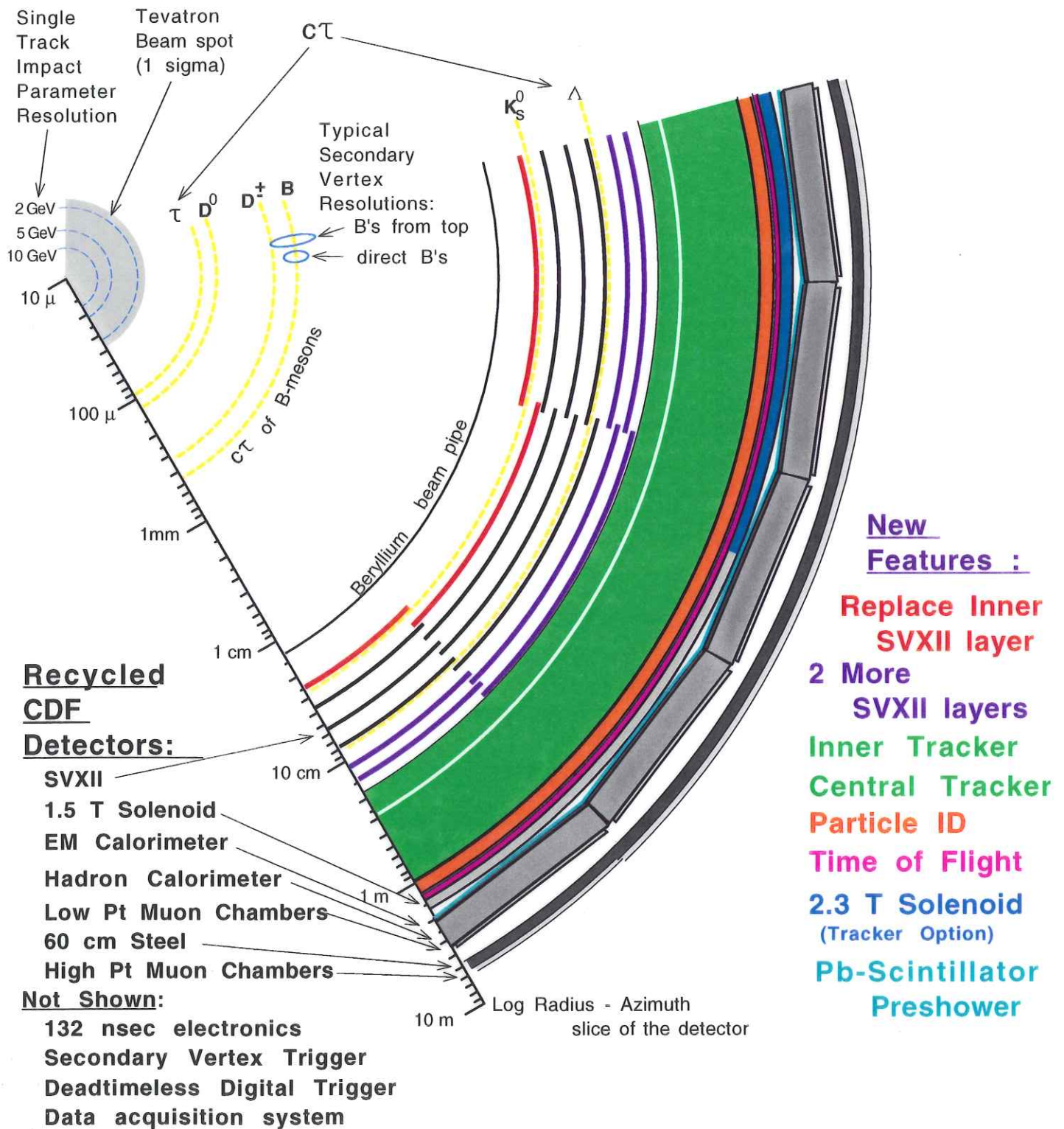


EXPRESSION OF INTEREST IN A FUTURE COLLIDER DETECTOR IN B0

from members of the CDF Collaboration and Others



1 INTRODUCTION

We express our interest in performing experiments in the high P_T , b -physics, electroweak, and QCD arenas, including:

- Measurement of M_{top} with precision of order 3 GeV/ c^2 , and M_W to the limit of systematic uncertainties.
- Anomalous triboson couplings with sensitivity exceeding that of LEP200.
- Broad-band search for new phenomena at the energy frontier.
- Search for CP violation in modes sensitive to unitarity triangle angles α , β , and γ and for non standard model phases in $B_s \rightarrow J/\psi\phi$ and $\Lambda_b \rightarrow J/\psi\Lambda$ with similar sensitivity to $B \rightarrow J/\psi K_S$.
- A broad program studying the spectroscopy of all b -particle species.

Through the early years of the next decade, a number of these measurements can only be done at the Tevatron Collider. The upgrades proposed in this EoI will also make us competitive with other facilities in areas where the Tevatron is not unique. A benchmark example, the "golden mode" CP -violating process $B \rightarrow J/\psi K_S$, is discussed in Section 3.

