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Techniques for B_s mixing at CDF

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Abstract. The techniques used to perform a measurement of the mixing frequency of the B_s meson (ΔM_s) with the CDF detector at the TeVatron collider are described. Particular stress is put on CDF techniques for flavour tagging, which is possibly the major issue for mixing measurements at a hadron collider. Also CDF performances on lifetime and final state reconstruction are described. The final result of the amplitude scanning presented at 2005 Winter Conferences is reported.

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1 Introduction

The measurement of the mixing frequency of the B_s meson (ΔM_s) is a key point for the determination of the CKM matrix. Knowledge of this parameter, together with the measurement of ΔM_d from the B-Factories, would constrain the Unitarity Triangle in the Standard Model by measuring one of its sides with an overall uncertainty $\approx 5\%$ (from theory). Furthermore, this is wide room for New Physics, as several non-SM particles are expected to contribute in the mixing *box* diagram.
At present, the B_s meson can only be produced in incoherent *parton-parton* collisions at the $p-\bar{p}$ TeVatron collider ($E_{CM} = 1.96\ TeV$). This renders the observation of the flavour oscillations in the B_s a major point in the B-physics program of both the TeVatron experiments, *CDFII* and *D0*; although its determination represents a big experimental challenge, in particular as far as the time resolution is concerned ($\Delta M_s \approx 20 \times \Delta M_d$).
In order to observe the oscillations, the following steps are needed: 1) determination of the flavour of the mixing B meson at creation; 2) measurement of the length the meson traveled from production point to decay; 3) knowledge of its flavour at decay.

2 Flavour Tagging

To infer the flavour of the mixing candidate at production, CDF has considered both Same Side (*SST*) and Opposite Side (*OST*) taggers: all of them exploit the correlation between the b-flavour and the electric charge of a track (or a weighted combination of tracks into a jet) topologically linked to the B. While SST looks at fragmentation particles close to the B meson, OST aim to tag the accompanying *b-hadron*'s flavour by looking at specific decay products (leptons, kaons or jets). In practice, a vast number of fragmentation tracks is produced in the primary interactions at hadron colliders, so that a tagger's prediction is highly diluted by their random flavour-charge correlation. For comparison, while at the B-factories the tagging figure of merit is $\varepsilon D^2 \approx 30\%$ ([1]) CDF has around 1.5%. [1]
So far, only 2 of these taggers were used at CDF for mixing analyses, both from Opposite Side.

2.1 Soft Lepton Taggers

These taggers exploit the fact that, in semileptonic decays of the OS b-hadron, $b \longrightarrow l^-$ ($l = \mu, e$), while $\bar{b} \longrightarrow l^+$. CDF implemented a likelihood based algorithm to select the lepton using our muon chamber system and calorimeter information. The main background for these taggers is given by sequential decays of the kind $\bar{B} \longrightarrow DX \longrightarrow l^+Y$, which returns a wrong sign in charge. To suppress this contribution, the dilution D is calculated on an *event-by-event* basis, weighting it for the lepton likelihood value and the p_t^{rel} of the tagging lepton with respect to the axis of the opposite B jet. The greater this is, the more likely the lepton is to come straight from the b.

2.2 Jet Charge Tagger

One can also look at the overall charge of the OS b-jet, weighting each track in a given cone around the jet axis (CDF: $\Delta R = 0.7$ [2]) for their p_t; three different types of jets are considered: a) look for Secondary Vertexes in the cone; b) if not any explicitly found, evaluate probability that tracks within cone are displaced (*JetProb*); c) use Jet with highest p_t.

2.3 OST calibration

The taggers' performances (shown in table 1) were evaluated using a high statistics inclusive *semileptonic* sample, by comparing the tagger's response to the charge

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[1] $\varepsilon = \frac{Nevents\ when\ decision\ possible}{N\ triggered\ events}$ and $D = 1 - 2W$, with W the mis-tag rate

[2] $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$

of the lepton; mixing on both sides and (mainly *charm*) background on trigger side have been accounted for by correcting raw dilution for a calibration factor. Finally,

Tag type	εD^2 (%)
Muon	(0.70 ± 0.04)
Electron	(0.37 ± 0.03)
SecVtx	(0.36 ± 0.02)
JetProb	(0.21 ± 0.02)
Highest P_t	(0.15 ± 0.01)
Total	$\approx 1.8\%$

