Searches for Leptoquark Production and Compositeness at the Tevatron

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on behalf of the DØ and CDF collaborations

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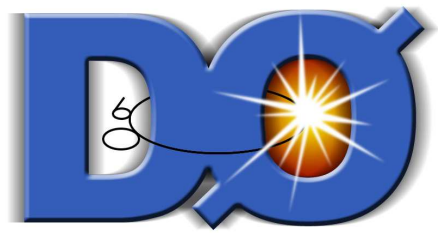


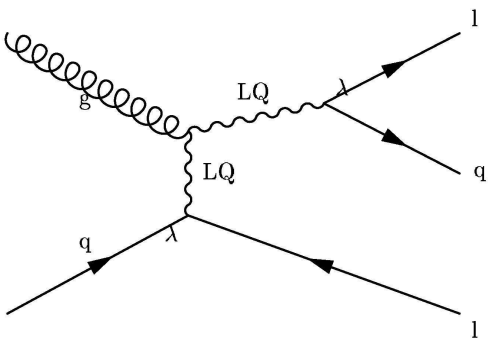
Outline

- searches for Leptoquarks (all based on pair production):
  - 2^{nd} generation scalar leptoquarks in $\mu j \mu j$ and $\mu j \nu j$ (DØ)
  - scalar leptoquarks in acoplanar jet topology (CDF, DØ)
  - 1^{st} generation scalar and vector leptoquarks in $ejej$ and $ej\nu j$ (DØ)
  - 3^{rd} generation scalar and vector leptoquarks in $\tau b \tau b$ (CDF, DØ)
  - 3^{rd} generation scalar leptoquarks in $bb\not\!\!E_T$ (DØ)
- searches for compositeness (and extra spatial dimensions) in dijet angular distributions (CDF, DØ)
- Note: all limits reported here are 95 % C.L.

Leptoquark Production and Decay

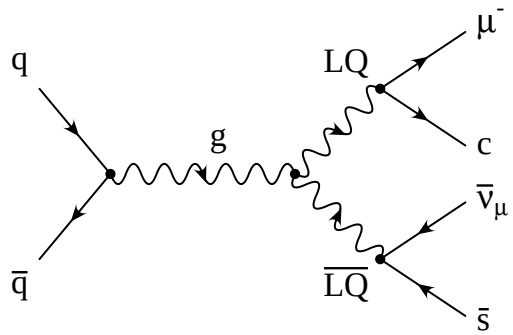
- Leptoquarks (LQ): hypothetical scalar or vector bosons with both baryon and lepton number, mediate lepton-quark transitions
  - in many extensions of SM: GUT, extended gauge models, compositeness etc.
- experimental bounds on proton decay, FCNC, LFV allow small LQ masses (in reach of Tevatron), if
  - LQs couple to only one quark and lepton family
  - conservation of both L and B number

Single LQ production:



depends on unknown $LQ - l - q$ coupling λ

LQ pair-production:

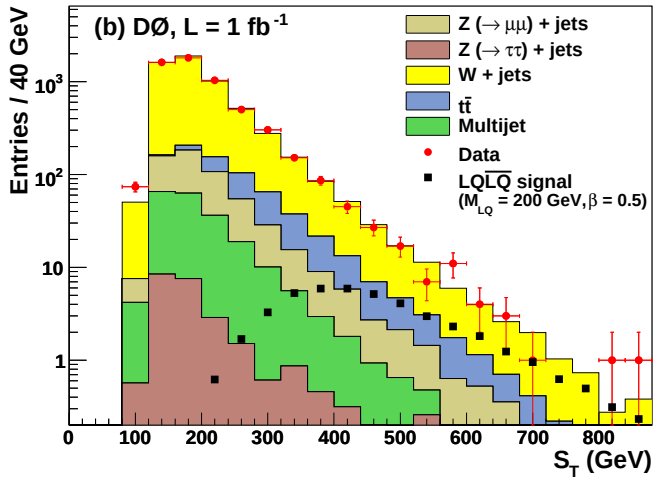


independent of λ, for scalar LQ: pure QCD coupling, cross section dep. only on $M(LQ)$

