Annual Progress Report for JFY 2001

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CDF Experiment

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The year 2001 marked the start of a new era for the CDF experiment. The Tevatron Run-II program officially started in March 2001. The upgrade of the detector and its commissioning had been completed previously. Now the Tevatron accelerator runs with 36 bunches of protons and anti-protons, respectively, and produces an increased center-of-mass energy of 2.0 TeV. Thus far a peak luminosity of $\mathcal{L} = 1.4 \times 10^{31}$ cm^{-2} s^{-1} has been achieved. This is comparable to the highest luminosity in Run I. The integrated luminosity recorded by CDF amounts to roughly 20 pb^{-1} (Figure 1). We expect the instantaneous luminosity value to improve significantly over the next several months, and hope to accumulate about 50 pb^{-1} of data by summer and 200 pb^{-1} by the end of this year.

The Tevatron Run IIa, scheduled through 2004, should deliver an integrated luminosity of 2 fb^{-1} to CDF. After that, in Run IIb, an instantaneous luminosity of 4×10^{32} cm^{-2} s^{-1} is expected, and a total integrated luminosity of 15 fb^{-1} will be accumulated by 2008 (Table1). For operations at such a high luminosity, CDF needs further upgrades of some of the detector components. They include the replacements of the silicon detector and the central preshower detector. R&D efforts for the upgrades are already under way, and the Japan group plans to make significant contributions.

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

1 Physics Prospects in Run II

We expect a data sample corresponding to an integrated luminosity of 2 fb^{-1} by the end of 2004. This means a twenty-fold increase in the amount of data compared with the previous run, Run I. Also, the Tevatron beam energy has been increased to give a center-of-mass energy of 2 TeV.

We plan on carrying out a broad physics program, and some of the physics topics are listed below:

- Precise measurements of top quark properties.
  The mass will be measured with a precision of about 3 GeV/c^2 [1, 2]. Other production and decay properties will be also measured precisely, including $t\bar{t}$ production cross section to 9%, single top production, measurement of $|V_{tb}|$ to 13%. And searches will be performed for new particles such as a charged Higgs boson through the top decay $t \to H^+ b$ 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 2 [1]. Also, detailed studies of self-couplings of the electroweak gauge bosons will be performed.

  Some early signals have already been observed in Run-II data. Figure 3 shows a distribution of electron transverse energy vs. missing transverse energy for $W \to e\nu$ candidates, and Figure 4 shows an invariant mass distribution for $Z^0 \to e^+e^-$ candidates.

- 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 [3]. 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 to 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}. This is shown in Figure 5. Also, a determination of the CKM angle γ to $\pm 10°$ using $B^0 \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$ decays is possible [3], and searches for various rare decay modes will be performed.

  Again, Run-II data show signals such as J/ψ, $\psi(2S) \to \mu^+\mu^-$ (Figure 6) and $B^\pm \to J/\psi K^\pm$ (Figure 7).

- Quantum chromodynamics.
  A wide variety of measurements will be performed at a new center-of-mass energy of 2 TeV. Also, increased statistics allow measurements in a wider range of spectra, e.g. highest E_T jets, photons and other objects, and with less statistical uncertainties. 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 [4]. This is shown in Figure 8.

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 still remained active in the fiscal year 2001.

2.1 QCD physics

K. Kurino (Hiroshima) has studied production of photons in association with muons [5]. 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 9 (left), 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. The data are studied further for sample composition using p_T^{rel}, the muon momentum component that is perpendicular to the axis of the jet that contains the muon. Figure 9 (right) shows the distribution of p_T^{rel}, and a fit gives a sample composition of $\gamma c/\gamma b = 2.2 \pm 1.2 \pm 0.3$.

2.2 Searches for new phenomena

Y. Miyazaki (Osaka City) performed a search for the pair production of scalar top quarks that subsequently decay, violating R-parity, into a tau lepton and a bottom quark [6]. The tau lepton is identified with its decay into one- and three-prong hadrons. The method is demonstrated by reconstructing the decay $Z^0 \to \tau^+\tau^-$, where one of the tau decays semileptonically into an electron or a muon, and the other tau decays hadronically. The charged multiplicity distribution for the hadronic tau decay candidates is shown in Figure 10(left). The scalar quark is looked for with a final state consisting of an electron, tau and two b-quark jets. No candidate event is found with an expected background of 1.92 ± 0.18 events. An upper limit on the production cross section has been placed, and a lower limit on the squark mass of 111 GeV/c^2 is obtained at 95% C.L. (Figure 10(right)).

