Search for Leptoquarks, Technicolour and Other Exotica at DØ

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DØ Searches Covered

- Searches motivated by specific theoretical models:
  - Leptoquarks in the 2 jets + MET mode
    - hep-ex/0106065
  - Technicolour: $\omega_T, \rho_T, Z' \rightarrow e^+e^-$
    - hep-ex/0102048
- General search aimed at any new physics:
  - Sleuth: A multi-variate, quasi-model independent algorithm for finding anomalous events
    - Phys. Rev. D 62, 92004 (2000)
    - hep-ex/0011067
    - Phys. Rev. Lett. {86}, 3712 (2001)

Leptoquarks $\rightarrow \nu\nu$ + jets

- Search for both scalar and vector LQs

$$p\bar{p} \rightarrow g \rightarrow LQ\overline{LQ}$$

  - Scalar production independent of couplings
  - Vector production consider:
    - Yang-Mills (YM), minimal coupling (MC) and minimal cross-section (σ_{min})
- $\int Ldt = 85.2 \pm 3.7\ pb^{-1}$
- Selection criteria used are:
  - 2 jets with $E_T > 50$ GeV
  - Missing $E_T > 40$ GeV
  - $\Delta\varphi(jet, MET) > 30°$
  - $\Delta R(jet, jet) > 1.5$ [$\Delta R = \sqrt{(\Delta\varphi^2 + \Delta\eta^2)}$]

Backgrounds + Analysis

- W+Z SM backgrounds from
  - jets and neutrinos processes
  - unobserved charged lepton
  - electron → jet mis-identification
- Multi-jet background
  - Mis-measured jet energy and/or vertex position
- Top background from tt and tb production
  - Unobserved charged lepton+MET+jets
- JETNET neural network program to improve S/B
  - Optimized for 100GeV/c^2 scalar & 200GeV/c^2 vector LQ
    - These would give ~2σ excess if present

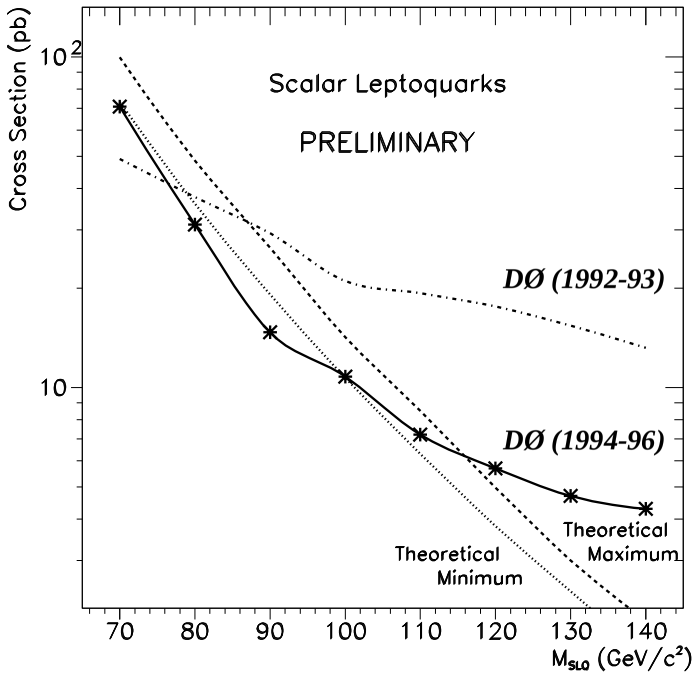
Total Background $= 242.0 \pm 18.9^{+23.3}_{-19.0}$

Data $= 231$

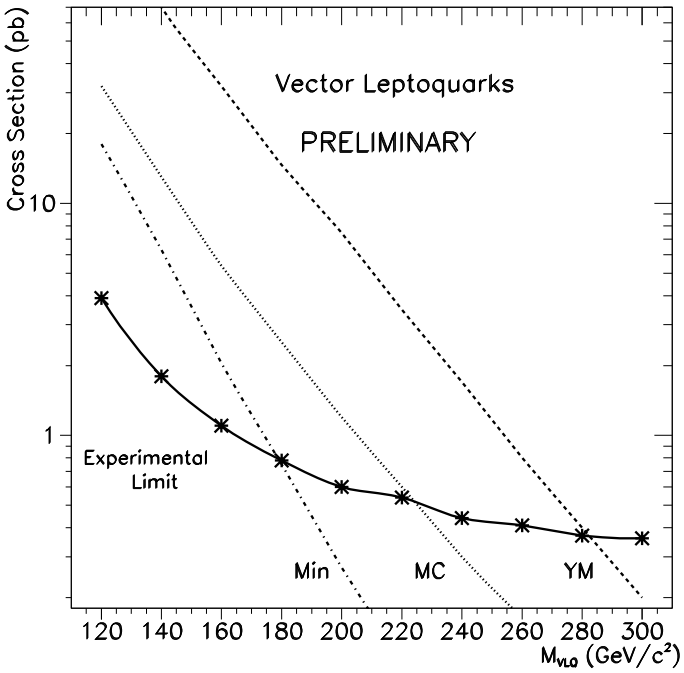
Limits (All generations)

