CDF note 10108

Calibration of the Same Side Kaon Tagger using 5.2 fb^{-1} of $p\bar{p}$ Collisions

The CDF Collaboration
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We present a measurement of the mixing amplitude using the Same Side Kaon Tagger on four fully reconstructed B_s^0 decay channels. The data amount used corresponds to an integrated luminosity of about 5.2 fb^{-1}. The value for the amplitude, which can now be used to scale the event-by-event dilutions of this flavor tagger, amounts

$$\mathcal{A} = 0.94 \pm 0.15\ (stat.) \pm 0.13\ (syst.)$$

The mean B_s^0 lifetime and the mixing frequency, which are measured at the same time, agree with previous results. The obtained amplitude is used to determine the tagging power of the Same Side Kaon Tagger. Here we find

$$\mathcal{T} = \varepsilon \mathcal{A}^2 D^2 = (3.2 \pm 1.4)\ \%.$$

I. INTRODUCTION

According to the Standard Model there are two neutral B-mesons showing the phenomenon of flavor oscillations: both the B^0 and the B_s^0 continuously transform themselves into their own anti-particle. There are many studies at the CDF-II experiment analyzing these mesons. Especially the B_s^0, which possesses still many unexplored properties, is a popular subject of research.

Some of those analyses rely or at least benefit from the assessment of the flavor eigenstate of those particles at production time. Procedures providing this information are called flavor taggers. Their output values are referred to as tagging decision and dilution. The former is an integer number, defined as $+1$ for a B meson, -1 for $\bar{B}$ and 0 if a decision could not be reached. The latter is related to the probability for the tagging decision to be correct.

It shall be understood that the event-by-event assignment of those probabilities is a non-trivial task. On the other hand analyses using this information depend on the correct assessment of these quantities. The most prominent one in these days is the measurement of the mixing induced CP violation in the $B_s/\bar{B}_s$ system. Flavor tagging hereby helps to reduce the solution space in the $\Delta\Gamma$-β_s-plane [1].

For all those analyses, the measurement of the mixing amplitude, which is presented inside this document, plays a prominent role. Its range of values is interpreted in the following way: an amplitude consistent with one means that a given tagger assesses its decisions and thus its performance correctly. A value smaller than one indicates that it overestimates itself. According to that a value greater than one implies an underestimation of the decision power.

After the mixing amplitude is determined, it serves as a scale factor for the dilution. Altogether this is the reason why the presented measurement possesses an outstanding role: it is the first calibration of a B_s^0 tagger on measured data.

To date, the Same Side Kaon Tagger (SSKT), which is used inside this analysis, is the most powerful stand-alone tagger at the CDF-II experiment. It has undergone several stages of development. For the following study, the SSKT version is used, which combines kinematic information with particle identification. Essentially it is the same configuration as was used for the observation of B_s^0 mixing [2]. The only difference is that information about the specific ionization loss dE/dx is not exploited for tracks with transverse momentum below 2 GeV/c because the calibration for that region is still in progress.

The mixing frequency is determined simultaneously together with the amplitude. The main reason for doing this is to have a physical quantity providing cross-checks and thus to inspire confidence into the measurement. Besides of this the mixing frequency of the B_s^0 is still an important physical parameter. So far there was only one result with a confidence level of five standard deviations [2] and it is interesting to check that measurement on a much larger data sample.

II. EVENT SELECTION

The CDF-II detector [3] consists of a magnetic spectrometer surrounded by electromagnetic and hadronic calorimeters and muon detectors. It allows for a precise determination of the decay point using a seven-layer double-sided silicon-strip detector and a single-sided layer of silicon mounted directly on the beampipe at an average radius of 1.5 cm. A 96-layer drift chamber is used for both precision tracking and measuring of the specific ionization loss, which is used for particle identification. It is complemented by a time-of-flight system located outside of the drift chamber which has the capability to identify low-momentum charged kaons.

A three-level trigger system selects, in real time, events containing charm and bottom hadrons by exploiting the kinematics of production and decay, and the long lifetimes of those particles.

