Beauty2014

Mixing and CP-Violation in the decay of $B_s \rightarrow J/\Psi\ \Phi$ in ATLAS

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on behalf of the ATLAS Collaboration

Introduction

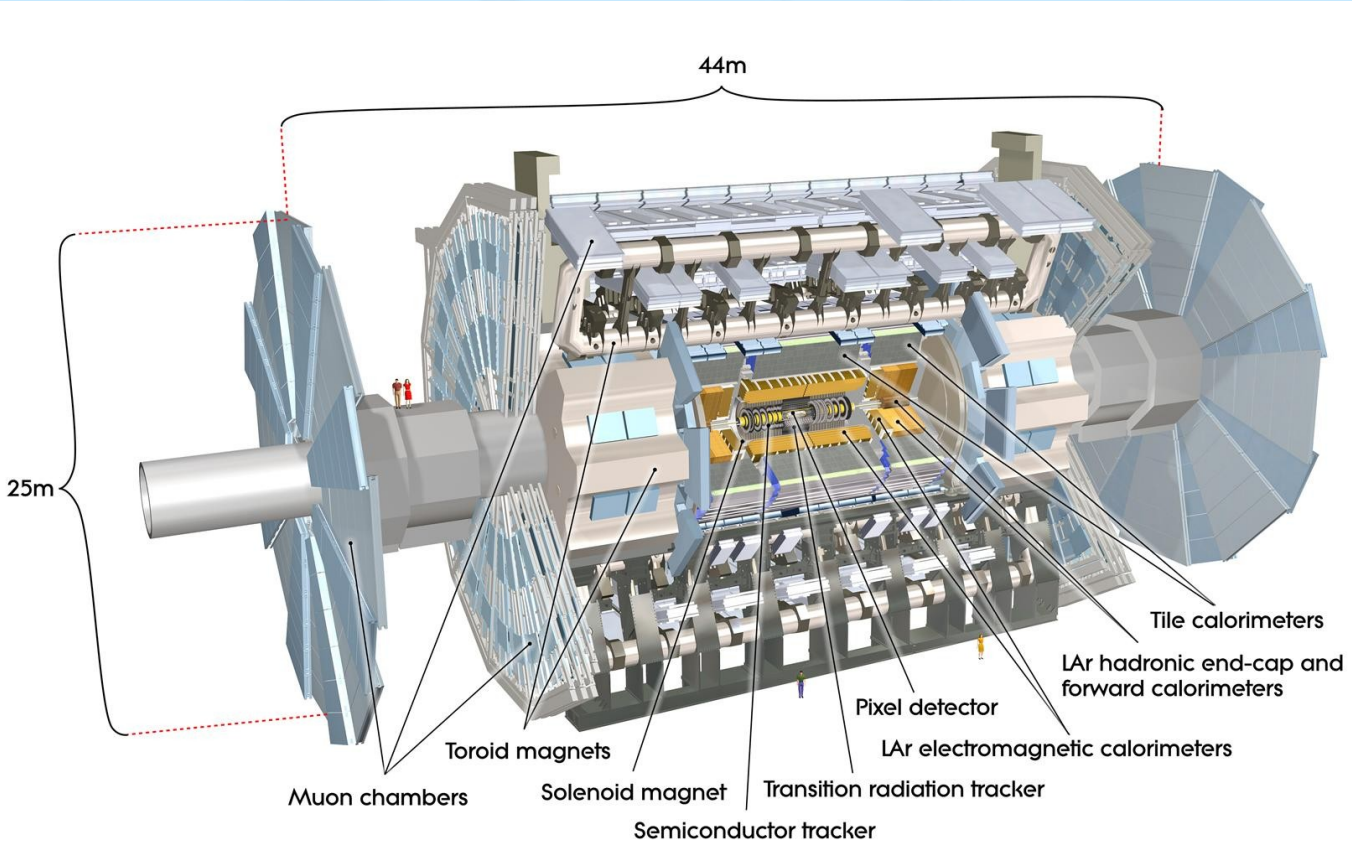
- Presenting latest public ATLAS $B_s \rightarrow J/\Psi\ \Phi$ results
- CERN-PH-EP-2014-043
- 4.9 fb^{-1} of data collected in 2011

- ATLAS detector and B-Physics
- CP-Violation in B_s system
- $B_s \rightarrow J/\Psi\ \Phi$ method
- $B_s \rightarrow J/\Psi\ \Phi$ analysis results

ATLAS Detector

ATLAS is multipurpose detector, built to study a vast array of particle physics channels.
Main components of use to B-Physics studies:

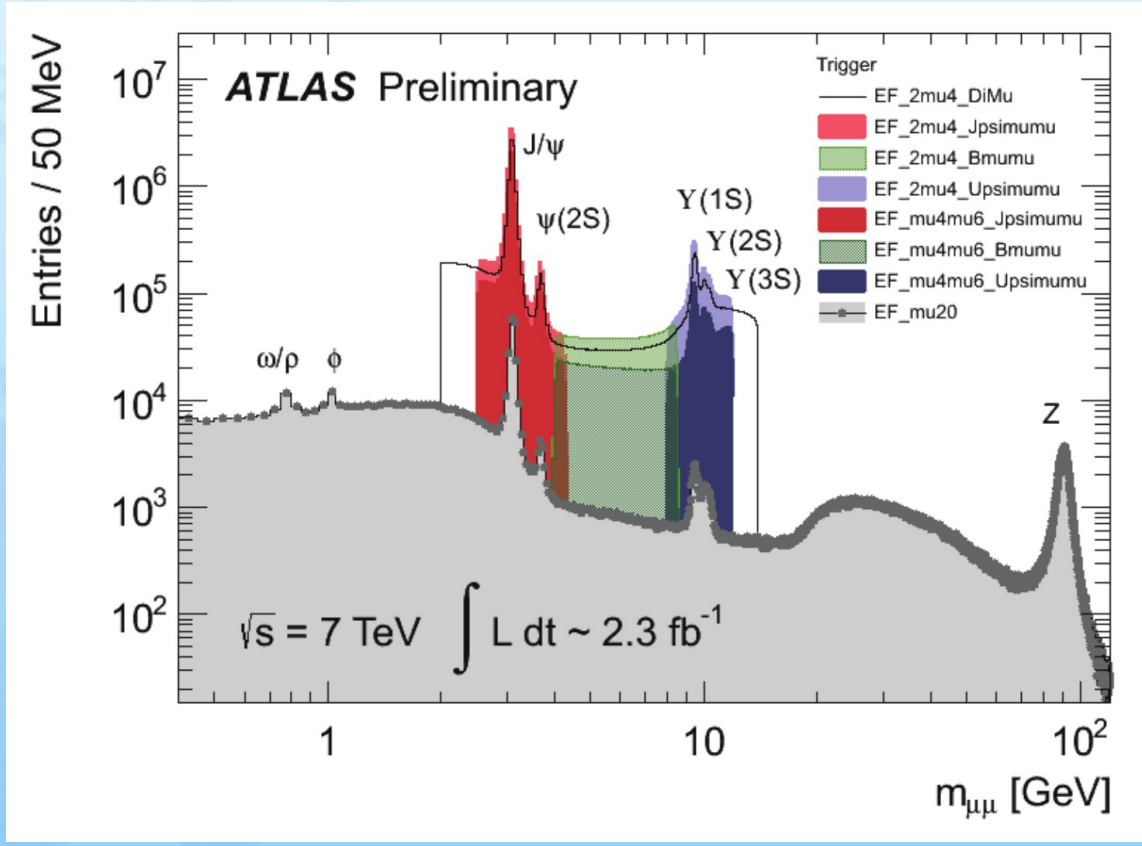
- Precision outer Muon Spectrometer for $|\eta| < 2.5$, with resolution ~40μm
- Inner Detector for $|\eta| < 2.5$ with resolution ~10μm



