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Search for Supersymmetry and Leptoquark States in DØ

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Abstract

Results are presented on the search for two types of exotic particles. First, a mass limit is given for first generation leptoquarks assuming pair production with the final state being either two electrons and two jets or one electron, a neutrino and two jets. This is followed by the presentation of a preliminary result on a search for the supersymmetric partners of the $W^{\pm}$ and Z^0, the lightest chargino, $\widetilde{W}_1$, and the second lightest neutralino, $\widetilde{Z}_2$ via a trilepton signature.

1. Introduction

Although the standard model seems to explain all experimental observations to date, it has long been held that the story is not complete. The strong similarities between the leptons and quarks as well as the structure of the forces through which they interact suggests that the mass spectrum and other parameters of the standard model may be explainable in terms of some larger, unified theory. Attempts to construct this unified theory frequently require the inclusion of exotic new particles. In the following, results are presented on the search for two different types of such particles — leptoquarks and the supersymmetric partners of the $W^{\pm}$ and Z^0 bosons.

The DØ experiment has just completed its first run at the Fermilab Tevatron Collider. Approximately 16 pb^{-1} of $p\bar{p}$ interactions were recorded at $\sqrt{s}$ = 1.8 TeV. The detector configuration and particle identification capability is described in detail elsewhere [1] and will not be covered here.

2. Search for First Generation Leptoquarks -S_1

In the sense that the $W^{\pm}$ boson couples members of the fermion isospin doublets — i.e. charged leptons to neutrinos, and up-type quarks to down-type quarks — it seemed quite reasonable to ask whether there are similar objects that couple the leptons to the quarks. Such objects, known as leptoquarks, would carry both color and electric charge. They appear naturally in many standard model extensions [2].

Should they exist, the dominant production mechanism for leptoquarks at the Tevatron would be pair production through gluon-gluon and quark-antiquark fusion. The first generation object would then decay into an electron and quark with branching fraction β and into a neutrino and quark with branching fraction $1-\beta$. Hence the expected signatures for a pair would be $e+jet, e+jet$ with probability β^2, $e+jet, \nu+jet$ with probability $2\beta(1-\beta)$

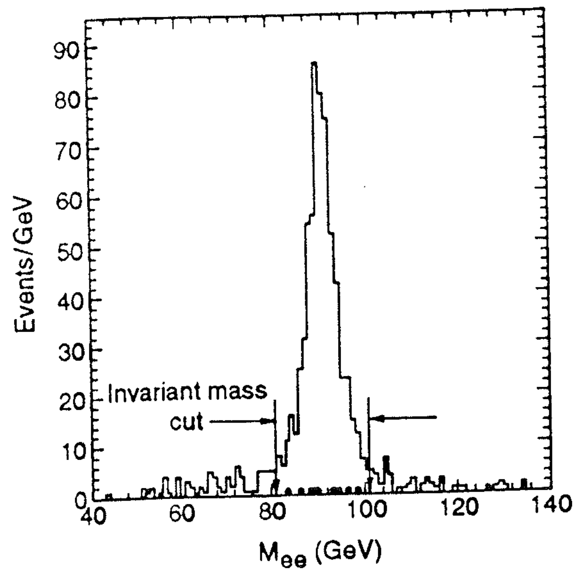

Figure 1: M_{ee} distribution for events with two electrons with $P_t > 25$ GeV/c. Stars denote events that also have two jets with $P_t > 25$ GeV/c. The electron energy scale was set using the mass of the Z^0 boson.

and $\nu + jet, \nu + jet$ with probability $(1-\beta)^2$. Here is reported a final result on the search for these particles using the first two signatures.

2.1 $S_1\bar{S}_1 \to e + jet, e + jet$

For the process where both leptoquarks decay into an electron and quark, events were selected by requiring two electrons with $P_t > 25$ GeV/c and two jets with $P_t > 25$ GeV/c. Electrons were required to pass shape and isolation cuts and jets were reconstructed using a cone of radius $\Delta R = 0.7$. For this channel, one would expect the missing P_t to be consistent with zero, and two electron-jet mass combinations should be equal within detector resolution. However, it turned out that neither of these cuts were required.

After applying these selection cuts 9 events remained. The largest background at this point was expected to be the $Z^0 + two\ jets$ process. The electron pair masses are shown in Fig. 1 for the selected events both before and after the two jet selection. All pairs lie within $\pm$ 10 GeV of the Z^0 peak and are therefore consistent with the expected background. Rejecting events within this range leaves no leptoquark candidates.

