Mixing and CP violation in the B_s system with ATLAS

Study from $B_s^0 \rightarrow J/\psi\ \phi$ decay with and without flavour tagging

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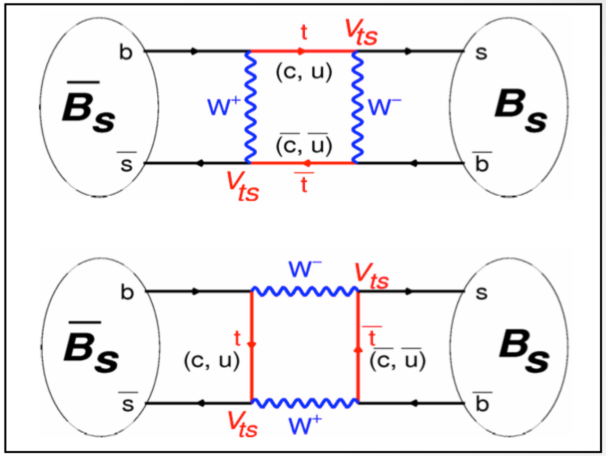
CP violation in B_s system

Mixing between flavour eigenstates give rise to heavy and light mass eigenstates as a results of Schrödinger's Equation

$$i\frac{d}{dt}\begin{pmatrix} |B^0(t)\rangle \\ |\bar{B}^0(t)\rangle \end{pmatrix} = \left(\begin{pmatrix} M_{11} & M_{12} \\ M_{12}^* & M_{11} \end{pmatrix} - \frac{i}{2}\begin{pmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma_{11} \end{pmatrix} \right) \begin{pmatrix} |B^0(t)\rangle \\ |\bar{B}^0(t)\rangle \end{pmatrix}$$



Mass Eigenstates

$$|B_s^H\rangle = p|B_s^0\rangle - q|\bar{B}_s^0\rangle$$

$$|B_s^L\rangle = p|B_s^0\rangle + q|\bar{B}_s^0\rangle$$

If $p = q = 1$:

B_s^H is purely CP-odd state,

B_s^L is purely CP-even state.

-The mass difference is already well measured by CDF and LHCb

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

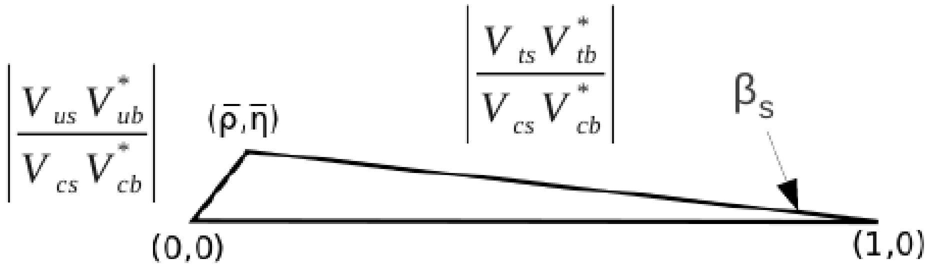
-The SM predicts lifetimes of B_s^H and B_s^L differ by ~O(10 %)

arXiv:hep-ex/060940
arXiv:1112.4311

Measurements of $\Delta\Gamma_s = \Gamma_s^L - \Gamma_s^H$ and $\Gamma_s = (\Gamma_s^L + \Gamma_s^H)/2$ are good test for SM.

CP violation in $B_s^0 \rightarrow J/\psi\ \phi$

CP Violation in $B_s \rightarrow J/\psi\ \phi$ occurs through interference of mixing and decay.

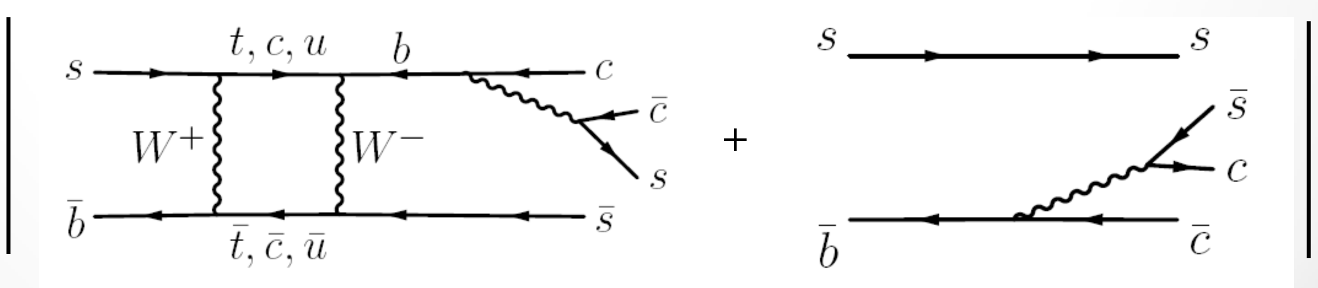


arXiv:
hep-ph/0605213

- CP violation phase: $\phi_s \approx -2\beta_s = -2\arg[\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}]$ is small in SM($\sim$ - 0.04)
- New particle could enter weak mixing box diagrams and enhance CP violation.

→ Measurements of ϕ_s is very sensitive to new physics

decay rate ~ $\left| \quad + \quad \right|^2$

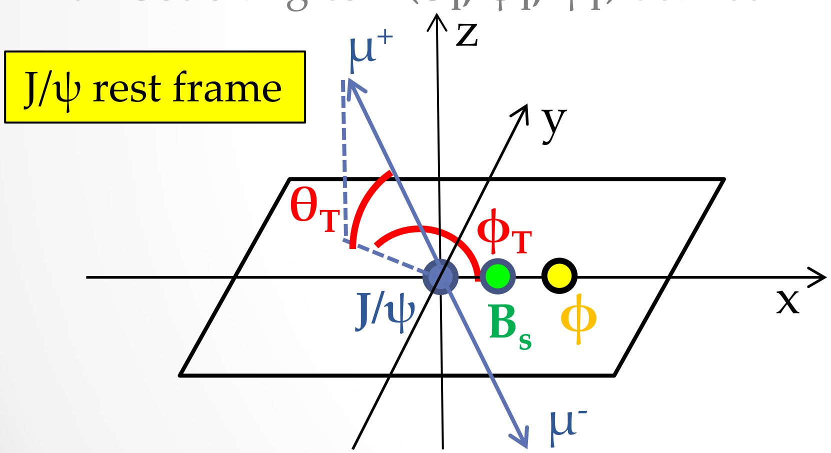


Angular Analysis

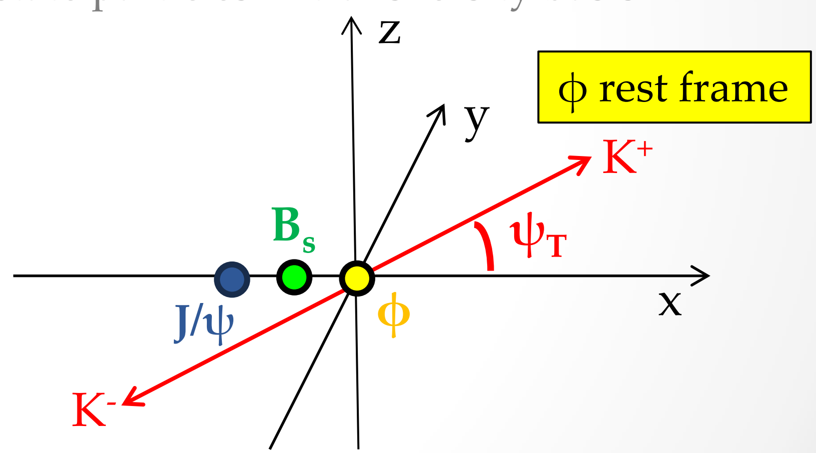
- $B_s^0 \rightarrow J/\psi\ \phi$: decay from a pseudo-scalar to vector vector mesons
  - CP-even(L=0, 2) and CP-odd (L=1) in final state

