ATLAS B-Physics & Quarkonia: Recent Results

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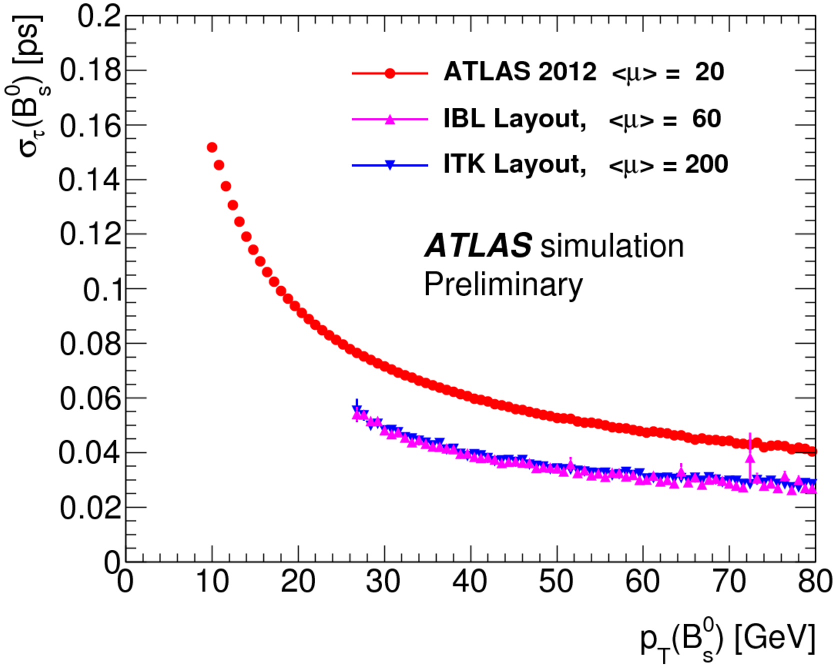
At ICNFP 2015 on behalf of the ATLAS Collaboration

Crete
August 2015

Heavy Flavours Overview



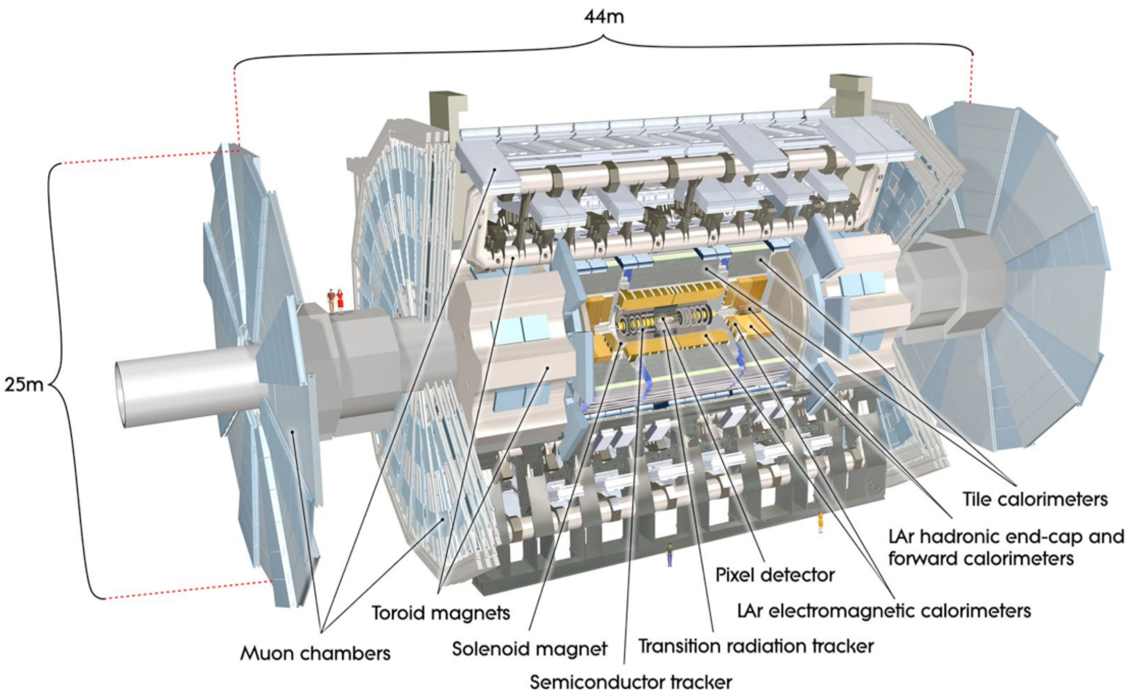
HF sensitive to new physics
  - ATLAS advantage: high luminosity

Wide programme
  - Inclusive b, c production
  - Production with jets
  - Charm production
  - Onia production
  - Di-onium/VB+onium production
  - B-hadron production
  - CP violation
  - Rare decays

- Trigger vital
- 3-level system O(20MHz) -> O(200Hz)
- B-physics statistics typically @ low-pT (J/ψ typically 10-100GeV pT)
- Primary B-physics triggers:
  - Two muon signals at L1
  - confirmed at L2/EF with vertexing and invariant mass criteria applied
    - but not lifetime cuts, avoiding potential bias
  - Varying thresholds and prescaling applied to maximise signal rate
    - Two muons; pT(μ) > 4 GeV ($\mu 4 \mu 4$) , $\mu 4 \mu 6$

The ATLAS Detector

- Muon identification from combined Muon Spectrometer and inner detector tracking:
  - Inner detector tracks (from muons) provides precision momentum and lifetime measurements for the range of momenta considered here

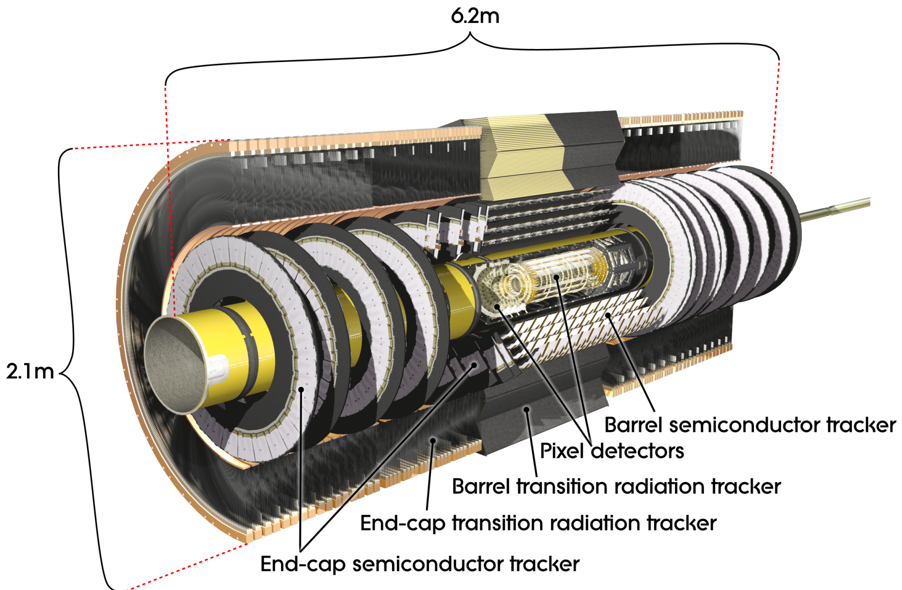


Muon Spectrometer

Toroid B-Field, average	0.5 T
$\|\eta\|$(max)	2.7
Track momentum resolution	$\sigma/p < 10\%$ up to 1 TeV

Inner Detector

Axial Magnetic field	2 T
Track momentum resolution σ/p_T^2 [GeV]$^{-1}$	~0.05%p_T + 0.015
$\|\eta\|$(max)	2.5
Lifetime resolution	~100 fs➔ ~50fs



Quarkonia

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

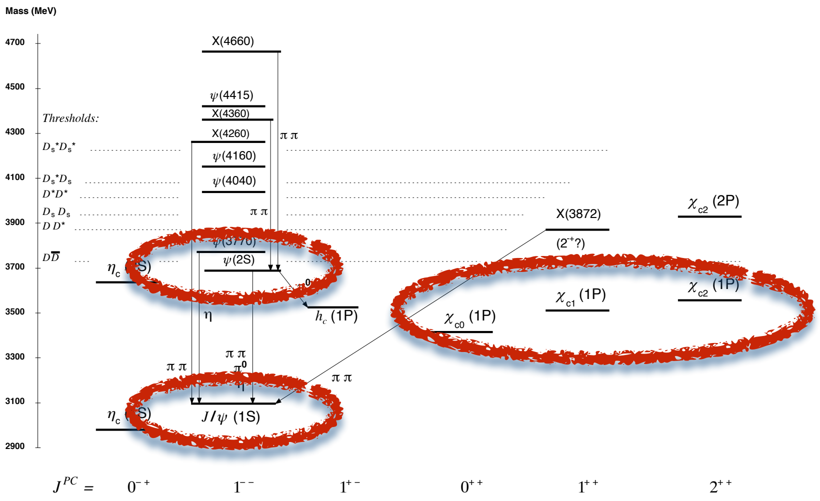
Production Cross-sections	
J/ψ and $\psi(2S) \to \mu\mu$ at 7 and 8 TeV	ATLAS-CONF-2015-024
Differential non-prompt J/ψ fraction at 13TeV	ATLAS-CONF-2015-030
Measurement of χ_{C1} and χ_{C2}	JHEP 07 (2014) 154
$\psi(2S) \to J/\psi\pi\pi$	JHEP 09 (2014) 079
$\Upsilon(nS)$ production	Phys. Rev. D 87 (2013) 052004
Spectroscopy	
$\chi_b(3P)$ Observation	Phys. Rev. Lett. 108 (2012) 152001
Search for X_b in $\Upsilon(1S)\pi\pi$	Phys. Lett. B740 (2015) 199-217
Associated Production	
$W^{\pm}$ + prompt J/Ψ	JHEP 04 (2014) 172
Z + (non-)prompt J/Ψ	Eur. Phys. J. C75 (2015) 229

New & Updated!

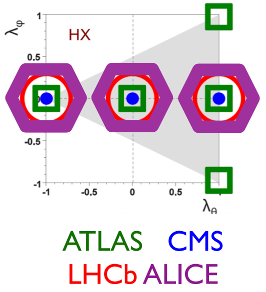
ATLAS-CONF-2015-024

J/Ψ and $\Psi(2S)$ Production Cross-Sections

- **Measurement of the prompt and non-prompt differential cross-sections of J/Ψ and $\Psi(2S)$ mesons in the dimuon decay mode.**
  - Measured in 7 TeV (2011, 2.1 fb^{-1}), and 8 TeV (2012, 11.4 fb^{-1}) - now 13TeV too
- $\Psi(2S)$: no significant feed-down, unique possibility to study $J^{PC}=1^{--}$ states.
- J/Ψ production: contributions from 1^{--} and J^{++} in comparable amounts



K.A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014)



- **Di-muon trigger pT(μ) > 4 GeV.**
- **Correct for Trigger & reconstruction efficiencies**
- **Acceptance: depends on Spin-Alignment:**

$$\frac{d^2N}{d\cos\theta^\star d\phi^\star} \propto 1+\lambda_\theta\cos^2\theta^\star+\lambda_\phi\sin^2\theta^\star\cos 2\phi^\star+\lambda_{\theta\phi}\sin 2\theta^\star\cos\phi^\star$$

