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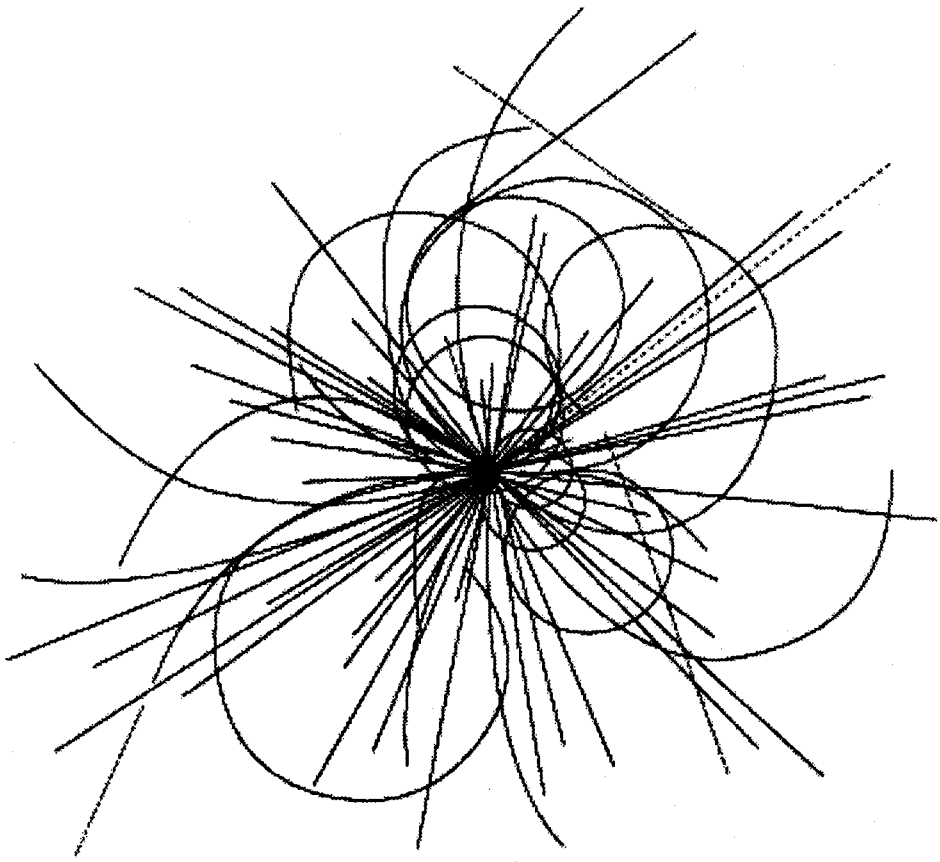

Superconducting Super Collider Laboratory

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The Prospect for Determining the Angle γ in the Decay $B_d^0 \to \psi\varrho^0$ at the SSC*

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The Prospect for Determining the Angle γ in the decay $B_d^0 \to \psi\rho^0$ at the SSC

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1. Introduction

The most compelling understanding of the evidence for CP violation in the neutral B meson system will require many redundant measurements of the angles of the unitarity triangle. The angle γ is presently considered to be the most difficult angle to measure. This is primarily due to mounting evidence that the mixing is almost complete in the neutral B_s system which implies rapid oscillations between $B_s^0 - \overline{B_s^0}$ mesons. A large oscillation rate will preclude the experimental observation of the B_s mixing due to inadequate detector resolution, where the most optimistic designs promise to allow measurement to no better than $x_s \approx 25$.

Due to this complication, alternative methods for extracting γ have been proposed. A candidate mode which has recently been proposed would require a study of the neutral B_d system in the $B_d^0 \to \psi\rho^0$ decay mode[1]. The measurement of the γ angle is via an asymmetry measurement as in the case of the β angle measurement in the $B_d^0 \to \psi K_s^0$ mode. Here, the extraction of γ necessarily depends upon, and so is coupled to, the measurement of β. However, as will become apparent, the measurement of the β angle will be known with sufficient precision by the time that a γ measurement can be attempted that the proposed technique remains interesting. In fact, many of the techniques required to observe β and those necessary to determine γ are identical so that both numbers can, in principal, be extracted within the same experiment, given a sufficient statistical sample and favorable decay parameters.