Efficiencies were determined using leptoquark events from the ISAJET Monte Carlo generator[3] along with $W^\pm$ and Z^0 events from the data. The Monte Carlo events were passed through a full DØ detector simulation using the GEANT Monte Carlo program [4]. The overall efficiency was determined to vary from 0.62% to 15.5% over the mass range from 45 to 160 GeV. The resulting 95% CL limit on $\sigma \times \beta^2$ as a function of leptoquark mass is shown in Fig. 2.

2.2 $S_1\bar{S}_1 \to e + jet, \nu + jet$

For the case with one electron, one neutrino and two jets, the selection required an electron and two jets, all with $P_t > 20$ GeV/c, and missing $P_t > 40$ GeV/c. The primary backgrounds for this channel include the $W^\pm$ + $jets$ reaction, QCD multi-jet events (with

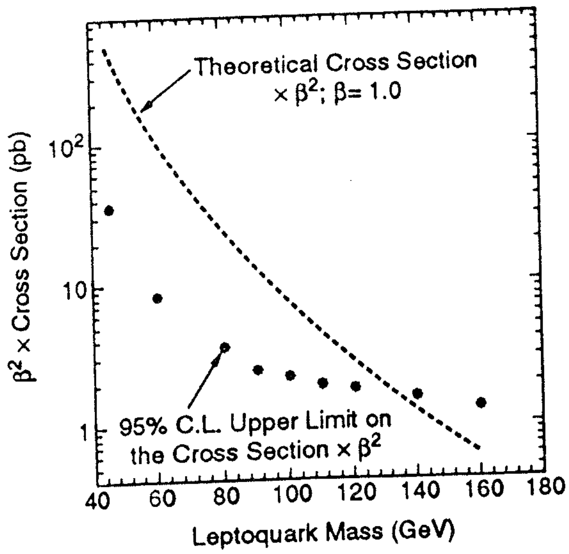

Figure 2: The 95% confidence level limits on the cross section times branching ratio ($\sigma \times \beta^2$) for the two electron plus two jet signature as a function of leptoquark mass. A theoretical prediction of the cross section times branching ratio for $\beta = 1$ is also shown.

poorly measured jets plus a fake electron) and heavy quark events. The electron-neutrino transverse mass for a sample of events passing a less restrictive selection is shown in Fig. 3. To reject events with missing P_t caused by poorly measured jets, the missing P_t vector was required not to lie along the azimuth of any jet. To eliminate heavy quark and $W^{\pm}$ decays to muons, events were rejected with a muons with $P_t > 15$ GeV/c and $|\eta| < 1.2$. After the cuts, 113 events remained with a transverse mass distribution consistent with expected backgrounds. A cut on the transverse mass at 105 GeV eliminated all these events while maintaining good acceptance for the signal. The acceptance was determined to vary from 0.45% to 12.7% over the mass range 45 to 140 GeV. The 95% CL limit resulting from this analysis is shown in Fig. 4.

2.3 Combined Result

Combining the results from the two decay modes using ISAJET cross sections for scalar leptoquarks with the MT-L0 particle distribution function [5] results in a limit in the $\beta - M_{S_1}$ plane as shown in Fig. 5. For the cross section chosen, the 95% CL mass limit is 133 GeV and 120 GeV for $\beta = 1$ and 0.5, respectively. This is a final result and has been submitted for publication.

3. Supersymmetry: Search for $\widetilde{W}_1, \widetilde{Z}_2$

The concept of supersymmetry (SUSY) as applied to extensions of the standard model not only has deep aesthetic appeal — i.e. it relates internal symmetries to spacetime — it also provides a basis for the solution of a wide range of fundamental theoretical problems, from unification of the coupling constants to providing an ideal candidate for the anticipated weakly interacting dark matter. Among the predictions is an approximate doubling of the number of "elementary" particles. Because of the initial state diversity at a $p\bar{p}$ collider, several of these new objects could, in principle, be produced at the Tevatron. Within

