Top B Physics at the LHC

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In top-pair events where at least one of the tops decays semileptonically, the identification of the lepton charge allows us to tag not only the top quark charge but also that of the subsequent b quark. In cases where the b also decays semileptonically, the charge of the two leptons can be used to probe CP violation in heavy flavor mixing and decays. This strategy to measure CP violation is independent of those adopted so far in experiments, and can already constrain non standard model sources of CP violation with current and near future LHC data. To demonstrate the potential of this method we construct two CP asymmetries based on same-sign and opposite-sign leptons and estimate their sensitivities. This proposal opens a new window for doing precision measurements of CP violation in b and c quark physics via high p_T processes at ATLAS and CMS.

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Introduction.—The copious production of top quarks at the LHC is usually exploited to explore various top properties or search for new heavy resonances. However, it also opens up the possibility to perform flavor precision measurements. Here we suggest to use the top quark decay products in order to probe CP violation (CPV) in heavy flavor mixing and decays.

All existing analyses of CPV in B physics rely on a coherent production of $b\bar{b}$ pairs, either from the decay of a $b\bar{b}$ resonance or from gluon splitting, where the total b flavor charge at production vanishes. However, top physics gives another source of b's, and due to the large top mass and small width, to a good approximation, a top decay yields a definite nonzero b flavor charge. This charge can be unambiguously tagged at the time of decay by the charge of the lepton daughter of the W (originating from the top). In cases where the b also decays semileptonically, we can construct two CP asymmetries, one in which the latter lepton and the one from the W are of the same sign, and the other with opposite signs. In principle, with a good mass resolution one can also use hadronic decay modes of the b; however, this would be hard to achieve in the near future at ATLAS and CMS.

To make our discussion more concrete, let us consider the interesting result obtained by the D0 collaboration at the Tevatron on the CP-violating like-sign dimuon asymmetry [1]:

$$A^b_{\rm sl}({\rm D0}) = (-7.87 \pm 1.96) \times 10^{-3}, \tag{1}$$

which differs by 3.8σ from the standard model (SM) prediction, $A^b_{\rm sl}({\rm SM}) = (-3.96^{+0.15}_{-0.04}) \times 10^{-4}$ [2]. The asymmetries we propose are conceptually similar although completely independent from $A^b_{\rm sl}$. Similarly, to $A^b_{\rm sl}$, our top-induced CP asymmetries are sensitive to CPV in B_q-$\bar{B}_q$ mixing ($q = d, s$) and to possible exotic sources of direct CPV in b and c decays [3]. As we will show, these sources appear in different combinations in the two top-induced CP asymmetries, providing a tool to test the origin of the anomalous result in Eq. (1).

Going back to top physics, one can identify three classes of inclusive top decay chains which produce two leptons of the same sign:

$$t \to \ell^+ \nu (b \to \bar{b}) \to \ell^+ \ell^+ X, \tag{2}$$

$$t \to \ell^+ \nu (b \to c) \to \ell^+ \ell^+ X, \tag{3}$$

$$t \to \ell^+ \nu (b \to \bar{b} \to c\bar{c}) \to \ell^+ \ell^+ X, \tag{4}$$

where throughout this Letter $\ell = e, \mu$ and in the process of Eq. (4) the second ℓ^+ comes from the c quark and the $\bar{c}$ decays hadronically. These processes are sensitive to CPV in B_q-$\bar{B}_q$ mixing, semileptonic b and c decays and $b \to c$. Similarly, two opposite-sign leptons emerge from the following processes:

$$t \to \ell^+ \nu b \to \ell^+ \ell^- X, \tag{5}$$

$$t \to \ell^+ \nu (b \to \bar{b} \to \bar{c}) \to \ell^+ \ell^- X, \tag{6}$$

$$t \to \ell^+ \nu (b \to c\bar{c}) \to \ell^+ \ell^- X, \tag{7}$$

where in the last process the ℓ^- originates from the $\bar{c}$ quark. Additional negligible contributions via charm mixing were omitted. We also assume that light mesons can be rejected by the experimental analysis.

