Annual Progress Report for JFY 2000

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CDF Experiment

Spokespersons
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The year 2000 was special for the CDF experiment. The upgrade of the detector, which started in 1996, has been completed, and the new CDF-II detector was commissioned during October and November 2000 with beams of protons and antiprotons in the also upgraded Tevatron accelerator. This commissioning run was very successful, allowing CDF to demonstrate that the detector actually works and that CDF is ready for the physics run. The Tevatron Run II, which started in March 2001, should deliver 2 fb^{-1} of integrated luminosity to CDF by the end of 2003 and eventually 15 fb^{-1} by 2007.

In this report, we summarize physics prospects in Run II, results of physics analyses of data from the previous run, and detector upgrade efforts, with an emphasis on contributions from the Japan group.

1 Physics Prospects in Run II

We expect an integrated luminosity of 2 fb^{-1} in the first two years of Run II. This is a twenty-fold increase in data compared with the previous run. Also the Tevatron beam energy has been increased to give a center-of-mass energy of 2 TeV.

Physics topics in Run II include the following:

- Precise measurements of the top quark properties.
  The mass will be measured with a precision of about 3 GeV/c^2. Other production and decay properties will be also measured precisely, including $t\bar{t}$ production cross section, single top production, measurement of $|V_{tb}|$, and searches for new particles such as a charged Higgs boson $t \to H^+ b$ and new resonance states decaying into $t\bar{t}$ pairs.

- Electroweak physics.
  The W boson mass will be measured with a precision of about 40 MeV/c^2. Combined with top quark mass measurements, it will provide constraints on the Higgs boson mass with a relative precision of 30%. This is illustrated in Figure 1. Also, detailed studies of self-couplings of the electroweak gauge bosons will be performed.

- B physics.
  Two major measurements contributing to the determination of the unitarity triangle of the Cabibbo-Kobayashi-Maskawa matrix is expected from CDF Run II. One is a measurement of $\sin 2\beta$ from $B^0/\overline{B}^0 \to J/\psi K^0_S$ decays with a precision of 0.04 - 0.08, and the other is an observation of $B^0_s\overline{B}^0_s$ oscillations with a frequency of up to 40 ps^{-1} (Figure 2). Also, a determination of the CKM angle γ to $\pm 10^\circ$ using $B^0 \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$ decays is possible, and searches for various rare decay modes will be performed.

- Quantum chromodynamics.
  A wide variety of measurements will be performed at a new center-of-mass energy of 2 TeV, and they will serve as precision tests of perturbative QCD calculations.

- New particle searches.
  Searches for the Higgs boson, supersymmetric particles and other new particles will be performed. The standard model Higgs boson can be searched for in a mass range up to 120 GeV/c^2 with 2 fb^{-1} of data. This is shown in Figure 3.

2 Analysis of Proton-Antiproton Collision Data

The collider Run I ended in February 1996, yielding 110 pb^{-1} of data for the CDF detector. Analyses of the data were still active in the fiscal year 2000.

2.1 Bottom quark physics

M. Tanaka (Tsukuba) has searched for exclusive radiative decays $b \to s\gamma$ of B hadrons using photons identified with converted electron-positron pairs [1]. The decay proceeds with the so-called penguin processes, and is considered to be sensitive to new physics effects.

The reconstructed B meson invariant mass spectra are shown in Figure 4 for $B^0_s \to \phi\gamma$ mode and for a normalization mode $B^+ \to J/\psi K^+$. The following upper limits on the branching fractions have been obtained at the 95% confidence level:

$$\begin{aligned} \mathcal{B}(B^0 \to K^{*0}\,\gamma) &< 2.2 \times 10^{-4}, \\ \mathcal{B}(B^0_s \to \phi\,\gamma) &< 3.3 \times 10^{-4}, \\ \mathcal{B}(\Lambda^0_b \to \Lambda^0\,\gamma) &< 1.9 \times 10^{-3}. \end{aligned}$$

2.2 QCD physics

K. Kurino (Hiroshima) has studied production of photons in association with muons. This process is expected to be dominated by photon plus charm production, and thus can probe the charm content of the proton structure. The production cross section is measured as a function of photon transverse momentum, as shown in Figure 5, and when integrated over p_T^γ from 12 GeV/c to 40 GeV/c, it is $46.3 \pm 5.7 \pm 7.2$ pb.