This physics can best be accomplished through an evolutionary continuation of the CDF experiment. We are well positioned to build upon the experience acquired from the operation of the CDF detector and the analysis methods developed in the study of hadron-collider physics. Major hardware assets are in place: the large volume solenoidal field for precision tracking, secondary b -vertex detection and lepton identification, fast calorimetry, and the ability to trigger on and reconstruct muons and electrons over a wide range of P_T and large solid angle.

We see no incompatibility between low P_T b -physics and high P_T physics in this approach. The CDF b -tag top analysis is an example of how low P_T capability is essential for high P_T sensitivity. Indeed, the addition of secondary vertex reconstruction and particle identification to the already powerful lepton discrimination results in a detector which is well optimized for flavor physics at the Collider.

We envisage upgrades to CDF which address the operational problem of high luminosity and the need for increased acceptance. The major element of this proposal is a reconfiguration of the systems in the solenoid. We consider the replacement of the SVX+VTX+CTC with a system of modern position sensitive detectors offering improved resolution, pattern recognition capability, rapidity coverage and rate capability. This system would be of reduced radius, leaving space in the solenoid for a particle identification system which is important to the b -physics goals. The solenoid coil could be replaced with a higher field version. In addition, we consider preradiators for enhanced electron identification in the central and plug region, new chambers for enhanced muon identification in the forward region, a new far forward calorimeter, and requisite upgrades to triggering and data acquisition.

We emphasize that these upgrades follow on those approved in the context of E-830, and that this is a single evolutionary program. Several of the upgrades proposed here could well be appropriate for E-830 in Run-II, and we suggest that they be implemented as soon as they are fiscally and technically feasible. An example is a low-cost time-of-flight system for the work described in Section 3.3. We assume that this proposed experiment will commence data taking in the year 2000, record 0.5 fb $^{-1}$ in the first year and 1.0 fb $^{-1}$ in subsequent years, culminating in an integrated sample of ~ 5 fb $^{-1}$ by the year 2005.

2 High P_T Physics

The CDF collaboration has a well accomplished program in high P_T physics, and our expertise and capability is perhaps best summarized by Fig. 2-1a, the long awaited comparison of M_W to M_{top} in the context of precision electroweak radiative corrections. With even the modest sensitivities of the present measurements, the potential of the comparison is clear. We discuss here the salient features of a continued physics program in high P_T physics, assuming the CDF detector of this EoI with an integrated luminosity of 5 fb $^{-1}$.

2.1 Top Physics

The present CDF top analysis [1] relies heavily on the identification of electrons and muons at high and low P_T and the reconstruction of b -vertices in high P_T jets. Extrapolating from the present efficiencies, we expect that the Run-II program and upgrades will yield a total of 60 $t\bar{t}$ events in the dilepton mode and 300 $t\bar{t}$ events in the

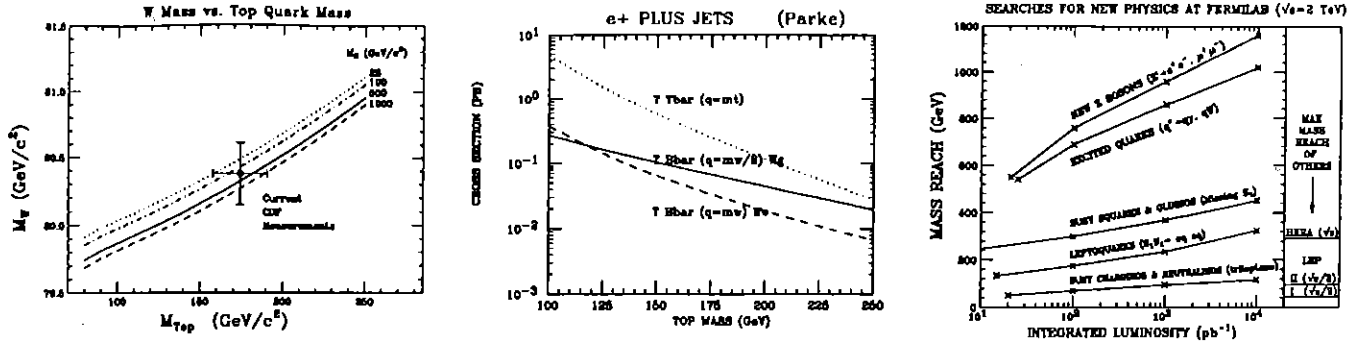


Figure 2-1: a) The left plot shows the present CDF uncertainty on the top quark and W mass. b) The middle plot shows cross sections for various top production mechanisms. c) The right plot shows expected CDF limits on searches for new phenomena.

ℓ +jet+ B -tag mode. Much more detailed studies will be possible with the enlarged sample from CDF in Run-III, where we anticipate samples of approximately 850 events in the dilepton mode and 4.3K in the lepton plus jets mode. Accumulating this large sample in the high luminosity environment depends on two detector changes:

- Ensuring survivability and performance of the existing central tracking and thus the existing lepton identification and b -tag efficiency.
- Extending to $|\eta| \leq 2.5$ the ability to tag b -vertices and the ability to trigger on and identify leptons, all with sensitivity and purity comparable to the present central system. If the tracking and lepton capability is not extended past the present $|\eta| \leq 1.0$, the above top sample is reduced by 40%.

