Fermilab FERMILAB-Conf-02/021-E March 2002

CDF at the Tevatron Collider in Run 2

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Abstract.
Run 2 of the Tevatron began in early 2001 after extensive upgrades to both the machine and the CDF and DØ detectors. For CDF, new tracking detectors, increased muon coverage, state-of-the-art front end electronics, pipelined triggering, and a complete overhaul of the DAQ have made it a very powerful tool to explore physics of all kinds. The status of CDF in Run 2 is presented, along with a first glimpse of CDF data.

INTRODUCTION

Run 1 of the Tevatron Collider at Fermilab lasted from 1992 to 1996, during which time $\sim$110 pb^{-1} of data were collected at an energy of 1.8 TeV. The Tevatron Run 2 began in the Spring of 2001, and for the next half decade (or until the LHC at CERN begins operation) the Tevatron will remain the high energy frontier in particle physics, with collisions at $\sqrt{s} \sim 2$ TeV. For Run 2, improvements to the Tevatron were made with the goal of achieving instantaneous luminosities on the order of 10^{32}cm^{-2}s^{-1}. To take advantage of the expected collision rates, CDF underwent a major overhaul, with upgrades to almost every system. CDF is now poised to exploit the approximate 150-fold increase in integrated luminosity for Run 2 in almost all areas of study.

RUN 2 TEVATRON COLLIDER UPGRADES

In the last five years, a new 150 GeV “Main Injector” synchrotron was built to boost Tevatron capabilities. The new injector is both faster in producing antiprotons and more efficient in transferring protons and antiprotons into the Tevatron ring. The upgrade is expected to provide a factor of five improvement in instantaneous luminosity. In addition, a new antiproton recycler has been built, in which antiprotons are re-cooled and re-used rather than dumped at the end of a store. The recycler is currently being commissioned and is expected to provide another factor of two in instantaneous luminosity. With these improvements, and the planned decrease in bunch spacing from 396 ns to 132 ns for Run 2b, the Tevatron hopes to eventually achieve luminosities $> 2 \times 10^{32}$ cm^{-2}s^{-1}. Although the accelerator complex has had a slower start than expected so far, it is hoped that as the machine performance is understood, the Tevatron can achieve a very high growth curve, and perhaps collect more than the projected 15 fb^{-1}.

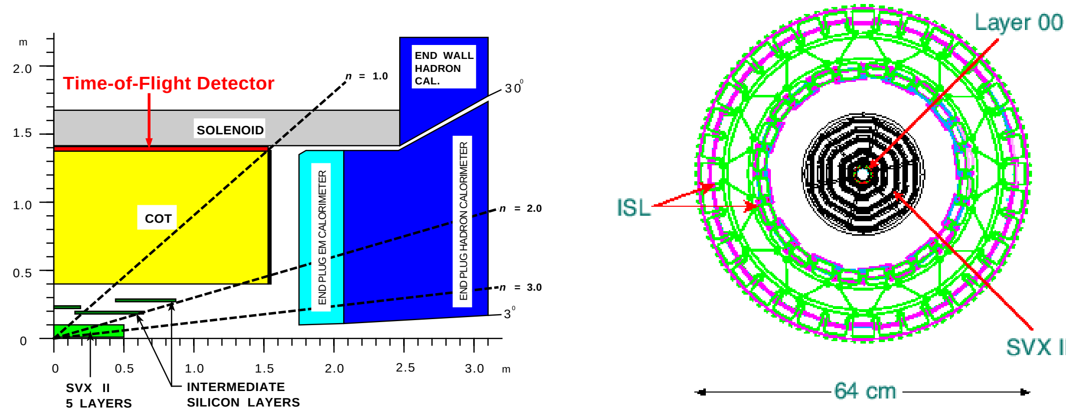

FIGURE 1. *(left)* Cutaway view of a quadrant of the Run 2 CDF detector. *(right)* Cross-sectional schematic of the CDF Run 2 silicon detector system, showing Layer 00, SVX II, and the ISL.