Assume BR(LQ→l±q)=0% i.e. BR(LQ→νq)=100%

Scalar Leptoquarks



Vector Leptoquarks



Scalar: M_{LQ} > 99 GeV/c^2

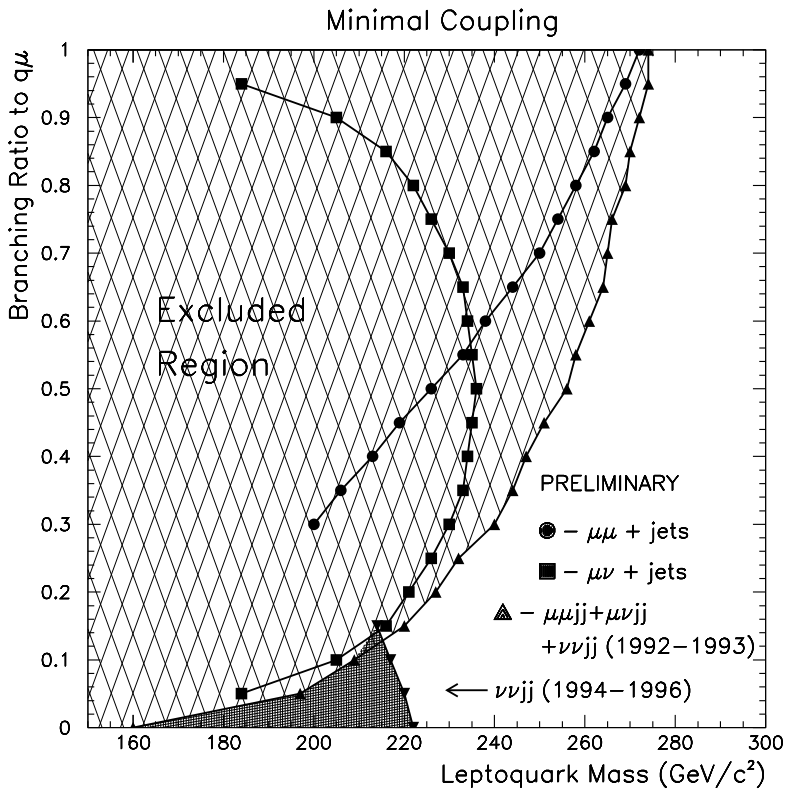
all @ 95% CL

Vector:
M_{LQ} > 178 GeV/c^2 (σ_{min})
M_{LQ} > 222 GeV/c^2 (MC)
M_{LQ} > 282 GeV/c^2 (Y-M)

