Fermi National Accelerator Laboratory

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t, b, and New Particle Searches at $p\bar{p}$ Colliders

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t, b, and New Particle Searches at $p\overline{p}$ Colliders

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Abstract

Experiments at the $p\bar{p}$ colliders at CERN and FNAL have an active program of heavy flavor physics. Recently, CDF at FNAL and UA1 at CERN have measured rare decays of the B meson, the b quark cross section, and $B^0 - \overline{B^0}$ mixing. CDF has signals for $B^{\pm} \rightarrow J/\psi K^{\pm}$ and $B^0 \rightarrow J/\psi K^{*0}$. Both CDF and UA1 have set limits on the branching ratio of $B^0 \rightarrow \mu^+\mu^-$ and have measured $B^0 - \overline{B^0}$ mixing. CDF, UA1 and UA2 at CERN have searched for the top quark and set limits on its mass. Prospects for t and b physics at FNAL in the near future are presented.

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1 Introduction

The $p\overline{p}$ colliders at CERN and FNAL have been very fruitful in producing physics. In addition to the electro-weak bosons discovered at CERN and confirmed with CDF at FNAL, both colliders have experiments that have actively pursued a program of heavy flavor physics. UA1 at CERN and CDF have measured many properties of b quarks. The experiments have searched for rare decays of the B meson, have measured b quark production and have measured $B^0 - \overline{B^0}$ mixing. UA1, UA2 at CERN and CDF have searched for the top quark and placed lower limits on its mass. There are plans for future runs of the Tevatron at FNAL that should allow discovery of the top quark with a mass of ≤ 250 GeV/c^2 by the end of the millennium.

2 Reconstructed B Mesons at CDF

The ability of CDF to do b physics in the $p\overline{p}$ collider environment is an unexpected success. Exclusive decays of the B meson have been reconstructed by CDF in the channels $B^{\pm} \rightarrow J/\psi K^{\pm}$ and $B^0 \rightarrow J/\psi K^{*0}$. These are the first fully reconstructed B decays at a $p\overline{p}$ collider.

The J/ψ is identified using its decay to $\mu^+\mu^-$. The di-muon trigger required two oppositely charged muon candidates with a p_T of at least 3 GeV/c for each muon candidate in the range $|\eta| < 0.6$ and a loose match between tracks in the Central Tracking Chamber (CTC) and the muon system. CDF collected 2.68 pb^{-1} of data using this trigger. The data selection additionally required that at least one of the muon candidates have a match in the azimuthal direction of ≤ 10 cm between a track in the CTC extrapolated to the muon chambers and hits in the four layer deep muon detection system. The final selection results in approximately 1100 J/ψ candidates in the mass range $3.05 - 3.14\,\mathrm{GeV}/c^2$. The $\mu^+\mu^-$ invariant mass distribution is shown in Figure 1.

The search for $B^{\pm} \rightarrow J/\psi K^{\pm}$ combines reconstructed J/ψ's with tracks that are assigned the K^+ mass. The $K^{\pm}$ candidate is required to have $p_T > 2.5$ GeV/c, to be within $|\eta| \leq 1.5$, and to be within a 60° cone centered on the J/ψ direction. The

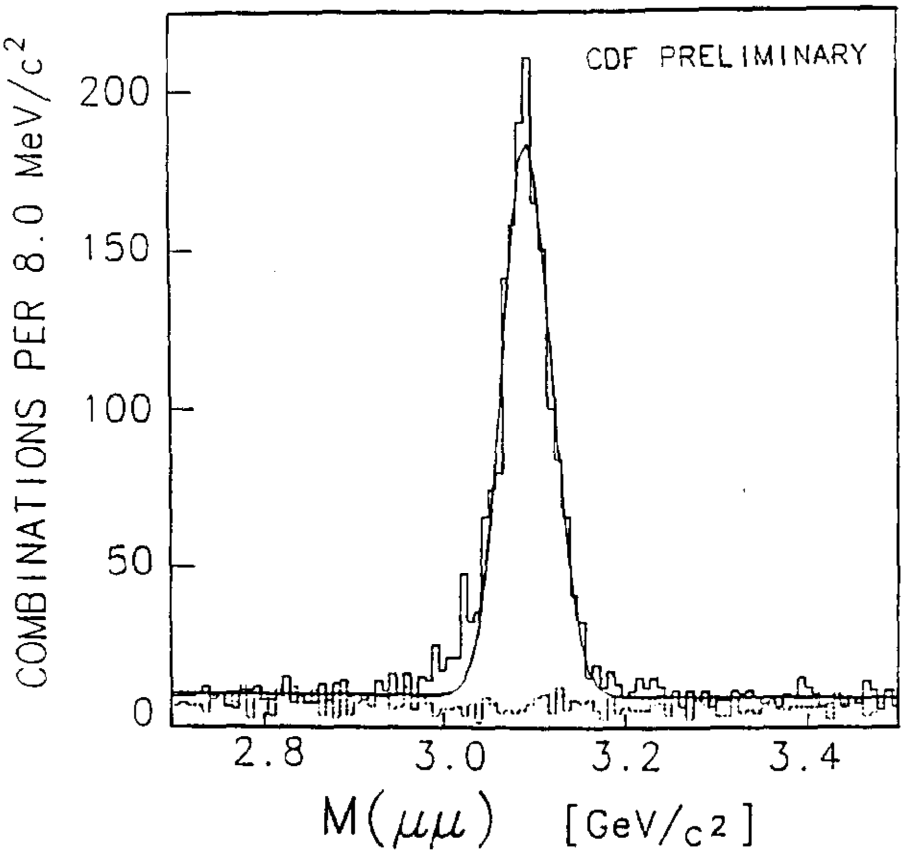

Figure 1: The $\mu^+\mu^-$ invariant mass distribution with a Gaussian fit to the J/ψ and the same sign $\mu\mu$ combinations plotted with the dotted line.

$\mu^+\mu^-$ combination is constrained to have the J/ψ mass of 3096 MeV/c^2. The preliminary $\mu^+\mu^-K^\pm$ invariant mass distribution is presented in Figure 2. There is a clear enhancement at the B with a fit mass of 5.279 $\pm$ 0.014 GeV/c^2.

The search for $B^0 \to J/\psi K^{*0}$ is affected by a large combinatorial background. For every pair of tracks, both $K\pi$ and πK mass assignments must be made in the attempt to identify $K^{*0} \to K^\pm\pi^\mp$ candidates. In order to reduce the combinatorial background, which is primarily due to low momentum tracks from the underlying event, only the three highest momentum tracks in a 60° cone centered on the J/ψ direction are used to search for K^{*0} candidates. Those pairs that have a $K\pi$ mass within $\pm$50 MeV/c^2 of the K^{*0} mass of 896 MeV/c^2 are retained as K^{*0} candidates. These candidates are combined with mass constrained J/ψ candidates to form the $J/\psi K^{*0}$ invariant mass distribution. Figure 3 shows the invariant mass distribution for the combined channels $B \to J/\psi K^\pm$ and $J/\psi K^{*0}$.

