Measurements of Heavy Flavour Production at ATLAS and CMS

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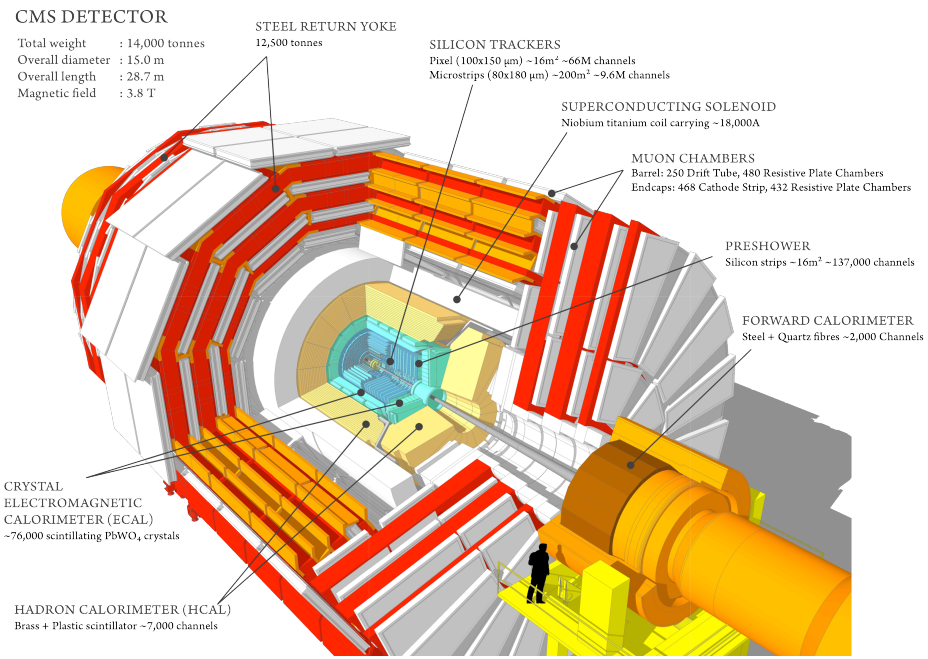
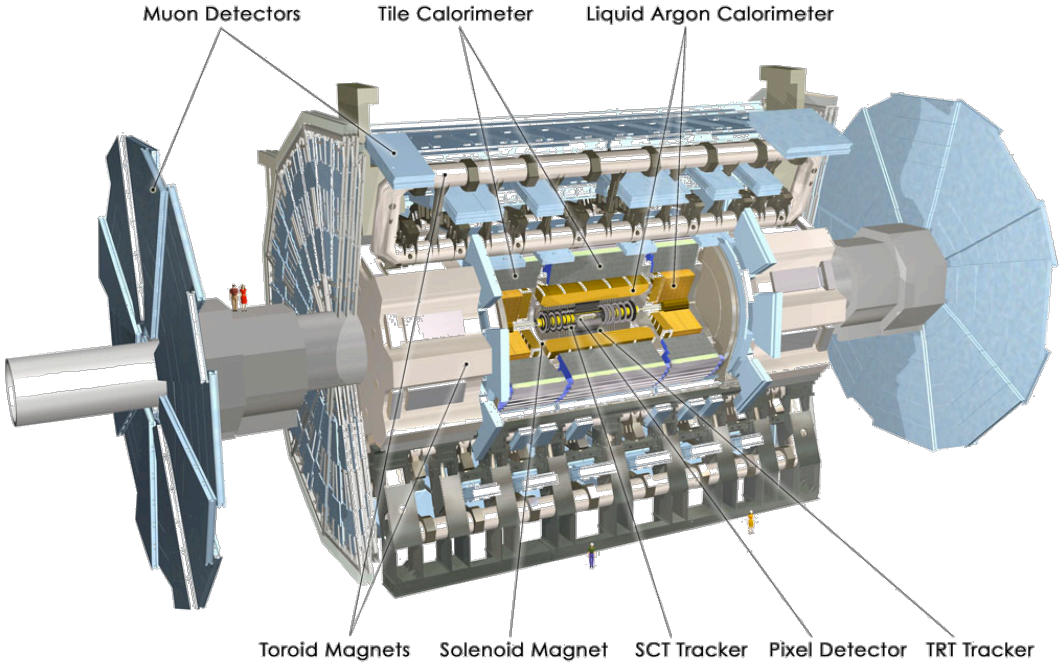
Introduction

- Heavy flavour production is an important test of perturbative QCD predictions at leading and next-to-leading orders.
- Production cross section measurements are essential for CP violation and B-decay studies, like precise SM measurements and BSM searches, as well as for understanding of the background composition for many other analyses.
- In this talk: beauty production, prompt and non-prompt charmonium production, J/Ψ+W, χ_c and χ_b relative production cross section measurements; all seeded by gg-fusion.
- More details on heavy flavour physics in talk by Ilse Kratschmer at the same session (link).

LHC ATLAS and CMS detectors and *pp* data collection in 2010—2012





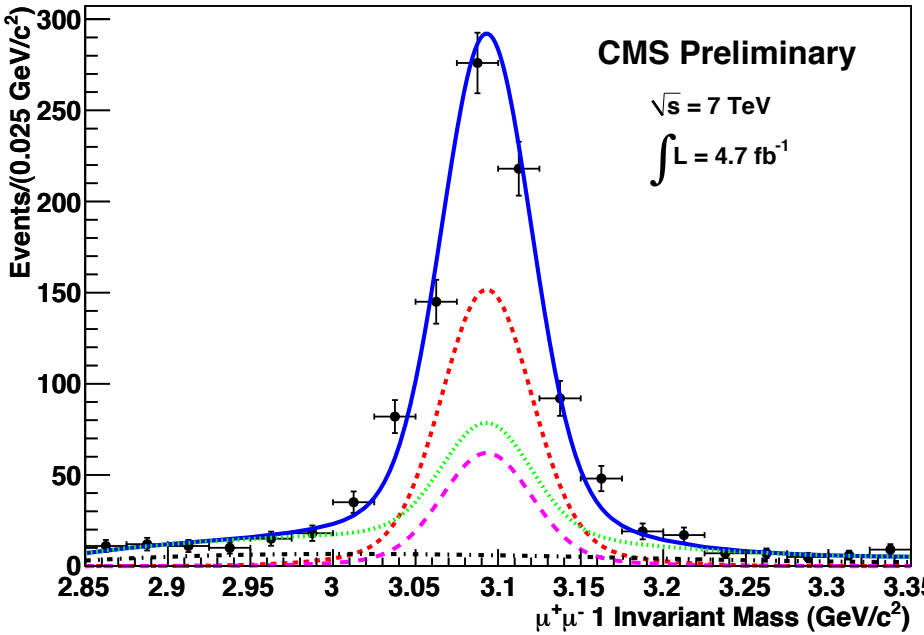
- Data taking for the analyses covered in this talk mostly starts with single and di-muon triggers, provided by the muon detector subsystems.
- Precise tracking allows separation of decays displaced from the production vertex → separation of prompt and non-prompt production.

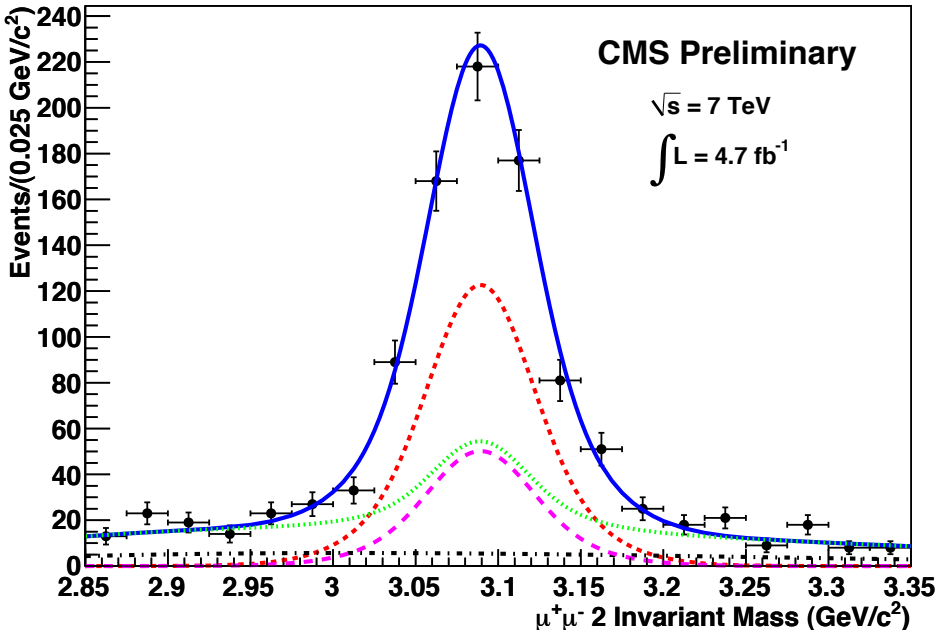
Year	Integrated luminosity
2010, 7 TeV	> 40 pb^{-1}
2011, 7 TeV	~ 5 fb^{-1}
2012, 8 TeV	~ 23 fb^{-1}

