Searches for vector-like quarks and leptoquarks at DØ

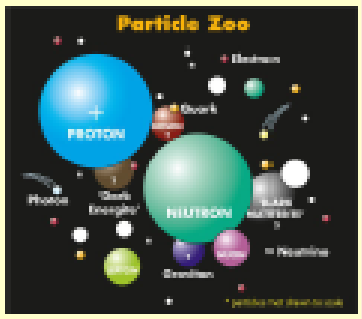
Lidija Živković,
Brown University
on behalf of the

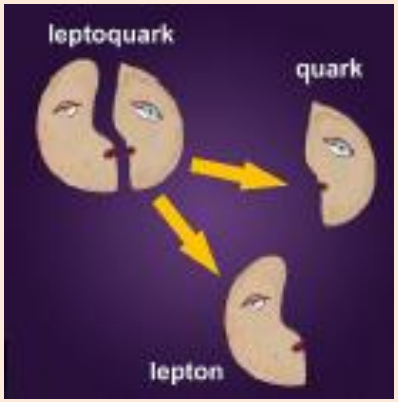
collaboration

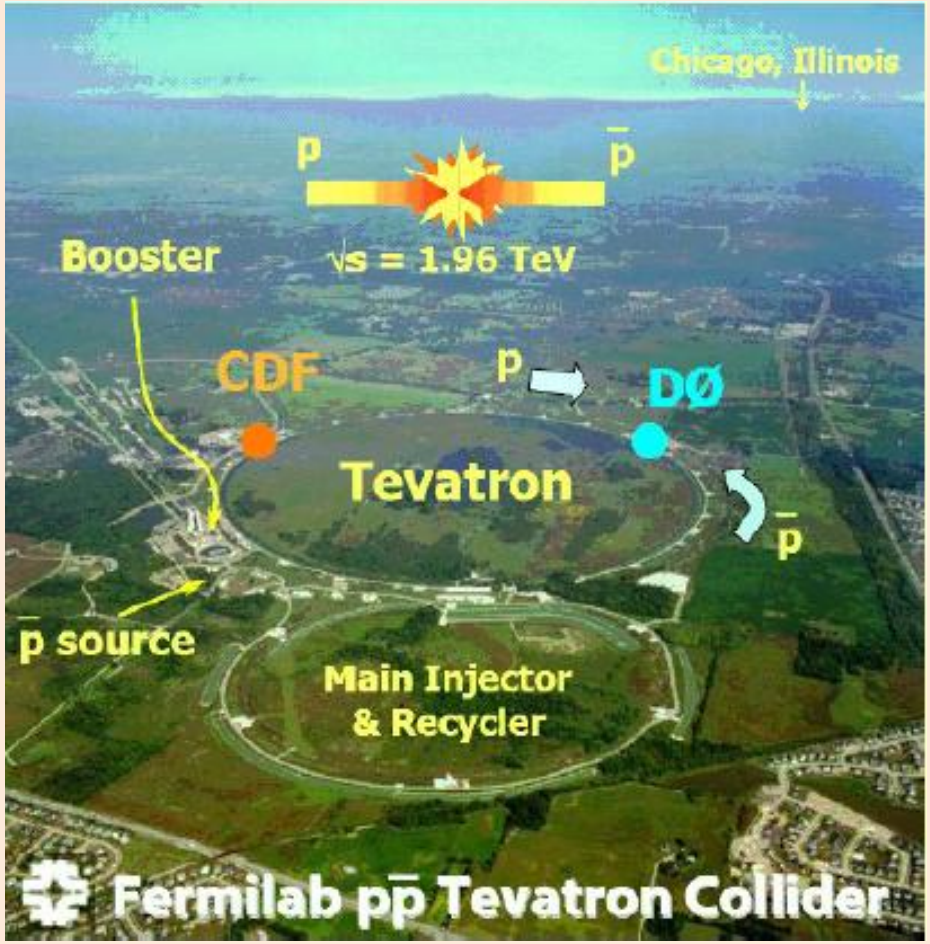
Meeting of the Division of Particles and Fields of the American Physical Society, DPF 2011
Brown University, Providence, Rhode Island,
August 9-13, 2011

Outline

- Leptoquarks
- Vector-like quarks







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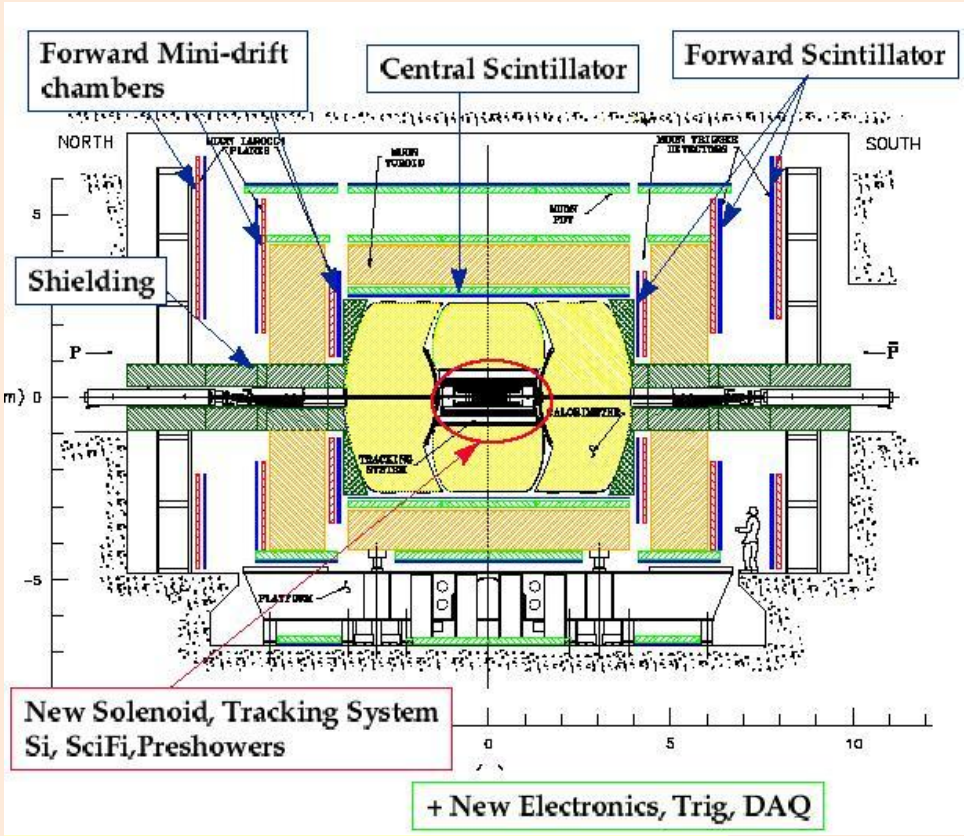
Motivation