The data used within this analysis were taken between February 2002 and June 2009 using the Two Track Trigger. Taking into account good-run lists, this corresponds to an integrated luminosity of 5.2 fb^{-1}. The following fully reconstructed decay modes are selected for the analysis at hand:

$$
\begin{aligned}
&B_s^0 \to D_s^- \pi^+,\ D_s^- \to \phi\pi^-,\ \phi \to K^+K^- \\
&B_s^0 \to D_s^- \pi^+,\ D_s^- \to K^*K^-,\ K^* \to K^+\pi^- \\
&B_s^0 \to D_s^- \pi^+,\ D_s^- \to \pi^-\pi^-\pi^+ \\
&B_s^0 \to D_s^- \pi^+\pi^+\pi^-,\ D_s^- \to \phi\pi^-,\ \phi \to K^+K^-
\end{aligned}
$$

In each case a specially trained neural network was used for the selection of events. They were optimized for the purpose of accepting as much signal events as possible while rejecting combinatorial background as much as possible. The figure of merit used for this optimization is the yield significance $S/\sqrt{S+B}$. S is hereby defined as the number of signal events, B the number of background events, located inside the signal range in invariant mass, which is chosen from 5.32 GeV/c^2 to 5.42 GeV/c^2.

III. SAMPLE COMPOSITION

After applying the reconstruction and selection algorithms, various kinds of signal and non-signal contributions are contained inside the data sample.

One way to classify these samples, is to ask, whether there is a real B_s meson in the initial state. This is of course the case for the signal decay $B_s \to D_s(3)\pi$. In addition, the charged particles may also emit bremsstrahlung. This affects the kinematics of the decay and is commonly referred to as final state radiation. It is denoted as $B_s \to D_s(3)\pi(n\gamma)$. There may also occur a kaon instead of a pion in the final state of the B_s. This phenomenon is referred to as Cabibbo suppression. Finally there are also partially reconstructed decays expected in the data sample. They are denoted as $B \to D_s X$. Except for invariant mass, all these contributions are treated in a similar way and are denoted in the following as Sig.

The contributions which do not originate from real B_s mesons can be divided into two classes. The first one are other heavy flavor decays, where a wrong particle hypothesis was assigned to one of the decay products. In the decay channel $B_s \to D_s\pi,\ D_s \to \phi\pi$, a significant fraction of these decays is not expected. Background coming from Λ_b-baryons are expected in $B_s \to D_s\pi,\ D_s \to K^*K$ and $B_s \to D_s\pi,\ D_s \to 3\pi$. Background coming from B^0-mesons are also expected in the decay $B_s \to D_s\pi,\ D_s \to K^*K$. Both contributions are denoted in the following as B and Λ_b respectively.

The second class of the non-B_s meson contribution is combinatorial background, which is denoted in the following as $Comb$.

In this way, the model is composed of four different contributions. The relative fractions of the physical backgrounds are estimated based on values taken from the PDG [4] or from earlier CDF-II studies. Except for the combinatorial background, simulated events are generated for each contribution. Pythia [5] is used for the signal decays. BGenerator II is used for all other decays.

IV. OBSERVABLES

Several B meson properties are used inside this measurement. The following list summarizes them along with the reason why they are used:

- The reconstructed **invariant mass** m of the B_s^0. The reason for using this quantity is that several contributions expected in our sample are clearly separated in mass. Therefore it is the best discriminating variable used inside the fit.

- The **proper decay time** ct of the B_s^0. It is obtained by dividing the decay length of the B-meson in the x-y plane L_{xy} by the its transverse momentum p_T and multiplying it by the reconstructed invariant mass m:

$$ct = \frac{L_{xy} m}{p_T} \tag{1}$$

  Seen in general, mixing is a temporal phenomenon. Therefore the proper decay time is an essential part of each measurement of the oscillation frequency Δm_s.

- The **resolution of the proper decay time** σ_{ct}. This expression can be acquired by applying Gaussian error propagation on the above expression. In doing so, the resolution of the transverse momentum σ_{p_T} is neglected because it is expected to be much better comparing to the decay length resolution $\sigma_{L_{xy}}$. In this way the following equation is acquired:

$$\sigma_{ct} = \frac{\sigma_{L_{xy}}\ m}{p_T} \tag{2}$$

  By using this variable, events with a more precise decay time measurement are implicitly considered with a greater weight.

- The **decay flavor** of the B_s^0 meson ξ_D. This variable is obtained by the decay reconstruction. It is derived using the charge of the pion originating from the B_s^0 candidate. The decay flavor is therefore a binary quantity taking either -1 or +1 as value. It is an inherent property of the reconstruction that this assignment is always correct for a given signal decay.