The Run-Ia CDF top analysis has established the technique of mass measurement via constrained fit of the top hypothesis to the ℓ +jet kinematics [2]. The dominant uncertainties are found to be the shape of the background spectrum and the deduction of the parton energies from the measured jets, each contributing about 5%. As in the case of the CDF W mass analysis, we believe these errors can be reduced by *in situ* studies with large control samples. For example, the identified $W \rightarrow jj$ decays in the fitted candidates measures the parton level complications in the environment of interest, and b -tagging in Z + jets can be used to normalize the $Wb\bar{b}$ backgrounds in W + jets. We expect the systematic uncertainty to continue to decrease as the integrated luminosity increases; although we do not now know what the ultimate limitation may be, we anticipate a top quark mass uncertainty of $< 3 \text{ GeV}/c^2$. As seen in Fig. 2-1a., the measurement of M_{Higgs} via electroweak corrections is saturated at this δM_{top} until δM_W falls below $30 \text{ MeV}/c^2$.

A number of other issues, such as branching ratios, rare decays, decay correlations in the final state, and single top production $Wg \rightarrow t\bar{b}$ are all under study. As seen in Fig. 2-1b, the cross section for the single top mechanism at $M_{top} = 175 \text{ GeV}/c^2$ is only a factor of five below that of $t\bar{t}$ [3]. This single top production rate is directly proportional to the top total decay width, and is probably the best way to measure the width, if the signal can be extracted from the backgrounds from W +jets and $t\bar{t}$. The \bar{b} from the final state $t\bar{b}$ is produced over a large rapidity interval, $|\eta| < 2$, and at low P_T , which makes lepton identification and vertex detection out to $|\eta| \leq 2.5$ very desirable. In general, all top studies benefit from the best possible vertex detection and the best possible angular coverage for tracking and lepton identification.

2.2 Electroweak Physics

The anticipated inclusive yields in leptonic modes, assuming good high P_T lepton identification down to $|\eta| \leq 2.5$, is 6 million W 's and 0.7 million Z 's.

The W mass is presently measured to an overall uncertainty of $230 \text{ MeV}/c^2$ with the 20 pb^{-1} of data from Run-Ia [4]. The statistical uncertainties are $150 \text{ MeV}/c^2$ and $190 \text{ MeV}/c^2$ for the electron and muon modes, respectively. We expect the statistical uncertainties to decrease with increased luminosity as long as the number of interactions per crossing does not exceed that of Run-Ia (typically 1-2/crossing), and as long as systematics allow us to use the same method of fitting for the mass. An exposure of 5 fb^{-1} would thus predict statistical uncertainties of $10 \text{ MeV}/c^2$ and $12 \text{ MeV}/c^2$, respectively. The present analysis suggests that the systematic uncertainty decreases with increased luminosity at least down to a total uncertainty of around $100 \text{ MeV}/c^2$. Beyond that, new effects may enter, but

the increased statistics on the Z and W samples may allow further progress. We have estimated in the past that we can reach $50 \text{ MeV}/c^2$; given that the Run-III statistical power is at the $10 \text{ MeV}/c^2$ level to study systematics, it is possible we could do better. The limitations will be in the understanding of the linearity of the calorimeter between the W and the Z (which can be studied using the Z) and in the understanding of the differences in Z and W production and decay properties (which can be studied in their own right—the W angular asymmetry being one example.) It is likely that CDF will be quite competitive with LEP200, for which the estimates are $50 \text{ MeV}/c^2$ uncertainty per detector.

The large luminosity of Run-III will allow precise measurements of electroweak diboson production cross sections, and sensitive tests for anomalous triboson couplings. A 5 fb^{-1} sample will contain 50K W pairs produced, and a sensitivity to $\delta\kappa$ of order 0.5-0.15 and λ of order 0.3-0.1 in the dilepton and lepton+jets modes respectively [5]. In the lepton+jets mode, reconstruction of the recoiling $W \rightarrow jj$ decays using parton level kinematic techniques will improve the limit while providing a calibration sample for the top mass analysis. The main competition on these measurements before LHC is LEP-200. Here, the expected sensitivities for the optimistic running conditions of 500 pb^{-1} at $\sqrt{s} = 190 \text{ GeV}$ are $\delta\kappa \leq 0.5$ and $\lambda \leq 0.2$ [6], and we see that the CDF Run-III expectation is very competitive. In the $W+\gamma$ sector, we expect sensitivities of $\delta\kappa \leq 0.164$ and $\lambda \leq 0.032$ (95% CL), as well as observation of the radiation zero in the $W+\gamma$ amplitude in the rapidity correlation of the photon and lepton [7]. The radiation zero is a very sensitive test of the gauge boson self-couplings which is unobservable at LHC due to the use of pp beams. [8]

2.3 New Physics

Until the LHC runs, the Tevatron defines the high energy frontier. CDF has already placed stringent limits on a variety of possible new phenomena [9], and these analyses allow a confident extrapolation of future capabilities. Our expectations are summarized as a function of luminosity in Fig. 2-1c. We project that 5 fb^{-1} will give a mass reach of $1100 \text{ GeV}/c^2$ for new Z bosons decaying to e^+e^- and $\mu^+\mu^-$, $1000 \text{ GeV}/c^2$ for excited quarks decaying to $q\gamma$ and qW , and $300 \text{ GeV}/c^2$ for first and second generation leptoquark pairs decaying to lepton-quark pairs [10].

