CDF CHARM PRODUCTION AT THE TEVATRON*

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This talk gives a brief overview of some of the CDF analyses involving charm production. New CDF triggers add a "charm factory" role for CDF and lead to huge data sets. Results on the J/Ψ cross section and charm decay rate ratios are given, along with limits on CP asymmetry and flavor-changing-neutral currents. The $X(3872)$ object reported by the Belle Collaboration is confirmed at the Tevatron, but the charm pentaquark reported by the H1 Collaboration is not in in evidence at this time at CDF. A search for anomalies in the production of displaced jets plus a hard photon found no deviations from QCD expectations. Finally, a mention is made of the Tevatron's improved luminosity.

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This talk gives a brief overview of some of the CDF analyses on charm production. Although the primary role for the Tevatron lies in searches for physics beyond the standard model (BSM), it turns out that the Tevatron is a very good charm factory. Of course, some of the Charm physics itself involves BSM searches. The credit for the excellent CDF efficiency for charm physics lies with its triggers, but there is no space to describe them here. The relevant components of the detector for this talk are the silicon vertex tracker (SVX II) near the beam line followed by the central outer tracker (COT) with its eXtremely Fast Tracker (XFT), the EM and hadronic calorimeters, and the muon detectors. The XFT is the heart of many of the triggers. At Level 1 the XFT forms tracks that can be matched to muon stubs or electron signals in the EM calorimeter. Missing E_{T} and sums of E_{T} values can also be formed. At Level 2 the silicon vertex tracker (SVT) associates SVX II

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hits with XFT track information to form matching tracks and measure the impact parameters — all with a processing time of 15 microseconds. The online resolution obtained is 48 microns and includes in quadrature the 33 micron beam spread. This is without $L00$ which is right on the beam pipe, so the resolution will improve later. Jet finding and refined electron or photon identification is also performed at Level 2. Level 3 is a computer farm carrying out a fast version of the full CDF reconstruction. Further selection is done there before the event is sent to mass storage. The XFT track is of very high quality. The XFT track and the same track after final offline reconstruction are almost identical. The turn-on of the XFT track efficiency is sharp and reaches 96% at 1.5 GeV/c.

The triggers of particular interest for this talk are (1) the di-muon trigger, (2) the displaced-track-plus-lepton trigger, and (3) the two-track trigger. The conventional dimuon trigger has been improved so that it is effective down to 1.5 GeV/c in transverse momentum, allowing measurement of J/Ψ production down to $P_{\mathrm{T}} = 0$. This is a Level 1 trigger requiring only two muon stubs matched to two XFT tracks that have been extrapolated to the muon detector locations. No further selection is required for this trigger until the Level 3 farm. Further selection can be made there before the event is passed to the mass storage. This trigger is particularly useful for quarkonia studies, CP violation, and masses and lifetimes of heavy quark mesons.

The displaced-track plus lepton trigger requires a lepton with a P_{T} of more than 4 GeV/c and another track with an impact parameter >120 microns. This is suitable for triggering on semileptonic decay modes and provides data for high statistic lifetime studies and tagging studies.

The two-track trigger requires at Level 1 two XFT tracks with $P_{\mathrm{T}} > 2$ GeV/c and a scalar sum > 5.5 GeV/c for hadronic charm decays. At Level 2 the SVT tracks are required to have impact parameters between 120 microns and 1 mm. The tracking is refined in the Level 3 farm, and the intersection of the two tracks is required to be 200 microns from the beam line.

1. J/Ψ cross section

J/Ψ signals obtained with 39.7 inverse picobarns of integrated luminosity are shown in Fig. 1. The signal in the very low range $0 < P_{\mathrm{T}}(J/\Psi) < 0.25$ GeV/c is clearly seen. The signal integrated over the full P_{T} range is also shown. Figure 2 shows the P_{T} distribution of the events and Fig. 3 the differential cross section *versus* the P_{T} of the J/Ψ for $|\,\eta\,| < 0.6$. The two smooth curves represent the systematic uncertainties. The integrated cross section for the dimuon mode is 240 ± 1 (stat.) $^{+35}_{-28}$ (syst.) nanobarns. Using the Particle Data Group branching ratio, a total cross section of 4.08 ± 0.02 (stat.) $^{+0.60}_{-0.48}$ (syst.) microbarns is obtained.

