CONF-9010291

SLAC-PUB--5319

DE91 005764

Remarks on B-Physics with Interactions of pp and e^+e^- *

A. Fridman[+] and A. Snyder

Stanford Linear Accelerator Center, Stanford University
Stanford, California 94309

Abstract

We compare the B-physics that could be studied with pp or e^+e^- interactions. The pp colliders at cm energies of 16 TeV (LHC) and 40 TeV (SSC) as well as asymmetric e^+e^- colliders at the $\Upsilon(4S)$ cm energy are considered. In the case of pp interactions, we discuss the B production using pp colliders and a p beam with an external fixed target. For this preliminary comparison we explore the possibility of searching CP violation in the B_d^0, $\bar{B}_d^0 \to J/\psi K_s^0$, $\pi^+\pi^-$ decays.

Contributed to the Large Hadron Collider Workshop:
Physics and Instrumentation, Aachen, W. Germany, October 4-9, 1990

* Work Supported by the Department of Energy, Contact DE-AC03-763f00515

+ LPHHE, Université de Paris VI et VII

1 - Introduction

In this note we briefly compare the B-physics that could be investigated with e^+e^- or pp interactions. During these last years the construction of B-factories has been envisioned[1−3] in order to increase the B statistics produced in e^+e^- collisions. In fact, a factor of ~ 100 in the statistics of the

$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$$

events is under investigation[1].

On the other hand, several pp collider projects have also been under consideration: the Large Hadron Collider (LHC) at a cm energy of $\sqrt{s}$=16 TeV, and the Superconducting Super Collider (SSC) at $\sqrt{s}$=40 TeV. These colliders would have the advantage of being intense sources of B mesons although they do have some inconveniences (see below). For instance, the B mesons are produced in final state with large multiplicity, which will complicate the identification of B mesons.

Because of the importance of the B-physics[1,4], it is useful to discuss the various advantages of the e^+e^- and pp colliders. To this end, we will investigate the possibility of searching for CP violation in the B_d^0 decay. We consider the case where B_d^0 and $\bar{B}_d^0$ decay into a self-conjugated state, $f = \bar{f}$. Thus CP violation would mean that differences should be observed between the $B_d^0 \rightarrow f$ and $\bar{B}_d^0 \rightarrow f$ decay rates. For the present discussion we consider the following decays:

$$\begin{aligned} B_d^0, \bar{B}_d^0 &\rightarrow J/\psi K_s^0 \\ &\rightarrow \pi^+\pi^- \end{aligned}$$

The branching ratio of the $B \rightarrow J/\psi K_s^0$ was found to be $\sim 4 \times 10^{-4}$ with a $J/\psi \rightarrow l^+l^-$ decay rate of 14 % (Ref. 5). Theoretical models[6] indicate that the $B \rightarrow \pi^+\pi^-$ branching ratio is expected to be of the order of $\sim 2 \times 10^{-5}$.

In the next section we discuss the theoretical aspects related to the measurement of CP violation[7,8]. Section 3 considers the measurement possibilities of pp collisions. We essentially investigate the properties of generated events for the LHC and SSC colliders. For e^+e^- interactions (Section 4) we discuss the results obtained from the investigation of an asymmetric collider[1] (9×3.1 GeV^2). Finally the discussion and conclusions are given in Section 5.

2 - The B_d^0, $\bar{B}_d^0$ decays

Because of mixing phenomena (and also because $f = \bar{f}$), the search for CP violation requires the tagging of the second B in each event. As usual, we consider that the tagging is given by the charge of the lepton (l) in the semileptonic decay ($B \to l^+X$, $\bar{B} \to l^-X$, X meaning anything). This means that CP violation will be observed if

$$A = \frac{N_+ - N_-}{N_+ + N_-} \neq 0\,.$$

Here N_+ (N_-) represents the number of l^+fX (l^-fX) events in a given experiment. Fig. 1a gives the number of events, $N = N_+ + N_-$, necessary to detect a given asymmetry with three or five standard deviations. To obtain the real number of $B\bar{B}$ events, we must take into account the branching ratios as well as the efficiency for detecting the decay channels. Clearly the number of $B\bar{B}$ events needed for the analysis will be very important.

For pp interactions the B and $\bar{B}$ are not produced in equal amount[9], thus complicating the measurement of the A parameter (See below). However, the decay time distribution of B_d^0, $\bar{B}_d^0 \to f$ obtained with the lepton tagging can be used for searching CP violation[10]. The time-correlation function between the decay of the two B mesons is given by[7,11]

$$\frac{d\sigma(l^\pm f)}{d\tau_l d\tau_f} = |T|^2\, e^{-(\tau_l+\tau_f)}\, [1 \pm n\, sin\, x(\tau_l - \tau_f)] \qquad (1)$$

where $\tau_{l,f}$ are the decay times in units of B lifetimes and $x = \Delta M/\Gamma$ is a parameter describing the mixing (ΔM is the mass difference between the heavy and light B and Γ is their average width). As usual, we assume that there is no CP violation in the decay amplitude (T) and in the $B^0 - \bar{B}^0$ mixing. The quantity $n \equiv Im\lambda$ is responsible for the CP violation in the B^0 decay.

For the reactions considered here, simple expressions can be obtained for

$$\lambda = \eta\, \frac{< f|\bar{B}^0 >}{< f|B^0 >}$$

where

$$\eta \simeq \frac{V_{tb}^*\, V_{td}}{V_{tb}\, V_{td}^*} \simeq \frac{V_{td}}{V_{td}^*} = e^{2i\varphi_1}$$

is due to the $B^0 - \bar{B}^0$ mixing, V_{ij} being the CKM matrix elements[7]. For the

$B_d^0 \to J/\psi\ K_s^0$, the ratio of the amplitudes becomes

$$\frac{< f|\bar{B}^0 >}{< f|B^0 >} = \frac{V_{cb}^*\ V_{cs}}{V_{cb}\ V_{cs}^*} \simeq 1\ .$$

Hence,

$$\lambda = e^{2i\varphi_1}$$

Neglecting penguin diagrams for the $B_d^0 \to \pi^+\pi^-$ decay, one obtains by a similar calculation

$$\lambda = \frac{V_{td}\ V_{ub}^*}{V_{td}^*\ V_{ub}} = e^{2i\varphi_2}\ .$$

Thus the measurement of the two decay channels will allow us to determine two angles ($\varphi_{1,2}$) present in the unitarity triangle of the 3×3 CKM matrix[12].

