SEARCH FOR LEPTOQUARKS AT THE TEVATRON

Philippe Calfayan

Ludwig-Maximilians University, Munich
On behalf of the DØ and CDF collaborations

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Outline

- Luminosity at DØ and CDF

- Leptoquark production at Tevatron

- Searches for Leptoquarks:
  - Pair production of 2nd generation scalar leptoquarks in $\mu\nu jj$ DØ
  - Single production of scalar leptoquarks in $\mu\mu j$ DØ
  - Pair production of 3rd generation scalar leptoquark in $\tau\tau bb$ DØ
  - Pair production of 3rd generation vector leptoquark in $\tau\tau bb$ CDF
  - Pair production of 3rd generation scalar leptoquarks in $bb\not{E}_T$ DØ
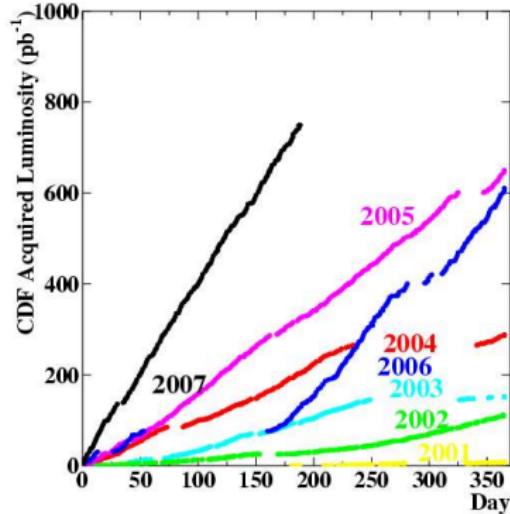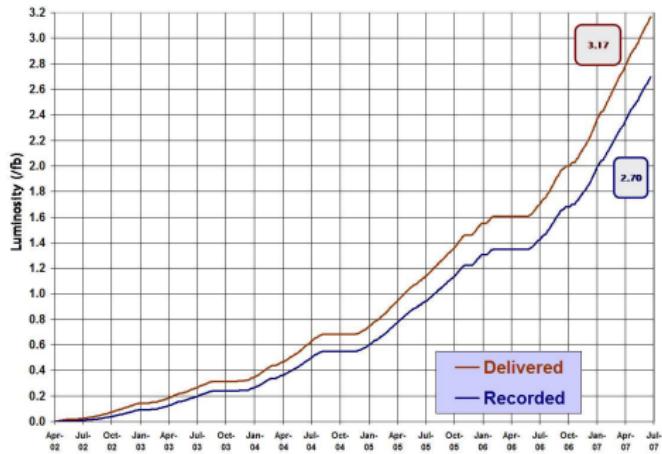
Luminosity at DØ and CDF
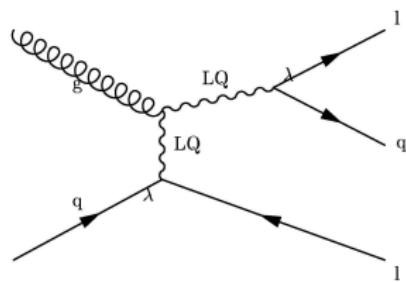
- The instantaneous luminosity has been increasing significantly.

- The integrated luminosity available at CDF and DØ is larger than 2.5 fb^{-1} ($\sim$3 fb^{-1} delivered).

- Analyses shown today include luminosities from 0.3 to 1 fb^{-1}.

Leptoquarks Production and Decay
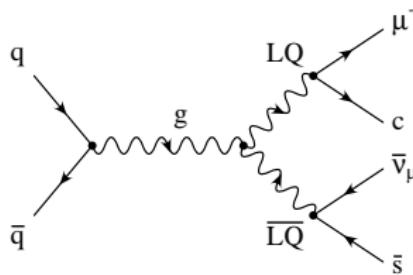
- Leptoquarks (LQ) are hypothetical bosons allowing lepton-quark transitions.

- The *Minimal Buchmüller-Rückl-Wyler model* allows relatively small LQ masses in reach of hadron colliders like Tevatron.

