ATLAS studies of spectroscopy and B-decays

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on behalf of the ATLAS Collaboration
Charles University in Prague

53rd International Winter Meeting on Nuclear Physics
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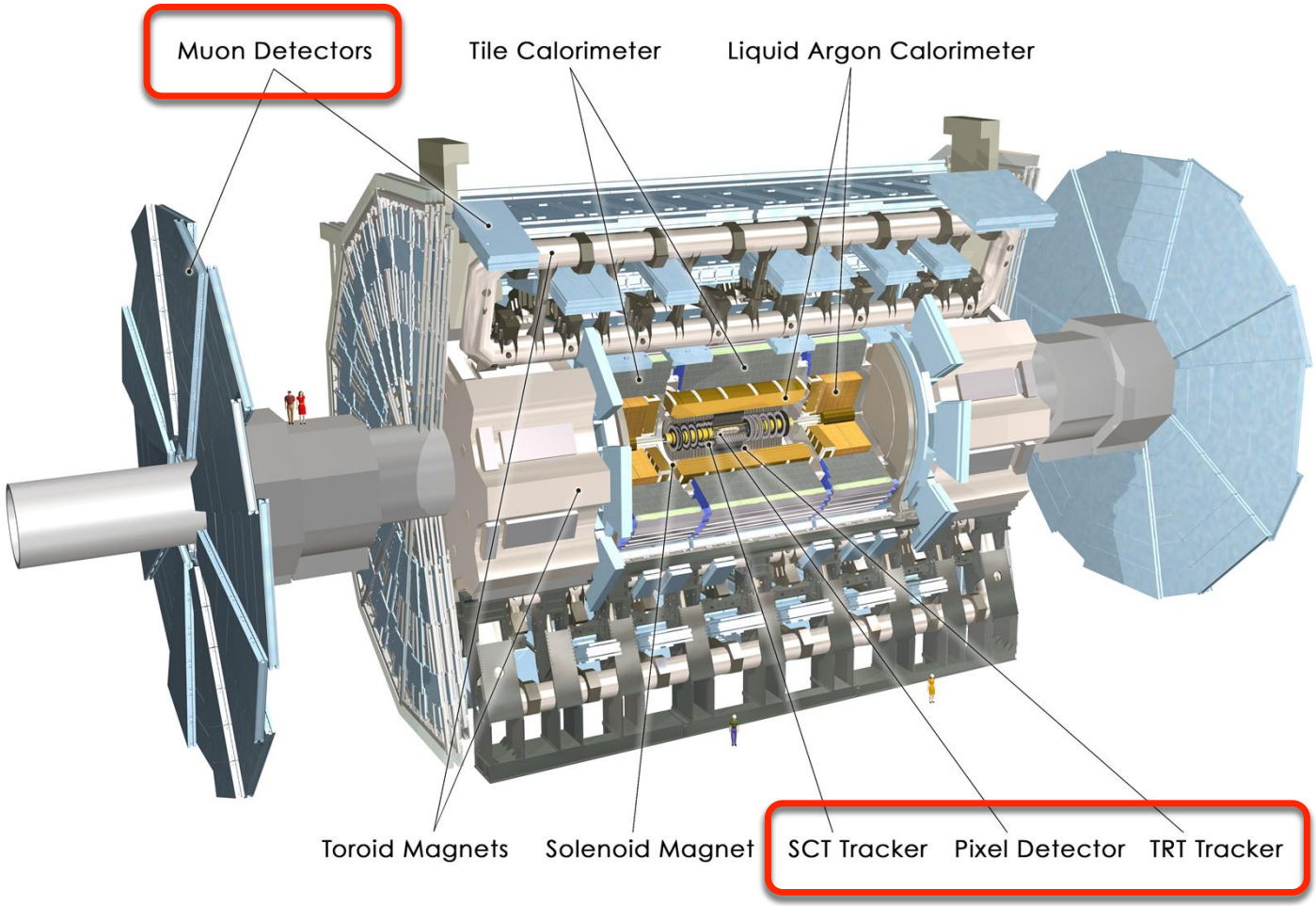
Outline

- ATLAS detector
- Spectroscopy
- B-decays
- Associated $J/\Psi + VB$ production
- $\Psi(2S)$ and heavy quarkonia production
- Future plans
- Summary

The ATLAS Detector



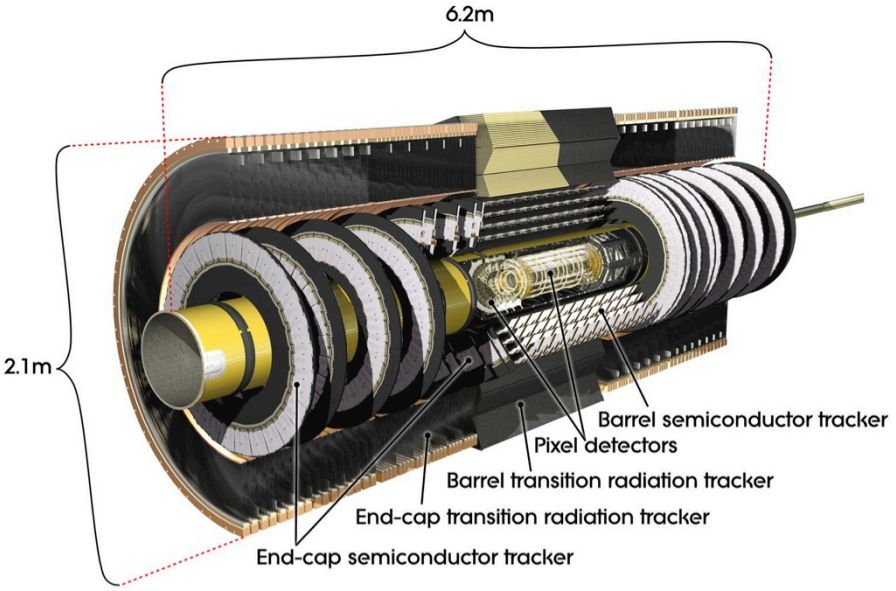
General purpose HEP detector

Inner detector and *muon system* crucial for heavy flavour studies

Overview of ATLAS results: J. Kroseberg, Friday 9:00

Hard Probes of QGP : T. Kosek, Thursday 18:40

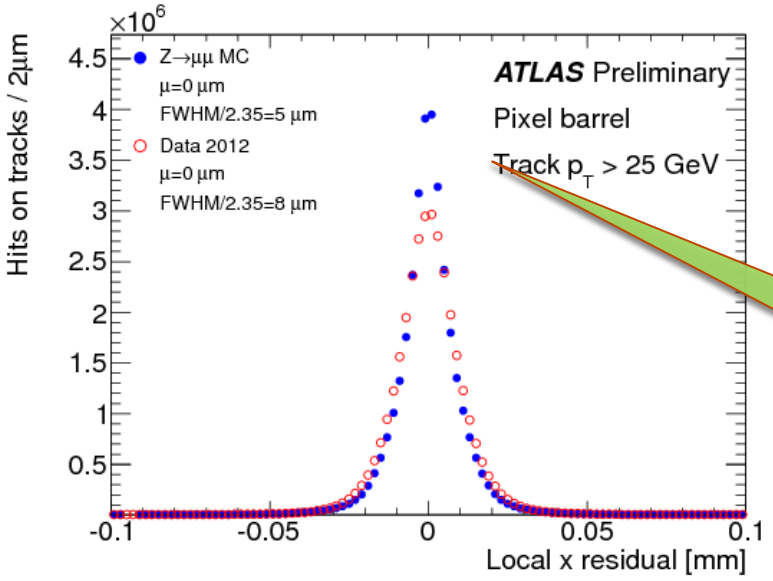
Inner Detector



Tracking detector in 2 T solenoidal field

3 subdetectors (resolution):

- Pixels: 10/115 μm in $R\varphi/z$
- Silicon strips: 17/580 μm
- Transition radiation tracker: 130 μm



ID provides about 3 pixel, 8 strip and 30 TRT measurements for a track at η=0

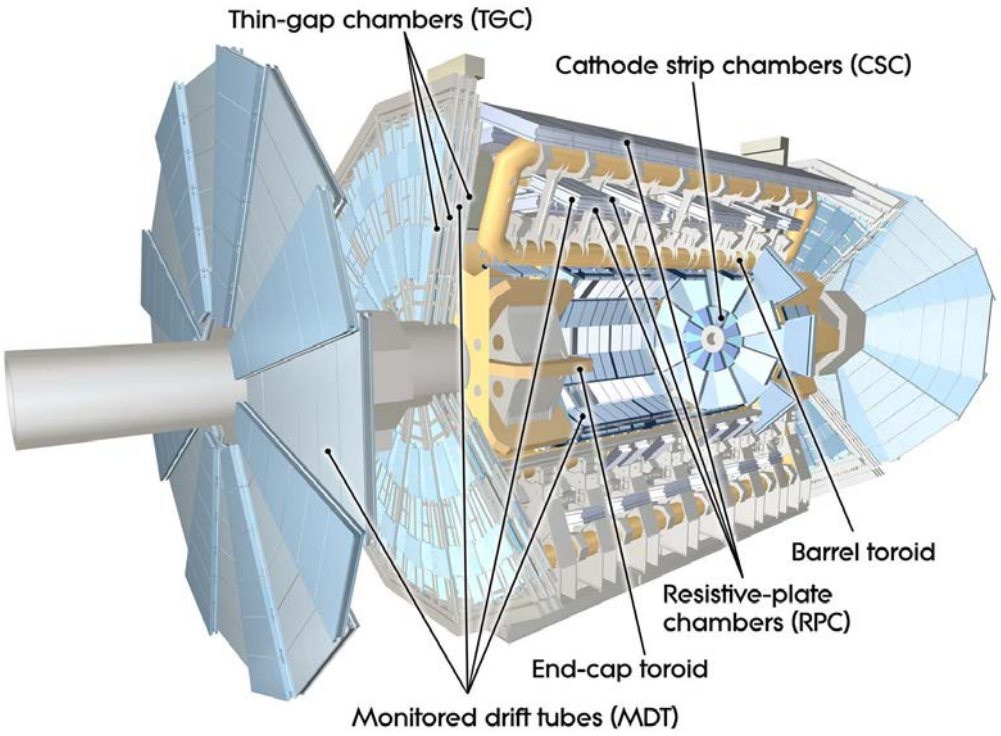
ID coverage: $|\eta|$<2.5 (2.0 for TRT)

