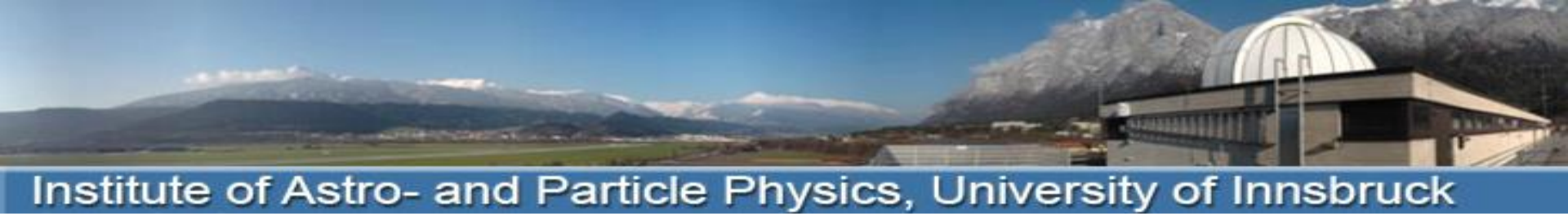
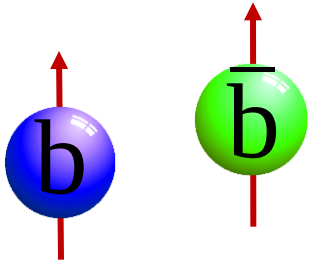


B-Physics and Quarkonia Results from ATLAS



E. Kneringer – University of Innsbruck

on behalf of the ATLAS collaboration

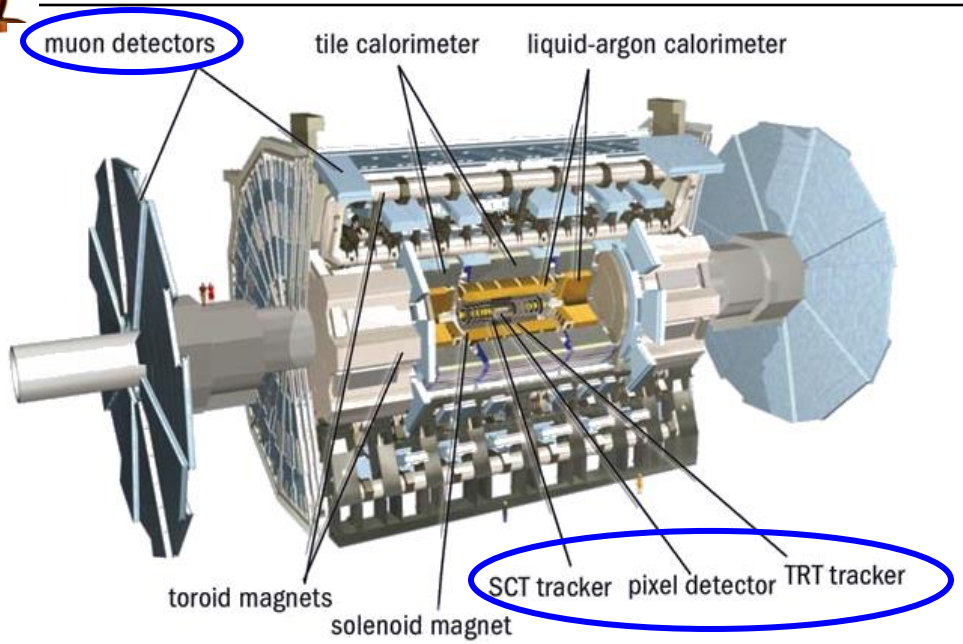
LISHEP2015, Aug. 2-9, Manaus, Brasil

Overview

Selected measurements and results

- The ATLAS experiment
- **Studies of Quarkonia**
  - *Spectroscopy*
  - *Cross sections*: J/ψ and ψ(2S) ATLAS-CONF-2015-024 ATLAS-CONF-2015-030
  - *1st result from run 2*: Non-prompt J/ψ production fraction
  - *Associated production*: Z + (non-)prompt J/ψ Eur. Phys. J. C75 (2015) 229
- **B-Physics results**
  - Excited $B_c^{\pm}$ meson states Phys. Rev. Lett. 113 (2014) 212004
  - Observation of Λ_b in the decay $\Lambda_b \rightarrow \psi(2S)\ \Lambda$ arXiv:1507.08202
  - $B_s \rightarrow J/\psi\ \phi$ and the CP-violating weak mixing phase ϕ_S Phys. Rev. D 90 (2014) 052007 + prelim. new result
- Summary

The ATLAS experiment

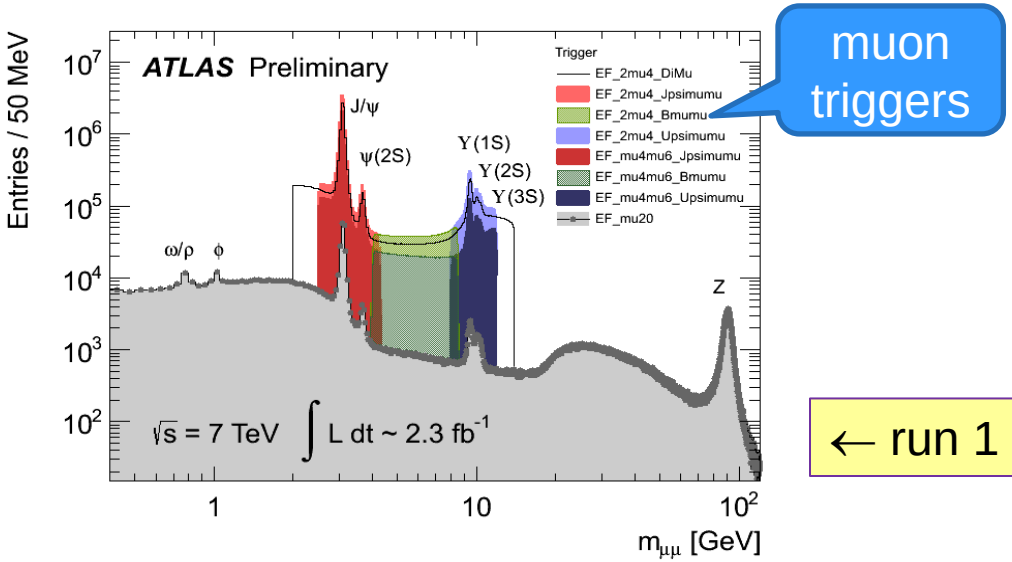


The ATLAS collaboration

38 Countries
178 Institutions
~2850 Scientific Authors

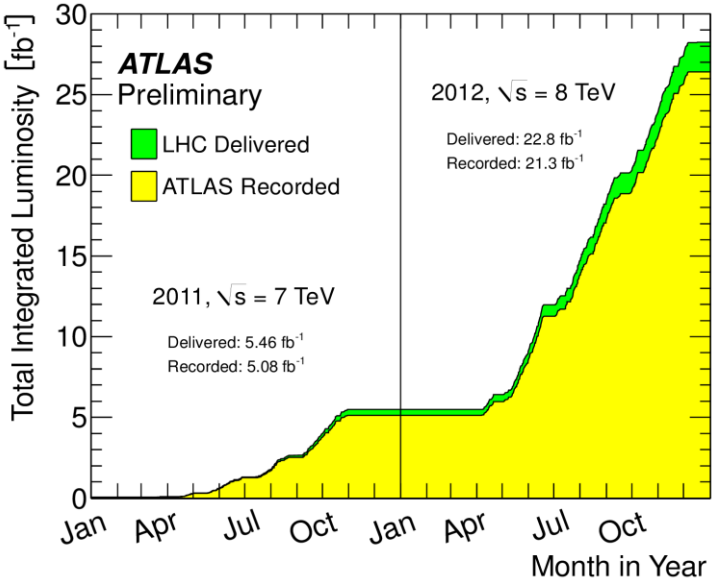
data recorded

7 TeV : 5.1 fb^{-1}
8 TeV : 21.3 fb^{-1}



muon triggers

← run 1 →



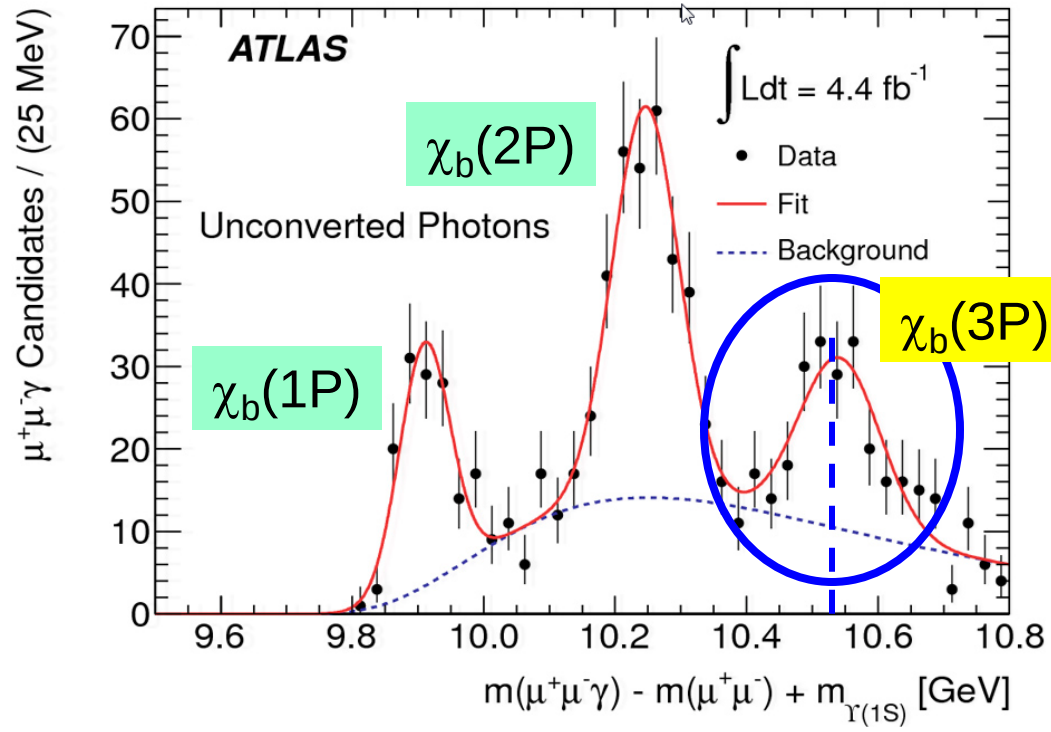
ATLAS 2011: $\chi_b(3P) \rightarrow \mu^+\mu^-\gamma$

