Searches for Leptoquarks
with the D0 detector

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On behalf of the D0 collaboration

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of the American Physical Society

Introduction

GUTs models

$SU(3)_C$ X $SU(2)_L$ X $U(1)_Y$

Quarks

Bosons

Leptons

SUSY theories
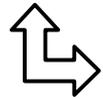
LEPTOQUARKS

**scalar/vector particles that have color,
fractional electric charge
barion and lepton numbers,
predicted by the SM extensions.**

LQ interactions

- invariant under SM
- separately conserve lepton and baryon numbers
- **no cross-generation coupling**

SM fermions		Search
Quarks	Leptons	**Leptoquarks ?**
u, d	e, ν	**LQ1**
s, c	μ, ν	**LQ2**
t, b	τ, ν	**LQ3**

In this talk

Most recent D0 LQ analyses (up to 4 fb^{-1} data)

Leptoquarks at the Tevatron

$q\bar{q}$ annihilation

dominant

M(LQ)>100 GeV

q,g

$\bar{q},g$

**LQ**

$\overline{LQ}$

g

gg fusion
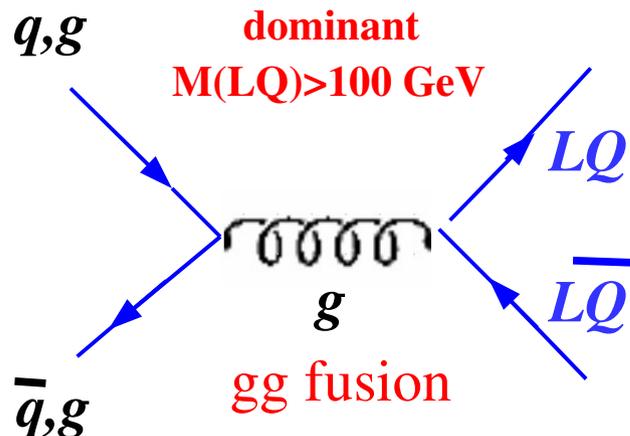
Pair Production

no dependency from unknown LQ– l–q coupling
Scalar LQ : well known (NLO) cross-section
Vector LQ : larger cross-section, model dependent

Single LQ Production

unknown LQ–l–q coupling

Decay Signatures

LQ_N q_N (β) l_N LQ_N q_N $(1-\beta)$ ν_N
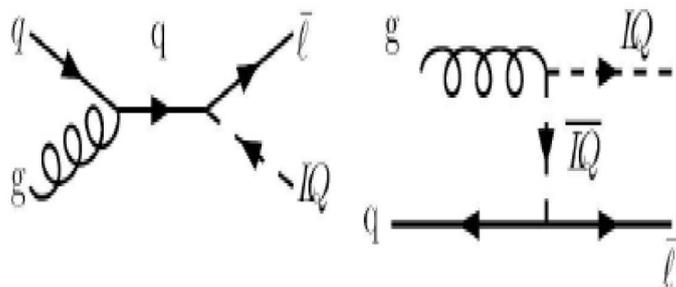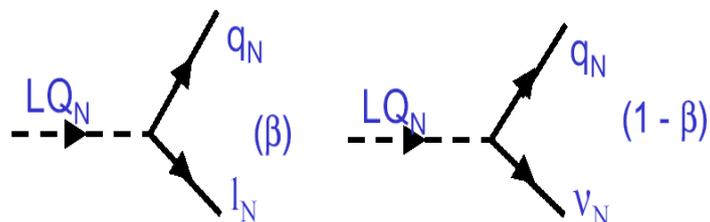
- 2 leptons + 2 jets, no missing energy (MET)
- 1 lepton + 2 jets + MET
- 2 jets + missing energy

$\beta = $ branching $LQ \rightarrow ql^{\pm}$

Outline.

- **Generation independent search**
  - $\nu\nu$jj, **2.5 fb^{-1}**, Phys. Lett. B 668, 357 (2008)

- **1st generation , scalar and vector pair production:**
  - eejj, eνjj ,   **1.0 fb^{-1}** , arXiv:0907.1048

- **2nd generation , scalar pair production:**
  - μjμj, μj$\mu\nu$, **1.0 fb^{-1}** , Phys. Lett. B 671, 224 (2009)

- **3rd generation , scalar pair production:**
  - τbτb , **1.05 fb^{-1}**, Phys. Rev. Lett. 101, 241802 (2008)
  - $\nu\nu$bb, **4.0 fb^{-1}**
  - **http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/NP/N68**

Backgrounds: Z(νν)+jets, W(lnu)+jets, dibosons, ttbar
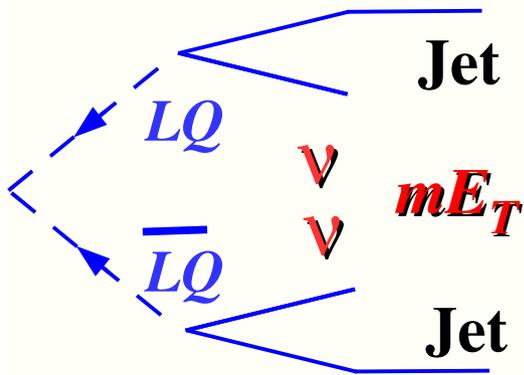
Signal selections

- exactly 2 jets $E_T > 35$ GeV, $|\eta| < 0.8$, **MET>75 GeV**
- angular correlations between jets and MET directions
- veto on isolated e/μ