Resolution goal:

$$\sigma_{p_T}/p_T = 0.05\% p_T \oplus 1\%$$

Residual close to MC expectations for perfect alignment (8 vs. 5 μm)

Muon System



Precision tracking chambers and trigger chambers

- Monitored drift tubes
- Cathode strip chambers
- Thin-gap chambers
- Resistive plate chambers

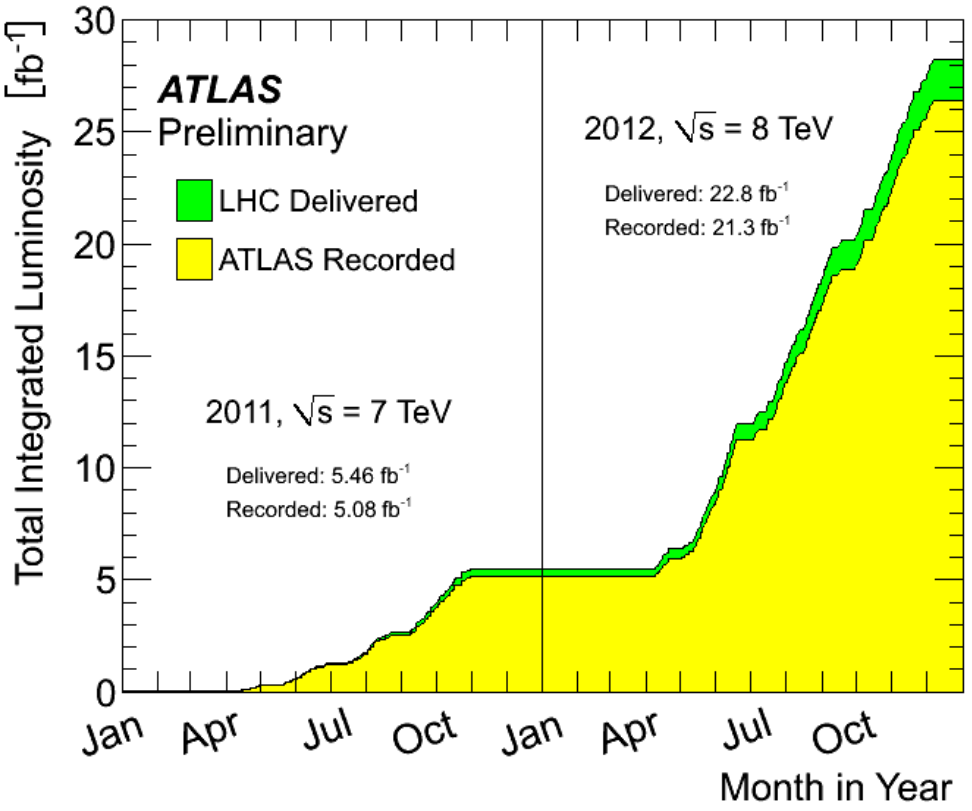
$|\eta| < 2.7$

Magnetic field of 3×8 air-core toroids

$$\sigma_{p_T}/p_T = 10\% \quad \text{at} \quad p_T = 1 \text{ TeV}$$

ATLAS flavour physics programme

- General purpose detector carrying also solid flavour programme:
  - Production and decays
  - Spectroscopy
  - Rare decays
  - CP Violation
- Impossible to cover all in 20'
- Personal choices made
- Complete list of results at



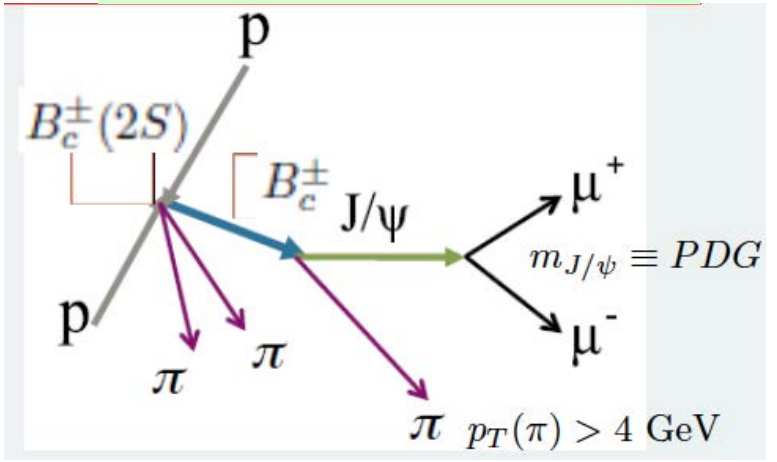
twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults

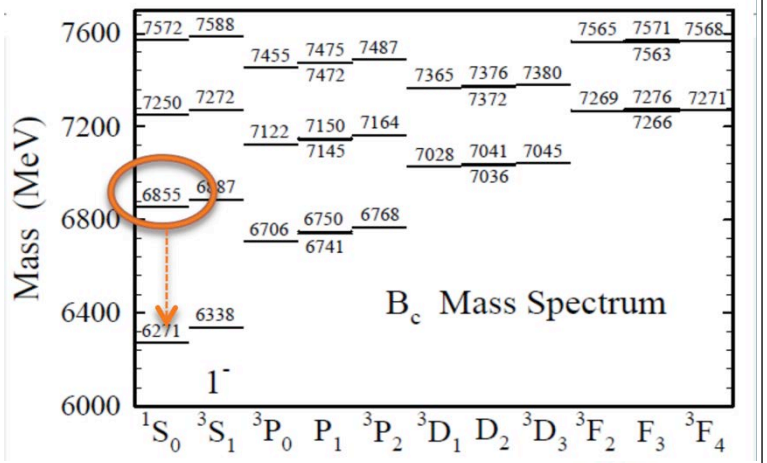
Observation of Excited $B_c^{\pm}$ Meson State

- B_c: bound state of (b,c)
- No states above ground state $B_c(1S)$ have been previously observed
- Spectrum can test TH predictions (NR potential models, pQCD and lattice)
- Search for $B_c(2S) \rightarrow B_c(1S)\pi^+\pi^-$
- $B_c(1S) \rightarrow J/\psi\ \pi^{\pm}$, $J/\psi \rightarrow \mu^-\ \mu^+$
- 2-vertex event - clear dimuon signature
- Systematics cancelled if looking at mass difference

$$Q = m(B_c^{\pm}\pi\pi) - m(B_c^{\pm}) - 2m(\pi)$$

PRL 113(2014)212004

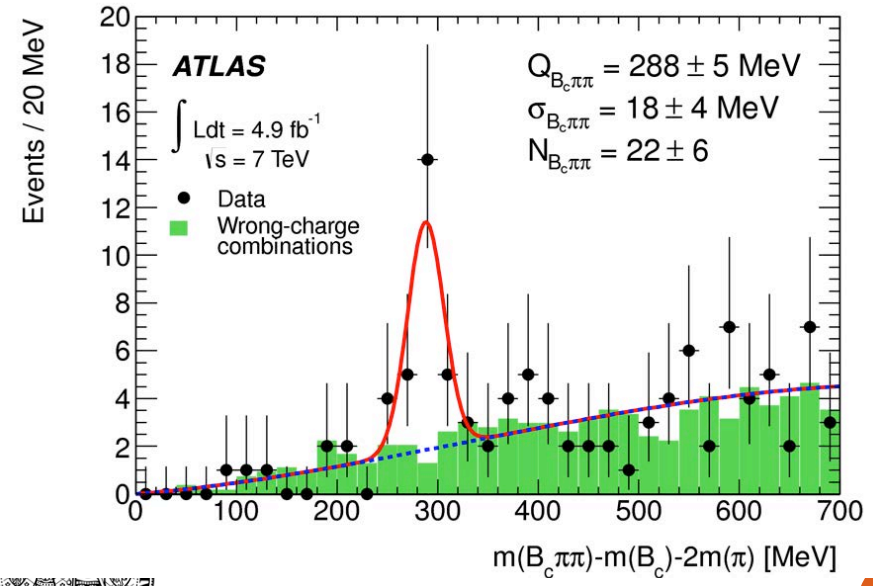


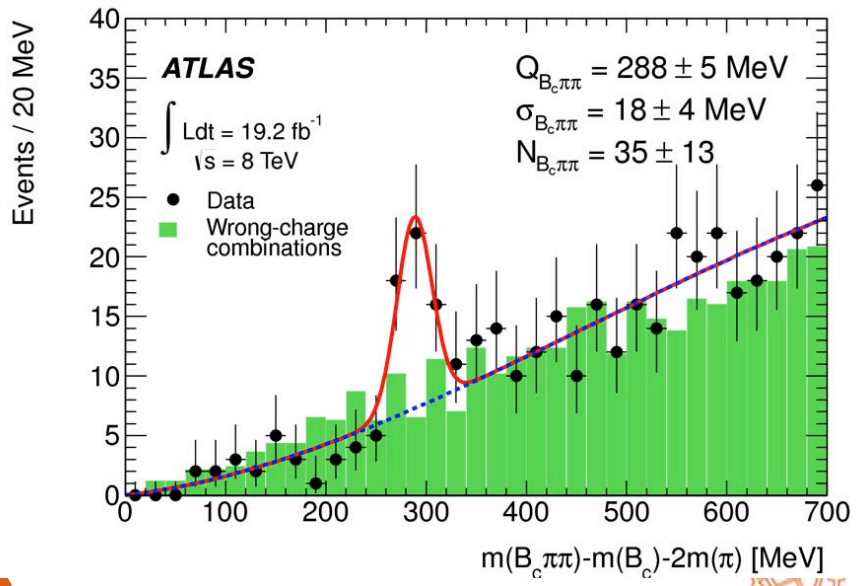


Observation of Excited $B_c^{\pm}$ Meson State

PRL 113(2014)212004

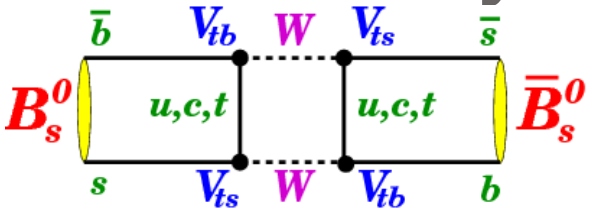
- Signal observed on both 2011 and 2012 data
- Q=(288.3±3.5±4.1) MeV, M=(6842±4±5)MeV
- Widths consistent with ATLAS resolution
- Combined significance 5.2σ