- The **production flavor** of the B_s^0-candidate ξ_P, which is also referred to as tagging decision. This variable is provided by the Same Side Kaon Tagger, which does not provide a decision for each event. The range of values is therefore not only -1 or +1 ($\bar{B}_s^0$ or B_s^0) but also 0 (no decision). The fraction of events a tagger gives an estimation on is called efficiency:

$$\varepsilon = \frac{N_+ + N_-}{N_+ + N_- + N_0} \tag{3}$$

  N_+ (N_-) hereby stands for the number of events tagged with a positive (negative) production flavor. N_0 denotes events without tagging decision.

- The **dilution** D is a unitless quantity which is also given by the flavor tagger algorithm. It is related to the probability for the tagging decision (see previous item) to be correct by the following equation:

$$D = \frac{N_R - N_W}{N_R + N_W} = 2 \cdot P - 1 \tag{4}$$

  N_R (N_W) denotes hereby the number of correct (incorrect) decisions. It is noteworthy that the dilution does not apply if the tagging algorithm did not reach a decision.

  The reason for using this quantity is to assign higher weights for B_s^0 meson candidates which possess more reliable tagging decisions.

By using the efficiency ε, the mean value of D^2 and the measured mixing amplitude $\mathcal{A}$, the tagging power can be determined:

$$\mathcal{T} = \varepsilon \mathcal{A}^2 D^2 \tag{5}$$

It can be seen as a benchmark quantity for a given tagger. Typical values for the tagging powers at hadron colliders vary up to approx. 5%.

V. FIT MODEL

A careful study of correlations between the variables described in the previous section was performed for the different contributions. The most prominent one was hereby the correlation between the proper decay time and the proper decay time resolution, which is observed both for the combinatorial background and for the signal. It is an instrumental effect which is mostly induced by the Two Track Trigger. Apart from that the distribution of the tagging quantities looks slightly different for positive and negative decay flavor. All other correlations are negligible. Based on these observations the following ansatz is made:

$$\begin{aligned} P(m, ct, \sigma_{ct}, \xi_D, \xi_P, D) = {} & f_{Sig} \cdot P_{Sig}(m) \cdot P_{Sig}(ct|\sigma_{ct}, \xi_D, \xi_P, D) \cdot P_{Sig}(\sigma_{ct}) \cdot P_{Sig}(\xi_P, D|\xi_D) \\ & + f_{Comb} \cdot P_{Comb}(m) \cdot P_{Comb}(ct|\sigma_{ct}) \cdot P_{Comb}(\sigma_{ct}) \cdot P_{Comb}(\xi_P, D|\xi_D) \\ & + f_{\Lambda_b} \cdot P_{\Lambda_b}(m) \cdot P_{\Lambda_b}(ct) \cdot P_{Sig}(\sigma_{ct}) \cdot P_{Sig}(\xi_P, D|\xi_D) \\ & + f_B \cdot P_B(m) \cdot P_B(ct) \cdot P_{Sig}(\sigma_{ct}) \cdot P_{Sig}(\xi_P, D|\xi_D) \end{aligned} \tag{6}$$

All parameters are omitted in this notation. The subfunctions are either phenomenological functions, which are determined using simulated or measured data, or histograms. The only exception is $P_{Sig}(ct|\sigma_{ct}, \xi_D, \xi_P, D)$. It has a physical meaning and contains all parameters of interest:

$$P_{Sig}(ct|\sigma_{ct}, \xi = \xi_D \cdot \xi_P, D) = \frac{1}{N} \cdot \left[\frac{1}{\tau} e^{-\tilde{t}/\tau} \cdot (1 + \xi \mathcal{A} D \cdot \cos(\Delta m_s \tilde{t})) \right] \otimes \mathcal{G}(c\tilde{t}|\sigma_{ct}) \ \cdot \epsilon(ct|\sigma_{ct}).$$

The exponential function represents the decay law. The cosine modulation contains the mixing frequency in its argument and the mixing amplitude as prefactor. ξ is the product of production and decay flavor and can be seen as the decision if the B_s^0 has mixed (-1) or not (+1). The product of both functions is convoluted with the proper decay time resolution function which is assumed as Gaussian. The result is a function which does not contain anymore the true decay time $c\tilde{t}$ but the measured one ct. The composition of events is the result of trigger and selection cuts. In order to compensate for the events which are not captured by that procedure, the expression is multiplied by the efficiency function $\epsilon(ct|\sigma_{ct})$, which is determined using simulated events.