LQ

LQ̄

Jet

Jet

ν

ν

mE_T

Optimization: H_T and MET for low/high LQ masses
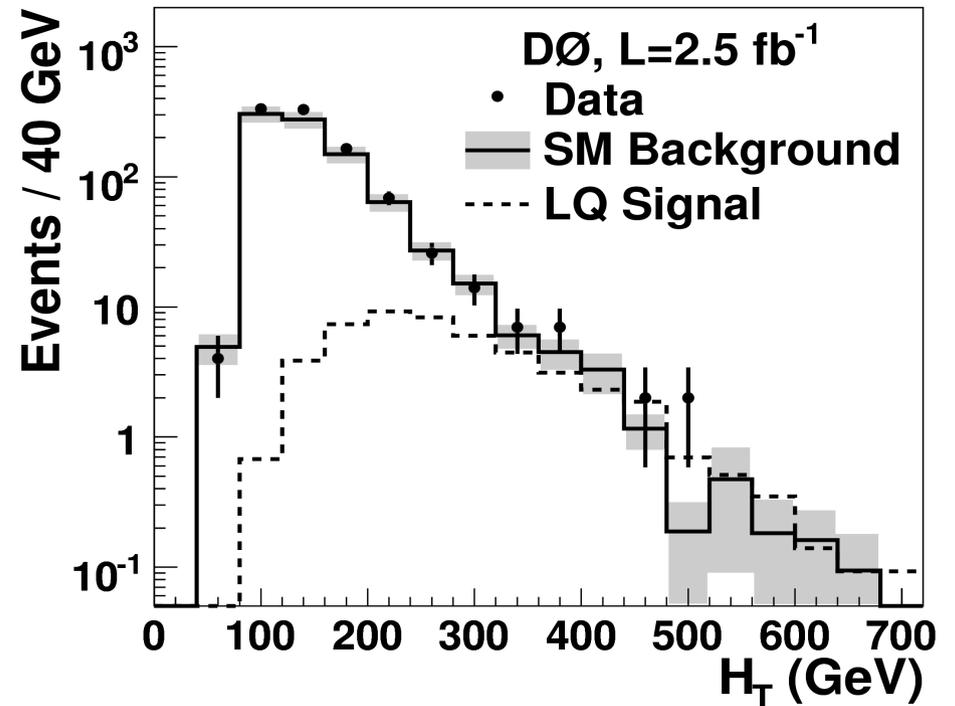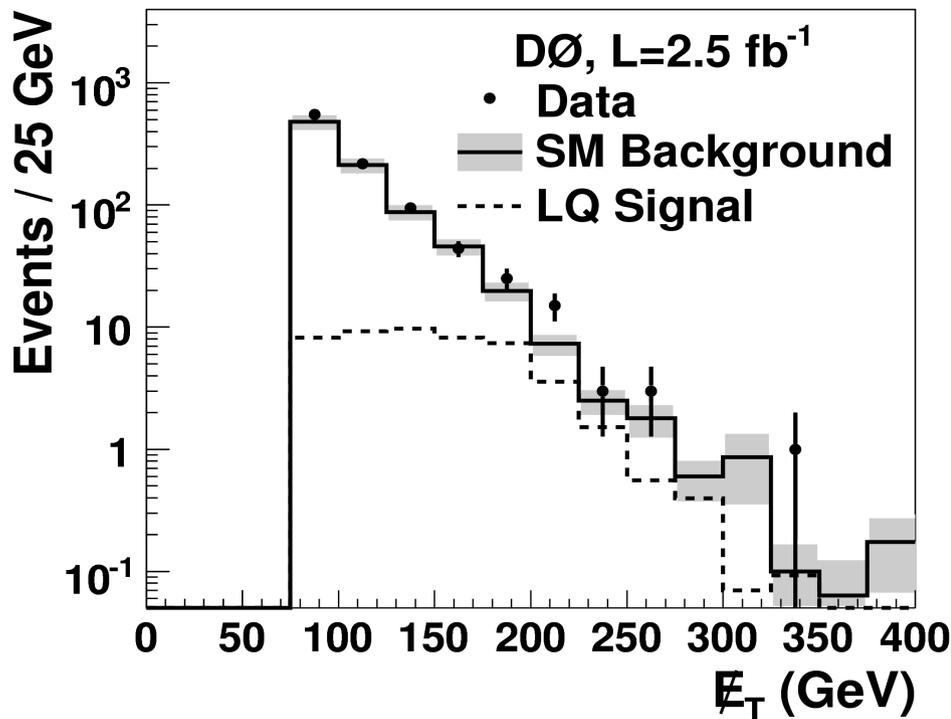
MET and HT distributions before optimization

| M$_{LQ}$	σ_{nom} (pb)	$(H_T, \not{E}_T)$ (GeV)	N$_{obs}$	N$_{backgrd.}$	N$_{sig.}$
140	2.38	(150, 75)	353	$328 \pm 11^{+56}_{-57}$	$229 \pm 8^{+24}_{-23}$
200	0.268	(300, 125)	12	$10.6 \pm 1.7^{+4.0}_{-2.0}$	$13.7 \pm 0.6^{+1.8}_{-2.0}$
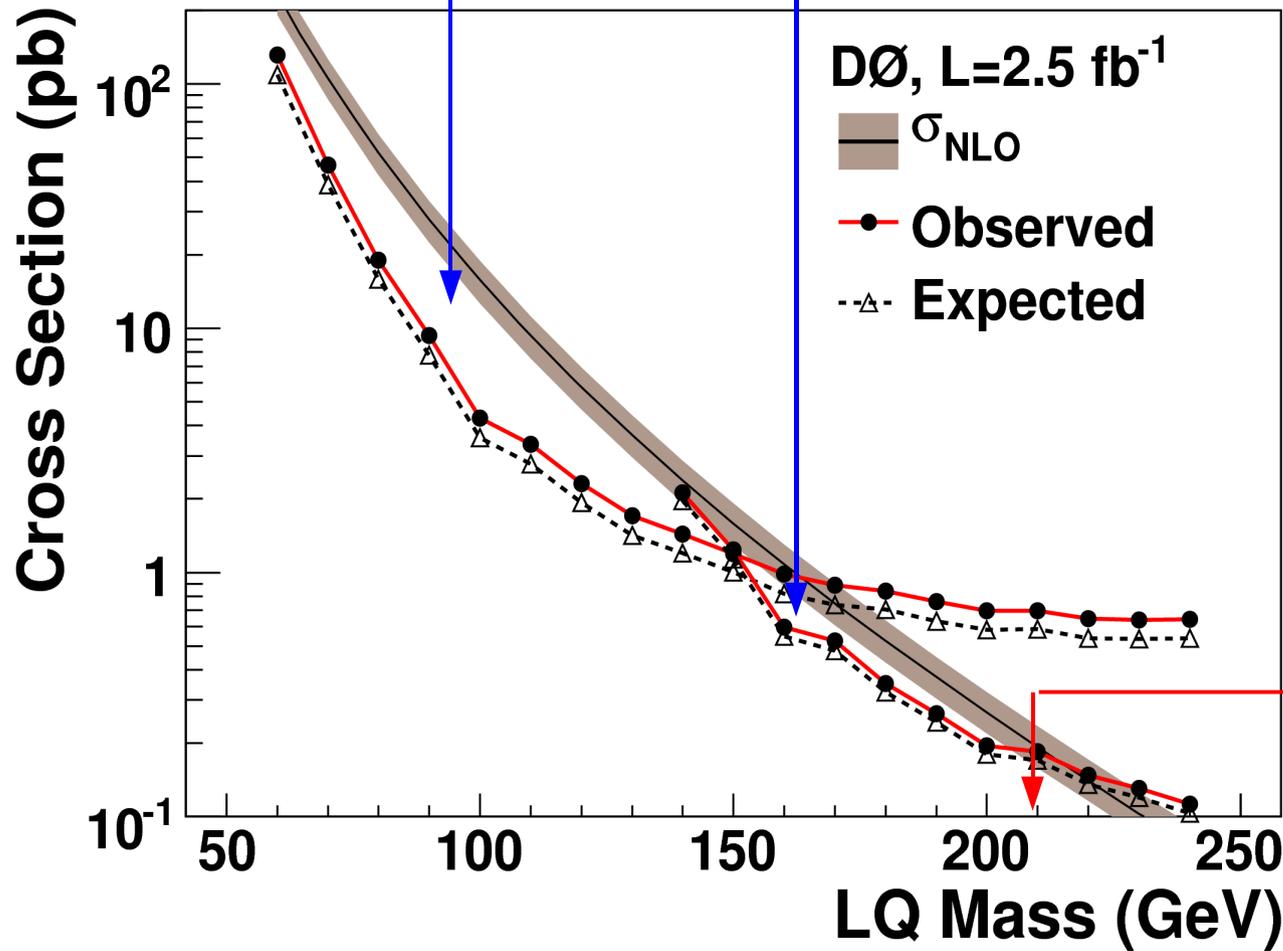
Phys. Lett. B 668, 357 (2008)

Result:

No LQ signal observed

excluded

M$_{LQ}$ < 205(214) GeV
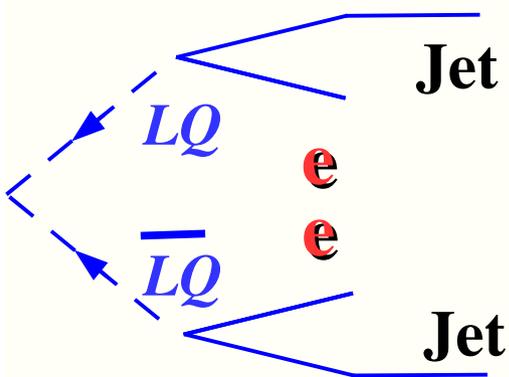
Backgrounds: **Z(ee)+jets**, top, diboson

Signal selections

- **2 jets** $E_T > 25$ GeV, $|\eta| < 2.5$; **2 electrons** $p_T > 25$ GeV
- M_{ee}, $S_T = \Sigma E_T(\text{jets}) + \Sigma p_T(e)$

Jet

LQ

e
e

LQ

Jet

Optimization: $S_T > 400$ GeV, $M_{ee} > 110$ GeV
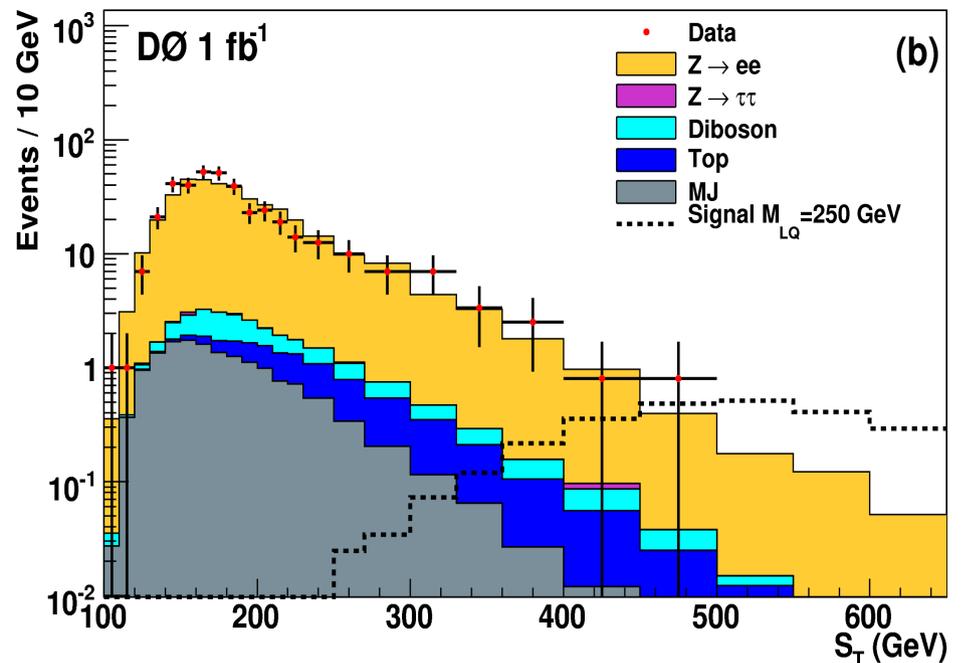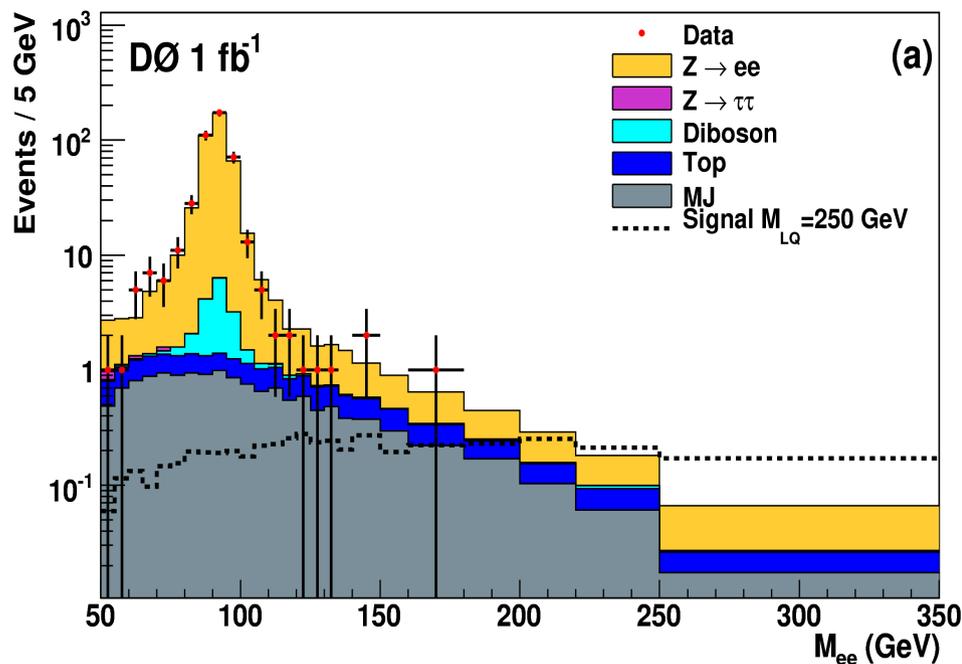
All selections: $N_{data} = 0$, $N_{bkg.} = 1.51 +/- 0.12 +/- 0.04$, LQ accept: 20-23%

Backgrounds: W(lν)+jets, top, diboson

(LQ decay diagram: LQ → Jet, e; $\overline{LQ}$ → ν, Jet; with mE$_T$)
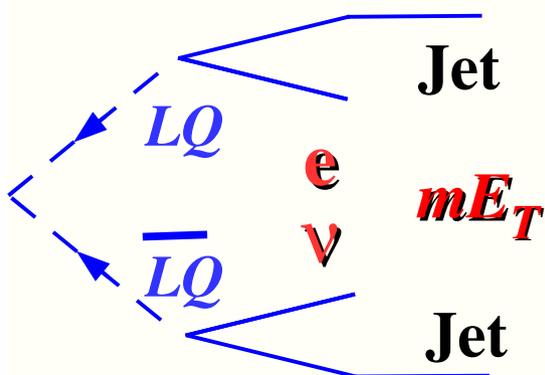
Signal selections

- **2 jets** $E_T > 40$ GeV, $E_T > 25$ GeV, $|\eta| < 2.5$;
- MET > 80 GeV, $p_T(e) > 80$ GeV, $M_T(e,MET) > 130$ GeV