- Standard model is believed to be low energy effective theory
  - There are evidences of the physics beyond SM
- Many additional models are proposed
- DØ performed extensive search for new particles and models over the years

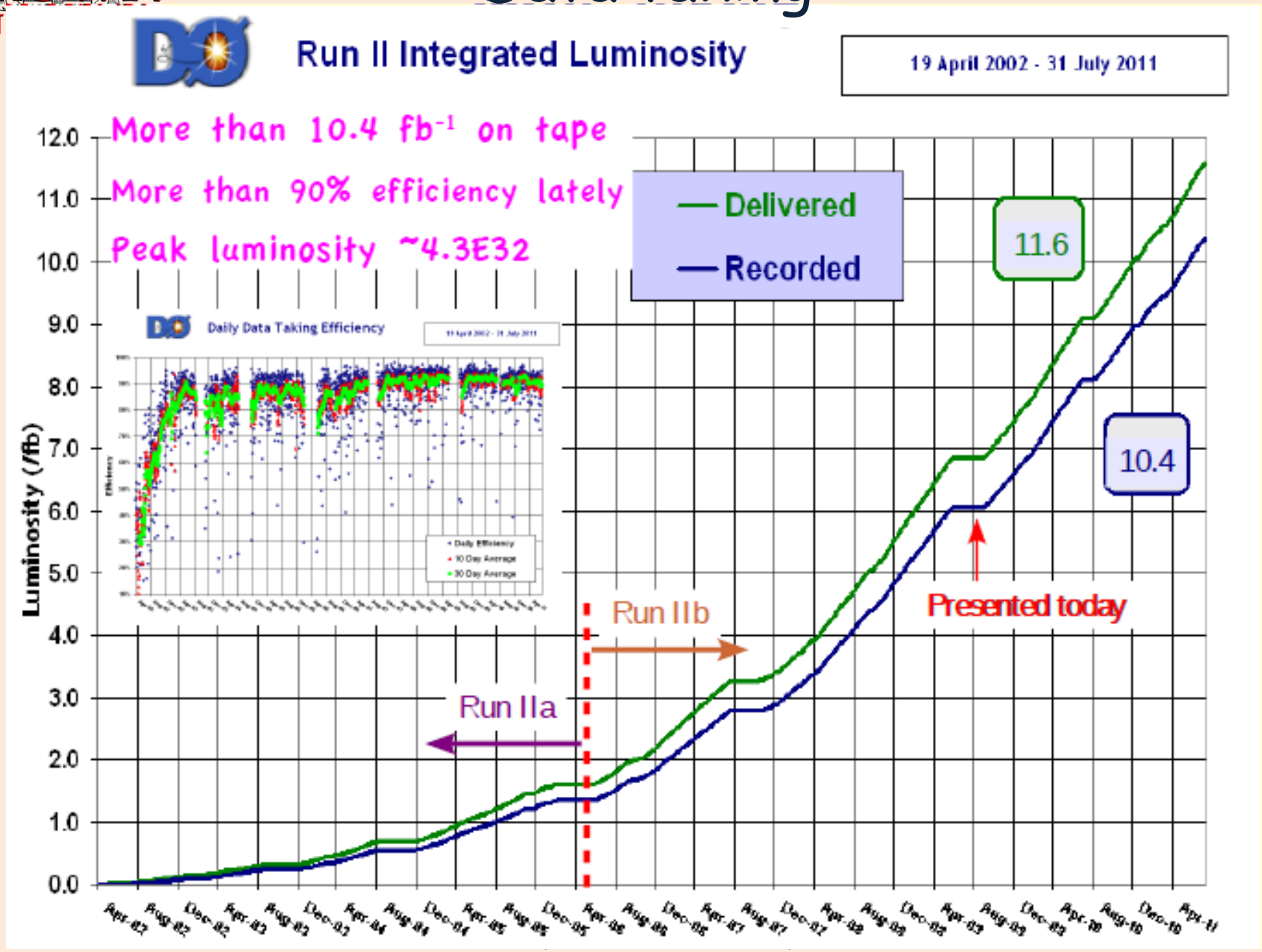
DØ experiment in Run II

- Multipurpose detector:
  - Central tracking system embedded in a solenoid magnetic field:
    - Silicon vertex detector
    - Fiber tracker
  - Preshowers
  - Electromagnetic and hadronic calorimeters
  - Muon system



Angular coverage	$\|\eta\|$
Muon ID	~2
Tracking	~2.5
EM / Jet ID	~4

Data taking


Run II Integrated Luminosity
19 April 2002 - 31 July 2011
More than 10.4 fb^{-1} on tape
More than 90% efficiency lately
Peak luminosity ~4.3E32
Delivered
Recorded
11.6
10.4
Daily Data Taking Efficiency
Run IIb
Run IIa
Presented today
Luminosity (/fb)
12.0
11.0
10.0
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Leptoquarks

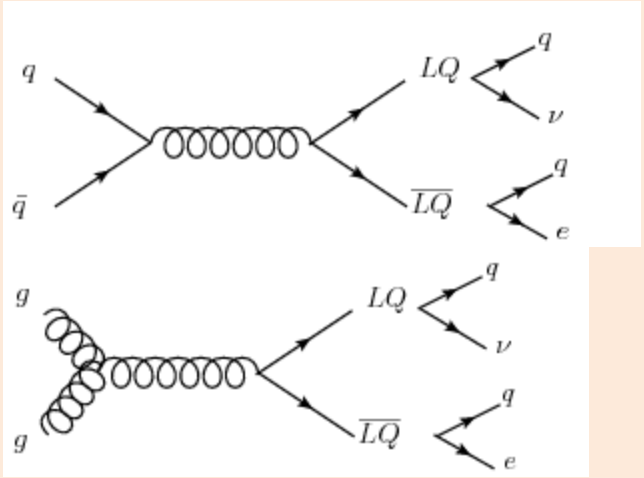
Motivation

- Leptoquark (LQ) is predicted by many extensions of the Standard Model (GUT, technicolor, etc.)
  - LQ can be a mediating boson, allowing interaction between leptons and quarks
    - In the SM, leptons and quarks do not directly interact
  - Can be scalar or vector field
    - has three generations
  - Short-lived and decays to a lepton and a quark

