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Statistical Significance of the Two Track Trigger for the Study of CP Violation in the B_s sector

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Abstract

The experimental study of the CP violation in $B_s^0 \to J/\psi\phi$ is a very promising process to test the new physics. The presence of a sizeable CP-violation phase in the $B_s^0 - \bar{B}_s^0$ meson system would be an unambiguous signal of physics beyond the Standard Model. For the precise determination of the CP violation parameters it is very important to use all the possible experimental stastistics currently available at the CDF experiment. Indeed the CDF experiment provides several dedicated triggers, which can be used for this particular channel selection. The present note describes the statistical and complementary significance of the two track trigger (also called hadron trigger) with respect to the dimuon trigger used so far to study the CP Violation in the $B_s \to J/\psi\phi$ channel.

1 Introduction

The study of the CP violation phenomena in the B_s^0 system is one of the current frontier for New Physics searches in flavour physics and an important issue of the Tevatron physics program and thus of the CDF experiment [1].

The Standard Model predicts a very small CP violation there, and the presence of a sizeable CP-violating phase in the $B_s\bar{B}_s$ mixing would be an unambiguous signal of physics beyond the Standard Model.

One of the powerful channel for the study of the CP violation at hadron colliders is the process $B_s \to J/\psi[l^+l^-]\phi[K^+K^-]$ with clear kinematics and experimental signature. The presence of J/ψ in this B_s^0 decay channel provides a clean signal and is important for reducing the combinatorial background. It also provides the powerful possibility of triggering on the two leptons, using in particular the low Pt dimuon trigger. Although the branching fractions of the J/ψ decays into di-electrons and di-muons are identical, the di-electron channel suffers lower acceptance because of the higher trigger thresholds and of the bremsstrahlung effect on the reconstructed mass distribution.

Up to now, this led the analyses developed for studying the CP Violation in $B_s^0 \to J/\psi\phi$, to use the data provided by the dedicated B Physics low Pt di-muon trigger [2].

However the CDF experiment has built several other B Physics triggers which are relevant for selecting in particular this process [3]. Moreover, they provide a different and complementary analysis with full reconstruction of this decay channel and an additional interesting sample of data.

2 CDF Triggers for selecting $B_s^0 \to J/\psi\phi$ candidates

The CDF II experiment developed three families of triggers for the B physics studies, namely: the Di-muon Trigger, the Semileptonic Trigger and the Hadronic or Two Track Trigger. We briefly remind here the basic features of these triggers [4].

As already mentioned, the main selection for the CP violation in the $B_s \to J/\psi\phi$ channel analysis is currenly based on the di-muon trigger [2].

The di-muon trigger selects muon pairs with transverse momentum as low as 1.5 GeV/c. It is mostly used to select J/ψs and $\psi(2S)$, to reconstruct the many decay modes of the B hadrons containing a J/ψ decaying into muon pairs, and to select Υ decays, or muon pairs for the search of the rare decays, or correlation studies.

For the mass regions around the J/ψ and $\psi(2S)$, CDF has a dedicated trigger that collects large samples, with 3.5 million J/ψ collected in the region $\eta \leq 0.6$.

Di-muon triggers for rare decay searches collect data with invariant masses up to 6 GeV/c^2. In the high invariant-mass region, CDF has a dedicated Upsilon trigger. In the first 360 pb^{-1} of integrated luminosity this trigger collected 18000 Upsilons; the excellent CDF tracking resolution allows separating the three Upsilon peaks. CDF also has a $b\bar{b}$ trigger that collects muon pairs with invariant masses greater than 5 GeV/c^2.

The semileptonic trigger is a displaced track plus lepton trigger. It select events with a lepton track (μ or e) with transverse momentum as high as 2 GeV/c and a Silicon Vertex Tracker (SVT) track with transverse momentum higher than 2 GeV/c and an impact parameter greater than 120 microns.

This trigger collects large samples of semi-leptonic decays. It is used for high statistics lifetime measurements, flavour tagging and B mixing studies.