VI. FIT PROCEDURE

The overall fit procedure consists of several steps. At first separate binned fits are performed in **invariant mass** for all contributions except for the combinatorial background. Simulated events are hereby used and their mass distribution shapes are afterwards fixed. The probability density function for the combinatorial background is assumed as exponential and is not determined prior to the combination of all subfunctions on data. Three Gaussians with different mean values and standard deviations are used to describe the signal in invariant mass including the radiative tail.

The fractions of the physical reflections are fixed with respect to the signal to values taken from external studies. All other fractions are determined on measured data using a combined binned fit performed in a mass window starting at 4.8 GeV/c^2 and ending at 6.0 GeV/c^2. This is done in order to get a first understanding of the different contributions the data sample is composed of. Another reason is to acquire good starting values for the parameters, which are left free inside the subsequent unbinned fit.

According to this wide range mass fit, the upper side band consists only of combinatorial background. Events which are located in the interval from 5.55 GeV/c^2 to 6.00 GeV/c^2 are therefore used as model distributions for $P_{Comb}(ct|\sigma_{ct})$, $P_{Comb}(\sigma_{ct})$ and $P_{Comb}(\xi_P, D|\xi_D)$.

Phenomenological functions are used for the probability density functions in **proper decay time** $P_{\Lambda_b}(ct)$ and $P_B(ct)$. They are determined using separate binned fits on simulated events. The efficiency function $\epsilon(ct|\sigma_{ct})$ is also determined using simulated events. In order to handle the correlation between ct and σ_{ct}, independent efficiency functions are determined in each of ten σ_{ct} ranges between 0.0 cm and 0.015 cm interval. The correlation present inside the combinatorial background is resolved by fitting the proper decay time significance $ct_{Signi} = ct/\sigma_{ct}$, which shows only a small correlation with respect to the other observables. The probability density function in proper decay time is afterwards obtained by the event-by-event transformation $P_{Comb}(ct|\sigma_{ct}) = P_{Comb}(ct_{Signi})/\sigma_{ct}$.

In order to acquire a description for the **uncertainty of the proper decay time** $P_{Sig}(\sigma_{ct})$, a sideband subtraction on measured data is performed. Afterwards a phenomenological function is used for fitting. The same function is also used for the physical reflections as they are expected to have rather signal-like properties. As described above $P_{Comb}(\sigma_{ct})$ is derived from the upper side band and is also described by a phenomenological function.

The probability density functions for the **tagging quantities** are obtained in a similar way. The only difference is that no regression functions are applied in that dimension. Instead histograms are used with variable bin width to maintain a sufficient number of events within each interval.

After the subfunctions are determined, unbinned maximum likelihood fits are performed to measure the parameters of interest. The fit range in invariant mass is hereby reduced to the interval $[5.31, 5.60]$ GeV/c^2, in order to exclude partially reconstructed events as much as possible. The fits are done separately for each decay mode. The following function is minimized with respect to its free parameters:

$$-2 \cdot ln(\mathcal{L}(\vec{a})) = -2 \cdot \sum_{i=1}^{N} \ln \left[P(m_i, ct_i, \sigma_{ct,i}, \xi_{D,i}, \xi_{P,i}, D_i|\vec{a}) \right] \quad (7)$$

The sum runs hereby over all considered events. The parameters are denoted by $\vec{a}$, The function P is defined in equation 6.

At first a fit for the mean lifetime is performed. This means that tagging information is not considered. The sub-functions which contain ξ_P and D as variables, e.g. $P_{Sig}(\xi_P, D|\xi_D)$, are also neglected. Parameters which are left free are the background fraction f_{Bg}, width and position of the biggest signal Gaussian and the mean lifetime. The fractions of the physical reflections enter with Gaussian constraints.

Projections into invariant mass for all four decay channels are shown in figure 1. The various signal yields can be found in table I.

Afterwards all parameters except for mixing frequency and mixing amplitude are fixed. The full probability density function (equation 6) is now used. The justification of this stepwise approach is based on the very small correlation between mixing frequency, mean lifetime and mixing amplitude.

