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New Particle and SUSY Searches

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Abstract

Recent results are presented for searches of new particles in three areas. First generation scalar leptoquark mass limits have been set at Fermilab by CDF and D0, and D0 has determined a vector leptoquark mass limit. Excited quark states have been studied at CDF, and mass limits established. Finally, two SUSY searches are summarized including Wino and Zino to tri-lepton signatures at Fermilab, and scalar top at LEP by OPAL.

1.0 Introduction

Of the many interesting subjects included under this title, this discussion will center on three topics. First, there are results from first generation scalar leptoquark searches at CDF and D0, and new mass limits have been established by D0 for first generation vector leptoquark production. Second, excited quark states have been searched for at CDF, and their results will be shown. Finally, there are searches for SUSY Wino-Zino to trilepton states at CDF and D0 and, also, preliminary new results from a Scalar top search at OPAL.

2.0 Leptoquarks

Leptoquarks (LQ) are exotic particles which would carry both color and lepton quantum numbers. Just as the W boson relates the isospin doublets for quarks and leptons, so the leptoquark would link quarks and leptons. They occur naturally in a wide variety of standard model extensions, are fractionally charged and can decay directly into a quark-lepton pair. Currently published first generation scalar leptoquark mass limits are shown in Table 1.

TABLE 1. Current first generation scalar leptoquark Mass Limits

Experiment	Limit (GeV/c ²)
e ⁺ e ⁻ LEP	45
pp CDF	113 for $\beta=1.0$, 80 for $\beta=0.5$
ep HERA	180 (assuming Electro-Weak coupling)
pp D0	133 for $\beta=1$, 120 for $\beta=0.5$

2.1 Search for leptoquarks at D0

The D0 leptoquark search is based on 15 pb⁻¹ from the 1993 Fermilab collider run. A first generation leptoquark, S₁, decays into an electron and a quark with branching ratio β , or ν_e and quark with branching ratio (1- β). For the two modes studied, S₁ $\bar{S}_1 \rightarrow eq+eq$ would have a branching ratio of β^2 , and S₁ $\bar{S}_1 \rightarrow eq + \nu_e q$ would have a branching ratio of $2\beta(1-\beta)$. Event selection is performed for the S₁ $\bar{S}_1 \rightarrow e \text{ jet} + e \text{ jet}$ mode by requiring two electrons with E_t>25 GeV, and two jets with E_t>25 GeV and excluding events with M_{ee} within ± 10 GeV of the Z mass. For the S₁ $\bar{S}_1 \rightarrow e \text{ jet} + \nu_e \text{ jet}$ mode the requirements are one electron with E_t > 20 GeV, missing E_t > 20 GeV and at least two jets, one with E_t > 15 GeV and one with E_t>10 GeV. The W background is removed by cutting all events with M_t < 105 GeV, with this requirement no events remain. Further details of this analysis can be found in [1] and [2].

The efficiency for finding leptoquarks is shown in Figure 1, as a function of LQ mass for the two modes. The Monte Carlo upon which the results are based uses ISAJET with LQ production turned on and Morfin-Tung lowest order structure functions. The predicted cross sections for LQ production [3] combined with this analysis provide the mass limits for scalar LQ shown in Figure 2.

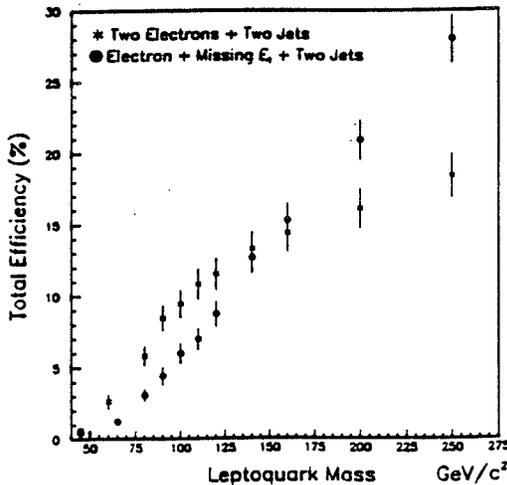


Figure 1. D0 Leptoquark efficiencies.

