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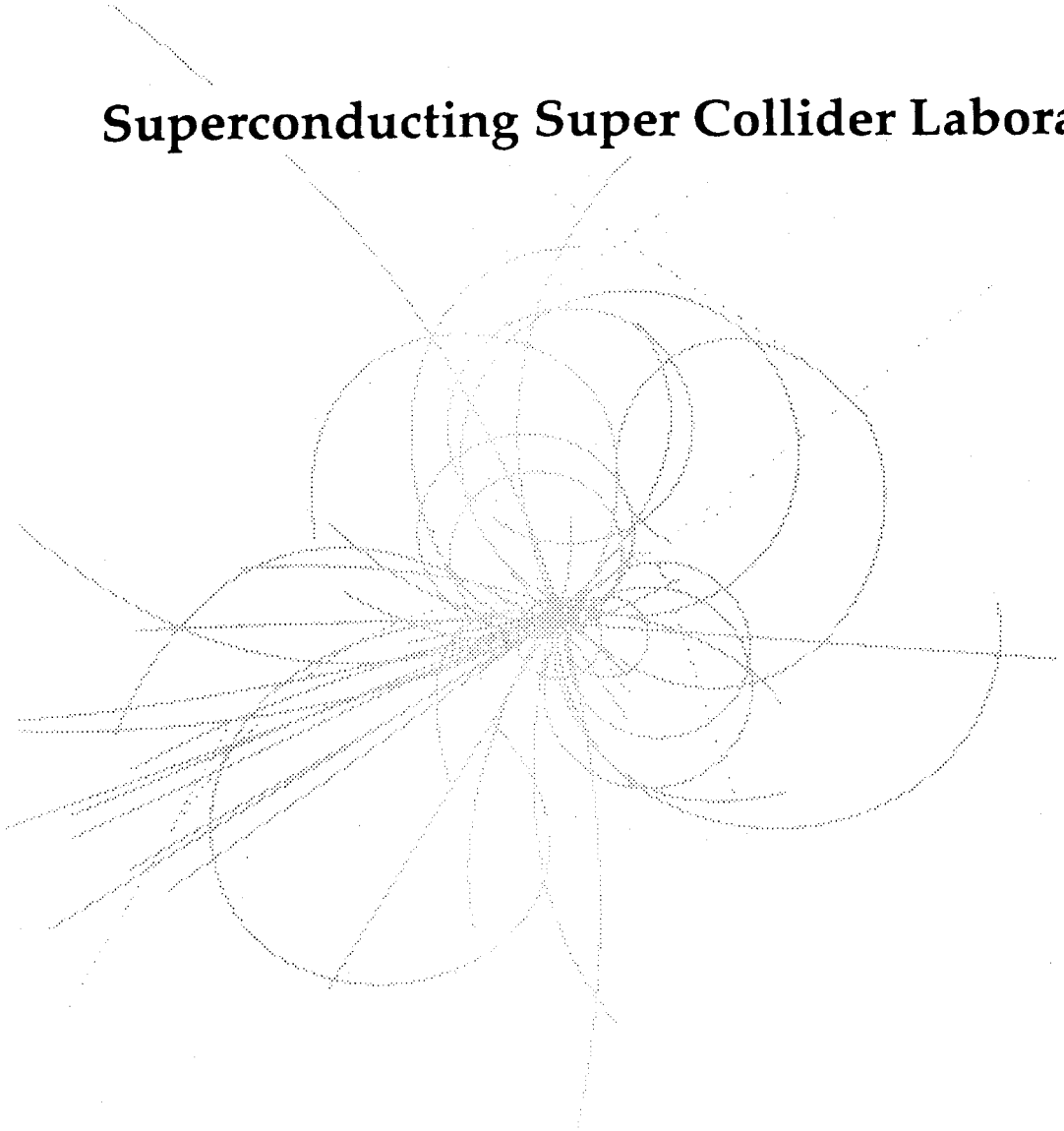

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Abstract

We present another approach for calculating the dilution appearing in the tagging used to search for CP violation in the $B_d^0, \bar{B}_d^0 \to f$ decay. Here, we consider hadron-hadron interactions at large c.m. energy ($\sqrt{s} \geq 0.1$ TeV) and final states that are self-conjugated ($f = \bar{f}$). The semileptonic decay into muons is considered to be used for tagging the associated production of the beauty hadron. The dilution due to the detection of wrongly charged muons is estimated from $B_{d,s}^0$ mixing and B cascade decays.