Introduction

- LQ can be produced singly or in pairs
- Produced via quark-antiquark annihilation or gluon-gluon fusion:
  q + q -> LQ + LQ

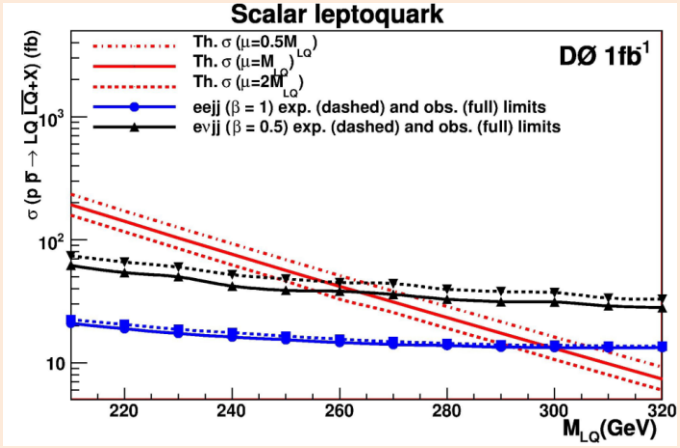
  g + g -> LQ + LQ

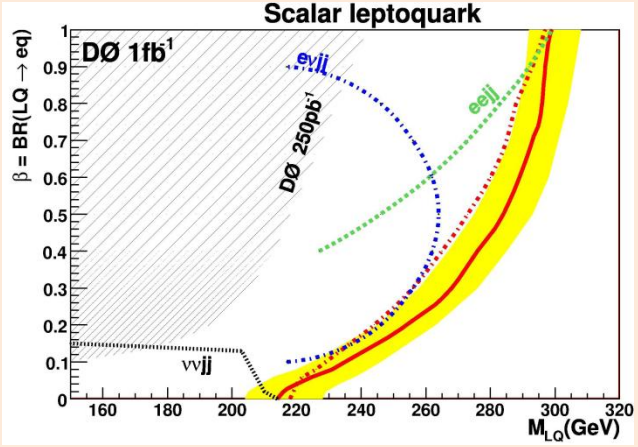


- Assume no intergenerational mixing
  - search for the first generation
- LQ pair decays to 1 of 3 final states: eqeq, eqνq, and νqνq.
  - Define branching ratio β = Br(LQ->e+q), then probability of LQ pair decaying to eqνq is 2β(1-β)
- Cross section times branching ratio is maximized for β=0.5

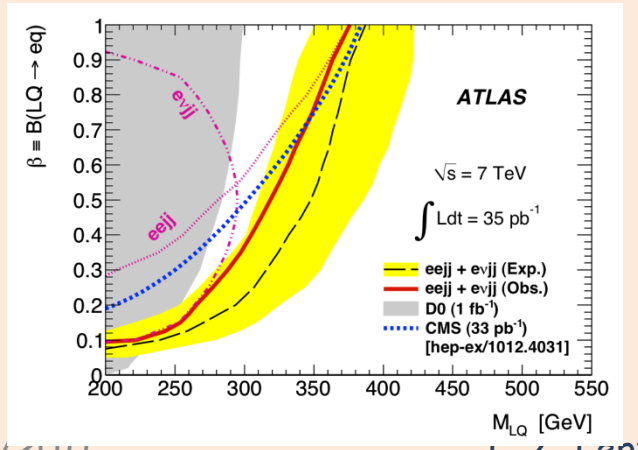
Previous results

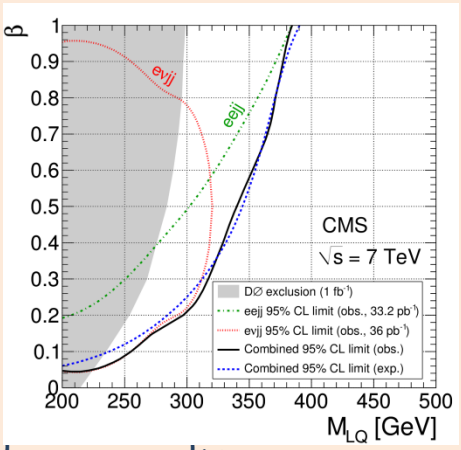
- Previous published DØ result puts lower limit on a scalar LQ mass at 264 GeV in ejvj channel, and 284 GeV when combined with ejej and vjvj (β=0.5)





- ATLAS and CMS released their first searches this year





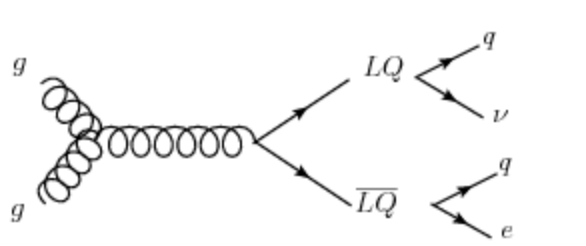
Data and backgrounds

- Data – 5.4 fb^{-1} collected with D0 between 2002 and 2009
- SM backgrounds:
  - modeled with MC:
    - W/Z+jets, tt, single top, diboson (WW, WZ and ZZ)
    - Normalized to the NLO
  - Multijet (MJ) background estimated from data
- Leptoquark signal normalized to NLO

TABLE I: Scalar LQ pair production cross sections, calculated at NLO, for different m_{LQ}.

m_{LQ} (GeV)	200	210	220	230	240	250	260	270
σ (fb)	270	190	140	100	76	56	42	31
m_{LQ} (GeV)	280	290	300	310	320	340	360	
σ (fb)	23	17	13	10	7.4	4.2	2.4	