A SUSY search using missing transverse energy will have a squark and gluino mass reach of $420 \text{ GeV}/c^2$ for 5 fb^{-1} ; searches for pair production of charginos and neutralinos using trileptons will be sensitive to masses up to $100 \text{ GeV}/c^2$ [10]. Several recent studies show that self consistent analyses including recent experimental data yield interesting constraints on the parameter space of low energy SUSY models [11]. In the context of these models, the CDF SUSY analyses above are found to be sensitive to 100% of the parameter space of the "minimal" SUSY+GUT model of MSSM+SU(5), and up to 50% of the parameter space of MSSM+SU(5) \times U(1) [12].

2.4 QCD and Parton Distributions

With the large data set of Run-III, CDF will continue the program of precision tests of next-to-leading order QCD using photons, jets, heavy flavor, and W and Z bosons. Measurements in the central region can constrain parton distributions in the range $0.01 < x < 0.1$, and the plug upgrade extends this range to roughly $0.0001 < x < 1.0$. CDF is directly sensitive to the flavor of parton distributions: the gluon distribution from γ production, the charm distribution from $\gamma + c$ production, the strange distribution from $W + c$ production, and the ratio of u to d quarks from W lepton angular charge asymmetry. These measurements rely critically on efficient identification of photons, secondary vertices, and soft leptons over the largest angular range possible. Plug calorimetry is essential for the study of rapidity gaps, partons scattering by the exchange of a colorless object, which is signalled by the absence of energy between two jets separated in pseudorapidity, already observed in the present data [13].

We are also studying the possibility of adding a small EM/Hadron calorimeter placed beyond the plug upgrade and covering the region $3.5 < |\eta| < 5.5$ [14]. The physics topics that will be addressed include the study of the gluon structure function down to $x = 5 \times 10^{-5}$, the study of coherent gluon effects, Pomeron structure functions, the search for centauros/mini-centauros, and disoriented chiral condensates [15].

3 B-PHYSICS

3.1 B-Physics Accomplishments

CDF has already produced many B -physics results. B -production at the Tevatron is relatively flat in rapidity in the central region ($|\eta| < 1$) where CDF has a high yield of detected B -decays. Excellent vertex and mass resolution and

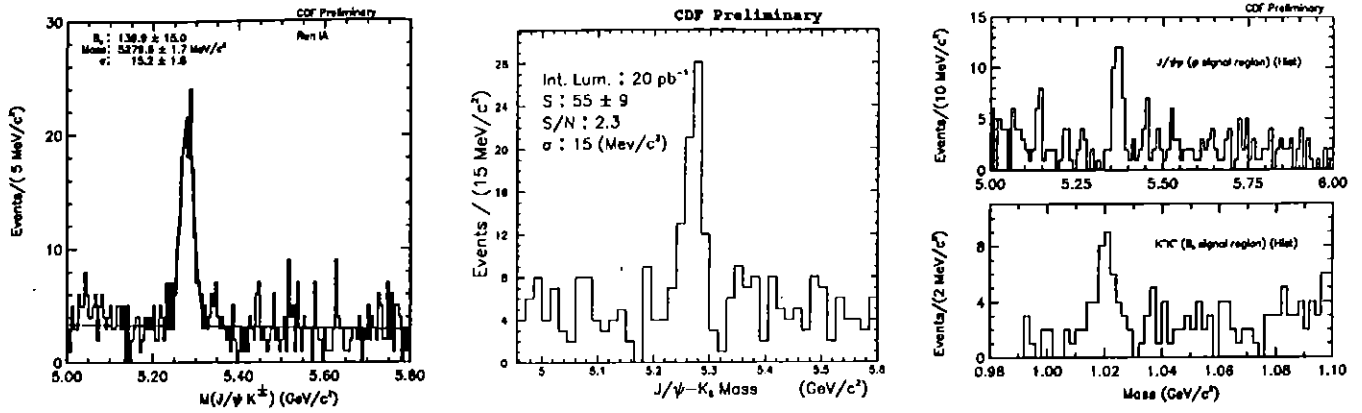


Figure 3-2: The left plot shows the $J/\psi K^\pm$ mass distribution. The center plot shows the $J/\psi K_S$ mass distribution with 55 events in the peak and a signal-to-noise of 2.3. The right upper plot shows the $J/\psi K^+ K^-$ mass distribution for $K^+ K^-$ within 10 MeV/c^2 of the ϕ mass. The right lower plot shows the $K^+ K^-$ mass distribution for the $J/\psi K^+ K^-$ combinations within 20 MeV/c^2 of 5370 MeV/c^2 . The full Run-Ia data sample of is used for these plots.

the ability to trigger on and identify low P_T leptons from B -decay in the central region are the principal reasons for the high reconstruction efficiencies. Furthermore, efficient track reconstruction is possible in the central region because charged tracks from B -decay are well separated from each other. We plan to emphasize improvements to the central region for the B -physics program and thereby build upon our experience. The following are some highlights of the CDF B -physics program.