Amplitudes	**Strong phases**
A_0 : L=0 CP-even	$\delta_0 : \equiv 0$
$A_\perp$: L=1 CP–odd	$\delta_\perp$: arg $[A_\perp(0)\ A_0{}^*(0)]$
$A_{/\!/}$: L=2 CP–even	$\delta_{/\!/}$: arg $[A_{/\!/}(0)\ A_0{}^*(0)]$

  - **Distinguishable through time-dependent angular analysis**
  - Use 3 angles $\Omega(\theta_T, \phi_T, \psi_T)$ between final state particles in transversity basis



θ_T: b.t.w. p(μ+) and X-Y plane
ϕ_T: b.t.w. p(μ+) and X axis



ψ_T: b.t.w p(K^+) and X axis

Untagged time-dependent decay rate

In absence of detector effect, time dependent decay rate can be written as follows:

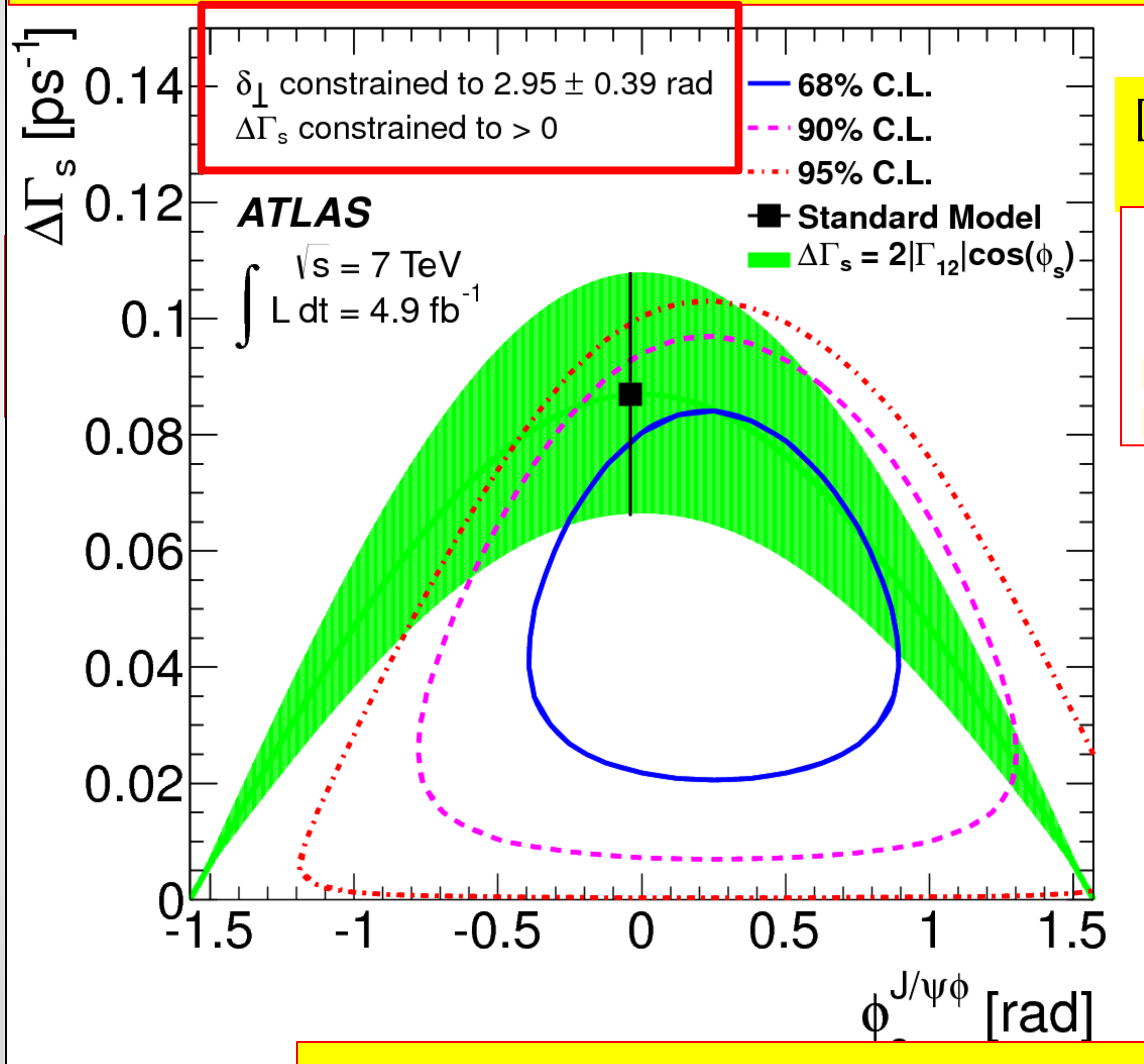
$$\frac{d^4\Gamma}{dt\,d\Omega} = \sum_{k=1}^{10} \mathscr{O}^{(k)}(t)\, g^{(k)}(\theta_T, \psi_T, \phi_T)$$

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

By multi-dimensional fit to the data, determine the physics quantities.

Untagged time-dependent decay rate

Constainted to LHCb result for $\delta_\perp$
because without flavour tagging, sensitivity on $\delta_\perp$ is poor…



[JHEP 12 (2012) 072]
Analysis without flavour tagging

$$\phi_s = 0.22 \pm 0.41\ (\text{stat.}) \pm 0.10\ (\text{syst.})\ \text{rad}$$
$$\Delta\Gamma_s = 0.053 \pm 0.021\ (\text{stat.}) \pm 0.010\ (\text{syst.})\ \text{ps}^{-1}$$
$$\Gamma_s = 0.677 \pm 0.007\ (\text{stat.}) \pm 0.004\ (\text{syst.})\ \text{ps}^{-1}$$
$$|A_0(0)|^2 = 0.528 \pm 0.006\ (\text{stat.}) \pm 0.009\ (\text{syst.})$$
$$|A_\parallel(0)|^2 = 0.220 \pm 0.008\ (\text{stat.}) \pm 0.007\ (\text{syst.})$$

$\sin^2\psi_T \sin 2\theta_T \sin\phi_T$

$\frac{1}{\sqrt{2}} \sin 2\psi_T \sin 2\theta_T \cos\phi_T$

$\frac{2}{3}(1 - \sin\theta_T \cos^2\phi_T)$

$\frac{1}{3}\sqrt{6} \sin\psi_T \sin^2\theta_T \sin 2\phi_T$

$\frac{1}{3}\sqrt{6} \sin\psi_T \sin 2\theta_T \cos\phi_T$

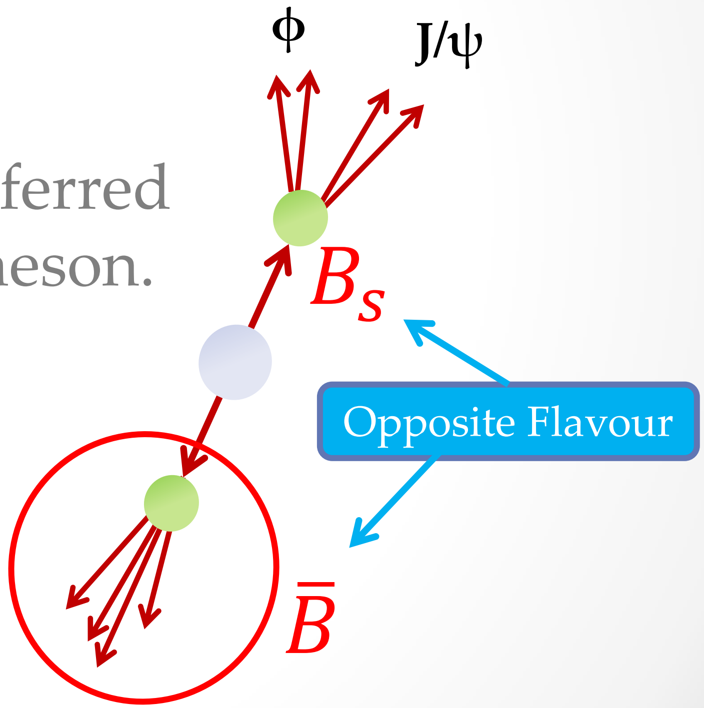
$\frac{4}{3}\sqrt{3} \cos\psi_T (1 - \sin^2\theta_T \cos^2\phi_T)$

Possible to increase the sensitivity … ?