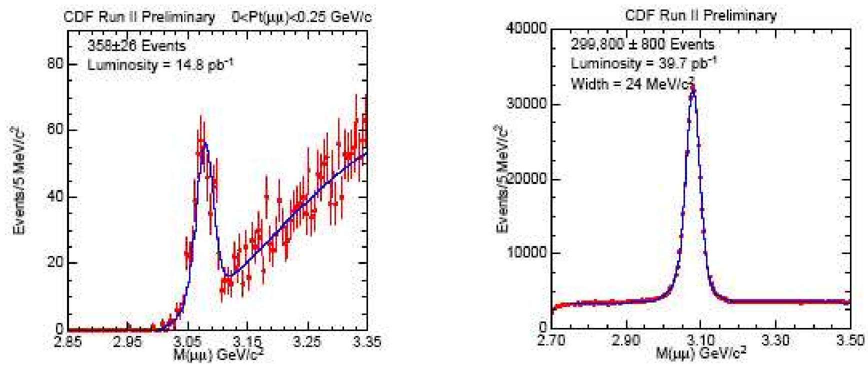

Fig. 1.

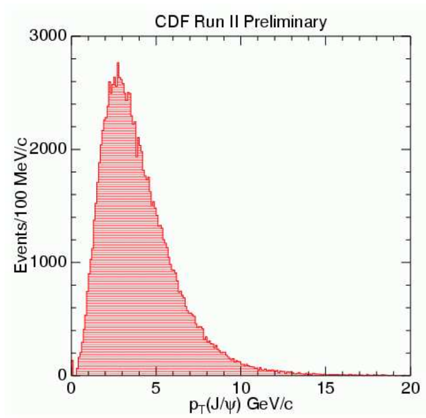

Fig. 2.

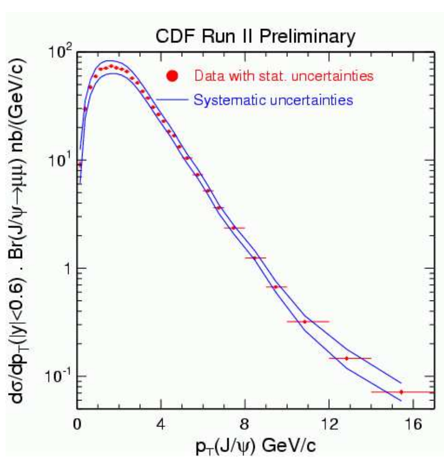

Fig. 3.

2. Charm decay rate ratios and CP asymmetry

The two-track trigger is used to select charm mesons. With about 70 inverse picobarns there are half a million $D^0 \to K\pi$ events. Mass distributions are shown in Figs. 4 and 5 for $K\pi\pi$ and $K\pi$ decay modes, respectively. In a future sample of two inverse femtobarns, CDF will have ten million fully reconstructed $D^0 \to K\pi$ events. These numbers make CDF more than competitive with FOCUS, todays standard for huge charm samples.

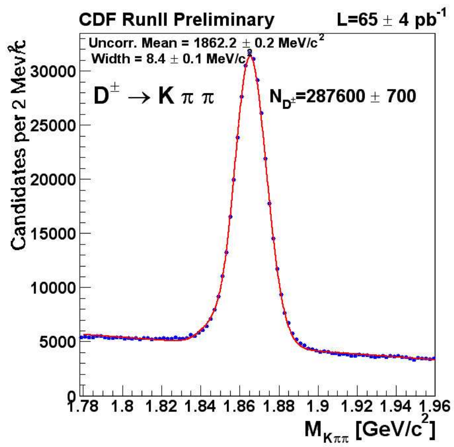

Fig. 4.

