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New Particle Searches at Tevatron (II)

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NEW PARTICLE SEARCHES AT TEVATRON (II)

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Abstract

This note contains the contents of my “New Particle Searches at Tevatron (II)” talk at XXXIst Rencontres de Moriond (QCD), March 23-30, 1996. See E. Gallas’ talk for “New Particle Searches at Tevatron (I).”

NEW PARTICLE SEARCHES AT TEVATRON (II)

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Abstract

Various recent results of new particle searches at the Fermilab Tevatron are presented. No evidence is found for supersymmetric particles (chargino, gluino), leptoquark bosons and heavy gauge bosons in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. Excluded mass regions for each particle are determined.

1 Introduction

With the data from CERN's LEP electron-positron collider, DESY's HERA electron-proton collider and Fermilab's Tevatron proton-antiproton collider, the Standard Model (SM) has received overwhelming experimental support. No new physics has been observed essentially at mass below $\frac{1}{2}M_Z$. Thus, it is imperative that the Fermilab Tevatron, the world's highest energy particle collider, be used for searches of new phenomena. The CDF and DØ experiments have been actively studying their data for evidence of previously unobserved particles. Presented below are the latest results of searches at the Tevatron for supersymmetric particles (chargino, gluino), leptoquark bosons and heavy gauge bosons.

2 Search for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ and $\tilde{g}\tilde{g}$ at CDF and DØ

The Minimal Supersymmetric Standard Model (MSSM) [1] is a *supersymmetrized* SM with two Higgs doublets, which is one of the most appealing theories proposed to test grand unification [2]. Conservation of R -parity requires the SUSY particles to be produced in pairs and prevents decays of the lightest supersymmetric particle (lightest neutralino $\tilde{\chi}_1^0$). The most distinctive signatures of chargino-neutralino ($\tilde{\chi}_1^\pm \tilde{\chi}_2^0$) and $\tilde{g}\tilde{g}$ ($\tilde{q}\tilde{q}$, $\tilde{g}\tilde{g}$) pair production are trilepton events [3] and like-sign (LS) dileptons associated with large missing transverse energy (\cancel{E}_T) plus multi-jets [4].

Pair-produced $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ decay as $\tilde{\chi}_1^\pm \rightarrow \ell^\pm \nu \tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \rightarrow \ell^+ \ell^- \tilde{\chi}_1^0$. The striking signature of these events is thus three isolated leptons plus \cancel{E}_T . The CDF search is based on 100 pb⁻¹ data. Most of the events are from inclusive e and μ triggers at $p_T \sim 10$ GeV/ c . The trilepton requirements are $p_T(\ell_1) > 11$ GeV/ c and $p_T(\ell_{2,3}) > 5$ (4) GeV/ c for e (μ), which is the same as in the previous analysis (based on 19 pb⁻¹) [5]. Eight events are left which are consistent with the SM background. A further cut of $\cancel{E}_T > 15$ GeV is imposed to reduce the background. There is no trilepton event candidate found, which is consistent with an expected background of 0.4 ± 0.1 for four trilepton (eee , $ee\mu$, $e\mu\mu$, $\mu\mu\mu$) modes. The DØ trilepton analysis requires a lower cut of $p_T(\ell_{1,2,3}) > 5$ GeV/ c , although the events are from several trigger paths (inclusive e and μ samples and ee , $e\mu$ and $\mu\mu$ dilepton samples). The acceptance difference due to those trigger thresholds are corrected using a Monte Carlo simulation. DØ also observes no trilepton event candidate in 14 pb⁻¹, which complies with an expected background of 0.8 ± 0.5 for eee , 0.8 ± 0.4 for $ee\mu$, 0.6 ± 0.2 for $e\mu\mu$, 0.1 ± 0.1 for $\mu\mu\mu$ [6].

Both CDF and DØ have a similar constraint inspired by supergravity models [7]. The CDF analysis [5] calculates slepton ($\tilde{\ell}$) and sneutrino ($\tilde{\nu}$) masses from $\tan\beta$, $M(\tilde{g})$, and $M(\tilde{q})$ using the renormalization group equations [8], while DØ [6] uses a minimal supergravity model in ISAJET [9]. In those models, chargino and neutralino have three-body decays. The CDF analysis excludes $M(\tilde{\chi}_1^\pm) < 66$ GeV/ c^2 (95% C.L.) at $\tan\beta = 2$, $M(\tilde{q}) = 1.05M(\tilde{g})$ and $\mu = -400$ GeV (the region of maximum experimental sensitivity). The CDF limit on $\tilde{\chi}_1^\pm$ (66 GeV/ c^2) is comparable to the LEP1.5 result [10]. The DØ result is not sensitive to set any mass limits for the ISAJET model. Limits on $\sigma \cdot BR(4 \text{ trilepton modes})$ are also obtained: 0.6 pb (CDF) and 4 pb (DØ) for 70-GeV/ c^2 chargino.