3 Detector Upgrade for Run II

3.1 Plug upgrade calorimeter

A new, scintillator-based plug calorimeter [7] has been constructed and installed in the CDF detector. The analysis of Run-II 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 off-line 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 was 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 11), and they were installed inside the CDF detector in February 2001. Since then they were gradually integrated into CDF for readout (Figure 12).

The production of double-sided silicon micro-strip 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.

Y. Takeuchi, S. Tsuno (Tsukuba), N. Tanimoto and T. Yamashita have developed a system for monitoring of the silicon detectors, with an example as shown in Figure 12.

3.3 Data acquisition system and monitoring

M. Shimojima and H. Matsunaga (Tsukuba) have responsibility for the consumer server-logger system, which, as 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. Arisawa and K. Ikado (Waseda) are responsible for the monitoring programs that check detector performance and data quality. Both of these systems have performed successfully in Run II.

A. Miyamoto and Y. Fujii (KEK) have contributed to the event display program, in particular the central calorimeter wedge display.

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) have been 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 the TOF detector itself was completed in 2000, and the installation of readout electronics was completed by summer 2001. All channels are read out and calibrations have been carried out using collision data. K. Sato has performed a measurement and equalization of PMT gains, achieving a uniform response among different channels. Figure 13 shows a distribution of the charged particle mass reconstructed using TOF information. A clear separation of protons, kaons and pions is visible for both positively and negatively charged particles at low momenta. 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. The most probable solution is to use single-sided sensors that can be operated at higher bias voltages. K. Hara, S. Aoki, K. Wakiya and S. Takei (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. Prototype sensors will be produced soon, and the production will follow.

In the past year, a design of the detector with a structure based on staves has been developed. K. Yamamoto (Osaka City) has contributed to an optimization of the layout of the layers.

K. Hara is a co-leader of the Run-IIb silicon project.

3.6 Central preshower detector upgrade for Run IIb

The central preshower detector (CPR) is located behind the CDF solenoid (about one radiation length thick) and before the central electromagnetic calorimeter CEM. It samples electromagnetic showers at their early development stage, and plays important roles in identification of electrons and photons.

The current CPR detector is a slow gas chamber with relatively coarse segmentation. This detector will suffer a serious occupancy problem once the Tevatron luminosity exceeds 10^{32} cm^{-2} s^{-1}. The solution will be to replace it with a fast, finely-segmented device. Our present choice is to use plastic scintillator with a wavelength shifting fiber for readout, like in the preshower detector for the upgraded plug calorimeter (PPR).

Photons will be read out with a photomultiplier tube. A total number of channels of 3072 is envisioned, and the plan is to use multi-anode PMTs to reduce cost as in PPR. The current choice is Hamamatsu H6568 (R5900-M16). This tube has 16 pixels with a pixel size of 4 mm $\times$ 4 mm. We would need 64 channels (four tubes) per CEM wedge, with a total of about 240 tubes including spares.

References

[1] CDF II Collaboration, "The CDF II detector, Technical design report", Fermilab-Pub-96/390-E (1996).

[2] R. Roser, CDF Collaboration, "Review and preview of top physics at CDF", talk at the Thinkshop, top-quark physics for Run II, Fermilab, November 10 - 12, 1998.

[3] "B Physics at the Tevatron : Run II and beyond",
hep-ph/0201071.

[4] M. Carena, J. S. Conway, H. E. Haber, J. D. Hobbs, Report of the Higgs working group of the Tevatron Run II SUSY/Higgs Workshop, hep-ph/0010338 (2000).

[5] "Cross Section and Heavy Quark Composition of $\gamma + \mu$ Events Produced in $p\bar{p}$ Collisions",
CDF Collaboration, T. Affolder *et al.*, Phys. Rev. D **65**, 012003 (2002).

[6] CDF Collaboration, see:
http://www-cdf.fnal.gov/physics/exotic/run_1b_rpv_stop_e/public.html

[7] M. Albrow, Y. Seiya *et al.*, Nucl. Instr. Methods Phys. Res. **A480**, 259 (2002).

Year	Lum (10^{32})	Months operation	Int. Lum (year) (fb^{-1})	Int. Lum (tot) (fb^{-1})	Shut-down months	Comments
2002	0.75	10	0.32	0.3	2	Shutdown for Recycler alignment (October).
2003	1.2	10	0.83	1.2	2	Assume Recycler is working. Install 312 ns hardware and electron cooling into the Recycler.
2004	2.2	9	1.31	2.5	3	Finish installation of 132 ns and electron cooling.
2005	3.1	8	1.81	4.3	4	Shutdown for Run-IIb silicon and C0 IR.
2006	4.1	11	3.38	7.6	1	
2007	4.1	11	3.85	11.5	1	
2008	4.1	11	3.85	15.0	1	

Table 1: Long term Tevatron schedule.

