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B-Physics Options at TEV I

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Summary

We present estimates of the sensitivity of upgraded CDF and D0, and of a new mini-BCD to B_s mixing and CP violation in the B meson system. This is a continuation of work begun at Snowmass '90.

CP-violation studies require a tag on the particle–antiparticle character of the second B in the event. This could be accomplished via leptons and pions only, but an order-of-magnitude larger event sample would be possible if Kaon identification were available.

For B_s mixing, both B's in the event must decay to modes that allow the particle–antiparticle character of each B to be determined. In particular, the mode $B_s \to J/\psi\phi$ (or $J/\psi K^0_S$) does not yield information about B_s mixing.

Only for modes $B \to J/\psi X$ with $J/\psi \to l\bar{l}$ is there a low-rate trigger (< 1 Hz) with reasonable efficiency. Otherwise a high-rate data-acquisition system ($> 1 - 10$ kHz) will be required.

Upgrades to CDF or D0 that place substantial emphasis on B physics could have a capability very similar to that of a dedicated Mini-BCD. However, even in the most ambitious scenarios presented here the prospects for observing CP violation are marginal. (Thus far, CP violation measurements have been among the most difficult ever performed in high-energy physics, and are unlikely to emerge from low-cost, low-priority upgrades to the collider program.) B_s mixing is within range of the TEV I collider, but only in experiments with Kaon identification and a rather high-rate data-acquisition system.

An upgrade to CDF or D0 consisting of a silicon tracker/vertex detector, a thin RICH counter, and a high-rate data-acquisition system could pursue B_s mixing largely independent of the rest of these detectors. A low-rate communication path between this upgrade and the other parts of the detector would suffice for $B \to J/\psi X$ physics. A high-rate selective trigger for B physics is lacking at present. Initially the experiment might operate with no trigger; if 1000 events/sec can be recorded there will be about 10^5 B events per day with which to learn how a selective trigger can be devised.

This upgrade could first be tested in C0, where a luminosity of only 2×10^{28} cm^{-2}sec^{-1} would saturate the data-acquisition system. A silicon vertex detector plus RICH counter designed to fit inside the CDF CTC would have an outer radius of only 25 cm. For the C0 test the detector could be placed inside a small solenoid magnet with a conventional coil; the magnet (plus flux return) would weigh about 8 tons and consume 1 MWatt.

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1 B Physics at an Upgraded D0

We present some estimates of the capability of an upgraded D0 for B physics. An essential feature of the upgrade is the addition of a magnet.

We first considered two sorts of upgrades:

1. Add a solenoid magnet to the central region, of radius 75 cm and length ±130 cm. See Fig. 1. The magnet is instrumented with:

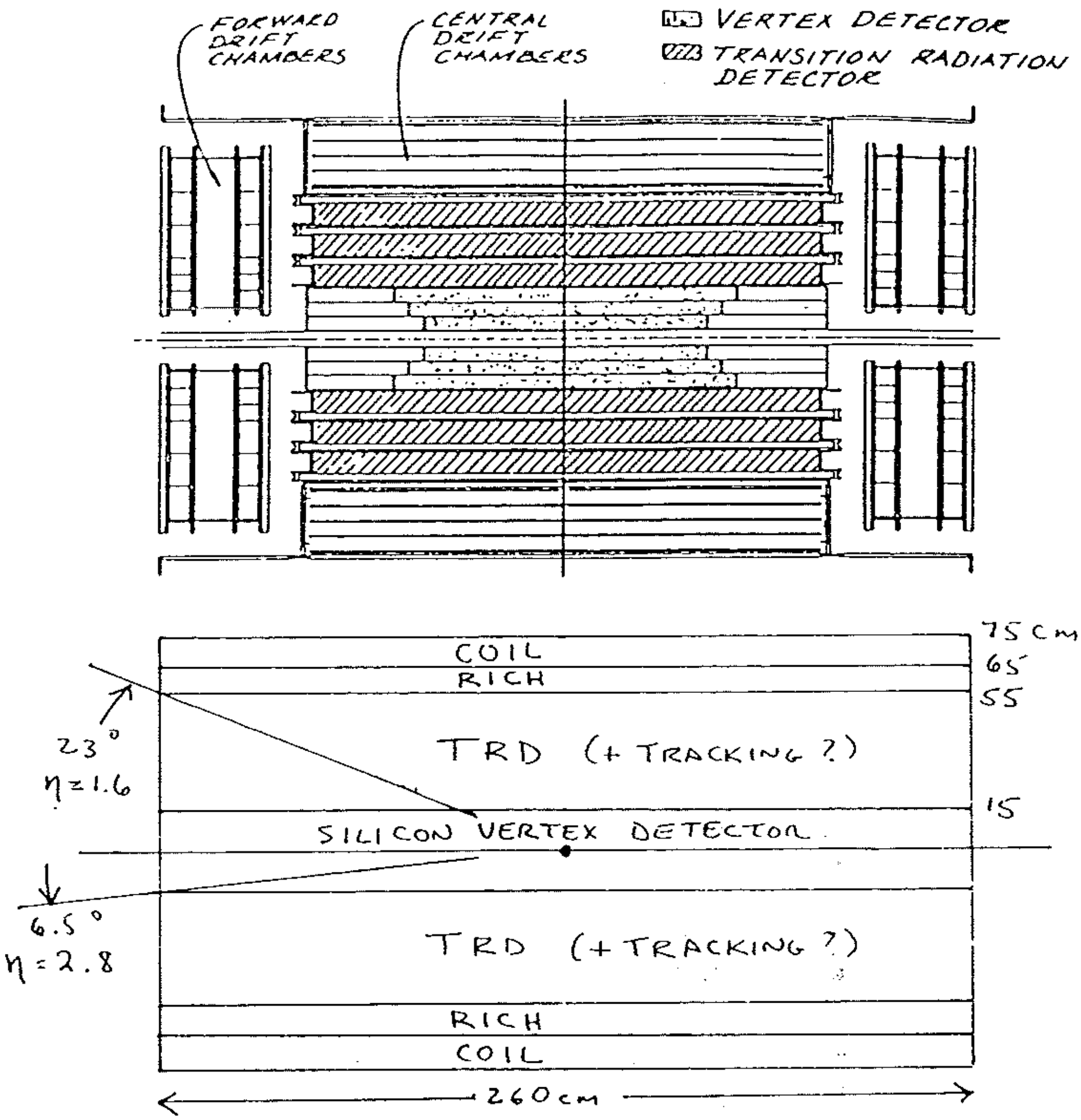

Figure 1: Central region of the D0 detector. Top: present configuration; bottom: proposed upgrade 1.

(a) A silicon vertex detector, from radius 1.5 cm to 15 cm. It is very advantageous if this detector would also serve as the tracker; this would permit good momentum resolution out to $\eta = 2.8$, and hence the use of forward muons as well as central electrons. A silicon detector has spatial resolution of 5-10 μm, which is about 10 times better than that of an ambitious straw-tube tracker. The path length available to a straw-tube tracker is only about three times that for the silicon detector, so the momentum resolution would be similar in either system. The silicon tracker/vertex detector would need several barrels, as well as forward disks, and would have more channels ($> 2 \times 10^6$?) than the BCD vertex detector

(b) A TRD system from radius 15 cm to 55 cm. Hopefully the existing TRD could still be used. Good electron identification would be available for $|\eta| < 1.6$.

(c) A RICH counter from radius 55 cm to 65 cm. This might have a NaF radiator and a pad readout with a solid photocathode. Kaon identification would be available for $|\eta| < 1.6$.

(d) Superconducting coil from radius 65 cm to 75 cm. The more field the better.

2. A $\cos\phi$-winding **dipole magnet** in the central region, instrumented as above. The D0 endcaps are replaced by forward arms roughly as in the recent mini-BCD configuration.

However, our initial Monte Carlo studies suggest that configuration 2 has only about twice the acceptance of configuration 1, so we do not pursue it further here.

We explore the capability of upgrade 1 for two physics topics:

- B_s mixing, which requires the observation of self-tagging decays such as $B_s \to D_s^- \pi^+$, as well as a tag of the particle/antiparticle character of the second B.
- Large signals of CP violation in the decay $B_d^0 \to J/\psi K_S^0$.

While the second topic does not require Kaon identification, it will benefit from to availability of the higher-rate Kaon tag discussed below. The study of B_s mixing requires Kaon identification. As B_s mixing is within reach of a suitably upgraded D0 while CP violation is likely to be elusive, it would be most productive to provide for Kaon identification. This is excluded in most scenarios of CDF upgrades.

1.1 CP Violation at D0

We begin with estimates of the possible event sample of decays $B_d^0 \to J/\psi K_S^0 \to e^+e^-\pi^+\pi^-$ or $\mu^+\mu^-\pi^+\pi^-$ in a run of integrated luminosity 500 pb^{-1}. We use a branching ratio of 3×10^{-4} to $J/\psi K_S^0$, and a combined branching ratio of 1.4×10^{-5} to the final state $e^+e^-\pi^+\pi^-$ (or $\mu^+\mu^-\pi^+\pi^-$).

A critical detector issue is the lowest transverse momentum at which the electrons can be detected. As this is not yet known for D0, we present event rates as a function of the P_t cut for electrons in Table 1.

For muons, we suppose they can be identified if their total momentum $P > 4$ GeV/c. The pseudorapidities of the muons from $B \to J/\psi K_S$ that pass this cut are shown in Fig. 2. As expected, the useful muons are rather forward.