CDF also examines one particular supergravity model, flipped SU(5) model [11]. In this model, $M(\tilde{\ell}_R) < M(\tilde{\chi}_2^0) < M(\tilde{\ell}_L)$, so that the trilepton signal is nearly maximized via $BR(\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_R^\pm \ell^\mp) \sim 66\%$ (e and μ) and $BR(\tilde{\ell}_R^\pm \rightarrow \ell^\pm \tilde{\chi}_1^0) = 100\%$. However, the mass difference of $\tilde{\ell}_R$ and $\tilde{\chi}_1^0$ decreases as $M(\tilde{\chi}_1^\pm)$ increases, so that the total trilepton acceptance as a function of $M(\tilde{\chi}_1^\pm)$ becomes flat at about 5% at 60 GeV/ c^2 and falls off for $M(\tilde{\chi}_1^\pm) \gtrsim 75$ GeV/ c^2 . Figure 1 shows the 95% C.L. upper limit curve on $\sigma \cdot BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow 3\ell X)$. The points in the figure are the ISAJET predictions for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production in the supergravity model. The limit on $M(\tilde{\chi}_1^\pm)$ is 73 GeV/ c^2 .

The LS dilepton approach is complementary to the classic multi-jets+ \cancel{E}_T analysis in the search for $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$ and $\tilde{q}\tilde{q}$ production. The signature arises mainly from $\tilde{g}\tilde{g}$ production followed by dominant decays of $\tilde{g} \rightarrow q\bar{q}'\tilde{\chi}_1^\pm$ and $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_2^0$ if $M(\tilde{q}) > M(\tilde{g})$. Thus, the final state contains two or more leptons (from $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ decays), \cancel{E}_T and jets. Since the gluino is a Majorana fermion, there is no charge correlation between these leptons. Such a data analysis begins with a dilepton sample ($p_T(\ell_{1(2)}) > 12$ (10) GeV/ c) and subsequently requires $\cancel{E}_T > 25$ GeV and $N(j) \geq 2$ with $E_T(j_{1(2)}) > 15$ GeV in