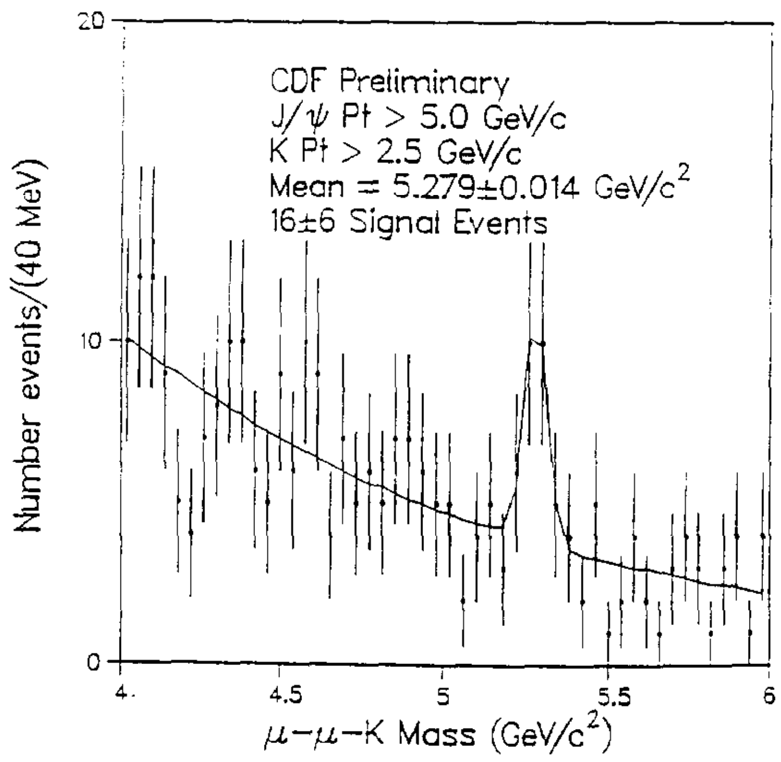

Figure 2: The $\mu^+\mu^-K^\pm$ invariant mass distribution with a $B^\pm$ signal of 16 ± 6 events.

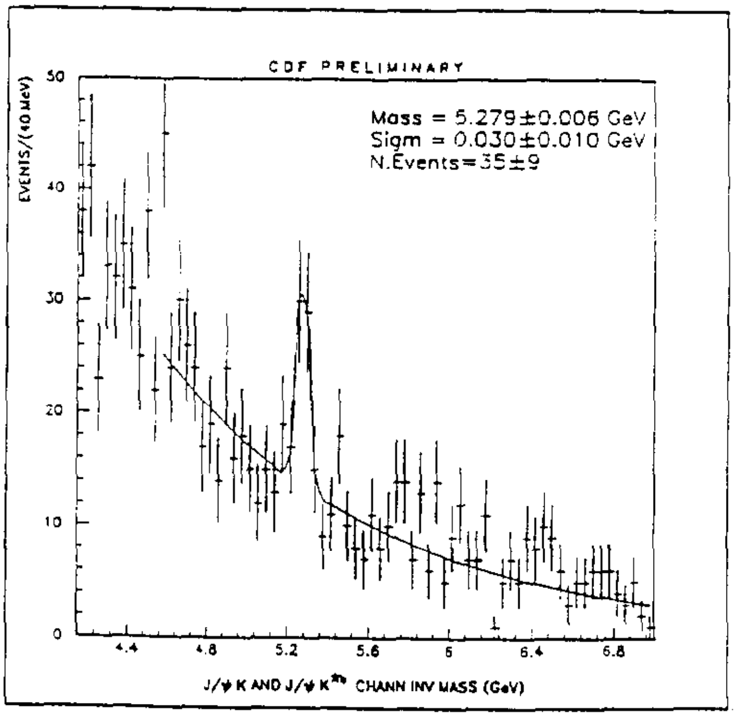

Figure 3: The sum of two decays modes, $B^0 \rightarrow J\psi K^{*0}$ and $B^\pm \rightarrow J/\psi K^\pm$, with a signal of 35 ± 9 events.

3 b Quark Cross Section Measurements

The b quark production cross section has been measured by UA1 for CERN energies.[1] The measurement agrees with the $O(\alpha^3)$ calculation of Nason, Dawson, and Ellis[2]. The b quark production cross section is measured by CDF using the exclusive decay $B^\pm \to J/\psi K^\pm$ and the inclusive electron sample.

The $J/\psi K^\pm$ sample described in Section 2 is used to measure the cross section, $\sigma(p\bar{p} \to bX)$. The b quark total cross section is determined using

$$\sigma = \frac{N_B}{2\epsilon \mathcal{L} BR(B^\pm \to J/\psi K^\pm) BR(J/\psi \to \mu^+\mu^-)}$$

where ϵ is the experimental efficiency, $\mathcal{L}$ is the integrated luminosity and N_B is the number of $B^\pm \to J/\psi K^\pm$ events. The experimental efficiency is determined by generating the $O(\alpha^3)$ shape of the Nason, Dawson, and Ellis b quark p_T spectrum, flat in rapidity, y, for the range $|y| < 1.0$. The probability that a $\bar{b}$ quark will fragment into a B^+ meson is measured to be 40% using the ISAJET Monte Carlo[3].

The b quark is then fragmented into a B meson using the Peterson model[4] to determine the fraction of the b quark energy E and momentum p that the B meson carries away. The meson energy E' and momentum p' are determined by

$$E' + p' = z(E + p)$$

where z is distributed using the Peterson fragmentation function

$$f(z) = \frac{z(1-z)^2}{((1-z)^2 + \epsilon z)^2}$$

with a mean value, determined from e^+e^- experiments[5], of

$$< z >= 0.83 \pm 0.01 \pm 0.02.$$

The polarization of the J/ψ in the decay $B^\pm \to J/\psi K^\pm$, the lifetime of the B, and the reconstruction efficiency of the event are all included in the detector simulation. The preliminary measured b quark production cross section for $p_T^b > 10$ GeV/c and $|y_b| < 1.0$ is $\sigma(p\bar{p} \to bX; p_T^b > 10\text{GeV/c}, |y^b| < 1) = 8.5 \pm 2.1 \pm 3.8 \mu b$, using the exclusive decays $B^\pm \to J/\psi K^\pm$.

The b quark production cross section is also measured by CDF using the inclusive electron sample. Two triggers define the sample, 4.4 pb^{-1} from a 12 GeV threshold and 180 nb^{-1} from a pre-scaled 7 GeV threshold. Electrons are identified in CDF using the finely segmented central calorimeter, the proportional gas chamber placed at shower maximum in the electromagnetic calorimeter (CES) and the CTC. Electrons are selected by requiring that

- the ratio of hadronic to electromagnetic energy deposition in the calorimeter, Had/Em < 0.04;
- only one track in the CTC points to the calorimeter cluster;
- the position in the CES must match the track extrapolated from the CTC and the shower shape must be compatible with measurements of single electrons in the test beam;
- the ratio of calorimeter energy to track momentum is in the range $0.75 < E/p < 1.40$.

