# Heavy flavour spectroscopy and b-decay properties with the ATLAS detector


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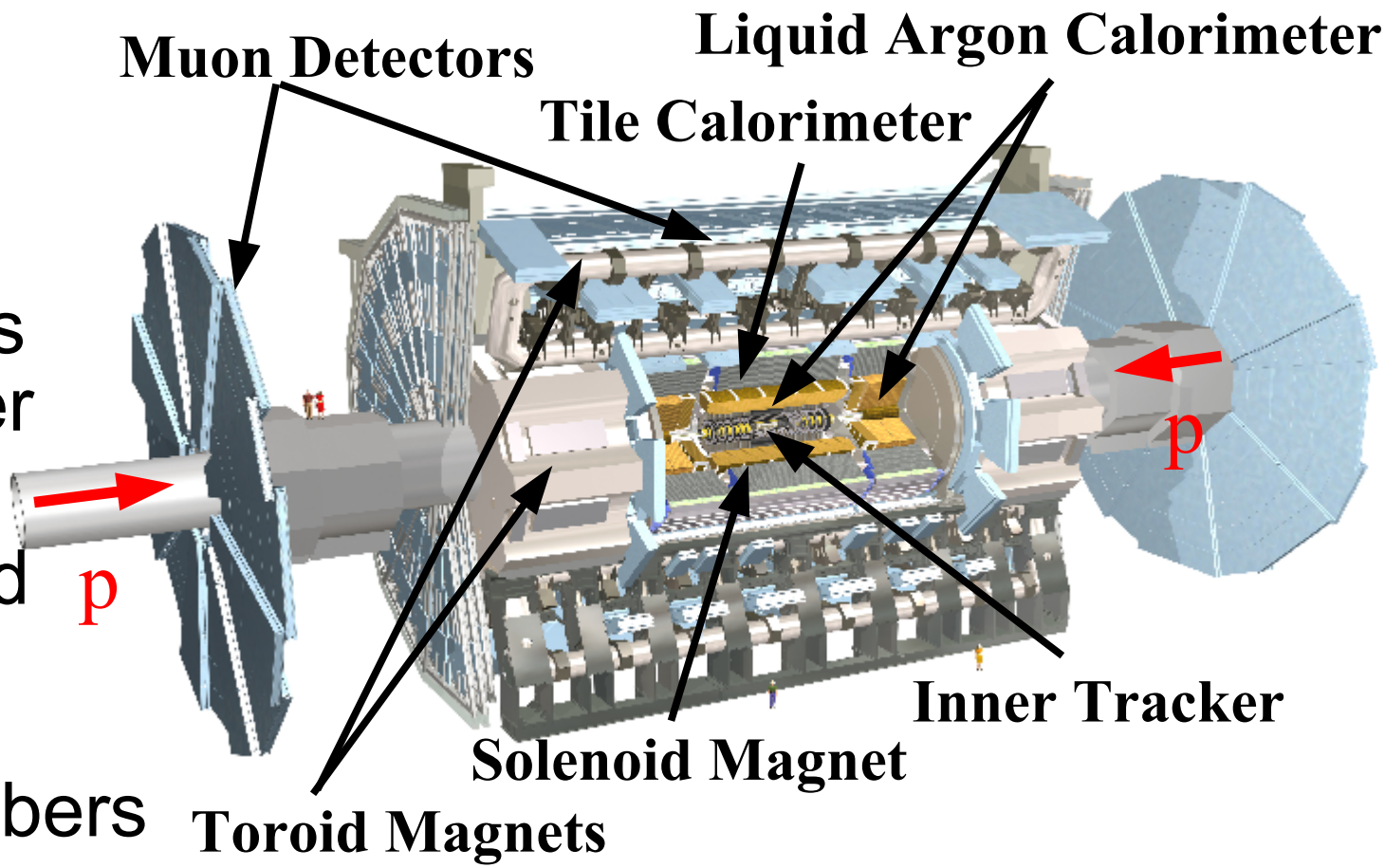
# ATLAS: a particle detector at the LHC

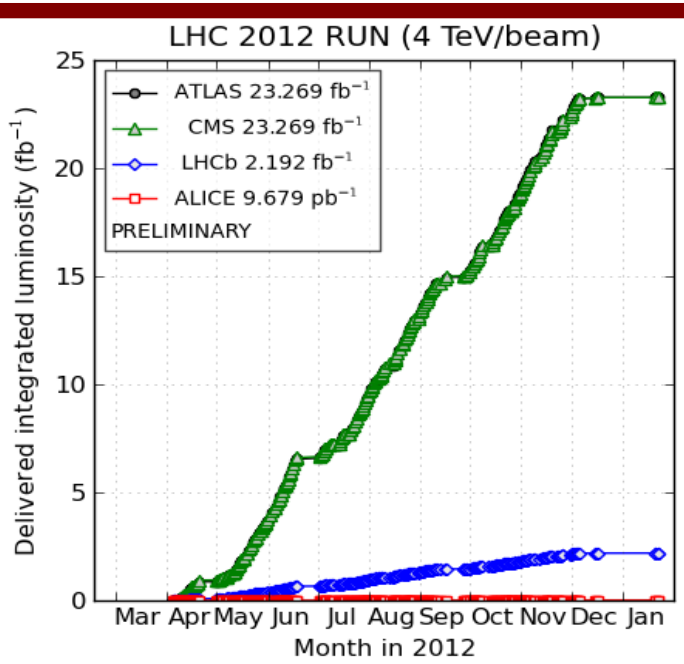
- Inner tracker
  - 2T solenoid
  - $|\eta|<2.5$
  - Silicon pixel
  - Silicon strips
  - straw tracker
- Muon system
  - 0.5-2T toroid
  - $|\eta|<2.7$
  - Precision & trigger chambers

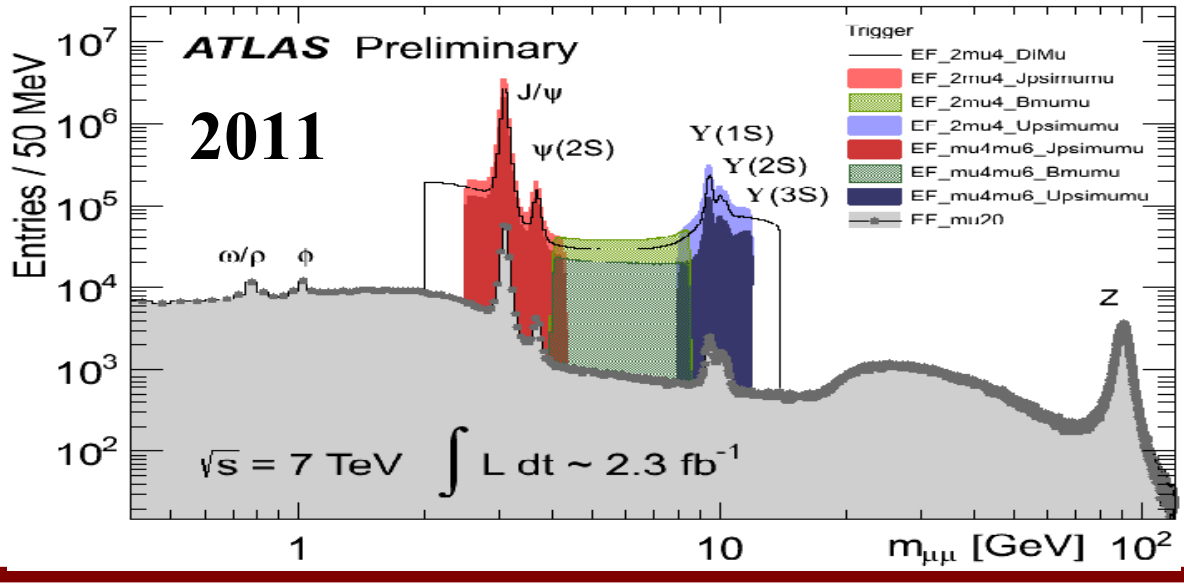



- $\sigma_{Pt}/Pt \sim 0.05\% Pt[GeV] \oplus 1.5\%$
- ~ 10 μm impact parameter resolution

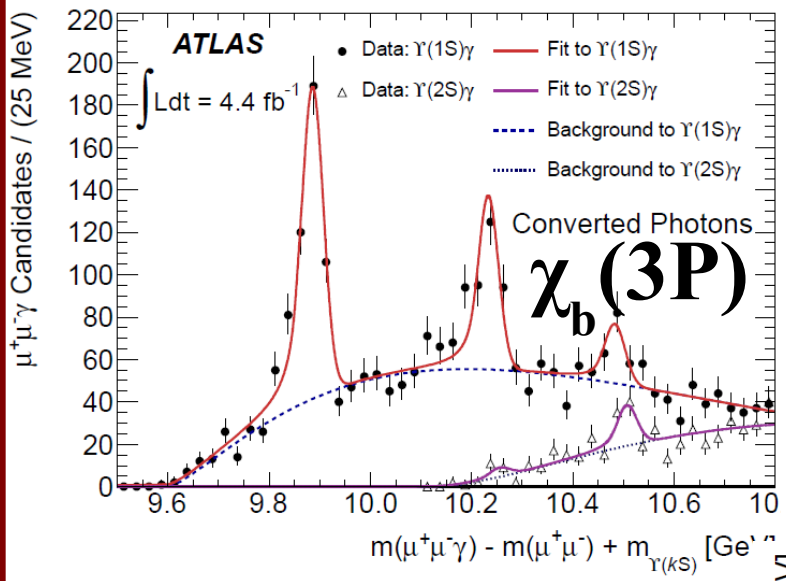
# ATLAS B-physics overview

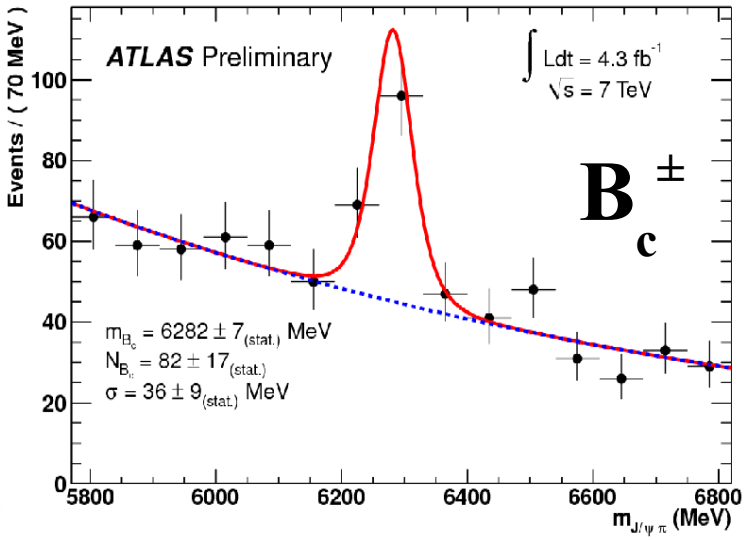
- B-physics sensitive to new physics
- ATLAS advantage: high luminosity
- Largely relies on dimuon triggers
- Rich flavour program
  - B-hadron production
  - Onia production
  - Charm production
  - Lifetimes
  - CP violation
  - Parity Violation
  - Rare decays