The theoretical motivation for the measurement is discussed below, followed by the experimental potential for such a measurement from one of the large high p_t detectors, SDC, proposed for the Superconducting Supercollider[2]. In all likelihood this measurement will require the SSC (at least), where the primary b yield is expected to be $\approx 10^{13}$ at the design luminosity of $10^{33}\text{cm}^{-2}\text{sec}^{-1}$, since the expected branching ratio for $B_d^0 \to \psi\rho^0$ is small, $\approx 5 \times 10^{-5}$. The final state will be readily observable in SDC. There are 4 tracks, 2 μ's (or e's, though they are not explicitly studied here) and 2π's, from the signal B_d^0, each pair of which should reconstruct to a resonance, and an additional μ from the $B_d^0 \to \mu\nu_\mu X$ decay of the associated tag B. Good tracking efficiency, good μ identification, and good mass resolution allow the signal to be observed.

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2. The Theory

The theoretical motivation for studying this channel is discussed by Dunietz[1]; only the salient experimental points are reviewed here. First, this decay is not the most apparent one in which to measure γ. For instance, measuring the asymmetry in the $B_s \to \psi\phi$ final state would yield γ, through a second-order penguin contribution. This final state is very accessible to experiment, however, it must be stressed that it requires clean tagging and excellent vertexing (required to observe the time-dependent mixing oscillations) which may both be precluded if x_s is large. The same comment applies to other potentially interesting B_s decays, e.g., $B_s^0 \to D_s^{(\pm)} K^{(\mp)}$.

The γ measurement in $B_d^0 \to \psi\rho^0$ is extracted from the measurement of the $Im\lambda(B_d^0 \to \psi\rho^0)$ which follows from a measurement of the asymmetry

$$A_{CP}(t) = \frac{\Gamma(B_d^0 \to \psi\rho^0) - \Gamma(\overline{B_d^0} \to \psi\rho^0)}{\Gamma(B_d^0 \to \psi\rho^0) + \Gamma(\overline{B_d^0} \to \psi\rho^0)} = Im\lambda \sin \Delta m t. \tag{1}$$

From eq. 40 of [1],

$$\lambda(B_d^0 \to \psi\rho^0) = -\lambda(B_d^0 \to \psi K_s^0)\frac{\overline{b}}{b} \tag{2}$$

which can be rewritten as

$$\lambda(B_d^0 \to \psi\rho^0) = -e^{-2i\beta}\frac{1 + z^* e^{-i\gamma}}{1 + z e^{-i\gamma}} = -e^{-2i\beta} e^{i\phi}. \tag{3}$$

where $b(\overline{b}) = 1 + z^{(*)} e^{(-)i\gamma}$. Figure 2 of [1] depicts the geometrical relationship of γ to the observables in the experiment. Due to strong matrix element effects in the final state, a measurement of $B_d^0 \to \psi K^{*0}$ is also required when determining b. However, that mode will be well known by the time that the present measurement could be attempted.

Now z (considering only case $z = z^*$) is expected to be a small number, $0.01 \leq z \leq 0.1$. In that case, neglecting second order terms in z, write

$$\lambda(B_d^0 \to \psi\rho^0) = -e^{-2i\beta} e^{i\phi} \approx -e^{-2i\beta} e^{-i2z\sin\gamma}. \tag{4}$$

Then,

$$Im\lambda \approx \sin(2z\sin\gamma + 2\beta) \tag{5}$$

and so the time integrated asymmetry is given by

$$A_{CP} = \sin(2z\sin\gamma + 2\beta). \tag{6}$$

Clearly, a good measurement of γ requires a good knowledge of β, which is expected to be well known by the time the γ measurement can be attempted.

3 The Signal Sample

This work is closely coupled to that of the proposed measurement of the β angle in the $B_d^0 \to \psi K_s^0$ channel with the SDC detector[3]. ISAJET is used to generate the pair-produced b quarks via gluon splitting. Events are selected which contain a b quark jet with

$p_t \geq 10$ GeV/c^2 within the acceptance of SDC. The $\psi\rho^0$ decay is studied in the $\mu^+\mu^-\pi^+\pi^-$ final state. The initial flavor of the b quark in the final state is determined (tagged) by the sign of the μ from the associated $\bar{b}$ semileptonic decay. The trigger discussion follows that of the ψK_s^0 decay[3]. However, here the SDC nominal single μ trigger with a $p_t = 20$ GeV/c threshold is chosen.