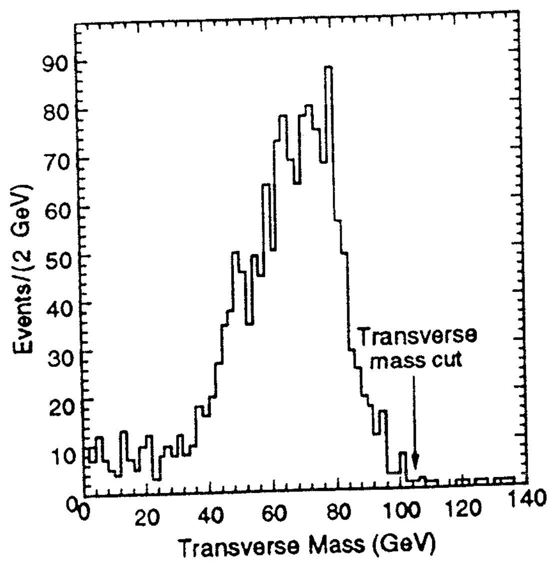

Figure 3: Electron and missing P_t transverse mass distribution for events with an electron with $P_t > 20$ GeV/c, missing $P_t > 20$ GeV/c, one jet with $P_t > 15$ GeV/c, and a second jet with $P_t > 10$ GeV/c.

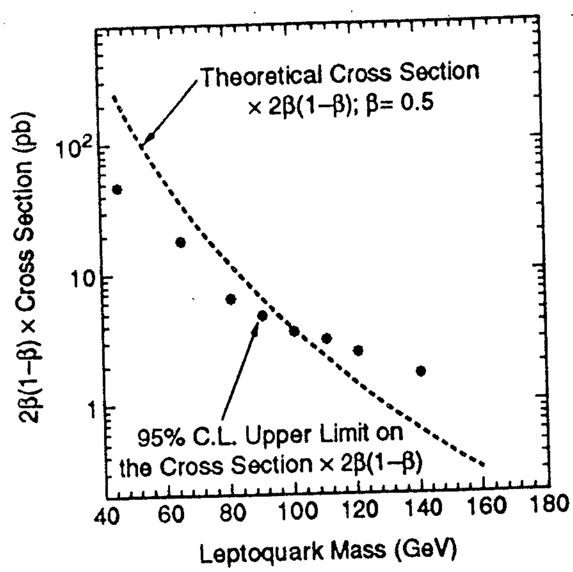

Figure 4: The 95% confidence level limits on the cross section times branching ratio ($\sigma \times 2(1-\beta)\beta$) for the one electron plus two jet plus missing P_t signature as a function of leptoquark mass. A theoretical prediction of the cross section times branching ratio for $\beta = 0.5$ is also shown.

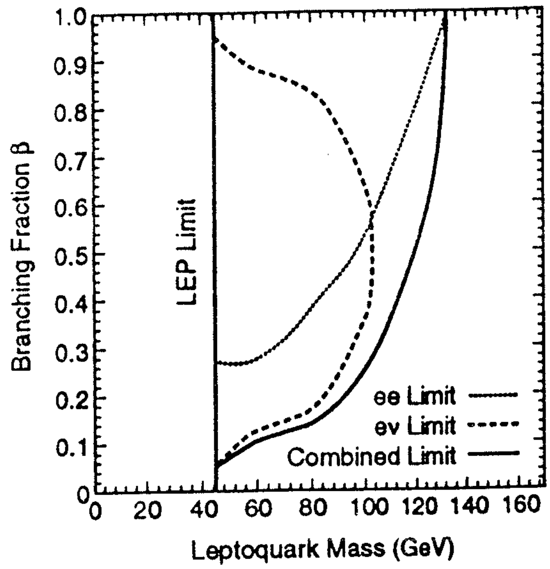

Figure 5: The 95% confidence level lower limit on the leptoquark mass as a function of β. Results are derived using theoretical predictions of the cross section based on ISAJET and the MT–LO particle distribution function.

supergravity models and the minimal supersymmetric standard model (MSSM), well defined relationships exist between SUSY parameters and the masses of the new particles. Also, definite predictions are possible concerning production cross sections and decays. The following analysis is based on these results.