After determining all parameters in each decay channel separately, the four measurements are combined. This is done by minimizing the sum of their respective negative log-likelihood functions,

$$-2 \cdot \sum_{j=1}^{4} \ln \left(\mathcal{L}_j(\vec{a_j}) \right), \quad (8)$$

where j identifies the decay channel. In a first step the the mean lifetime is determined. It amounts

$$c\tau = (451.2 \pm 5.5)\ \mu\text{m}. \quad (9)$$

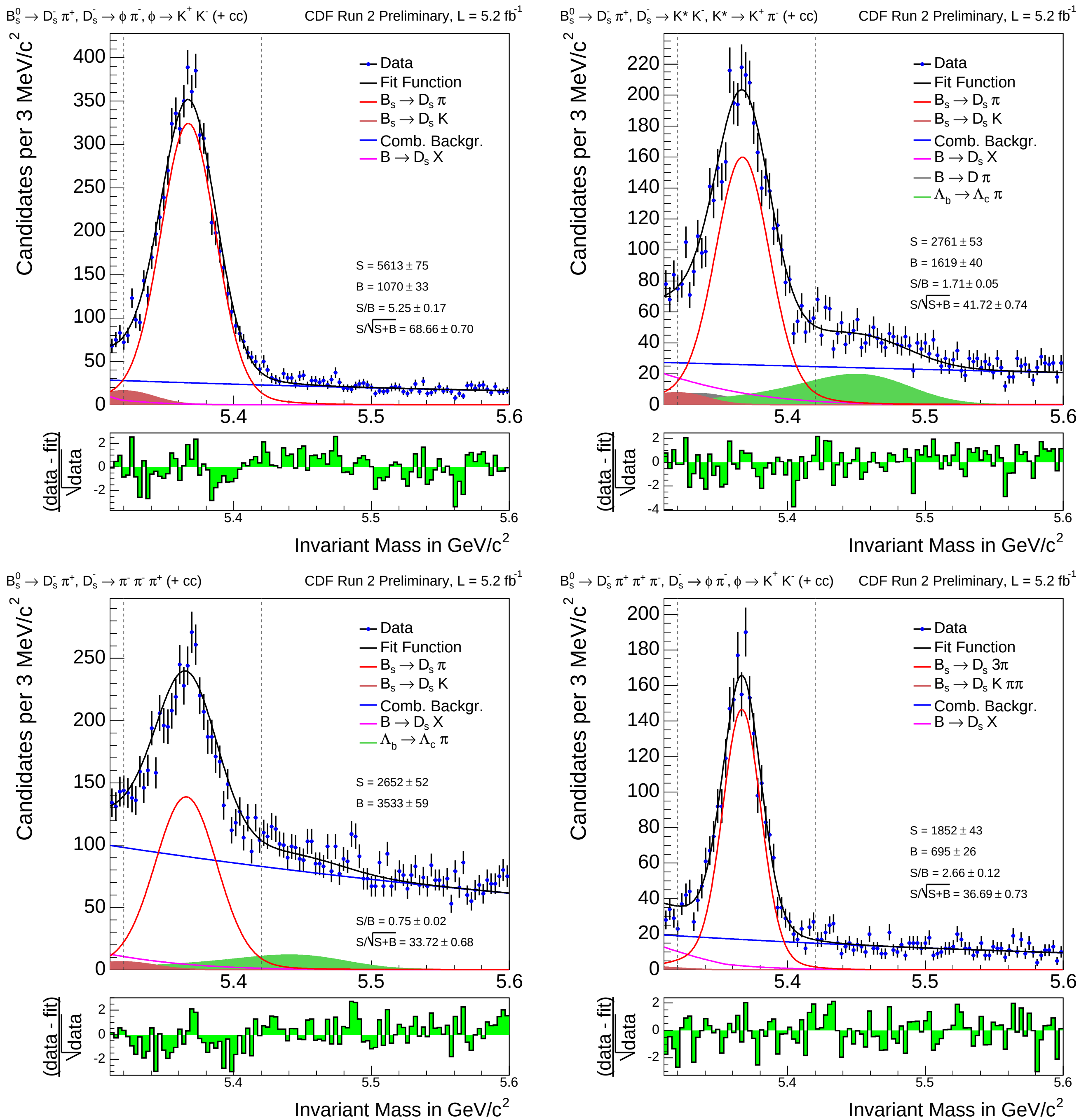

FIG. 1: Projections into invariant mass for all decay channels.