- **Current measurements support central assumption λ_i = 0**

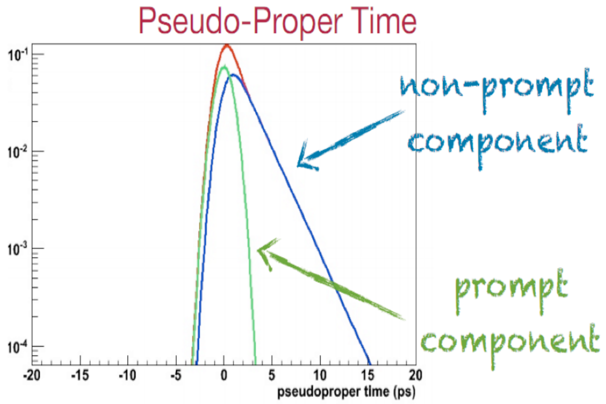
- **Use decay point to distinguish prompt Ψ from b-hadron decays**
  - **Construct variable: pseudo-proper decay time**

xy displacement of candidate from PV

Invariant mass of candidate

$$\tau = \frac{\boxed{L_{xy}}\,\boxed{m(J/\psi\,)}}{\boxed{p_T(J/\psi\,)}}$$

pT of candidate



J/Ψ and Ψ(2S): Prompt cross-section

- Double-differential cross-sections:
  - **Prompt**
  - pT covers 8-110 GeV.
  - 8 slices of |rapidity| (0 – 2.0)

$$\frac{d^2\sigma(pp\to\psi)}{dp_T dy}\times\mathcal{B}(\psi\to\mu^+\mu^-)=\frac{N_\psi^p}{\Delta p_T\Delta y\times\int\mathcal{L}dt}$$

7 TeV

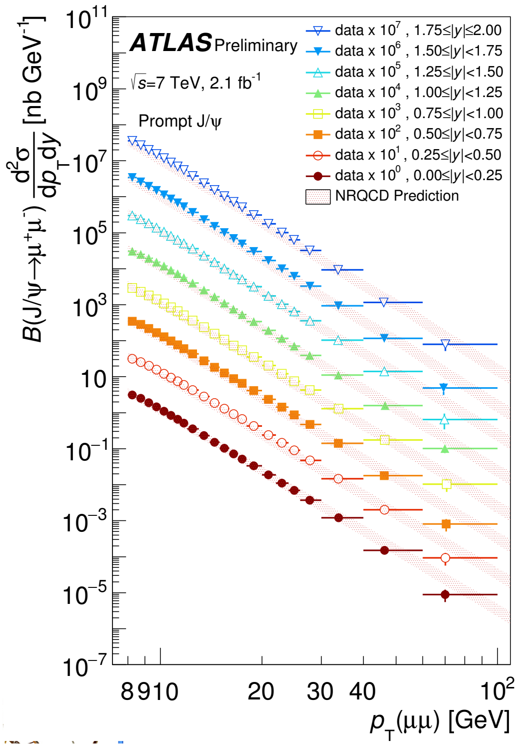
J/Ψ

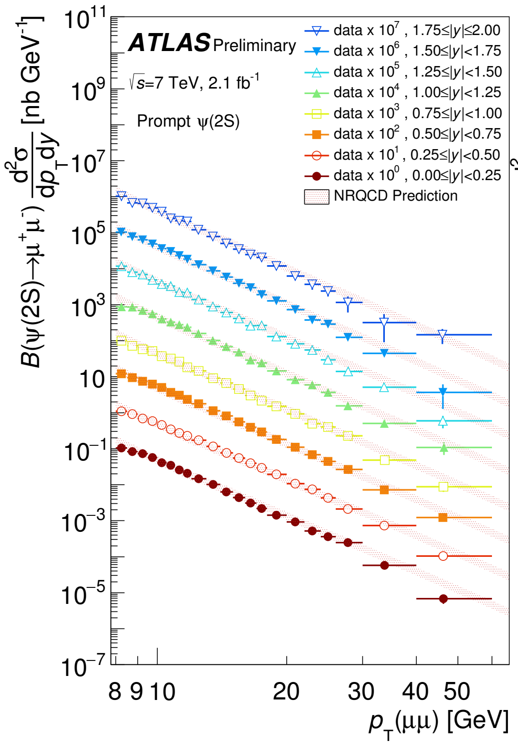
Ψ(2S)

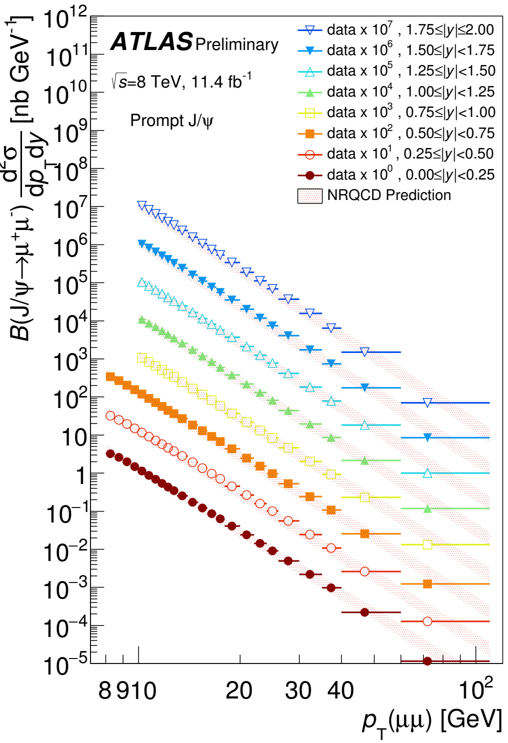
8 TeV

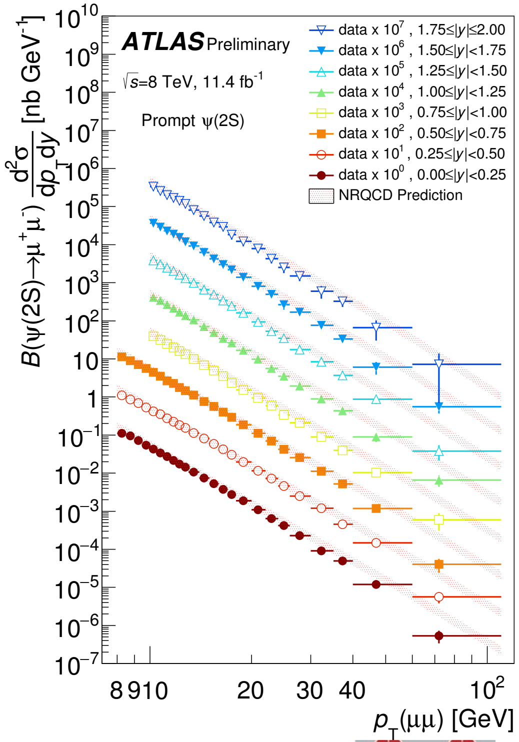
J/Ψ

Ψ(2S)









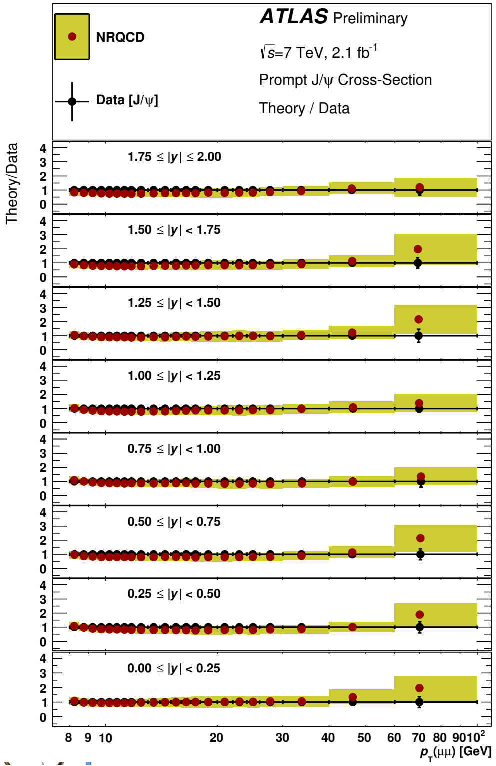
J/Ψ and Ψ(2S): Results – Theory Comparison

- Comparison with theory: **Prompt** compared to NRQCD
  - Good agreement across range of pT,
  - No observed dependence with rapidity

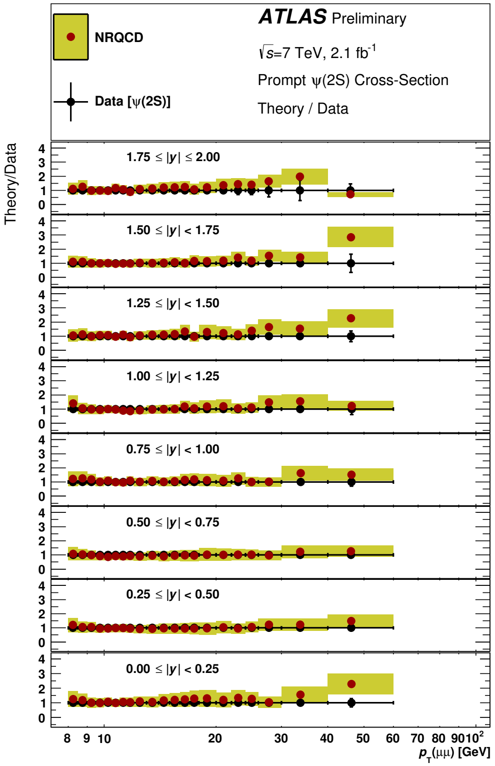
- NLO derived using
- HELAC-ONIA
- tuned from Tevatron data

7 TeV

J/Ψ

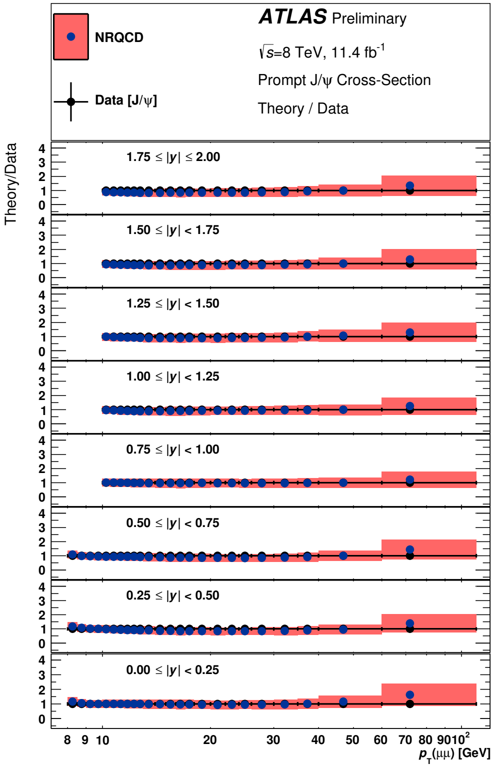


Ψ(2S)

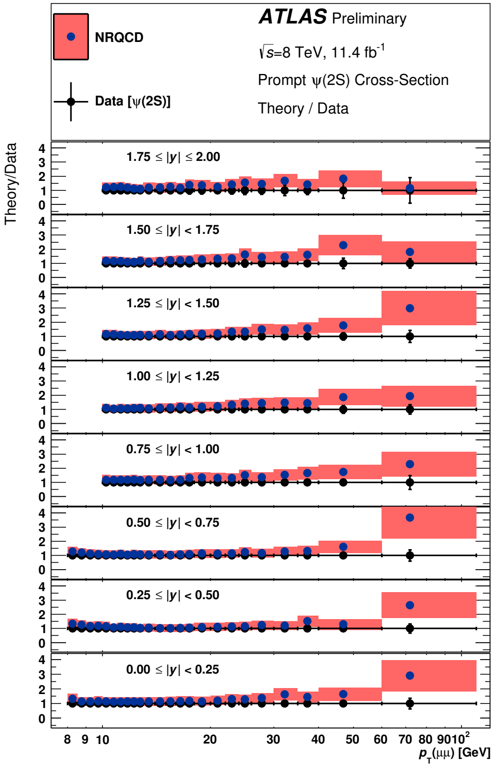


8 TeV

J/Ψ



Ψ(2S)



J/Ψ and $\Psi(2S)$: Results – Theory Comparison

- Comparison with theory: **Non-Prompt** compared to FONLL
  - Generally good agreement; theory predicts slightly harder pT spectra
    - Small tendency for $\Psi(2S)$ prediction to overestimate data