Flavour Tagging

- If initial flavour of B_s^0 is known, additional terms appear in the likelihood description of the time-dependent decay rate.
  → **Enable to increase sensitivity on ϕ_s and $\delta_\perp$**

- Initial state flavour of B_s^0 can be inferred using information of the other B meson.
  - Typically it has an opposite flavour.



Flavour tagged time-dependent decay rate

With initial flavour tagging, additional term appear.

	k	$\mathcal{O}^{(k)}(t)$	$g^{(k)}(\theta_T,\psi_T,\phi_T)$
L=0	1	$\frac{1}{2}\|A_0(0)\|^2\left[(1+\cos\phi_s)e^{-\Gamma_L^{(s)}t}+(1-\cos\phi_s)e^{-\Gamma_H^{(s)}t}\pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\phi_T)$
L=2	2	$\frac{1}{2}\|A_\parallel(0)\|^2\left[(1+\cos\phi_s)e^{-\Gamma_L^{(s)}t}+(1-\cos\phi_s)e^{-\Gamma_H^{(s)}t}\pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\sin^2\psi_T(1-\sin^2\theta_T\sin^2\phi_T)$
L=1	3	$\frac{1}{2}\|A_\perp(0)\|^2\left[(1-\cos\phi_s)e^{-\Gamma_L^{(s)}t}+(1+\cos\phi_s)e^{-\Gamma_H^{(s)}t}\mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\sin^2\psi_T\sin^2\theta_T$
Inter-ference terms	4	$\frac{1}{2}\|A_0(0)\|\|A_\parallel(0)\|\cos\delta_\parallel$ $\left[(1+\cos\phi_s)e^{-\Gamma_L^{(s)}t}+(1-\cos\phi_s)e^{-\Gamma_H^{(s)}t}\pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$-\frac{1}{\sqrt{2}}\sin 2\psi_T\sin^2\theta_T\sin 2\phi_T$
	5	$\|A_\parallel(0)\|\|A_\perp(0)\|[\frac{1}{2}(e^{-\Gamma_L^{(s)}t}-e^{-\Gamma_H^{(s)}t})\cos(\delta_\perp-\delta_\parallel)\sin\phi_s$ $\pm e^{-\Gamma_s t}(\sin(\delta_\perp-\delta_\parallel)\cos(\Delta m_s t)-\cos(\delta_\perp-\delta_\parallel)\cos\phi_s\sin(\Delta m_s t))]$	$\sin^2\psi_T\sin 2\theta_T\sin\phi_T$
	6	$\|A_0(0)\|\|A_\perp(0)\|[\frac{1}{2}(e^{-\Gamma_L^{(s)}t}-e^{-\Gamma_H^{(s)}t})\cos\delta_\perp\sin\phi_s$ $\pm e^{-\Gamma_s t}(\sin\delta_\perp\cos(\Delta m_s t)-\cos\delta_\perp\cos\phi_s\sin(\Delta m_s t))]$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin 2\theta_T\cos\phi_T$
S-wave terms	7	$\frac{1}{2}\|A_S(0)\|^2\left[(1-\cos\phi_s)e^{-\Gamma_L^{(s)}t}+(1+\cos\phi_s)e^{-\Gamma_H^{(s)}t}\mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\frac{2}{3}(1-\sin\theta_T\cos^2\phi_T)$
	8	$\|A_S\|\|A_\parallel(0)\|[\frac{1}{2}(e^{-\Gamma_L^{(s)}t}-e^{-\Gamma_H^{(s)}t})\sin(\delta_\parallel-\delta_S)\sin\phi_s$ $\pm e^{-\Gamma_s t}(\cos(\delta_\parallel-\delta_S)\cos(\Delta m_s t)-\sin(\delta_\parallel-\delta_S)\cos\phi_s\sin(\Delta m_s t))]$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin^2\theta_T\sin 2\phi_T$
	9	$\frac{1}{2}\|A_S\|\|A_\perp(0)\|\sin(\delta_\perp-\delta_S)$ $\left[(1-\cos\phi_s)e^{-\Gamma_L^{(s)}t}+(1+\cos\phi_s)e^{-\Gamma_H^{(s)}t}\mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin 2\theta_T\cos\phi_T$
	10	$\|A_0(0)\|\|A_S(0)\|[\frac{1}{2}(e^{-\Gamma_H^{(s)}t}-e^{-\Gamma_L^{(s)}t})\sin\delta_S\sin\phi_s$ $\pm e^{-\Gamma_s t}(\cos\delta_S\cos(\Delta m_s t)+\sin\delta_S\cos\phi_s\sin(\Delta m_s t))]$	$\frac{4}{3}\sqrt{3}\cos\psi_T(1-\sin^2\theta_T\cos^2\phi_T)$

$\pm$ *or* $\mp$

The upper sign reflects initial B_s^0

The lower sign reflects initial $\bar{B}_s^0$

sensitive on CP violation phase ϕ_s

Event Selection

- 4.9 fb^{-1} pp collisions at $\sqrt{s}$ = 7 TeV run collected in 2011 with ATLAS detector
- Collected by triggers based on identification of $J/\psi \to \mu^+\mu^-$
  - At least one muon which $p_T > 4$ GeV

Event Selection:

J/ψ

- Oppositely-charged muon pair
- $p_T(\mu) > 4$ GeV
- $|\eta|$ dependent mass cuts (retains 99.8 % of signal)
- Vertexing χ^2 / ndf < 10

ϕ

- Oppositely-chargedtrack pair (no PID)
- $p_T(K) > 1$ GeV
- $|m(KK) - m^{PDG}(\phi)| < 11$ MeV