Afterwards a simultaneous fit for mixing frequency and amplitude is performed. Here the following results are acquired for the Same Side Kaon Tagger:

$$\Delta m_s = (17.79 \pm 0.07)\ \mathrm{ps}^{-1} \tag{10}$$
$$\mathcal{A} = 0.94 \pm 0.15 \tag{11}$$

The uncertainties of the three results presented above are statistical only. The value on the amplitude is consistent within one standard deviation with the optimal value of 1.0. The obtained mixing frequency is in agreement with the previous CDF-II measurement. In comparison, its statistical uncertainty improved by 30 %. Based on the integrated luminosity one would naively expect a smaller value here. However this is not the case because in the previous

Decay Channel	S	B	S/B	$S/\sqrt{S+B}$
$B_s^0 \to D_s^- \pi^+,\ D_s^- \to \phi\pi^-$	5613 ± 75	1070 ± 33	5.25 ± 0.17	68.66 ± 0.70
$B_s^0 \to D_s^- \pi^+,\ D_s^- \to K^* K^-$	2761 ± 53	1619 ± 40	1.71 ± 0.05	41.72 ± 0.74
$B_s^0 \to D_s^- \pi^+,\ D_s^- \to (3\pi)^-$	2652 ± 52	3533 ± 59	0.75 ± 0.02	33.72 ± 0.68
$B_s^0 \to D_s^- (3\pi)^+,\ D_s^- \to \phi\pi^-$	1852 ± 43	695 ± 26	2.66 ± 0.12	36.69 ± 0.73
Sum	$\mathbf{12877 \pm 113}$			

TABLE I: Estimated number of signal events (S), background events (B), ratio of signal to background (S/B) and significance ($S/\sqrt{S+B}$) for all four B_s^0 decay channels. A data amount corresponding to an integrated luminosity of 5.2 fb^{-1} was hereby used. The evaluation was done inside the signal range, chosen from 5.32 GeV/c^2 to 5.42 GeV/c^2. For signal and background, the square root of the value is used as uncertainty. All other uncertainties are derived by Gaussian error propagation neglecting correlations.

measurement a combination of Same Side Kaon Tagger and Opposite Side Tagger was employed. Furthermore the tendency of the Tevatron to run at higher instantaneous luminosities is a disadvantage for the triggers used within this analysis. Therefore a doubling of the integrated luminosity does not necessarily imply a doubling of the available candidates.

VII. SYSTEMATIC UNCERTAINTIES ON THE AMPLITUDE

The following sources of systematic uncertainties on the mixing amplitude are considered:

- It is known from several studies that the measured proper decay time resolution is underestimated at the CDF-II experiment [6]. Therefore a resolution scaling technique is employed for the study at hand: each value is multiplied by the pseudo-rapidity-dependent function $s(\eta)$, which is derived using simulated events. Its mean value is approximately 1.38. In order to evaluate the systematic effect of this scaling technique on the amplitude, it is replaced by a constant function with a mean value of 1.29. As a consequence, the measured amplitude is reduced by 0.11. This value is added to the list of systematic uncertainties.

- It can be seen from equation 7, that the proper decay time resolution is assumed as Gaussian. Earlier measurements showed that the sum of two Gaussians with different standard deviations give a better description. Therefore 1000 simulated experiments are used to examine the extend of this simplification on the measured amplitude. The simulated data hereby considers the refined model, the fit function does not. The obtained amplitude shows a deviation of 0.06 which is taken as systematic uncertainty.

- A given B_s^0 may not only go into $D_s^- K^+$, but also into $D_s^+ K^-$. While both processes are Cabibbo suppressed, the former is expected to occur more often [7]. Consequences of the presence of the latter, charge conjugated final state are evaluated by completely removing tagging information for the Cabibbo reflection. A change of 0.03 is observed for the mixing amplitude and used as systematic uncertainty.

- The actual fraction of Cabibbo suppressed decays enters with Gaussians constraint during the unbinned maximum likelihood fit. A deliberate increase of that fraction had no effect on neither mixing frequency nor amplitude.

- The fit function, given in equation 7, does not take into account effects of the decay width difference $\Delta\Gamma$ in the B_s^0 system. This neglection is studied using 1000 simulated experiments, which are generated with an assumed value of $\Delta\Gamma/\Gamma = 0.12$. The fit function is retained as it is. The absolute deviation observed is smaller than 0.01.

