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SDC
SOLENOIDAL DETECTOR NOTES

ELEMENTARY VIEW OF B PHYSICS IN SDC

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Elementary view of B physics in SDC

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"Small-angle syndrome" for hadron-collider B physics

At the SSC, $\langle p_\perp(B)\rangle \approx 8$ GeV/c independent of η;
$\langle p(B)\rangle \approx 180$ GeV/c.

$\Rightarrow \eta \approx 3.8$ for these average values;
η distribution is fairly flat, extending beyond 7.

Since $d\cos\theta = sin^2\theta d\eta$, the B angular distribution is strongly peaked near 0°.

$\Rightarrow$ B production is characterized as "far forward".

(Editorial note:
Neglecting trigger bias, the most probable η is zero: $\approx$70% of B secondaries have $|\eta| < 2.5$.)

Overemphasis on far forward B's can lead to circular reasoning in detector design:

- Small-angle B detectors must approach the beam closely.
- This leads to severe limits on the peak $\mathcal{L}$ that the detector is designed to withstand (Schlein 10^{31}, BCD 10^{32}).
- With limited $\mathcal{L}$, one strives even harder to accept the far forward B's, *etc., etc.*

However, SSC and SDC are designed to operate at $\mathcal{L}\geq 10^{33}$.

$\Rightarrow$ Depart from the "small-angle syndrome" to assess the potential for B physics within SDC's natural range, $|\eta| < 2.5$.

B physics at central η

For $|\eta|<2.5$, triggering can require a higher $p_\perp$ than at larger $|\eta|$, *e.g.* because of μ energy loss in the toroid.

But smaller $|\eta|$ and higher $p_\perp$ offer compensating advantages for B physics:

- For fixed $p_\perp$, the effect of beam pipe scattering on impact parameter resolution $\sigma(b_i)$ is reduced at smaller $|\eta|$ ($\propto \sin^{-1/2}\theta$).
- The effect of Si scattering on $\sigma(b_i)$ is reduced at high $p_\perp$ ($\propto p_\perp^{-1}$).
- Wrong tagging by semileptonic b decay (caused by semileptonic decay of cascaded c's) is reduced at high leptonic $p_\perp$.
- Decays of back-to-back B's (from g fusion) are more readily dissociated at high $p_\perp$.
- At central η, the ψ decay products are well separated for easier triggering.

$p_\perp$ range for SDC B physics

For CP study we consider the standard process $B_d^0 \to \psi K_S^0 \to \mu^+\mu^-\pi^+\pi^-$, tagged by $\bar{b} \to \mu^+ X$.

1. Lower limit on $p_\perp$.

- μ trigger hardware.
  - Thun (SDC-90-77) obtains a Level 1 μ trigger threshold $p_\perp^{\min} \approx$ (9, 12, 19) GeV/c for efficiency ϵ = (0.1, 0.5, 0.9), based on effective scintillator width W=15 cm at η=0.
  - Ignoring μ energy loss ΔE, $p_\perp^{\min} \propto W^{-1}$ and is easily reduced by increasing W. However, at η=0, $\Delta E \approx 4$ GeV. Then $p_\perp^{\min} \approx 5$ GeV is the lowest conceivable threshold.
  - Scattering in the toroid permits $p_\perp^{\min}$ to become $> 4\times$ sharper (Simon, SDC-91-20). To sharpen $p_\perp^{\min}$, one may combine several scintillators to form W, using more sophisticated trigger logic. (If W is to be enlarged and is to become the sum of several scintillator widths, the presently planned scintillators may still be appropriate.)

- μ trigger rate.
  - The SDC EOI estimates Level 1 rates of 1 μb with $p_\perp^{\min}$ = 15 or 10 GeV/c for 1 or 2 μ's.
  - We imagine that a 3μ trigger would allow $p_\perp^{\min}$ = 5 GeV/c. (For CP study, regardless of the trigger, 3 μ's must be reconstructed.)
  - If emitted at 90° in the B_d^0 C.M., a ψ decaying symmetrically into $\mu^+\mu^-$ imparts $\approx$1/3 of $p_\perp(B_d^0)$ to each μ. Then a 5 GeV/c threshold in $p_\perp(\mu)$ becomes a $\approx$15 GeV/c threshold in $p_\perp(B_d^0)$.

