Search for First Generation Leptoquarks in the 2electron + 2jet Channel at DØ

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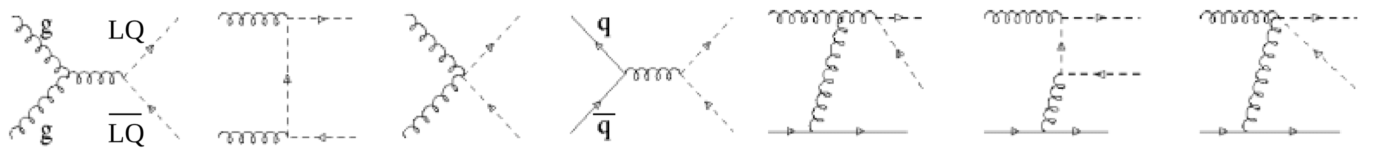
Lepton Photon 2003, 11-16 August 2003, Fermi National Accelerator Laboratory, Batavia, Illinois

Introduction

- Leptoquarks (LQ) are exotic particles which appear in many SM extensions to explain the symmetry between leptons and quarks.
  - LQ are directly coupled to both Leptons and Quarks. q-l-LQ coupling ~λ where λ is assumed to be of electromagnetic order (small).
  - LQ carry color, fractional electric charge, lepton number and baryon number.
  - LQ can be Scalar (spin 0) or Vector (spin 1). Vector LQ coupling is model dependent, e.g. Yang-Mills coupling and Minimal coupling.
  - LQ appear in 3 generations corresponding to 3 lepton/quark generations. The intergenerational mixing is severely restricted by Flavor Changing Neutral Current (FCNC) data.
- At the Tevatron LQ pair production via gluon splitting (strong interactions) dominates.
  - Pair production is insensitive to the coupling constant λ and it has very little model dependence (such as Parton Distribution Function choice, etc.)
  - Cross sections for vector leptoquarks are generally larger than that for scalar leptoquarks.
  - Feynman diagrams for gluon fusion (dominant), quark anti-quark annihilation, and some next-to-leading order sub-process:

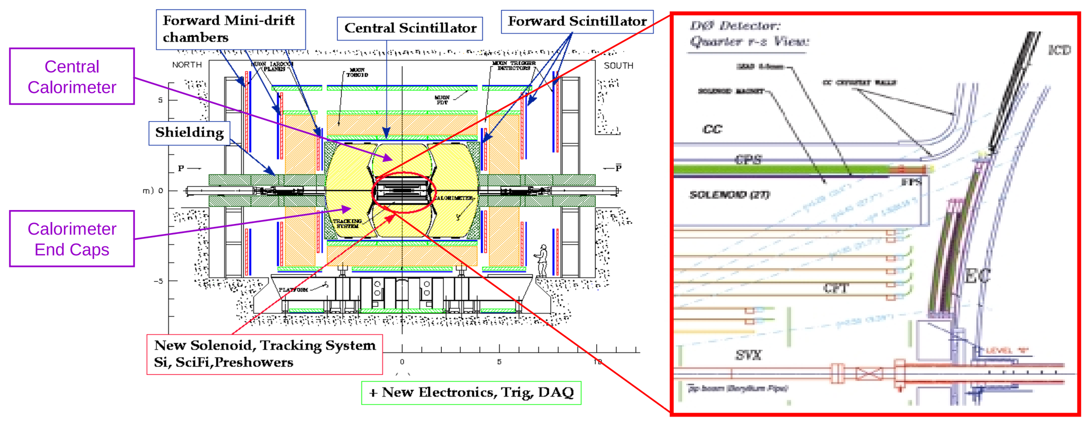


- Leptoquark decay into lepton and quark.
  - $LQ \to l^{\pm}q$ or νq We define $\beta \equiv$ Branching Ratio ($LQ \to l^{\pm}q$)
  - LQ decay signatures include: 2 Leptons + 2 Jets, Lepton + Jet + $\not{E}_T$, 2 Jets + $\not{E}_T$
  - For first generation LQ, the decay branching ratio in the *eejj*, *eνjj* and *ννjj* channels are β^2, $2\beta(1-\beta)$ and $(1-\beta)^2$ respectively.
  - ➢ **Here we discuss the first generation LQ search in 2e2j channel with DØ Run 2 data.**
- Run 1 mass limits of first generation LQ
  - DØ Run1 (Lum = 115 pb^{-1}) Phys. Rev., **D64**, 092004 (2001)

