PROCEEDINGS OF SCIENCE

Latest Results on the CP-violating weak phase ϕ_S and the decay width difference $\Delta\Gamma_S$ From the CMS Experiment

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The decay $B^0_S \to J/\psi\phi(1020) \to \mu^+\mu^-K^+K^-$ is used to measure the CP-violating weak phase ϕ_S and the decay width difference $\Delta\Gamma_S$ of the B^0_S light and heavy mass eigenstates are measured with the CMS detector at the LHC. The analysis is performed using an integrated luminosity of 19.7 fb^- collected in pp collisions at a centre-of-mass energy of 8 TeV corresponds to a total of 49, 200 reconstructed B^0_s decays. A time-dependent and flavour-tagged angular analysis is performed. The weak phase is measured to be $\phi_S = -0.075 \pm 0.097(\text{stat.}) \pm 0.031(\text{syst.})$ rad, and the decay width difference is $\Delta\Gamma_s = 0.095 \pm 0.013(\text{stat.}) \pm 0.007(\text{syst.})\text{ps}^{-1}$

9th International Workshop on the CKM Unitarity Triangle
28 November - 3 December 2016
Tata Institute for Fundamental Research (TIFR), Mumbai, India

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PoS(CKM2016)082

1. Introduction

The standard model (SM) is found to be consistent with measurements from many experiments. The B_s^0 meson provides another avenue to test consistency of standard model. In this letter, a measurement of the weak phase ϕ_s of the B_s^0 meson and the decay width difference $\Delta\Gamma_s$ between the light and heavy B_s^0 mass eigenstates is presented, using the data collected by the CMS experiment in pp collisions at the LHC with a centre-of-mass energy of 8 TeV, corresponding to an integrated luminosity of 19.7 fb^{-1}.

The Cp-violating weak phase ϕ_s originated from the interference between direct B_s^0 meson decays in a CP eigenstate $c\bar{c}s\bar{s}$ and decays through $B_s^0 - \bar{B}_s^0$ mixing to the same final state. Neglecting the penguin diagram contributions [1][2], ϕ_s is related to the elements of the Cabibbo-Kobayashi-Maskawa quark mixing matrix by $\phi_s \simeq -2\beta_s$, where $\beta_s = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$. The prediction for 2βs, determind via a global fit to experimental data within the SM, is $2\beta_s = 0.00363^{+0.0016}_{-0.0015}$ rad [3]. Any deviation of measured value from the SM prediction would indicate a possible contribution of new, unknown particles to the loop diagram describing B_s^0 mixing. The theoretical prediction for the decay width difference $\Delta\Gamma_s$ between the light and heavy B_s^0 mass eigenstates B_L and B_H, assuming no new physics in B_s^0 - $\bar{B}_s^0$ mixing, is $\Gamma\Delta_s = \Gamma_L - \Gamma_H = 0.087 \pm 0.012 ps^{-1}$ [4].

The weak phase ϕ_s was first measured by the many experiments [5, 6, 7, 8]. The B_s^0 decay where the final states do not have a single CP eigenvalue require an angular analysis to disentangle the CP-odd and CP-even components. In this letter, the decay $B_s^0 \to J/\psi\phi(1020) \to \mu^+\mu^-K^+K^-$ is analysed including a contribution from non-resonant contribution. The transversity basis is used [9] where three angles $\Theta = (\theta_T, ct, \alpha)$ of transversity basis os illustrated in Fig. 1. The differential decay rate of $B_s^0 \to J/\psi\phi(1020)$ is followed using the function $f(\Theta, ct, \alpha)$ as given in Ref. [10].

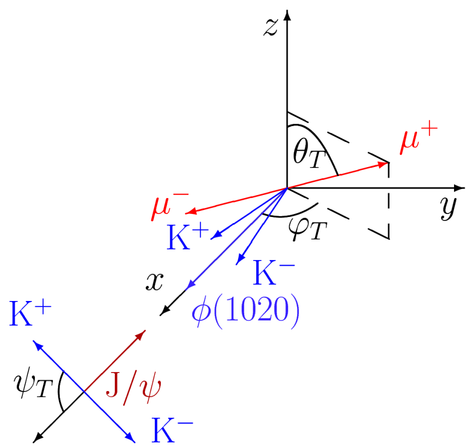

Figure 1: Definition of three angles θ_T, ψ_T, and ϕ_T describing the decay topology of $B_s^0 \to J/\psi\phi(1020)$.

