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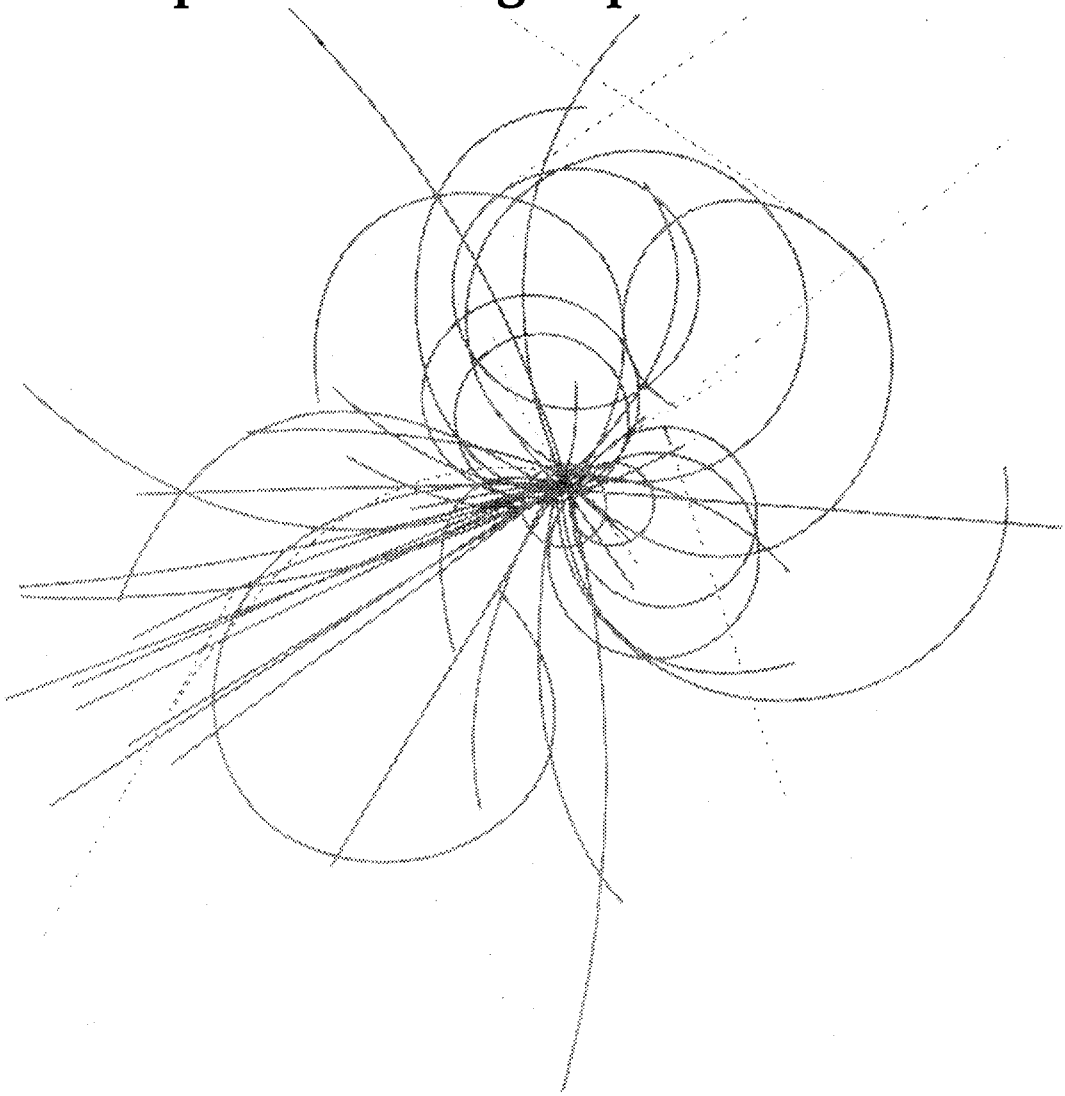

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B-Physics with pp Interactions

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ABSTRACT

Some aspects of the B-physics that could be studied at the pp colliders are discussed. We consider B_s^0 decays and the search for CP violation in the B^0 decay. The dilution effect in semileptonic decay of the beauty hadrons used for tagging B^0 decays is also discussed.

