Flavour tagged time dependent angular analysis of the $B_s \to J/\psi\phi$ decay on Run 1 data in ATLAS

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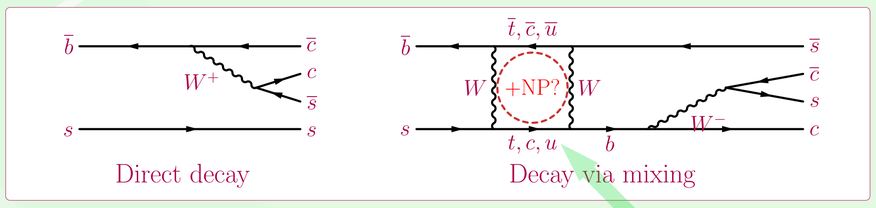
CP violation in $B_s \to J/\psi\phi$ decay



- Flavour-changing term in the SM Lagrangian $\Longrightarrow$ Particle-antiparticle oscillations possible for K^0, D^0, B^0 and B_s^0-mesons through **loops with two W bosons**
- Time evolution of the B_s mixing is defined by mass difference $\Delta m_s = m_s^H - m_s^L$ of the heavy and light mass eigenstates, their width difference $\Delta\Gamma_s = \Gamma_s^L - \Gamma_s^H$ and the CP violating phase ϕ_s

Weak phase difference between $B_s - \overline{B}_s$ mixing amplitude and $b \to c\bar{c}s$ decay amplitude

It is predicted to be of $-0.0363^{+0.0016}_{-0.0015}$ within SM [1]

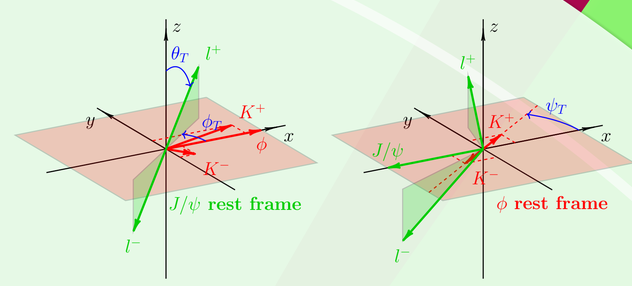
Might be changed significantly by the New Physics contributions

$\Delta\Gamma_s$ is predicted to be 0.087 ± 0.021 ps^{-1} [2]

Not expected to be affected significantly by the New Physics

Still interesting in terms of testing the theory

Analysis strategy



- Time dependent angular analysis
  - CP-even — $L = 0, 2$
  - CP-odd — $L = 1$
- 3 transversity angles (θ_T, ψ_T, ϕ_T) used
- Tagging the flavour of B candidate (see Flavour Tagging section)

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

Weights for proper decay time trigger efficiency

Signal with amplitude f_s

Prompt and non-prompt combinatorial background described with empirical angular distribution (no $K-\pi$ discrimination) — parameters fitted in the likelihood

Background from $B^0 \to J/\psi K^*$ and $B^0 \to J/\psi K\pi$ with amplitude f_{B^0} — fixed shapes

Flavour Tagging

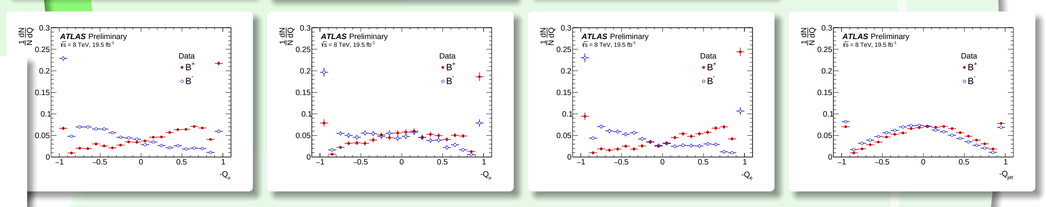
- b and $\bar{b}$ quarks usually come in pairs
- Second quark might also form a B meson
- Using information from that B meson to determine flavour of our candidate

From opposite side **combined muon** cone charge

From opposite side **segment-tagged muon** cone charge

From opposite side **electron** cone charge

From opposite side **jet**-charge



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

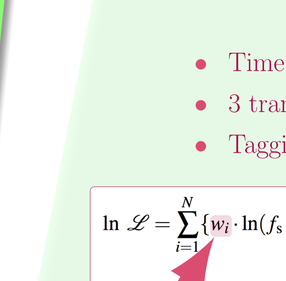
— sum over tracks within a cone $\sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.5$ around the μ/e direction/over tracks associated with the jet

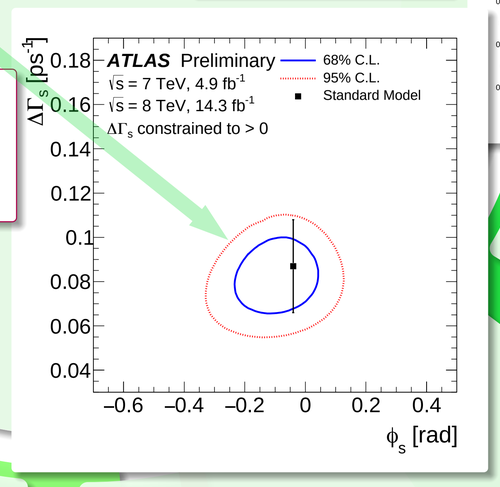
$\kappa_\mu = 1.1$, $\kappa_e = 1.0$ and $\kappa_{\text{jet}} = 1.1$