ATLAS and CMS heavy flavour results

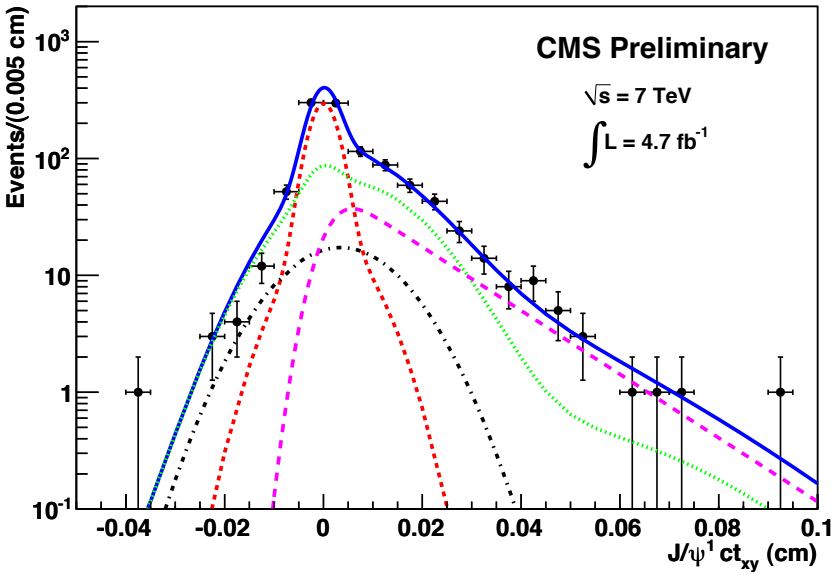
- Prompt and non-prompt J/Ψ and Ψ(2S) production:
  - ATLAS: Nucl. Phys. B 850 (2012) 387; ATLAS-CONF-2013-094
  - CMS: JHEP 02 (2012) 11
- Inclusive B-hadrons production:
  - ATLAS: Nucl. Phys. B 864 (2012) 341
  - CMS: JHEP 06 (2012) 110
- Λ_b production:
  - ATLAS: arXiv: 1207.2284 (observation)
  - CMS: Phys. Lett. B 714 (2012) 136
- Inclusive muons from heavy flavours:
  - ATLAS: Phys. Lett. B 707 (2012) 438
  - CMS: JHEP 1103 (2011) 090, JHEP 06 (2012) 110
- **Recent results covered in this talk:**
- Prompt double J/ψ production (CMS)
- J/ψ + W associated production (ATLAS)
- χ_c, χ_b, and X(3872) measurements (ATLAS and CMS)
- B^+ meson absolute production cross section (ATLAS)
- $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$ production (ATLAS)
- B_c/B^+ relative production cross section (CMS)

Prompt double J/Ψ production (CMS)

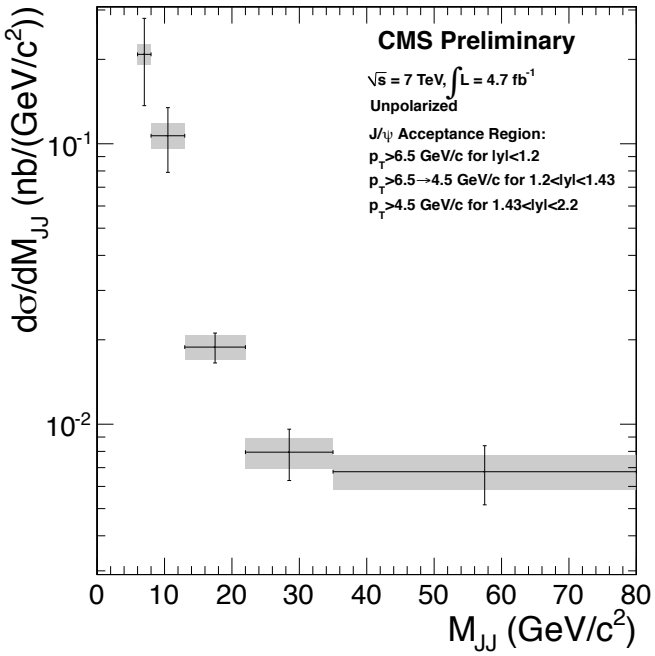


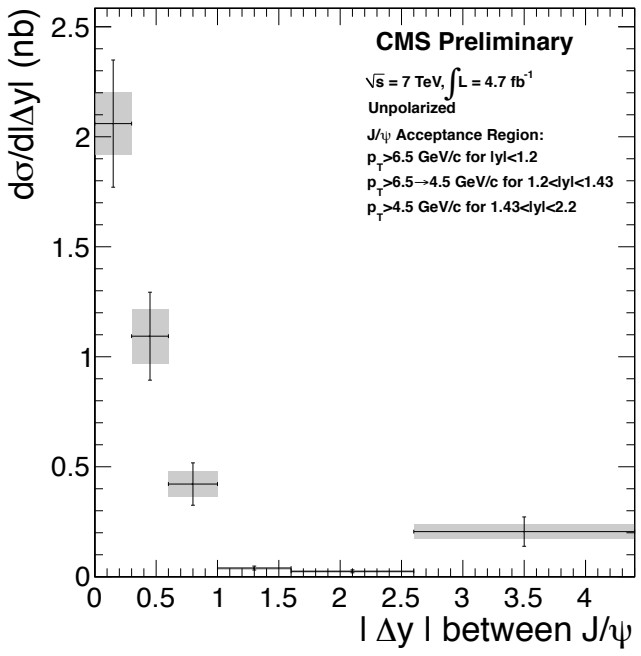


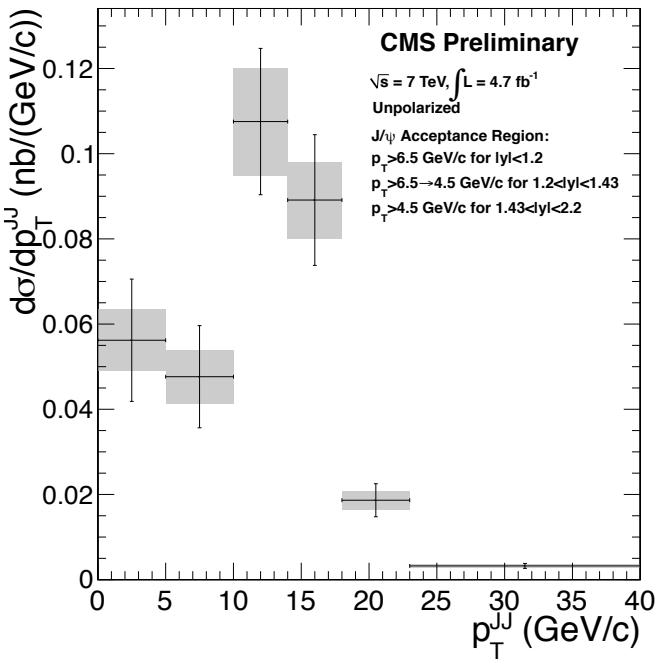
- CMS-PAS-BPH-11-021
- Multi-parton scattering → difficult to address in QCD, experimental input in essential.
- Double prompt J/ψ yield is 443 ± 23 events in 4.7 fb^{-1} of 7 TeV.
- Signal – red; non-prompt BG – purple; all combinatorics – green; pure comb. – black.



Prompt double J/Ψ production, cont.





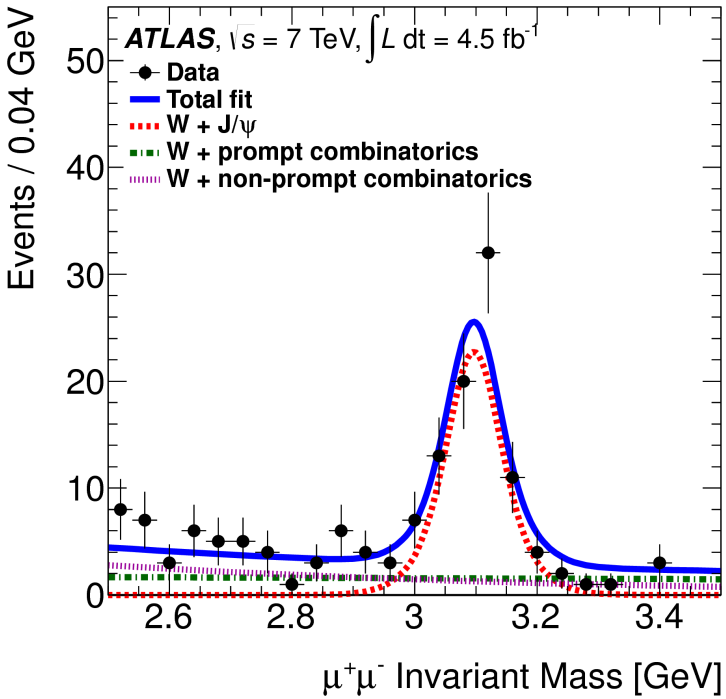


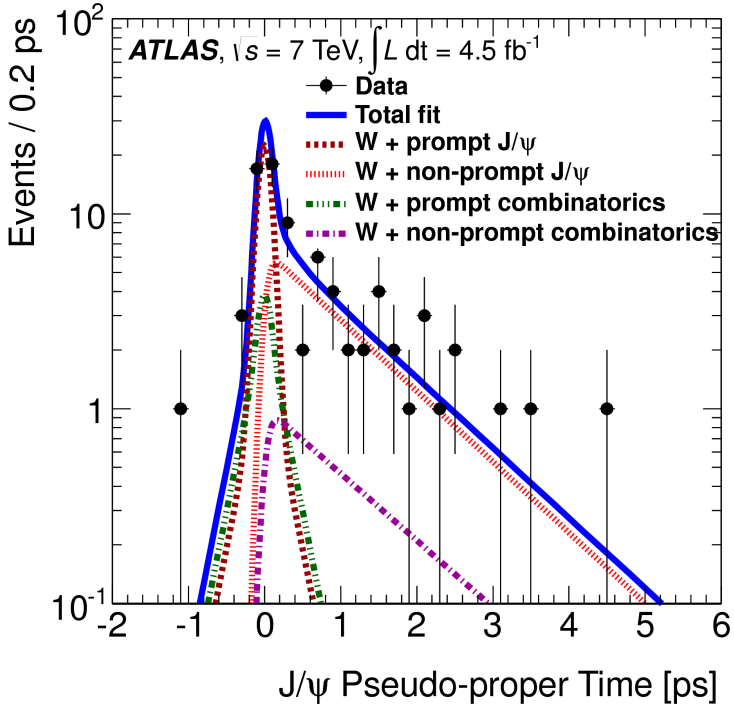
- The differential cross section is measured in bins of the double J/ψ invariant mass, the absolute difference in rapidity of the two J/ψ mesons, and the transverse momentum of the double J/ψ system.
- The total cross section assuming unpolarized prompt double J/ψ production