Photon conversion electrons are removed from the sample by searching for a partner track to the candidate electron with a small opening angle. Electrons from W and Z decay are removed by requiring that the missing E_T in the event is less than $8\sqrt{E_T}$ and that the invariant mass of the candidate and a second electromagnetic cluster in the event is less than 80 GeV/c^2. Figure 4 shows the inclusive electron spectrum before and after removal of the contribution from W and Z decays along with the shape of the ISAJET electron p_T spectrum. The electron cross section is measured and needs to be related to the b quark cross section. The ISAJET Monte Carlo, with lowest order processes only, is used to get the electron to b quark relationship. The decay of $B_{u,d}$ mesons is described by the CLEO Monte Carlo[6] and the decay of other B hadrons is described by ISAJET. CDF uses the method of UA1[7] to extract the b quark cross section from the decay electron cross section by relating them over kinematic ranges using Monte Carlo,

$$\sigma_b(\text{data}) = \sigma_e(\text{data})\frac{\sigma_b(\text{MC})}{\sigma_e(\text{MC})}.$$

Three p_T intervals are chosen for the electrons, 10-15, 15-20 and 20-25 GeV/c, corresponding to b quark p_T thresholds of 15, 23 and 32 GeV/c, respectively.

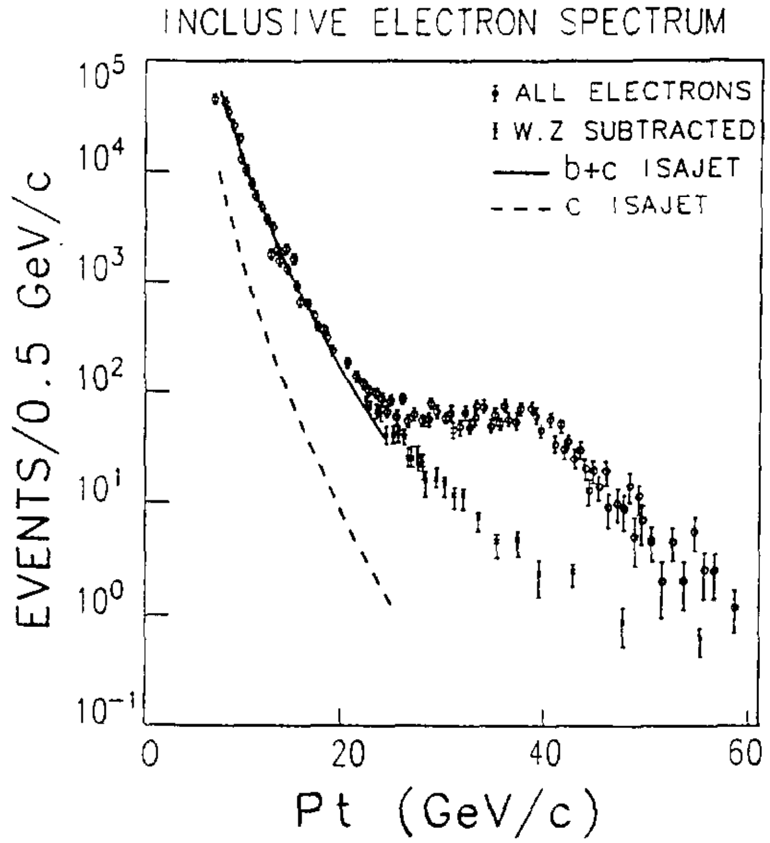

Figure 4: The CDF inclusive electron spectrum from 4.1 pb^{-1} of data. All electrons are shown by circles, electrons after W and Z subtraction are shown by points and an ISAJET prediction that is arbitrarily normalized is shown by a solid line for b and c quark production and by a dashed line for c production only.

The electrons from sequential decays, $b \to e\nu_e c$, and direct production of $c\bar{c}$ are an important background in the electron sample. The contribution of these processes is estimated to be 10% from the ISAJET Monte Carlo. A check of the ISAJET prediction is performed by looking for associated charm from $B \to e\nu_e D^0 X; D^0 \to K\pi$. Figure 5 shows the $D^0 \to K\pi$ peak from the electron sample. If the $e - D^0$ rate were from direct production of $c\bar{c}$ pairs, the rates of K^{*0} and $\overline{K^{*0}}$ would be roughly equal. Examination of Figure 6 indicates that there is a significant excess of the right sign $K\pi$ combination from b decay, $b \to e^- \nu_e \overline{K^{*0}} X; \overline{K^{*0}} \to K^- \pi^+$ compared to the wrong sign, $e^- K^{*0}$. The observed D^0 rate agrees with the ISAJET prediction and indicates that roughly 75% of the inclusive electron sample is from semileptonic b decay.

The semileptonic branching ratio of the B hadrons is taken to be 10.3% and the Peterson fragmentation function is as described above. The b quark cross section for

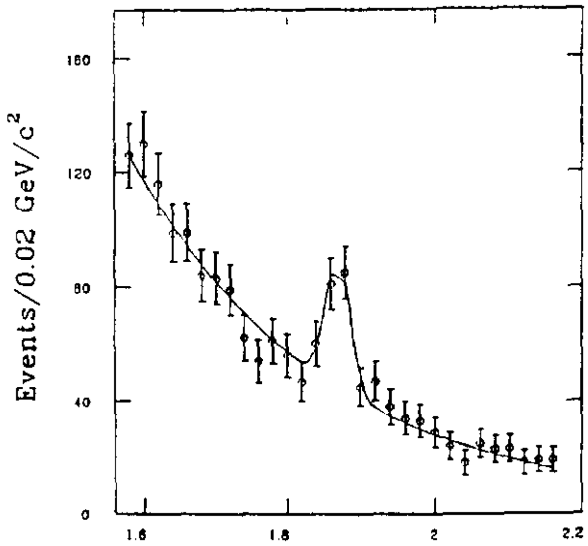

Figure 5: Two particle mass combinations assuming $K-\pi$ masses for tracks within an $\eta-\phi$ cone of 0.6 around the electron candidate. Kaon candidates are required to have the same charge as the electron and have $p_T > 1.5$ GeV/c.

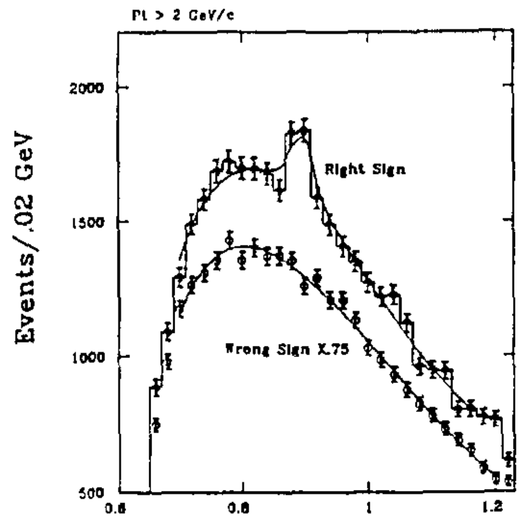

Figure 6: $K-\pi$ mass spectra in the $K^{*0}(890)$ region for 'right sign' combinations from b decay ($e^-\overline{K^{*0}}$) and for 'wrong sign' (e^-K^{*0}) combinations, scaled by 0.75.

the three kinematic regions is

$$\sigma(p\overline{p} \to bX; p_T < 15\text{GeV/c}, |y^b| < 1) = 1220 \pm 390\, nb;$$

$$\sigma(p\overline{p} \to bX; p_T < 23\text{GeV/c}, |y^b| < 1) = 220 \pm 70\, nb;$$

$$\sigma(p\overline{p} \to bX; p_T < 32\text{GeV/c}, |y^b| < 1) = 56 \pm 18\, nb.$$

The result is compared to the Nason, Dawson and Ellis calculation and the measurement from the decay $B^\pm \to J/\psi K^\pm$ in Figure 7.