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1 - Introduction

During these last years several methods have been discussed to search for CP violation in the $B_d^0, \bar{B}_d^0 \to f$ decay where f is a self-conjugated states ($f = \bar{f}$). We discuss these cases as CP violation effects are expected to be larger[1] than for the decays with $f \neq \bar{f}$. We consider hadron-hadron interactions at large c.m. energy ($\sqrt{s} \geq 0.1$ TeV). Search for CP violation in these decays requires the tagging of the associated beauty hadron in each event. We discuss here the case where the tag is given by the charge of the muon in the semileptonic decay of the associated beauty hadron, namely $B, \bar{\Lambda}_b \to \mu^+ X$ and $\bar{B}, \Lambda_b \to \mu^- X$. Here $\Lambda_b \equiv bqq$ ($\bar{\Lambda}_b = \bar{b}\bar{q}\bar{q}$) represents a beauty baryon, X denoting anything. The CP violation could then be detected by comparing the number of $\mu^- X f$ (N_-) and $\mu^+ X f$ (N_+) events in a given experiment. This means that CP violation in the B_d^0 decay will be observed if the measured asymmetry parameter

$$A_m = \frac{N_+ - N_-}{N_+ + N_-} \neq 0$$

In practice, A_m contains a dilution due to the mistagging of the muon. This dilution effect has been discussed for several experiments[2]. Here we would like to use a somewhat different approach in order to estimate the dilution effect for hadron-hadron interactions at large c.m. energies.

The dilution effect can be due to:

1) the mixing of the neutral produced mesons ($B_{d,s}^0$ or $\bar{B}_{d,s}^0$) before decaying into muons
2) the $b \to c \to \mu$ ($\bar{b} \to \bar{c} \to \mu$) where the μ has the opposite charge of the $b \to \mu$ ($\bar{b} \to \mu$) decay
3) the μ's coming from other decaying particles (K, π...)
4) the punchthrough in the detector (particles identified wrongly as muons).

The first case can be calculated easily (Section 2). Point 2, the so-called cascade case, will be discussed in Section 3. The last two cases depend on the detector chosen for a given experiment. They contribute equally to the dilution of the μ^+ and μ^- in the final state. Note that the asymmetry parameter without the cases 2 to 4 (see below) will be defined by A.

2 - Tagging with the $B \to \mu X$ decay

For the present discussion, let us first consider the production of the $\mu^+ f$ final state. The following beauty hadron combinations can lead to the $\mu^+ f$ state:

1) $B^+\bar{B}^0_d$

2) $B^0_s\bar{B}^0_d$ and $\bar{B}^0_s B^0_d$ (coherent mixture)

3) $B^0_d\bar{B}^0_d$

4) $\bar{\Lambda}_b\bar{B}^0_d$

where the particles are those appearing at the production time ($t = 0$). The first and fourth cases are trivial as the hadrons decay independently of each other. Here we assume that the semileptonic decay rates of B^+ and $\bar{\Lambda}_b$ (or B^- and Λ_b) are identical. This is because we consider that the semileptonic decay is essentially due to the decay of the b (or $\bar{b}$) quark. For the other cases the mixing has to be taken into account. Case 3 will depend on the charge conjugation of the $B^0_d\bar{B}^0_d$ system. At large c.m. energy, however, both charge conjugation values have the same probability.