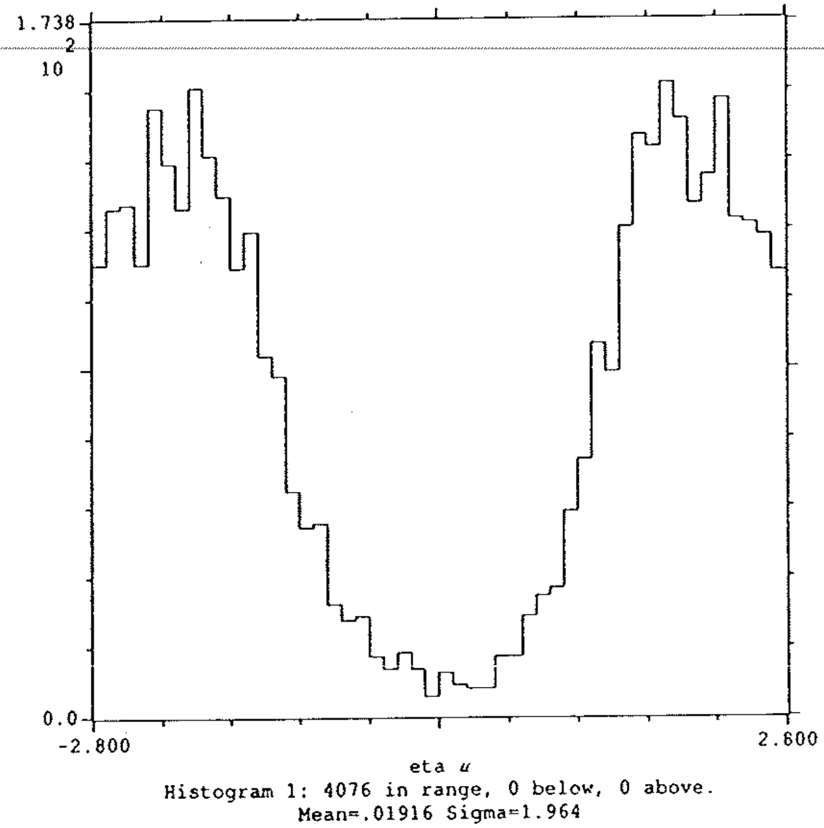

Figure 2: η of muons from $B_d^0 \to J/\psi K_S^0$. The muons must have $P > 4$ GeV/c, and the pions from the K_S^0 satisfy the pion cuts.

In this note we suppose that $\sigma_{b\bar{b}} = 40$ μb, and that the fraction of B's that are B_d^0 is 0.375. Then there would be 1.5×10^{10} B_d^0 (or $\bar{B}_d^0$) produced in a run of 500 pb^{-1}.

To study CP violation we must tag the particle/antiparticle character of the B, which we propose to due via a partial reconstruction of the second B in the event. We consider two tags:

1. The **Kaon tag**, based on the sign of the Kaon from the cascade decay $b \to c \to s$. About 60% of all B decays include a charged Kaon, although of these some 30% actually have the 'wrong' sign and lead to a mistag. See section 4.1 of the BCD Reply to the SSC PAC. In the Kaon tag, one other charged particle from the B must be reconstructed.

2. The **lepton tag** based on the signs of the electron (or muon) and Kaon in the decays $B \to Ke\nu X$. Only about 5% of all B's can be tagged this way, but the tag is very reliable (aside from the tagging 'dilution' due to mixing suffered by both tags). [In this note, $J/\psi \to ee$ events are only tagged by electrons if the lepton tag is used, and $J/\psi \to \mu\mu$ events are only tagged by muons.]

Our simulation of the acceptance for tagging was based on the representative decay $B_d^0 \to D^{*-}e^+\nu$.

Table 1: Rates in an upgraded D0 for $B \to J/\psi K_S^0$, estimated with an ISAJET simulation. Electrons and Kaons must have $|\eta| < 1.6$, while pions and muons must have $|\eta| < 2.8$. The minimum transverse momentum for electrons is listed in the Table, while pions and Kaons must have $P_t > 0.3$ Gev/c. Muons must have $P > 4$ GeV/c, but have no P_t cut. The efficiency used in the rate estimate is the product of the Geometric Acceptance and a factor 0.33 for the efficiency of tracking and vertexing. The reconstructed-event samples are for an integrated luminosity of 500 pb^{-1}, collectable in 1 year of running at a luminosity of 5×10^{31} cm^{-2}sec^{-1}.

Final State	$P_{t,e,\min}$ (GeV/c)	Geometric Acceptance	Recon. Decays
$e^+e^-\pi^+\pi^-$	1.0	0.121	8,400
$e^+e^-\pi^+\pi^-$	1.5	0.052	3,600
$e^+e^-\pi^+\pi^-$	2.0	0.022	1,520
$e^+e^-\pi^+\pi^-$	2.5	0.010	690
$\mu^+\mu^-\pi^+\pi^-$	–	0.053	3,670

Table 2: Rate estimates for tagged and reconstructed $B \to J/\psi K_S^0$ decays in an upgraded D0. The efficiency used is the product of the Geometric Acceptance and a factor $(0.33)^2$ for the efficiency of tracking and vertexing of both B's in the event. Also, for the Kaon tag only 60% of the second B's can be used, while for the electron tag only 5% can be used The reconstructed-event samples are for an integrated luminosity of 500 pb^{-1}, collectable in 1 year of running at a luminosity of 5×10^{31} cm^{-2}sec^{-1}.

Final State	$P_{t,e,\min}$ (GeV/c)	Tag	Geometric Acceptance	Recon. Decays
$e^+e^-\pi^+\pi^-$	1.0	K	0.071	970
$e^+e^-\pi^+\pi^-$	1.5	K	0.031	425
$e^+e^-\pi^+\pi^-$	2.0	K	0.013	178
$e^+e^-\pi^+\pi^-$	2.5	K	0.006	86
$e^+e^-\pi^+\pi^-$	1.0	eK	0.040	46
$e^+e^-\pi^+\pi^-$	1.5	eK	0.013	15
$e^+e^-\pi^+\pi^-$	2.0	eK	0.006	6
$e^+e^-\pi^+\pi^-$	2.5	eK	0.003	3
$\mu^+\mu^-\pi^+\pi^-$	–	K	0.025	343
$\mu^+\mu^-\pi^+\pi^-$	–	μK	0.006	6

Estimates of the number of tagged, reconstructed decays are given in Table 2. The most optimistic case, $P_{t,e,\rm min} = 1$ GeV/c and the use of the Kaon tag, appears to be roughly equivalent to the mini-BCD discussed below. With 970 tagged, reconstructed events we could measure $\sin 2\varphi_1$ to 3-σ accuracy if it is greater than 0.6, taking into account the various penalty factors as discussed in the BCD EOI and Reply to the SSC PAC.

1.2 B_s Mixing at D0

Next we estimate the sensitivity of an upgraded D0 for B_s mixing via the representative decay $B_s^0 \to D_s^- \pi^+$, with $D_s^- \to \phi\pi^-$ and $\phi \to K^+K^-$.

The cuts on the pions and Kaons are as in the previous subsection. The branching ratio for $B_s^0 \to D_s^- \pi^+$ is estimated to be 0.005, and the combined branching ratio for $B_s^0 \to K^+K^-\pi^+\pi^-$ is taken as 1.5×10^{-4}. We suppose that there are 1/2 B_s or $\bar{B}_s$ per B-$\bar{B}$ pair produced.

The acceptance was estimated to be 0.32, so after including the usual factor of 0.33 for vertexing and tracking efficiency, we could reconstruct some 160,000 $B_s^0 \to K^+K^-\pi^+\pi^-$ events in a run of 500 pb^{-1}. This assumes a perfect trigger, however.

The effect of including a trigger/tag on the other B is shown in Table 3. The Kaon tag is not a trigger by itself, so the high rates shown could not be obtained unless something like a secondary-vertex trigger can be implemented.

Table 3: Rate estimates for tagged and reconstructed $B_s^0 \to D_s^- \pi^+ \to K^+K^-\pi^+\pi^-$ decays in an upgraded D0. The efficiency used is the product of the Geometric Acceptance and a factor $(0.33)^2$ for the efficiency of tracking and vertexing of both B's in the event. Also, for the Kaon tag only 60% of the second B's can be used, while for the electron tag only 5% can be used The reconstructed-event samples are for an integrated luminosity of 500 pb^{-1}, collectable in 1 year of running at a luminosity of 5×10^{31} cm^{-2}sec^{-1}.

$P_{t,e,\rm min}$ (GeV/c)	Tag	Geometric Acceptance	Recon. Decays
–	K	0.180	18,000
1.0	eK	0.102	840
1.5	eK	0.073	600
2.0	eK	0.051	420
2.5	eK	0.035	290

Following the discussion of section 2.2 of the BCD EOI, B_s mixing could be resolved at the 3-σ level for a mixing parameter of $x_s < 20$ if we have 4000 tagged, reconstructed B_s decays using a Kaon tag, or 1500 events using the electron tag. These events can be accumulated is several channels and combined into a single analysis, as the mixing parameter x_s is independent of the decay mode. Hence we can be optimistic that an upgraded D0 could resolve B_s mixing, provided it includes Kaon identification.

1.3 Comments

- The D0 upgrade assumed here is technically ambitious, and our quick estimates of resulting performance are likely only upper bounds.
- To obtain momentum analysis of the forward muons with a solenoid magnet, we have assumed all tracking is within 15 cm of the beams, and is done in silicon detectors.
- This might permit keeping the present TRD. But if it is desired to have a gas tracking chamber yielding momentum resolution comparable to that of the silicon, the tracker must extend up to a radius of about 60 cm, and have $\sim 75\ \mu$m spatial resolution. This likely precludes a TRD.
- The highest rates of tagged events, and the study of B_s mixing all require Kaon identification. We propose a thin RICH counter for this.
- If any physics other than $B \to J/\psi X$ is to be studied we need a high-rate trigger. This would likely require a new data-acquisition system, and attendant processor farm, as proposed in the BCD EOI.

2 Mini-BCD and CDF

(This section is extracted from the BCD Reply to the SSC PAC, July 11, 1990.)

In the BCD EOI we remarked that the technical challenges of B physics could be more confidently met if there is an opportunity for an interim physics program at Fermilab that incorporates some of the advanced technology needed for the BCD at the SSC. It is natural to consider whether CDF upgrades provide such an opportunity, or whether a new, dedicated B collider experiment would be more appropriate. Here we make a comparison of such options, based in part on discussion with the B-Physics Working Group at Snowmass '90.

We conclude that a mini-BCD would have about 50 times the sensitivity of 'modest' upgrades to CDF for tagged, reconstructed decays involving a J/ψ, and 1000 times the sensitivity for decays that involve Kaons. The first category would give a mini-BCD access to the only very largest signals for CP violation, but the second category of events would permit a good study of B_s mixing.[1]

In the CDF upgrade we suppose they adopt the BCD vertex detector with its 3-d reconstruction capability, as needed for low-P_t tracks. In principle, CDF might also adopt a BCD-style data-acquisition system, and even implement a secondary-vertex trigger. However, as these would not enhance CDF's capability for top-quark physics there is considerable skepticism that such upgrades could occur.

At CDF, we suppose that tracking is available for charged particles with $P_t > 0.3$ GeV/c, and $|\eta| < 1.25$. There is no Kaon identification, but single lepton identification is available for $P_t > 2$ GeV/c (B. Wicklund, private communication), and for $|\eta| < 1.1$. Single-lepton triggering, however, can only be done for $P_t > 7.5$ GeV/c. Lepton-pair triggering can be done when each lepton has $P_t > 2.5$ GeV/c.