3 - *pp* interactions

There are essentially two methods for studying the $pp \to B\bar{B}X$ interactions. The first one consists of using the *pp* collider[13], whereas the second method uses the interaction of a p beam with an external fixed target[14]. Table 1 compares the characteristics of the $B\bar{B}$ production in various accelerator cases. The total (σ_T) and $b\bar{b}X$ ($\sigma(b\bar{b})$) cross sections are theoretical predictions for the *pp* interactions[15–17]. The uncertainty is rather important for the $pp \to b\bar{b}X$ case[17]. Nevertheless it appears that σ_T and $\sigma(b\bar{b})$ are much larger in *pp* than in e^+e^- interactions (Table 1).

Table 2 presents the advantages and inconveniences of the various cases. Note that the number of $b\bar{b}X$ events per year ($10^7 s$) is much larger in the suggested *pp* interactions than in the e^+e^- collisions. For the LHC collider we use a luminosity of $10^{32} cm^{-2} s^{-1}$ so that two or more interactions per bunch crossing is unlikely. The average charged multiplicity $< n_c >$ (Ref. 18) and the $\sigma(b\bar{b})/\sigma_T$ values show, however, that it will not be easy to extract the B signal from the *pp* final state. In addition, the tremendous production rate (10^7 events per second for the SSC and LHC colliders) indicates that the triggering will be a major problem[13,14]. For *pp* interactions, searching for CP violation by measuring the A parameter might have some complications because the B and $\bar{B}$ are not produced in equal amount. The first effect is due to a combination of produced b or $\bar{b}$ quarks with the u and d quarks contained in the beam particle (B^+, B_d^0 or beauty-baryon). In this case the produced B mesons have a small transverse momentum ($p_T \leq 5$ Gev/c) and the number of B mesons is larger than the $\bar{B}$ ones[9]. The second effect appears when the produced b and $\bar{b}$ quarks have a large transverse momentum $p_T >> 5$ GeV/c (and hence the produced B mesons). For such p_T values the structure functions contribute mainly to the production of the u quarks. This leads to additional B^+ production and decreases the B_d^0 and B_s^0 in the final state[19]. To estimate the influence of the unequal B and $\bar{B}$ amounts, we present in Fig. 1b, $A_m - A$ as a function of A, A_m being the measured asymmetry parameter

$$A_m = \frac{N_+(1+\epsilon) - N_-}{N_+(1+\epsilon) + N_-} .$$

Here ϵ is due to the unequal B and $\bar{B}$ quantities, which are estimated to be in the $|\epsilon| = (2-10) \times 10^{-3}$ domain[9]. Note that the order of magnitude of $A - A_m$ is mainly important for small A values. In any case the ratio of B to $\bar{B}$ production should be measured. This could be done, for instance, for the $B^{\pm}$ by using their decay into states without CP violation.

In the following we investigate the possibility of identifying B mesons and in particular those that decay into the $J/\psi K_s^0$ and $\pi^+\pi^-$ states. To this end, we use the PYTHIA Monte Carlo program[20]. For each calculation we used about 2000 generated events. We first consider the pp collider and then the p interactions with a fixed target.

a) The collider

Table 3 presents the average momentum ($< p >$) and transverse momentum ($< p_T >$) of the produced B or $\bar{B}$ for various θ_B limits. Here θ_B is the B or $\bar{B}$ emission angle defined with respect to the beam direction ($0 \leq \theta_B \leq 90°$). Table 3a (3b) corresponds to the LHC (SSC) project. We first notice that $< p_T >$ does not depend very much on the θ_B limit, whereas $< p >$ decreases strongly when the angular limit is increased. Apart from $< p >$ for $\theta_B > 0°$, the calculated values for the LHC and SSC collider are nearly equal.

Smaller B momentum and wider emission angle may simplify detection of B mesons, but the number of $B\bar{B}$ events decreases. (The fraction of events with B or $\bar{B}$ is $F(B) \simeq 30$ % for $\theta_B > 20°$, Table 3) As expected in large pp cm energy, a large amount of B and $\bar{B}$ tend to be emitted with a relatively small opening angle $\theta_{B\bar{B}}$ ($< cos\ \theta_{B\bar{B}} > \sim 0.5$ for $\theta_B > 0°$). However, for $\theta_B > 20°$ the $cos\ \theta_{B\bar{B}}$ distribution tends to become symmetric (see Table 3). This means that the detection of two B mesons in an event becomes more difficult. The study of the opening angle in the transverse plane (with respect to the beam direction) indicates that

$$f(160° < \theta_{XY} < 180°) \simeq 0.2$$

of the $B\bar{B}$ events have the B and $\bar{B}$ produced back to back in the transverse plane

(Table 3). This percentage does not depend strongly of the θ_B limit. The back-to-back configuration simplifies the detection of the two B mesons, but it further reduces the statistics.

Table 4 presents the average momentum and transverse momentum of the charged unbiased tracks and those coming from the B decay. These values are calculated for $\theta > 0°,\ 1°,\ 20°$ where θ is the track emission angle with respect to the beam direction ($0 \leq \theta \leq 90°$). In the general B decay case (for the LHC and SSC) we see that $< p >$ and $< p_T >$ of the unbiased tracks are nearly equal to the B decay tracks for $\theta > 1°,\ 20°$. However, for the decay channels under discussion, the situation is different, particularly for the $B \rightarrow \pi^+\pi^-$. Here cuts on p or p_T of the charged decay tracks might decrease the background without doing much harm to the signal (see also Fig. 2).

For the $B^0 \rightarrow J/\psi K_s^0$ one has, in particular, to estimate the background due to the misidentification of outgoing particles. In any case the $J/\psi \rightarrow l^+l^-$ and $K_s^0 \rightarrow \pi^+\pi^-$ will be very efficient for reconstructing the B^0 decay and decreasing the background. One has also to estimate the branching ratio $B^0 \rightarrow J/\psi K_s^0 \pi^0$ and to verify that this decay will not simulate the $B^0 \rightarrow J/\psi K_s^0$ channel, both decays can have an opposite CP violation sign. Reference (13) estimated that they will be able to reconstruct 3×10^6 $B_d^0 \rightarrow J/\psi K_s^0$ decays in one year (10^7 s) of running the SSC project with a luminosity of 10^{32} $cm^{-2}s^{-1}$. In addition, an efficient tagging method has to be investigated in order to search for CP violation.