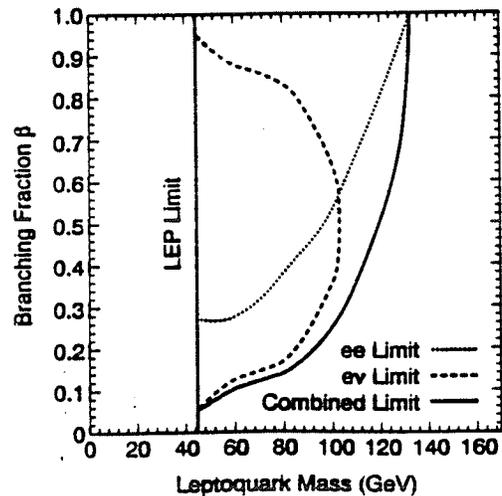


Figure 2. D0 scalar leptoquark results.

Recently, the cross section has been calculated for production of Vector leptoquarks [4]. With this, and *assuming* the same detection efficiencies as for the scalar LQ analysis, the mass limit for vector LQ's has been determined. In the calculations of the vector LQ production cross section, there is an additional parameter κ , which is the amount of anomalous coupling of the LQ to the gluon. The cross section is decreased most when $\kappa = 0$. Shown in Figures 3a and 3b are the results for the $\kappa=0$ and $\kappa=1$ cases.

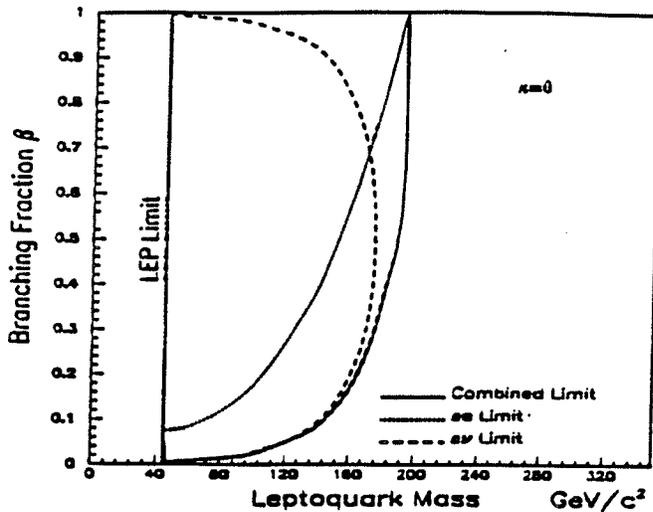


Figure 3a. D0 vector leptoquark mass limits for $\kappa=0$.

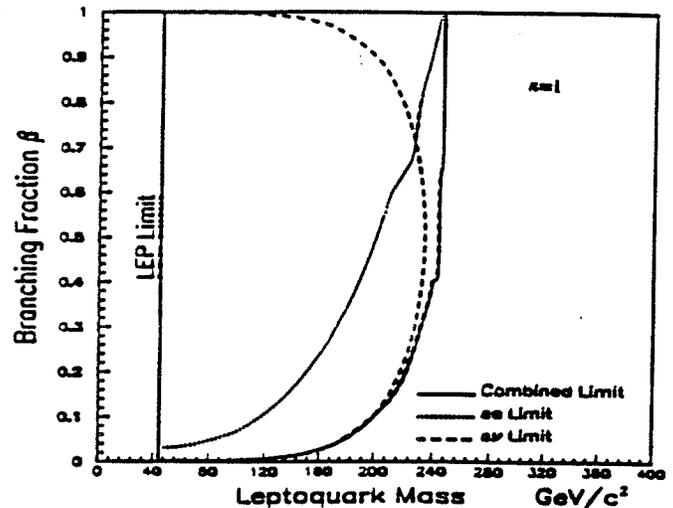


Figure 3b. D0 vector leptoquark mass limits for $\kappa=1$.

2.2 Leptoquark search at CDF

An analysis based on 4.05 pb^{-1} from the 1989 data has been recently published by CDF collaboration [5]. In this analysis 4997 events were selected in the Inclusive High E_t electron sample. The vertex was required to be within 60 cm of the nominal interaction point. An electron was defined as being a central electromagnetic cluster with E_t greater than 20 GeV with central tracking, shower shape and isolation consistent with an electron. Jet selection was based on a fixed cone algorithm. The backgrounds are $q\bar{q} \rightarrow \gamma/Z^0 \rightarrow e^+e^-$ and associated jet(s). The cuts include E_t for the electrons, and jets to be greater than 20 GeV, and exclude the mass region for the e^+e^- pair between 75 and 105 GeV/c^2 . They observe no events with a predicted background of $0.7 \pm 0.1 \pm 0.2$; results for this analysis are shown in Figure 4 for 95% C.L. .