Single LQ production:

The single production cross section depends on the unknown λ coupling between a LQ, a lepton and a quark.
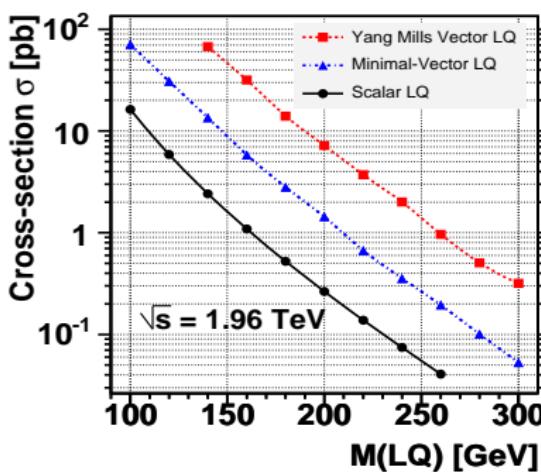
Pair LQ production:
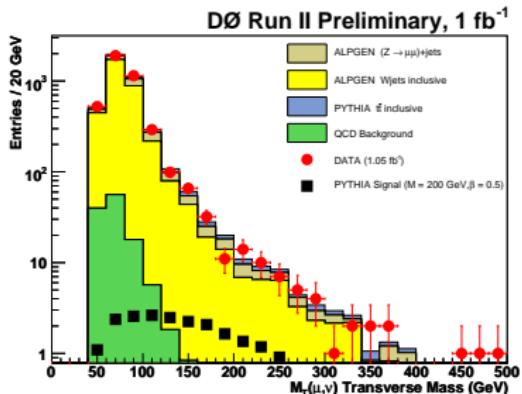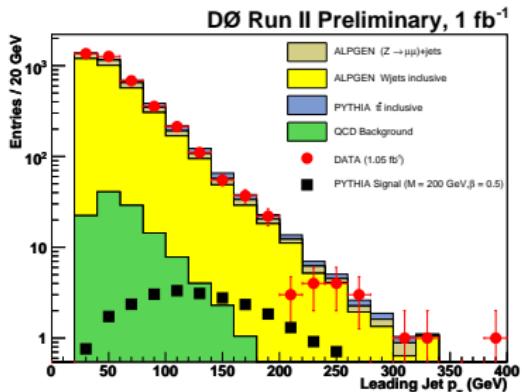
The pair production cross section of scalar LQ only depends on the assumed LQ mass.

Leptoquarks Production and Decay

- **Scalar LQ** pair production is a pure QCD process. NLO prediction is available.

- **Vector LQ** pair production cross section is higher. Only LO prediction is available.
  - Yang-Mills model: anomalous couplings set to 0
  - Minimal Vector model: anomalous couplings chosen to approximately minimize the cross section
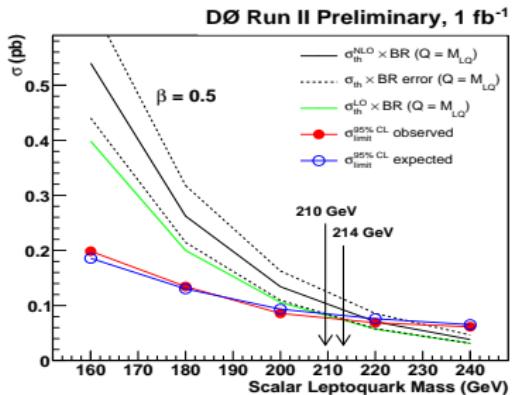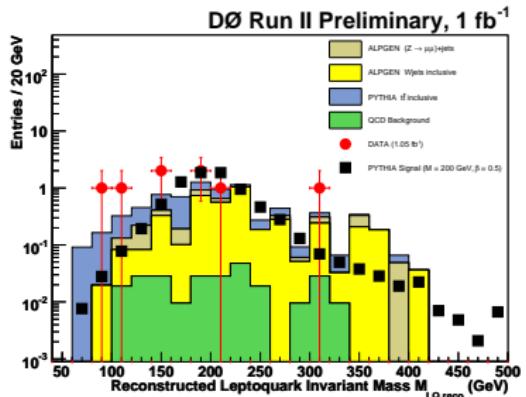
Search for Pair Production of 2nd Generation Scalar LQ in $\boxed{\mu\nu jj}$

- Recent: March 2007

- $\mathcal{L} = 1$ fb^{-1}

- Main backgrounds: $W+jets$, $t\bar{t}$

- $W+jets$: ALPGEN normalized to data in the W peak region at preselection level.