ATLAS B-Physics Triggers

- L1:
  - Single and Di-muon triggers from 4 → 40 GeV $P_{\perp}$

- L2 & EF:
  - Searches for muons from a common vertex with opposing charges
  - Applies loose mass cuts, shown in plot:
    - J/ψ: 2.5 < M(μμ) < 4.3 GeV
    - B: 4.0 < M(μμ) < 8.5 GeV

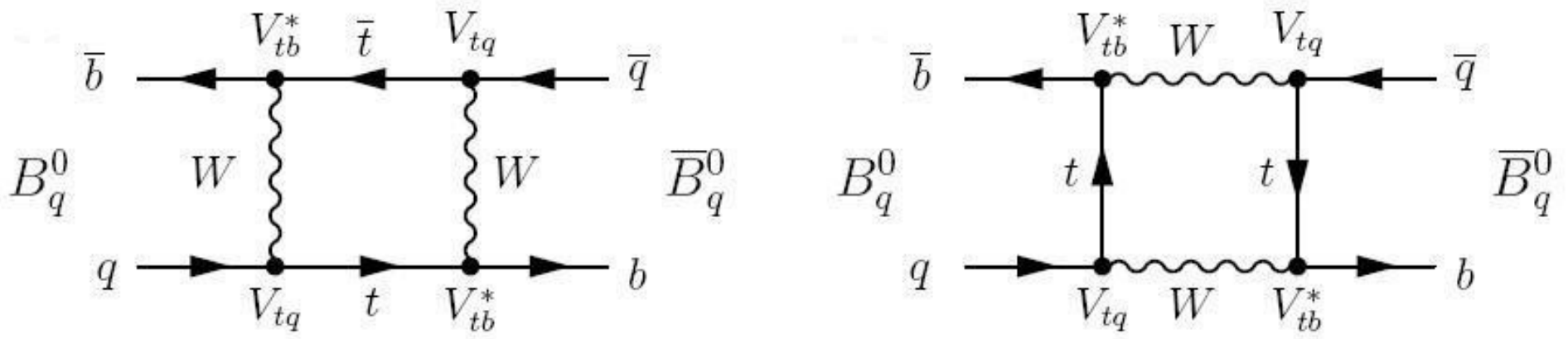


CP-Violation in the B_s system

- Mixing between flavour states results in heavy and light mass eigenstates

$$\Delta m_s = m_s^H - m_s^L \approx 2|M_{12}|\,, \qquad \Delta m_s \approx 17.77 ps^{-1}$$

$$\Delta\Gamma_s = \Gamma_s^L - \Gamma_s^H, \qquad \Delta\Gamma_s = 0.087 \pm 0.021\ ps^{-1}$$

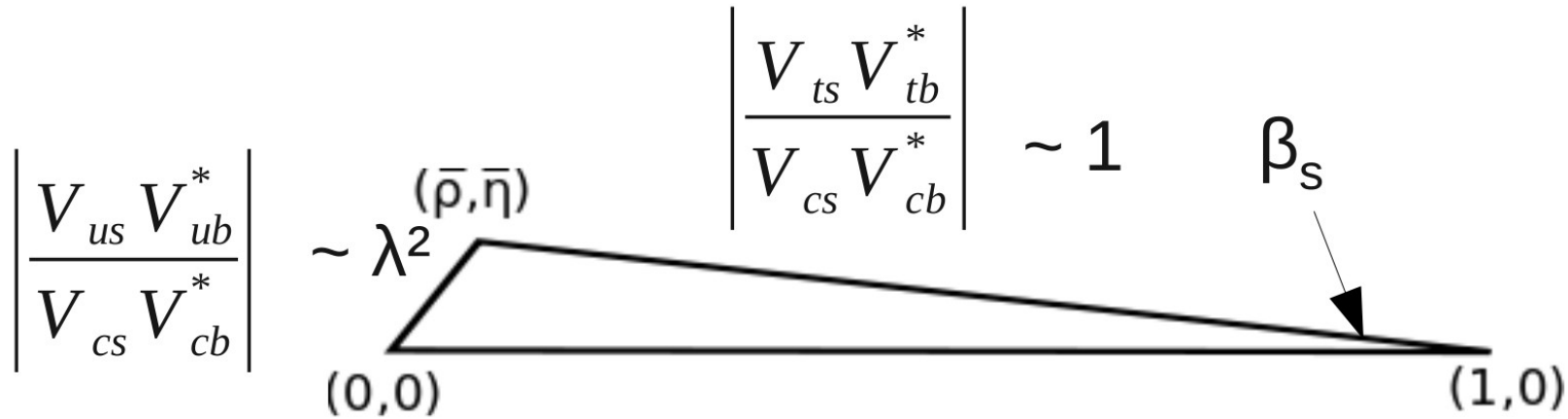


Feynman box diagrams for B mixing.

- In the Standard Model, CP-Violation is described by a single complex phase in CKM matrix
- In the B_s system, Φ_s is predicted by the Standard Model to be small:
  $\Phi_s \approx -2\beta_s = -0.0368 \pm 0.0018$ rad
- $B_s \rightarrow J/\Psi\ \Phi$ gives a clean extraction of Φ_s

