ELECTROWEAK TESTS AND SEARCHES FOR NEW PHENOMENA FROM THE TEVATRON

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Representing the DØ and CDF Collaborations

ABSTRACT

Recent results in precision electroweak measurements and searches for new phenomena from the DØ and CDF experiments at the Fermilab Tevatron collider are reviewed.

1 Introduction

The Fermilab Tevatron $\overline{p}p$ collider, the world's highest energy accelerator (1.8 TeV), has recently completed a very successful run. Here we review results from the two major collider experiments, CDF and DØ, in the areas of electroweak measurements and precision tests of the Standard Model (SM), and searches for new phenomena beyond the SM.

In the period 1992-1996 the Tevatron delivered an integrated luminosity to both experiments of ≈ 130 pb^{-1}. The run was divided into two distinct running periods - ≈ 20 pb^{-1} was delivered in 1992-93 (referred to as run 1A), and ≈ 110 pb^{-1} in 1994-96 (run 1B). Most (but not all) results from run 1A given here have been previously published, while most run 1B results are preliminary.

The two detectors are both general purpose collider detectors. The CDF detector[1] features a superconducting solenoid, tracking system consisting of a central drift chamber and silicon strip vertex detector, scintillator and gas-based calorimetry, and muon detectors. The DØ detector[2] includes central tracking chambers (without magnetic field), a uranium/liquid argon calorimeter, and magnetized iron toroids and drift tubes for muon detection. Both detectors provide excellent measurement of leptons, jets and missing energy.

The large data sample now available provides considerably higher precision in tests of the SM, and significantly higher reach in searches for new particles and processes than previous experiments. In this paper we present a selection of results - measurements of production properties of W and Z bosons, determination of the W mass, results of searches for diboson final states, and searches for a zoo of non-standard particles.

2 W and Z Production Properties

Production properties of W and Z bosons provide stringent tests of the SM, and constraints on parton distribution functions (pdf's). Here we review measurements of W and Z cross-sections, determinations of the W width, and charge asymmetries in W and Z production and decay.

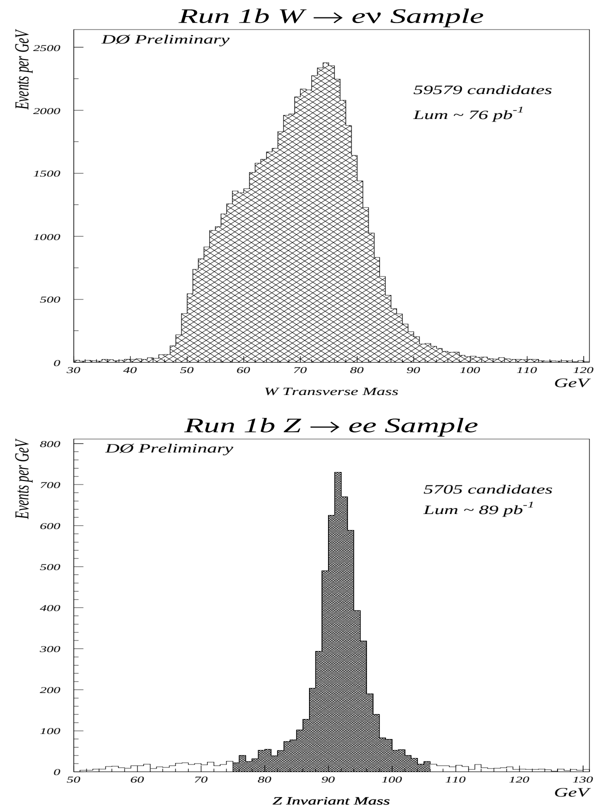

Figure 1: W and Z distributions

2.1 W and Z Production Cross-sections

W and Z bosons are identified in hadron collider experiments through their leptonic decays. The signature for a $W \rightarrow l\nu$ decay is a high p_T lepton (electron or muon) together with a large missing missing transverse energy ($\not{E}_T$), signalling a high p_T neutrino. $Z \rightarrow l^+l^-$ decays are detected by reconstructing the invariant mass of lepton pairs. The main backgrounds to these signals come from QCD multijet production (where one or more jet fakes an electron), cosmic rays (for muon channels), and W and Z decays to final states containing τ leptons. Figure 1 shows the distribution in transverse mass

$$M_T = \sqrt{2E_T^l \not{E}_T (1 - cos\Delta\phi)}$$

for $W \rightarrow e\nu$ candidates, and the invariant mass distribution of $Z \rightarrow ee$ candidates from DØ.

Measured values of the W and Z cross-sections are shown in figure 2: published run 1A results and preliminary run (1A+1B) results for both electron and muon

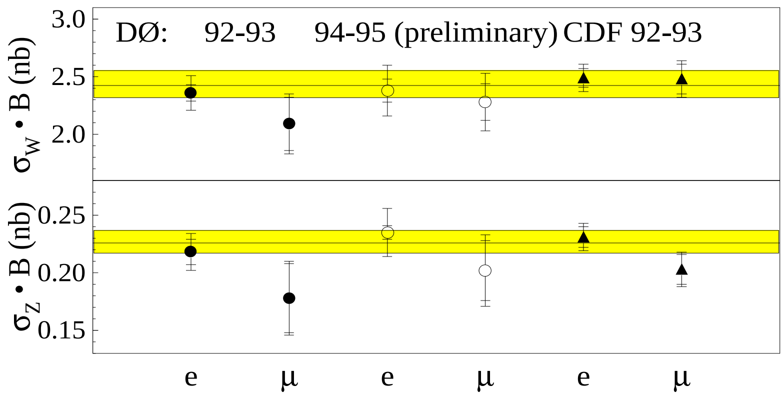

Figure 2: Measurements of W and Z cross-sections

channels from DØ,[3] and published run 1A electron results and preliminary run 1A muon results from CDF.[4] The shaded band shows the prediction of an order α^2 calculation.[5,6] CDF measures

$$\sigma_W \cdot B(W \rightarrow e\nu) = 2.49 \pm 0.02(stat) \pm 0.08(sys) \pm 0.09(lum)\ nb$$

$$\sigma_Z \cdot B(Z \rightarrow e^+e^-) = 0.231 \pm 0.006(stat) \pm 0.007(sys) \pm 0.008(lum)\ nb$$

DØ reports

$$\sigma_W \cdot B(W \rightarrow e\nu) = 2.38 \pm 0.01(stat) \pm 0.09(sys) \pm 0.20(lum)\ nb$$

$$\sigma_Z \cdot B(Z \rightarrow e^+e^-) = 0.235 \pm 0.003(stat) \pm 0.005(sys) \pm 0.020(lum)\ nb$$

$$\sigma_W \cdot B(W \rightarrow \mu\nu) = 2.28 \pm 0.04(stat) \pm 0.16(sys) \pm 0.19(lum)\ nb$$

$$\sigma_Z \cdot B(Z \rightarrow \mu^+\mu^-) = 0.202 \pm 0.016(stat) \pm 0.020(sys) \pm 0.017(lum)\ nb$$

2.2 Indirect and Direct Determinations of Γ_W

The measurements of the W and Z cross-sections can be combined to determine the ratio

$$R = \frac{\sigma_W \cdot B(W \rightarrow l\nu)}{\sigma_Z \cdot B(Z \rightarrow l^+l^-)}$$

Many systematic errors in the individual measurements cancel, at least partially, in the ratio. In particular errors in luminosity cancel completely. Figure 3 shows the R value as determined in several measurements, both by the Fermilab experiments, and by UA1 and UA2 at the CERN collider.

