# B Physics with an Asymmetric Collider at KEK

K.Abe

KEK, Tsukuba, Ibaraki, Japan 305

Talk given at the meeting on Physics at TeV Scale

KEK, Japan September 1989

## Abstract

Advantages of using an asymmetric collider in studying the B Physics was described. With a machine which can provide the luminosity of $1 \times 10^{33} \mathrm{cm}^{-2} \mathrm{s}^{-1}$, we will be able to perform decisive measurements of the KM matrix element. Direct observation of the CP asymmetry in the B meson system may also be possible with this new facility. A preliminary plan for constructing such an accelerator and a detector is described.

## 1. Introduction

Recently several new results regarding the quark sector of the Standard Model were reported.[1] The MarkII reported the lower top quark mass limit of 40 GeV from the $e^+e^-$ experiment. The CDF performed an analysis of the $\bar{p}p$ event which contains electron + jet and electron + muon and reported that the limit is 80 GeV. It is expected that CDF and D0 eventually can search the top quark up to about 150 GeV. If not found by then, we must wait for SSC to turn on. Two years ago the first finite result on the $\epsilon'/\epsilon$ was reported by CERN experiment NA31.[2] Their result, $\epsilon'/\epsilon = (3.3 \pm 1.1) \times 10^{-3}$, is in good agreement with partially known KM parameters. However a new result from Fermilab experiment

E731, based on their 20% of data, gives $\epsilon'/\epsilon = (-0.5 \pm 1.5) \times 10^{-3}$. There is a difference of about three sigma and a new experiment will be required to resolve the discrepancy. The $B_d^0\bar{B}_d^0$ mixing, which was first observed by ARGUS[3] and subsequently confirmed by CLEO, is now well established experimental fact. This large mixing, $x_d = 0.73 \pm 0.18$, and also the observed large $B^0$ meson life time allow a possibility of observing the CP violation according to the KM model.

New results were also reported on the b → u transition element of the KM matrix. Both ARGUS and CLEO reported $|V_{bu}/V_{bc}|$ is the order of 0.1 from the measurement of lepton spectrum near the end point. This method requires subtraction of large numbers.There is also large model dependence in converting from the branching fraction to the KM element. Much cleaner method for getting this element requires reconstructing specific charmless non leptonic or semileptonic decay mode of the B meson. Only about 100 events out of total of 242000 $B\bar{B}$ events were fully reconstructed by CLEO. It seems we have long way before any result on $|V_{bu}/V_{bc}|$ by this method becomes available. The large $B_d^0\bar{B}_d^0$ mixing strongly suggests large $B_s^0\bar{B}_s^0$ mixing. But it will be hard to measure this quantity with the existing accelerator facilities.

2. Constraints on KM matrix

The KM matrix is described conveniently by Wolfenstein representation in which matrix elements are expanded in terms of the Cabbibo angle.[4]

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & \lambda^2 A \\ \lambda^3 A(1-\rho-i\eta) & -\lambda^2 A & 1 \end{pmatrix} \tag{1}$$

Here, $\lambda$=0.22 is the Cabbibo angle which is experimentally well established from strange particle decays, nuclear $\beta$ decays, and charm productions from $\nu$ interactions. The value of A is also reasonably well established to be $0.93 \pm 0.17$ from B meson life time and $Br(b \rightarrow cl\nu)$. However two other parameters, $\rho$ and $\eta$, are poorly known.

Figure 1 summarizes the constraint on $\rho$ and $\eta$ from various experiments. The $\epsilon$ from the neutral K decay which is experimentally well established requires knowledge of the bag factor $B_K$ and the top quark mass in order to make a meaningfull constraint. However finite and positive value of $\epsilon$ strongly suggests that $\eta$ takes a finite and positive value and therefore there exists CP violation in the B meson system. The $\epsilon'/\epsilon$ constrains the value of $\eta$ with the strange quark mass as a parameter. The $b \rightarrow u$ transition constrains $\rho$ and $\eta$ to within a width of a circle drawn from $\rho = \eta = 0$. In order to convert the branching fraction of a specific charmless decay mode to $V_{bu}$, model dependent parameters must be introduced. However, by measuring several different decay modes, these parameters can be well understood. Therefore the $b \rightarrow u$ transition can provide a clean measurement of $\rho$ and $\eta$. A constrained region coming from $x_d$, which is determined from the $B_d^0\bar{B}_d^0$ mixing is a width of a circle drawn from $\eta = 0$ and $\rho = 1$. But this requires a knowledge of $B_B f_B{}^2 m_t{}^2$. If we can determine $x_s$ from measuring the $B_s^0\bar{B}_s^0$ mixing, however, all these parameters cancel and the ratio $x_s/x_d$ is described by only KM elements.

