

## Search for Violation of *CPT* and Lorentz Invariance in $B_s^0$ Meson Oscillations

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We present the first search for  $CPT$ -violating effects in the mixing of  $B_s^0$  mesons using the full Run II data set with an integrated luminosity of  $10.4 \text{ fb}^{-1}$  of proton-antiproton collisions collected using the D0 detector at the Fermilab Tevatron Collider. We measure the  $CPT$ -violating asymmetry in the decay  $B_s^0 \rightarrow \mu^\pm D_s^\pm$  as a function of celestial direction and sidereal phase. We find no evidence for  $CPT$ -violating effects and place limits on the direction and magnitude of flavor-dependent  $CPT$ - and Lorentz-invariance violating coupling coefficients. We find 95% confidence intervals of  $\Delta a_\perp < 1.2 \times 10^{-12} \text{ GeV}$  and  $(-0.8 < \Delta a_T - 0.396 \Delta a_Z < 3.9) \times 10^{-13} \text{ GeV}$ .

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Lorentz invariance requires that the description of a particle is independent of its direction of motion or boost velocity. The standard model extension (SME) [1] provides a framework for potential Lorentz- and  $CPT$ -invariance violation (CPTV), suggesting that such violations can occur at the Planck scale but still result in potentially observable effects at currently available collider energies. The process of neutral meson oscillations is described by a  $2 \times 2$  effective Hamiltonian with mass eigenvalues of the propagating particles having very small differences between them that drive the oscillation probability. For the  $B_s^0 - \bar{B}_s^0$  system, the fractional difference between the eigenvalues is of the order of  $10^{-12}$ . Because of this,  $B_s^0 - \bar{B}_s^0$  oscillations form an interferometric system that is very sensitive to small couplings between the valence quarks and a possible Lorentz-invariance violating field, making it an ideal place to search for new physics [2].

The measurement of the like-sign dimuon asymmetry by the D0 Collaboration [3] shows evidence of anomalously large  $CP$ -violating effects. This is currently one of the few significant deviations from the standard model of particle physics. One of the interpretations of this effect could be a  $CPT$ -invariant  $CP$  violation (CPV) in neutral  $B$ -meson mixing. The propagating “light” ( $L$ ) and “heavy” ( $H$ ) mass eigenvalues of the  $B_s^0 - \bar{B}_s^0$  system can be written as [4]

$$|B_{sL}\rangle \propto p\sqrt{1-\xi_s}|B_s^0\rangle + q\sqrt{1+\xi_s}|\bar{B}_s^0\rangle, \quad (1)$$

$$|B_{sH}\rangle \propto p\sqrt{1+\xi_s}|B_s^0\rangle - q\sqrt{1-\xi_s}|\bar{B}_s^0\rangle. \quad (2)$$

If the complex parameter  $\xi_s$  is zero,  $CPT$  is conserved and CPV is due to  $|q/p| \neq 1$ , so that the oscillation probability  $P(B_s^0 \rightarrow \bar{B}_s^0)$  is different from  $P(\bar{B}_s^0 \rightarrow B_s^0)$ . An alternative interpretation is that the asymmetry could arise from  $T$ -invariant CPV in a  $B_s^0 - \bar{B}_s^0$  mixing [5] where  $|q/p|=1$ , but  $\xi_s$  is nonzero, so the probability of nonoscillation or oscillation back to the original state  $P(B_s^0 \rightarrow B_s^0)$  is different from  $P(\bar{B}_s^0 \rightarrow \bar{B}_s^0)$ . By integrating these two probabilities in time, the asymmetry  $\mathcal{A}_{CPT}$  between the  $B_s^0$  and  $\bar{B}_s^0$  meson decays can be investigated. It can be shown that the CPTV contributions to the  $2 \times 2$  effective Hamiltonian governing  $B_s^0 - \bar{B}_s^0$  oscillations depend on the difference between the diagonal mass and decay rate terms [4]:

$$\xi_s = \frac{(M_{11} - M_{22}) - \frac{i}{2}(\Gamma_{11} - \Gamma_{22})}{-\Delta m_s + i\Delta\Gamma_s/2} \approx \frac{-\beta^\mu \Delta a_\mu}{\Delta m_s - i\Delta\Gamma_s/2}, \quad (3)$$