The CP asymmetries.—The following CP asymmetries related to B_q-$\bar{B}_q$ mixing are defined

$$A_{\rm mix}^{b\ell} = \frac{\Gamma(b \to \bar{b} \to \ell^+ X) - \Gamma(\bar{b} \to b \to \ell^- X)}{\Gamma(b \to \bar{b} \to \ell^+ X) + \Gamma(\bar{b} \to b \to \ell^- X)}, \quad (8)$$

$$A_{\rm mix}^{bc} = \frac{\Gamma(b \to \bar{b} \to \bar{c} X) - \Gamma(\bar{b} \to b \to c X)}{\Gamma(b \to \bar{b} \to \bar{c} X) + \Gamma(\bar{b} \to b \to c X)}. \quad (9)$$

In addition, we define the following direct CPV asymmetries in the different b and c decay modes,

$$A_{\rm dir}^{b\ell} = \frac{\Gamma(b \to \ell^- X) - \Gamma(\bar{b} \to \ell^+ X)}{\Gamma(b \to \ell^- X) + \Gamma(\bar{b} \to \ell^+ X)}, \quad (10)$$

$$A_{\rm dir}^{c\ell} = \frac{\Gamma(\bar{c} \to \ell^- X_L) - \Gamma(c \to \ell^+ X_L)}{\Gamma(\bar{c} \to \ell^- X_L) + \Gamma(c \to \ell^+ X_L)}, \quad (11)$$

$$A_{\rm dir}^{bc} = \frac{\Gamma(b \to c X_L) - \Gamma(\bar{b} \to \bar{c} X_L)}{\Gamma(b \to c X_L) + \Gamma(\bar{b} \to \bar{c} X_L)}, \quad (12)$$

where X (X_L) denotes an inclusive hadronic final state with no leptons and with both light and charm quarks (with light quarks only). We assume for simplicity no direct CPV in $b \to c\bar{c}$. It is straightforward to generalize the analysis and incorporate this contribution.

Using these definitions, the same-sign lepton asymmetry in $t\bar{t}$ events, $A_{\rm sl}^{ss}$, can be decomposed as follows

$$A_{\rm sl}^{ss} \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = r_b A_{\rm mix}^{b\ell} + r_c (A_{\rm dir}^{bc} - A_{\rm dir}^{c\ell}) + r_{c\bar{c}} (A_{\rm mix}^{bc} - A_{\rm dir}^{c\ell}), \quad (13)$$

with $N^{\pm\pm}$ being the number of events where the sign of the lepton that originates from the W and the sign of the lepton from the b are both $\pm$. In addition, we have defined

$$r_q \equiv \frac{N_q^{++} + N_q^{--}}{N^{++} + N^{--}}, \quad (14)$$

with $q = b, c, c\bar{c}$, and $N^{\pm\pm}_{b,c,c\bar{c}}$ are the corresponding numbers of events coming from Eqs. (2)–(4), respectively, similar to $N^{\pm\pm}$. The r_q's depend on the choice of the final event selection, designed to enhance the signal.

Proceeding in a similar way, the opposite-sign lepton asymmetry in $t\bar{t}$ events, $A_{\rm sl}^{os}$, is defined and decomposed as follows

$$A_{\rm sl}^{os} \equiv \frac{N^{+-} - N^{-+}}{N^{+-} + N^{-+}} = \tilde{r}_b A_{\rm dir}^{b\ell} + \tilde{r}_c (A_{\rm mix}^{bc} + A_{\rm dir}^{c\ell}) + \tilde{r}_{c\bar{c}} A_{\rm dir}^{c\ell}, \quad (15)$$

where $\tilde{r}_b$, $\tilde{r}_c$, and $\tilde{r}_{c\bar{c}}$ are the corresponding fractions of events for the decay chains defined in Eqs. (5)–(7), respectively (the parameters of the opposite-sign sample are marked with a tilde).