H. Nakada (Tsukuba) has measured the diffractive structure function of the antiproton using two-jet production in single-diffractive events identified with a Roman-pot antiproton spectrometer. The distribution of β, the fraction of Pomeron's momentum carried by a parton, is shown in Figure 6.

2.3 Searches for new phenomena

Analyses on new particle searches that are under way by Japanese collaborators include searches for R-parity violating supersymmetric particles, and a search for new particles using multi-jet final states.

3 Detector Upgrade for Run II

3.1 Plug upgrade calorimeter

The new, scintillator-based plug calorimeter has been constructed and installed in the CDF detector. The detector was successfully commissioned in October - November 2000 using Tevatron beam. The analysis of the data is in progress, in order to evaluate overall performance of the calorimeter such as calibration of the energy scale. Also, efforts have been made to establish offline reconstruction algorithms for the identification of electrons and photons in the plug region.

Y. Seiya and S. Uozumi from Tsukuba have contributed to the plug calorimeter efforts. Y. Seiya is a co-leader for the plug calorimeter project.

3.2 Silicon detectors: SVX II and ISL

The Silicon Vertex Detector (SVX II) and the Intermediate Silicon Layers (ISL) will provide precision charged particle tracking essential for detection of long-lived particles such as B hadrons. The construction of the both detectors has been complete (Figure 7), and they were installed inside the CDF detector in February 2001.

The production of double-sided silicon microstrip sensors for SVX II had been completed previously. The sensors for the Layer 3 of SVX II were assembled into quarter-ladders at Hamamatsu Photonics. They were tested for electrical connections to hybrid readout electronics and for dead channels. T. Ohsugi, Y. Iwata (Hiroshima), I. Nakano, R. Tanaka,

N. Tanimoto, T. Yamashita (Okayama), and R. Takashima (Kyoto University of Education) have been working on the SVX II project.

K. Hara, M. Shimojima and Y. Takeuchi from Tsukuba have worked on the silicon sensors of the ISL detector. The production of double-sided silicon micro-strip sensors was completed at Hamamatsu. Sampling probing tests were performed to assure quality, including $I-V$ characteristics, leakage current, and dead channel fraction.

T. Okusawa, T. Yoshida (Osaka City) and Y. Kato (Kinki) have been working on the data acquisition system to be used for testing hybrids.

3.3 Data acquisition system (DAQ)

M. Shimojima and H. Matsunaga (Tsukuba) have responsibility for the data logger, which, as a part of the online data acquisition system, receives events from the level-3 trigger and sends to disk and tape storage devices as well as to online monitoring programs. T. Tarisawa and K. Ikado (Waseda) are responsible for the monitoring programs that check detector performance and data quality. Both of these systems have been developed and constructed, and they performed successfully during the commissioning run.

3.4 Time-of-flight detector (TOF)

The TOF detector is a set of scintillation counters that provides K/π separation up to 1.6 GeV/c in momentum. K. Sato and F. Ukegawa (Tsukuba) are in charge of production and quality control of photomultiplier tubes. The tubes have been tested at KEK for performance in a 1.5-T magnetic field, sent to FNAL, and installed in the CDF detector. The construction of TOF is complete in year 2000 except for readout electronics (Figure 8). F. Ukegawa is a co-leader of the TOF project.

3.5 Silicon detector upgrade for Run IIb

Inner layers of the SVX II detector will need to be replaced because of radiation damage they suffer from once CDF accumulates an integrated luminosity of about 5 fb^{-1} around 2004. The R&D efforts for the replacement have already been started. One option is to use single-sided sensors that can be operated at higher bias voltages. K. Hara, K. Wakiya and S. Aoki (Tsukuba) have started addressing issues such as cooling, support structure and the amount of material. I. Nakano (Okayama) has started development of high density, printed-circuit flat cables for readout.