The double-differential cross sections in the decay time of the two hadrons have been calculated[3] for cases 1 to 3. By integrating these distributions[3,4] one obtains the following expressions for the cross sections:

$$\sigma(\mu^+ f)_{1+4} = (p_\pm + p_\Lambda)\; p_d\; |T|^2 \left[1 - n\,\frac{x_d}{1+x_d^2}\right] \tag{1}$$

$$\sigma(\mu^+ f)_2 = p_s\; p_d\; |T|^2 \left[1 - n\,\frac{(x_s + x_d)}{(1+x_s^2)\,(1+x_d^2)}\right] \tag{2}$$

$$\sigma(\mu^+ f)_3 = p_d\; p_d\; |T|^2 \left[1 - n\,\frac{x_d}{(1+x_d^2)^2}\right] \tag{3}$$

Here T is the amplitude taken to be the same in all cases[5,6]. The effect of CP violation is described by the parameter $n \equiv sin2\phi$. The $p_\pm$, p_d, p_s and p_Λ quantities are the production rates of the $B^\pm$, B^0_d, B^0_s and Λ_b, respectively. The mixing of the $B^0_{d,s}$ meson is given by $x_{d,s}$, related to the mixing by[6]:

$$\alpha_{d,s} \equiv \frac{B^0_{d,s} \to \bar{B}^0_{d,s}}{B^0_{d,s} \to \bar{B}^0_{d,s} + B^0_{d,s} \to B^0_{d,s}} = \frac{1}{2}\,\frac{x^2_{d,s}}{1+x^2_{d,s}}$$

$$\beta_{d,s} \equiv \frac{B^0_{d,s} \to B^0_{d,s}}{B^0_{d,s} \to \bar{B}^0_{d,s} + B^0_{d,s} \to B^0_{d,s}} = 1 - \alpha_{d,s}$$

The total $\mu^+ f$ cross section will then be obtained by adding (incoherently) the above expressions. In the absence of CP violation in the decay amplitudes[3],

one has $|T| = |\bar{T}|$. The above formula can then be applied to the $\mu^- f$ case by changing $n \to -n$. With the $\Sigma(\sigma_i(\mu^+ f) \pm \sigma_i(\mu^- f))$ expressions one obtains

$$A = -\left[\frac{nx_d}{1+x_d^2}\,(p_\pm + p_\Lambda) + \frac{n(x_s + x_d)}{(1+x_s^2)(1+x_d^2)}\,p_s + \frac{nx_d}{(1+x_d^2)^2}\,p_d\right] \tag{4}$$

This expression does not depend strongly of x_s. In the $5 \leq x_s \leq 20$ range, A/n will vary by less than 4 per cent using $x_d = 0.66$ (Ref. 7) and

$$p_\pm : p_d : p_s : p_\Lambda = 0.38 : 0.38 : 0.14 : 0.10 \tag{5}$$

These last values are usually taken for $pp \to b\bar{b}X$ reactions. Note that A is much smaller than the value that could be obtained by tagging only charged B mesons. In this latter case one would have $A_\pm = -nx_d/(1+x_d^2)$ while in the general case

$$A = A_\pm \times 0.77 = -sin2\phi \times 0.35 \tag{6}$$

using $x_s = 8$ and the production rates given above.

3 - Mistagging effects

Let us now estimate the effects due to the mistagging of the muons for cases 2 to 4. Assuming that the correct (wrong) number of events is represented by $N_\pm^c$ ($N_\pm^w$), one has

$$A_m = \frac{N_+^c + N_+^w - N_-^c - N_-^w}{N_t}$$

where N_t represents the total number of (true and wrong) tagged events. The real A value and the fraction of wrong tagging (w) are here defined by

$$A = \frac{N_+^c - N_-^c}{N_+^c + N_-^c} = \frac{N_-^w - N_+^w}{N_+^w + N_-^w}$$
$$w = \frac{N_+^w + N_-^w}{N_t} = 1 - \frac{N_+^c + N_-^c}{N_t}$$

One obtains then $A_m = A(1-2w)$.

We first estimate the w value with the $\mu^+ f$ case by considering the cascade decays. In this case we use reactions where there are no $b \to \mu$ or $\bar{b} \to \mu$ decays (no di-muon due to the decay of the associated beauty hadron). One has then

$$\begin{aligned} w' = & p_\Lambda \; Br(\Lambda_b \to \Lambda_c, D^+, D^0 \to \mu^+) + p_\pm \; Br(B^- \to c\bar{u} \to \mu^+) \\ & + p_d \; [\beta_d(\bar{B}^0_d \to \bar{B}^0_d) + \alpha_d(B^0_d \to \bar{B}^0_d)] \times Br(\bar{B}^0_d \to c\bar{d} \to \mu^+) \\ & + p_s \; [\beta_s(\bar{B}^0_s \to \bar{B}^0_s) + \alpha_s(B^0_s \to \bar{B}^0_s)] \times Br(\bar{B}^0_s \to c\bar{s} \to \mu^+) \end{aligned} \tag{7}$$

