Annual Progress Report for JFY 1998

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CDF Experiment

Spokespersons
Japan K. Takikawa (University of Tsukuba)
U.S.A. F. Bedeschi (University of Pisa), A. T. Goshaw (Duke University)

The CDF experiment is currently in a transition stage. The upgrade of the detector and preparation for the collider Run II, scheduled to begin in early 2000, proceed in full swing. On the other hand, important physics results continue to come out from analyses of the data sample collected during the Run I period.

1 Physics Analysis of Proton-Antiproton Collision Data

The collider Run I ended in February 1996, yielding 110 pb^{-1} of data recorded by the CDF detector. Analyses of the data continued in the fiscal year 1998, and have led to publication of several important results.

1.1 Top quark physics

Since its discovery in 1994 [1] the CDF experiment has concentrated on precision measurements of the mass and the production and decay properties of the top quark. In 1998 CDF refined the top quark mass measurements using all of the dilepton, lepton+jets, and all-hadronic channels. In particular, the dilepton channel has employed a new likelihood reconstruction technique and resulted in an improvement in the measurement precision. The mass value from this channel is $m_{\rm top} = 167.4 \pm 11.4$ GeV/c^2 [2]. This result was combined with measurements using the other channels to obtain a mass value of 176.0 ± 6.5 GeV/c^2. This will be the final measurement of the top quark mass from CDF using Run I data.

T. Kikuchi (Tsukuba) has searched for single top production. Two subprocesses are considered, one being "Wg fusion" process that leads to the $t\bar{b}$ final state (estimated cross section of 1.7 pb^{-1}), the other being a virtual W boson production followed by its decay to a $t\bar{b}$ pair (cross section of 0.7 pb^{-1}). These processes are of interest because the cross section is proportional to the partial width $\Gamma(t \rightarrow Wb)$, which depends on the CKM matrix element $|V_{tb}|$. So far the search has produced upper limits on the production cross section of about 15 pb for each channel.

1.2 Bottom quark physics

CDF continues to produce rich physics results in the area of B physics, and the year 1998 is no exception.

One of them is the observation [3] of the B_c^- meson, a bound state of two different kinds of heavy quarks (b and $\bar{c}$). CDF searched for and observed the B_c^- meson through the semileptonic decay $B_c^- \to \ell^- \bar{\nu} J/\psi X$, where ℓ^- is either e^- or μ^- and $J/\psi \to \mu^+\mu^-$. A total of 38 candidate events are seen, and $20.4^{+6.2}_{-5.5}$ events out of them are found to be the signals of the B_c^- meson. The probability that the background events fluctuate to produce the observed excess is 0.63×10^{-6}, or equivalent to 4.8 standard deviations. CDF measures the mass and lifetime of the B_c^- meson to be $m(B_c^-) = 6.40 \pm 0.39 \pm 0.13$ GeV$/c^2$ and $\tau(B_c^-) = 0.46\,^{+0.18}_{-0.16} \pm 0.05$ ps. The mass value is consistent with recent theoretical predictions, and the lifetime is close to that of charm hadrons rather than bottom hadrons. CDF also measures the production rate of the B_c^- meson relative to that of the B^- meson with $B^- \to J/\psi K^-$ to be $0.132\,^{+0.041}_{-0.037} \pm 0.031\,^{+0.032}_{-0.020}$. The B_c^- analysis is the thesis topic of J. Suzuki (Tsukuba) and S. Kim (Tsukuba) also contributed to this analysis.