Optimization: $S_T = \Sigma\ E_T(jets) + p_T(e) + MET$
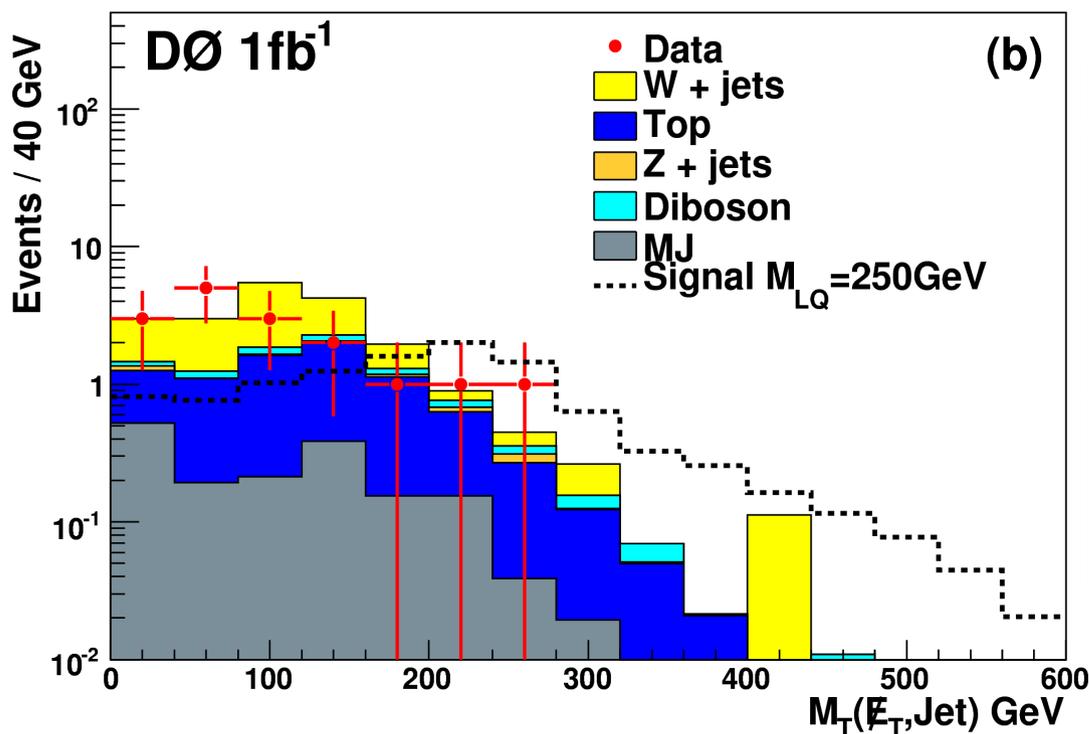
| Sample	Number of events
Data	8
Total expected background	$9.8 \pm 0.8 \pm 0.8$
W + jets	$5.0 \pm 0.7 \pm 0.3$
Top	$3.29 \pm 0.07 \pm 0.26$
Z/γ^* + jets	$0.15 \pm 0.06 \pm 0.01$
Diboson	$0.48 \pm 0.05 \pm 0.04$
Multijet	$0.9 \pm 0.2 \pm 0.07$

LQ accept.: 18-20%

1st generation LQs, 1.0 fb^{-1}

arXiv:0907.1048

Scalar leptoquark

DØ 1fb^{-1}

DØ 250pb^{-1}

eνjj

eejj

ννjj

β = BR(LQ → eq)

M_{LQ}(GeV)

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
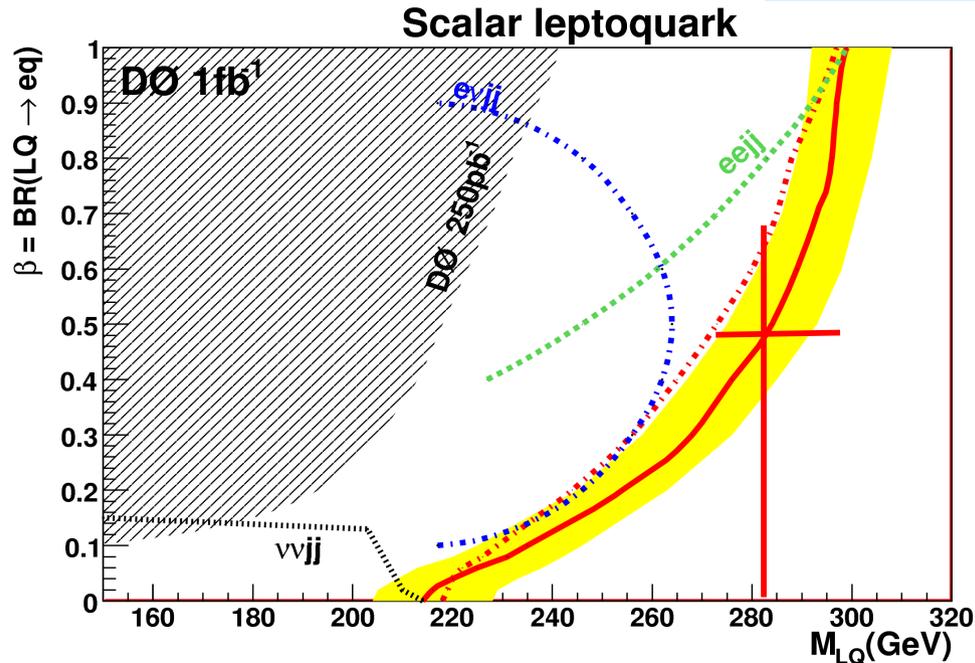
Exclusion (β=0.5):

Scalar: M_{LQ}< 284 GeV

Vector:	**MC**	**YM**	**MM**
M_{LQ},GeV	**357**	**415**	**464**

Vector leptoquark

DØ 1 fb^{-1}

MC coupling

YM coupling

MM coupling

β = BR(LQ → eq)

M_{LQ}(GeV)
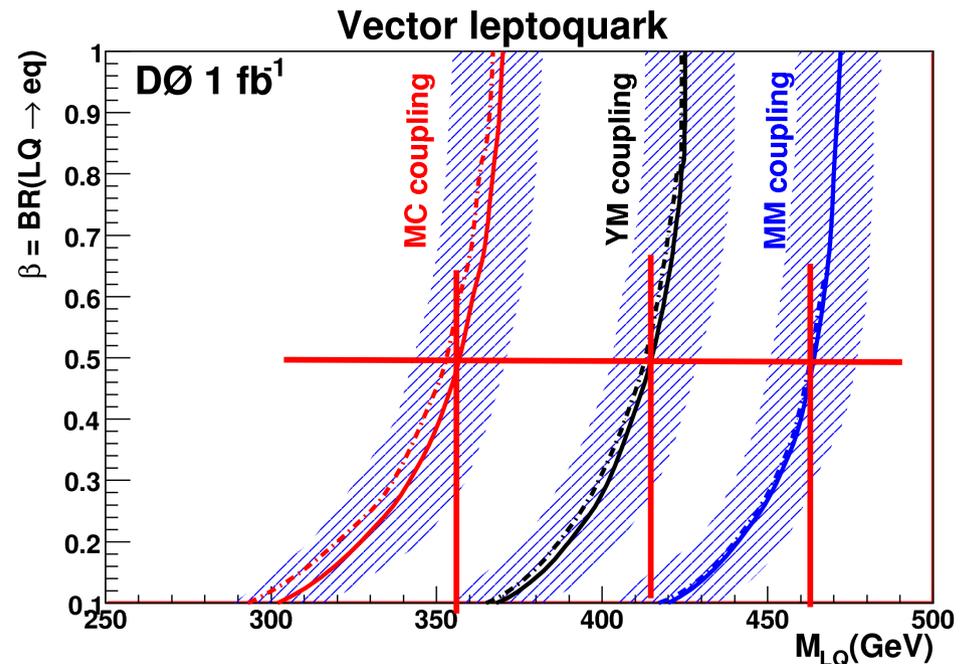
Most constraining LQ1 limits to date

2nd generation LQ$_2$LQ$_2$→μjμj (β=1), 1.0 fb^{-1}

Backgrounds: Z(μμ)+jets, W(lν)+jets, dibosons, single top
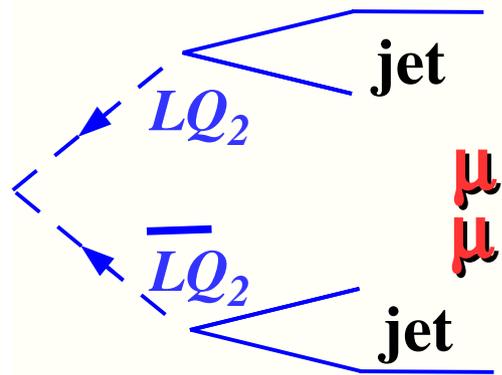
Signal selections