- The first experiment to demonstrate exclusive B -meson reconstruction at a hadron collider using the decay mode $B \rightarrow J/\psi K^\pm$ [16].
- CDF has the largest sample in the world of fully reconstructed $B \rightarrow J/\psi K_S (55 \pm 9)$ [17], $J/\psi K^{*0} (112 \pm 18)$ [18], $J/\psi K^\pm (139 \pm 15)$ and $B_s \rightarrow J/\psi \phi (33 \pm 7)$ [19]. See Fig. 3-2.
- Measured the B lifetime with inclusive J/ψ 's and exclusive decay modes with a precision comparable to the best available[20].
- Reported the observation and mass measurement of the fully reconstructed B_s mesons through the decay chain $B_s \rightarrow J/\psi \phi$ [19]. An updated signal of 33.0 ± 7 events is shown in Fig. 3-2.
- Measured the B_s lifetime from $B_s \rightarrow D_s \ell \nu$ and $B_s \rightarrow J/\psi \phi$ which are competitive with the LEP results[21, 22].
- Measured the differential B cross section from inclusive and exclusive decay modes and the correlation in production between the B and \bar{B} mesons[23, 24].
- CDF has presented a preliminary limit[26] on $B \rightarrow K^\pm \mu^+ \mu^-$ competitive with current CLEO results.
- Measurement of polarizations in $B_d \rightarrow J/\psi K^*$ decays[27].

This successful program allows us to benchmark more ambitious measurements.

3.2 B -Physics Goals

A broad b -physics program is possible in a hadron collider because all b -particle species, B_u, B_d, B_s, B_c and b -baryons are copiously produced. We divide this program into two areas: B -decays that contain J/ψ 's and those that do not. We will continue to extrapolate our reach in decay modes containing the J/ψ in order to:

- Measure $\sin 2\beta$ of the unitarity triangle with sensitivity $\delta \sin 2\beta \sim 0.02$.
- Search for the CP violating asymmetry A_{CP} in $B_s \rightarrow J/\psi \phi$ and $\Lambda_b \rightarrow J/\psi \Lambda$ (expected $A_{CP} \sim 0$) to check for non standard model sources of complex phases;

- Measure the charged and neutral B lifetimes to the systematic limit of $\sim 2\%$. This corresponds to a travel distance of about $10 \mu\text{m}$;
- Measure the B_s lifetime to $\sim 3\%/\sqrt{\mathcal{L}}$ and b -baryon lifetimes;
- Record 25 million $J/\psi \rightarrow \ell^+ \ell^-$ decays per fb^{-1} for high statistics studies of $B \rightarrow J/\psi X$ decays.

Further important B -physics goals of this EoI will be to exploit the high statistics sample of $\sim 2 \times 10^8$ low P_T inclusive leptons and as well as non-leptonic decays triggered with the SVT. We envisage a broad program to measure the sides and angles of the unitarity triangle and rare decays. Here we indicate a few topics we plan to address in the LoI:

- Measurement of the time dependence of the A_{CP} in $B \rightarrow \pi^+ \pi^-$.
- Search for evidence of time dependent B_s mixing. The EoI sensitivity should reach $X_s \sim 20$ [28, 29].
- Measurement of branching ratios and lifetimes of B_s , B_c and b -baryons.
- Measurement of rare decays at the standard model predictions in $B \rightarrow K^* \mu^+ \mu^-$ and search for $B \rightarrow \mu^+ \mu^-$.
- Determine the sensitivity to V_{ub} by studying the decay $B \rightarrow \rho e \nu$ [30].
- Measurement of CKM angles using $B \rightarrow K^* \gamma$ and $B \rightarrow \rho \gamma$ [31].
- Search for direct CP violation in charged B -decays.

The detailed studies will be presented in the LoI.

3.3 Estimate of Reach for $\sin 2\beta$ and Comparisons

Although we plan to address all three angles of the unitarity triangle in detail in the LoI, as an example we present here a detailed estimate for the angle β . The magnitude of CP violation in the standard model in $B \rightarrow J/\psi K_S$ is characterized by $\sin 2\beta$, the value of which is constrained to lie in the range $\sim 0.6-0.8$ if the CKM phase is responsible for CP violation [32]. The CP asymmetry measured in a hadron collider can be written as $A_{CP} = x_d / (1 + x_d^2) (1 - 2\bar{\chi}) D_{\text{tag}} \sin 2\beta$ where the first term describes mixing of the $B \rightarrow J/\psi K_S$ and the second term is the mixing of the other B -meson. The dilution factor is given by $D_{\text{tag}} = (RS - WS) / (RS + WS)$ where RS (WS) is the right (wrong) sign tag. The error on $\sin 2\beta$ is then estimated by $\delta(\sin 2\beta) = (1/0.46)(1/0.76)(1/\sqrt{\epsilon} D_{\text{tag}})(1/\sqrt{N_B S/(S+N)})$. The $\sqrt{\epsilon} D_{\text{tag}}$ is the tagging efficiency times the dilution factor and is measured in CDF data to be 0.08 ± 0.01 for lepton tags with $P_T > 1.5$ and $|\eta| < 1$, and x_d and $\bar{\chi}$ are also measured from data [33, 34, 35]. N_B is the number of detected $B \rightarrow J/\psi K_S$ events and $\sqrt{S/(S+N)} = 0.83$ accounts for background under the mass peak. The signal-to-noise will increase with the improved 3-D vertexing capability of the SVX-II.