Another important B physics analysis from CDF is the search for CP violation in the decay of the neutral B meson $B^0/\overline{B}^0 \to J/\psi K_S^0$. The Kobayashi-Maskawa picture of CP violation predicts a large asymmetry in the decay rates to the $J/\psi K_S^0$ final state between the B^0 meson and its anti-particle $\overline{B}^0$. The asymmetry can be cleanly related to the angle β of the unitarity triangle. CDF has reconstructed about 200 such decays and applied a flavor tagging method called "same-side tagging" [4], yielding $\sin 2\beta = 1.8 \pm 1.1$ [5]. CDF has extended this analysis to include the B^0 candidates where the muons from the J/ψ are not reconstructed in the SVX detector. These events have less precise lifetime information, but they are still useful because, unlike the $\Upsilon(4S)$ experiments, the asymmetry in the decay rates would not vanish even if it is integrated over decay time. The inclusion of these events roughly doubles the sample size to about 400 signal events. In addition to the same-side tagging, lepton and jet-charge flavor tagging methods [6] are applied to the sample, and CDF finds $\sin 2\beta = 0.79\,^{+0.40}_{-0.44}$ [7] as a preliminary result. Figure 1 shows the observed decay asymmetry. These results, although statistically not significant yet, firmly establish the methods that will lead to precise CP violation measurements in Run II.

Other B physics results published this year include precise measurements of the B^- and $\overline{B}^0$ meson lifetimes and their ratio [8] (work of F. Ukegawa, Tsukuba), of the $\overline{B}_s^0$ meson [9] lifetime, and of the $B^0\overline{B}^0$ oscillation frequency Δm_d [4, 6].

1.3 Electroweak physics

CDF has completed the measurement of the W boson mass using the electron channel. Combined with the measurement using the muon channel, it gives a CDF W mass value of $m_W = 80.433 \pm 0.079$ GeV$/c^2$ as a preliminary result. The precision is comparable to that from the LEP2 experiments.

H. Minato (Tsukuba) has made a measurement of the transverse momentum distribution of the W boson using the electron channel [10]. The measurement tests the perturbative QCD calculations in the next-to-leading order with the soft gluon resummation technique. The neutrino transverse momentum is inferred from the missing transverse energy in the event, and is used to reconstruct the W boson transverse momentum. Figure 2 shows the W transverse momentum distribution, along with a theoretical prediction.

Other electroweak studies in progress by Japanese collaborators include a measurement of the strength of the tau lepton coupling to the W boson relative to the electron coupling.

1.4 QCD physics

A few studies are in progress in the area of diffractive physics. H. Ikeda (Tsukuba) has investigated the bottom quark production in diffractive events [11]. The bottom quark is identified with semileptonic decay electrons produced in the central rapidity region. The diffractive nature of the events is identified with the existence of a rapidity gap between the antiproton and the rest of the event. The fraction of the diffractively produced bottom quarks among the total bottom quark production is measured to be $0.62 \pm 0.19 \pm 0.14\,\%$ when the pomeron has a flat gluon structure, and to be $1.18 \pm 0.36 \pm 0.27\,\%$ when the pomeron has a hard quark structure. Either measurement is lower than theoretical predictions by a factor of about five.

Other diffractive analyses under way by Japanese collaborators include studies of double-pomeron exchange process and diffractive two-jet production.

1.5 Searches for new phenomena

T. Handa (Hiroshima) has searched for [12] the production of technicolor particles, an alternative to the Higgs mechanism. In this analysis color-singlet techni-rho ($\rho_T^{\pm,0}$) particles are looked for, which can be produced in s-channel $q\bar{q}$ annihilation and subsequently decay into techni-pion ($\pi_T^{\pm,0}$) and a W boson. The neutral (charged) techni-pions decay predominantly to $b\bar{b}$ ($b\bar{c}$) pairs. The leptonic decay channel of the W boson is used, and it leads to a lepton plus two-jet signature with at least one b quark. No evidence for signal is observed, and upper limits on the techni-rho production cross section are placed. Figure 3 shows the excluded region in the plane of the ρ_T mass and the π_T mass.

Other analyses under way by Japanese collaborators include searches for R-parity violating supersymmetric particles, and a search for new particles using multi-jet events.

2 Detector Upgrade for Run II

2.1 Plug upgrade calorimeter

The analysis of test beam data using the test module is complete; performance characteristics such as energy resolution, response linearity, and response uniformity along the surface of the calorimeter are studied. The test beam module has performed according to design specifications. These data will be used to establish methods for electron and photon identification.