7 TeV

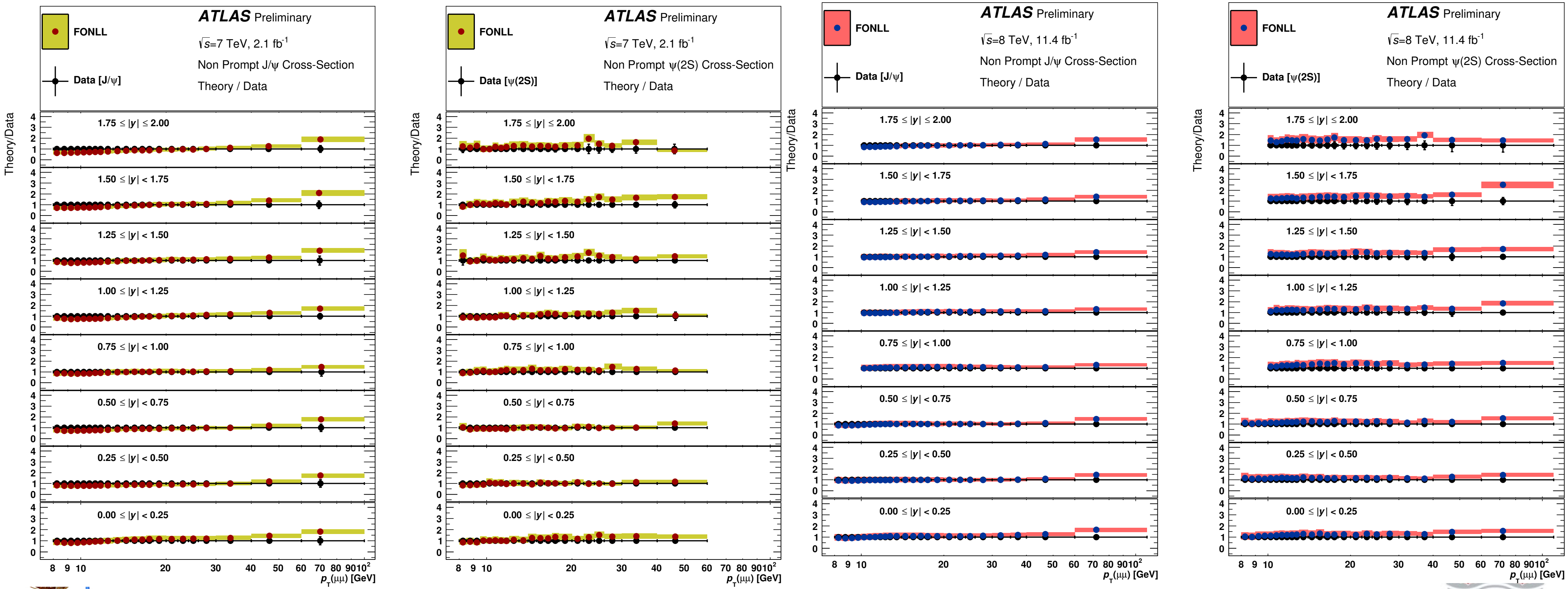
8 TeV

J/Ψ

$\Psi(2S)$

J/Ψ

$\Psi(2S)$

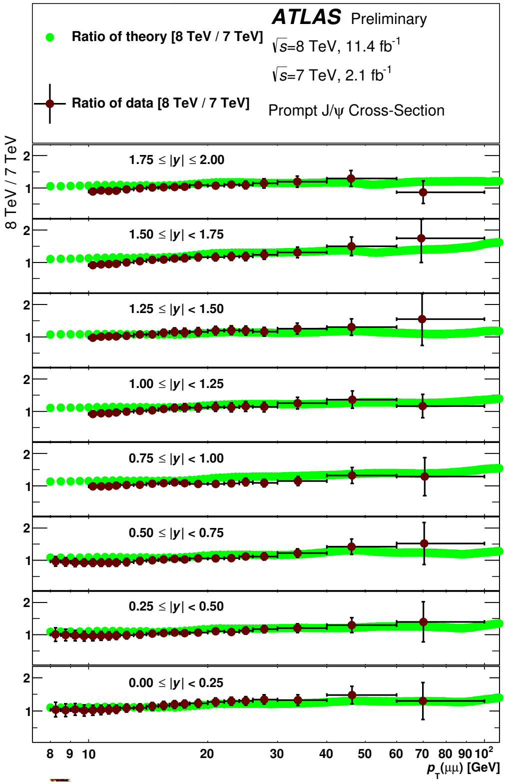


J/Ψ and $\Psi(2S)$: Results – 8 TeV vs 7 TeV

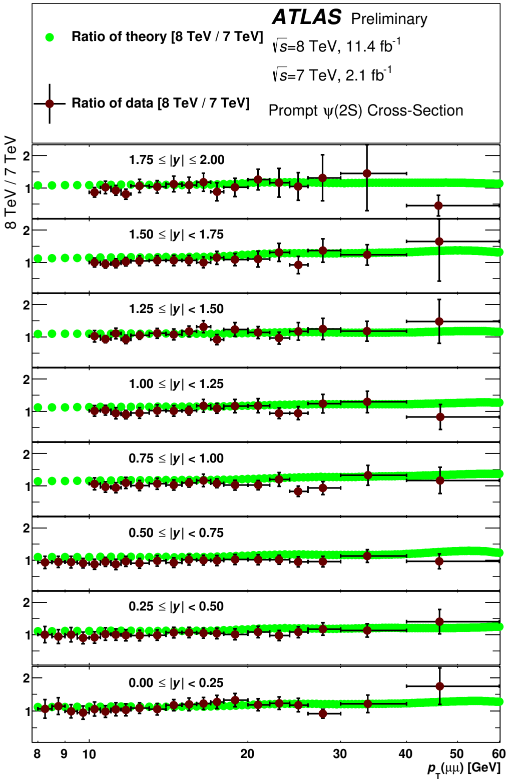
- Ratio of 8 TeV to 7TeV for prompt and non-prompt cross-sections
  - Green: Ratio of theory
  - Black: Ratio of data
- 8 TeV slightly harder pT spectra than at 7 TeV
  - Overall good agreement over several orders of magnitude of cross-section