β = BR($LQ \to eq$)		**Scalar LQ** Mass Limit (GeV/c^2)	**Vector Minimal Coupling** (GeV/c^2)	**Vector Yang-Mills Coupling** (GeV/c^2)
DØ	1	225	292	345
	0.5	204	282	337
	0	98	238	298

  - Run1 DØ / CDF combined result: β = 1, scalar LQ mass > 242 GeV hep-ex/9810015 (1998)

DØ Detector



- Tevatron provides Proton on Anti-Proton Collisions at center of mass energy 1.96 TeV.
- DØ experiment upgrade in Run 2
  - Excellent calorimetry with faster readout
  - Upgraded muon system for better muon-id
  - Inner tracking system (silicon tracker, fiber tracker) with 2T superconducting solenoid
  - Preshower detectors
  - Pipelined 3-level trigger and new Data Acquisition system

Data Selection

- Data Sample
  - The data used were collected with the Run 2 DØ detector, from September 2002 to June 2003.
  - The selected events were required to pass un-prescaled single †EM trigger or &di-EM trigger.
  - The integrated luminosity is estimated to be 135 ± 14 pb^{-1}.
- Event selection
  - Two EM candidates with E_T > 25 GeV in Central Calorimeter ($|\eta|$ < 1.1) or Calorimeter End Caps (1.5 < $|\eta|$ < 2.4), which pass EM Identification requirements.
  - At least one of the EM candidates has a track match.
  - The event has at least two 0.5 cone jets with E_T > 20 GeV within $-2.5 < \eta < 2.5$, which pass Jet Identification requirements.
  - Jets are separated from EM objects by a distance ΔR_{ej} > 0.5
  - Z-veto: invariant mass of the two EM objects should be outside of the Z-mass window, i.e. M_{ee} < 80 GeV or M_{ee} > 102 GeV. This gets rid of the majority of the background from Z/Drell-Yan process decaying into the di-EM channel.
  - S_T is defined as the scalar sum of the transverse energies of the two electrons and the two leading jets. S_T can serve as a powerful cut to suppress background while maintaining high efficiency for the LQ signal. The S_T cut value will be chosen at the final stage.

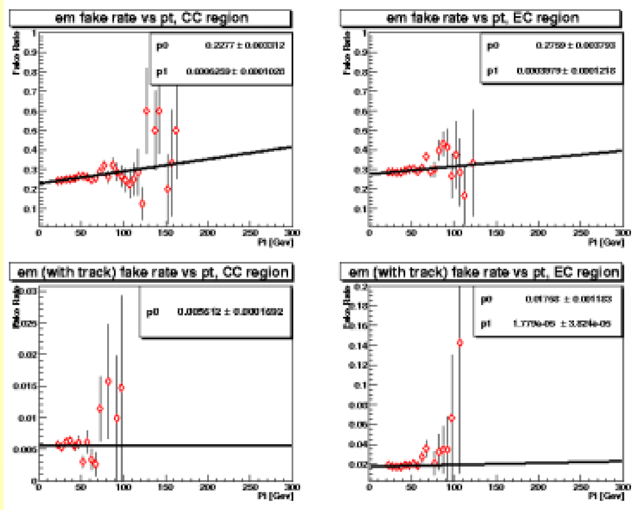
Selection Criteria	*Events*
2 EM objects (E_T > 25 GeV, in CC/EC, at least one EM has track match)	8208
2 or more jets (E_T > 20 GeV, $|\eta|$ < 2.5, ΔR_{ej} > 0.5)	173
Z veto (M_{ee} < 80 GeV or M_{ee} > 102 GeV)	36