The construction of the production modules and the assembly into the plug calorimeter are now complete. The east plug calorimeter was installed in the CDF detector in December 1998. The west plug calorimeter has undergone pre-installation tests using cosmic rays, including gain adjustments of photomultiplier tubes, measurements of response to cosmic ray muons, and calibration using radioactive wire source. The west calorimeter is currently being installed to the CDF detector (see Figure 4).

In 1999 the installation of the west plug calorimeter will be complete. The readout electronics will also be produced, tested and installed, and the plug calorimeter as a whole will be ready for Run II.

Y. Seiya, T. Asakawa, R. Oishi from Tsukuba and J. Iwai from Waseda have contributed to the plug calorimeter efforts. Y. Seiya is a co-leader for the plug calorimeter project.

2.2 Silicon vertex detector (SVX II)

The production of double-sided silicon micro-strip sensors continued at Hamamatsu Photonics. They have been tested for quality and performance, including total and individual channel leakage current, $I - V$ characteristics, and dead channel fraction.

At the same time, preparation for assembly of the sensors into unit ladders is complete and the delivery of ceramic hybrids and readout chips is awaited.

T. Ohsugi, Y. Iwata from Hiroshima, I. Nakano from Okayama and R. Takashima from the Kyoto University of Education have been working on the SVX II project.

2.3 Intermediate silicon layers (ISL)

K. Hara and M. Shimojima from Tsukuba have worked on the silicon sensors of the ISL detector. The production of double-sided silicon micro-strip sensors has started at Hamamatsu. Sampling probing tests are performed to assure quality, including $I - V$ characteristics, leakage current, and dead channel fraction. The production of ladders will start soon.

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

2.4 Data acquisition system

M. Shimojima (Tsukuba) has assumed 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 as well as to online monitoring programs. The conceptual design of the data logger is complete in 1998, and in 1999 a prototype will be constructed and evaluated for performance.

References

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[7] CDF Collaboration, "A measurement of $\sin 2\beta$ from $B \to J/\psi K^0_S$ with the CDF detector", CDF/PUB/BOTTOM/CDF/4855, February 1999.

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[12] T. Handa, Ph. D. Thesis, "Search for technicolor particles in 1.8-TeV $p\bar{p}$ collisions at $\sqrt{=}1.8$ TeV", Hiroshima University, January 1999.