2. The CMS Detector and Event Selection

The CMS detector is composed of a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass a brass scintillator hadron calorimeter, each having a barrel and endcap sections. The detector also contain a 13. long superconductor solenoid of 6m internal diameter, providing a magnetic field of 3.8 T. The main sub-detectors used for the analysis are silicon tracker and the muon detector. It consists of 66 million pixels and more than 9 million silicon strip. It covers a pseudorapidity range $|\eta| < 2.5$ [11]. Muons are measured in the pseudorapidity range $|\eta| < 2.4$, with detection planes are made using three technologies, drift tubes, cathode strip chambers, and resistive plate chambers [12]. A more detailed description of the CMS detector can be found in Ref. [13].

The analysis require two muons, each with p_T greater then 3 GeV and $|\eta| < 2.1$ at the L1 trigger. At the HLT, J/ψ candidate requires to have displaced vertex from primary production vertex. Each muon p_T is required to be greater than 4 GeV and the p_T of the reconstructed muon pair required to be greater than 6.9 GeV. The invariant mass of Jψ candidate is required to be 2.9-3.3 GeV. The three-dimensional distance of closest approach of the two muons to each other is required to be smaller than 0.5 cm. The two muon trajectories are fitted with a common decay vertex. The transverse decay length significance $L_{xy}/\sigma_{xy} > 3.0$, where L_{xy} is the distance between the centre of the primary vertex and secondary vertex in the transverse plane, and σ_{xy} is the uncertainty on L_{xx}. The secondary-vertex probability is to be greater than 10%. The angle ρ between the dimuon transverse momentum and the L_{xy} direction is required to satisfy cos$\rho > 0.9$.

For the analysis, a tighter selection was used to reduce the combinatorial background. The muons used for Jψ reconstruction are required to have $p_T > 4$ GeV and $|\eta| < 2.1$. The invariant mass of J/ψ candidates are required to be within 150 MeV of the world-average J/ψ mass [14]. The $\phi(1020)$ mesons are reconstructed from pairs of oppositely charged tracks assumed to be kaon with $p_T > 0.7$ GeV and invariant mass within 10 MeV of the world-average ϕ mass [14].

The B^0_S candidates are formed by combining J/ψ and $\phi(1020)$ candidates. A kinematic fit is performed using two muons and two kaons and required to have common vertex. To improve the mass resolution of B^0_S, a mass constraint fit is performed the J/ψ using nominal J/ψ mass [14]. The B^0_S mass is required to be between 5.20 and 5.65 GeV and the χ^2 vertex fit probability is greater than 2%. The average number of primary vertices in an event is approximately 16, and each selected event should at least one reconstructed primary vertex. If there are multiple vertices, the one that minimises the angle between the flight direction and the momentum of the B^0_S is selected. The selected primary vertex is used to calculate ct. The quantity ct is calculated from the transverse decay length vector of the B^0_S, $\vec{L}_{xy}^{B^0_S}$, as $ct = m_{PDG}^{B^0_S}\ \vec{L}_{xy}^{B^0_S}\ .\ \vec{p}_T/p_T^2$, where $m_{PDG}^{B^0_S}$ is the world-average B^0_S mass citepdg and $\vec{p}_T$ is the B^0_S transverse momentum vector. The decay length is calculated in the transverse plane to minimise effects due to pileup.

Simulated events are produced using the PYTHIA v6.424 Monte Carlo event generator [15]. Simulated event are used to estimate signal reconstruction efficiencies and background contributions. The contributions of nonprompt J/ψ mesons from decay of B hadrons, such as B^0, $B^\pm$, Λ_b, and B_c are found to be negligible. The mass distribution in the signal region is shown in Fig. 2. The proper decay length, ct and it's error are shown in Fig. 3 and Fig. 4, respectively.

3. Data Analysis and Fitting to the data

The reconstructed B^0_S candidates are flavour tagged using electron or muon decays from other B hadron. The tagged muon is required to have $p_T > 2.2 GeV$, the 3D impact parameter d_{xyz} with respect to B^0_S to be less than 0.1 cm, and the angular separation $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$ to be

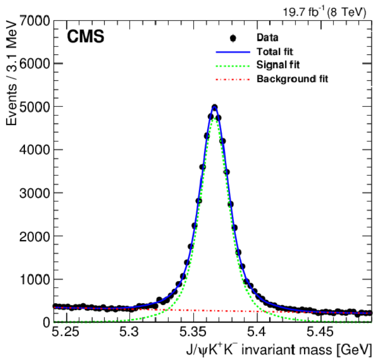

Figure 2: The $J/\psi K^+K^-$ mass of the B^0_S.