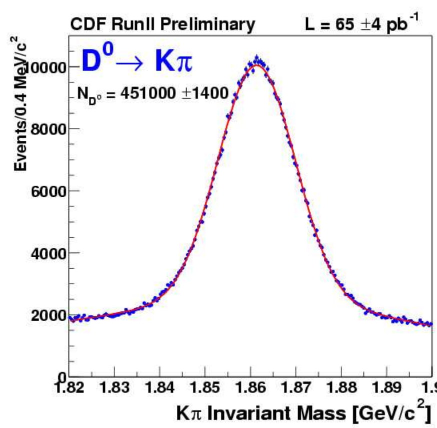

Fig. 5.

For decay rate ratios and CP asymmetry studies, the D^0 is always obtained from a D^* decay. The very clean D^0 and $\bar{D}^0$ signals obtained in this way are shown in Fig. 6 for both the KK and $\pi\pi$ channels. D^0 decay rate ratios for KK, $\pi\pi$, and K π modes are shown in Table I. The values are consistent with those of FOCUS, with somewhat smaller errors. The KK to $\pi\pi$ ratio, 2.7%, is significantly larger than the theoretical value, 1.4%. The discrepancy is thought to be due to final state interactions, and has ramifications for heavy quark effective theory and lattice gauge work. The charm production cross section has been reported at ISMD 03 and is compatible with the Standard Model.

CP asymmetries in Cabbibo-suppressed decays can signal new physics, and CDF has measured the ratio

$$\frac{D^0 \to \pi\pi(KK) - \bar{D}^0 \to \pi\pi(KK)}{D^0 \to \pi\pi(KK) + \bar{D}^0 \to \pi\pi(KK)}\,.$$

TABLE I

Decay rate ratios.

Ratio	CDF	FOCUS
$\frac{\Gamma(D^0 \to KK)}{(D^0 \to K\pi)}$	(9.96 +/− 0.11 +/− 0.12)%	(9.93 +/− 0.14 +/− 0.14)%
$\frac{\Gamma(D^0 \to \pi\pi)}{(D^0 \to K\pi)}$	(3.608 +/− 0.054 +/− 0.040)%	(3.53 +/− 0.12 +/− 0.06)%
$\frac{\Gamma(D^0 \to KK)}{(D^0 \to \pi\pi)}$	(2.762 +/− 0.040 +/− 0.034)%	(2.81 +/− 0.10 +/− 0.06)%

Theory says this value should be about 10^{-3} to $10^{-2,}$ but new physics might enhance the effect. Since the asymmetry depends on the correct identification of the soft pion from the D^*, a correction must be made for the intrinsic charge asymmetry of the CDF detector response and tracking algorithms. Figure 7 shows the asymmetry observed for both generic tracks and tracks from Ks decays. A small asymmetry can be seen. The correction has a residual uncertainty of ± 0.6%, and this is assigned as a systematic uncertainty to the observed D^0–$\bar{D}^0$ decay asymmetry. The observed asymmetry is (2.0 ± 1.2 (stat.) ± 0.6 (syst.))% for the KK mode and (1.0 $\pm$ 1.3 (stat.)$\pm$0.6 (syst.))% for the $\pi\pi$ mode. These values are consistent with

TABLE II

Asymmetries

	CDF	CLEO-II	PDG
$A(D^0 \to KK)$	(2.0 +/− 0.12 +/− 0.6)%	(0.0 +/− 2.2 +/− 0.8)	(0.5 +/− 1.6) %
$A(D^0 \to \pi\pi)$	(1.0 +/− 1.3 +/− 0.6)%	(1.9 +/− 3.2 +/− 0.8)%	(2.1 +/− 2.6)%

