Leptoquark search at the Tevatron

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Introduction

• Leptoquarks have both lepton and quark flavor
  - Connection of lepton and quark sector
  - Predicted by many extensions of the Standard Model
    ▪ GUT, extended gauge models, compositeness
  - Leptoquark-like couplings in R-parity Violation SUSY

• Description with effective couplings
  - invariant under $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$
  - Conserves lepton and baryon number separately (proton lifetime)
  - Couples only to one lepton and one quark family (FCNC)
  - Scalar and vector leptoquarks are possible
  - Only limits for scalar leptoquarks are shown
    ▪ scalar LQ have lower cross-sections (⇒ limit also valid for vector LQ)
    ▪ scalar LQ are less model dependent
The Tevatron

at Fermilab near Chicago

Run I: 1992-1996
100 pb\(^{-1}\) at \(\sqrt{s} = 1.8\) TeV

Run II: since 2001
proton antiproton collisions
at \(\sqrt{s} = 1.96\) TeV

Data sets of analyses shown
range from 72 pb\(^{-1}\) to 200 pb\(^{-1}\)
The DØ Run II Detector

- Jet
  - Calorimeter
- Electrons
  - Signal mostly in the electromag. calorimeter
  - Track
- Muon
  - Track
  - Muon system
- Missing energy
  - calorimeter corrected for muons and jet energy scale

New Solenoid, Tracking System
Si, SciFi, Preshowers

+ New Electronics, Trig, DAQ
Leptoquarks at the Tevatron

- pair produced by strong coupling
  - large cross-section
  - cross-section is model independent
- the LQ decays either into a quark and a charged lepton (with probability $\beta$) or a quark and a neutrino

Possible signature:
- 2 jets + 2 leptons (both $e$ or both $\mu$) no missing energy
- 2 jets + 1 lepton + missing energy
- 2 jets + missing energy

Interesting leptoquark masses are $\sim$ 200 GeV
$\Rightarrow$ All objects are high energetic.
2 Jets and 2 Electrons

2 jets with $E_T > 20$ GeV
2 electrons with $E_T > 25$ GeV

Main backgrounds

- 2 jets+2 real electrons from $Z^0$/Drell-Yan events.
  - estimated from MC

- 2 jets and 2 fake electrons from fake ("electron like") jets.
  - estimated from data with 4 jets and fake probability.

\[ \Rightarrow \text{veto on } Z^0 \text{ mass region} \]
2 Jets and 2 Electrons

Exploit high energy of objects:

\[ S_T = E_{T}^{Jet \_1} + E_{T}^{Jet \_2} + E_{T}^{e \_1} + E_{T}^{e \_2} \]

Extract mass limit from comparison of predicted cross-section and crosssection limit

Select cut to optimize expected limit (or expected discovery significance)

0.4 ± 0.1 background events expected
28% Signal efficiency
0 events observed.

CDF preliminary 200 pb⁻¹

\[ M_{LQ}^{scalar} (1^{st} Gen.) > 230 GeV \quad (for \beta = 1) \]
2 Jets, 1 electron, and missing energy

2 jets with $E_T > 25$ GeV
1 electron with $E_T > 35$ GeV
missing $E_T > 30$ GeV

Main background
- $W +$ jets
- fake electron (from $\gamma$ or jet) + 2 jets
  - Normalize at low missing $E_T$
2 Jets, 1 electron, and missing energy

Cut on $M_T$ ($M_T > 130$ GeV) to veto $W+\text{Jets}$

Cut on $S_T$ ($S_T > 330$ GeV) to exploit high energy of objects.

$$S_T = E_T^{\text{Jet}_1} + E_T^{\text{Jet}_2} + E_T^e + E_T^{\text{miss}}$$

2 events observed
$4.78 \pm 0.78$ expected

DØ preliminary 175 pb$^{-1}$

$$M_{LQ}^{\text{scalar}} (1^{\text{st Gen.}}) > 194 \text{ GeV} \quad (\text{for } \beta = 0.5)$$

CDF preliminary 72 pb$^{-1}$

$$M_{LQ}^{\text{scalar}} (1^{\text{st Gen.}}) > 166 \text{ GeV} \quad (\text{for } \beta = 0.5)$$
2 Jets and Missing Energy

2 jets with $E_T > 20$ GeV
missing $E_T > 60$ GeV
124 events observed
118±14 expected
First-Generation LQ Limits

![Graphs showing branching ratio vs. scalar leptoquark mass](image-url)

- **DØ Run II Preliminary**
- **Search For First Generation Scalar Leptoquarks**
2 Jets and 2 Muons

2 jets with $E_T > 30$ GeV, 15 GeV
2 muons with $p_T > 25$ GeV

Main background:
$Z^0$/Drell-Yan events
⇒ veto on $M_{\mu\mu} < 15$GeV and
75 GeV < $M_{\mu\mu} < 105$ GeV

CDF Run II
2-dim cut on Jet $E_T$ and muon $p_T$

2 events observed
3.17 ±1.17 expected
Different ways to exploit the LQ decay-kinematics have been studied

Reconstructed LQ Mass
- pick $\mu$-jet combination for which the mass difference between the 2 pairs is smallest
- Use the average of the two masses

$D\O$ preliminary 104 pb$^{-1}$

$M_{LQ}^{scalar} (2^{\text{nd}} \text{ Gen.}) > 186 \text{ GeV} \quad (\text{for } \beta = 1)$
Conclusions and Outlook

- Hadron collider is a good place to search for leptoquark pairs
  - Leptoquark pairs can be produced in strong interactions
  - Highly energetic leptons and jets result in clean signatures

- Limits for scalar leptoquarks have surpassed Run I results
  - Publications are in preparation

- Outlook
  - Work on missing channels
  - Sensitivity will increase with integrated luminosity
    (there is a lot of separation power left to exploit.)