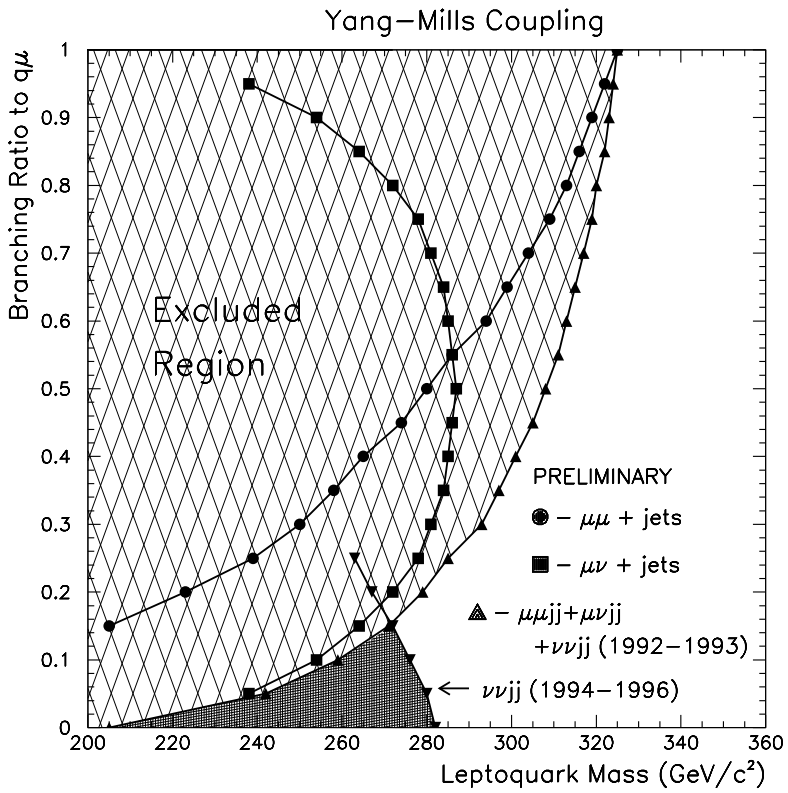
DØ Combined Limits

Limits on 2nd Generation vector leptoquarks: BR vs M

Minimal Coupling



Yang-Mills Coupling

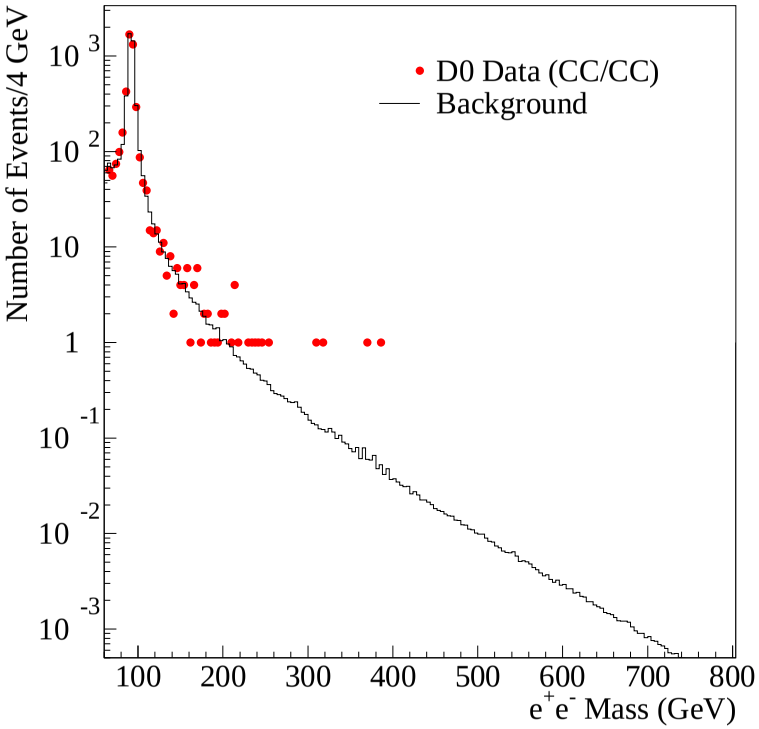


Heavy Particles $\rightarrow e^+e^-$

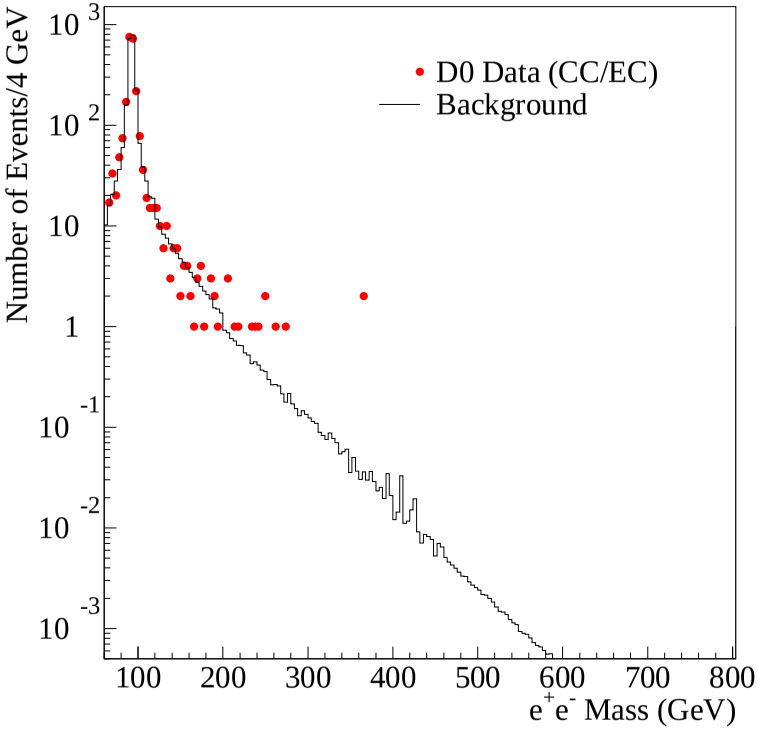
- Primary theoretical models
  - Techni-omega(ω_T), Techni-rho(ρ_T), $Z' \rightarrow e^+e^-$
- Dominant SM backgrounds
  - Drell-Yan process (via γ^* or Z^*)
  - Jets mis-identified as electrons
    - Di-jet events (both jets $\Rightarrow e$)
    - W($\rightarrow e\nu$)+jets (1 jet $\Rightarrow e$)
    - γ +jets (γ+jet $\Rightarrow e$)
- Two types of events considered
  - CC/CC: both e in central calorimeter ($|\eta|<1.1$)
    - $\varepsilon=0.814 \pm 0.014$
  - CC/EC: one central, one forward ($1.5<|\eta|<2.5$)
    - $\varepsilon=0.479 \pm 0.010$