2. Upper limit on $p_\perp$.

- Requiring the transverse K_S^0 mean decay length $\lambda_\perp^S < 40$ cm forces $p_\perp(K_S^0) < 7.5$ GeV/c.
- If emitted at 90° in the B_d^0 C.M., the K_S^0 would carry $\approx$1/3 of the B_d^0 $p_\perp$. However, $\psi \to \mu^+\mu^-$ triggering will bias the K_S^0 backward. This will allow $p_\perp(B_d^0)$ to range well above 22.5 GeV/c.

3. Range of $p_\perp(B_d^0)$.

- The resulting crude estimate of SDC's working range is $15 < p_\perp(B_d^0) < 35$ GeV/c.
- This is a reasonable range. The minimum is not too far above the typical $p_\perp$ for B production. The maximum is large enough that not much rate is lost beyond it.

Tagged ψK_S^0 rate

σ for $b\bar{b}$ (μb):	400
$f(b \to B_d^0)$:	0.375
B(tagging $\bar{b} \to \mu^+$):	0.1
$B(B_d^0 \to \psi K_S^0)$:	5×10^{-4}
$B(\psi \to \mu^+\mu^-)$:	0.07
$B(K_S^0 \to \pi^+\pi^-)$:	0.69
Factor for charge conjugate:	2
$\Rightarrow f(b\bar{b} \to \mu$-tagged $\mu^+\mu^-\pi^+\pi^-)$:	1.8×10^{-6}
Overall $\sigma \times f$ (nb):	0.7
Produced μ-tagged $\mu^+\mu^-\pi^+\pi^-$ / SSC year:	7×10^6

Tagged ψK_S^0 acceptance in SDC

Roughly estimated fraction of:	
$b\bar{b}$ with $15 < p_\perp(b) < 35$ GeV/c:	5×10^{-3}
$\bar{b} \to \mu^+$ with $\lvert\eta(\mu^+)\rvert < 2.5$:	0.7
$B_d^0 \to \mu^+\mu^-\pi^+\pi^-$ with $\lvert\eta\rvert_{\max} < 2.5$:	0.5
ψ in forward hemisphere of B_d^0:	0.5
K_S^0 decay within Si:	0.7
ϵ(tracking and vertexing):	$(0.33)^2$
$\Rightarrow$ Overall acceptance:	7×10^{-5}
Verticized tagged $B_d^0 \to \psi K_S^0$ per SSC year:	500 ($\mathcal{L}$=10^{33}, l=μ only)

Tagged ψK_S^0 acceptance from BCD proposal

Cuts on ψ and K_S^0:	0.174
• $\lvert\eta\rvert < 5.5$	
• $p_\perp(e^+,e^- > 1$ GeV/c	
• $p_\perp(\pi^+,\pi^- > 0.3$ GeV/c	
• $\lvert\phi\rvert < 75°$ or $\lvert\phi\rvert > 105°$	
• K_S^0 decays within Si	
Same cuts on $e^\pm$ and 2 $h^\pm$ from tag:	0.48
ϵ(tracking and vertexing):	$(0.33)^2$
Triggering efficiency after above cuts:	1.0
$\Rightarrow$ Overall acceptance:	9×10^{-3}
Verticized tagged $B_d^0 \to \psi K_S^0$ per SSC year:	6000 ($\mathcal{L}$=10^{32}, l=e only)