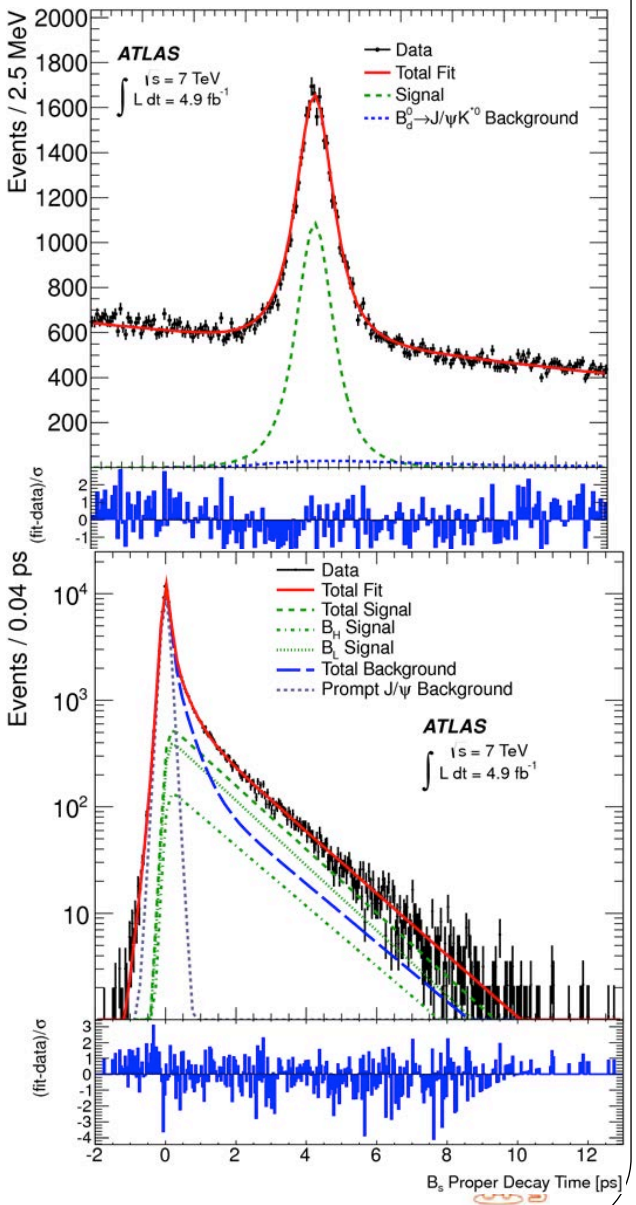
PRD 90(2014)052007

New Physics in $B_s^0 \rightarrow J/\Psi\,\Phi$



- Explanation of matter-dominated universe requires CP violation much beyond the SM/KM mechanism
- CP Violation occurs in interference between direct decays and decays via B_s mixing
- 2 parameters determined:

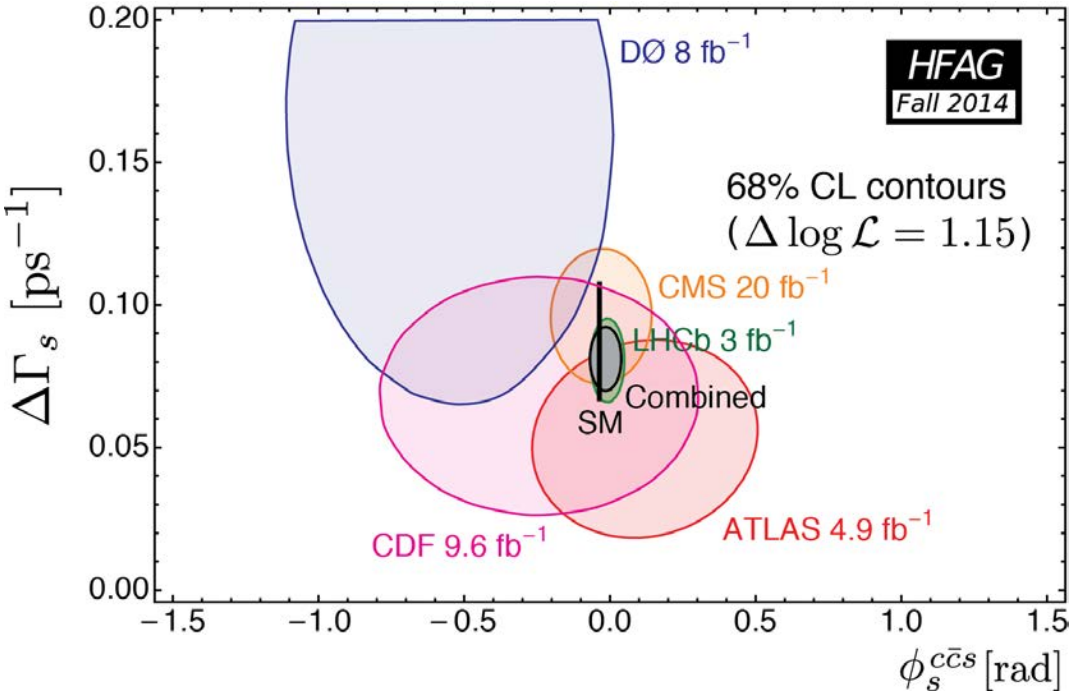
$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \quad \Phi_s = -2\arg[-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}]$$



New Physics in $B_s^0 \rightarrow J/\Psi\,\Phi$

PRD 90(2014)052007

- Flavour tagging B or $\bar{B}$
- Time dependent angular analysis
- 25 parameter unbinned max. likelihood fit
- Results from 7 TeV data consistent with SM as well as with other experiments
- 8 TeV data analysis ongoing



Glossary: Hidden/Open Charm/Beauty

Hidden flavour:

- No net charm/beauty: $c\bar{c}$ $b\bar{b}$

Open flavour:

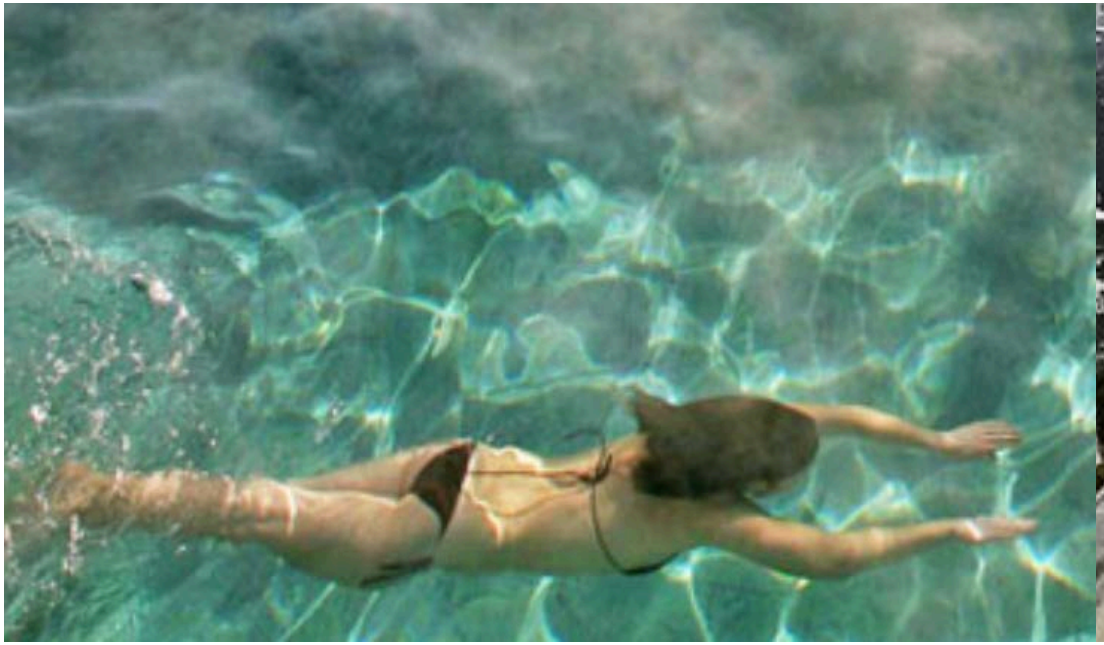
- charm or beauty is not compensated:

$$D^+ = c\bar{d},\ D^0 = c\bar{u},\ \overline{D}^0 = \bar{c}\,u,\ D^- = \bar{c}\,d,$$
$$B_c^+ = c\bar{b},\ B_c^- = \bar{c}\,b,$$

Glossary: Hidden Charm/Beauty

Glossary: Hidden Charm/Beauty

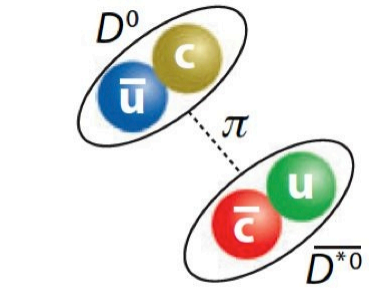
Glossary: Open Charm/Beauty



Search for the X_b and Other Hidden Beauty States

PLB 740(2015)199-217

- X(3872): narrow resonance discovered by Belle
- Called Hidden charm, but its nature not clear, interpreted as molecule or tetra-quark
- Heavy quark symmetry suggests existence of Hidden Beauty around 10.5 GeV
- ATLAS performed search: $X_b \to \pi^+\pi^-\Upsilon(1S)(\to \mu^+\mu^-)$
- Reference mode: $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)(\to \mu^+\mu^-)$