and

$$w = \frac{w' \times [1 - Br(b \to \mu^+)]}{Br(b \to \mu^+) + w'}$$

where Br represents the branching ratio. As there is no CP violation expected in the $B^0_{d,s}$ mixing, the mixing factors disappear in equation 7 ($\alpha_{d,s} + \beta_{d,s} = 1$) yielding

$$\begin{aligned} w' = & p_\Lambda \; Br(\Lambda_b \to \Lambda_c, D^+, D^0 \to \mu^+) + p_\pm \; Br(B^- \to c\bar{u} \to \mu^+) \\ & + p_d \; Br(\bar{B}^0_d \to c\bar{d} \to \mu^+) + p_s \; Br(\bar{B}^0_s \to c\bar{s} \to \mu^+) \; . \end{aligned} \tag{8}$$

As the branching ratios of the $\Lambda_b \to \Lambda_c, D^+, D^0$ decay are not known we use the following assumptions:

$$\Lambda_c : D^+ : D^0 = 1 : 1 : 1 \tag{9}$$

$$= 3 : 1 : 3 \; . \tag{10}$$

The non-semileptonic branching ratios of the B mesons are estimated by assuming that

$$Br(B \to DX, D^*X) = \frac{Br(B \to l\nu D, l\nu D^*)}{Br(B \to l\nu X)} \; . \tag{11}$$

Using $Br(B^- \to D^0 l\nu, D^{*0} l\nu) = Br(B^0 \to D^+ l\nu, D^{*+} l\nu) = 0.02,\ 0.05$ (Ref. 8), the measured B and D decay rates[9] and equation (9), one obtains the results given in the Table. With this method one has $w \simeq 0.31$ whereas with equation 10, w will change by $\sim 2\%$. From the values given in the Table one obtains

$$A_m = A_\pm \times 0.77 \times (1 - 0.62) \simeq -sin2\phi \times 0.13 \; .$$

We notice that this expression taking only into account the cascade mistagging is smaller than equation 6. In the Figure we present the number of $b\bar{b}X$ events,

Table - Branching ratios used to estimate w'. The values are taken from references 8,9 and by using equations 10 and 11. Here the B_d^0 and B_s^0 branching ratios are assumed to be equal.

cascade decay	Branching ratio	Total$\times p_j$
$\Lambda_b \to \Lambda_c \to \mu^+$	0.33×0.04	0.010
$\Lambda_b \to D^+ \to \mu^+$	0.33×0.19	
$\Lambda_b \to D^0 \to \mu^+$	0.33×0.08	
$B^- \to D^0 \to \mu^+$	0.17×0.08	0.018
$B^- \to D^{*0} \to D^0\pi^0, D^0\gamma \to \mu^+$	$0.43 \times 1 \times 0.08$	
$B_d^0 \to D^+ \to \mu^+$	0.17×0.19	0.033
$B_d^0 \to D^{*+} \to D^+\pi^0, D^+\gamma \to \mu^+$	$0.43 \times 0.45 \times 0.19$	
$B_d^0 \to D^{*+} \to D^0 \to \mu^+$	$0.43 \times 0.55 \times 0.08$	
$B_s^0 \to D_s^+ \to \mu^+$	"	0.013
$B_s^0 \to D_s^{*+} \to D_s^+\pi^0, D_s^+\gamma \to \mu^+$		
$B_s^0 \to D_s^{*+} \to D_s^0 \to \mu^+$		

necessary to detect a given $|sin2\phi|$ value with five standard deviations (no di-muon due to the the associated beauty hadron decay is included). For comparison we also give in the Figure the number of events necessary for only tagging with $B^\pm$ mesons.. To obtain the real number of $b\bar{b}X$ events, one must, of course, take into account the branching ratios $(B, \bar{B} \to \mu X, f)$ as well as the efficiency for detecting the decay channels.