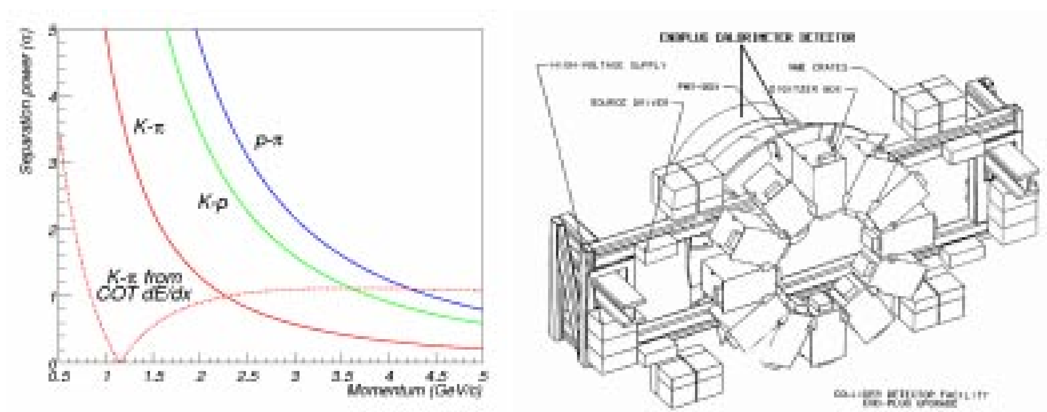

FIGURE 2. *(left)* Expected time-of-flight detector particle ID resolution versus momentum for low momentum events, compared to K-π separation from COT dE/dx. The measurements are complementary. *(right)* End-view diagram of the endplug upgrade and support structure.

CDF DETECTOR IMPROVEMENTS

The CDF detector is almost entirely new for Run 2. While the solenoid, the central calorimeters, and portions of the muon detectors remain the same as for Run 1, the rest of the detector systems were replaced or upgraded. Figure 1 shows a cutaway view of a quadrant of the Run 2 detector.

CDF will enjoy an entirely new tracking system, consisting of a three-component silicon detector package, a new wire chamber, and a time-of-flight detector. A cross-sectional layout of the silicon system is shown in Figure 1. The five-layer SVX II detector extends coverage in z and ϕ, allows 3-D vertexing with stereo channels on double-sided silicon, and enables Level 2 triggering on displaced vertices. The Intermediate Silicon Layers (ISL) is the largest double-sided silicon detector ever made. It extends b-tagging to $|\eta| = 2$, and helps to link tracks in the drift chamber to the SVX. The Layer 00 (L00) detector, which sits on the beryllium beam pipe inside of SVX, was added to the

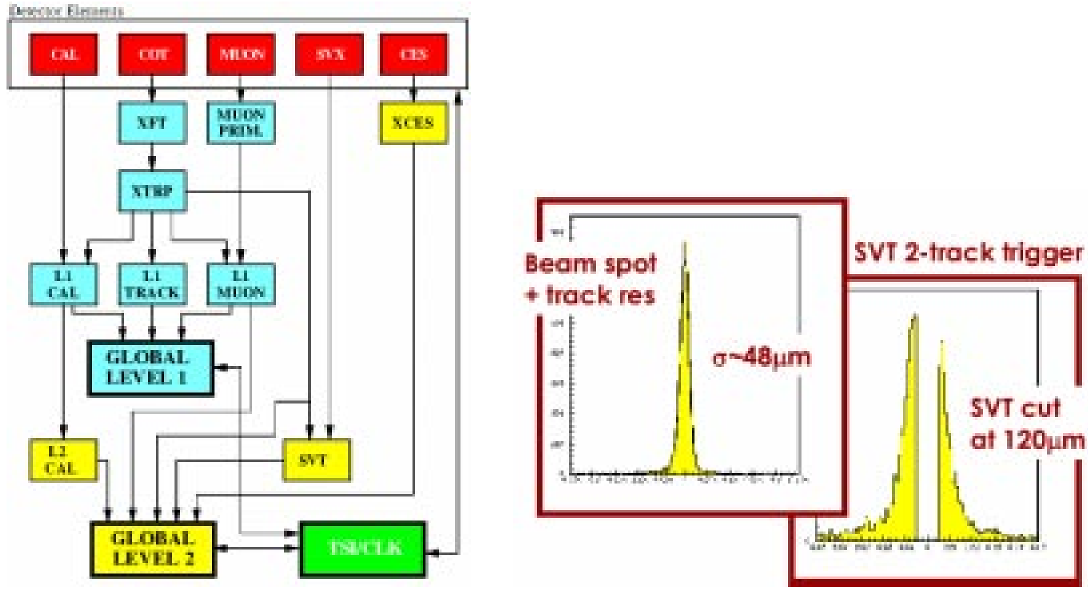

FIGURE 3. *(left)* Trigger pathways from the detectors through Level 2. *(right)* Secondary Vertex Trigger (SVT) data, showing a beam spot plus track resolution of $\sigma \sim 48\mu$m, and a potential impact parameter cut at 120μm.

silicon system to improve the impact parameter resolution and hence increase b-tagging efficiency; it may be used in the level 2 SVT trigger for b-tagging. L00 could also extend the CDF lifetime, as it will likely outlast SVX II as radiation exposure accumulates. Tracking with the silicon system is going well, with signal-to-noise levels and alignment tolerances meeting design specifications.