In the following subsection we consider more ambitious upgrades to CDF that would put its B-physics capability on a par with mini-BCD.

Table 4: Geometric acceptance for single B decays, estimated with an ISAJET simulation. The geometric (and P_t) cuts are described in the text. 'mBCD' = mini-BCD, 'CDF' = Collider Detector at Fermilab. The subscripts 1, and 2 refer to maximum angles of 20, and 40°, respectively, for the forward arms of the mini-BCD.

Decay Mode	All-Charged Daughters	Detector mBCD$_1$	mBCD$_2$	CDF
$B^+ \to \bar{D}^0\pi^+$	$K^+\pi^-\pi^+$	0.116	0.214	0.185
$B^+ \to D_s^+\bar{D}^0$	$K^+K^-\pi^+K^+\pi^-$	0.066	0.123	0.105
$B^+ \to J/\psi K^+$	$e^+e^-K^+$	0.095	0.188	0.011
$B_d^0 \to D^-\pi^+$	$K^+\pi^-\pi^-\pi^+$	0.072	0.141	0.121
$B_d^0 \to J/\psi K_S^0$	$e^+e^-\pi^+\pi^-$	0.044	0.095	0.005
$B_d^0 \to \pi^+\pi^-$	$\pi^+\pi^-$	0.383	0.613	0.251
$B_s^0 \to D_s^-\pi^+$	$K^+K^-\pi^-\pi^+$	0.098	0.181	0.150
$B_s^0 \to D_s^-\pi^+$	$K^+K^-\pi^-\pi^+\pi^-\pi^+$	0.034	0.060	0.055
$B_s^0 \to D_s^-\pi^+\pi^+\pi^-$	$K^+K^-\pi^-\pi^+\pi^-\pi^+\pi^+\pi^-$	0.012	0.020	0.020
$B_s^0 \to \bar{D}^0K^{*0}$	$K^+\pi^-K^+\pi^-$	0.075	0.145	0.134
$B_s^0 \to \rho^0K_S^0$	$\pi^+\pi^-\pi^+\pi^-$	0.110	0.199	0.096
Average		0.100	0.180	0.103

The mini-BCD considered here would have smaller-scale versions of all the major subsystems of the full BCD. See the following section for details. It consists of a central dipole magnet surrounding a silicon vertex detector and straw-tube tracking system. One forward arm is instrumented with Kaon and electron identification between angles 2 and 20° ($1.7 < \eta < 4$), or 2 and 40° ($1 < \eta < 4$). We suppose the electron identification can be made to operate down to a P_t of 1 GeV/c, the demonstration of which would be a major goal of the mini-BCD. Tracking and Kaon identification is done for $P_t > 0.3$ GeV/c. The mini-BCD would be triggered by lepton-pairs, single leptons, and secondary vertices. The last trigger is very ambitious, but would yield the greatest sensitivity to B_s mixing (which could also be studied via the single-lepton trigger).

Tables 4 and 5 compare the acceptance and potential number of reconstructed B decays, assuming 100% triggering efficiency. The integrated luminosity assumed for Table 5 is 500 pb^{-1}, which could be collected in one year of 10^7 sec at a luminosity of 5×10^{31} cm^{-2}sec^{-1} with the Main Ring Upgrade. Only for modes that involve a J/ψ is the triggering assumption valid in practice (*i.e.*, the efficiency of triggering on a lepton pair is already included in the Tables). The acceptance for decays without leptons is rather similar in CDF and a 40° mini-BCD. Of course, CDF has no Kaon identification so it is not immediately clear that the events with Kaons can be reconstructed by CDF. For decays with leptons the mini-BCD is about 6 times better than CDF, assuming that the minimum-P_t cut for leptons in mini-BCD is actually 1 GeV/c.

Table 5: Rate estimates for reconstructed B decays, assuming 100% trigger efficiency. B.R.(B) is the branching ratio for the two-body B decay, estimated according to Bauer *et al.*[2] B.R.(Tot) is the product of B.R.(B) and the secondary branching ratios. The efficiency used is the product of the geometric acceptance from Table 4 and a factor 0.33 for the efficiency of tracking and vertexing. However, for the decays at CDF involving a J/ψ we suppose the vertexing efficiency is 0.9 due to the larger transverse momentum of the tracks. The reconstructed-event samples are for an integrated luminosity of 500 pb^{-1}, collectable in 1 year of running at a luminosity of 5×10^{31} cm^{-2}sec^{-1}.

Decay Mode	All-Charged Daughters	B.R.(B)	B.R.(Tot)	Recon. Decays mBCD$_2$	CDF
$B^+ \to \bar{D}^0\pi^+$	$K^+\pi^-\pi^+$	0.004	1.6×10^{-4}	160,000	140,000
$B^+ \to D_s^+\bar{D}^0$	$K^+K^-\pi^+K^+\pi^-$	0.008	4.8×10^{-6}	2,900	2,500
$B^+ \to J/\psi K^+$	$e^+e^-K^+$	6×10^{-4}	4.2×10^{-5}	39,000	6,200
$B_d^0 \to D^-\pi^+$	$K^+\pi^-\pi^-\pi^+$	0.006	4.8×10^{-4}	340,000	290,000
$B_d^0 \to J/\psi K_S^0$	$e^+e^-\pi^+\pi^-$	3×10^{-4}	1.4×10^{-5}	6,600	1,000
$B_d^0 \to \pi^+\pi^-$	$\pi^+\pi^-$	2×10^{-5}	2×10^{-5}	61,000	25,000
$B_s^0 \to D_s^-\pi^+$	$K^+K^-\pi^-\pi^+$	0.005	1.5×10^{-4}	90,000	74,000
$B_s^0 \to D_s^-\pi^+$	$K^+K^-\pi^-\pi^+\pi^-\pi^+$	0.005	2×10^{-4}	40,000	36,000
$B_s^0 \to D_s^-\pi^+\pi^+\pi^-$	$K^+K^-\pi^-\pi^+\pi^-\pi^+\pi^+\pi^-$	0.01	4×10^{-4}	26,000	26,000
$B_s^0 \to \bar{D}^0K^{*0}$	$K^+\pi^-K^+\pi^-$	0.005	1.3×10^{-4}	62,000	57,000
$B_s^0 \to \rho^0K_S^0$	$\pi^+\pi^-\pi^+\pi^-$	10^{-6}	7×10^{-7}	460	220

However, all decays except those involving a J/ψ require a trigger on the second B in the event (unless a secondary-vertex trigger can be implemented.) We consider two possibilities; a trigger on a single lepton, and a secondary-vertex trigger plus Kaon identification (possibly offline). The latter trigger cannot be implemented at CDF as presently configured because of the high-data rate implied by a secondary vertex trigger, and because of the lack of Kaon identification.

Table 6 shows our estimate of the geometric acceptance for the two types of triggers, which also have the merit of tagging the particle/antiparticle character of the second B. The lepton trigger applies to only 20% of all decays of the second B (if both electron and muon detectors are present), while 60% of the decays could be used for the Kaon trigger, as discussed in section 4.1 The secondary vertex trigger/Kaon tag at the mini-BCD would be about 1000 times more effective than the lepton trigger/tag at CDF.

Table 7 gives the combined acceptance for the decay of the first B and a tag via the second B. Table 8 the number of tagged, reconstructed events collectable in a run of 500 pb^{-1}.

The mini-BCD, with its optimistic trigger and tagging scenarios, should significantly outperform CDF according to our present understanding. We expect and encourage all

Table 6: Acceptance for the tagging decay $B_d^0 \rightarrow D^{*-}e^+\nu$, estimated with an ISAJET simulation. For the electron tag we require the e^+ and two of three hadrons. For the Kaon tag we require the Kaon and one other charged particle. Subscripts 1, 2, and 3 to CDF correspond to a minimum-P_t cut of 5, 7.5, and 10 GeV/c for a single electron.

Decay Mode	All-Charged Daughters	Tag Type	Detector				
			$mBCD_1$	$mBCD_2$	CDF_1	CDF_2	CDF_3
$B_d^0 \rightarrow D^{*-}e^+\nu$	$K^+\pi^-\pi^-e^+$	e	0.072	0.127	6.4×10^{-4}	3.3×10^{-4}	2.9×10^{-4}
$B_d^0 \rightarrow D^{*-}e^+\nu$	$K^+\pi^-\pi^-e^+$	K	0.178	0.289	–	–	–

Table 7: Acceptance for tagged B decays, estimated with an ISAJET simulation. For the mini-BCD we use the 40° configuration and assume the Kaon tag is used; the acceptance includes a factor of 60% as the fraction of all decays of the second B that are useful for this tag. For CDF we use the lepton tag, and include a factor of 20% in the acceptance as the fraction of all decays of the second B that include an electron or muon. However, for the decays that include a J/ψ in CDF, a lepton-pair trigger can be used; then the tagging lepton from the second B need only be identified but not used in the trigger; in this case we have reduced the P_t threshold to 2.5 GeV/c. We use the decay $B_d^0 \rightarrow D^{*-}e^+\nu$ to estimate the correlation in acceptance of the tagging and tagged B's. The acceptances for the tagging decays only have been presented in Table 6 above.