This EoI is unique among hadron collider proposals in its ability to extrapolate B -decay detection efficiencies using real data. Detailed extrapolations for $\delta \sin 2\beta$ are shown in Table 3-1 and the numbers can be reconstructed from the formulae provided in the previous paragraph. We seek four basic improvements over the present CDF performance. First, we plan to use the decay of $J/\psi \rightarrow e^+ e^-$ in future analyses to improve detection rates by a factor of two. We are confident in this extrapolation because the trigger hardware is tested, and we have a demonstrated signal in $B \rightarrow J/\psi K^\pm$, $J/\psi \rightarrow e^+ e^-$ in our present data. Lowering the muon P_T trigger thresholds to $1.5 \text{ GeV}/c$ improves the acceptance by a factor of two, but implementation of the trigger awaits the Run-II DAQ even though the trigger rate increase is only 50%. Finally, we plan to tag low P_T kaons from B -decay using a TOF [36] system and increase the tracking and triggering acceptance to at least $|\eta| < 1.5$. We emphasize that all trigger and dilution factors will be measured *in situ* using semi-leptonic B -decays.

A comparison in $\delta \sin 2\beta$ has been made to other experiments. We find that CDF (see TOF line in Table 3-1, where $\delta \sin 2\beta = 0.18$) is comparable with HeraB ($\delta \sin 2\beta = 0.16/10^7 \text{ s}$) and the SLAC/KEK B -factories ($\delta \sin 2\beta = 0.09/10^7 \text{ s}$) on the timescale of 1999 given the uncertainty in luminosities and efficiencies. We estimate a RHIC experiment could measure $\delta \sin 2\beta = 0.12/10^7 \text{ s}$ by the year 2001, which is not competitive with the Tevatron. The LHC dedicated B -detectors have sensitivities in the range $\delta \sin 2\beta = 0.02/10^7 \text{ s}$, which is the expected level of our extrapolated sensitivity by the time they can produce results in 2005.

In summary, we note the evolutionary approach described in this EoI will challenge in a timely manner the standard model prediction for CP violation.

Table 3-1: Successive improvements to $\delta \sin 2\beta$ in CDF. Below the line we indicate the reach of this EoI, which is more speculative but includes benefits from tagging with a Čerenkov detector, increased acceptance and a lower P_T trigger threshold on the leptons.

No. $J/\psi K_S$	$ \eta $ range	$\mu P_{T,\min}$	Tag	$\sqrt{\epsilon} D_{tag}$	$\delta \sin 2\beta$	Lum	Comments
50	$ \eta < 1$	$> 1.7 - 2.7$	$e+\mu$	0.08	-	20 pb ⁻¹	run-Ia
3750	$ \eta < 1$	$> 1.7 - 2.7$	$e+\mu$	0.08	0.70	1.5 fb ⁻¹	no changes
1.5×10^4	$ \eta < 1$	1.5 - 1.5	$e+\mu$	0.08	0.35	1.5 fb ⁻¹	$J/\psi \rightarrow e^\pm$
1.5×10^4	$ \eta < 1$	1.5 - 1.5	$e+\mu+K$	0.15	0.18	1.5 fb ⁻¹	add TOF and low $P_{T\mu}$
3×10^4	$ \eta < 1.5$	1.5 - 1.5	$e+\mu+K$	0.15	0.13	1.5 fb ⁻¹	increase accept.
1×10^5	$ \eta < 1.5$	1.5 - 1.5	$e+\mu+K$	0.15	0.07	5 fb ⁻¹	more luminosity
3.0×10^5	$ \eta < 1.5$	0.8 - 1.5	$e+\mu+K$	0.15	0.04	5 fb ⁻¹	lower P_T trigger
4.5×10^5	$ \eta < 3.5$	0.8 - 1.5	$e+\mu+K$	0.25	0.02	5 fb ⁻¹	Čerenkov K -tagging

3.4 Unitarity Triangle Angles α and γ

CDF will likely observe in Run-II a signal in the decay $B \rightarrow \pi^+ \pi^-$, which is related to the unitarity triangle angle α . The SVT and new DAQ trigger systems will keep 4% of decays which leads to 8.5×10^3 signal events recorded[37]. The signal-to-noise is estimated to be 1:1.[38]. There are several backgrounds due to misidentification of charged K 's under the $B \rightarrow \pi^+ \pi^-$ mass peak. Particle identification is needed to separate π 's from K^\pm below 5 GeV/c and Čerenkov detectors could cover this momentum range. This leads us to estimate for the EoI $\delta \sin 2\alpha = 0.04$ for 5 fb⁻¹. [39].

The determination of $\sin 2\gamma$ has been studied by comparing the $B_s^0 \rightarrow D_s^- K^+$ and $D_s^+ K^-$ branching ratios to the $\bar{B}_s^0 \rightarrow D_s^+ K^-$ and $D_s^- K^+$ branching ratios. This method is not promising[41]. The Gronau-Wyler[40] method was studied and the results indicate that with favorable magnitude of strong phases and the angle γ , observation of CP violation is not ruled out[41].