- **2 jets** E$_T$>25 GeV, |η|< 2.5 ; **2 muons** p$_T$>20 GeV
- S$_T$ = Σ E$_T$(jet) + Σ E$_T$(μ) > 200 GeV

Optimization: Neural Net (S$_T$, M(μμ), M(μ$_i$, J$_i$)
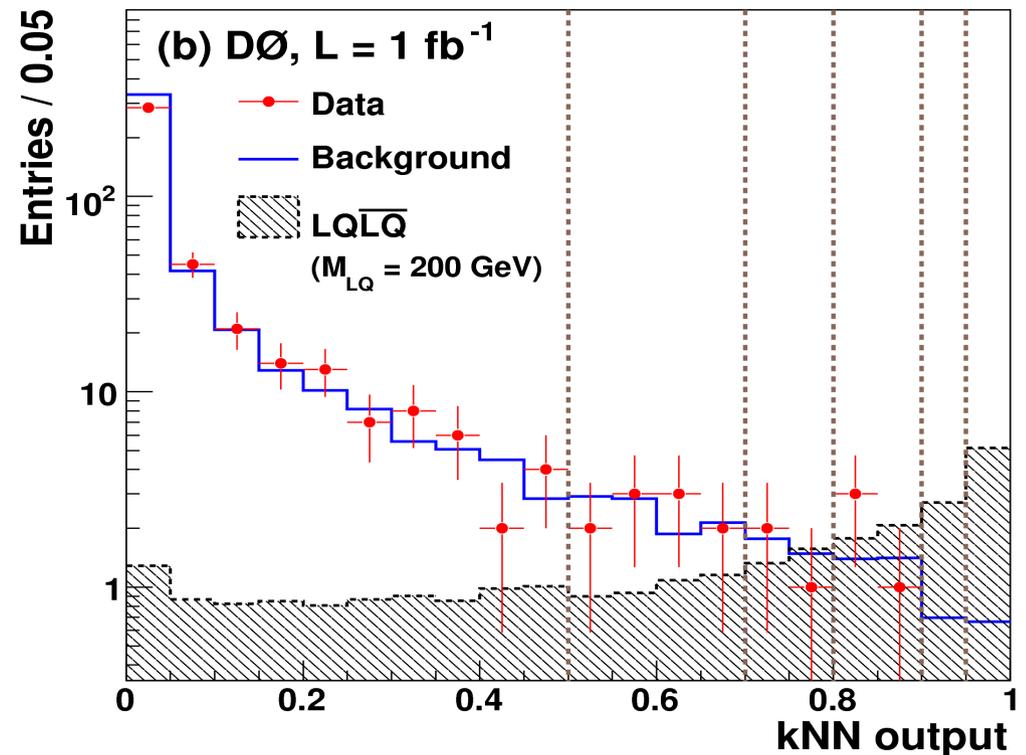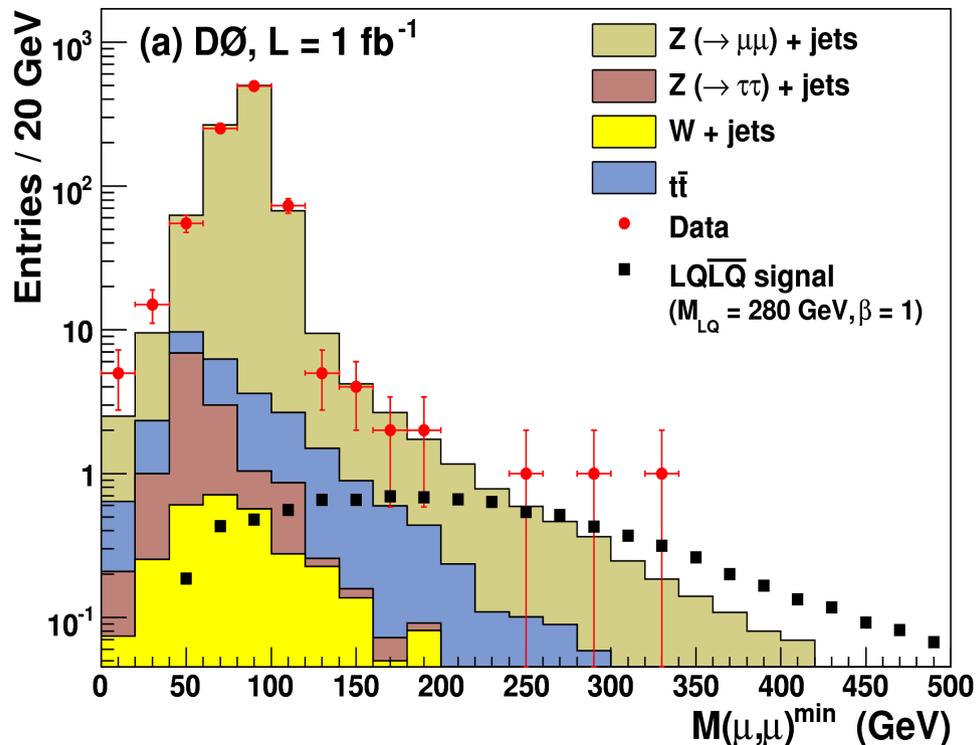
2nd generation LQ$_2$LQ$_2 \to \mu\nu\mu$j(β=0.5), 1.0 fb^{-1}

Backgrounds: Z($\mu\mu$)+jets, W(lν)+jets, dibosons, single top

jet

LQ$_2$

μ

$\overline{\nu}$ *mE$_T$*

$\overline{LQ_2}$

jet
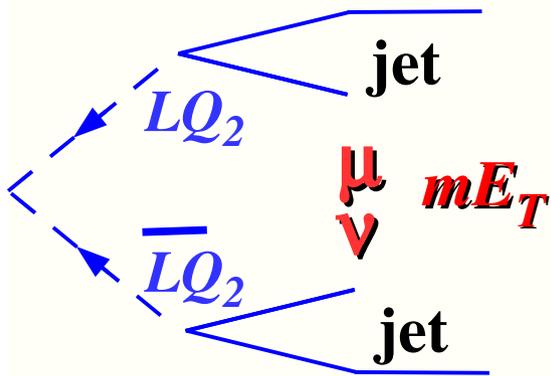
Signal selections

- **2 jets** E$_T$>25 GeV, | η |< 2.5 ; 1 **muon** E$_T$>20 GeV
- **MET > 30 GeV,** M$_T$($\mu\nu$) > 50 GeV

Optimization: Neural Net (S$_T$,M$_T$($\mu\nu$), M(μ, j$_i$) M$_T$(μ,j$_i$)

(b) DØ, L = 1 fb^{-1}

- Z ($\to \mu\mu$) + jets
- Z ($\to \tau\tau$) + jets
- W + jets
- t$\bar{t}$
- Multijet
- Data
- LQ$\overline{LQ}$ signal (M$_{LQ}$ = 200 GeV, β = 0.5)

Entries / 40 GeV

S$_T$ (GeV)