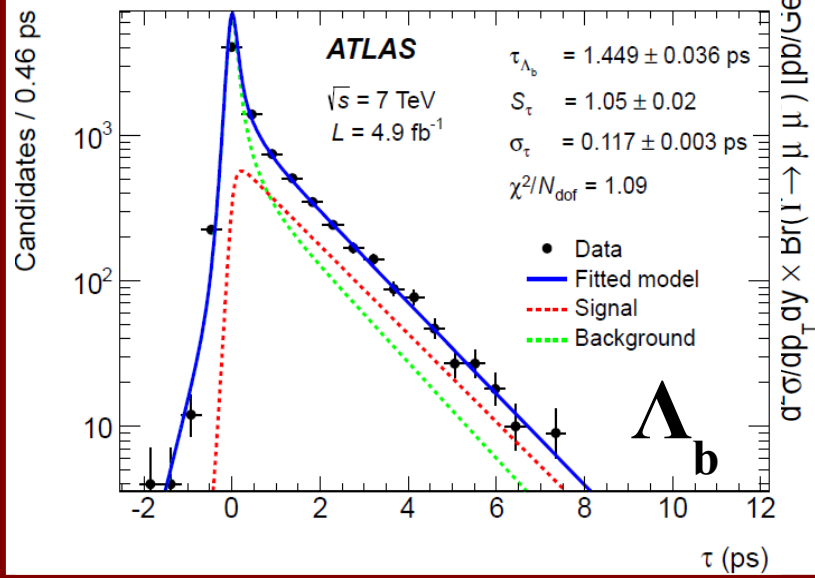


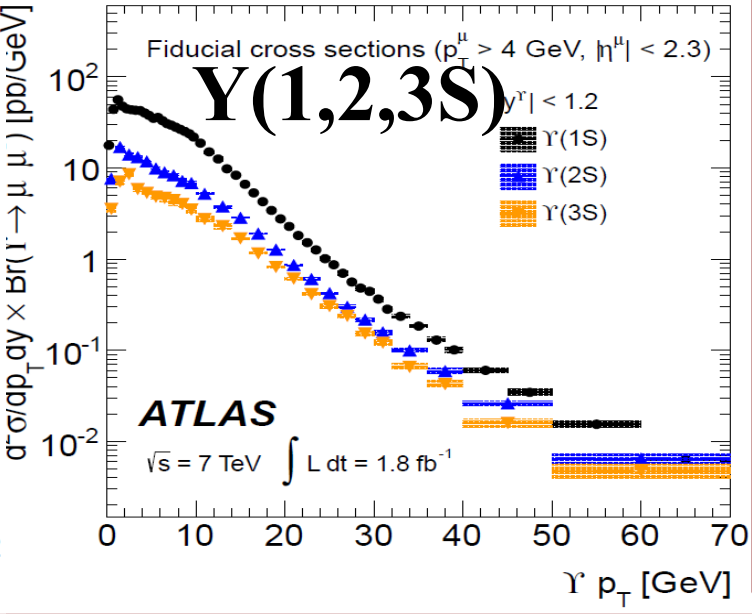



# ATLAS B-physics Highlights



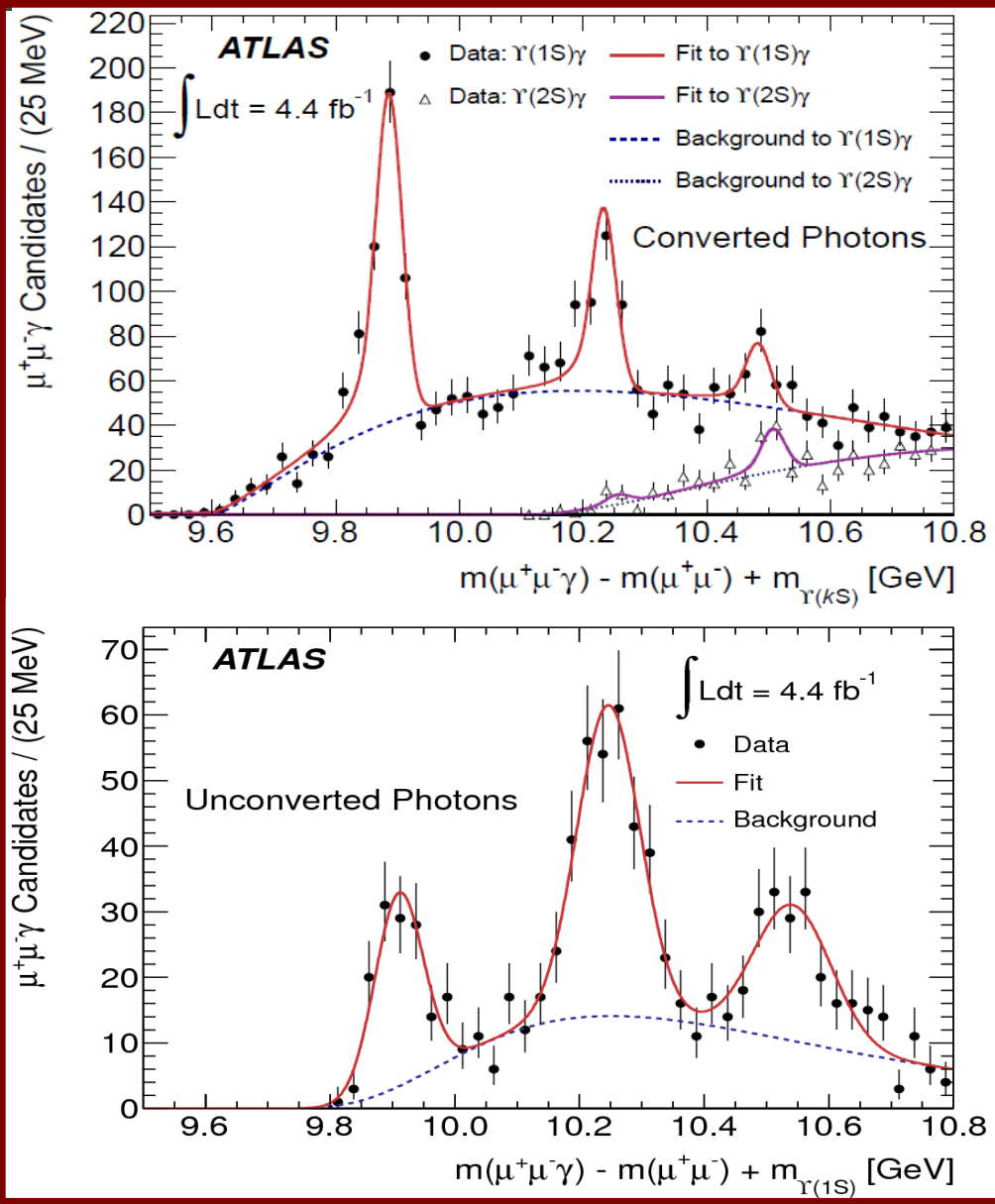



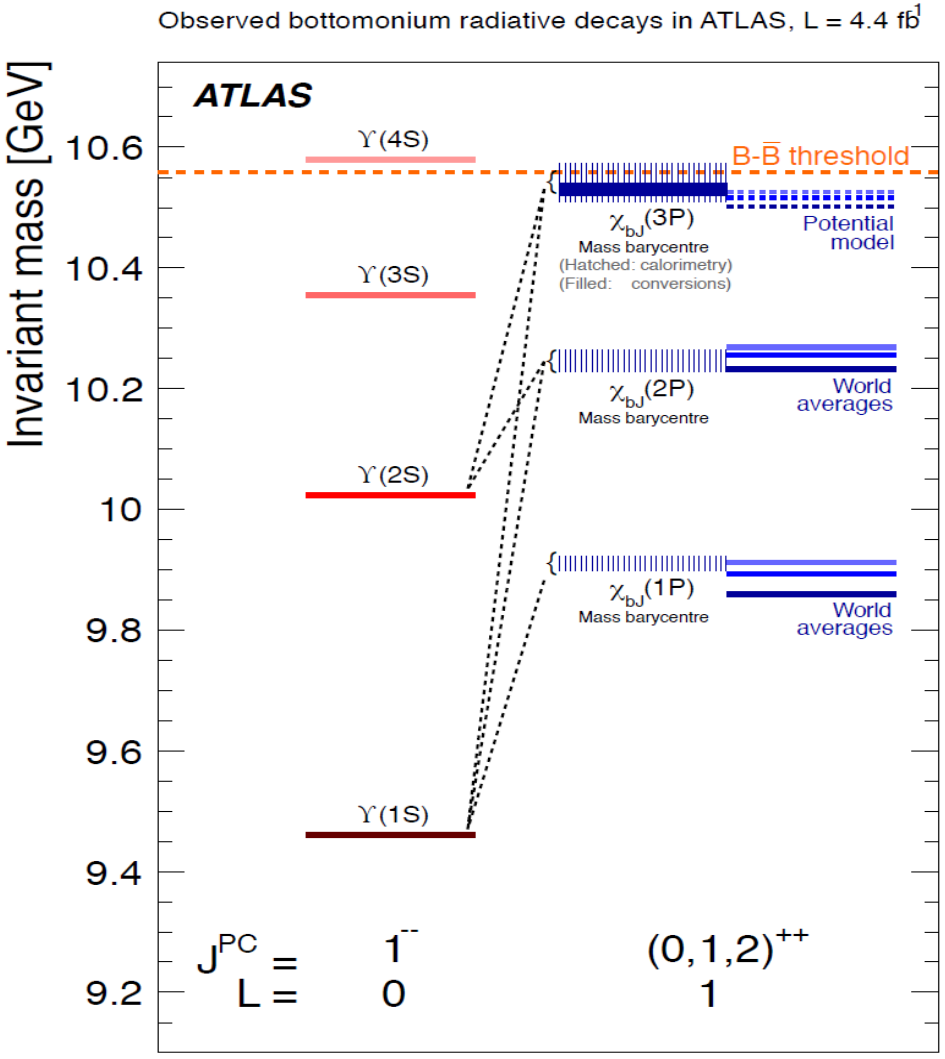




- Discovery of χb(3P) (Phys. Rev. Lett.108 (2012) 152001)
- Heavy b-states: $B_c$, $\Lambda_b$ (ATLAS-CONF-2012-028)
- Best measurement of $\Lambda_b$ life time: (Phys. Rev. D 87, 032002 (2013)) $\tau = 1.449 \pm 0.036_{stat} \pm 0.017_{syst}$ ps
- Flavour Production
- ϒ cross sections up to $p_T$~70 GeV (arXiv:1211.7255)
- Rare decay $B_s \rightarrow \mu\mu$
- CP violation in $B_s \rightarrow J/\psi\varphi$ decays

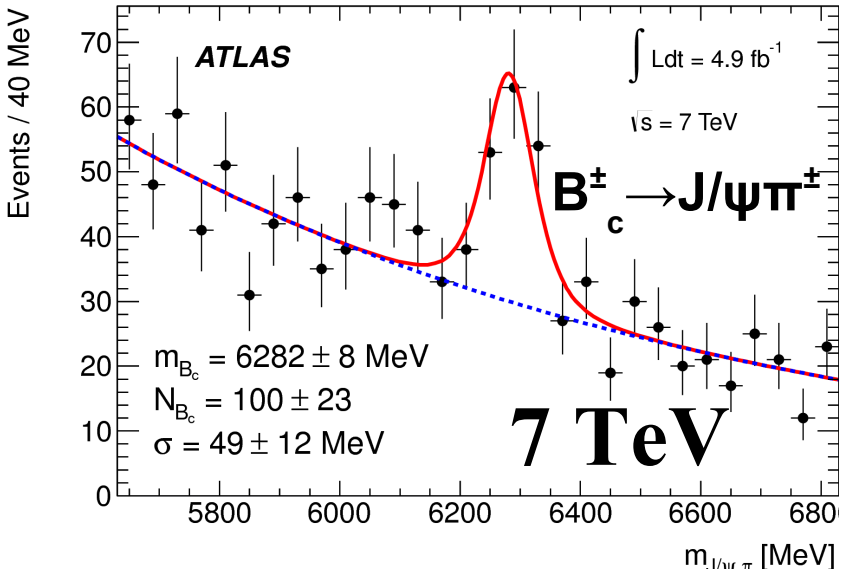
# Observation of $\chi_b(3P) \to \Upsilon(2,3s)\gamma$

