Tagged time-dependent angular analysis of $B^0_s \to J/\psi \phi$ decays at LHCb

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CKM angle $\phi_s$ and the golden channel $B^0_s \to J/\psi \phi$

The CKM unitary triangle that can be characterised by $B^0_s$ meson decays is predicted to be much flatter than "the" unitary triangle (describing $B^0$ decays) due to the smallness of the angle, $\beta_s$.

The weak phase of the decay $B^0_s \to J/\psi \phi$:

$$\phi_s^{J/\psi \phi} = \phi_M - 2\phi_D$$

is related, within the Standard Model (SM), to $\beta_s$ and is predicted to be:

$$\phi_s^{J/\psi \phi} \approx (0.036 \pm 0.002) \text{ rad}$$

Therefore measuring $\phi_s$ in this channel makes $B^0_s \to J/\psi \phi$ one of the prime decays for indirect searches of new physics.

Tagged time-dependent angular analysis

The $B^0_s \to J/\psi \phi$ channel is made of a pseudo-scalar decaying into two vector mesons leading to an admixture of CP-even and CP-odd final states. The measurement of $\phi_s^{J/\psi \phi}$ requires disentangling the CP admixture using an angular analysis of the decay products.

The differential decay rates are made of typical terms like:

$$\sin(\phi_s) \cdot D_{\text{mis}} + \Gamma_s \cdot \sin(\Delta \tau_s c)$$

where $D_{\text{mis}}$ is the dilution due to mistag and $\Gamma_s$ is the dilution induced by finite decay time resolution.

In addition, angular and decay time acceptances must be taken into account.

Decay time resolution

The decay time resolution is described by a Gaussian of width $\sigma_s \cdot \sigma_c$ where $\sigma_c$ is the event-by-event decay time error and $\sigma_s$, a scale factor. $\langle \sigma_s \rangle = 45 \text{ fs, } \sigma_s = 1.45 \pm 0.06$ [1] has been measured using the $J/\psi \rightarrow \mu^+ \mu^-$ component of the prompt background in data.

Flavour tagging

We use the «opposite-side» tagging [1]:

$$\epsilon_{\text{tag}} = (2.29 \pm 0.07 \pm 0.26)\%$$

$\rightarrow$ LHCC poster: «Optimisation and calibration of the LHCb flavour tagging using 2011 data».

Solving the ambiguity: Sign of $\Delta \Gamma_s$ with 0.37 fb$^{-1}$

The $B^0 \to J/\psi \phi$ decay rates are invariant under the transformation $(\phi_s, \Delta \Gamma_s) \leftrightarrow (\pi - \phi_s, -\Delta \Gamma_s)$. The LHCb analysis of $B^0 \to J/\psi \phi$ decays with 0.37 fb$^{-1}$ showed that almost all CP-even mass eigenstate decays faster than the CP-odd state [2]. The ambiguity can be solved by measuring the strong phase difference between the P-wave and the S-wave of the $K^*K^*$ final state around the $\phi_s(1020)$ meson [3]. The physical solution has decreasing phase difference as function of $K^*K^*$ mass.

• Solution I: $\Delta \Gamma_s > 0$ and $\phi_s$ close to $0$
• Solution II: $\Delta \Gamma_s < 0$ and $\phi_s$ close to $\pi$

The solution with $\Delta \Gamma > 0$ and $\phi_s$ close to $0$ is favoured [3].

Preliminary results with 1.0 fb$^{-1}$

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Using $\Delta \tau_s = 17.63 \pm 0.11 \text{ ps}^{-1}$ from the analysis of $B^0_s \to D^{-} \pi^0$ decays [5] as input, the world’s most precise measurement of $\phi_s^{J/\psi \phi}$ and the first direct observation of non-zero $\Delta \Gamma_s$ has been measured [1]:

$$\phi_s^{J/\psi \phi} = -0.001 \pm 0.101 \text{ (stat) } \pm 0.027 \text{ (syst) rad},$$

$$\Gamma_s = 0.6580 \pm 0.0054 \text{ (stat) } \pm 0.0066 \text{ (syst) ps}^{-1},$$

$$\Delta \Gamma_s = 0.116 \pm 0.018 \text{ (stat) } \pm 0.006 \text{ (syst) ps}^{-1}$$

A tagged time-dependent analysis of $B^0_s \to J/\psi \pi^+ \pi^-$ [4] has been performed and the preliminary combined result gives for $\phi_s$ [1]:

$$\phi_s = -0.002 \pm 0.083 \text{ (stat) } \pm 0.027 \text{ (syst) rad}$$

that is in good agreement with SM predictions and gives no sign of new physics yet.

References

[1] LHCb Collaboration, "Tagged time-dependent angular analysis of $B^0 \to J/\psi \phi$ decays at LHCb", LHCb-CONF-2012-002.
[4] LHCb Collaboration, "Measurement of the CP-violating phase $\phi_s$ in the decay $B^0_s \to J/\psi \phi$", LHCB-PAPER-2012-003, for submission to PLB.