Extending the sensitivity to sin2β in the $B^0_d/\bar{B}^0{}_d$ system using a low p_T electron $J/\psi \to e^-e^+$ trigger with the upgrade DØ detector

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thanks to A. Maciel, G. Lima and F. Stichelbaut

Abstract

The sensitivity to the sin2β parameter descrbing the CP violation in the $B^0_d/\bar{B}^0{}_d$ system has already been estimated at DØ in the $J/\Psi + K^0_s$ channel where $J/\Psi \to \mu^-\mu^+$ to be:

$$\delta\text{sin}2\beta = 0.15 \text{ for } \mathcal{L} = 2 \text{ fb}^{-1}$$

We investigate here the improvement that could be made on this number by the use of the $J/\psi \to e^-e^+$ channel. This implies the possibility to triger on low p_T di-electron. Such triggers have been defined in [1] for the central pseudo-rapidity region and in [2] in the forward region. Both algorithms are based on the combination of preshower and calorimeter information at level 1 and at level 2. With the efficiencies given in the cited references, $\approx 5,000$ B^0_d mesons are expected to be triggered during the run II. The effects of the full reconstruction of the events, detailed in [4], and of the use of the different tagging methods described in [8] are then evaluated. We conclude that a sensitivity of

$$\delta\text{sin}2\beta = 0.24 \text{ for } \mathcal{L} = 2 \text{ fb}^{-1}$$

is achievable in this channel alone, , leading to a combined sensitivity of ($ee + \mu\mu$):

$$\delta\text{sin}2\beta = 0.125 \text{ for } \mathcal{L} = 2\text{fb}^{-1}$$

This number corresponds to a 4-5 σ significance in the direct measurement of the CP violation in B system.

Contents

1 Motivations for a $J/\psi \rightarrow e^-e^+$ trigger at DØ

The main motivations for a J/ψ trigger at D0 are:

- to ensure a high statistic samples for B-physics studies
- to provide a efficient way to calibrate the EC, CC calorimeter, as well as the cross-calibration of these two detectors

We consider in the following on the B-meson production. We indicate the expected numbers of events summing all B-meson production, where $B \rightarrow J/\Psi + X$, and focuse on the specific chanel $B^0_d \rightarrow J/\Psi + K^0_s$. Indeed indirect CP violation (or CP violation in the mixing) in B-systems can be seen as a difference in the widths $\Delta\Gamma$ of the two B mass eigenstates. Such effects are expected to be small but visible with a difference in lifetimes of $\approx 10^{-2}$ in the $B^0_d/\bar{B}^0{}_d$ system. In this context $B^0_d/\bar{B}^0{}_d$ events are used to measure the sin2β angle of the unitarity triangle via the measurement of the asymmetry in the $B^0_d/\bar{B}^0{}_d$ production rates:

$$\mathcal{A}_{CP}(t) \equiv \frac{\bar{B}^0{}_d(t) - B^0_d(t)}{\bar{B}^0{}_d(t) + B^0_d(t)} = \sin(2\beta)\sin(\Delta m_d t)$$

where Δm_d is the mass difference between B^0_d eigenstates.

In the following, the trigger efficiency is estimated and the efficiency of the full reconstruction of B^0_d events is evaluated. This latter result is exctracted using CDF results [5] from the Run I and from an analysis by A. Maciel and G. Lima using DØfast Monte Carlo [4].

2 Cross-section and BR's for B-mesons production

The total cross-section of the MC samples used to compute the trigger efficiency is derived from the $b\bar{b}$-dijets cross-section given by the ISAJET MC:

$$\sigma(b\bar{b}) = 50.6\ \mu b \quad \text{for} \quad p_T(\text{jet}) > 1.5\ \text{GeV/c}$$

The branching ratios in B-meson production are computed assuming that [3]:

$$BR(\bar{b} \rightarrow B^+) = BR(\bar{b} \rightarrow B^0_d)$$

$$BR(\bar{b} \rightarrow B^+) + BR(\bar{b} \rightarrow B^0_d) + BR(\bar{b} \rightarrow B^0_s) + BR(b \rightarrow \Lambda_b) = 100\%$$

The table below reports the BR's for the different flavours of B-mesons produced in the hadronization of b-quark.

