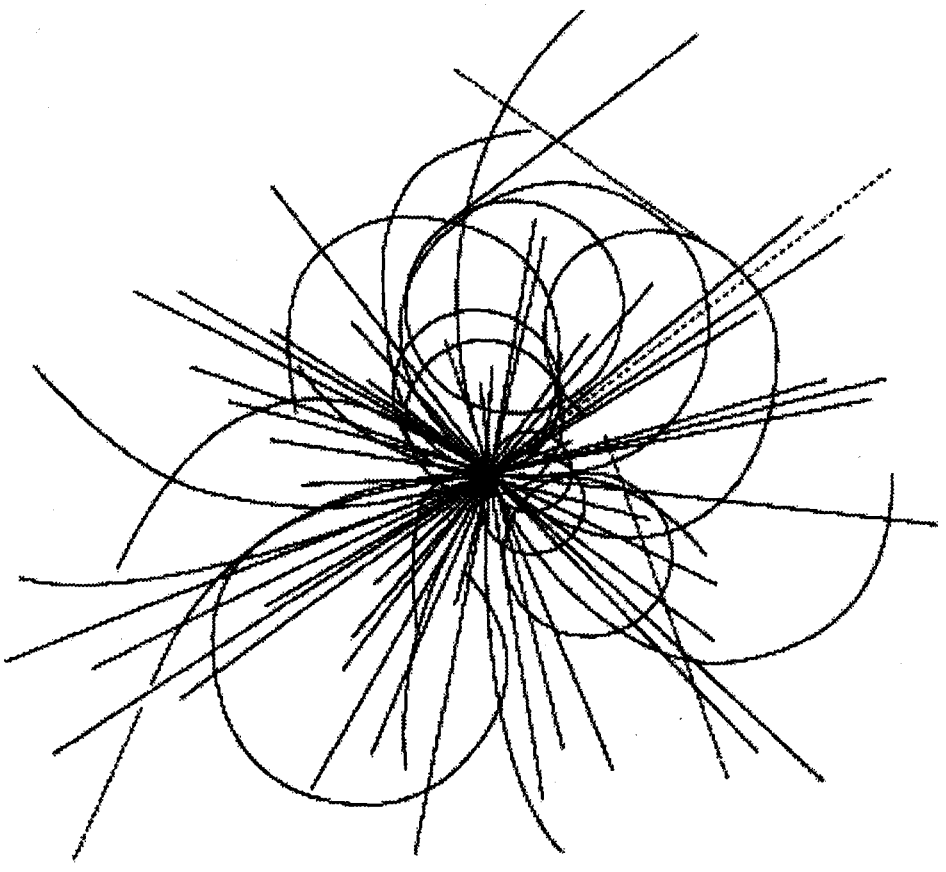
SSCL-Preprint-530

SSCL-Preprint-530
June 1993
Distribution Category: 41-

D. Coupal

Prospects for Measuring CP Violation in SDC Using $B_d^0 \to \psi K_S^0$



Superconducting Super Collider Laboratory

SSCL-Preprint-530

Prospects for Measuring CP Violation in SDC Using $B_d^0 \to \psi K_S^0$

D. Coupal

Superconducting Super Collider Laboratory†
2550 Beckleymeade Ave.
Dallas, TX 75237, USA

June 1993

*Presented at the Workshop on B Physics at Hadron Accelerators, June 21–July 2, 1993, Snowmass, Colorado.
†Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

Prospects for Measuring CP Violation in SDC Using $B_d^0 \to \psi K_S^0$

DAVID P. COUPAL

Superconducting Super Collider Laboratory,
2550 Beckleymeade Avenue, Dallas, TX 75237

1. INTRODUCTION

This note describes results of a study of acceptance and backgrounds in the SDC detector for the neutral B meson decay $B_d^0 \to \psi K_S^0$. The aim here is to explore the possibility of observing CP violation in the B system – a significant physics measurement that may be possible at the SSC during the period of time when the accelerator is ramping up to design luminosity.

Section 2 describes the theoretical predictions for $b\bar{b}$ quark production at the SSC and the signal for CP violation in the B meson system. The following section outlines the cuts used to isolate $B_d^0 \to \psi K_S^0$ decays and presents the expected rates for signal and background. The next section discusses the sensitivity to CP violation parameters and the final section contains some additional comments.