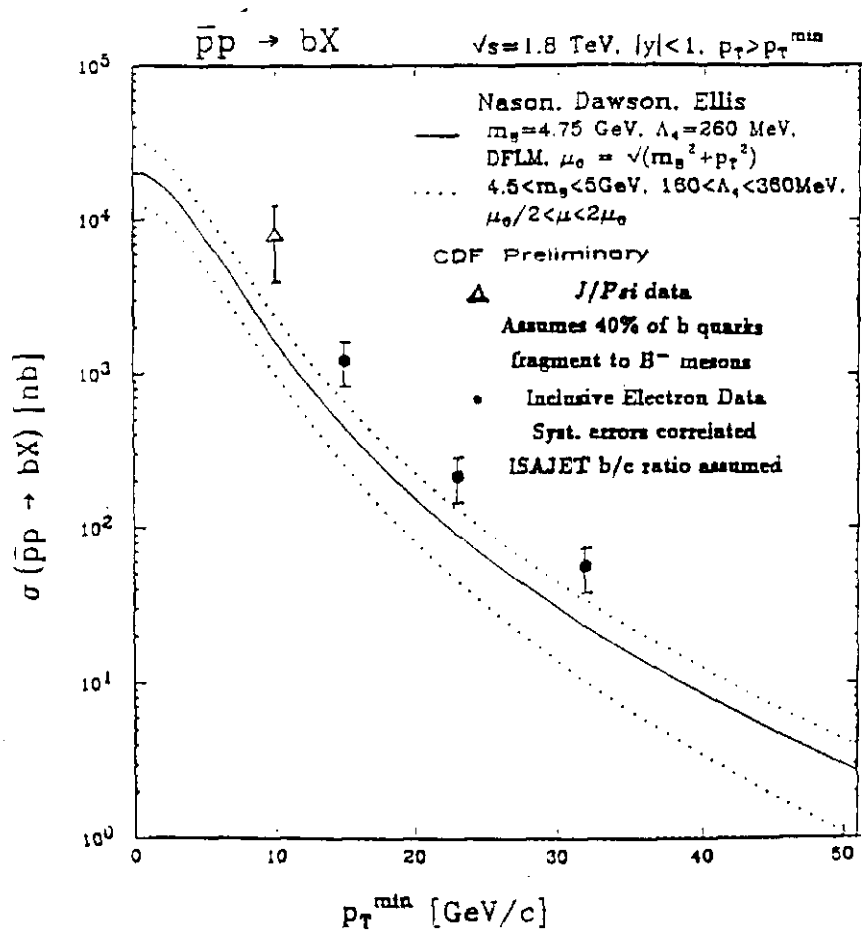

Figure 7: The b quark cross section measured as a function of b quark p_T from the inclusive electron yield (points) and from the exclusive decay rate of $B^\pm \rightarrow J/\psi K^\pm$ (triangle).

4 $B^0 \rightarrow \mu^+\mu^-$ Limits

Both UA1 and CDF have conducted searches for the flavor changing neutral current rare decay $B^0 \rightarrow \mu^+\mu^-$. Examples of diagrams that contribute to this decay are shown in Figure 8.

UA1 searches for evidence of a mass peak in the region 5.1 GeV/c^2 $< M_{\mu\mu} <$ 5.5 GeV/c^2. Each μ must have $p_T >$ 3 GeV/c and be within the range $|\eta| < 2.3$. The combined $p_T^{\mu\mu}$ must be greater than 7 GeV/c for the greatest sensitivity to a signal. In order to place an upper limit on the rare decay, the production cross section, detection efficiency and background must be determined. The measured cross section by UA1[7]

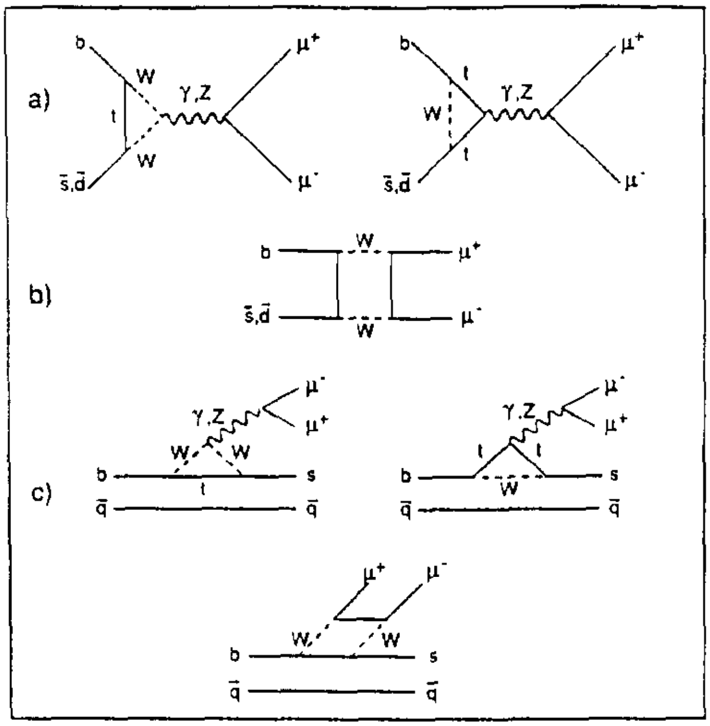

Figure 8: Examples of diagrams that contribute to the rare decay $B^0 \to \mu^+\mu^-$.

is used in the ISAJET Monte Carlo to generate decays of the B_d^0 and B_s^0 mesons into muon pairs with the assumption that the B_d^0 : B_s^0 ratio is 2:1. The B^+ : B_d^0 ratio and the baryon fraction are assumed to be 1:1 and 10%, respectively. After a detailed detector simulation, the efficiency is determined to be $4.0 \pm 0.8\%$. The background is determined from a fit to the data, excluding the $B^0 \to \mu^+\mu^-$ search region. The estimated background is 5.0 ± 1.0 events. There are 6 events in the search region. The 90% confidence level (C.L.) limit on the branching ratio for B_d^0 and B_s^0 to two muons is

$$BR(B^0 \to \mu^+\mu^-) < 8.3 \times 10^{-6}.$$

Assuming that 36% (18%) of $\bar{b}$ quarks become $B_d^0(B_s^0)$ mesons, the $BR(B_d^0 \to \mu^+\mu^-) < 1.2 \times 10^{-5}$ and $BR(B_s^0 \to \mu^+\mu^-) < 2.5 \times 10^{-5}$ at the 90% C.L..

CDF uses the observed decay $B^\pm \to J/\psi K^\pm$ and the Monte Carlo described in

Section 2 to determine the efficiency, $\epsilon_{\mu\mu}$, for observing $B^0 \to \mu^+\mu^-$:

$$\epsilon_{\mu\mu} = \frac{\epsilon(B^0 \to \mu^+\mu^-)}{\epsilon(B^+ \to J/\psi K^+ \to \mu^+\mu^- K^+)} = 7.788.$$

The branching ratio for $B^0 \to \mu^+\mu^-$ can be expressed as

$$BR(B^0 \to \mu^+\mu^-) = \frac{N(B^0 \to \mu^+\mu^-)}{N(B^+ \to J/\psi K^+ \to \mu^+\mu^- K^+)} \cdot \epsilon_{\mu\mu} \cdot BR(B^+ \to J/\psi K^+ \to \mu^+\mu^- K^+).$$

The rate of B_d^0 production is assumed to be twice the rate of B_s^0 production. The observed $\mu^+\mu^-$ invariant mass distribution is shown in Figure 9.