ψK_S^0 asymmetry with perfect tagging

We measure

$$A \equiv \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}$$

where Γ is the decay rate of B^0 to a CP eigenstate. A hadronically produced B^0-$\bar{B}^0$ system is an incoherent sum of partial waves, so that each B mixes independently of the other. Then, for B_d^0 decay into ψK_S^0,

$$A(t) = \sin 2\beta \sin x_d t/\tau_d$$

where β is a CP violating phase, $x_d \equiv \tau_d \Delta M_d \approx 0.7$, and τ_d is the B_d^0 ($\approx \bar{B}_d^0$) lifetime. Here we integrate over decays collected between t=0 and ∞, relying on the vertex detector only to purify the B sample. Then

$$A = \frac{x_d}{1 + x_d^2} \sin 2\beta \approx 0.47 \sin 2\beta.$$

Tagging dilution

The wrong tagging fraction w has been studied for leptonic B tagging at the Tevatron by N. Roe (DØ1122). Assuming that no information is available from the tagging decay other than from the tagging lepton, she finds:

$$w = \alpha F_B + (1 - \alpha) F_C + \tfrac{1}{2}(F_D + F_P)$$

where

$$2\alpha = f_s + \frac{x_d^2}{1 + x_d^2} f_0;$$

f_s and f_0 are the fractions of b's that hadronize to B_s and B_d^0; and F_B, F_C, F_P, and F_D are the fraction of tagged μ's due to $b \to \mu$, $b \to c \to \mu$, other hadron decay, and punchthrough. Using $f_s = 0.15$, $f_0 = 0.375$, and $x_d = 0.7$,

$$w = 0.14 F_B + 0.86 F_C + 0.5(F_D + F_P)$$

The ratio F_C/F_B of cascade to direct μ's depends on kinematics, and the πK decay and punchthrough fractions F_D and F_P depend on the muon filter. Using ISAJET at $\sqrt{s}$=2 TeV and a parameterization of the DØ muon filter, N. Roe finds:

For $p_\perp(\mu) > 5$ GeV/c, $F_C/F_B \approx 0.033$, and F_D+F_P is negligible.

For $p_\perp(\mu) > 1$ GeV/c, $F_C/F_B \approx 0.38$.

Ignoring the difference in $\sqrt{s}$, a wrong tagging fraction $w_{\rm SDC} \approx 0.16$ would be implied.

Assuming perfect e^- identification, with the same assumptions $w_{\rm BCD} \approx 0.34$. (In the BCD proposal, w=0.2.)

Assuming a 10% CP symmetric background, the total dilution D of the asymmetry A is

$$D \approx 0.47(1 - 2w)/1.1$$

$$D_{\rm SDC} \approx 0.29$$

$$D_{\rm BCD} \approx 0.14$$

Sensitivity to $\sin 2\beta$

The expected range of $\sin 2\beta$ is $0.1 < \sin 2\beta < 0.6$.

From measuring (N) ψK_S^0 decays, the expected statistical error is $1/\sqrt{ND^2}$. Using N=500 and D=0.29 for one year of SDC (N=6000 and D=0.14 for BCD),

$$\sigma_{\rm SDC}(\sin 2\beta) \approx 0.15$$
$$\sigma_{\rm BCD}(\sin 2\beta) \approx 0.09,$$

where in the SDC (BCD) case the tagging and ψ decay leptons are only μ's (e's).

In an asymmetric B factory operating for 1 SSC year (*i.e.* at $\mathcal{L}_{\rm peak}$ for 10^7 sec), with $\mathcal{L}_{\rm peak} = 3\times10^{33}$, the statistical error would be

$$\sigma_{e^+e^-}(\sin 2\beta) \approx 0.06$$

according to SLAC-353, using all possible leptons and tagging methods.

Concluding comments

- Estimates given here for SDC are based on a 3μ trigger threshold $p_\perp > 5$ GeV/c and upon acceptances that have not yet been shown by calculations to be realistic.
- Unless it is believed that BCD could trigger efficiently at the SSC on electrons with $p_\perp > 1$ GeV/c, SDC could likely measure $\sin 2\beta$ at least as well.
- For CP studies, SDC would require more sophisticated μ trigger logic than is now planned.
- Also, SDC likely would need a vertex detector with good (<30 μm) b resolution at $p_\perp > 5$ GeV/c. This seems achievable if a first Si measurement could be made within an 8-10 cm radius.
- For CP studies, SDC probably could not compete with an optimized detector at a full-luminosity asymmetric B factory.