$$\sigma = 1.49 \pm 0.07_{stat.} \pm 0.014_{syst.} \text{ nb}.$$

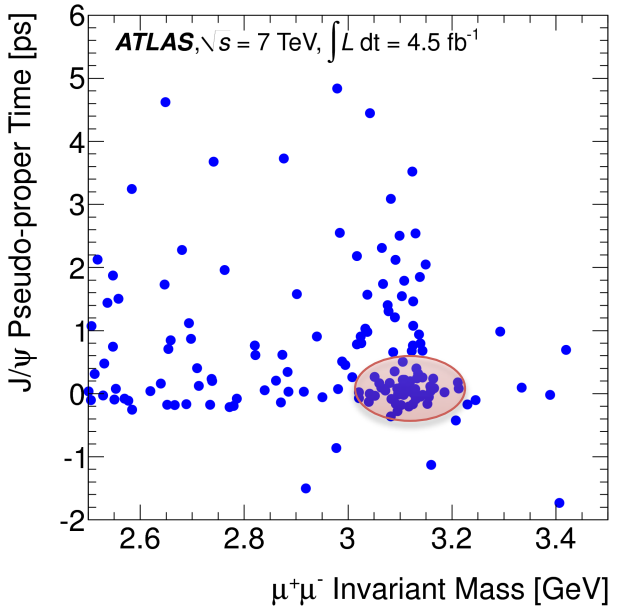
- Evidence of excess at $|\Delta y|>2.6$ which is predicted to have a large Double Parton Scattering contribution.
- Data-driven method for acceptance and efficiency to minimize the model dependence.

J/Ψ + W associated production (ATLAS)

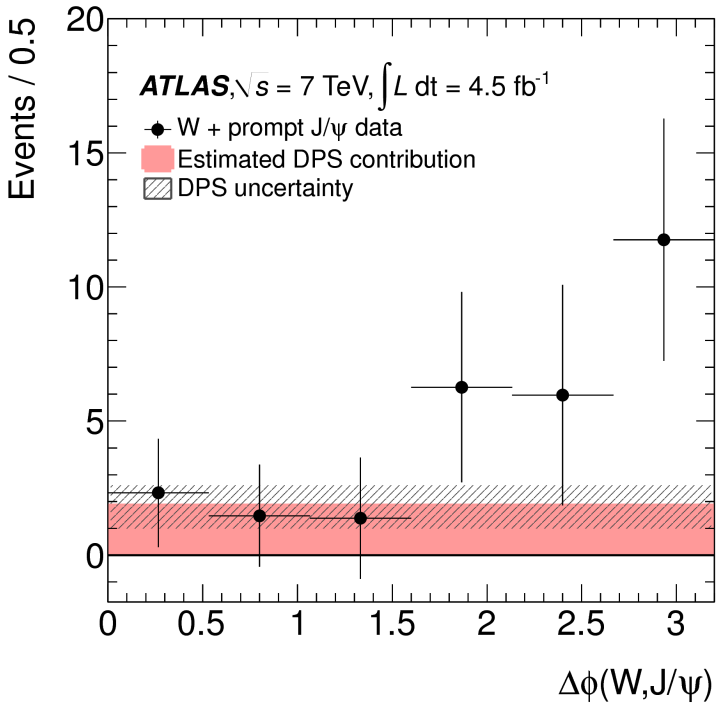


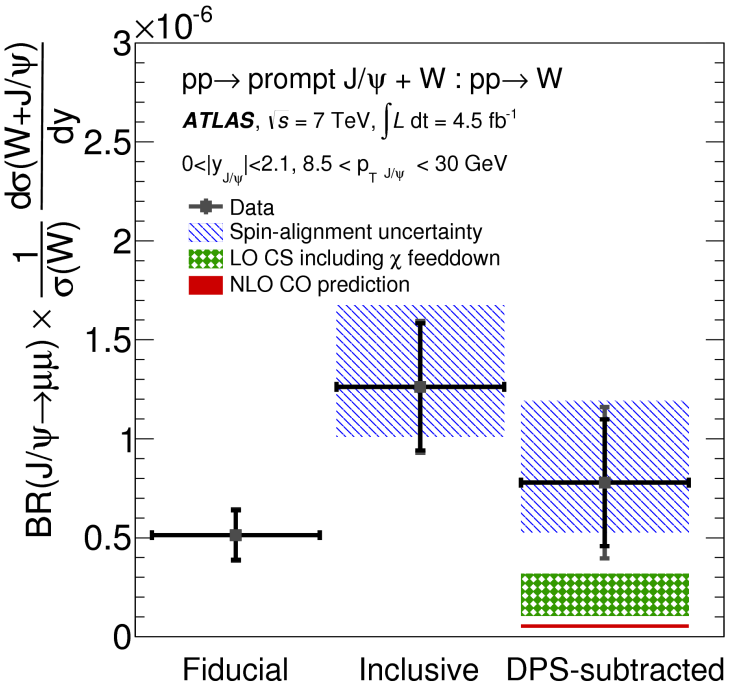


- JHEP 04 (2014) 172; first observation
- Yield of $27.4^{+7.5}_{-6.5}$ events with 4.5 fb^{-1} of 7 TeV. Significance > 5σ.
- Important test to distinguish between Color Singlet and Color Octet QCD predictions for the $q\bar{q}$ production.
- The production rate as a ratio to the inclusive W production rate is measured, and the double parton scattering contribution to the cross section is estimated.

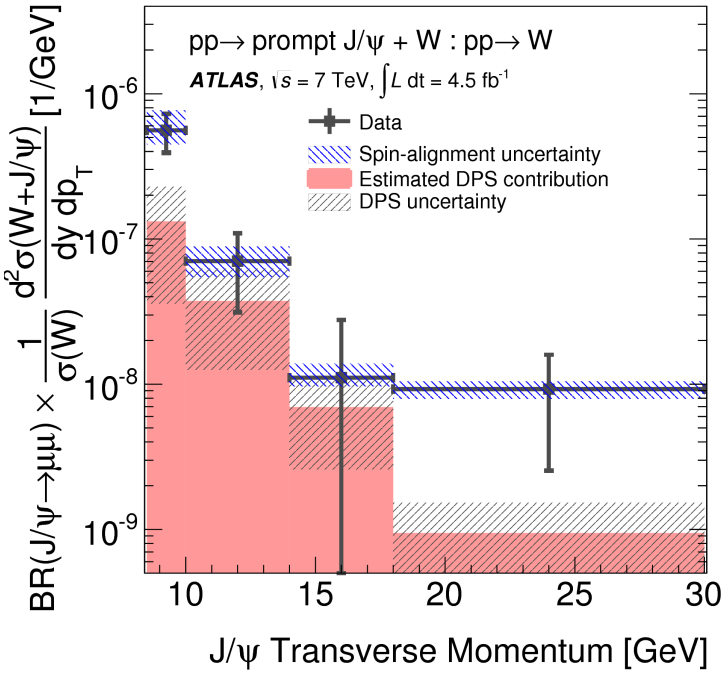


J/ψ + W, cont.

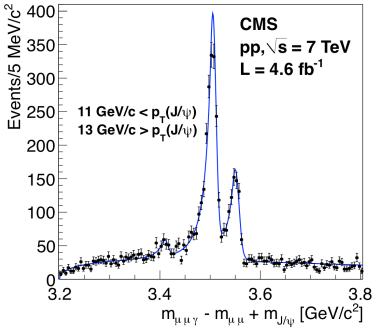


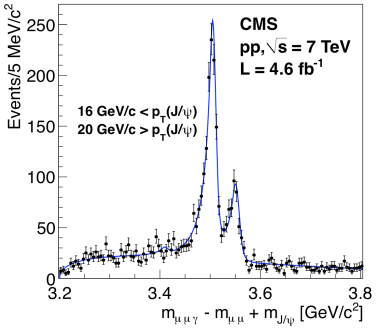


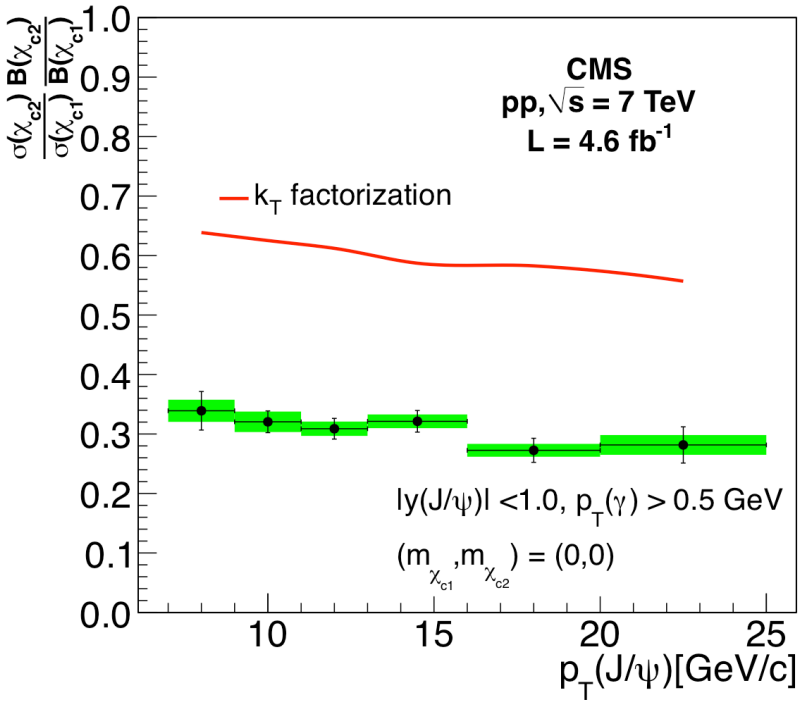
- Δφ of J/ψ and W estimations from J/ψ cross section measurements confirmed expected DPS contributions flat in Δφ; → both DPS and SPS in data
- $R_{fid}(\psi) = (51 \pm 13_{stat.} \pm 4_{syst.}) \times 10^{-8}$
- $R_{incl}(\psi) = (126 \pm 39_{stat.} \pm 9_{syst.}{}^{+41}_{-25}) \times 10^{-8}$
- $R_{DPS\_sub}(\psi) = (78 \pm 32_{stat.} \pm 22_{syst.}{}^{+41}_{-25}) \times 10^{-8}$
- Third error – J/ψ spin alignment
- Data suggests that SPS is the dominant at low J/ψ p_T