The third class of B Physics triggers *i.e.* the hadronic triggers or Two displaced Track Trigger (TTT) requires two displaced tracks with $p_T > 2GeV$, $p_{T1}+p_{T2} \geq 4$, 5.5 or 6 GeV/c, an opening angle in the transverse plane below 135^o, an impact parameter greater than 100 microns and a decay length above 200 microns (slightly varying along the runs periods).

More details about the B Physics triggers of CDF II experiment when applied to Bs physics study can be found in [6].

The various options of the two track trigger give access to large samples of fully reconstructed hadronic decays. Examples of its application are the CP asymmetry measurements in the two-body charm-less B decays, the B^0 mixing and the application to study the charm physics.

The hadronic two track triggers are of potential interest for the analysis of the CP violation in the $B_s \to J/\psi\phi$ channel because complementary to the di-muon trigger selection. This trigger indeed is intended to select the other leg of the B_s decay we are interested in, namely the ϕ decaying into two hadrons. A detailed analysis of the TTT selection for this process has been performed and can be found in the Internal Note [5].

The two Track Trigger gives access to large samples of fully-reconstructed hadronic Bs decays.

3 Observables used in this study

The observables for this study based on the events selected by the Two Track Trigger can be defined as follows:

- Number of B_s candidates in the B_s mass region of the B_s mass spectrum obtained with the selected TTT triggered events,

- Number of B_s candidates contributing to the relevant part of the $c\tau$ spectrum obtained with the selected TTT triggered events.

A more detailed description of the TTT selection for the $B_s \to J/\psi\phi$ candidates is given here below.

A sample enriched with heavy-flavour particles is selected by a three-level displaced track trigger.

At Level 1, charged tracks are reconstructed in the COT by the eXtremely Fast Tracker (XFT).

The trigger requires two charged tracks with transverse momentum p_T greater than 2 GeV/c and the scalar sum $p_{T1} + p_{T2}$ greater than 4.0, 5.5 or 6.5 GeV/c, depending on the TTT trigger type.

At Level 2, the Silicon Vertex Tracker (SVT) provides a precise measurement of the track impact parameter (d_0), defined as the distance of closest approach of the track trajectory to the beam axis in the transverse plane. Decays of heavy flavour particles are identified by requiring two tracks with d_0 between 120 microns and 1.0 mm and with an opening angle of 290 degrees.

A requirement on L_{xy} is also applied, where the two-dimensional (transverse) decay length, L_{xy}, is calculated as the displacement of the two-track intersection point with respect to the beam axis projected onto the total transverse momentum of the track pair. It is related to the selection of the B_s decay length.

A complete event reconstruction is performed at Level 3. The B_s^0 mesons are reconstructed by first forming the K^+K^- system and the J/ψ candidate decays. Opposite-sign track pairs are used in both cases; for identifying the J/ψ, at least one track is required to match a segment reconstructed in the muon detectors.

Subsequently two or more J/ψ candidates are subject to a common vertex in order to form a B_s^0 candidate. In the $B_s^0 \to J/\psi\phi$ case the vertex includes a further constraint on the invariant mass of the two tracks forming the J/ψ , using the world average mass.

At least one pair of tracks in the quadruplet must satisfy the trigger requirements. Combinatorial background and partially reconstructed decays are reduced by exploiting several variables sensitive to the long lifetime and the relatively hard p_T spectrum of B mesons; for example, requiring a good vertex reduces background from mismeasured tracks, while requiring the B_s flight direction to extrapolate back to the beam axis suppresses partially reconstructed decays.

The cut values on the discriminating variables are set by maximizing $S/\sqrt{S+B}$. The signal (S) is derived from a Monte Carlo (MC) simulation of the CDF II detector and trigger.

The B meson momentum and rapidity distributions are matched to those observed in real $B^0{}_s$ decays. The background (B) is represented by appropriately normalized data selected with the same requirements as the signal except that the $B^0{}_s$ candidate mass is required to lay in the sideband region: (5:02; 5:22)[(5:52; 5:72) GeV/c^2. The invariant mass of the B$^0{}_s$ candidates after selection is displayed in 1.