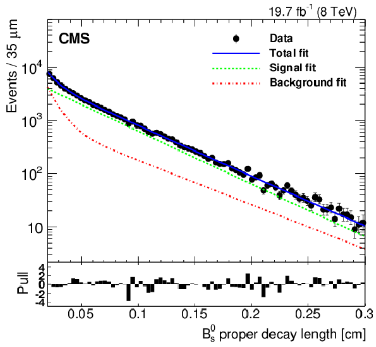

Figure 3: The *ct* distribution of the the B^0_S candidates

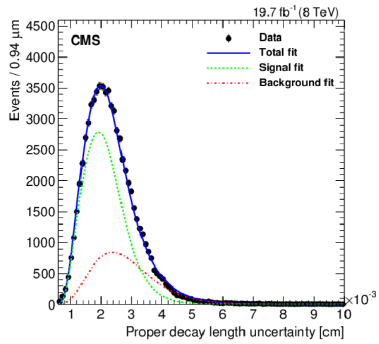

Figure 4: The error on *ct* of the the B^0_S candidates

greater than 0.3. For electron, $p_T > 2.0 GeV$, $d_{xyz} < 0.1$ cm, and $\Delta R > 0.2$. The tagging algorithm is optimised for tagging power $P_{tag} = \varepsilon_{tag}(1-2\omega)^2$, where ω is the mistag probability and ε_{tag} is the tagging efficiency. The tagging efficiency evaluated with the $B^{\pm} \to J/\psi K^{\pm}$ data sample is $(4.56 \pm 0.02)\%$ and $(3.92 \pm 0.02)\%$ for muons and electrons, respectively, where the uncertainties are statistical.

An unbinned maximum-likelihood fit to the data is performed. The likelihood function is composed of probability density functions (pdf) describing the signal and background components. The information used in the likelihood are invariant B^0_S mass, three decay angles (Θ) of the reconstructed B^0_S candidates, and the flavour tagging decision. The fit includes 70 500 events, out of which 5650 are tagged events selected in the range 5.24 - 5.49 GeV and *ct* = 200-300 μm.

The signal mass pdf is the sum of three Gaussian functions with a common mean and background mass distribution is described by an exponential function. The angular parts of the background pdfs are described analytically by a series of Legendre polynomials for $\cos\theta_T$ and $\cos\psi_T$ and sinusoidal function for $\cos\phi_T$. The signal decay time uncertainty pdf is a sum of two Gamma functions, with all the parameters fixed to the values obtained by fitting a background subtracted events. The background decay time is modelled by a single Gamma function.

4. Results and Conclusions

The central value and the 68%, 90%, and 95% confidence level (CL) likelihood counters of the fit in the $\Delta\Gamma_S - \phi_S$ plane are shown in Fig. 5. Several sources of systematic uncertainties including fit model and fit procedure. The dominant systematic uncertainty comes from tagging. The measured values for the weak phase ϕ_S, and the decay width difference $\Delta\Gamma_S$ are:

$$\phi_S = -0.075 \pm 0.097\,(\text{stat.}) \pm 0.031\,(\text{syst.})\ \text{rad},$$
$$\Delta\Gamma_S = 0.095 \pm 0.013\,(\text{stat.}) \pm 0.007\,(\text{syst.})\ \text{ps}^{-1}$$

The measured value of ϕ_S is in agreement with SM prediction. The nonzero value of $\Delta\Gamma_S$ is consistent with theoretical predictions.

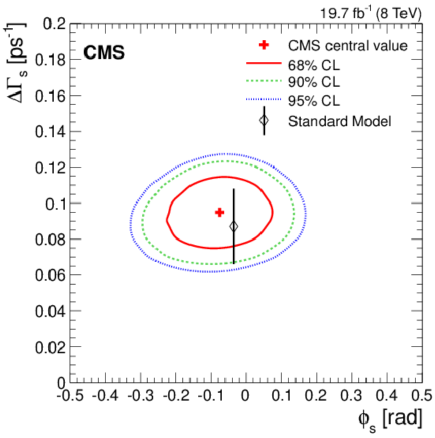

Figure 5: The CMS measured central value and the 68%, 90%, and 95% CL counters in the $\Delta\Gamma_S$ versus ϕ_S plane, together with SM prediction [3, 4]. Uncertainties are statistical only.

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