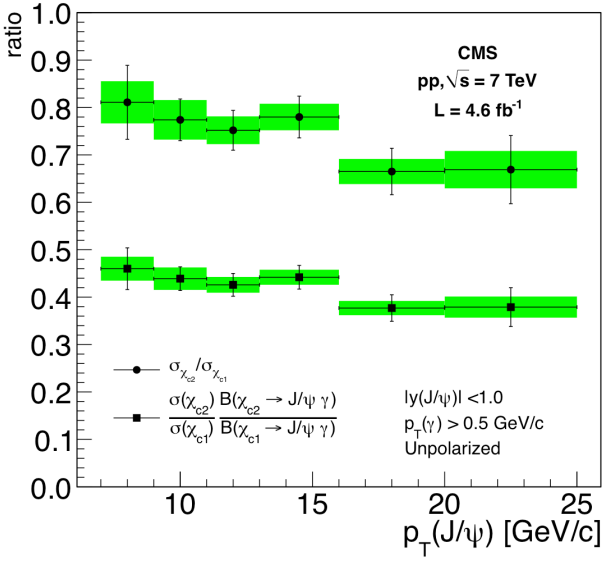


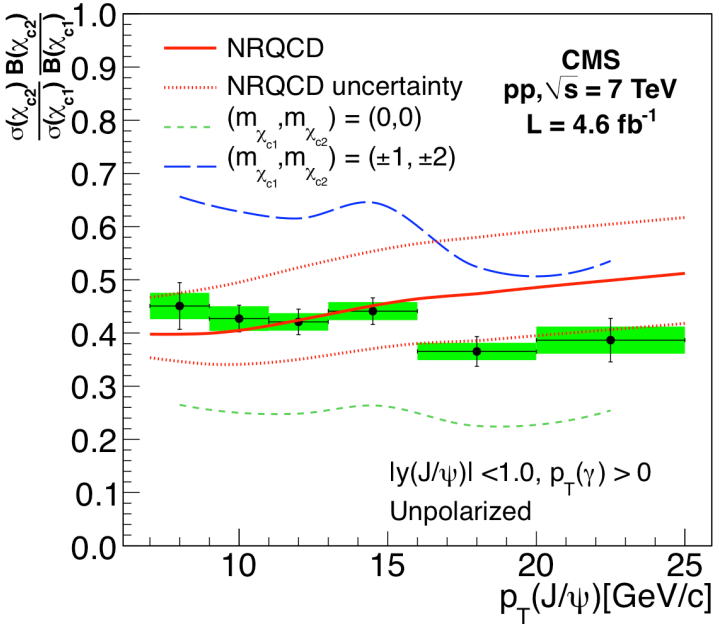
$\chi_{c1,\,c2}$ production, CMS





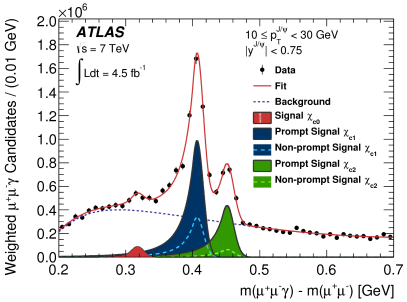


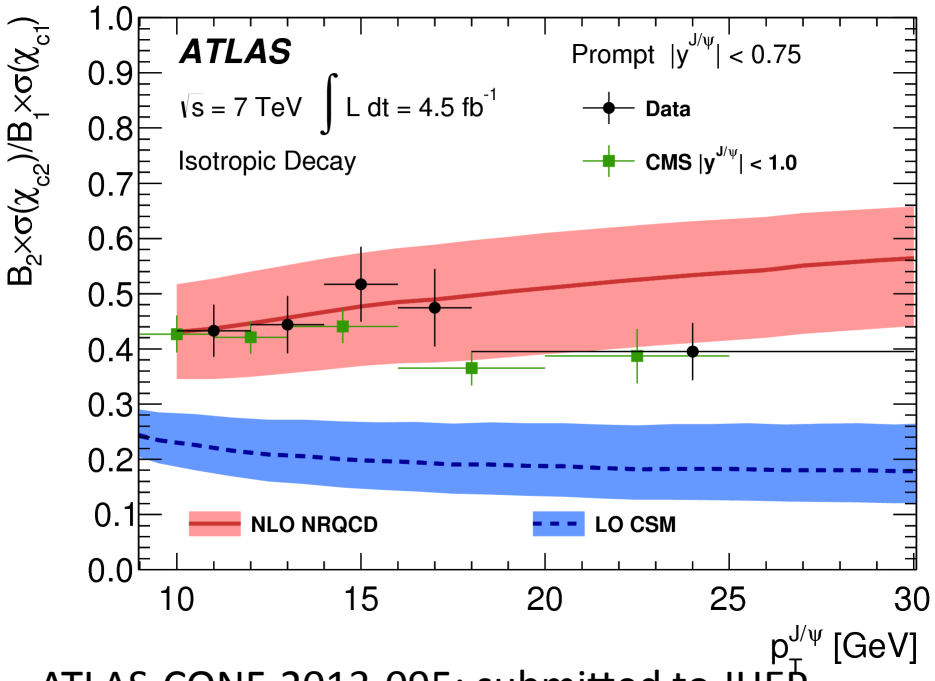


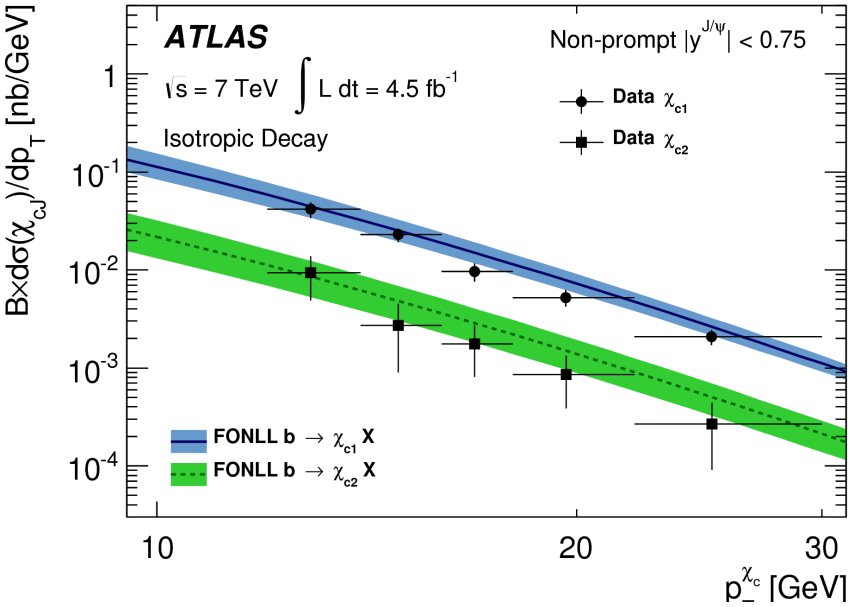


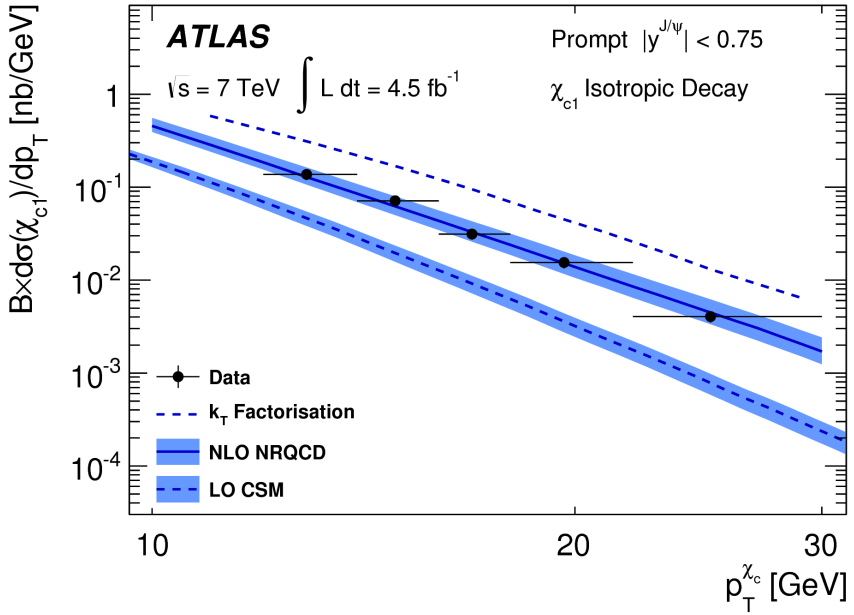
- Eur. Phys. J. C 72 (2012) 2251
- $\chi_c \rightarrow J/\psi\ \gamma$ ($\gamma \rightarrow e^+e^-$)
- Compatible with NRQCD, not with k_T factorization
- Compatible with ATLAS (next slide)