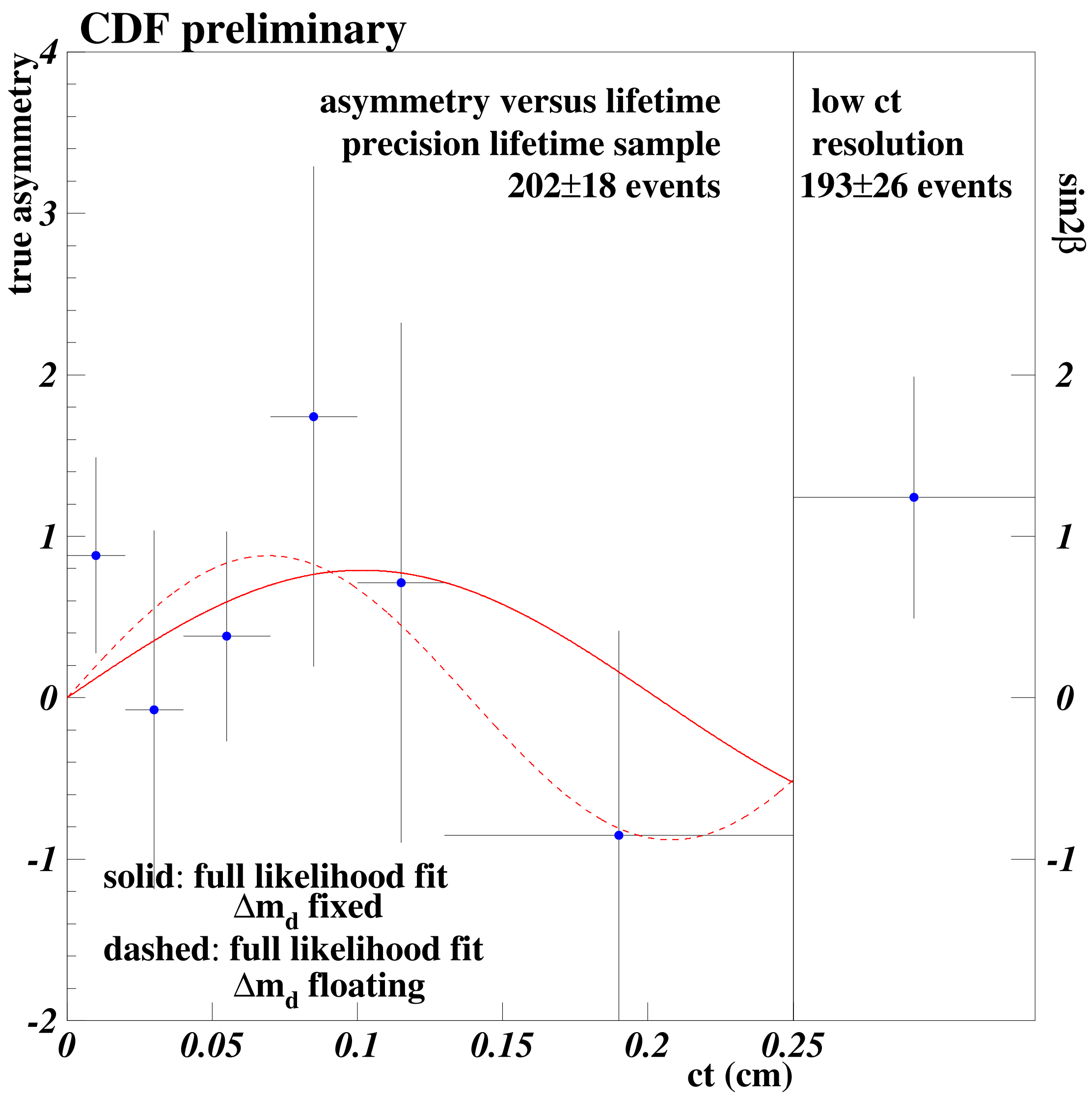

Figure 1: Left: Asymmetry in the $\overline{B}^0$ and B^0 decay rates to the $J/\psi K^0_S$ final state as a function of the proper decay time for events with precise decay time information. Right: Asymmetry in the decay rates integrated over decay time (converted to $\sin 2\beta$) for events with less precise decay time information.

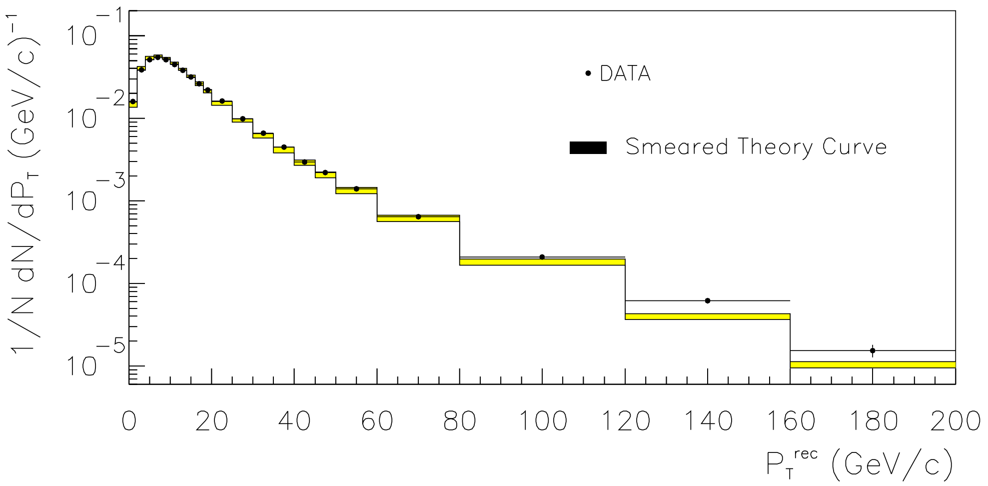

Figure 2: Distribution of the reconstructed transverse momentum of the W boson (points). Range of smeared theory predictions is shown as the shaded region of the histogram.