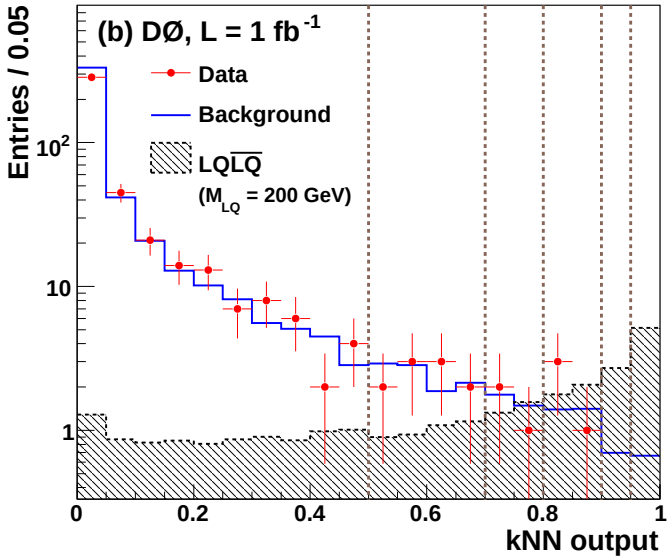
final state depends on $\mathcal{B}(LQ \to \ell^{\pm} q) \equiv \beta$, $\mathcal{B}(LQ \to \nu q)$

Search for pair prod. of 2nd generation scalar LQ in $\mu j \mu j$ and $\mu j \not\!\!E_T j$

- Phys. Lett. B 671, 224 (2009)
- $\mathcal{L} = 1\,\text{fb}^{-1}$
- main backgrounds:
  - $\mu j \mu j$: $Z/\gamma^* +$ jets, $t\bar{t}$
  - $\mu j \not\!\!E_T j$: $W +$ jets, $t\bar{t}$
- multivariate discrimination using *k-Nearest-Neighbors* algorithm, 6 input variables for each channel:
  - $\mu j \mu j$: $M(\mu,\mu)^{\min}$, S_T, $M_T(\mu_{1,2}, \text{jet}_{1,2})$
  - $\mu j \not\!\!E_T j$: $M_T(\mu, \not\!\!E_T)$, S_T, $M_T(\not\!\!E_T, \text{jet}_{1,2})$, $M_T(\mu, \text{jet}_{1,2})$
- dominating systematic uncertainty: modeling of W/Z background, jet energy scale, muon p_T resolution



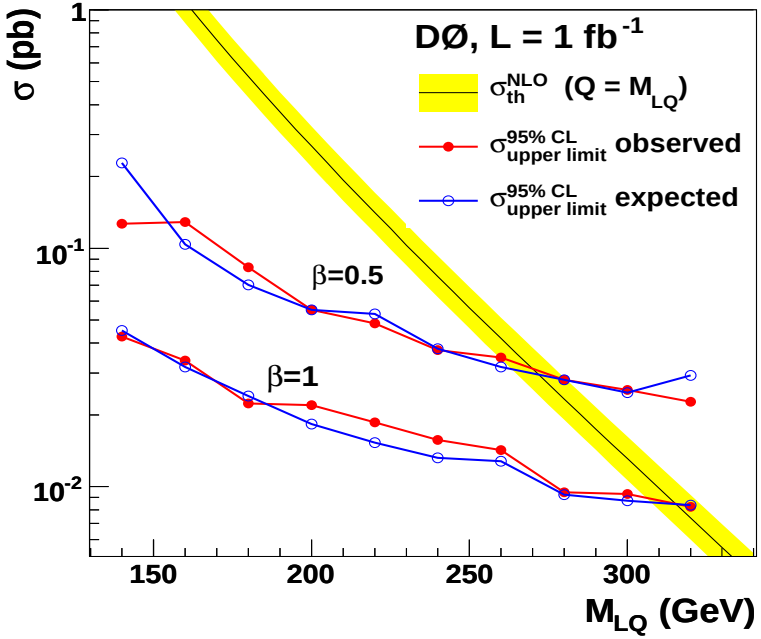
$\mu j \not\!\!E_T j$: $S_T = \sum_{FS} p_T$

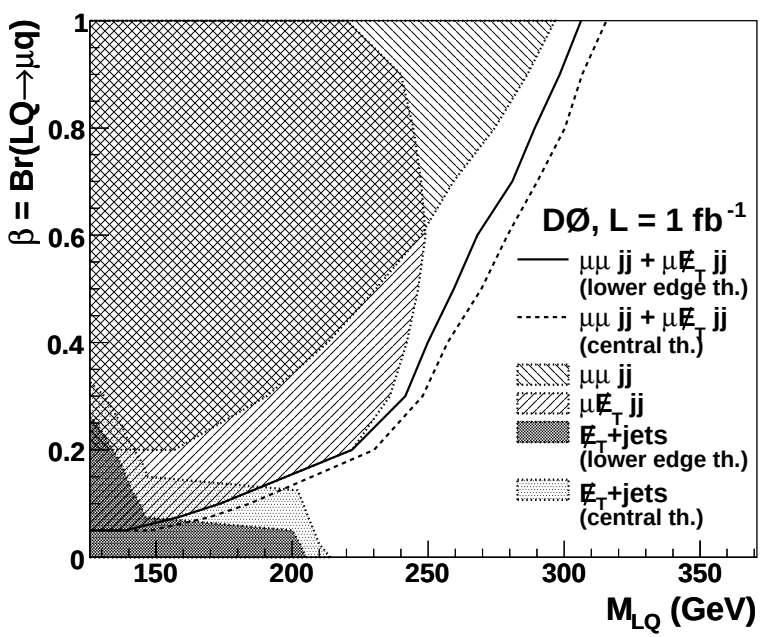


Search for pair prod. of 2nd generation scalar LQ in $\mu j \mu j$ and $\mu j \not\!\!E_T j$

