Fermi National Accelerator Laboratory

FERMILAB-Pub-93/070-E
CDF

A Search for First-Generation Leptoquarks in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV

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April 1993

Submitted to *Physical Review D, Rapid Communications*

Disclaimer

CDF/PUB/EXOTIC/CDFR/1978
FERMILAB-PUB-93/070-E

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Submitted to Physical Review D, Rapid Communications, April 1, 1993

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Abstract

We present results of a search for a first-generation leptoquark $\mathcal{S}_1$ in $\overline{p}p$ collisions at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron. Using 4.05 pb^{-1} of data collected during the 1988-89 CDF run, we have searched for evidence of $\mathcal{S}_1\overline{\mathcal{S}}_1$ production assuming that each leptoquark decays to an electron+quark pair with branching ratio β. Three events with two high energy electrons and two high energy jets were found, but are consistent with Z^0 decay. No events were found in the signal region. Assuming a short lived scalar leptoquark with Yukawa coupling strength $\lambda > \mathcal{O}(2 \cdot 10^{-7})$, we exclude $\sigma \cdot \beta^2 > 55(4.0)$ pb at 95% CL for $M_{\mathcal{S}} = 45(125)$ GeV/c^2. Using a Monte Carlo prediction for $\sigma(\overline{p}p \to \mathcal{S}_1\overline{\mathcal{S}}_1 + X)$, we exclude $M_{\mathcal{S}} < 113(80)$ GeV/c^2 for $\beta = 100(50)\%$.

PACS numbers: 14.80.Pb, 12.10.-g

1 Introduction

Leptoquarks belong to a new class of particles carrying both color and lepton quantum numbers that appear in many theories extending the standard model. The observed symmetry in the generation structure of quark and lepton families, leading to two mirror sets of elementary fermions, remains unexplained and suggests that quarks and leptons are related at a fundamental level. Leptoquarks appear in almost any model where a quark-lepton connection is made. Their discovery would deepen our understanding of elementary particle physics, while a determination of their detailed properties would help to distinguish competing models. Several theories place quarks and leptons in the same multiplet of a higher gauge symmetry group such as $SU(4)$ [1], $SU(5)$ [2], and superstring-inspired models based on E_6 [3]. These theories predict new gauge-bosons that can transform quarks into leptons. Models of compositeness, on the other hand, are based on the idea of quark and lepton substructure [4]. In these theories leptoquarks then arise as new 'preon' bound states.

In most models, the leptoquark is a fractionally charged color-triplet boson. Since the lightest leptoquark is usually spin-0, our acceptances and final results are calculated assuming a scalar leptoquark $\mathcal{S}$, although this search is also sensitive to leptoquarks of higher spin. Constraints on leptoquark properties come from limits on rare decays. For example, the $X^{4/3}$ and $Y^{1/3}$ of $SU(5)$ appear to be ruled out by nucleon decay experiments [5]. Limits on rare meson decays such as $K^+ \rightarrow \pi^+ \nu_\mu \bar{\nu}_e$ and $D^0 \rightarrow \mu^+\mu^-$ are consistent with a relatively light leptoquark provided: (i) there are three distinct generations of leptoquark $\mathcal{S}_i (i = 1 - 3)$; (ii) each $\mathcal{S}_i$ couples only to the corresponding generation of quarks and leptons. Under these conditions experimental constraints can be satisfied without requiring large $M_\mathcal{S}$ suppression, thereby making leptoquarks accessible at current energies. At $\bar{p}p$ colliders, color-triplet $\mathcal{S}_1\overline{\mathcal{S}}_1$ pairs can be produced through $\mathcal{O}(\alpha_s^2)$ processes such as $q\bar{q}$ annihilation or gluon-gluon fusion. Unlike $\mathcal{S}_1$ production at ep colliders, these processes are independent of any assumption about the size of the new $eq\mathcal{S}_1$ coupling, λ.