Historically, the strongly interacting squarks and gluino were considered to be the most accessible sparticles at the Tevatron and the well known missing P_t + *jets* analysis has produced significant limits on the existence of these objects [6]. However, it has been realized that the weakly interacting partners of the $W^{\pm}$ and Z^0 bosons — the lightest chargino, $\widetilde{W}_1$, and second lightest neutralino, $\widetilde{Z}_2$, are also potentially observable. Within the MSSM, the masses of these objects obey the rule $M_{\widetilde{W}_1} \approx M_{\widetilde{Z}_2} \approx 2M_{\widetilde{Z}_1}$, where $\widetilde{Z}_1$ is the lightest SUSY particle (LSP) and is assumed to be stable and weakly interacting. The dominant decays of the $\widetilde{W}_1$ include the intermediate states $\widetilde{W}_1 \rightarrow W^*\widetilde{Z}_1$, $l\tilde{\nu}$, $\nu\tilde{l}$, and $q\tilde{q}$, where $\tilde{\nu} \rightarrow \nu\widetilde{Z}_1$, $\tilde{l} \rightarrow l\widetilde{Z}_1$ and $\tilde{q} \rightarrow q\widetilde{Z}_1$. Similarly, $\widetilde{Z}_2 \rightarrow Z^*\widetilde{Z}_1$, $l\tilde{l}$, $\nu\tilde{\nu}$, and $q\tilde{q}$.

Early studies showed [7] that these objects can be produced in the combination $\widetilde{W}_1, \widetilde{Z}_2$ with a sizable cross section at the Tevatron via offshell $W^{\pm}$'s, and that the decay combinations resulting in a trilepton signal had the best chances of being observable from signal to background considerations. More recent theoretical investigations [8][9][10] confirm this and suggest that for some regions of SUSY parameter space the trilepton signal may be the most sensitive probe for supersymmetry at the Tevatron.

The total production cross section for a $\widetilde{W}_1, \widetilde{Z}_2$ pair exceeds the picobarn level for masses up to approximately 100 GeV. However, the branching fraction to trileptons is a function of several SUSY parameters. In particular, because the intermediate states listed above involve $\tilde{l}, \tilde{\nu}$ and $\tilde{q}$, the branching fractions depend strongly on the relative masses of

Process	eee	$ee\mu$	$e\mu\mu$	$\mu\mu\mu$
Trigger	1 EM > 20 or 2 EM > 10	EM > 7, μ > 5 or 2 EM > 20 or EM > 20, $\not\!p_T$ > 20	EM > 7, μ > 5 or μ > 15, μ > 10 or EM > 20, $\not\!p_T$ > 20	1 μ > 15 or 2 μ > 3
Offline Selection	3 e's, > 7 + $\not\!p_T$ > 10	1 μ > 10 + 1 e > 10 + 1 e > 7	1 μ > 10 + 1 e > 10 + 1 μ > 5 + $m_{\mu\mu}$ > 5	e μ's > 5 + $m_{\mu\mu}$ > 5
$\int Ldt$	$(14.8 \pm 1.8)\mathrm{pb}^{-1}$	$(15.2 \pm 1.8)\mathrm{pb}^{-1}$	$(15.2 \pm 1.8)\mathrm{pb}^{-1}$	$(5.0 \pm 0.6)\mathrm{pb}^{-1}$
Result	0 events	1 event	0 events	0 events
Est. Bkg. (PRELIM.)	< 1.1 events	< 0.5 events	< 0.5 events	< 0.2 events

Table 1: Required trigger, offline selection criteria, integrated luminosity, number of events passing selection and estimated backgrounds for the four trilepton combinations. The background estimate for each channel is preliminary.

these objects.

3.1 $\widetilde{W}_1, \widetilde{Z}_2 \rightarrow$ *trileptons : eee, eeμ, e$\mu\mu$, $\mu\mu\mu$*

The expected signal for the trilepton events has four main features: 1) the three leptons tend to be isolated and central; 2) the events should be hadronically quiet; 3) there will be an imbalance in the transverse momentum since a neutrino and two weakly interacting $\widetilde{Z}_1$'s are produced; and 4) the P_t spectrum of the leptons can be relatively soft since the decays are three body decays and a massive $\widetilde{Z}_1$ is included. An example of the lepton P_t and η distributions and the missing P_t spectrum for $M_{\widetilde{W}_1} \approx M_{\widetilde{Z}_2} = 65$ GeV is shown in Fig. 6. In the event selection process, electrons were defined using shape and isolation cuts plus track matching and were required to be moderately central with $|\eta| < 2.4$. Muons were required to pass track quality cuts and either match with a drift chamber track or with an energy deposition in the calorimeter. They were required to be in the region $|\eta| < 1.7$, and to eliminate heavy quarks, the muon and nearest jet were required to have $\Delta R > 0.4$. The jet here was reconstructed with $P_t > 8$ GeV and a cone $\Delta R = 0.5$.