1. INTRODUCTION

The $pp \to b\bar{b}X$ cross section is expected to be large at the SSC collider[1], ($\sigma(b\bar{b}) \simeq 500\ \mu b$). It seems, therefore, useful to define the B-physics domain that could be investigated at the SSC c.m. energy ($\sqrt{s} = 40$ TeV). It would also be important to evaluate if this domain could complete the B-physics knowledge that we expect to have in the year 2000.

Here we discuss some aspects of the B-physics that can be studied with pp interactions. Section 2 presents some interests of measuring the B_s^0 decays that could not be studied in an e^+e^- B factory ($\sqrt{s} \simeq 10$ GeV). Section 3 describes a method for estimating the dilution effect in semileptonic decay of the beauty hadron used for tagging B^0 decays. Finally we make some comments about the Gronau-Wyler method[2] searching for CP violation in self-tagging B decay channels.

Let us remember that to search for CP violation in the B^0 decay, one usually considers a luminosity of $10^{32}\text{cm}^{-2}\text{s}^{-1}$ in the pp collider (SSC or LHC) in order to decrease the multiple pp interactions per bunch crossing (the SSC could, in principle, reach $L \geq 10^{33}\text{cm}^{-2}\text{s}^{-1}$). This should decrease the difficulty of tagging the beauty hadron associated to the B^0 decay under study. The smaller L value might also facilitate the B^0 reconstruction. In the case of minimum bias events, the above luminosity would correspond to an average number of interactions per bunch crossing of ~ 0.17.

2. THE B_s^0 DECAY

The $B_s^0, \bar{B}_s^0$ have a small production rate in B factories. For instance, with the $e^+e^- \to \Upsilon(5S) \to B_s^0\bar{B}_s^0$ process, a number of only 3×10^6 B_s^0 (or $\bar{B}_s^0$) will be produced in one year of running[3] with $L = 3 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$. In contrast, at the SSC about 10^{11} B_s^0 or/and $\bar{B}_s^0$ are expected in one year of running[1] allowing thus a detailed study of the B_s^0. We consider here two examples that can be studied with pp interactions, rare decay and search for CP violation.

2.1 Rare B_s^0 Decay

As an example let us consider the $B_s^0 \to \mu^+\mu^-$ decay. The branching ratio has been calculated theoretically[4] and increases with the mass of the top quark (m_t). With $m_t = 150$ GeV and a B decay constant of $f_B \simeq 0.2$ GeV, one has a branching ratio of $\sim 10^{-9}$ (Ref. [4]). One can also express the branching ratio by[5]

$$Br(B_s^0 \to \mu^+\mu^-) = x_s\ F(m_t, B_B)$$

where the function F depends[5] on m_t and on the bag parameter $B_B \simeq 1$. Here x_s is a mixing parameter of the B_s^0 meson. Thus, the measurement of this branching ratio would allow

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one to measure x_s (if the m_t and B_B are known). An increase of x_s increases the branching ratio and facilitates its measurement. This is in contrast with the measurement of $r_s = N(B_s^0 \to \bar{B}_s^0)/N(B_s^0 \to B_s^0)$ and the B_s^0 time-dependence measurement (N is the number of events) from which it is difficult to extract x_s when $x_s > 8$. In any case the comparison of r_s with the value obtained by measuring x_s ($r_s \equiv x_s^2/(2+x_s^2)$) could verify the standard model[5].

2.2 CP Violation in the B_s^0 Decay

In the standard model no CP violation effect is expected for the $B_s^0, \bar{B}_s^0 \to f$ decay when $f = \bar{f}$ and $b \to c$ (or $\bar{b} \to \bar{c}$). Table 1 gives some examples of such processes with their branching ratio corresponding the indicated final states[6]. Here we consider decay having only charged particles in the final note. The search for CP violation effect in these decays will allow one to test the usual standard model assumptions. Tagging of the associated beauty hadrons is, of course, necessary.