$\chi_{c1,\,c2}$ production, ATLAS



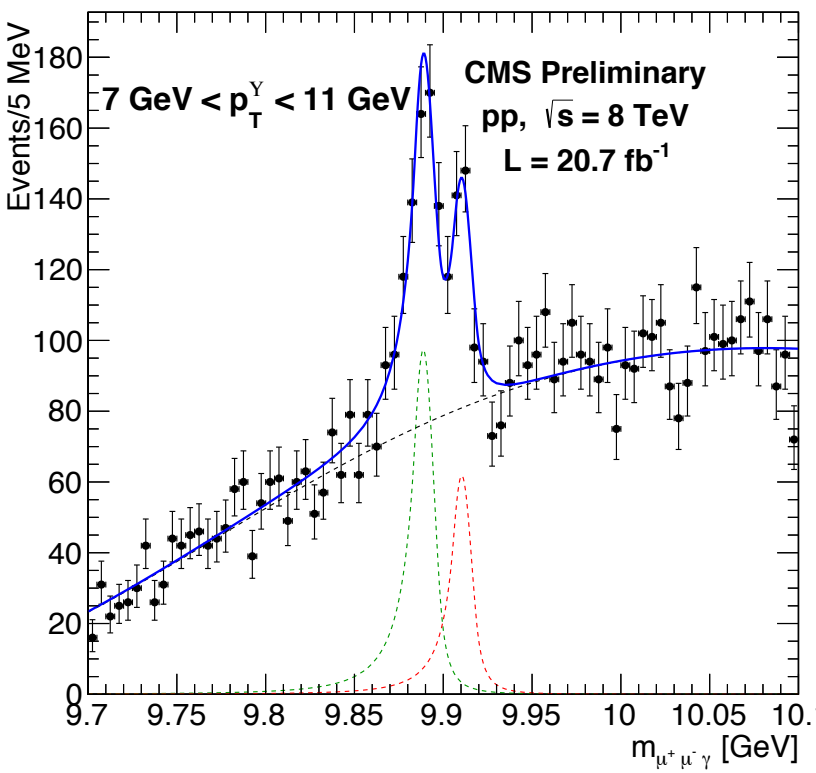


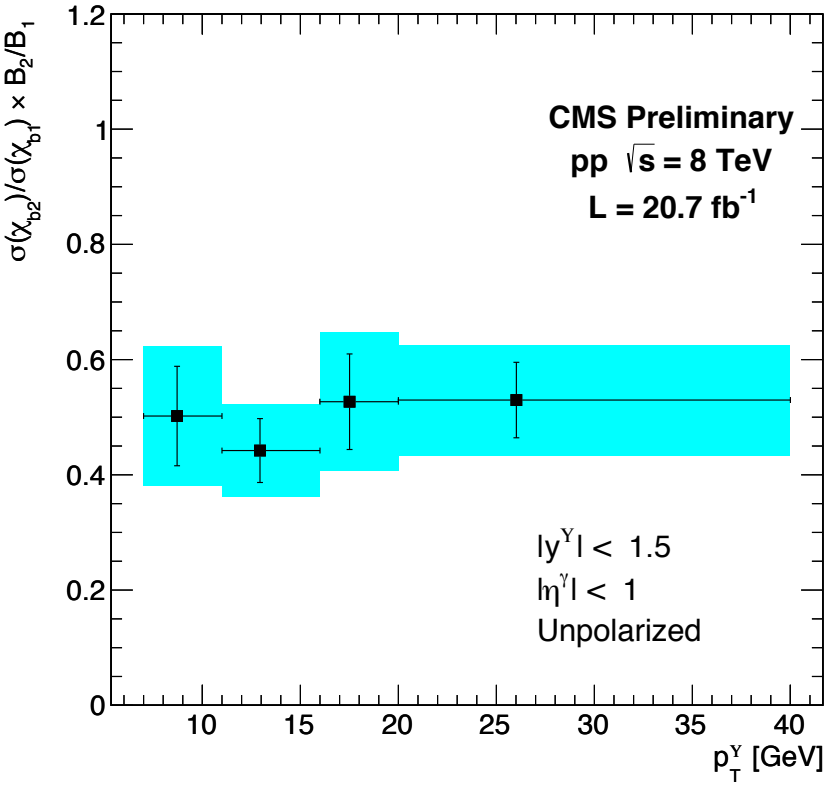




- ATLAS-CONF-2013-095; submitted to JHEP
- $\chi_c \rightarrow J/\psi\ \gamma$ ($\gamma \rightarrow e^+e^-$)
- Non−prompt $\chi_{c1,c2}$ compatible with FONLL.
- Prompt $\chi_{c1,c2}$ compatible with NLO NRQCD, but not with k_T factorization and LO CSM.
- Ratio of prompt χ_{c2}/χ_{c1} compared to CMS.

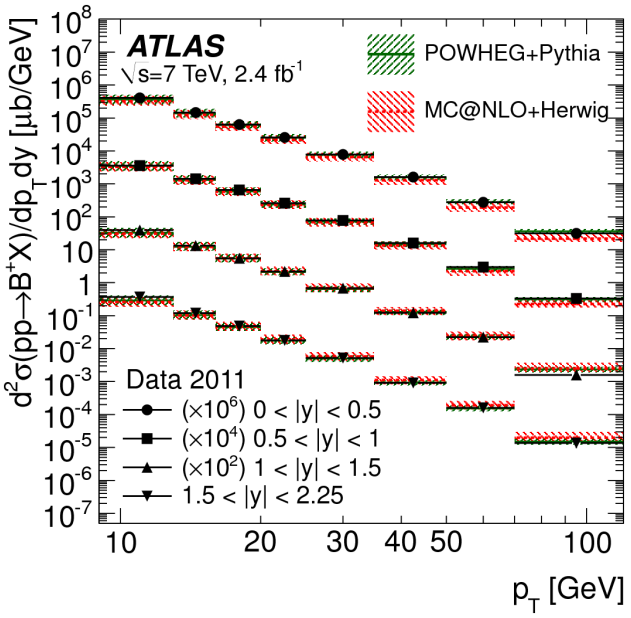
χ_{b2}/χ_{b1} relative production cross section (CMS)

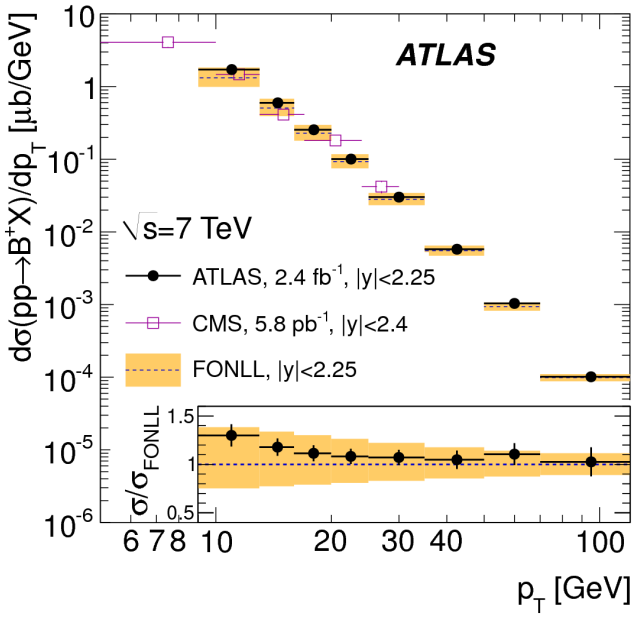


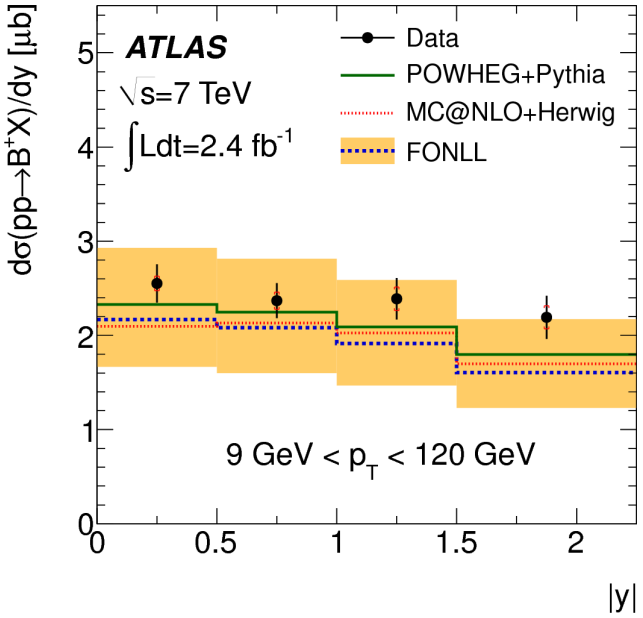


- CMS-PAS-BPH-13-005
- 20.7 fb^{-1}, 8 TeV
- $\chi_b(2P) \rightarrow \Upsilon(1S)\,\gamma$
- 4 p_T bins, $7<p_T(\chi_b)<40$ GeV, $|\eta(\gamma)|<1.0$, $|y(\Upsilon)|<1.5$
- The measured cross-section ratio is around 0.9, with no significant dependence on $p_T(\Upsilon)$

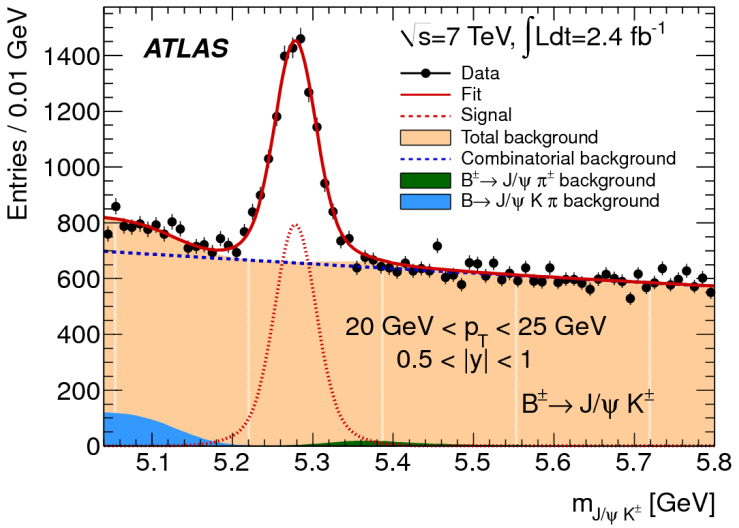
$B^{\pm}$ production cross section, ATLAS