2. $b\bar{b}$ PRODUCTION AND CP VIOLATION

Berger and Meng[1] present calculations of the $b\bar{b}$ production up to SSC energies based on next-to-leading-order QCD hard scattering cross sections.[2] At $\sqrt{s} = 40TeV$ they find a total cross section of 1-3 mb. A central detector like SDC would probably trigger on the p_t components of the b quark decay products (at least at level 1). We therefore limit the study to b quarks with p_t greater than 10 GeV/c, a region dominated by higher-order gluon splitting diagrams. Berger and Meng predict a cross section $\sigma(pp \to bX, p_T(b) > 10) = 80 - 170\mu b$ with resummation effects boosting it to around ~ 250 μb. This number will be used in the signal and background estimates that follow.

We look for CP violation in the decay of the neutral B_d^0 meson to the CP eigenstate ψK_S^0. The time-integrated asymmetry is:

$$A = \frac{N - \bar{N}}{N + \bar{N}} = \frac{x_d}{1 + x_d^2} sin2\beta \tag{2.1}$$

The sensitivity to $sin2\beta$ is diluted due to mixing ($x_d = \Delta m_d/\Gamma_d$ = degree of mixing in B_d^0). The above equations assume a knowledge of the initial state(B^0 or $\bar{B}^0$). In practice one uses the fact that b and $\bar{b}$ are pair produced and tags the flavor of the B meson by observing the sign of the lepton in the semileptonic decay of the other B. This demand introduces additional dilution due to mixing of the tagging B meson and mistagging contributions from cascade decays or detector limitations (e.g. π or K decay, punchthrough, etc.). The measured asymmetry can be written $A_{meas} = (1 - 2\omega)A$ where ω is the fraction of wrong tags from mixing, cascade decays and detector effects .

The probability of mistagging from mixing of the tagging B meson is $\omega_{mix} = \alpha \times F_B$ where

$$\alpha = .5 \times f_s + f_d \times \frac{x_d^2}{2 + 2x_d^2} \tag{2.2}$$

is the probability of mixing, F_B is the relative fraction of tags from B semileptonic decays and f_s and f_d are the relative fractions of B_s^0 and B_d^0 production. B_s^0 is assumed to be fully mixed. For tags from cascade decays to charm, a wrong-sign tag is produced only if the initial B meson does not mix, otherwise a correct sign tag will result. Therefore the cascade term is $\omega_{cascade} = (1-\alpha)F_C$ where F_C is the fraction of tags from charm. Similarly, decay in flight and punchthrough backgrounds will have a random charge so $\omega_{decay} = F_D/2$ and $\omega_{punch} = F_P/2$ where F_D and F_P are the decay in flight and punchthrough fractions, respectively. Assuming relative fractions: $f_\pm : f_d : f_s : f_\Lambda = 0.38 : 0.38 : 0.14 : 0.10$ and $x_d = .7$, then $\alpha = .132$. An estimate of the tagging fractions (F_B,etc.) derived from a Monte Carlo simulation of the detector response is given in section 5.

3. CP VIOLATION SIGNAL

Bottom quark production via gluon splitting was simulated with ISAJET by generating lowest order parton-parton scattering to non-b partons and accepting only events in which a b quark with $p_t > 10 GeV/c$ is produced in the parton shower. This study used the decays $B_d^0 \rightarrow \psi K_S^0$, $\psi \rightarrow \mu^+\mu^-$and tagged the flavor using the semileptonic decay $B \rightarrow \mu + X$. K_S^0's were required to decay to $\pi^+\pi^-$. Half of the MC data sample selected on the $\bar{b}$ quark rather than the b. The mean p_t of the B_d^0 is ~12 GeV/c; the mean momentum is ~27 GeV/c.

Fig. 3.1 shows the SDC detector, with tracking, calorimetry and muon identification out to $|\eta| < 2.5$. For triggering and eliminating low p_t backgrounds such as π and K decay we impose a minimum p_t cut on the muons. For events with all 3 muons within $|\eta| < 2.5$, Fig. 3.2 shows the acceptance versus the minimum p_t cut for one, two or all three muons passing the cut. The acceptance for 3 muons with $p_t > 5$ is roughly equal to requiring 2 muons with $p_t > 10$ or one muon with $p_t > 20$. The effect of different combinations of p_t cuts is discussed further in section 5.

The B meson is reconstructed by first taking opposite sign muon pairs to reconstruct the J/ψ. A cut of $\pm 50 MeV/c^2$ around the J/ψ mass is used. The J/ψ are combined with K_S^0's in the event that satisfy $|\eta| < 2.5$ and $p_t > 1.0$ GeV/c. K_S^0 were required to decay within a cylinder of .33 meter radius (layer 6 of SDC silicon barrel) and .33 meter in z (layer 1 of forward disks) to insure efficient K_S^0 reconstruction. The $\pi^+\pi^-$ are not tracked to insure that they are within the η acceptance (though we do so for the parent K_S^0) so there will be a small additional loss in acceptance due to this approximation. Cuts on $p_t(K_S) > 1.0$ and $\cos(\Theta(J/\psi, K_S)) > .8$, where Θ is the angle between the J/ψ and the K_S^0, remove much of the background discussed in the next section.