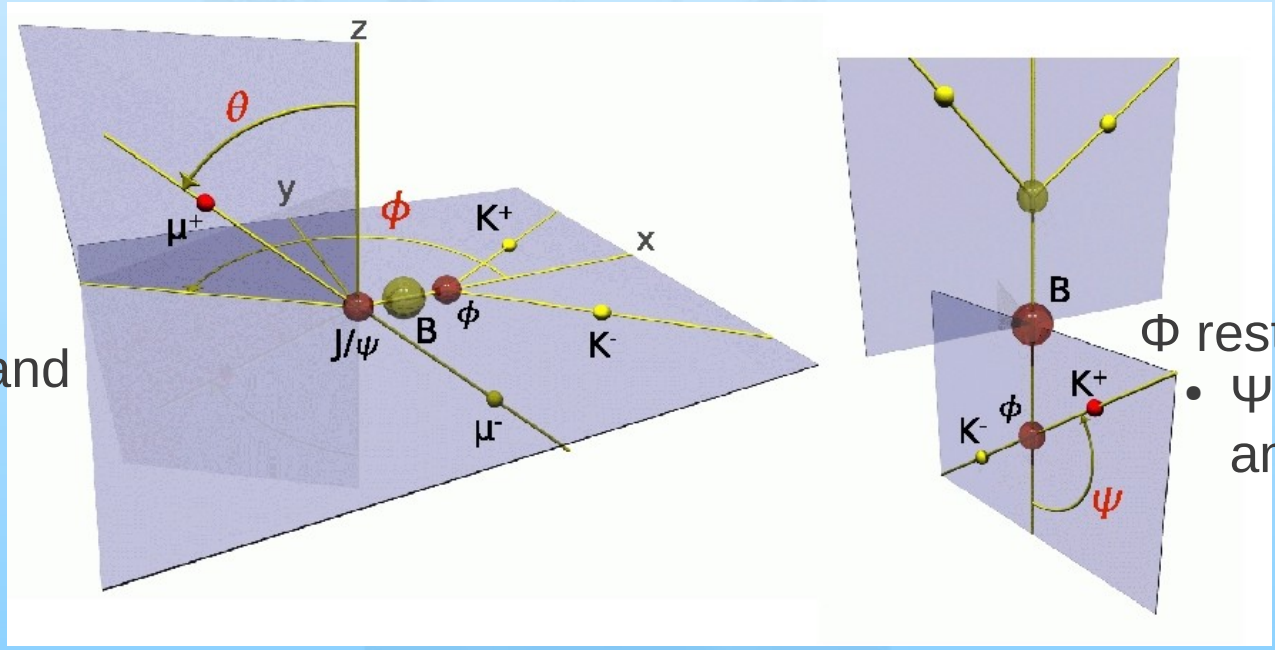
$$\beta_s \equiv arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$

- Many new physics models predict large values for Φ_s, whilst still satisfying current constraints



Angular Analysis

- $B_s \rightarrow J/\Psi\ \Phi$ described with amplitudes and strong phases:
  - Amplitudes
    - A_0: L=0, CP-even
    - $A_\perp$: L=1, CP-odd
    - $A_\parallel$: L=2, CP-even
  - Strong phases
    - $\delta_0 = 0$
    - $\delta_\perp$: $\arg[A_0(0)\, A_0^*(0)]$
    - $\delta_\parallel$: $\arg[A_\parallel(0)\, A_0^*(0)]$
- 3 angle time-dependent angular analysis used to extract parameters



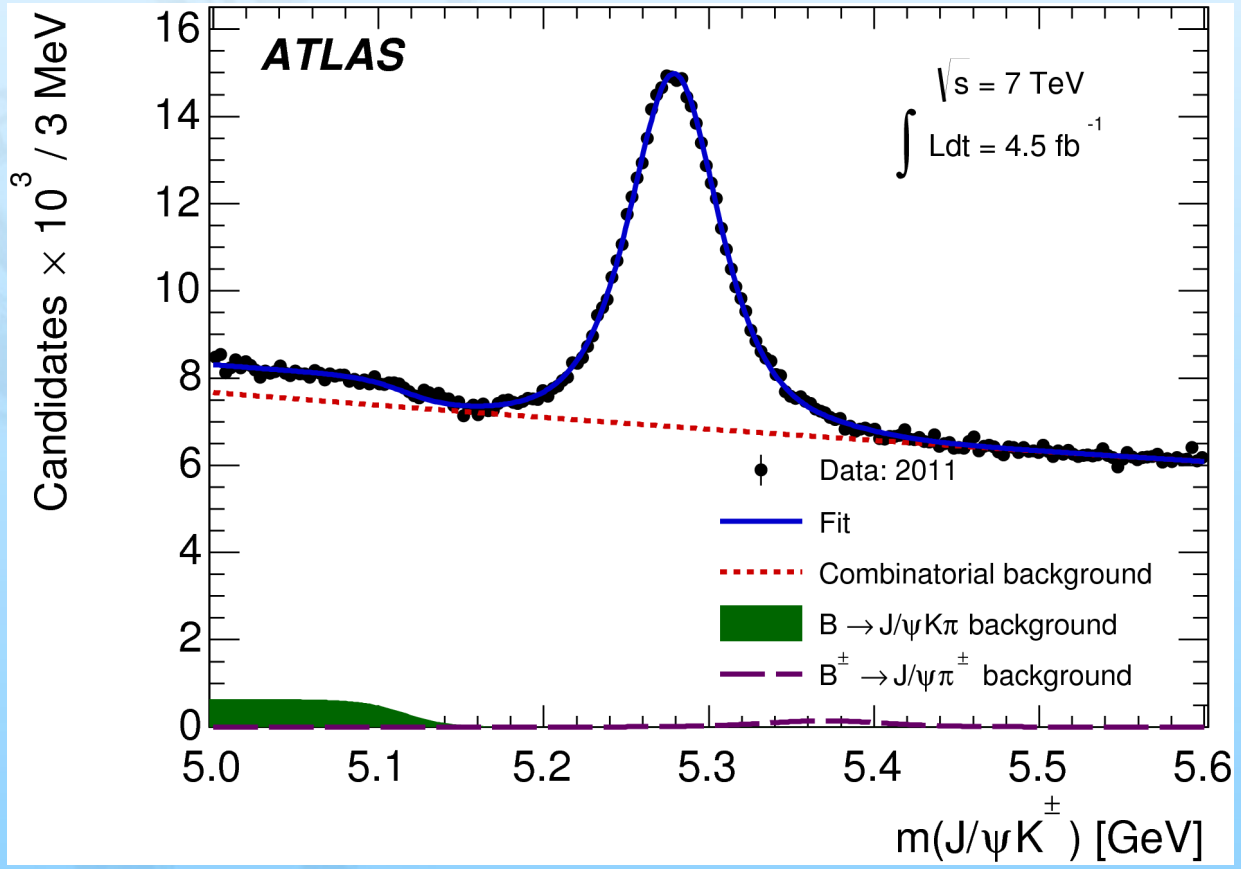
J/Ψ rest frame:
- θ: between μ^+ and x-y plane
- Φ: between μ^+ and x axis

Φ rest frame:
- Ψ: between K^+ and x axis

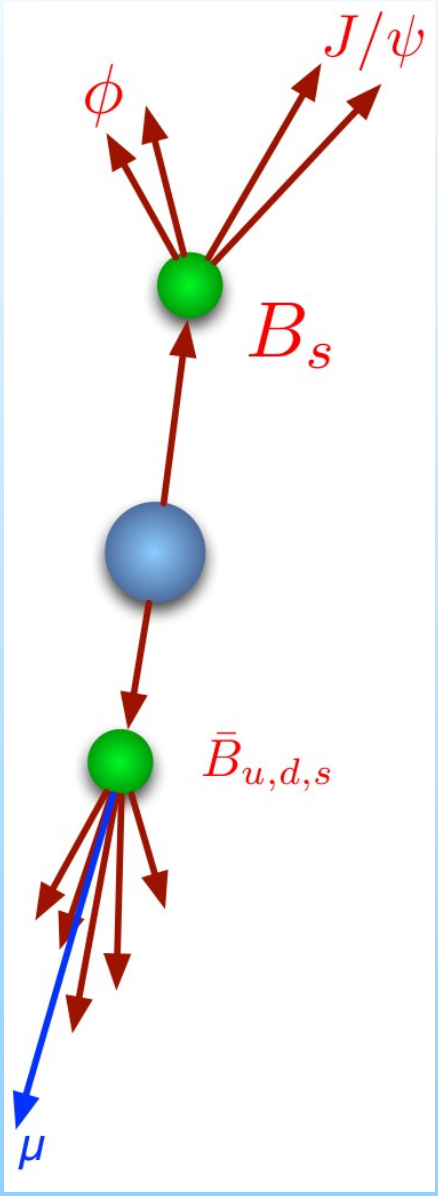
- A_s is the contribution of CP-odd $B_s \rightarrow J/\Psi\ K^+K^-(f_0)$ where the non-resonant K^+K^- or f_0 meson is an S-wave state