Thus, decisive measurements on the $b \rightarrow u$ and the $B_s^0\bar{B}_s^0$ mixing completely determine the KM element. Then every aspect of the weak decay of quarks can be calculated from the KM model. One of the most important prediction is an existence of the CP violation in the B meson system. With a sufficient luminosity, direct observation of the CP violation might become possible. A comparison between the measurement and the prediction will be extremely interesting for our understanding the origin of the flavor and the CP violation.

## 3. Advantage of Asymmetric Collider

Present study of B meson decays is almost exclusively done by the $e^+e^-$ experiment at the $\gamma(4S)$, because it is a clean source of $B\bar{B}$ mesons. The production cross section is much larger here than in the continuum. However, here B and $\bar{B}$ mesons are produced almost at rest and typically five charged and five neutral tracks are produced from one B meson. Thus ten charged and neutral tracks emerge from the interaction point. It is difficult to sort out which tracks are associated with which B meson, making a full event reconstruction difficult. In an asymmetric collider, in which 12GeV $e^+$ and $2.33 GeV e^-$ collide for example, the CM energy is still the same as the $\gamma(4S)$ ,but the CM is moving in the lab frame. This causes B and $\bar{B}$ mesons move before they decay. The decay length in this case is about $300\mu$, which is long enough so that not only we can measure two vertex points but also we can observe time evolution of neutral B mesons using existing micro vertex detector technology. Advantage of this scheme over the conventional symmetric collider in reconstructing events is obvious. Observing the time evolution of neutral B meson decay is essential for measuring the $B_s^0\bar{B}_s^0$ mixing. This scheme also allows measurements of CP asymmetry occuring through mixing of the initial state, which are believed to produce larger observable effect compared with other types.[5]

The $x_d$ in the $B_d^0\bar{B}_d^0$ mixing was determined by measuring

$$r_d = \frac{N(l^{\pm}l^{\pm})}{N(l^{+}l^{-})} \tag{2}$$

where $N(l^{\pm}l^{\pm})$ and $N(l^{+}l^{-})$ are the yield of same sign and opposite sign dilepton events. The $x_d = \Delta m/\Gamma$ was then determined from a relation

$$x_d = \sqrt{\frac{2r}{(1-r)}} \quad (3)$$

As can be seen in Figure 2, this method works fine when r is relatively small. This is the case of the $B_d^0\bar{B}_d^0$ mixing. However, since $x_s$ is proportional to $x_d|V_{ts}|^2/|V_{td}|^2$, it is likely to take a large value. Using presently availabe constraints on the KM matrix, an expected value is 6±3. Accurate determination of $x_s$ from the r mesurement will be difficult in this range.

In an experiment using the asymmetric collider, on the other hand, we can measure the time evolution of the same sign dilepton event. A probability to observe a same sign dilepton event, one lepton at $t_1$ and the other at $t_2$ is given by

$$P(l^{\pm}l^{\pm}) = \exp(-\frac{t_1+t_2}{\tau}) \times \sin^2(\frac{x_s}{2}\frac{t_2-t_1}{\tau}) \quad (4)$$

for L=odd, where L is the angular momentum of initially produced $B\bar{B}$ system. In the case of L=even, $(t_2-t_1)$ inside the sin term is replaced by $(t_2+t_1)$. The exact content in $\gamma(5S)$ is not well known, but one can expect that it contains L=even states such as $B_d\bar{B}_d^*$ and $B_s\bar{B}_s^*$ as well as L=odd states such as $B_d\bar{B}_d$, $B_s\bar{B}_s$, $B_d^*\bar{B}_d^*$, and $B_s^*\bar{B}_s^*$. So the oscillation frequency induced by the $x_s$ must be extracted from the $(t_2-t_1)$ dependence of the same sign dilepton yield which has an oscillation pattern contributed by all channels.