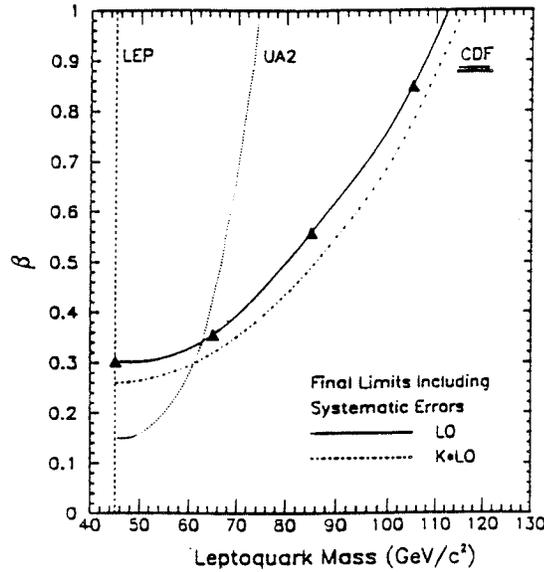


Figure 4. CDF scalar leptoquark mass limits.results.

3.0 Excited Quarks

Excited states of quarks are expected if quarks are composite particles. CDF has conducted a search for such states [6] and compared their data to a model by Baur, Hinchliffe and Zeppenfeld [7]. In the model the excited quarks have spin 1/2, isospin 1/2 and the u^* and d^* are degenerate in mass. The Lagrangian for the production and decay of the excited state, $q^* \leftrightarrow q + (\gamma, g, W, Z)$ is of the magnetic moment type.

$$L = 1/(2M^*) \bar{q}_R \sigma^{\mu\nu} [g_s f_s \lambda^a / 2 G_{\mu\nu}^a + g f \tau / 2 W_{\mu\nu} + g' f' Y / 2 B_{\mu\nu}] q_L.$$

where $f_s = f = f' = 1$ are unknown anomalous coupling constants determined by preon dynamics.

The search in the CDF data is for the modes $qg \rightarrow q^* \rightarrow q\gamma$ and $qg \rightarrow q^* \rightarrow qW$. The search for $\gamma + \text{jet}$ states is based on 3.3 pb^{-1} from the 1989 data with $E_t > 23 \text{ GeV}/c$ and 21 pb^{-1} of 1992 data with $E_t > 70 \text{ GeV}$. The results of the search are shown as upper limits on the cross section in Figure 5, together with expected signal for masses of 100, 200, 300 and 500 GeV/c^2 . The $W + \text{jet}$ search is based on 4.1 pb^{-1} of 1989 data for $W \rightarrow e + \nu$, 3.5 pb^{-1} of 1989 data with $W \rightarrow \mu + \nu$, and 21 pb^{-1} of 1992 data. Figure 6 shows the smaller of the 2 solutions for the $W + \text{leading jet}$ invariant mass for the data, with hypothetical signals for 3 masses representing the model.

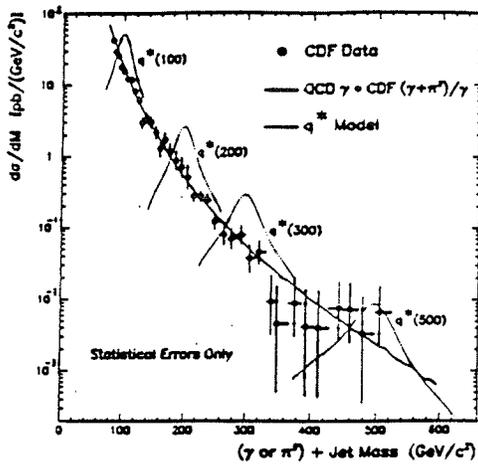


Figure 5. CDF $q^* \rightarrow q\gamma$. Photon candidates plus leading jets (points) compared to estimates of QCD background (curve).