$B_s \rightarrow J/\Psi\ \Phi$ method – Event Selection

- J/Ψ mass windows are tuned to different widths, depending on the final location of daughter muons. Barrel / Endcap
- Φ mass window is 22 MeV wide
- Kaon $P_\perp > 1$GeV
- For B vertex from 4 tracks χ^2 / d.o.f. < 3
- 4.9 fb^{-1} of data collected in 2011
- ~131,000 B_s candidates within $5.15 < m(B_s) < 5.65$ GeV used in fit



Flavour Tagging



- Opposite side tagging uses $b\bar{b}$ pairs to infer the signal flavour of the other B meson
- Calibrated on self tagging $B^{\pm} \rightarrow J/\Psi\ K^{\pm}$
- Muon tagging:
  - Additional muon pt>2.5 GeV, |η|<2.5
  - Originating near signal primary interaction |Δz|<5mm
  - Use muon and tracks within cone ΔR<0.5, and construct weighted cone charge
- Jet charge tagging
  - Absence of a muon
  - Use tracks within cone ΔR<1.0, and construct weighted cone charge

$$Q_{\mu}, Q_{\text{jet}} = \frac{\sum_i^{N\ \text{tracks}} q^i \cdot (p_T^i)^{\kappa}}{\sum_i^{N\ \text{tracks}} (p_T^i)^{\kappa}}$$

Tag Performance

Tagger	Efficiency [%]	Dilution [%]	Tagging Power [%]
Combined μ	3.37 ± 0.04	50.6 ± 0.5	0.86 ± 0.04
Segment Tagged μ	1.08 ± 0.02	36.7 ± 0.7	0.15 ± 0.02
Jet charge	27.7 ± 0.1	12.68 ± 0.06	0.45 ± 0.03
Total	32.1 ± 0.1	21.3 ± 0.08	1.45 ± 0.05

Efficiency: $\epsilon_{tag} = \frac{N_r + N_w}{N_t}$

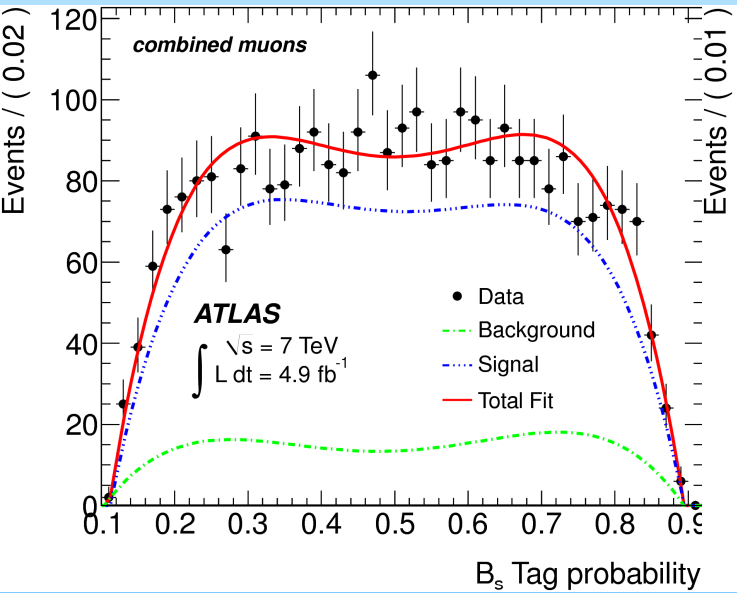
Dilution: $D_{tag} = \frac{N_r - N_w}{N_r + N_w}$

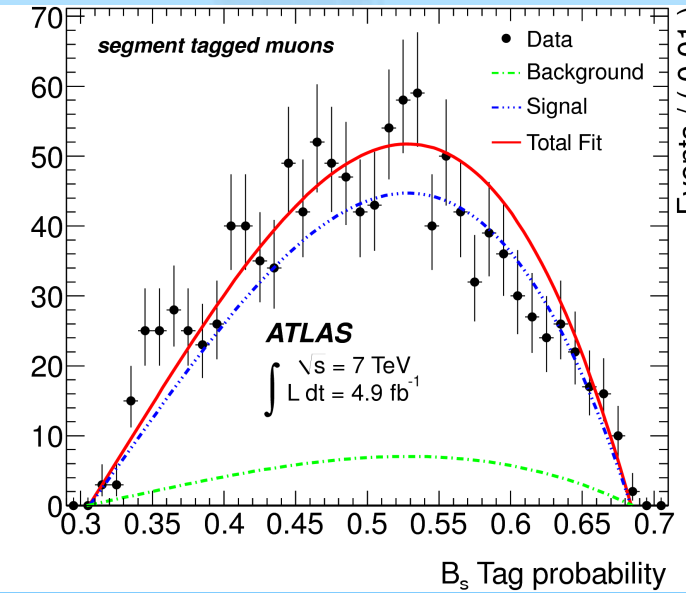
Fraction: $w_{tag} = \frac{N_w}{N_r + N_w}$

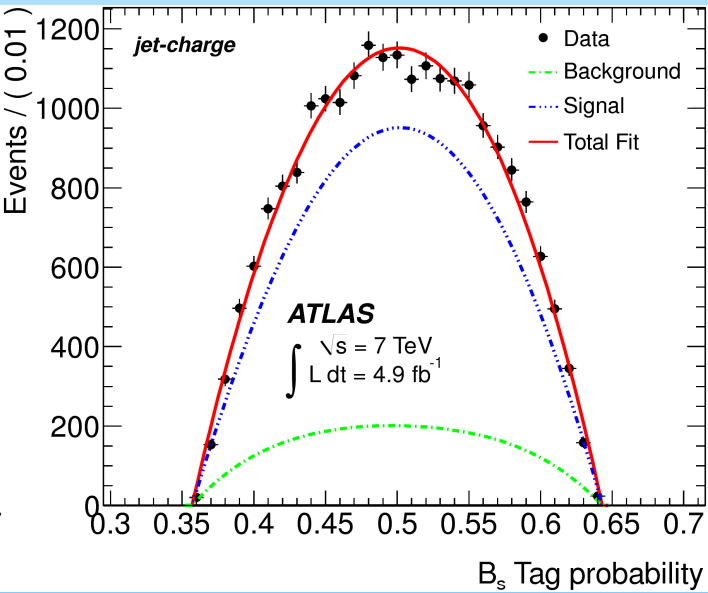
Tagging Power: $Q_{tag} = \epsilon_{tag} D_{tag}^2$