Figure 3 shows a result of a Monte Carlo study. The number of same sign dilepton events corresponds to data taken at $\gamma(5S)$ for one year($10^7$ seconds) with a luminosity of $1 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. We generated events with $x_s = 10$. Using a vertex detector with a resolution $\sigma_z = 40\mu$, we obtained a yield as a function of $\Delta t = t_2 - t_1$ normalized by the B life time. An oscillation pattern caused by $x_s$=10 is clearly observable above the background. Our study indicates that $x_s$ as large as 15 can be measured by this method.

Advantage of the asymmetric collider over the symmetric collider, such as CESR, or the LEP is also noticeable in the measurement of the CP violation. As an example, we consider here CP asymmetry between $B_d^0 \to \psi K_s$ and $\bar{B}_d^0 \to \psi K_s$. This is one of the most prominent channel in a category where CP asymmetry appears through mixing of the initial state.

When $B_d^0 \bar{B}_d^0$ is produced at $\gamma(4S)$, it is in L=odd states. Since they are both spin 0 particle, they obey the Bose-Einstein statistics. As a consequence their time evolution takes place coherently. Thus, when one side is identified as $B_d^0$ from its decay at $t = t_1$, the other side must be $\bar{B}_d^0$. By observing its decay at $t = t_2$, we can observe a time evolution of $\bar{B}_d^0$ for a time period of $(t_2 - t_1)$. By reconstructing $\psi K_s$ at $t_2$ and determining whether it was $B_d^0$ or $\bar{B}_d^0$ at $t_1$ from the tagging of the other side, we can measure the rate of $B_d^0(\bar{B}_d^0)$ evolving to $\psi K_s$ in $(t_2 - t_1)$. They must obey following relations.

$$R(B_d^0 \to \psi K_s) \propto e^{-\Gamma(t_1+t_2)}[1 + \sin\phi \sin\Delta m(t_2 - t_1)] \tag{5}$$

$$R(\bar{B}_d^0 \to \psi K_s) \propto e^{-\Gamma(t_1+t_2)}[1 - \sin\phi \sin\Delta m(t_2 - t_1)] \tag{6}$$

The result of a Monte Carlo study performed by Aleksan *etal.*[6] is shown in Figure 4. Number of events corresponds to data accumulated for one year of running at $\gamma(4S)$ with a luminosity $10^33\mathrm{cm}^{-2}\mathrm{s}^{-1}$. In generating the event, $\mathrm{Br}(\mathrm{B}_d^0 \to \psi\mathrm{K}_s) = 5 \times 10^{-4}$, and $\sin\phi = -0.40$ were used. By simultaneously fitting the time evolution patterns to equations (5) and (6), $\sin\phi = -0.41 \pm 0.06$ was obtained.

In order to increase the sensitivity on $\sin\phi$ measurement, it is important to have a good reconstruction efficiency of $\psi\mathrm{K}_s$, a good z vertex measurement for $(t_2 - t_1)$ determination, and a good tagging efficiency of the other B. For all these three items, the asymmetric collider is preferable compared with the symmetric collider or the Z factory. At the symmetric collider, since decay time cannot be measured, one must integrate the relation in Eq.5 and Eq.6 by both $t_1$ and $t_2$. Then the rate in $\mathrm{B}_d^0 \to \psi\mathrm{K}_s$ and $\bar{\mathrm{B}}_d^0 \to \psi\mathrm{K}_s$ becomes same and no CP asymmetry appears. In order to see the CP asymmetry in this channel, one must run at the energy where $\mathrm{B}_d^0\bar{\mathrm{B}}_d^{0*}$ are produced. Here the state has L=even and $(t_2 - t_1)$ in Eq.5 and 6 becomes $(t_1 + t_2)$, and integration by both $t_1$ and $t_2$ still produce a finite CP asymmetry. However $\mathrm{B}_d^0\bar{\mathrm{B}}_d^{0*}$ state must be separated from $\mathrm{B}_d^0\bar{\mathrm{B}}_d^0$ and $\mathrm{B}_d^{0*}\bar{\mathrm{B}}_d^{0*}$, which makes this method rather difficult.