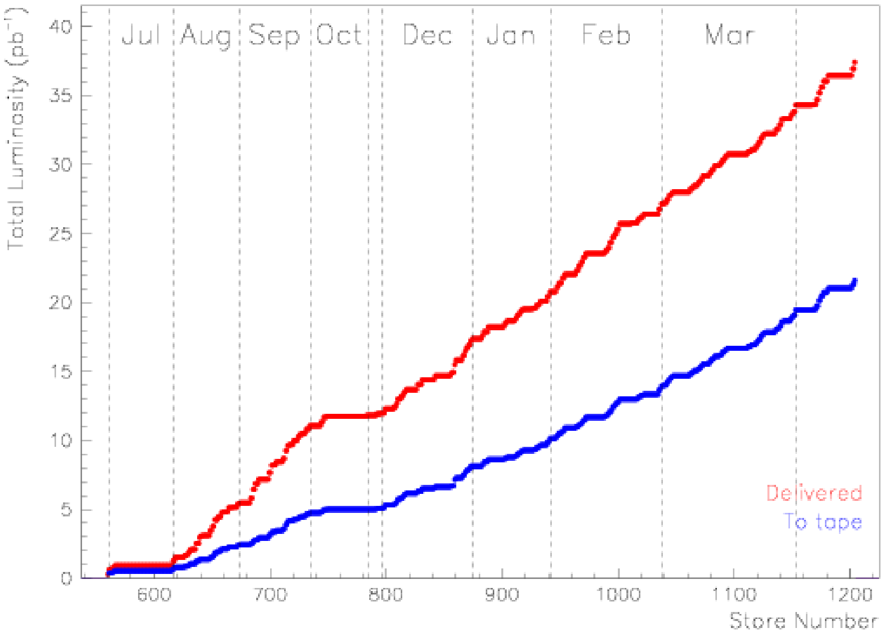

Figure 1: Run-II integrated luminosity delivered (top) and recorded by CDF (bottom) thus far.

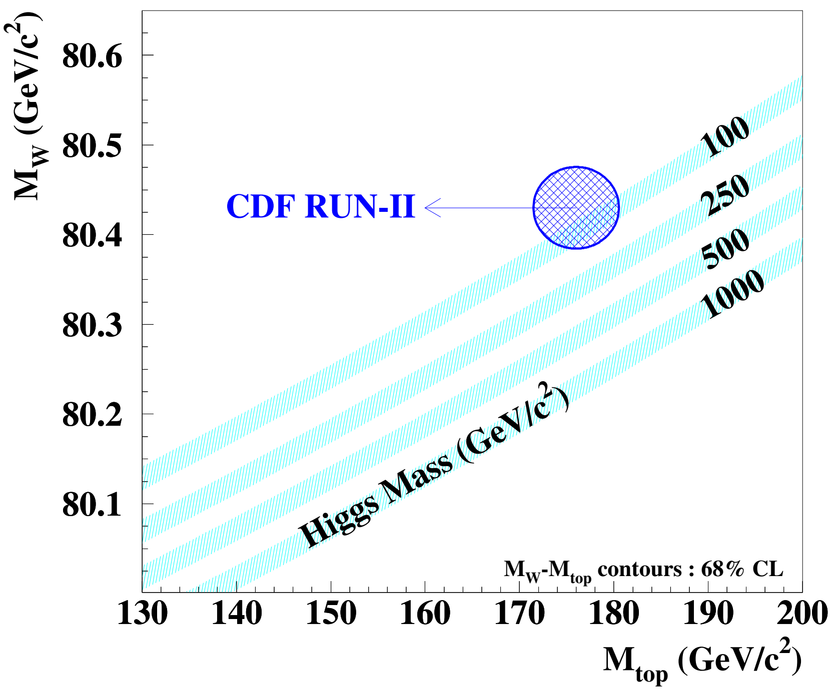

Figure 2: Expected precision in top quark and W boson mass measurements in Run II, and possible constraints on the Higgs boson mass.