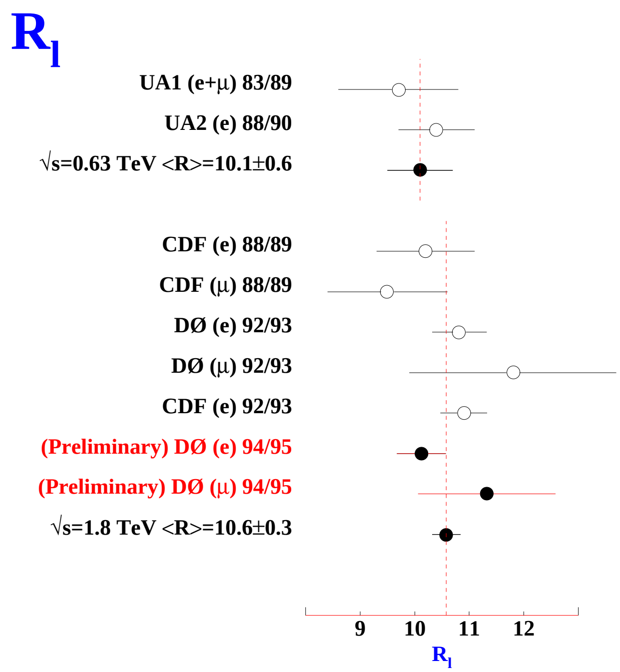

Figure 3: Measurements of R

The cross-section ratio can be used to indirectly determine the width of the W. Using theoretical predicted values[6,7] for $\sigma_W/\sigma_Z = 3.33 \pm 0.03$ and $\Gamma(W \rightarrow l\nu) = 225.2 \pm 1.5$ MeV together with measurements of $BR(Z \rightarrow l^+l^-)$ from LEP/SLC[8] allows Γ_W to be extracted. CDF using electron data from run 1A determines $\Gamma_W = 2.06 \pm 0.09\, GeV$. DØ obtains $\Gamma_W = 2.159 \pm 0.092\, GeV$ using electrons and muons from the full run 1 data set.

CDF has also measured Γ_W directly,[9] by fitting the high mass tail of the M_T distribution of $W \rightarrow e\nu$ events. The fit is shown in figure 4. The result is $\Gamma_W = 2.11 \pm 0.28(stat) \pm 0.16(sys) GeV$. This result is less precise than the indirect determinations, but has the advantage of model independence. All measurements are consistent with the SM prediction $\Gamma_W = 2.077 \pm 0.014\, GeV$.

2.3 W and Z Charge Asymmetries

Decay products of W and Z bosons produced in $\overline{p}p$ collisions display charge asymmetries due to asymmetries in production (for $W^\pm$) and in decay (for both W and Z). The charge asymmetry in W production arises from the imbalance in momentum carried by u and d quarks in the proton - u quarks carry a larger momentum fraction than d quarks. Thus W^+ are preferentially produced in the proton direction. This production asymmetry is diluted by a decay asymmetry - the charged lepton in the decay $W \rightarrow l\nu$ is preferentially emitted opposite the direction of

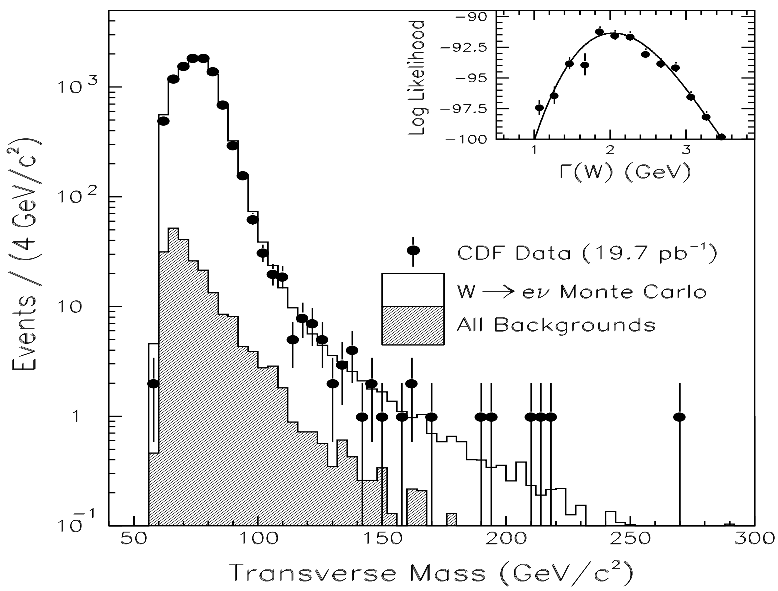

Figure 4: Direct Determination of Γ_W

the W, due to the $(V - A)$ coupling of W to quarks and leptons. The observed distribution of leptons in pseudorapidity $\eta = -ln(tan(\frac{\theta}{2}))$ is sensitive to the pdf's $u(x)$ and $d(x)$, and in particular to the slope of the ratio $u(x)/d(x)$. The folded distributions of charged leptons from W decay[10,11] are shown in figure 5, compared to predicted distributions from various pdf sets.[12] CDF measures the asymmetry for both muon and electron channels, since DØ does not measure the sign of electrons they use only the muon channel.

Decays of Z bosons also exhibit a charge asymmetry, which is sensitive both to pdf's and to the V and A couplings of the Z to quarks and leptons. While the asymmetry is small at the Z pole itself, it is substantial off-peak. This asymmetry is also sensitive to various non-SM effects, *e.g.* a heavy Z' boson. Figure 6 shows CDF's preliminary measurement[13] of the forward-backward asymmetry of e^+e^- pairs as a function of the mass of the pair, compared to a standard model prediction calculated using MRSA pdf's. No significant deviation is observed.