Signal reconstruction



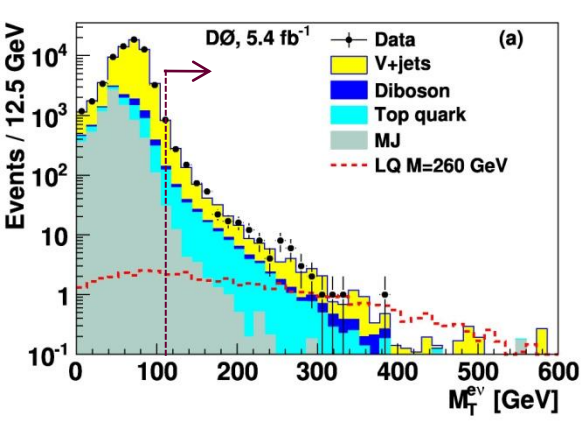
- Channel LQLQ -> eqνq;
  - explored ways to pair jets and e/ν coming from the same LQ
- Two possible combinations: [(j1,e),(j2,ν)] and [(j1,ν),(j2,e)]
  1. matching by minimizing differences in p_T from the combination of (jet,e) and (jet,ν)
  2. reconstruct LQ from the both combinations, and pick the combination such that Δφ(LQ1,LQ2) is closest to π
  3. matching by minimizing Δφ between the decay products of LQs
  4. matching by minimizing the differences in m_T reconstructed from (jet,e) and (jet,ν), since the LQs are produced with the same mass

m_{LQ} (GeV)	200	240	280
p_T	0.46	0.47	0.47
$\Delta\varphi(LQ_1,LQ_2)$	0.61	0.59	0.58
Δφ(dec. products)	0.48	0.47	0.45
$m_{T1}=m_{T2}$	0.77	0.75	0.74

Selection

- Few very simple cuts to achieve higher sensitivity
- Preselection: 1 electron with p_T > 15 GeV, MET > 15 GeV, at least 2 jets with p_T > 20 GeV,
  MJ cleaning cut: MET/50 + m_T(e, MET)/70 >= 1

	Data	Total BG	LQ (m=260 GeV)
Preselection	65992	65703.4 ± 5957.5	50.4 ± 6.8
m_T (e,MET) > 110 GeV	990	986.3 ± 81.6	33.5 ± 4.6
$\Sigma(m_{LQ})$ > 350 GeV	64	54.5 ± 4.1	27.3 ± 3.7
Σp_T(rec. objects) > 450 GeV	15	14.8 ± 1.1	24.4 ± 3.3



Selection

- Few very simple cuts to achieve higher sensitivity
- $\Sigma(m_{LQ}) = m_{ej} + m^{vis}_{\nu j}$, $m^{vis}_{\nu j}$ is mass of electron and visible part of neutrino, i.e. $\nu^{vis} = (MET_x, MET_y, 0, MET)$

	Data	Total BG	LQ (m=260 GeV)
Preselection	65992	65703.4 ± 5957.5	50.4 ± 6.8
m_T (e,MET) > 110 GeV	990	986.3 ± 81.6	33.5 ± 4.6
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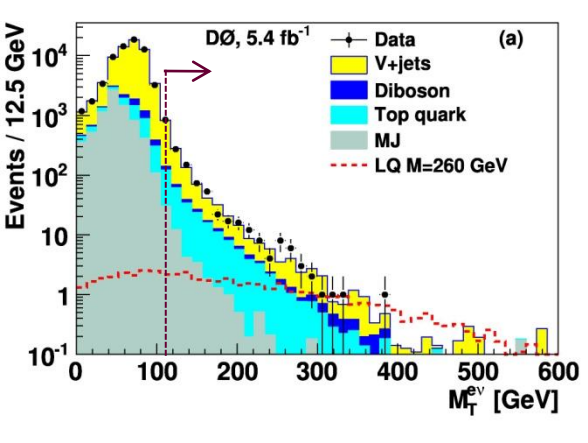

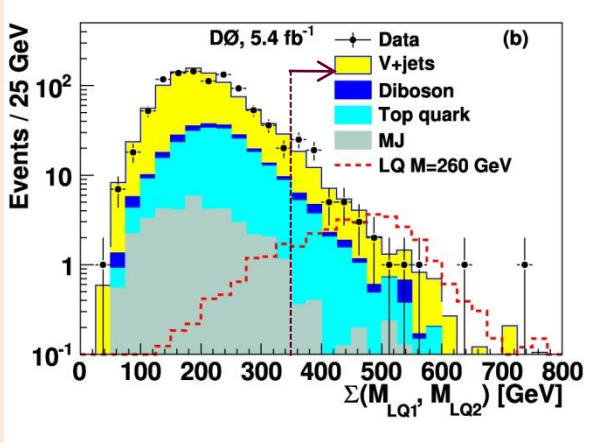

Selection

- Few very simple cuts to achieve higher sensitivity
- $S_T = \Sigma p_T(\text{rec. objects}) = p_T(e)+MET+p_T(jet_1)+p_T(jet_2)$

	Data	Total BG	LQ (m=260 GeV)
Preselection	65992	65703.4 ± 5957.5	50.4 ± 6.8
m_T (e,MET) > 110 GeV	990	986.3 ± 81.6	33.5 ± 4.6
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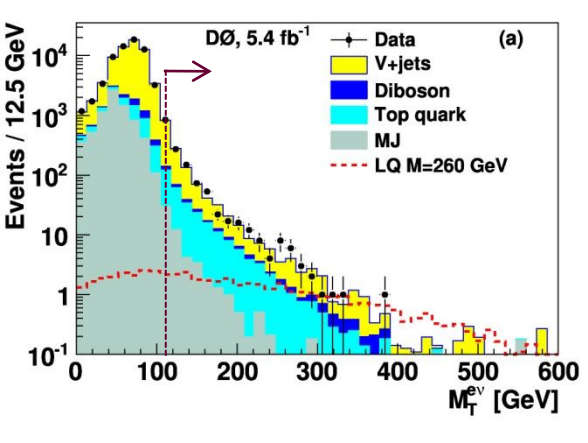
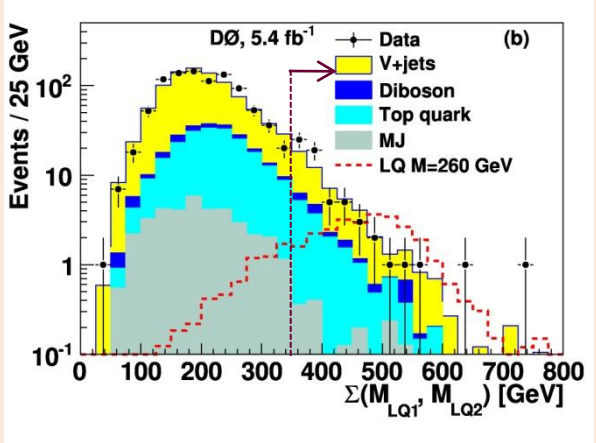
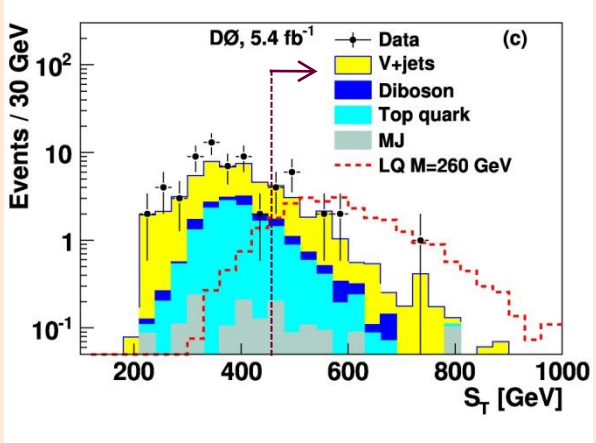