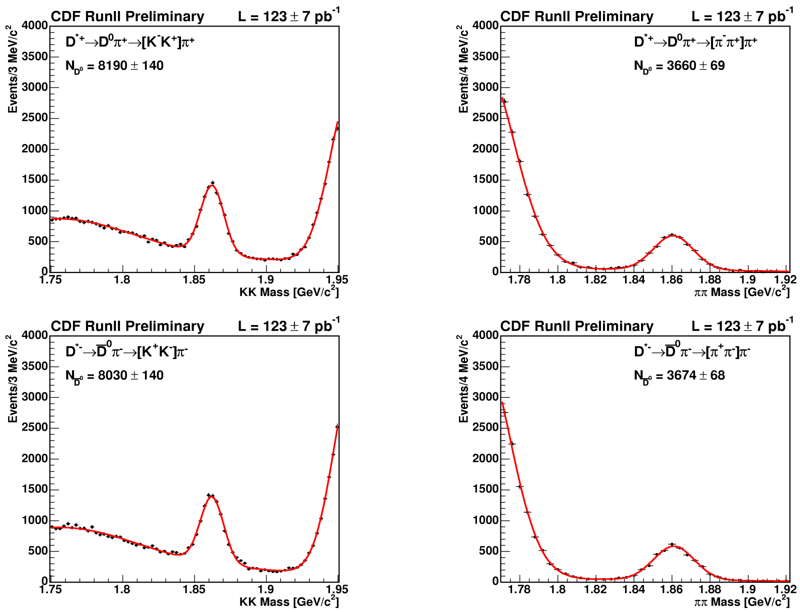

Fig. 6.

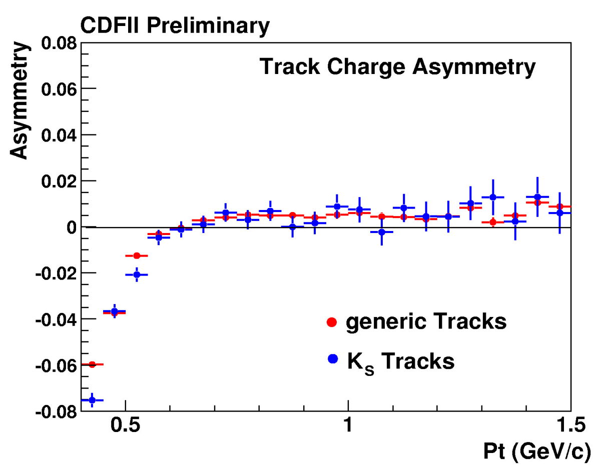

Fig. 7.

zero. Although they have statistical errors larger than those of the PDG, it is interesting to note that the systematic errors are smaller than those of either the PDG or the CLEO-II experiment. See Table II. In time, the CDF statistical errors will be reduced considerably.

3. Flavor changing neutral currents

The branching ratio for $D^0 \to \mu\mu$ in the standard model is of order 10^{-13}. However, new physics such as R-parity-violating SUSY could enhance the branching ratio to $\sim 10^{-6}$. To reduce background, the $D^{*0} \to D^0 + \pi$ decay is used to select D^0 mesons, and the decay $D^0 \to \mu\mu$ is looked for. Normalizing this mode to the $\pi\pi$ mode cancels trigger efficiencies and systematics. Figure 8 shows the $\pi\pi$ mass spectrum and the search window. When the $\mu\mu$ window was unblinded there were no events in the corresponding mass window. This null result corresponds, at the 90% confidence level, to 2.3 events, and the branching ratio for $D^0 \to \mu\mu$ is 2.4×10^{-6}. This is about two times smaller than the previous limit, although Hera-B should soon have a better value.