- combination of both channels

→ limits on LQ production cross section and mass as function of $\beta = \mathcal{B}(LQ \to \ell^{\pm} q)$:

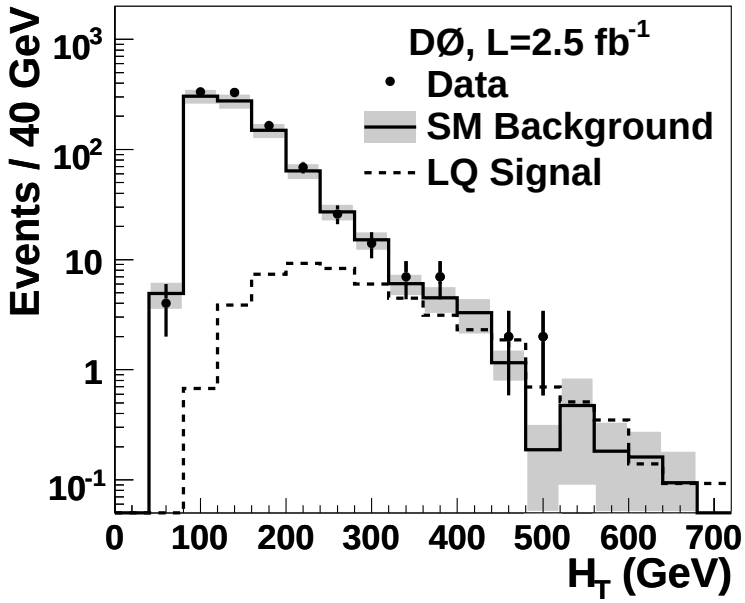


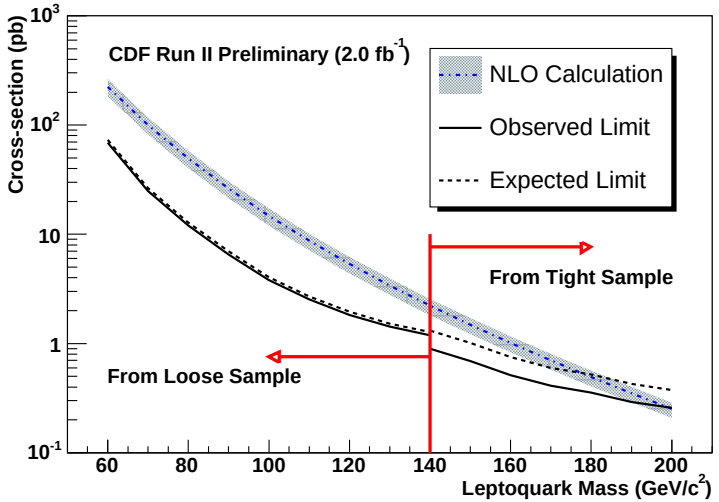


	central theory		lower edge theory	
β	$M_{LQ}^{\rm obs}$ (GeV)	$M_{LQ}^{\rm exp}$ (GeV)	$M_{LQ}^{\rm obs}$ (GeV)	$M_{LQ}^{\rm exp}$ (GeV)
0.1	185	181	174	175
0.5	270	272	259	263
1	316	316	306	308

Search for pair prod. of scalar LQ in the acoplanar jet topology

- CDF: preliminary, $\mathcal{L} = 2\,\mathrm{fb}^{-1}$
- DØ: Phys. Lett. B 668, 357 (2008), $\mathcal{L} = 2.5\,\mathrm{fb}^{-1}$
- two acoplanar jets and $\not\!\!E_T$
- main background: $Z(\to \nu\nu) + jets$ $W(\to \ell\nu) + jets$
- final selection: $\not\!\!E_T$ and $H_T = \sum_{jets} p_T$ optimized for low and high M_{LQ}
- mass limits for 1st and 2nd gene. LQ assuming $\beta = 0$:
  - CDF: $M_{LQ} > 190\,\mathrm{GeV}$ (w.r.t. lower edge theory)
  - DØ: $M_{LQ} > 205\,\mathrm{GeV}$ (w.r.t. nominal theory: 214 GeV)