The background for the $B \rightarrow \pi^+\pi^-$ case is more important because, among other things, the branching ratio of this decay is expected to be small ($\sim 2 \times 10^{-5}$). Fig. 2 presents the fraction of $B \rightarrow \pi^+\pi^-$ events left after taking only $\pi^\pm$ having a transverse momentum larger than $p_T(cut)$. The same figure also presents the fraction of $\pi^+\pi^-$ due to background as a function of $p_T(cut)$. Here the background is only calculated from $B\bar{B}$ events. These curves are practically identical for the LHC and SSC cases. We see that by increasing $p_T(cut)$, one decreases the background, whereas the number of $B \rightarrow \pi^+\pi^-$ events decreases much more slowly.

As an example, we present in Fig. 3 for the SSC case, the S/B ratio as a function of $p_T(cut)$ for $\theta > 1°$, and where the $\pi^+\pi^-$ mass is within ± 0.05 GeV of the B mass. Here S/B is the signal-to-background ratio obtained in a sample of $B\bar{B}$ events and found to be very small. Also shown is a curve where, in addition, we require that $cos\ \theta_{\pi\pi} > 0.9$. Here, $\theta_{\pi\pi}$ is the angle between the two pions. Note from Fig. 3 that S/B increases with $p_T(cut)$, whereas the fraction of $B\bar{B}$ events ($F(\theta)$ in this figure) does not decrease very much. For one year of running at the SSC project, 2×10^6 $B_d^0 \rightarrow \pi^+\pi^-$ decays could be reconstructed according to reference (13). However, an efficient tagging method must also be envisioned for this case.

b) The fixed target

For the LHC (SSC) the interaction with a fixed target will occur at a rather low cm energy, $\sqrt{s} = 0.123$ TeV (0.193 TeV), although the momentum of the outgoing particles will be very large (Table 5). The small cm energy may lead to several advantages[14], namely

- higher momentum of the outgoing tracks leads to a better momentum resolution because multiple scattering is decreased
- highest momentum of the produced B's allows them to pass through a large microvertex device before decaying
- higher momentum of μ and e coming from the B decay may decrease the triggering difficulties
- lower multiplicity ($< n_c > \simeq 20$) will decrease the background for the reconstruction of B meson.

Fig. 2 presents the fraction of $B \rightarrow \pi^+\pi^-$ events left after taking $\pi^\pm$ with transverse momentum larger than $p_T(cut)$. We see that $p_T(cut)$ will be very useful for detecting the $B \rightarrow \pi^+\pi^-$ and will also increase the S/B ratio (similar to Fig. 3). The level of S/B is about one order of magnitude larger in the fixed target than for the collider (but still very small). However, the decay length of the B mesons are large for the fixed target experiment (See Table 5). This might help the reconstruction of B mesons and therefore improve the S/B ratio. The difficulty of the target experiment is mainly related to the small emission angle of the outgoing particles with respect to the beam line (Table 6). In addition, the large momentum of the tracks may also complicate the reconstruction and the measurement of the outgoing particles. A final consideration is that the construction of a p beam will require large efforts.

Table 1 - Some properties of the various accelerator possibilities for $B\bar{B}$ production. For pp interactions we consider the target (T) and the collider (C) cases. They are compared with e^+e^- possibilities, CESR and the new CESR and SLAC B factory projects (P). Note that the CESR (SLAC) project is a symmetric (asymmetric) collider. Here σ_T is the total pp or e^+e^- cross section, $\sigma(b\bar{b})$ is the $b\bar{b}X$ cross section, and L is the luminosity of the collider.

	$\sqrt{s}$ TeV	L $cm^{-2}s^{-1}$	σ_T mb	$\sigma(b\bar{b})$ μb
LHC (T)	0.123	-	$\sim 50^{(16)}$	~ 2
SSC (T)	0.193	-	$\sim 58^{(b)}$	$2.5 - 10^{(14)}$
LHC (C)	16	10^{34} (a)	$\sim 110^{(16)}$	$\sim 200^{(17)}$
SSC (C)	40	10^{32} (13)	$\sim 100^{(13)}$	$\sim 500^{(13)}$
CESR	10.58 GeV	$3.6\ 10^{31}$ (3)	$\sim 4\ nb^{(3)}$	$1.2\ nb^{(3)}$
CESR (P)	"	10^{34} (3)	"	"
SLAC (P)	"	$3\ 10^{33}$ (1)	"	"

(a) G. Brianti, ECFA meeting at CERN in June 1990.
(b) This is the cross section used for calculating that obtained with a mixture of Be and Si, reference (14).

Table 2 - The advantages and inconveniences of the various cases. Same definitions and references as in Table 1 with $N(b\bar{b})$ representing the number of $b\bar{b}$ events. For pp interactions the $< n_c >$ are calculated for non-diffractive events[18]. In the case of the LHC (C) we used a luminosity of $10^{32} cm^{-2}s^{-1}$ (see text).

	$< n_c >$	$\sigma(b\bar{b})/\sigma_T$	$N(b\bar{b})/(10^7 s)$
LHC (T)	~ 17	$\sim 1/25K$	$\sim 9.6\ 10^9$
SSC (T)	~ 20	$\sim 1/8000$	$(1-5)10^{10}$
LHC (C)	~ 80	$\sim 1/550$	$\sim 2\ 10^{11}$
SSC (C)	~ 115	$\sim 1/200$	$\sim 5\ 10^{11}$
CESR	~ 12	1/4	$4.3\ 10^5$
CESR (P)	"	"	$1.2\ 10^8$
SLAC (P)	"	"	$3.6\ 10^7$

Table 3a - The Monte Carlo predictions of the average momentum (p)and the transverse momentum (p_T) of the B meson in the laboratory system (GeV/c) of the LHC collider for various θ_B limits. Here θ_B is the B emission angle with respect to the beam direction. We also give $< cos\ \theta_{B\bar{B}} >$ and $< cos\ \theta_{XY} >$, where $\theta_{B\bar{B}}$ and θ_{XY} are the $B\bar{B}$ opening angle in the laboratory system and in the transverse plane with respect to the beam direction, respectively. The parameter F denotes the fraction of B or $\bar{B}$, whereas f represents the fraction of $B\bar{B}$ events.

	$\theta_B \geq 0°$	$\theta_B \geq 1°$	$\theta_B \geq 20°$
$< p >$	124	64	26
$< p_T >$	6.9	7.2	7.7
$F(\theta_B)$	100 %	~91 %	~36 %
$< cos\ \theta_{B\bar{B}} >$	0.54	0.46	-0.05
$f(\theta_{B\bar{B}} < 20°)$	0.43	0.33	0.03
$f(160° < \theta_{B\bar{B}} < 180°)$	0.03	0.04	0.07
$< cos\ \theta_{XY} >$	-0.25	-0.28	-0.29
$f(\theta_{XY} < 20°)$	0.04	0.04	0.04
$f(160° < \theta_{XY} < 180°)$	0.17	0.18	0.19

Table 3b - Same as in Table 3a but for the SSC collider.