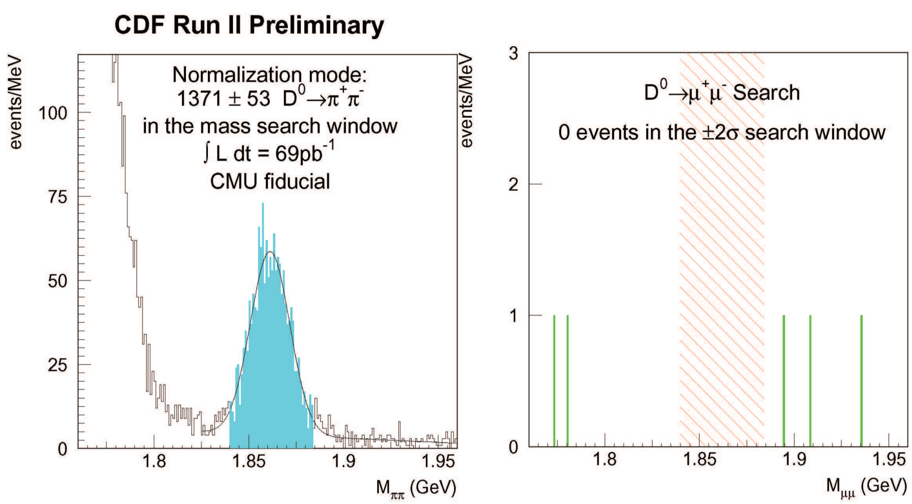

Fig. 8.

4. X(3872)

The Belle Collaboration at the KEK asymmetric e^+e^- collider has observed a new state in the decay $B \to XK$, with $X \to J/\Psi\pi\pi$ [1]. CDF has searched for this object by first selecting events with $J/\Psi \to \mu\mu$ using the dimuon trigger. Offline, the J/Ψ is paired with two opposite sign tracks assumed to be pions, and the $J/\Psi\pi\pi$ mass is calculated. With 220 inverse picobarns of data, the mass distribution exhibits a large peak at the $J/\Psi(2S)$ mass value and a small peak at 3872 MeV/c^2. See Fig. 9. The Belle data favored large $\pi\pi$ mass values. When the CDF $\pi\pi$ mass is required to be grater than 500 MeV/c^2, the background under the small peak is reduced by a factor two, while the number of events in the peak remains the same within statistical errors, Fig. 10. This supports the Belle observation that the signal favors high $\pi\pi$ masses. The CDF mass value is 3871.3 ± 0.7 (stat.) ± 0.4 (syst.) MeV/c^2.

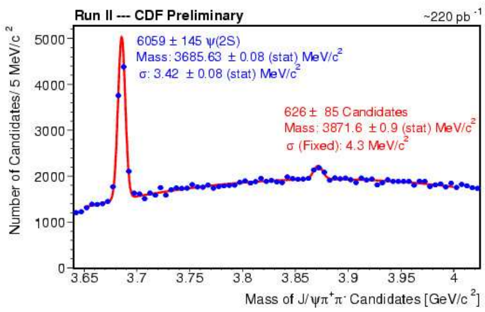

Fig. 9.

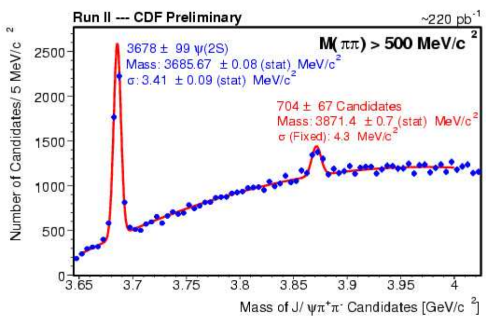

Fig. 10.

The 3872 might be another $c\bar{c}$ state, or possibly a $\bar{D}^*D$ "molecule" state, as suggested by Belle. The observed mass is within errors of the $\bar{D}^*D$ threshold and Belle has not yet seen a radiative decay that would be expected for a $c\bar{c}$ state.