Decay Mode	All-Charged Daughters	Detector	
		$mBCD_2$	CDF_2
$B^+ \rightarrow \bar{D}^0\pi^+$	$K^+\pi^-\pi^+$	0.070	10×10^{-5}
$B^+ \rightarrow D_s^+\bar{D}^0$	$K^+K^-\pi^+K^+\pi^-$	0.041	6.6×10^{-5}
$B^+ \rightarrow J/\psi K^+$	$e^+e^-K^+$	0.066	20×10^{-5}
$B_d^0 \rightarrow D^-\pi^+$	$K^+\pi^-\pi^-\pi^+$	0.045	13×10^{-5}
$B_d^0 \rightarrow J/\psi K_S^0$	$e^+e^-\pi^+\pi^-$	0.031	10×10^{-5}
$B_d^0 \rightarrow \pi^+\pi^-$	$\pi^+\pi^-$	0.110	10×10^{-5}
$B_s^0 \rightarrow D_s^-\pi^+$	$K^+K^-\pi^-\pi^+$	0.060	3.3×10^{-5}
$B_s^0 \rightarrow D_s^-\pi^+$	$K^+K^-\pi^-\pi^+\pi^-\pi^+$	0.019	6.6×10^{-5}
$B_s^0 \rightarrow D_s^-\pi^+\pi^+\pi^-$	$K^+K^-\pi^-\pi^+\pi^-\pi^+\pi^+\pi^-$	0.006	$< 10^{-5}$
$B_s^0 \rightarrow \bar{D}^0K^{*0}$	$K^+\pi^-K^+\pi^-$	0.045	1.0×10^{-5}
$B_s^0 \rightarrow \rho^0K_S^0$	$\pi^+\pi^-\pi^+\pi^-$	0.037	3.3×10^{-5}
Average		0.048	7×10^{-5}

Table 8: Rate estimates for tagged and reconstructed B decays. B.R.(B) is the branching ratio for the two-body B decay, estimated according to Bauer *et al.*[2] B.R.(Tot) is the product of B.R.(B) and the secondary branching ratios. The efficiency used is the product of the geometric acceptance from Table 7 and a factor ϵ for the efficiency of tracking and vertexing. For the mini-BCD we use the Kaon tag and take $\epsilon = (0.33)^2 = 0.11$, for CDF we use the lepton trigger and suppose that $\epsilon = (0.33)(0.6) = 0.2$ for decays not involving a J/ψ, and $\epsilon = (0.9)(0.6) = 0.54$ for those decays that do. The reconstructed-event samples are for an integrated luminosity of 500 pb^{-1}, collectable in 1 year of running at a luminosity of 5×10^{31} $\mathrm{cm}^{-2}\mathrm{sec}^{-1}$.

Decay Mode	All-Charged Daughters	B.R.(B)	B.R.(Tot)	Recon. Decays mBCD$_2$	CDF
$B^+ \to \bar{D}^0\pi^+$	$K^+\pi^-\pi^+$	0.004	1.6×10^{-4}	18,000	48
$B^+ \to D_s^+\bar{D}^0$	$K^+K^-\pi^+K^+\pi^-$	0.008	4.8×10^{-6}	320	1
$B^+ \to J/\psi K^+$	$e^+e^-K^+$	6×10^{-4}	4.2×10^{-5}	4,600	68
$B_d^0 \to D^-\pi^+$	$K^+\pi^-\pi^-\pi^+$	0.006	4.8×10^{-4}	36,000	187
$B_d^0 \to J/\psi K_S^0$	$e^+e^-\pi^+\pi^-$	3×10^{-4}	1.4×10^{-5}	720	12
$B_d^0 \to \pi^+\pi^-$	$\pi^+\pi^-$	2×10^{-5}	2×10^{-5}	3,600	6
$B_s^0 \to D_s^-\pi^+$	$K^+K^-\pi^-\pi^+$	0.005	1.5×10^{-4}	10,000	10
$B_s^0 \to D_s^-\pi^+$	$K^+K^-\pi^-\pi^+\pi^-\pi^+$	0.005	2×10^{-4}	4,200	26
$B_s^0 \to D_s^-\pi^+\pi^+\pi^-$	$K^+K^-\pi^-\pi^+\pi^-\pi^+\pi^+\pi^-$	0.01	4×10^{-4}	2,600	4
$B_s^0 \to \bar{D}^0K^{*0}$	$K^+\pi^-K^+\pi^-$	0.005	1.3×10^{-4}	6,400	3
$B_s^0 \to \rho^0K_S^0$	$\pi^+\pi^-\pi^+\pi^-$	10^{-6}	7×10^{-7}	28	0

possible progress at CDF to improve their capability for B physics, which may yield results better than those estimated here.

A CP-violation study will require $\sim$ 1000 tagged, reconstructed events in decays to CP eigenstates such as $J/\psi K_S^0$, $\pi^+\pi^-$, or $\rho^0K_S^0$. The mini-BCD already comes close to this threshold for CP-violation physics at TEV I, and a full BCD would certainly exceed it. A sample of 720 tagged, reconstructed $B \to J/\psi K_S^0$ events would measure $\sin 2\varphi_1$ to 3-σ accuracy if it is greater than 2/3 (which is within the presently allowed region). Note that a two-arm mini-BCD would have the same capability for measuring $\sin 2\varphi_1$ as an asymmetric e^+e^- collier operating at a luminosity of 10^{33} $\mathrm{cm}^{-2}\mathrm{sec}^{-1}$, according to Table 2 of the BCD Reply to the SSC PAC.

In the BCD EOI we estimated that a study of B_s mixing will require about 1500 tagged, reconstructed decays of B_s meson to self-tagging final states. This number assumed the use of a lepton tag. Supposing the Kaon tag (and secondary vertex trigger) can be implemented, the number of required tagged, reconstructed decays increases to about 4000 The large number is needed because of mistagging of the second B. However, it is quite appropriate to sum over all possible B_s decays, as the all have the same mixing parameter. Table 8 indicates

Table 9: Rates in an ambitious upgrade of CDF for $B \to J/\psi K_S^0$, estimated with an ISAJET simulation. Pions, Kaons, electrons and muons are all accepted with the pseudorapidity interval listed in the Table. The minimum transverse momentum for pions and Kaons is 0.3 Gev/c, while electrons must have $P_t > 2$ GeV/c. Muons must have $P > 3$ GeV/c, but have no P_t cut. Kaon identification is available only for $P < 3$ GeV/c. The efficiency used in the rate estimate is the product of the Geometric Acceptance and a factor 0.33 for the efficiency of tracking and vertexing. The reconstructed-event samples are for an integrated luminosity of 500 pb^{-1}, collectable in 1 year of running at a luminosity of 5×10^{31} cm^{-2}sec^{-1}.

Final State	$\|\eta\|_{max}$	Geometric Acceptance	Recon. Decays
$e^+e^-\pi^+\pi^-$	1.0	0.009	620
$e^+e^-\pi^+\pi^-$	1.5	0.017	1,180
$e^+e^-\pi^+\pi^-$	2.0	0.024	1,660
$e^+e^-\pi^+\pi^-$	2.5	0.031	2,140
$e^+e^-\pi^+\pi^-$	3.0	0.036	2,490
$\mu^+\mu^-\pi^+\pi^-$	1.0	0.004	240
$\mu^+\mu^-\pi^+\pi^-$	1.5	0.011	760
$\mu^+\mu^-\pi^+\pi^-$	2.0	0.029	2,000
$\mu^+\mu^-\pi^+\pi^-$	2.5	0.059	4,070
$\mu^+\mu^-\pi^+\pi^-$	3.0	0.098	6,760

that in the mini-BCD with 40° coverage some 23,000 tagged, reconstructed B_s decays can be collected in four relevant channels. Other channels will contribute at least an equal number of reconstructed events, and we judge that B_s mixing is within reach.

Note that the mini-BCD with 20° coverage would have 1/4 the acceptance for tagged, reconstructed decays, and would still be sufficient for a B_s-mixing study, albeit with little safety margin.

2.1 More Ambitious Upgrades to CDF

We consider here upgrades to CDF of a more dramatic nature. The main features of the upgrade are:

- Install a silicon vertex detector/tracker at radii up to 15 cm. This should provide tracking and good momentum measurement for $|\eta| \lesssim 3$.

- Replace the vertex-TPC's with a RICH counter with a solid radiator, occupying radii from 15 to 30 cm. This might permit K/π separation for momenta between 0.3 and 3 GeV/c. Alternatively, the RICH counter might be placed in the 4 cm between the outer radius of the CTC and the inner radius of the magnet coil. This would restrict Kaon identification to $|\eta| < 1$.

- We suppose that electron identification is possible for $P_t > 2$ GeV/c, while muon identification is available for $P > 3$ GeV/c (not P_t).

- We would then have both the Kaon tag and the lepton tag available, as described on p. 3 of section 1 above.

Table 10: Rate estimates for tagged and reconstructed $B \to J/\psi K_S^0$ decays in an ambitious upgrade to CDF. The cuts are as in Table 9. The efficiency used is the product of the Geometric Acceptance and a factor $(0.33)^2$ for the efficiency of tracking and vertexing of both B's in the event. Also, for the Kaon tag only 60% of the second B's can be used, while for the electron tag only 5% can be used The reconstructed-event samples are for an integrated luminosity of 500 pb^{-1}, collectable in 1 year of running at a luminosity of 5×10^{31} cm^{-2}sec^{-1}.

Final State	$\lvert\eta\rvert_{max}$	Tag	Geometric Acceptance	Recon. Decays
$e^+e^-\pi^+\pi^-$	1.0	K	0.002	27
$e^+e^-\pi^+\pi^-$	1.5	K	0.006	82
$e^+e^-\pi^+\pi^-$	2.0	K	0.010	137
$e^+e^-\pi^+\pi^-$	2.5	K	0.013	178
$e^+e^-\pi^+\pi^-$	3.0	K	0.016	212
$e^+e^-\pi^+\pi^-$	1.0	eK	0.001	14
$e^+e^-\pi^+\pi^-$	1.5	eK	0.003	38
$e^+e^-\pi^+\pi^-$	2.0	eK	0.004	55
$e^+e^-\pi^+\pi^-$	2.5	eK	0.006	82
$e^+e^-\pi^+\pi^-$	3.0	eK	0.008	110
$\mu^+\mu^-\pi^+\pi^-$	1.0	K	0.001	13
$\mu^+\mu^-\pi^+\pi^-$	1.5	K	0.004	52
$\mu^+\mu^-\pi^+\pi^-$	2.0	K	0.012	157
$\mu^+\mu^-\pi^+\pi^-$	2.5	K	0.023	300
$\mu^+\mu^-\pi^+\pi^-$	3.0	K	0.038	497
$\mu^+\mu^-\pi^+\pi^-$	1.0	μK	0.000	4
$\mu^+\mu^-\pi^+\pi^-$	1.5	μK	0.001	20
$\mu^+\mu^-\pi^+\pi^-$	2.0	μK	0.004	55
$\mu^+\mu^-\pi^+\pi^-$	2.5	μK	0.009	124
$\mu^+\mu^-\pi^+\pi^-$	3.0	μK	0.015	206

Tables 9 and 10 give estimates of the reconstructed samples for $B_d \to J/\psi K_S^0$ decays, without and with tagging. With the cut $|\eta| < 3$ in CDF, these rates are nearly equal to those in mini-BCD or an ambitious upgrade to D0.

Figure 3 shows the pseudorapidity distributions of Kaons, electrons, and muons that are part of the tagged, reconstructed B decays with the cut $|\eta| < 3$ in Tables 10 and 11. A substantial fraction of all Kaons with $P < 3$ GeV/c also have $|\eta| < 1$, so that a RICH counter just outside the CDF CTC would be quite useful. The requirement that $P_\mu > 3$ GeV/c leads to the peaking at forward angles seen in the Figure.