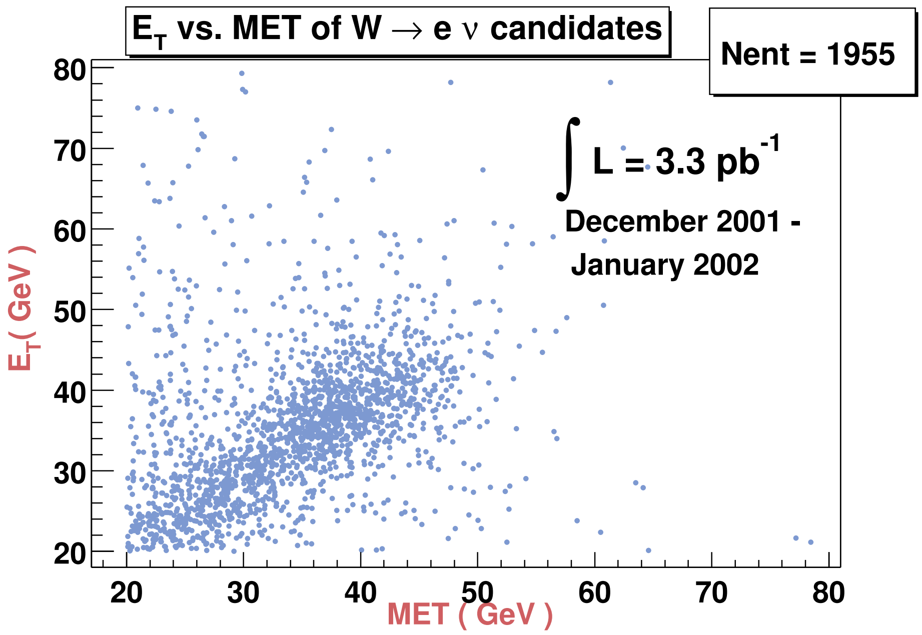

Figure 3: Run-II $W \rightarrow e\nu$ candidates.

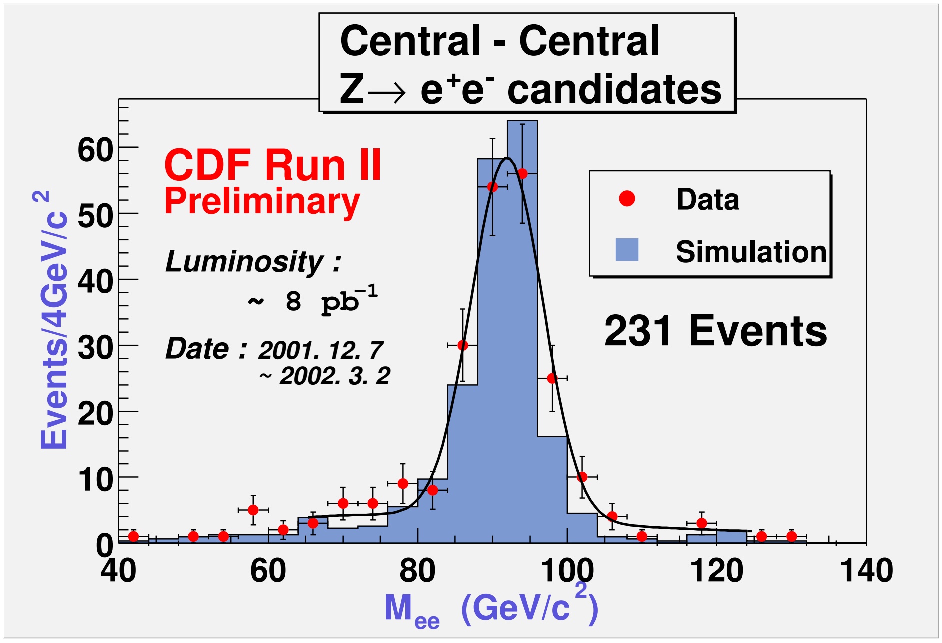

Figure 4: Run-II $Z^0 \to e^+e^-$ candidates.