By construction, all the asymmetries in Eqs. (8)–(12) are phase-convention independent. The mixing asymmetries can be nonzero either because of CPV in mixing or because of direct CPV in the subsequent decays of the neutral $B_{s,d}$. On the other hand, the asymmetries in Eqs. (10)–(12) are manifestly due to direct CPV only. The latter are inclusive partonic asymmetries that should be interpreted as appropriate averages of the corresponding exclusive asymmetries involved in a given decay chain. In principle, the different hadron compositions in processes with or without mixing (where only the neutral $B_{s,d}$ mesons are involved) may lead to differences between the direct CPV asymmetries appearing in $A_{\rm sl}^{ss}$ and $A_{\rm sl}^{os}$. For simplicity, we neglect such differences.

The expressions of the asymmetries are greatly simplified in the limit where we can neglect direct CPV. In this limit $A_{\rm dir}^{q\ell} = A_{\rm dir}^{bc} = 0$, and the mixing asymmetries can be related to the theoretical parameters describing meson-antimeson mixing. Following the convention of [4] we have

$$A_{\rm mix}^{b\ell} = A_{\rm mix}^{bc} = f_d a_{\rm SL}^d + f_s a_{\rm SL}^s = f_d \frac{1 - |q_{B_d}/p_{B_d}|^4}{1 + |q_{B_d}/p_{B_d}|^4} + f_s \frac{1 - |q_{B_s}/p_{B_s}|^4}{1 + |q_{B_s}/p_{B_s}|^4}, \quad (16)$$

where q_X and p_X are the parameters describing the mass eigenstates in the flavor basis and $f_{d,s}$ are the fractions of b quarks forming $B_{d,s}$ mesons.

LHC sensitivity.—The sensitivity of the proposed measurements can be naively estimated by counting the expected number of events and deriving the statistical uncertainty. Systematic uncertainties are not taken into account here. We consider only the dominant production mechanism, namely of top pairs. In principle, the contribution of single tops can be incorporated by using an appropriate data-based normalization to compensate for the different production rates of tops and antitops at the LHC. Yet, the statistical gain is small; hence, we do not include such a signal in our analysis.

We focus on events where one of the tops decays semileptonically. The resulting lepton enables us to tag the charges of the b quarks from the top and the antitop, such that both can be included in the analysis. The association of each b jet (b-charge association) with the appropriate top is done by using the matrix element method, as discussed below. Note that events where both b and c from the same top decay semileptonically are rejected. In principle, one could extend the analysis to include such finals states; however, their inclusion makes the analysis more complicated without a significant gain in sensitivity.

We use Monte Carlo tools to study the efficiencies of the b-charge association and the kinematical cuts. The $t\bar{t}$ sample of events at $\sqrt{s} = 14$ TeV is generated using MADGRAPH/MADEVENT 5 v1.5.5 [5], PYTHIA 6.4 [6] and DELPHES 2.0.3 [7] for the detector response. In order to capture QCD radiation effects, we have included $t\bar{t}$ events with up to three extra partons employing the MLM-k_T merging procedure [8]. We select events with at least one charged lepton ($p_T > 10$ GeV) and four jets

($p_T > 20$ GeV), two of which are b tagged. It is interesting to note that the requirement of two b jets ensures that a potential contribution of CPV in $t \to b$ decays is absent in the sample.

The number of events in each channel is given by

$$N_q^{\pm\pm}(N_q^{\pm\mp}) = \sigma_{t\bar{t}}\mathcal{L}\mathrm{BR}(t\bar{t} \to b\bar{b}\ell\nu\,\mathrm{had})\epsilon_{\mathrm{sel}}\epsilon_b^2\epsilon_A\mathcal{B}_q, \quad (17)$$

where q represents the various processes in Eqs. (2)–(7), $\sigma_{t\bar{t}}$ is the top-pair production cross section, $\mathcal{L}$ is the integrated luminosity, $\mathrm{BR}(t\bar{t} \to b\bar{b}\ell\nu\,\mathrm{had}) \approx 0.30$, $\epsilon_{\mathrm{sel}} \approx 0.55$ is the efficiency of selecting the lepton and the four jets, $\epsilon_b \approx 0.60$ is the b-tagging efficiency and $\epsilon_A \approx 0.70$ is the b-charge association efficiency (see below). In addition, for each of the processes in Eqs. (2)–(7) we have