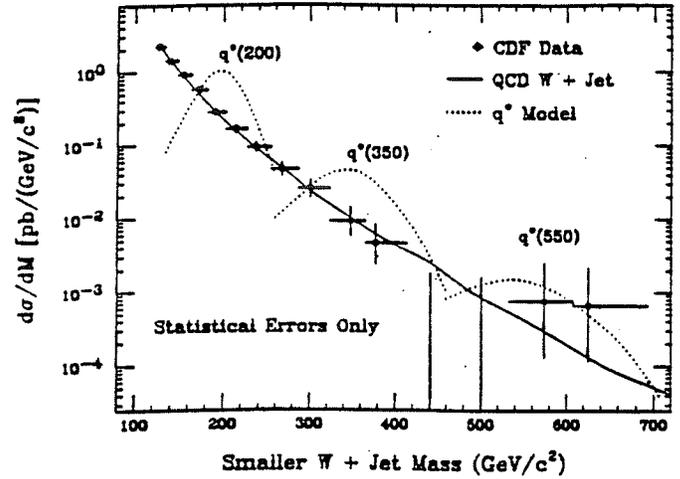


Figure 6. CDF $q^* \rightarrow qW$. The smaller of the two solutions for $W +$ leading jet invariant mass compared to Monte Carlo of QCD background (curve).

By combining these two results and comparing it to the calculated cross section, a lower mass limit of $540 \text{ GeV}/c^2$ is established. The limit as a function of the coupling constant f is shown in Figure 7 for this result and previous results from LEP and UA2.

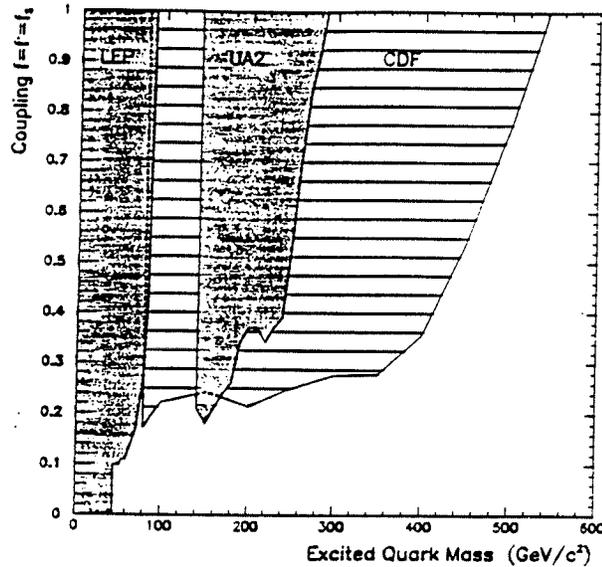


Figure 7. Region of the coupling vs. mass plane excluded at 95% C.L. by CDF measurement (hatched) compared to LEP at 95% C.L. for $q^* \rightarrow q\gamma, qg$ (shaded) and UA2 at 90% C.L. in $q^* \rightarrow qg$ (shaded).

4.0 Supersymmetry

Searches for SUSY charginos and neutralinos have been conducted at the Tevatron by CDF and D0, and a very recent result from OPAL searching for the scalar top is presented. Production and decay are based on the Minimal SUSY Standard Model (MSSM). The following nomenclature is used in this section:

- Wino — $\tilde{W}_{1,2}^{\pm}, \tilde{\chi}_{1,2}^{\pm}$, (Chargino)
- Zino — $\tilde{Z}_{2,3}^0, \tilde{\chi}_{2,3}^0$, (Neutralino)
- LSP — $\tilde{Z}_{1,2}^0, \tilde{\chi}_{1,2}^0$, (Lightest SUSY Particle)

Here the $\tilde{W}_{1,2}^{\pm}$ and $\tilde{Z}_{2,3}^0$ are mass eigenstates in the mixing of $(\tilde{W}^{\pm}, \tilde{H}^{\pm})$ with $(\tilde{B}, \tilde{W}^3, \tilde{H}^0_1, \tilde{H}^0_2)$. In the model, the following mass relationships arise between the lowest mass chargino, neutralinos, and the mass of the gluino:

- $M(\tilde{W}_{1,2}^{\pm}) \approx M(\tilde{Z}_{2,3}^0) \approx 2M(\tilde{Z}_{1,2}^0)$
- $M(\tilde{g}) \approx 3-4 M(\tilde{W}_{1,2}^{\pm})$

4.1 Wino Zino Search

Winos and Zinos may be produced at the Tevatron through off-shell W production[8]. The $\tilde{W}_{1,2}^{\pm}$ and $\tilde{Z}_{2,3}^0$ would subsequently decay with a characteristic signature of 3 leptons and large missing P_t . These tri-lepton signatures should be observable, establishing mass limits on the Wino and Zino production which would imply limits on the gluino mass.