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b hadron decays	Fraction
BR(b hadron $\rightarrow$ B^-)	$39.7^{+1.8}_{-2.2}\%$
BR(b hadron $\rightarrow$ $\bar{\mathrm{B}}^0$)	$39.7^{+1.8}_{-2.2}\%$
BR(b hadron $\rightarrow$ B^0_s)	$10.5^{+1.8}_{-1.7}\%$
BR(b hadron $\rightarrow$ b baryons)	$10.1^{+3.9}_{-3.1}\%$

2.1 Production of $\mathrm{B}^0_\mathrm{d} \rightarrow \mathrm{J}/\Psi + \mathrm{K}^0_\mathrm{s}$ events

For B^0_d mesons production, we use the Branching ratios reported below [3]:

$$\begin{aligned}
\mathrm{BR}(\mathrm{b} \rightarrow \mathrm{B}^0_\mathrm{d}) &= \quad (37.9 \pm 2.2) \times 10^{-2} \\
\mathrm{BR}(\mathrm{B} \rightarrow \mathrm{J}/\Psi + \mathrm{K}^0_\mathrm{s}) &= \quad (8.9 \pm 1.2) \times 10^{-4} \times \tfrac{1}{2} \\
\mathrm{BR}(\mathrm{J}/\Psi \rightarrow \mathrm{e}^+\mathrm{e}^-) &= \quad (6.02 \pm 0.19) \times 10^{-2}
\end{aligned}$$

The cross-section for $\mathrm{B}^0_\mathrm{d}/\bar{\mathrm{B}}^0_\mathrm{d} \rightarrow (\mathrm{J}/\Psi \rightarrow \mathrm{e}^+\mathrm{e}^-) + \mathrm{K}^0_\mathrm{s}$ derived from the $\mathrm{b}\bar{\mathrm{b}}$-dijets cross-section expected is:

$$\sigma(\mathrm{B}^0_\mathrm{d} \rightarrow (\mathrm{J}/\Psi \rightarrow \mathrm{e}^+\mathrm{e}^-) + \mathrm{K}^0_\mathrm{s}) = 515 \pm 120 \text{ pb}$$

The effective luminosity for a sample of 14,239 events is therefore: $0.0276\pm$ 0.005 fb^{-1}. The event weight for an integrated luminosity of 1 fb^{-1} therefore is 36±6 event/fb.

3 Triggerring on $\mathrm{J}/\psi \rightarrow \mathrm{e}^-\mathrm{e}^+$ from B-mesons

The conception of di-electron triggers is described in [1] for events in the central rapidity region, and in [2] for J/ψ in the forward region. They are based on the detection of two EM depositions confirmed by the presence of pre-shower signals in front (central and forward events) and associated tracks candidate(s) (central events only). All the numbers given below are computed for $\mathrm{B}^0_\mathrm{d} \rightarrow \mathrm{J}/\Psi\mathrm{K}^0_\mathrm{s}$ events. Only the B-meson production are considered so far, although direct J/ψ production is expected to be more important, and is still under investigation.

3.1 Trigger efficiency for $\mathrm{J}/\psi \rightarrow \mathrm{e}^-\mathrm{e}^+$ in B events

The trigger efficiency is estimated for a central ($|\eta| < 1.5$) and a forward ($|\eta| > 1.5$) pseudo-rapidity region using events reconstructed through an upgrade version of GEANT. The trigger algorithms include so far the CCEM, the PreShower and the CFT for central events, the ECEM and the Preshower for forward events. The benefit of a use of the STT is currently under investigation.

About 1/3 of the events point towards the forward region, while 2/3 are contained in the central part [2]. Trigger efficiencies are computed for generated electrons with $p_t \geq 1.5$ GeV/c which corresponds roughly to a J/ψ with a minimum of 3 GeV/c. In the forward+central region, about 70 events are selected, corresponding to a trigger efficiency:

$$\epsilon_{trigger}^{Central+Forward} \approx 12\%$$

This result depends mainly on the EM threshold used in the calorimeter. Efficiencies of 15% are observed at the cost of extra rates at L1. The increase of the QCD rates could be reduced by the use of the sign of the tracks, available at L2 (for invariant mass cuts) and at L1 (for tracks associated with PS clusters) [**?**] in the central pseudo-rapidity region. The details of the algorithms may be found in [1] and [2]. In the following numbers are computed with a 12% efficiency in the whole acceptance.