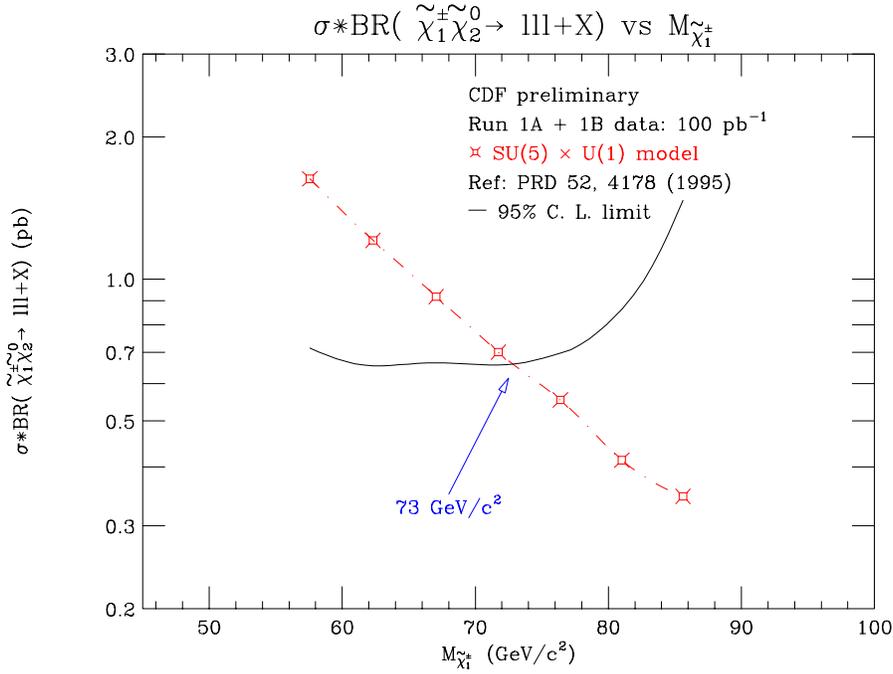


Figure 1: 95% C.L. upper limit on $\sigma \cdot BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow 3\ell X)$ vs. $M(\tilde{\chi}_1^\pm)$. The points are the predictions of ISAJET. Note that $BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow 3\ell X) = BR(\tilde{\chi}_1^\pm \rightarrow \ell^\pm \nu \tilde{\chi}_1^0) \cdot BR(\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_R^\pm \ell^\mp) \cdot BR(\tilde{\ell}_R^\pm \rightarrow \ell^\pm \tilde{\chi}_1^0)$ for four trilepton modes.

$|\eta(j_{1(2)})| < 1.1(2.4)$. Since the production cross section times branching ratio is small, CDF searched for the dilepton signature without the LS requirement. In 19 pb⁻¹, one event ($\mu^+ \mu^-$) is observed, which is consistent with an expected background of $2.39_{-0.76}^{+0.99}$. The lower gluino mass at 95% C.L. is calculated to be 154 GeV/ c^2 for $M(\tilde{q}) \gg M(\tilde{g})$ and 224 GeV/ c^2 for $M(\tilde{q}) = M(\tilde{g})$ at $\tan \beta = 4$ and $\mu = -400$ GeV [12]. Those limits weakly depend on the $\tan \beta$ values (2-8) and the μ values (200 GeV $< |\mu| < 1000$ GeV).

3 Search for Leptoquark Bosons at CDF and DØ

Leptoquark is a generic term for color-triplet bosons which couple both to a quark and a lepton. They appear in many SM extensions which join the quark and lepton sectors at more fundamental levels [13]. Both CDF and DØ search for pair-produced lepton quarks. The signatures are $\ell^+ \ell^- + 2$ jets and $\ell + \cancel{E}_T + 2$ jets.

The DØ analyses of the first and second generation scalar leptoquarks ($LQ1$ and $LQ2$) searches using $\ell^+ \ell^- jj$ and $\ell \nu jj$ events are based on 15 pb⁻¹ data [14, 15]. Neither analysis finds evidence for a leptoquark signal. The mass limits are 130 (116) GeV/ c^2 at $\beta = 1$ (0.5) for $LQ1$ with HMRS-B; 119 (97) GeV/ c^2 at $\beta = 1$ (0.5) for $LQ2$ with CTEQ2pM. Here $\beta = BR(LQ_i \rightarrow \ell_i q_i)$. Note that MT-LO is the nominal choice in DØ's $LQ1$ and $LQ2$ analyses. The CDF results on the $LQ1$ and $LQ2$ searches are based on 4.1 pb⁻¹ [16] and 67 pb⁻¹ data [17]. The limits at $\beta = 1$ (0.5) are 113 (80) GeV/ c^2 for $LQ1$ with HMRS-B and 180 (141) GeV/ c^2 for $LQ2$ with CTEQ2pM.

CDF also searches for the third generation leptoquark ($LQ3$) in $\tau^+ \tau^- jj$ mode, where one of the τ leptons decays semileptonically and the second τ has 1 or 3-prong hadronic decays. The τ -decay lepton (e or μ) is required to have $p_T > 20$ GeV/ c ($|\eta| < 1.1$). The hadronic decay τ must have uncorrected $E_T > 15$ GeV ($|\eta| < 1$) associated 1 or 3 tracks (the leading track $p_T > 10$ GeV/ c) in a 10° cone around the energy cluster. The charge of the τ candidate is defined to be the total charge of 1 or 3 tracks and required to be an opposite sign to the lepton charge. This reduces the QCD