- QCD:
  - shape from QCD enriched data sample (muon anti-isolation)
  - normalization to preselected data in QCD-dominant region ($\not{E}_T < 10$ GeV)

Search for Pair Production of 2nd Generation Scalar LQ in $\boxed{\mu\nu jj}$

DØ Run II Preliminary, 1 fb^{-1}

DØ Run II Preliminary, 1 fb^{-1}

- Selection variables:
  - $M_T(\mu, \nu)$, $M_T(jet_1, \nu)$
  - $S_T = p_T^\mu + \not{E}_T + p_T^{jet_1} + p_T^{jet_2}$
  - $M_{LQ,reco}$: $M(\mu, jet_i)$ closest to $M_{LQ,gen}$
  - $\Rightarrow |M_{LQ,reco} - M_{LQ,gen}| < 100$ GeV

- Main systematics:
  - Jet energy scale (background): 9-11%
  - W sample jet p_T modeling: 17%
  - $t\bar{t}$ production cross section: 18%
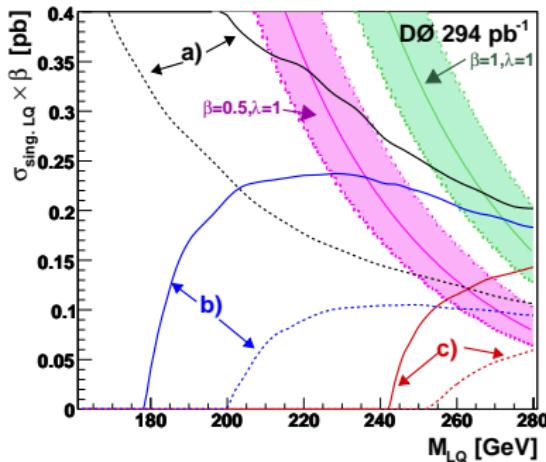
- Mass limit:
  $BR(LQ \to \mu q) = \beta$
  $BR(LQ\overline{LQ} \to \mu\nu qq) = 2\beta(1 - \beta)$
  Assumption: $\beta = 0.5$ (best sensitivity)

$\Rightarrow$ $\boxed{M_{LQ} > 214 \text{ GeV}}$
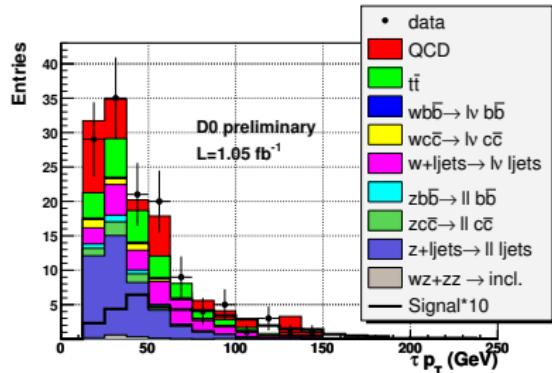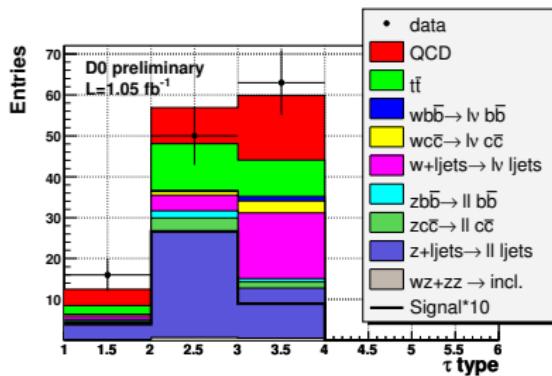
DØ Search for Single Production of Scalar LQ in $\boxed{\mu\mu j}$

- Published (*Phys.Lett.B647:74–81,2007*), first search for single LQ production at hadron colliders

- $\mathcal{L} = 294$ pb^{-1}

- Assumption: LQ couples to 1st generation quark and 2nd generation lepton $\Rightarrow$ no suppression due to PDF in IS