4 Data Samples and Selection

The estimate of the statistical significance of the two track trigger with respect to the dimuon trigger for the analysis of this process is described in this section.

Dimuon Trigger: The selection for the Dimuon Trigger follows the selection usually applied for the $B_s^0 \to J/\psi\phi$ analysis:

- 5.24 GeV$< m_{B_s^0} < 5.48\ GeV/c^2$;
- $d_0(B_s) < 0.0065\ cm$
- $3.052 < m_{J/\Psi} < 3.142$ ($\pm 3\sigma$);
- $p_T(J/\psi) \geq 2.0\ GeV/c$;
- $\chi^2_{xy} < 18$;
- $1.011 < m_\phi < 1.029$ ($\pm 3\sigma$);
- $p_T(\phi) \geq 1.36\ GeV/c$;
- $p_T(K^+, K^-) \geq 1.25$ GeV/c;

- $p_T(\mu^+, \mu^-) \geq 1.0$ GeV/c;

Two Track Trigger The two track trigger paths preferentially select events containing $J/\Psi \rightarrow \mu^+\mu^-$ decays with each μ having a minimum transverse momentum of 1.5 GeV/c.

Selection of the $B_s \rightarrow J/\psi\phi$ candidates for the Two Track Trigger:

- 5.24 GeV$< m_{B_s^0} < 5.48\ GeV/c^2$;
- $d_0(B_s) < 0.0065\ cm$;
- $b\chi 2(xy) < 22$;
- $L_{xy}(B_s^0) \geq 0.010cm$:
- $p_T(B_s^0) \geq 1.0\ GeV/c$;
- $3.05 < m_{J/\Psi} < 3.15\ (\pm 3\sigma)$
- $p_T(J/\psi) \geq 1.0\ Gev/c$
- at least one μ stab;
- $1.011 < m_\phi < 1.029\ (\pm 3\sigma)$
- $p_T(\phi) \geq 1.36\ GeV/c$;

The mass spectrum of the selected B_s candidates is shown in Figure 1, for both the dimuon and the TTT data samples.

5 Statistical study based on the B_s Mass and Proper Decay Time Analysis

5.1 Statistical Estimate of the TTT versus dimuon candidates based on the B_s Mass Fit

This estimate is performed, for the time being, using the data collected by CDF II in the periods 0 to 17 corresponding to the (id-ik) data.

The fit of the B_s mass for the dimuon trigger contains the Gaussian peak for the B_s signal plus an exponential shape fit for the combinatorial background. The result of the fits is shown in Figure 1.

The statistical estimate from the dimuon trigger in the periods 0 to 17 is:

- B_s^0 signal events estimate ($\pm 3\sigma$): 2120.67

- Background events ($\pm 3\sigma$): 2191.25

- Signal/Background : 0.967792
- $S/\sqrt{S+B}$: 32.2952

The fit on the B_s mass for the Two Track Trigger contains the Gaussian peak for the B_s signal plus an exponential shape for the background. The results of the fits are shown in Figure 1.

One can clearly notice that the visible improvement in the signal to noise ratio is due to the L_{xy} cut, which is applied to the TTT trigger.

The statistics for the Two Track Trigger in the periods 0 to 17 is:

- B_s^0 signal events estimate in $\pm 3\sigma$ around the B_s^0 mass: 1645.31

- Background events in $\pm 3\sigma$ around the B_s^0 mass: 726.235

- Signal/Background : 2.26553
- $S/\sqrt{S+B}$: 33.7856

The estimate of the statistical relevance of the number of candidates from Two Track Trigger as compared to those from the dimuon trigger for the periods 0 to 17 is

