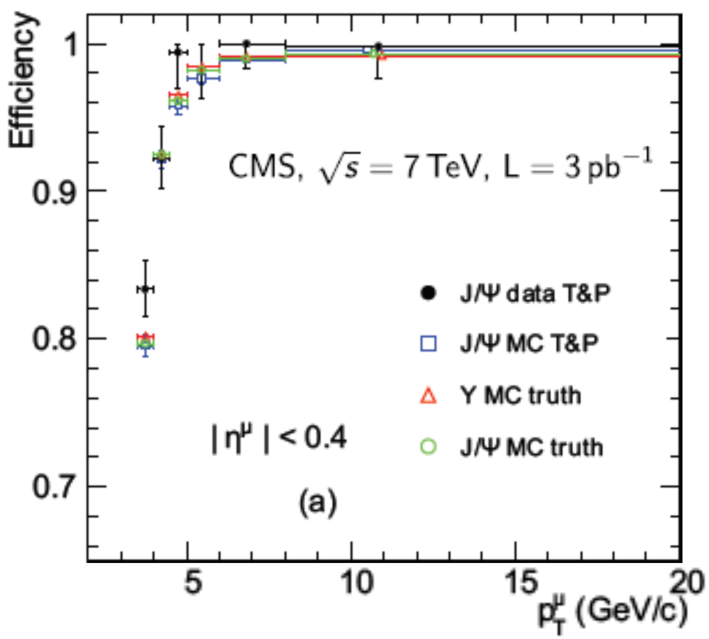
CMS vs. LHCb and CDF

χ_{c2} / χ_{c1} cross-section ratio vs. p_T measured by CMS, LHCb and CDF, for different y windows and collision energies

CMS data extends to higher p_T and has smaller uncertainties than previous measurements



Muon efficiencIES



- Use data-driven measurements of the muon efficiency ("tag-and-probe" method) on dedicated trigger streams
  - In events with a J/ψ candidate, ask for one well-identified muon ("tag")
  - The other muon ("probe") can pass or not pass the selection *S* under investigation
  - The fitted N_{pass-S}/N_{all} yield gives an unbiased estimate of the efficiency ε_S

- Limitation of the method: assumes efficiency factorization, does not take into account correlations due e.g. to trigger requirements

} (Small) MC corrections required

Converted Photon