$$\mathcal{B}_b = \mathrm{BR}(b \to \ell)\bar{\chi}[1 - \mathrm{BR}(b \to c \to \ell)] = 0.024, \quad (18)$$

$$\mathcal{B}_c = \mathrm{BR}(b \to c \to \ell)[1 - \mathrm{BR}(b \to \ell)] = 0.12, \quad (19)$$

$$\mathcal{B}_{c\bar{c}} = \mathrm{BR}(b \to \bar{c} \to \ell)\bar{\chi}[1 - \mathrm{BR}(b \to c \to \ell)] = 3.4 \times 10^{-3}, \quad (20)$$

$$\tilde{\mathcal{B}}_b = \mathrm{BR}(b \to \ell)(1 - \bar{\chi})[1 - \mathrm{BR}(b \to c \to \ell)] = 0.17, \quad (21)$$

$$\tilde{\mathcal{B}}_c = \mathrm{BR}(b \to c \to \ell)\bar{\chi}[1 - \mathrm{BR}(b \to \ell)] = 0.016, \quad (22)$$

$$\times [1 - \mathrm{BR}(b \to \ell)] = 4.7 \times 10^{-4}, \quad (23)$$

$$\tilde{\mathcal{B}}_{c\bar{c}} = \mathrm{BR}(b \to \bar{c} \to \ell)[1 - \mathrm{BR}(b \to c \to \ell)] = 0.027, \quad (24)$$

respectively. Here $\mathrm{BR}(b \to \ell) = 0.23$ (for e and μ including leptonic τ's), $\mathrm{BR}(b \to c \to \ell) = 0.16$ and $\mathrm{BR}(b \to \bar{c} \to \ell) = 0.032$, where the last two are without B mixing [9]. Furthermore, $\bar{\chi} = 0.13$ is the mixing probability for a b quark [10]. The last factor in each of the above equations removes events where both b and c (or c and $\bar{c}$ in $b \to c\bar{c}$ events) decay semileptonically [assuming that $\mathrm{BR}(b \to c) \approx 1$]. The r_q's can be calculated from Eqs. (17)–(24)

$$r_b = 0.16, \quad r_c = 0.82, \quad r_{c\bar{c}} = 0.022,$$
$$\tilde{r}_b = 0.79, \quad \tilde{r}_c = 0.075, \quad \tilde{r}_{c\bar{c}} = 0.13. \quad (25)$$

The statistical uncertainty in estimating the asymmetries is given by $\delta A_{\mathrm{sl}}^{ss} = 1/\sqrt{N^{++} + N^{--}}$ and similarly for the opposite sign. Plugging in the above numbers leads to

$$\delta A_{\mathrm{sl}}^{ss} = \frac{9.0}{\sqrt{\sigma_{t\bar{t}}\mathcal{L}}}, \qquad \delta A_{\mathrm{sl}}^{os} = \frac{7.6}{\sqrt{\sigma_{t\bar{t}}\mathcal{L}}}. \quad (26)$$

The measured asymmetries $A_{\mathrm{sl}}^{ss,os}$ can be used to extract information on the various CPV sources in Eqs. (8)–(12). One may hope that the sensitivity to each of these sources

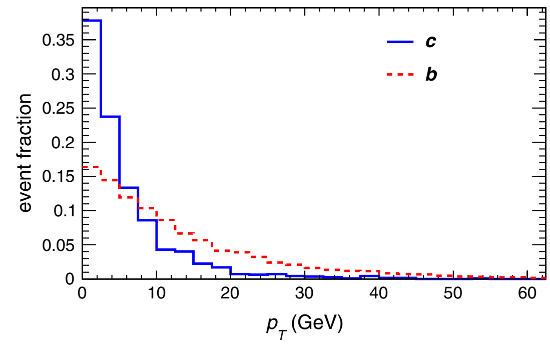

FIG. 1 (color online). The p_T distribution of the lepton coming from the b quark (dotted red) and the one coming from the c quark (solid blue). The distributions are normalized separately.

separately will be improved by applying appropriate kinematical cuts [thus changing the values in Eq. (25)]. In particular, it is expected that the lepton coming from a b semileptonic decay would be more energetic than the lepton from a subsequent c decay. The corresponding p_T distributions are plotted in Fig. 1. A detailed analysis of the selection criteria may lead to an improved sensitivity, but in our study we found no significant gain.