Prompt

J/Ψ

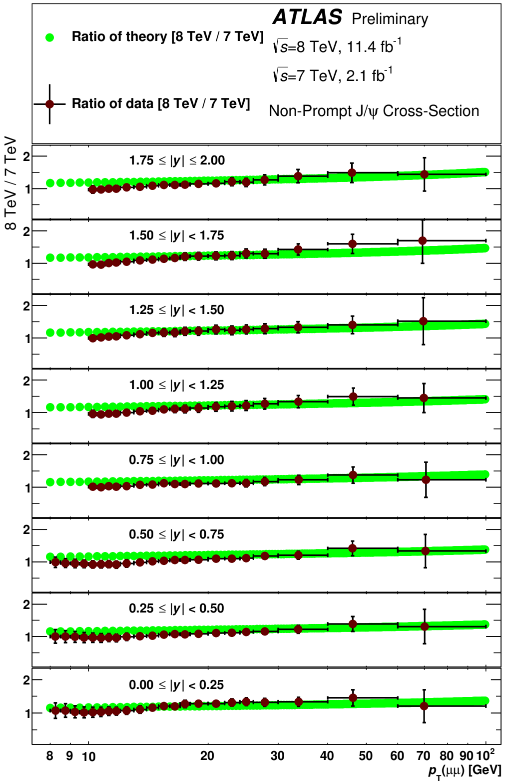


$\Psi(2S)$

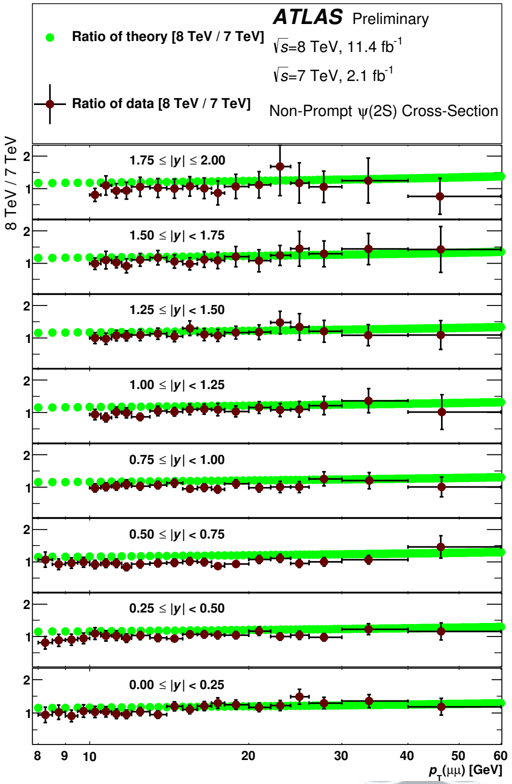


Non-Prompt

J/Ψ

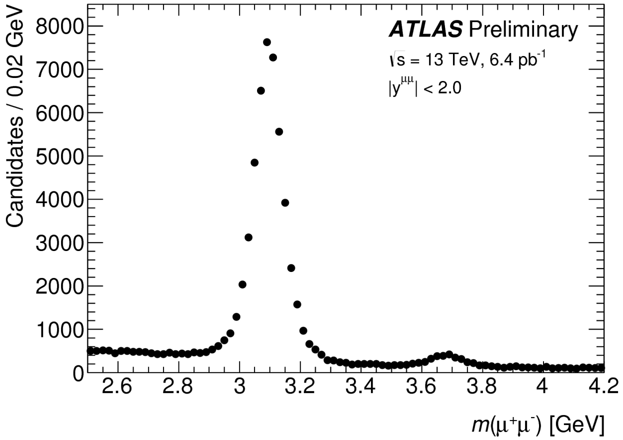


$\Psi(2S)$

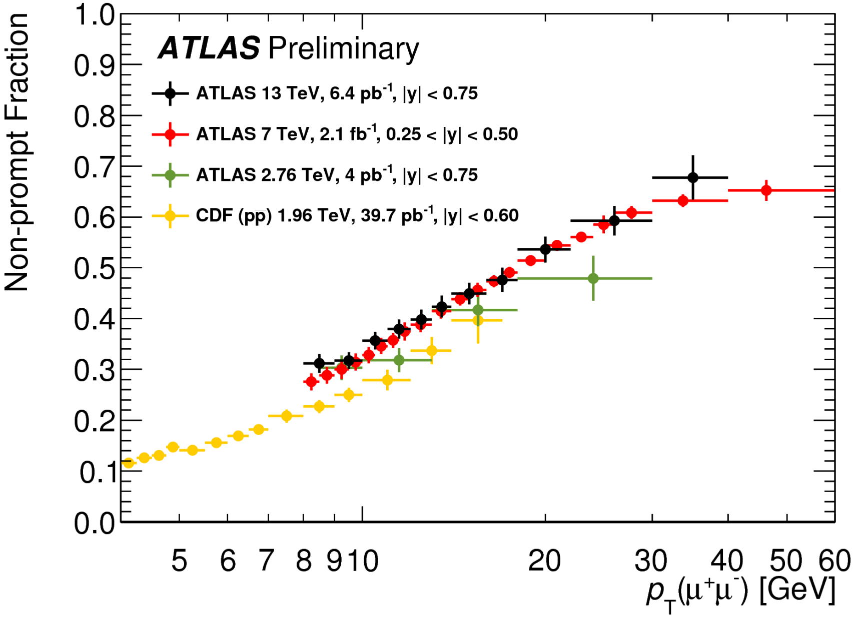


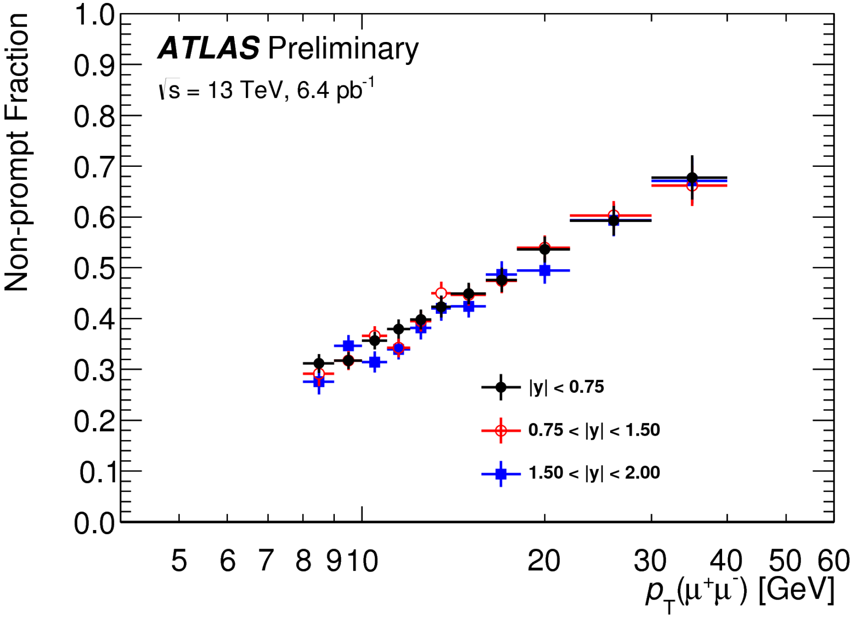
ATLAS-CONF-2015-030

Now getting 13TeV results



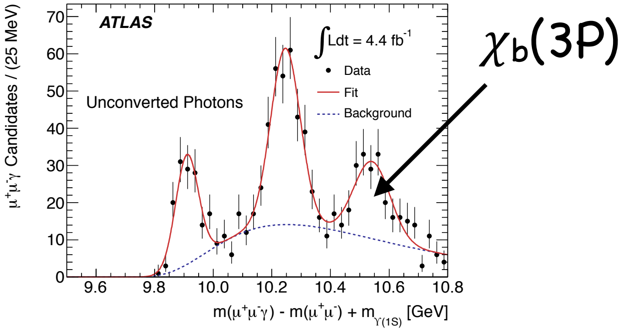
- Already analysed 6.4pb^{-1}, μ <= 27
- $\mu4\mu4$ or $\mu14$ at Level 1
- Can now span 2.76-13TeV in one experiment
- No significant change in fraction with rapidity or between 7 and 13TeV





Phys. Rev. Lett. 113 (2014) 212004

Observations: Excited B_c Meson



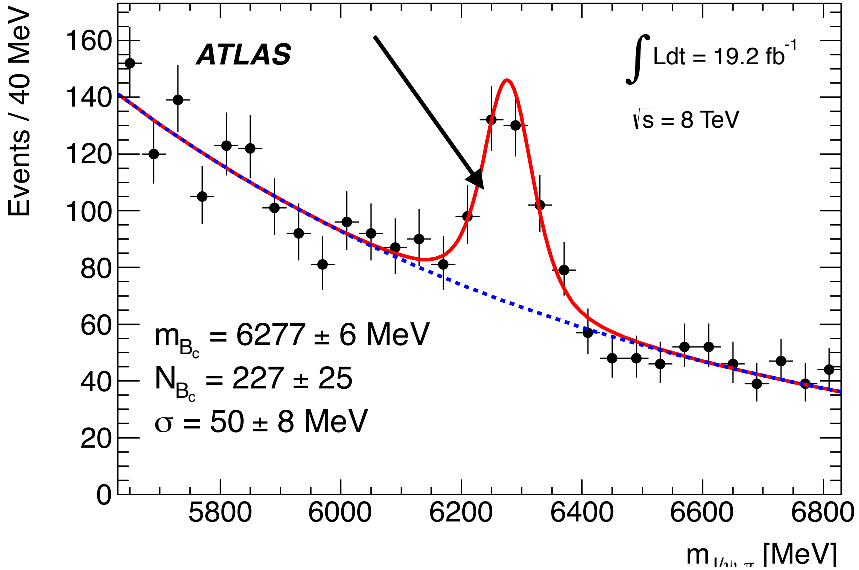
- First observations started with $\chi_b(3P)$ in 2012
- More recent is the B_c^*
- Dataset: 7 TeV (4.9 fb^{-1}) + 8 TeV (19.2 fb^{-1}).

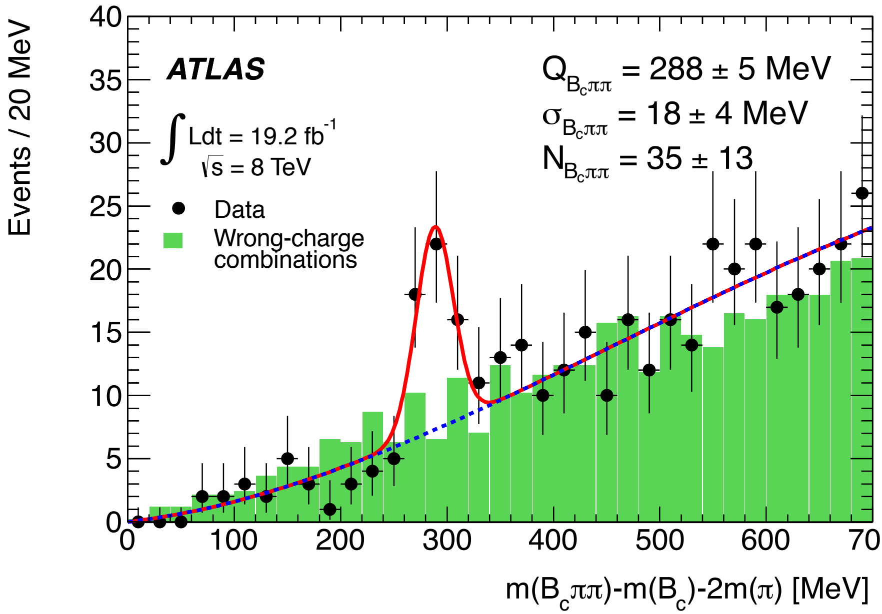
- $B^\pm_c$ reconstructed in $J/\Psi(\mu\mu)\ \pi^\pm$ decay mode
- Selection criteria optimised: $S/\sqrt{(S+B)}$ to $J/\Psi(\mu\mu)\ \pi^\pm$ from MC
- Two additional charged pions combined with $B^\pm_c$ system
- Mass-difference:

$$Q = m(B_c^\pm\pi^+\pi^-) - m(B_c^\pm) - 2\cdot m(\pi^\pm)$$

- New structure observed at mass:
- $M(B_c\pi\pi)$ = 6,842 ± 4 (stat.) ± 5 (syst.) MeV
  - Mass consistent with predictions of $B_c^\pm(2S)$ meson.
- Total significance 5.2σ inc. look-elsewhere

$B_c^\pm \rightarrow J/\psi\pi^\pm$





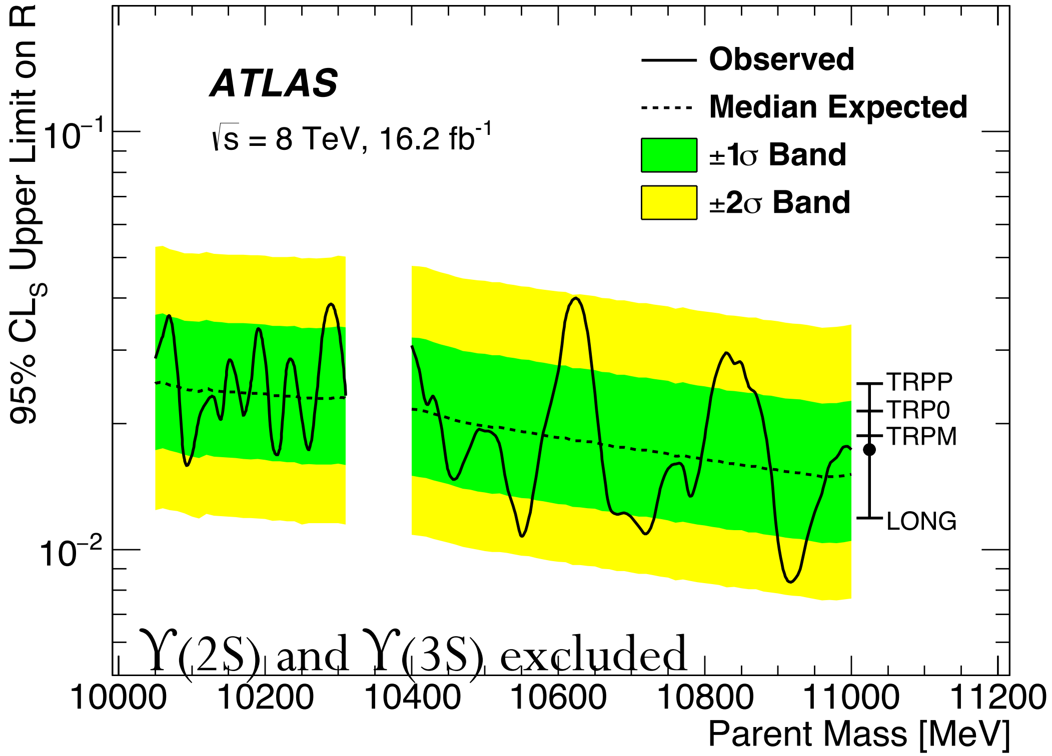
Search for hidden-beauty in $\Upsilon(1S)\pi\pi$

- Search strategy:
  - Perform hypothesis test, 10 MeV intervals: 10–11 GeV (veto Υ(2,3S))
    - Mass window $m_{hypo} \pm 8\sigma$:
  - Ratio relative to Υ(2S)
    -

$$N = N_{2S} \cdot R \cdot \frac{\mathcal{A}}{\mathcal{A}_{2S}} \cdot \frac{\epsilon}{\epsilon_{2S}}$$

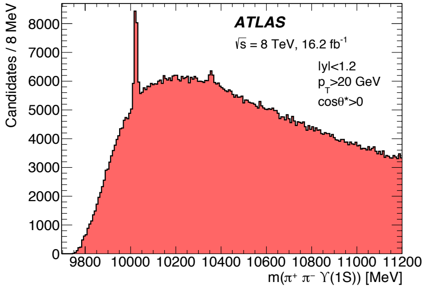
$$R = \frac{\sigma \cdot \mathcal{B}}{\sigma_{2S} \cdot \mathcal{B}_{2S}}$$

    - R=6.56%, X(3872) value



Υ(2S) and Υ(3S) excluded

- Most sensitive X_b production search in mass range $m(\Upsilon(1S)\pi\pi)$ > 10.1 GeV
    - Analogue to X(3872) narrow resonance in the charmonium sector; still unresolved mystery.
  - Limit on R of 0.8 – 4% (@95% CL$_S$), excludes analogous value from X(3872),
    - No evidence for $\Upsilon(1^3D_J)$, Υ(10860) and Υ(11020)

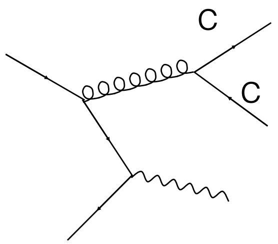


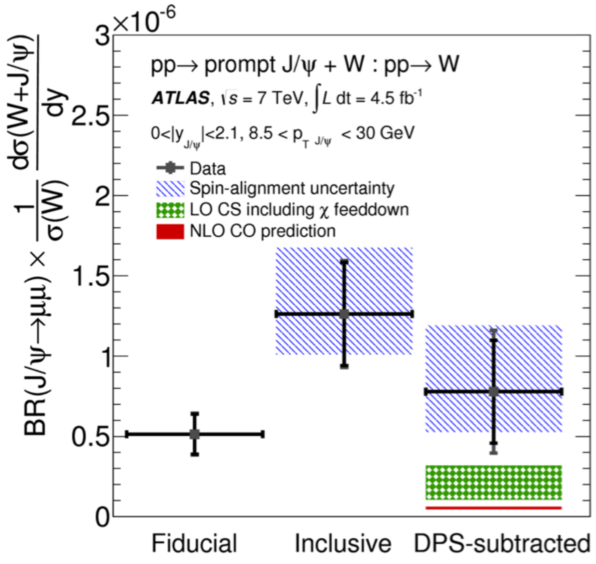
Associated Production

- Associated production: Vector boson + Charmonium
  - Tests of QCD predictions at the Perturbative / non-Pert. boundary
  - Anomalous rate could indicate BSM from charged Higgs, light scalar…
  - Prompt production **C**olour **O**ctet & **C**olour **S**inglet contributions uncertain
  - **S**ingle **P**arton **S**cattering (Vector boson + J/Ψ from same process)
  - **D**ouble **P**arton **S**cattering (Vector boson + J/Ψ from separate processes)

- ATLAS measurement $W^{\pm}$ + prompt J/Ψ @ 7TeV (4.5 fb^{-1}

JHEP 04 (2014) 172

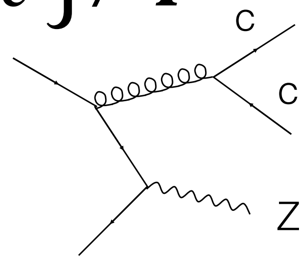


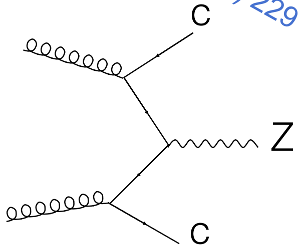


- CS is similar in magnitude to data
- CO significantly smaller contribution (at NLO)
  - higher-order contributions required,
    - or limitations in NRQCD?
- SPS is dominant contribution at low pT(J/Ψ) although considerable DPS is evident.