Table 11: Rate estimates for tagged and reconstructed $B_s^0 \to D_s^- \pi^+ \to K^+ K^- \pi^+ \pi^-$ decays in an ambitious upgrade to CDF. The cuts are as in Table 9. The efficiency used is the product of the Geometric Acceptance and a factor $(0.33)^2$ for the efficiency of tracking and vertexing of both B's in the event. Also, for the Kaon tag only 60% of the second B's can be used, while for the electron tag only 5% can be used. The rates using a muon tag as very similar to those using the electron tag. The reconstructed-event samples are for an integrated luminosity of 500 pb^{-1}, collectable in 1 year of running at a luminosity of 5×10^{31} cm^{-2}sec^{-1}.

$\lvert\eta\rvert_{max}$	Tag	Geometric Acceptance	Recon. Decays
1.0	K	0.021	2,100
1.5	K	0.065	6,500
2.0	K	0.112	11,200
2.5	K	0.143	14,300
3.0	K	0.157	15,700
1.0	eK	0.007	60
1.5	eK	0.021	170
2.0	eK	0.033	270
2.5	eK	0.042	340
3.0	eK	0.045	370

Next we estimate the sensitivity of an upgraded D0 for B_s mixing via the representative decay $B_s^0 \to D_s^- \pi^+$, with $D_s^- \to \phi\pi^-$ and $\phi \to K^+K^-$. The discussion here closely parallels section 1.2 above.

The cuts on the pions and Kaons are as in the previous subsection. The branching ratio for $B_s^0 \to D_s^- \pi^+$ is estimated to be 0.005, and the combined branching ratio for $B_s^0 \to K^+K^-\pi^+\pi^-$ is taken as 1.5×10^{-4}. We suppose that there are 1/2 B_s or $\bar{B}_s$ per B-$\bar{B}$ pair produced.

The acceptance was estimated to be 0.26 assuming, for example, that $|\eta| < 2$, so after including the usual factor of 0.33 for vertexing and tracking efficiency, we could reconstruct some 130,000 $B_s^0 \to K^+K^-\pi^+\pi^-$ events in a run of 500 pb^{-1}. This assumes a perfect trigger, however.

The effect of including a trigger/tag on the other B is shown in Table 11. The Kaon tag is not a trigger by itself, so the high rates shown could not be obtained unless something

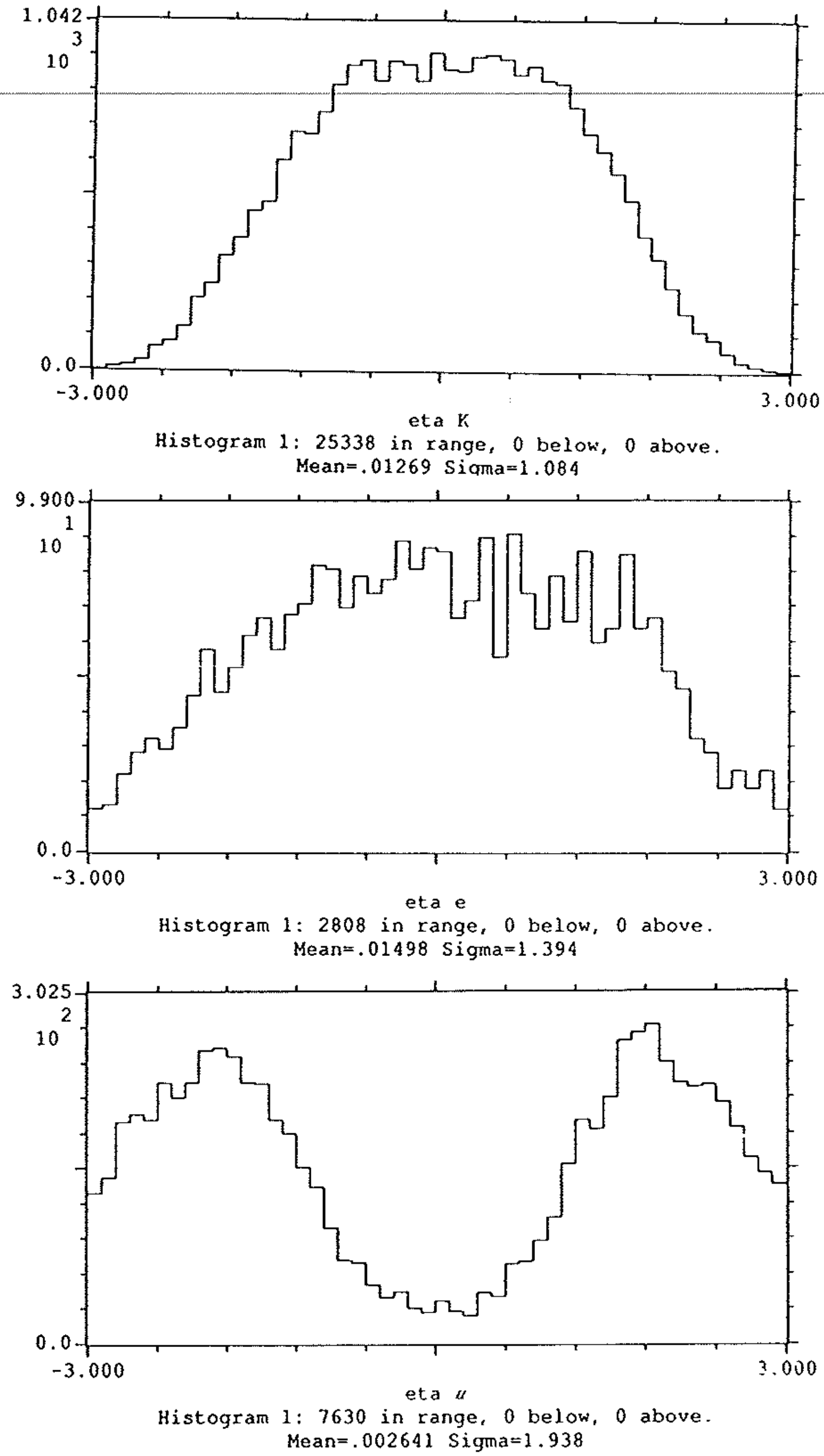

Figure 3: The η of K, e, and μ from tagged, reconstructed B decays in an upgrade of CDF with tracking out to $|\eta| = 3$. Other cuts as as described in Table 9.

like a secondary-vertex trigger can be implemented. (A solenoidal magnetic field permits relatively straightforward implementation of a P_t trigger, which might prove useful for B physics.)

Following the discussion of section 2.2 of the BCD EOI, B_s mixing could be resolved at the 3-σ level for a mixing parameter of $x_s < 20$ if we have 4000 tagged, reconstructed B_s decays using a Kaon tag, or 1500 events using the electron tag. These events can be accumulated is several channels and combined into a single analysis, as the mixing parameter x_s is independent of the decay mode. Hence we can be optimistic that an upgraded CDF could resolve B_s mixing, provided it includes Kaon identification. However, if the Kaon identification is outside the CDF CTC, covering only $|\eta| \lesssim 1$, and the eK tag is used, the signal for B_s mixing may be rather weak.

3 Overview of a Mini-BCD

We sketch a mini-BCD detector configuration for the Tevatron collider that could realize the goals discussed in the previous section:

- A study of B_s mixing via full reconstruction of self-tagging B_s decays (involving Kaons), with the required tag on the second B via partial reconstruction involving an electron, a Kaon, or both.
- A possible first look at CP violation in the decay $B_d^0 \to J/\psi K_S^0$.
- Implementation of all BCD detector systems except the muon detector, but in a modest configuration with central tracking in a small dipole magnet and particle identification in a single Forward arm covering $2° < \theta < 40°$.
- The Central region could include a time-of-flight system as well as tracking, so that pion and Kaon identification would be available there as well as in the Forward arm.

A preliminary sketch of the mini-BCD is shown in Fig. 4.

3.1 Detector Subsystems

We introduce briefly the various subsystems of the mini-BCD, indicating their function, technology, and approximate channel count.

1. **Dipole Magnet.** The Chicago Cyclotron Magnet would be excellent for the mini-BCD (or not-so-mini-BCD!), but we consider here a window-frame magnet with a gap $3 \times 3 \times 3$ m^3. The coils might be around each of the yoke pieces (rather than a saddle arrangement around the gap) if such geometry is more compatible with construction of superconducting coils. The outer dimensions of the magnet steel are 7 m wide by 6 m high by 3 m deep, for a total weight of 710 tonnes. For a field of 10 kG about 2.5×10^6 amp-turns will be needed. If the coils were of conventional aluminum construction, 50-cm thick, they would weigh 75 tonnes, and the power consumption would be 840 kWatts.