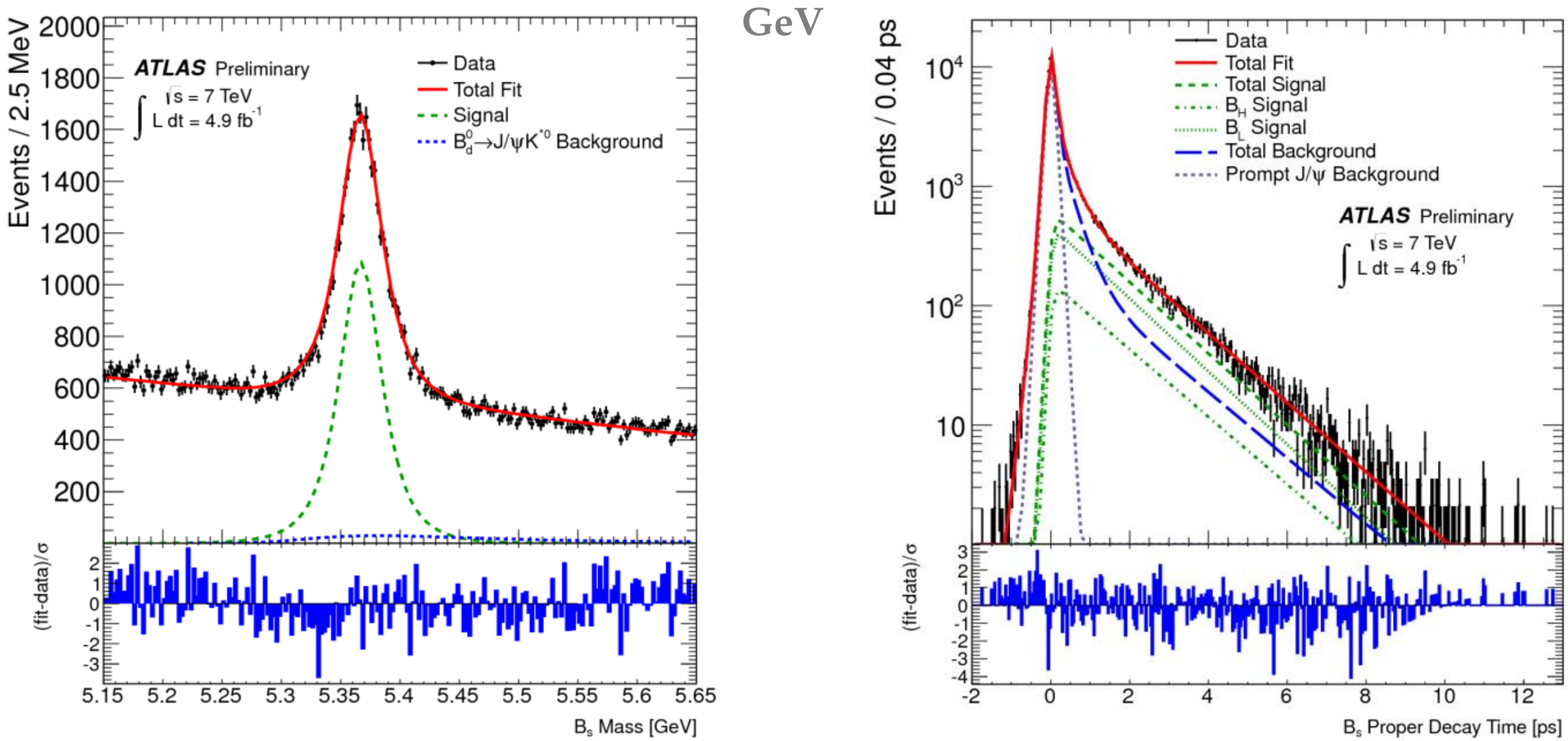
B_s^0

- Coming from same vertex
- $\mu\mu KK$ vertex fitting with J/ψ mass constraint
- Vertex χ^2 / ndf < 3
- Proper lifetime error: $\delta\tau < 0.3$ ps
- $5.15 < m(J/\psi KK) < 5.65$ GeV

Event Selection

- 4.9 fb^{-1} pp collisions at $\sqrt{s}$ = 7 TeV run collected in 2011 with ATLAS detector
- Collected by triggers based on identification of $J/\psi \to \mu^+\mu^-$

GeV



131k B_s^0 candidate within [5.15 – 5.65] GeV, after the selections

Flavour tagging methods

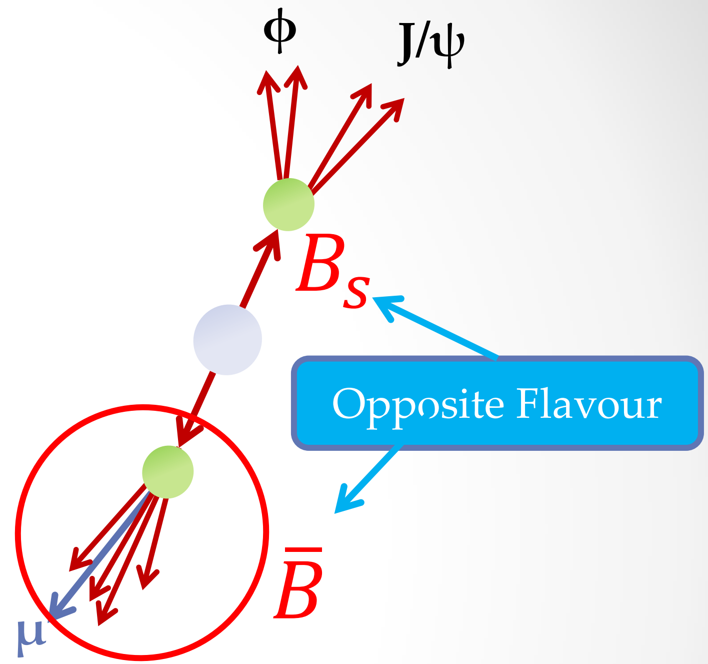
- 2 tagging methods for the other B.

Muon Tagging

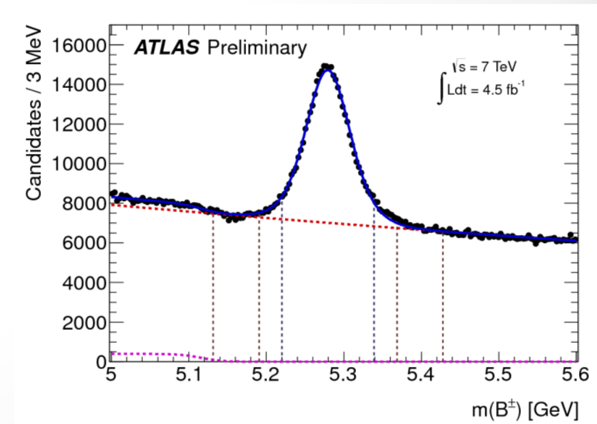
- Use semi-leptonic decay of the B.
- Use momentum weighed charge of muon and tracks around the muon.
- diluted through b → c → μ, but even have good separation power.

Jet-charge Tagging

- Used if the additional muon is absent
- Use momentum-weighted track-charge in jet

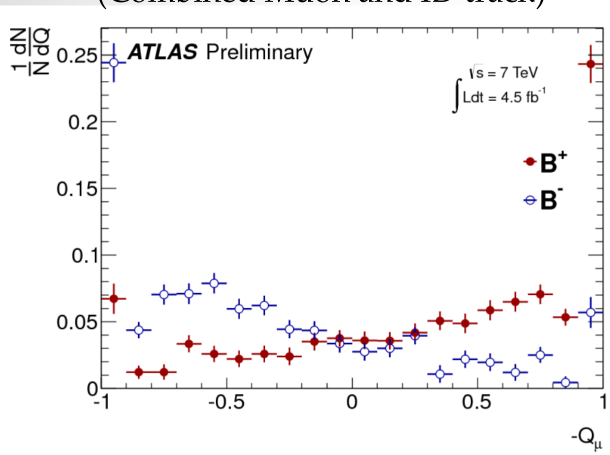


- Self-tagging $B^{\pm} \rightarrow J/\psi\, K^{\pm}$ is used for calibration and performance estimation