	$\theta_B \geq 0°$	$\theta_B \geq 1°$	$\theta_B \geq 20°$
$< p >$	180	70	27
$< p_T >$	7.6	7.9	8.4
$F(\theta_B)$	100 %	~89 %	~41 %
$< cos\ \theta_{B\bar{B}} >$	0.57	0.49	-0.06
$f(\theta_{B\bar{B}} < 20°)$	0.42	0.32	0.02
$f(160° < \theta_{B\bar{B}} < 180°)$	0.03	0.03	0.04
$< cos\ \theta_{XY} >$	-0.19	-0.24	-0.31
$f(\theta_{XY} < 20°)$	0.06	0.05	0.02
$f(160° < \theta_{XY} < 180°)$	0.15	0.16	0.17

Table 4a - The order of magnitude of the average momentum ($< p >$) and transverse momentum ($< p_T >$) for the unbiased charged tracks and for those coming from the B decay in GeV/c. The Monte Carlo calculations have also been done for tracks having an angle θ greater than 1 and 20 degrees with respect to the beam direction. The values correspond to the LHC collider.

		unbiased tracks	tracks from B or $\bar{B}$	tracks from $B \rightarrow \pi\pi$	tracks from $B \rightarrow \psi K_s$
All	$< p >$	89	12	53	27
	$< p_T >$	0.49	0.90	4.1	2.1
$\theta > 1°$	$< p >$	5.9	7.0	32	16
	$< p_T >$	0.54	0.91	4.2	2.4
$\theta > 20°$	$< p >$	0.94	1.5	6.6	3.3
	$< p_T >$	0.59	0.98	4.2	2.1

Table 4b - Same as in Table 4a but for the SSC collider.

		unbiased tracks	tracks from B or $\bar{B}$	tracks from $B \rightarrow \pi\pi$	tracks from $B \rightarrow \psi K_s$
All	$< p >$	190	21	58	41
	$< p_T >$	0.5	1.0	4.0	2.3
$\theta > 1°$	$< p >$	6.2	7.7	32	17
	$< p_T >$	0.6	1.0	4.2	2.3
$\theta > 20°$	$< p >$	1.0	1.6	7.0	3.7
	$< p_T >$	0.6	1.0	4.5	2.3

Table 5 - The average momentum (p) and transverse momentum (p_T) of the B meson in the laboratory system for the LHC and SSC target experiments (GeV/c). The θ_{XY} and the fraction f of $B\bar{B}$ events (same as in Table 3a and 3b) are also given in this table.

	LHC	SSC
$< p >$	617	1165
$< p_T >$	3.3	3.6
$< cos\ \theta_{XY} >$	-0.63	-0.55
$f(\theta_{XY} < 20°)$	0.02	0.03
$f(160° < \theta_{XY} < 180°)$	0.42	0.35

Table 6a - Results for the target case in the LHC. The momentum and transverse momentum are given in GeV/c.

	unbiased tracks	tracks from B or $\bar{B}$	tracks from $B \rightarrow \pi\pi$	tracks from $B \rightarrow \psi K_s$
$< p >$	165	67	306	151
$< p_T >$	0.46	0.57	2.7	1.4
$< cos\ \theta >$	0.989	0.999	0.998	0.998

Table 6b - Same as in Table 6a but for the target experiment with the SSC.

	unbiased tracks	tracks from B or $\bar{B}$	tracks from $B \rightarrow \pi\pi$	tracks from $B \rightarrow \psi K_s$
$< p >$	342	126	565	287
$< p_T >$	0.47	0.60	2.8	1.4
$< cos\ \theta >$	0.991	0.999	0.999	0.999

4 - e^+e^- interactions

With a symmetric collider the $e^+e^- \to \Upsilon(4S) \to B_d^0 \bar{B}_d^0$ reaction cannot be used to search for CP violation in the B^0 decay when $f = \bar{f}$ (Ref. 21). This is because the relative orbital momentum (L) between the outgoing B mesons is odd, yielding $A = 0$ (even in the presence of CP violation). However, time-dependent quantities obtained from formula (1) are still sensitive to CP violation in the B decay. Note that at the cm just above the $\Upsilon(4S)$ ($\sqrt{s} \simeq 10.72$ GeV), the $B\bar{B}^*$ or $\bar{B}B^*$ pair can be produced. Here, the even value of L between the $B\bar{B}$ in the $B\bar{B}\gamma$ final state would allow us to search for CP violation. However, the $B\bar{B}$ cross section at $\sqrt{s} \simeq 10.72$ Gev is much smaller than the $\Upsilon(4S)$ production cross section[22].

We reiterate that even in the case of CP violation ($n \neq 0$) the number of l^+fX and l^-fX events are equal ($N_+ = N_- = N/2$) for the $\Upsilon(4S) \to B^0\bar{B}^0$ decay. However, by using formula (1) one obtains[23]

$$N_\pm(\tau_l > \tau_f) = \frac{N}{2}\left[1 \pm \frac{nx}{1+x^2}\right] \qquad (2)$$
$$N_\pm(\tau_l < \tau_f) = \frac{N}{2}\left[1 \mp \frac{nx}{1+x^2}\right]$$

This means that a possible observation of differences between N_+ (or N_-) in the $\tau_l < \tau_f$ and $\tau_l > \tau_f$ regions would indicate CP violation in the B^0 decay[23,24]. One could then obtain an estimate of n from the rate

$$\begin{aligned} r &= \frac{N_+(\tau_l > \tau_f) + N_-(\tau_l < \tau_f) - N_+(\tau_l < \tau_f) - N_-(\tau_l > \tau_f)}{N_+(\tau_l > \tau_f) + N_-(\tau_l < \tau_f) + N_+(\tau_l < \tau_f) - N_+(\tau_l > \tau_f)} \\ &= \frac{nx}{1+x^2} \end{aligned} \qquad (3)$$

with a statistical error of

$$\frac{\Delta r}{r} = \frac{1}{\sqrt{2N}}\,\frac{1}{nx}\,\sqrt{(1+x^2)^2 - n^2x^2}$$

In e^+e^- symmetric colliders, the produced B or $\bar{B}$ have very small momenta, leading to an average decay length of about 20 μm. Thus time-dependent measurements appear not to be possible.