where  $\Delta a_\mu$  is a four vector direction and magnitude in space-time characterizing Lorentz-invariance violation which in the SME is given by  $\Delta a_\mu = r_s a_\mu^s - r_b a_\mu^b$ , where  $a_\mu^q$  are Lorentz-violating coupling constants for the two valence quarks in the  $B_s^0$  meson, and where the factors  $r_q$  allow for quark-binding or other normalization effects. The four velocity of the  $B_s^0$  meson is given by  $\beta^\mu = \gamma(1, \vec{\beta})$ ,  $\beta^\mu \Delta a_\mu$  is the difference between the diagonal elements of the effective Hamiltonian, and the mass and decay rate differences of the mass eigenstates are  $\Delta m_s = m_H - m_L$  and  $\Delta\Gamma_s = \Gamma_L - \Gamma_H$  [6]. The small fractional values of

$\Delta m_s$  and  $\Delta \Gamma_s$  make the  $B_s^0$  system sensitive to CPTV effects. In the underlying theory, spontaneous Lorentz symmetry breaking generates constant background expectation values for the quark fields that are Lorentz vectors represented by  $\Delta a_\mu$  or tensors instead of scalars [4].

Any observed CPT violation should vary in the frame of the detector denoted with indices  $(t, x, y, z)$ . The period will be one sidereal day ( $\approx 0.99727$  solar days) as the direction of the proton beam follows Earth's rotation with respect to the distant stars [4]. In the SME the variation would depend on CPT- and Lorentz-invariance violation coupling coefficients  $\Delta a_\mu$  with indices  $(T, X, Y, Z)$ . We choose  $(T, X, Y, Z)$  as coordinates in the standard Sun-centered frame, with the rotation axis of Earth taken as the Z axis and X (Y) at right ascension  $0^\circ$  ( $90^\circ$ ) [7] (see the Supplemental Material [8] for a diagram of the coordinate system). If CPTV in  $B_s^0 - \bar{B}_s^0$  oscillations is allowed, then  $\mathcal{A}_{CPT} = (\Delta m_s / \Gamma_s) \text{Im}(\xi_s)$  if  $\xi_s$  is small. By translating from the Sun-centered frame to the detector frame we have [4]

$$\mathcal{A}_{CPT} = \frac{-\Delta \Gamma_s \gamma^{D0}}{\Gamma_s \Delta m_s} \left[ \Delta a_T - C_\alpha S_\chi \beta_z^{D0} \Delta a_Z + \sqrt{C_\alpha^2 C_\chi^2 + S_\alpha^2} \sin(\Omega \hat{t} + \delta + \kappa) \beta_z^{D0} \Delta a_\perp \right], \quad (4)$$

where  $C_x = \cos(x)$ ,  $S_x = \sin(x)$ ,  $\hat{t}$  is the elapsed time with respect to the vernal equinox of the year 2000,  $\Omega = 2\pi$  rad/sidereal day,  $\beta_z^{D0} = \beta^{D0} \cos \theta$  is the velocity  $\vec{\beta}$  of the  $B_s^0$  meson in the detector frame projected onto the  $z$  axis (proton beam direction) of the D0 detector,  $\theta$  is the polar angle between the  $B_s^0$  momentum and the proton beam direction,  $\gamma^{D0} = 1/\sqrt{1 - (\beta^{D0})^2}$ ,  $\chi$  is the colatitude of the D0 detector,  $\alpha$  is the orientation of the  $z$  axis of the detector in Earth's coordinate system, where the proton beam has a bearing of  $219.53^\circ$ ,  $\Delta a_\perp = \sqrt{\Delta a_X^2 + \Delta a_Y^2}$  is the transverse and  $\Delta a_Z$  the longitudinal components of  $\Delta a_\mu$ ,  $\delta = \tan^{-1}(\Delta a_Y / \Delta a_X)$ ,  $\kappa = \tan^{-1}(-S_\alpha / C_\alpha C_\chi)$ , and  $\Delta a_T$  is the time component of the  $\Delta a_\mu$  four-vector. A variation with sidereal time could arise from the rotation of  $\beta_z^{D0}$  with respect to  $\Delta \vec{a}$ . In this Letter we place limits on  $\Delta a_\perp$  and  $\Delta a_T - C_\alpha S_\chi \beta_z^{D0} \Delta a_Z$ .