$$\frac{N_{ttt}}{N_{dim}} = \frac{1645.31}{2120.67} = 77.6\% \tag{1}$$

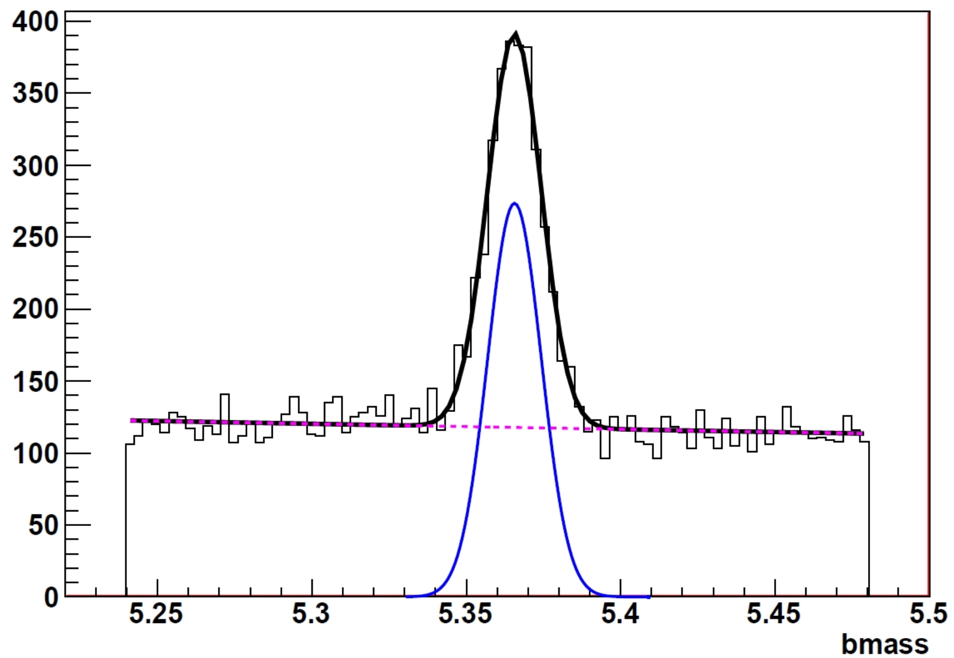
5.2 Statistical estimate of the TTT versus the dimuon candidates based on the B_s Proper Decay Time Fit

The fitting of the proper time spectrum was performed on the basis of an unbinning procedure.

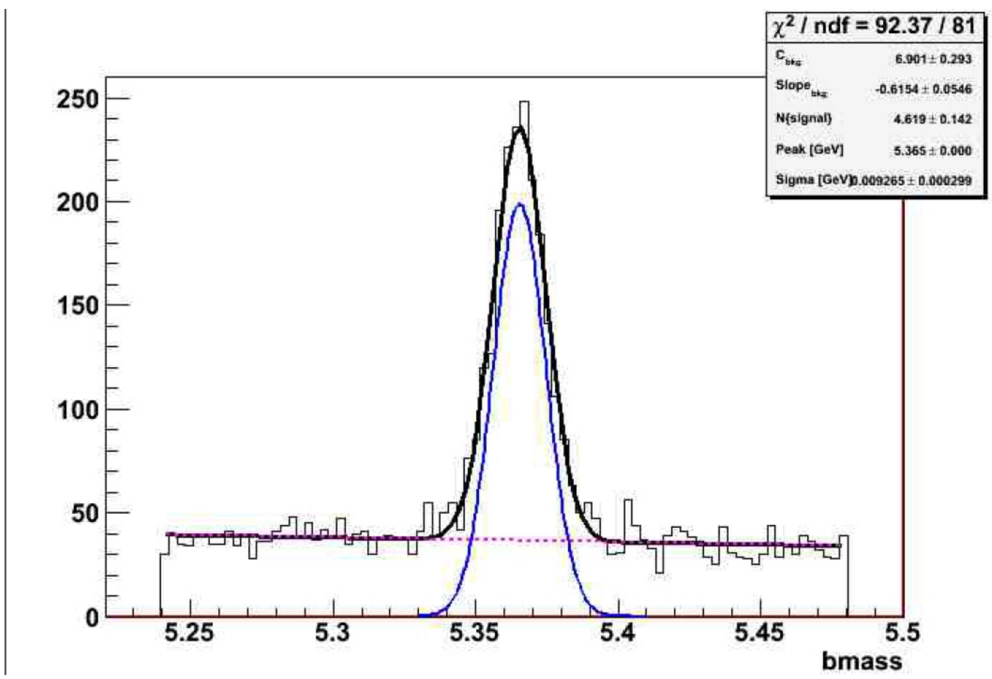
The fit of the B_s proper time performed with the dimuon trigger data contains the Gaussian peak for the prompt peak - background and an exponential with a smearing based on the proper time errors for the B_s decay time signal. The result of the fits is shown in Figure 2.