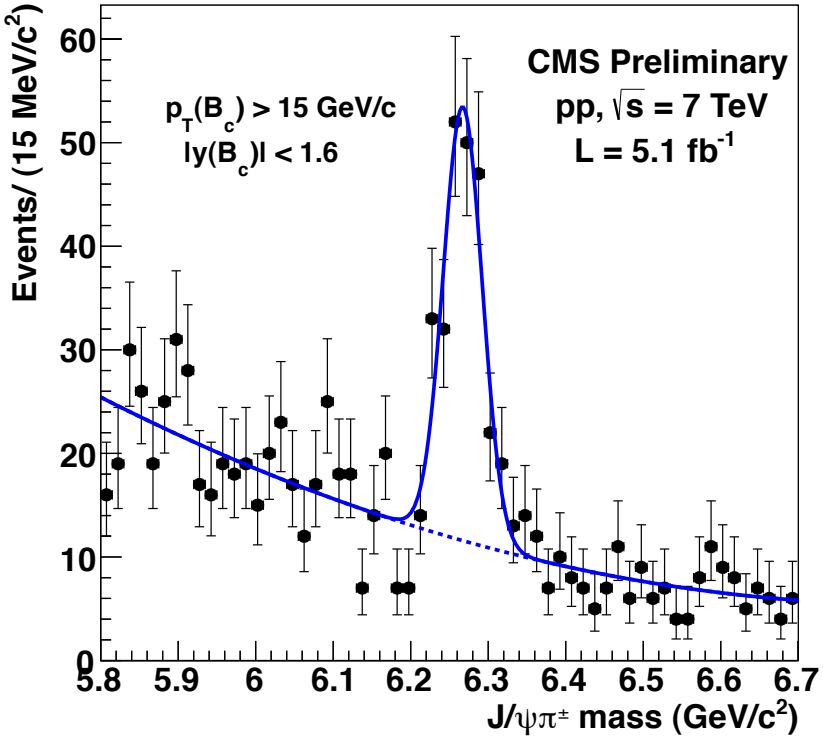


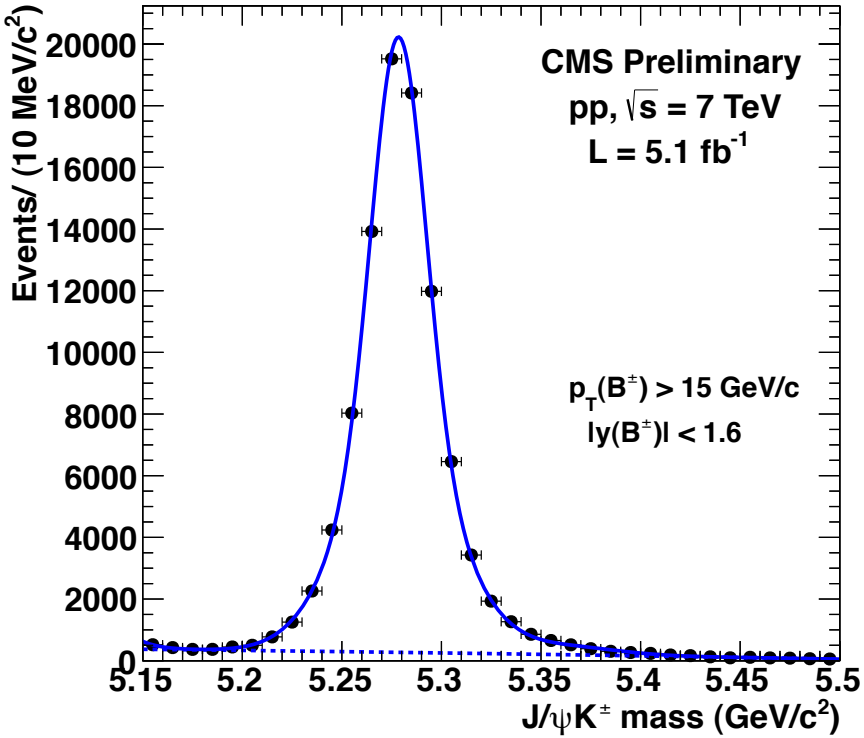


- JHEP 10 (2013) 042
- $B^{\pm} \rightarrow J/\Psi\ K^{\pm}$
- 2.4 fb^{-1}, 7 TeV
- Compared to:
  - POWHEG+Pythia, agreement
  - MC@NLO+Herwig, small discrepancies
  - FONLL, good agreement



B_c/B^+ production cross section, CMS

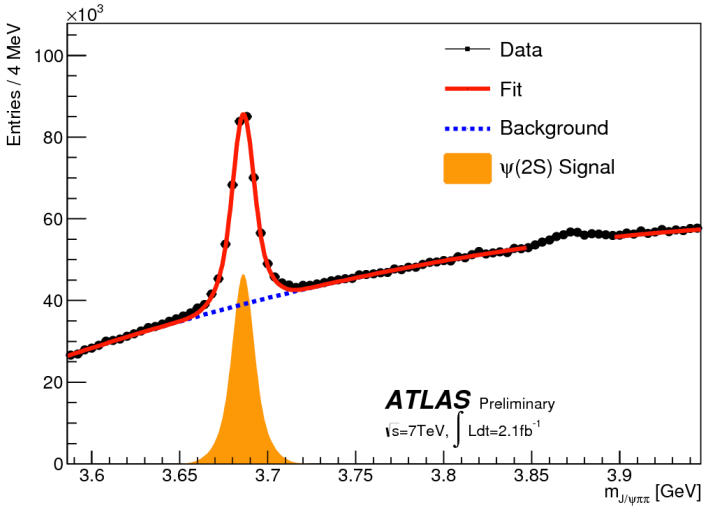


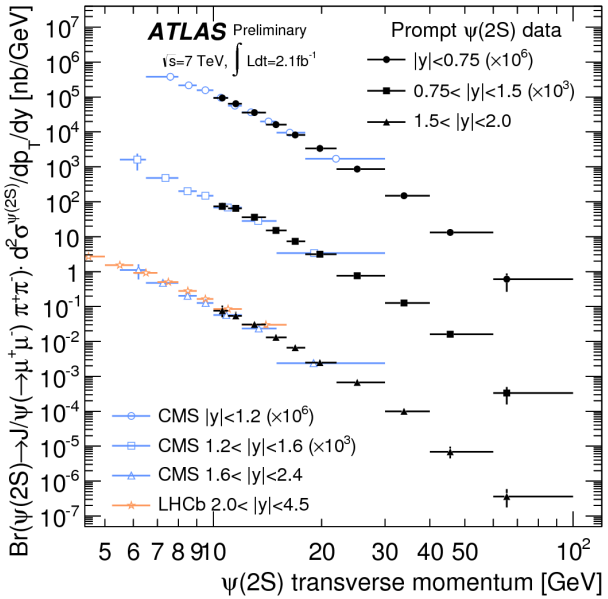


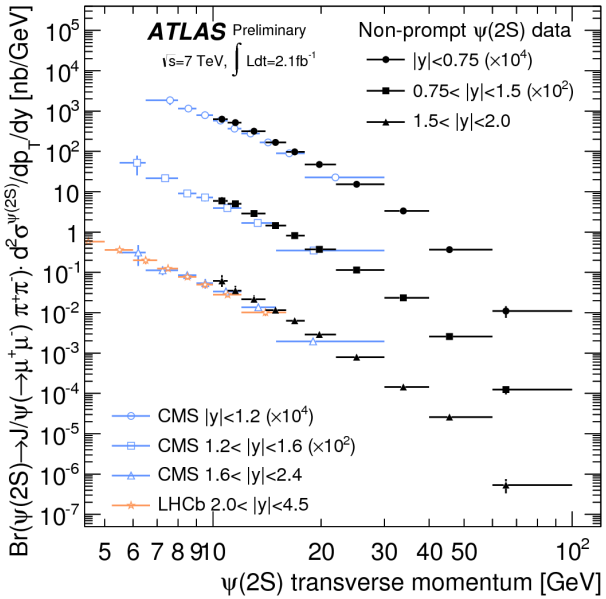
- CMS-PAS-BPH-12-011
- $p_T(B_c)>15$ GeV, $|y(B_c)|< 1.6$
- Ratio measured:

$$[\sigma(B^{\pm}_c)\times Br(B^{\pm}_c \rightarrow J/\Psi\pi^{\pm})]/[\sigma(B^{\pm})\times Br(Bc \rightarrow J/\Psi K^{\pm})] = [\ 0.48 \pm 0.05_{stat.} \pm 0.04_{syst.}\ ^{+0.05}_{-0.03}(\tau_{Bc})\ ] \times 10^{-2}$$

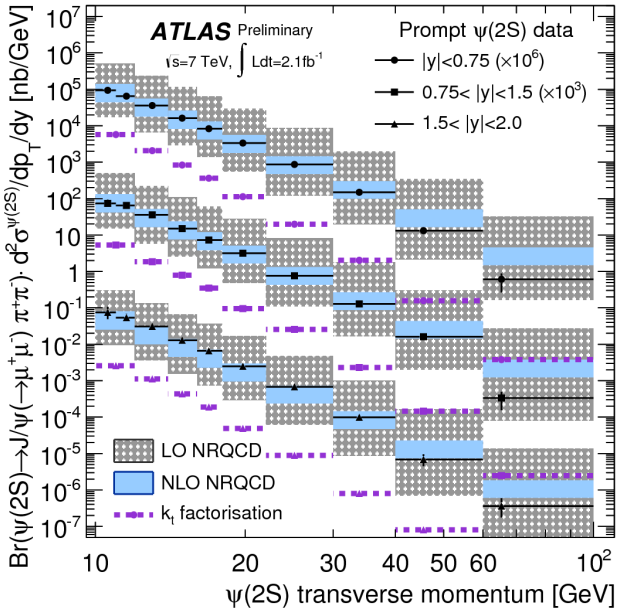
ψ(2S)→J/ψπ⁺π⁻ production cross section, ATLAS