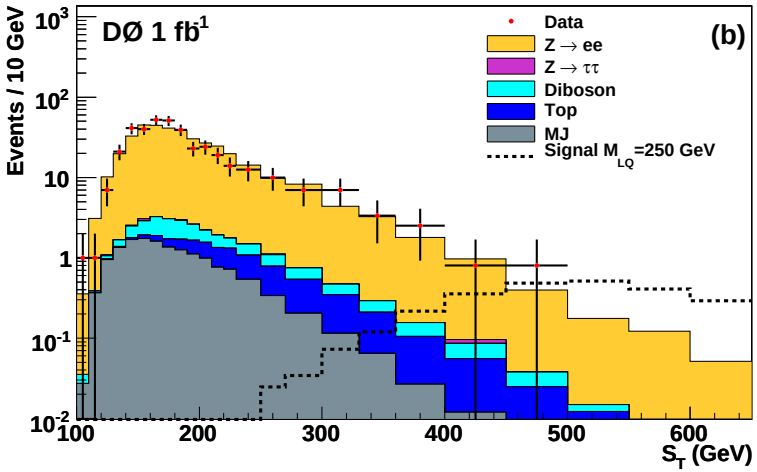




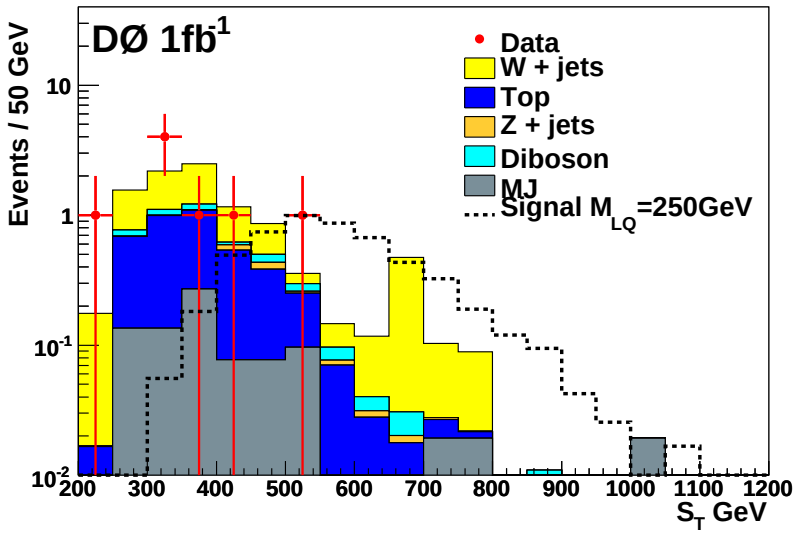
Search for pair prod. of 1^{st} generation scalar LQ in ejej and ej$\not\!\!E_T$j

- submitted to PLB, arXiv:0907.1048
- $\mathcal{L} = 1\,\text{fb}^{-1}$
- main backgrounds:
  - *ejej*: $Z/\gamma^* +$ jets, $t\bar{t}$
  - *ej*$\not\!\!E_T$*j*: $W +$ jets, $t\bar{t}$
- signal discrimination:
  - *ejej*: $M(e,e)$, S_T
    limit from average $M(e,j)$ distribution
  - *ej*$\not\!\!E_T$*j*: $p_T(e)$, $p_T(j_1)$, $p_T(j_2)$, $\not\!\!E_T$
    limit from S_T distribution

ejej: $S_T = \sum_{FS} p_T$



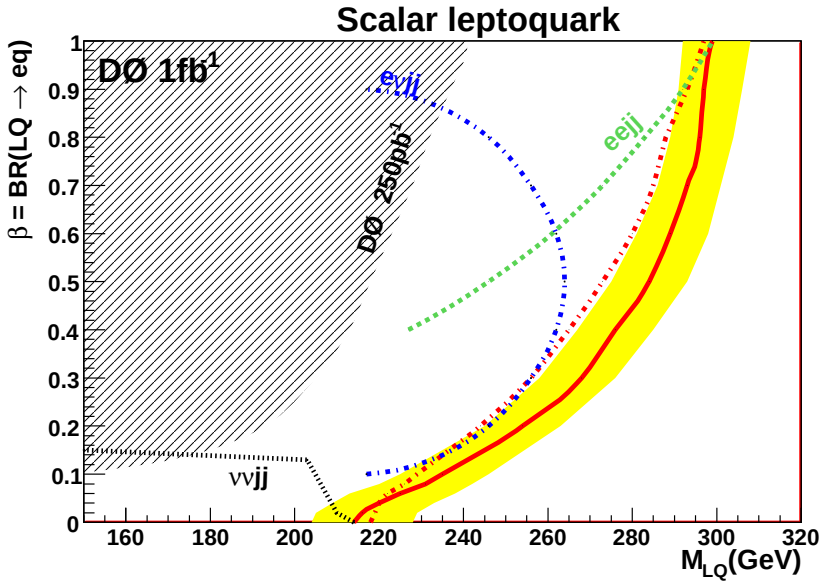
ej$\not\!\!E_T$*j*:

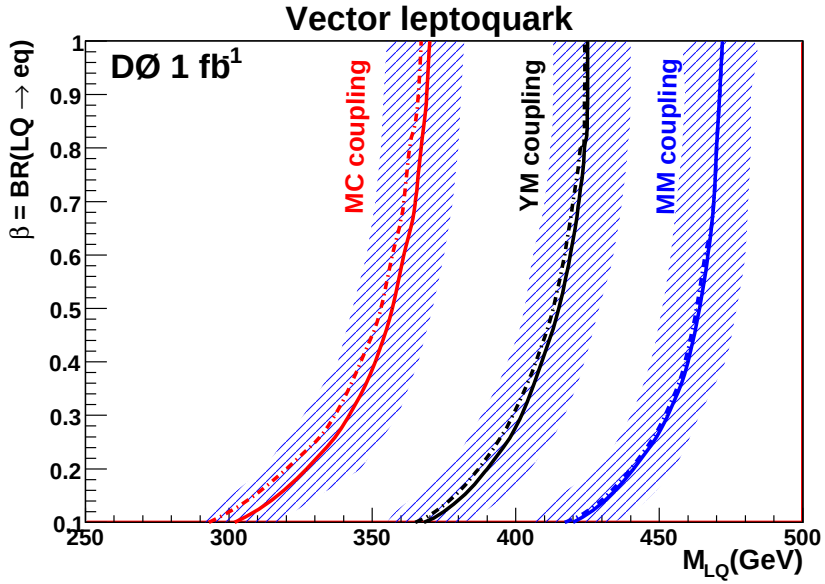


Search for pair prod. of 1st generation scalar LQ in ejej and ej$\not\!\!E_T$j

- combination of *ejej*, *ej*$\not\!\!E_T$*j* and acoplanar jets

$\longrightarrow$ exclusion on M_{LQ} and β for scalar and vector LQs





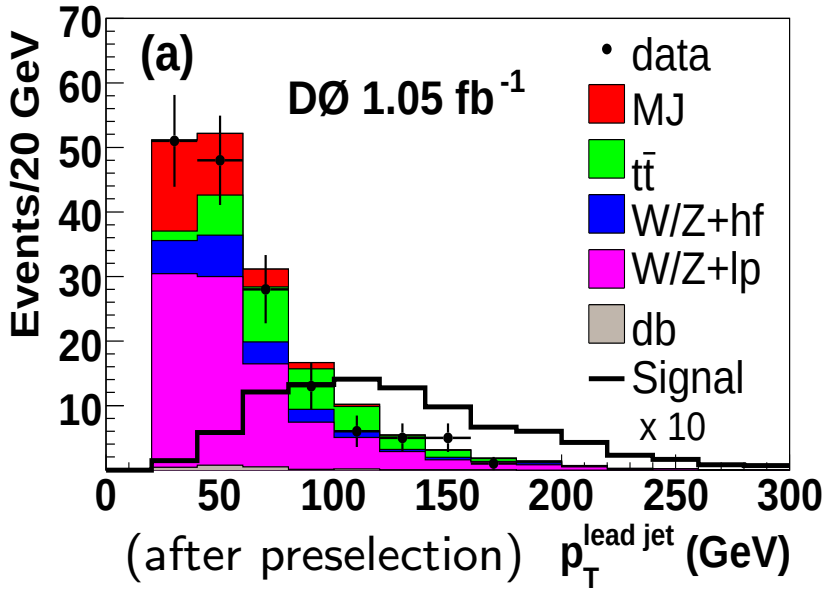
	$M_{LQ}^{\rm obs}$ (GeV), central theory			
β	scalar	vector: MC	YM	MM
0.1	235	302	368	420
0.5	284	357	415	464
1	299	370	425	472