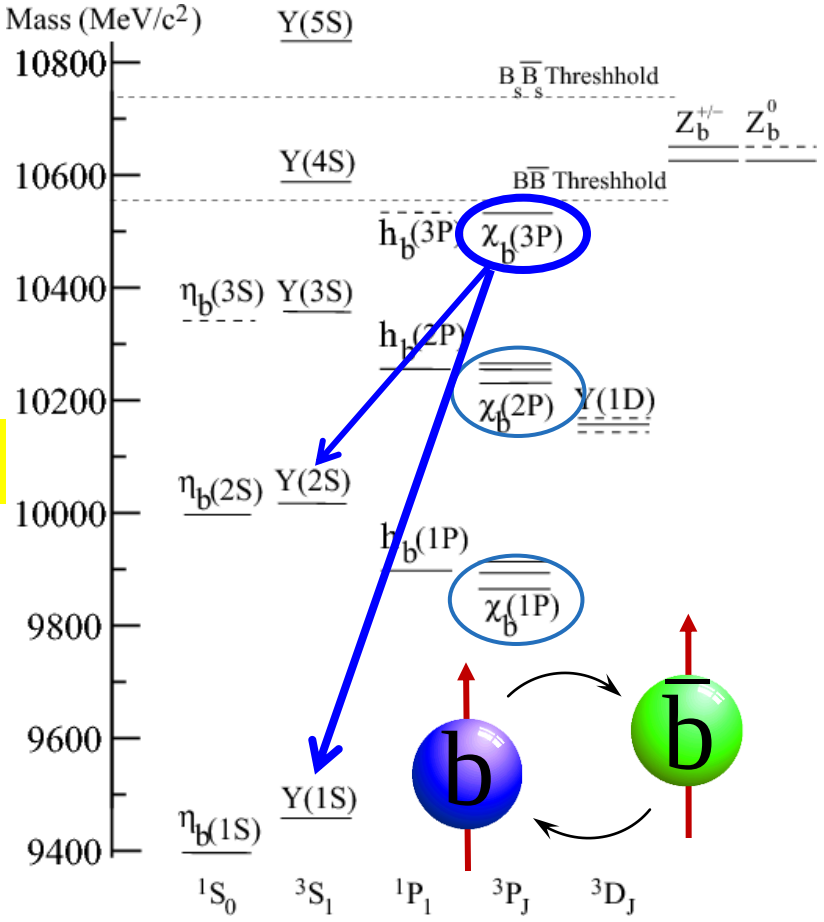
7 TeV

Phys. Rev. Lett. 108 (2012) 152001

Quarkonium spectroscopy

ATLAS discovers its **first new particle**!



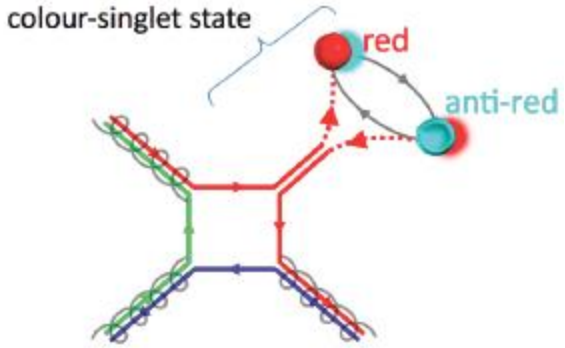


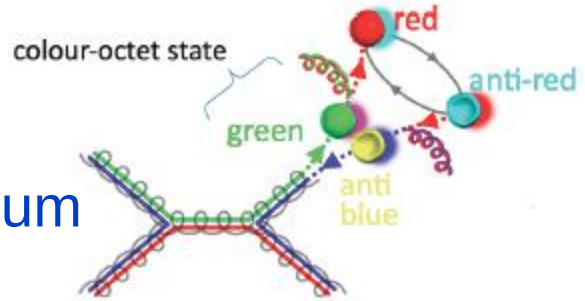
$m(\chi_b(3P)) = (\mathbf{10.530} \pm 0.005 \pm 0.009)$ GeV

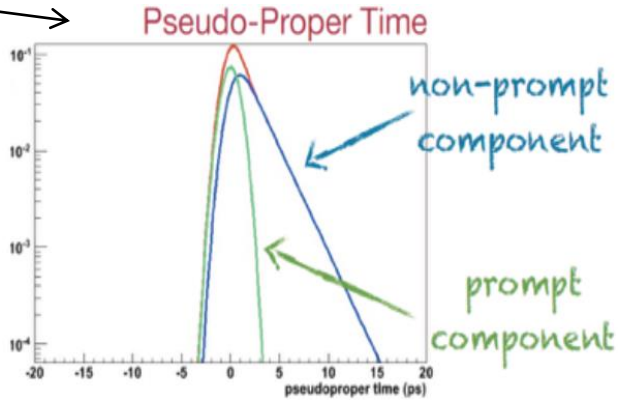
Basics on Quarkonia

- discovered about 40 years ago
- provide unique opportunity to study QCD
- not fully understood, still challenges
  - polarization, hidden flavor

1. many **theoretical models** available
   - non-relativistic QCD (**NRQCD**), …
   - models differ in prediction of:
     - **Color Singlet** prod. processes
     - **Color Octet** prod. processes
2. different **production modes** of Charmonium
   - **prompt** (from QCD processes)
   - **non-prompt** (from decays of B hadrons)
     - cut on pseudo-proper time to separate
3. **observables**
   - **differential cross sections**
     - absolute and relative
   - spin alignment
   - **associated production**







New!

J/ψ and ψ(2S) differential *prompt* and *non-prompt* production cross-sections

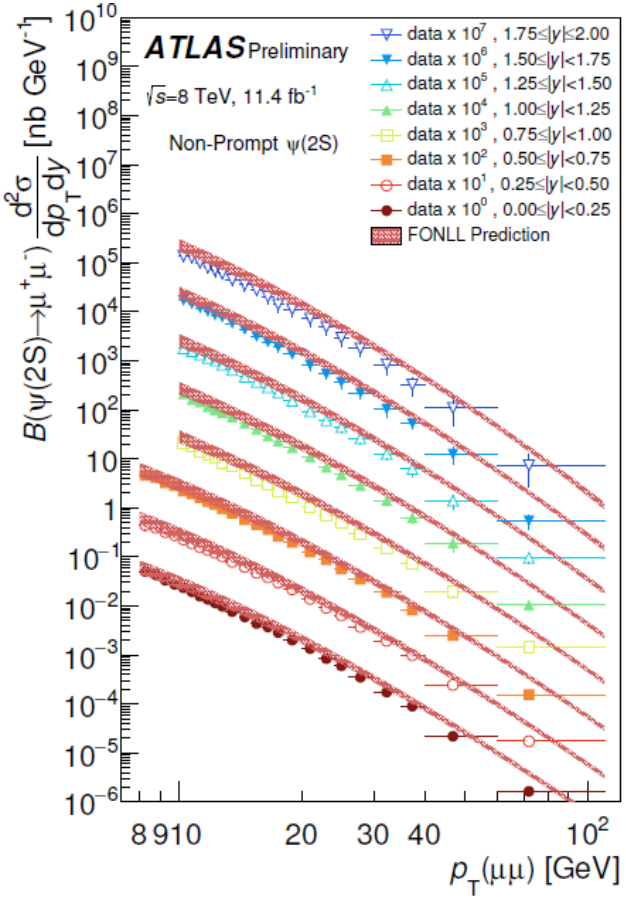
(using their exclusive di-muon decay modes)

- Double-differential measurements (p_T, rapidity) (22 bins, 8 bins)
  - Production cross sections
  - Production ratios of ψ(2S) to J/ψ
  - Non-prompt production fractions
- Comparisons
  - … with theory (*NLO NRQCD*, *FONLL*)
  - … of cross-sections 8 TeV with 7 TeV
  - … with results from other LHC experiments