In an experiment at LEP, one can measure an absolute decay length of B mesons from the primary vertex which is supposed to be accompanied with about five charged tracks and five neutral tracks in LEP energies. And the decay length is the order of 2 mm as compared with $300\mu$ of the asymmetric collider. The $(t_2 - t_1)$ and $(t_2 + t_1)$ terms will be replaced by just t. However two B's evolve incoherently in this case, reducing the tagging efficiency. If the beam can be polarized, one can use a large forward-backward asymmetry in $e^+e^- \to b\bar{b}$ for the tagging. Table 1 summarizes number of years needed to measure the CP asymmetry as a $3\sigma$ effect when $\sin\phi$ takes a value between 0.1 and 0.6.

4. Construction of Asymmetric Collider

Various schemes were considered to construct an asymmetric collider using as many parts of the existing KEK facilities as possible. Most prominent scheme so far is the one in which both 12GeV ring and 2.3 GeV ring are housed inside the present Main Ring tunnel. They are both dedicated storage rings and no acceleration is done by these rings. The 2.3 GeV beam will be injected from the present linac directly. The 12 GeV beam must be supplied from a new booster which takes 2.3 GeV beam from the linac and accelerate up to 12 GeV. This new booster ring can be constructed also inside the Main Ring tunnel. According to a prelimenary design by K.Sato, it is necessary to inject 320 bunches in both 12GeV and 2.3GeV rings in order to reach $1 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ luminosity.

5. Detector

Because tracks from $B\bar{B}$ decays are boosted along the direction of the 12GeV beam, good angular coverage down to $\theta = 10°$ is required. On the other hand, only 2% of tracks go into the region between 135° and 180°. Thus the detector will become somewhat asymmetric. One possible design is shown in Figure 5. Various detector components are arranged by using the existing VENUS superconducting solenoid magnet which can provide up to 1 Tesla.

6. Schedule

For both accelerator and detector, it will require about one more year of study before we can finalize the desin. Then it will take additional two years to build various components. Until these are done, possibly by the end of 1992, we will not disturb the operation of present TRISTAN experiments. We then will be ready to stop the Main Ring running and start to install accelerator components and assemble the detector, which will take about one year. After an extensive machine tuning and detector debugging for one year, we will be ready to take data by 1995.

## 7. Summary

It is not likely that existing facilities can provide decisive informations about the quark sector of the Standard Model. By building an asymmetric collider, in which $e^+$ and $e^-$ of different energy collide and produce $\gamma(4S)$ and $\gamma(5S)$ in the moving CM system, we can make decisive measurements of the $|V_{bu}/V_{bc}|$ and the $B_s^0\bar{B}_s^0$ mixing. These together with the $B_d^0\bar{B}_d^0$ mixing completely determine the KM matrix element. Direct observation of the CP violation in the B meson system will be almost within reach if a newly constructed accelerator can provide a luminosity greater than $1 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Comparisons between the measured CP asymmetry and the prediction from the KM matrix might provide a hint of new physics before the SSC becomes operational.

## REFERENCES


1) Talks presented in the 14th International Symposium on Lepton and Photon Interactions, Stanford, August 1989

2) H.Burkhardt *etal.*, Phys. Lett. **B206**, 169 (1988)

3) A.Albrecht *etal.*, Phys. Lett. **B192**, 245 (1987)

4) L.Wolfenstein, Phys.Rev. Lett. **51**, 1945 (1983)

5) G.J.Feldman *etal.*, Proceedings on High Energy Physics in The 1990's, Snowmass, Colorado 1988

6) R. Alexan *etal.*, Phys.Rev. **D39**, 1283 (1989)


Table 1

Number of years ( one year is $10^7$ sec) needed to measure $\sin\phi$ with $3\sigma$ effect when $\sin\phi$ takes a value between 0.1 and 0.6 in $\psi k_S$ final state

| CLEO | Asym-collider | LEP | polarized LEP |
|---|---|---|---|
| $2\times10^{32}cm^{-2}s^{-1}$ | $1\times10^{33}$ | $1.5\times10^{31}$ | $1.5\times10^{31}$ |
| 4.4-154 yrs | 0.5-18 | 45-1650 | 9-330 |