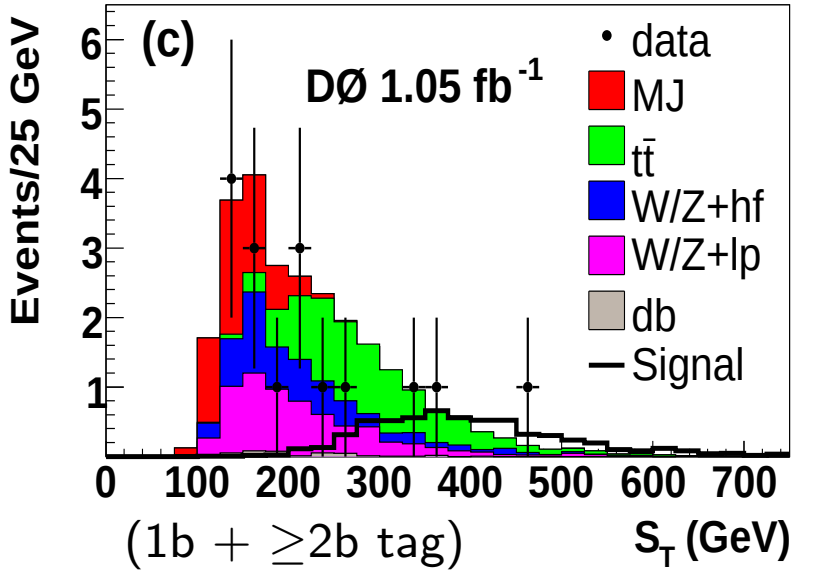
- vector LQ: additional anomalous LQ-gluon couplings (κ_G, λ_G)
  Minimal **C**oupling: $\kappa_G = 1$, $\lambda_G = 0$
  Young-**M**ills: $\kappa_G = 0$, $\lambda_G = 0$
  Minus **M**inus: $\kappa_G = -1$, $\lambda_G = -1$
- cross sections only at LO

Search for pair prod. of 3^{rd} generation scalar LQ in $\tau\mathrm{b}\tau\mathrm{b}$

- Phys. Rev. Lett. 101, 241802 (2008)
- $\mathcal{L} = 1\,\mathrm{fb}^{-1}$
- τ decays:
  - $\tau_1 \longrightarrow \mu\nu_\mu\nu_\tau$, muonic decay ($\tau_\mu$)
  - τ_2 decays hadronically (τ_h)
- final state: μ,τ_h,$\not\!\!E_T$, and 2 jets (≥ 1 loose b-tag, NN)
- main backgrounds:
  - $t\bar{t}$
  - QCD multijet estimated from events with like-sign τ_μ and τ_h candidates
  - $Z + jets$ (heavy and light flavours)
- final discriminant for limit calculation:

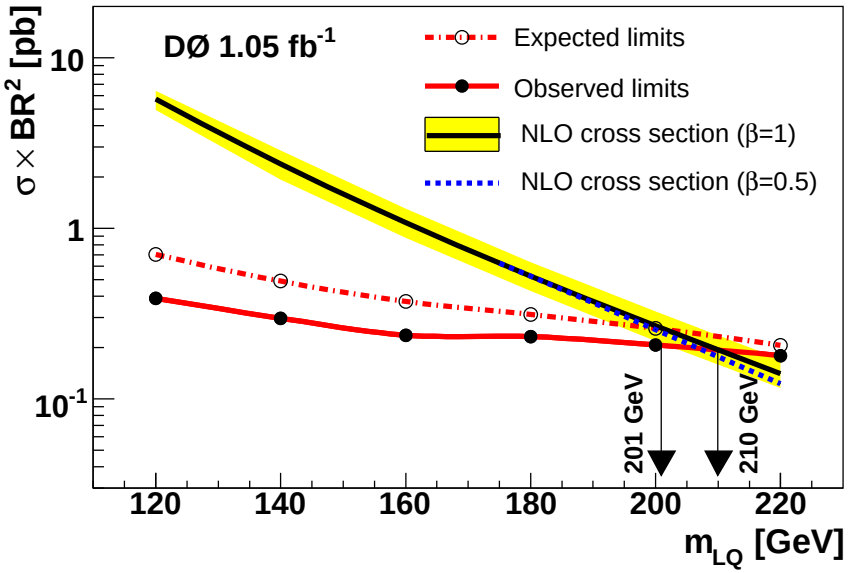
  $S_T = p_T^{\mu} + p_T^{\tau_h} + p_T^{jet_1} + p_T^{jet_2} + \not\!\!E_T$





Search for pair prod. of 3rd generation scalar LQ in $\tau b \tau b$

- limits on M_{LQ} w.r.t nominal (lower edge) theory (combination of results with $= 1$ and ≥ 2 tagged b-jets)
  - charge-$\frac{4}{3}$ LQ:
    - $\rightarrow$ $\mathcal{B}(LQ \to \tau b) = 1$
    - $\Rightarrow$ $M_{LQ} > 210\,\mathrm{GeV}$ (201 GeV)
      ($\widehat{=}\ \sigma_{95\%CL} \times \mathcal{B}^2 = 0.19\,\mathrm{pb}$)
  - charge-$\frac{2}{3}$ LQ:
    - $\rightarrow$ $LQ \to \nu_\tau t$ allowed (kinematically suppressed by F_{SP})
    - $\rightarrow$ assume equal LQ couplings to τb and $\nu_\tau t$ ($\beta = 0.5$)
    - $\rightarrow$ $\mathrm{Br}(LQ \to \tau b) = 1 - (1-\beta) \times F_{sp}$
    - $\Rightarrow$ $M_{LQ} > 207\,\mathrm{GeV}$ (201 GeV)