Results – ψ(2S)@8TeV

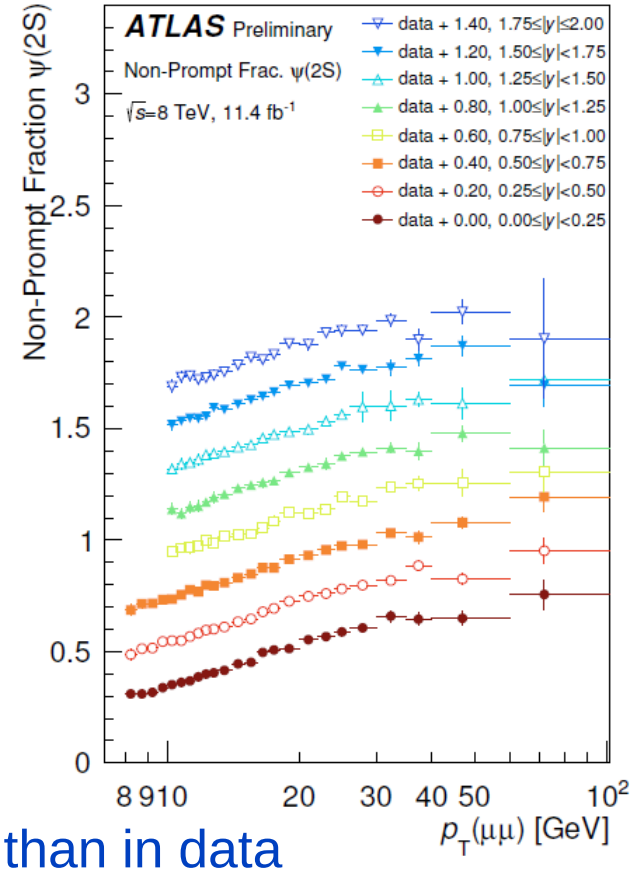
- selected plots:

non-prompt diff. cross-section:



non-prompt fraction:

$$\frac{\frac{\mathrm{d}\sigma}{\mathrm{d}p_T}(pp \to bb \to \psi(2S)+X)}{\frac{\mathrm{d}\sigma}{\mathrm{d}p_T}\left(pp \xrightarrow{incl.} \psi(2S)+X\right)}$$



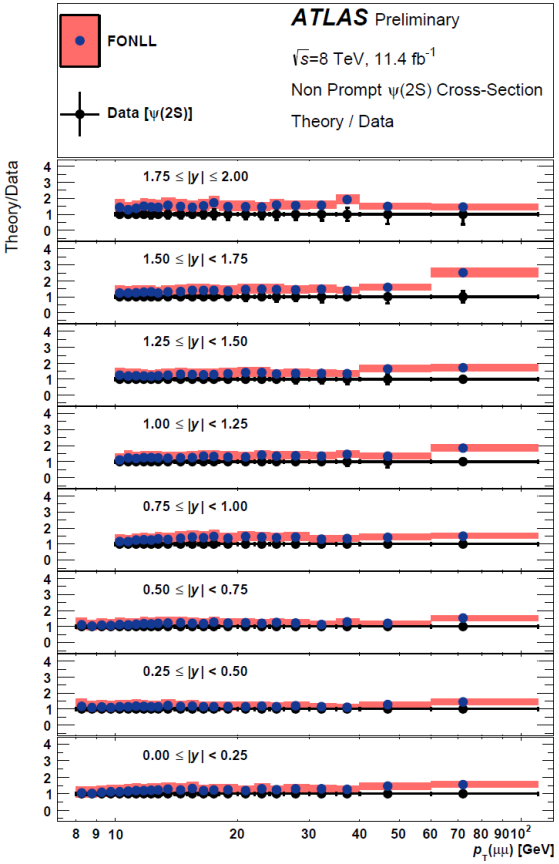
- p_T spectra tend to be harder in theory than in data
- for ψ(2S) theory tends to predict a slightly higher yield than observed

Results – ψ(2S)@8TeV

- selected plots:

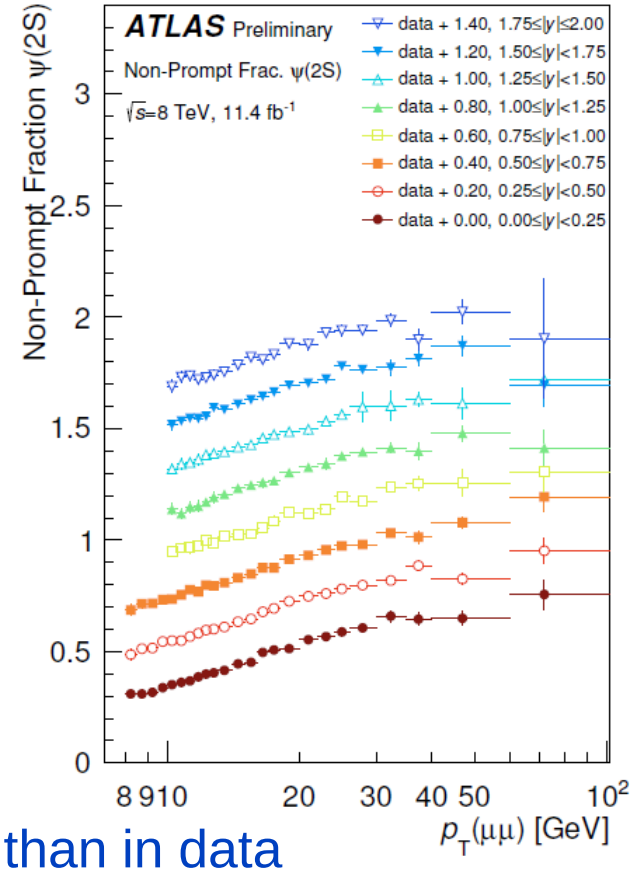
non-prompt diff. cross-section:

Theory / Data



non-prompt fraction:

$$\frac{\frac{d\sigma}{dp_T}(pp \rightarrow bb \rightarrow \psi(2S)+X)}{\frac{d\sigma}{dp_T}\left(pp \xrightarrow{incl.} \psi(2S)+X\right)}$$

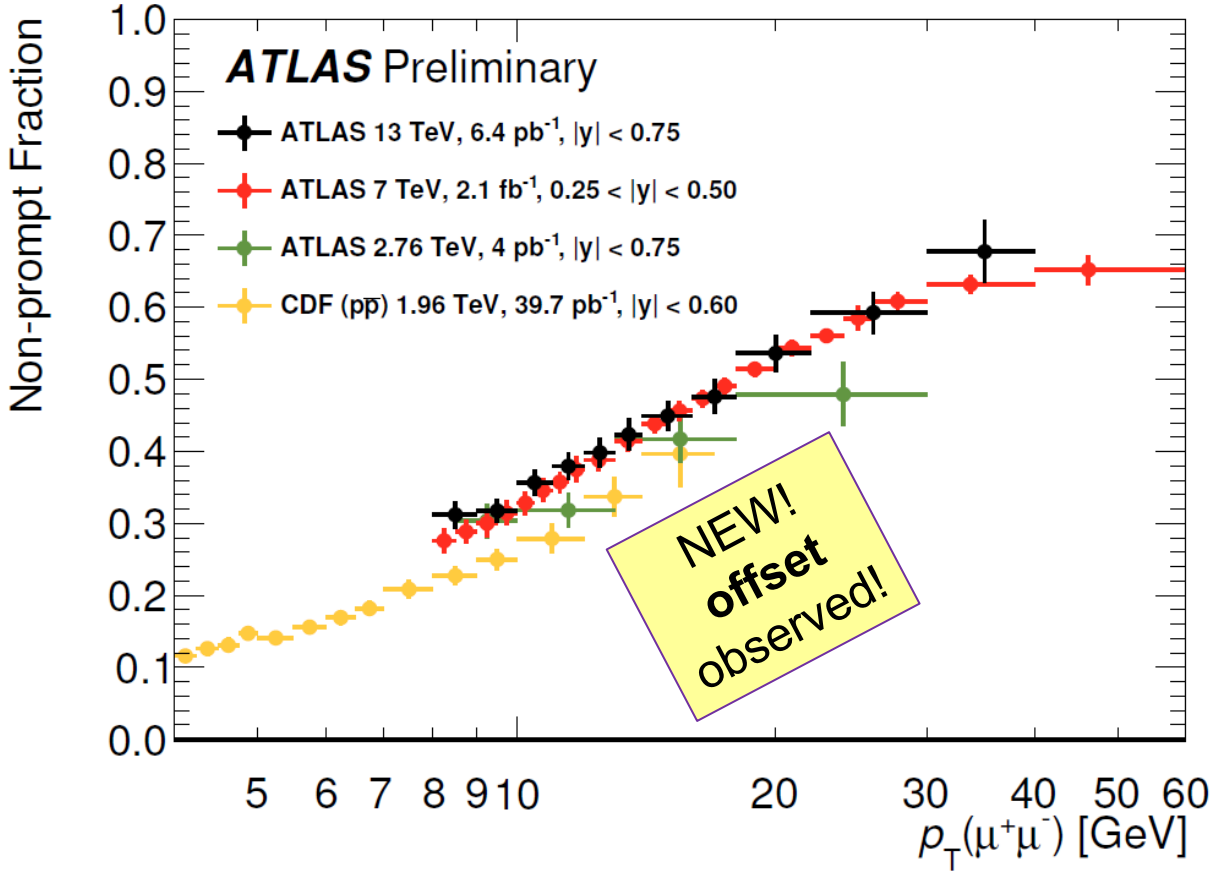


- p_T spectra tend to be harder in theory than in data
- for ψ(2S) theory tends to predict a slightly higher yield than observed