Past experiments and analyses have placed constraints on the flavor-dependent  $\Delta a_\mu$  in other neutral meson oscillating systems:  $K^0 - \bar{K}^0$  [9],  $D^0 - \bar{D}^0$  [10], and  $B^0 - \bar{B}^0$  [11], as well as indirect limits for  $B_s^0 - \bar{B}_s^0$  [5].

This Letter presents a search for CPT and Lorentz violation using the decay  $B_s^0 \rightarrow \mu^+ D_s^- X$ , where  $D_s^- \rightarrow \phi \pi^-$  and  $\phi \rightarrow K^+ K^-$  (charge conjugate states are assumed in this article). CP-violating asymmetries are usually between “wrong-sign” decays  $B_s^0 \rightarrow \bar{B}_s^0 \rightarrow \mu^+ D_s^-$ , but we want to study the asymmetry between the “right-sign” decays  $B_s^0 \rightarrow B_s^0 \rightarrow \mu^- D_s^+$  and their charge conjugate.

We extract the CPT-violating parameter using the asymmetry

$$A = \frac{N_+ - N_-}{N_+ + N_-}, \quad (5)$$

where  $N_+$  [ $N_-$ ] is the number of reconstructed  $B_s^0 \rightarrow \mu^\pm D_s^\mp X$  events where  $\text{sgn}(\cos \theta) Q > 0$  [ $\text{sgn}(\cos \theta) Q < 0$ ], which results from the  $\beta_z^{D0} = \beta^{D0} \cos \theta$  terms in Eq. (4) and  $Q$  is the charge of the muon. The direction of the  $\mu^+ D_s^-$  system differs from that of the parent  $B_s^0$  due to the missing neutrino. However, the migration between  $N_+$  and  $N_-$  terms near  $\theta = \pi/2$  causes a negligible correction to the measured asymmetry. The initial state at production is not flavor tagged in our study, but after experimental selection requirements, the  $B_s^0$  system is fully mixed, so that the probability of observing a  $B_s^0$  or  $\bar{B}_s^0$  is essentially equal regardless of the flavor at production. We assume no CP violation in the mixing [12], so only about half of the observed  $B_s^0$ 's have the same flavor as they had at birth. We assume no CP violation, so those observed  $B_s^0$  mesons which have changed their flavor do not contribute to CPTV, leading to a 50% dilution in the measured asymmetry. In the presence of CPT violation, the asymmetry is expected to have a period of one sidereal day, so a search is made for variations of the form

$$A(\hat{t}) = A_0 - A_1 \sin(\Omega \hat{t} + \phi), \quad (6)$$

where  $A_0$ ,  $A_1$ , and  $\phi = \delta + \kappa$  are constants and are extracted by measuring the asymmetry  $A$  in Eq. (5) in bins of the sidereal phase  $\Omega \hat{t}$ , and a fitting to the value in each bin with Eq. (6). Measurements of  $A_0$  and  $A_1$  are then interpreted as limits on  $\Delta a_\mu$  from  $B_s^0 - \bar{B}_s^0$  oscillations. A nonzero value of  $\Delta a_z$  and  $\Delta a_T$  would lead to a CPTV asymmetry that does not vary with sidereal time.

The data selection and the signal extraction are identical to those used in Ref. [13]. The main details of the data selection using the D0 detector [14] are described here.

The data are collected with a suite of single and dimuon triggers. The selection and the reconstruction of  $\mu^+ D_s^- X$  decays require tracks with at least two hits in both the central fiber tracker and the silicon microstrip tracker. The muon track segment outside the calorimeter has to be matched to a particle found in the central tracking system which has momentum  $p > 3$  GeV and transverse momentum  $2 < p_T < 25$  GeV. The  $D_s^- \rightarrow \phi \pi^-$ ,  $\phi \rightarrow K^+ K^-$  decay is reconstructed by assuming the two  $\phi$  decay particles are kaons, requiring  $p_T > 0.7$  GeV, opposite charges, and  $M(K^+ K^-) < 1.07$  GeV. The charge of the third particle, assumed to be the charged pion, must have charge opposite to that of the muon and  $0.5 < p_T < 25$  GeV. The three tracks are combined to create a common  $D_s^-$  decay vertex using the algorithm described in Ref. [15]. The reconstructed  $\mu^\pm D_s^\mp$  candidate is required to pass

several kinematic selection criteria and satisfy likelihood ratio criteria that are identical to those described in Ref. [13].