## Figure Captions

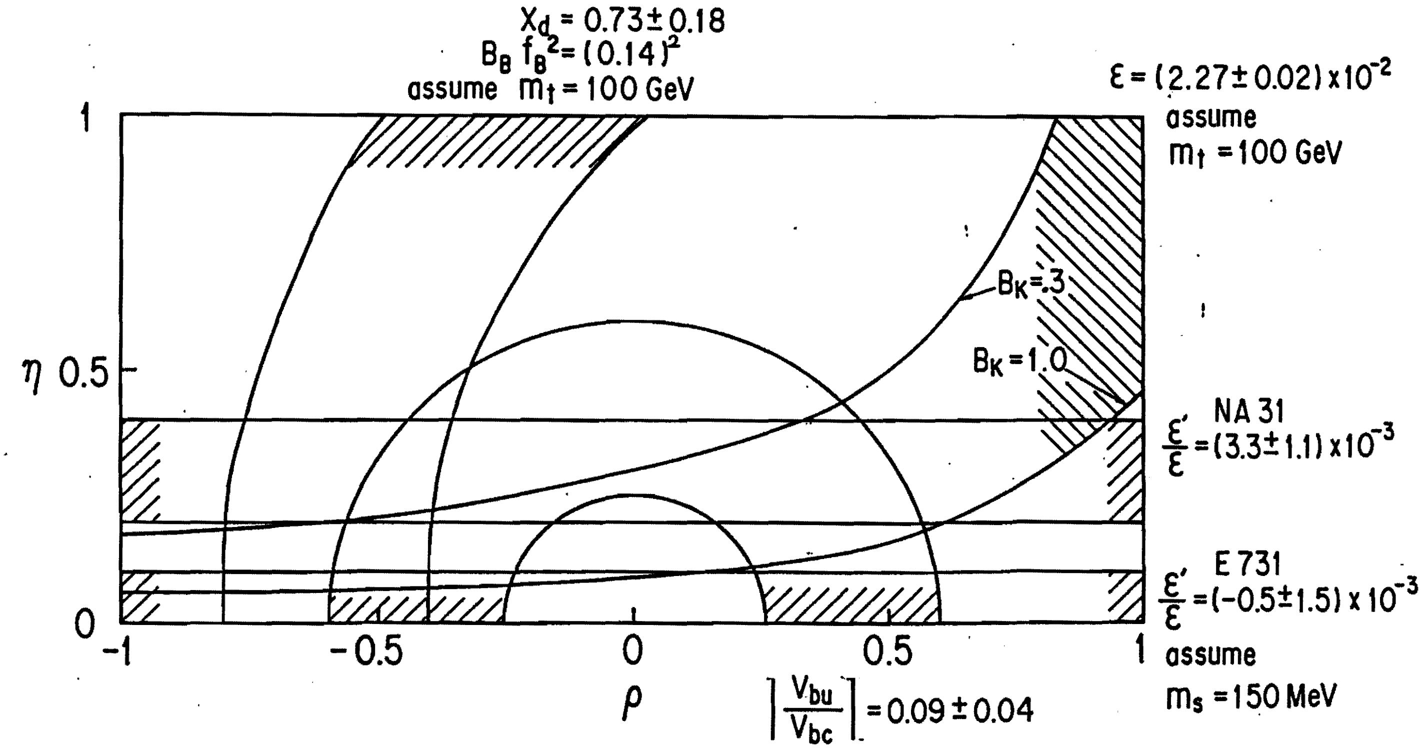
**Figure1** Allowed region in th $\rho - \eta$ plane from presently available experiments.

**Figure2** Relation between x and r. As the r value becomes larger, the precise determination of x from measurement of r becomes difficult.

**Figure3** A result of a Monte Carlo study on determining the $B_s^0\bar{B}_s^0$ mixing from measuring the time evolution of the same sign dilepton yield.