3 Measurement of the W Mass

Since W bosons are produced in $\overline{p}p$ collisions with an unknown (and typically large) longitudinal momentum, only the transverse momenta of the decay products can be used practically to determine the W mass. While the p_T distributions of

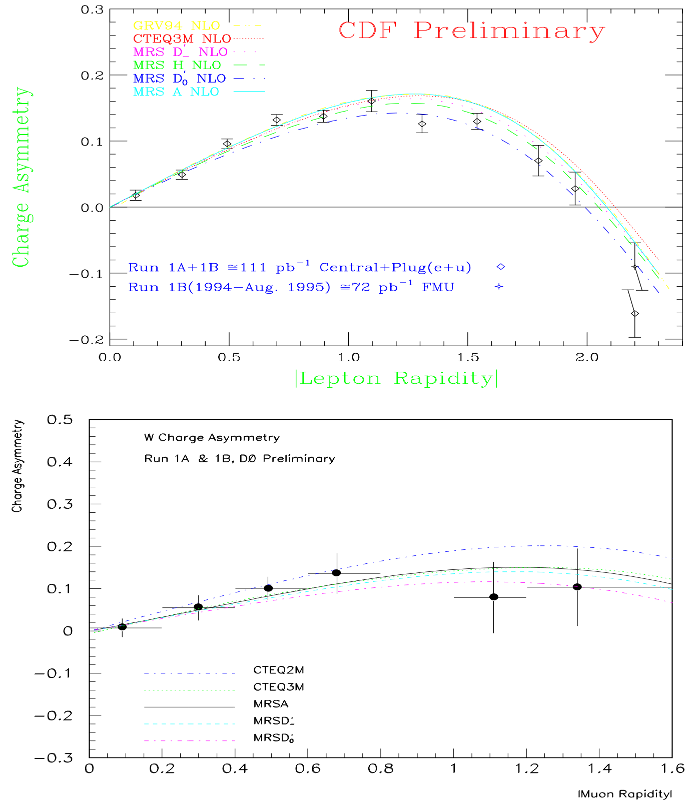

Figure 5: $A = \frac{N_+(\eta) - N_-(\eta)}{N_+(\eta) + N_-(\eta)}$

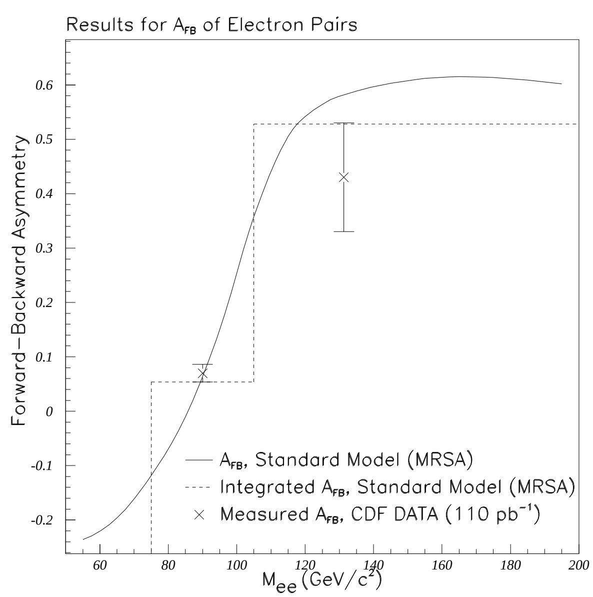

Figure 6: Z charge asymmetry (CDF preliminary)

charged leptons and of neutrinos (as measured by $\not{E}_T$) can be used to determine M_W, these distributions are quite sensitive to the p_T distribution of the W, and therefore to pdf's. The transverse mass of the $l\nu$ pair is considerably less sensitive to the $P_T(W)$ distribution, and we use this distribution to determine M_W.

Here we discuss the measurements of M_W from fits to the $M_T(l\nu)$ distribution from CDF[14] and DØ,[15] and also a preliminary result from DØ of an alternative determination, using the ratio of $M_T(W)$ to a 'transverse mass' of the Z.[16]

In the standard approach, $M_T(l\nu)$ distributions are simulated by Monte Carlo for various values of M_W, and this ensemble of spectra is then used to fit the observed distribution from data. The main systematic errors come from uncertainties in lepton energy/momentum response and resolution, the W production model (pdf's), recoil momentum response and resolution, effects of underlying events, efficiency and acceptance effects and backgrounds. The W production model is checked with the measured W and Z cross-sections and asymmetries. Recoil momentum response is determined using Z+jet events.

3.1 Energy Scale Calibration

CDF and DØ calibrate lepton response in quite different ways. CDF uses a sample of $\approx$ 60,000 $J/\psi \to \mu^+\mu^-$ events to calibrate the momentum scale of their central tracker to an accuracy of $\approx$ 6 parts in 10^4, corresponding to an error in M_W of $\approx$ 50 MeV. The energy scale of the calorimeter is then determined by the E/p distribution of good electrons (in fact the $W \to e\nu$ sample is used). This transfers the momentum calibration to the calorimeter, the resulting error in M_W is $\approx$ 105 MeV. The calibration is checked using Z and υ events.

DØ calibrates their calorimeter's electron response using $Z \to e^+e^-$, $J/\psi \to e^+e^-$ and π^0 samples. The EM energy response is parameterized in terms of a scale α and an offset δ. The measured $M(ee)$ of Z and J/ψ events together with the distribution of $E(e)$ as a function of opening angle provide constraints on α and δ. Although the 2 photons from π^0 decay are not separated in the calorimeter, a sample of π^0 events in which both photons convert can be used to determine a 'symmetric mass',

$$M_{sym} = \sqrt{\frac{E(\pi^0)^2}{2}(1 - cos\omega)}$$

where ω is the opening angle between the two tracks. The M_{sym} distribution is then fit for $M(\pi^0)$. Figure 7 shows the constraints on energy scale and offset. The

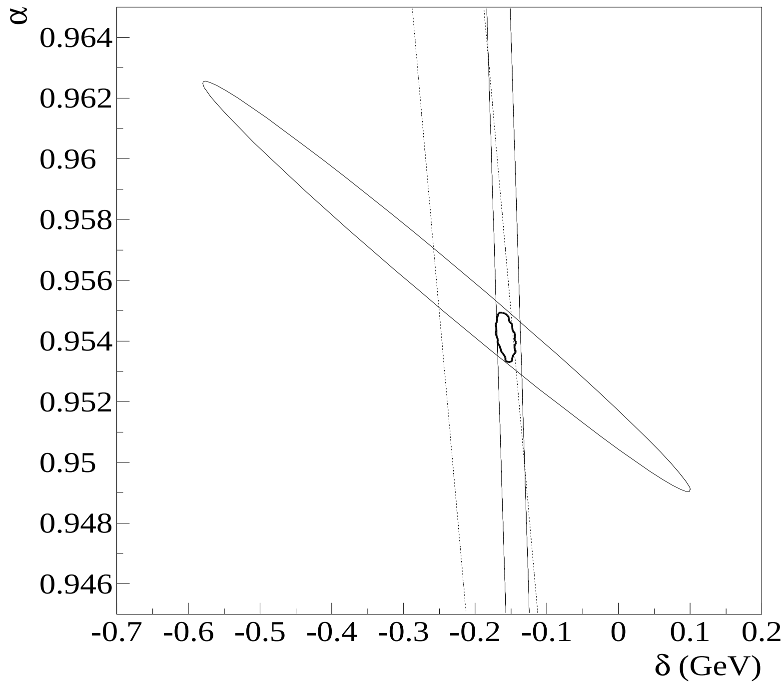

Figure 7: DØ preliminary EM scale and offset

diagonal ellipse is the constraint from Z events, the near-vertical ellipse is from the π^0 data. The small oval shows the overlap of all constraints. The resulting error in M_W from the energy scale is $\approx$ 75 MeV.