The contributions to the total rate for $B_d^0 \rightarrow \psi K_S^0$ in SDC are given in Table 3.1. Assuming a run of 10^7 seconds at a luminosity of $10^{32} cm^{-2} sec^{-1}$(.1 × design) and a b quark production cross section of $\sigma(b\bar{b}, p_t(b) > 10 GeV/c) = 250 \mu b$, the above acceptance predicts a sample of 1050 events.

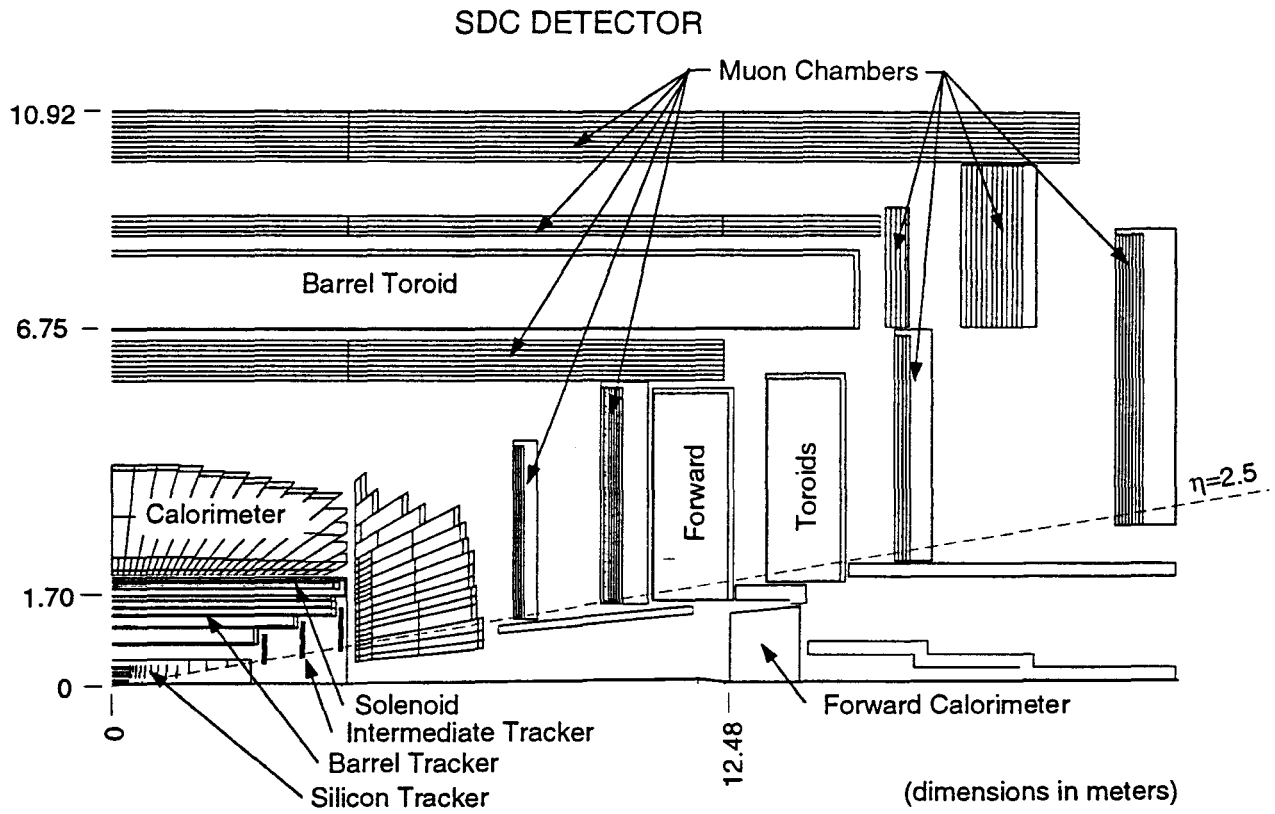


Figure 3.1: The SDC detector.

4. BACKGROUNDS

The large $b\bar{b}$ cross section at SSC (1-3 mb) implies of order 2×10^{12} produced $b\bar{b}$ pairs. Hence, even limiting consideration to backgrounds from b quarks, there is the computational problem of generating such a large number of events and one must make guesses of modes likely to contribute to the 3μ final state. The backgrounds considered in this study are:

1. Muons from semileptonic decay of b or $\bar{b}$.
2. Muons from semileptonic decay of c or $\bar{c}$.
3. Muons from π or K decay.
4. Inclusive J/ψ production in B meson decay together with a tagging muon from above sources.