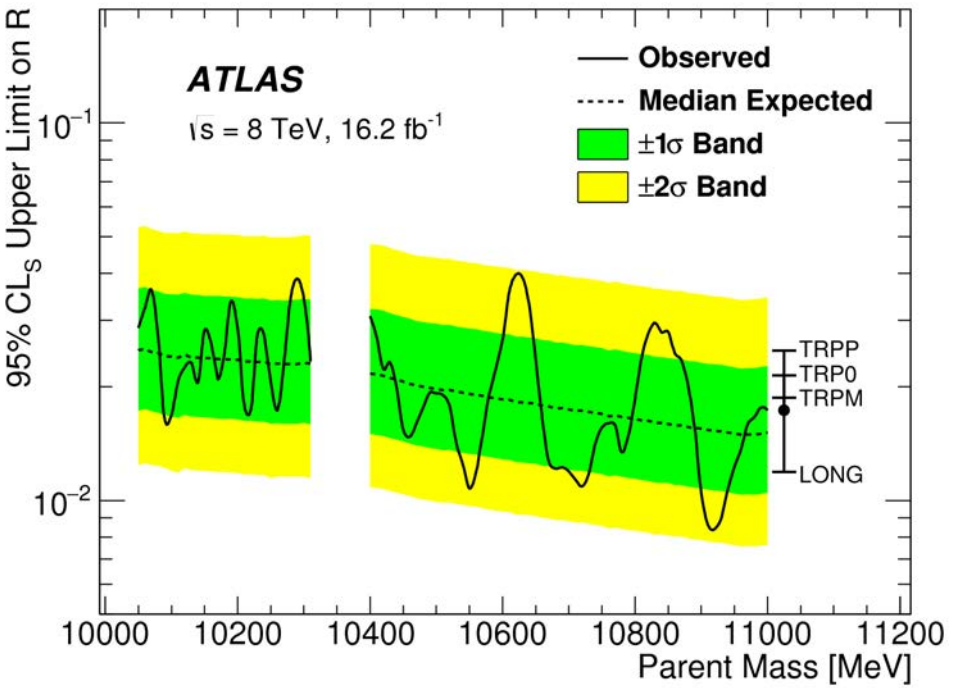
D^0–$\overline{D^{*0}}$ "molecule"

Diquark–diantiquark

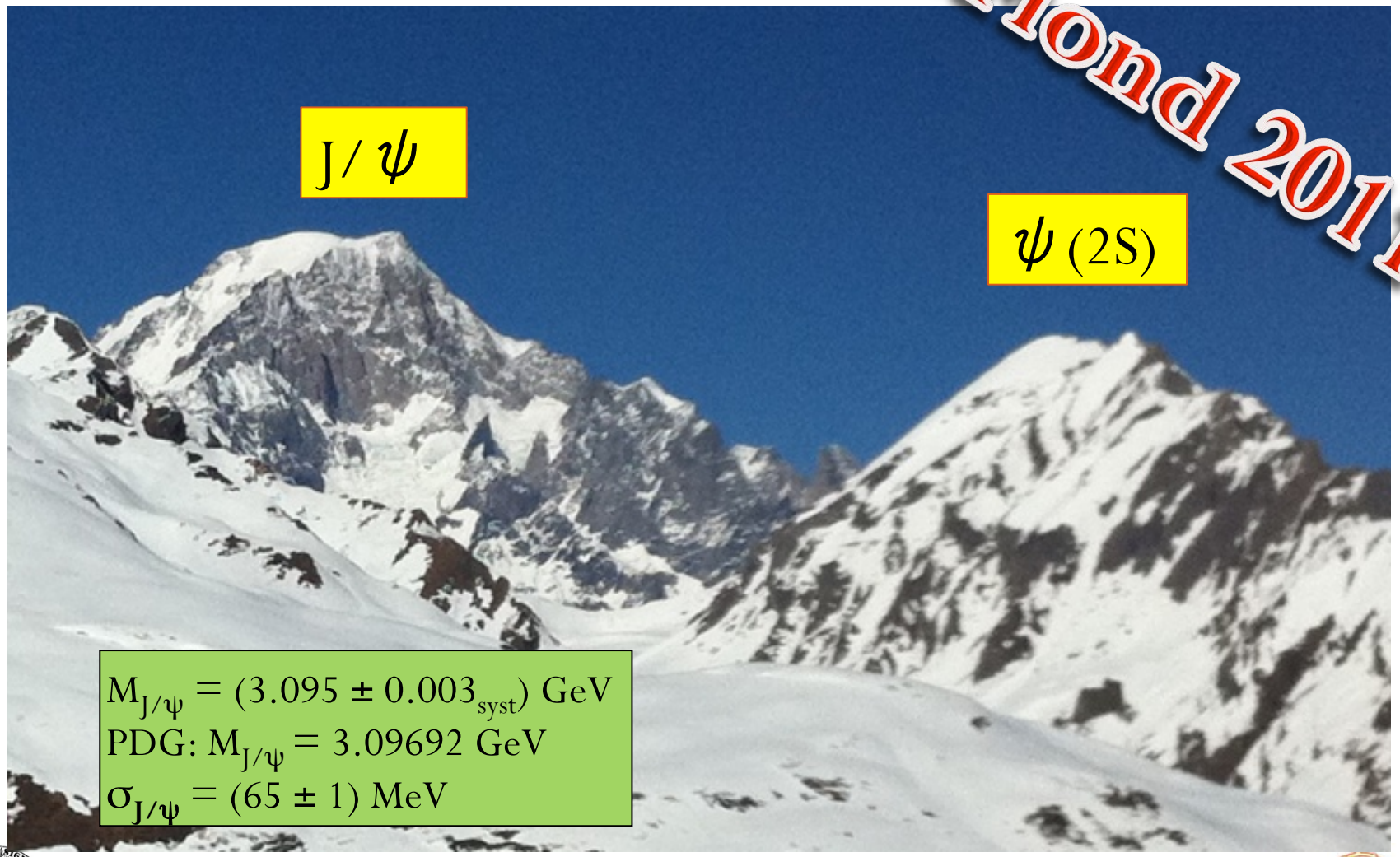
Search for the X_b and Other Hidden Beauty States

PLB 740(2015)199-217

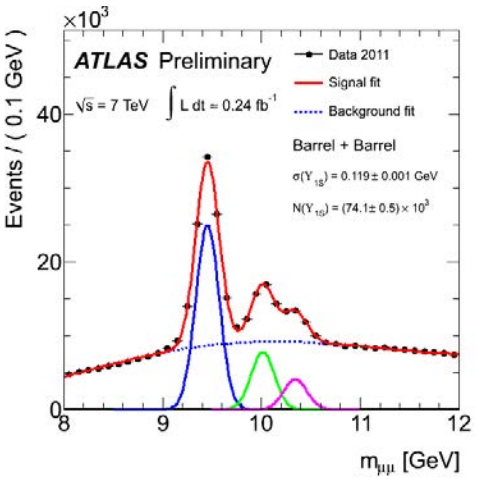
- Reference mode Y(2S)
- 10 MeV step scan between 10 and 11 GeV
- Narrow peak searched, with 3-body phase space characteristics
- No signal found
- Limits few % (most restrictive above 10.1 GeV)
- Other decay modes under studies