By taking into account the other mistagging effects, one has to add $F(\mu)/2 + F(P)/2$ into equation 8. Here $F(\mu)$ and $F(P)$ are the fraction of $\mu f X$ events where the muon is due to hadrons $(\pi, K...)$ decays or to punchtrough effects.

4 - Conclusions

We estimate the influence of muon mistagging in the search for CP violation effect in the $B_d^0, \bar{B}_d^0 \to f$ decay $(f = \bar{f})$. We only consider cases where no di-muon are in the final state of the associated beauty hadron decay. In our approach the so-called cascade decay $(b \to c \to \mu)$ does appear to be important. Kinematical cuts could certainly decrease the mistagging effect but will also decrease the number of events with B_d^0 (or $\bar{B}_d^0$) decays. Detailed investigations have to be made for a given experiment as cuts will depend on the c.m. energy and the

detector properties. In that case one will also be able to estimate the mistagging effect due to the decay of K, π... into muons and to the punchthrough effect.

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5) Strictly speaking, the amplitudes T_{1-4} of the four cases are not equal as one has $T_1 =< \mu^+ X|B^+ >< f|\bar{B}_d^0 >$, $T_2 =< \mu^+ X|B_S^0 >< f|\bar{B}_d^0 >$, $T_3 = < \mu^+ X|B_d^0 >< f|B_d^0 >$ and $T_4 =< \mu^+ X|\bar{\Lambda}_b >< f|\bar{B}_d^0 >$. In the spectator model all the semileptonic parts of T_1 to T_3 are equal. For $\bar{\Lambda}_b \to \mu^+ X$ we use the same amplitude although the Λ_b lifetime is expected to be shorter than those of the meson (I.I. Bigi, private communication).

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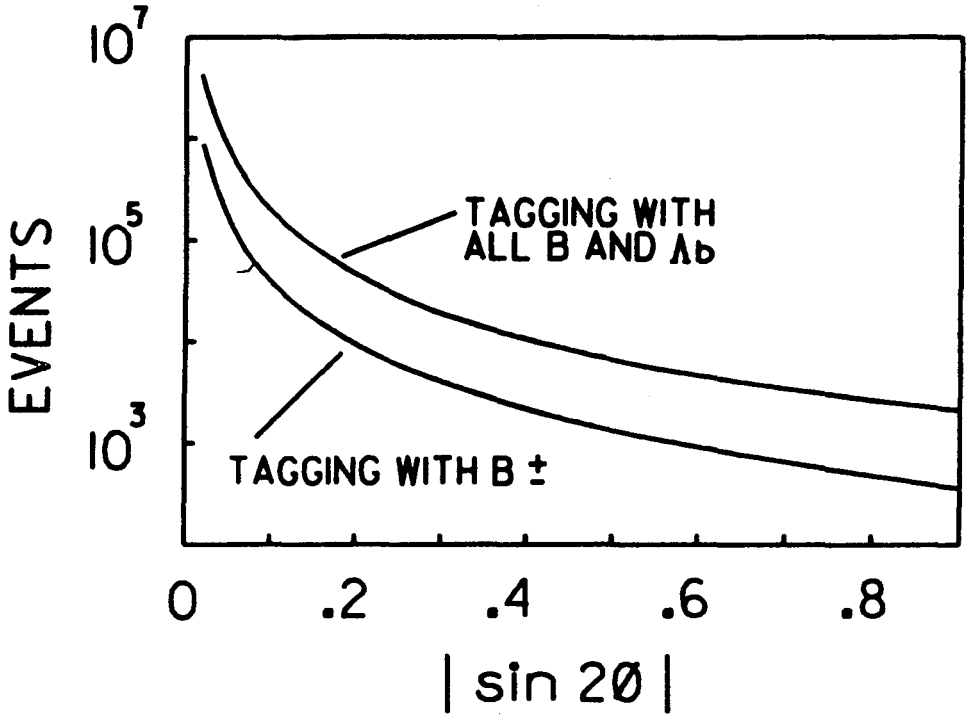

Figure - Estimates of the number of $b\bar{b}X$ events necessary to detect a CP violation parameter value ($|sin2\phi|$) with 5 standard deviations. The calculation was made with the Br values given in the Table.