The new CDF drift chamber, the Central Outer Tracker (COT), consists of 30,240 sense wires: ∼five times that of the drift chamber in Run 1. There are 96 wire planes total, and eight superlayers, half of which are 3° stereo. In place of field wires, the COT employs Au-plated Mylar cathode sheets to enclose "supercells", each containing 12 sense and potential wires. This design provides uniform drift over the 0.88 cm cells. An Ar:Eth:CF_4 gas mixture allows 100 ns drift times, well within the bunch crossing window. Although there is some variation with luminosity, the expected momentum resolution for events with transverse momenta $p_T >$2 GeV is $\delta p_T/p_T^2 \approx 0.33\%$ (GeV/c)$^{-1}$ [1].

The Time-of-Flight detector (TOF) for particle identification was added to the Run 2 upgrade to complement the dE/dx measurement from the COT. The detector consists of 216 scintillator bars mounted longitudinally on the inside of the solenoid, and read out on both ends by fine-mesh phototubes. The TOF is expected to obtain 100 ps resolution, allowing 2σ separation between K/π for p < 1.6 GeV, K/p for p < 2.7 GeV, and p/π for p < 3.2 GeV. Figure 2 shows the separation power for the TOF compared to the COT. The ability to identify low momentum kaons will significantly improve flavor-tagging in B decays– important for the measurement of $sin2\beta$ and the observation of B_s-mixing for example. [2]

Calorimetry in the central (low η) portion of CDF has not changed from Run 1 aside from the front end read-out electronics and triggering. The endplug calorimeters, however, were replaced entirely. Figure 2 shows a diagram of the new endplug and support structure. The new scintillating tile detectors are faster and have a better sampling fraction than the gas calorimeters used in Run 1. They also provide more complete coverage, with the 10° forward gap gone and the 30° gap greatly reduced. The design is such that CDF now has the same calorimeter technology over the full solid angle to $|\eta| = 3.6$. Consequently, identical readout electronics and triggering are used for this entire region. The new custom-built VME readout boards hold single-channel daughter cards, which feature the QIE (Charge Integrating and Encoding) ASIC [1] [3], developed originally at Fermilab for the SSC, and used initially on the KTeV experiment. This chip together with a 10-bit ADC provides 18 bits of dynamic range per channel. The readout boards also have Xilinx FPGAs which contain a fully pipelined 42-clock-cycle event buffer for the Level 1 trigger decision. The upgraded calorimeter and readout systems were the earliest systems ready for commissioning data, and have been the most stable.

The muon detector upgrades for Run 2 focused on preserving the existing Run 1 detectors and increasing the muon coverage in η and ϕ. Additional coverage in the $|\eta| > 1$ region was added: new IMU detectors will allow triggering on muons in some regions out to $|\eta| = 1.5$ and identification out to $|\eta| = 2$. Since the 1.4 μs drift times in the muon chambers are greater than the bunch spacing, scintillators are used to tag muon events. Due to the higher rates expected in Run 2, some central counters from Run 1 were removed and shielding was added to reduce occupancies in the muon detectors.

The DAQ and trigger system was completely overhauled for Run 2. Figure 3 shows the the Run 2 trigger paths. The pipelined Level 1 trigger and buffered Level 2 design gives CDF a nearly deadtimeless trigger. At Level 1, calorimeter energies, tracking p_T and ϕ (with the help of the new eXtremely Fast Tracker (XFT)), and muon stubs are combined to form objects, such as electrons and photons, on which to trigger at a <50 kHz accept rate. Level 2 uses custom Alpha processors and four event buffers to first refine Level 1 information, and then to combine it with silicon tracks and shower position information, forming a Level 2 decision at 300 Hz output rate. The silicon information is acquired at Level 2 via the SVT (Secondary Vertex Trigger), which finds displaced tracks and provides an impact parameter cut at Level 2. The SVT greatly enhances the efficiency for collecting B events. Figure 3 shows SVT data, with resolution of the beam spot plus tracks of $\sigma \sim 48$ μm. Also shown is an impact parameter cut at 120 μm for triggering on B mesons. The Level 3 trigger consists of a farm of Linux PCs running fast versions of the offline code to make more sophisticated selections on events. The upgraded DAQ model is similar to the successful Run 1b system. The design logging rate of 20 MB/sec was met long before the commissioning run, and recently was achieved with 8 different data streams. Finally, data from a new Cerenkov Luminosity Counter (CLC) [4], designed for precise measurement even at the highest luminosities, is now both part of the data stream and sent from CDF to the Tevatron for monitoring purposes.