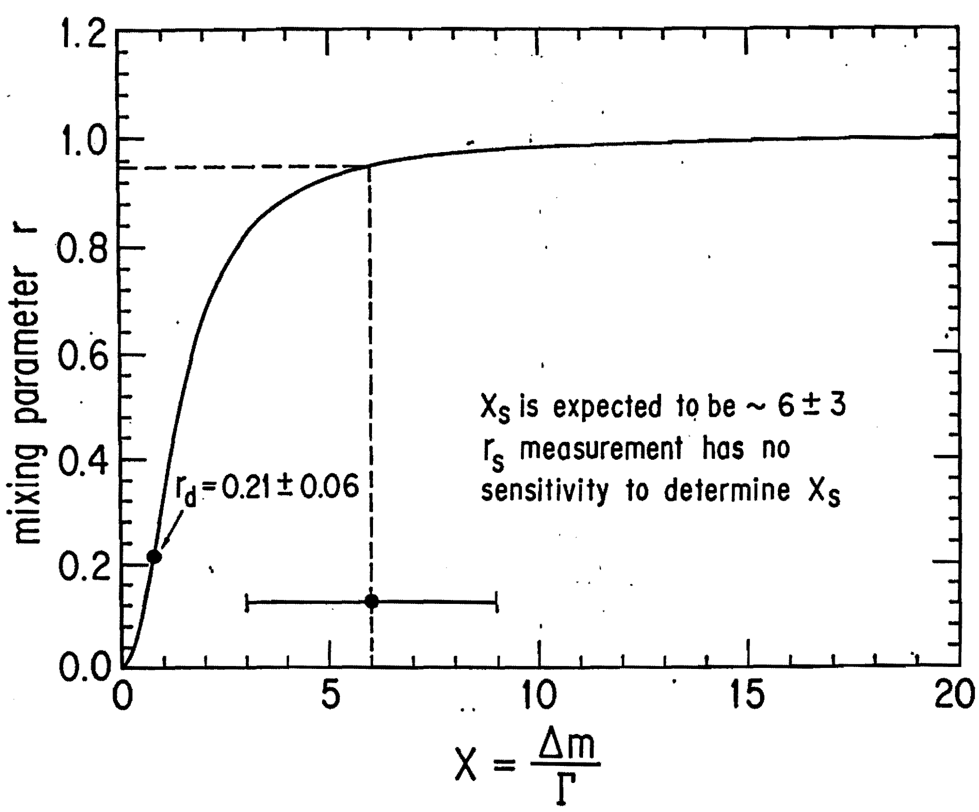
**Figure4** A result of a Monte Carlo study by Aleksan *etal.* on the CP asymmetry in the $B_d^0(\bar{B}_d^0) \rightarrow \psi K_s$.

**Figure5** One possible design for the Asymmetric collider detector which uses the VENUS solenoid.



$X_d = 0.73 \pm 0.18$
$B_B f_B^2 = (0.14)^2$
assume $m_t = 100$ GeV
$\varepsilon = (2.27 \pm 0.02) \times 10^{-2}$
assume
$m_t = 100$ GeV
$B_K = .3$
$B_K = 1.0$
NA 31
$\frac{\varepsilon'}{\varepsilon} = (3.3 \pm 1.1) \times 10^{-3}$
E 731
$\frac{\varepsilon'}{\varepsilon} = (-0.5 \pm 1.5) \times 10^{-3}$
assume
$m_s = 150$ MeV
$\eta$
$\rho$
$\left|\frac{V_{bu}}{V_{bc}}\right| = 0.09 \pm 0.04$


Fig. 1



mixing parameter r
$X_s$ is expected to be ~ $6 \pm 3$
$r_s$ measurement has no
sensitivity to determine $X_s$
$r_d = 0.21 \pm 0.06$
$X = \frac{\Delta m}{\Gamma}$