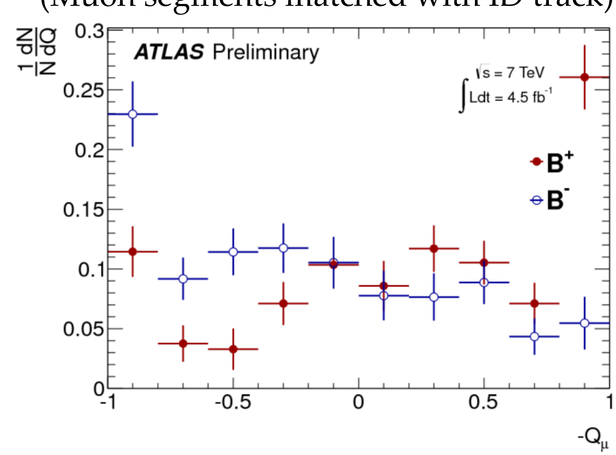


Tagging Performance

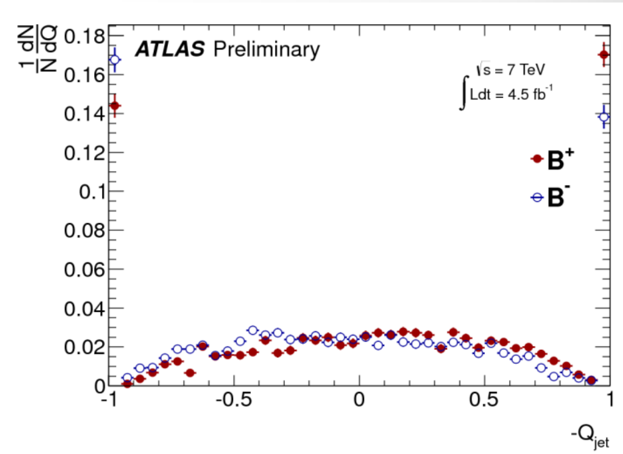
Combined Muon
(Combined Muon and ID track)



Segment Tagged Muon
(Muon segments matched with ID track)



Jet – charged Tagging



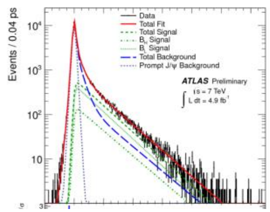
Tagger	**Efficiency [%]**	**Dilution [%]**	**Tagging Power [%]**
Combined Muon	3.37±0.04	50.6±0.5	0.86±0.04
Segment Tagged Muon	1.08±0.02	36.7±0.7	0.15±0.02
Jet-charge	27.7±0.1	12.68±0.06	0.45±0.03
Total	**32.1±0.1**	**21.3±0.08**	**1.45±0.05**

- Tagging Performance estimated to be:
  - Tagging power = 1.45 ± 0.05(stat only) %

$$Efficiency: \varepsilon = \frac{N_{tagging}}{N_{candidate}}, \qquad Dilution: D = |2P(B|Q) - 1|$$

$$Tagging\ Power: \varepsilon D^2 = \sum_{candidate} \varepsilon_i (2P_i(B|Q_i) - 1)^2$$

Fitting Model for $B_s^0 \rightarrow J/\psi\ \phi$ decay



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

Observed Variables:

- B_s mass m_i and its uncertainty
- B_s proper decay time t_i and its uncertainty
- 3 angles b.t.w. final state particle in transversity basis $\Omega_i(\theta_{Ti}, \phi_{Ti}, \psi_{Ti})$
- Bs momentum p_{Ti}
- Bs tag probability $p_{B|Qi}$
- Tagging method M_i

Determine 9 physics variables to describe $Bs \rightarrow J/\psi\ \phi$ and S-wave component:
$\Delta\Gamma$, ϕ_s, Γ_s,
$|A_0(0)|^2$, $|A_{||}(0)|^2$, $|A_S(0)|^2$,
$\delta_{||}$, $\delta_{\perp}$, δ_S

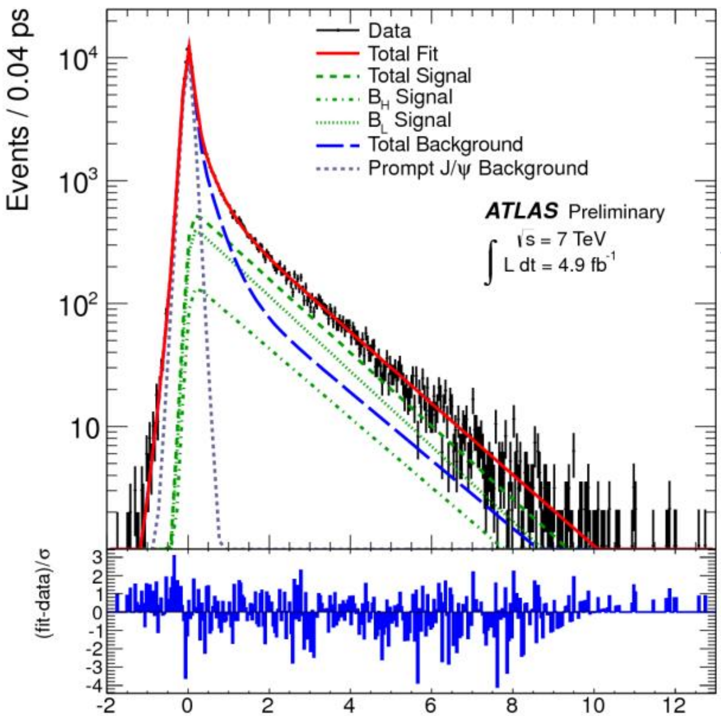
Time depend trigger efficiency

Signal Probability Density Functions

Peaking background: Reflection from $B^0 \rightarrow J/\psi K^{*0}$ and $B^0 \rightarrow J/\psi K\pi$