The statistics for the dimuon trigger for the periods 0 to 17 is:

- B_s^0 signal events estimate in $\pm 3\sigma$ around the B_s^0 mass: 2775
- Background events in $\pm 3\sigma$ around the B_s^0 mass: 1386.

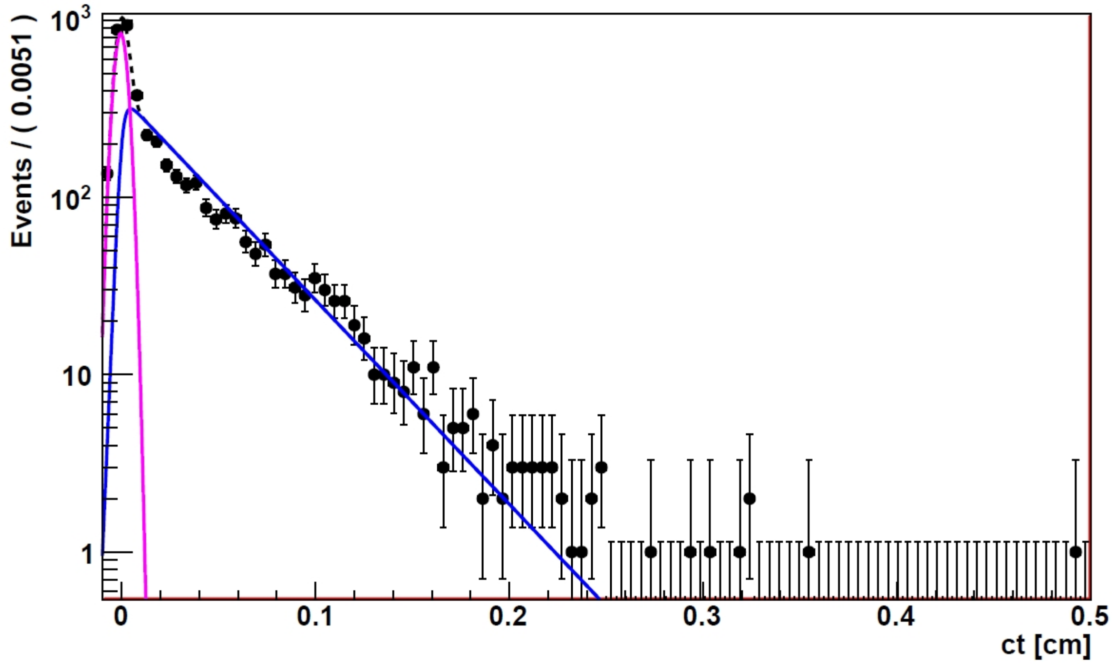


(a)