PREPARING FOR PHYSICS: FIRST DATA

CDF had the opportunity to commission the upgraded detector during a short run in Fall 2000, and much experience was gained with the new detector and DAQ systems.

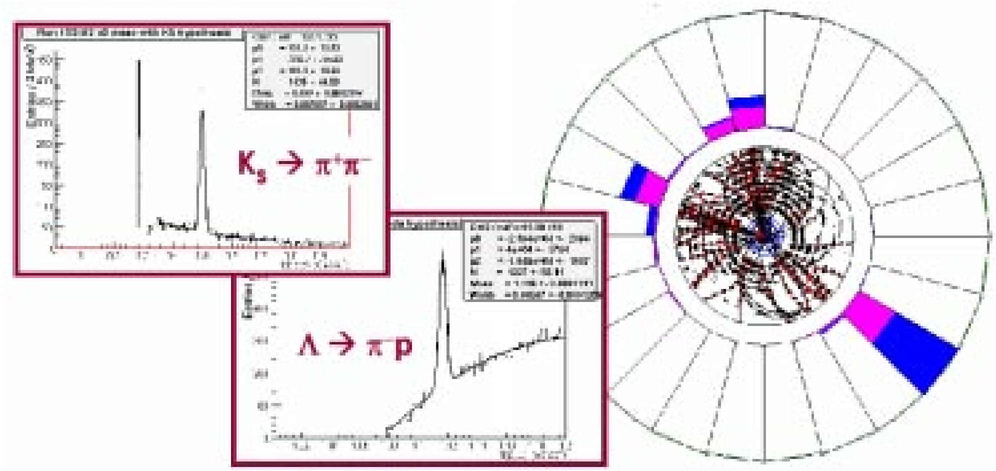

FIGURE 4. K_s and Λ peaks, found during the CDF commissioning run in Fall 2000. Silicon tracking, COT tracking, and calorimetry are shown in the event display on the right.

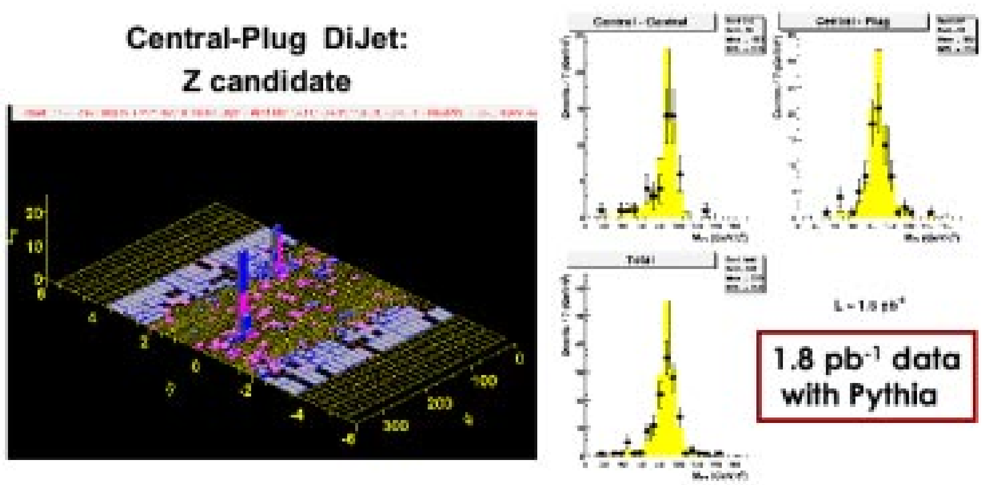

FIGURE 5. *(left)* η-ϕ map of the calorimeter showing two lepton jets from a Z candidate. *(right)* Z event distributions for leptons in the central calorimeter, in the endplug, and for one in each of these. 1.8 pb^{-1} was used and Pythia distributions are superimposed.