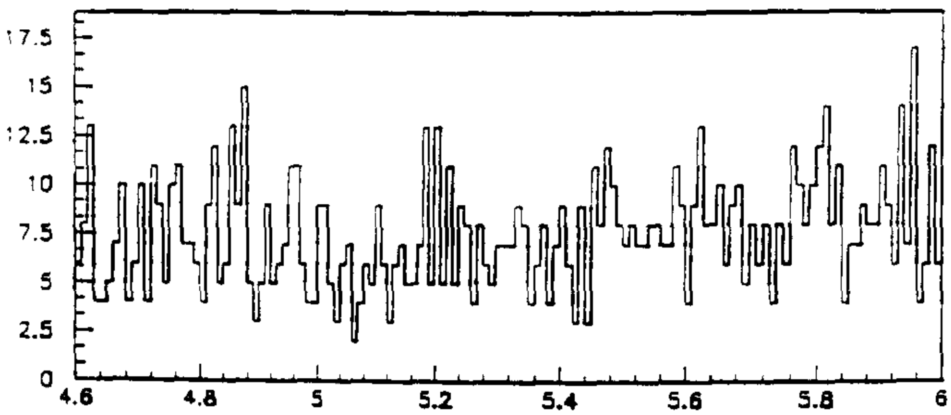

Figure 9: The dimuon invariant mass from CDF with $p_T^\mu > 3$ GeV/c.

A binned log-likelihood method is used to fit for the separate branching ratios of B_d^0 and B_s^0 to muons. The preliminary results are $BR(B_d^0 \to \mu^+\mu^-) < 3.3 \times 10^{-6}$ and $BR(B_s^0 \to \mu^+\mu^-) < 6.0 \times 10^{-6}$.

5 $B^0 - \overline{B^0}$ Mixing

Mixing in the B^0 system that is analogous to that for K^0's is averaged over B_d^0 and B_s^0 at $p\overline{p}$ colliders, while only B_d^0 mixing is measured at CLEO and ARGUS. The parameter χ is used to describe $B^0 - \overline{B^0}$ mixing, where

$$\chi = \frac{BR(B^0 \to \overline{B^0} \to l^-\nu X)}{BR(B^0 \to l^+\nu X) + BR(B^0 \to \overline{B}^0 \to l^-\nu X)} \equiv f_d\chi_d + f_s\chi_s.$$

The UA1 experiment has analyzed additional data and combined the new results with the first observation of mixing in the $B^0 - \overline{B^0}$ system[8]. The $\mu\mu$ channel with an integrated luminosity of 4.7 pb^{-1} is used to measure mixing.[9] The muons for the data sample must have a $P_T > 3$ GeV/c. Requiring the di-muon mass, $M_{\mu\mu} > 6$ GeV/c^2, removes muons that originate from low mass mesons such as the J/ψ and from b sequential decay ($b \to \mu^- \overline{\nu} c; c \to \mu^+ \nu s$). The muons are required to be non-isolated in order to remove Drell-Yan and $\Upsilon \to \mu^+\mu^-$ decays and to allow definition of P_T^{rel}, the P_T of the muon relative to associated jet activity. The associated jet must have at least one track with $P_T > 1$ GeV/c and its axis must lie within a cone of $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 1.0$ around the muon track. Each muon must have $P_T < 20$ GeV/c in order to remove sign ambiguities and $P_T^{rel} < 3$ GeV/c, because the $b\overline{b}$ contribution to the sample is negligible above this value.[10]

The processes that contribute to the like sign and opposite sign samples are

- Both B^0 and $\overline{B^0}$ decay directly into leptons. For the case of no mixing, this contributes to the opposite sign sample by $\overline{b} \to l^+\nu\overline{c}$ and $b \to l^-\overline{\nu}c$. If there is mixing, this will contribute to the like sign sample.

- Second generation $b\overline{b}$ decays where one b decays directly to a lepton and the other decays to a c quark that then decays to a lepton. For no mixing, this contributes to the opposite sign sample by $\overline{b} \to l^+\nu\overline{c}; b \to cX$ and $c \to l^+\nu s$. With mixing, this decay will contribute to the opposite sign sample.

- Opposite sign leptons also result from $c\overline{c}$ production and decay.

The ISAJET Monte Carlo is used to determine the shape of P_T^{rel} distributions for the signal and background. An event by event log-likelihood fit of the P_T^{rel} distributions is used to determine the number of $b\overline{b}$ events in the like and opposite sign samples. Figure 10 shows the distributions for P_T^{rel}. The larger P_T^{rel} values have the most contribution for $b\overline{b}$ direct decays. The value of χ is determined from the fitted number of events in each process to be