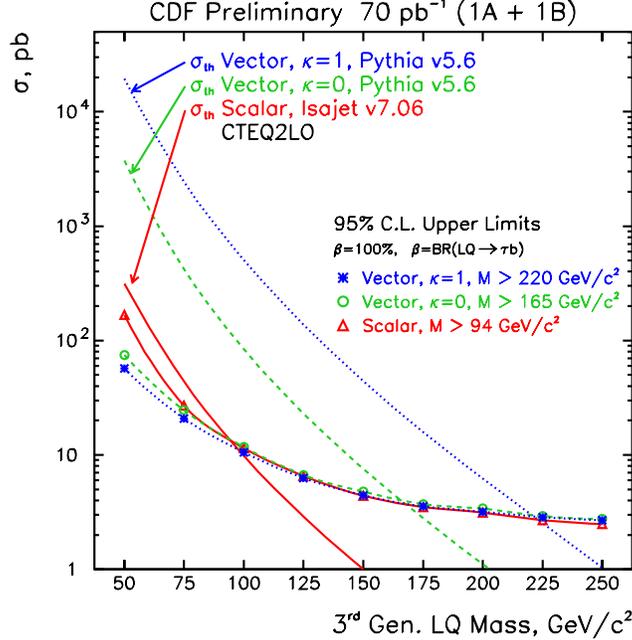


Figure 2: 95% C.L. upper limit on σ vs. $M(LQ3)$ for $\beta = BR(LQ3 \rightarrow \tau b) = 1$.

background by a factor of ~ 2 . The azimuthal separation between the lepton and \cancel{E}_T directions should be less than 50° to reduce the $W(\rightarrow \ell\nu) + \text{jets}$ events. Finally, two jets are required with uncorrected $E_T > 10$ GeV in $|\eta| < 4.2$. No events are left; consistent with the expected SM background of $1.2 \pm_{0.2}^{1.0}$ events including $1.0 Z \rightarrow \tau\tau$ event.

Figure 2 shows the results of the mass limits on $LQ3$ for the scalar boson and the vector bosons (both $\kappa = 0$ and 1 , where κ is an anomalous chromomagnetic moment). All limits on $M(LQ3)$ are obtained at $\beta = 1$.

4 Search for $W' \rightarrow WZ \rightarrow e\nu jj$ at CDF

In extended gauge models [21] proposed to restore left-right symmetry to the weak force, the right-handed, charged bosons W' can decay with large probability to right-handed $\ell_R \bar{\nu}_R$ pairs. Both DØ and CDF have searched for the heavy W' through the process $p\bar{p} \rightarrow W' \rightarrow e\nu$ (or $eR\nu_R$ if $M(\nu_R) \ll M(W')$) in 74.4 pb^{-1} and 19.7 pb^{-1} , respectively. The searches were made by assuming a standard strength of the coupling and the decay $W' \rightarrow WZ$ to be suppressed by a left-right mixing angle $\xi = C [M(W)/M(W')]^2$ where C is $\mathcal{O}(1)$. The limits are $720 \text{ GeV}/c^2$ [19] and $652 \text{ GeV}/c^2$ [20].

The CDF experiment is conducting a complementary search for W' in the decay to $WZ \rightarrow e\nu jj$ with $E_T(e) > 30 \text{ GeV}/c^2$ ($|\eta| < 1.05$), $\cancel{E}_T > 30 \text{ GeV}$, $E_T(j_{1(2)}) > 50$ (20) GeV. Additional tracking, isolation and electron identification criteria are also imposed. The previous result [17] is updated using 110 pb^{-1} data: 512 W' candidate events are left. We observe 7 events for $M(W + jj) > 600 \text{ GeV}/c^2$, compared to 4.2 expected events. We find no significant evidence for excess Z production produced in association with a W .

The limits are obtained by a likelihood fit with the data, background and signal shapes. The results of the excluded region in the ξ - $M(W')$ plane are shown in Fig. 3. The range of 200 - $560 \text{ GeV}/c^2$ is excluded at $\xi = 1$, which is consistent with the limits above. However, the CDF analysis is insensitive to setting any limit at $C = 1$.