N_r = # correctly tagged
N_w = # incorrectly tagged
N_t = # total

- In the likelihood fit to B_s data, per-candidate probability for signal and background are considered seperately
- Additional terms are parameterised from fits to sideband-subtracted (signal) and sideband (B_s data) B_s data
- Single track results (tagged charge as -1 or 1) are treated separately







Likelihood fit model

Unbinned maximum likelihood fit with PDFs for signal, B_0 background and all other backgrounds

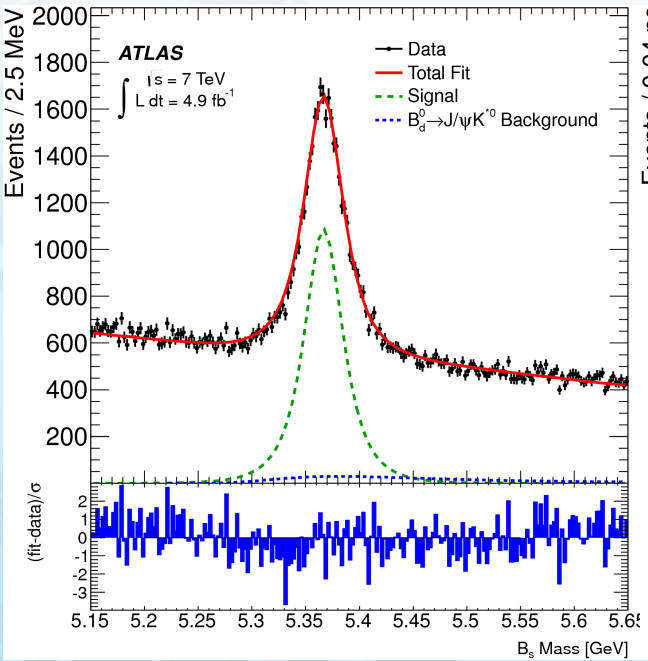
$$\ln \mathcal{L} = \sum_{i=1}^{N} \ln\left(f_s \cdot \mathcal{F}_s(m_i, t_i, \Omega_i) + f_s \cdot f_{B^0} \cdot \mathcal{F}_{B^0}(m_i, t_i, \Omega_i) + (1 - f_s \cdot (1 + f_{B^0}))\mathcal{F}_{\text{bkg}}(m_i, t_i, \Omega_i)\right)$$

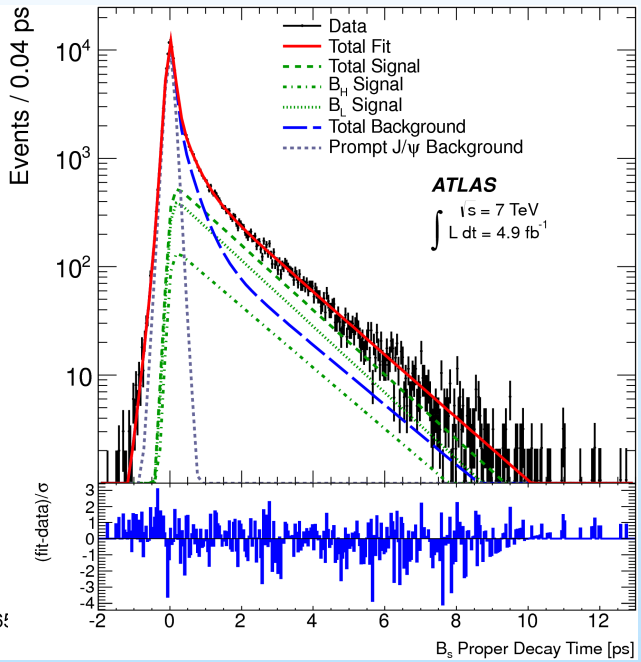
$$\mathcal{F}_s(m_i, t_i, \Omega_i, P(B|Q)) = P_s(m_i|\sigma_{m_i}) \cdot P_s(\sigma_{m_i}) \cdot P_s(\Omega_i, t_i, P(B|Q)|\sigma_{t_i}) \cdot P_s(\sigma_{t_i}) \cdot P_s(P(B|Q)) \cdot A(\Omega_i, p_{Ti}) \cdot P_s(p_{Ti})$$

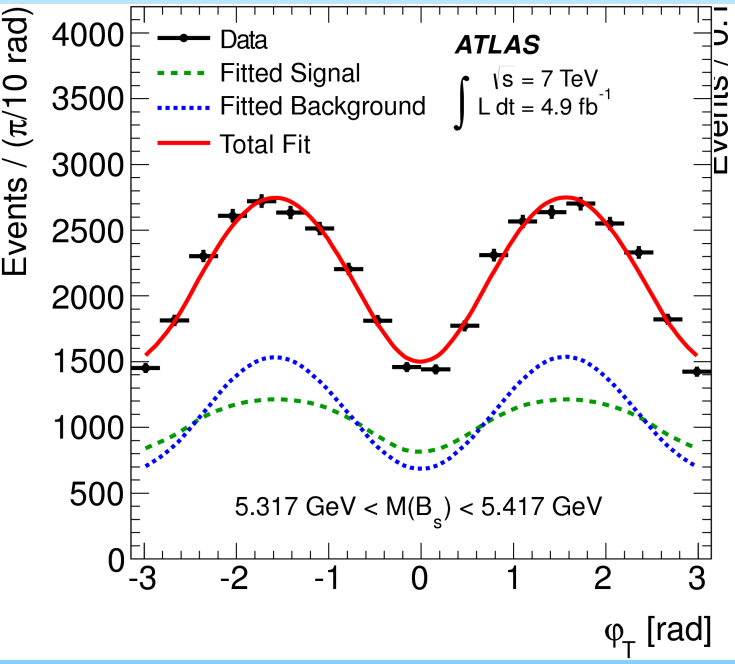
- 26 free parameters extracted from fit
- 9 physical variables describing $B_s \rightarrow J/\Psi\ \Phi$ and S-wave component: $\Delta\Gamma$, Γ_s, Φ_s, $|A_0(0)|^2$, $|A_{||}(0)|^2$, $|A_s(0)|^2$, $\delta_{||}$, $\delta_\perp$, δ_s
- Measured variables:
  - Proper decay time and corresponding error: t_i, σ_{t_i}
  - Mass and corresponding error: m_i, σ_{m_i}
  - Transversity angles $\Omega_i(\theta, \varphi, \psi)$
  - Tagging probability