3.2 M_W Results

The M_T distributions for $W \to e\nu$ and $W \to \mu\nu$ events from CDF's run 1A data sample are shown in figure 8. They determine the following values:

$$M_W = 80.490 \pm 0.145(stat) \pm 0.175(sys)\, GeV\ (e)$$

$$M_W = 80.310 \pm 0.205(stat) \pm 0.130(sys)\, GeV\ (\mu)$$

$$M_W = 80.41 \pm 0.18\, GeV\ (combined)$$

Analysis of run 1B data is in progress, and an error $\delta(M_W)$ less than ≈ 100 MeV is expected.

DØ 's M_T distribution of $W \to e\nu$ events from run 1B is shown in figure 9. The W mass is determined to be

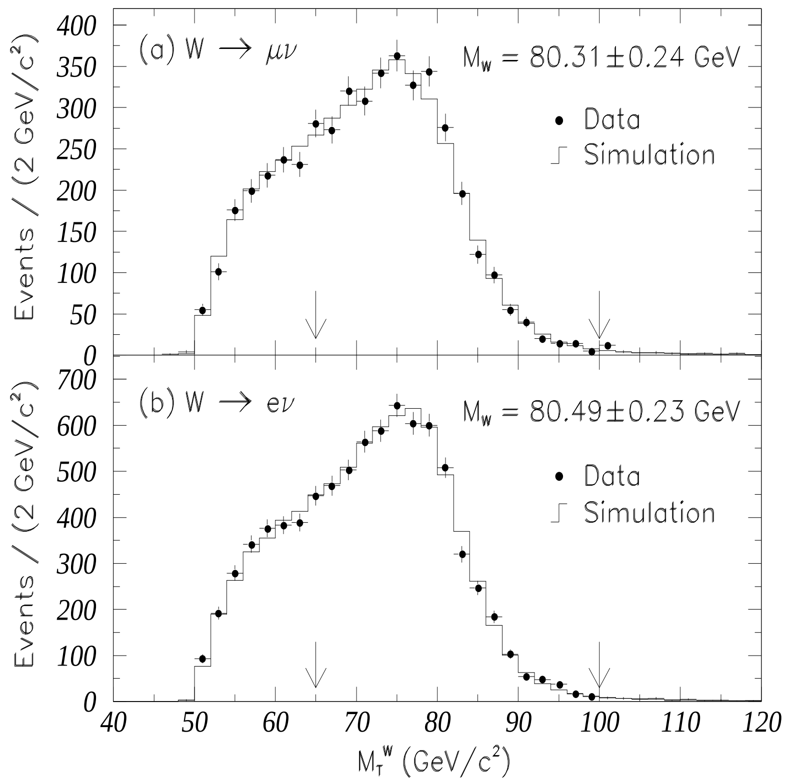

Figure 8: CDF $M_T(l\nu)$, Run 1A published

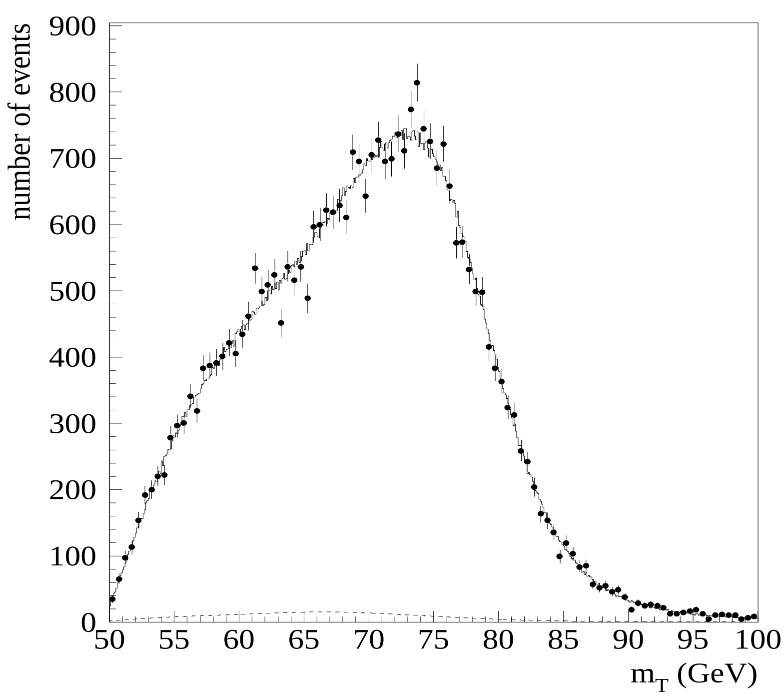

Figure 9: DØ Run 1B $M_T(e\nu)$ (preliminary)

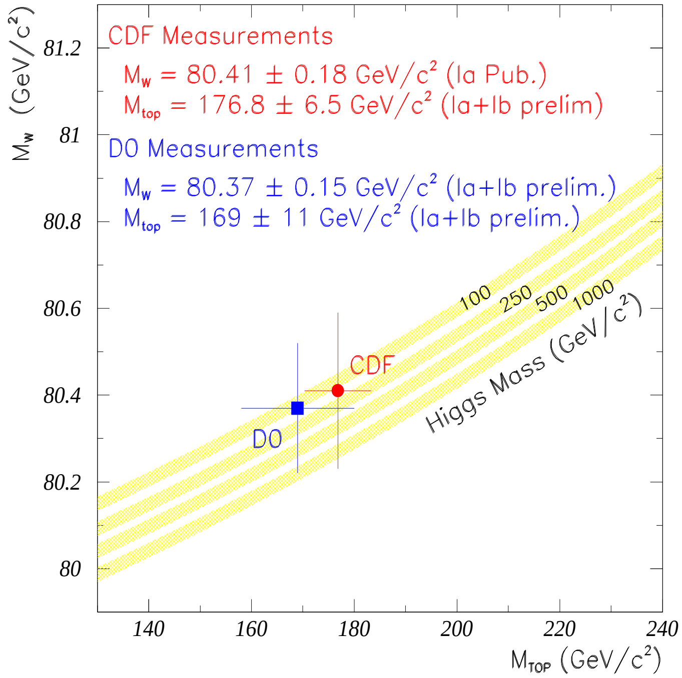

Figure 10: M_W *vs.* m_t

$$M_W = 80.38 \pm 0.07(W stat) \pm 0.08(Z stat) \pm 0.13(sys)\, GeV$$

Combining this with the DØ Run IA result give

$$M_W = 80.37 \pm 0.15\, GeV$$

The dominant systematic errors are energy scale (due mainly to Z statistics), energy underlying the electron, multiple interaction effects, and the W production model.

The CDF and DØ results can be combined with the earlier UA2 measurement[17] to give a world average value from $\overline{p}p$ experiments

$$M_W = 80.35 \pm\ 0.13\, GeV(CDF + DØ + UA2)$$

The recent measurement of M_W in e^+e^- collisions is presented elsewhere in these proceedings.[18]

The ratio M_W/M_Z is related by radiative corrections to the measured value of $sin^2\theta_W$ from LEP/SLC and other sources, to the top mass, and to the mass of the Higgs boson. Figure 10 shows the measured values of M_W and m_t from CDF and DØ, the shaded bands show the corresponding values of M_H.