Pending reconstruction of the full data set, the analysis was carried out using a subset of the data that had been filtered and processed with the latest reconstruction program. The lepton P_t cuts and trigger requirements for each of the four channels were selected to be consistent with the cuts already imposed on the data sets. Table 1 gives a summary of the requirements for each of the four channels along with the integrated luminosity and number of events passing selection. The efficiency for each channel was determined using Monte Carlo events generated with the ISASUSY [11] program plus $W^{\pm}$ and Z^0 events from the data.

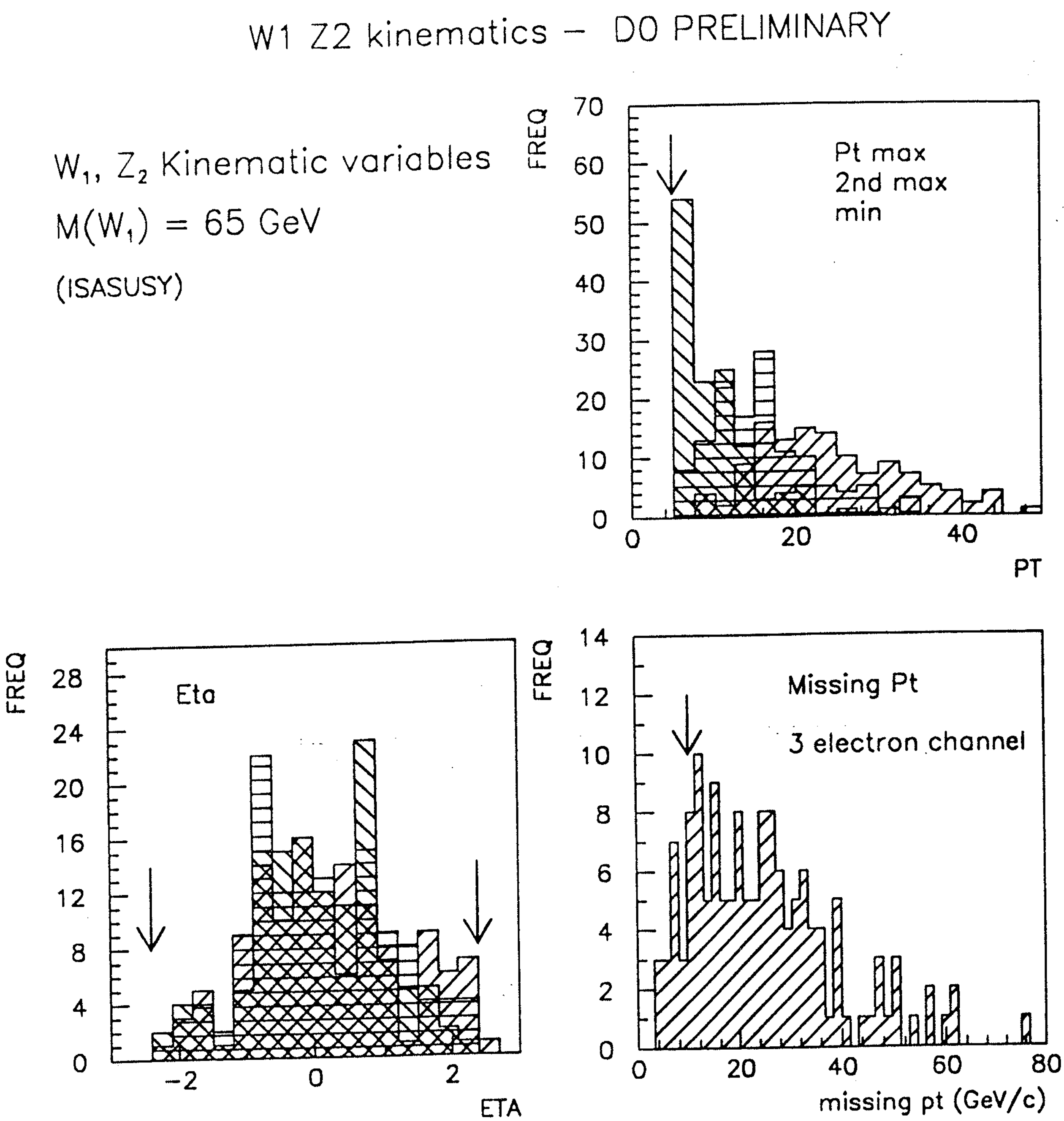

Figure 6: The lepton P_t and η distributions and the missing P_t spectrum for $M_{\widetilde{W}_1} \approx M_{\widetilde{Z}_2} = 65$ GeV