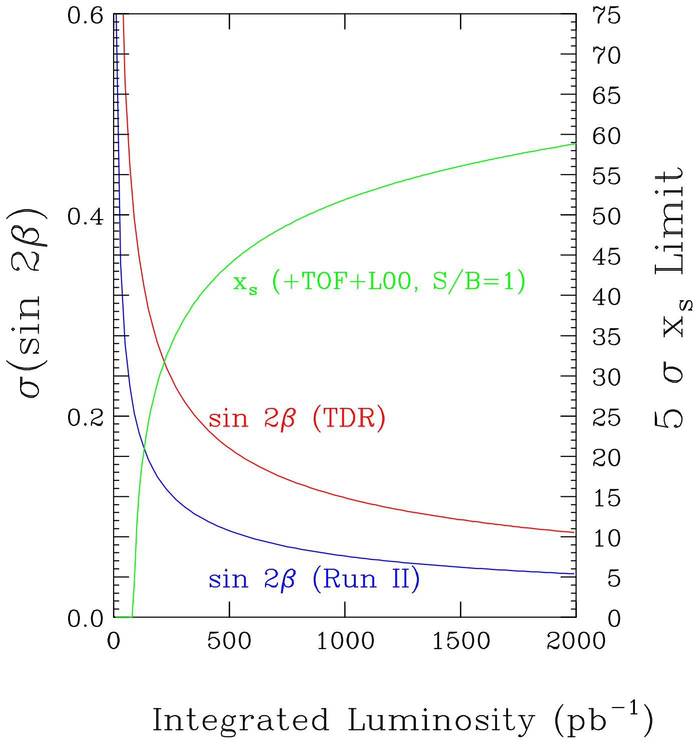

Figure 5: Expected precision in $\sin 2\beta$ measurement (left axis) and $B_s^0\overline{B}_s^0$ mixing reach (right axis) as a function of accumulated amount of data in Run II.

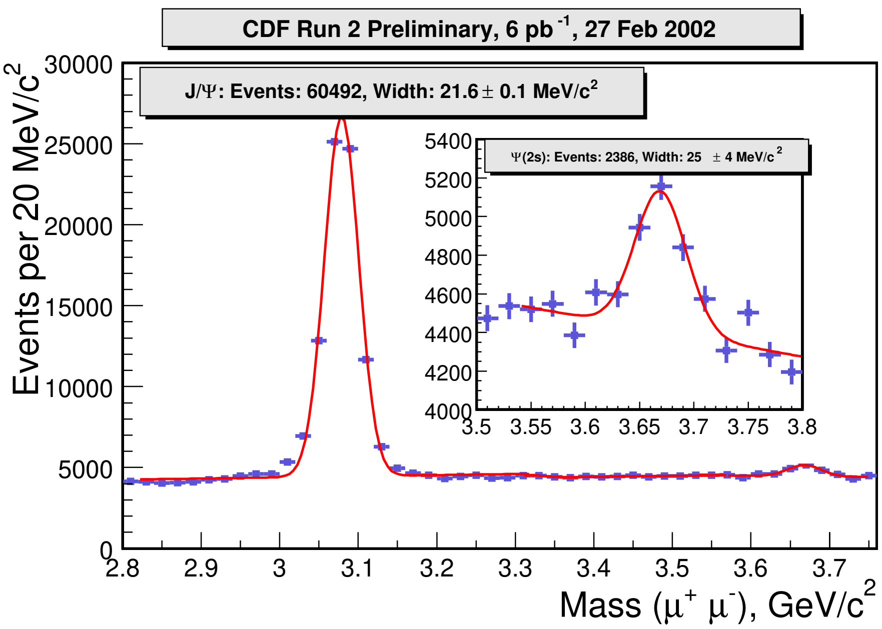

Figure 6: Run-II dimuon invariant mass distribution. Inset shows $\psi(2S)$ region.

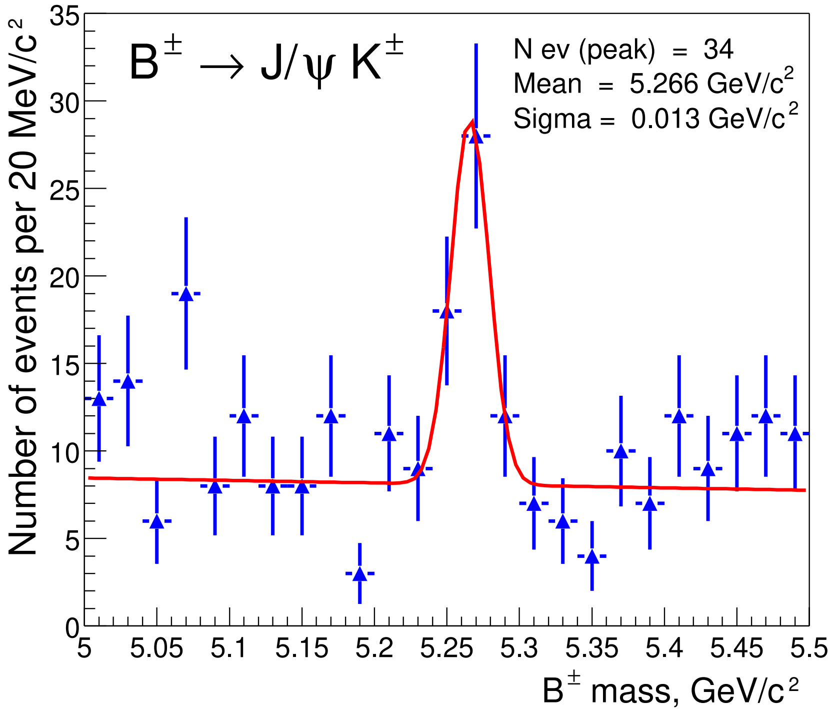

Figure 7: Run-II data for $B^\pm \to J/\psi K^\pm$ candidates.