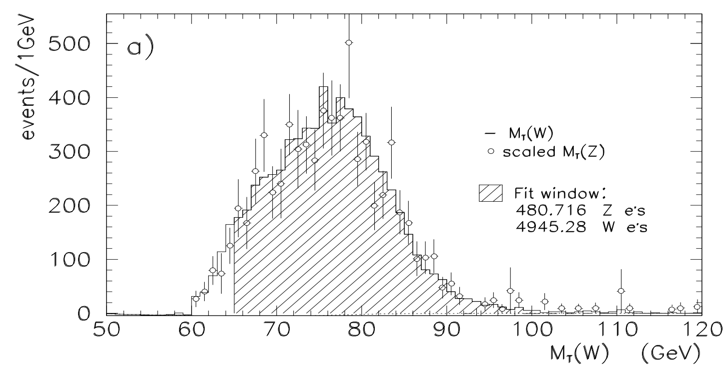

Figure 11: W, Z M_T Ratio (DØ Preliminary)

3.3 Transverse Mass Ratio of W and Z

DØ has also analysed their $W \rightarrow e\nu$ data using an alternative approach: a comparison between the W transverse mass distribution and a distribution of 'transverse mass' of $Z \rightarrow ee$ events. For each Z event, one electron is removed, and replaced by missing energy. The transverse mass of the remaining electron and the $\not{E}_T$is then calculated. (Each $Z \rightarrow ee$ event is used twice). The ratio M_W/M_Z is then determined by scaling the $M_T(Z)$ distribution and fitting to the $M_T(W)$ distribution. Since the W and Z p_T distributions are related, this direct comparison is somewhat less sensitive to the W production model than the standard $M_T(W)$ analysis. Figure 11 shows the $M_T(W)$ and scaled $M_T(Z)$ distributions. The fit result using run 1A data electron data only is

$$M_W = 80.160 \pm 0.360(stat) \pm 0.075(sys)\, GeV$$

where the statistical error is dominated by Z statistics (in includes the scale error). The dominant systematic errors come from uncertainty in energy underlying electrons and multiple interaction effects.

4 Diboson Final States

Measurement of cross-sections and distributions of final states containing two electroweak gauge bosons (W, Z, γ) provides a sensitive test of gauge couplings. These processes are sensitive to anomalous triple boson couplings. Since unitarity requires that these couplings take their SM values in the limit of high energy, all anomalous couplings are assumed to be modified by form factors $1/(1 + \hat{s}/\Lambda^2)^n$, where Λ is the form factor scale.

4.1 $W\gamma$ Production

$W\gamma$ final states can be produced both via $WW\gamma$ and $W\gamma\gamma$ vertices, and by initial or final state radiation. Anomalous $WW\gamma$ couplings are described by parameters $\Delta\kappa$ and λ, both are zero in the SM. $\Delta\kappa$ measures the anomalous magnetic moment of the W, and λ measures the W electric quadrupole moment. Non-zero anomalous couplings lead to both an increase in the $W\gamma$ cross-section, and a harder $P_T(\gamma)$ spectrum.

DØ[19] and CDF[20] have both measured $W\gamma$ production in ($l + \gamma + \not{E}_T$) channels. Isolation cuts are applied to photons to reduce contributions from final state radiation. Constraints on $\Delta\kappa$ and λ derived from the cross-section measurements and fits to the $P_T(\gamma)$ spectra are shown in figure 12, along with constraints from CLEO measurements.[21]

4.2 $Z\gamma$ Production

$ZZ\gamma$ and $Z\gamma\gamma$ couplings vanish at tree level in the SM. Anomalous values of these couplings are characterized by parameters h_i^V, $i = 1{-}4$, $V = Z, \gamma$. The $h_{1,2}^V$ violate CP, while $h_{3,4}^V$ are CP conserving. DØ[22] and CDF[20] have measured $Z\gamma$ production in both the $ee\gamma$ and $\mu\mu\gamma$ channels, and derived limits on the h_i^V parameters from cross-sections and P_T spectra.

A preliminary analysis from DØ[22] has searched in the run 1A data sample for $Z\gamma$ production in the $Z \to \nu\nu$ mode. This mode has the advantages of a factor of 6 increase in branching ratio relative to $Z \to ee$, and of no final state radiation. The signature for this final state is a single $\gamma + \not{E}_T$. The principal backgrounds are (1)

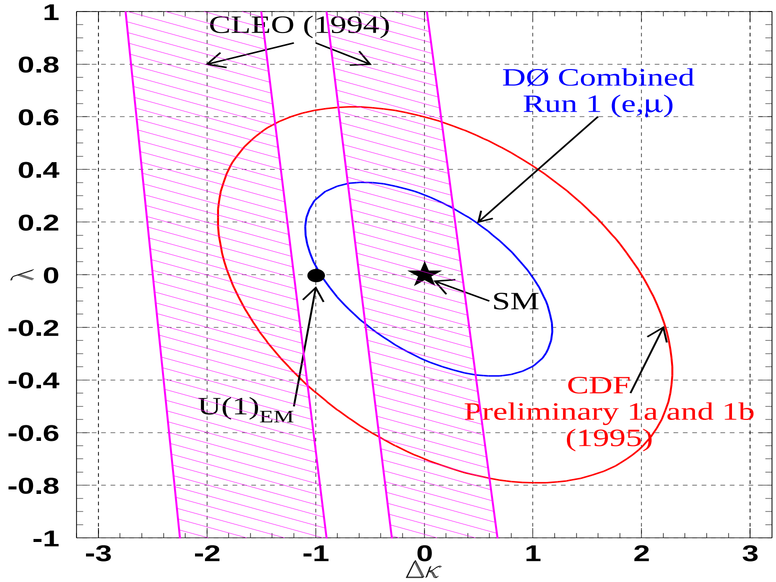

Figure 12: Limits on W Anomalous Couplings

$W \rightarrow e\nu$ events, where the electron track is undetected, and (2) bremsstrahlung photons from cosmic ray or beam halo muons. The first background is reduced by requiring $E_T(\gamma) > 40\ GeV$, above the endpoint of the W electron spectrum. The second background is reduced by using the photon shower shape to reconstruct the photon's direction, and require that the photon be consistent with the event vertex, both along and transverse to the beam axis. The final sample contains 4 events. Figure 13 shows the photon p_T spectrum.

Figure 14 shows limits on anomalous couplings $h^Z_{3,4}$ derived from the various measurements. The tightest limits to date come from the $\nu\nu\gamma$ measurement, although only the run 1A data has been analysed so far. Analysis of the full data set is in progress.

4.3 WW and WZ Production

Searches for WW and WZ final states have also been carried out, with some candidates seen. Figure 15 shows CDF results[20] for cross-sections for diboson final states. DØ has set limits[19] on the sum of WW and WZ cross-sections, using searches in dilepton and (e + jets + $\not{E}_T$) channels.