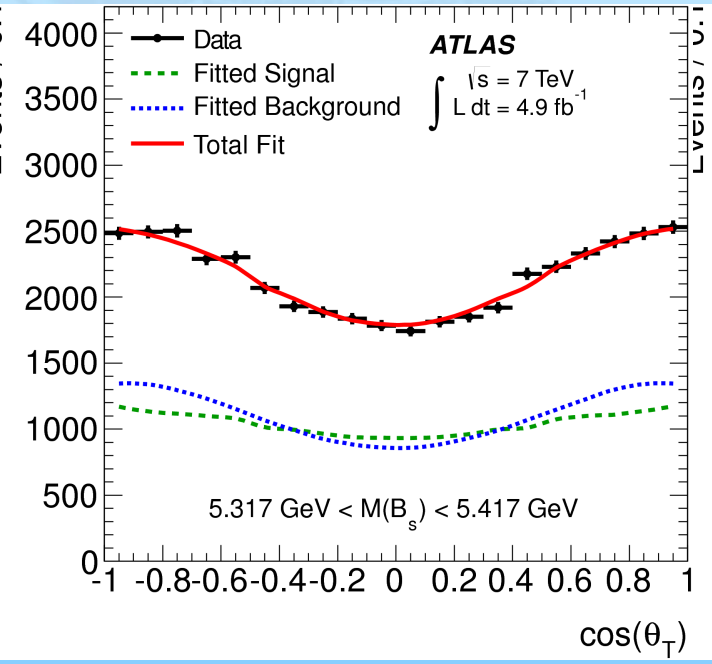
Fit Projections

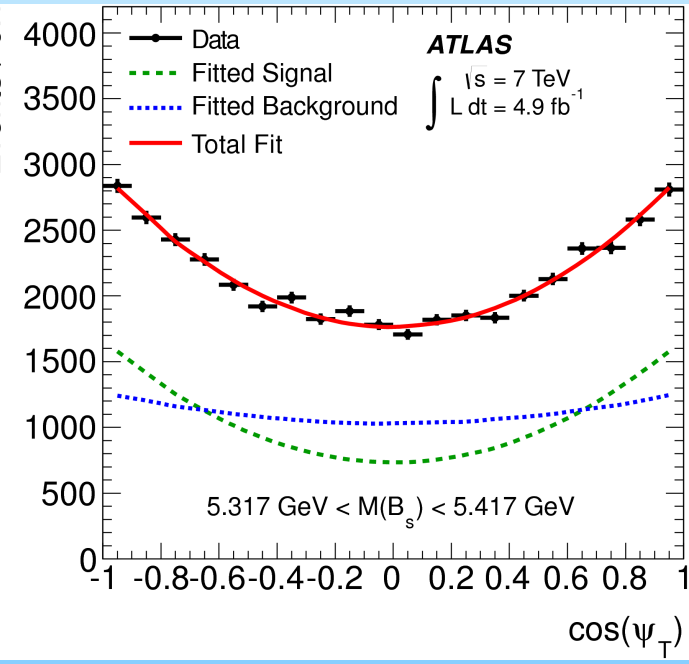
- Fit projections to all data passing selections
- 22690±160 candidates extracted











$B_s \to J/\Psi\,\Phi$ analysis results

- Φ_s consistent with Standard Model predictions and previous untagged analysis results
- S-wave amplitude compatible with 0
- $\delta_{\parallel}$ and $\delta_{\perp} - \delta_s$ are given as 68% CL
- Tagged analysis allows for $\delta_{\perp}$ to be determined from the fit, where it was previously constrained

$$\phi_s = 0.12 \pm 0.25\ (\text{stat.}) \pm 0.05\ (\text{syst.})\ \text{rad}$$

$$\Delta\Gamma_s = 0.053 \pm 0.021\ (\text{stat.}) \pm 0.010\ (\text{syst.})\ \text{ps}^{-1}$$

$$\Gamma_s = 0.677 \pm 0.007\ (\text{stat.}) \pm 0.004\ (\text{syst.})\ \text{ps}^{-1}$$

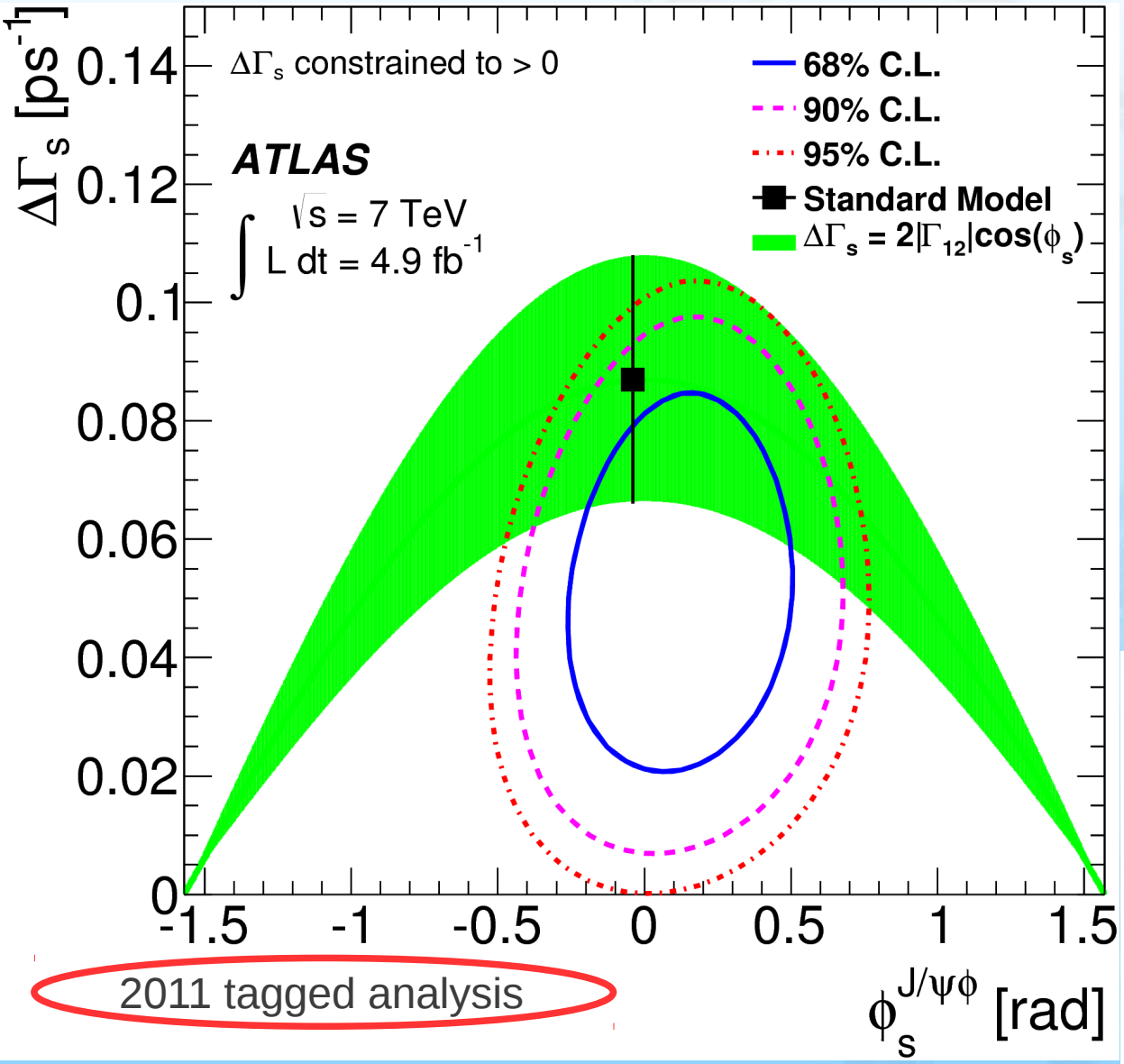
$$|A_{\parallel}(0)|^2 = 0.220 \pm 0.008\ (\text{stat.}) \pm 0.009\ (\text{syst.})$$

$$|A_0(0)|^2 = 0.529 \pm 0.006\ (\text{stat.}) \pm 0.012\ (\text{syst.})$$

$$\delta_{\perp} = 3.89 \pm 0.47\ (\text{stat.}) \pm\ 0.11\ (\text{syst.})\ \text{rad}$$