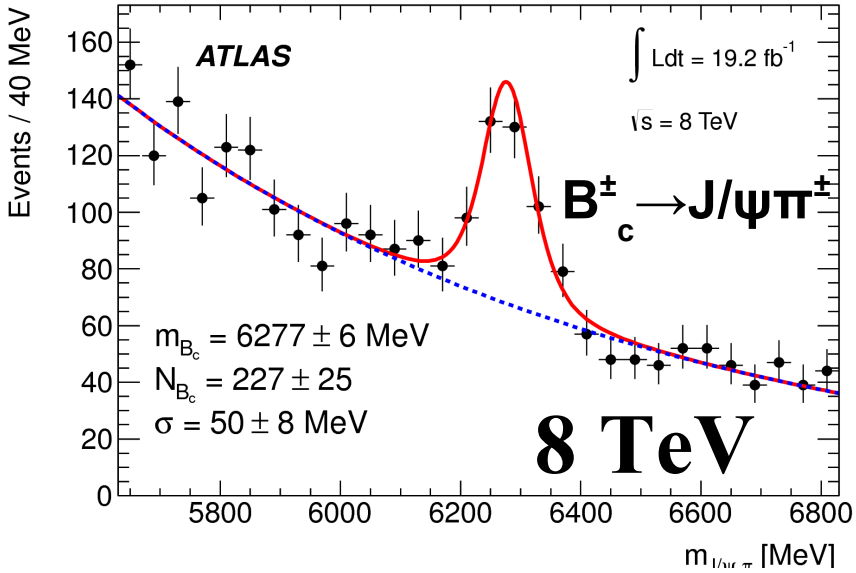



Phys. Rev. Lett. 108, 152001 (2012)

# $B_c(2S) \rightarrow B^{\pm}_c \pi\pi$ with $B^{\pm}_c \rightarrow J/\psi\pi^{\pm}$

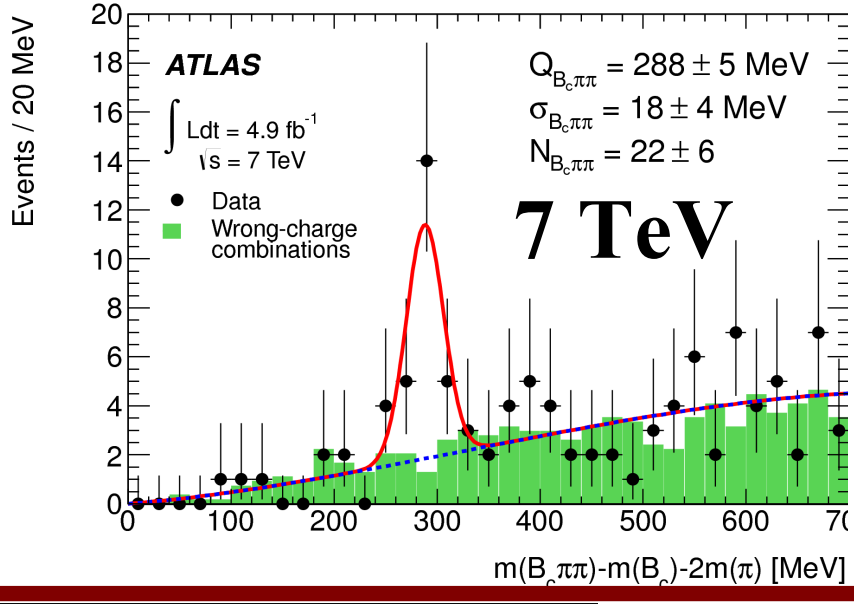


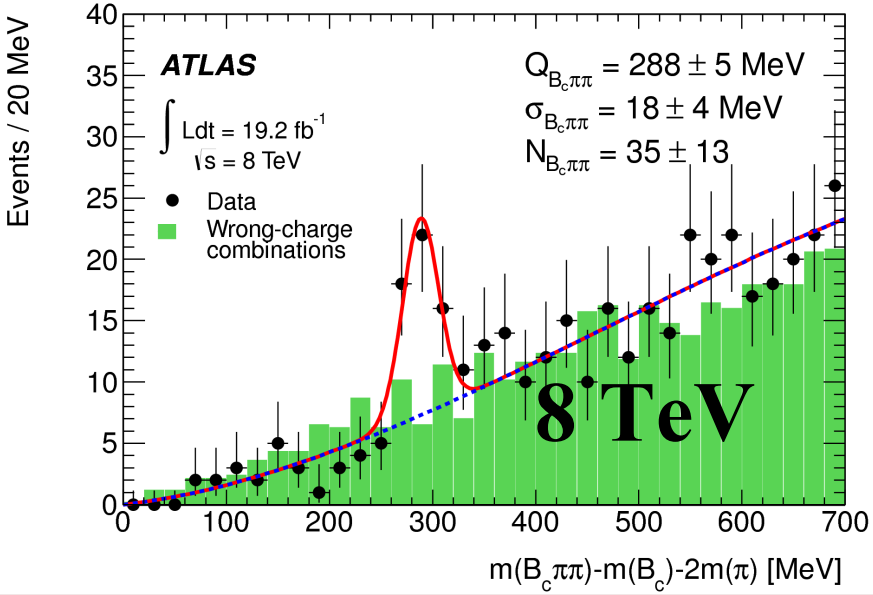




**Mass:**
**6842 ± 4 ± 5 MeV**

**Significance:**
**5.2 sigma**

**arXiv:1407.1032**



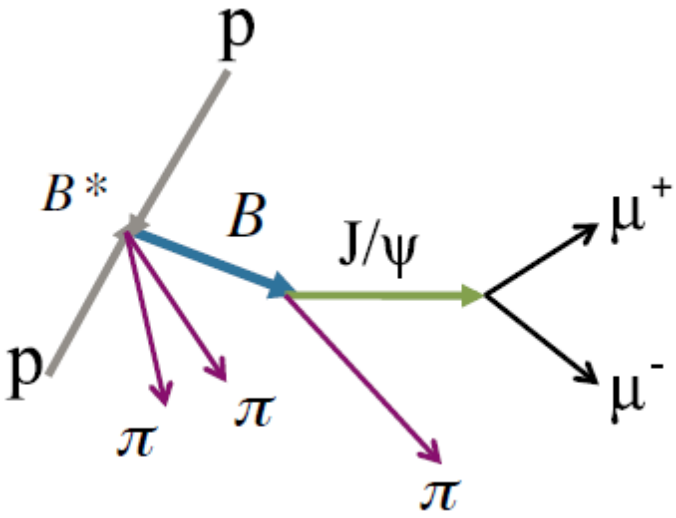
# $B_c(2S) \rightarrow B^{\pm}_c \pi\pi$ with $B^{\pm}_c \rightarrow J/\psi\pi^{\pm}$

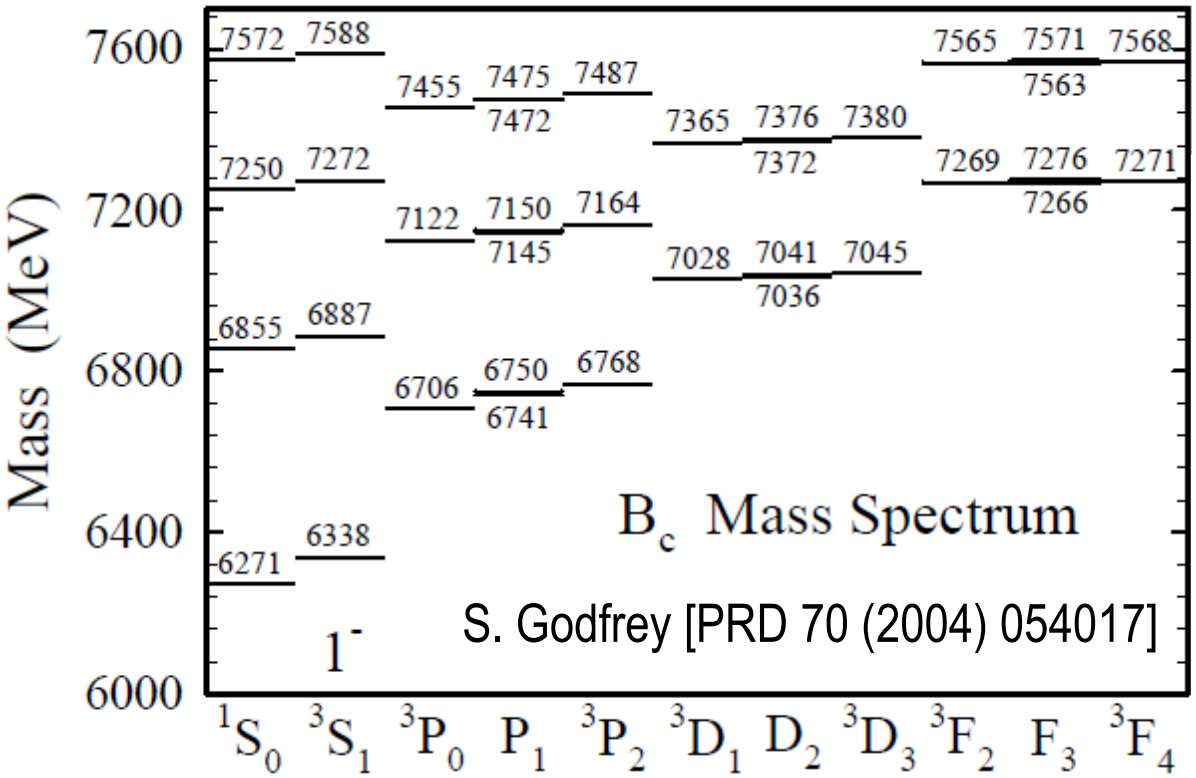
**Observe $B_c(2S) \rightarrow B^{\pm}_c \pi\pi$ with $B^{\pm}_c \rightarrow J/\psi\pi^{\pm}$**

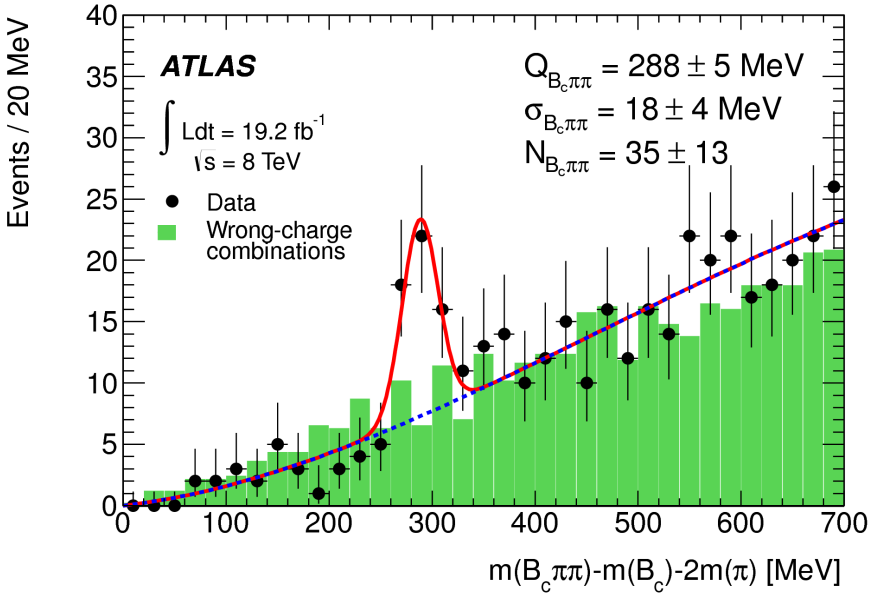
**(as $B_c(2P) \rightarrow B^{\pm}_c \gamma$)**