4 DESCRIPTION OF DETECTOR

The CDF detector is described elsewhere and we limit discussion here to systems being considered for upgrade. Operation of the detector at high luminosity will require upgrades to tracking, triggering, data acquisition, and offline data handling. Most physics topics benefit from extending the tracking and triggering coverage from the present $|\eta| < 1.0$ to $|\eta| < 2.5$. Improved electron identification from preshower upgrades, and improved muon identification from new systems in the forward region will increase the b -acceptance and the S/N ratio for the semi-leptonic top b -tag. Calorimetry in the forward 3° region to observe diffractive physics is also under study.

Before giving details on detector components, we mention the issue of multiple interactions. We have begun to study the effects of overlapping minimum bias events in the J/ψ sample using the present detector[42]. We find with 3 overlapping events the J/ψ width increases by 15% and the efficiency drops by 3%. We believe that the present detector could probably tolerate 3 interactions per crossing but not more. The performance of the tracking upgrades under discussion below in the multiple interaction environment is an important topic for further study. This needs additional study and bears directly on the Tevatron bunch structure in all future runs.

4.1 CENTRAL TRACKING

The present silicon vertex detector and Central Tracking Chamber (CTC) provide very good performance under the present operating conditions, albeit limited to the central rapidity region. However at high luminosity the inner region of the CTC will have insufficient granularity. Since there is also a need for Particle Identification (PID) in the central region, we are considering the general design of a "second generation" hybrid detector for the solenoid interior. In addition to surviving at higher luminosity, the goals are to increase the rapidity coverage, and to retain the excellent momentum resolution required, for example, to separate $B \rightarrow \pi^+ \pi^-$ from $B \rightarrow \pi^+ K^-$ using invariant mass. We have made no final technology choices or decisions, but we have identified some of the constraints and tradeoffs:

- Due to radiation damage the inner silicon layer will need to be replaced during the life of the experiment. We are considering using radiation-hard technologies, including pixels or diamond detectors, at the inner-most radius.
- Forward disks of silicon or gas microstrips are required to extend the tracking to $|\eta| < 2.5$.
- A new technology replacing the VTX/CTC can simultaneously address the goals of improved granularity, pattern recognition, and rapidity coverage. This could be more than one device, such as additional layers of silicon strips with small angle stereo, followed by superlayers of straws and/or scintillating fibers and/or a wire chamber optimised for high luminosity. The technology and geometry choices are strongly dependent on the expected luminosity and bunch spacing.
- Increased granularity in general comes at the expense of additional material. Since the P_T resolution of tracks from B 's is multiple-scattering limited, the resolution is degraded by the additional material. In contrast, the superior position resolution of the technologies under consideration could improve the P_T resolution at high P_T .
- The introduction of PID systems at large radii will compromise the tracking lever arm, degrading the resolution, while a PID system at smaller radii adds material, but would have more coverage at a lower cost.
- An increase in the magnetic field strength by replacing the solenoid coil is under consideration. This could recover the P_T resolution lost above.

As an intermediate step, the insertion of a small straw or fiber prototype superlayer to replace the VTX for Run-II is motivated as follows: 1) The VTX is no longer needed because of the SVX-II z -measurements. 2) The prototype superlayer replaces the hits lost as the inner layer of the CTC degrades with higher luminosity. 3) The extra superlayer should allow a tracking trigger to larger rapidity. 4) The prototype provides performance information and experience with the technologies that will replace the CTC for Run-III.

4.2 CENTRAL PARTICLE ID

The identification of and separation of K^\pm , π^\pm , and protons is important for increasing the sensitivity of the CP -measurements. The average momentum of K^\pm 's in the central region from B -decay is ~ 1.8 GeV/c. We consider a two step approach. A conventional time-of-flight system placed at the outer radius of the CTC replacing the present Central Drift Tube system (CDT) is being considered. The second step provides hadron identification to 5 GeV/c and is located inside the solenoid. This momentum range covers much of the background spectrum to $B \rightarrow \pi^+\pi^-$ from $B_s \rightarrow K\pi$, KK , and $B_d \rightarrow K\pi$. (see plot in ref.[39]) A Čerenkov system based on solid cesium-iodide photocathodes is one option or alternatively a time-of-flight system using quartz bars and Čerenkov light.

4.3 LEPTON IDENTIFICATION

We propose adding "new CMXX" detectors to increase muon coverage from $\eta=1.0$ to $\eta=1.4$. These detectors will probably be mounted on the FMU toroid face. The FMU chambers should be replaced by a new scintillator/chamber system ("new FMU") with finer segmentation, increased coverage, and increased tolerance for a high rate environment. We are also studying the case for additional coverage with chambers or scintillator on the toroid exterior in order to measure muons that exit the toroids after passing through only one or two planes. The sum of these upgrades will result in almost continuous muon coverage from $\eta=0.0$ to $\eta=2.9$.

For electrons, we consider enhanced preradiator coverage. In the central region, we propose an upgrade to a lead-scintillator system, which will be able to operate at very high rates and short crossing times. In the forward region, the E-830 end plug will be built with a preshower counter but without instrumentation for readout; study of the gains from instrumenting this device will be a topic of the LoI.