Di-Electron Mass Spectrum

CC/CC Events



CC/EC Events



$\int L\,dt = 125\ pb^{-1}$ 2 isolated $e^{\pm}$ p_T>25 GeV/c

Comparison and Limits

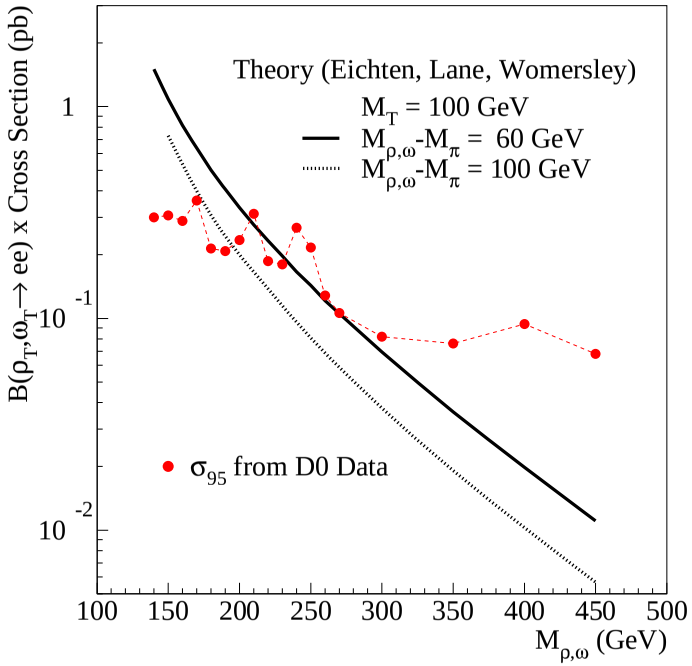
- Data agrees well with SM

Mass Region	Expected	Observed
>100GeV/c^2	609±73	571
>200GeV/c^2	26±3.4	32
>300GeV/c^2	4.7±0.6	6
>400GeV/c^2	1.1±0.1	0

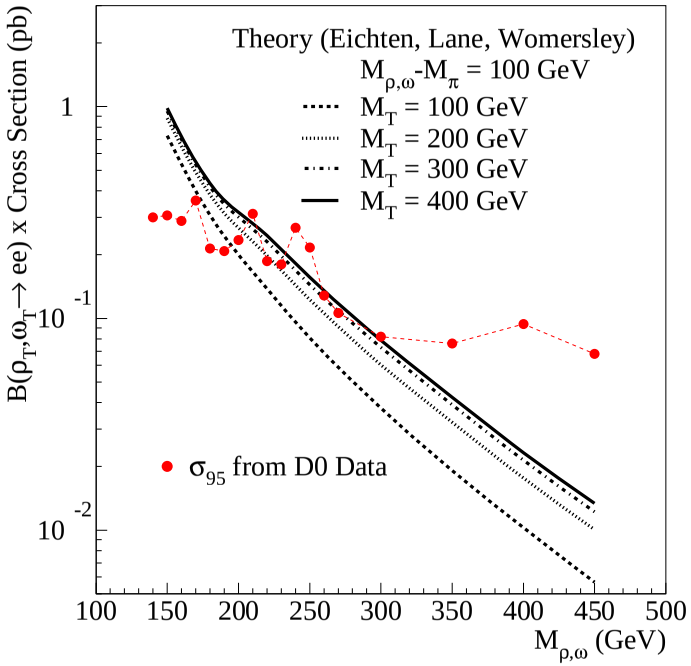
- Limits depend on
  - $M_\rho - M_\pi > M_W$ since $\rho_T \rightarrow \pi_T + W$
  - BR($\omega_T \rightarrow \pi^0_T + \gamma$) which depends on M_T
    - Scaling $\omega \rightarrow \pi^0 + \gamma$ gives M_T ~ few 100GeV/c^2
  - Assume $M(\omega_T) = M(\rho_T)$

ω_T, ρ_T Limits

Limit as $M_\rho - M_\pi$ varies



Limit as M_T varies



For $M_\rho - M_\pi < M_W$:

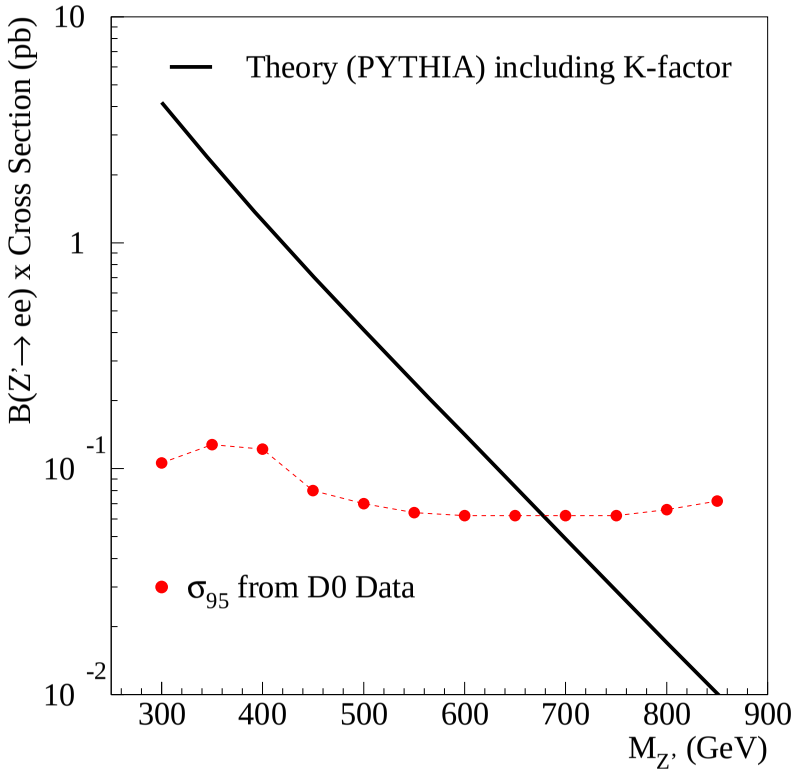
$M(\omega_T, \rho_T) > 207$ GeV/c^2

For $M_T > 200$ GeV/c^2:

$M(\omega_T, \rho_T) > 203$ GeV/c^2

Z' Limit

- No unique prediction for Z' couplings
  - Assume same as standard model Z
  - $\Gamma(Z')$ scales $\propto M_{Z'}$
- With assumptions:
  - Z' excluded below a mass of 670GeV/c^2 @ 95% CL



Sleuth

- Generic algorithm designed to search for new physics in a model independent way
  - Define region, R, about any set of N data points
  - Estimate the background expected within R
  - Calculate the probability that the background fluctuates up to N ($=p^R_N$)
  - Determine the region for which p^R_N is a minimum
  - Determine the fraction of hypothetical similar experiments for which $p_N(HSE) < p_N(data)$
  - Determine the N for which P_N is minimized. Define $P=\min(P_N)$
  - Determine the fraction, $\wp$, of HSEs for which $P(HSE) < P(data)$

Defining a Region

- Region around N data points defined as area closer to those points than to others
  - Use transformed variable space where background is uniformly distributed within the unit hypercube ($[0,1]^d$)
- Constraints applied to reduce possibilities
  - Must be connected
  - Must be convex i.e. no 'tentacles'
- Heuristic employed to further reduce possibilities
- Hypothetical experiments
  - random number of background events uniformly distributed in search area

Applying to Data

- Four groups of final states are considered
  - 1 electron + 1 muon [$e\mu X$]
  - 1 lepton, missing ET, 2+ jets [W+jets]
  - 2 same flavour leptons + jets [Z+jets]
  - Sum of leptons+photons > 3 [$3(e/\mu/\gamma)X$]

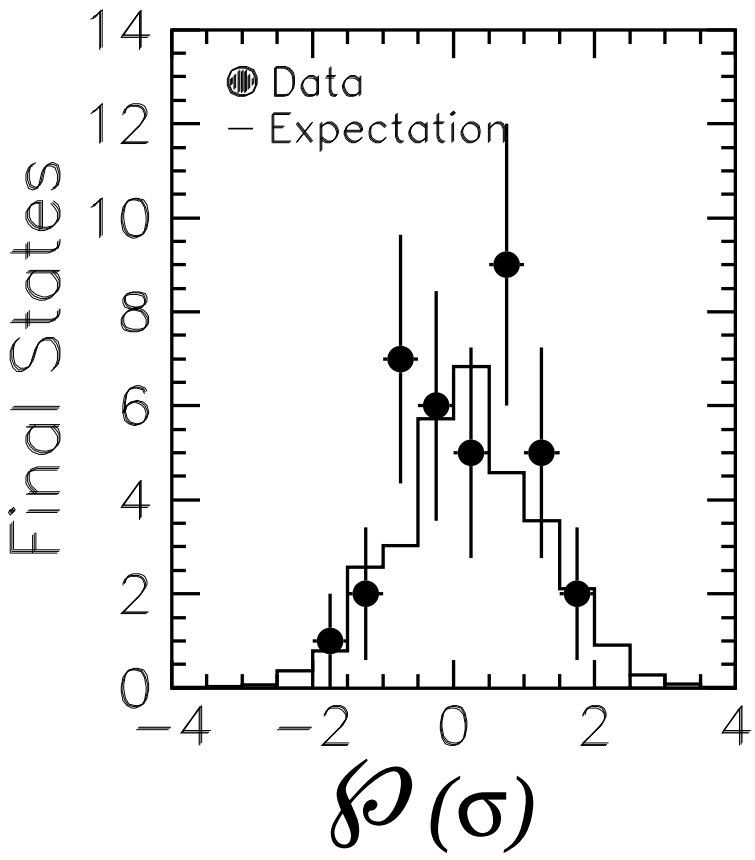
  $\Rightarrow$**32 final states in total**
- Variables used (when applicable)

1+ charged leptons: $\sum p_T^{l}$ | 1+ EW bosons: $\sum p_T^{\gamma/W/Z}$ | $\not\!\!E_T$

1 jet: $p_T^{j_1}$ | n ≥ 2 jets in FS: $\sum_{i=2}^{n} p_T^{j_i}$ | n ≥ 3 jets ONLY in FS: $\sum_{i=3}^{n} p_T^{j_i}$

Results

- Good agreement with SM backgrounds
  - Histogram $\wp$ for all final states
  - Good agreement with expected deviations
- Combining all $\wp$ gives
  - 89% probability that hypothetically similar experimental runs give candidate signal data more interesting than the most we observed