If we neglect the direct CPV sources, the measurement of $A_{\mathrm{sl}}^{ss,os}$ can be used to estimate the CPV in B_q-$\bar{B}_q$ mixing:

$$\delta A_{\mathrm{mix}}^{b\ell} \approx 7 \times 10^{-3}(3 \times 10^{-3}), \quad (27)$$

for $\sqrt{s} = 14$ TeV and $\mathcal{L} = 50(300)\ \mathrm{fb}^{-1}$ using $\sigma_{t\bar{t}} = 852$ pb [11]. This sensitivity is somewhat inferior to the result of Eq. (1). The B factories report the flavor-specific CP asymmetry in $B_d - \bar{B}_d$ with a combined sensitivity of 3×10^{-3} [10]. Furthermore, the sensitivity obtained by LHCb for $B_s - \bar{B}_s$ mixing is 6×10^{-3}, and it is expected to improve to the per mil level by 2018 [12].

Similarly, our proposed measurements will be able to provide strong upper bounds on the direct CPV sources in Eqs. (10)–(12) in case of null signals. With 50 fb^{-1} at 14 TeV we can obtain

$$|A_{\mathrm{dir}}^{b\ell}| \lesssim |0.3\%|, \qquad |A_{\mathrm{dir}}^{c\ell}| \lesssim 0.3\%, \qquad |A_{\mathrm{dir}}^{bc}| \lesssim 0.3\%, \quad (28)$$

at 2σ, assuming no cancellations. The first two bounds above are stronger than existing bounds of 1.2% and 6%, respectively [3]. Even with the 8 TeV run, bounds of 1% or better can be obtained for the direct CPV sources.

In the above discussion we assumed prefect identification of the lepton originating from the B meson. We now consider the systematic uncertainty induced by a wrong association of the b with the top. The observed number of events N_*^{XY} is then given by

$$N_*^{\pm\pm} = (1 - \epsilon_{\mathrm{F}})N^{\pm\pm} + \epsilon_{\mathrm{F}}N^{\mp\pm}, \quad (29)$$

$$N_*^{\pm\mp} = (1 - \epsilon_{\mathrm{F}})N^{\pm\mp} + \epsilon_{\mathrm{F}}N^{\mp\mp}, \quad (30)$$

where ϵ_F is the probability for a wrong association. The measured CP asymmetries, $A^{ss,os}_{sl*}$, can be related to $A^{ss,os}_{sl}$ as follows

$$A^{ss}_{sl*} \approx A^{ss}_{sl} - \epsilon_F \frac{N^{+-}}{N^{++}}(A^{os}_{sl} + A^{ss}_{sl}), \tag{31}$$

$$A^{os}_{sl*} \approx A^{os}_{sl} - \epsilon_F \frac{N^{++}}{N^{+-}}(A^{ss}_{sl} + A^{os}_{sl}), \tag{32}$$

where we expand to first order in ϵ_F and in the asymmetries and $N^{+-}/N^{++} \sim 1.4$. We learn that as long as $\epsilon_F \lesssim 10\%$, the error in the measured mean values would be smaller than the estimated statistical uncertainty. If ϵ_F is known to a good accuracy, then the two equations above can be used to extract $A^{ss,os}_{sl}$ from the measured asymmetries.

b-charge association.—Given a pure semileptonic $t\bar{t}$ sample with two reconstructed b jets, b_1 and b_2, two light jets and at least one charged lepton, our goal is to determine the charge of b_1 and b_2. We call this procedure b-charge association. Naively, this can be done by reconstructing the top mass. Without any particular optimization, this method gives a high misassociation rate ($\epsilon_F \approx 35\%$). Hereafter we propose an alternative method.