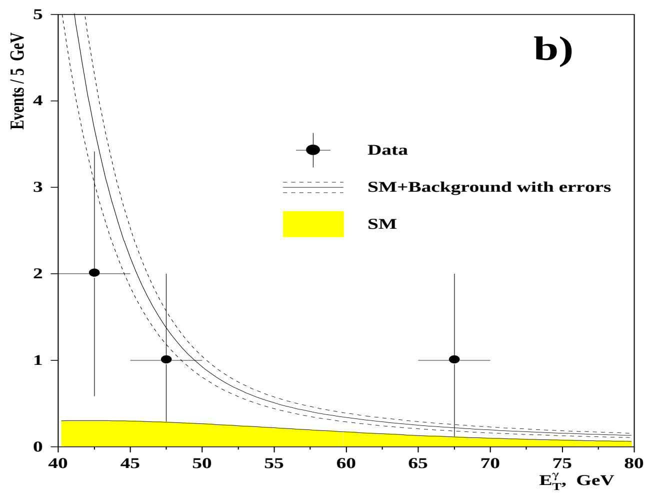

Figure 13: $P_T(\gamma)$ Spectrum of $\nu\nu\gamma$ Candidates

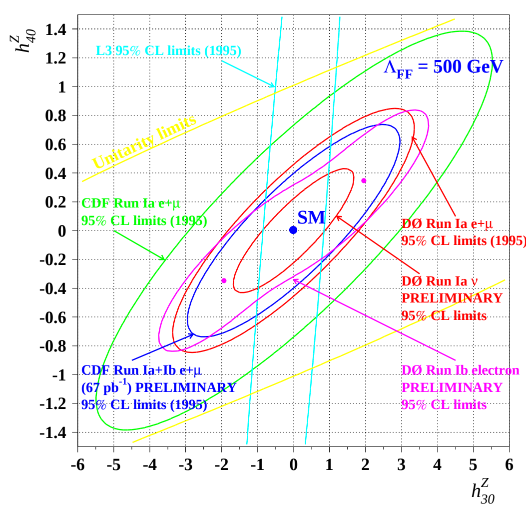

Figure 14: Limits on $Z\gamma$ Anomalous Couplings

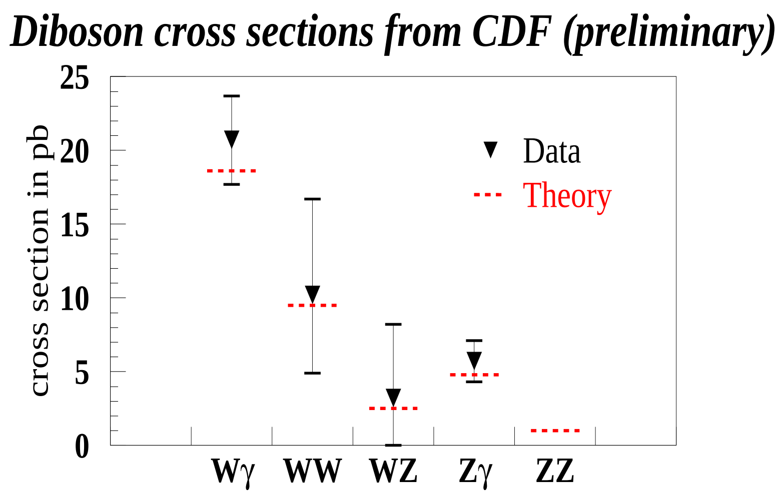

Figure 15: CDF Diboson Cross-Sections

5 Searches for W' and Z'

Many extensions to the SM predict additional gauge bosons with decays similar to W and Z bosons. Searches for W' decays to $l\nu$ have been carried out for both light and heavy neutrinos. A recently published DØ result[23] reports a search for a right-handed W with associated heavy ν_R. If the ν_R is undetected, the W' can be detected as a Jacobian peak in the electron p_T spectrum. Decays $\nu_R \rightarrow e+$ 2 jets are also searched for, in the final state $ee+$ 2 jets. Limits in the $M(W_R) vs. M(\nu_R)$ are shown in figure 16 . Other searches for W' decays to a light neutrino have been previously reported.

Searches for $Z' \rightarrow l^+l^-$ have also been carried out. The most stringent limit at present is a preliminary CDF result[31] $M(Z') > 690 GeV$, assuming SM couplings for the Z'.

6 Supersymmetry Searches

Supersymmetric (SUSY) theories predict partners for all SM particles. SUSY particles are assumed to be pair produced, with the lightest SUSY particle (LSP) stable. Final states will contain LSP's, and a general signal for SUSY particles is $\not{E}_T$. The partners of W, Z and Higgs bosons can mix, and these particles are referred to as charginos $\widetilde{\chi^+}$ and neutralinos $\widetilde{\chi^0}$. The lightest neutralino $\widetilde{\chi}_1^0$ is often assumed to be the LSP. While the parameter space (particle spectra and couplings)

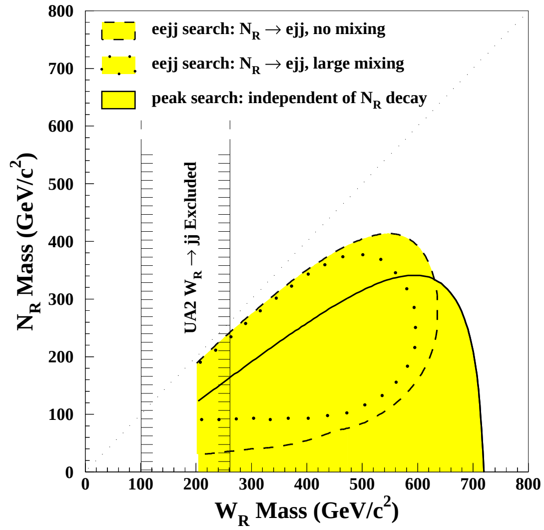

Figure 16: DØ Right-handed W Search

of SUSY models is quite large, many results are interpreted in the framework of the 'minimal SUSY standard model' (MSSM), or supergravity (SUGRA) inspired models. The parameter space in these models is somewhat more restricted than the general case.

6.1 Squark, Gluino, and Stop Squark Searches

Searches for partners of quarks and gluons (squarks $\tilde{q}$ and gluinos $\tilde{g}$) have been carried out. Decays $\tilde{q}, \tilde{g} \to q, g+$ LSP are searched for in multijet + $\not{E}_T$ final states, and cascade decays $\tilde{q}, \tilde{g} \to q, g + \tilde{\chi}$, where the $\tilde{\chi}$ decays to W or Z + LSP are searched for in ll + jets + $\not{E}_T$ final states. A representative plot of limits[34] in the $m(\tilde{q}), m(\tilde{g})$ plane is shown in figure 17.

DØ has also searched for a light partner of the top quark, the stop $(\tilde{t})$.[24] If the $\tilde{t}$ is lighter than the top quark, decays to top are not kinematically allowed, and the stop could decay via a flavor-changing neutral current to a c-quark and the $\widetilde{\chi_1^0}$. If the $\widetilde{\chi_1^0}$ is the LSP, then stop pair production would result in a final state with 2 jets + $\not{E}_T$. No signal above background is observed in the search and a region of the $M(\tilde{t})$, $M(\widetilde{\chi_1^0})$ is excluded.