The effective  $K^+K^-\pi^\pm$  mass distribution is fitted using bins of 6 MeV over a range of  $1.7 < M(K^+K^-\pi^\pm) < 2.3$  GeV, and the number of signal and background events is extracted by a  $\chi^2$  fit of an empirical model to the data. The  $D_s^\pm$  meson mass distribution is well modeled by two Gaussian functions constrained to have the same mean, but with different widths and normalizations. There is a negligible peaking background under the  $D_s^\pm$  peak. A second peak in the  $M(K^+K^-\pi^\pm)$  distribution corresponding to the Cabibbo-suppressed  $D^\pm \rightarrow \phi\pi^\pm$  decay is also modeled by two Gaussian functions with widths set to those of the  $D_s^\pm$  meson model scaled by the ratio of the fitted  $D^\pm$  and  $D_s^\pm$  masses. The combinatoric background is modeled by a fifth-order polynomial function. Partially reconstructed decays such as  $D_s^\pm \rightarrow \phi\pi^\pm\pi^0$ , where the  $\pi^0$  is not reconstructed, are modeled with a threshold function that extends to the  $D_s^\pm$  mass after the  $\pi^0$  mass has been subtracted, given by  $T(m) = \tan^{-1}[p_1(mc^2 - p_2)] + p_3$ , where  $p_i$  are the fit parameters.

The raw asymmetry [Eq. (5)] is extracted by fitting the  $M(K^+K^-\pi^\pm)$  distribution of the  $\mu^\pm D_s^\mp$  candidates using a  $\chi^2$  minimization. The fit is performed simultaneously, using the same models, on the sum and the difference of the  $M(K^+K^-\pi^\pm)$  distribution of  $N_+$  candidates and  $N_-$  candidates. The functions used to model the two distributions are

$$W_{\text{sum}} = W_{D_s} + W_D + W_{\text{cb}} + W_{\text{pt}}, \quad (7)$$

$$W_{\text{diff}} = AW_{D_s} + A_D W_D + A_{\text{cb}} W_{\text{cb}} + A_{\text{pt}} W_{\text{pt}}, \quad (8)$$

where  $W_{D_s}$ ,  $W_D$ ,  $W_{\text{cb}}$ , and  $W_{\text{pt}}$  describe the distribution of the  $D_s^\pm$  and  $D^\pm$  mass peaks, the combinatorial background, and the partially reconstructed events, respectively, and the  $A$  factors are the corresponding asymmetries which are extracted from the fit. The number of signal events in the sample is  $N(D_s^\pm) = 205865 \pm 626$ .

Following previous conventions [16] we shift the origin of the time coordinate to correspond to the vernal equinox of the year 2000. The value of  $A_1$  is extracted by dividing the data into  $n$  data sets, each containing a fraction  $f_i$  of the data based on the sidereal phase  $\Omega\hat{t} + \phi$ . In the fit, the parameters that describe the mass distributions  $W_{\text{sum}}$  and  $W_{\text{diff}}$  are the same for all sidereal bins, except for  $A$  and  $A_D$ , which may vary with the sidereal phase.

The number of sidereal bins used to extract the asymmetry is determined by finding the smallest uncertainty on  $A_1$ . By using a MC input of asymmetries that ranges from 0% to 2%, we find that the optimum number of bins is 11. One of the 11 distributions produced in the fit to the data is shown in Fig. 1.