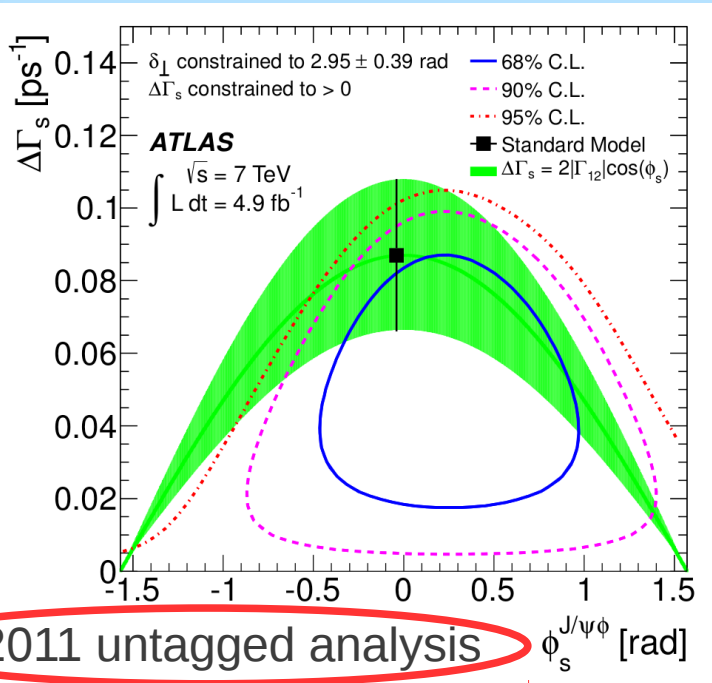
	ϕ_s [rad]	$\Delta\Gamma_s$ [ps^{-1}]	Γ_s [ps^{-1}]	$\lvert A_{\parallel}(0)\rvert^2$	$\lvert A_0(0)\rvert^2$	$\lvert A_S(0)\rvert^2$	$\delta_{\perp}$ [rad]	$\delta_{\parallel}$ [rad]	$\delta_{\perp} - \delta_S$ [rad]
ID alignment	$<10^{-2}$	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	-	$<10^{-2}$	$<10^{-2}$	-
Trigger efficiency	$<10^{-2}$	$<10^{-3}$	0.002	$<10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-2}$	$<10^{-2}$	$<10^{-2}$
B^0 contribution	0.03	0.001	$<10^{-3}$	$<10^{-3}$	0.005	0.001	0.02	$<10^{-2}$	$<10^{-2}$
Tagging	0.03	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	0.04	$<10^{-2}$	$<10^{-2}$
Acceptance	0.02	0.004	0.002	0.002	0.004	-	-	$<10^{-2}$	-
Models:									
Default fit	$<10^{-2}$	0.003	$<10^{-3}$	0.001	0.001	0.006	0.07	0.01	0.01
Signal mass	$<10^{-2}$	0.001	$<10^{-3}$	$<10^{-3}$	0.001	$<10^{-3}$	0.03	0.04	0.01
Background mass	$<10^{-2}$	0.001	0.001	$<10^{-3}$	$<10^{-3}$	0.002	0.06	0.02	0.02
Resolution	0.02	$<10^{-3}$	0.001	0.001	$<10^{-3}$	0.002	0.04	0.02	0.01
Background time	0.01	0.001	$<10^{-3}$	0.001	$<10^{-3}$	0.002	0.01	0.02	0.02
Background angles	0.02	0.008	0.002	0.008	0.009	0.027	0.06	0.07	0.03
Total	0.05	0.010	0.004	0.009	0.012	0.028	0.11	0.09	0.04