Fig.2

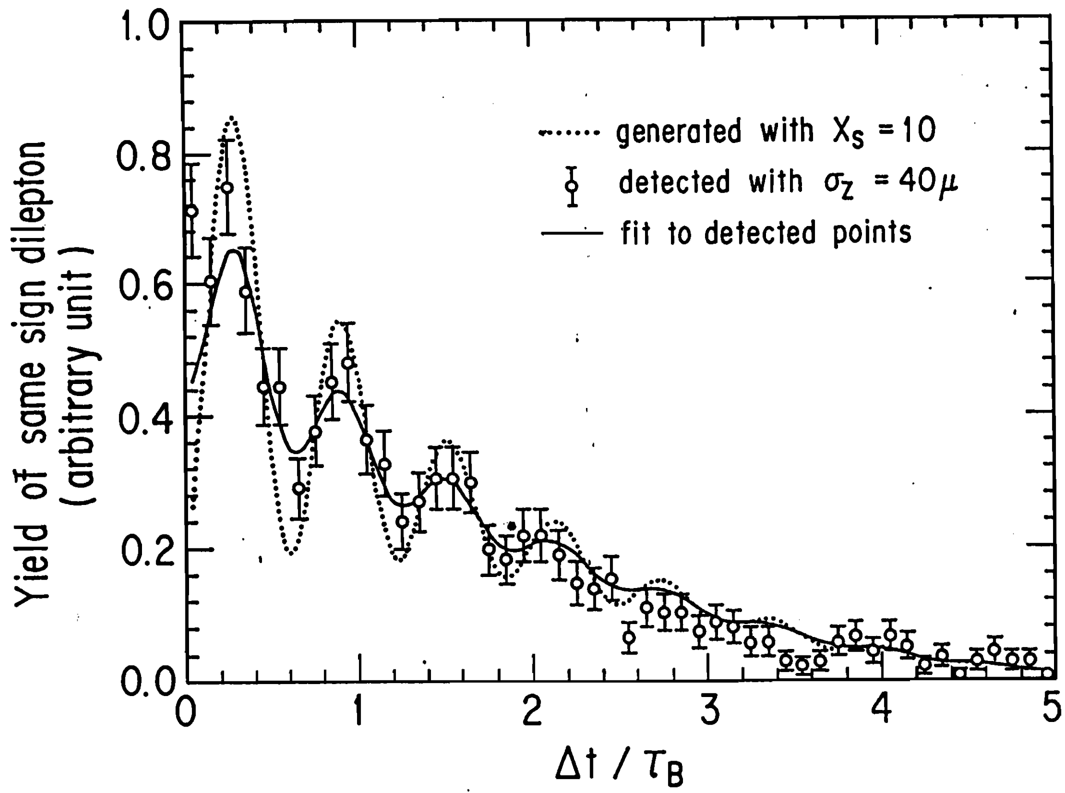

generated with $X_S = 10$
detected with $\sigma_Z = 40\mu$
fit to detected points
Yield of same sign dilepton (arbitrary unit)
$\Delta t / \tau_B$