$$\chi = 0.145 \pm 0.035(\text{stat}) \pm 0.014(\text{syst}).$$

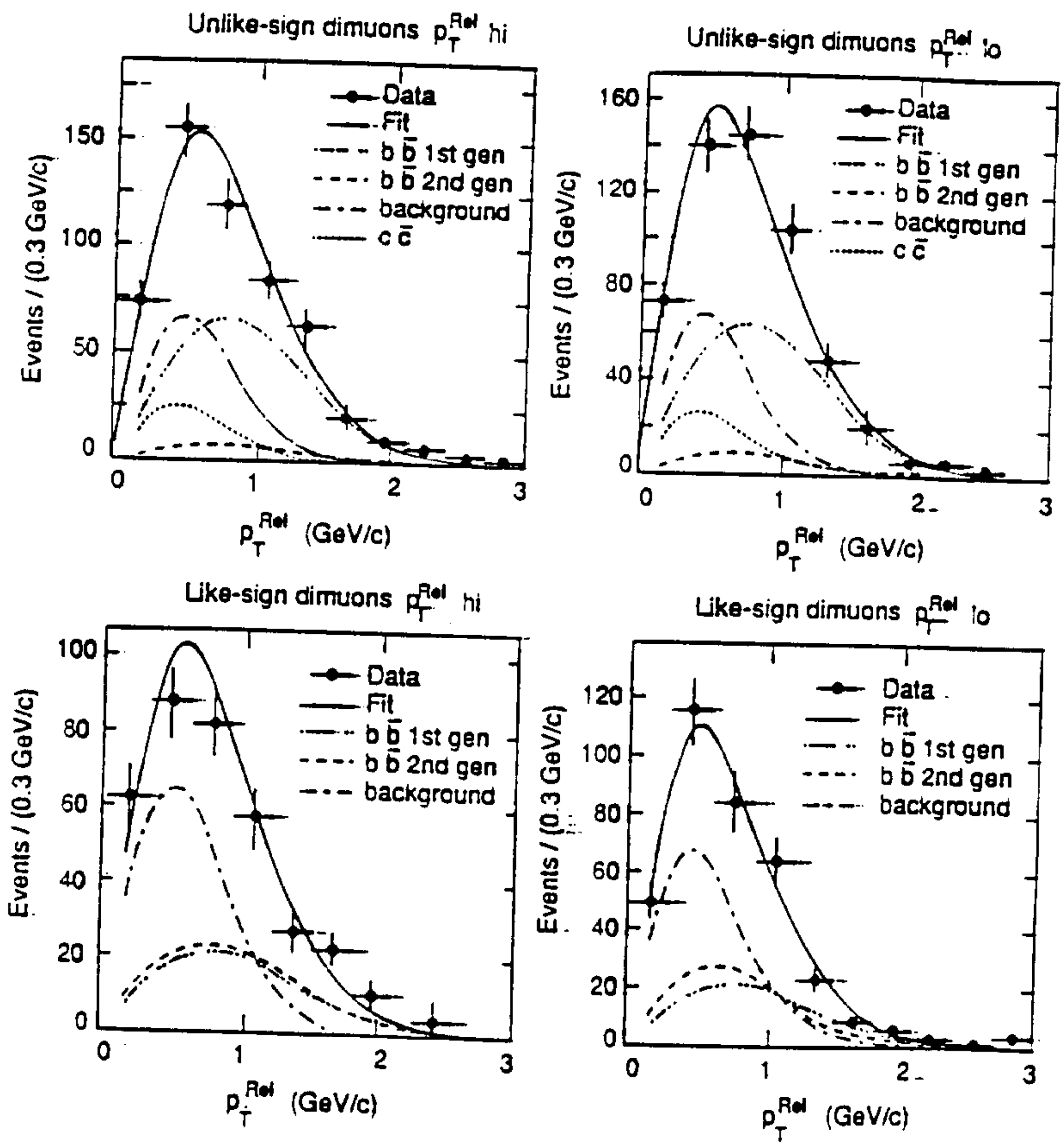

Figure 10: The p_T^{rel} distributions for the UA1 dimuon sample.

The earlier measurement by UA1 was $\chi = 0.158 \pm 0.052 \pm 0.026$ using 0.7 pb^{-1} of data. The combined measurement with full correlation of the systematic uncertainties is

$$\chi = 0.148 \pm 0.029 \pm 0.017.$$

This measurement results in a lower limit on the value of $\chi_s > 0.17$ at the 90% C.L. when combined with the ARGUS and CLEO measurements of χ_d.

The CDF experiment measures $B^0 - \overline{B^0}$ mixing using electron - muon events.[11] There is no background from Drell-Yan or J/ψ and Υ mesons, but the contributions from other processes must still be considered. The ratio

$$R = \frac{N(e^+\mu^+) + N(e^-\mu^-)}{N(e^+\mu^-) + N(e^-\mu^+)}$$

is the measured quantity. The electron candidates are required to have $P_T^e > 5$ GeV/c and the muon candidates are required to have $P_T^\mu > 3$ GeV/c with similar criteria to that described above. Additional criteria for the rejection of hadrons mis-identified as leptons are described in the literature.[12] An additional requirement that the invariant mass of the di-leptons, $M_{e\mu} > 5$ GeV/c^2, removes a background in the opposite sign sample from $B \rightarrow e^+\nu_e\bar{c} \rightarrow e^+\nu_e\mu^-\overline{\nu_\mu s}$.

The ratio of like sign to opposite sign $e\mu$ events is

$$R = 0.556 \pm 0.048(\text{stat})^{+0.035}_{-0.042}(\text{syst}).$$

The expected value of R in the absence of mixing is $R = 0.23 \pm 0.06$. The ratio of $c\bar{c}/b\bar{b}$ production is determined from the ISAJET Monte Carlo. The ratio is necessary in order to relate R to χ. An additional uncertainty is quoted in the value of χ that is an estimate of the uncertainty for determining the $c\bar{c}/b\bar{b}$ production ratio. From the observed value of R,

$$\chi = 0.179 \pm 0.027(\text{stat}) \pm 0.022(\text{syst}) \pm 0.032(\text{MonteCarlo}).$$

Figure 11 shows a comparison of the data and a Monte Carlo that has mixing at the level measured by CDF along with the background. The agreement between the data and Monte Carlo is quite good. Figure 12 presents the CDF measurement in the $\chi_d - \chi_s$ plane along with the combined ARGUS and CLEO results and the prediction of the Standard Model. The measurements of $B^0 - \overline{B^0}$ mixing made by UA1 and CDF are consistent with each other and indicate $B_s^0 - \overline{B_s^0}$ mixing exists.

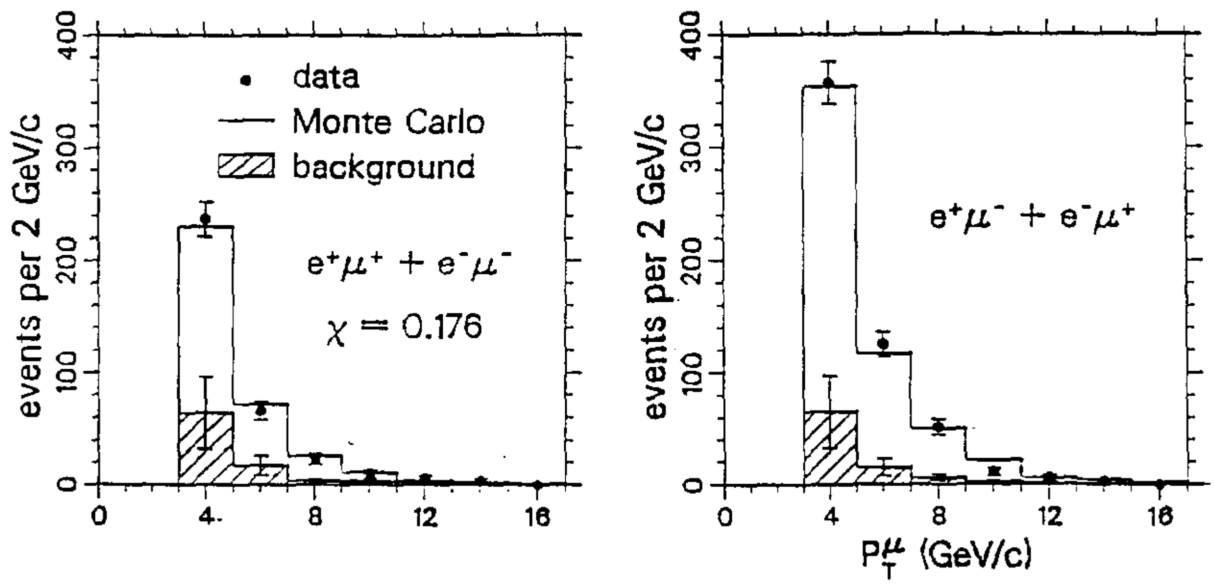

Figure 11: Muon p_T spectra for the data and the Monte Carlo with the observed mixing, including background, for like sign and opposite sign $e\mu$ events.