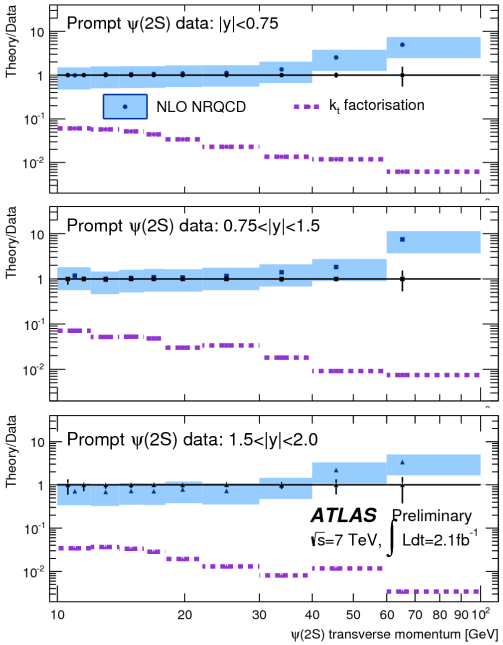




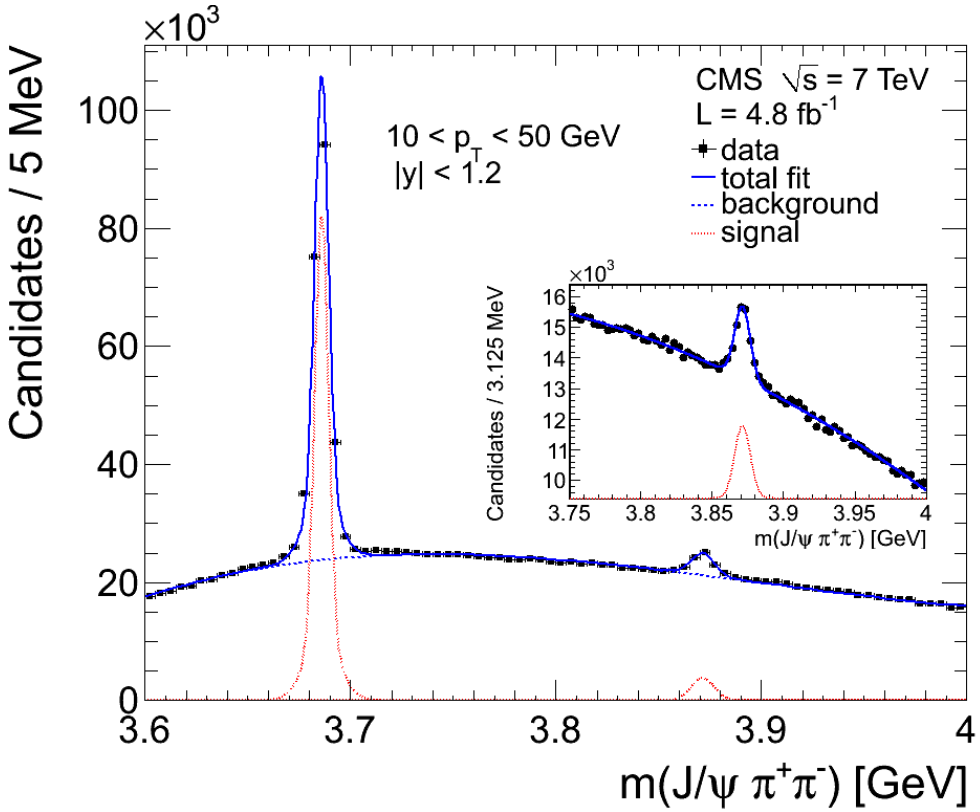


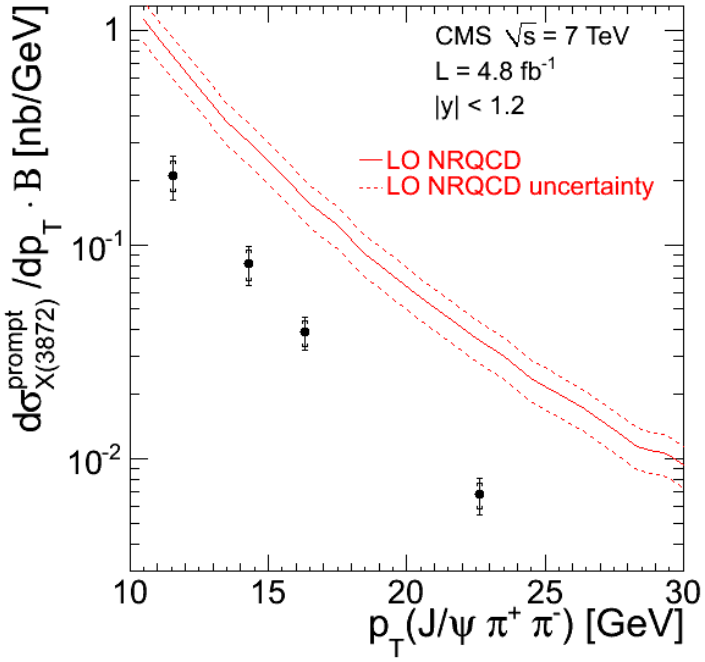
- ATLAS-CONF-2013-094
- 2.1 fb^{-1} at 7 TeV. Prompt and non-prompt.
- p_T 10—100 GeV; |y|<2.0
- Compared to LHCb and CMS.

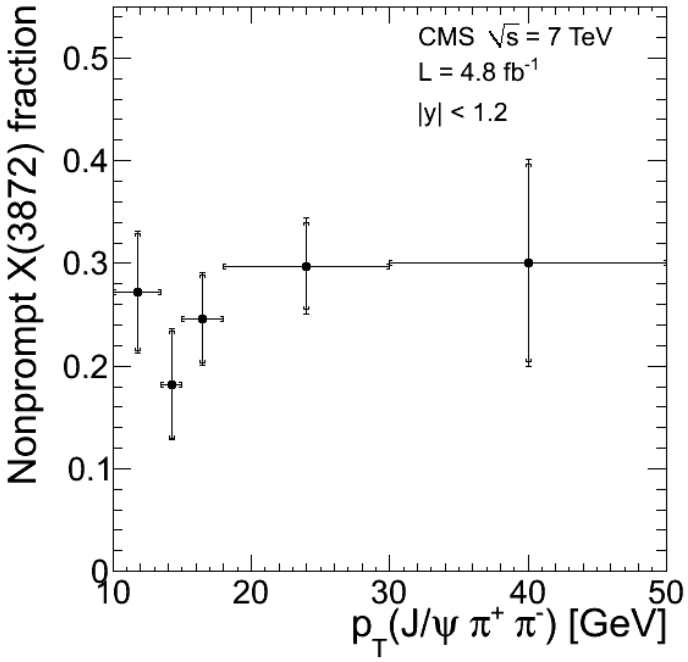




X(3872), CMS







- JHEP 04 (2013) 154
- Tetratuark vs. hadronic molecule
- Assuming $J^{PC}=1^{++}$; NRQCD above data; no significant p_T dependence

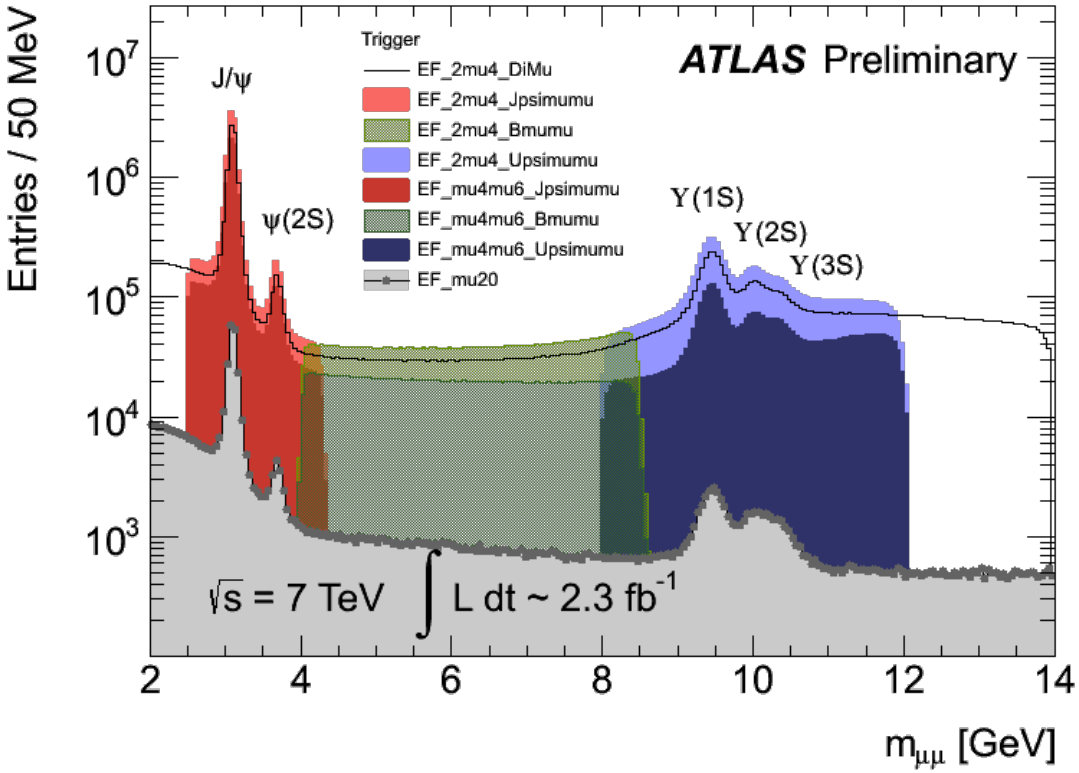
Conclusions

- LHC and ATLAS both made many good measurements of heavy flavour production.
- Reasonable agreement with perturbative QCD models in most cases.
- Many precise analysis ongoing, more results to come soon!