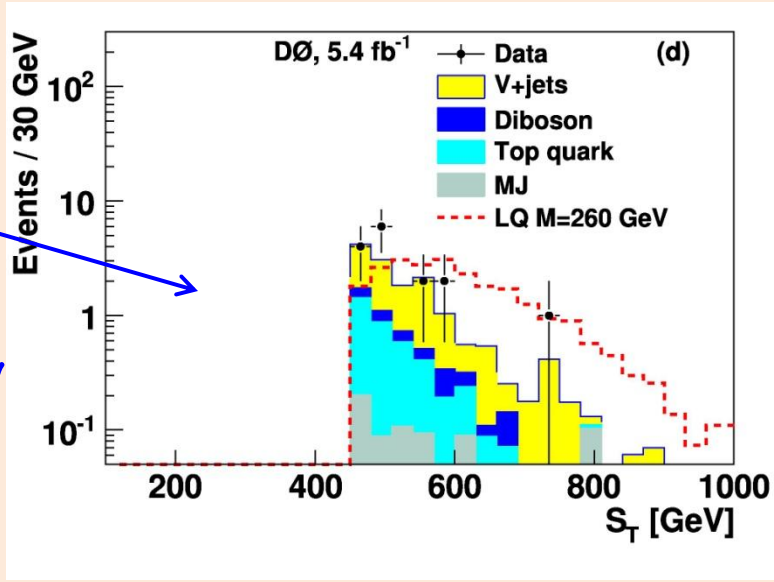


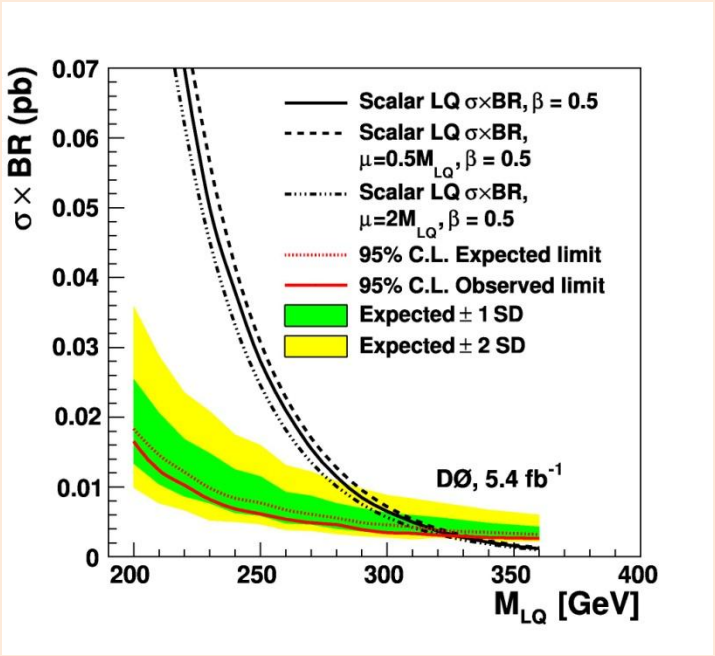


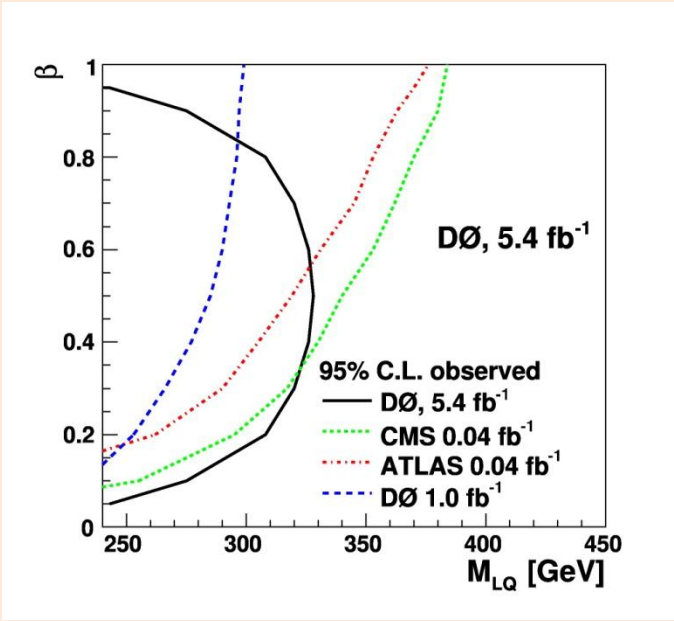
Result

[arXiv:1107.1849 [hep-ex]](arXiv:1107.1849 [hep-ex])

- S_T after final cut used to search for signal
- No excess in data => limits set
  - For β=0.5 LQ with mass below 326 GeV is excluded
  - Below β=0.3 we set the best limits