Table 1. The branching ratios (Br) for B_s^0 decay where no CP violation is expected in the standard model. We assume that $Br(\bar{B}_s^0 \to D_s^+ D_s^-) \simeq Br(B_d^0 \to D^+ D_s^-) \simeq 2 \times 10^{-2}$ (see Reference [3]) and that[1,3] $Br(B_s^0 \to J/\psi\phi) \simeq 2\ Br(B_d^0 \to J/\psi K_s^0) \simeq 8 \times 10^{-4}$.

Decay channel	$Br(B)$	Final state	$Br(tot)$
$B_s^0 \to D_s^+ D_s^-$	$\sim 2\ 10^{-2}$	$K^+K^-2\pi^+2\pi^-$	$\sim 1.7\ 10^{-6}$
$D_s^+ \to \bar{K}^0 K^+$	$2.6\ 10^{-2}$		
$B_s^0 \to D_s^+ D_s^-$	$\sim 2\ 10^{-2}$	$2K^+2K^-\pi^+\pi^-$	$\sim 6.1\ 10^{-6}$
$D_s^+ \to \bar{K}^{*0} K^+$	$2.6\ 10^{-2}$		
$\bar{K}^{*0} \to K^-\pi^+$	0.67		
$B_s^0 \to D_s^+ D_s^-$	$\sim 2\ 10^{-2}$	$2K^+2K^-\pi^+\pi^-$	$\sim 3.6\ 10^{-6}$
$D_s^0 \to \phi\pi^+$	$2.7\ 10^{-2}$		
$\phi \to K^+K^-$	0.50		
$B_s^0 \to J/\psi\ \phi$	$\sim 8\ 10^{-4}$	$\mu^+\mu^-K^+K^-$	$\sim 3\ 10^{-5}$
$J/\psi \to \mu^+\mu^-$	0.07		
$\phi \to K^+K^-$	0.50		

3. The dilution effect

Let us consider the search for CP violation in the $B_d^0, \bar{B}_d^0 \to f$ decay where f is a self-conjugated state ($f = \bar{f}$). We consider that the tagging of the associated beauty hadron 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 $\Lambda_b \equiv bqq$ ($\bar{\Lambda}_b \equiv \bar{b}\bar{q}\bar{q}$) 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. A CP violation in the B_d^0 decay will then be observed if the measured asymmetry parameter $A_m = (N_+ - N_-)/(N_+ + N_-) \neq 0$. In practice, A_m contains a dilution effect due to the mistagging of the muon that can be due to[7,8]:

(1) the mixing of the $B_{d,s}^0$ 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, the so-called cascade case

(3) the μ's coming from other decaying particles (K, π...)

(4) the punchthrough in the detector (particles identified wrongly as muons).

The last two cases depend on the detector chosen for a given experiment. They contribute equally to the mistagging of the μ^+ and μ^- in the final state. Note that the asymmetry parameter without cases 2 to 4 will be defined by A.

Here we would like to describe the influence of the mixing (case 1) in hadron-hadron interactions at large c.m. energies. To this end let us first consider the production of the $\mu^+ f$ final state. The following beauty hadron combinations can lead to the $\mu^+ f$ state:

(a) $B^+ \bar{B}_d^0$

(b) $B_s^0 \bar{B}_d^0$ and $\bar{B}_s^0 B_d^0$ (coherent mixture)

(c) $B_d^0 \bar{B}_d^0$

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

where the particles are those appearing at the production time ($t = 0$). For the four cases one

obtains the following cross sections taking into account the mixing of the $B^0_{d,s}$ (Refs. [9,10]).