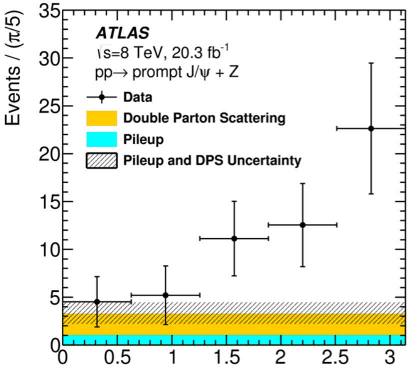
Eur. Phys. J. C75 (2015) 229

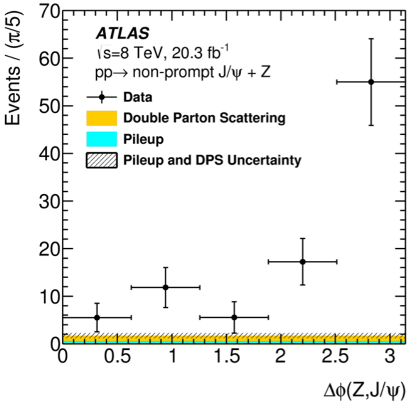
$Z(ee,\mu\mu)$ + (non-)prompt J/Ψ





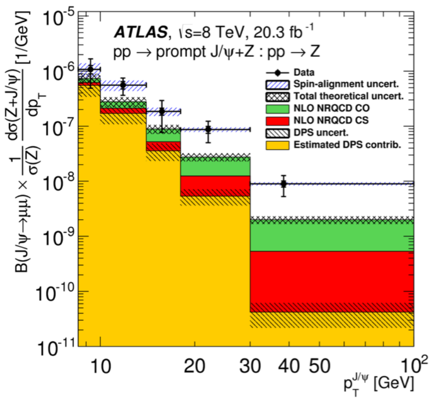
- Relative cross-section of Z decays in association with J/Ψ ($O(10^{-6})$) wrt to inclusive Z decays
    - fiducial cross-section ~ 2 fb.
- 8TeV (20.3 fb^{-1})
- Z boson from high-pT single-lepton triggers

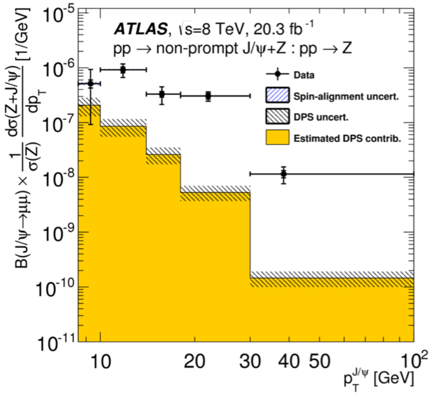




- Azimuthal angle between Z & J/Ψ
- DPS estimates from W+2 jet:
- Limit of max. rate of DPS estimated from prompt $\Delta\varphi$ smallest bin.

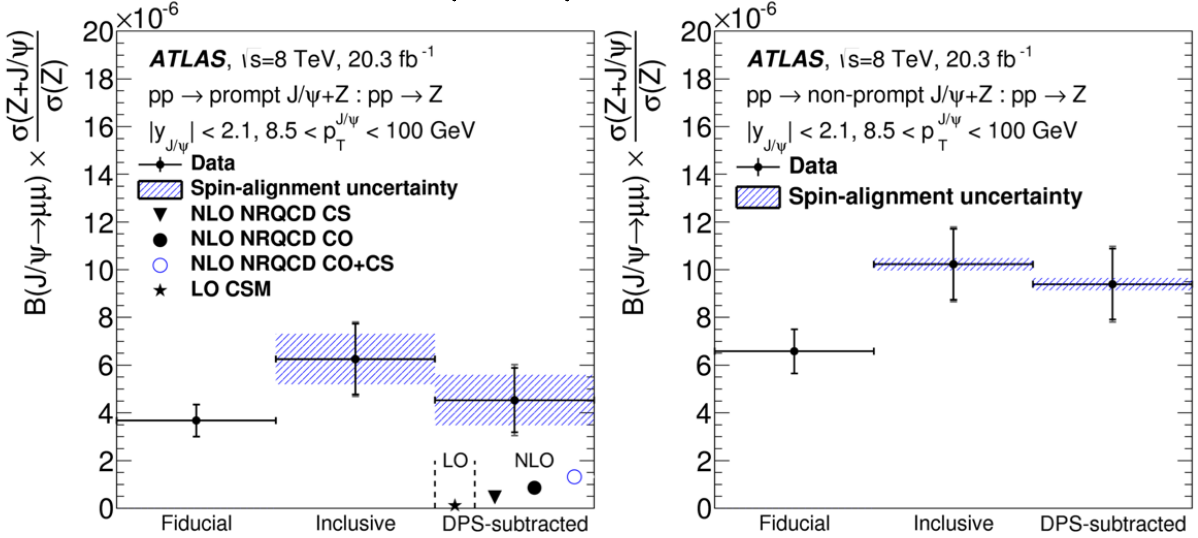
- Differential relative cross-section results vs pT(J/Ψ)
- CO, CS and DPS estimates





Z + (non-)prompt J/Ψ

- First observation of associated Z + J/Ψ in both prompt (5σ) and non-prompt (9σ) modes



- For prompt, CO has higher predicted contribution than CS, however sum of contributions is ~2-5 x lower than data.

- DPS contributes (29±9)% prompt, (8±2) % non-prompt
  - Limit on maximum rate of DPS in signal set;
    - corresponds to minimum limits on DPS Effective cross-section σ_{eff} = 5.3 mb (3.7 mb) at 68% (95%) CL

- Ratio of associated production (non-)prompt to inclusive Z production:

$$R^{\text{incl}}_{Z+J/\psi} = \mathcal{B}(J/\psi \to \mu^+\mu^-)\,\frac{\sigma_{\text{incl}}(pp \to Z + J/\psi)}{\sigma_{\text{incl}}(pp \to Z)}$$

$$\text{prompt: } {}^{\text{p}}R^{\text{incl}}_{Z+J/\psi} = (\ \ 63 \pm 13 \pm 5 \pm 10) \times 10^{-7}$$

$$\text{non-prompt: } {}^{\text{np}}R^{\text{incl}}_{Z+J/\psi} = (102 \pm 15 \pm 5 \pm \ \ 3) \times 10^{-7}$$

|y(J/Ψ)|<2.1
8.5 < pT(J/Ψ) < 100 GeV

B-Physics Measurements

Observation of an excited $B_c^\pm$ meson state with the ATLAS detector	Phys. Rev. Lett. 113 (2014) 212004
Parity violating asymmetry parameter αb and the helicity amplitudes for the decay $\Lambda_b^0 \rightarrow J/\psi\ \Lambda^0$	Phys. Rev. D 89 (2014) 092009
Production cross section of B+ at $\sqrt{s}$ = 7TeV	JHEP 10 (2013) 042
Limit on $B^0_s \rightarrow \mu\mu$ branching fraction based on 4.9 fb-1 of integrated luminosity	ATLAS-CONF-2013-076
Measurement of the Λ_b lifetime and mass	Phys. Rev. D 87 (2013) 032002
Branching fractions of $B_c^+ \rightarrow J/\psi D_s^+$ and $B_c^+ \rightarrow J/\psi D_s^+$ and transverse polarization fraction in the latter decay	arXiv:1507.070 Submitted to EPJC
Observation of Λ_b in the decay $\Lambda_b^0 \rightarrow \psi(2S)\ \Lambda^0$	arXiv:1507.08202 Submitted PLB
ϕ_s and $\Delta\Gamma_s$ time dependent angular analysis of $B^0_s \rightarrow J/\psi\ \phi$	Preliminary New Result
Measurement of b-quark fragmentation fractions fs/fd	arXiv:1507.08925 Submitted to PRL
Associated production of prompt and non-prompt J/ψ mesons and Z boson at $\sqrt{s}$ = 8TeV	Eur. Phys. J. C75 (2015) 229

arXiv:1507.070 Submitted to EPJC

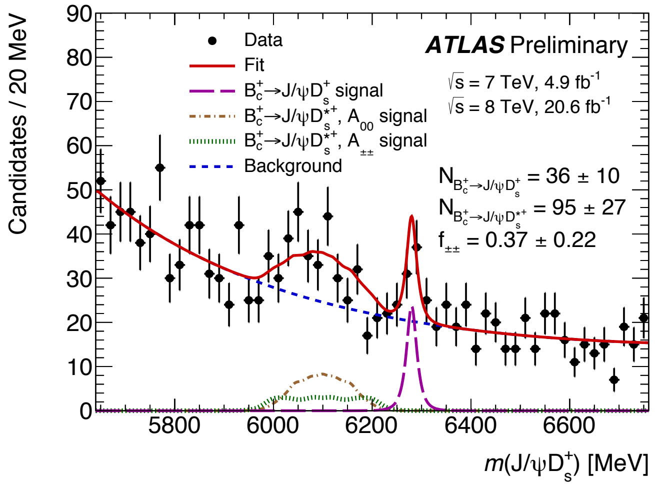
Study of the decays of $B_c^+ \to J/\psi D_s^+$, $B_c^+ \to J/\psi D_s^{*+}$

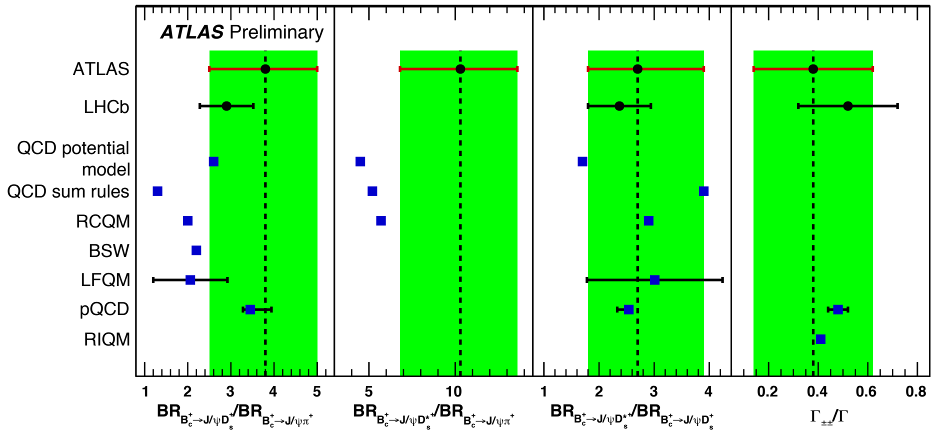
- Events collected from 4.9 fb^{-1} (7 TeV) & 20.6 fb^{-1} (8 TeV) using suite of single-, di-, tri-muon triggers.
  - Reconstructed through the decay:

    $B_c^+ \to J/\psi D_s^+ \quad D_s^+ \to \phi(K^+K^-)\pi^+$
- soft π^0 or photon from D_s^{*+} not reconstructed
  - Cascade vertex fit; pointing, mass & vertex constraints.
- 2-dimensional fit to mass x helicity angle
  - Measure Branching Ratios, relative transverse polarisation

$$\Gamma_{\pm\pm}/\Gamma = \Gamma_{\pm\pm}(B_c^+ \to J/\psi D_s^{*+})/\Gamma(B_c^+ \to J/\psi D_s^{*+})$$

$$\Gamma_{\pm\pm}/\Gamma = 0.38 \pm 0.23\ \text{(stat.)}\ {}^{+0.06}_{-0.07}\ \text{(syst.)}$$





Study of the decays of $B_c^+ \to J/\psi D_s^+$, $B_c^+ \to J/\psi D_s^{*+}$

- Dominant systematic from the signal extraction of $B_c^+ \to J/\psi D_s^{(*)+}$
- Branching ratio results :

$$\mathcal{R}_{D_s^+/\pi^+} = \frac{\mathcal{B}_{B_c^+\to J/\psi D_s^+}}{\mathcal{B}_{B_c^+\to J/\psi\pi^+}} = 3.8 \pm 1.1\ (\text{stat.})\ ^{+0.2}_{-0.6}\ (\text{syst.}) \pm 0.2\ (\text{BF}),$$

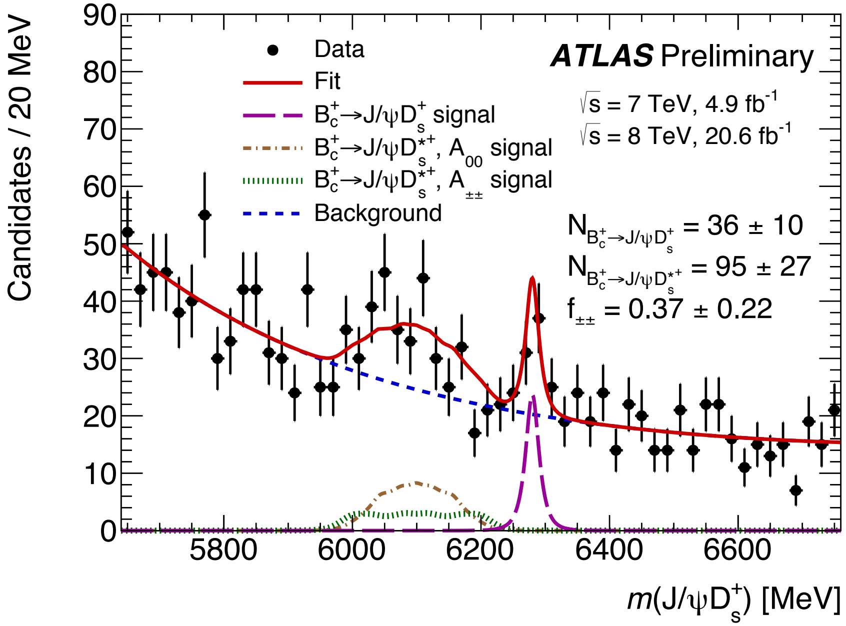
$$\mathcal{R}_{D_s^{*+}/\pi^+} = \frac{\mathcal{B}_{B_c^+\to J/\psi D_s^{*+}}}{\mathcal{B}_{B_c^+\to J/\psi\pi^+}} = 10.3 \pm 3.1\ (\text{stat.})\ ^{+0.8}_{-1.5}\ (\text{syst.}) \pm 0.6\ (\text{BF}),$$

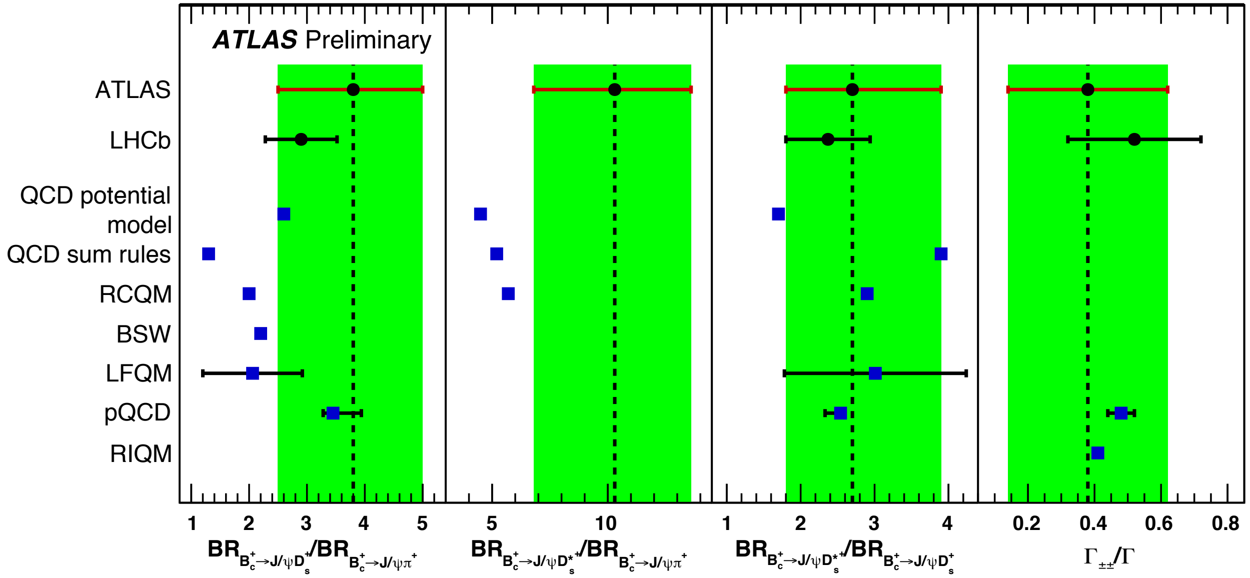
$$\mathcal{R}_{D_s^{*+}/D_s^+} = \frac{\mathcal{B}_{B_c^+\to J/\psi D_s^{*+}}}{\mathcal{B}_{B_c^+\to J/\psi D_s^+}} = 2.7^{+1.1}_{-0.8}\ (\text{stat.})\ ^{+0.4}_{-0.3}\ (\text{syst.}),$$

$$\mathcal{B}_{D_s^+\to\phi(K^+K^-)\pi}$$

- Relative contribution of transverse polarisation:

$$\Gamma_{\pm\pm}/\Gamma = 0.38 \pm 0.23\ (\text{stat.})\ ^{+0.06}_{-0.07}\ (\text{syst.})$$





LHCb :Phys. Rev. D **87** (2013) 112012, New!

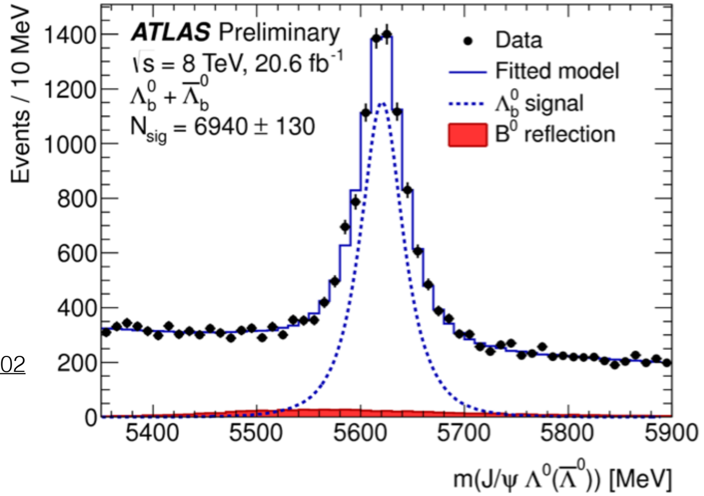
arXiv:1507.08202 submitted PLB

Observation of Λ_b in the decay: $\Lambda_b^0 \rightarrow \psi(2S)\Lambda^0$

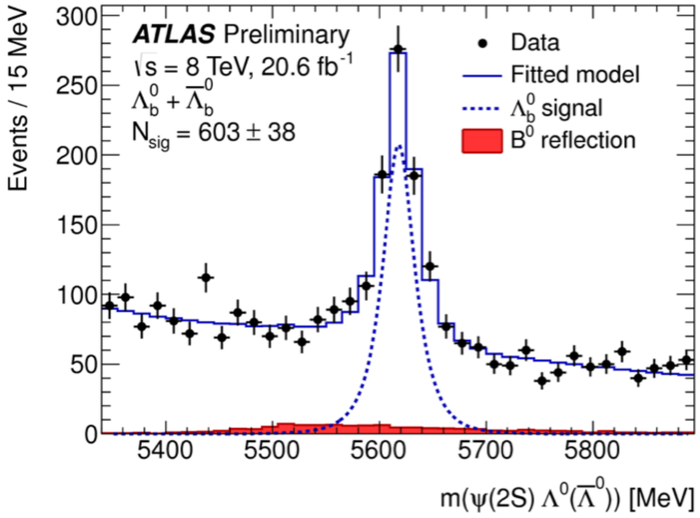
- First observation of decay mode of $\Lambda_b^0 \rightarrow \psi(2S)\Lambda^0$
  - 8 TeV, 20.6 fb^{-1}.
- Determined in the kinematic range:

$$p_T(\Lambda_b^0) > 10\ \mathrm{GeV} \qquad |\eta(\Lambda_b^0)| < 2.1$$

$$\frac{\Gamma(\Lambda_b^0 \rightarrow \psi(2S)\Lambda^0)}{\Gamma(\Lambda_b^0 \rightarrow J/\psi\,\Lambda^0)} = 0.501 \pm 0.033(\mathrm{stat}) \pm 0.016(\mathrm{syst}) \pm 0.011(\mathcal{B}),$$



  - $\Lambda_b \rightarrow \mu\mu\Lambda$ rare decay process Phys. Rev. Lett. 107 (2011) 201802 LHCb-PAPER-2015-009
    - < 0.5% bias to ratio
  - Consistent with ratios from other B decays: Br ~ 0.5-0.8
    - Comparison with theory Br ~ 0.8



arXiv:1507.08925 Submitted to PRL

Fragmentation function ratio f_s/f_d

- Integrated fragmentation function important for studies like $B_s \rightarrow \mu\mu$
- Obtained as a function of η and p_T from $B_s \rightarrow J/\psi\varphi$ & $B_d \rightarrow J/\psi K^*$

$$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0 \to J/\psi\phi)}{\mathcal{B}(B_d^0 \to J/\psi K^{*0})} = 0.199 \pm 0.004(\text{stat}) \pm 0.010(\text{sys}).$$

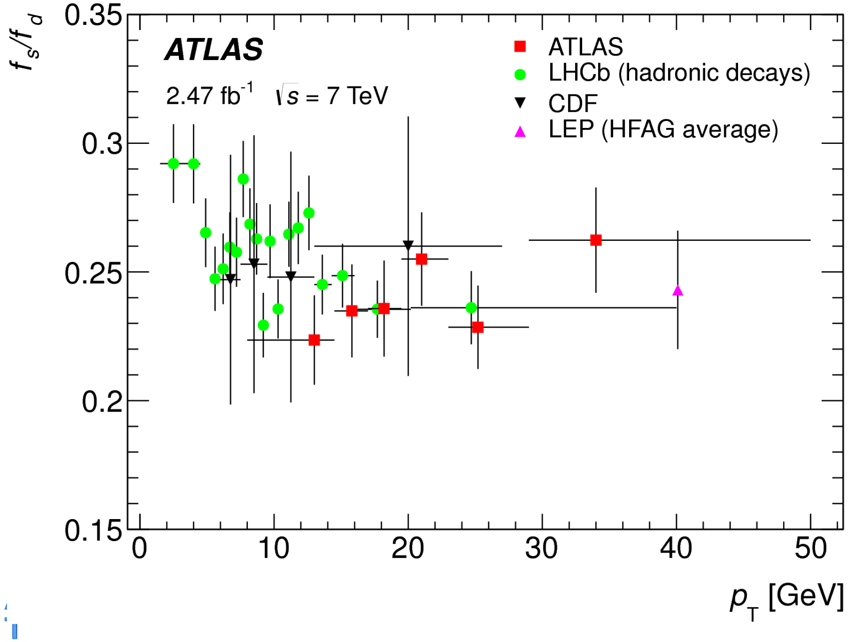
c.f.