**Mass: 6842 ± 4 ± 5 MeV  Q = 288.3 ± 3.5 ± 4.1 MeV**

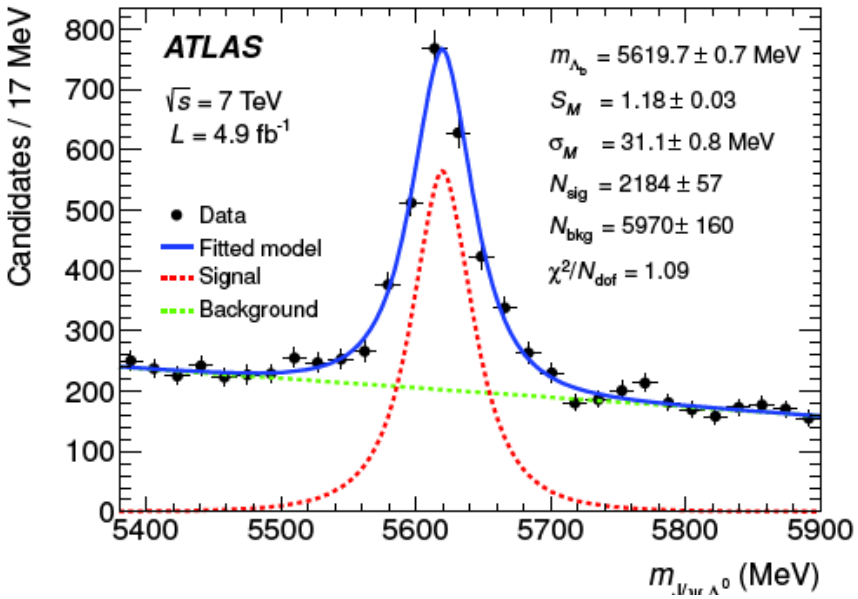
**Significance:  5.2 sigma**

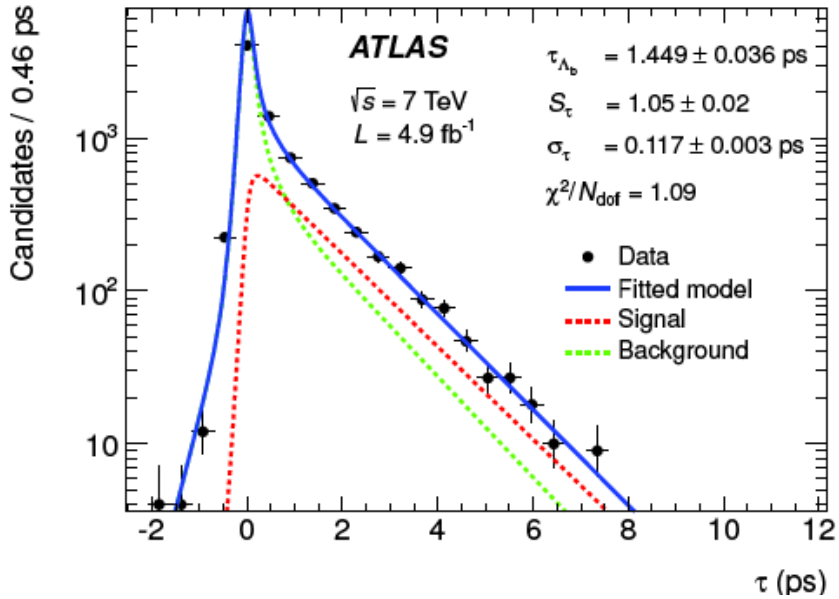


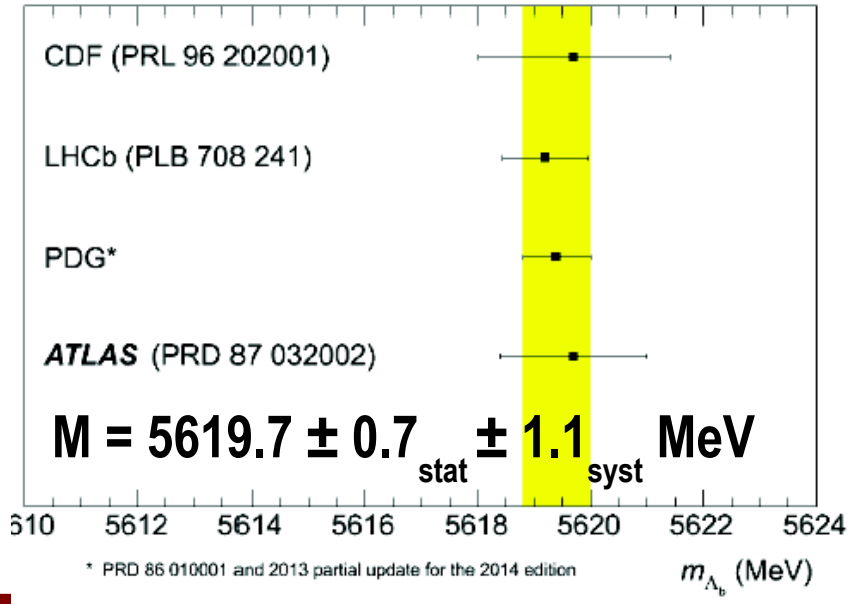



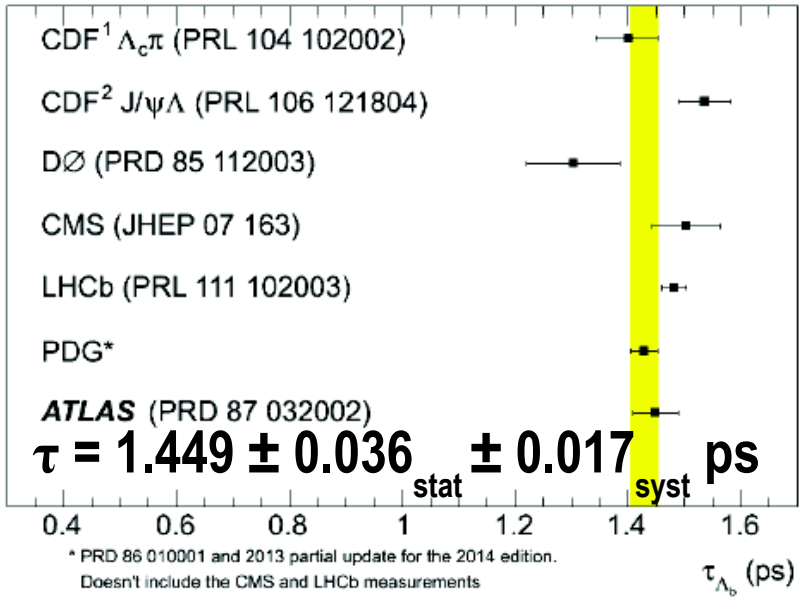



# $\Lambda_b \rightarrow J/\psi\Lambda$ mass & lifetime

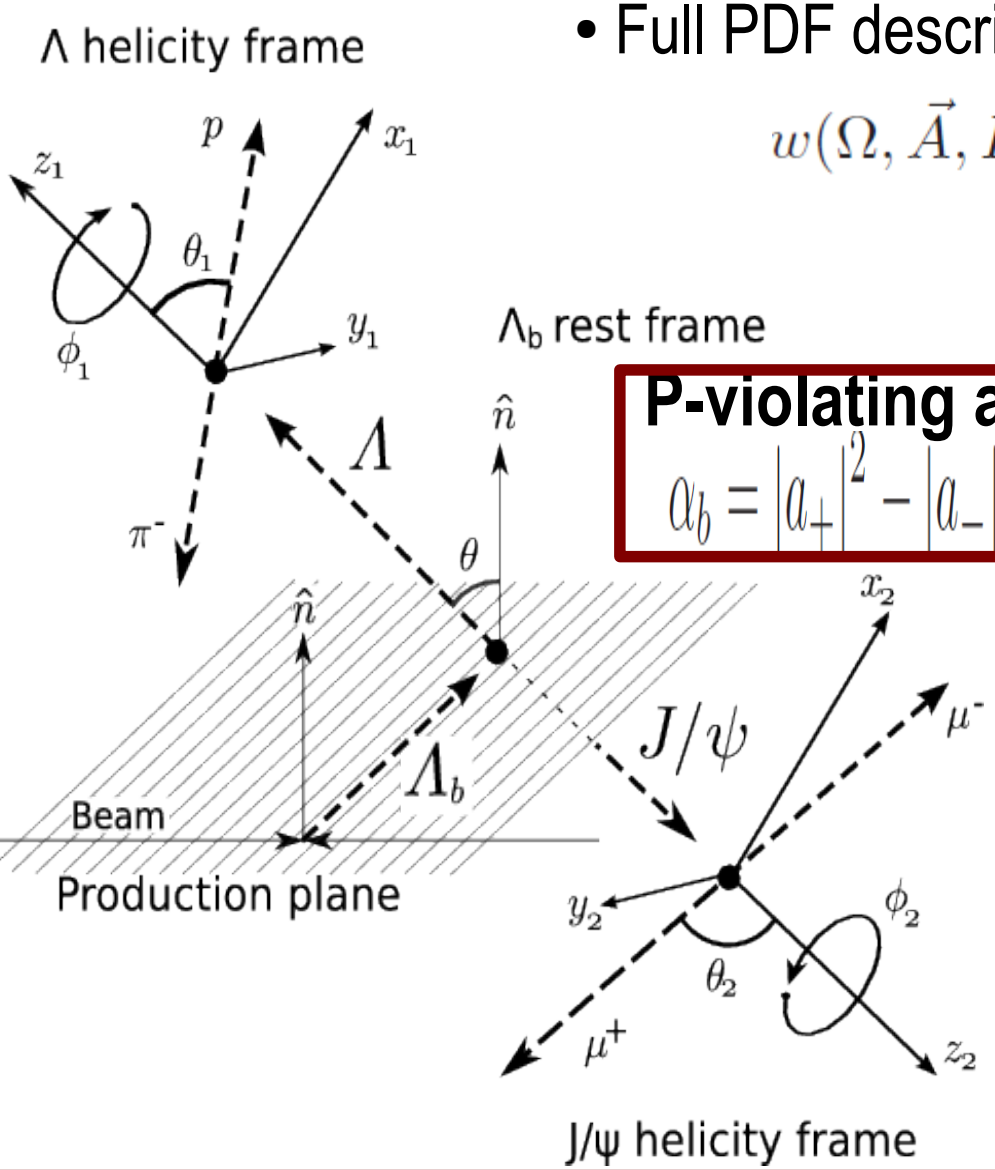


# Parity violation in $\Lambda_b \rightarrow J/\psi\Lambda$



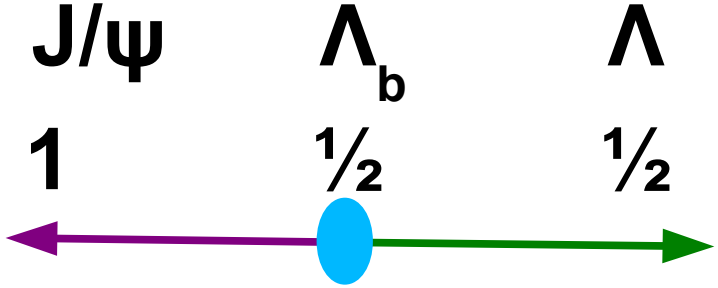

- Full PDF described by

$$w(\Omega, \vec{A}, P) = \frac{1}{(4\pi)^3} \sum_{i=0}^{19} f_{1i}(\vec{A}) f_{2i}(P, \alpha_\Lambda) F_i(\Omega),$$

$$\Omega = (\theta, \phi, \theta_1, \phi_1, \theta_2, \phi_2)$$

**P-violating asymmetry**

$$\alpha_b = |a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2$$




**A Helicity**

| Amplitude | $\lambda_{J/\psi}$ | $\lambda_\Lambda$ |
|---|---|---|
| $a_+$ | 0 | 1/2 |
| $a_-$ | 0 | -1/2 |
| $b_+$ | -1 | -1/2 |
| $b_-$ | 1 | 1/2 |