References

[1] M. Tanaka, Ph. D. Thesis, "Search for radiative B-hadron decays with the Collider Detector at Fermilab", University of Tsukuba, January 2001.

[2] H. Nakada, Ph. D. Thesis, "Measurement of the diffractive structure function of the antiproton in 1.8-TeV proton-antiproton collisions", University of Tsukuba, January 2001.

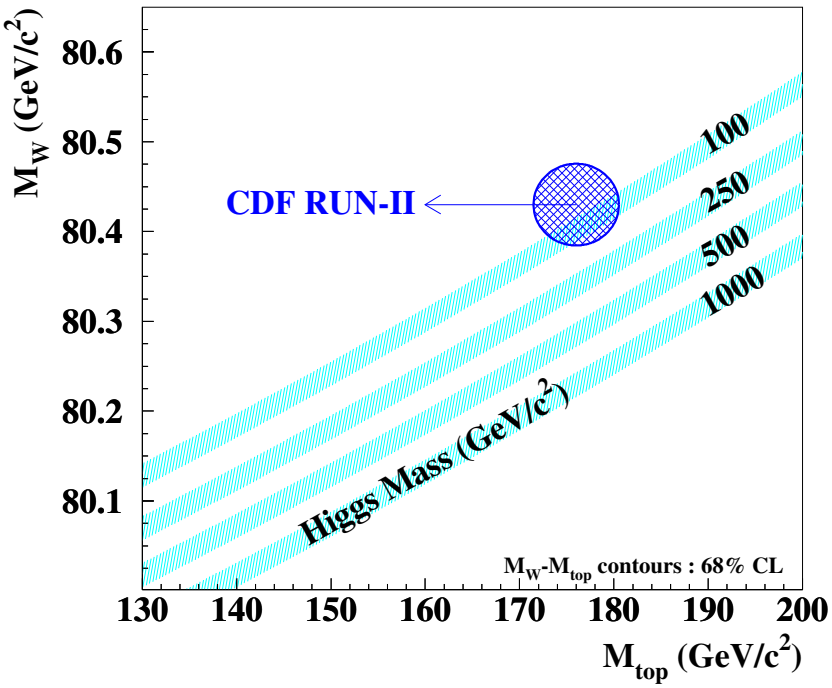

Figure 1: Expected precision in top quark and W boson mass measurements in Run II, and possible constraints on the Higgs boson mass.

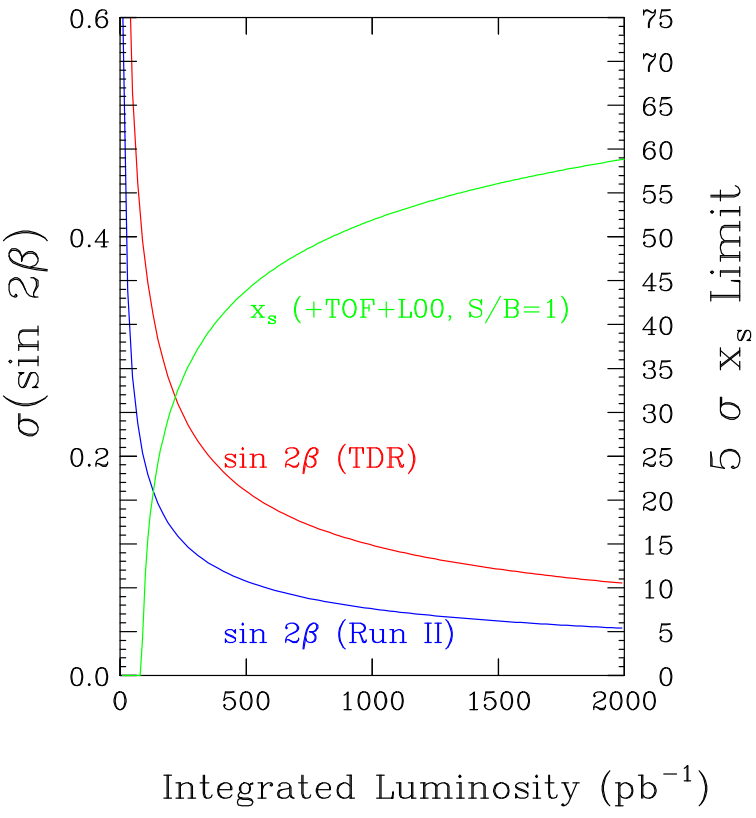

Figure 2: Expected precision in $\sin 2\beta$ measurement (left axis) and $B_s^0\overline{B}_s^0$ mixing reach (right axis) as a function of accumulated amount of data in Run II.