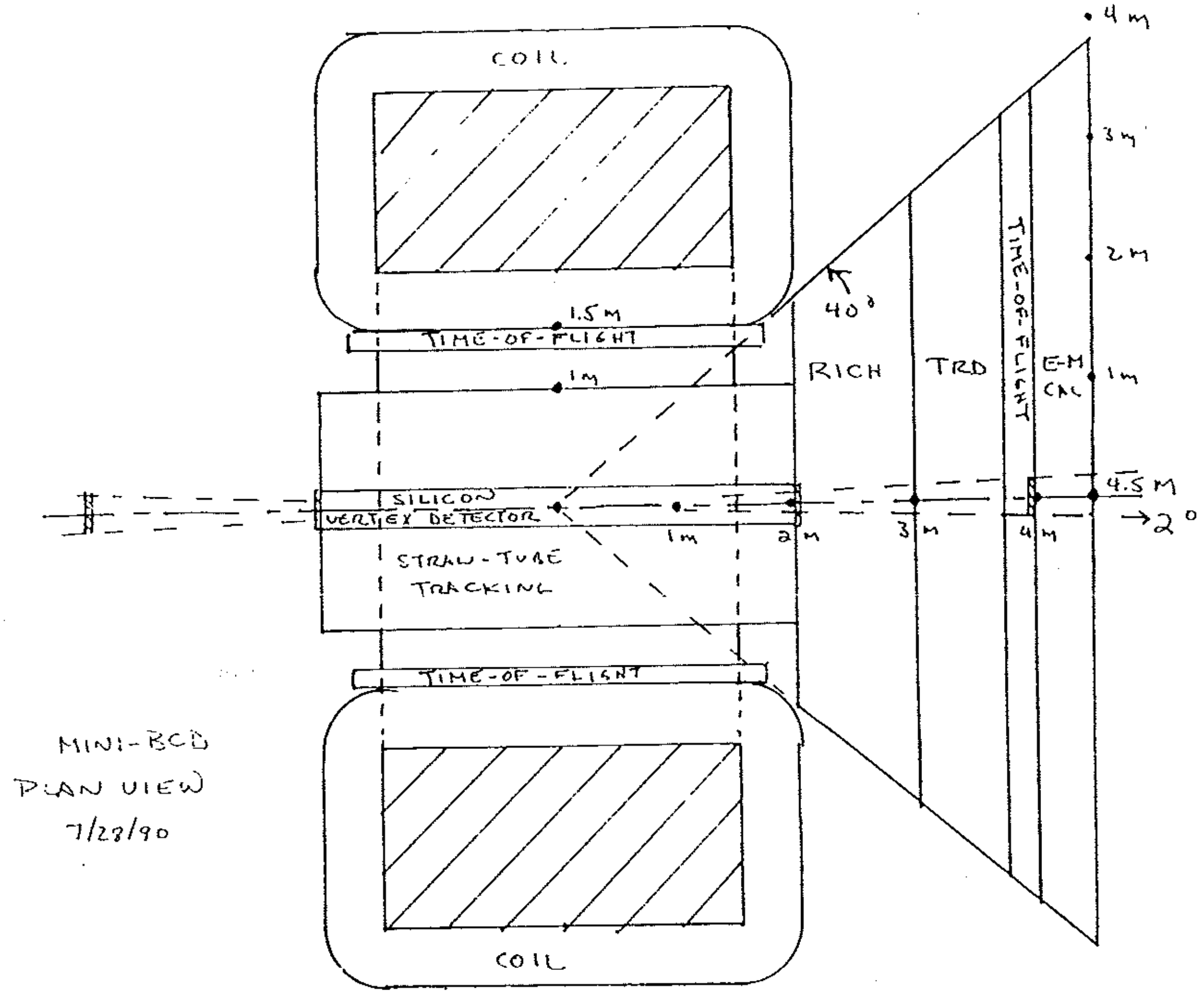

Figure 4: Plan view of a mini-BCD.

The field of the Central dipole magnet deflects the proton beams, and must be compensated.

2. **Silicon Vertex Detector.** The silicon vertex detector would follow the design developed in the FNAL Letter of Intent, and the SSC EOI. To aid in finding the primary vertex, as well as providing hadron tracking over a large solid angle, the vertex detector would be 4-m long (or perhaps 3-m long if we sacrifice tracking in the second forward region).

   We propose to build the vertex detector using silicon *p-i-n* diode arrays with local VLSI readout. In an option based on ministrips, the size of the detector element varies from 25 μm $\times 5$ mm at a radius of 1.25 cm to 50 μm $\times$ 5 cm at a radius of 10 cm. These sizes are chosen to provide the required spatial resolution and to limit the confusion of hits from different tracks to less than 0.5% per detector layer. The technologies to build these devices will be an extension of those now used to make ac-coupled, double-sided *p-i-n* diode arrays and associated readout chips. This extension includes the development of fast, radiation-hard readout chips.

The silicon detectors will be arrayed with both 'barrel' and 'disk' detectors near the interaction point, but only disk detectors at forward angles. The average number of strips on a detector that are struck by a charged particle is ~ 5 in the 4π collider geometry. The goal of only 1% strip occupancy in a system with an average of 10 strip planes per track (counting both sides of the detectors) leads to a total of $\sim 10^6$ strips. These are located on ~ 1000 silicon wafers that are read out via $\sim 10{,}000$ custom VLSI chips with 128 channels each.

The silicon detectors come within 1.25 cm of the beams to minimize the extrapolation to the vertices, but which exposes the detectors to considerable radiation. The vertex detector extends to a maximum radius of 10 cm, and has total length of 6 m along the beam. The vertex detector has a projected power consumption of 1-5 kWatts, which can be cooled by gas flow.

The vertex detector also provides substantial track-pattern recognition and excellent momentum measurement for tracks at small angles ($\eta \gtrsim 3$), as shown in Fig. 5.

3. **Straw-Tube Tracking System.** The goal of the tracking system is to provide a resolution of 25 MeV/c^2 at the B-meson mass. This requires a momentum resolution of about 0.7% for the B-decay products that have P_t in the range 0.3-2.5 GeV/c, and laboratory momentum up to 75 GeV/c at forward angles. The tracking system must also permit extrapolation of tracks into the silicon vertex detector with sufficient spatial accuracy to match the track segments properly.

   We propose to use gaseous drift chambers in the form of straw-tube detectors for the tracking system. These offer relatively good accuracy (~ 50 μm with a 'cool' gas; a slower drift velocity is not a problem at a luminosity of $< 10^{32}$ cm^{-2}sec^{-1}), moderately low mass (~ 0.1 radiation length), and good reliability (due to the physical isolation of each sense wire). The straw tubes will be arrayed in 'superlayers' of 8-10 layers thick, which leads to the use of 'minivectors' defined by the hits in a superlayer as intermediate quantities in track pattern recognition. The straws will be arrayed vertically, and at angles of $\pm 15°$ to the vertical to provide small-angle-stereo measurements. The maximum straw-tube length will be 2 m. The straw tubes extend to within 10-15 cm from the beams, where they encounter the vertex detector; this restriction is sufficient avoid aging of the chambers due to radiation.

   Tracking for particles in the Central and Forward detectors will be performed in a combined tracking system 4 m long and 2×2 m^2 in cross section. Each track will traverse about 64 straw tubes (8 superlayers). The system would include about 80,000 straws if they are 7-mm in diameter. If the second forward arm is not covered this number would drop to about 60,000. If a smaller diameter than 7 mm is used, the straw count rises inversely.

4. **Time-of-Flight System.** We desire to identify $\pi^\pm$ and $K^\pm$ with transverse momenta between 0.3 and 3 GeV/c. The lower limit arises as softer particles suffer too much

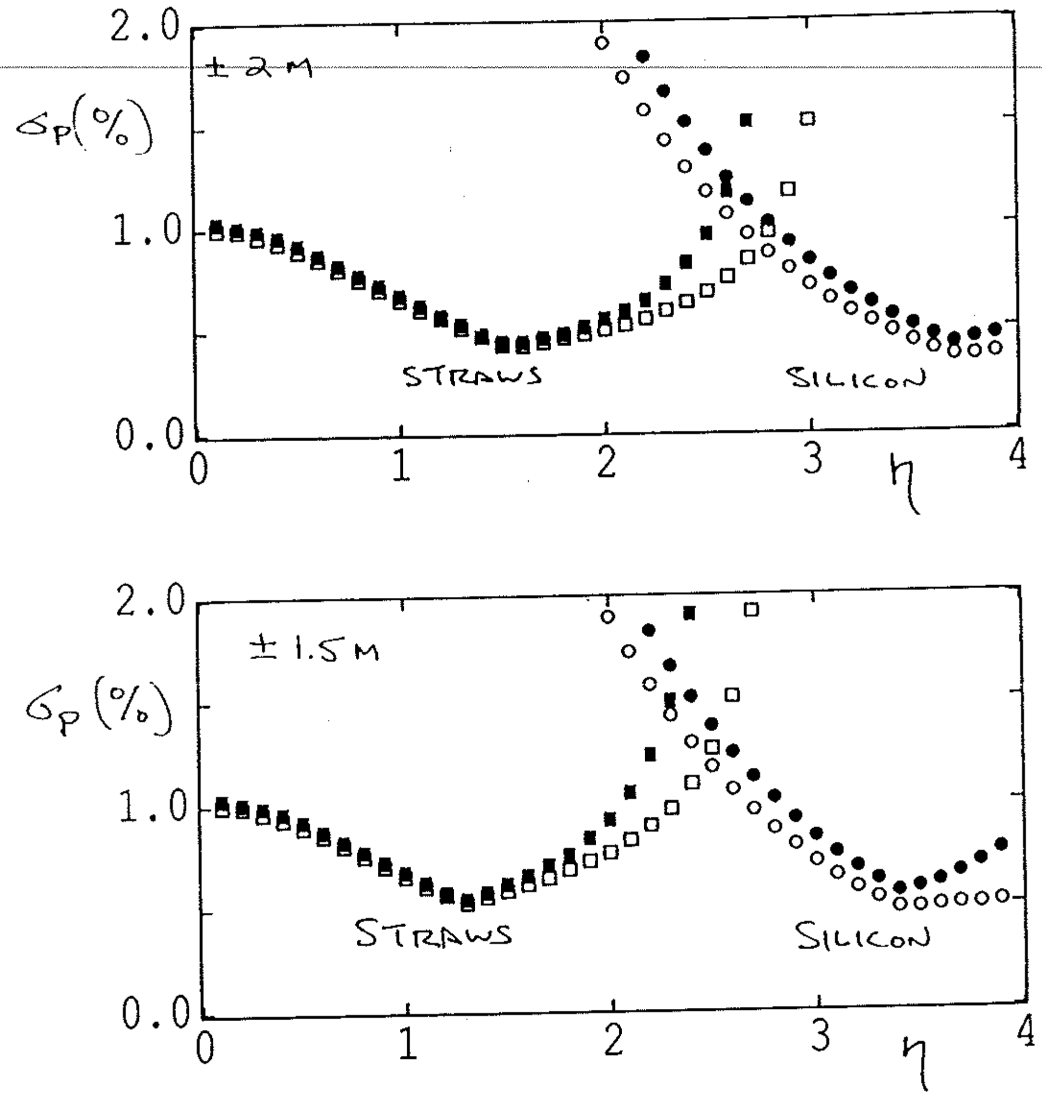

Figure 5: The expected momentum resolution for particles of $P_T = 2.5$ GeV/c as a function of pseudorapidity η. The straw-tube resolution is taken to be 50 μm, and the silicon detector resolution is 5 μm. The upper figure is for a tracking system of length ± 2 m, and the lower figure is for length ± 1.5 m. The open points indicate the contribution of multiple scattering to the resolution, which is the same for all P_T, and hence sets a lower limit on the resolution.

multiple scattering to be reliably associated with secondary vertices, while the upper limit is chosen to contain 80% of all B-decay products. Hadron identification will be accomplished by a combination of a time-of flight system at lower momenta, and RICH counters (item 5) at higher momenta. In addition to providing π-K (and heavier charged particle) separation, the time-of-flight system will be useful in identifying multiple interactions within a single bunch crossing, and could be used in a multiplicity trigger.