# Parity Violation in $\Lambda_b \to J/\psi\Lambda$

- Full PDF described by
- Simplifies for Polarization P = 0

$$w(\Omega, \vec{A}, P) = \frac{1}{(4\pi)^3} \sum_{i=0}^{19} f_{1i}(\vec{A}) f_{2i}(P, \alpha_\Lambda) F_i(\Omega),$$

| $i$ | $f_{1i}$ | $f_{2i}$ | $F_i$ |
|---|---|---|---|
| 0 | $a_+a_+^* + a_-a_-^* + b_+b_+^* + b_-b_-^*$ | 1 | 1 |
| 1 | $a_+a_+^* - a_-a_-^* + b_+b_+^* - b_-b_-^*$ | $P$ | $\cos\theta$ |
| 2 | $a_+a_+^* - a_-a_-^* - b_+b_+^* + b_-b_-^*$ | $\alpha_\Lambda$ | $\cos\theta_1$ |
| 3 | $a_+a_+^* + a_-a_-^* - b_+b_+^* - b_-b_-^*$ | $P\,\alpha_\Lambda$ | $\cos\theta\,\cos\theta_1$ |
| 4 | $-a_+a_+^* - a_-a_-^* + \frac{1}{2}b_+b_+^* + \frac{1}{2}b_-b_-^*$ | 1 | $\frac{1}{2}(3\cos^2\theta_2 - 1)$ |
| 5 | $-a_+a_+^* + a_-a_-^* + \frac{1}{2}b_+b_+^* - \frac{1}{2}b_-b_-^*$ | $P$ | $\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta$ |
| 6 | $-a_+a_+^* + a_-a_-^* - \frac{1}{2}b_+b_+^* + \frac{1}{2}b_-b_-^*$ | $\alpha_\Lambda$ | $\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta_1$ |
| 7 | $-a_+a_+^* - a_-a_-^* - \frac{1}{2}b_+b_+^* - \frac{1}{2}b_-b_-^*$ | $P\,\alpha_\Lambda$ | $\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta\cos\theta_1$ |
| 8 | $-3\mathrm{Re}(a_+a_-^*)$ | $P\,\alpha_\Lambda$ | $\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\cos\phi_1$ |
| 9 | $3\mathrm{Im}(a_+a_-^*)$ | $P\,\alpha_\Lambda$ | $\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\sin\phi_1$ |
| 10 | $-\frac{3}{2}\mathrm{Re}(b_-b_+^*)$ | $P\,\alpha_\Lambda$ | $\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\cos(\phi_1 + 2\phi_2)$ |
| 11 | $\frac{3}{2}\mathrm{Im}(b_-b_+^*)$ | $P\,\alpha_\Lambda$ | $\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\sin(\phi_1 + 2\phi_2)$ |
| 12 | $-\frac{3}{\sqrt{2}}\mathrm{Re}(b_-a_+^* + a_-b_+^*)$ | $P\,\alpha_\Lambda$ | $\sin\theta\,\cos\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos\phi_2$ |
| 13 | $\frac{3}{\sqrt{2}}\mathrm{Im}(b_-a_+^* + a_-b_+^*)$ | $P\,\alpha_\Lambda$ | $\sin\theta\,\cos\theta_1\,\sin\theta_2\,\cos\theta_2\,\sin\phi_2$ |
| 14 | $-\frac{3}{\sqrt{2}}\mathrm{Re}(b_-a_-^* + a_+b_+^*)$ | $P\,\alpha_\Lambda$ | $\cos\theta\,\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos(\phi_1 + \phi_2)$ |
| 15 | $\frac{3}{\sqrt{2}}\mathrm{Im}(b_-a_-^* + a_+b_+^*)$ | $P\,\alpha_\Lambda$ | $\cos\theta\,\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\sin(\phi_1 + \phi_2)$ |
| 16 | $\frac{3}{\sqrt{2}}\mathrm{Re}(a_-b_+^* - b_-a_+^*)$ | $P$ | $\sin\theta\,\sin\theta_2\,\cos\theta_2\,\cos\phi_2$ |
| 17 | $-\frac{3}{\sqrt{2}}\mathrm{Im}(a_-b_+^* - b_-a_+^*)$ | $P$ | $\sin\theta\,\sin\theta_2\,\cos\theta_2\,\sin\phi_2$ |
| 18 | $\frac{3}{\sqrt{2}}\mathrm{Re}(b_-a_-^* - a_+b_+^*)$ | $\alpha_\Lambda$ | $\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos(\phi_1 + \phi_2)$ |
| 19 | $-\frac{3}{\sqrt{2}}\mathrm{Im}(b_-a_-^* - a_+b_+^*)$ | $\alpha_\Lambda$ | $\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\sin(\phi_1 + \phi_2)$ |

- 6 of 19 terms remain:

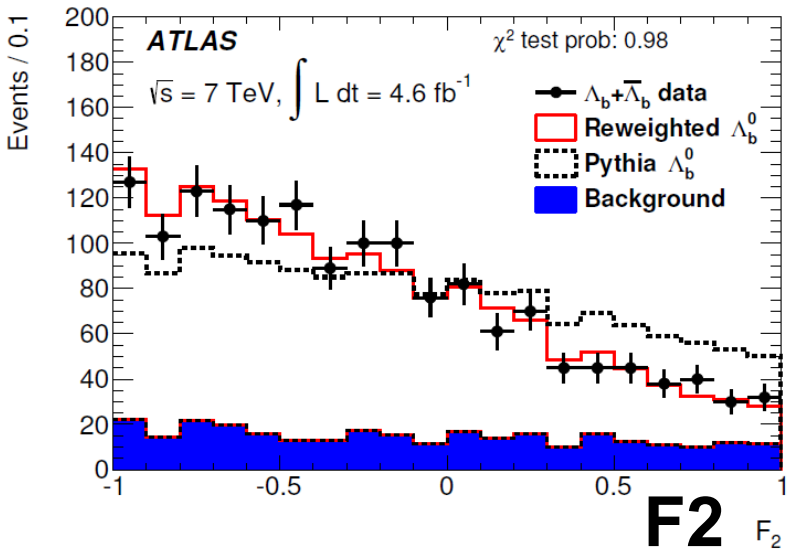
| $i$ | $f_{1i}$ |
|---|---|
| 0 | 1 |
| 2 | $(k_+^2 + k_-^2 - 1) + \alpha_b(k_+^2 - k_-^2)$ |
| 4 | $\frac{1}{4}[(3k_-^2 - 3k_+^2 - 1) + 3\alpha_b(1 - k_-^2 - k_+^2)]$ |
| 6 | $-\frac{1}{4}[(k_+^2 + k_-^2 - 1) + \alpha_b(3 + k_+^2 - k_-^2)]$ |
| 18 | $\frac{3}{\sqrt{2}}[\frac{1-\alpha_b}{2}\sqrt{k_-^2(1-k_-^2)}\cos(-\Delta_-) - \frac{1+\alpha_b}{2}\sqrt{k_+^2(1-k_+^2)}\cos(\Delta_+)]$ |
| 19 | $-\frac{3}{\sqrt{2}}[\frac{1-\alpha_b}{2}\sqrt{k_-^2(1-k_-^2)}\sin(-\Delta_-) - \frac{1+\alpha_b}{2}\sqrt{k_+^2(1-k_+^2)}\sin(\Delta_+)]$ |

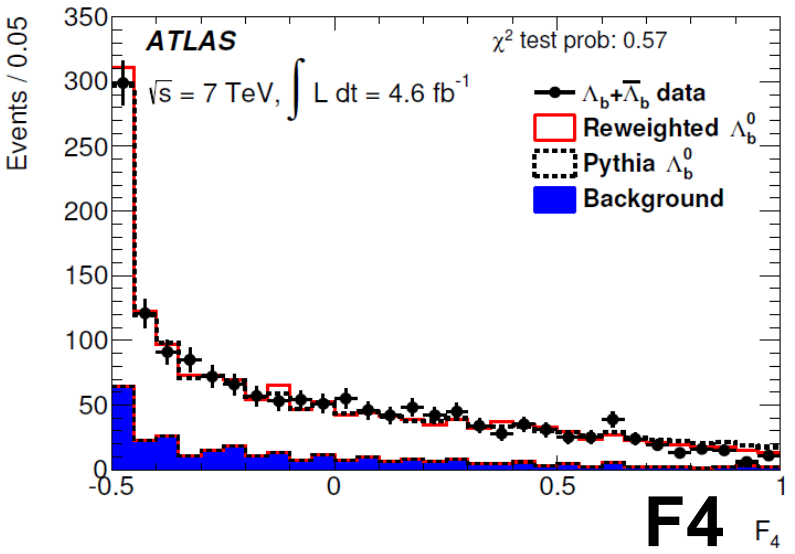
$$k_- = \frac{|b_-|}{\sqrt{|a_-|^2 + |b_-|^2}}$$

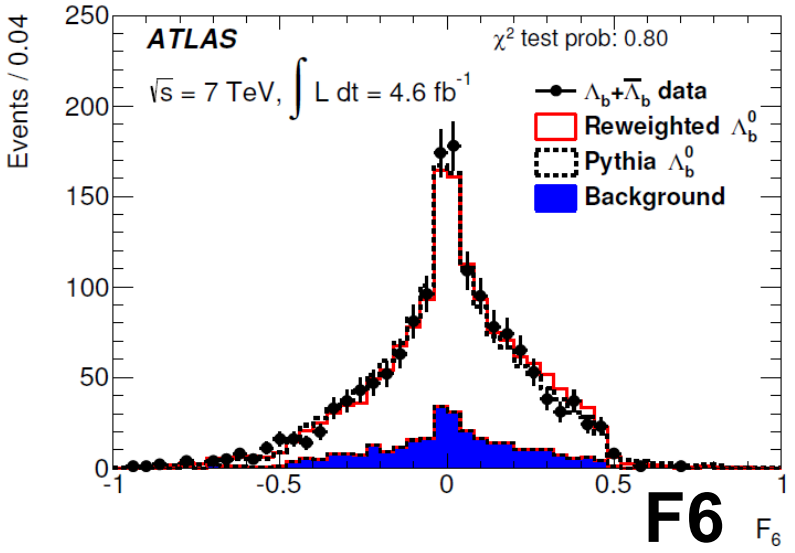
$$k_+ = \frac{|a_+|}{\sqrt{|a_+|^2 + |b_+|^2}},$$