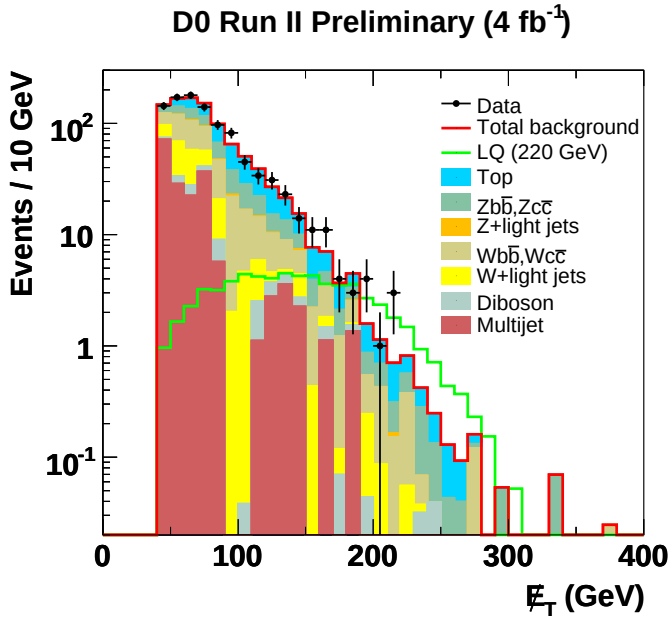


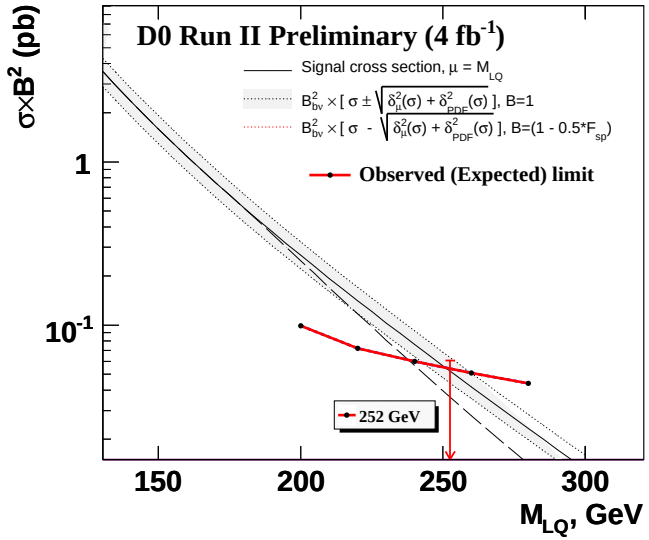
Comparison to CDF's 3rd gene. vector LQ search:

- PRD 77, 091105 (2008), $\mathcal{L} = 322\ \mathrm{pb}^{-1}$, $\tau_e\tau_h$ and $\tau_\mu\tau_h$ channels
- minimal coupling: $M_{LQ} > 251\,\mathrm{GeV}$, Yang-Mills C.: $M_{LQ} > 317\,\mathrm{GeV}$
- $\widehat{=}\ \sigma_{95\%CL} = \sim 1.0\,\mathrm{pb}\,(M_{LQ} = 180\,\mathrm{GeV}, MC) - 0.34\,\mathrm{pb}\,(320\,\mathrm{GeV}, YM)$