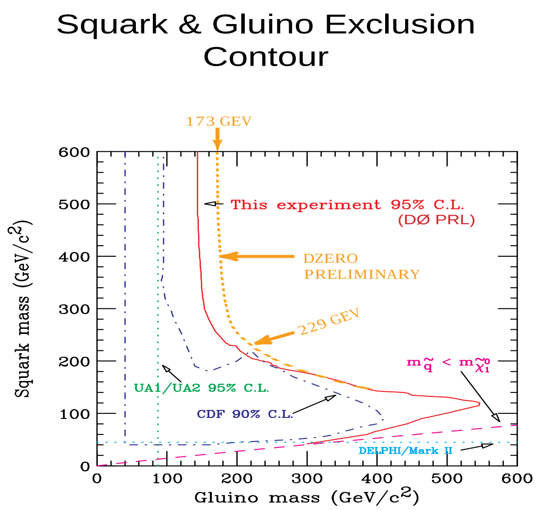

Figure 17: Squark, Gluino Limits

6.2 Chargino/Neutralino Searches

Searches for partners of $W/Z/$Higgs bosons have been carried out in the mode $\widetilde{\chi_1^+}\widetilde{\chi_2^0} \rightarrow W+Z+2\widetilde{\chi_1^0}$. The signature is a final state containing three leptons + $\not{E}_T$. Both CDF[25] and DØ[26] have set limits as functions of masses and the branching ration for $\widetilde{\chi_1^+}\widetilde{\chi_2^0}$ decay to trileptons. Figure 18 shows preliminary DØ limits on the cross-section vs. chargino mass.

6.3 $ee\gamma\gamma\not{E}_T$ Event

CDF's observation[27] of a single event containing two high $p_T$electrons, two high $p_T$photons and a large $\not{E}_T$has aroused considerable speculation.[28] Several scenarios have been suggested in which this event is interpreted as an example of production of a selectron $\tilde{e}$ (electron partner) pair. CDF[27] and DØ[29] have carried out searches in a related channel for $\gamma\gamma + \not{E}_T$ final states, with null results. No positive confirmation for a SUSY signal has been found to date, but the single event is difficult to interpret within the SM.

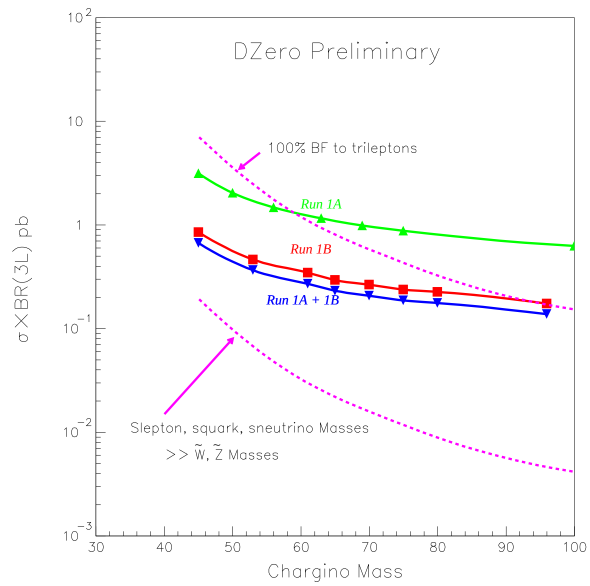

Figure 18: Limits on $\widetilde{\chi}^{+}\widetilde{\chi}^{0} \rightarrow lll$

7 Dijet Resonances

A number of exotic particles might be detected as resonances in the dijet mass spectrum. Examples include technicolor particles, excited quarks, and (possibly) Higgs bosons.

7.1 Searches for Excited Quarks

Both DØ[30] and CDF[31] have searched for resonances in their inclusive dijet mass spectra. No bumps have been found, CDF excludes an excited quark q^* decaying to qg in the mass region $20 - 750 GeV$. DØ sets a slightly lower limit.

7.2 Search for $W+$ Dijet Resonance

DØ has searched for dijet resonances produced in association with a W boson.[32] A signal in this channel could indicate Higgs production. No signal above background is observed, and limits on resonance cross-section vs. mass are set both from the number of events observed, and a fit to event shape. The level of sensitivity is not sufficient to exclude a SM Higgs, but can exclude some non-SM models.

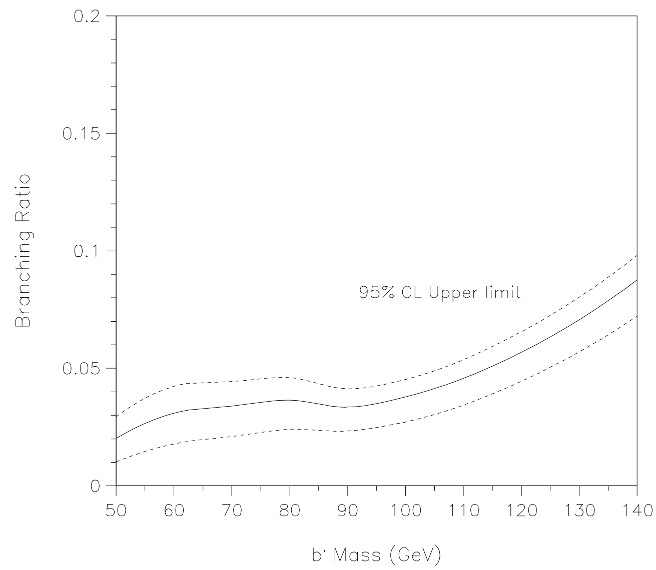

Figure 19: b' Search (DØ preliminary)

8 4th Generation Particles

Searches have been carried out for pair produced 4th generation particles. DØ has reported[33] results of a search for a b' quark with mass $m_{b'} < m_t$. The dominant decay for the b' in this mass region is by a flavor-changing neutral current, $b' \rightarrow b + (\gamma \; or \; g)$. Searches are performed for final states $\gamma + 3$ jets, with at least one jet tagged with a muon, and for $2\gamma + 2$ jets. Limits are set on $BR(b' \rightarrow b + \gamma)$ as a function of $m_{b'}$. Figure 19 shows limits derived from the $2\gamma + 2$ jet mode.

DØ has also searched for a 4th generation neutrino ν_4[34] decaying via mixing to a $W + e$ final state. No candidates are observed, and limits are set as a function of $m(\nu_4)$ vs. the mixing parameter.

9 Search for Heavy Stable Charged Particles

CDF has searched for production of heavy, stable charged particles.[31] The experimental signature for such particles would be a high $p_T$penetrating charged particle moving slowly. With a requirement of large ionization energy loss in both the silicon vertex detector and central tracking chamber, no candidates are found in a

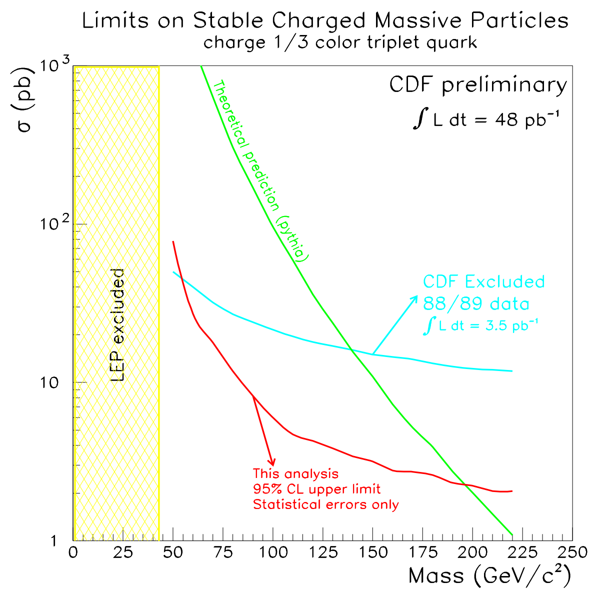

Figure 20: Limit on Heavy Stable Particle

data sample of 48 pb^{-1}. This result can be interpreted as a limit on production cross-section for a variety of non-SM particles. Figure 20 shows the cross-section limit for a color triplet charge-1/3 quark compared to a model prediction. Analysis of the full run 1 data set is underway.