With an asymmetric collider having an $\Upsilon(4S)$ cm energy, the decay length can be an order of magnitude larger than in the symmetric case[23]. In this case the $\Upsilon(4S)$ will move in the laboratory system while the B will travel in the same direction (but with a small emission angle with respect to the beam line). In principle we can measure the difference ΔR between the decay vertices. Strictly speaking, the τ_l, τ_f order in the $\Upsilon(4S)$ rest frame is not always equal to the decay vertex order in the laboratory system. The fraction of events that will have their proper time and their laboratory decay length ordering reversed is of the order of 2 % (Ref. 23). By neglecting this fraction as well as the B momentum in the $\Upsilon(4S)$ rest frame, we can relate ΔR with $\Delta = \tau_l - \tau_f$, namely

$$\Delta R \simeq \beta\gamma c\Gamma(\tau_l - \tau_f)$$

(β, γ are the parameters transforming quantities from the $\Upsilon(4S)$ rest frame to the laboratory system, Γ is the B^0 decay width) and then measure the $N_\pm(\tau_l > \tau_f)$ and $N_\pm(\tau_l < \tau_f)$ parameters.

With the above assumptions, one can also use the Δ distribution, which will be more efficient in searching the CP violation than the measurement of r (formula (3)). Indeed formula (1) can be transformed to[23,24]

$$\frac{d\sigma(l^\pm f)}{d\Delta} = |T|^2\, e^{-\Delta}\, [1 - n\ sin\ x\Delta] \qquad (4a)$$
$$\Delta = \tau_{l^+} - \tau_f,\ \tau_f - \tau_{l^-} > 0$$

and

$$\frac{d\sigma(l^\pm f)}{d\Delta} = |T|^2\, e^{-\Delta}\, [1 + n\ sin\ x\Delta] \qquad (4b)$$
$$\Delta = \tau_f - \tau_{l^+},\ \tau_{l^-} - \tau_f > 0.$$

Thus the comparison of these Δ (or decay length difference) distributions with a purely exponential distribution would be an efficient method of searching for CP violation.

As an example Fig. 3 presents the distributions of the decay length difference given in reference (1) between the meson decay into the $J/\psi K_s^0$ and that used for the tagging purpose. The curves are obtained using 6914 events generated with $x = 0.75$ and $n = -0.4$. The simultaneous fit of the two distributions shown in Fig. 3 (full lines) allows them to obtain $n = -0.408 \pm 0.023$, which is very close to the input value. In this framework the background has also been studied[1] by considering the following among the 6914 events

- having a hadron misidentified as a lepton to form a $J/\psi K_s^0$ candidate
- having both B decaying semileptonically and simulating $J/\psi \rightarrow l^+l^-$
- having $B \rightarrow J/\psi K_s^0\pi^0$ simulating the $B \rightarrow J/\psi K_s^0$ channel, both decays having opposite CP violation signs.

The study of these channels leads to a background of $\sim$ 6 %. With one year of running, reference (1) estimates that n could be measured to an accuracy of ± 0.07.

The $B \rightarrow \pi^+\pi^-$ branching ratio is expected to be much smaller ($\sim 2 \times 10^{-5}$) than the above case. In addition, particle identification is necessary to decrease the background due to the $B \rightarrow \pi^\pm K^\mp$, K^+K^- which may simulate the $B \rightarrow \pi^+\pi^-$ decay. With a Cerenkov ring imaging detector (CRID) in the project of reference (1), it would be possible to decrease this background. To obtain 1000 events where one meson is decaying into the $\pi^+\pi^-$ and the other one in semileptonic decay, the project of reference (1) estimates that $\sim 4 \times 10^8 B\bar{B}$ would be necessary. The error of n will be now much larger, namely $\sim$ 0.06.

5 - Discussion and Conclusion

We see that the LHC and SSC colliders are very similar for studying B-physics. The high luminosity of the LHC project compensates partly the higher $pp \rightarrow b\bar{b}X$ cross section expected at the SSC cm energy. The ratio of the number of $B\bar{B}$ events between the SSC and the LHC is $\sim$ 2.5. Furthermore we note that for B mesons emitted with angles greater than 20°, the $\cos\,\theta_{BB}$ distribution becomes symmetric (θ_{BB} is the opening angle between the produced B mesons). This difficulty in identifying $B\bar{B}$ events might be overcome by studying the tracks in the transverse plane (transverse to the beam direction). In this case about $\sim$ 20 % of the $B\bar{B}$ events will appear back-to-back in the transverse plane. From the present discussion it appears that it will not be easy to detect the $B_d^0 \rightarrow \pi^+\pi^-$ channel because of the large background and the small value of signal to background.

The SSC letter of intent[13] indicates that the large statistics of $B\bar{B}$ events should allow us to increase our knowledge concerning the B decays. However, to search for CP violation in the B^0 decay, the tagging of the other B is necessary as well as the measurement of the relative amount of B and $\bar{B}$ production.

The experiment with a fixed target has many advantages[14] but also some inconveniences. The fact that the particles are emitted with a small angle (with respect to the beam line) may complicate the momentum measurements of outgoing tracks, the identification of B mesons, and tagging purposes.

With an asymmetric collider the study of the $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ reaction is much simpler than the $B\bar{B}$ production in pp collisions. The charged multiplicity and the momentum of the outgoing particles are low in these e^+e^- interactions[1] thus allowing an easy identification of the charged particles. The search for CP violation in the B_d^0 decay can simply be done by measuring the length difference between the meson decaying into a given f state (here we consider states where $f = \bar{f}$) and that used for tagging purpose. The inconvenience, however, is that the number of $B\bar{B}$ per year for the SLAC project[1] (3×10^7) is not large, and in fact is much smaller than for the pp colliders ($\sim 5 \times 10^{11}$ at the SSC). However, the CP violation at the level assumed by the SLAC project could be investigated.

To summarize, we can say that the pp interactions at large cm energies (LHC and SSC) as well as the asymmetric e^+e^- collider (the SLAC project) might allow us to increase our understanding of B physics. Both approaches have advantages and inconveniences although the $B \to \pi^+\pi^-$ does not appear to be measurable in pp interactions. Nevertheless, the continuation of the present investigations will be of great interest for our future experiments.

Acknowledgments

It is a pleasure to thank E. Bloom, J. Dorfan and T. Sjostrand for useful discussions.