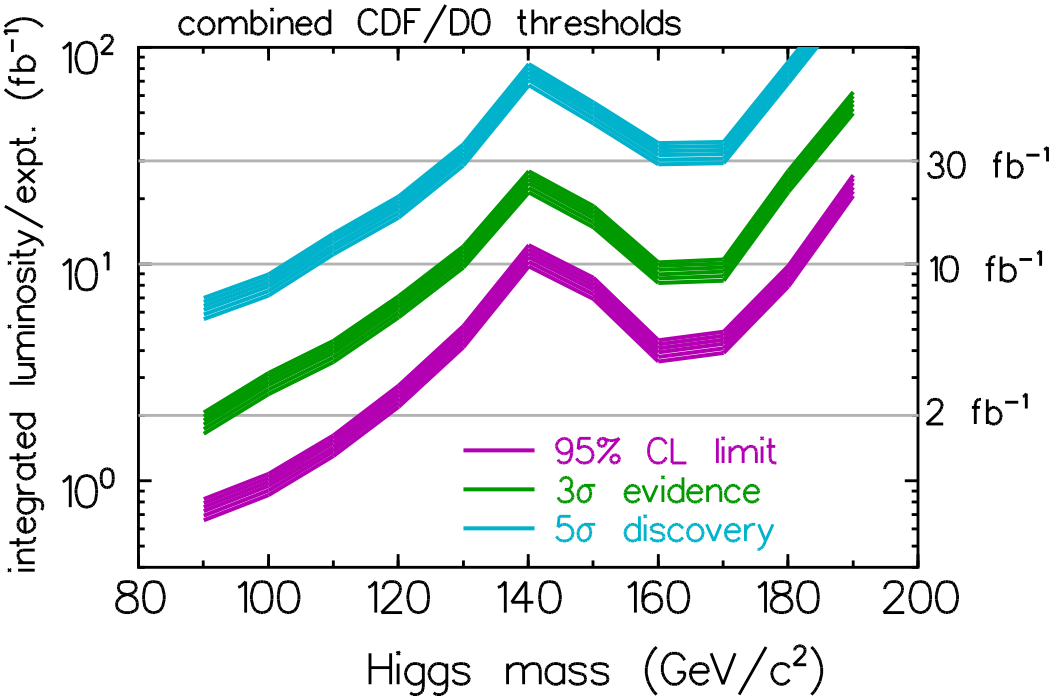

Figure 3: Tevatron reach for the standard model Higgs boson. Three bands show, as a function of the Higgs mass, the amount of data that are necessary (a) to exclude at 95% CL if the Higgs does not exist at that mass (bottom band), (b) to provide 3σ evidence for existence (middle), and (c) to discover with 5σ significance (top).