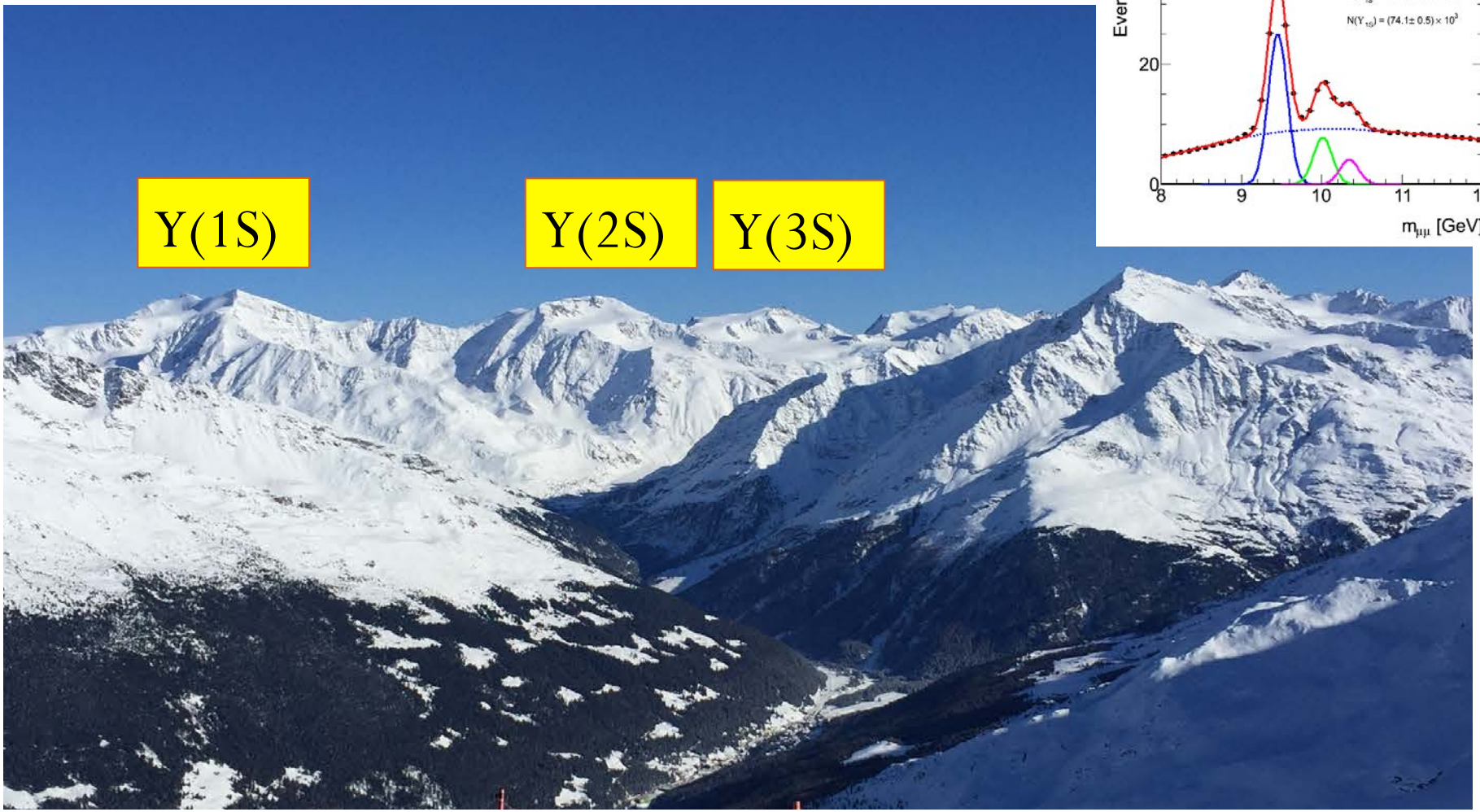


Chamonium observation



Bormionium


×10³
ATLAS Preliminary
√s = 7 TeV ∫ L dt = 0.24 fb⁻¹
Data 2011
Signal fit
Background fit
Barrel + Barrel
σ(Υ1S) = 0.119 ± 0.001 GeV
N(Υ1S) = (74.1 ± 0.5) × 10³
Events / (0.1 GeV)
40
20
0
8
9
10
11
12
mμμ [GeV]


Υ(1S)
Υ(2S)
Υ(3S)

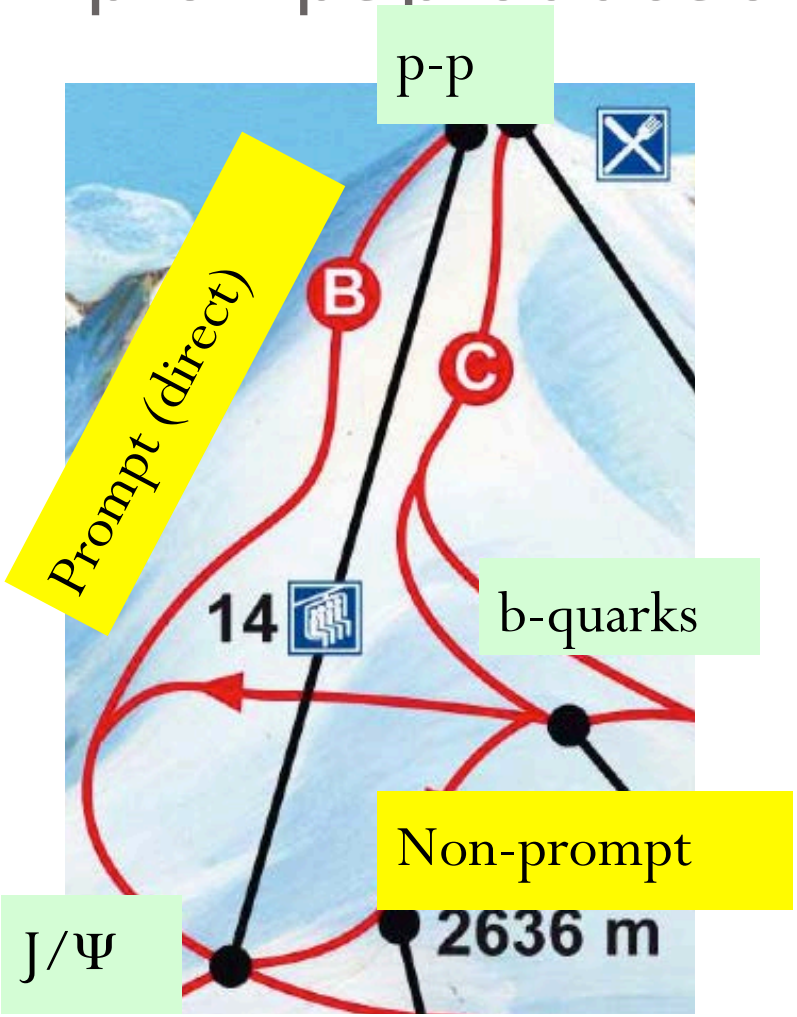
Glossary: Prompt/Non-prompt production

Prompt:

- pp ➔ J/ψ
- Feed-down from other $c\bar{c}$
- Vertex displacement below detector resolution

Non-prompt:

- pp ➔ b-hadrons ➔ J/ψ
- Displaced decay vertex



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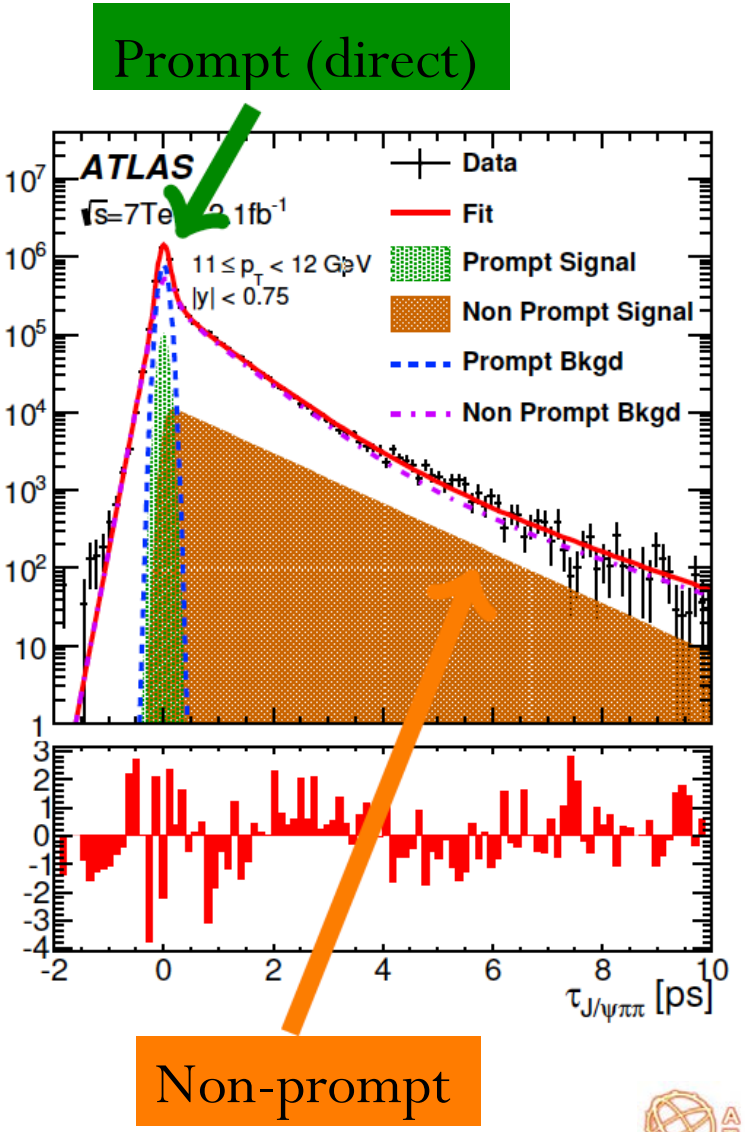
Pseudo-proper lifetime serves as a discriminant

$$\tau = L_{xy} m_{\mu^+\mu^-} / p_{\mathrm{T}}$$



Why quarkonia?

Motivation:

- Tests of QCD at the perturbative/non perturbative boundary
- Important input to background estimates for Higgs and other studies

Models available:

Prompt:

- NLO NR QCD (CO: colour octet, CS: colour singlet)
- k_T factorisation
- LO CS mechanism
- Colour Evaporation Model (CEM)

Non-prompt:

- FONLL (fixed order+next-to-leading log)
- NLO

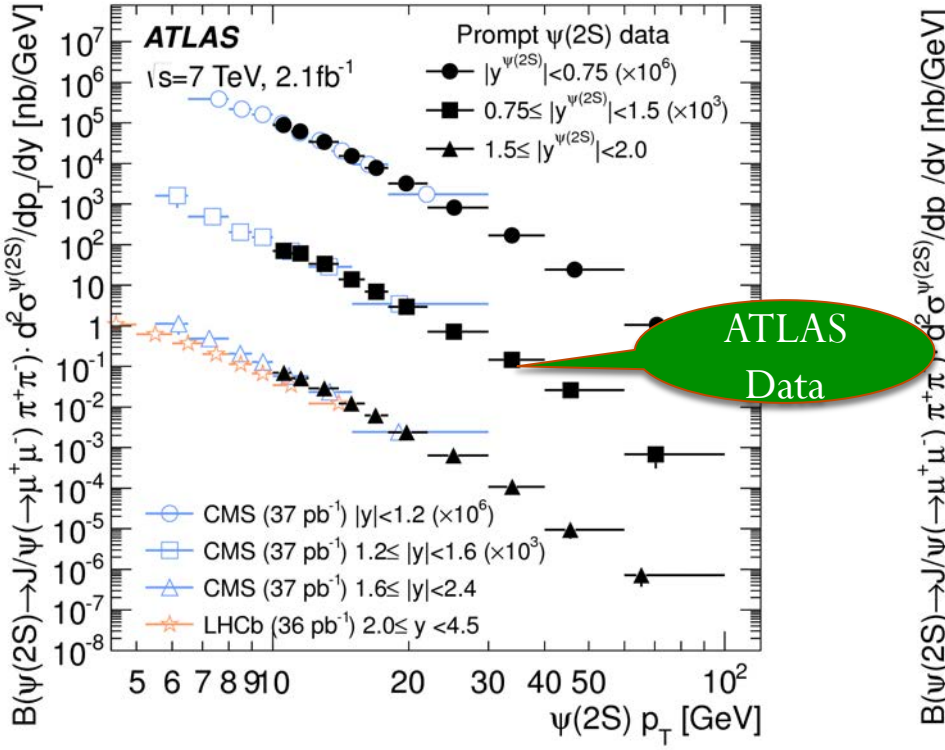
Production Cross section of ψ(2S)