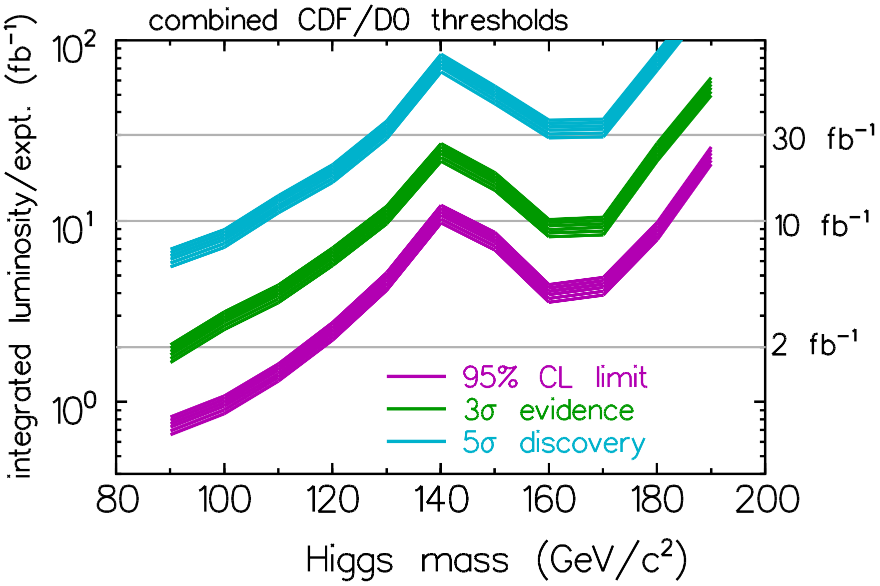

Figure 8: Tevatron reach for the standard model Higgs boson. Three bands show, as a function of the Higgs mass, the amount of data that are necessary (a) to exclude at 95% CL if the Higgs does not exist at that mass (bottom band), (b) to provide 3σ evidence for existence (middle), and (c) to discover with 5σ significance (top).

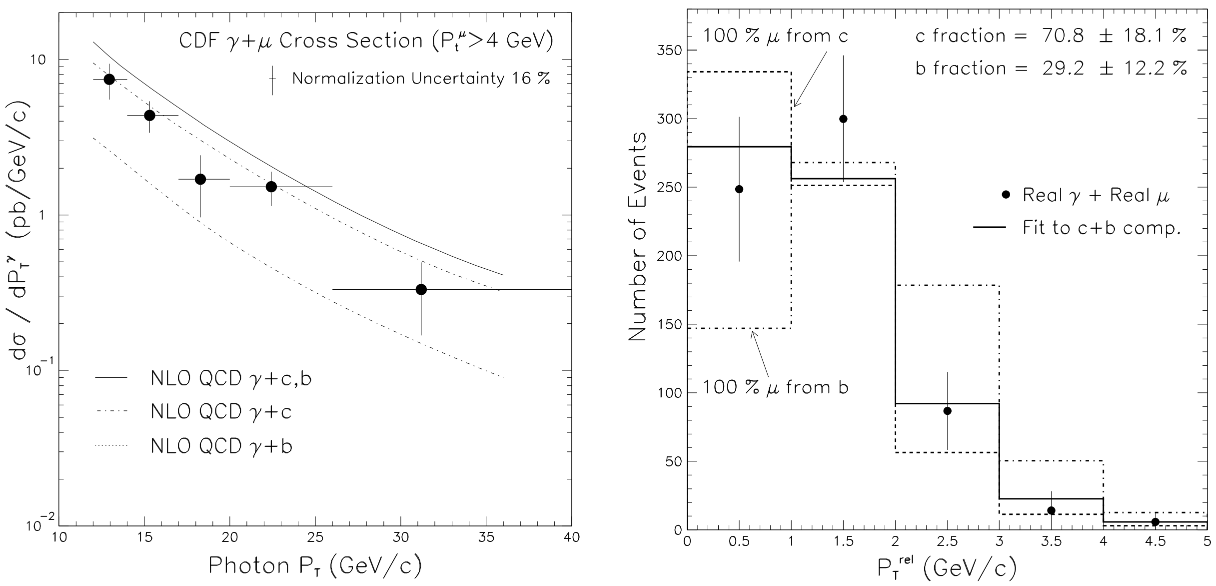

Figure 9: Left: cross section for associated $\gamma + \mu$ production as a function of γ transverse momentum. Right: Distribution of $p_T^{\rm rel}$, muon momentum component transverse to the jet axis containing the muon. This quantity is used to estimate the composition of the source of the muons, charm vs. bottom.