Punchthrough is a possibly significant background not studied in this analysis.

Pion and kaon decay-in-flight backgrounds are evaluated by assigning a weight corresponding to the probability of decay to $\mu+X$ before the calorimetry, assigning the direction of the decay muon to be the same as the parent, the p_t to be .79 (.53) of parent π (K) and assuming that all such muons are identified in the muon system. The $p_t > 5$ cut eliminated much of the π and K decay background so we do not consider events where all 3 muons come from this background source. Given the 3 background muons, we apply the

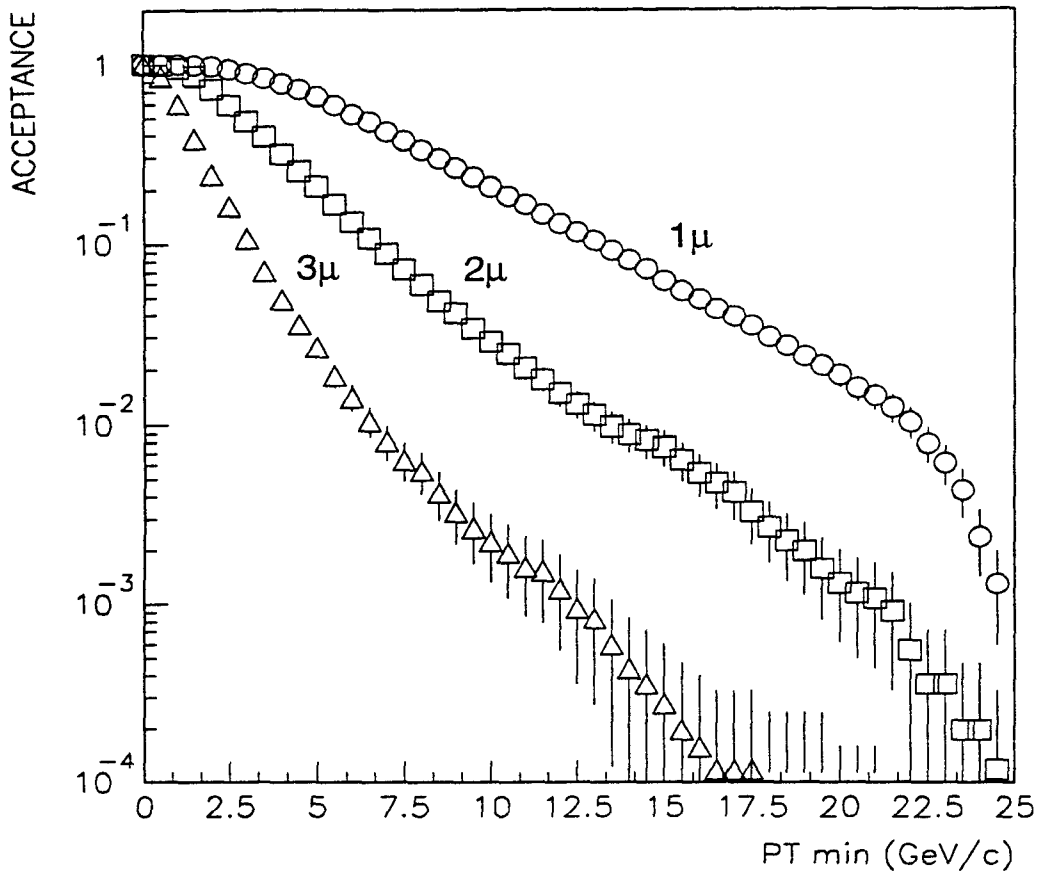


Figure 3.2: Acceptance versus minimum p_t after requiring that the 3 final state muons fall within $|\eta| < 2.5$ for one, two or three muons above p_t cut.

Table 3.1: Contributions to the rate for $B_d^0 \to \psi K_S^0$ detected in SDC

Contribution	Acceptance factor
$b \to \bar{B}_d^0$ or $\bar{b} \to B_d^0$	$.38 \times 2$
$B_d^0 \to \psi K_S^0, \psi \to \mu^+\mu^-, K_S^0 \to \pi^+\pi^-$	1.9×10^{-5}
$b \to \mu + X$	.12
3μ's with $\eta < 2.5$	.46
3μ's with $p_t > 5$ GeV/c	.025
K_S^0 with $\eta < 2.5, p_t > 1$ GeV/c	.91
K_S^0 decaying within $r < 33cm, z < 33cm$	.50
$cos\Theta(J/\psi, K_S^0) > .8$	.90
Tracking and μ id efficiency	$(0.80)^3$
Total	4.2×10^{-9}

same reconstruction outlined in the previous section. To boost statistics, the background is measured with wider cuts around the J/ψ and B mass and scaled down to the smaller cuts.