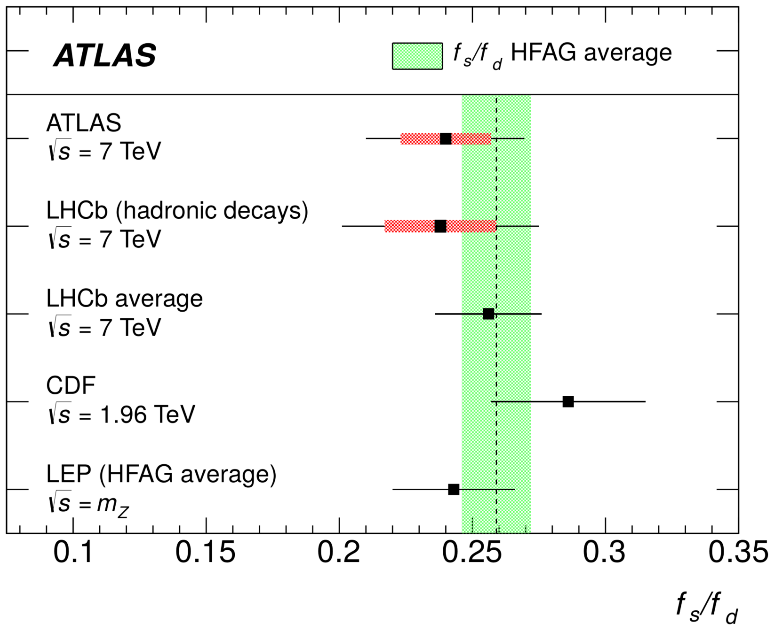
$$\frac{\mathcal{B}(B_s^0 \to J/\psi\phi)}{\mathcal{B}(B_d^0 \to J/\psi K^{*0})} = 0.83^{+0.03}_{-0.02}(\omega_B)^{+0.01}_{-0.00}(f_M)^{+0.01}_{-0.02}(a_i)^{+0.01}_{-0.02}(m_c)$$

pert. QCD Liu, Wang & Xie PRD89 (2014) 094010
http://arxiv.org/abs/1309.0313v2

$$\frac{f_s}{f_d} = 0.240 \pm 0.004(\text{stat}) \pm 0.013(\text{sys}) \pm 0.017(\text{th}).$$

- No evident η or p_T dependence





New!

Measurement of the CP-violating phase, ϕ_s, and the $B^0{}_s$ meson decay width difference in decays of $B_s \to J/\psi\phi$

- Presentation of updated measurement to [PRD 90 (2014) 052007], includes data collected at 8 TeV;
  - Statistical combination with 7TeV result.

- The CP-violating phase angle $\varphi_s^{(SM)} = -0.0363^{+16}_{-15}$ rad.

PRD 84 (2011) 033005

$$\begin{tikzcd}
B_s^0 \arrow[rr] \arrow[dr] & & J/\psi\,\phi \\
& \bar{B}_s^0 \arrow[ur] &
\end{tikzcd}$$

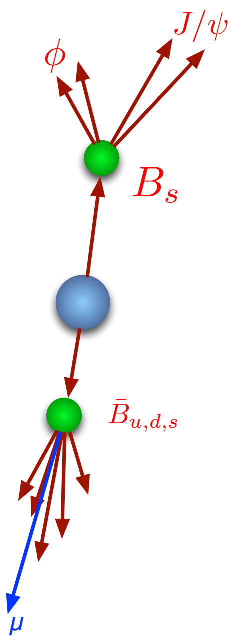
- Width difference $\Delta\Gamma_s^{(SM)} = 0.087 \pm 0.021\ \mathrm{ps}^{-1}$
  - Less sensitive to NP; constrains models

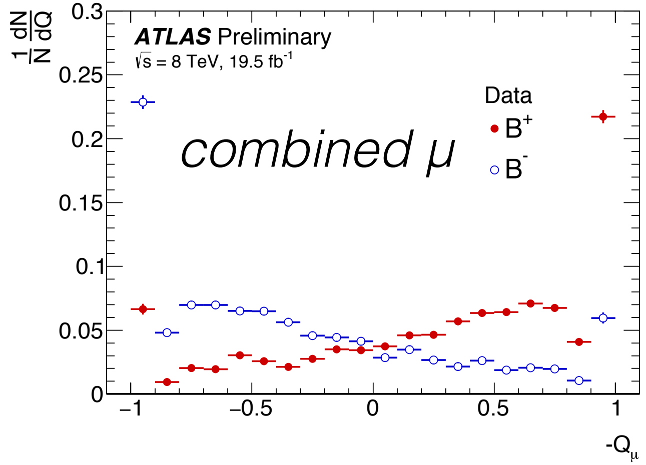
- $B_s \to J/\psi\ \varphi$ PS -> VV decay mode,
  - time-dependent flavour-tagged analysis separates CP-even/-odd states
    - Characterised by 3 angles, choose Transversity basis

- 376k events in 'B_s' range: 5.150 – 5.650 GeV - no Bs lifetime cuts

B-Charge Flavour Tagging

- Identification of B_s flavour at point of production,
  - improved sensitivity, sign ambiguities
- Opposite-side tagging:
  - information from the non-signal b-hadron used to infer the initial flavour of the signal B_s system.
- Self-tagging calibration sample: $B^{\pm} \to J/\psi K^{\pm}$
  - Search for additional lepton in the event (μ,e)
  - If no lepton, look for b-tagged jet (track-based, anti-kT, R=0.8)
  - Untagged events: P=0.5





Tagger	Efficiency [%]	Dilution [%]	Tagging Power
Combined μ	4.12 ± 0.02	47.4 ± 0.2	0.92 ± 0.02
Electron	1.19 ± 0.01	49.2 ± 0.3	0.29 ± 0.01
Segment-tagged μ	1.20 ± 0.01	28.6 ± 0.2	0.10 ± 0.01
Jet-charge	13.15 ± 0.03	11.85 ± 0.03	0.19 ± 0.01
Total	19.7 ± 0.04	27.6 ± 0.06	**1.49 ± 0.02**

Fit Model

- Unbinned likelihood fit: 9 physics parameters

$$\ln \mathscr{L} = \sum_{i=1}^{N} \{ w_i \cdot \ln(f_s \cdot \mathscr{F}_s(m_i, t_i, \sigma_{t_i}, \Omega_i, P(B|Q)) + f_s \cdot f_{B^0} \cdot \mathscr{F}_{B^0}(m_i, t_i, \sigma_{t_i}, \Omega_i, P(B|Q))$$
$$+ (1 - f_s \cdot (1 + f_{B^0}))\mathscr{F}_{\mathrm{bkg}}(m_i, t_i, , \sigma_{t_i}, \Omega_i, P(B|Q))\}$$

- Observables:
  - m(J/ψKK), τ, σ(τ)
  - $\Omega = (\theta_T, \psi_T, \phi_T)$
  - Tagging probability

Lifetime correction weight for small trigger bias at high proper time

Amplitudes **Lifetime** **Tagging**

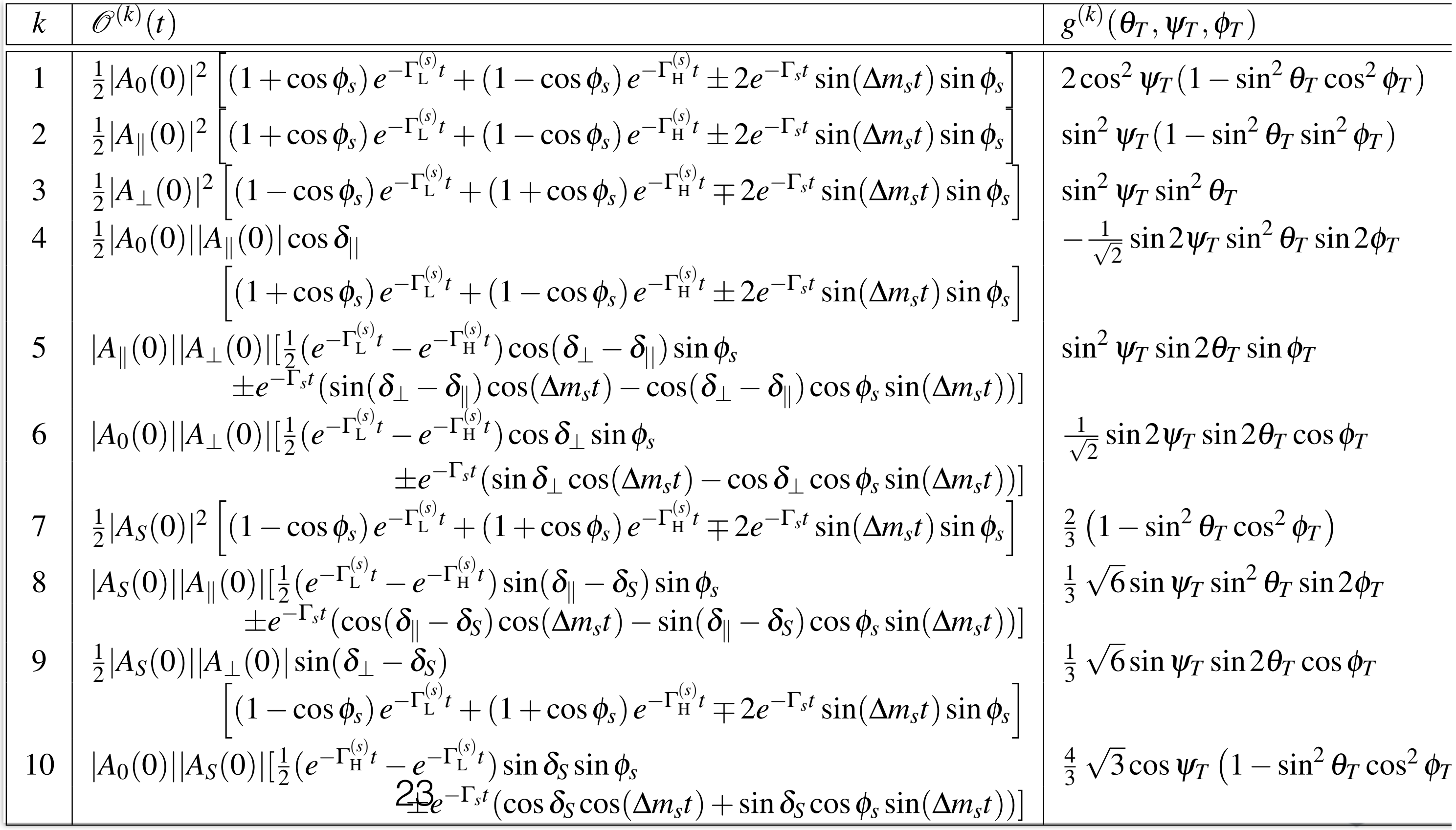
Signal Component:

Mass: Triple-Gaussian

Lifetime: Expo. ⊗ Gaussian (per-candidate errors)