5. Charm pentaquark?

Earlier, pentaquark states had been observed as resonances in n–K^+ [2] and K_s^0–p states at 1555 MeV/c^2. This is the θ^+ interpreted as $(ddu)(u\bar{s})$ state. The H1 Collaboration has now reported the observation of a narrow resonance in the $D^{-*}p$ and $D^{+*}\bar{p}$ channels at a mass of 3099 ± 3 (stat.) ± 5 (syst.) MeV/c^2 and with a width of 12 ± 3 (stat.) MeV/c^2. They interpret it as a state of two up and two down quarks and an anticharm quark (and the charge conjugate). ZEUS has not found it. CDF has searched for this object in the $D^{+*}\bar{p}$ channel with 240 pb^{-1} of data. Antiprotons were identified by ionization density for momenta greater than 2.75 GeV/c, Fig. 12, and by time-of-flight for momenta below that value, Fig. 11. No evidence of a peak in the mass distribution is seen. An upper limit (90% confidence level) of fewer than 29 events is obtained.

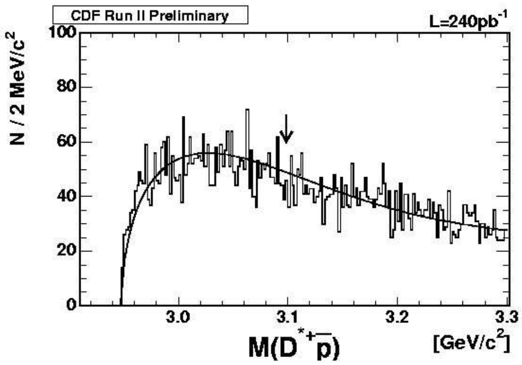

Fig. 11.

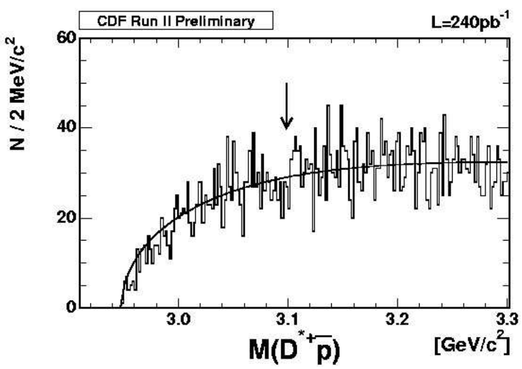

Fig. 12.

6. Photon plus displaced-vertex jet

Certain exotic particles may decay to a high-energy photon plus a jet. For example, a Techni-omega may decay to a photon plus a Techni-pion, with the Techni-pion producing two b jets. CDF searched 67 inverse picobarns of data for events with a photon of 25 GeV or greater energy and two jets, where one of the jets contained a secondary vertex (a displaced vertex). The invariant mass of the tracks forming the secondary vertex was then calculated and the mass distribution was plotted. Monte Carlo templates of QCD jet mass distributions (b jets, c jets and light quark jets) were fit to the observed distribution. The light quark (u, d, s) jets with apparent displaced vertices are fakes. Fluctuations due to finite resolution will sometimes give two or three tracks with a vertex displaced from the primary vertex. This does not happen often, but as the u, d, s jet cross section is larger than the heavy quark cross sections, some fake events are formed. Figure 13 shows the templates and Fig. 14 shows the data points and the fit (solid line).

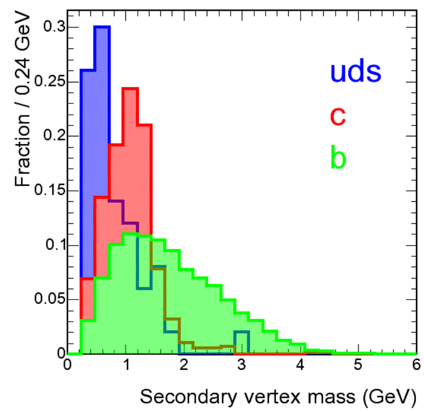

Fig. 13.