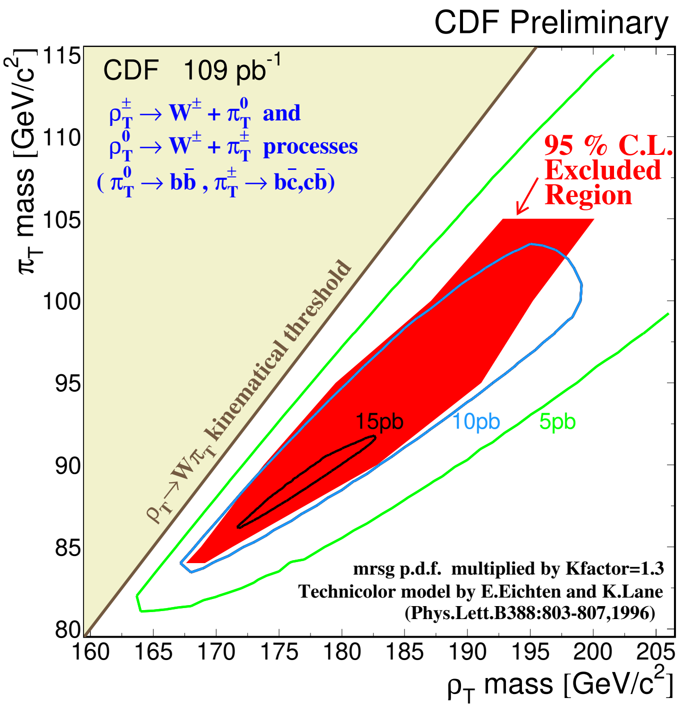

Figure 3: Region excluded at 95% C.L. in the plane of the ρ_T mass versus the π_T mass.

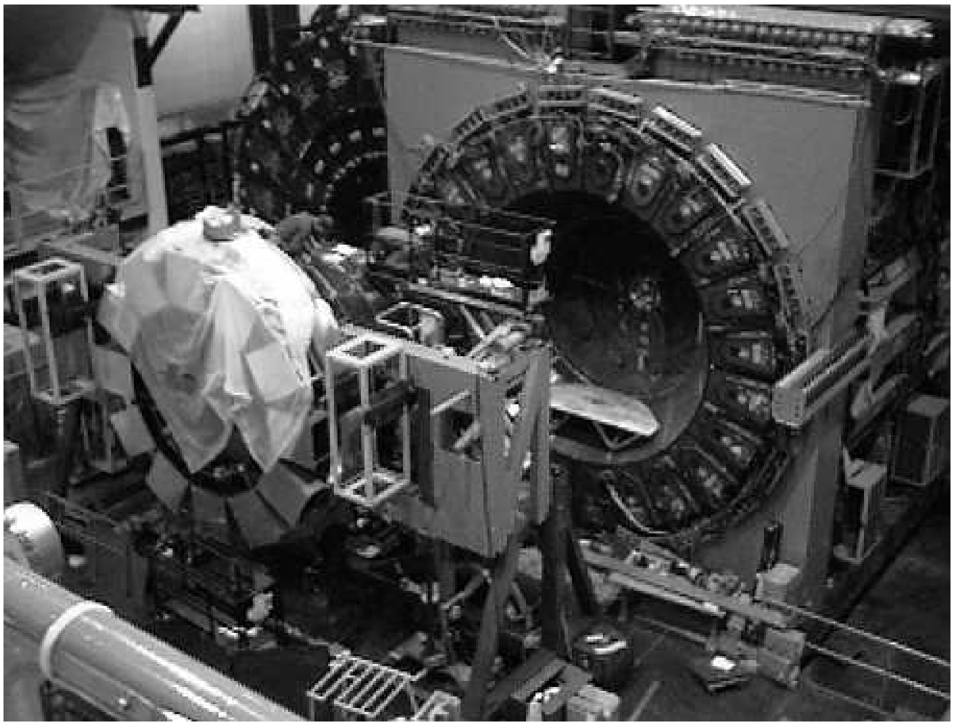

Figure 4: The west endplug calorimeter being installed to the CDF detector.