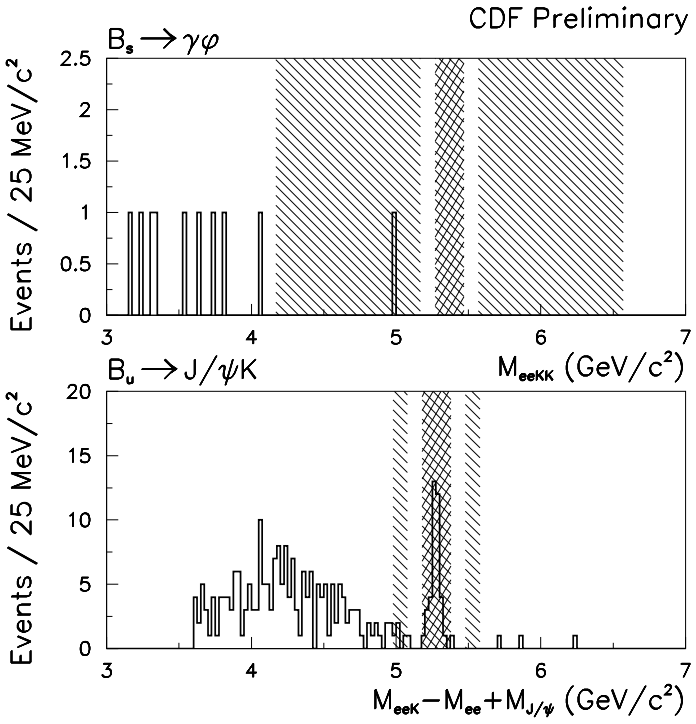

Figure 4: Invariant mass spectra for $B_s^0 \rightarrow \phi\gamma$ candidates (top), and for a normalization mode $B^+ \rightarrow J/\psi K^+$, $J/\psi \rightarrow e^+e^-$ (bottom).

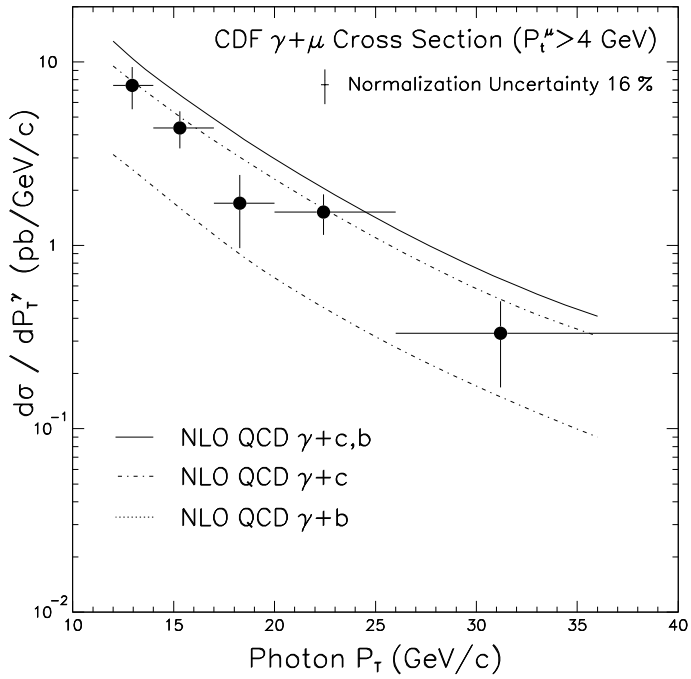

Figure 5: Cross section for associated $\gamma + \mu$ production as a function of γ transverse momentum.

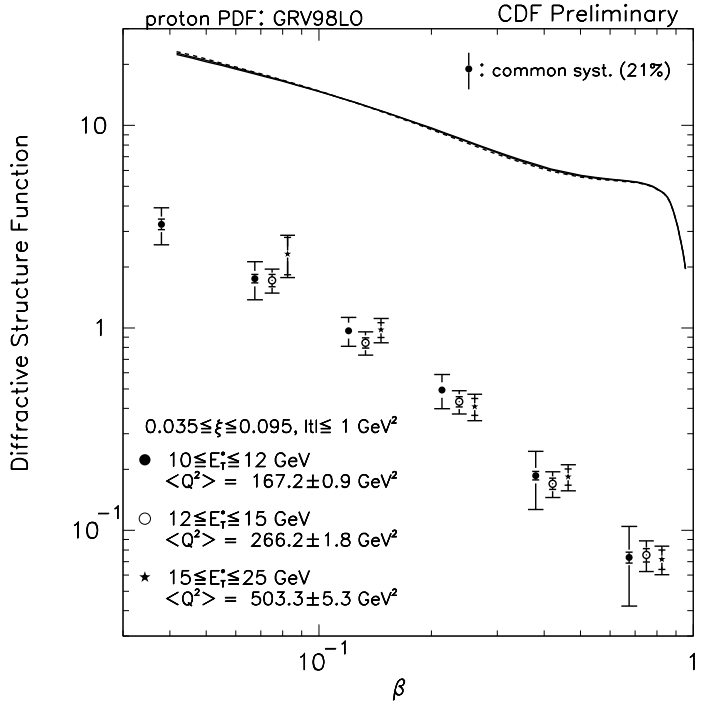

Figure 6: Diffractive structure function of the antiproton measured using two-jet production.