First-generation leptoquarks satisfying the constraints listed above are assumed to decay through one of two possible channels:

$$\mathcal{S}_1 \longrightarrow e^\pm q_1 \quad BR = \beta$$

$$\mathcal{S}_1 \longrightarrow \nu_e q_1^{'} \quad BR = 1 - \beta.$$

The identity of the first-generation quark in the $\mathcal{S}_1$ decay depends upon the $\mathcal{S}_1$ charge assignment. However, since we only observe final state jets, we are insensitive to this choice and for illustration will assume $Q_{\mathcal{S}} = -1/3$. This leads to the decays $\mathcal{S}_1 \rightarrow e^- + u$ $(BR = \beta)$ and $\mathcal{S}_1 \rightarrow \nu_e + d$ $(BR = 1 - \beta)$. The event reconstruction algorithms used later in this analysis limit the $\mathcal{S}_1$ decay length to $c\tau < \mathcal{O}(1mm)$. However, this only weakly constrains our results through the coupling limit $\lambda > \mathcal{O}(2 \cdot 10^{-7})$. The leptoquark mass $M_{\mathcal{S}}$ is unspecified and will be taken as a free parameter. For generality we also consider values of the branching ratio in the range $0 \leq \beta \leq 1$, although in the absence of a right-handed ν_e we expect $\beta \geq 50\%$.

In this paper we present results of a search for a first-generation scalar leptoquark $\mathcal{S}_1$. We look for evidence of the process

$$\overline{p}p \longrightarrow \overline{\mathcal{S}}_1 \mathcal{S}_1 + X \longrightarrow (e^+ \overline{q}_1)(e^- q_1) + X$$

in $\overline{p}p$ collisions at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron. Our analysis is based on 4.05 pb^{-1} of data collected with the Collider Detector at Fermilab (CDF) during the 1988-89 run. Since the number of expected events in the e^+e^-+dijet channel is proportional to β^2, our sensitivity to the signal is maximum for $\beta = 100\%$. Prior to this search, the highest mass limits for the $\mathcal{S}_1$ come from the UA2 collaboration [6], which excludes $M_{\mathcal{S}} < 74(67)$ GeV/c^2 at 95% CL assuming $\beta = 100(50)\%$. Other limits come from LEP where all four experiments have searched for $\mathcal{S}\overline{\mathcal{S}}$ pairs [7]. No evidence for leptoquarks of any generation is found and masses less than around 45 GeV/c^2 are excluded at 95% CL, independent of any branching ratio assumptions.

2 CDF Detector and Data Set

The CDF detector and the data sample used in this analysis have been described in detail elsewhere [8]. CDF is a general purpose detector with almost complete 4π coverage. A set of time projection chambers (VTPC) surrounding the beam pipe allows event vertex reconstruction with charged-particle tracking information over the pseudorapidity range $|\eta| < 3.25$. We define $\eta = -\ln\tan(\theta/2)$ where θ is the polar angle measured from the proton beam. The Central Tracking Chamber (CTC) is a 2.76m diameter cylindrical drift chamber operating inside a 1.412 T solenoidal magnetic field. The CTC tracks charged particles in the central region $|\eta| < 1.1$ and makes precision measurements of the corresponding transverse momenta. In the central region, electromagnetic (CEM) and hadronic (CHA) sampling calorimeters are used with a projective tower segmentation $\Delta\eta \times \Delta\phi = 0.1 \times 15^\circ$. In the plug $(1.1 < |\eta| < 2.4)$ and forward $(2.4 < |\eta| < 4.2)$ regions, calorimeters with a finer tower segmentation $\Delta\eta \times \Delta\phi = 0.1 \times 5^\circ$ are used.

The inclusive high-E_T electron data sample contains 4997 events and corresponds to an integrated luminosity of 4.05 ± 0.28 pb^{-1} [8]. The primary event vertex Z_V must lie within ± 60 cm of the nominal interaction point. We consider candidate electrons to be energy clusters in the CEM with a transverse energy $E_T \equiv E \sin\theta > 20$ GeV, after all calorimeter response corrections have been applied. We also require a CTC track associated with the cluster with a track momentum P consistent with the CEM energy E $(E/P < 1.5)$. We require that the observed pattern of energy deposition in adjacent towers be statistically compatible with lateral energy sharing profiles measured using test-beam electrons. Other cuts are based on the matching between the extrapolated CTC track position and the shower centroid measured at shower-maximum using a set of strip chambers (CES) located within the CEM. The shape of the CES shower profile must also be consistent with profiles obtained under test conditions. To ensure the electron candidate is well separated from any additional energy flow, we impose an isolation cut $I = (E_T^{0.4} - E_T^{cl})/E_T^{cl} < 0.1$. Here $E_T^{0.4}$ is the total transverse energy in a cone of radius $\sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$, centered on the electron, and E_T^{cl} is the transverse EM energy of the electron cluster.