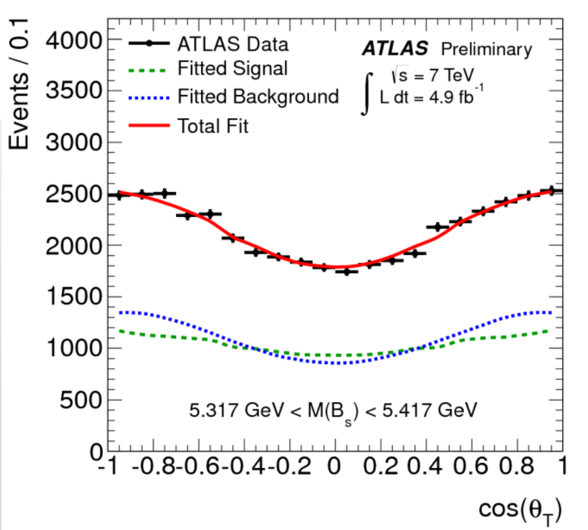
Combinatorial background

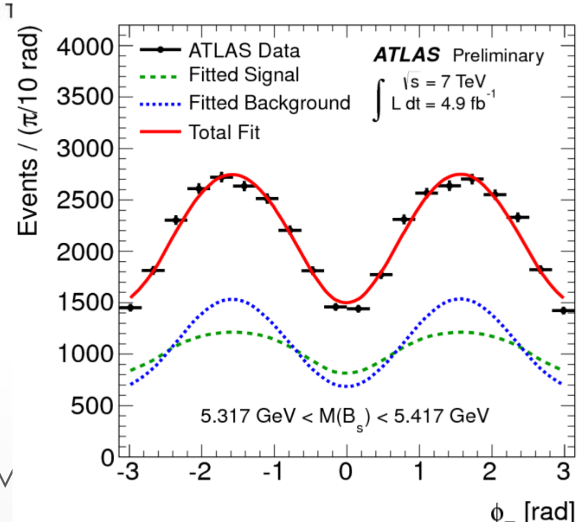
Fit Projection

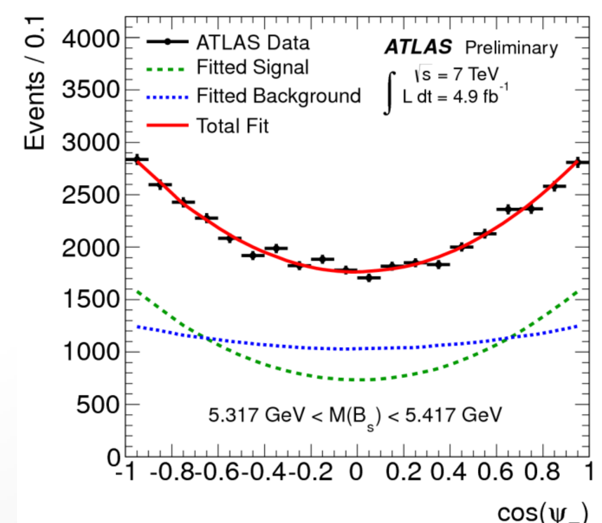


:Data
:Total Fit
:Total Signal
:Bs^H Signal
:Bs^L Signal
:Total Background
:Prompt J/ψ Background

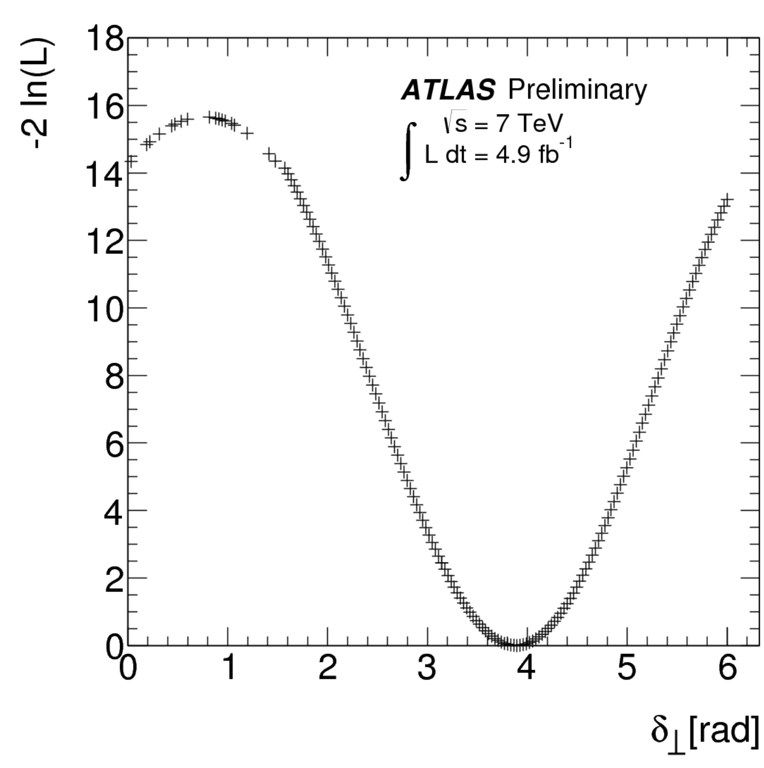
- Fit projection to all data passing selections.
- 22,670 ± 150 signal B_s^0 from fit.
- Generally fits seems to be fine



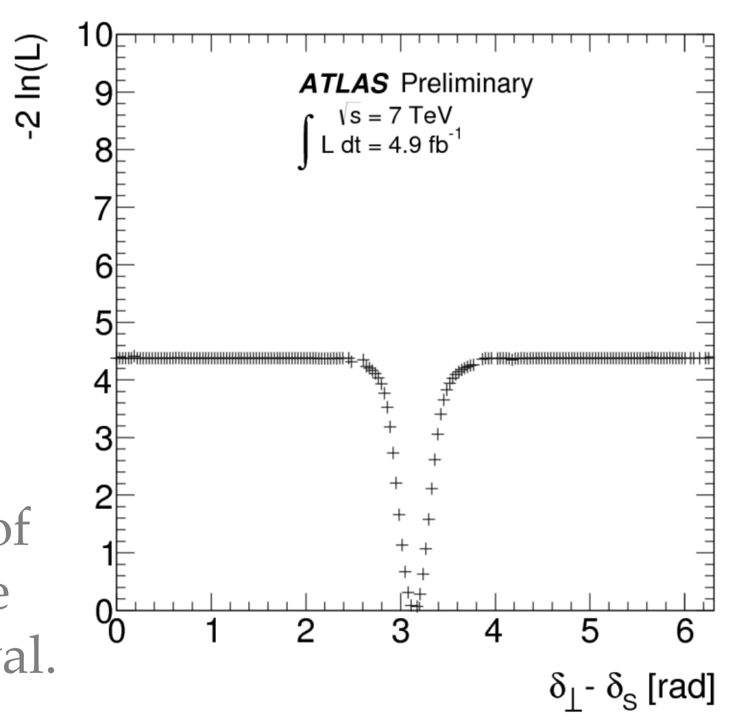




1-D Likelihood Scan Check



- To study uncertainties of individual parameters, behavior of 1D likelihood scans have been checked.
- Most quantities (include $\delta_{\perp}$) have fine local minimum.