The available flight paths are 1.5-2.25 m in the Central detector, and 4 m in the Forward detector. It would be very advantageous to achieve a 60-ps accuracy, which would effect π-K separation for momenta up to 1.9, and 3.5 GeV/c in the Central, and Forward detectors, respectively. These are very aggressive specifications. To meet them we propose to have three time-of-flight scintillators, each 3-cm thick, traversed by each particle, and the scintillators in the Central region will be read out at both ends. The goal of 1% occupancy leads to 2500 azimuthal cells in each of the Central and Forward detectors. The total number of channels is 15,000, given the multiple sampling of 3 per cell in angle.

The possible merits of including tracking and Kaon identification in the Central region are illustrated in Figs. 6 and 7. In these we have generated events containing a $B \rightarrow J/\psi K_S^0$ and a $\bar{B} \rightarrow D^\star e\nu$ in an ISAJET/GEANT simulation. We require all hadrons to have $P_T > 0.3$ GeV/c to be detected, and electrons must have $P_T > 1$ GeV/c. We first require that both electrons from $J/\psi \rightarrow ee$ satisfy the P_t cut and also have $1 < \eta < 4$, *i.e.*, they must be in the Forward arm. Then we plot the rapidities and P_T of the other B-decay products in the event in Fig. 6. We see that a large fraction of the decay product have $\eta < 1$. In Fig. 7 we make the additional requirement that the electron from $\bar{B} \rightarrow D^\star e\nu$ also have $1 < \eta < 4$. In this case the associated Kaon from the $D^\star$ decay seldom has $\eta < 0$, but still a significant fraction of the Kaons have $\eta < 1$.

5. **Ring Imaging Čerenkov Counters.** Hadrons with momenta too large to be analyzed in the time-of-flight system will be identified in RICH counters in the Forward arm only. To cover the part of the transverse-momentum range 0.3-3 GeV/c not identified in the time-of flight system, the RICH counters must operate in the momentum range 3.5-50 GeV/c in the Forward detector. The separation of pions and Kaons in these ranges is to be at least three standard deviations, and the Čerenkov rings should have 25 photoelectrons each to insure reliable pattern recognition.

   These goals can be accomplished in the Forward region with a 1-m gas radiator, C_5F_{12}. The photodetector is some variation of a multistep avalanche chamber filled with TMAE gas (or with the very promising CsI-TMAE solid radiator being developed by Bruce Hoeneisen) at only a few-torr pressure. The readout is based on 'smart' cathode pads, perhaps with wedge and strip electrodes or with an array of resistively coupled pads, yielding position resolution $\sim 1/20$ the pad size.

   Supposing each ring image has 25 photoelectrons, there would be about 2500 hits per event in the RICH counters. We design for 2×10^5 detector elements, yielding slightly more than 1% occupancy. There will be about 80,000 pads of size 2×2 cm^2 in the Forward RICH counter.

6. **Transition Radiation Detector.** Electron identification is provided by a combination of a transition radiation detector (TRD) and an electromagnetic calorimeter. The 'fine-sampling' transition radiation detector consists of 25 layers, each with 100 15-μm-thick polyethylene foils spaced over 2 cm, followed by a xenon proportional chamber to detect the x-rays. This should permit an electron efficiency of 90% with only a 1% probability to misidentify pions as electrons. Such a TRD would be 75-cm thick. The TRD is located in front of the time-of-flight system.

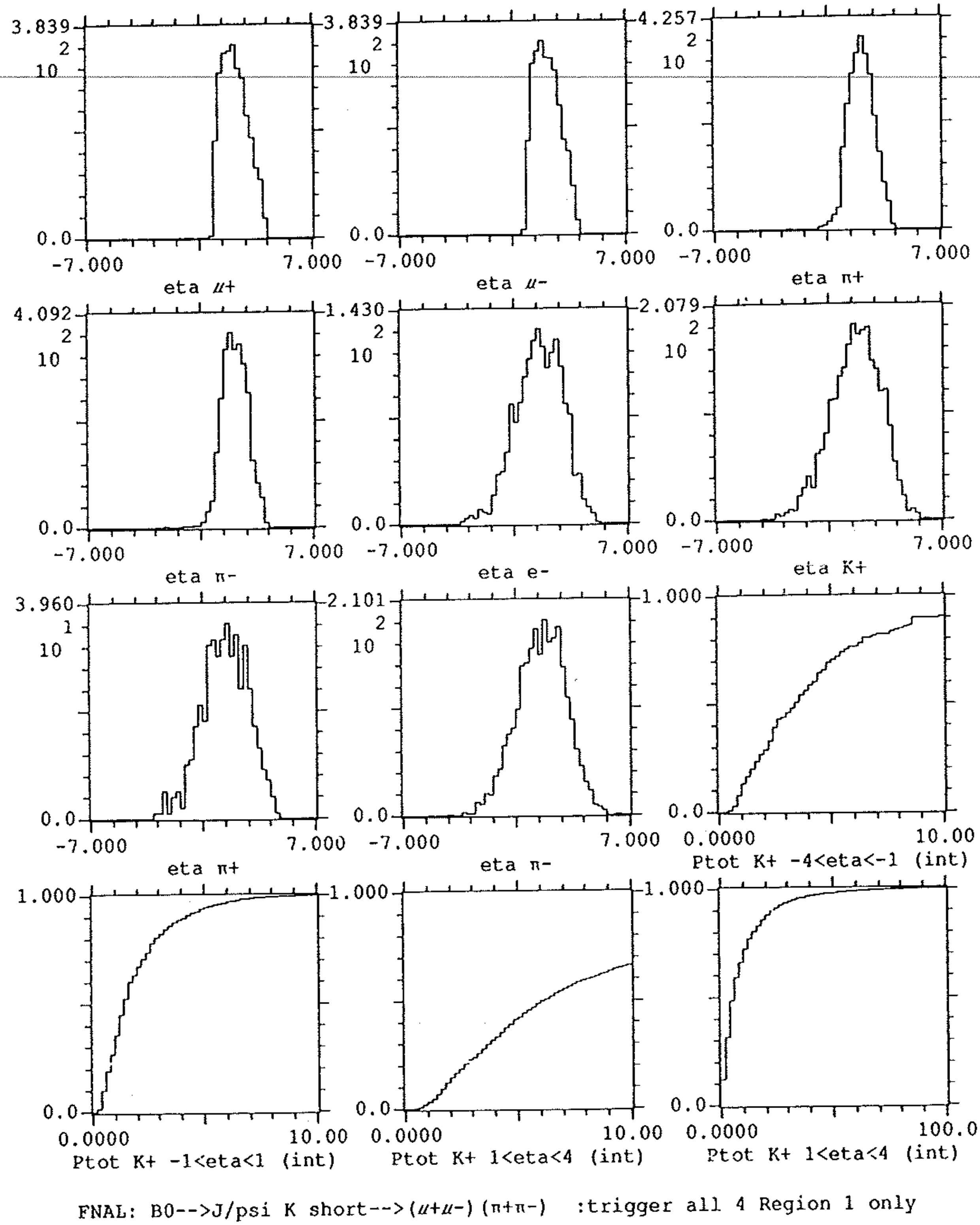

Figure 6: The η and P_t for the decay products from $B \to J/\psi K_S^0$ and $\bar{B} \to D^* e\nu$, subject to cuts described in the text. One cut is that both electrons from the J/ψ decay have $1 < \eta < 4$.

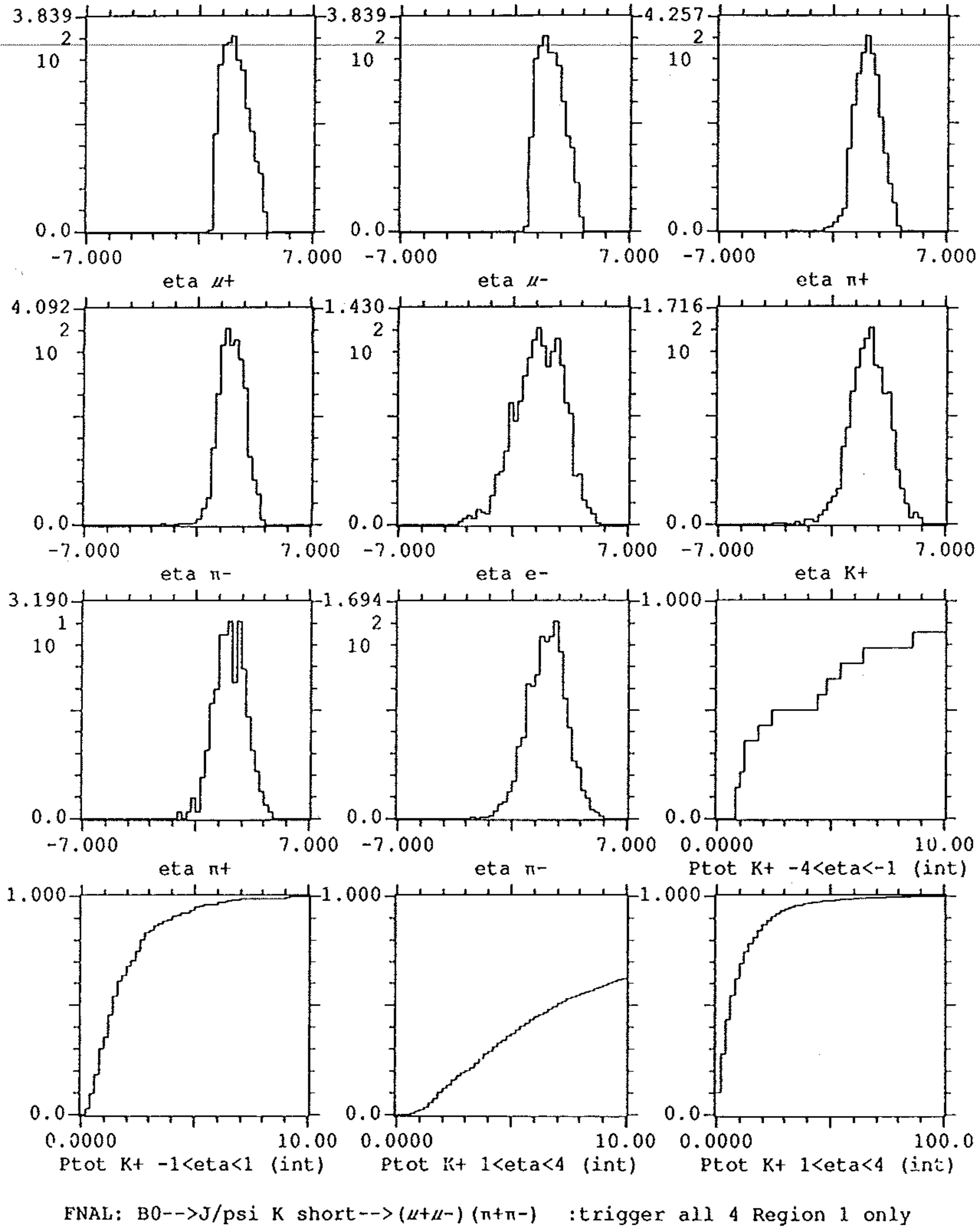

Figure 7: The η and P_t for the decay products from $B \rightarrow J/\psi K^0_S$ and $\bar{B} \rightarrow D^* e\nu$, subject to cuts described in the text. In addition to the cuts applied to Fig. 6, the electron from the $\bar{B}$ decay must also have $1 < \eta < 4$.