4.1.1 Wino Zino search at CDF

The trilepton SUSY search at CDF [9] is based on an integrated luminosity of 18pb^{-1} . The data sample included the inclusive muon and electron trigger samples; some details are shown in Table 2. The lepton selection required there to be one high quality lepton with $p_t(\mu) > 10 \text{ GeV}/c$ or $E_t(e) > 10 \text{ GeV}$ and 2 (or more) other leptons with $p_t(\mu) > 4 \text{ GeV}/c$ and $E_t(e) > 5 \text{ GeV}$. For the analysis, ISAJET V7.02 was used with the SUSY generator by Baer et al. [9], the parameters used in the Monte Carlo are summarized in Table 3. The excluded region as $M(\tilde{g})$ vs. μ are shown in Figure 8.

TABLE 2. Details of CDF trilepton event selection

Analysis stage	μ Data (events)	e Data (events)
Original Sample	2,404,920	3,166,571
Dilepton selection	25,483	29,361
Trilepton selection	172	94
Trilepton event selection	2	2
Z^0 removal (80-100 GeV/c^2)	1	0

TABLE 2. Details of CDF trilepton event selection

Analysis stage	μ Data (events)	e Data (events)
Υ Removal (9-11 GeV/c ²)	0	0
J/ ψ removal (2.9-3.3 GeV/c ²)	0	0

TABLE 3. Parameters used in CDF MSSM simulation

Parameter	value	Description
$\tan \beta$	4.0	Ratio of the Higgs vacuum expectation values
$M(H^+)$	500 GeV/c ²	Mass of the charged Higgs
μ	-300 to -450 GeV	Higgsino mass mixing parameter
$M(\tilde{g})$	140 to 200 GeV/c ²	Gluino mass
$M(\tilde{q})$	1.2 x $M(\tilde{g})$	Squark Mass
$M(t)$	160 GeV/c ²	Mass of the top quark

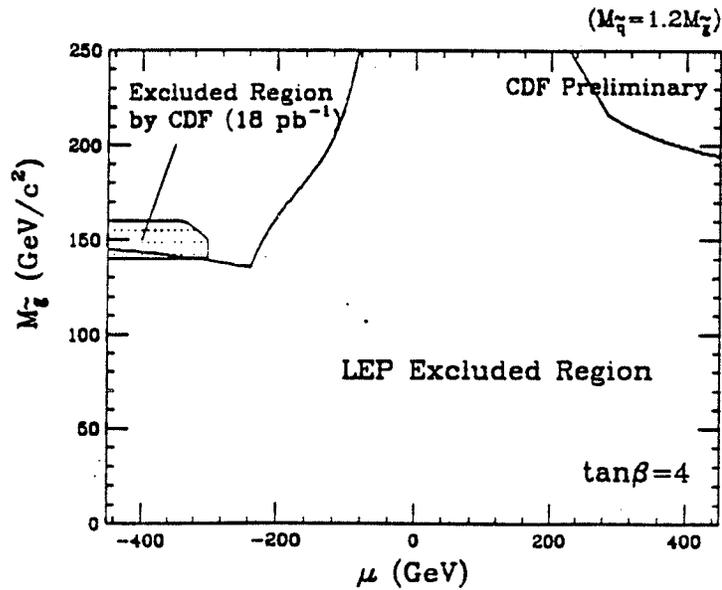


Figure 8. Mass of gluino vs. μ showing region excluded by CDF measurement.

4.1.2 Wino Zino search at D0

A summary of a similar analysis underway at D0 [11] is shown in Table 3 for the 4 tri-lepton channels. One event was observed in the $ee\mu$ channel and is shown in Figure 9. This event has the following parameters: Muon; $\eta=1.1$, $p_t=17.2$ GeV/c, Electron candidates; $\eta=2.0$, $E_t=37.8$ GeV, and $\eta=1.8$, $E_t=8.0$ GeV, and missing E_t ; $E_{t-miss}=23.3\pm 11.6$ GeV. More detailed results from this analysis will be available soon.