†EM – Electro-Magnetic &di-EM – 2 Electro-Magnetic objects

‡$\Delta R_{ej} = \sqrt{\Delta\eta_{ej}^2 + \Delta\phi_{ej}^2}$

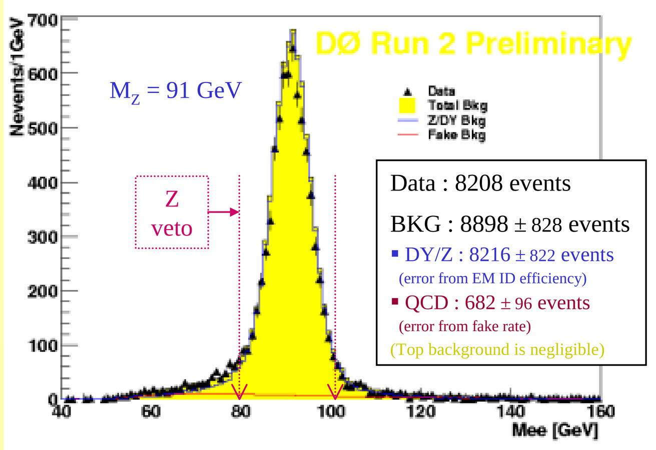
Background

- QCD Background



  - The probability of a jet to "fake" an electron/photon (called "fake rate") is calculated using the loose single EM sample.
  - To get rid of the W/Z events the selection requires that there be one and only one loose EM object and that the $\not{E}_T$ in the event be less than 15 GeV.
  - The fake rates we use are shown in the left plot.
  - To estimate the QCD background to eejj sample, we use the loose di-EM sample.
  - For events passing our kinematic and geometric cuts, we loop over all possible permutations of the event that would give us 2 electrons and 2 jets.
  - The QCD contribution to the background is then given by multiplying the number of combinations with the fake rates.

- Z/Drell-Yan Background



  - Z/Drell-Yan → ee Monte Carlo (MC) samples generated using PYTHIA are used.
  - To illustrate that we understand this source of background we compare the Z/Drell-Yan Monte Carlo events with data, selecting 2 EM objects with E_T > 25 GeV (no jet requirement).
  - The left plot shows that the di-EM data is consistent with a Z/Drell-Yan MC plus QCD background.
  - To evaluate the contribution to the first generation LQ signal we further make the requirement that there be two or more jets in the events.

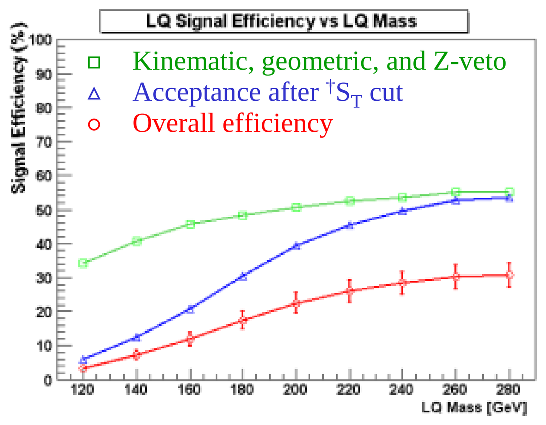
- Top Background
  - The $t\bar{t} \to$ di-electron Monte Carlo samples generated using PYTHIA are used (M_{top} = 175 GeV).
  - The next-next-to-leading order (NNLO) cross section for top pair production in Run 2 is calculated to be about 8.8 pb, thus the cross section times branching ratio is about 0.109 pb.

- Background Uncertainties

Background	*Uncertainty (Source)*
Z/Drell-Yan	**28 %** (Jet Energy Scale and EMID efficiency errors)
QCD	**29 %** (Jet Energy Scale errors and fake rate errors)
Top	**28 %** (Jet Energy Scale and EMID efficiency errors)

Signal

- LQ pair → eejj Monte Carlo samples are generated using PYTHIA.
  - Next-to-leading order (NLO) theory cross sections of scalar LQ pair production are calculated.
- Signal acceptance and overall efficiency



†S_T cut and its value are explained later.

LQ mass (GeV/c^2)	NLO σ (pb)	Overall Efficiency (%)
120	5.86	3.4 ± 0.6
140	2.40	7.2 ± 1.3
160	1.08	11.9 ± 2.0
180	0.522	17.4 ± 2.6
200	0.264	22.5 ± 3.0
220	0.138	26.0 ± 3.2
240	0.0746	28.3 ± 3.3
260	0.0408	30.2 ± 3.5
280	0.0228	30.7 ± 3.6

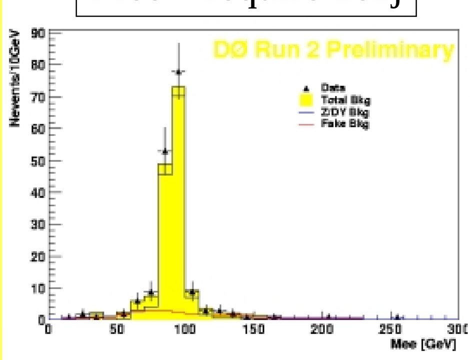
- Systematic uncertainties

Source of Uncertainty	*Uncertainty*
Particle ID efficiency	8.4 %
Jet Energy Scale (JES)	14.5 % – 6.8 % – 1.9 % (for M_{LQ} = 120 – 200 – 280 GeV/c^2)
PDF and Q^2	2.1 %
Gluon Radiation	7 %
MC Statistics	1.4 %
Total	**18.4 % – 13.3 % – 11.5 %** (for M_{LQ} = 120 – 200 – 280 GeV/c^2)