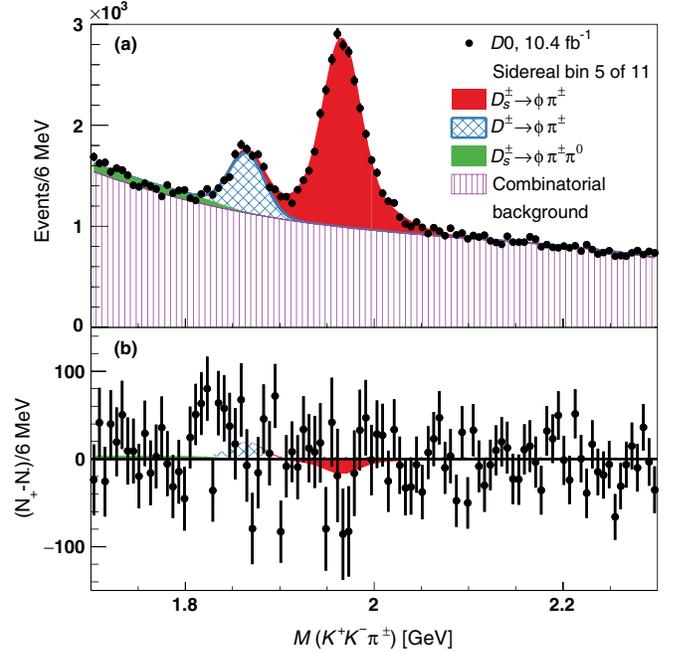


FIG. 1 (color online). (a) The  $K^+K^-\pi^\mp$  invariant mass distribution for one of the 11 sidereal bins of the data (bin 5) of the  $\mu^\pm\phi\pi^\mp$  sample. The lower mass peak is due to the decay  $D^\mp \rightarrow \phi\pi^\mp$  and the second peak is due to the  $D_s^\mp$  meson decay. (b) The fit to the  $(N_+ - N_-)$  distribution for one of the 11 sidereal bins of the data (bin 5).

Systematic uncertainties of the fitting method on the extracted values of  $A$  in sidereal bin  $i$ ,  $A(i)$  are evaluated by varying the fitting procedure and are assigned to be half of the maximal variation in the asymmetry. The mass range of the fit is shifted from  $1.700 < M(K^+K^-\pi^\pm) < 2.300$  GeV to  $1.724 < M(K^+K^-\pi^\pm) < 2.270$  GeV in steps of 6 MeV resulting in an absolute uncertainty on the measured asymmetries of 0.035%. The width of the mass bins is changed between 1 and 12 MeV, resulting in an absolute uncertainty of 0.071%. The functions modeling the signal are modified to fit the  $D^\pm$  and  $D_s^\pm$  mass peaks by single Gaussian functions, the background is fitted by varying between a fourth- and seventh-order polynomial function, and the parameter  $p_1$  in the threshold function is allowed to vary. As a test, the fraction of data in each sidereal bin,  $f_i$ , is fixed to exactly 1/11. These variations of the signal modeling yield an absolute uncertainty on the asymmetry of 0.085%. The uncertainty for each of these sources is added in quadrature to give the total systematic uncertainty of the fitting procedure of 0.12%. This uncertainty on the measured values of  $A(i)$  is found to be independent of the sidereal bin, and it is added in quadrature to the statistical uncertainty to extract the  $CPT$ -violating parameters by fitting to Eq. (6) (see Table I). The measured values of the asymmetries,  $A(i)$ , are plotted in Fig. 2 and are tabulated in the Supplemental Material [8].

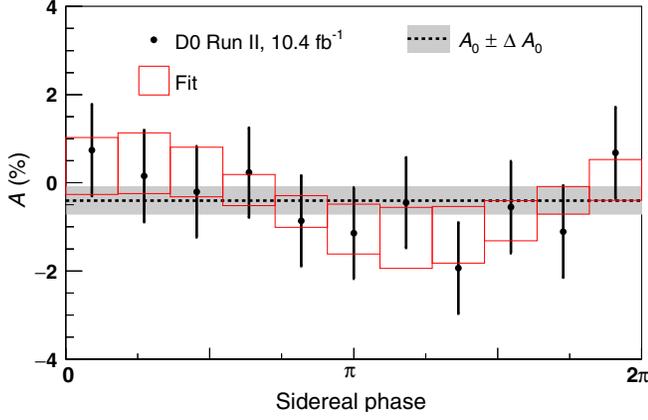


FIG. 2 (color online). The measured asymmetries,  $A(i)$ , versus the sidereal phase. The uncertainty on each value of  $A(i)$  is the sum in quadrature of the statistical and systematic uncertainties. The red boxes show the fit and its uncertainties to the data points [Eq. (6)]. The dashed line shows the extracted value of  $A_0$  and the grey box shows  $\Delta A_0$ .