4.4 FORWARD CALORIMETER

We plan to instrument the forward region with a small EM/Hadron calorimeter placed beyond the plug upgrade and covering the region $3.5 < |\eta| < 5.5$ [14].

4.5 TRIGGER, DATA ACQUISITION

Efficient and deadtimeless triggering are critical to the success of the physics program. The goal of the upgraded trigger and DAQ system is the ability to run deadtimeless at $L=1 \times 10^{32}$ and bunch spacing of 132 nsec, with a maximum data rate into Level-3 of 1 kHz.

The trigger will be upgraded from the Run II design to include tracking information from new tracking devices. The level 1 trigger will include calorimeter, muon and tracking information, and a low p_t two track requirement that will be used to trigger on $B \rightarrow \pi\pi$. The level 2 trigger will include calorimeter energy clusters, muon isolation cuts, and tracks with impact parameters from the silicon vertex tracker. The DAQ system will be an expansion of the Run II DAQ system to increase the throughput and level 3 processing capability.

4.6 OFFLINE CAPABILITY

The present CDF offline system requires 1100 MIPS to process 1.5 Tb per year. We estimate this number will be roughly 100 times larger per year for Run-III. This significant data access problem will be addressed in the LoI.

5 RESOURCES NEEDED TO GENERATE LoI

We identify five areas requiring resources in order to make technology choices for presentation in the LoI: tracking, radiation-hard vertex detectors, magnet coil replacement, particle identification, and pre-radiators.

The straw tracking, open cell geometry, and scintillating fiber prototype developments are the three candidates for replacing the VTX. This prototyping requires R&D funds. This small prototype inner superlayer could be operational in Run-II and thus would provide critical performance information for CDF before proceeding with the CTC replacement for the EoI. We also request support to convert the CDF simulation package to a common package recommended by the computer division. This will permit detailed comparisons with other proposals.

Development of radiation hard alternatives for the inner-most layer of the vertex detector should be pursued. We are considering both pixel detectors and chemical vapor deposition diamond microstrip detectors. Funding will be needed for purchasing and developing prototypes and for beam tests to determine the most promising technology.

Replacing the CDF solenoid coil with one that operates at 2.3 T will require a feasibility study. We request 2-3 person months of engineering effort to resurrect the solenoid analysis program and study forces due to larger fringe fields.

The particle identification program has been divided into two steps. The time-of-flight system requires modest R&D funds to purchase several high-field mesh photomultiplier tubes, several types of fast scintillator, and machine shop support for building a small 1.5 Tesla solenoid magnet. CDF is considering a test outside the coil during Run-Ib. We would like to build a prototype Čerenkov detector in time for the next fixed target run when test beam will be available. Support is needed now to meet that schedule. We request one FTE scientist with technical support for one-year to assist in the development of a prototype cesium iodide photocathode system. This person would require R&D funds to purchase the materials and fabricate prototype devices. We also request a programmer to simulate the performance of a Čerenkov system using the full CDF detector simulation. This system has a major impact on the tracker design and it is critical we understand as soon as possible what is technically achievable.

The central pre-radiator system, called CPR, will require an upgrade to tolerate higher rates. A lead-scintillator system is being considered to replace the present gas proportional chambers. R&D funds are needed to build prototype quantities of scintillator, lead, and a readout system. We would like to test a prototype in Run-Ib.

6 Cost and Level of Effort to Complete Construction

An overall cost estimate for this detector is shown in Table 6-2 including the level of effort required. The total estimated cost of the EOI detector upgrade is $> \$47$ M (materials and services only) and requires of order 400 person-years of engineering, design and technical effort.

The size of the collaboration needed to complete the upgrades is estimated from our experience. CDF is currently performing analysis with Run-Ia data, operating a detector in Run-Ib, upgrading the detector for Run-II, and we find that everyone (210 staff physicists, 88 post-docs, and 142 students) is fully employed. We expect this situation to continue into Run-II. However, with more construction anticipated (to upgrade the detector for the EoI) and as

many as 50 current members shifting to full time LHC work, we estimate CDF would have to grow by about 100 physicists (net of 50) to carry out this experiment in a timely fashion.

Table 6-2: Cost estimate for Preparing an LoI and Upgrades to CDF.

Detector System	LoI R&D(\$K)	Equipment(\$K)	Manpower(Person-Years)
Central Region $\eta < 1$			
Inner Layer of SVX-II	100	1500	20
New Outer layers of SVX-II	0	3500	60
Prototype Inner Superlayer	135	1000	15
New Central Tracker + coil	0	11500	75
TOF	20	950	15
Cerenkov (PID)	5	12000	75
Scintillator pre-radiator	5	800	10
Plug and Forward Region			
Tracking disks	0	3400	60
Plug TOF	0	700	10
Instrument Plug Pre-radiator	0	300	5
CMXX Muon Detectors	0	1550	15
FMU Muon Detectors	0	1500	15
Mini-Plug calorimeter	10	700	5
Electronics			
Most included above	0	500	0
Data Acquisition and Trigger			
Fast track processor for new tracker	0	600	5
Scanners/Switch/Interfaces/Software	0	1600	3
Level 3 expansion	0	5000	2
Total	275	47100	390

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