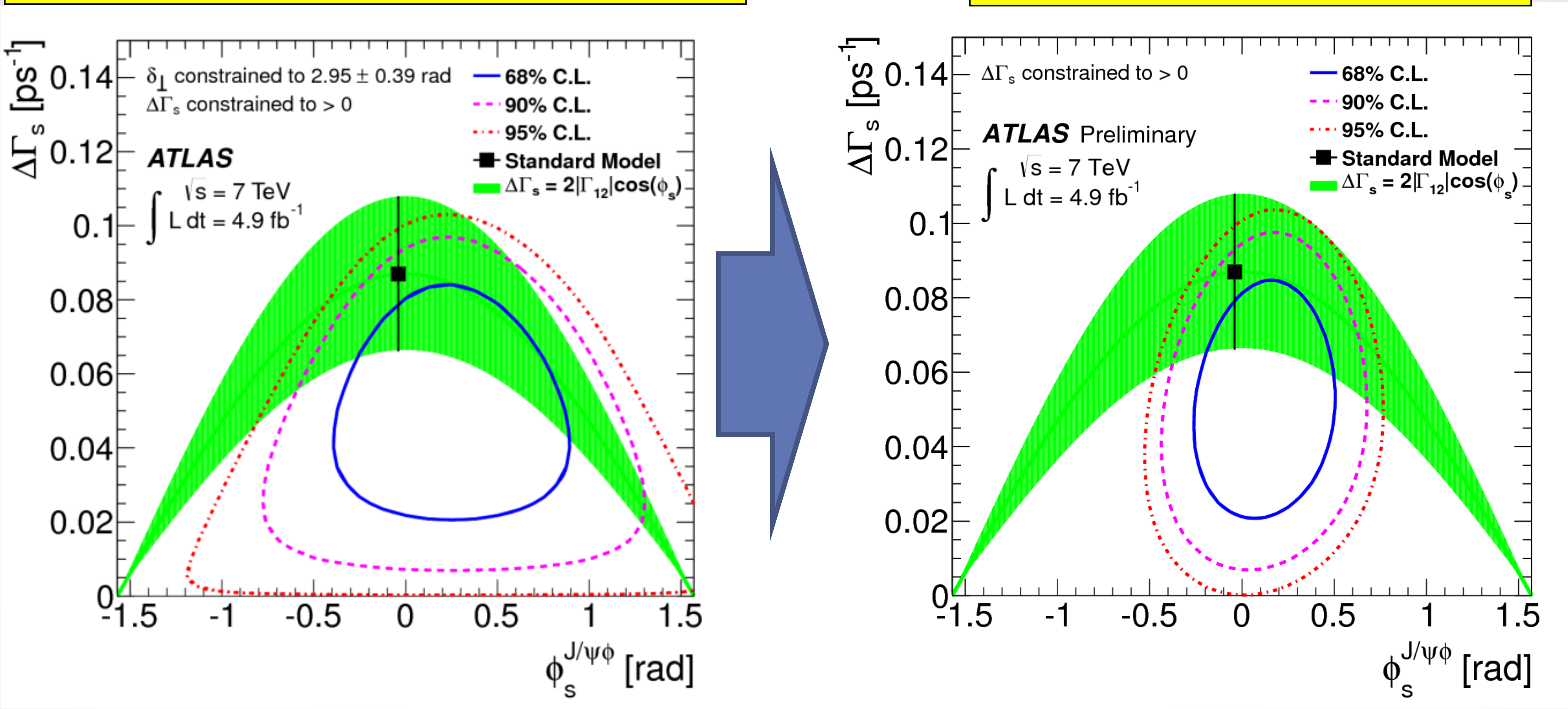


For $\delta_{\perp}$ - δ_{S}, the likelihood scan show a minimum close to π, however it is insensitive over the rest of the scan at Level of 2.1 σ . So we didn't decide the center value and just give as 1σ confidence interval.

Results with flavour tagging

Without flavour tagging, as already shown [JHEP 12 (2012) 072]

With Flavour Tagging, ATLAS-CONF-2013-039



- The sensitivity on ϕ_s is much improved by flavour tagging (40 %).
- The sensitivity on $\delta_\perp$ is improved and it enable to remove constraint for $\delta_\perp$
- Consistent with SM prediction.

Results with flavour tagging

Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s(rad)	0.12	0.25	0.11
$\Delta\Gamma_s(\mathrm{ps}^{-1})$	0.053	0.021	0.009
$\Gamma_s(\mathrm{ps}^{-1})$	0.677	0.007	0.003
$\lvert A_{\parallel}(0)\rvert^2$	0.220	0.008	0.009
$\lvert A_0(0)\rvert^2$	0.529	0.006	0.011
$\lvert A_S\rvert^2$	0.024	0.014	0.028
$\delta_\perp$	3.89	0.46	0.13
$\delta_\parallel$	[3.04-3.23]		0.09
$\delta_\perp - \delta_S$	[3.02-3.25]		0.04

ATLAS-CONF-2013-039

CP-odd amplitude:

$$|A_\perp|^2 = 1 - |A_\parallel|^2 - |A_0|^2 - |A_s|^2 \neq 0$$

- **Γs , ΔΓs results are consistent with SM prediction.**
- **$|A_s|^2$ is consistent to 0.**
- **The results are consistent to the SM prediction.**
  - **Also consistent with other experiments.**
- Statistically limited in most measured quantities
  - Analysis using data collected in 2012 (8TeV, 20 fb^{-1}) ongoing

Summary

- Decay parameters describing the $B_s^0 \to J/\psi\ \phi$ are measured from data sample of 4.9 fb^{-1} pp collisions, collected with ATLAS detector in 2011.

- By tagging initial state B flavour, sensitivity on weak phase ϕ_s was much increased.
  - Sensitivity on $\delta_{\perp}$ was also increased and could remove the constraint for it.

- The results are consistent with prediction from the SM.
  - No sign for physics beyond the Standard Model
  - Also consistent with other experiments.

- Statistically limited in most measured quantities.
  - Analysis including 2012 data (20 fb^{-1}, $\sqrt{s} = 8$TeV) ongoing

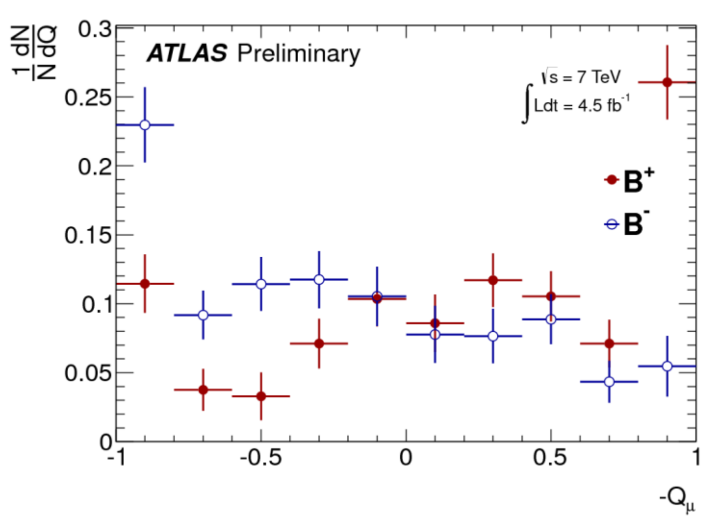
BackUp

Muon tagging

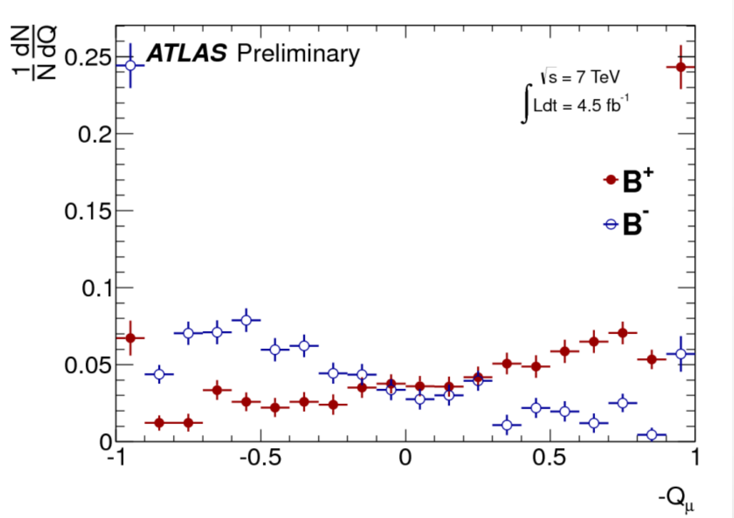
- Additional muon $p_T(\mu) > 2.5$ GeV
- Originating near the signal primary vertex : $|\Delta z| < 5$ mm
- If multiple muons, select the one with highest p_T
- Use muon and tracks within $\Delta R < 0.5$ around the muon to calculate momentum-weighted value: **muon-cone charge**

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

$\kappa = 1.1$, was tuned to optimise the tagging power.