References

1) The Physics Program of a High-Luminosity Asymmetric B-Factory, SLAC-353 (1989);

2) Proposal for an Electron Positron Collider for Heavy Flavor Particle Physics and Synchrotron Radiation, PSI, PR-88-09, July 1988;

3) Prospects for a CESR B-Factory Upgrade, CLNS 89/962 (1989);

4) See, for instance, Justification for an Asymmetric B Factory, presented at the HEPAP Subpanel, J. Dorfan, March 8, 1990;

5) Particle Data Group, Phys. Letters, B239 (1990);

6) The $B \rightarrow \pi^+\pi^-$ branching ratio is predicted to be 2.1×10^{-3} $|V_{ub}/V_{cb}|^2$ by M. Braun, B, Stech and M. Wirblel, Z. Phys. C34, 103 (1987). The V_{ij} are CKM matrix elements using here $|V_{ub}/V_{cb}| = 0.1$

7) I.I. Bigi and A.L Sanda, Nucl. Phys. B281, 41 (1987);

8) I. Dunietz and J.L. Rosner, Phys. Rev. D34, 1404 (1986);

9) Remarks about CP Violation Measurements for B-Mesons Produced in pp Interactions, A. Fridman, CERN-EP/90-87 (1990);

10) Remarks about Measuring CP Violation Effects in B Decays, A. Boden and A. Fridman, UCLA-HEP-89-002 (1989);

11) See also the lectures "Mixing and CP Violation in the B-System", A. Fridman, CERN-EP/88-123 (1988);

12) C.O. Dib, I. Dunietz, F.J. Gilman and Y. Nir, Phys. Rev. D41, 1522 (1990);

13) Expression of Interest for a Bottom Collider Detector at the SSC, Letter of Intent (1990);

14) An Expression of Interest in a Super Fixed Target Beauty Facility at the SSC, Letter of Intent (1990);

15) G.J. Alner et al., Z. Phys. C32, 153 (1986);

16) M.M. Block and R.N. Cahn, Nucl. Phys. 188B, 143 (1987);

17) K.J. Foley et al., Proceedings of the Workshop on Experiments, Detectors, and Experimental Areas for the Supercollider, July 7-17, 1987, Berkeley; Private communications: R.K. Ellis (1989) and E.L. Berger (1990);

18) The $< n_c >$ in Table 2 are calculated for non-diffractive events. See T. Sjostrand and M. van Zijl, Phys. Rev. D36, 2019 (1987);

19) For large p_T, the number of B^+ increases whereas the numbers of B_d^0 and B_s^0 decrease. The numbers are small but not equal, see 9.

20) H-U. Bengtsson and T. Sjostrand, Computer Phys. Comm. 46, 43 (1987);

21) I.I. Bigi and A.L. Sanda, Nucl. Phys. B193, 85 (1981);

22) The Need for a B-Factory, presented at the HEPAP Subpanel, N. Mistry, February 1990;

23) Estimate of the CP Violation Effects at the $\Upsilon(4S)$ Using Decay Length Differences, E. Bloom and A. Fridman, Report presented at the Snowmass meeting (1988);

24) R. Aleksan, J. Bartelt, P.R. Burchat and A. Seiden, Phys. Rev.,D39, 1283 (1989);

25) Note that with formula (1) one has $N_-(\tau_l > \tau_f) = N_+(\tau_l < \tau_f)$ and $N_-(\tau_l < \tau_f) = N_+(\tau_l > \tau_f)$.

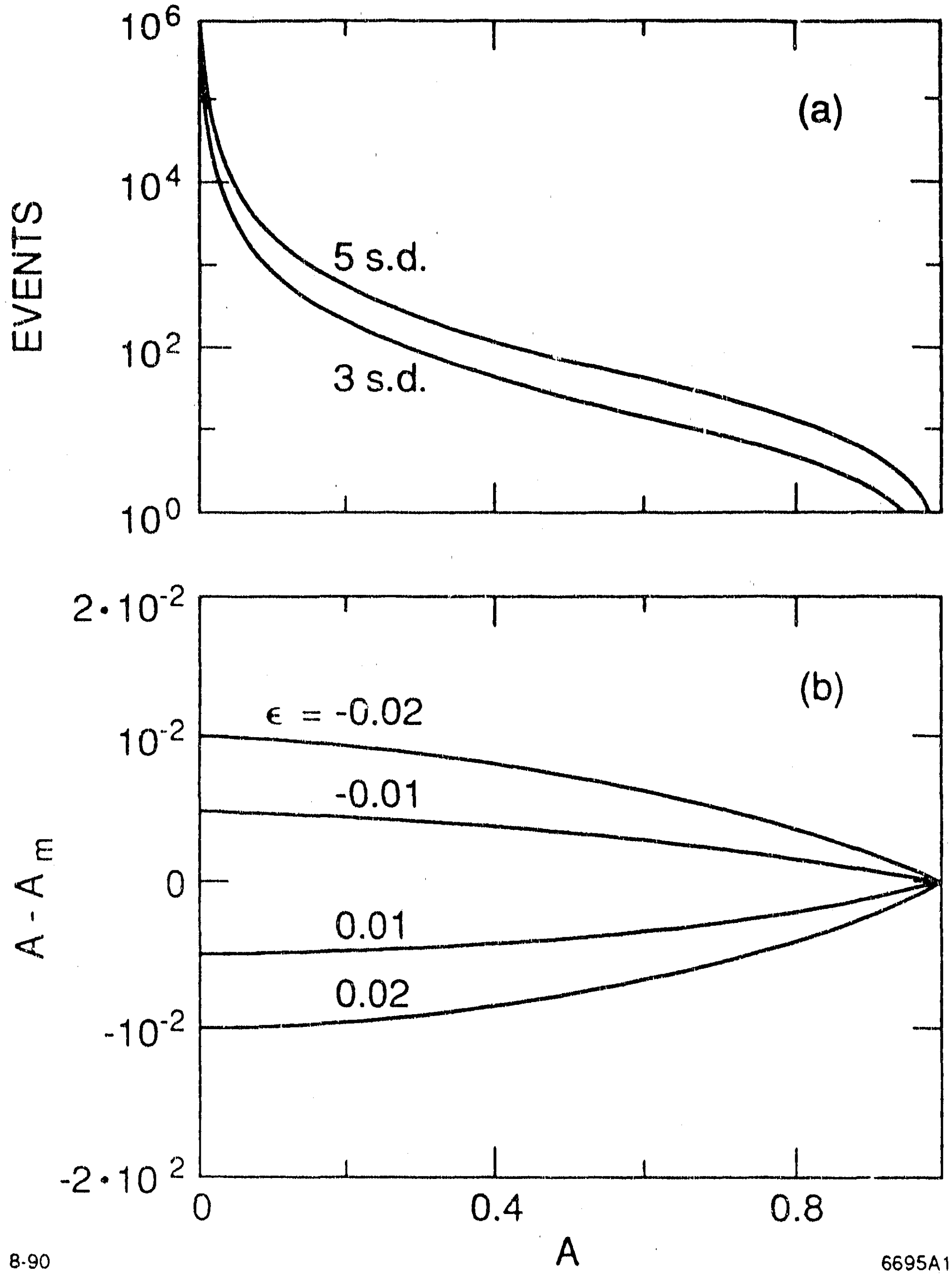

Fig 1 - a) The number of $B\bar{B} \rightarrow lfX$ events necessary to detect a given asymmetry A with 3 or 5 standard deviations. The curves are only valid for $A \leq 0.9$.
b) The $A - A_m$ as a function of A. Here A_m is the measured asymmetry due to CP violation effects and to the unequal amount of B and $\bar{B}$ production. The latter case is described by the parameter $\epsilon \neq 0$ (see text).