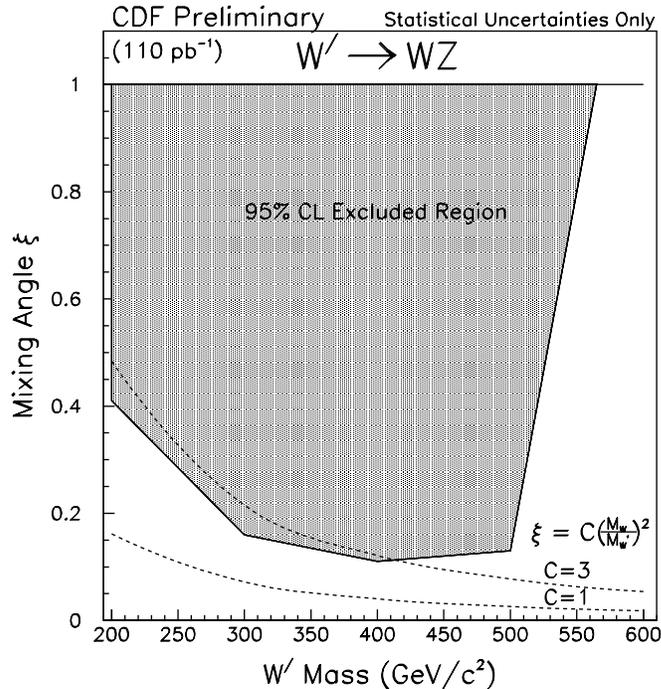


Figure 3: 95% C.L. upper limit excluded region of $\sigma \cdot BR(W' \rightarrow WZ) \cdot BR(W \rightarrow e\nu)$ for ξ vs. $M(W')$. Note that systematic uncertainties are not included. The dashed lines with $C = 1$ and 3 are for illustration purposes only to show what an excluded region vs. C would look like.

5 Search for $Z' \rightarrow \ell^+\ell^-$ at CDF and DØ

Neutral gauge bosons in addition to the Z^0 are expected in many extensions of the SM [22]. These models typically specify the strength of the couplings of such bosons to quarks and leptons but make no mass prediction. Z' bosons may be observed directly via their decay to lepton pairs (e^+e^- , $\mu^+\mu^-$). The CDF and DØ results presented below are derived assuming SM coupling strengths.

For $Z' \rightarrow ee$, the CDF criteria are $E_T(e) > 25$ GeV in $|\eta(e_{1(2)})| < 1.1(2.4)$. The DØ requirements are similar: $E_T(e) > 30$ GeV in $|\eta(e_{1(2)})| < 1.1(2.5)$. Additional tracking, electron identification and isolation cuts are imposed. The only appreciable background is from Drell-Yan γ in the high mass region. For $M(ee) > 250$ GeV/ c^2 , CDF (DØ) observes 8 (1) events in 67.6 (14.4) pb $^{-1}$ data which is consistent with the expected background of 8.1 (1.4) events.

For $Z' \rightarrow \mu\mu$, the CDF criteria are $p_T(\mu) > 20$ GeV in $|\eta(\mu_{1(2)})| < 0.6(1.1)$ with additional quality cuts. In 67 pb $^{-1}$ data, seven events with $M(\mu\mu) > 200$ GeV/ c^2 are observed consistent with the expected rate from Drell-Yan production.

The mass limits are extracted by a binned maximum likelihood analysis on the data comparing the data to a sum of the Drell-Yan background and the Z' expectation. The Drell-Yan and Z' distributions are modeled by the leading order Monte Carlo. The CDF mass limits on Z' are 620 GeV/ c^2 for e^+e^- and 590 GeV/ c^2 for $\mu^+\mu^-$. At this time, a combined limit of 650 GeV/ c^2 is available from 67.6 pb $^{-1}$ e^+e^- data and 71.3 pb $^{-1}$ $\mu^+\mu^-$ data [17]. The DØ mass limit from e^+e^- data is 490 GeV/ c^2 [23].

6 Summary

The CDF and DØ experiments have searched for various new physics phenomena. In these studies, there is no evidence for physics beyond the Standard Model.