Angular: Lifetime/transversity/ Tagging PDF

$$\frac{d^4\Gamma}{dt\ d\Omega} = \sum_{k=1}^{10} \mathscr{O}^{(k)}(t) g^{(k)}(\theta_T, \psi_T, \phi_T),$$



k	$\mathscr{O}^{(k)}(t)$	$g^{(k)}(\theta_T, \psi_T, \phi_T)$
1	$\frac{1}{2}\lvert A_0(0)\rvert^2 \left[(1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\phi_T)$
2	$\frac{1}{2}\lvert A_\parallel(0)\rvert^2 \left[(1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\sin^2\psi_T(1-\sin^2\theta_T\sin^2\phi_T)$
3	$\frac{1}{2}\lvert A_\perp(0)\rvert^2 \left[(1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\sin^2\psi_T\sin^2\theta_T$
4	$\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\parallel(0)\rvert\cos\delta_\parallel$ $\left[(1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$-\frac{1}{\sqrt{2}}\sin 2\psi_T\sin^2\theta_T\sin 2\phi_T$
5	$\lvert A_\parallel(0)\rvert\lvert A_\perp(0)\rvert[\frac{1}{2}(e^{-\Gamma_{\mathrm{L}}^{(s)}t} - e^{-\Gamma_{\mathrm{H}}^{(s)}t})\cos(\delta_\perp - \delta_\parallel)\sin\phi_s$ $\pm e^{-\Gamma_s t}(\sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp - \delta_\parallel)\cos\phi_s\sin(\Delta m_s t))]$	$\sin^2\psi_T\sin 2\theta_T\sin\phi_T$
6	$\lvert A_0(0)\rvert\lvert A_\perp(0)\rvert[\frac{1}{2}(e^{-\Gamma_{\mathrm{L}}^{(s)}t} - e^{-\Gamma_{\mathrm{H}}^{(s)}t})\cos\delta_\perp\sin\phi_s$ $\pm e^{-\Gamma_s t}(\sin\delta_\perp\cos(\Delta m_s t) - \cos\delta_\perp\cos\phi_s\sin(\Delta m_s t))]$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin 2\theta_T\cos\phi_T$
7	$\frac{1}{2}\lvert A_S(0)\rvert^2 \left[(1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\frac{2}{3}\left(1-\sin^2\theta_T\cos^2\phi_T\right)$
8	$\lvert A_S(0)\rvert\lvert A_\parallel(0)\rvert[\frac{1}{2}(e^{-\Gamma_{\mathrm{L}}^{(s)}t} - e^{-\Gamma_{\mathrm{H}}^{(s)}t})\sin(\delta_\parallel - \delta_S)\sin\phi_s$ $\pm e^{-\Gamma_s t}(\cos(\delta_\parallel - \delta_S)\cos(\Delta m_s t) - \sin(\delta_\parallel - \delta_S)\cos\phi_s\sin(\Delta m_s t))]$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin^2\theta_T\sin 2\phi_T$
9	$\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\perp(0)\rvert\sin(\delta_\perp - \delta_S)$ $\left[(1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin 2\theta_T\cos\phi_T$
10	$\lvert A_0(0)\rvert\lvert A_S(0)\rvert[\frac{1}{2}(e^{-\Gamma_{\mathrm{H}}^{(s)}t} - e^{-\Gamma_{\mathrm{L}}^{(s)}t})\sin\delta_S\sin\phi_s$ $\pm e^{-\Gamma_s t}(\cos\delta_S\cos(\Delta m_s t) + \sin\delta_S\cos\phi_s\sin(\Delta m_s t))]$	$\frac{4}{3}\sqrt{3}\cos\psi_T\left(1-\sin^2\theta_T\cos^2\phi_T\right.$

A_S

$B_s \to J/\psi\phi$: Results

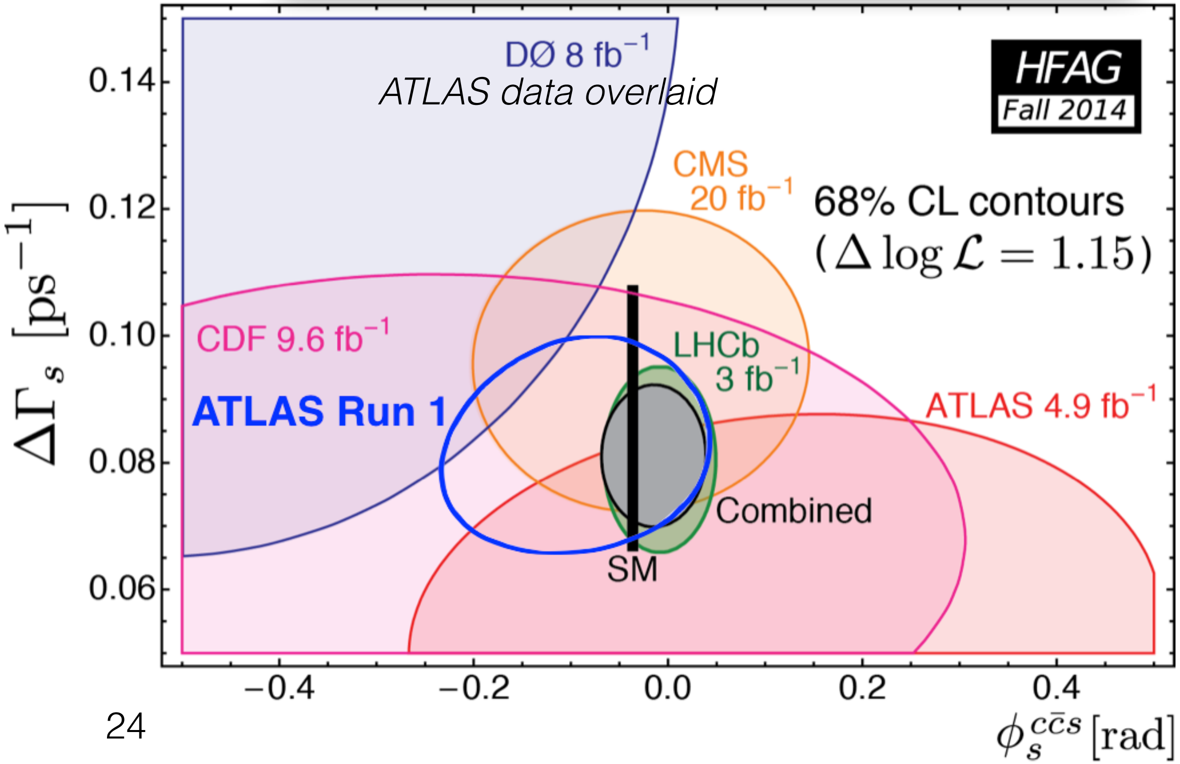
- Preliminary measurement of the time-dependent flavour-tagged CP asymmetry parameters in decays of $B_s \to J/\psi\phi$

- 14.3 fb^{-1} from 8 TeV
  - statistically combined with previous result, 7 TeV 4.9 fb^{-1}

Phys.Rev. D90 (2014) 052007

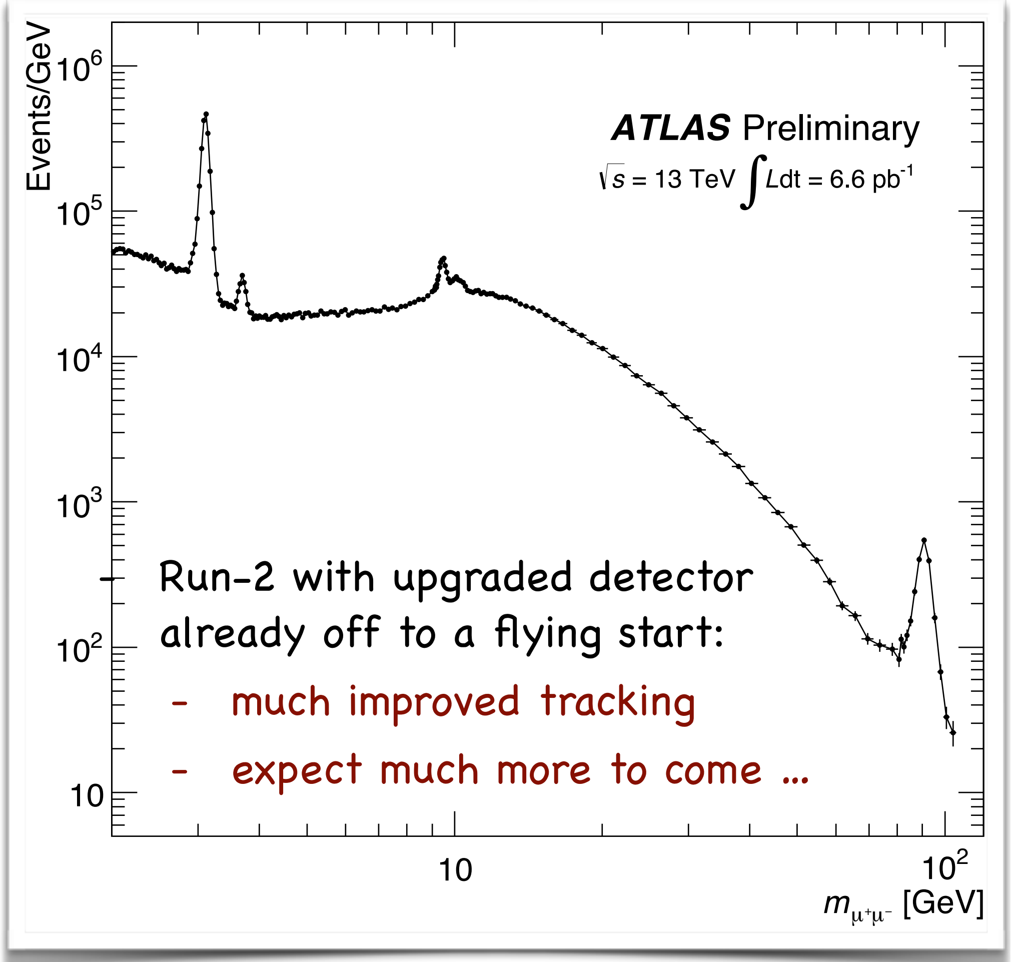
- CP-violating phase, ϕ_s, consistent with other experiments and SM predictions
- $\varphi_s^{(SM)} = -0.0363^{+16}_{-15}$ rad.
- $\Delta\Gamma_s^{(SM)} = 0.087 \pm 0.021\ \text{ps}^{-1}$

Parameter	Value	Stat.	Syst.	
Φ_s	-0.094	0.083	0.033	rad
$\Delta\Gamma_s$	0.082	0.011	0.007	ps^{-1}
Γ_s	0.677	0.003	0.003	ps^{-1}
$\lvert A_{\parallel}(0)\rvert^2$	0.227	0.004	0.006	
$\lvert A_0(0)\rvert^2$	0.515	0.004	0.002	
$\lvert A_S(0)\rvert^2$	0.086	0.007	0.012	
$\delta_\perp$	4.13	0.34	0.15	rad
$\delta_\parallel$	3.16	0.13	0.05	rad
$\delta_\perp$ **-** δ_S	-0.08	0.03	0.01	rad



Summary

- ATLAS B-Physics and Quarkonium programme from Run-I provided significant contributions, with:
  - Observations of (and searches for) new states
    - Also search for H & Z➔ bbγ, ccγ (PRL 114 (2015) 121801)
  - BSM processes
  - Precise mass, lifetime, branching fraction measurements
  - CP violation
- Still many interesting run-I results to be released, and Run 2 perfect for CPV
- Quarkonium sector explored in variety of decay modes and feed-down processes,
  - Synergy across LHC experiments with comprehensive measurements covering $0 < pT < 120$ GeV, and $y < 4.5$, to constrain next generation of theoretical models.
- No significant deviations from SM expectations observed across the range of measurements shown



Run-2 with upgraded detector already off to a flying start:
- much improved tracking
- expect much more to come …