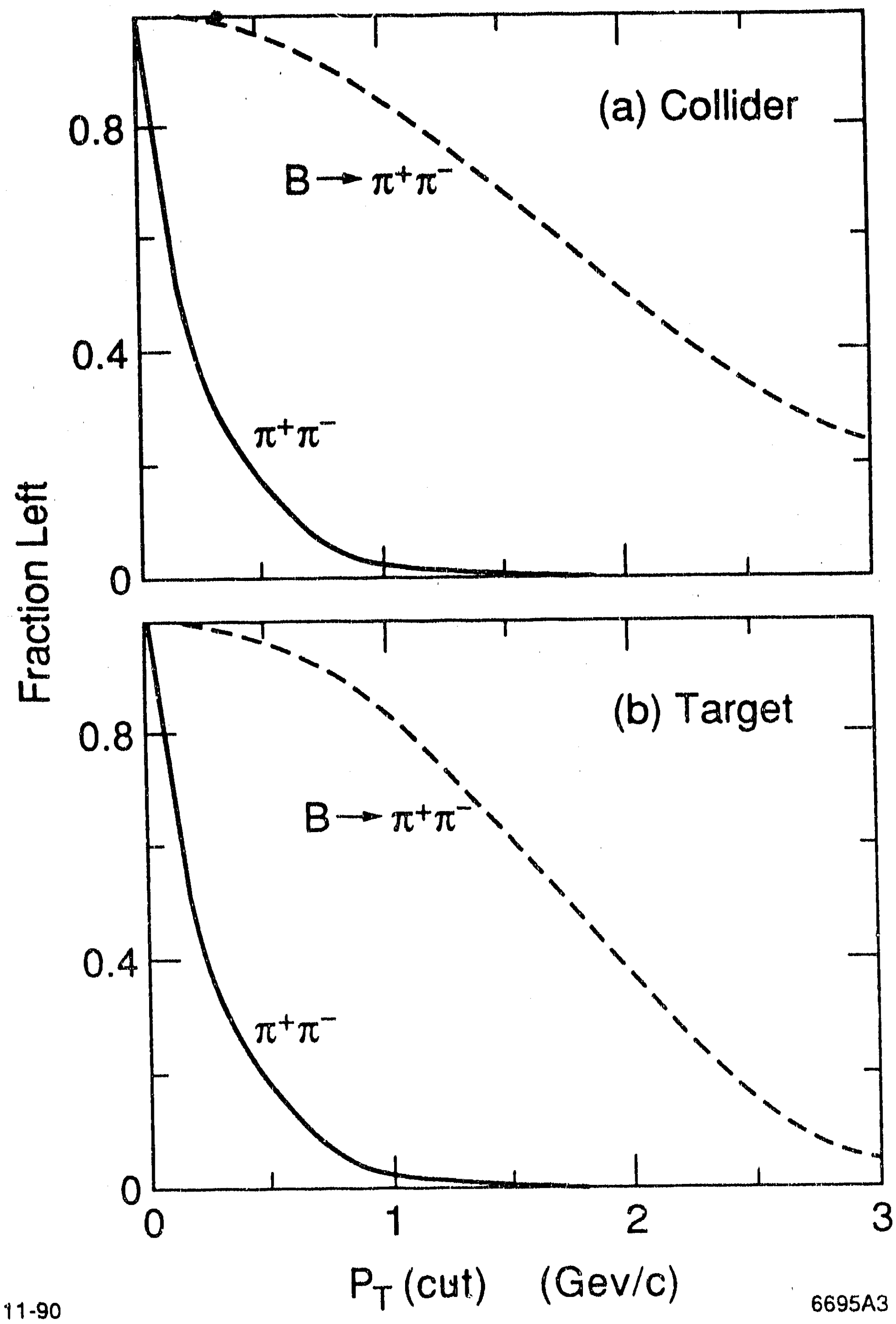

Fig. 2 - The fraction of $B \to \pi^+\pi^-$ and $\pi^+\pi^-$ background (see text) left after taking $\pi^\pm$ having a momentum transfer greater than $p_T(cut)$. The SSC collider and target are represented by (a) and (b), respectively.