First run 2 result: J/ψ@13TeV

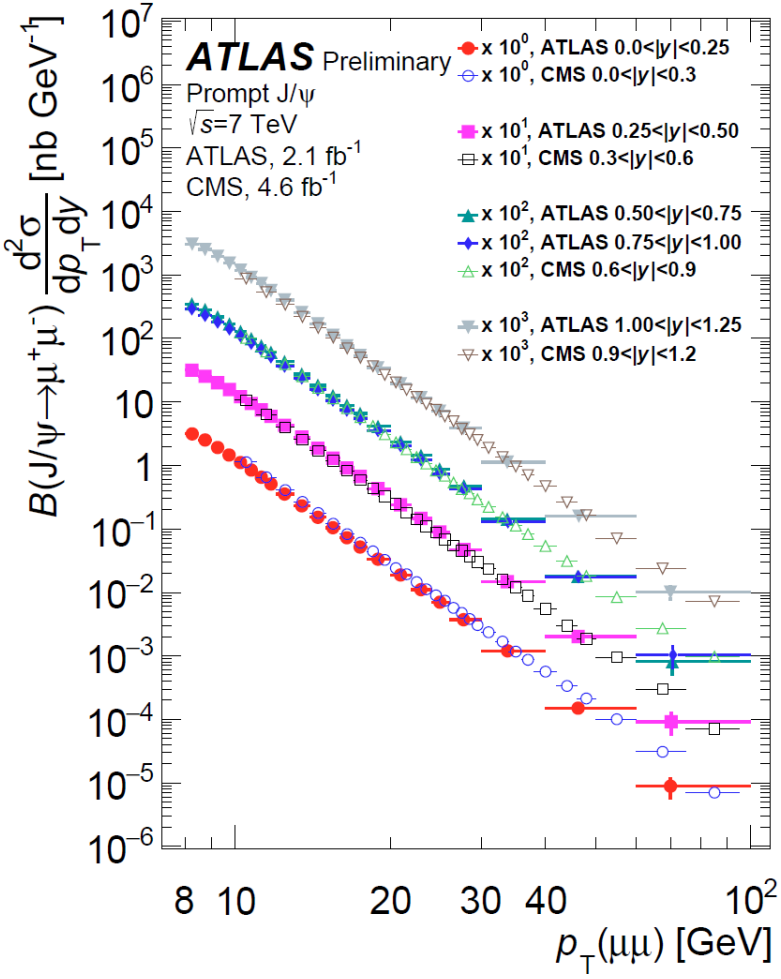
- **Differential non-prompt J/ψ production fraction** $\frac{\mathrm{d}\sigma}{\mathrm{d}p_T}(pp \to bb \to J/\psi{+}X) \Big/ \frac{\mathrm{d}\sigma}{\mathrm{d}p_T}\left(pp \xrightarrow{incl.} J/\psi{+}X\right)$

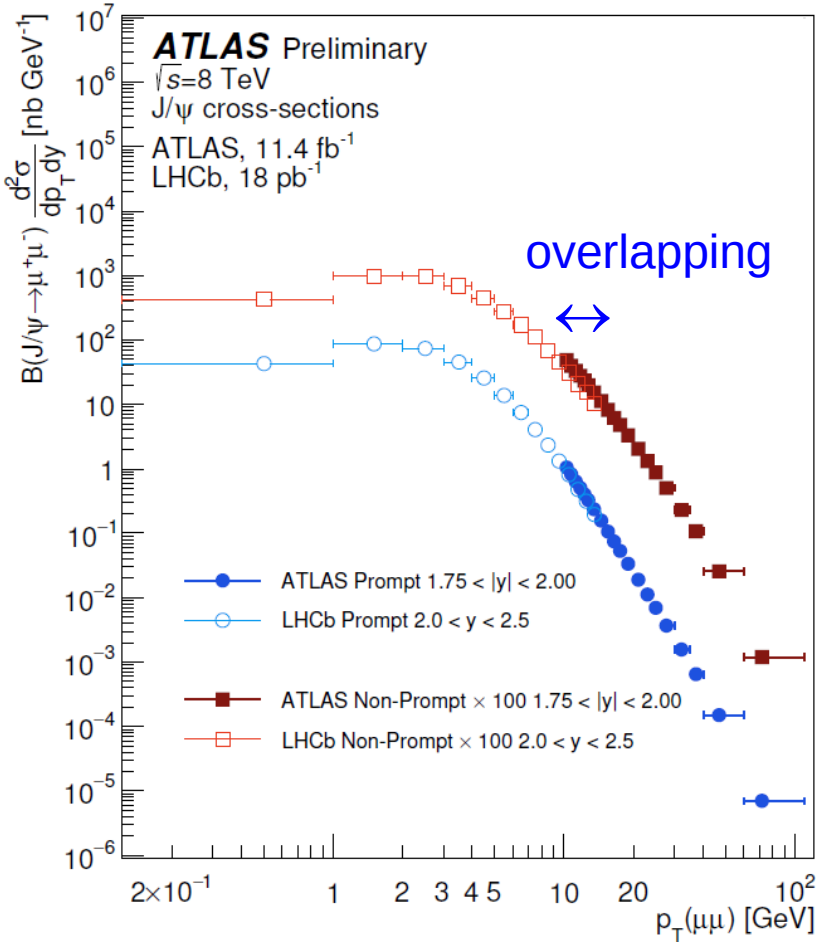
  using di-muon decay mode $J/\psi \to \mu^+\mu^-$
  - p_T dependence: **0.3** @8GeV to **0.7** @40GeV
  - $\sqrt{s}$ dependence: **offset** between (1.96, 2.76) TeV and (**7**,**13**) TeV data



Comparison with other LHC experiments

- **Prompt and non-prompt J/ψ cross sections**
  - CMS left: for overlapping rapidity slices (7 TeV data)
  - LHCb right: for a similar but non-overlapping rapidity interval (8 TeV data)



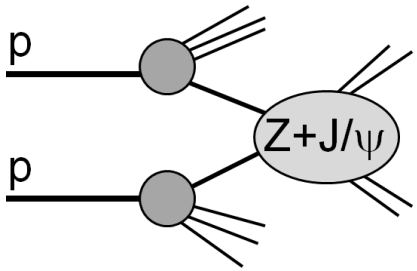


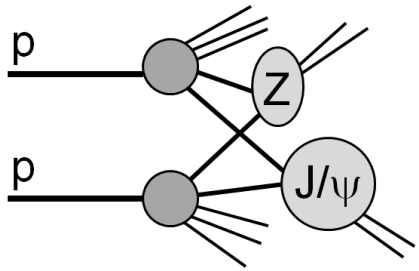
Associated production:

Charmonium (J/ψ) + Vector boson (Z)

J/ψ + Z production

- **single** parton scattering vs. **double** parton scattering
  - distinguished statistically using discriminating variable ($\Delta\phi$)





e^+e^-, $\mu^+\mu^-$

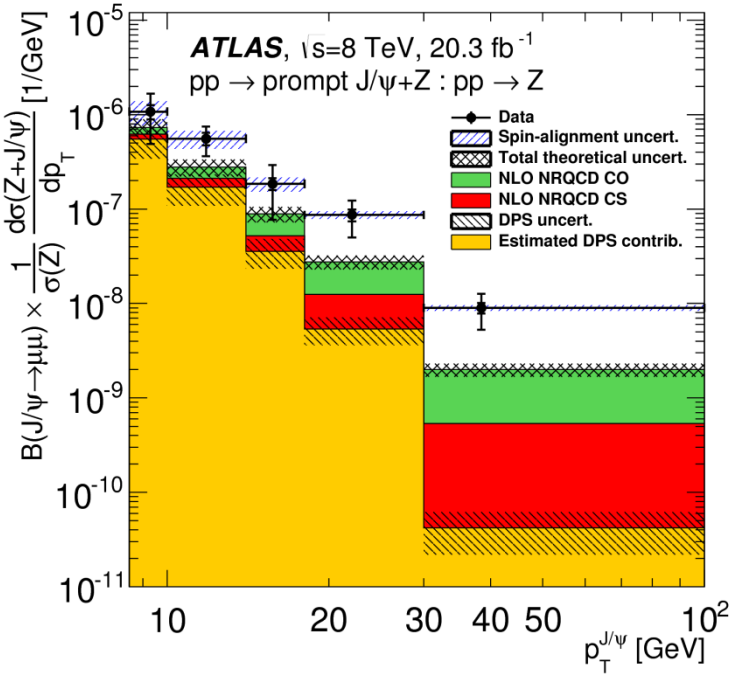
$\mu^+\mu^-$

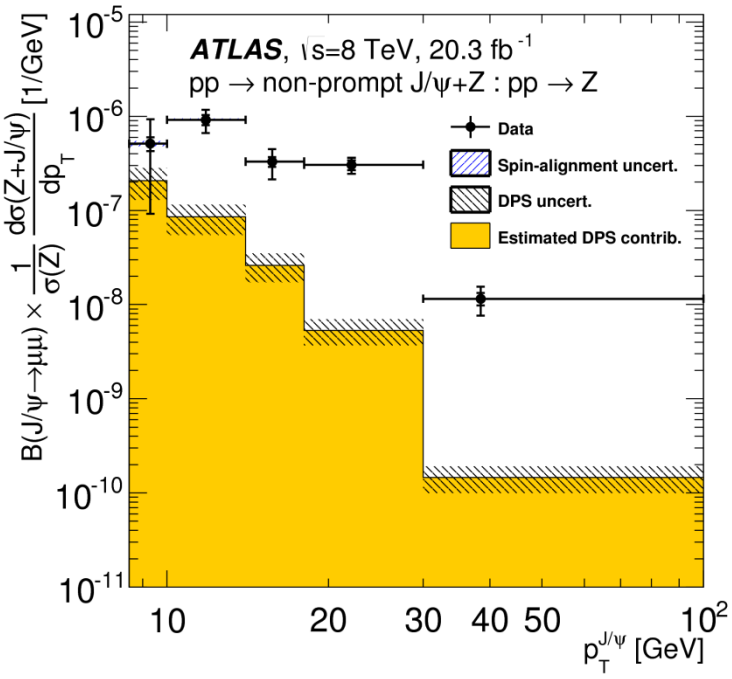
J/ψ production

- **prompt**
  - **color singlet** / **color octet** contributions
- **non-prompt**
  - distinguished by means of a cut on pseudo-proper time