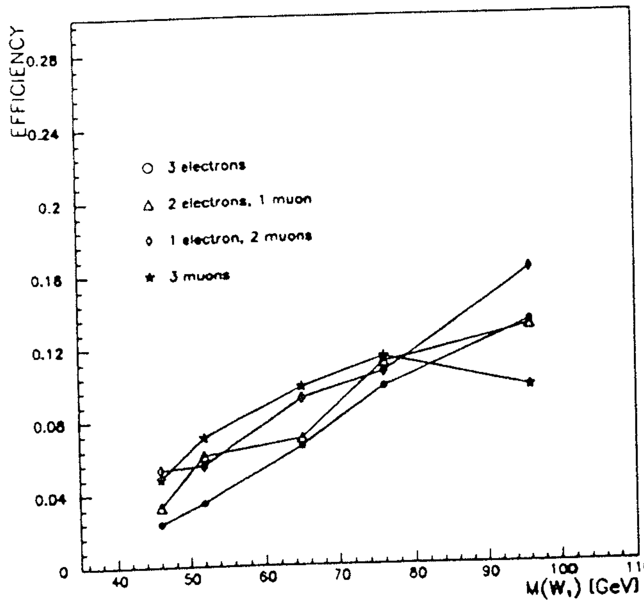

Figure 7: Acceptance for each trilepton combination as a function of $M_{\widetilde{W}_1}$.

These events were passed through a full DØ detector simulation using the GEANT Monte Carlo program. The resulting efficiency for each channel as a function of $M_{\widetilde{W}_1}$ is shown in Fig. 7. A large number of possible backgrounds were investigated for each channel. Included were QCD multi-jet, Drell-Yan + jets, Drell-Yan + gamma, and $W^{\pm}Z^0$ events. For jets, both the probability for producing a fake electron or muon was determined as well as the probability for producing a real isolated electron or muon from heavy quark decays. These probabilities were then multiplied by the appropriate cross sections to estimate the background rates from each combination. Similarly, for gammas, the probability of faking an isolated electron was folded into the relevant cross sections. The cross sections were determined using the ISAJET Monte Carlo program plus the WGAMMA[12] and ZGAMMA[13] generators. The only background with three truly isolated leptons, missing P_t and no intrinsic hadronic activity are $W^{\pm}Z^0$ events, but the rate is estimated to be small. The preliminary estimates at this time suggest that the most serious background comes from the Drell-Yan + gamma events, where a τ pair is produced and both decay into leptons, and the gamma fakes an electron.

As seen in Table 1, one event passes all the cuts in the $ee\mu$ channel. A display of this event is shown in Fig. 8. It contains a muon at $\eta = 1.1$ with measured $P_t = 17.2$ GeV/c and two isolated electromatic objects with η's of 2.0 and 1.9 and P_t's of 37.8 and 8.0, respectively. The missing P_t is (39.1 ± 2.7) GeV/c without, and (23.3 ± 11.6) GeV/c with the muon included. Both electromagnetic objects have good track matches. The muon and leading electron are approximately back-to-back in ϕ and the topology is not inconsistent with the process $Z^0 \rightarrow \tau\tau + \gamma$, $\tau\tau \rightarrow e\mu$, $\gamma \rightarrow$ *fake e*. Approximately 0.3 such events are expected