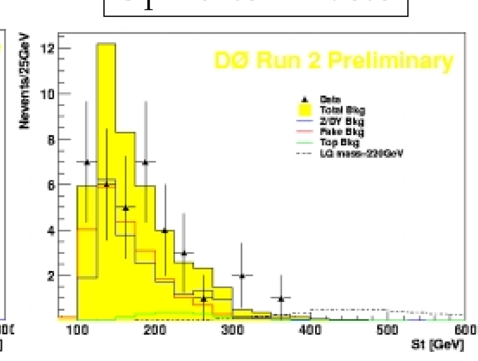
Results

- Compare the distributions from data and the expected background (BKG)

Mee – require 2e2j



S_T – after Z-veto

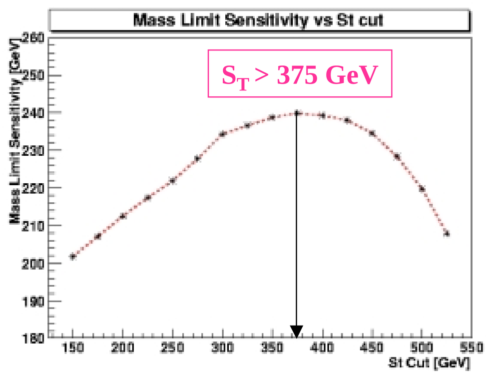


	Require 2e2j	*After Z-veto*
Data	**173**	**36**
Total BKG	**169 ± 45**	**44.4 ± 11.4**
Drell-Yan	138 ± 39	20.2 ± 5.6
QCD	27.8 ± 8.0	22.0 ± 6.3
Top	2.76 ± 0.30	2.26 ± 0.25
LQ (mass = 220 GeV/c^2)		**5.58 ± 0.64**

- The data are consistent with Standard Model background. No evidence for leptoquark production is observed.

Optimized S_T cut

- Since no evidence for LQ is observed, we apply an additional S_T cut to optimize the limit setting.

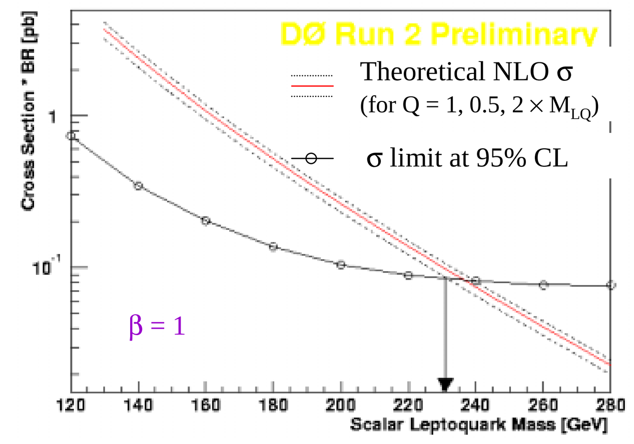


  - S_T is defined as the scalar sum of E_T of the two electrons and the two leading jets.
  - The S_T cut value is chosen to be **S_T > 375 GeV** based on an estimate of the extreme reached by the Mass Limit Setting Significance as a function of S_T cut, as shown in the left plot.
  - *Mass Limit Significance* $\equiv \sum_{i=0}^{+\infty} M_{95\%}(i|B,dB,A{\times}L,dAL)\exp(-B)B^i/i!$

  Where $M_{95\%}$ is the 95% Confidence Level (CL) mass limit for the signal assuming *i* events observed, *B* is the expected background, *A×L* is acceptance times luminosity for the signal Monte Carlo, and *dB*, *dAL* are the uncertainties of *B*, *A×L*.