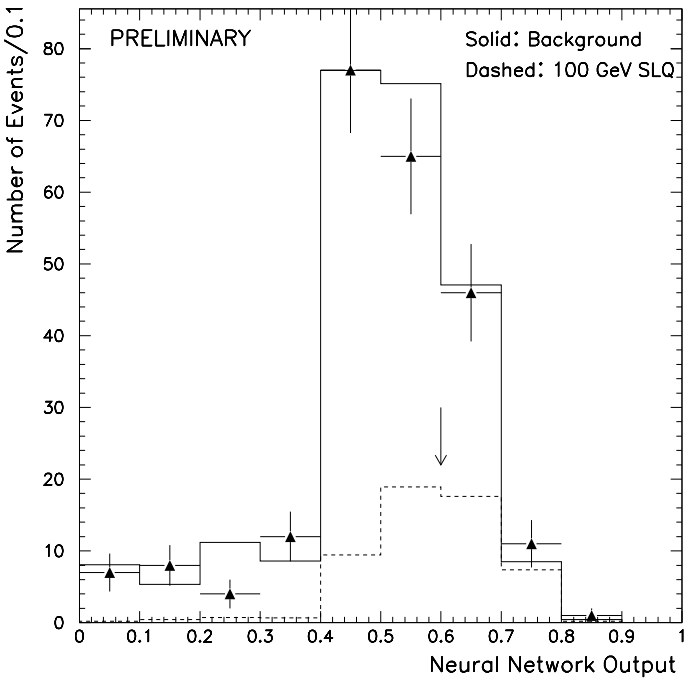


LQ Backgrounds

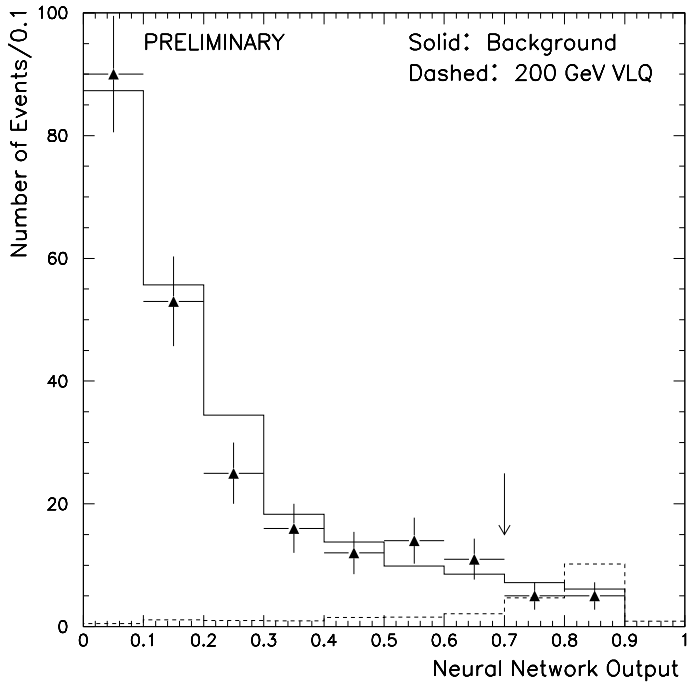
- W+Z SM backgrounds from
  - Processes with jets and neutrinos
    - $W \rightarrow \tau_h \nu_\tau$ + jet $Z \rightarrow \nu\nu$ + 2 jets
  - Processes with unobserved charged lepton
    - $W \rightarrow l^{\pm}\nu$ + 2 jets $Z \rightarrow \mu\mu$ + 2 jets …etc
  - Processes with electron → jet mis-identification
    - $W \rightarrow e\nu_e$ + jet $W \rightarrow \tau_e \nu_\tau$ + jet
- Multi-jet background
  - Mis-measured jet energy
    - Drop events with $\Delta\varphi$(jet 2,MET) < 60°
  - Vertex mis-measurement
    - Use jet tracks and require jet vertex <15cm from event vertex

Neural Network Output

Scalar Leptoquarks



Vector Leptoquarks

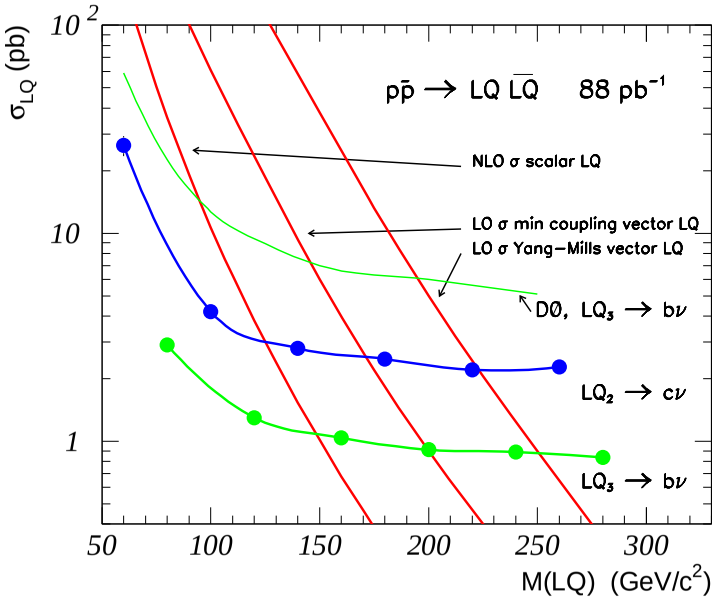


Cuts maximize inverse of fractional error:

$$n_\sigma = \frac{N_{LQ}}{\sqrt{N_{LQ} + N_{bckgrd} + \Delta N_{LQ}^2 + \Delta N_{bckgrd}^2}}$$