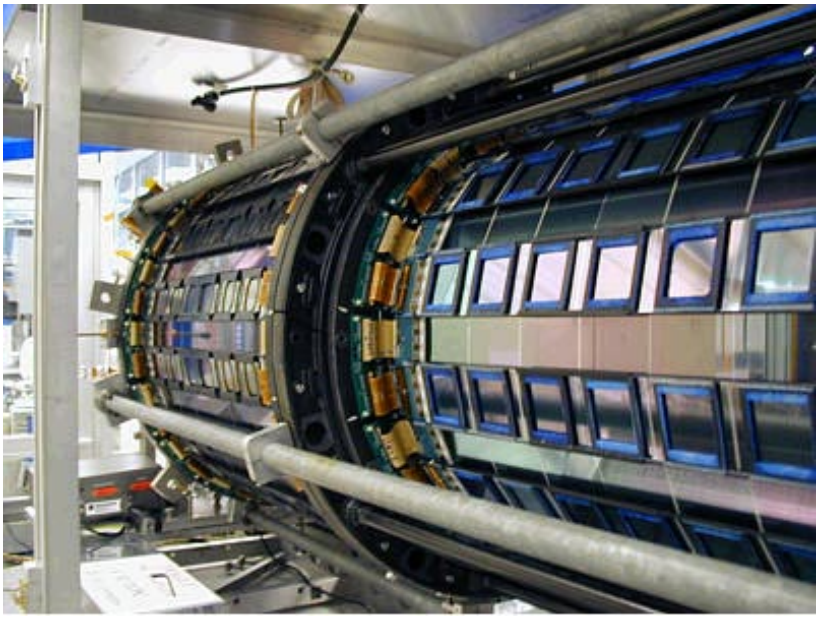

Figure 7: ISL detector being assembled at the SiDet facility at Fermilab.

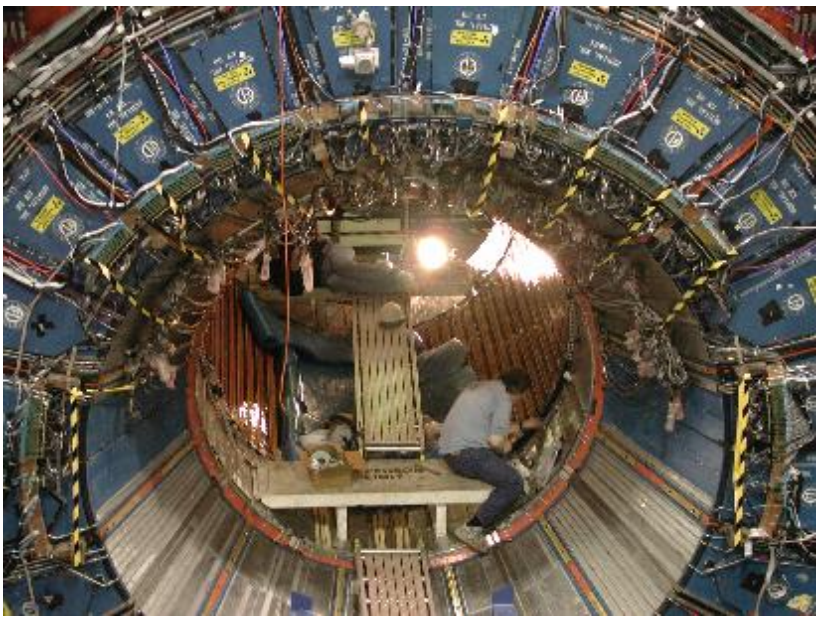

Figure 8: TOF detector being installed to the bore of the CDF solenoid.