- Main background: $Z + jets$

- Selection: 2D cut in ($M_{\mu\mu}$, $E^{jet}_{T,max}$) plane $\rightarrow$ 4 signal bins

- Combination with 3 signal bins of $\mu\mu jj$ analysis (published, *Phys.Lett.B636:183–190,2006*)
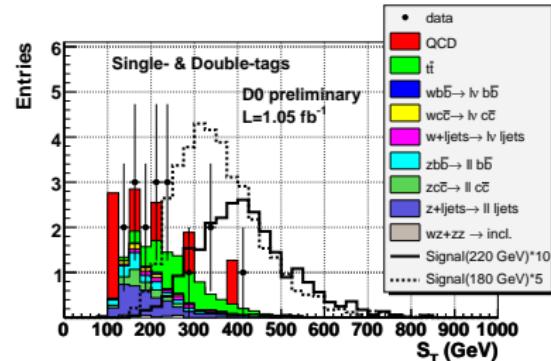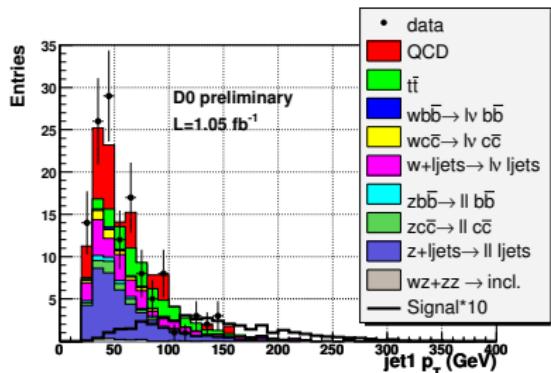
- 3 scenarios are considered:
 - (a): no contribution from $LQ\overline{LQ} \rightarrow \mu\mu jj$
  - (b): pairs contributes with $\beta = \frac{1}{2}$
  - (c): pairs contributes with $\beta = 1$
    ($\beta = BR(LQ \rightarrow \mu q)$)

- Limits on M_{LQ}:
  $\Rightarrow \beta = 1$, $\lambda^2 \ll 1$: $\boxed{M_{LQ} > 247 \text{ GeV}}$
  $\Rightarrow \beta = 1$, $\lambda^2 = 1$: $\boxed{M_{LQ} > 274 \text{ GeV}}$

DØ Search for Pair Production of 3rd Generation Scalar LQ in $\boxed{\tau\tau bb}$

- New: July 2007,
  first DØ measurement in $\tau\tau bb$

- $\mathcal{L} = 1 \text{ fb}^{-1}$

- τ decays:

  - $\tau_1 \to \mu\nu_\mu\nu_\tau$, muonic decay ($\tau_\mu$)
  - τ_2 decays hadronically (τ_h)

- Identification of τ_h:

  - Type 1: $\tau_h^\pm \to \pi^\pm \nu_\tau$
  - Type 2: $\tau_h^\pm \to \pi^\pm \pi^0 \nu_\tau$
  - Type 3: $\tau_h^\pm \to \pi^\pm \pi^\pm \pi^\mp \pi^0 \nu_\tau$

$\to$ Neural networks to distinguish each τ_h type from background
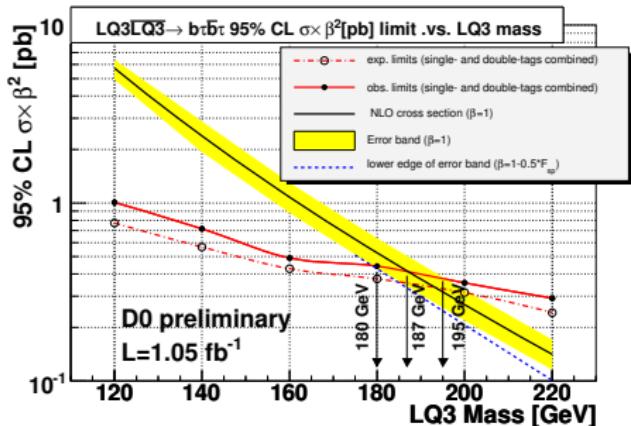
D0 Search for Pair Production of 3rd Generation Scalar LQ in $\boxed{\tau\tau bb}$