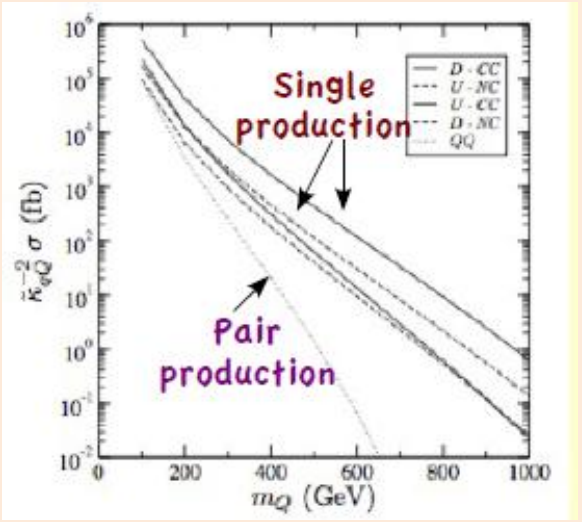
Vector-like quarks

Motivation

- Many new theories predict vector-like quarks:
  - Little Higgs
  - Warped extra dimensions
  - Universal extra dimensions => lowest KK excitation of SM fermions comprises a vector-like 4th generation
- Vector-like quarks are:
  - Ferminos despite the name
  - Their left- and right-handed components transform in the same way under $SU(3)xSU(2)_L xU(1)$

Introduction

- Vector-like quarks can be produced via strong or electroweak interaction
  - Pair production
  - Single production
- In some scenarios (e.g. warped extra dimensions), corrections to SM quark couplings due to mixing with vector-like quarks can cancel.
- No constraints from precision EW measurements
- Single weak production is possible at the Tevatron

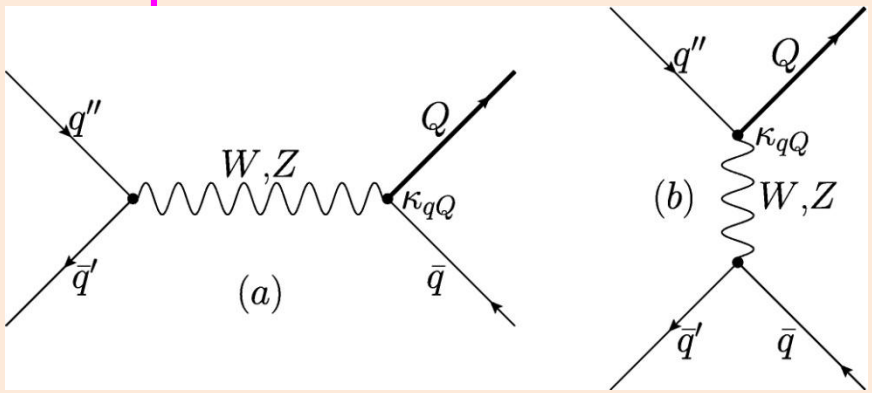


$$\kappa_{qQ} = \frac{v}{m_Q}\tilde{\kappa}_{qQ}$$

VEV

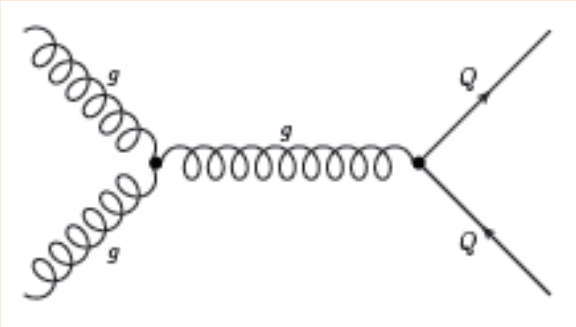
Coupling strength

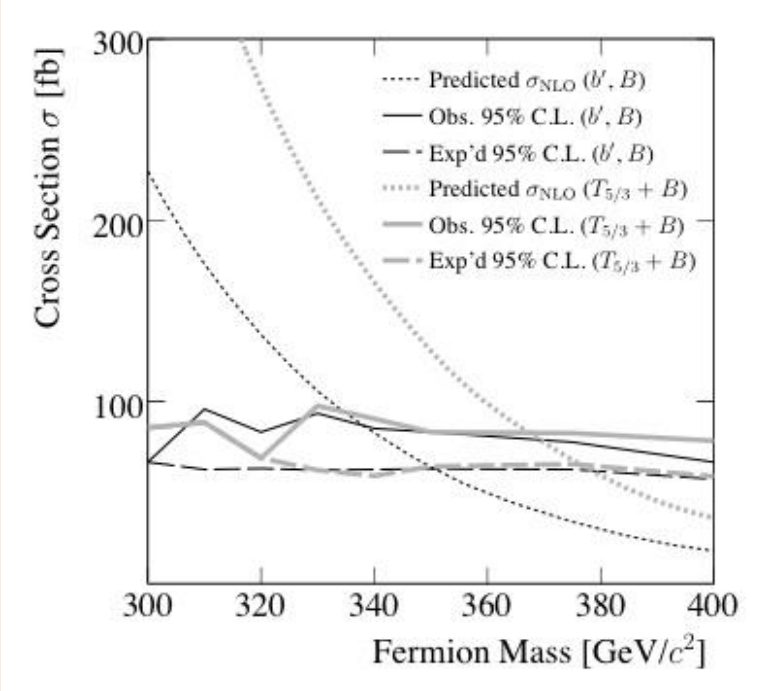
Heavy quark mass



Previous result

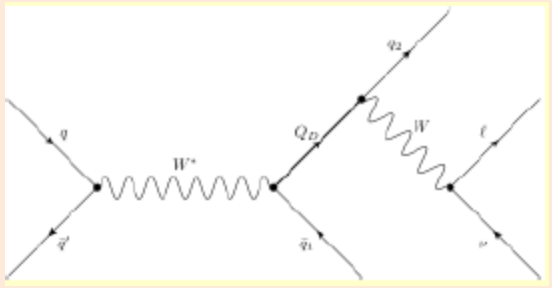
- Search for pair-produced heavy quarks: heavily constrained by the kinematic reach of the Tevatron
- CDF: $m_Q > 338$ GeV at 95% C.L. (PRL 104, 091801 (2010))