TABLE 4. Summary of D0 trilepton analysis

Process	eee	ee μ	e $\mu\mu$	$\mu\mu\mu$
On-line Trigger (GeV) EM= Electro-Magnetic cluster	1 EM $E_t > 20$ or 2 EM $E_t > 10$	1 EM $E_t > 7$ & 1 μ $p_t > 5$ or 2 EM $E_t > 20$ or 1 EM $E_t > 20$ & missing $E_t > 20$	1 EM $E_t > 7$ & 1 μ $p_t > 5$ or 1 $\mu p_t > 15$ & 1 μ $p_t > 10$ or 1 EM $E_t > 20$ & missing $E_t > 20$	1 $\mu > 15$ or 2 μ 's > 3
Off-line selection (GeV)	3 e's with $E_t > 7$ & missing $E_t > 10$	1 μ $p_t > 10$ 1 e $E_t > 10$ 1 e $E_t > 7$	1 μ $p_t > 10$ 1 e $E_t > 10$ 1 μ $p_t > 5$ $M_{\mu\mu} > 5$	3 μ $p_t > 5$ $M_{\mu\mu} > 5$
$\int L dt$ (pb^{-1})	14.8 \pm 1.8	15.2 \pm 1.8	15.2 \pm 1.8	5.0 \pm 0.6
Result	0 events	1 event	0 events	0 events
Est. Bkg. (Preliminary)	< 1.1 event	< 0.5 event	< 0.5 event	< 0.2 event

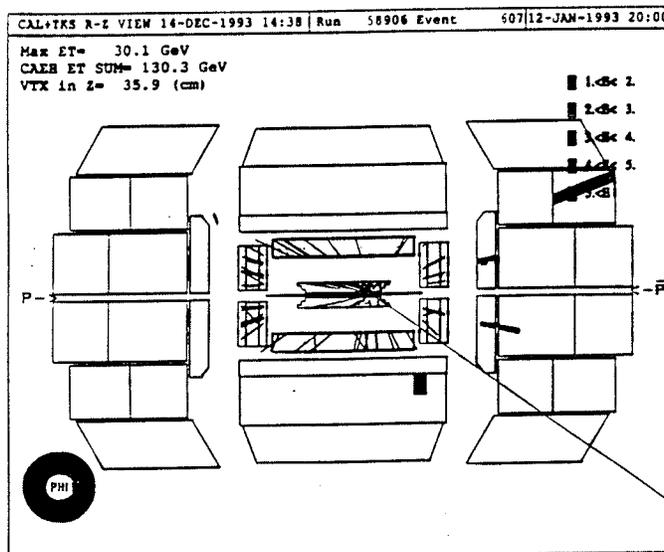


Figure 9. D0 tri-lepton event candidate for mode $ee\mu$. Parameters for each particle are given in the text.

4.2 Scalar top search at OPAL

The OPAL collaboration has obtained new results in a search for the scalar top (stop) SUSY particle [12]. The scalar top can be the lightest charged SUSY particle because there is a large radiative correction due to the heavy top quark mass. The stop states, \tilde{t}_R and \tilde{t}_L , mix to form \tilde{t}_1 and \tilde{t}_2 , with the \tilde{t}_1 being the lighter mass eigenstate,

$$\tilde{t}_1 = \tilde{t}_R \cos(\vartheta_{\text{mix}}) + \tilde{t}_L \sin(\vartheta_{\text{mix}}).$$

The production of the stop would be through e^+e^- to γ or Z^0 , which would decay to a $\tilde{t}_1\tilde{t}_1^*$ pair; the Z^0 channel decouples for $\vartheta_{\text{mix}} \approx 0.98$ rad. The stop would decay dominantly through a single loop to $\tilde{\chi}_1^0$ (LSP) and a charm quark, thus the typical event would have two jets accompanied by large missing p_t .

The result is based on 56.4 pb^{-1} of e^+e^- data taken during the period of 1991 to August 1993 with the OPAL detector at LEP. Shown in Figure 10 is the excluded region in the $(\vartheta_{\text{mix}}, m_{\tilde{t}_1})$ plane at 95% C.L., where the mass difference between the \tilde{t}_1 and the $\tilde{\chi}_1^0$ is as small as $2.2 \text{ GeV}/c^2$. The region excluded by the limit on the Z^0 total decay width ($\Delta\Gamma_Z \leq 26 \text{ MeV}$ at 95% C.L.) is also shown. Figure 11 shows the excluded region in the $(m_{\tilde{t}_1}, m_{\text{LSP}})$ plane at 95% C.L. where the mixing angle is assumed to be ≤ 0.85 rad or ≥ 1.15 rad. The dotted lines indicate the mass differences ($\Delta m = m_{\tilde{t}_1} - m_{\text{LSP}}$) $\Delta m = 0$ and $\Delta m = 5 \text{ GeV}/c^2$.