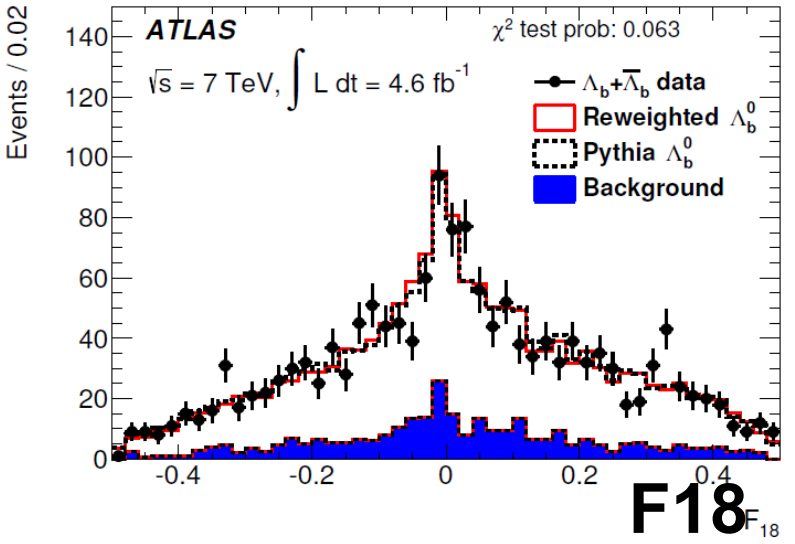
$$\alpha_b = |a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2$$

# Angular moments $\Lambda_b \rightarrow J/\psi\Lambda$



# $\Lambda_b \rightarrow J/\psi\Lambda$ Results

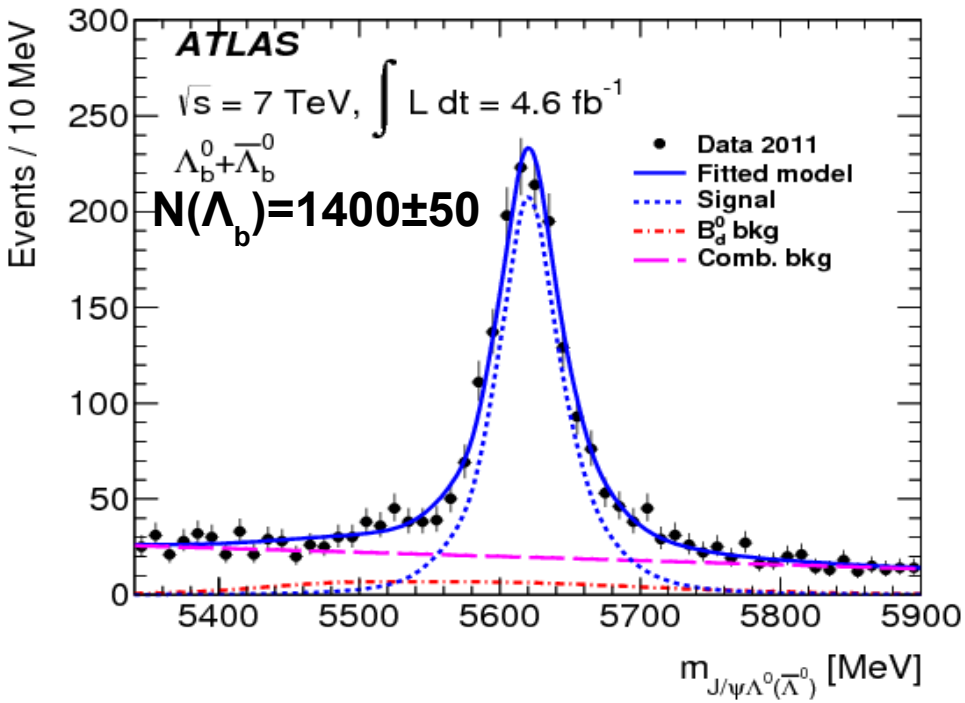
$$\alpha_b = 0.30 \pm 0.16(\text{stat}) \pm 0.06(\text{syst}),$$
$$k_+ = 0.21^{+0.14}_{-0.21}(\text{stat}) \pm 0.13(\text{syst}),$$
$$k_- = 0.13^{+0.20}_{-0.13}(\text{stat}) \pm 0.15(\text{syst}),$$

Phys. Rev. D 89 (2014) 092009

$$k_- = \frac{|b_-|}{\sqrt{|a_-|^2+|b_-|^2}}$$

$$k_+ = \frac{|a_+|}{\sqrt{|a_+|^2+|b_+|^2}},$$

- Compare with
  - LHCb: $\alpha_b = 0.05 \pm 0.17_{\text{stat}} \pm 0.07_{\text{syst}}$
    Phys. Lett. B 724, 27 (2013)
  - HQET: $\alpha_b = 0.78$
    Nucl.Phys A755, 435 (2005)
  - pQCD: $-0.17 < \alpha_b < -0.14$
    Phys. Rev. D 65, 074030 (2002)

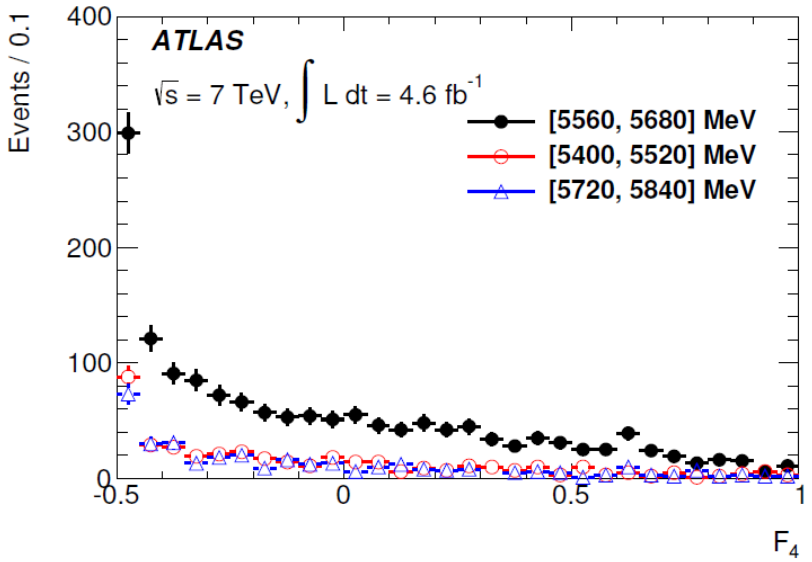


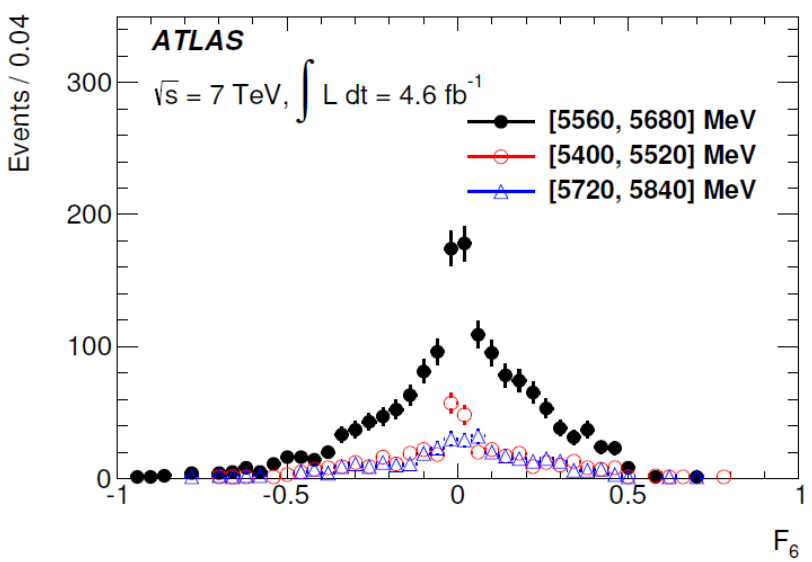
# Conclusion

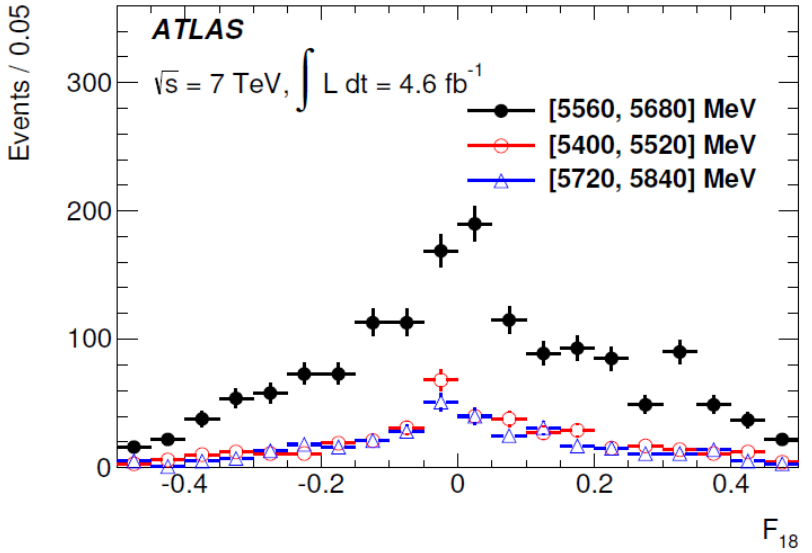
- ATLAS has an active B-physics program
- Benefits from higher luminosity but also more difficult environment due to pileup
- Interesting Results on
  - New particles:
    - $\chi_b(3P)$, $B_c^*$
  - Parity Violation $\Lambda_b$ : $\alpha_b = 0.30 \pm 0.16_{stat.} \pm 0.06_{syst.}$
- See also other ATLAS B-physics talks ( L. Smirnova, R. Jones, S. Prell )
- Further results and updates in progress
- New Physics is still hiding out

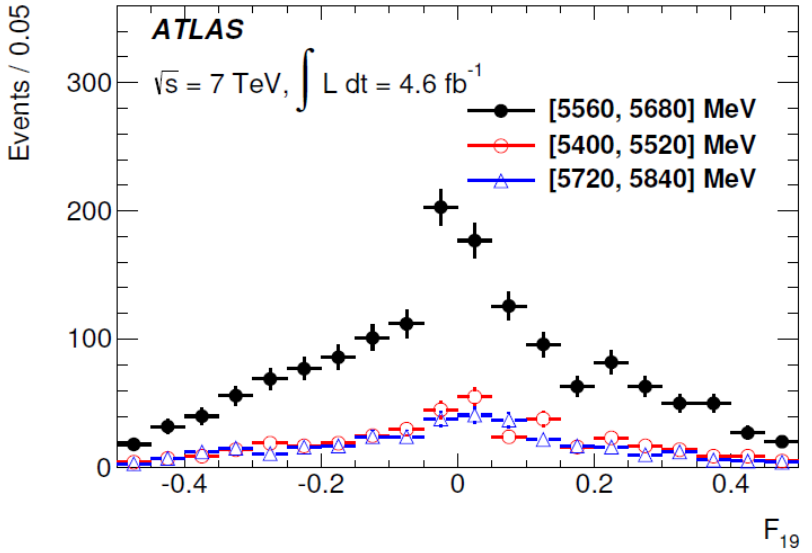
# Bonus Slides

# Parity Violation in $\Lambda_b \rightarrow J/\psi\Lambda$



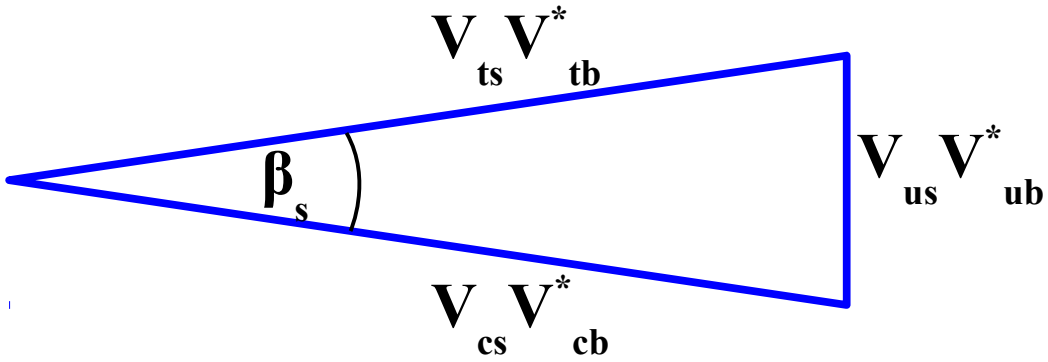
# $B_s \rightarrow J/\psi\phi$ Likelihood