The limits on  $\Delta a_\mu$  are extracted using

$$A_1 \sin(\Omega\hat{t} + \phi) = \frac{F_{B_s^0}^{\text{non-osc}} \Delta\Gamma_s \langle \gamma^{D0} \beta_z^{D0} \rangle}{\Gamma_s \Delta m_s} \times \sqrt{C_\alpha^2 C_\chi^2 + S_\alpha^2} \sin(\Omega\hat{t} + \delta + \kappa) \Delta a_\perp, \quad (9)$$

$$A_0 = -\frac{F_{B_s^0}^{\text{non-osc}} \Delta\Gamma_s \langle \gamma^{D0} \rangle}{\Gamma_s \Delta m_s} [\Delta a_T - C_\alpha S_\chi \langle \beta_z^{D0} \rangle \Delta a_Z], \quad (10)$$

where the angle brackets denote average values. The  $F_{B_s^0}^{\text{non-osc}}$  factor is the fraction of  $D_s^\pm \rightarrow \phi\pi^\pm$  decays for which an observed  $B_s^0$  has the same flavor as at birth [13]. Combining the fraction of  $B_s^0$  decays in the sample and the 50% dilution factor described earlier gives  $F_{B_s^0}^{\text{non-osc}} = 0.465$ . Limits are extracted from the probability distribution which is given by  $\exp(-\chi^2/2)$ , where  $\chi^2$  is the  $\chi$  square as a function of  $A_1$ ,  $A_0$ , and  $\delta$  using Eq. (6). Since we are setting limits, the probability distribution will be characterized by two quantities, the most probable value of  $A_1$  and the 95% upper limit (UL) which is extracted by integrating the normalized probability distribution at the value of  $\delta$  that gives the most conservative limit.

To extract limits, we measure the average values of  $\langle \gamma^{D0} \rangle = \langle E_{B_s^0} \rangle / m_{B_s^0}$ ,  $\langle \beta_z^{D0} \rangle = \langle p_z \rangle / \langle E_{B_s^0} \rangle$ , and  $\langle \gamma^{D0} \beta_z^{D0} \rangle = \langle p_z \rangle / m_{B_s^0}$ , where  $\langle p_z \rangle$  is the average momentum in the  $z$  direction and  $\langle E_{B_s^0} \rangle$  is the average energy of the  $B_s^0$  meson. The average momentum of the  $\mu D_s^\pm$  candidates is measured using sideband subtraction. The signal region is  $1.92 < M(K^+K^-\pi^-) < 2.00$  GeV and the sideband regions are  $1.75 < M(K^+K^-\pi^-) < 1.79$  GeV and

TABLE I. Parameters and uncertainties in the extraction of the  $CPT$ -violating parameters. The uncertainties on  $A_0$ ,  $A_1$ , and  $\phi$  are fit uncertainties and are dominated by the statistical uncertainty of the raw asymmetries. All of the other uncertainties are systematic.

Parameter	Value	Ref.
$A_0$	$(-0.40 \pm 0.31)\%$	Eq. (6)
$A_1$	$(0.87 \pm 0.45)\%$	Eq. (6)
$\phi$	$-2.28 \pm 0.51$	Eq. (6)
$m_{B_s^0}$	$(5.36677 \pm 0.00024)$ GeV	[17]
$\Delta m_s$	$(17.761 \pm 0.022) \times 10^{12} \text{ } \hbar s^{-1}$	[17]
$\Delta\Gamma_s/\Gamma_s$	$(0.138 \pm 0.012)$	[17]
$F_{B_s^0}^{\text{non-osc}} = F_{B_s^0}^{\text{osc}}$	$(0.465 \pm 0.017)$	[13]
$\langle p_z \rangle$	$(17.8 \pm 1.6)$ GeV	
$\langle p \rangle$	$(25.3 \pm 2.3)$ GeV	
Proton beam dir <sup>n</sup>	$219.53^\circ$	
Colatitude $\chi$	$48.17^\circ$	