- b-tagging: neural network method

  Very loose tagger: $\begin{cases} \mathcal{E}_b = 72.2\% \\ \mathcal{E}_{fake} = 5.9\% \end{cases}$

- Main backgrounds (bgd):

  ○ $t\bar{t}$

  ○ QCD estimated from like-sign $\tau_\mu - \tau_h$ candidates

  ○ $Z(W)+jets$
    (both heavy and light flavours)

- Final discriminant for limit calculation:
  $S_T = p_T^\mu + p_T^{\tau_h} + p_T^{jet_1} + p_T^{jet_2} + \not{E}_T$

D∅ Search for Pair Production of 3rd Generation Scalar LQ in $\boxed{\tau\tau bb}$

- Main systematics:

    - QCD: 12% (bgd)
    - $W(Z)$+jets production: 22% (bgd)
    - $t\bar{t}$ production: 18% (bgd)
    - b-tagging: 7.5-15.2% (bgd+signal)

- Mass limits (results with single and double tagged b-jets have been combined):

    - charge-$\frac{4}{3}$ LQ:

        $\Rightarrow BR(LQ \to \tau b) = 1$
        $\Rightarrow M_{LQ} > 180$ GeV
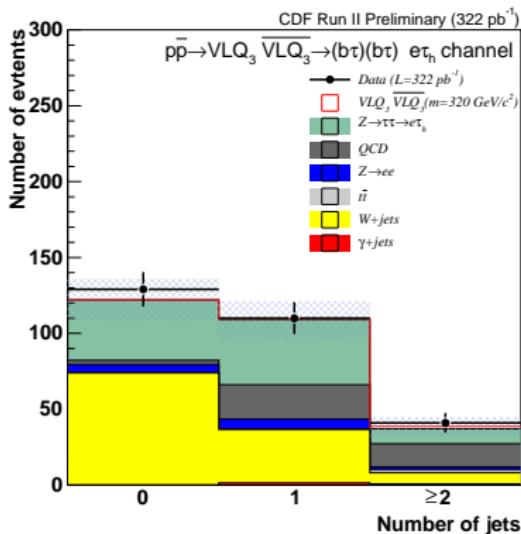
    - charge-$\frac{2}{3}$ LQ:

        $\Rightarrow LQ \to t\nu_\tau$ allowed
          (kinematically suppressed)
        $\Rightarrow$ assume equal couplings ($\beta = 0.5$)
 $\Rightarrow BR(LQ \to \tau b) = 1 - \beta \times F_{sp}$
        $\Rightarrow$ no change in limit

Search for Pair Production of 3rd Generation Vector LQ in $\boxed{\tau\tau bb}$
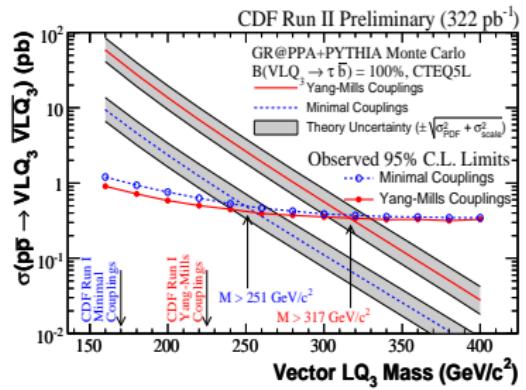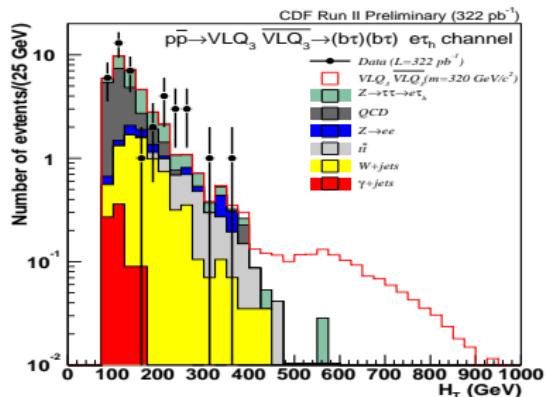
- Recent: March 2007