We identify jets using a fixed cone clustering algorithm to locate clusters of calorimeter energy throughout the region $|\eta| < 4.2$. Corrections to the measured jet energy are also made, as described in [9].

3 Analysis

3.1 Monte Carlo Expectations

We use the ISAJET Monte Carlo (MC) [10] to estimate the pair production cross section and to study the detailed properties of the signal for M_S between 45 and 125 GeV/c^2. We use HMRS-B structure functions [11, 12] assuming $\Lambda_4^{QCD} = 190$ MeV. With this choice, we find $\sigma(\overline{p}p \rightarrow S_1\overline{S}_1) = 600(2.5)$pb for $M_S = 45(125)$ GeV/c^2. We also estimate M_S-dependent effective K-factors based on the separate $q\overline{q} \rightarrow S_1\overline{S}_1$ and $gg \rightarrow S_1\overline{S}_1$ K-factors given in Ref.[13]. We find that these range from 1.30 at $M_S = 45$ GeV/c^2 to 1.11 at $M_S = 125$ GeV/c^2. Results will be presented with and without these corrections.

All MC events are passed through the CDF detector simulation and are then subjected to the same event reconstruction algorithms that are applied to the CDF data. As expected from the two-body decay of a massive leptoquark, we find that the electrons and final-state jets are, on average, well separated from each other with mean transverse energies given by $< E_T > \simeq M_S/2$. The electrons and jets are also found predominantly in the central region. We require any electron to be in the fiducial volume of the CEM, PEM, or FEM detectors [8] since through this cut we ensure that the electron energy is well measured.

Backgrounds to the signal are reduced by imposing a series of kinematic and geometric cuts. Standard model processes leading to two high energy electrons and two jets include γ, Z^0+multijet production, and a double semi-leptonic decay of a heavy-quark pair.

A leading source of high energy pairs at CDF is the process $q\overline{q} \rightarrow \gamma, Z^0 \rightarrow e^+e^-$. Higher-order QCD effects can lead to e^+e^-+dijet events. We estimate the differential cross section, $d\sigma/dM_{ee}$, for such processes using the PAPAGENO MC [14] after imposing cuts on the electron and radiated-parton E_T (Fig.1). Requiring $E_T^e, E_T^j > 20$ GeV, we find that by removing any event with $75 < M_{ee} < 105$ GeV/c^2 we eliminate 86% of the γ, Z^0+2jet background. The same dielectron mass cut retains between 74% and 81% of the signal, depending on M_S.

Background events from $b\overline{b}$ production followed by the semi-leptonic decay of both b quarks to electron final states is essentially eliminated by electron-isolation and $E_T^{e,j}$ cuts, and we expect much less than one event in our sample from this source. The contribution from top-quark production however, could contain several events, though no evidence has yet been found for $t\overline{t}$ decays [15].

Based on our MC study of signal and background, we apply the following set of cuts to any candidate event: (i) require at least two jets and two electrons, each with corrected $E_T > 20$ GeV; (ii) require that both electrons are in the fiducial part of the detector with at least one candidate in the CEM; the acceptance for this cut is found to be 90(96)% for $M_S = 45(125)$ GeV/c^2; (iii) demand that both electrons be isolated with $I < 0.1$ and that they must pass quality cuts such as those described in Sec.II; (iv) remove electron pairs with $75 < M_{ee} < 105$ GeV/c^2; (v) require $|Z_V| < 60$ cm. The cross section, signal acceptances, and the total number of expected events in our data sample after all cuts (assuming $\beta = 100\%$) are presented in Table I.