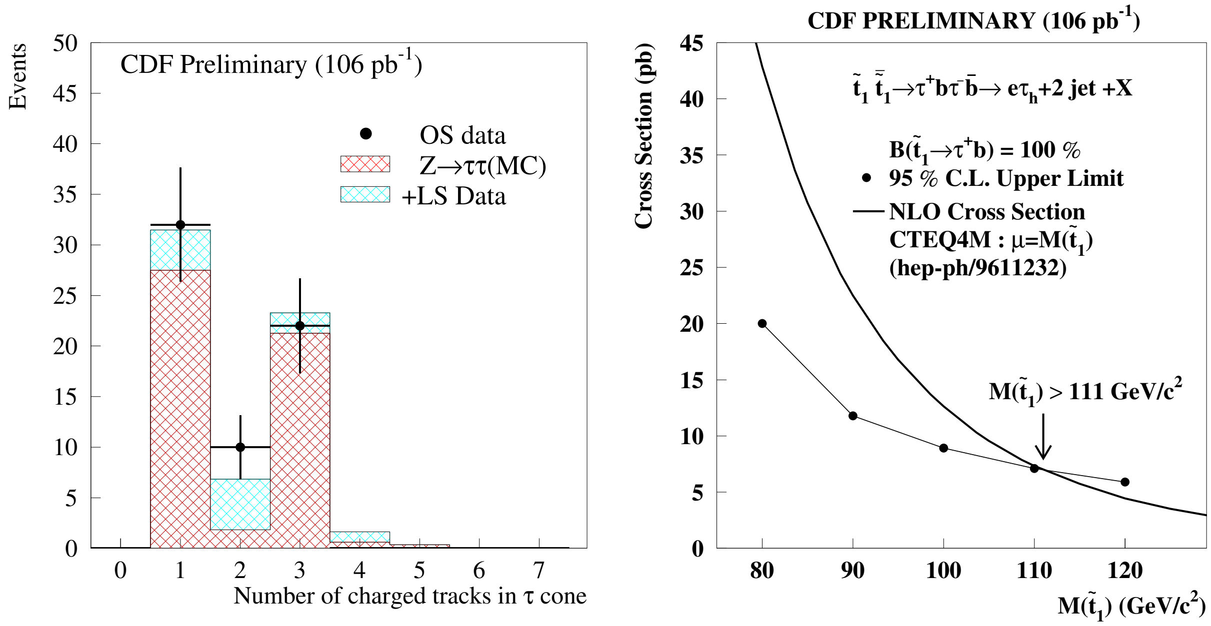

Figure 10: Left: charged multiplicity distribution for tau candidates in $Z^0 \to \tau^+\tau^-$. Right: Theoretical prediction and experimental upper limit on the cross section for the production of scalar top quark pairs.

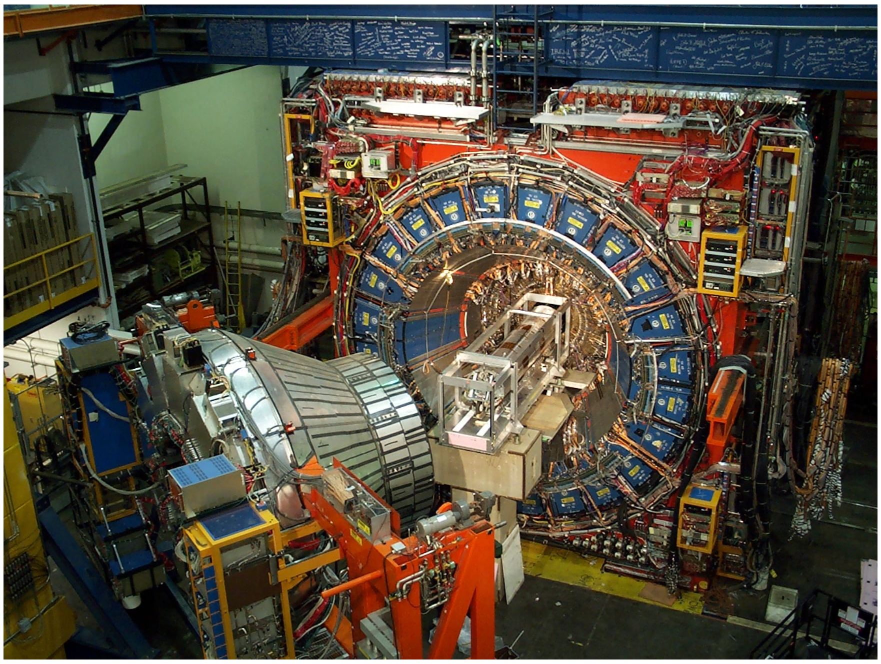

Figure 11: Silicon detectors being installed inside the central tracking chamber.