- As a test the measurement of mixing frequency and amplitude is repeated with different values for the mean lifetime. The reason for doing this is to evaluate consequences of a wrong lifetime measurement. However variations of the mean lifetime between 420 μm and 490 μm have no effect on neither mixing frequency nor amplitude.

- As mentioned above, a Λ_b reflection is present in some decay channels. In the tagging quantities, the same template is used for it as for the signal. The actual size and location of that reflection makes it hard to check if this modelling is appropriate. However its effect on the actual result can be determined by replacing it by the distribution derived for the combinatorial background. In doing so the same result is obtained as above.

- Variations of the mass window used in the unbinned fit or the choice of the upper side band did not have any effects on the mixing amplitude as well.

Modification	Systematic Uncertainty
Proper decay time resolution scaling	0.11
Resolution model	0.06
Cabibbo reflection	0.03
Cabibbo fraction	negligible
Mass window	negligible
Selection of upper side band	negligible
Λ_b template	negligible
$\Delta\Gamma/\Gamma$	negligible
Mean Lifetime	negligible
Trigger Composition	negligible
Signal Mass Model	negligible
Total	**0.13**

TABLE II: Systematic uncertainties on the mixing amplitude. The total number is the root of the sum of each contribution squared.

- Different trigger paths are applied for the data taking. The information which one was responsible for the taking of a given event is available both on the measured and the simulated data. However a comparison between both shows that the composition is different. Because of this a reweighting is performed in order to adjust the simulated events to the measured data. A measurement without that treatment revealed the same results for mixing frequency and amplitude.
- The model for the signal in invariant mass consists of three Gaussians. A simplification of it to one Gaussian had no effect on the mixing amplitude.

The different contributions are summarized in table II. In total, a systematic uncertainty of 0.13 is achieved.

VIII. RESULTS

Using the systematic uncertainty determined in the previous section, the result on the mixing amplitude of the Same Side Kaon Tagger on a data amount corresponding to an integrated luminosity of 5.2 fb^{-1} amounts

$$\mathcal{A} = 0.94 \pm 0.15\ (\text{stat.}) \pm 0.13\ (\text{syst.}). \tag{12}$$

With this value it is now possible to calculate a final value for the tagging power. In order to do so, both the systematic and the statistical uncertainty are merged. In this way, a value of $\mathcal{A} = 0.94 \pm 0.20$ is obtained. The mixing amplitude is a scale factor for the dilution. Therefore it enters the equation as square. The raw value of εD^2 is determined by performing a sideband subtraction channel-by-channel. Afterwards all four distributions are added up and the mean value is determined. Using this result the final tagging power of the Same Side Kaon Tagger is acquired as

$$\mathcal{T} = \varepsilon \mathcal{A}^2 D^2 \approx (3.2 \pm 1.4)\ \%. \tag{13}$$

One nice way to observe mixing is referred to as amplitude scan. It resembles a Fourier transformation and is produced in the following way: frequencies are chosen in equidistant steps within a certain interval. For each such frequency an unbinned maximum likelihood fit is performed with mixing frequency fixed to the corresponding position and mixing amplitude as the only free parameter.

In this way a set of value pairs are acquired. They are plotted with frequency on the x-axis and amplitude on the y-axis. At the frequency measured in the previous section, the amplitude should assume a value consistent with one. Figure 2 shows the result plot which is obtained using all four B_s^0 decay channels combined.

Another way to visualize the position and significance of the mixing frequency is presented in the following. It is done by plotting the following quantity as a function of Δm_s:

$$-2 \cdot \left[\ln\Big(\mathcal{L}(\mathcal{A}=1)\Big) - \ln\Big(\mathcal{L}(\mathcal{A}=0)\Big) \right] \tag{14}$$

This term consists of the difference between two negative logarithmic likelihood expressions. The amplitude is set to 1 for the first one. For the second expression, the amplitude is set to zero. In this sense it can be seen as a quantitative comparison of the two hypotheses of mixing ($\mathcal{A} = 1$) and no mixing ($\mathcal{A} = 0$). The result plot created by combining all decay channels can be found in figure 3.