- $\mathcal{L} = 322$ pb^{-1}

- τ decays:
    - $\tau_1 \to \mu\nu_\mu\nu_\tau$, or $\tau_1 \to e\nu_e\nu_\tau$ leptonic decay (τ_μ or τ_e)
    - τ_2 decays hadronically (τ_h)

- no b-tagging

- Main backgrounds:
    - $t\bar{t}$
    - $W/Z+jets$

- QCD multijets events contribution estimated from QCD enriched sample (muon anti-isolation)

## Search for Pair Production of 3rd Generation Vector LQ in $\boxed{\tau\tau bb}$

- $H_T = E_T(e,\mu) + E_T(\tau_h) + \not{E}_T + \sum_{jets} E_T(jets)$
- Signal enhancement:
  - $N_{jets} \geq 2$
  - 2 regions in H_T: $\begin{cases} 250 < \frac{H_T}{\text{GeV}} < 400 \\ \frac{H_T}{\text{GeV}} > 400 \end{cases}$

    used in likelihood for discrimination

- Mass limits:
  - Given w.r.t. nominal theory prediction
  - Assumption: $BR(LQ \to \tau b) = 1$
  - $\sigma_{vector} \gg \sigma_{scalar}$: compare to DØ cross-section limit (0.42pb for $\frac{M_{LQ}}{\text{GeV}} = 180$)

  $\Rightarrow$ $\boxed{M_{LQ} > 251 \text{ GeV}}$ (Minimal couplings)

  $\Rightarrow$ $\boxed{M_{LQ} > 317 \text{ GeV}}$ (Yang-Mills couplings)

D0 **Search for Pair Production of 3rd Generation Scalar LQ in** $\boxed{bb\not{E}_T}$

- Accepted (*hep-ex/0705.0812*)

- $\mathcal{L} = 425$ pb^{-1}

- Combination of single μ- and $\not{E}_T$-triggers

- require 2 tagged b-jets:
  - ≥ 1 tag with significant impact parameter ($\mathcal{E}_b = 45\%$)
  - for μ-selection: 1 soft μ tag ($\mathcal{E}_b = 11\%$)
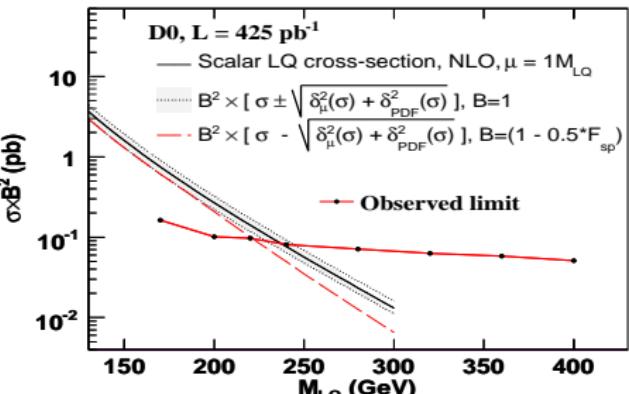
- Main backgrounds:
  - $t\bar{t}$
  - W/Z + heavy flavour quarks

- To suppress $t\bar{t}$ contribution:
  $\frac{p_T^{tag1} + p_T^{tag2}}{\sum_{jets} p_T} > 0.8$

- Selection cuts on $\not{E}_T$ and $H_T = \sum_{jets} |\vec{p_T}|$

- Mass limits (charge-$\frac{1}{3}$ LQ):
  - $BR(LQ \rightarrow b\nu_\tau) = 1$
  - $\Rightarrow$ $M_{LQ} > 229$ GeV
  - with $LQ \rightarrow \tau t$ assume $\beta = 0.5$
    $\Rightarrow BR(LQ \rightarrow b\nu_\tau) = 1 - \beta \times F_{sp}$
  - $\Rightarrow$ $M_{LQ} > 221$ GeV

Conclusion

- No evidence of LQ by either DØ or CDF, but significant improvement of limits
- BSM signal with characteristic topologies involving *leptons*, *jets*, and $\displaystyle{\not}E_T$
- Results shown based on 0.3 to 1 fb^{-1}
$\Rightarrow$ Prospects for luminosity: up to 8 fb^{-1} by 2009

- For further details, see:
    - http://www-cdf.fnal.gov/physics/physics.html
    - http://www-d0.fnal.gov/Run2Physics/WWW/results.htm