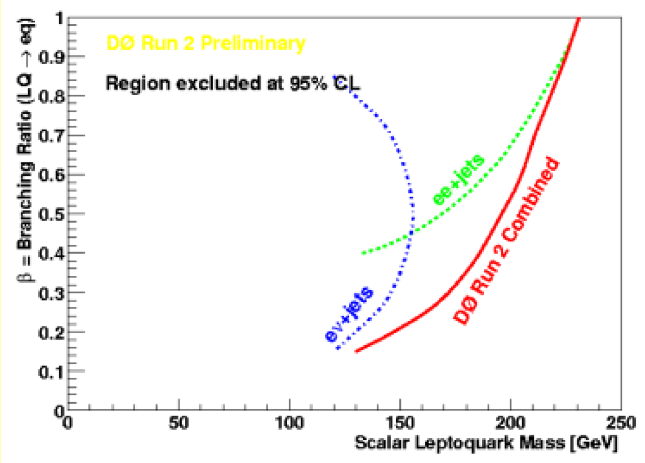
Limit Setting

	After S_T cut
Data	**0**
Total BKG	**0.45 ± 0.12**
Drell-Yan	0.19 ± 0.05
QCD	0.13 ± 0.04
Top	0.13 ± 0.04
LQ (mass = 220 GeV/c^2)	**4.85 ± 0.59**



- 95% Confidence Level upper limit for LQ cross section as a function of LQ mass is shown in the above plot.
- Using the lower bound of the theoretical NLO cross section band, we find an upper cross section limit of **0.086 pb** at 95% CL, and a lower mass limit of **231 GeV/c^2** for the first generation scalar LQ, assuming a LQ decay branching ratio β = 1.

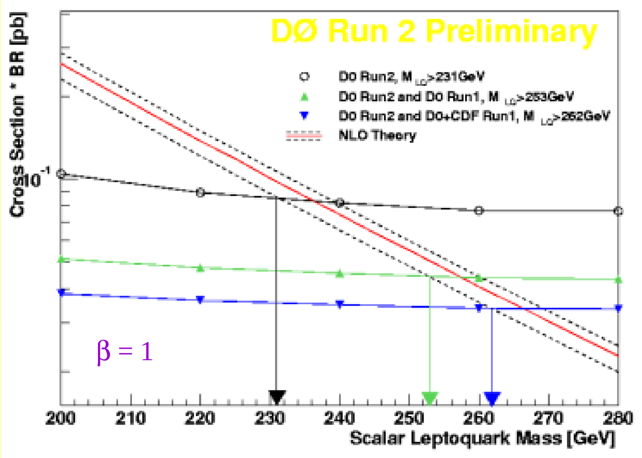
- Combine DØ Run 2 results from LQ→eejj channel and LQ→eνjj (electron + jets + $\not{E}_T$) channel



  - The left plot shows the lower mass limit on the first generation scalar LQ at 95% CL as a function of β (the branching ratio of a LQ decaying into an electron and a quark) for eejj channel, eνjj channel, and the combined exclusion curve.
  - Combined mass limit for Scalar LQ at various β:

β = BR ($LQ \to eq$)	LQ mass limit (GeV/c^2)
1.0	231
0.5	196
0.2	147

- Combine DØ Run 2 result with DØ Run 1 result, and with DØ/CDF Run 1 result, for β = 1.



  - When combine Run 2 result with Run 1 result, we assume the uncertainties are completely uncorrelated.
  - Considering the difference in LQ production cross sections due to the energy difference between Run 1 and Run 2, we normalize Run 1 cross section limit to Run 2 equivalent cross section in order to make correct combination.
  - The left plot shows the 95% CL upper limits from DØ Run 2 only (open circles), DØ Run 2 combined with DØ Run 1 (triangles), and DØ Run 2 combined with DØ/CDF Run 1 (inverted triangles) LQ analyses.
  - Combined mass limit for Scalar LQ at β = 1:

LQ mass limit (GeV/c^2)	
DØ Run2	231
DØ Run2 and DØ Run1	253
DØ Run2 and DØ+CDF Run1	262

Summary

- This analysis is a direct search for first generation leptoquarks in the eejj final state with the DØ detector at the Fermilab Tevatron.
- This search is based on 135 pb^{-1} of integrated luminosity collected in Run 2.
- Leptoquarks are assumed to be produced in pairs and to decay into an electron and a quark with a branching ratio β.
- The data are consistent with Standard Model background and no evidence for leptoquark production is observed.
- We set an upper cross section limit of 0.086 pb at 95% confidence level and a lower mass limit of 231 GeV/c^2 for the first generation scalar leptoquark at β = 1.
- We then combine this result with the Run 1 results. The combined mass limit is 253 GeV/c^2 from DØ Run 2 and Run 1 results, which is the most stringent limit to date.