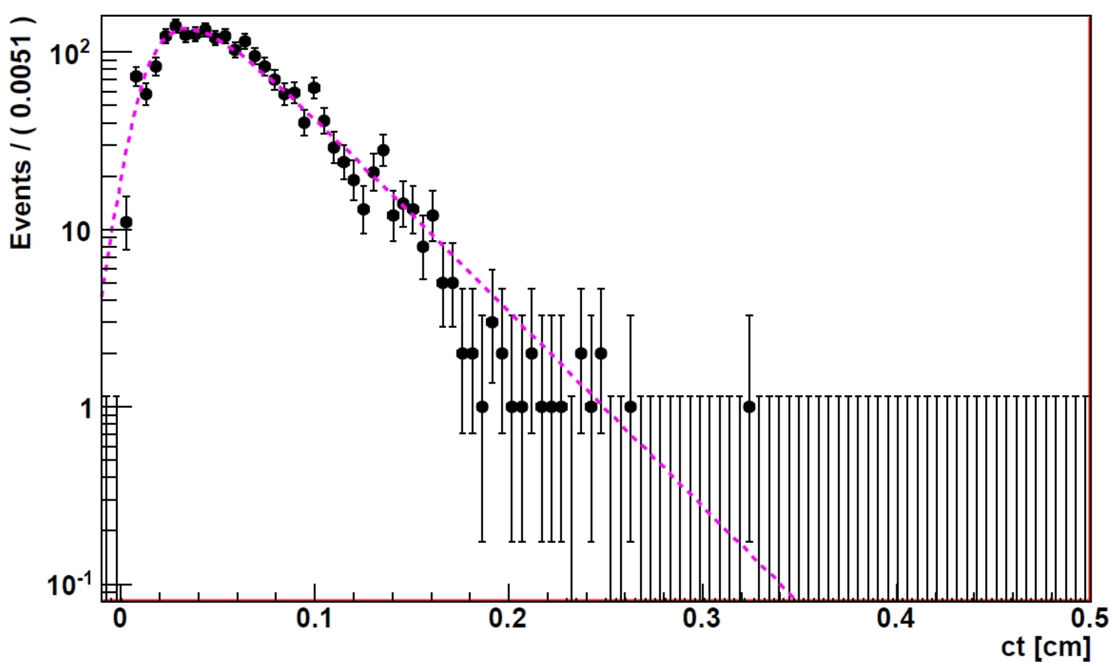


(b)

Figure 1: Statistical significance of the Dimuon Trigger Selection based on the $B0_s$ mass spectrum for xpmmgd-xpmmik data (a) and for xpmmfm data(b).



(a)



(b)

Figure 2: Statistical significance of the Two Track Trigger Selection based on the $B0_s$ mass spectrum for xbhdid-xbhdik (a) and for xbhdfm (b).

The fit of the B_s proper time performed with the Two Track Trigger only contains the B_s exponential shape for the signal, smeared with the proper time errors. The results of the fits are shown in Figure 2.

The proper time of the Two Track Trigger data does not show practically any prompt peak; this is due to the applied ct threshold of 200 microns.

The statistics for the Two Track Trigger for the periods 0 to 17 is:

- B_s^0 signal events estimate ($\pm 3\sigma$): 2070

The estimate of the statistical significance of Two Track Trigger data in comparison to dimuon data for the period 0-17 is:

$$\frac{N_{ttt}}{N_{dim}} = \frac{2070}{2775} = 74.6\% \tag{2}$$

6 Summary

The estimate of the relative statistical significance, for the CP violation Study with physics channel $B_s \rightarrow J/\psi\phi$, provided by two classes of B Physics triggers in CDF, namely the dimuon Trigger and the Two Track Trigger was performed.

The analysis of the $c\tau$ spectrum for the Dimuon and the Two Track Trigger data shows that the L_{xy} cut, applied at the Trigger level for the TTT, mainly affects the background events, namely the prompt peak in the $c\tau$ spectrum. Indeed, our B_s^0 candidates selection cuts most of the prompt peak in the dimuon selection; this explains why we get a larger fraction of B_s^0 candidates from the two track trigger w.r.t. those from dimuons, than in previous estimates.

The result of this study is that the complementary statistics from the Two Track Trigger data gives a significant contribution to the CP violation study in the $B_s \rightarrow J/\psi\phi$. The additional contribution provided by the two track trigger paths in the study of this CP violation process is estimated at the level of 75% as compared to the events selected with the dimuon trigger path and taking into account the overlap between the two data sets. This estimate is being carried on with all the available statistics namely period 0 to 31 and this Note will be updated accordingly.

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