Clean: not affected by feed-down

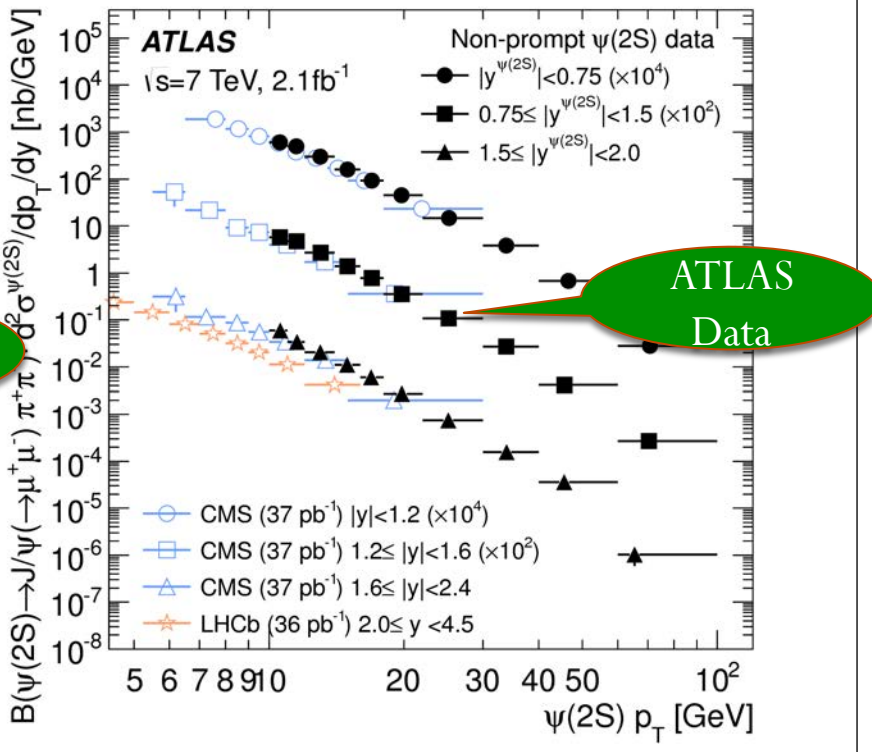
JHEP 07(2014)079

Good agreement with CMS and LHCb / Sensitivity to high p_T region

$$\psi(2S) \rightarrow J/\psi(\rightarrow \mu^+\mu^-) + \pi^+\pi^-$$



Prompt production



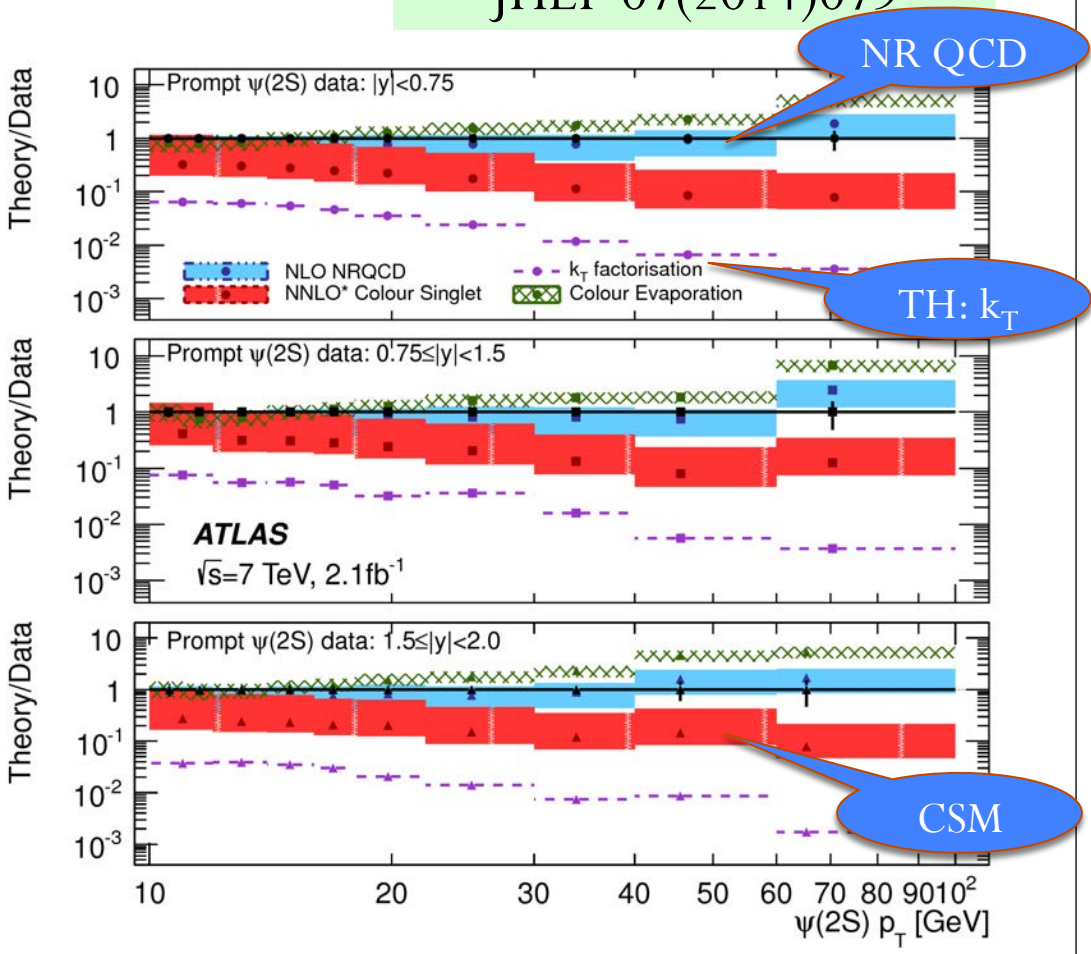
Non-prompt production

Production Cross Section of ψ(2S)

JHEP 07(2014)079

Prompt production:

- Good agreement with NR QCD LO and NLO
- Deviations at higher p_T
- k_T , CSM and CEM do not describe data well

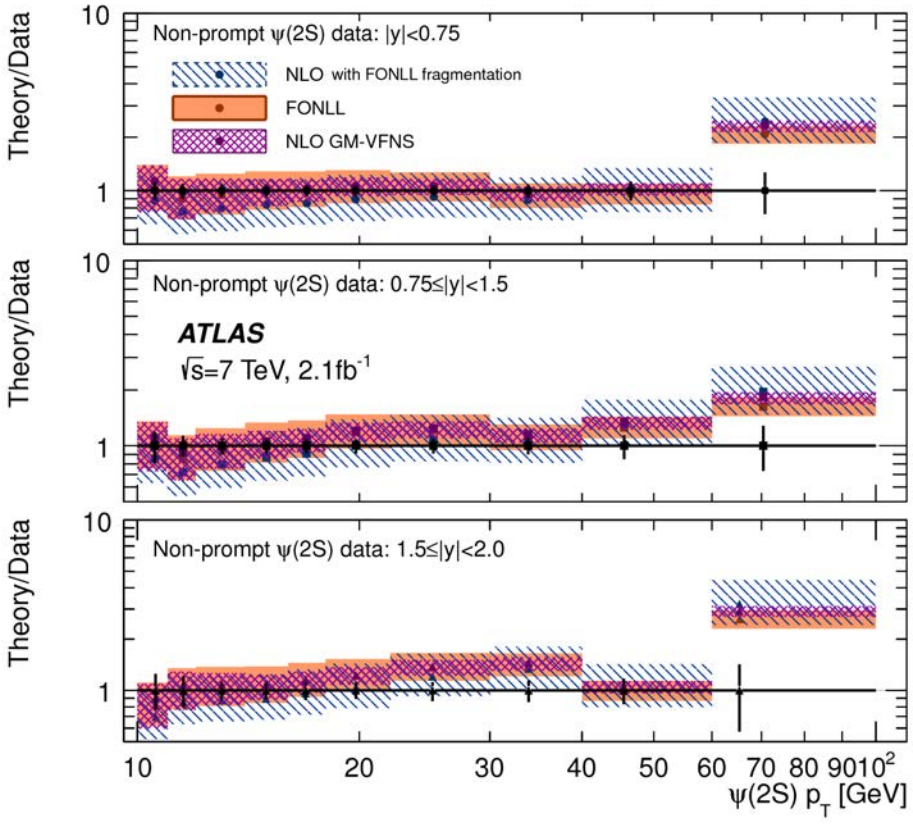


Production Cross Section of ψ(2S)