The goal of 1% occupancy suggests that there be 1000 cells per unit of pseudorapidity for electron identification. However, the TRD may be operated with a threshold such that each layer has only 10% efficiency for pions. Then we may permit 4% or even 9% geometrical occupancy of the TRD cells and remain at less than 1% detected occupancy. If we design for 4% geometric occupancy there will be 720 cells for $1 < \eta < 4$ each with 25 radial samples, for a total of 19,000 detector elements.

7. **Electromagnetic Calorimeter.** Electron identification is also accomplished with an electromagnetic calorimeter. As the BCD has an analysis magnet, the calorimeter need not provide a precision energy measurement, but must emphasize e-π separation via characterization of the transverse and longitudinal profiles of the shower. We desire electron identification down to 1-GeV/c transverse momentum, and that substantial pion rejection be available at the trigger level.

   Our present design consists of a preconverter, two longitudinal sections, and a hadron catcher. We expect to take full advantage of the current R&D efforts in calorimetry. The calorimeter and the hadron catcher will be arranged in towers with $\Delta\eta \times \Delta\phi = 0.08 \times 0.08$ so as to keep the occupancy and the $\pi^{\pm}$-π^0 overlap probability below 1%. This segmentation leads to 3000 cells (9000 channels) in the Forward detector. The preconverter will be integrated with the time-of-flight system. The preconverter will provide a shower-centroid measurement of approximately 1-mm accuracy. The combined rejection against pions in the TRD and E-M calorimeter should be better than $10^5 : 1$.

8. **Muon Detector.** No muon detector is planned for the mini-BCD. But if the mini-BCD runs push-pull in B0, the CDF muon toroids might be of use.

9. **Luminosity Monitor.** Four planes of 0.5-mm-square scintillating fibers located at ± 2 and ± 4 m from the intersection point will monitor the luminosity, and provide a fast measure of the longitudinal position of the interaction vertex. The latter function is accomplished by matching hits in the two planes of fibers, which are oriented to measure tracks in the nonbend plane. There will be about 4000 fibers in all.

10. **Prompt Trigger.** A prompt and efficient trigger for B production at a hadron collider is difficult because events with B's are only slightly different than 'minimum bias' events. About 1 event in 1000 at TEV I will contain a B. The goal of the prompt trigger is to reduce the rate of events off the detector to about 1/10 of the primary event rate. Three types of triggers are under consideration: i) single electrons above a P_t cut as low as 1 GeV/c; ii) a lepton pair consistent with J/ψ decay; iii) evidence for a secondary vertex in the nonbend plane.

    Trigger ii) is the most straightforward, but studies only particular modes. The 'vertex trigger,' iii), will require considerable specialized processing power on the detector, as may be possible with devices such as the '3-D' processors from Hughes Aircraft. The lepton triggers, i), have significant backgrounds that require software processing to eliminate.

The trigger scenario is the most difficult aspect of the BCD to project without actual experience, and an empirical understanding of effective trigger strategies would be one of the most important results of a mini-BCD.

11. **Data-Acquisition System.** Because of the large cross section for B production at TEV I, the data rate off the detector will be very high. The initial design of the data-acquisition system to to feed about 50,000 events/sec of average length 50 kBytes into the online processor farm. This will require a barrel switch of about 2.6 GByte/sec throughput, and a farm of about 10^5 MIPS.

3.2 Cost Estimate

Our quick estimate:

Magnet	$2M
Silicon Vertex Detector: $\sim 10^6$ stripes, $\sim 10^4$ BVX chips	$5M
Straw Tube Tracking: 80,000 channels @ $60 each	$5M
Time-of-Flight System: 15,000 channels @ $200 each	$3M
RICH Counters: 80,000 channels @ $60 each	$5M
TRD: 20,000 channels @ $100 each	$2M
E-M CAL: 10,000 channels @ $300 each	$3M
Barrel Switch	$1M
Processor Farm	$5M
Total	**$31M**

The cost of an upgrade to instrument the second Forward arm would be about $20M.

4 Micro-BCD

In reviewing the preceding options several conclusions emerge:

- The physics that can be done by CDF with $B \to J/\psi X$ decays will likely be done without major upgrades. However, this physics falls short of a clear signal for CP violation.
- B_s mixing is accessible at the TEV I, but requires a detector with Kaon identification and a high-rate data-acquisition system.
- Kaon identification and a high-rate data-acquisition system are not needed for top-quark searches, and are unlikely to be emphasized in upgrades to CDF and D0. Yet devices for these purposes must be demonstrated if there is ever to be a hadron-collider B experiment of large scope.
- To extend the acceptance for B decays, the silicon vertex detector upgrades CDF and D0 magnets should also extend the tracking of particles to much smaller angles than in conventional tracking systems. Ideally, the silicon vertex detector should provide tracking performance equal to that of the CDF CTC, but out to rapidity 3.

- The above considerations suggest upgrades to CDF with a silicon tracker/vertex detector out to radius 15 cm, followed by a thin RICH counter from 15 to 25 cm radius. These detectors would be read into a high-rate data-acquisition system (1000 events/sec written to tape) for B decays not involving a J/ψ. For events with a J/ψ trigger from the rest of the experiment, these detectors would pass their information into the main data-acquisition system.

- Such a configuration actually has excellent stand-alone capability for B physics if it were placed in a small solenoid magnet. We call this option a **Micro-BCD**. The solenoid magnet would have a field of 1.5 T, an inner radius of 25 cm, and field length of 300 cm. A conventional copper coil would consume about 1 MWatt. The flux return would have an outer radius of 50 cm, a length of 325 cm, and would wiegh only 8 tons. See Fig. 8

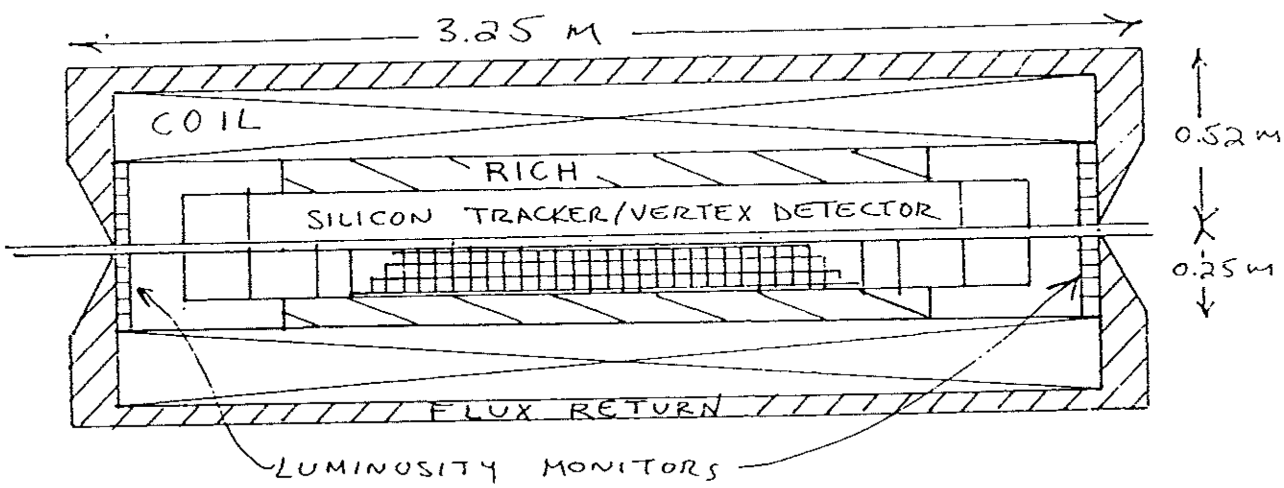

Figure 8: Plan view of a Micro-BCD, with a conventional solenoid magnet for operation in C0.

- The Micro-BCD could be tested in C0 prior to installation in CDF or D0. A luminosity of only 2×10^{28} would yield 1000 events/sec, sufficient to saturate the Micro-BCD when operated with no trigger. This would yield 1 B-$\bar{B}$ event on tape each second – equivalent to an e^+e^- collider operating at a luminosity of 10^{33} cm^{-2}sec^{-1}. In a run of 30 days, the Micro-BCD could reconstruct 10 events in an all-charged B-decay mode with a branching fraction of 10^{-4}, assuming an efficiency of 3%. This includes several

$B \to J/\psi X$ modes, and as well modes like $B_s \to D_s\pi$ which are useful in B_s-mixing studies.

- With the addition of an online processor farm that implements a software trigger, the yield of B events might increase by at least a factor of ten.
- A Micro-BCD in C0, or installed inside CDF or D0, would demonstrate most of the ingredients needed for an eventual larger-scale, dedicated B-physics experiment to study B_s mixing and CP violation:
  1. A 3-dimensional silicon vertex detector with tracking capability as well.
  2. Hadron identification.
  3. High-rate data-acquistion system.
  4. Software triggers for B physics.
- Referring to section 3.2 above, we estimate the cost of the Micro-BCD as about $16M. No civil construction would be required to operate it in C0. Minimal modifications to the accelerator would be required: the electrostatic separators would need to be reconfigured to permit a low luminosity in C0 again.

5 References

[1] C. Haber has suggested that CDF could observe B_s mixing via partial reconstruction of leptonic decays; see M. Gold *et al.*, *B Physics with Existing Collider Detectors*, in Physics at Fermilab in the 1990's (Breckenridge, 1989), p. 247. We have not critically evaluated this difficult approach.

[2] M. Bauer, B. Stech, and M. Wirbel, *Exclusive Non-Leptonic Decays of D-, D_s-, and B-Mesons*, Z. Phys. C **34**, 103 (1987). The estimate of the branching ratio of $B_s \to \rho^0 K^0_S$ as 10^{-6} is taken from that for its exact analog $B^0_d \to \rho^0\pi^0$.