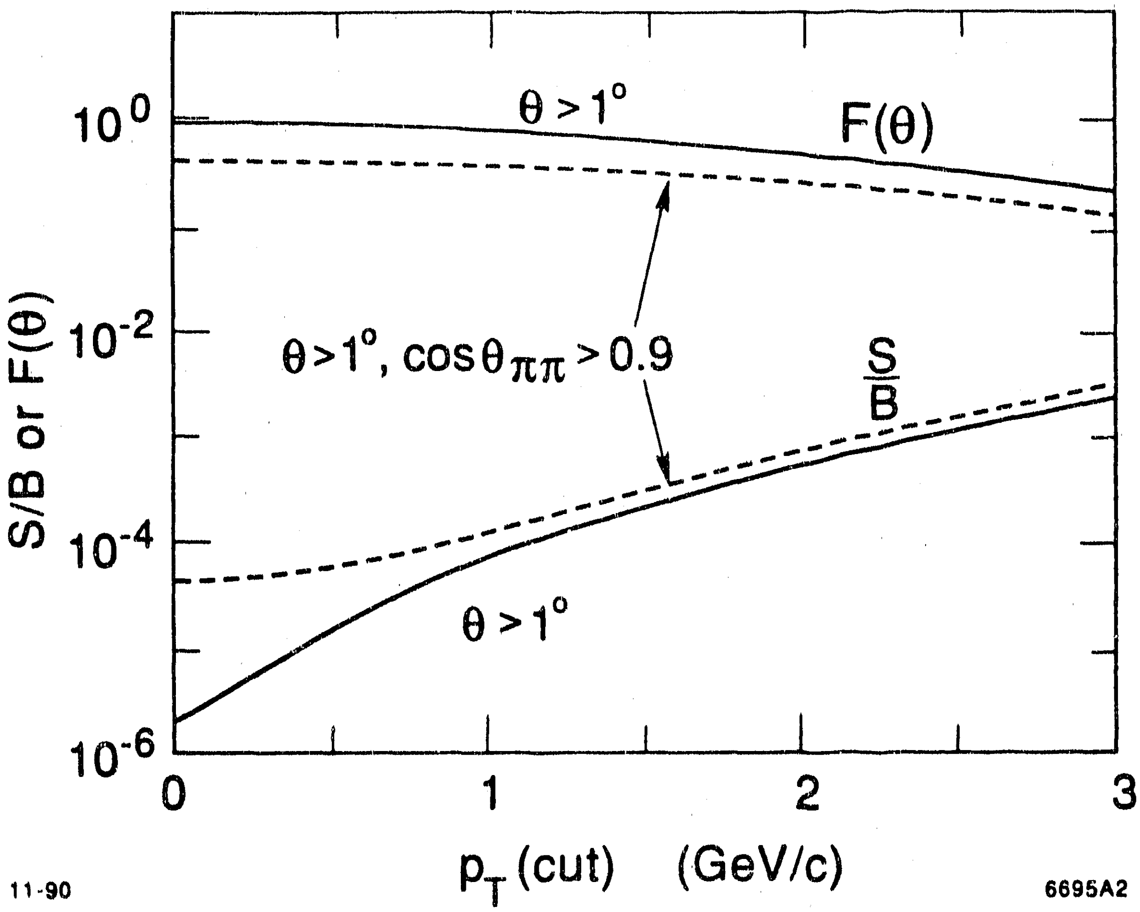

Fig. 3 - For the SSC collider the signal-to-background ratio (S/B) as a function of $p_T(cut)$ for the $B \to \pi^+\pi^-$ using also θ and $\theta_{\pi\pi}$ cuts (the two lower curves). Here θ is the angle of the $\pi^\pm$ with respect to the beam direction while $\theta_{\pi\pi}$ is the opening angle between the two pions. The upper curves indicate the fraction of $B \to \pi^+\pi^-$ ($F(\theta)$) passing the various cuts.

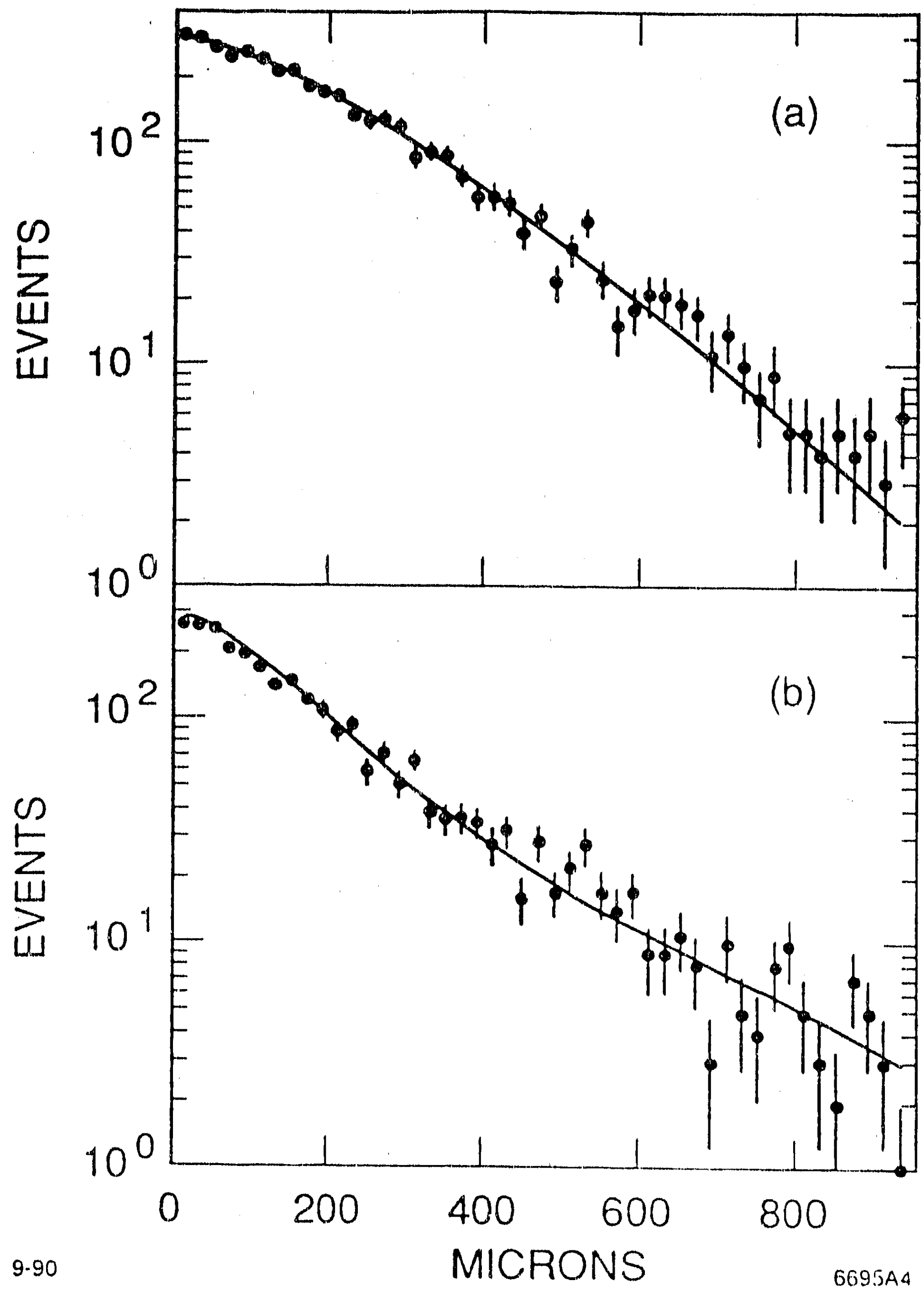

Fig 4 - The decay lenght difference between the meson decaying into the $J/\psi K_s^0$ and that used for the tagging purpose[1]. The upper plot corresponds to $\tau_{l^-} - \tau_f$, $\tau_f - \tau_{l^+} > 0$ whereas the lower plot is obtained for $\tau_{l^+} - \tau_f$, $\tau_f - \tau_{l^-} > 0$.

END

DATE FILMED

02 / 07 / 91