A predominant background is inclusive J/ψ production by b quarks combined with other K_S^0's in the event. The branching ratio BR(B $\rightarrow$ J/ψ + X) is measured to be approximately 1%. Cuts on the K_S^0 momentum and angle relative to the J/ψ direction reduce this background significantly.

The number of background events is still limited by MC statistics. The 90% CL limit is 2500 events for one μ from b and two from charm or π/K decay, 600 events for one μ from b, one from $\bar{b}$ and one from charm or π/K decay and 300 events for inclusive J/ψ plus one other muon from b,c or π/K decay. Based on extrapolating the p_t distribution of μ's from charm or π/K decay the first background is probably small in spite of the size of the limit quoted.

5. IMPLICATIONS

Assuming 1050 $B_d^0 \rightarrow \psi K_S^0$ events in one year of running at $10^{32}\text{cm}^{-2}\text{sec}^{-1}$ and the background is indeed negligible, the expected error on sin2β is:

$$\delta\,(sin2\beta) = \frac{1}{D}\frac{1}{\sqrt{N}} \tag{5.1}$$

where N is the number of events, D is the *dilution factor*

$$D = (1 - 2\omega)\,\frac{x_d}{1 + x_d^2} \tag{5.2}$$

and ω is the mis-tagging probability. Monte Carlo simulations were used to get the tagging fractions from bottom and charm. π and K decay contribuitions to mistagging are assumed to be negligible. No estimate was done of punchthrough probabilities. The fraction of B tags is found to be $F_B = .77$ and for charm $F_C = .23$. Using these numbers in the equations of section 2, gives $\omega_{total} = .30$. The predicted error then is:

$$\delta\,(sin2\beta) = .16 \tag{5.3}$$

6. FURTHER COMMENTS

1. Refering to Fig. 3.2, the acceptance for requiring 3 μ's with $p_t > 5$ is about the same as requiring 2 μ's with $p_t > 10$ and one μ with $p_t > 20$, so there is some flexibility in how one might consider triggering on these events. Tracks with p_t around 5 GeV/c will barely penetrate the calorimeter+toroid. The case where one requires 2 μ's with $p_t > 10$ then adds a third μ with $p_t > 5$ reduces the total acceptance of Table 3.1 by 0.32. One μ with $p_t > 20$ and 2 μ's with $p_t > 5$ reduces it by 0.43. Finally requiring one μ with $p_t > 10$ and 2 μ's with $p_t > 5$ reduces it by 0.81. A J/ψ mass cut at level 2 could also be considered to significantly cut the rate into level 3.
2. Electrons have not been considered. If one can make similar cuts then the statistics increase by a factor of 4. The error then is $\delta(sin2\beta)_{e+\mu} = .08$. An

isolation requirement on the electrons will likely reduce the acceptance but a study of this is yet to be done. In addition, SDC studies[3] indicate that a trigger of one muon with $p_t > 20$ is viable at a luminosity of 10^{33}. Given the acceptance loss mentioned above, a one-year run at 10^{33} will give a muon-only measurement error of $\delta(sin2\beta)_{\mu-only,10^{33}} = .08$

3. Also lacking in this study is any estimate of muon punchthrough backgrounds. Tools now exist for studying this possible source of background and mistagging.
4. No use was made of the displaced vertex of the B meson decays. It doesn't appear to be necessary for this clean decay mode but could be considered if the backgrounds increase (from punchthrough, for example). For SDC to measure other decay modes (for example, measuring sin2α through the decay mode $B_d^0 \rightarrow \pi^+\pi^-$ or sin2γ using $B_s^0 \rightarrow \rho K_S^0$) would likely require vertexing in the reconstruction and probably at the trigger level. This is left to future studies.

7. ACKNOWLEDGEMENTS

The author thanks F. Bird, A. Fridman, P. McBride and E. Wang for useful discussions.

8. REFERENCES

1. E.L. Berger and R. Meng, Phys. Rev. D46, 169 (1992).
2. P. Nason, S. Dawson, and R.K. Ellis, Nucl. Phys. B303, 607 (1988);**B327**,49 (1989).
3. P. McBride, these proceedings.