10 Leptoquark Searches

Leptoquarks are (hypothetical) particles carrying both quark and lepton quantum numbers, predicted in a number of extensions to the SM. Leptoquarks could be pair produced in $\overline{p}p$ collisions and detected through decays $LQ \to l^+q$ or $LQ \to \nu q$. Separate searches are conducted for 1st (eq), 2nd (μq) and 3rd (τq) generation leptoquarks. Limits are expressed in terms of a parameter $\beta = BR(LQ \to l^+q)$.

Searches in for final states $ll+$ 2 jets, and l + jets + $\not{E}_T$have been carried out. The $\nu\nu qq$ mode can also be searched for, via a jets + $\not{E}_T$signature. DØ reports a preliminary limit[35] on a 1st generation scalar leptoquark $M(LQ1) > 147 GeV$ for $\beta = 0.5$, from a search in the ee + 2 jet and E + jets + $\not{E}_T$modes in run (1A+1B) data set, and a search for $\nu\nu jj$ in the run 1A data only. Figure 21 shows 95% CL limits on the production cross-section, compared to several models. CDF reports a preliminary limit[31] on a 2nd generation scalar leptoquark $M(LQ2) > 141 GeV$ for $\beta = 0.5$, from the $\mu\mu$ + 2 jet channel, using their full run 1 data set. CDF has also

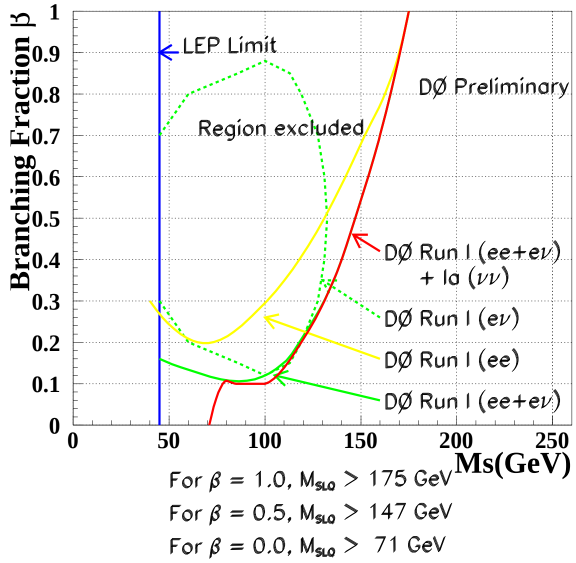

Figure 21: 1st Generation Leptoquark Limits

searched for 3rd generation leptoquarks.[31] The search is carried out in the channel $\tau\tau$ + 2 jets, where one τ decays a lepton and the other decays hadronically.

11 Compositeness Limits

Quark and/or lepton compositeness would lead to several observable effects in $\overline{p}p$collisions. Jet production in collisions of composite quarks would be modified by an effective 4-fermion contact interaction, characterized by a compositeness scale Λ. Such a contact interaction could be detected as an excess in the jet cross-section at very high p_T, and modifications in dijet angular distributions. Limits on quark compositeness from these processes are discussed elsewhere in these proceedings.[36]

If quarks and leptons were composite, an effective ($llqq$) contact term would modify the mass spectrum of Drell-Yan lepton pairs. Figure 22 shows the mass spectrum of electron and muon pairs measured by CDF.[37] No deviation from the SM prediction is observed. The individual ee and $\mu\mu$ spectra can be fit to derive limits on the scale of $eeqq$ and $\mu\mu qq$ contact terms. If the $llqq$ interaction is assumed to be universal a combined limit $\Lambda_+ > 2.9 TeV$, $\Lambda_+ > 3.8 TeV$ is obtained (where $+, -$ refer to the sign of the contact term).

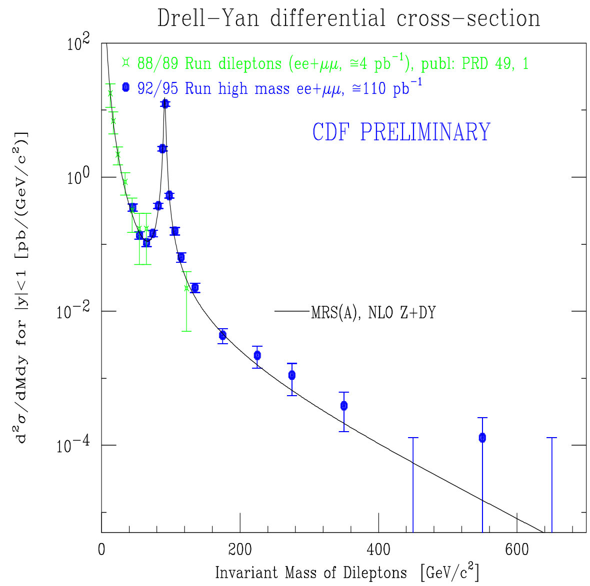

Figure 22: CDF Drell-Yan Lepton Mass Spectrum

12 Conclusions

A very large data set from the Tevatron's 1992-1996 run has been collected and is still in the process of analysis. Results obtained so far include precise determinations of W and Z cross-sections, a new measurement of the W mass, $M_W = 80.35 \pm 0.13$ GeV, and measurements of diboson production in a variety of channels, with corresponding limits on anomalous gauge couplings. Many searches for new phenomena have been carried out. Improved mass limits are placed on a number of non-standard particles, including heavy gauge bosons, leptoquarks and SUSY particles. In the near future, we can expect improved results as the analysis of the full run 1 data is completed, and systematic errors are reduced.

In the longer term, we can look forward to Tevatron run II. A major upgrade to the accelerator, replacement of the Main Ring with a new Main Injector, is underway. This will provide an increase in luminosity of about a factor 10. The next run is planned to begin in 1999, and expected to deliver an integrated luminosity of $\approx 2fb^{-1}$. Both detectors are being upgraded as well. CDF will have a new tracking chamber and silicon detector, improved calorimetry in the forward region, and extended muon coverage. DØ will replace their tracking systems, add a solenoid, and upgrade muon systems. The 20-fold increase in luminosity along with enhanced detector capabilities will provide significant improvements. Mass reach for searches will be greatly extended, and higher precision electroweak measurements can be expected. The resulting precision in the measurement of the W mass is expected to reach $\delta(M_W) \approx 40-50$ MeV, which may be competitive with LEP II.

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