Z + (non-)prompt J/ψ results

- First observation of (Z + J/ψ) in both prompt (5σ) and non-prompt (9σ) associated production modes
- Differential cross-section vs. $p_T(J/\psi)$, normalized to inclusive Z cross section
  - for prompt production: **color octet** (CO), **color singlet** (CS) and **double parton scattering** (DPS) contributions overlaid
    - CO has factor 2 higher predicted contribution than CS, sum of expected contributions is 2x - 5x lower than data, however, error bars are still large!





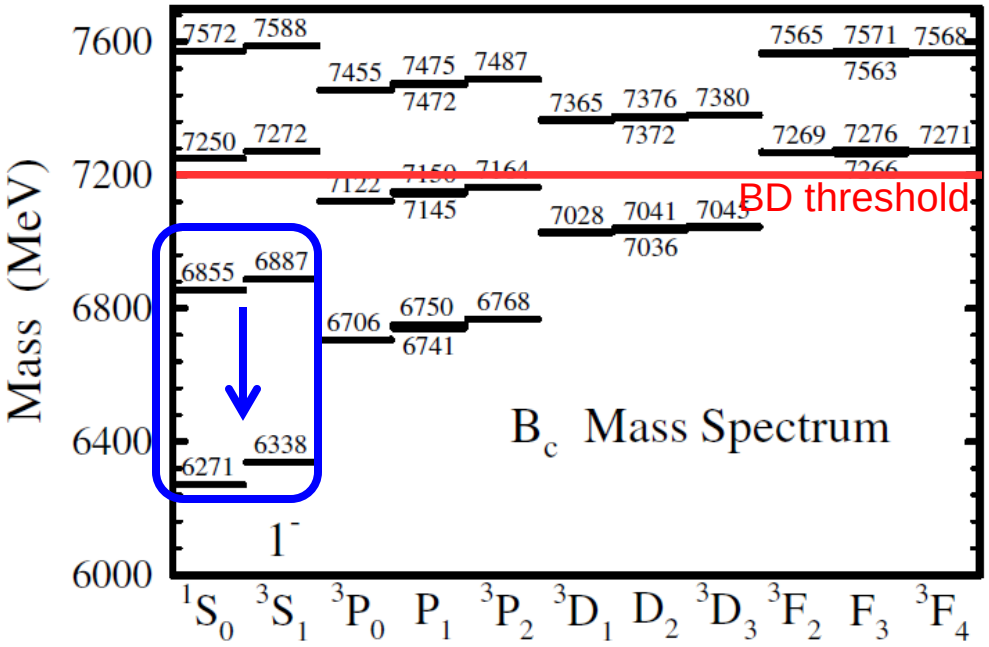
B-Physics measurements

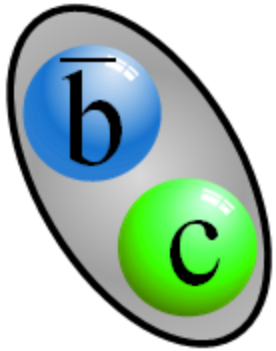
Excited $B_c^{\pm}$ states

$B_c^{\pm}(2S)$

↓

$B_c^{\pm}(1S)$



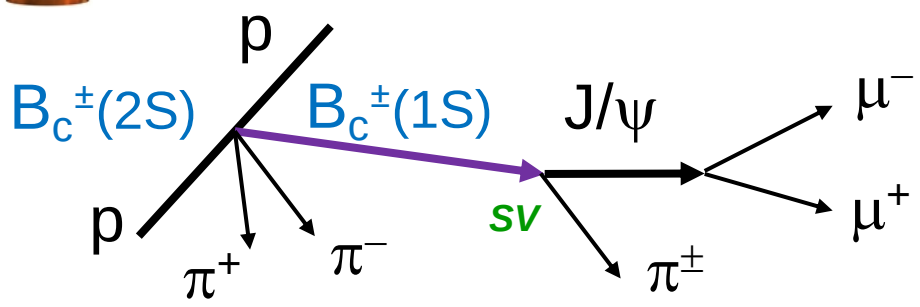


theoretical calculation using relativized quark model

Phys. Rev. D 70 (2004) 054017

7+8 TeV

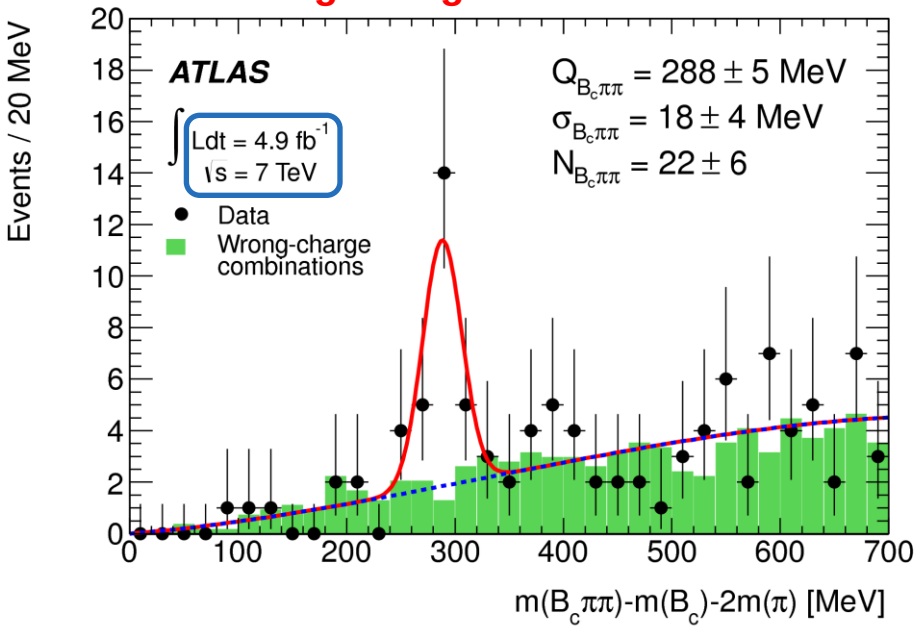
Observation of $B_c^{\pm}(2S)$ @ATLAS



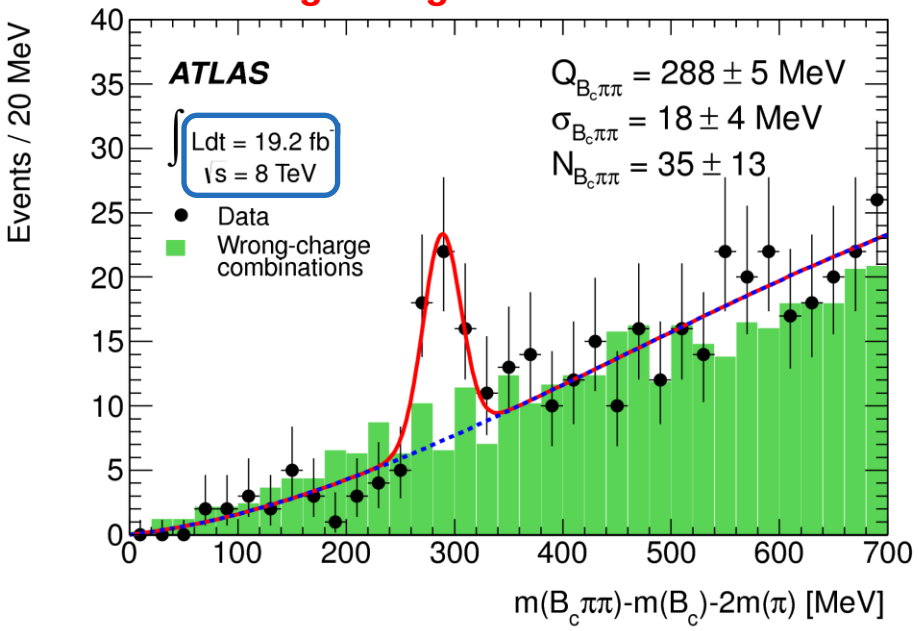
Using **mass difference:**

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

signal significance ~ 3.7σ



signal significance ~ 4.5σ

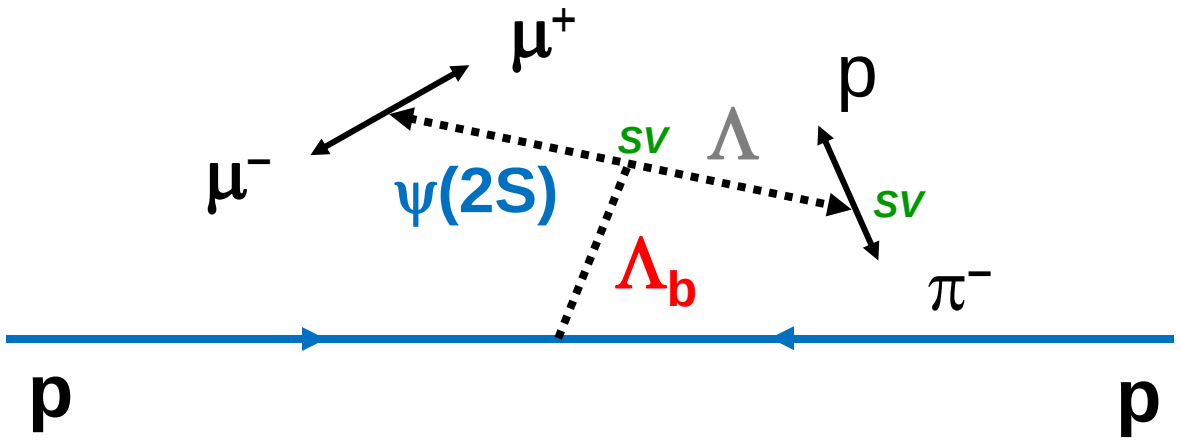


- Significance calculated using pseudo-experiments and accounting for look-elsewhere effect
- New state observed at Q = 288.3 ± 3.5 ± 4.1 MeV ⇒ **m = 6842** ± 4 ± 5 MeV with significance of **5.2σ** for combined 7 TeV and 8 TeV datasets; consistent with prediction!