3.2 CDF Data

We require at least two isolated electron candidates in the fiducial region with $E_T > 20$ GeV. This rejects 95% of the data sample and leaves 267 events. Though we expect the electrons to be oppositely charged for both signal and background processes, no explicit check of this assumption is made. However, around 87% of the remaining events appear to be consistent with Z^0 decay, having $75 < M_{ee} < 105$ GeV/c^2. We define a leptoquark signal(background) region as the set of events with $E_T^{j1,j2} > 20$ GeV, $E_T^{e1,e2} > 20$ GeV, and M_{ee} outside(inside) the range $75 - 105$ GeV/c^2. Applying all cuts to the data leaves 3 events in the background region and 0 events in the signal region. Lowering the jet-E_T cut to 15-GeV to increase acceptance for low values of M_S, we find 8 Z^0 candidate events and 1 signal event at $M_{ee} = 54$ GeV/c^2. These numbers, and those predicted by PAPAGENO, are summarized in Table II. The first uncertainty quoted on the MC rates arises from statistical and CDF acceptance uncertainties, while the second reflects an assumed 25% theoretical uncertainty on the normalization of the PAPAGENO cross section.

With zero events observed in the signal region we evaluate 95% CL limits on the production cross section $\sigma(\mathcal{S}_1\overline{\mathcal{S}}_1) \cdot \beta^2$, given by

$$\sigma \cdot \beta^2(95\%CL) < \frac{N_{95}}{\mathcal{L} \cdot A}.$$

The parameter N_{95} is the maximum number of events in our data sample that would be statistically compatible at 95% CL with our observation of zero events, $\mathcal{L}$ is the integrated luminosity (4.05 pb^{-1}), and A represents the $M_{\mathcal{S}}$-dependent signal acceptance. To evaluate N_{95}, we convolute a Poisson distribution with a Gaussian whose width reflects the overall systematic and statistical uncertainties present in our acceptance estimate. Systematic errors arise from: (i) integrated luminosity uncertainty, (ii) choice of structure function, (iii) uncertainties on the electron quality cut efficiencies, and (iv) jet-energy correction uncertainties. At low $M_{\mathcal{S}}$ the jet energy-scale uncertainty is the leading source of systematic uncertainty on the acceptance (26.1(3.6)% at $M_{\mathcal{S}} = 45(125)$ GeV/c^2), while at high $M_{\mathcal{S}}$ the 6.9% uncertainty on $\mathcal{L}$ dominates. The effects of structure function choice on the acceptance were estimated using three different parameterizations taken from PDFLIB [12]. We add all uncertainties in quadrature. The combined errors $\Delta A/A$ and the corresponding limits on $\sigma \cdot \beta^2$ are given in Table I. These results are also shown in Fig.2, as is the ISAJET prediction for $\beta = 100\%$. We exclude $M_{\mathcal{S}} < 113$ GeV/c^2 at 95% CL, or 116 GeV/c^2 using the higher-order K-factor

Using ISAJET values for $\sigma(\mathcal{S}_1\overline{\mathcal{S}}_1)$ we extract limits on β as a function of $M_{\mathcal{S}}$ from

$$\beta^2(95\%\text{CL}) < \frac{N(95\%\text{CL})}{N(\text{MC}; \beta = 100\%)}.$$

The results are shown in Fig.3.

4 Conclusions

We find no evidence for $\mathcal{S}_1\overline{\mathcal{S}}_1$ production. There are no candidate events found in our signal region, while the three events in the background region are consistent with Z^0+multijet production. Based on an observation of zero events, we set limits on the $\mathcal{S}_1\overline{\mathcal{S}}_1$-pair production cross section $\sigma \cdot \beta^2 < 54.6(4.0)$ pb for $M_{\mathcal{S}} = 45(125)$ GeV/c^2 at 95% CL. Using the ISAJET LO cross section we find $M_{\mathcal{S}} > 113$ GeV/c^2 for $\beta = 100\%$, or 116 GeV/c^2 using a higher-order K-factor. For $\beta = 50\%$ we exclude $M_{\mathcal{S}} < 80(86)$ GeV/c^2 at leading(higher)-order. At $M_{\mathcal{S}} = 45$ GeV/c^2 we find $\beta > 30(26)\%$ at leading(higher)-order.

ACKNOWLEDGEMENTS

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. We also thank JoAnne Hewett for useful discussions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Science, Culture, and Education of Japan; the Natural Sciences and Engineering Research Council of Canada; and the A. P. Sloan Foundation.