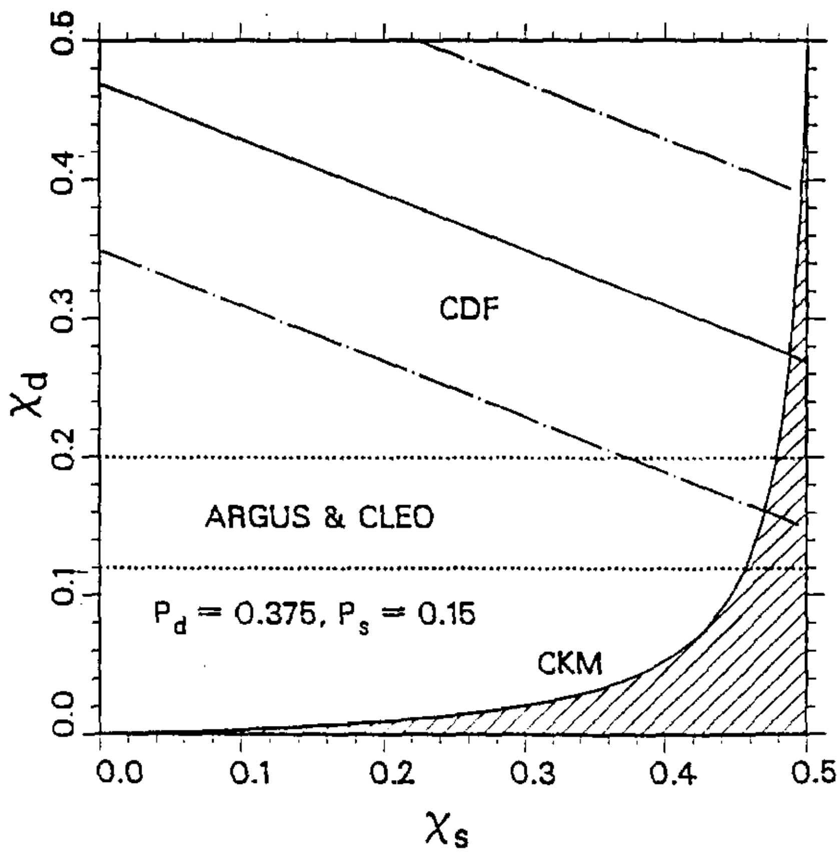

Figure 12: The mixing probability of B_d^0 versus that of B_s^0. The χ_d range is the ARGUS and CLEO combined result of 0.16 ± 0.04.

6 New Particle Searches

Searches for heavy W (W') and heavy Z (Z') bosons have recently been completed by CDF. The W' analysis requires one good electron with $E_T > 30$ GeV and missing $E_T > 30$ GeV. The transverse mass is formed and compared to a Monte Carlo calculation that includes the width of the W and the detector resolution and acceptance. The spectrum is in excellent agreement with the expectation from W alone with no contribution from the W'. The W' cross section depends mildly on the width of W', $\Gamma_{W'}$. The width is assumed to increase linearly with the mass of the W', $M_{W'}$.

The calculation for the measured 95% C.L. limit assumes that a very heavy W' has the top channel open to it so the branching ratio to $e\nu$ is taken to be 1/12. The combined limit from the $e\nu$ and $\mu\nu$ channels crosses the predicted cross section with standard couplings at a value of $M_{W'} = 520$ GeV, so the 95% C.L. is $M_{W'} > 520$ GeV with standard strength couplings.

The search for Z' requires one good electron in the central calorimeter with $E_T > 15$ GeV and another electron in the central or plug calorimeter with $E_T > 7$ GeV or a track with $p_T > 20$ GeV/c in the CTC. The invariant mass distribution is in excellent agreement with an order α_s Drell-Yan calculation. The 95% C.L. limit for $M_{Z'}$ from e^+e^- pairs with the same assumptions as above is $M_{Z'} > 380$ GeV. A similar analysis with muons, requiring that both muons have $p_T > 20$ GeV, results in a limit $M_{Z'} > 320$ GeV.

7 Top Quark Limits

Various measurements of b quark production and decay provide evidence for the existence of the top quark. The unobserved flavor changing neutral current decays of the b quark rules out most models without a top quark.[13] The standard model weak isodoublet couplings for the b quark has been verified with a measurement of the forward-backward asymmetry for the process $e^+e^- \rightarrow b\bar{b}$, implying a top quark as an isospin partner of the b quark.[14] The level of mixing measured in the B_d^0 system is inconsistent with the b quark being an SU(2) singlet.[15] Direct searches for the top quark have taken place at e^+e^- and $p\bar{p}$ colliders.

The limit for the mass of the top quark is $M_{top} > 44.5$ GeV/c^2 from e^+e^- colliders[16], $M_{top} > 69$ GeV/c^2 from UA2[17] and $M_{top} > 89$ GeV/c^2 from CDF. The M_{top} limit from CDF has increased from the published limit[18], $M_{top} > 77$ GeV/c^2, by combining the $e\mu$, ee, and $\mu\mu$ dilepton channels. Since this led to a limit greater than the $W^\pm$ mass, a search for a low p_T muon from the b quark in the decay $t \to Wb$ is done in the $\mu\mu$ sample. The upper limit for the $t\bar{t}$ production cross section as a function of top mass from each analysis is shown in Figure 13. The region above the curves is excluded at 95% C.L. Also shown in Figure 13 is a band including the uncertainties of the calculation of the $t\bar{t}$ production cross section by Altarelli *et al.*[19] based on the $O(\alpha_s^3)$ cross section formulas of Nason, Dawson, and Ellis[2]. The lower limit for M_{top} is determined from where the upper limit for the cross section intersects the lower band of uncertainty for the calculated cross section.

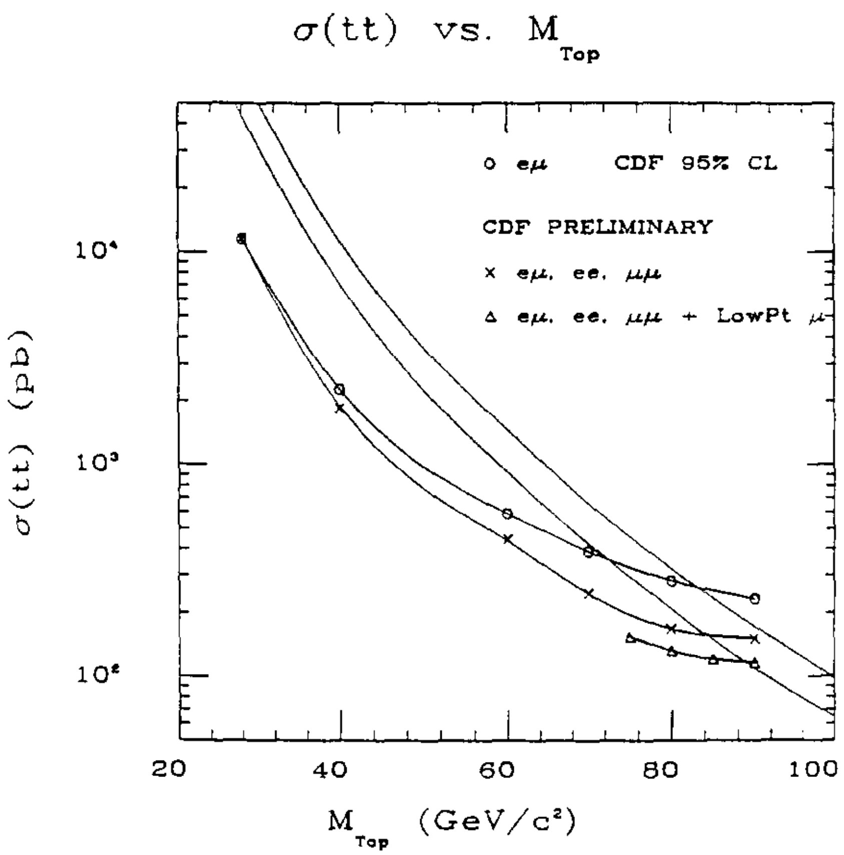

Figure 13: The measured 95% C.L. upper limits on the $t\bar{t}$ production cross section for CDF di-lepton channels compared to the theoretical calculation with its uncertainty.