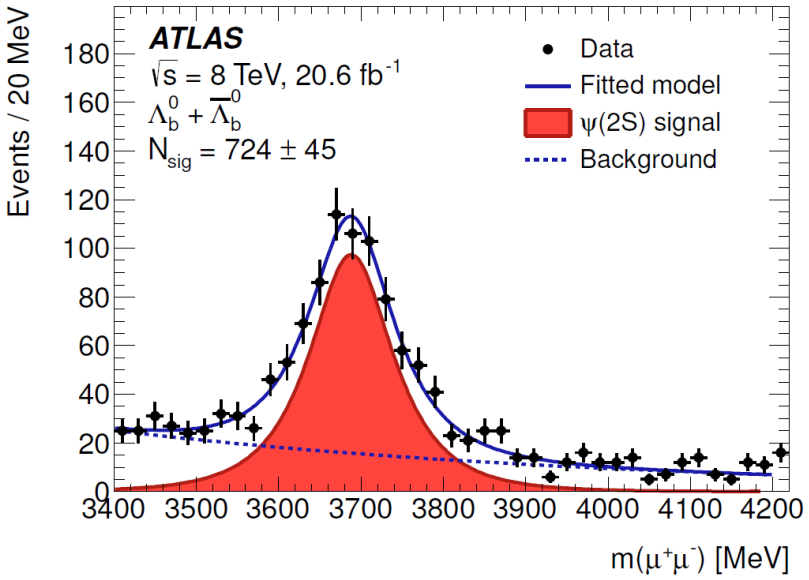
New!

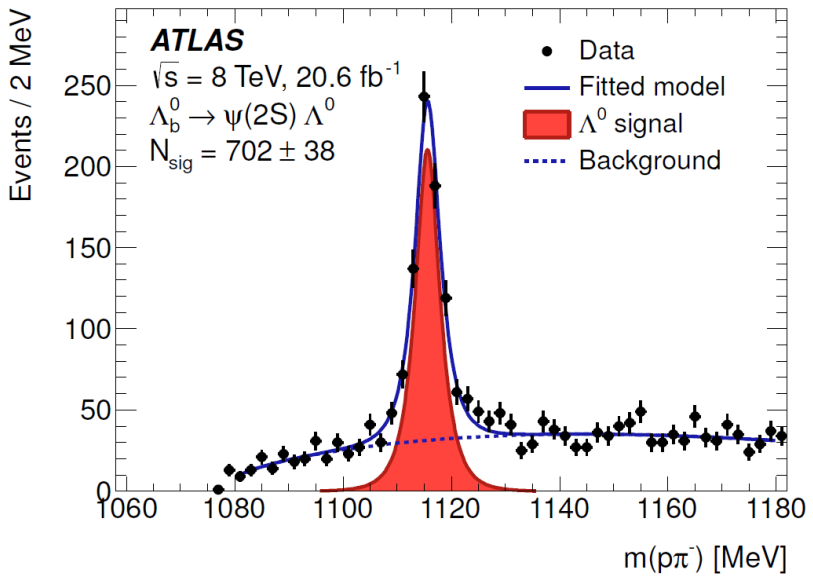
Observation of $\Lambda_b \to \psi(2S)\Lambda$ and measurement of the ratio of branching fractions

$$\frac{\Gamma(\Lambda_b \to \psi(2S)\Lambda)}{\Gamma(\Lambda_b \to J/\psi\,\Lambda)}$$

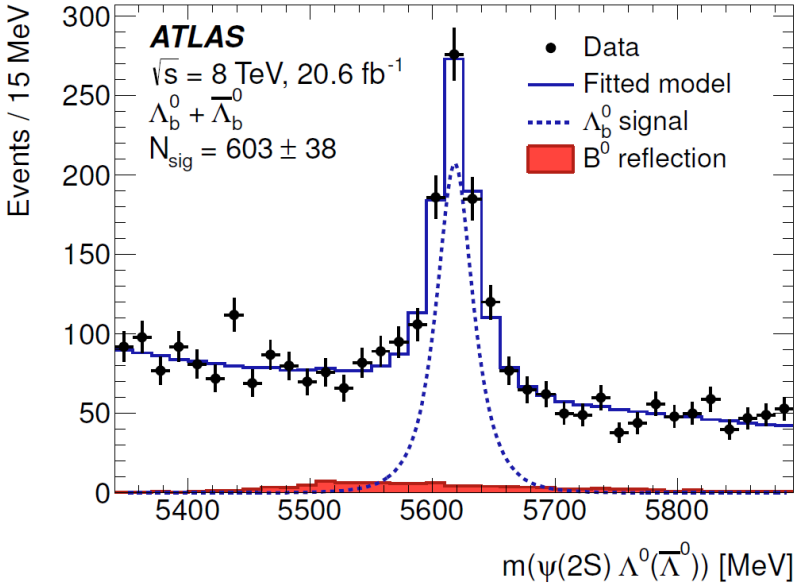


Observation of $\Lambda_b \to \psi(2S)\Lambda$





- $\psi(2S)$ [and J/ψ]
  - reconstructed in $\mu^+\mu^-$ decays
- $\Lambda \to p\pi^-$
  - proton mass assigned to higher momentum track
- Kinematic range for Λ_b
  - $p_T(\Lambda_b) > 10$ GeV, $|\eta(\Lambda_b)| < 2.1$



Λ_b: Ratio of branching fractions

$$\frac{\Gamma(\Lambda_b \to \psi(2S)\Lambda)}{\Gamma(\Lambda_b \to J/\psi\Lambda)} = \frac{N_{\mathrm{cor}}(\Lambda_b \to \psi(2S)(\mu^+\mu^-)\Lambda)}{N_{\mathrm{cor}}(\Lambda_b \to J/\psi(\mu^+\mu^-)\Lambda)} \cdot \frac{Br(J/\psi \to l^+l^-)}{Br(\psi(2S) \to l^+l^-)}$$

= **0.501** $\pm$ 0.033(stat) $\pm$ 0.016 (syst) $\pm$ 0.011(*Br*)

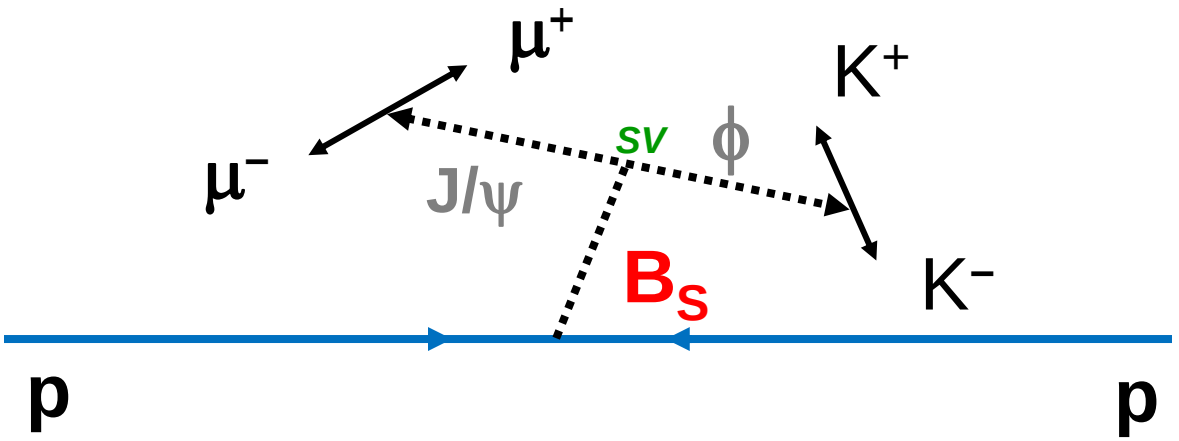
- Ratio is independent of transverse momentum $p_T(\Lambda_b)$
- Consistent with similar ratios from other B-hadron decays
  - range 0.5 – 0.8
- Significantly lower than the prediction of the **covariant quark model**

  Phys. Rev. D 88 (2013) 114018
  - predicts 0.8 $\pm$ 0.1

New!