BACKUP

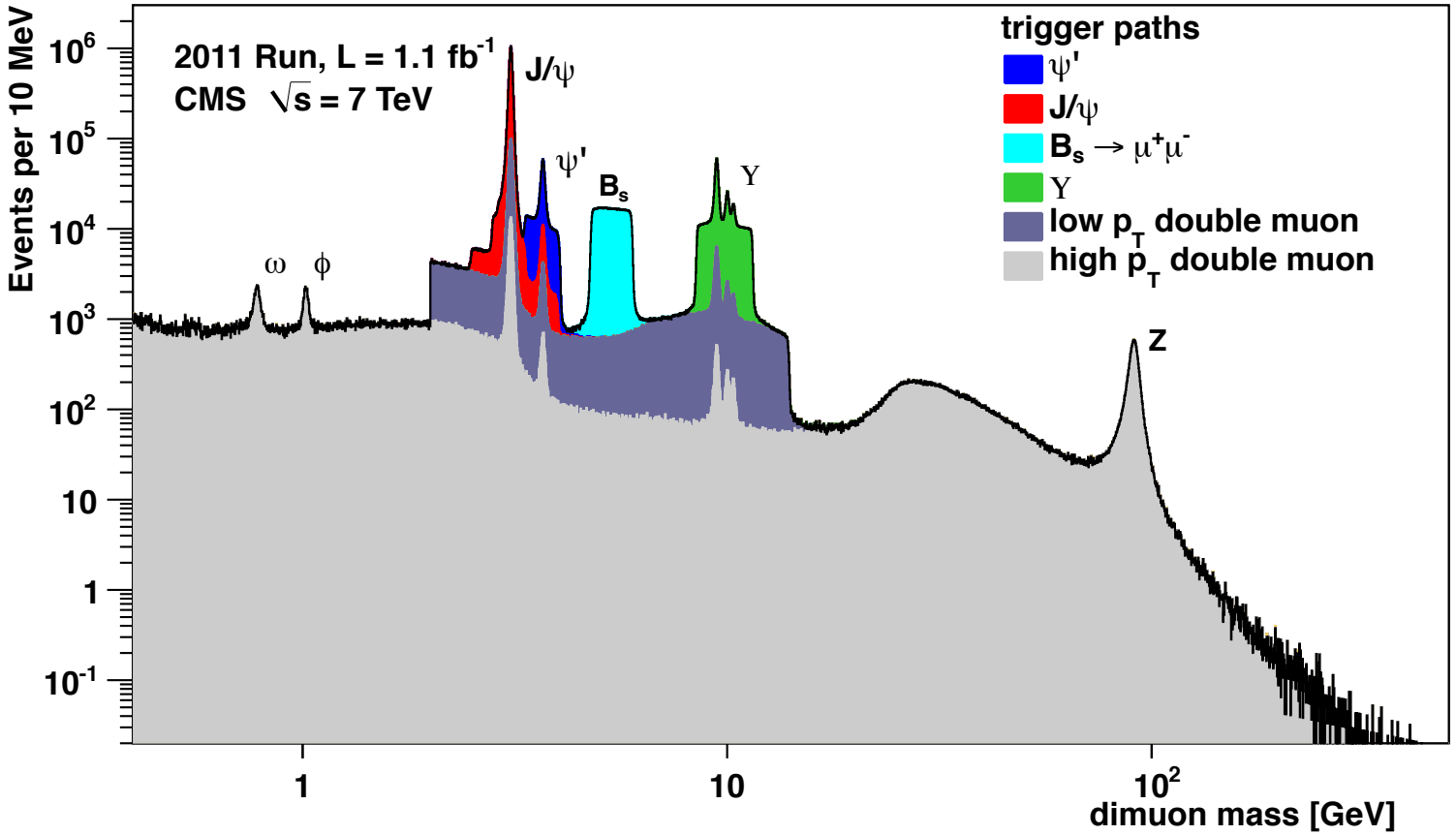
B-trigger at ATLAS

- B-physics starts with single or di-muon triggers with various thresholds:
  - $p_T(\mu) > 6$ GeV
  - $p_T(\mu) > 18$ GeV
  - $p_T(\mu_1) > 4$ GeV & $p_T(\mu_2) > 4$ GeV
  - $p_T(\mu_1) > 6$ GeV & $p_T(\mu_2) > 4$ GeV
  - $p_T(\mu_1) > 6$ GeV & $p_T(\mu_2) > 6$ GeV

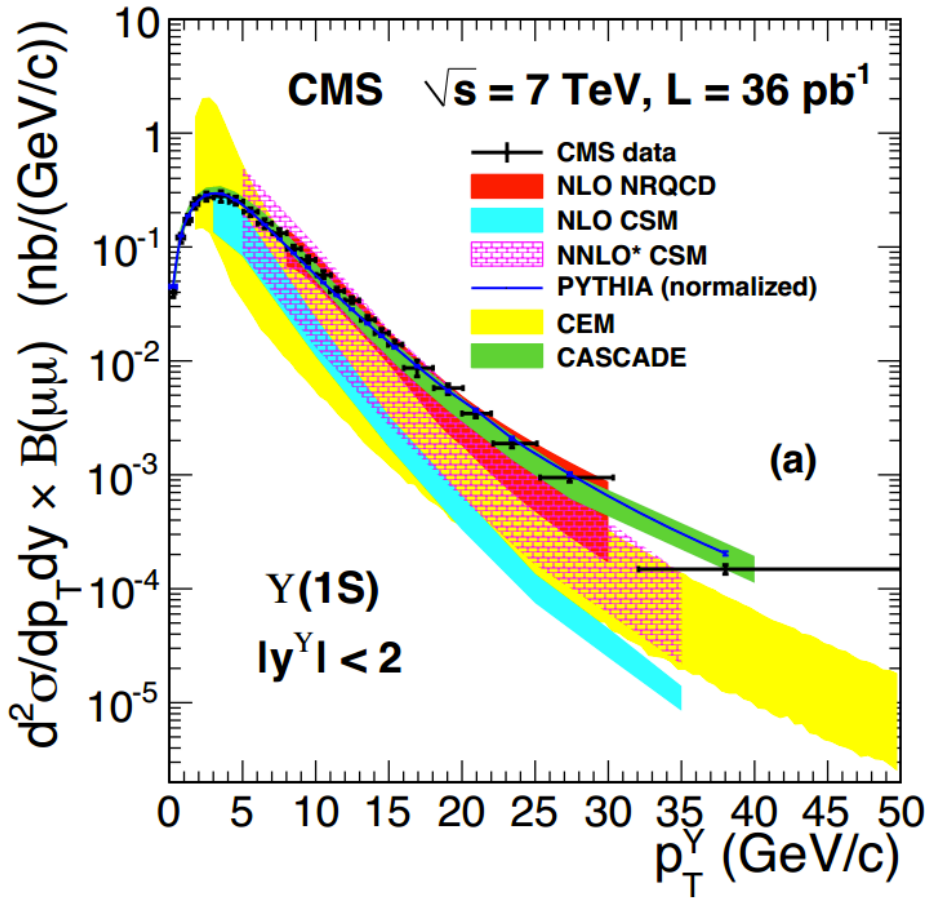


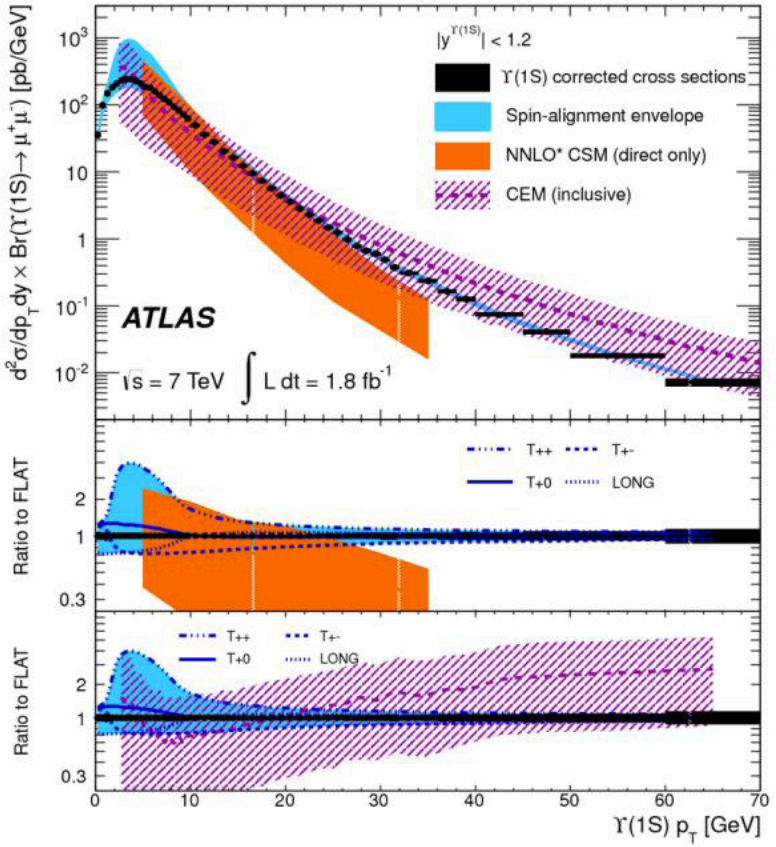
- Di-muon mass range: $m(\mu\mu) \in [2.5; 4.3]$ GeV (final states containing J/ψ) and $m(\mu\mu) \in [4.0; 8.5]$ GeV (B to μ transitions).
- No displaced vertex selection requirements: advantage for lifetime measurements.

Triggers for B-physics at CMS



Υ(1S,2S,3S) production at ATLAS and CMS





- CMS: Phys. Rev. D 83, 112004 (2011), CERN-PH-EP-2012-373, CMS-PAS-BPH-12-006
- ATLAS: Phys. Rev. D 87, 052004 (2013)