- T

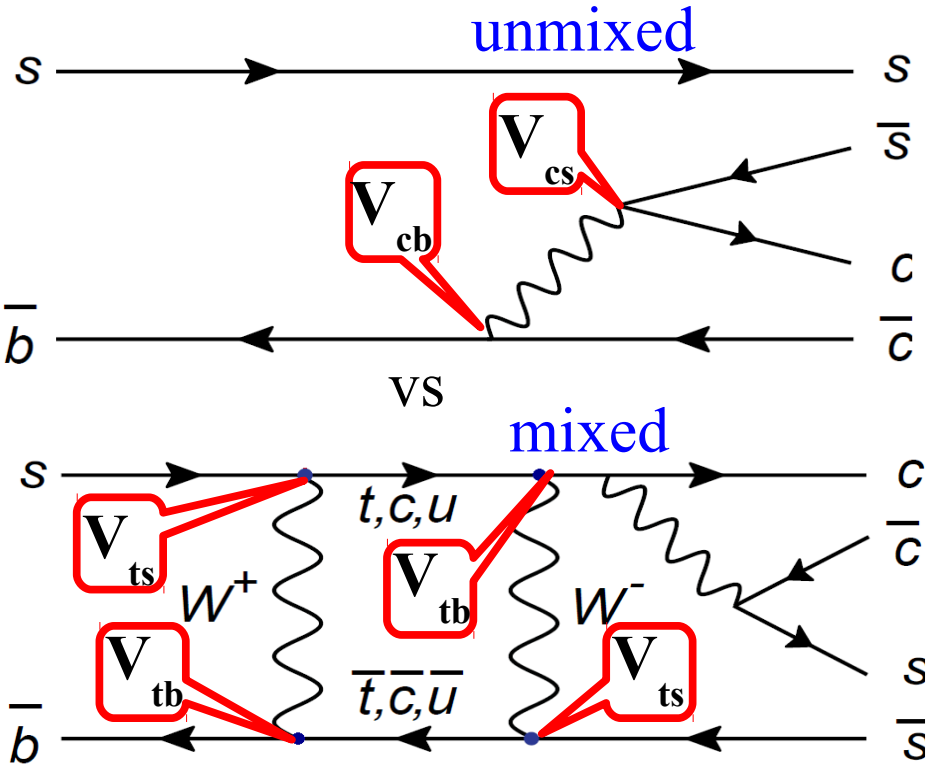
| | | | |
|---|---|---|---|
| 1 | $\lvert A_0\rvert^2(t)$ | = | $\lvert A_0\rvert^2 e^{-\Gamma_s t}[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \pm \sin\phi_s \sin(\Delta m t)]$, |
| 2 | $\lvert A_\parallel(t)\rvert^2$ | = | $\lvert A_\parallel\rvert^2 e^{-\Gamma_s t}[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \pm \sin\phi_s \sin(\Delta m t)]$, |
| 3 | $\lvert A_\perp(t)\rvert^2$ | = | $\lvert A_\perp\rvert^2 e^{-\Gamma_s t}[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \mp \sin\phi_s \sin(\Delta m t)]$, |
| 4 | $\Im(A_\parallel(t)\, A_\perp(t))$ | = | $\lvert A_\parallel\rvert\lvert A_\perp\rvert e^{-\Gamma_s t}[-\cos(\delta_\perp - \delta_\parallel)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \mp \cos(\delta_\perp - \delta_{-\parallel})\cos\phi_s \sin(\Delta m t) \pm \sin(\delta_\perp - \delta_\parallel)\cos(\Delta m t)]$, |
| 5 | $\Re(A_0(t)\, A_\parallel(t))$ | = | $\lvert A_0\rvert\lvert A_\parallel\rvert e^{-\Gamma_s t}\cos(\delta_\parallel - \delta_0)[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \pm \sin\phi_s \sin(\Delta m t)]$, |
| 6 | $\Im(A_0(t)\, A_\perp(t))$ | = | $\lvert A_0\rvert\lvert A_\perp\rvert e^{-\Gamma_s t}[-\cos(\delta_\perp - \delta_0)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \mp \cos(\delta_\perp - \delta_0)\cos\phi_s \sin(\Delta m t) \pm \sin(\delta_\perp - \delta_0)\cos(\Delta m t)]$, |
| 7 | $\lvert A_s(t)\rvert^2$ | = | $\lvert A_s\rvert^2 e^{-\Gamma_s t}[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \mp \sin\phi_s \sin(\Delta m t]$, |
| 8 | $\Re(A_s^*(t)A_\parallel(t))$ | = | $\lvert A_s\rvert\lvert A_\parallel\rvert e^{-\Gamma_s t}[-\sin(\delta_\parallel - \delta_s)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \mp \sin(\delta_\parallel - \delta_s)\ \cos\phi_s \sin(\Delta m t) \pm \cos(\delta_\parallel - \delta_s)\cos(\Delta m t)]$, |
| 9 | $\Im(A_s^*(t)A_\perp(t))$ | = | $\lvert A_s\rvert\lvert A_\perp\rvert e^{-\Gamma_s t}\sin(\delta_\perp - \delta_s)[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \mp \sin\phi_s \sin(\Delta m t)]$, |
| 10 | $\Re(A_s^*(t)A_0(t))$ | = | $\lvert A_s\rvert\lvert A_0\rvert e^{-\Gamma_s t}[-\sin(\delta_0 - \delta_s)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \mp \sin(\delta_0 - \delta_s)\cos\phi_s \sin(\Delta m t) \pm \cos(\delta_0 - \delta_s)\cos(\Delta m t)]$. |

# $B_s \rightarrow J/\psi\phi$ Introduction

- Interference between mixed and unmixed decays
- $B_s \rightarrow$ Vector-Vector decay, three spin states
  L=0,2 ($A_0$,$A_\parallel$) CP-even L=1 ($A_\perp$) CP-odd CP=CP(J/ψ)CP(φ)$(-1)^L$
- Use angular analysis to disentangle contributions

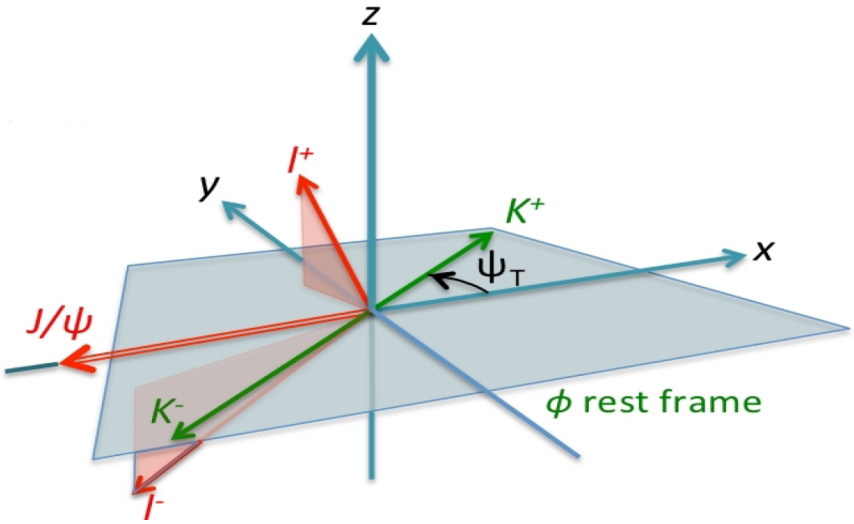


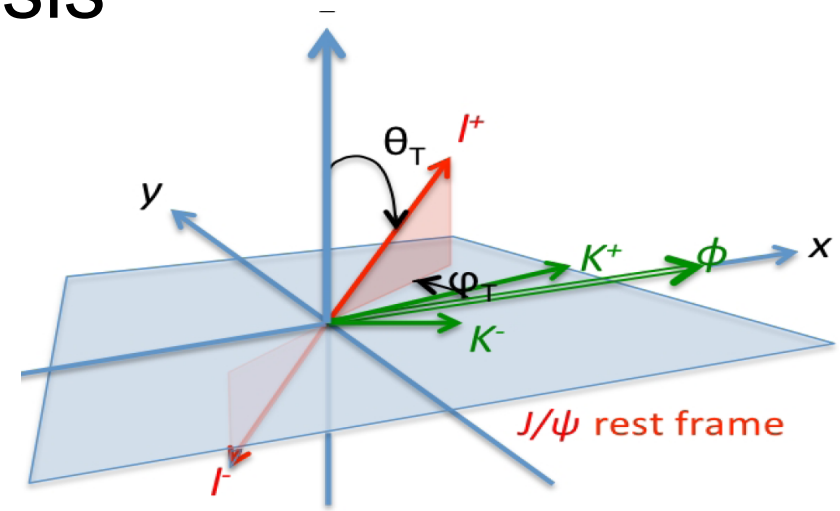

$$\Psi_{J/\psi\phi} = \Psi_{mix} - 2\Psi_{dec}$$
$$= 2\arg V_{ts}V_{tb}^* - 2\arg V_{cs}V_{cb}^*$$
$$= 2\arg\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*} = -2\beta_s$$