Fig. 3

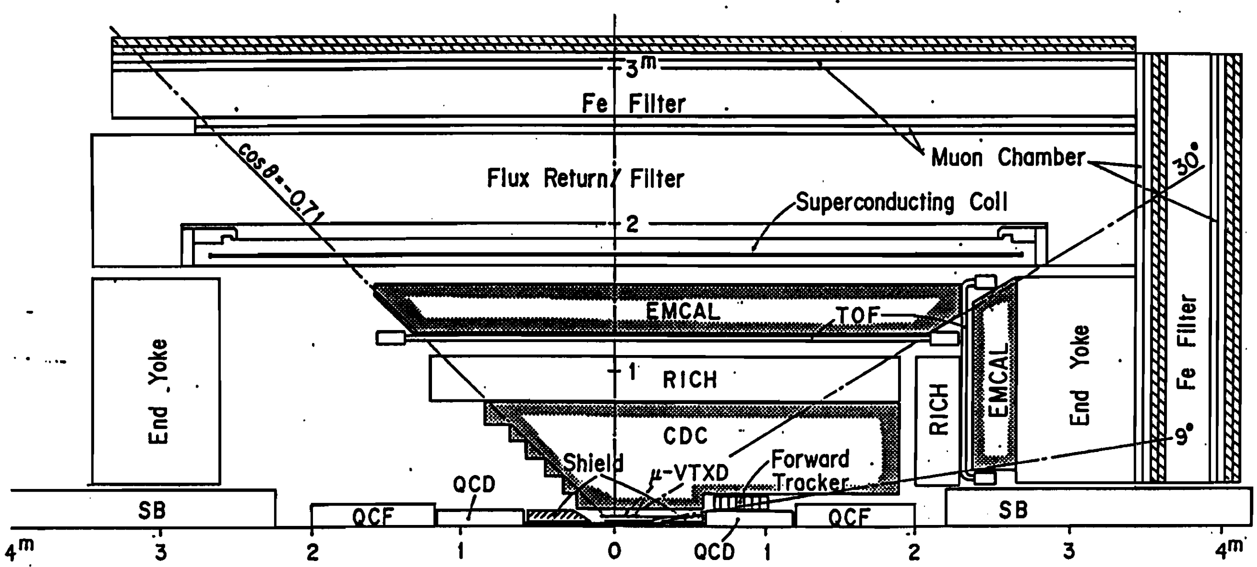
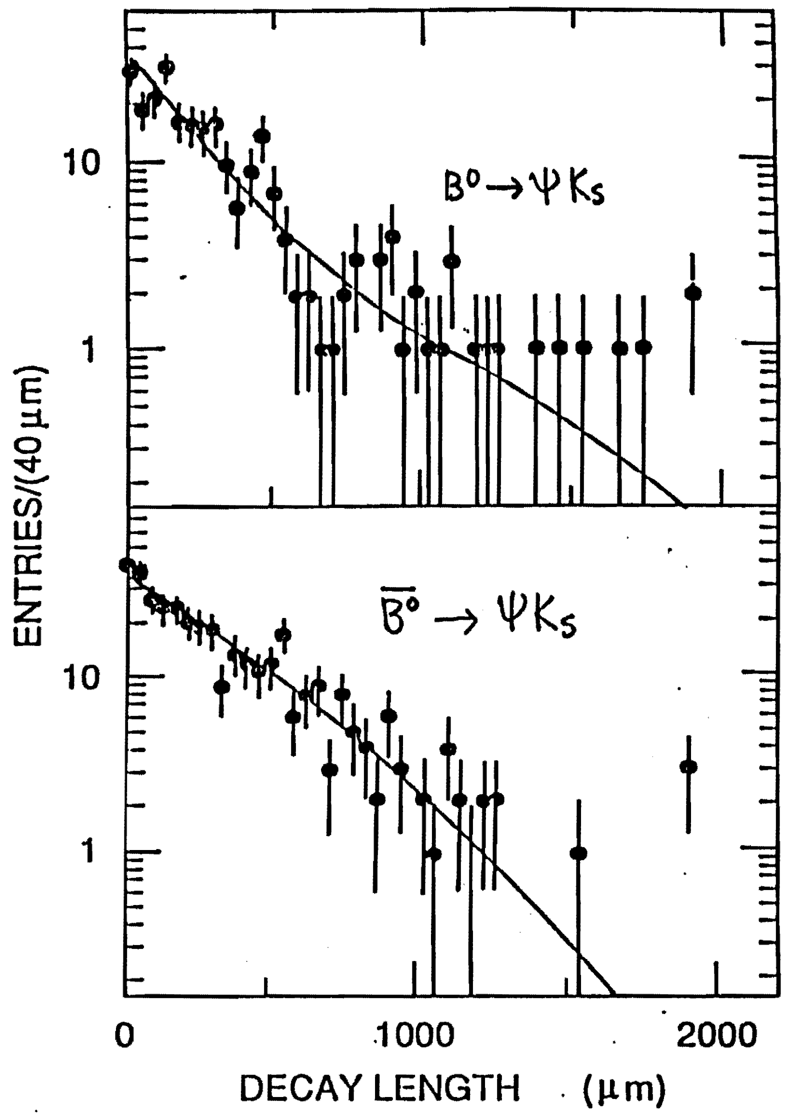

Fe Filter
Flux Return/ Filter
Muon Chamber
Superconducting Coil
$\cos\theta = -0.71$
30°
EMCAL
TOF
End Yoke
RICH
CDC
Shield
$\mu$-VTXD
Forward Tracker
9°
QCD
SB
QCF

Fig. 5



ENTRIES/(40 μm)
10
1
$B^0 \to \psi K_s$
10
1
$\overline{B}^0 \to \psi K_s$
0
1000
2000
DECAY LENGTH (μm)


Fig. 4