$$\sigma(\mu^+ f)_{a+d} = (p_\pm + p_\Lambda)\ p_d\ |T|^2 \left[1 - n\ \frac{x_d}{1+x_d^2}\right]$$
$$\sigma(\mu^+ f)_b = p_s\ p_d\ |T|^2 \left[1 - n\ \frac{(x_s + x_d)}{(1+x_s^2)\ (1+x_d^2)}\right]$$
$$\sigma(\mu^+ f)_c = p_d\ p_d\ |T|^2 \left[1 - n\ \frac{x_d}{(1+x_d^2)^2}\right] .$$

Here T is the amplitude taken to be the same in all cases[11]. The effect of CP violation is described by the parameter $n \equiv \sin 2\phi$. 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, taken here as:

$$p_\pm : p_d : p_s : p_\Lambda = 0.38 : 0.38 : 0.14 : 0.10 .$$

The total $\mu^+ f$ cross section will be obtained by adding incoherently the preceding expressions. Within the present approximations the $\mu^- f$ cross section is obtained by changing $n \to -n$, yielding[7]

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

The mistagging of the μ due to point 2 to 4 leads to a measured asymmetry $A_m = A(1-2w)$ with

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

The correct (wrong) number of events is represented by $N_\pm^c$ ($N_\pm^W$) whereas N_t represents the total number of (true and wrong) tagged events. In the framework of our discussion we obtain the following asymmetry estimates by tagging with the semileptonic decay of:

— $B^\pm$ leading to, $|A_\pm| \simeq |0.45\ \sin\ 2\phi|$

— any beauty hadron yielding, $|A| \simeq |0.35\ \sin\ 2\phi|$

— any beauty hadron or the cascade process, $|A_m| \simeq |0.13\ \sin\ 2\phi|$.

In the last case the cascade decays were calculated with the branching ratios estimates given in Reference [7]. Further kinematical cuts in hadron-hadron interactions may decrease the cascade contribution (and increasing $|A_m|$) but will also decrease the number of events. Detailed investigations have to be made for a given experiment as cuts will depend on the c.m. energy and on the detector properties. In that case one could also estimate the mistagging effect due to the decay of K and π into muons and to the punchthrough effect. Note that the asymmetry will also decrease by a factor S/(S+B) where B is the background in the determination of the signal S (the $l^\pm X f$ events).

4. The GW method

The observation of an eventual CP violation parameter in the $B^0_s \to \rho^0 K^0_s$ channel (denoted here by $n = \sin 2\phi_3$) would allow one to obtain the ϕ_3 angle in the triangle due to the unitarity of a CKM matrix (with three generations). This decay, however, is expected to have a small branching ratio, $7 \times (10^{-6} - 10^{-5})$, for the $2\pi^+ 2\pi^-$ final state and to compete with a large background[1].

The Gronau-Wyler (GM) method[2] suggests to measure ϕ_3 with self-tagging channels but with a two-fold ambiguity (instead of a four-fold one as one assumes that $\sin\phi_3 > 0$, a CP constraint due to the K^0 system[2]). One of the two solutions corresponds to ϕ_3 whereas the second one is due to the phases of the final states interactions. The proposed channels are $B^\pm \to D^0(\bar{D}^0)K^\pm$ and $B^\pm \to D^0_1(D^0_2)K^\pm$. Here D^0_1 (D^0_2) is the CP even (odd) state of the charmed meson. For instance, the decay of mesons into $\pi^+\pi^-$, K^+K^-, etc., identify D^0_1 whereas the $K^0_s\rho^0$, $K^0_s\phi$, etc., will indicate the D^0_2. Thus the flavor of the $B^\pm$ is tagged by the $K^\pm$, whereas the D^0 or $\bar{D}^0$ are identified by the $D^0 \to K^- X^+$ or $\bar{D}^0 \to K^+ X^-$ processes.