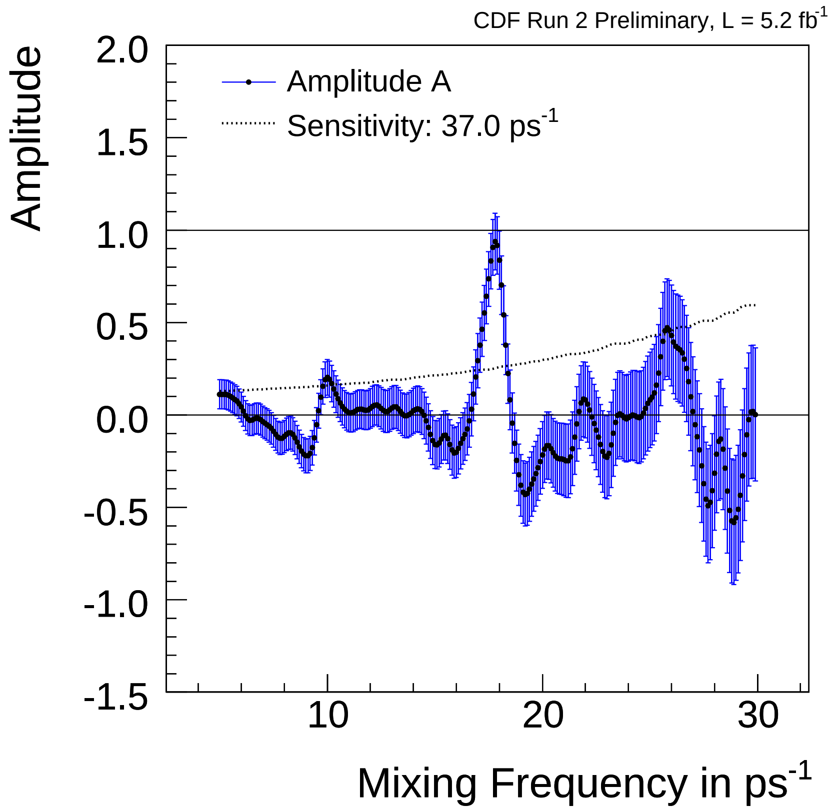

FIG. 2: Amplitude scan using all decay channels on a data amount corresponding to 5.2 fb^{-1}.

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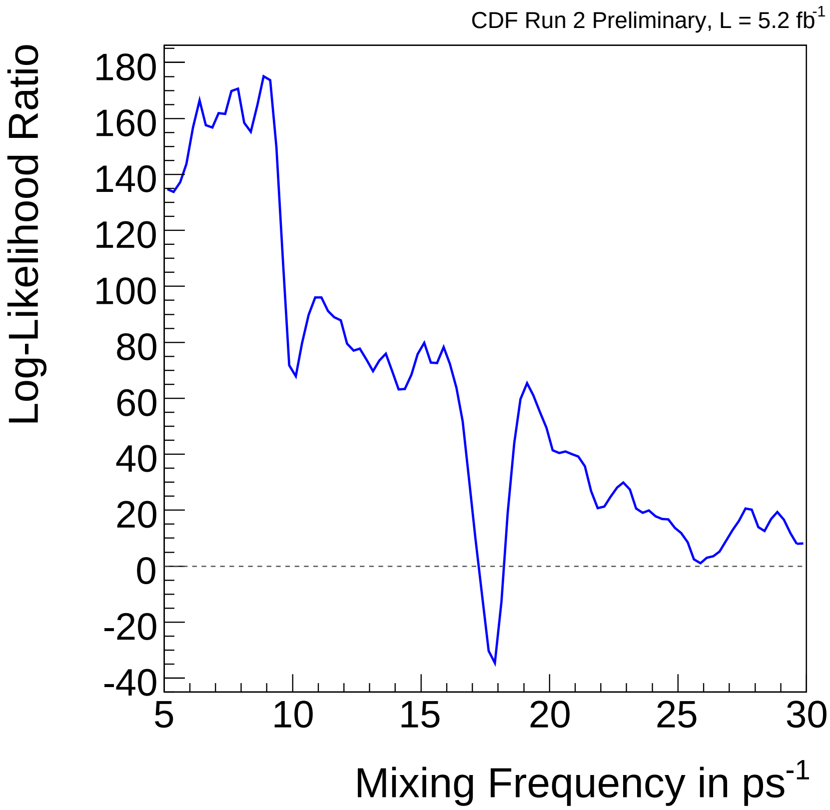

FIG. 3: The difference of the logarithmic likelihood between the two assumptions $\mathcal{A} = 1$ and $\mathcal{A} = 0$ is drawn as a function of mixing frequency. All four decay channels were combined and the Same Side Kaon Tagger was applied.