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[1] J.Pati and A.Salam, Phys.Rev.D **10**, 275 (1974).

[2] H.Georgi and S.Glashow, Phys.Rev.Lett. **32**, 438 (1974).

[3] J.L.Hewett and T.G.Rizzo, Phys.Rep. **183**, 193 (1989).

[4] E.Eichten *et al.*, Phys.Rev.Lett **50** 811 (1983).

[5] IMB Collaboration, R.Becker-Szendy *et al.*, Phys.Rev.D **42**, 2974 (1990).

[6] UA2 Collaboration, J.Alitti *et al.*, Phys.Lett.B **274**, 507 (1992).

[7] L3 Collaboration, B.Adeva *et al.*, Phys.Lett.B **261**, 169 (1991); OPAL Collaboration, G.Alexander *et al.*, Phys.Lett.B **263** 123 (1991); DELPHI Collaboration, P.Abreu *et al.*, Phys.Lett.B **275** 222 (1992) ; ALEPH Collaboration, D.Decamp *et al.*, Phys.Rep.C **216**, 253 (1992).

[8] CDF Collaboration, F.Abe *et al.*, Phys.Rev.D **44**, 29 (1991).

[9] CDF Collaboration, F.Abe *et al.*, Phys.Rev.Lett. **69**, 2896 (1992)

[10] F.Paige and S.D.Protopopescu, Brookhaven National Laboratory Report No. BNL 38034, 1986 (unpublished). V6.36 was used to generate the $\mathcal{S}_1\overline{\mathcal{S}}_1$ event samples.

[11] P.N.Harriman *et al.*, Phys.Rev.D **42** 798 (1990).

[12] H.Plothow-Besch, PDFLIB Library, CERN-PPE/92-123, (1992) (submitted to Comput.Phys.Commun.).

[13] M. de Montigny and L.Marleau, Phys.Rev.D **40** 2869 (1989) ; *ibid.* **40**, 3616 (1989).

[14] I.Hinchliffe (private communication). V3.41 was used.

[15] CDF Collaboration, F.Abe *et al.*, Phys.Rev.D **45**, 3921 (1992).

$M_{\mathcal{S}}$ (GeV/c^2)	45	65	85	105	125
σ_{MC} (pb)	600	95	22	6.9	2.5
A (%)	1.6	6.6	12	15	19
$\Delta A/A$ (%)	30	20	13	11	9
N_{TOT}	39	25	11	4.3	1.8
$\sigma \cdot \beta^2$ (pb)	55	12	7.1	5.0	4.0

Table 1: Predicted $\mathcal{S}_1\overline{\mathcal{S}}_1$ production cross section (σ_{MC}), event acceptances (A), combined systematic and statistical acceptance uncertainties ($\Delta A/A$), total number of expected events (N_{TOT}) in CDF data for $\beta = 100\%$, and CDF limits on $\sigma \cdot \beta^2$.

E_T^e (GeV)	E_T^j (GeV)	Observed (Predicted) Under Z-peak	Observed (Predicted) Outside Z-peak
20	20	3 $(4.2 \pm 0.5 \pm 1.1)$	0 $(0.7 \pm 0.1 \pm 0.2)$
20	15	8 $(8.0 \pm 1.0 \pm 2.0)$	1 $(1.2 \pm 0.1 \pm 0.3)$

Table 2: Number of observed and predicted e^+e^-+dijet events in CDF data as a function of transverse energy cuts for electrons (E_T^e) and jets (E_T^j).

Figure Captions

Fig.1: $d\sigma/dM_{ee}$ for γ, Z^0 + 2jet events calculated using the PAPAGENO MC. Kinematic cuts are: (a) $E_T^e > 20$ GeV and $E_T^j > 15$ GeV (b) $E_T^e > 20$ GeV and $E_T^j > 20$ GeV.

Fig.2: Upper Limits on $\sigma(\mathcal{S}_1\overline{\mathcal{S}}_1)\cdot\beta^2$ at 95% CL where $\beta = BR(\mathcal{S}_1 \rightarrow e + q_1)$. Also shown is the ISAJET prediction using HMRS-B structure functions and $\beta = 100\%$. The dot-dash curve shows the effect including the higher-order K-factor.