8 Prospects for b and t at FNAL

Both CDF and D0 will be taking data during the next FNAL collider run. The improvement in shielding at the laboratory has been completed and low intensity operation of the Tevatron commenced on June 21. The unofficial schedule for Fermilab has a five month fixed target run beginning in July and lasting until December. There will be about two months to install low β quadrupoles at D0; finish installation of separators in the Tevatron; complete other accelerator work; and to roll CDF and D0 into their collision halls. The 1992 collider run, designated Run 1A, should begin in March and last until 20-25 pb^{-1} has been delivered. This is expected to occur in September, 1992. It is then planned to upgrade the linac and, possibly, to install equipment that will allow the Tevatron to run at a center of mass energy of 2 TeV. Barring any unforseen difficulties, the 1993 collider run, designated Run 1B, should begin in February of 1993 and last until 50-75 pb^{-1} has been delivered. So by 1994 CDF and D0 may collect between 70 and 100 pb^{-1}.

With 100 pb^{-1} and planned upgrades to CDF, such as the new Silicon Vertex Detector (SVX), a muon system extension to cover $|\eta| < 1$, and improvements to the trigger, CDF expects to be able to do extensive b physics. Using CDF's measured b cross section, it is expected that there will be approximately 350,000 J/ψ's, approximately 3,000,000 semi-leptonic b decays, hundreds of $B_s^0 \rightarrow J/\psi\phi$ and approximately 100 $\Lambda_b \rightarrow J/\psi\Lambda$ written to tape. It may be possible to discover the B_c mesons. CDF should be able to measure the production ratio of B_s/B_d, measure B lifetimes, study rare decay modes and exploit the huge semi-leptonic b decay sample.

The search for top will be extended to higher masses as more data are available. Figure 14 shows the expected top mass reach for planned future collider runs. The 95% C.L. limit is shown for the number of $t\bar{t}$ events that decay to dileptons, ee, $e\mu$ and $\mu\mu$. The curves are a calculation by Eichten[20] and include changes in CDF acceptance and efficiency due to planned upgrades and for the expected change in Tevatron energy from 1.8 TeV to 2.0 TeV. The curves do not include $t\bar{t}$ decays to a lepton plus jets, which should extend the mass reach farther than shown.

Precision measurements of the Z^0 from the experiments at LEP[21] indicate that the top quark mass is in the range $M_{top} = 155 \pm 40$ GeV/c^2. This result assumes that the top has minimal standard model decays. An examination of Figure 14 indicates that for standard model top decays, the experiments at Fermilab have an excellent chance of discovering top by the end of the century.

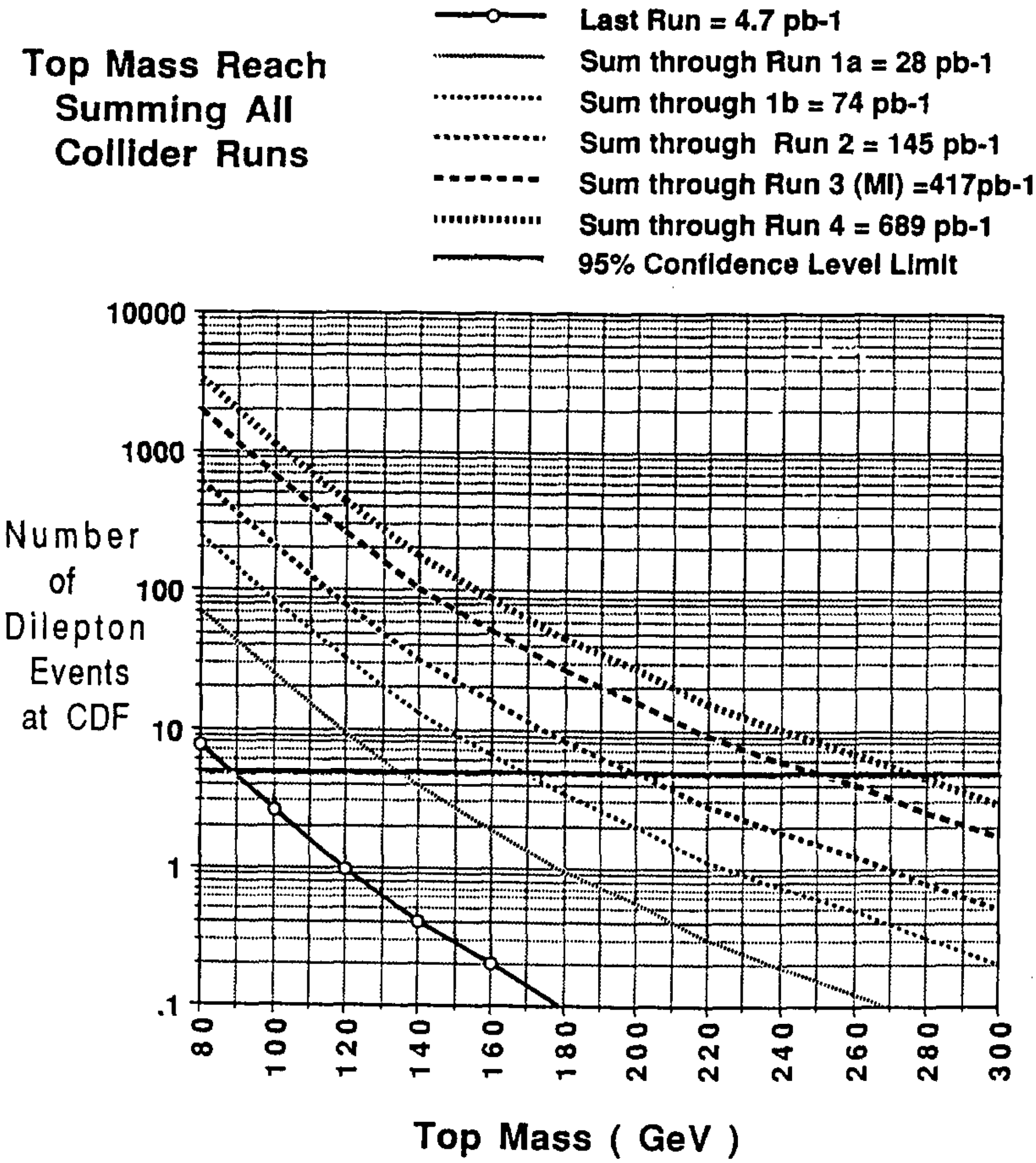

Figure 14: The expected top mass reach at CDF summing all planned collider runs versus the number of observed $t\bar{t} \to l^{\pm}l^{\mp}$.

9 Conclusions

The experiments at $p\overline{p}$ colliders have impressive results in heavy flavor physics. The potential for future discoveries is quite good for CDF and D0 at Fermilab, both in b physics and for discovering and studying the top quark.

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