IL NUOVO CIMENTO Vol. 36 C, N. 1 Gennaio-Febbraio 2013
DOI 10.1393/ncc/i2013-11397-5

Colloquia: IFAE 2012

Final measurement of B_s^0 mixing phase in the full CDF Run II data set

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ricevuto il 31 Agosto 2012

Summary. — We report the final CDF measurement of the B_s^0 mixing phase, mean lifetime, and decay width difference through the fit of the time evolution of flavour-tagged $B_s^0 \to J/\psi\phi$ decays. The measurement is based on the full data set of 1.96 TeV $p\bar{p}$ collisions collected between February 2002 and September 2011 by the CDF experiment. The results are consistent with the standard model and other experimental determinations and are amongst the most precise to date.

PACS `11.30.Er` – Charge conjugation, parity, time reversal, and other discrete symmetries.
PACS `12.38.Qk` – Experimental tests.
PACS `13.25.Hw` – Hadronic decays of mesons: Decays of bottom mesons.
PACS `14.40.Nd` – Bottom mesons.

1. – Introduction

Flavor physics of quarks is considered one of the most promising sectors for indirect signs of new particles or interactions beyond the standard model (SM). The B_s^0 dinamics in particular offers rich opportunities since its experimental exploration has not reached in extension and precision stringent constraints on the presence of NP in contrast to what happened in leading (and some subleading) processes involving charged and neutral kaons and bottom mesons. The B_s^0 oscillations are explained in terms of second-order weak processes involving the the CKM matrix element V_{ts}: a broad class of generic extensions of the SM is expected to affect the mixing amplitude, modifying the mixing "intensity"—that is the oscillation frequency—and the phase, β_s. A non-SM enhancement of β_s would also decrease the size of the decay-width difference between the light and heavy-mass eigenstates of the B_s^0 meson, $\Delta\Gamma_s$ [1]. While the oscillation intensity has been measured precisely [2], only loose constraints on the phase were available until recently. The most effective determination of β_s and $\Delta\Gamma_s$ is achieved through the analysis of the time evolution of flavour–tagged $B_s^0 \to J/\psi\phi$ decays.

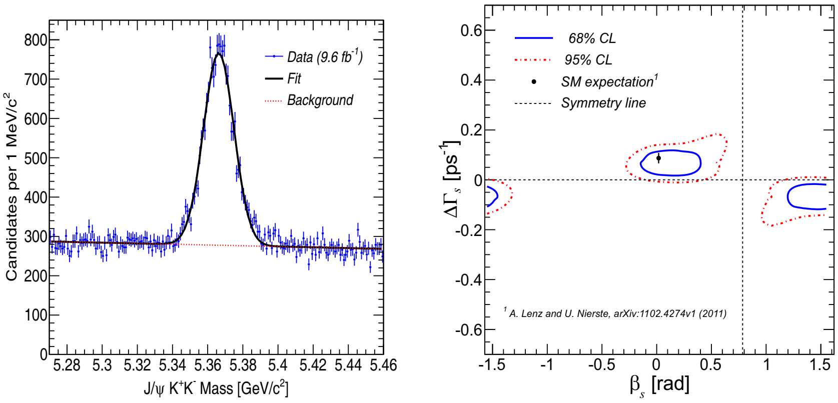

Fig. 1. – Left: Distribution of $J/\psi K^+K^-$ mass with fit projection overlaid. Right: Confidence regions at the 68% and 95% CL in the $(\beta_s,\Delta\Gamma_s)$-plane.

The first such analysis was performed by the CDF experiment in 2008. Immediately after D0 joined [3]. In 2010 the combination of CDF and D0 results suggested a mild deviation from the SM expectation. However, updated measurements [4-6] showed increased consistency with the SM, calling for additional experimental information to clarify the picture.

Here we report the new CDF update using the final data set of $10\,\mathrm{fb}^{-1}$.

2. – Analysis

The decays, collected by a low–momentum dimuon trigger, are fully reconstructed using four tracks originating from a common displaced vertex, two matched to muon pairs consistent with a J/ψ decay ($3.04 < m_{\mu\mu} < 3.14\,\mathrm{GeV}/c^2$), and two consistent with a $\phi \to K^+K^-$ decay ($1.009 < m_{KK} < 1.028\,\mathrm{GeV}/c^2$). The dimuon mass constraint to the known J/ψ mass combined with a transverse momentum resolution of $\sigma_{p_T}/p_T \approx 0.07\% p_T$ (p_T in GeV/c) yield a mass resolution for our signals of about $9\,\mathrm{MeV}/c^2$. The $J/\psi K^+K^-$ mass distribution (fig. 1, left), shows a signal of approximately 11000 decays, overlapping a similar amount of constant background dominated by the prompt combinatorial component, and smaller contributions from mis-reconstructed B decays.