References

- [1] For reviews of the MSSM, see H. P. Nilles, Phys. Rep. **110** (1984) 1; H.E. Haber and G.L. Kane, Phys. Rep. **117** (1985) 75.
- [2] P. Langacker, Proceedings of PASCOS 90 symposium, eds. P.Nath and S.Reucroft (World Scientific, Singapore, 1990); J. Ellis, S. Kelley, and D.V. Nanopoulos, Phys. Lett. **B249**, 441 (1990); U. Amaldi, W. de Boer, and H. Fürstenau, Phys. Lett. **B260**, 447 (1991); P. Langacker and M.-X. Luo, Phys. Rev. **D44**, 817 (1991).
- [3] P. Nath and R. Arnowitt, Mod. Phys. Lett. **A2**, 331 (1987); R. Barbieri, F. Caravaglios, M. Frigeni and M. Mangano, Nucl. Phys. **B367**, 28 (1991); H. Baer and X. Tata, Phys. Rev. **D47**, 2739 (1993); J.L. Lopez, D.V. Nanopoulos, X. Wang and A. Zichichi, Phys. Rev. **D48**, 2062 (1993); H. Baer, C. Kao, and X. Tata, Phys. Rev. **D48**, 5175 (1993).
- [4] H. Baer, X. Tata and J. Woodside, Phys. Rev. **D41**, 906 (1990); R.M. Barnett, J.F. Gunion and H.E. Haber, Phys. Lett. **B315**, 349(1993).
- [5] CDF Collaboration, Fermilab-Pub-96/029-E, to appear in Phys. Rev. Lett. (1996).
- [6] DØ Collaboration, Phys. Rev. Lett. **76**, 2228 (1996).
- [7] For a recent review, see R. Arnowitt and P. Nath, "Supersymmetry and Supergravity: Phenomenology and Grand Unification," Proceedings of VIIth J.A. Swieca Summer School, Campos de Jordao, Brazil, 1993 (World Scientific, Singapore, 1994).
- [8] L.E. Ibañez, C. Lopez, and C. Muñoz, Nucl. Phys. **B256**, 218 (1985). G.G. Ross and R.G. Roberts, Nucl. Phys. **B377**, 571 (1992); R. Arnowitt and P. Nath, Phys. Rev. Lett. **69**, 725 (1992); S. Kelley, J.L. Lopez, D.V. Nanopoulos, H. Pois, and K. Yuan, Nucl. Phys. **B398**, 31 (1993); G.L. Kane, C. Kolda, L. Roszkowski, and J.D. Wells, Phys. Rev. **D49**, 6173 (1994). We used an approximate formula ($\tilde{\ell}$ and $\tilde{\nu}$ masses to \tilde{q} and \tilde{g} masses) in H.Baer *et al.*, Phys. Rev. **D47**, 2739 (1993).
- [9] H. Baer, F.E. Paige, S. D. Protopopescu and X. Tata, *Proceedings of Workshop on Physics at Current Accelerators and the Supercollider*, eds. J. Hewett, A. White and D. Zeppenfeld (Argonne National Laboratory, 1993).
- [10] ALEPH Collaboration, CERN-PPE/96-10, submitted to Phys. Lett. B (1996); OPAL Collaboration, CERN-PPE/96-20, submitted to Phys. Lett. B (1996).
- [11] J.L. Lopez, D.V. Nanopoulos, and A. Zichichi, Phys. Rev. **D52**, 4178 (1995). Input parameters for ISAJET are provided by J.L. Lopez.
- [12] CDF Collaboration, Phys. Rev. Lett. **76**, 2006 (1996).
- [13] J. Pati and A. Salam, Phys. Rev. **D10**, 275 (1974); H. Georgi and S. Glashow, Phys. Rev. Lett. **32**, 438 (1974), E. Eichten *et al.*, Phys. Rev. Lett. **50**, 811 (1983).
- [14] DØ Collaboration, Phys. Rev. Lett. **72**, 965 (1994). The DØ total integrated luminosity has changed since the publication due to an update of the total inelastic cross section (averaged new CDF and E710) used to calculate the luminosity. The new luminosity is 13.8 pb^{-1} .
- [15] DØ Collaboration, Phys. Rev. Lett. **75**, 3618 (1995).
- [16] CDF Collaboration, Phys. Rev. **D48**, 3939 (1993).
- [17] S. Park (CDF Collaboration), Fermilab-Conf-95/155-E, Proceedings of 10th Topical Workshop on Proton-Antiproton Collider Physics, Fermilab National Accelerator Laboratory, May 1995.
- [18] G. Altarelli, B. Mele and M. Ruiz-Altaba, CERN Preprint CERN-TH. 5323/89 (1989).
- [19] DØ Collaboration, Phys. Rev. Lett. **76**, 3271 (1996).
- [20] CDF Collaboration, Phys. Rev. Lett. **74**, 2900 (1995).
- [21] J.C. Pati and A. Salam, Phys. Lett. **31**, 661 (1973); R.N. Mohapatra and J.C. Pati, Phys. Rev. **D11**, 566 (1975) and 2558 (1975); P. Ramond, Ann. Rev. Nucl. Part. Sci. **33**, 31 (1983).
- [22] G.G. Ross, *Grand Unified Theories*, (Cambridge U.P., Cambridge, 1987) and references therein.
- [23] DØ Collaboration, Fermilab-Conf-95/210-E, International Europhysics Conference on High Energy Physics, Brussels, Belgium, July 27-August 2, 1995.