(a) DØ, L = 1 fb^{-1}

- Data
- Background
- LQ$\overline{LQ}$ (M$_{LQ}$ = 280 GeV)

kNN output
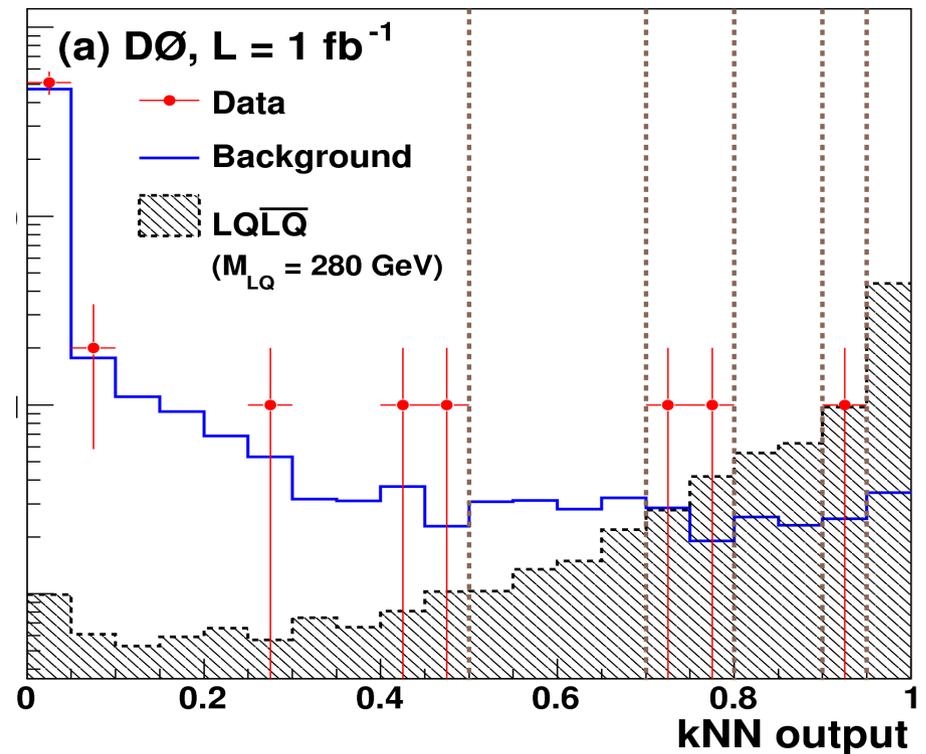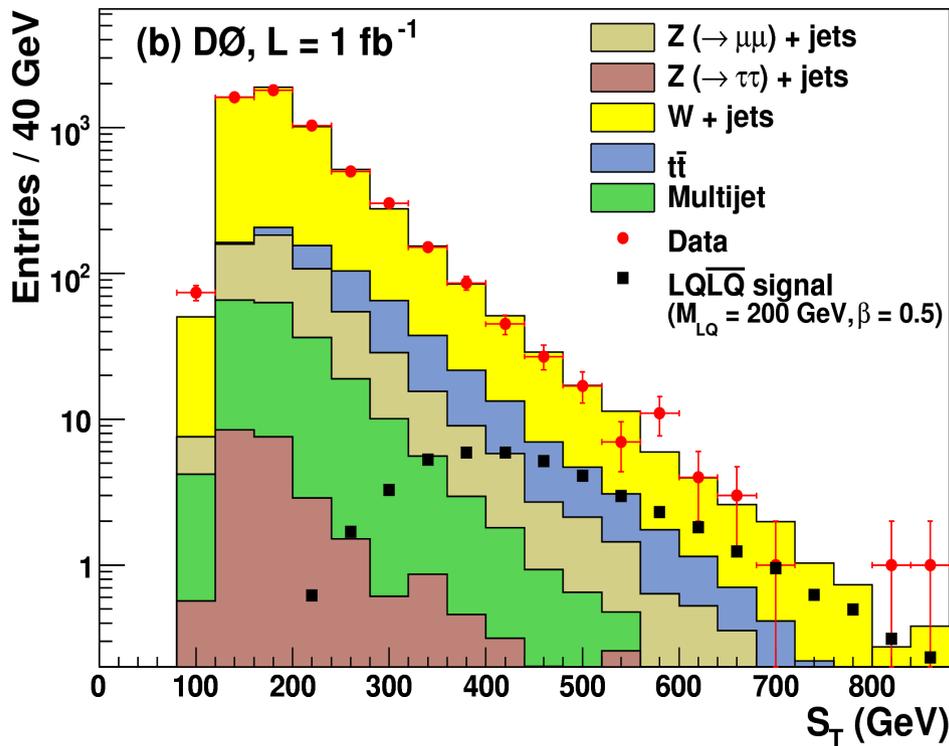
Phys. Lett. B 671, 224 (2009)
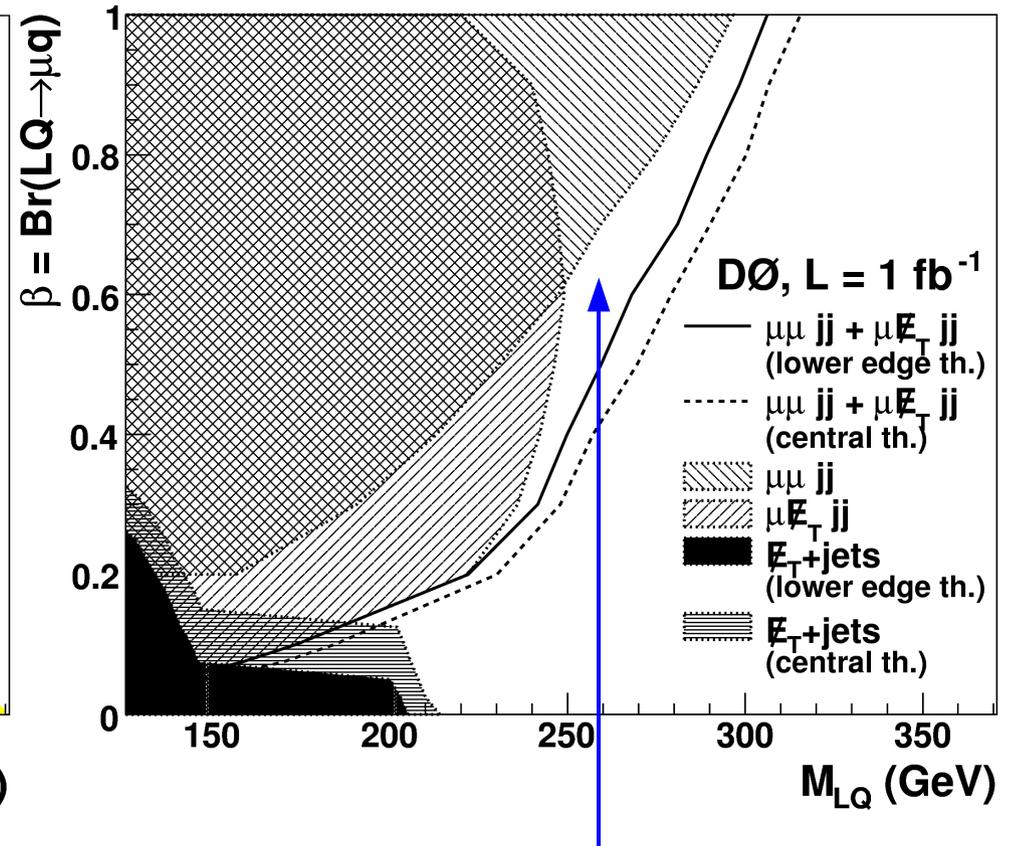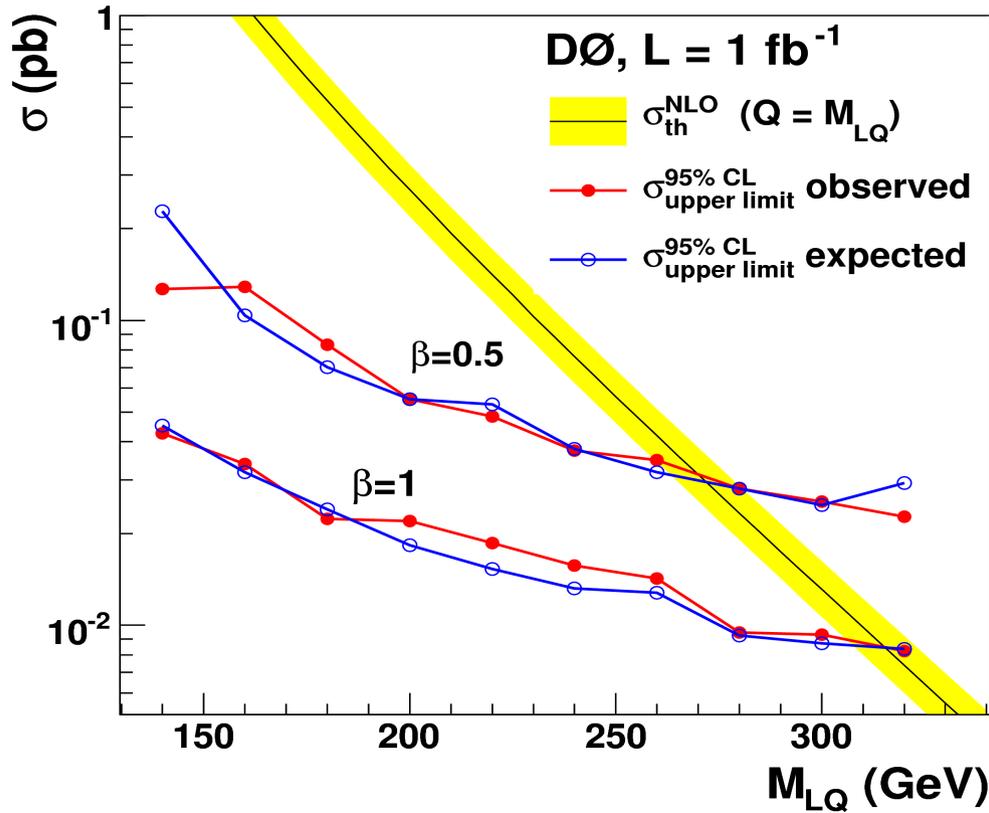
No signal observed