JHEP 07(2014)079

Non-prompt

- Good agreement with predictions at all p_T

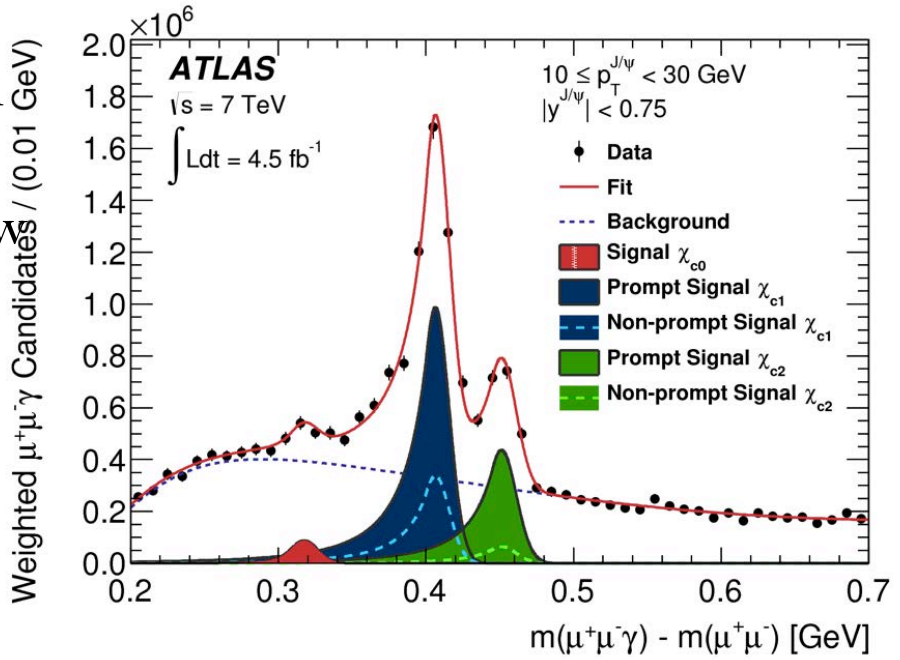


Production of Heavy Quarkonia χ_{c1} and χ_{c2}

JHEP 07(2014)154

Motivation:

- J/ψ production studies hampered by large feed-down from heavier states: χ
- Triplet of P-states exists below open charm threshold
- Heavy quarkonium (HQ) production understanding crucial
- HQ difficult to describe:
  - mass does not justify NR approximation
  - detailed HQ measurement missing



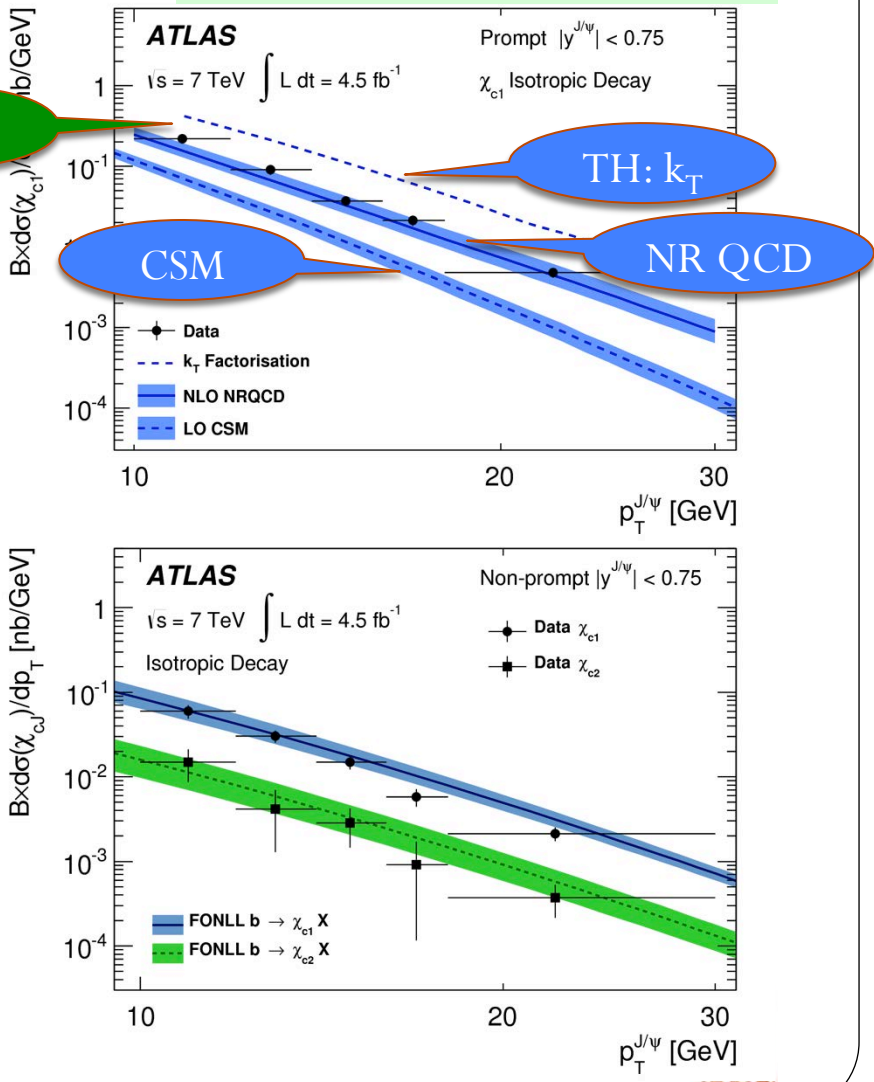
$$\chi_{cJ} \to J/\psi(\to \mu^+\mu^-)\gamma$$

Production of heavy quarkonia χ_{c1} and χ_{c2}

Results:

- Differential cross sections of prompt and non-prompt χ_{c1} and χ_{c2} measured
- This is the first absolute production χ_c cross-section measurements at a hadron collider
- Results compared to predictions:
  - Good agreement with NLO NRQCD
  - k_T factorization too high
  - LO CSM too low
- Strong constraint on quarkonium models

JHEP 07(2014)154



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JHEP 07(2014)154

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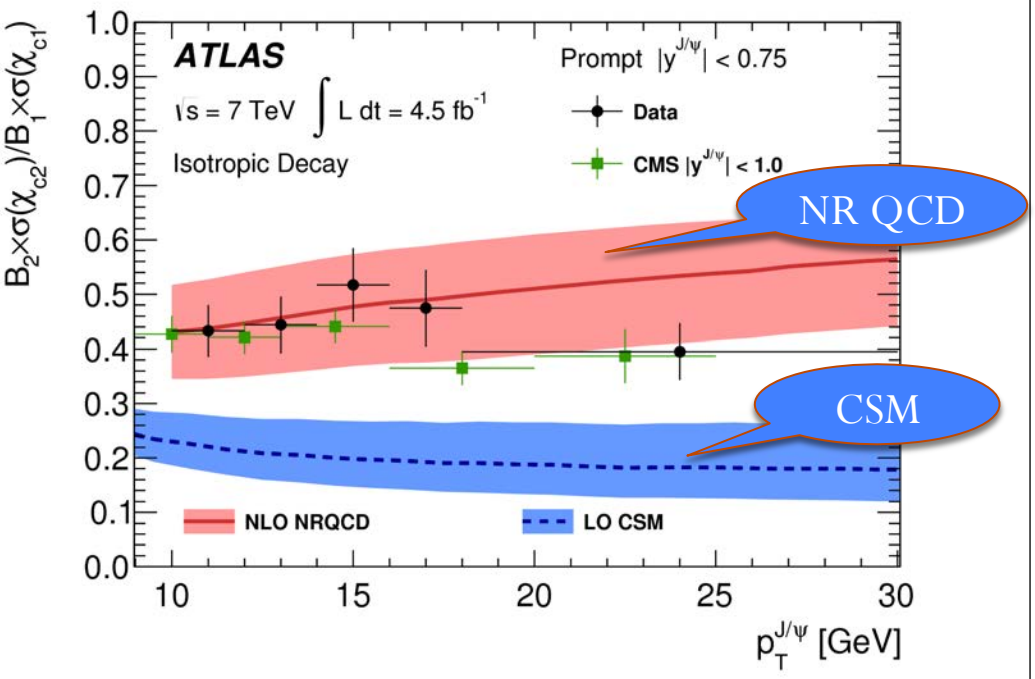


Associated Production of Prompt J/Ψ+W±

JHEP 04(2014)172

- Tests of QCD at the perturbative/nonP boundary
- Probes of Higgs sector in charm couplings and BSM models
- Prompt J/ψ (from the same vertex) production: distinctive test of QCD frameworks:
  - LO pQCD CS (Colour Singlet)
  - NLO CO (Colour Octet)

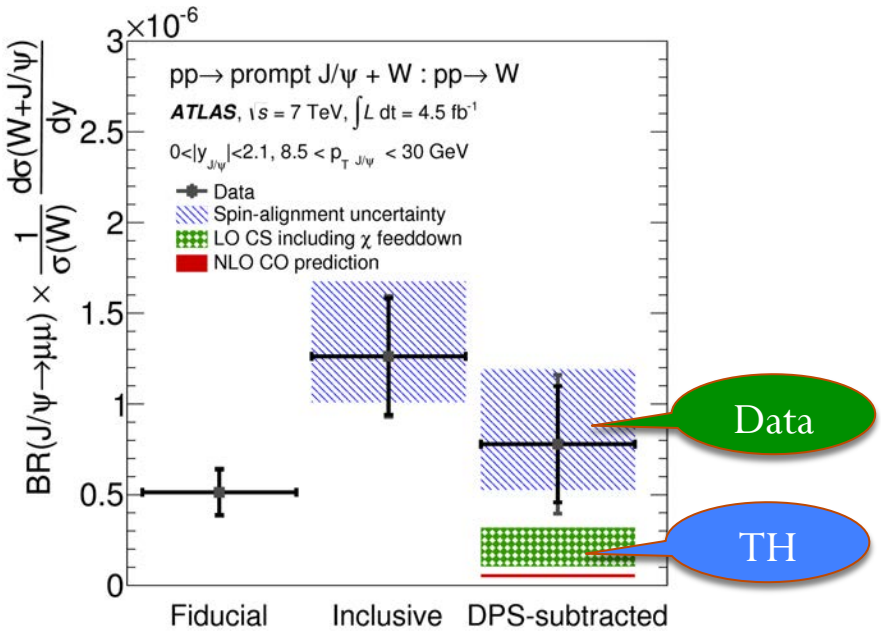
Several effects considered

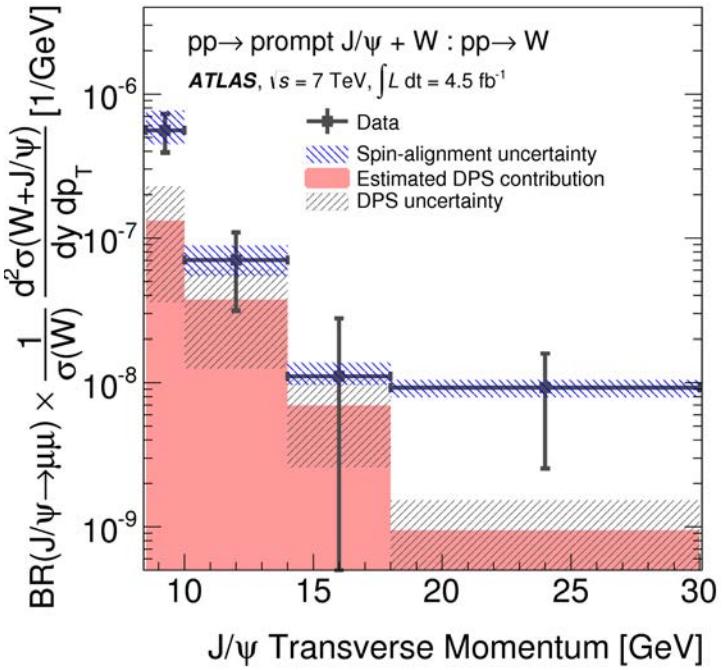
- Single Parton Scatters
  - W and J/ψ produced together
- Double Parton Scatters
  - W and J/ψ from different parton interaction
- W+b(decaying to J/ψ)
- Pileup of events from different interactions