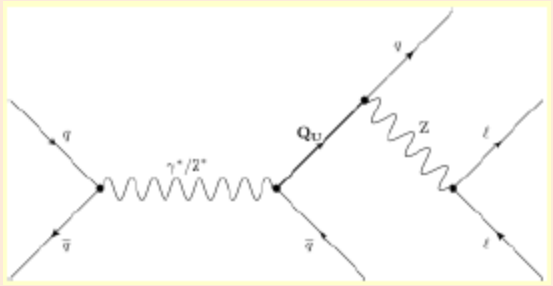




Vector-like quark signatures

- Vector-like quark can decay to W+q and to Z+q
- We assume $\tilde{\kappa}_{uD} = 1, \tilde{\kappa}_{uU} = \sqrt{2}, \tilde{\kappa}_{dU} = \tilde{\kappa}_{dD} = 0,$ i.e. BR(Q_D->Wq) = BR(Q_U->Zq) = 100%





- One isolated lepton, p_T>15 GeV, missing E_T>15 GeV, and at least two jets, p_T > 20 GeV
- Main background W+jets

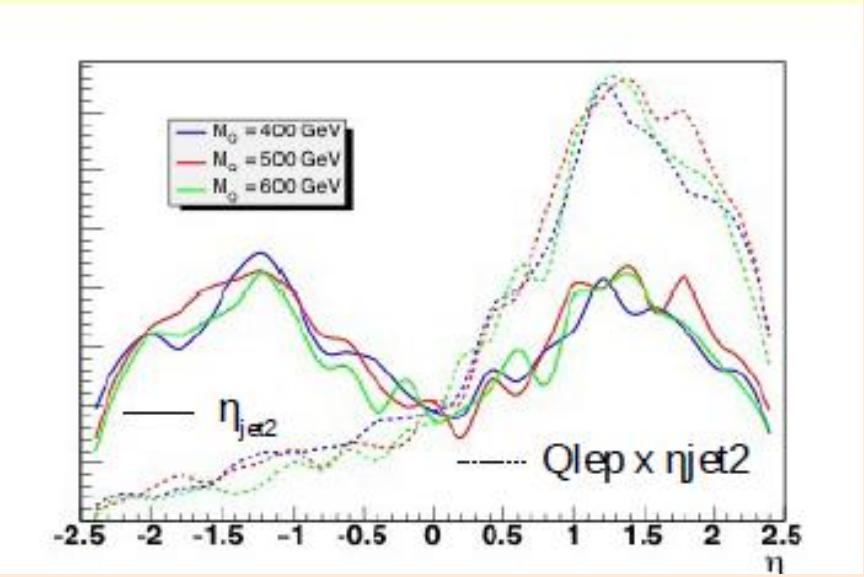
- Two isolated leptons, p_T>15 GeV from a Z boson, 70<M_{ll}<110 GeV, and at least two jets p_T>20 GeV; no MET, i.e. < 50 GeV
- Main background Z+jets

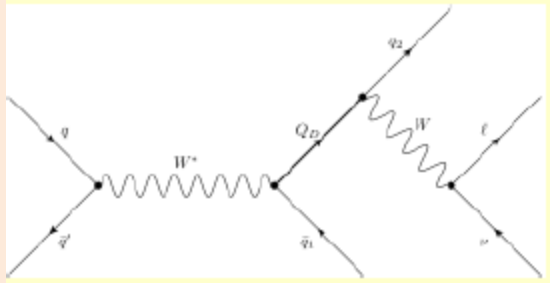
- Other backgrounds tt, single top, diboson (WW, WZ, ZZ) and instrumental multijet background
- Data – 5.4 fb^{-1} collected with DØ between 2002 and 2009

Final selection

- Single lepton channel:
  - Lepton p_T > 50 GeV
  - Leading jet p_T > 100 GeV
  - $\Delta\phi$(lep,MET) < 2.0
  - M_{TR} < 150 GeV
  - MET > 40(50) GeV
  - $Q_{lep} \times \eta_{jet2} > 0$
- 2nd jet in Qq->Wqq signal comes from SM quark produced in association with vector quark => forward, relatively soft
- Direction of 2nd jet is correlated with production of VQ/anti-VQ, and therefore correlated with the sign of the lepton in W decay mode

- Dilepton channel:
  - Z->ll p_T>100 GeV
  - Leading jet p_T>100 GeV
  - $\Delta R(l,l)$<2.0