The matrix element method has been successfully used in the determination of the top quark mass [13] and the first single top observation at the Tevatron [14]. One can compute the probability that a given experimental event originates from some process

$$P(x) = \frac{1}{\sigma}\int dy|M(y)|^2 T(x|y), \tag{33}$$

where σ denotes the effective cross section, M is the partonic amplitude and T is the transfer function, which gives the probability of reconstructing particles of momenta x originating from parton level momenta y.

We use MADWEIGHT [15] to compute two probabilities P_1 and P_2 per event, corresponding to the two possible associations of b_1 and b_2 with the initial partons b and $\bar{b}$. The larger probability tells us which configuration is more likely. The larger the difference between P_1 and P_2, the more confident we are in the association. The discriminant variable $W \equiv (P_1 - P_2)/(P_1 + P_2)$ can be used to interpolate continuously between a low purity (high efficiency) and high purity (low efficiency) b association. In Fig. 2 the efficiency vs the misassociation rate is shown. The working point is chosen such that $\epsilon_F \approx 10\%$, which corresponds to a signal efficiency $\epsilon_A \approx 70\%$. We find that the impact of removing the matching slightly increases ϵ_A by order of 5%.

Relation to the D0 dimuon anomaly.—The possibility to explain the D0 anomaly by allowing not only CPV in B_q-$\bar{B}_q$ mixing but also direct CPV in b and c semileptonic decays was discussed in [3]. This was done by considering each of these CPV sources separately while taking the other two to be SM-like. It was found that the D0 result

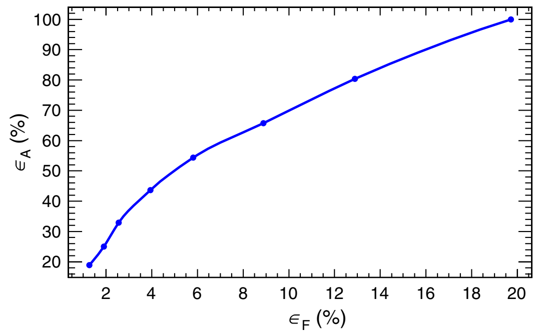

FIG. 2 (color online). Efficiency of the b-charge association as a function of the misassociation probability.

can be accommodated by the value in Eq. (1) for B_q-$\bar{B}_q$ mixing, $A^{b\ell}_{dir}(D0) \sim (3 \pm 1) \times 10^{-3}$ or $A^{c\ell}_{dir}(D0) \sim (9 \pm 3) \times 10^{-3}$. Within the SM, the latter two are $A^{b\ell}_{dir}(SM) \sim 10^{-7}$ and $A^{c\ell}_{dir}(SM) \sim 10^{-11}$ [3].

For each of these cases, we can estimate the asymmetries $A^{ss,os}_{sl}$ and the discrimination power in measuring them (assuming no CPV in $b \to c$ decays). If the D0 result originates from direct CPV in semileptonic charm decays, A^{ss}_{sl} should be non-vanishing at significance of 2.8σ with 50 fb^{-1} at 14 TeV. Similarly, A^{ss}_{sl} (A^{os}_{sl}) should be probed at 2.1σ (2.9σ) for CPV in B_q-$\bar{B}_q$ mixing (direct CPV in semileptonic b decays) for the 14 TeV run with a sample of 300 fb^{-1}.

Discussion.—In this Letter we have proposed to probe CP violation in B mixing and in b and c decays in top-pair events, by exploiting the b-charge tagging ability inherent to the top (semileptonic) decay. This presents a striking opportunity to explore low-energy flavor observables in processes at a much higher scale of $\mathcal{O}(100)$ GeV.