Search for pair-produced 3rd generation scalar LQ in $bb\not\!\!E_T$

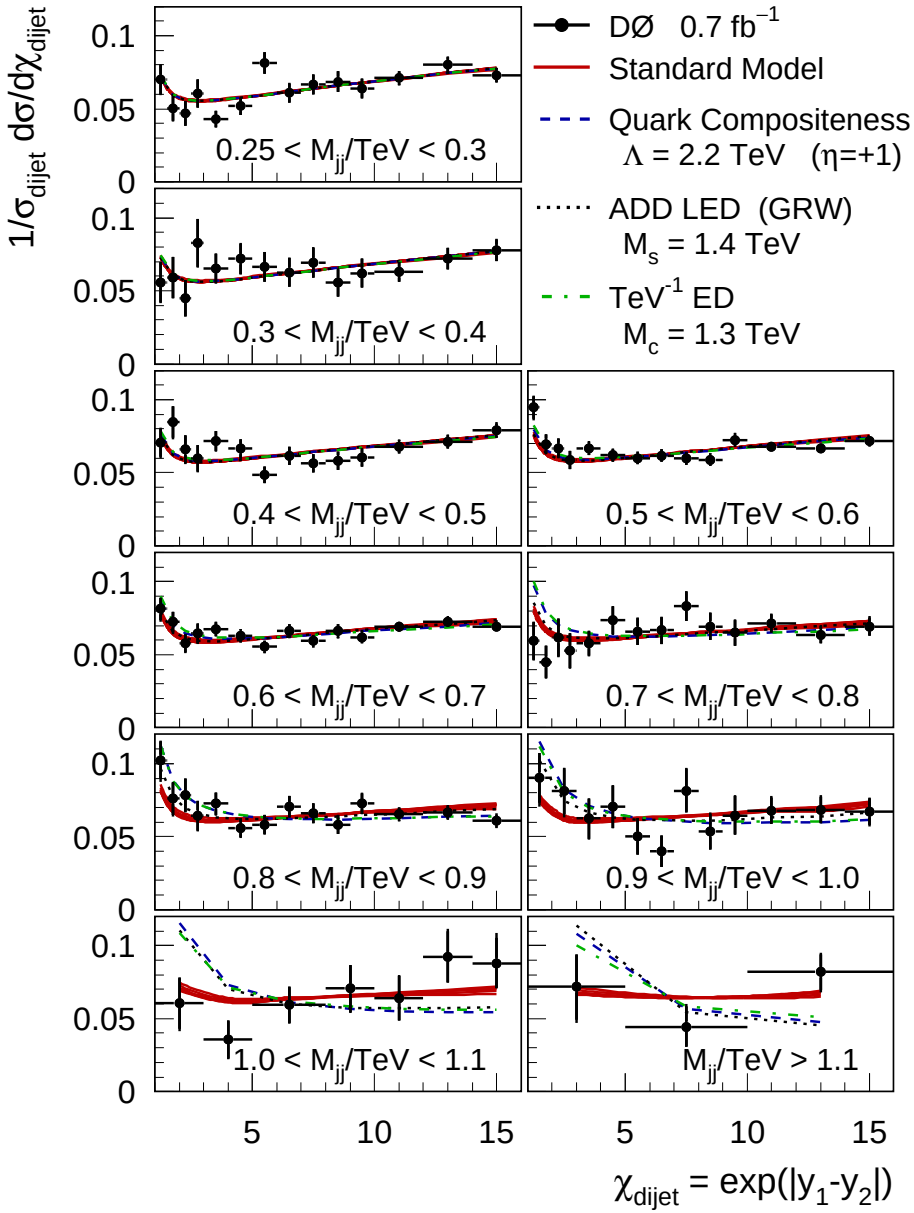
- preliminary, $\mathcal{L} = 4\,\text{fb}^{-1}$
- based on $\not\!\!E_T$-trigger
- 2 or 3 jets: 1 loose and 1 tight b-tag (NN)
- main background: $t\bar{t}$, $Zb\bar{b}/c\bar{c}$, $Wb\bar{b}/c\bar{c}$
- to suppress $t\bar{t}$ contribution:
  $$\frac{E_T^{\text{jet1}} + E_T^{\text{jet2}}}{\sum_{\text{jets}} p_T} > 0.9$$
- selection cuts on:
  $\not\!\!E_T$ and $H_T = \sum_{jets} |\overrightarrow{pT}|$
- charge-$\frac{1}{3}$ LQ:
  assuming $\mathcal{B}(LQ \to \nu b) = 1$
  $\Rightarrow M_{LQ} > 252\,\text{GeV}$





Search for Compositeness and LED in dijet angular distributions

- measurement of $\chi_{\rm dijet} = \exp(|y_1 - y_2|)$ in bins of M_{jj}
  - massless $2 \to 2$ scattering: $\chi_{\rm dijet} = \frac{(1+\cos\theta^\star)}{(1-\cos\theta^\star)}$
  - BSM: excess at large M_{jj} and small $\chi_{\rm dijet}$
- CDF: preliminary, 1.1 fb^{-1}
- DØ: submitted to PRL, arXiv:0906.4819, 0.7 fb^{-1}
- limits on BSM mass scales:
  - quark compositeness: CDF: 2.4 TeV, DØ: 2.8 TeV
  - large extra dimensions (DØ): ADD (GRW) and TeV^{-1}: 1.6 TeV
- see talk by N. Parua in QCD session (Th. 9:50)



Conclusion

- Leptoquarks
  - BSM signal with characteristic topologies involving *leptons*, *jets*, and $\not\!\!E_T$
  - results shown based on 1 to 4 fb^{-1}
  - significant improvements in mass limits: up to $> 300\,\mathrm{GeV}$
- dijet angular distributions
  - sensitive to compositeness and large extra dimensions
- for further details, see:

  http://www-cdf.fnal.gov/physics/physics.html
  http://www-d0.fnal.gov/Run2Physics/WWW/results.htm