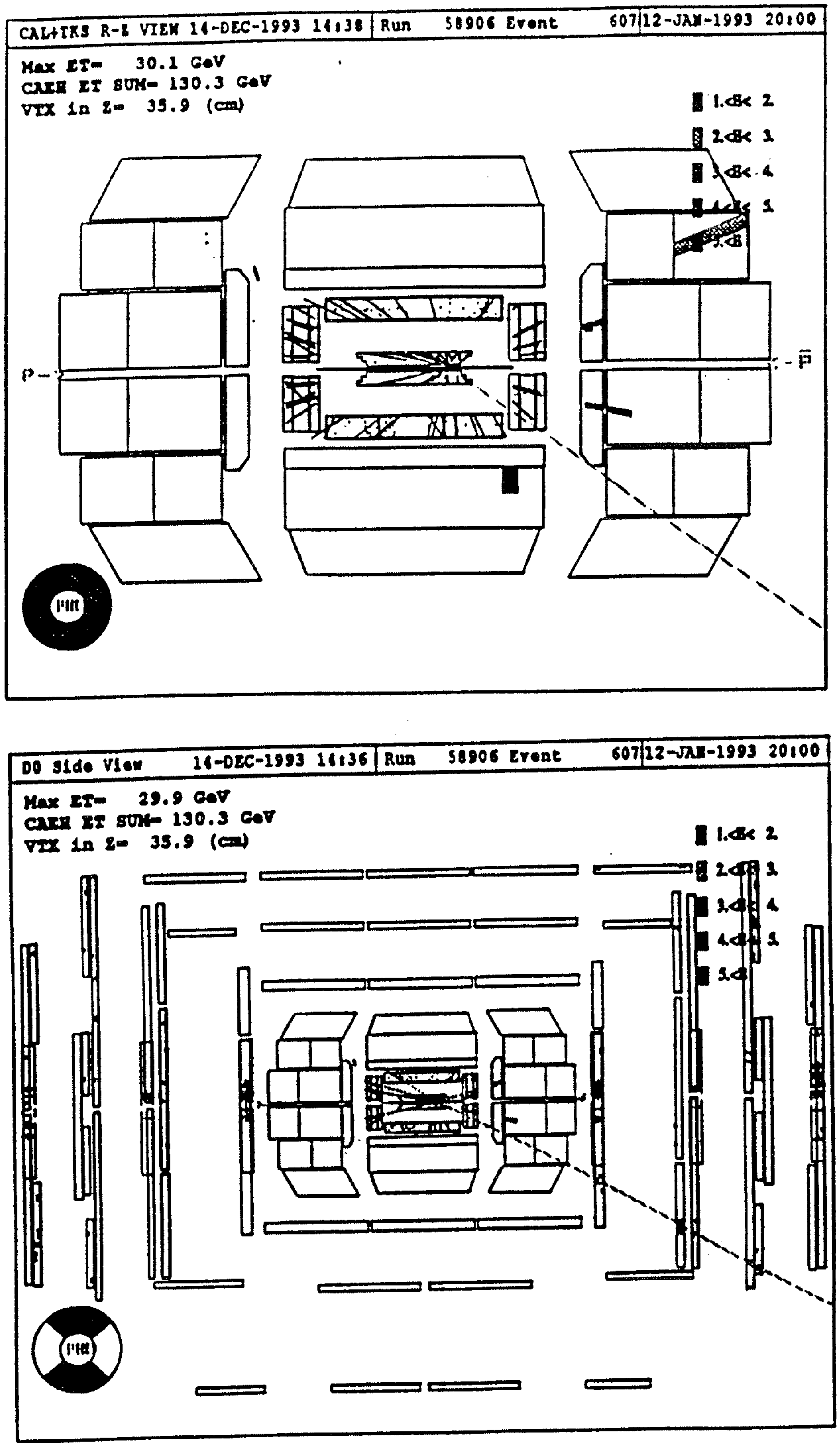

Figure 8: Trilepton $ee\mu$ candidate from the DØ experiment. The muon has $\eta = 1.1$ and the two electron candidates are at $\eta = 2.0$ and 1.9 and can be seen as clusters in the endcap. More details are given in the text.

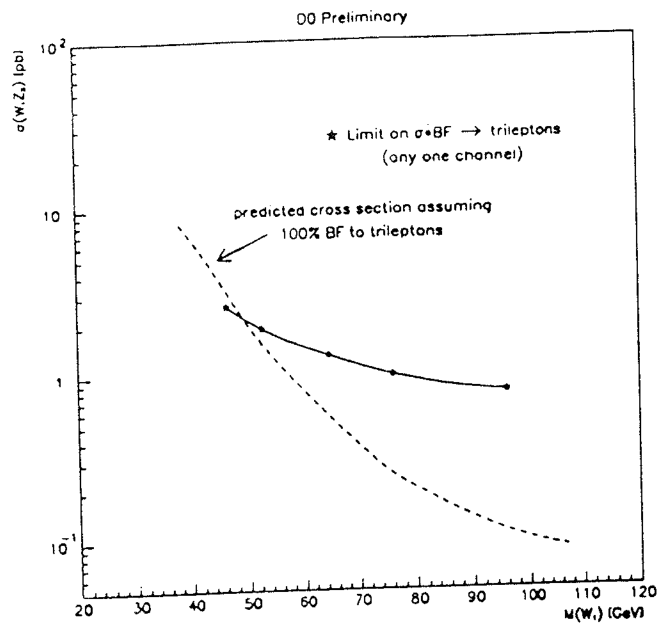

Figure 9: The solid curve represents the 95% limit on $\sigma \times BF \rightarrow$ ***trileptons*** for any one channel. The dashed curve represents the theoretical prediction for any one mode for the case where both the $\widetilde{W}_1$ and $\widetilde{Z}_2$ decay with 100% branching fraction to leptons.

with these cuts.