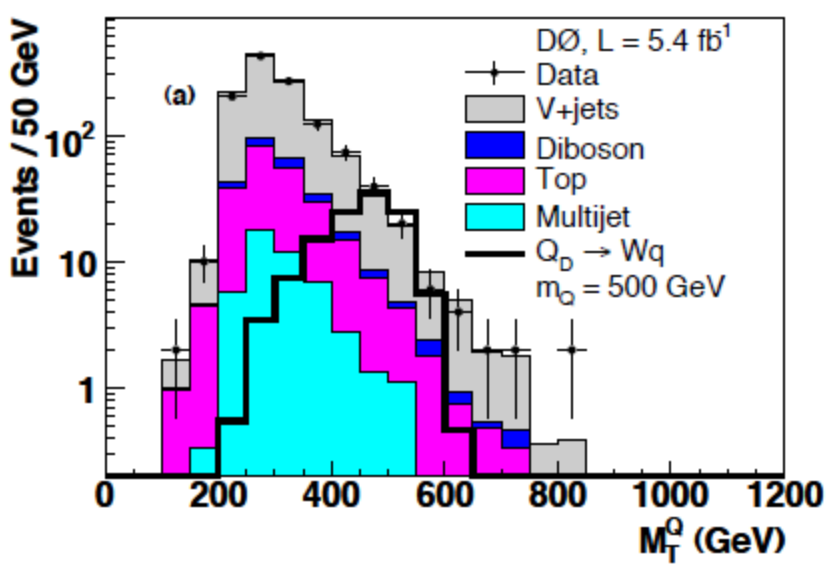


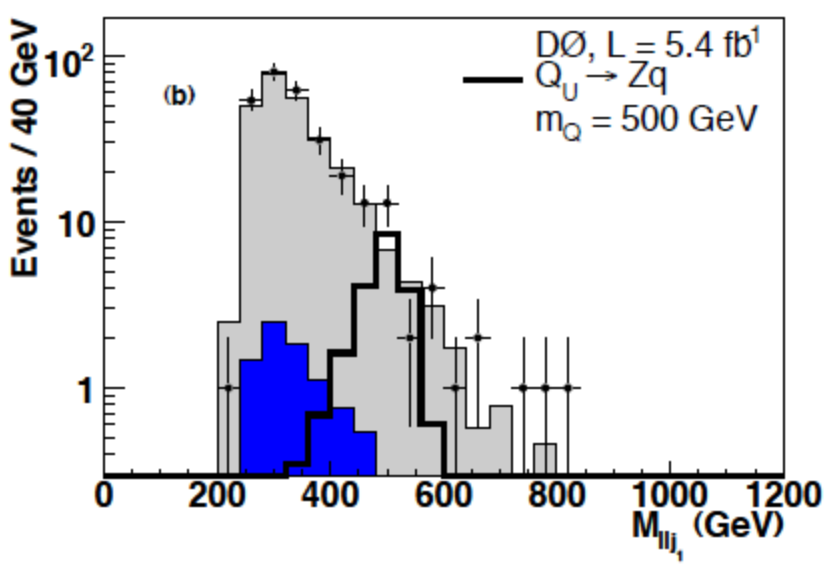


Result

- W+q
- m_T(l+ν+lead jet) used to search for a signal

- Z+q
- $m(l_1+l_2+\text{lead jet})$ used to search for a signal



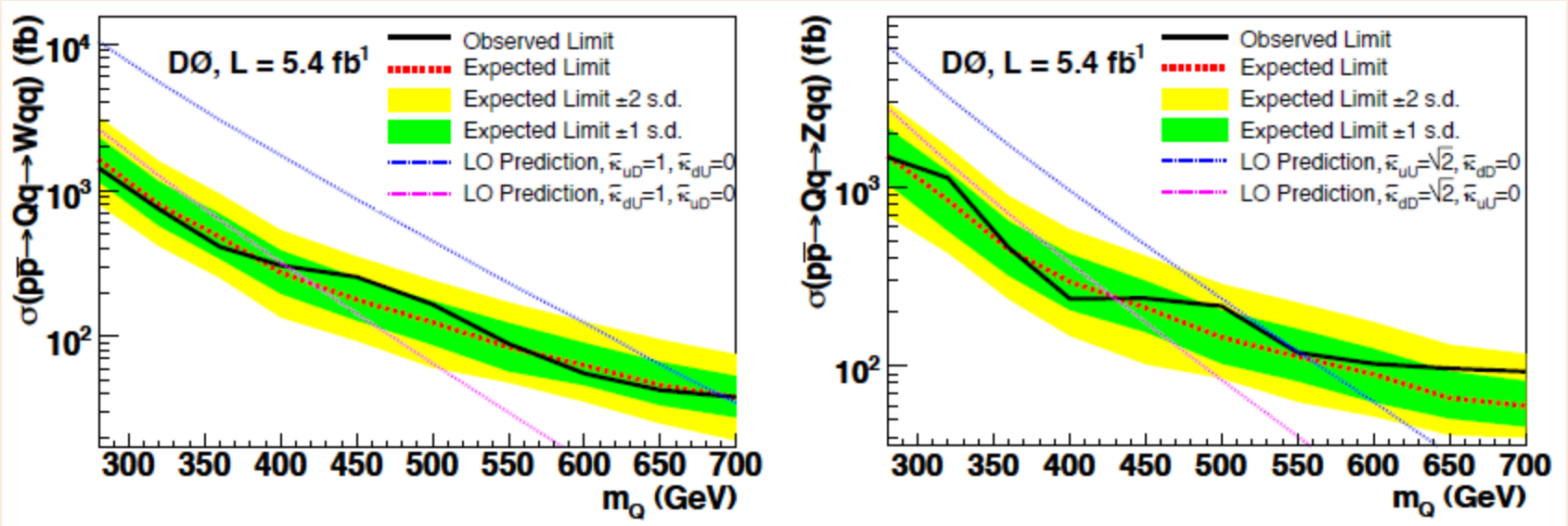


- No significant excess
- Limits are set on production cross sections

Limit

Phys.Rev.Lett.106:081801,2011

- W+q
- Z+q



- For $\tilde{\kappa}_{uD}=1, \tilde{\kappa}_{uU}=\sqrt{2}, \tilde{\kappa}_{dQ}=0$
  - m_Q > 693 GeV for Q->Wq, m_Q > 551 GeV for Q->Zq
- For $\tilde{\kappa}_{dU}=1, \tilde{\kappa}_{dD}=\sqrt{2}, \tilde{\kappa}_{uQ}=0$
  - m_Q > 403 GeV for Q->Wq, m_Q > 430 GeV for Q->Zq

Summary

- Tevatron is running well and reliably and we are thankful to accelerator people that made it all happen
- Two mature experiments, performing very well
  - The Tevatron has now delivered more than 11 fb^{-1}.
- DØ has been searching for new physics signals over many years and produced dozens of papers
- LHC has started and surpassed many of our results
- We present results on the search for the first generation scalar LQ pair production in $e\nu jj$ final state
  - We exclude scalar LQ with mass below 326 GeV for β=0.5
- We also searched for the heavy vector-like quark
  - We set the most stringent limits to date on the production of the heavy vector-like quark

Back up

LQ systematics

- Flat:
  - Production cross sections: on W/Z+jets (6%), ttbar (7%), diboson (10%) and signal (10%)
  - Multijet production (QCD): 20%
  - Luminosity: 6.1%
  - Lepton ID and trigger: Combined 4%
- Shape:
  - Jet energy scale (JES)
  - Jet energy resolution (JER)
  - Jet ID and reconstruction efficiency
  - PDF (signal only)
  - Jet pT missmodeling (W+jets only)

Systematic Uncertainties

VQ

dominant sources

Source	Single Lepton Channel	Dilepton Channel
Integrated lumi	6.1%	--
Global MC norm.	--	5%
V+jets modeling	15%	
top x-section	9%	
W/Z+jets x-section	4%	
diboson x-section	4%	
lepton ID	3%	--
Trigger	1% (electron)	--
	4% (muon)	
Jet energy scale	1-5%*	3%
Jet energy resolution	1-5%*	2%
Jet ID efficiency	1-5%*	3%
Jet vertex confirmation	1-5%*	--
high-p_T muon modeling	3-5%*	--
QCD modeling	6.5% (electron)	100%
	30% (muon)	

*: shape-dependent systematic uncertainty

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23/02/11