The B_d^0 is reconstructed by first reconstructing the two final state resonances. The ψ is made from a pair of oppositely charged μ's which have a mass within ± 50 MeV/c^2 of the nominal ψ mass. Each μ must have $p_t \geq 1$ GeV/c and $|\eta| \leq 2.5$. A pair of unlike sign π's, each of which meet the same kinematic criteria as the ψ decay muons, which reconstruct within ± 50 MeV/c^2 of the ρ^0 mass are also selected. It is also required that $p_t(\rho^0) \geq 1$ GeV/c. To further suppress background, the ψ and the ρ^0 are required to be close together, here $\cos\theta(\psi, \rho^0) \geq 0.9$.

The full set of cuts required to isolate a clean $\psi\rho^0$ sample is shown in table 1. For 1 SSC year of running at design luminosity (10^7 seconds at 10^{33} cm^{-2} sec^{-1}), and a b quark production cross section of 250μb [3], there will be of order 2000 $B_d^0 \rightarrow \psi\rho^0$ events reconstructed.

Contribution	Acceptance factor
$b \rightarrow \bar{B}_d^0$ or $\bar{b} \rightarrow B_d^0$	2×0.38
$B_d^0 \rightarrow \psi\rho^0, \psi \rightarrow \mu^+\mu^-, \rho^0 \rightarrow \pi^+\pi^-$	3×10^{-6}
$b \rightarrow \mu + X$	0.12
1 trigger $\mu, p_t > 20$, $\|\eta\| \leq 2.5^\dagger$	0.015
2 other μ's, $p_t \geq 3, \|\eta\| \leq 2.5$	0.46
$p_t(\rho) \geq 1$	0.97
$\cos\theta(J/\psi, \rho^0) > 0.9$	0.95
tracking and μ id efficiency	$(0.8)^3$
Total (εBr)	9×10^{-10}

Table 1: Contributions to the rate for $B_d^0 \rightarrow \psi\rho^0$ detected in SDC. †From figure 3.1 of Coupal[3].

4. Backgrounds

Much of the background to the $\psi\rho^0$ signal arises from the same sources as in the background discussion of the ψK_s^0 channel[3]. Briefly, spurious μ's which could give rise to false signals will arise from other true c, b decays, decays in flight, or punchthrough. In particular, μ's due to inclusive ψ production from b decays in combination with other unassociated π's and ρ^0's in the event are the most serious. The angle cut reduces the fake rate. The μ's from charm decays and from decays in flight are generally at low p_t and so of less concern. The punchthrough contamination has not been evaluated. If these background μ's prove unwieldy, there can be loose requirements placed on a common vertex for the ψ and ρ^0 which should reduce the problem considerably at a minimal cost to the signal. A very serious problem may arise from the production of $B_d^0 \rightarrow \psi\omega$, where the π^0 from the ω decay is very soft. Future studies should address and quantify these points.

5. Measurement of γ

For the present purposes then, assume that the background to the signal can be neglected. Then, the measured asymmetry will be given by $A = DA_{CP}$ where the dilution factor, D, represents the loss of analyzing power due to incorrect identification of the final state. There are several contributions to D including that due to mixing of both the signal and tag Bs, those due to the cascade decays of the tagging b, and to detection difficulties. A thorough Monte Carlo study of these errors has been made[3] and gives $D \approx 0.19$. The number of events required to measure the angle to a given precision follows from eq. (6);

$$N = \frac{1}{\delta^2 A_{CP}} \frac{1}{D^2 \varepsilon Br} = \frac{1}{\delta^2(\sin\gamma)} \frac{1}{D^2} \frac{1}{\cos^2 2\beta} \frac{1}{z^2}, \tag{7}$$

where it has been assumed that $2z\sin\gamma \ll 2\beta$. Again, this will require that $\sin 2\beta$ has been well measured, in fact well enough that $\delta\beta < z\sin\gamma$.

At this point, some assumptions must be made regarding the sizes of the different parameters in order to extract an example γ measurement. In the most optimistic scenario, with z near a maximum ($z = 0.1$) and $\cos 2\beta \approx 1$ (or $2\beta \approx 0$), the analysis indicates that it would take on the order of 10 SSC years at design luminosity to reach $\delta(\sin\gamma) \approx 0.2$.

Unfortunately, full vertexing of the $\psi\rho^0$ pair will probably be required, which would cost signal. However, a factor of perhaps four in improvement could be expected if the e's from $B_d^0 \to e\nu_e X$ on the tagging side and $\psi \to e^+e^-$ from the signal side can be used. It is clear that a good measurement of γ will require a great deal of patience...and luck.

5. REFERENCES

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3. D. Coupal,'Prospects for Measuring CP Violation in SDC Using $B_d^0 \to \psi K_s^0$',these proceedings.