$2.13 < M(K^+K^-\pi^-) < 2.17$  GeV, and the average is  $\langle p \rangle = 21.41 \pm 0.03$  GeV. This momentum needs to be corrected for the missing neutrino in the decay using a  $k$ -factor correction. These  $k$  factors are taken from Ref. [18] and applied to give a momentum of  $\langle p \rangle = 25.3$  GeV. The systematic uncertainty on  $\langle p \rangle$  of 1.6 GeV is obtained from the difference between the momentum extracted using sideband subtraction and using a weighted average of the number of signal events in momentum bins, which is then added in quadrature to the uncertainty due to the  $k$  factors. The effect of possible reconstruction variations in the  $x$  and  $y$  directions is found to be less than 1%. If we vary the number of sidereal bins the most probable value of  $A_1$  varies by 8%. These variations are added in quadrature as the relative systematic uncertainty on the value of  $A_1$ .

The final results are obtained by scaling the probability distributions obtained for  $A_0$ ,  $A_1$  with the multiplicative factors given in Table I. The systematic uncertainties on the multiplicative factors, the number of sidereal bins, and the reconstruction effects are included by convoluting the probability distribution with a Gaussian function with the width given by the sum in quadrature of the systematic uncertainties. We obtain a 95% UL of  $\Delta a_\perp < 1.2 \times 10^{-12}$  GeV. The most probable values of  $\delta$  and  $\Delta a_\perp$  are  $\delta = 4.901$  and  $\Delta a_\perp = 5.7 \times 10^{-13}$  GeV.

The limit on  $\Delta a_T - C_\alpha S_\chi \beta_z^{D0} \Delta a_Z$  is obtained from a fit to the asymmetries using Eq. (6). This results in a value of  $A_0 = (-0.40 \pm 0.31)\%$ . In this case, the systematic uncertainties on the measured values of  $A(i)$  are assumed to be 100% correlated between sidereal bins to obtain the most conservative limits and are added to the statistical uncertainty obtained from the fit. Using Eq. (10), we obtain  $\Delta a_T - C_\alpha S_\chi \beta_z^{D0} \Delta a_Z = \Delta a_T - 0.396 \Delta a_Z = (1.5 \pm 1.2) \times 10^{-13}$  GeV, resulting in a two sided 95% confidence interval  $(-0.8 < \Delta a_T - 0.396 \Delta a_Z < 3.9) \times 10^{-13}$  GeV.

We did a cross-check using the periodogram methodology [19] which sees no anomalous behavior for the frequency 1/sidereal day [8].

For CPTV to explain the difference between the like-sign dimuon asymmetry [3] and the SM requires that  $(\Delta a_T - 0.396\Delta a_Z)$  be of the order of  $10^{-12}$  GeV [5]. These limits imply that *CPT* violation is unlikely to contribute a significant fraction of the observed dimuon charge asymmetry, and that other explanations need to be sought.

In conclusion, we have carried out the first search for *CPT*-violating effects exclusively in the  $B_s^0 - \bar{B}_s^0$  oscillation system via semileptonic decays of the  $B_s^0$  mesons. We find no significant evidence for *CPT*-violating effects and place limits on the size of the Lorentz-violating effects,  $\Delta a_\mu$ . These limits constrain a linear combination of the Lorentz-violating coupling constants  $a_\mu^q$  for the *b* and *s* valence quarks in the  $B_s^0$  meson that are different from the linear combinations of valence quarks in the  $B^0$  [11] or  $K^0$  [9] mesons, and therefore they further constrain the possible separate values of the three coefficients  $a_\mu^b$ ,  $a_\mu^s$ , and  $a_\mu^d$ . We find 95% confidence intervals for the flavor-dependent coefficients  $\Delta a_\perp < 1.2 \times 10^{-12}$  GeV and  $(-0.8 < \Delta a_T - 0.396\Delta a_Z < 3.9) \times 10^{-13}$  GeV.

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