Fig.3: Limits on the $\mathcal{S}_1$ mass as a function of β. Results are derived from Fig.2 assuming the ISAJET cross section values.

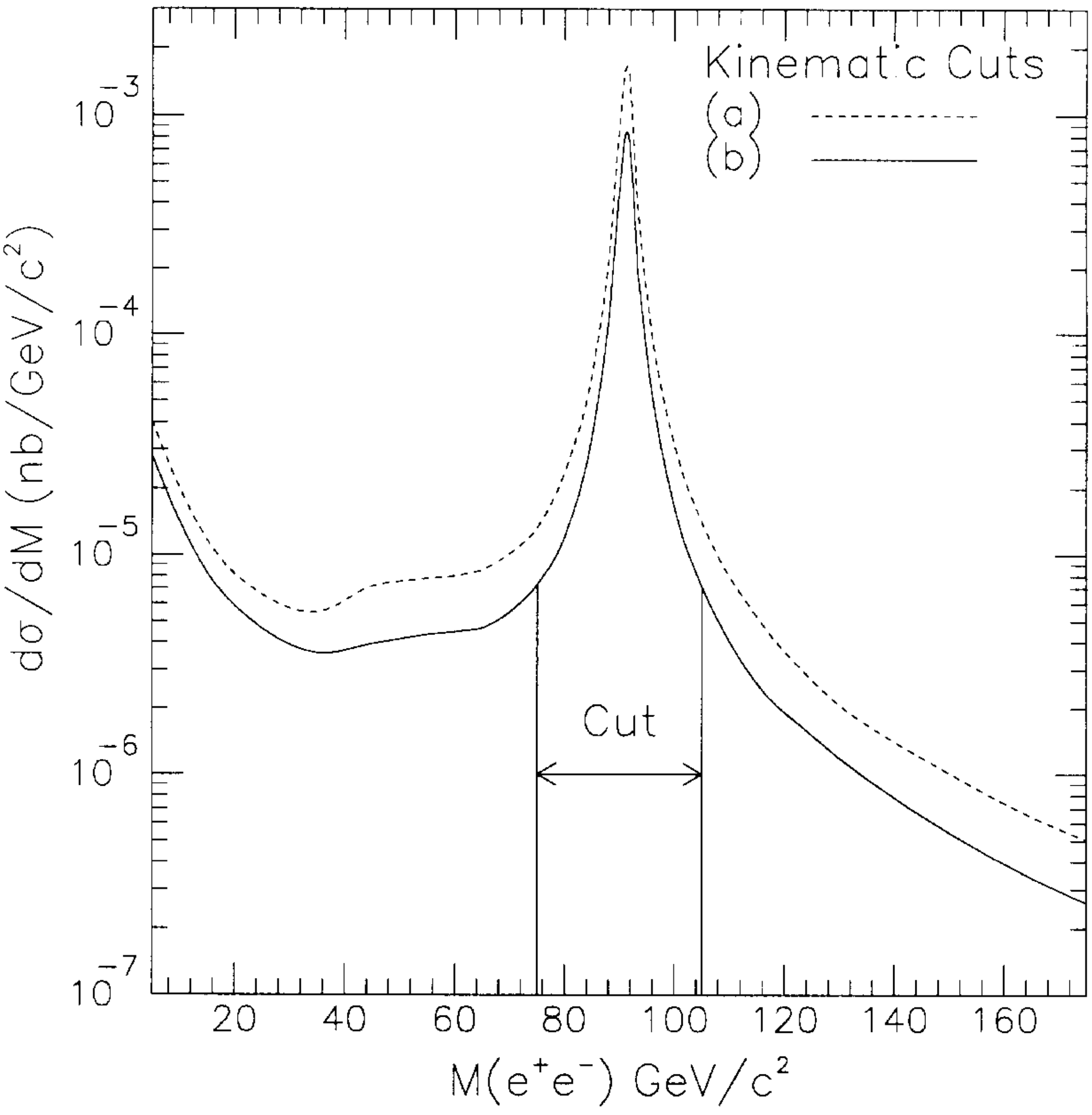
Kinematic Cuts
(a)
(b)
Cut
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
20
40
60
80
100
120
140
160
$d\sigma/dM$ (nb/GeV/c^2)
$M(e^+e^-)$ GeV/c^2