ϕ_s and $\Delta\Gamma_s$ from flavor tagged time dependent angular analysis of $B_s \rightarrow J/\psi\,\phi$ (7 + 8 TeV data)

ϕ_s = **CP-violating** weak mixing phase
$\Delta\Gamma_s$ = width difference of B_H and B_L



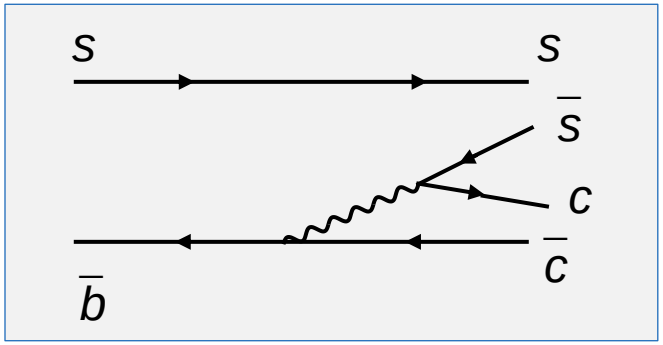
CP violation: neutral B_s system

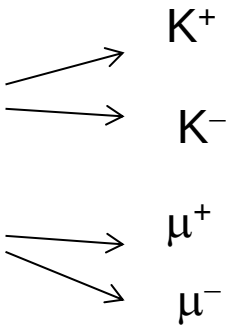
- Interference of decays with and without mixing
  - Mixing induced CP violation
    - Phase difference $\phi_S = 2 \cdot \arg[V_{ts}] = -2\,\beta_s$

SM prediction: $\phi_S = -0.0363 \pm 0.0016$ rad

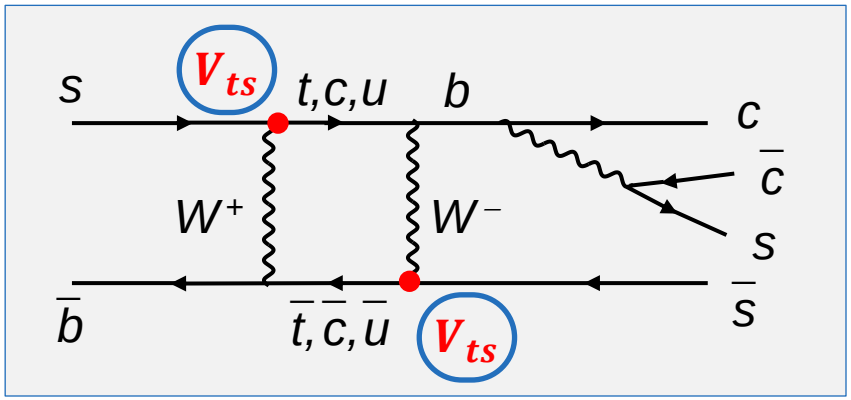
$$B_S \rightarrow J/\psi\,\phi$$

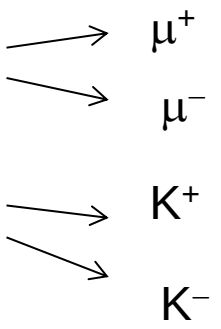
$$B_S \rightarrow \overline{B}_S \rightarrow J/\psi\,\phi$$





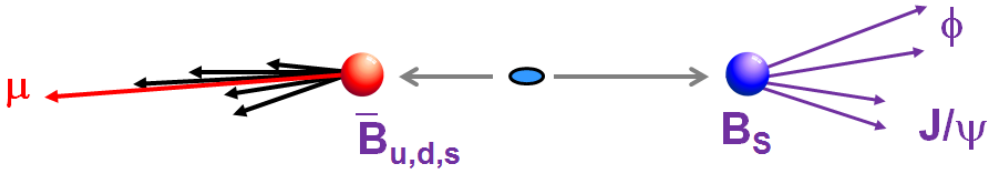
ϕ_S : This diagram justifies the name *weak mixing phase*.

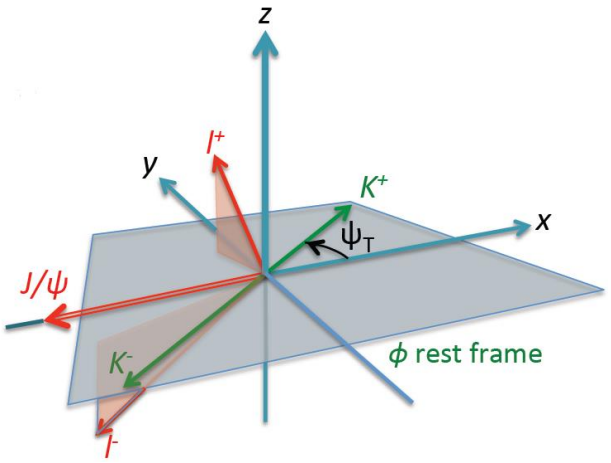


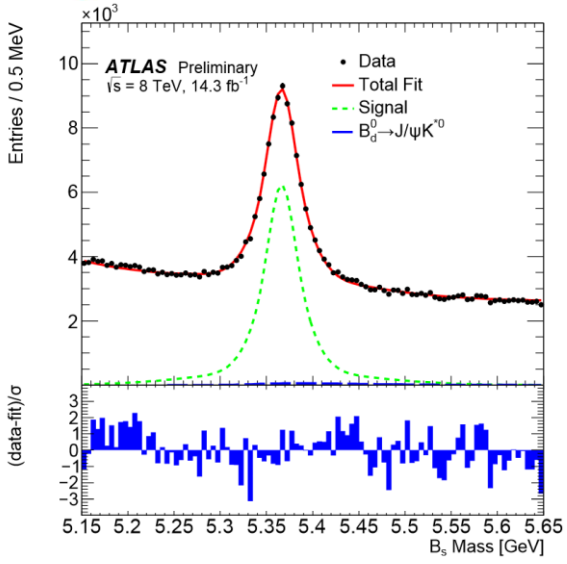


Analysis method

- B-charge flavor tagging
  - Identification of B_S flavor at production vertex through opposite side tagging
- Measured kinematic variables
  - (m, σ_m), (t, σ_t)
  - decay angles $(\psi_T, \theta_T, \phi_T)$ in the transversity basis
- Unbinned max. likelihood fit
  - extract 9 physics parameters describing the neutral B_S system
    - ϕ_s, $\Delta\Gamma_s$, Γ_s
      transversity amplitudes $|A_0|$, $|A_{||}|$, $|A_S|$
      strong phases $\delta_\perp$, $\delta_{||}$, δ_S