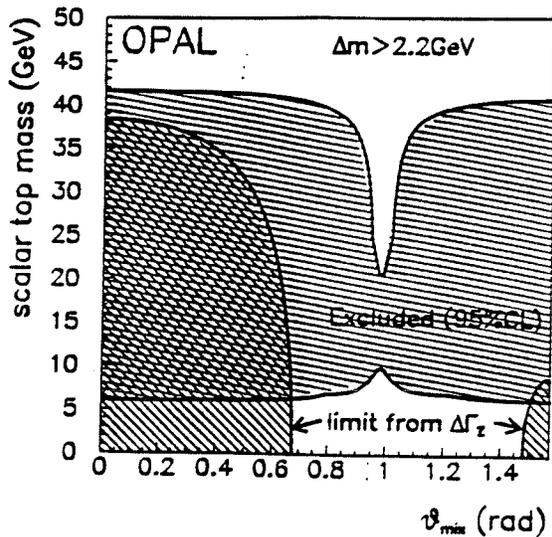


Figure 10. OPAL stop result showing the excluded region in the ϑ_{mix} vs. $m_{\tilde{t}_1}$ plane at 95% C.L. Details are described in the text.

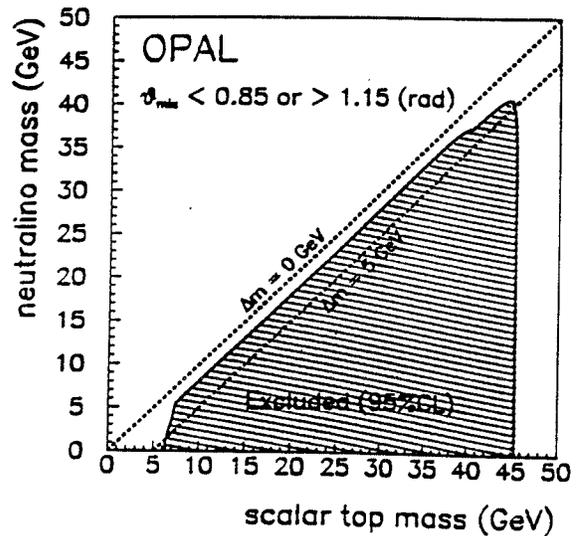


Figure 11. The excluded region in the mass of the \tilde{t}_1 vs. mass of lightest neutralino at the 95% C.L. Details are included in the text.

5.0 Summary and conclusion

Results have been presented for three searches; Leptoquarks, excited quark states and SUSY particles. The search for pair produced first generation scalar Leptoquarks exclude masses up to 133 GeV for $\beta=1$ and 120 GeV for $\beta=0.5$ at the 95% C.L. . Recent calculations of the cross section for the production of vector leptoquarks applied to the same data enable D0 to exclude their produc-

tion to $244 \text{ GeV}/c^2$ for $\beta=1$ and $243 \text{ GeV}/c^2$ for $\beta=0.5$, when $\kappa=1$; for $\kappa=0$, the limits are $193 \text{ GeV}/c^2$ for $\beta=1$ and $189 \text{ GeV}/c^2$ for $\beta=0.5$. A search at CDF for excited quarks decaying into the modes qW and $q\gamma$ excludes, with the simplest model, masses below $540 \text{ GeV}/c^2$ at the 95% C.L. . For the trilepton signature, in the region of μ from -450 to -350 , at $\tan \beta = 4$ and $M(q) = 1.2 M(g)$, \tilde{W} and \tilde{Z} are excluded up to a mass of $50 \text{ GeV}/c^2$, by CDF, implying a limit on the gluino mass of greater than $150 \text{ GeV}/c^2$. A search for $\tilde{W}-\tilde{Z}$ to trileptons is also underway at D0. A search for the scalar top quark at OPAL has excluded its existence in the mass region from 6.3 to $45.0 \text{ GeV}/c^2$ at the 95% C.L. where the mixing angle of the left- and right-handed stop partners is less than 0.85 rad or greater than 1.15 rad, and the mass difference between the stop and the lightest neutralino is greater than 5 GeV .

6.0 References

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