Associated Production of prompt J/Ψ+W±

JHEP 04(2014)172

- First observation (5.1σ) of associated prompt J/ψ and W production
- Both CS and CO underrepresent observed data
  - LO pQCD CS (Colour Singlet)
  - NLO CO (Colour Octet)
- SPS dominant (but not the only) contributor

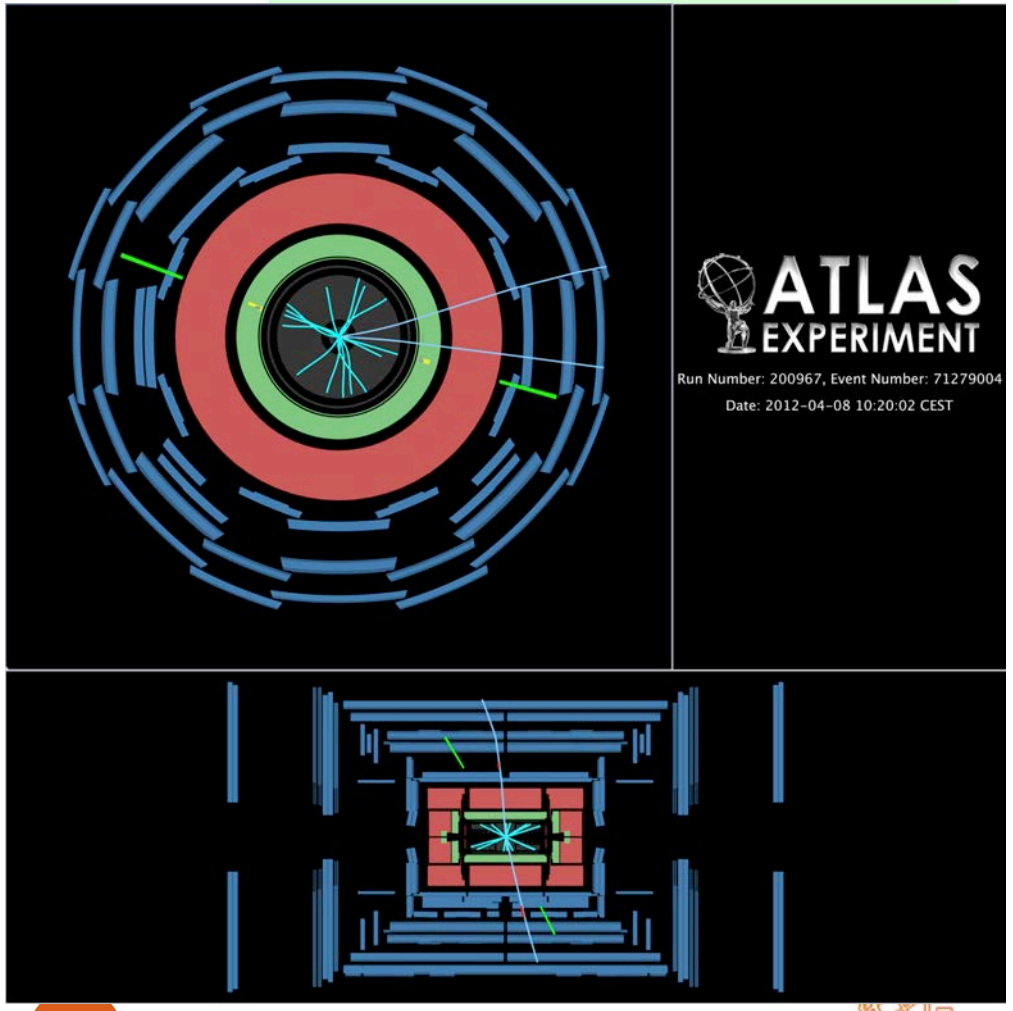




Associated Production of $J/\Psi+Z^0$

Subm. to EPJC, arXiv:1412:6428

- Similar study
- Z+non-prompt probes the b-hadron production models
- Z boson: background to many other processes
- Single parton scatter and Double parton scatter studied

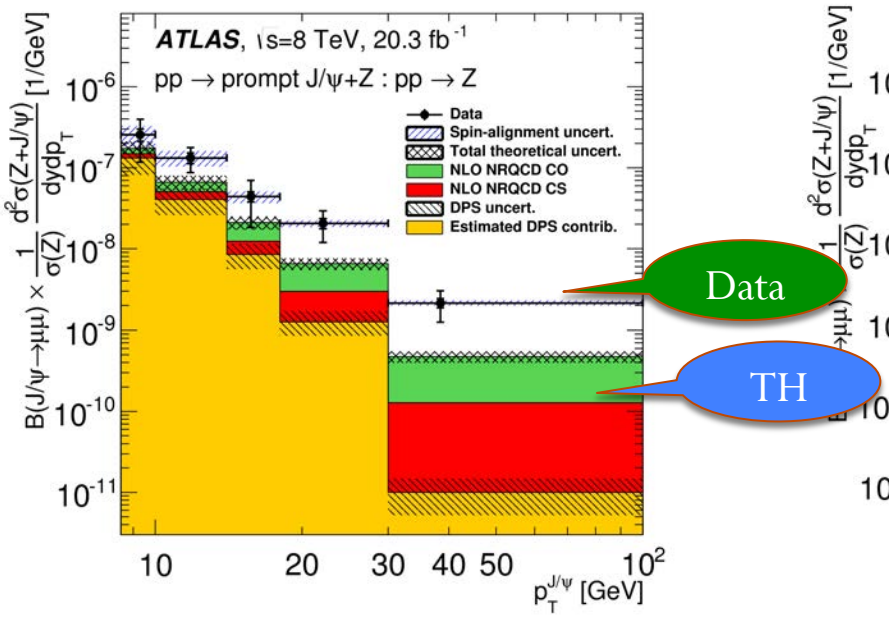


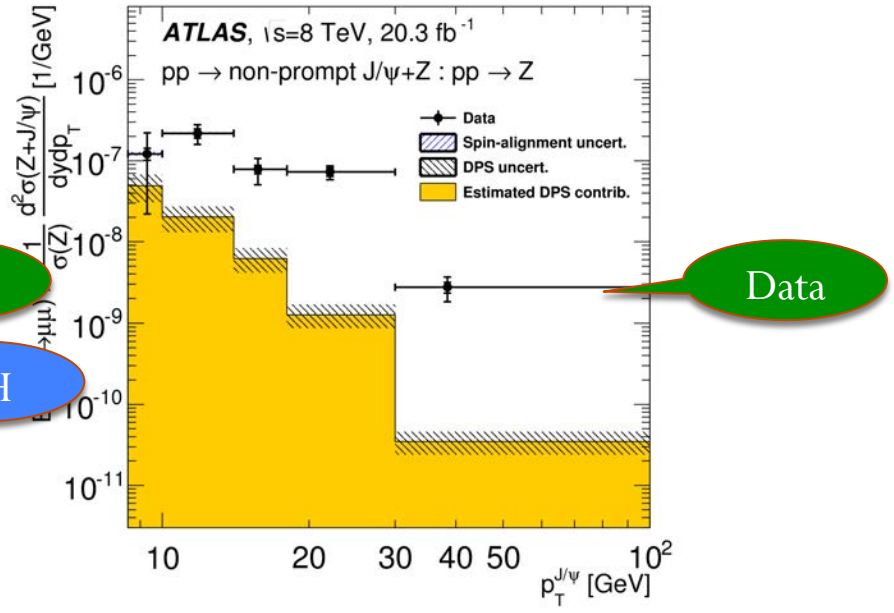
Associated Production of J/ψ+Z^0

Subm. to EPJC, arXiv:1412:6428

Results:

- First observation: Prompt (5 σ), non-prompt mode (9 σ)
- DPS <29% (prompt) and <8% (non-prompt)





Future Plans

- Still ongoing Run 1 analyses in all areas
- Updates with full Run 1 data:
  - Rare decay searches
    - $B_s \rightarrow \mu\mu$ and
    - $B_d \rightarrow K^*\mu\mu$
  - CPV studies $B_s^0 \rightarrow J/\Psi\,\Phi$
- Run 2 (statistics, better detector, improved trigger)

ATLAS-PHYS-PUB-2013-010

Summary

- Discovery of the first excited B_c meson
- Search for new physics in $B_s^0 \rightarrow J/\psi\,\phi$ decay
- Search for hidden beauty states
- Studies of associated J/ψ + vector boson production both prompt and non-prompt (QCD tests)
- Heavy charmonium production (QCD tests)
- $\psi(2S)$ production
- Future plans