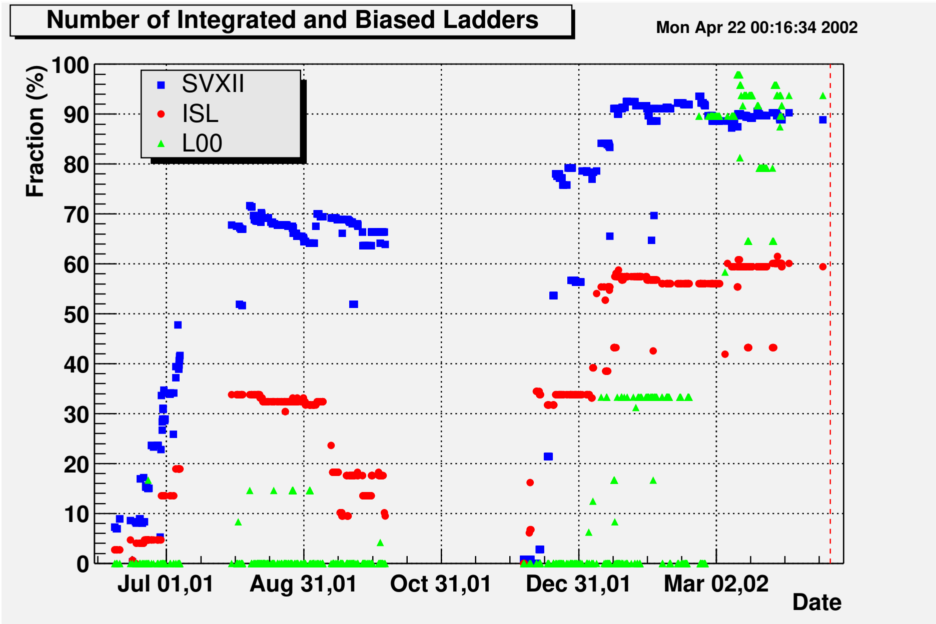

Figure 12: CDF-II silicon detector commissioning status. Fractions of channels read out are shown for Layer 00, SVXII and ISL detectors.

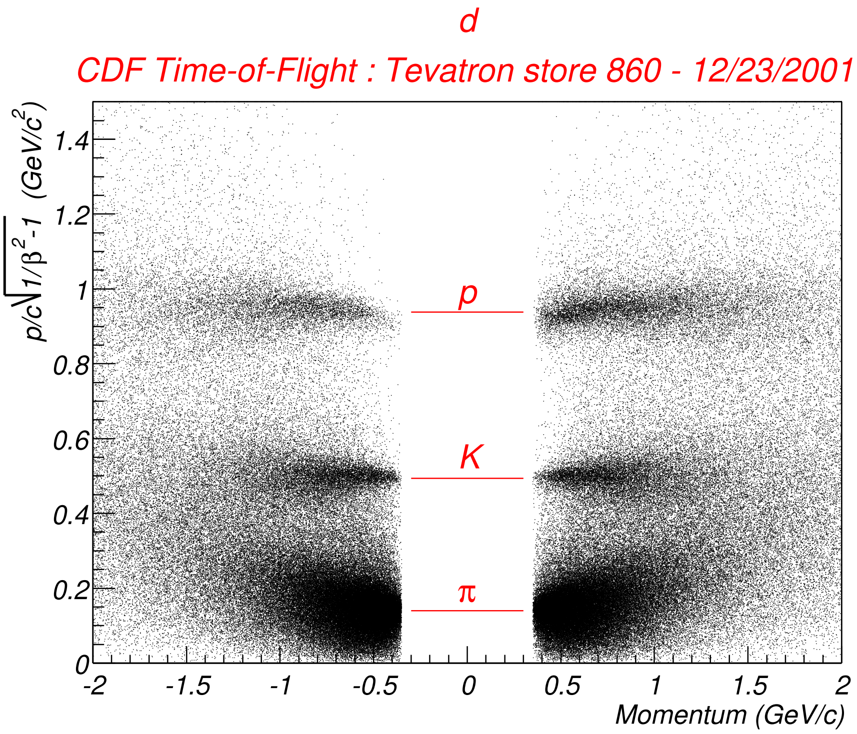

Figure 13: Distribution of charged particle mass vs. momentum. Mass is reconstructed using TOF detector.