Figure 4 shows a three-jet event containing tracks in the silicon, the COT, and energy in the calorimeter. Also shown are K_s and Λ peaks as reconstructed from early data. One can see that CDF was functioning well from the start. Figure 5 shows a sample of Z events using 1.8 pb^{-1} with Pythia events superimposed. Such samples are being used to calibrate the detectors and to understand efficiencies and detector behavior. Some samples will already be used in upcoming CDF physics analyses as well. Figure 6 contains a selection of Run 2 physics: reconstructed charged B mesons, K°'s, and J/ψ's. While studies of the new detector's behavior and performance are ongoing, CDF is well on its way to many interesting physics results.

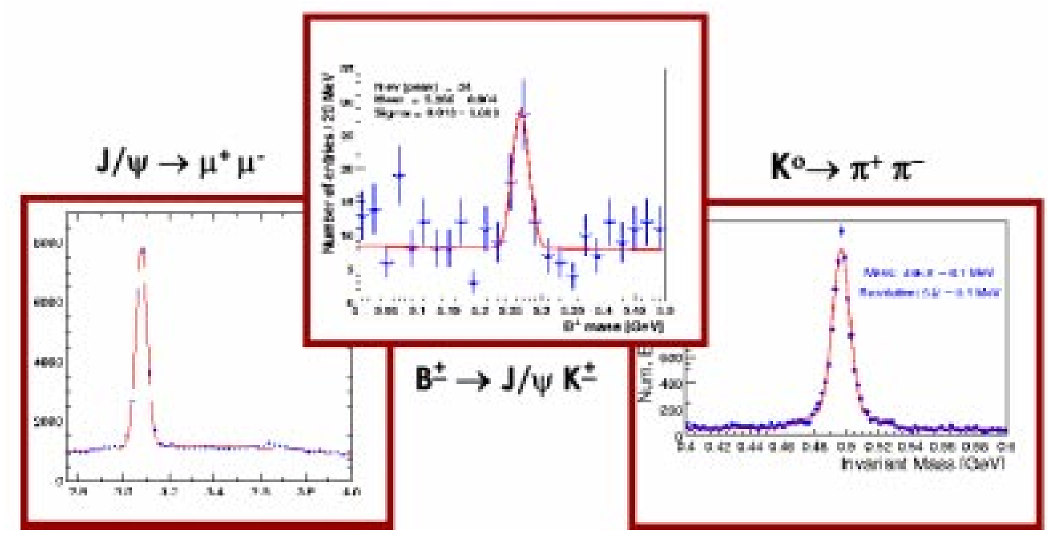

FIGURE 6. First Run 2 samples of $J/\psi \rightarrow \mu^+\mu^-$ *(left)*, $B^{\pm} \rightarrow J/\psi K^{\pm}$ *(center)*, and $K^{\circ} \rightarrow \pi^+\pi^-$ *(right)*, demonstrating that the tracking system is in good shape, and that we are well on our way to first physics analyses.

PHYSICS GOALS FOR RUN 2

With successful upgrades to the entire detector, trigger, and offline reconstruction package, CDF is poised to lead the world with insights into the high energy frontier for the remainder of the decade. Run 2 of the Tevatron will provide both the CDF and DØ collaborations with exciting results in top physics, the electroweak sector, B physics, QCD, and physics beyond the Standard Model. One of the major goals for CDF is elucidation of the properties of the newly-discovered top quark. We can look forward to the careful studies of top mass (an important electroweak parameter), top cross-sections, single top production, Drell-Yan, M_t - $M_{\bar{t}}$, spin correlations, anomalous couplings, QCD tests, form factors, and possibly new physics. Using the $t\bar{t}$ dilepton channel, the lepton+jets channel, and the all hadronic decay channel, CDF can expect to obtain a top mass measurement to $\delta M_t \sim 3$ GeV/c^2 with the first 2 fb^{-1}. CDF will also make high-precision electroweak measurements. With 2(10) fb^{-1}, CDF and DØ combined will obtain the world's most precise measurement of the mass of the W, to $\delta M_W = 30(20)$ MeV/c^2. Combined knowledge of M_{top} and M_W will set even more stringent limits on the Standard Model Higgs. As shown in Figure 7, with current measurements, the Standard Model Higgs is already close to being ruled out, making Run 2 top and electroweak studies extremely important. For more on Higgs and SUSY-Higgs prospects in Run 2, see the contribution by J. Conway in these proceedings [5].