Table 1. Performance of OST's

the taggers have been tuned for combined use in mixing (reweighting e.g. for different p_t spectra w.r.t. the sample used in development) applying tagging in a measurement of the known quantity ΔM_d to return the effective dilution:

$$\begin{aligned} \varepsilon D^2 &= 1.1(hadronic) - 1.4(semilept) \ \% \\ \Delta M_d &= 0.503 \pm 0.063(stat) \pm 0.015(syst) \ ps^{-1} \end{aligned}$$

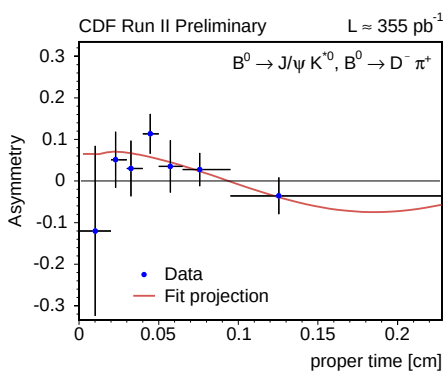

Fig. 1. B_d mixing asymmetry from fully reconstructed decays using OST

2.4 Possible improvements

Flavour tagging is the largest room for improvement of our sensitivity. CDF has undergone a major study and implementation of Same Side Kaon Tagging. The comprehension of the production and fragmentation processes is the main point to control sources of dilution, so that Montecarlo tuning for TeVatron environment is the main effort at this point. At the same time, CDF is also evaluating the feasibility of an Opposite Side Kaon Tagger, following the same principles of SLT. MC shows this should be doable and needs to be studied on data. Both of them use the CDF Particle ID system (Time of Flight + dE/dx from ionization in the COT chamber), whose informations are combined using a ratio of likelihoods.

3 Decay lenght

The amplitude of mixing asymmetry is diluted by an exponential factor $D_{\sigma_{ct}} = \exp(-\frac{(\Delta m \times \sigma_t)^2}{2})$, where the resolution on mixing meson's proper time is

$$\sigma_t = \sqrt{(\sigma_{ct}^0)^2 + (ct \times \frac{\sigma_{p_t}}{p_t}^2)}$$

where σ_{ct}^0 is the resolution on Primary Vertex. In the case of fully hadronic final states, the kinematics is completely reconstructed, so that only the vertexing counts: we achieve a $< \sigma_{ct}^0 > \approx 30\mu m$, while $\frac{\sigma_{p_t}}{p_t} \leq 1\%$. CDF has so far used the average beamline position to find the PV: recently, though, an event-by-event vertex finder has been developed, which is expected to improve time resolution in the hadronic case of 10 to 20%. In the semileptonic case, the missing neutrino accounts for a significant part of the B momentum, so that $\frac{\sigma_{p_t}}{p_t} \approx 15\%$: CDF corrects this effect using a so called K factor extracted from MC.

4 Final state reconstruction

CDF performed a mixing amplitude scanning both for the semileptonic and the hadronic sample, thanks to the Two Track (displaced) Trigger, new for RunII. Up to now only the $B_s \longrightarrow D_s\pi$ (or $D_s l\nu$), with $D_s \longrightarrow \phi\pi, K^*\pi, 3\pi$ have been considered. At present CDF is also trying to include the $B_s \longrightarrow D_s 3\pi$ modes and a further semileptonic sample triggered with the TTT, to increse our statistics. The yields we find out of 355 pb^{-1} are: $\approx$ 7700 (semileptonic), $\approx$ 900 (hadronic). It has to be noticed that 20% of the semileptonic yield is background from prompt $c\bar{c}$ and $B \longrightarrow DDX$ decays (*with one D decaying semileptonically*), which cannot be fully suppressed due to missing kinematics.

5 Significance and results

Given the above numbers, the final CDF combined limit on ΔM_s is [2]:

$$\Delta M_s \geq 7.9 \ ps^{-1}, \ sensitivity = 8.4 \ ps^{-1}$$

With the above improvements, if a gain of +2% in εD^2, and a −20% in σ_t are achieved, we expect to enhance our sensitivity up to $\approx 35 \ ps^{-1}$ at the end of Run II ($\int \mathcal{L} = 8 \ fb^{-1}$) [3].

References

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