The branching ratios of $B^\pm \to D^0_1(D^0_2)K^\pm$ are not known. Estimates of the $B^\pm \to D^0(\bar{D}^0)K^\pm$ branching ratios into charged particles are given in Table 2, using

$$\frac{Br(B^+ \to \bar{D}^0 K^+)}{Br(B^+ \to D^0 K^+)} \simeq \left|\frac{V_{cb}^* V_{us}}{V_{ub}^* V_{cs}}\right|^2 \simeq 6.3 ,$$

$$\frac{Br(B^+ \to \bar{D}^0 K^+)}{Br(B^+ \to \bar{D}^0 \pi^+)} \simeq \left|\frac{V_{us}}{V_{ud}}\right|^2 \simeq 0.05 \ .$$

Table 2. Branching ratios (Br) for channels that can be used for the GW method in order to estimate ϕ_3. The $Br(tot)$ was calculated by adding the charge conjugated decay channels (c.d.).

Decay channel	Br	Final state	$Br(tot)$
$B^+ \to \bar{D}^0 K^+$	$\sim 1.5\ 10^{-4}$	$2K^+\pi^-$	$1.1\ 10^{-5}$
$\bar{D}^0 \to K^+\pi^-$	$3.7\ 10^{-2}$		with c.d.
$B^+ \to D^0 K^+$	$\sim 2.3\ 10^{-5}$	$K^+K^-\pi^+$	$1.7\ 10^{-6}$
$D^0 \to K^-\pi^+$	$3.7\ 10^{-2}$		with c.d.
$B^+ \to \bar{D}^0 K^+$	$\sim 1.5\ 10^{-4}$	$2K^+\pi^+2\pi^-$	$2.3\ 10^{-5}$
$\bar{D}^0 \to K^+\pi^+2\pi^-$	$7.8\ 10^{-2}$		with c.d.
$B^+ \to D^0 K^+$	$\sim 2.3\ 10^{-4}$	$K^+K^-2\pi^+\pi^-$	$3.6\ 10^{-5}$
$D^0 \to K^-2\pi^+\pi^-$	$7.8\ 10^{-2}$		with c.d.

The two-fold ambiguity could be resolved by choosing several $B^\pm \to D^0(\bar{D}^0)X^\pm, D_{1,2}X^\pm$ where $X^\pm = K^\pm, K^\pm\pi^0, K^\pm\pi^+\pi^-$... (Ref. [2]). One could then find a solution as the weak phase has to be common to all processes. It was also proposed[12] to measure $B_d^0 \to D_{1,2}^0 K^{*0}, \bar{B}_d^0 \to D_{1,2}^0 \bar{K}^{*0}$ as well as the $B^0 \to D^0(\bar{D}^0)K^{*0}$ (see Table 3). The values are, however, smaller than in Table 2. Nevertheless, the measurement of the mentioned B decays could be attempted in pp interactions where the B production rate is important at $\sqrt{s} = 40$ TeV.

Table 3. Similar to Table 2, but this time using B_d^0 and $\bar{B}_d^0$ decays in order to estimate ϕ_3. The estimate of $Br(B_d^0 \to D^0 K^{*0})$ was taken from Reference [12].

Decay channel	$Br(B)$	Final state	$Br(tot)$
$B_d^0 \to \bar{D}^0 K^{*0}$	$\sim 6.3\ 10^{-5}$	$2K^+2\pi^-$	$3.1\ 10^{-6}$
$\bar{D}^0 \to K^+\pi^-$	$3.7\ 10^{-2}$		with c.d
$K^{*0} \to K^+\pi^-$	0.67		
$B_d^0 \to D^0 K^{*0}$	$\sim 10^{-5}$	$K^+K^-\pi^+\pi^-$	$5\ 10^{-7}$
$D^0 \to K^-\pi^+$	$3.7\ 10^{-2}$		with c.d.
$K^{*0} \to K^+\pi^-$	0.67		

5. Summary

The B-physics has no priority in the actual experimental programs at the pp colliders. It is, however, worthwhile to evaluate the possibility of studying B-physics with colliders where the B production rate is large. Here we discussed some of the advantages and inconveniences of using pp interactions for studying B decays.

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