Given the estimated uncertainties, a significant nonzero signal in each of the asymmetries introduced above will unambiguously imply the existence of new physics beyond the SM (which gives $A^{ss,os}_{sl}(SM) < 10^{-4}$). The sources of the systematic uncertainties in this measurement are different than those of other experiments such as LHCb and the B factories; hence it will serve as an important contribution to the study of CP violation in the quark sector, even if the overall sensitivity is lower.

There are a few issues in the above analysis which call for a more detailed study. First, we have neglected systematic effects at the detector level that might lead to an asymmetry in the measured rates of leptons vs antileptons. Second, we have only partially included higher-order QCD effects (up to three extra matched jets) in our $t\bar{t}$ sample simulation, and not the full NLO contributions. At the LHC these effects are known to induce a (small) charge asymmetry between the rapidity distributions of the top and the antitop. Depending on the details of the selection and the analysis, these effects might feed down to the asymmetries $A^{ss,os}$. The impact of such detector and physics effects can be studied in data.

Concerning the backgrounds, we have verified that our selection and reconstruction procedure keeps the contribution of W + jets low enough to be neglected at this proposal stage. W + jets is charge asymmetric and therefore could alter the asymmetries. In addition, backgrounds could affect the misassociation rate. It is reasonable to believe that a significant fraction of these processes can be rejected with an appropriate b-tagging algorithm and the b-charge association selection.

As further improvement, we note that the sample statistics could be increased by including $t\bar{t}$ events where only one b jet is tagged. In that case, it could be advantageous to incorporate single top events into one combined analysis, thus avoiding the need to treat them as background, by suitably redefining the asymmetries $A^{ss,os}$ in terms of fractions of events relative to the measured (and different) top and antitop rates.

Last but not least, we mention that this study could be extended by analyzing the time dependence of B decays produced from top decays. Indeed the lepton from the initial W does not only provide a perfect flavor tag, it also provides an indication of the position (time) where (when) the flavor eigenstate has been produced. This allows us to reproduce in high p_T physics a time- and flavor-tag configuration conceptually similar to that obtained at the B factories.

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[1] V. M. Abazov *et al.* (D0 Collaboration), Phys. Rev. D **82**, 032001 (2010); Phys. Rev. Lett. **105**, 081801 (2010); Phys. Rev. D **84**, 052007 (2011).
[2] A. Lenz, U. Nierste, J. Charles, S. Descotes-Genon, A. Jantsch, C. Kaufhold, H. Lacker, S. Monteil, V. Niess, and S. T'Jampens, Phys. Rev. D **83**, 036004 (2011).
[3] S. Descotes-Genon and J. F. Kamenik, arXiv:1207.4483.
[4] Y. Grossman, Y. Nir, and G. Perez, Phys. Rev. Lett. **103**, 071602 (2009); A. L. Kagan and M. D. Sokoloff, Phys. Rev. D **80**, 076008 (2009).
[5] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, and T. Stelzer, J. High Energy Phys. 06 (2011) 128.
[6] T. Sjostrand, S. Mrenna, and P. Z. Skands, J. High Energy Phys. 05 (2006) 026.
[7] S. Ovyn, X. Rouby, and V. Lemaitre, arXiv:0903.2225 [Comp. Phys. Comm. (to be published)].
[8] J. Alwall, S. de Visscher, and F. Maltoni, J. High Energy Phys. 02 (2009) 017.
[9] K. Nakamura *et al.* (Particle Data Group Collaboration), J. Phys. G **37**, 075021 (2010).
[10] Y. Amhis *et al.* (Heavy Flavor Averaging Group Collaboration), arXiv:1207.1158.
[11] M. Czakon and A. Mitov, J. High Energy Phys. 12 (2012) 054; arXiv:1210.6832.
[12] RAaij *et al.* (LHCb Collaboration), arXiv:1208.3355.
[13] V. M. Abazov *et al.* (D0 Collaboration), Phys. Rev. D **74**, 092005 (2006).
[14] T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. **103**, 092002 (2009).
[15] P. Artoisenet, V. Lemaitre, F. Maltoni, and O. Mattelaer, J. High Energy Phys. 12 (2010) 068.