3.2 Expected number of $\mathrm{B_d^0} \rightarrow \mathrm{J/\Psi K_s^0}$ events

Expected number of $\mathrm{B_d^0}$ and $\mathrm{\bar{B}_d^0}$ where the B-meson decay into $J/\Psi K_s^0$ events are:

$$\mathrm{N(event)} \approx 800 \pm 130/\mathrm{fb}^{-1} \quad [|\eta| \geq 1.5]$$

$$\mathrm{N(event)} \approx 1,900 \pm 270/\mathrm{fb}^{-1} \quad [|\eta| \leq 1.5]$$

The total number of events for a luminosity of 2 fb^{-1} is therefore about 5,400$\pm$400 events.

4 Reconstruction and selection of $\mathrm{B_d^0} \rightarrow \mathrm{J/\Psi} + \mathrm{K_s^0}$ events

The results used are those by A. Maciel and G. Lima described in [4] computed for J/ψ decaying into di-muon. We are interested here in the $\mathrm{K_s^0} \rightarrow \pi^+\pi^-$ reconstruction and therefore assume a similar performance for the di-electron channel.

4.1 Reconstruction of $\mathrm{B_d^0}$ mesons

Only the $\mathrm{K_s^0} \rightarrow \pi^+\pi^-$ channel is considered in the following, which represents $\mathrm{BR}(\mathrm{K_s^0} \rightarrow \pi^+\pi^-) = 0.69$ The $\mathrm{K_s^0}$ finding algorithm requires two opposite-sign pions, with $p_t^\pi > 0.5$ GeV/c and $|\eta_\pi| < 2.0$. The $ee\pi\pi$ invariant mass is then formed using both pion and electron pairs. If we assume a track reconstruction efficiency of 95% per track, the numbers of reconstructed events is then:

$$5,400 \times 0.69 \times 0.81 = 3,000 \pm 200 \text{ events} \quad \text{for } 2\ \mathrm{fb}^{-1}$$

4.2 B-flavour Tagging

The asymmetry in the $B_d^0/\bar{B}^0{}_d$ production rates requires the flavour tagging of the B-meson not only at the decay time, but also at the production time. Several techniques may be used. One distinguishes the Opposite Side Tag technique, based on the determination of the other B-meson flavour present in the event, and the Same Side Tag technique, using the correlation between the charged tracks produced with the B-meson. We give here the performance already measured during the Run I by CDF or extrapolated for the Run II. It is convenient to report the tagging performance in terms of $\epsilon_{tag} D^2_{tag}$, the "effective tagging efficiency", where ϵ_{tag} is the tagging efficiency of the algorithm, and D^2_{tag} the dilution factor due to a mistag.

4.2.1 Opposite Side Tagging

1. **Lepton Flavour Tagging:** this method uses semi-leptonic decays of the other b-quark (in the non-signal side). The correlation between the lepton sign and the B-meson flavour is used for both electron and muon with $p_T^l > 1.5$ GeV/c and $|\eta_l| < 2.0$. In both cases, the B-sample may be identified by requiring a secondary vertex to reduce the lepton misidentification [5]:

   (a) **Soft muon:** The efficiency of detection of these (soft) leptons has been found to be $\epsilon_{tag} \approx 5.6\%$ [4], translating into a $\epsilon_{tag} D^2_{tag} \approx 1.4\%$.

   (b) **Soft electron:** The efficiency measured by CDF [5] in this channel leads to : $\epsilon_{tag} D^2_{tag} \approx 0.7\%$, which is half the muon estimate. This number should be improved at DØthanks to the use of the pre-shower and the calorimeter.

2. **Jet Charge Tagging:** the correlation of the reconstructed sign and the B-meson flavour is here used, and benefit from greater statisctics. The B-sample may also be identified by requiring a secondary vertex. The efficiency measured by CDF for the run I are: $\epsilon_{tag} D^2_{tag} \approx 3.0\%$. Of course these events include (part) of the event selected by a lepton tagging.

In both cases, corrections are required for direct $c\bar{c}$ production.