CDF LQ Results

2nd & 3rd LQ Generation CDF Limits



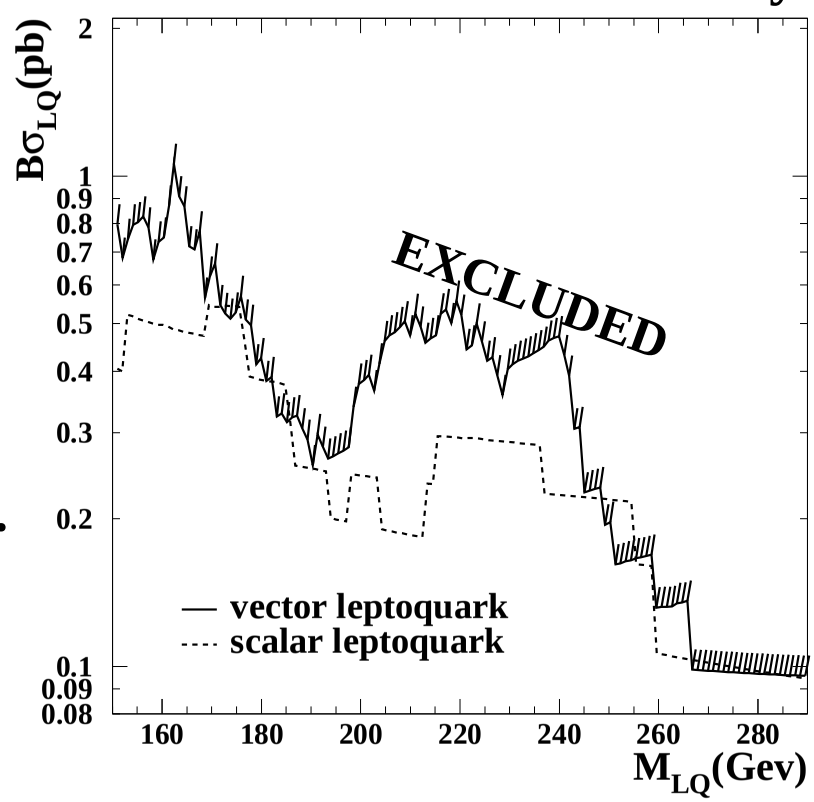
hep-ex/0010064

- Search for MET + 2 jets at CDF
  - Identify jet flavour (initial b or c quark)
- Scalar LQ 95% CL
  - M_{LQ2}>123 GeV/c^2
  - M_{LQ3}>148 GeV/c^2
- Vector LQ 95% CL
  - Minimal coupling
    - M_{LQ2}>171 GeV/c^2
    - M_{LQ3}>199 GeV/c^2
  - Yang-Mills
    - M_{LQ2}>222 GeV/c^2
    - M_{LQ3}>250 GeV/c^2