The analysis relies on a joint fit to the time evolution of B_s^0 mesons that resolve the fast oscillations by exploiting the 90 fs time resolution of the CDF micro-vertex detector for these final states. Because the B_s^0 meson has spin zero and J/ψ and ϕ have spin one, the $B_s^0 \to J/\psi\phi$ decay involve three independent amplitudes, each corresponding to one possible angular momentum state of the $J/\psi\phi$ system which is also a CP-odd or CP-even eigenstate. To enhance the sensitivity to β_s, the time-evolution of the decay amplitudes is fitted independently by exploiting differences in the distribution of the kaons' and muons' decay angles. Sensitivity to β_s can be further enhanced accounting for the difference in the time evolution of initially produced B_s^0 and $\bar{B}_s^0$. The flavour of the meson at the time of production is inferred by two independent classes of algorithms: the opposite-side flavour tag (OST) and the same-side kaon tag (SSKT) [2].

The OST performances have been determined with 82000 $B^\pm \to J/\psi(\to \mu^+\mu^-)K^\pm$ decays fully reconstructed in the same sample as the signal. We found an efficiency of

$\varepsilon_{\rm OST} = (92.8 \pm 0.1)\%$, an observed averaged dilution, $D_{\rm OST}$, equal to $(12.3 \pm 0.4)\%$ and a resulting effective tagging power of $\varepsilon_{\rm OST} D^2_{\rm OST} = (1.39 \pm 0.05)\%$. The SSKT algorithms tag a smaller fraction of candidates with better precision. Its performances have been previously determined [4] to be $\varepsilon_{\rm SSKT} = (52.2 \pm 0.7)\%$, $D_{\rm SSKT} = (21.8 \pm 0.3)\%$ and $\varepsilon_{\rm SSKT} D^2_{\rm SSKT} = (3.2 \pm 1.4)\%$.

Since SSKT algorithm has been calibrated for early data only, we conservatively restrict its use to the events collected in that period. Simulation shows that this results in a modest degradation in β_s resolution.

The unbinned maximum likelihood joint fit uses 9 observables from each event to determine 32 parameters including β_s and $\Delta\Gamma$, other physics parameters (B_s^0 lifetime, decay amplitudes at $t = 0$ and phases, etc.), and several other ("nuisance") parameters (experimental scale factors, etc.).

3. – Results

If β_s is fixed to its SM value, the fit shows unbiased estimates and gaussian uncertainties for $\Delta\Gamma_s$, τ_s. We found $\Delta\Gamma_s = 0.068 \pm 0.026({\rm stat}) \pm 0.007({\rm syst})\,{\rm ps}^{-1}$, and mean B_s^0 lifetime, $\tau_s = 1.528 \pm 0.019({\rm stat}) \pm 0.009({\rm syst})\,{\rm ps}$. Systematic uncertainties include mismodeling of the signal mass model, lifetime resolution, acceptance description, and angular distribution of the background; a $\mathcal{O}(2\%)$ contamination by $B^0 \to J/\psi K^*(892)^0$ decays misreconstructed as $B_s^0 \to J/\psi\phi$ decays; and the silicon detector misalignment. These results are among the most precise measurements from a single experiment.

If β_s is free to float in the fit, tests in statistical trials show that the maximum likelihood estimate is biased for the parameters of interest, and the biases depend on the true values of the parameters. Hence, we determine confidence regions in the β_s and $(\beta_s, \Delta\Gamma_s)$ spaces (fig. 1, right), by using a profile-likelihood ratio statistic as a χ^2 variable and considering all other likelihood variables as nuisance parameters. Confidence regions are corrected for non-Gaussian likelihood and systematic uncertainties such as to ensure nominal coverage. By treating $\Delta\Gamma_s$ as a nuisance parameter, we also obtain $\beta_s \in [-\pi/2, -1.51] \cup [-0.06, 0.30] \cup [1.26, \pi/2]\,{\rm rad}$ at the 68% CL, and $\beta_s \in [-\pi/2, -1.36] \cup [-0.21, 0.53] \cup [1.04, \pi/2]\,{\rm rad}$ at the 95% CL. Included in the fit is also the CP-odd component originated by non-resonant K^+K^- pair or by the $f_0(980)$ decays. The resulting S-wave decay amplitude is found to be negligible. All results are consistent with the SM expectation and with determinations of the same quantities from other experiments [5-7].

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