Φ_s - $\Delta\Gamma$ contour plot



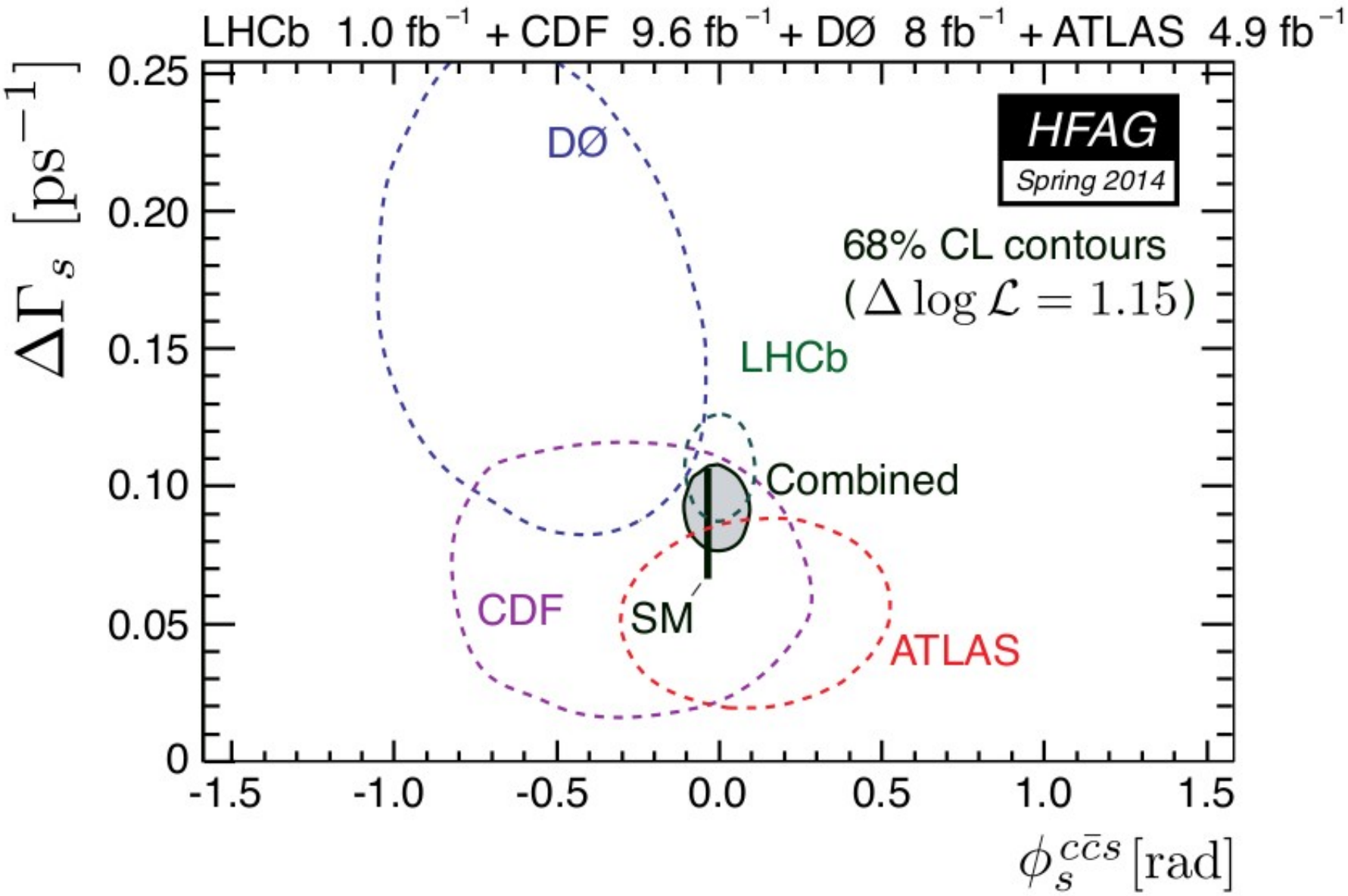
2011 tagged analysis

- Uncertainty of Φ_s has improved ~40% since previous publication
- No constraint on $\delta_\perp$
- $\Delta\Gamma$ central value and uncertainty unchanged



2011 untagged analysis

Contour plot comparison



Conclusion

- Latest ATLAS results for $B_s \rightarrow J/\psi\ \Phi$ analysis of 2011 data now include tagging
  - Muon cone charge tagging
  - Jet charge tagging
- Final results are an improvement on previous results on the same data due to inclusion of tagging
- ATLAS $B_s \rightarrow J/\Psi\ \Phi$ are in generally good agreement with other experiments
- No current evidence for physics beyond the Standard Model
- ATLAS is currently working towards publishing results for $B_s \rightarrow J/\psi\ \Phi$ using 2012 data
- Possible improvements in future due to addition of IBL

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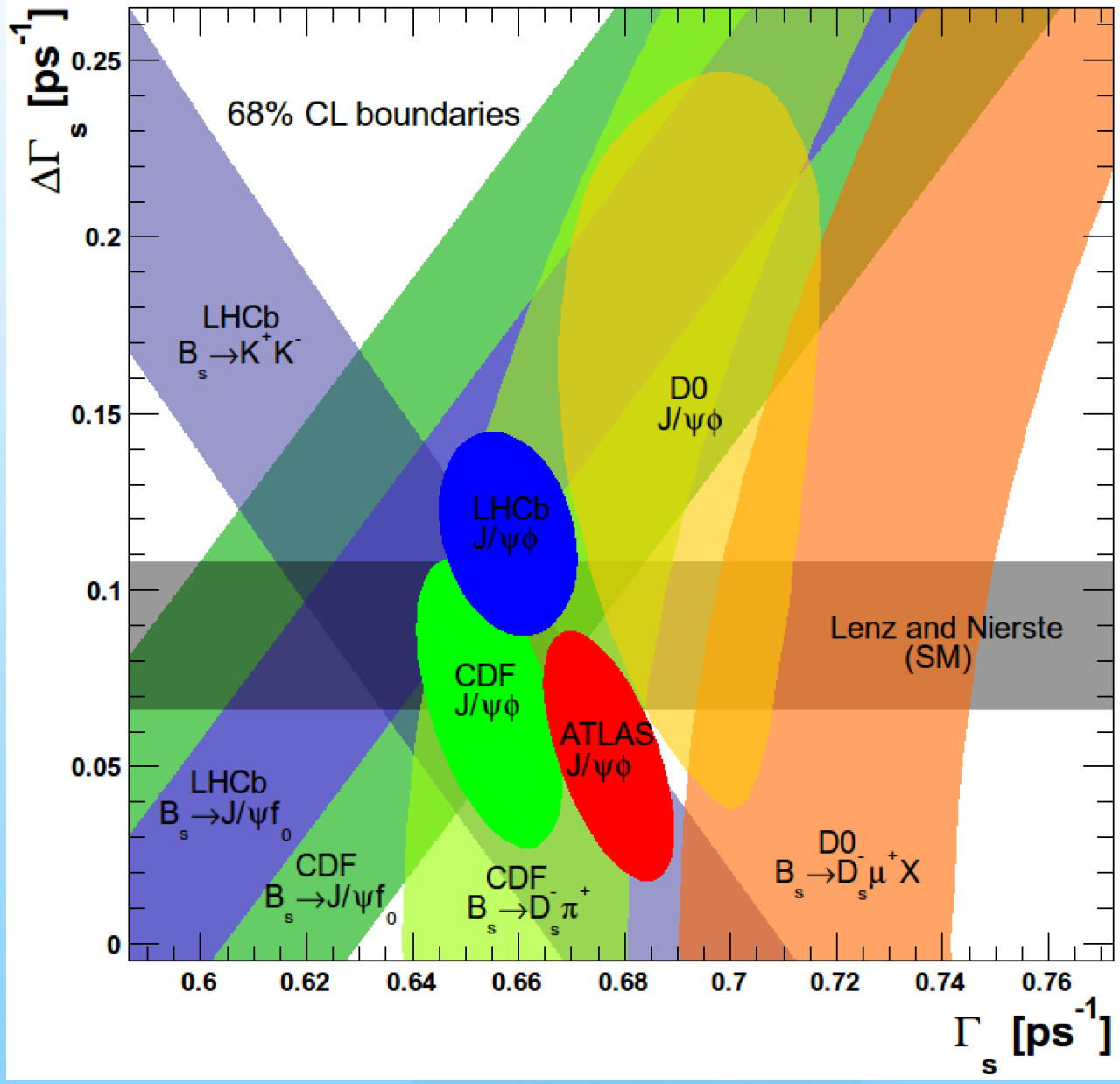
Backup Slides

ΔΓ - Γ Plot comparison



Plot taken from:
http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/BPHY-2011-05/

Reference Material:

- Paper:
  - CERN-PH-EP-2014-043 – "Flavour tagged time dependent angular analysis of the $B^0_s \to J/\psi\,\varphi$ decay and extraction of $\Delta\Gamma_s$ and the weak phase Φ_s in ATLAS"

- Slides:
  - Sandro Palestini – ATL-PHYS-SLIDE-2012-491
  - James Walder – ATL-PHYS-SLIDE-2013-306
  - Adam Barton – ATL-PHYS-SLIDE-2012-781
  - Jochen Sckieck – ATL-PHYS-SLIDE-2013-529
  - Alastair Dewhurst – ATL-PHYS-SLIDE-2013-217