Figure 1

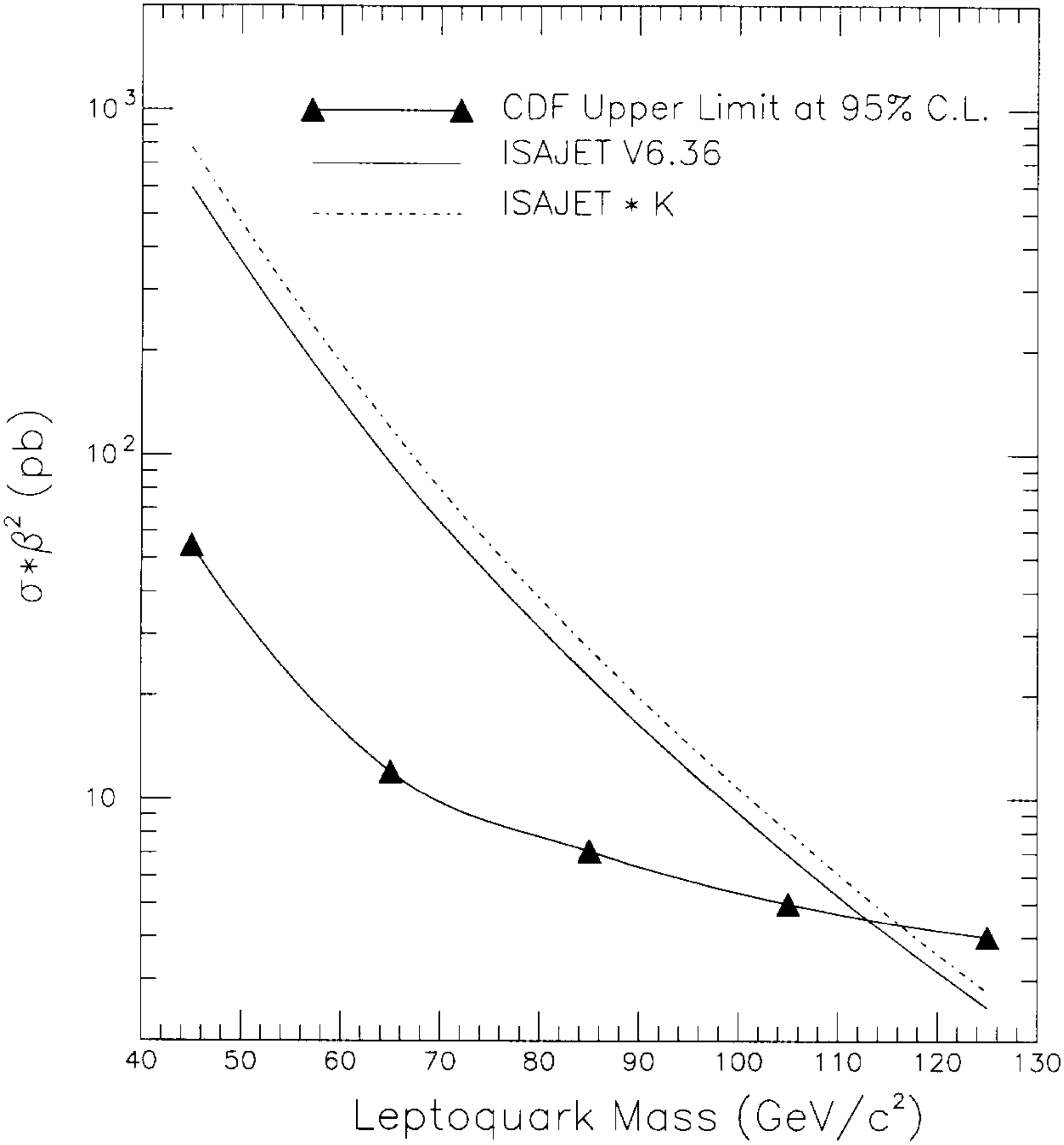
CDF Upper Limit at 95% C.L.
ISAJET V6.36
ISAJET * K
10^3
10^2
10
$\sigma * \beta^2$ (pb)
40
50
60
70
80
90
100
110
120
130
Leptoquark Mass (GeV/c^2)