The Tevatron will serve as a B-Factory for many years, as all species of B mesons are produced, and B-production rate is very high: data collection is limited only by offline bandwidth. The addition of silicon Layer 00 and the TOF detector will greatly improve our B capabilities. CDF can look forward to strong measurements of the CKM parameters: goals include CP violation in $B^{\circ} \rightarrow J/\psi K_s^{\circ}$ and $sin2\beta$ to better than ± 0.08, a significant measurement of the CP asymmetry in $B^{\circ} \rightarrow \pi^+\pi^-$, determination of $|V_{td}/V_{ts}|$

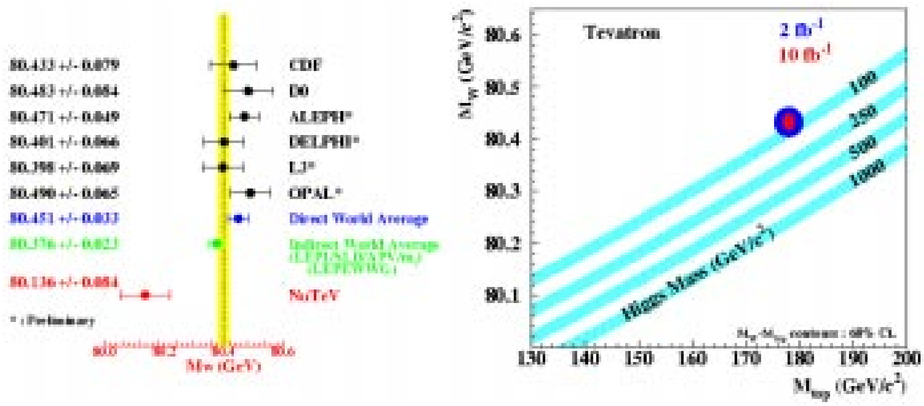

FIGURE 7. *(left)* Status from 2001 of world data on precision W mass measurements. CDF and DØ combined will have the most accurate result, with $\delta M_W < 20$ MeV/c^2 by the end of Run 2. *(right)* Prediction for indirect electroweak constraints on Standard Model Higgs (for different Higgs mass regimes) with knowledge of M_W and M_{top} for two (dark circle) or ten (light circle) fb^{-1}.

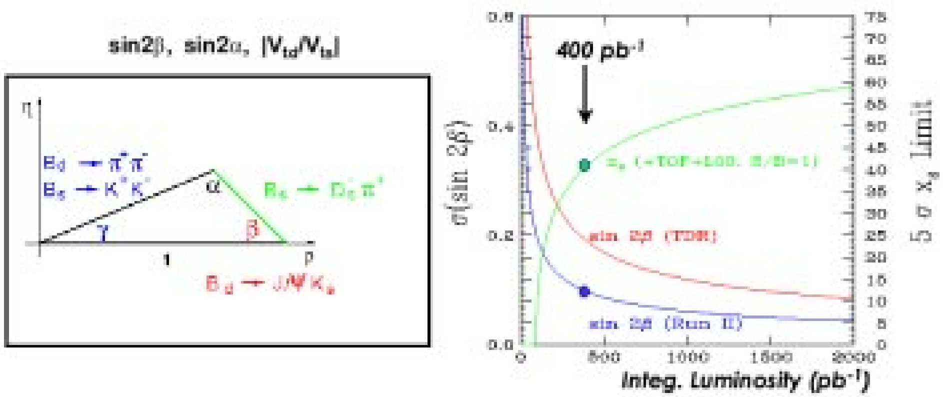

FIGURE 8. *(left)* The CKM triangle along with various decays necessary to measure some of the parameters of it. *(right)* Physics reach for $\sigma(\sin 2\beta)$ and for the B_s mixing parameter x_s with increasing luminosity for CDF, both with the L00 and TOF detector additions (blue and green curves) and without these (red curve).

to 20% over the full Standard Model range, and a rich program of rare B decays, among other things. Figure 8 shows that with only 400 pb^{-1} we can place a 5σ limit on the B_s mixing parameter out to $x_s = 40$, and we can achieve $\sigma(sin2\beta)$ of 0.1.

REFERENCES

1. CDF II Detector - Technical Design Report - Fermilab-Pub-96/390-E
2. CDF Collaboration, *A Time-of-Flight System for CDF*, CDF2573 (May 1994)
3. CDF Collaboration, *Results of the QIE6 Test with Calorimeter Phototubes*, CDF4388 (Nov. 1997)
4. CDF Collaboration, *The Cerenkov Luminosity Counter*, NIM A461:540(2001), FNALPUB-01-031-E
5. J. Conway, *Search for the Higgs at the Tevatron in Run 2*, Proceedings of the VIII Mexican Workshop on Particles and Fields (held Nov. 2001).