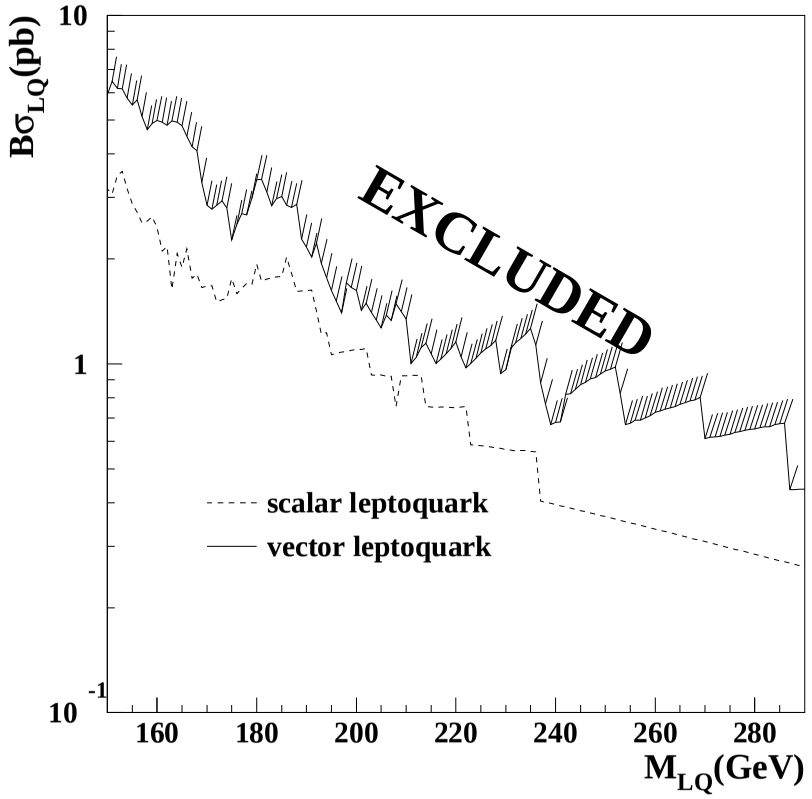
LQ Results from Zeus

1st Generation LQ Limits in LQ → $\ell^{\pm}q$ channel

e^+p



e^-p



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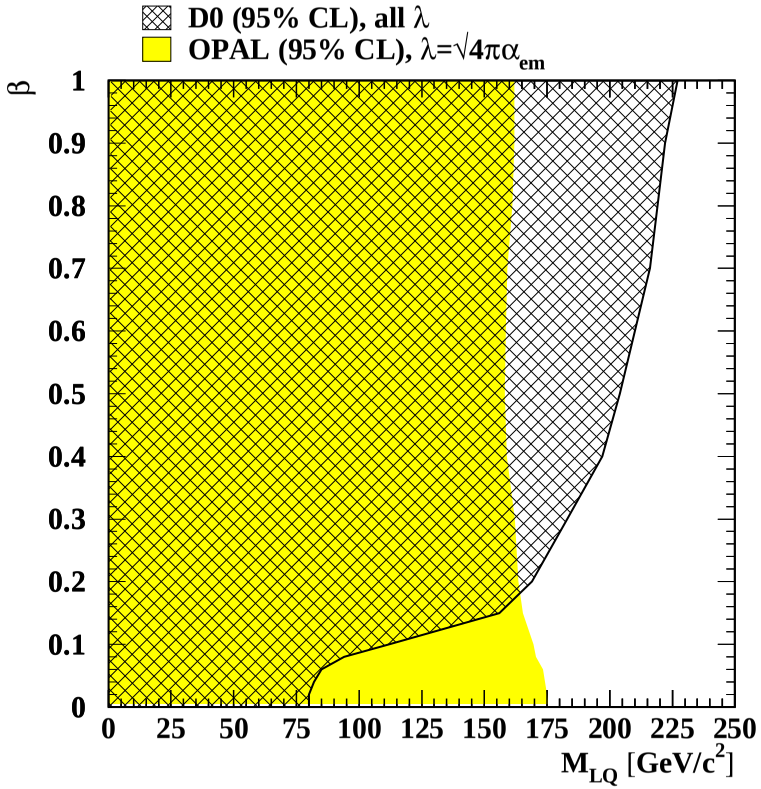
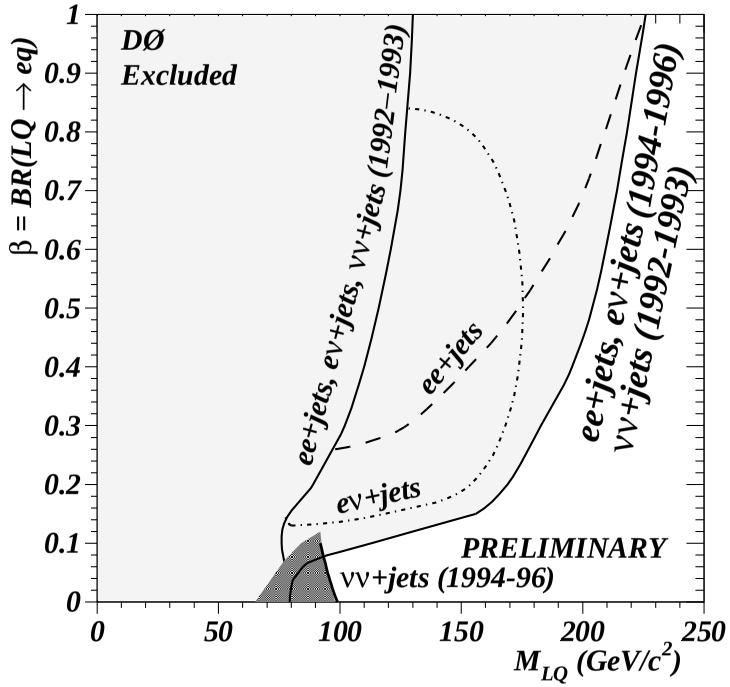
LQ Limits from OPAL

OPAL + DØ Limits



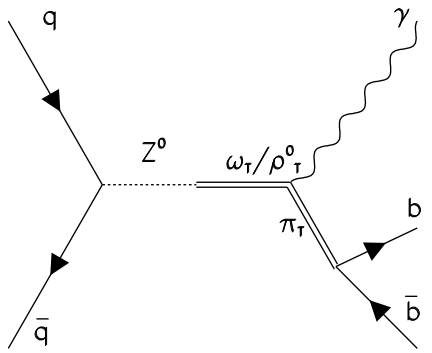
DØ Limits including this analysis



hep-ex/0106031

$\omega_T, \rho_T \rightarrow \gamma + \pi_T$

- Final state signal is γbb
  - $\omega_T, \rho_T \rightarrow \gamma + \pi_T$; $\pi_T \rightarrow bb$



Background from

- 3+ jets (jet $\rightarrow \gamma$ via $\pi^0, \eta \rightarrow \gamma\gamma$)
- Single, direct photon production (QCD)
- electron + 2 jets (e $\rightarrow \gamma$)
- Hadronic modes of $Z\gamma$ and $W\gamma$

- Analysis awaiting collaboration approval…

Testing Sleuth with Top

- Run same data feigning ignorance of top quark
  - Find excess of 1.9σ in *eμ*+MET+2jets
    - Combined $\wp$=0.11 (1.2σ) when accounting for all final states searched
  - Top analysis found 4.6σ with half as much data (only 2.5σ in *eμ*+MET+2jets channel)
- Sleuth knows nothing about top quark
  - Useful for measuring "interesting-ness" of data
  - Can detect hints of new physics
  - Useful safety net to detect new physics that theorists have not thought of!