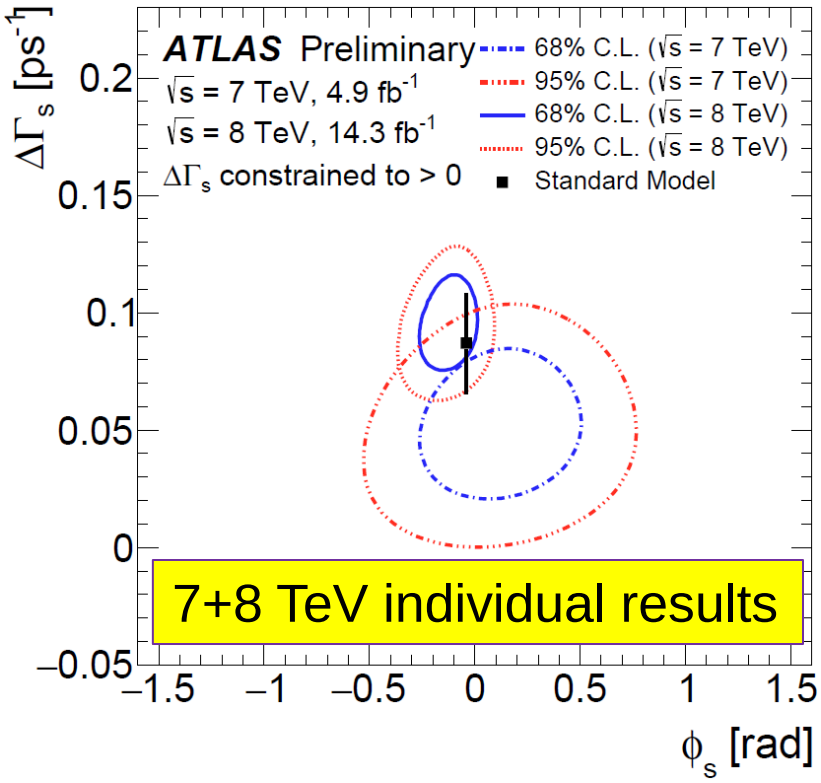


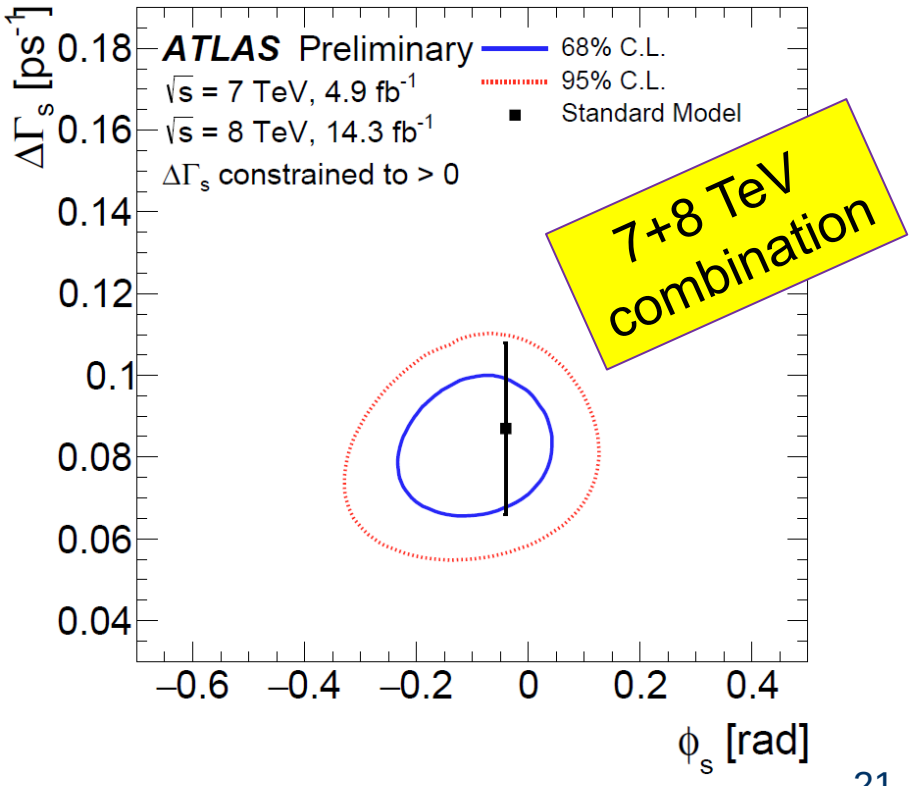




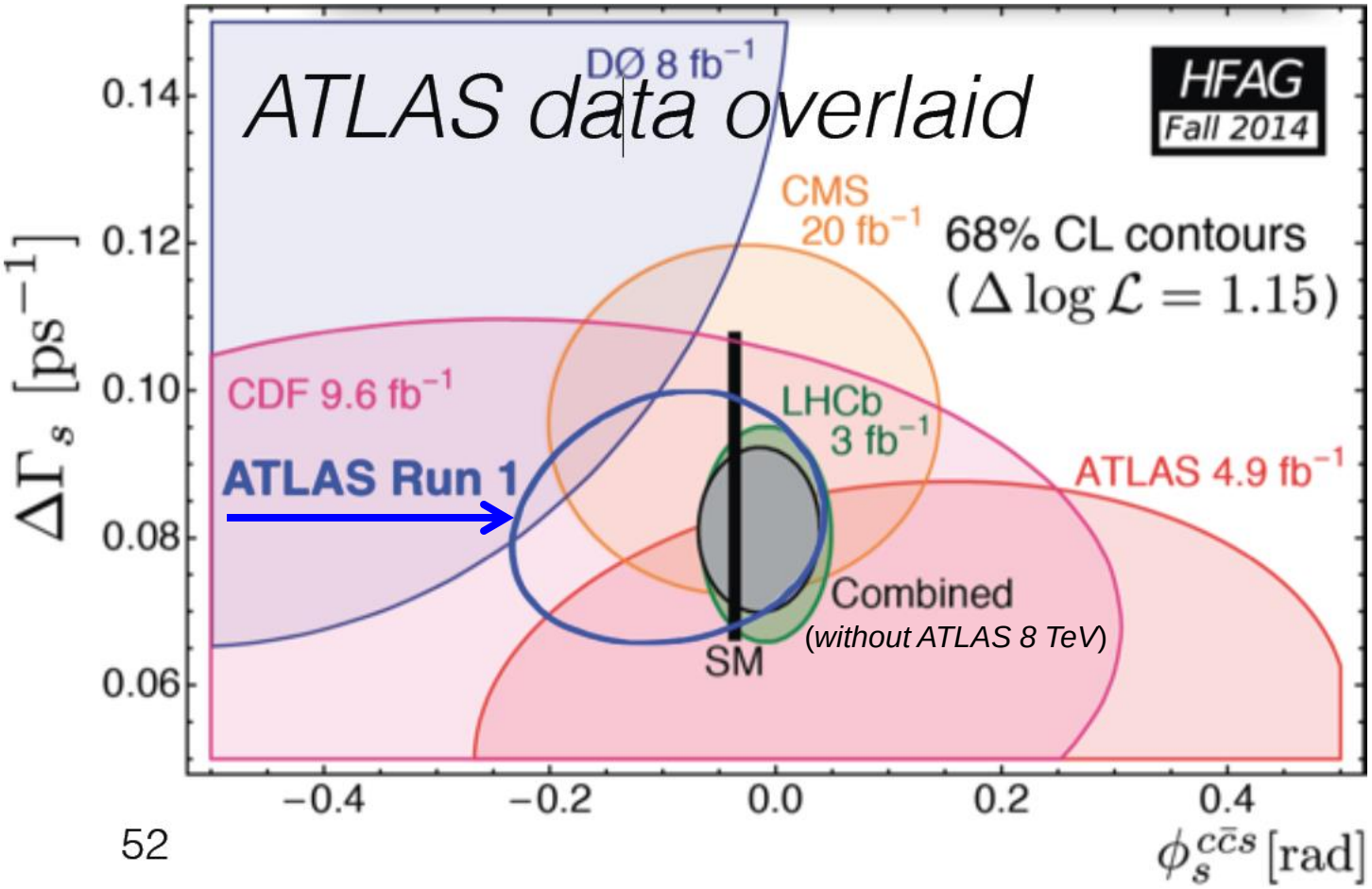
Results and combination

- Measurement at 8 TeV:
  - ϕ_S = -0.119 ± 0.088 (stat.) ± 0.036 (syst.) rad
  - $\Delta\Gamma_S$ = 0.096 ± 0.013 (stat.) ± 0.007 (syst.) ps^{-1}
  - also measured:
    - Γ_S, $|A_0|$, $|A_{||}|$, $|A_S|$, $\delta_\perp$, $\delta_{||}$, δ_S





Comparision: ϕ_s–$\Delta\Gamma_s$ plane



- ATLAS Run 1 result consistent with other experiments and SM prediction.

Summary

Studies of Quarkonia

Production Cross-sections

- J/ψ and ψ(2S) → μμ at 7 and 8 TeV (New!)
- Measurement of χ_{C1} and χ_{C2}
- ψ(2S) → J/ψππ
- Υ(nS) production

Spectroscopy

- χ_b(3P) Observation
- Search for X_b in Υ(1S)ππ

Associated Production

- W± + prompt J/Ψ
- Z + (non-)prompt J/Ψ

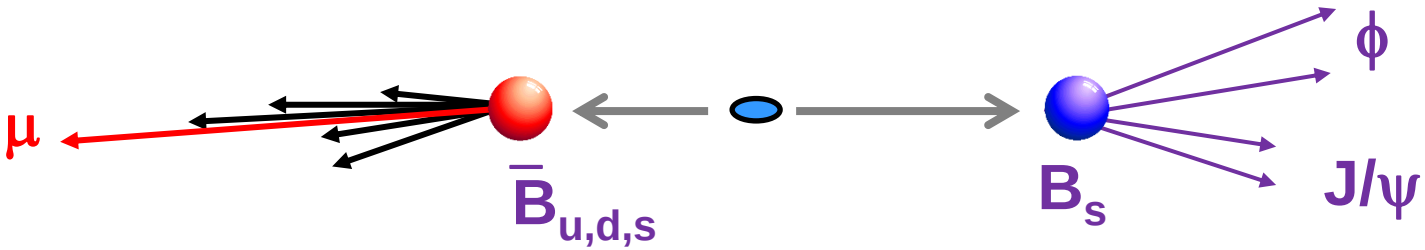
B-Physics measurements

- Observation of an excited $B_c^{\pm}$ meson state with the ATLAS detector
- Parity violating asymmetry parameter αb and the helicity amplitudes for the decay $\Lambda_b^0 \rightarrow J/\psi\, \Lambda^0$
- Production cross section of B+ at $\sqrt{s}$ = 7TeV
- Limit on $B^0_s \rightarrow \mu\mu$ branching fraction based on 4.9 fb-1 of integrated luminosity
- Measurement of the Λ_b lifetime and mass
- 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
- Observation of Λb in the decay $\Lambda_b^0 \rightarrow \psi(2S)\, \Lambda^0$
- ϕ_s and $\Delta\Gamma_s$ time dependent angular analysis of $B^0_s \rightarrow J/\psi\, \phi$

For a complete list of topics and results see:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults

backup slides

B-charge flavor tagging



- Identification of B_s flavor at production vertex
  - gives improved sensitivity
  - resolves sign ambiguities
- Opposite-side tagging
  - use information from the non-signal b-hadron to infer the initial flavor of the signal B_s
- Self tagging calibration sample: $B^{\pm} \rightarrow J/\psi\ K^{\pm}$
  - search for additional lepton in the event (e,μ)

7+8 TeV

$B^0_s \rightarrow J/\psi\,\phi$: combined results

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
$\delta_\perp - \delta_s$	-0.08	0.03	0.01	rad