- Methods combined according to the hierarchy of performance
- Optimized and calibrated using $B^+ \to J/\psi K^+$ sample

Summary

- 14.3 fb^{-1} from 8 TeV data
- 4.9 fb^{-1} from 7 TeV data
- **Statistically combined 7 & 8 TeV data** (note the different scale)





7 & 8 TeV combined result

$\phi_s = -0.094 \pm 0.083(\text{stat.}) \pm 0.033(\text{syst.})\text{rad}$

$\Delta\Gamma_s = 0.082 \pm 0.011(\text{stat.}) \pm 0.007(\text{syst.})\text{ps}^{-1}$

Result consistent with the SM predictions (black marker and line)

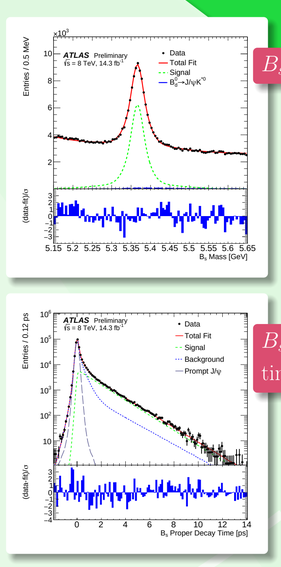
Results (8 TeV)

Fit results

Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s[rad]	−0.119	0.088	0.036
$\Delta\Gamma_s$[ps^{-1}]	0.096	0.013	0.007
Γ_s[ps^{-1}]	0.679	0.004	0.003
$\lvert A_\parallel(0)\rvert^2$	0.230	0.005	0.006
$\lvert A_0(0)\rvert^2$	0.514	0.004	0.001
$\lvert A_S(0)\rvert^2$	0.093	0.008	0.013
$\delta_\perp$ [rad]	4.46	0.49	0.25
$\delta_\parallel$ [rad]	3.16	0.13	0.05
$\delta_\perp - \delta_S$ [rad]	−0.08	0.03	0.01

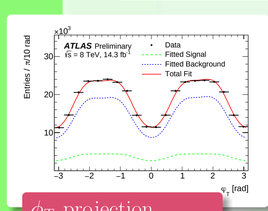
Summary of systematic uncertainties

	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]
Tagging	0.026	0.003	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	0.001	0.238	0.014	0.004
Acceptance	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	0.003	$<10^{-3}$	0.001	0.004	0.008	$<10^{-3}$
Background angles model:									
Choice of p_T bins	0.02	0.006	0.003	0.003	$<10^{-3}$	0.008	0.004	0.006	0.008
Choice of mass interval	0.008	0.001	0.001	$<10^{-3}$	$<10^{-3}$	0.002	0.021	0.005	0.003
B_s^0 background model	0.008	$<10^{-3}$	$<10^{-3}$	0.001	$<10^{-3}$	0.008	0.007	$<10^{-3}$	0.005
Fit model:									
Default fit	0.001	0.002	$<10^{-3}$	0.002	$<10^{-3}$	0.002	0.025	0.015	0.002
Mass Signal model	0.004	$<10^{-3}$	$<10^{-3}$	0.002	$<10^{-3}$	0.001	0.035	0.017	$<10^{-3}$
Mass Background model	$<10^{-3}$	0.002	$<10^{-3}$	0.002	$<10^{-3}$	0.002	0.027	0.038	$<10^{-3}$
Time Resolution model	0.003	$<10^{-3}$	0.001	0.002	$<10^{-3}$	0.002	0.057	0.013	0.001
Total	0.036	0.007	0.003	0.006	0.001	0.013	0.25	0.05	0.01

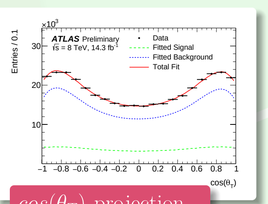


B_s mass projection

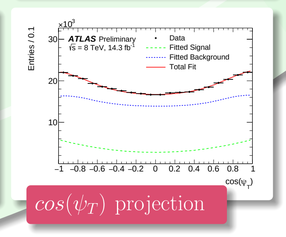
B_s proper decay time projection



ϕ_T projection



$cos(\theta_T)$ projection



$cos(\psi_T)$ projection

References

[1] J. Charles et al., *Predictions of selected flavor observables within the standard model*, D **84** (2011) 033005.

[2] A. Lenz and U. Nierste, *Numerical Updates of Lifetimes and Mixing Parameters of B Mesons*, arXiv:1102.4274 [hep-ph].

[3] ATLAS Collaboration, *Flavour tagged time dependent angular analysis of the $B_s \to J/\psi\phi$ decay and extraction of $\Delta\Gamma$ and the weak phase ϕ_s in ATLAS*, Phys.Rev. **D90** (2014) 052007.

Be the first one to solve the puzzle:

$$\left(-i\hbar(\vec{r} \times \vec{\nabla})\right)\left(i\hbar\frac{\partial}{\partial t}\right)|-\tilde{\mathfrak{Z}}\text{I}\mathfrak{O}\mathfrak{Z}\rangle$$