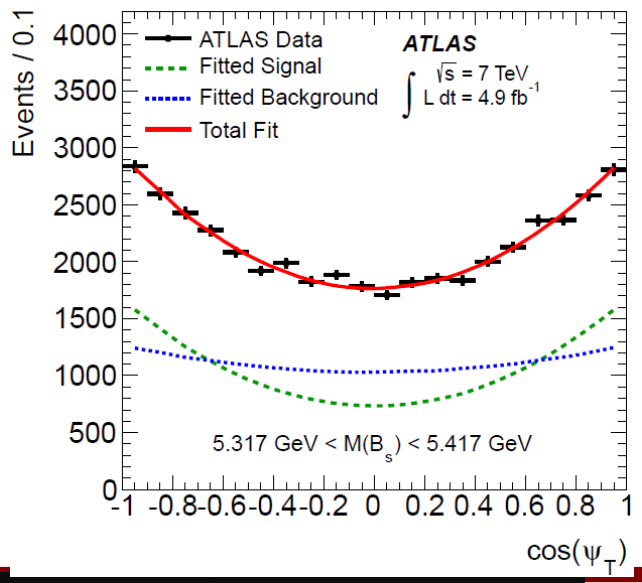


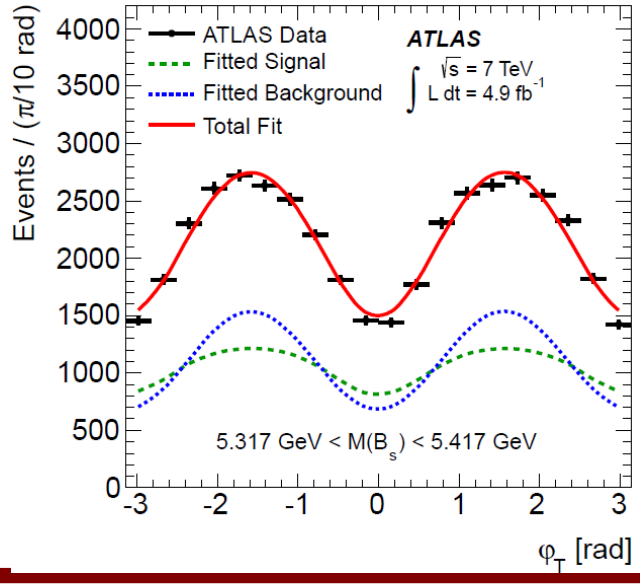
# $B_s \rightarrow J/\psi\phi$ Angular Analysis

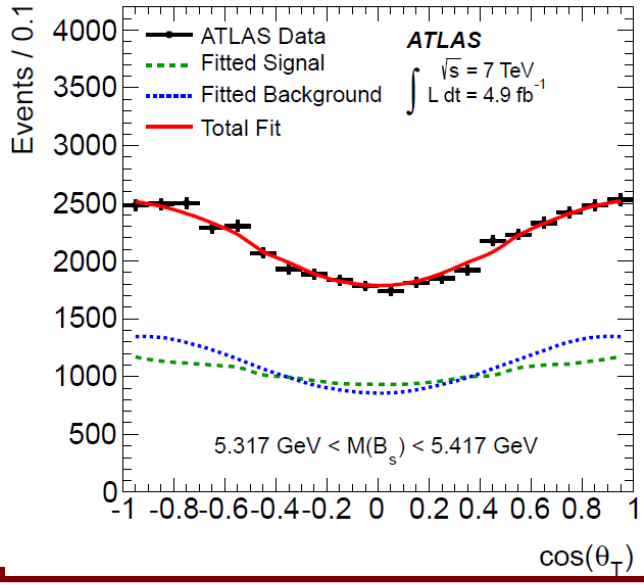
- Angles in transversity basis



# $B_s \rightarrow J/\psi\phi$ Likelihood

- Unbinned likelihood fit, 25 free parameters

$$\mathcal{L} = \prod \Big[ f_s \cdot \mathcal{F}_{sig}(m_i, t_i, \Omega_i, \sigma_m, \sigma_t, \Gamma_s, \Delta\Gamma_s, \phi_s, A_0, A_\parallel, A_S, \delta_\parallel, \delta_\perp, \delta_s) \, P(B|Q) + f_s \cdot f_{B0} \cdot \mathcal{F}_{B0}(m_i, t_i, \Omega_i, \sigma_m, \sigma_t) \, P(\bar{B}|Q) + (1 - f_s \cdot (1 + f_{B0})) \cdot \mathcal{F}_{bkg}(m_i, t_i, \Omega_i, \sigma_m, \sigma_t) \, P(B|Q) \Big]$$

$$\Omega = (\psi_T, \theta_T, \phi_T)$$

- Signal
  - Untagged analysis: oscillation terms drop out
  - New Tagged analysis with extra information
- $B^0$ background, continuum background,
- New: B-tagging
  - Muon & jetcharge taggers to identify B vs $\bar{B}$ ($\varepsilon D^2 = (1.45 \pm 0.05)\%$)

# $B_s \rightarrow J/\psi\phi$ Likelihood

- Unbinned likelihood fit, 25 free parameters

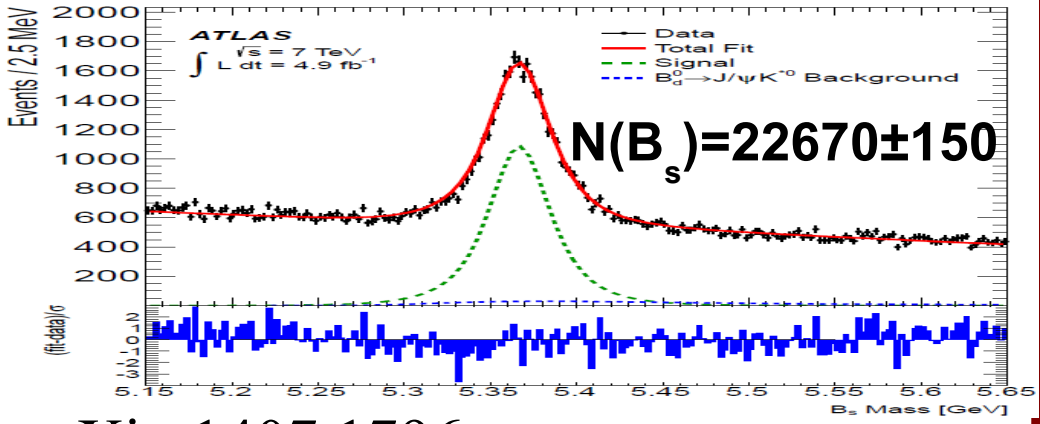
$$\mathcal{L} = \prod \Big[ f_s \cdot \mathcal{F}_{sig}(m_i, t_i, \Omega_i, \sigma_m, \sigma_t, \Gamma_s, \Delta\Gamma_s, \phi_s, A_0, A_\parallel, A_S, \delta_\parallel, \delta_\perp, \delta_s, P(B|Q) \Big] +$$

- Signal

| | |
|---|---|
| $\frac{1}{2}\lvert A_0(0)\rvert^2 \left[(1+\cos\phi_s)\, e^{-\Gamma_{\rm L}^{(s)} t} + (1-\cos\phi_s)\, e^{-\Gamma_{\rm H}^{(s)} t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$ | $2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\phi_T)$ |
| $\frac{1}{2}\lvert A_\parallel(0)\rvert^2 \left[(1+\cos\phi_s)\, e^{-\Gamma_{\rm L}^{(s)} t} + (1-\cos\phi_s)\, e^{-\Gamma_{\rm H}^{(s)} t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$ | $\sin^2\psi_T(1-\sin^2\theta_T\sin^2\phi_T)$ |
| $\frac{1}{2}\lvert A_\perp(0)\rvert^2 \left[(1-\cos\phi_s)\, e^{-\Gamma_{\rm L}^{(s)} t} + (1+\cos\phi_s)\, e^{-\Gamma_{\rm H}^{(s)} t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$ | $\sin^2\psi_T\sin^2\theta_T$ |
| $\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\parallel(0)\rvert\cos\delta_\parallel$ $\left[(1+\cos\phi_s)\, e^{-\Gamma_{\rm L}^{(s)} t} + (1-\cos\phi_s)\, e^{-\Gamma_{\rm H}^{(s)} t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$ | $-\frac{1}{\sqrt{2}}\sin 2\psi_T\sin^2\theta_T\sin 2\phi_T$ |
| $\lvert A_\parallel(0)\rvert\lvert A_\perp(0)\rvert[\frac{1}{2}(e^{-\Gamma_{\rm L}^{(s)} t} - e^{-\Gamma_{\rm H}^{(s)} t})\cos(\delta_\perp-\delta_\parallel)\sin\phi_s$ $\pm e^{-\Gamma_s t}(\sin(\delta_\perp-\delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp-\delta_\parallel)\cos\phi_s\sin(\Delta m_s t))]$ | $\sin^2\psi_T\sin 2\theta_T\sin\phi_T$ |
| $\lvert A_0(0)\rvert\lvert A_\perp(0)\rvert[\frac{1}{2}(e^{-\Gamma_{\rm L}^{(s)} t} - e^{-\Gamma_{\rm H}^{(s)} t})\cos\delta_\perp\sin\phi_s$ $\pm e^{-\Gamma_s t}(\sin\delta_\perp\cos(\Delta m_s t) - \cos\delta_\perp\cos\phi_s\sin(\Delta m_s t))]$ | $\frac{1}{\sqrt{2}}\sin 2\psi_T\sin 2\theta_T\cos\phi_T$ |
| $\frac{1}{2}\lvert A_S(0)\rvert^2 \left[(1-\cos\phi_s)\, e^{-\Gamma_{\rm L}^{(s)} t} + (1+\cos\phi_s)\, e^{-\Gamma_{\rm H}^{(s)} t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$ | $\frac{2}{3}\left(1-\sin^2\theta_T\cos^2\phi_T\right)$ |
| $\lvert A_S(0)\rvert\lvert A_\parallel(0)\rvert[\frac{1}{2}(e^{-\Gamma_{\rm L}^{(s)} t} - e^{-\Gamma_{\rm H}^{(s)} t})\sin(\delta_\parallel-\delta_S)\sin\phi_s$ $\pm e^{-\Gamma_s t}(\cos(\delta_\parallel-\delta_S)\cos(\Delta m_s t) - \sin(\delta_\parallel-\delta_S)\cos\phi_s\sin(\Delta m_s t))]$ | $\frac{1}{3}\sqrt{6}\sin\psi_T\sin^2\theta_T\sin 2\phi_T$ |
| $\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\perp(0)\rvert\sin(\delta_\perp-\delta_S)$ $\left[(1-\cos\phi_s)\, e^{-\Gamma_{\rm L}^{(s)} t} + (1+\cos\phi_s)\, e^{-\Gamma_{\rm H}^{(s)} t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$ | $\frac{1}{3}\sqrt{6}\sin\psi_T\sin 2\theta_T\cos\phi_T$ |
| $\lvert A_0(0)\rvert\lvert A_S(0)\rvert[\frac{1}{2}(e^{-\Gamma_{\rm H}^{(s)} t} - e^{-\Gamma_{\rm L}^{(s)} t})\sin\delta_S\sin\phi_s$ $\pm e^{-\Gamma_s t}(\cos\delta_S\cos(\Delta m_s t) + \sin\delta_S\cos\phi_s\sin(\Delta m_s t))]$ | $\frac{4}{3}\sqrt{3}\cos\psi_T\left(1-\sin^2\theta_T\cos^2\phi_T\right)$ |

# $B_s \rightarrow J/\psi\phi$ results

$$\phi_s = 0.12 \pm 0.25\ (\text{stat.}) \pm 0.05\ (\text{syst.})\ \text{rad}$$
$$\Delta\Gamma_s = 0.053 \pm 0.021\ (\text{stat.}) \pm 0.010\ (\text{syst.})\ \text{ps}^{-1}$$
$$\Gamma_s = 0.677 \pm 0.007\ (\text{stat.}) \pm 0.004\ (\text{syst.})\ \text{ps}^{-1}$$
$$|A_{\parallel}(0)|^2 = 0.220 \pm 0.008\ (\text{stat.}) \pm 0.009\ (\text{syst.})$$
$$|A_0(0)|^2 = 0.529 \pm 0.006\ (\text{stat.}) \pm 0.012\ (\text{syst.})$$
$$\delta_{\perp} = 3.89 \pm 0.47\ (\text{stat.}) \pm 0.11\ (\text{syst.})\ \text{rad}$$




Untagged: JHEP 12 (2012) 072 Tagged: arXiv:1407.1796