4.2.2 Same Side Tagging

The identification of the B-flavor is based on the charge tracks that are produced with the B. The effective tagging efficiency for this method is typically [5]:

$$\epsilon_{tag} D^2_{tag} \approx 2.0\%$$

5 CP Asymmetry measurement

The (time integrated) observed asymmetry in the $B^0_d/\bar{B}^0{}_d$ system is given by:

$$A_{obs} = D_{mix} \times D_{bckg} \times D_{tag} \times A_{CP}$$

where D_{mix} is the dilution factor due to the mixing of the $B^0_d/\bar{B}^0{}_d$ components, and is characterized by $x_d \approx 0.66$; $D_{bckg} = \sqrt{S/(S+B)}$ is the asymmetry due to the backgrounds to the signal, written in terms of the ratio S/B; finally D_{tag} is the asymmetry arisen from the mistag(s) of the B flavour, and is given by:

$$D_{tag} = \frac{(N_R - N_W)}{(N_R + N_W)}$$

where $N_R(N_W)$ is the number of correct (wrong) tag. It can also be written in term of mistag probability w as $D_{tag} = 1 - 2w$.

5.1 Sensitivity to $\delta \sin 2\beta$

The sensitivity to to $\sin 2\beta$ is then given by:

$$\delta \sin 2\beta = \frac{1}{D_{mix} D_{bckd}} \frac{1}{\sqrt{\epsilon_{tag} D^2_{tag}}} \times \frac{1}{\sqrt{N_{sel}}}$$

We set the values of these parameters to their measured values:

$D_{mix} = x_d/(1+x_d^2) \approx 0.47$ (with $x_d = 0.66$)

$D_{bckg} = \sqrt{S/(S+B)} \approx 0.7$ (for a ratio $S/B = 1/1$)

An estimate of the total "effective tagging efficiency" for the Run II, considering all the techniques summarized in the previous section is [8]:

$$\epsilon_{tag} D^2_{tag} = 5.0\%$$

which translates to a sensitivity on $\delta \sin 2\beta$ of:

$$\delta \sin 2\beta = \frac{13.40}{\sqrt{N_{sel}}}$$

For the 3,000 reconstructed events in the electron channel, this corresponds to:

$$\delta \sin 2\beta = 0.24$$

5.2 Cross-checks and comparison with the di-muon channel

The number of selected $J/\psi \to \mu^+\mu^-$ events is expected to be greater than the number of $J/\psi \to e^-e^+$. This comes from the difference in the trigger efficiency, which is about 10% in the electron channel against 30% in the muon channel. This is explained by the necessity to set threshold above 2.25-2.5 GeV in the EM towers, in order to reduce the background rates at Level 1. This L1 rates constitute the main limitation in the electron channel.

We start here from an estimation of $\mathrm{B_d^0}/\mathrm{\bar{B}_d^0}$ events expected at the run II in 2 fb^{-1}. This number comes from [8] and includes the BRs and the acceptance cuts for leptons and pions coming from $\mathrm{K_s^0}$ decays. The number of expected events for both di-muon and di-electron channel inthis case is:

	Di-muon channel		Di-electron channel	
	(%)	Number events	(%)	Number events
events for L=2^{-1}		33,000		33,000
Trigger efficiency	32%	10,560	12%	3,960
Event Reconstruction	$(95\%)^4$	8,580	$(95\%)^4$	3,225

Given the assumptions presented previously, and for a 12% trigger efficiency in the di-electron channel, the sensitivity to $\delta \sin 2\beta$ results in:

$$\begin{array}{cc} \text{di-muon} & \delta \sin 2\beta = 0.15 \\ \text{di-electron} & \delta \sin 2\beta = 0.24 \\ \text{Combination} & \delta \sin 2\beta = 0.125 \end{array}$$

5.3 Comparison with existing constraint on $\sin 2\beta$

The fit of the CKM matrix elements has been performed in [6]. Indirect constraints using the Δm_d measurement from $B_d^0/\bar{B}_d^0$ oscillation frequency, the ratio $|V_{ub}|/|V_{cb}|$ and the ϵ values obtained in the kaons system measurement. The constraints on the three angles of the unitarity triangle are shown in Fig. 5.1. This fit results in [6]:

$$\delta \sin 2\beta = 0.75 \pm 0.09$$

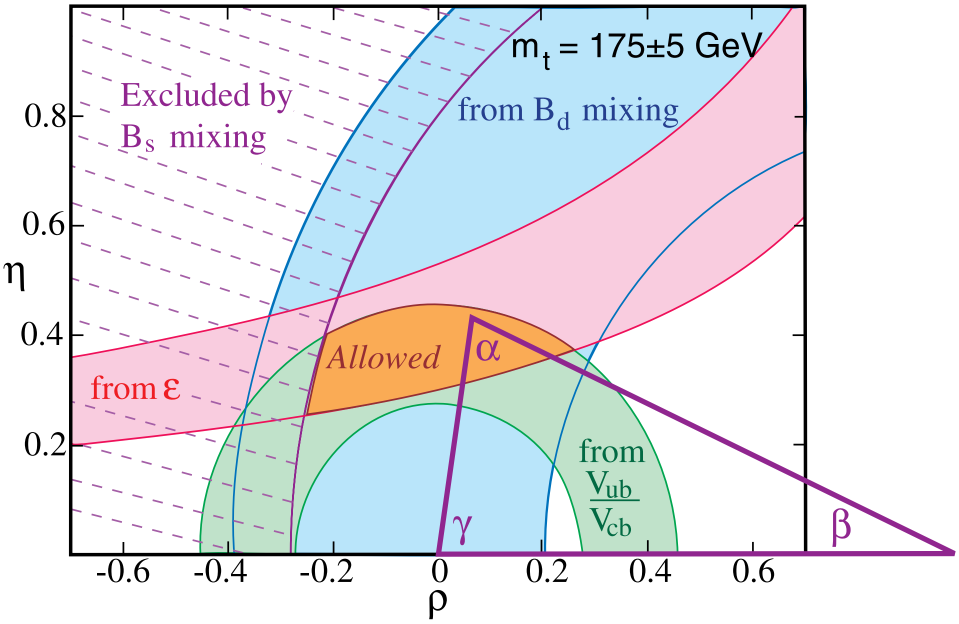

Figure 5.1: *Constraints from the fit of the CKM matrix using the B_d mixing measurements, the ϵ from the kaons systems and the* V_{ub}/V_{cb} *measurements [6].*

A measurement at the 0.15 level (statistical uncertainty only) therefore corresponds to a $4\,\sigma$ effect of the CP violation in the $B_d^0/\bar{B}_d^0$ system.

5.4 Comparison to CDF and B-factories

These expectations have been compared to the numbers given by CDF [5] and B-factories in one year of data taking. They are summed up in the table below:

(*) We sum here the two channels (electron+muon) of the J/Ψ decays, considering a 12% efficiency for di-electron trigger (1.6K) and 32% efficiency for dimuon (4.3K). (**) CDF here considers that 5K $J/\psi \to \mu\mu$ events will be selected, and 2.5K in the dielectron channel. The better sensitivity for CDF is due to:

	BELLE [9]	BaBar [10]	DØ	CDF
$\mathcal{L}$ in fb^{-1}	100	30	1	1
$N(B^0_d \to J/\Psi K^0_s)$	2,000	1,100	5.9K(*)	7.5 K(**)
$\delta \sin 2\beta$ $J/\Psi K^0_s$	0.080	0.098	0.18	0.12
+ All modes	0.062	0.059	0.18	0.12

- a higher "effective tagging efficiency" of $\epsilon_{tag} D^2_{tag} = 6.7\%$ (against 5.0% for DØ) due to the use of the "time-of-flight" system, which introduces a "kaon" tag. Tagging charged kaons ix expected to improve the statistics by 35%.
- a higher S/B rejection (better Mass resolution), with a ratio of 2 expected for the run II.

which leads to $\delta \sin 2\beta = \frac{10.06}{\sqrt{N_{sel}}}$

6 Conclusion

We investigate here the improvement that could be made on the $\sin 2\beta$ parameter, describing the CP violation in $B^0_d/\bar{B}^0_d$ system, by using the electron decays of J/Ψ produced by the B-meson.
This implies the possibility of a low p_T di-electron triggering. Such triggers have been defined in [1] for the central pseudo-rapidity region and in [2] in the forward region. Both algorithms are based on the combination of track, preshower and calorimeter information at level 1 and at level 2. With the efficiencies given in the cited references, $\approx 5,000$ B^0_d mesons are expected to be triggered during the run II. The effects of the full reconstruction of the events, detailed in [4], and of the use of the different tagging methods described in [8] are then evaluated. We conclude that a sensitivity of

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This number corresponds to a 4-5 σ significance in the direct measurement of the CP violation in B system.

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