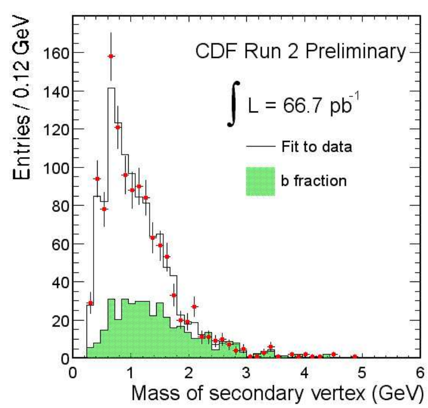

Fig. 14.

The b jet component of the fit is shown shaded. On the chance that a signal may be more clearly defined at a particular photon energy, the analysis was repeated for various photon energy selections. Figures 15 and 16 show separately the cross sections for photon plus charm jet and photon plus

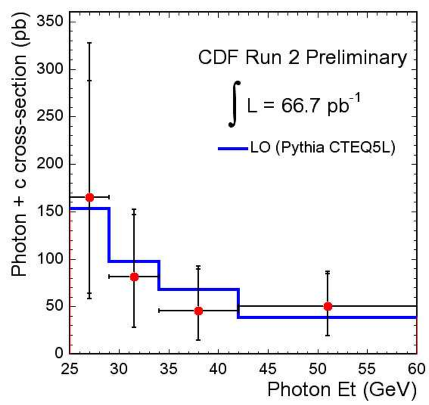

Fig. 15.

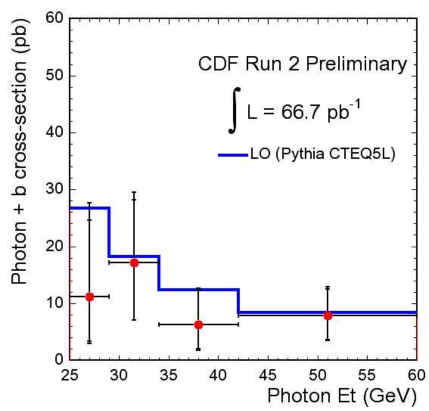

Fig. 16.

bottom jet respectively for various values of the transverse energy of the photon. No excess over Standard Model expectation is seen in any of the distributions. The cross section for b-jet plus photon is $40 + / - 19.5\ ^{+7.4}_{-7.8}$ pb and for c-jet plus photon is $486.2 + / - 152.9\ ^{+86.5}_{-90.9}$ pb.

7. Concluding remarks

It is clear that the Tevatron is a fine charm factory, and very good for beauty, too. The luminosity has been improving greatly each year, with a peak instantaneous luminosity of $1.03 \times 10^{+32}$ cm^{-2}sec^{-1} reached on July 16, 2004. The integrated luminosity acquired by CDF has grown with an increasing slope, as shown in Fig. 17. The studies described here, and others, will continue in the future. The triggers are great, the luminosity is looking good, and there is still a lot of charming physics to do.

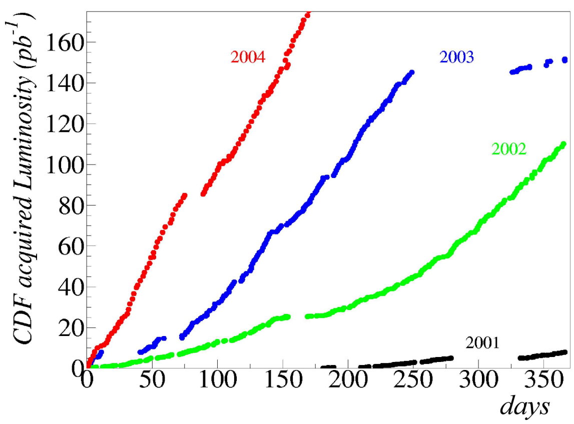

Fig. 17.

I thank the organizers for the excellent facilities and hospitality and the many CDF members who made the slides.

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