Figure 2

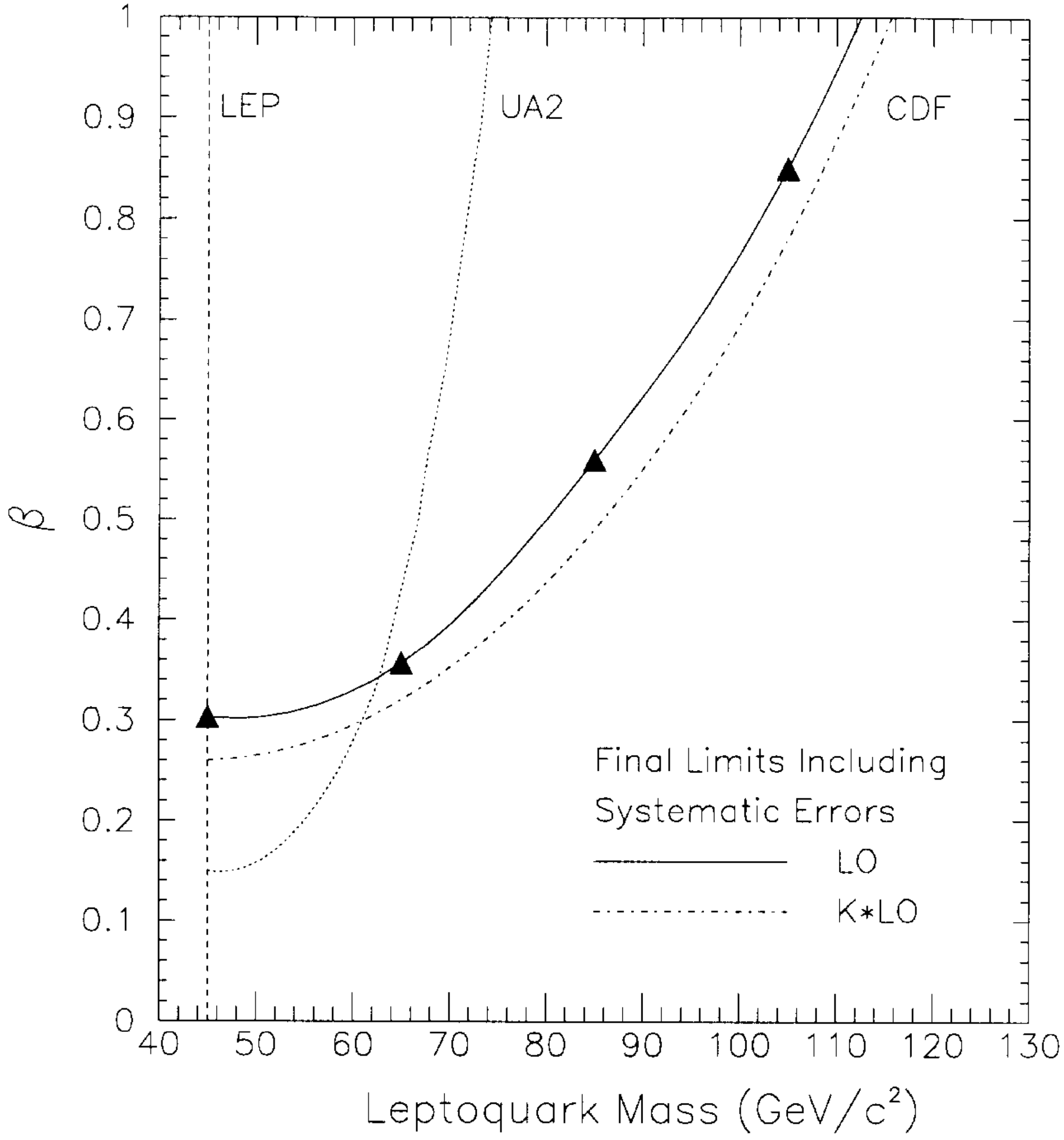
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
β
40
50
60
70
80
90
100
110
120
130
Leptoquark Mass (GeV/c²)
LEP
UA2
CDF
Final Limits Including
Systematic Errors
LO
K∗LO

Figure 3