3.2 Result

The preliminary result is presented in Fig. 9. Shown is the 95% CL limit on $\sigma \times BF \rightarrow$ ***trileptons*** as a function of $M_{\widetilde{W}_1}$ based on the observation of one signal event. This result is calculated as[14]

$$\sigma \times BF_{3\,leptons} = \frac{4.74(1 + 4.74\sigma_T^2/2)}{\sum_{i=1}^{4} \mathcal{L}_i \epsilon_i}$$

where σ_T is the sum of the errors in overall efficiency and luminosity, and $\mathcal{L}_i$ and ϵ_i are the luminosity and efficiency, respectively, for each channel. Note that as calculated, the limit is defined for any one mode.

4. Summary

Final results on a search for first generation scalar leptoquarks have been presented based on 15 pb^{-1} data from run Ia. The 95% confidence level for the excluded mass region is given in Fig. 5. For specific values of the branching fraction to electron plus quark, β, the limits are are $M_{S_1} > 133$ GeV for $\beta = 1$, and $M_{S_1} > 120$ GeV for $\beta = 0.5$.

Preliminary results of a search for $\widetilde{W}_1, \widetilde{Z}_2 \rightarrow$ ***trileptons*** were presented. The main result, Fig. 9, is given in terms of a 95% CL limit on $\sigma \times BF \rightarrow$ ***trileptons*** (any one mode) as a function of the mass of the $\widetilde{W}_1$. This result was determined by combining the four final states eee, , $ee\mu$, $e\mu\mu$ and $\mu\mu\mu$ and is based on a subset of the data from run Ia. The candidate $ee\mu$ event is treated as a signal event in the limit calculation. Analysis of the full data set is in progress.

Run Ib is scheduled to begin this fall and DØ expects to record ≥ 50 pb^{-1} additional data at $\sqrt{s} \approx 2$ TeV. With this data set, we anticipate a factor of $3 \rightarrow 5$ increase in reach for $\widetilde{W}_1, \widetilde{Z}_2 \rightarrow$ *trileptons*.

5. Acknowledgements

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6. References

1. S. Abachi *et al.*, Fermilab-PUB-93/179, to be published in Nucl. Instr. and Meth. **A.**, and references therein.
2. J. Pati and A. Salam, Phys. Rev. D. **10**, 275 (1974); H. Georgi and S. Glashow, Phys. Rev. Lett. **32**, 438 (1974); E. Eichten *et al.*, Phys. Rev. Lett, **50**, 811 (1983); J.L. Hewett and T.G. Rizzo, Phys. Rep. **183**, 193 (1989).
3. F. Paige and S.D. Protopopescu, BNL Report No. 38304, 1986 (unpublished). We use ISAJET V6.49.
4. R.Brun and F.Carminati, CERN Program Library Long Writeup W5013, 1993 (unpublished).
5. J.G. Morfin and W.K. Tung, Z. Phys. C. **52**, 13 (1991); H.Plothow-Besch, Comp. Phys. Comm. **75**, 396 (1993).
6. CDF Collaboration (F. Abe *et al.*), Phys. Rev. Lett. **69**, 3439 (1992).
7. P. Nath and R. Arnowitt, Mod. Phys. Lett. **A2** 331 (1987).
8. R. Barbieri et. al., Nucl. Phys. **B367** 28 (1991).
9. H. Baer and X. Tata, Phys. Rev. **D47**, 2739 (1993).
10. J. Lopez, D. Nanopoulos, X. Wang and A. Zichichi, Phys. Rev. **D48**, 2062 (1993).
11. H. Baer, F. Paige, S. Protopopescu and X. Tata, FSU-HEP-930329 (1993).
12. U. Baur and E. L. Berger, Phys. Rev. **D41**, 1476 (1990).
13. U. Baur and E. L. Berger, Phys. Rev. **D47**, 4889 (1993).
14. R. Cousins and V. Highland, Nucl. Instr. and Meth. **A320**, 331 (1992).