Segment Tagged Muon
(Muon segments mathced with ID track)



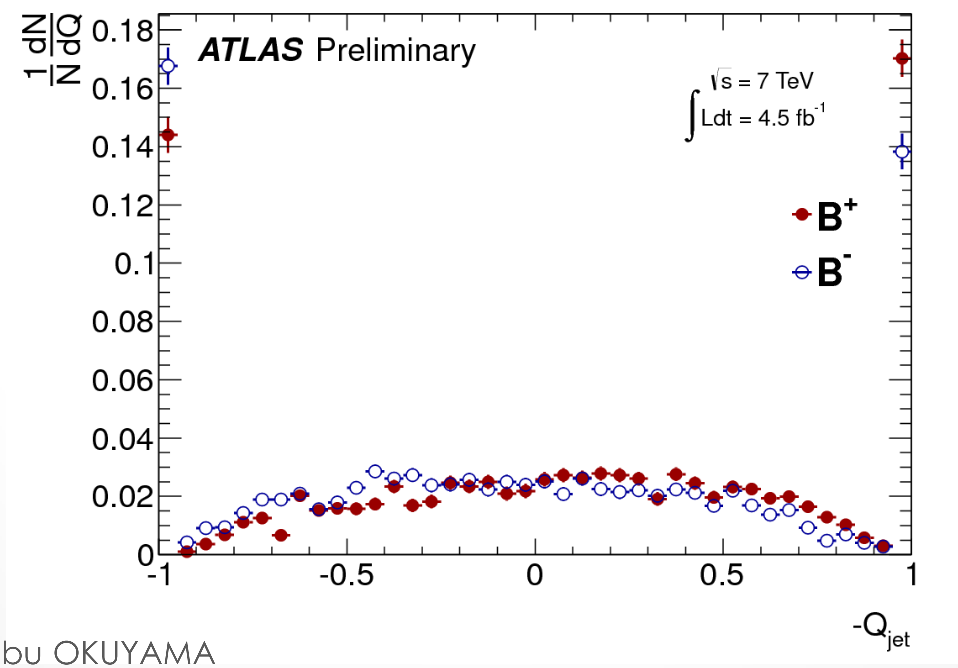
Combined Muon
(Combined Muon and ID track)

Jet-charge tagging

- In absence of muon, use b-tagged jet
- Jet was reconstructed by Anti-Kt algorithm with con size: dR=0.6
- Use tracks within ΔR < 1.0 from center of the jet to calculate momentum-weighted value: ***jet-charge***

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

κ = 1.1, was tuned to optimise the tagging power.

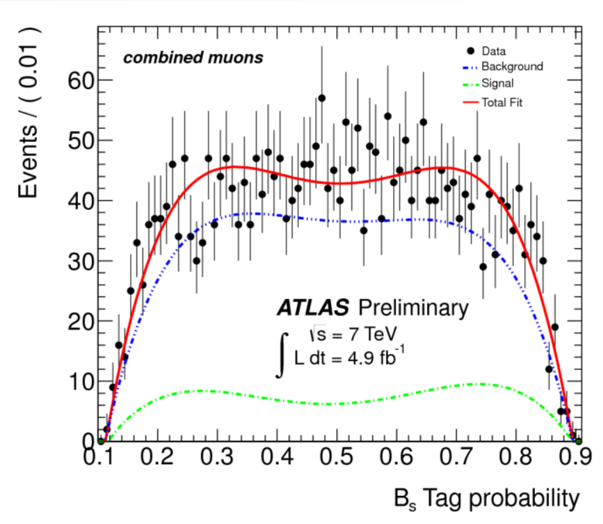


Systematic Uncertainty

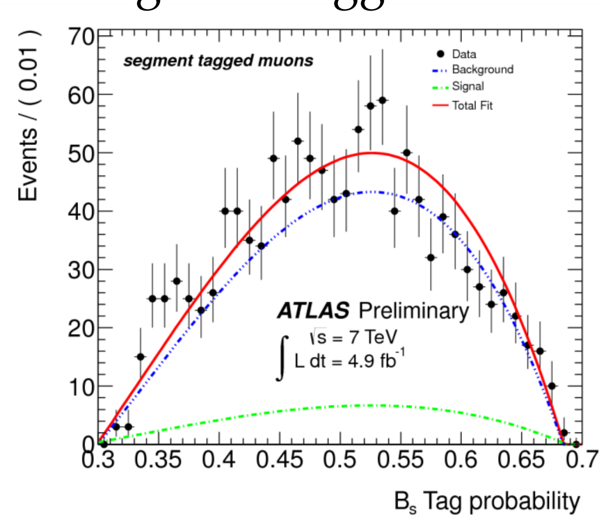
	ϕ_s (rad)	$\Delta\Gamma_s$ (ps^{-1})	Γ_s (ps^{-1})	$\|A_{\|\|}(0)\|^2$	$\|A_0(0)\|^2$	$\|A_S(0)\|^2$	$\delta_\perp$ (rad)	$\delta_{\|\|}$ (rad)	$\delta_\perp - \delta_S$ (rad)
ID alignment	$<10^{-2}$	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	-	$<10^{-2}$	$<10^{-2}$	-
Trigger efficiency	$<10^{-2}$	$<10^{-3}$	0.002	$<10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-2}$	$<10^{-2}$	$<10^{-2}$
B_d^0 contribution	0.03	0.001	$<10^{-3}$	$<10^{-3}$	0.005	0.001	0.02	$<10^{-2}$	$<10^{-2}$
Tagging	0.10	0.001	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	0.002	0.05	$<10^{-2}$	$<10^{-2}$
Models:									
default fit	$<10^{-2}$	0.002	$<10^{-3}$	0.003	0.002	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	0.11	0.009	0.003	0.009	0.011	0.028	0.13	0.09	0.04

Probability for tagging

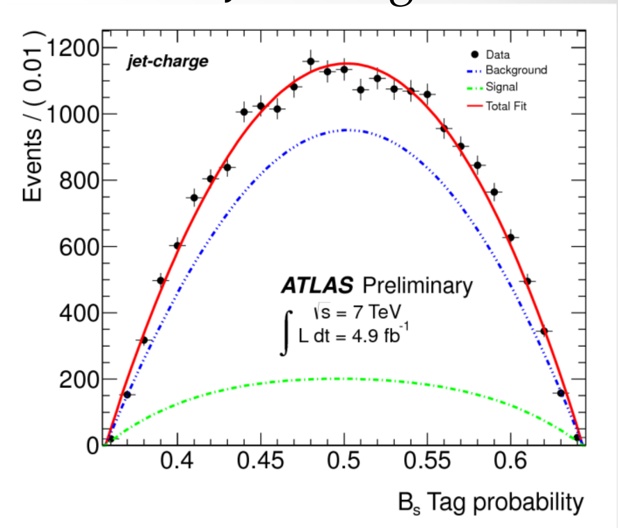
Combined Muon



Segment Tagged Muon



Jet-charge



Comparison with other experiment

	φ_s	Stat.	Syst.
ATLAS	0.12	0.25	0.11
CDF	- 0.60 - 0.12		
CMS	-		
D0	-0.56	+0.36 / -0.32	
LHCb	0.01	0.07	0.01

	$\Delta\Gamma_s$ [ps^{-1}]	Stat.	Syst.
ATLAS	0.053	0.021	0.009
CDF	0.068	0.026	0.009
CMS	0.048	0.024	0.003
D0	0.179	+ 0.060 / - 0.059	
LHCb	0.106	0.011	0.007

	$\delta_\perp$ [rad]	Stat.	Syst.
ATLAS	3.89	0.46	0.13
CDF	2.79	0.53	0.15
CMS	-		
D0	$\cos(\delta_\perp \delta_s)=-0.2$	+0.26 / -0.27	
LHCb	3.07	0.22	0.08

	Γ_ss [ps^{-1}]	Stat.	Syst.
ATLAS	0.677	0.007	0.003
CDF	0.654	0.008	0.004
CMS	0.653	0.008	0.003
D0	0.693	+ 0.016 / - 0.020	
LHCb	0.663	0.005	0.006

	$\|A_0\|^2$	Stat.	Syst.
ATLAS	0.529	0.006	0.011
CDF	0.512	0.012	0.018
CMS	0.528	0.010	0.015
D0	0.565	0.017	
LHCb	0.521	0.006	0.010

	$\|A_\parallel\|^2$	Stat.	Syst.
ATLAS	0.220	0.008	0.009
CDF	0.229	0.010	0.018
CMS	0.221	<0.016	<0.021
D0	0.249	+ 0.021 / - 0.020	
LHCb	-		