$M_{LQ} > 316$ GeV($\beta = 1$)

$M_{LQ} > 270$ GeV($\beta = .5$)

Excluded area in the

(M_{LQ}, β) plane,

combined limits

3rd generation LQ₃LQ₃→τbτb, 1.05 fb⁻¹

Backgrounds: W/Z+light jets, top, QCD, W/Z+bb(cc) jets
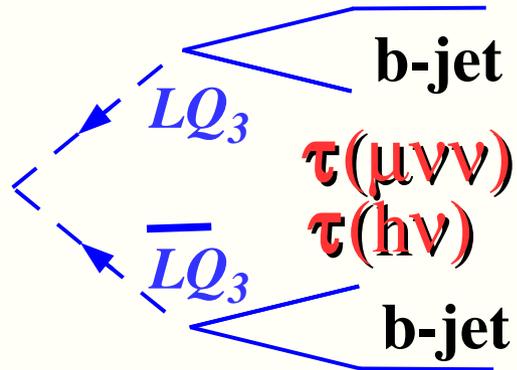
Signal selections : 2 taus: τ_μ ($p_T(\mu)$>15 GeV);

τ_h (3 types, NN id vs track and cal info, E_T>15-20 GeV)

- 2 jets: E_T> 20 GeV, | η |< 2.5 ; NN b-tagging
- M*(W) = $\sqrt{2E^\mu E^\nu(1-\cos\Delta\phi)}, \; E^\nu = \not{E}_T(E^\mu/p_T^\mu)$

Optimization: $S_T=p_T(\mu)+p_T(\tau)+E_T$(2 leading jets), 1 and 2-btag subsamples
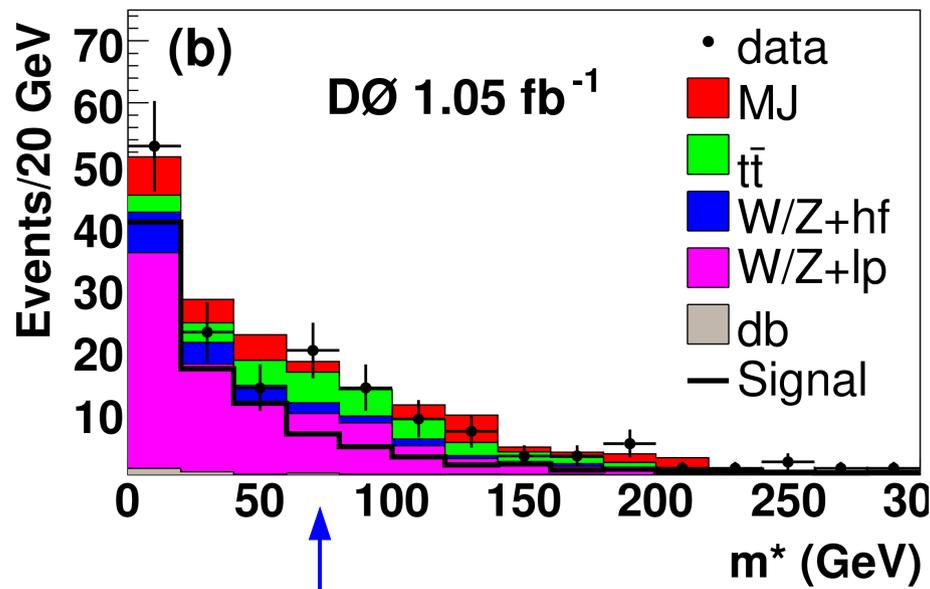
M*(W) < 60 GeV
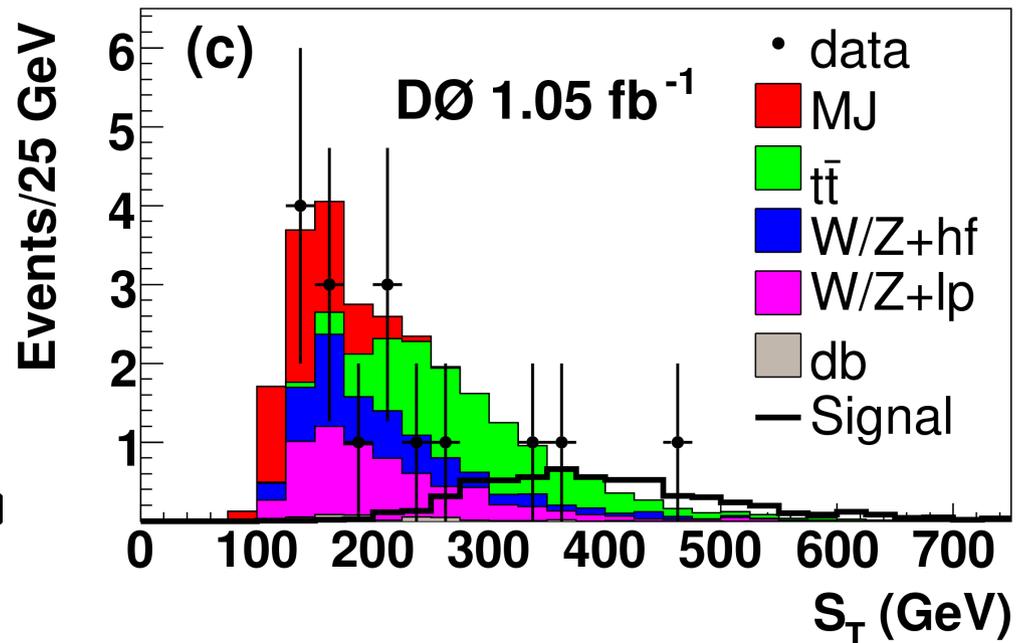
Agreement with SM expectations:

| Source	Preselect	$m^* < 60$ GeV	1 b-tag	≥ 2 b-tag
Sum Bknd	169.6 ± 7.9	109.2 ± 5.7	19.6 ± 2.5	4.8 ± 1.0
Data	157	94	15	1
LQ pair signal	9.0 ± 0.2	7.4 ± 0.1	3.4 ± 0.1	2.6 ± 0.1
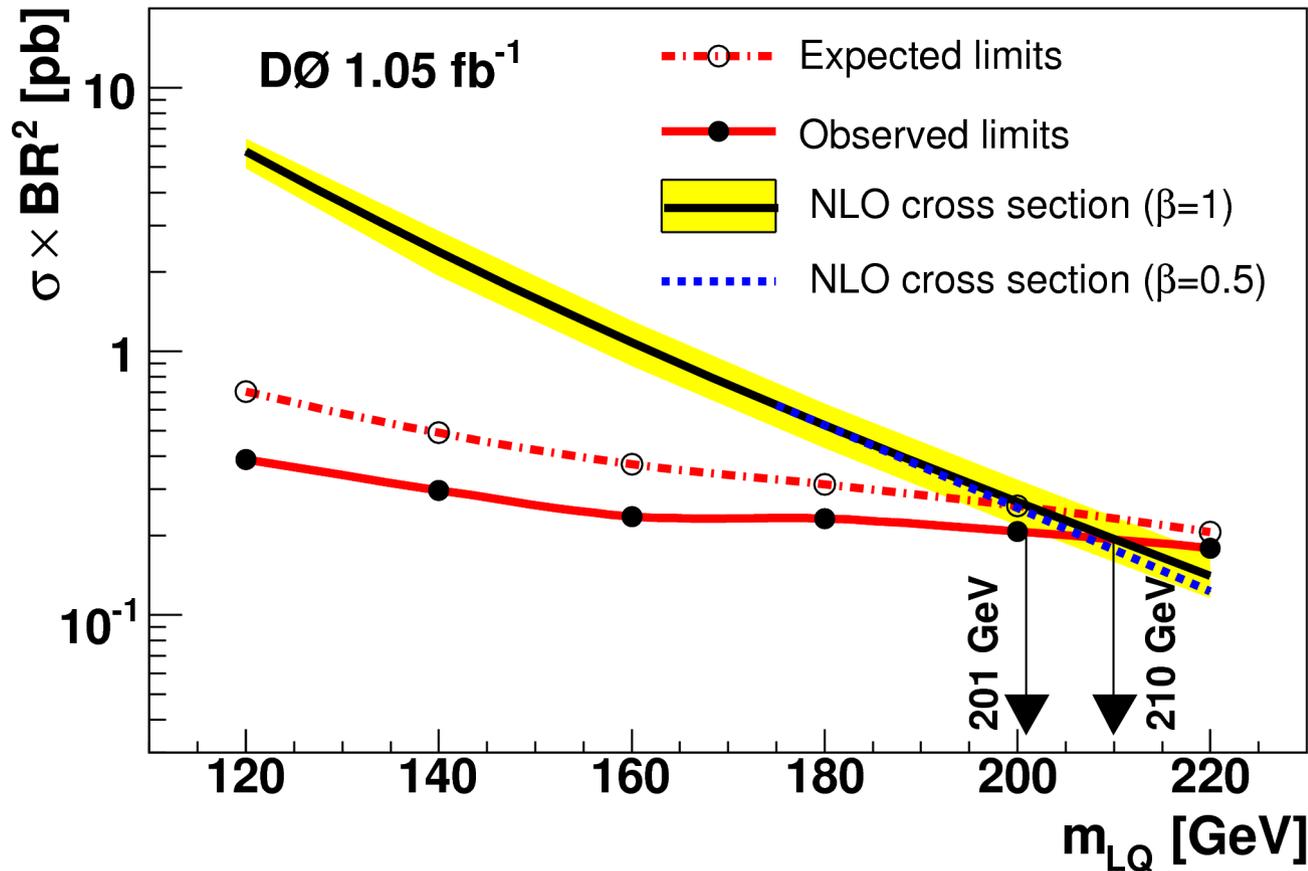
Phys. Rev. Lett. 101, 241802 (2008) **Exclusion: M$_{LQ3}$ < 210 GeV**

3rd generation LQ₃LQ₃→ννbb, 4.0 fb⁻¹

3rd generation $LQ_3 LQ_3 \rightarrow \nu\nu bb$, 4.0 fb⁻¹

Backgrounds: W/Z+jets, ttbar, QCD (neglig. at MET>70 GeV)

LQ_3

b-jet

ν

mE_T

ν

$\overline{LQ_3}$

b-jet
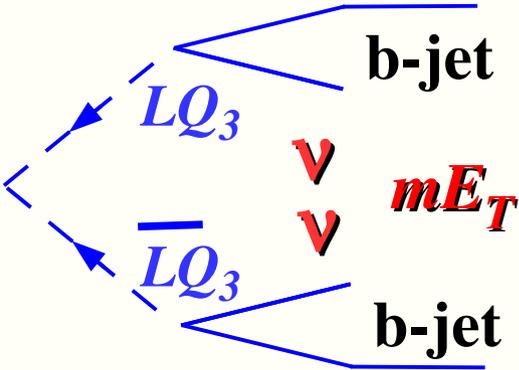
Signal selections : MET> 40 GeV

- **2,3 jets:** $E_T > 20$ GeV, $(E_T^{jet1} + E_T^{jet2})/(\Sigma_{jets} E_T) > 0.9$
- $\Delta\phi_{min}(\not{E}_T, jets) > 0.6$ rad, $\not{E}_T > -40 \times \Delta\phi_{min}(\not{E}_T, jets) + 80$
- **Double b-tag** (NN using track and vertex information)

Optimization: MET and H_T cuts for the minimum of the expected x-section limit


D0 Run II Preliminary (4 fb⁻¹)

D0 Run II Preliminary (4 fb⁻¹)

Result: no LQ$_3$ signal observed, improved result of the previous search

| M_{LQ} (GeV)	$(\not{E}_T, H_T)$ (GeV)	Data	(SM+QCD)$\pm$stat$\pm$sys	Signal (acpt,%)	95% CL, pb obs/exp
200	(130,220)	7	7.1$\pm$0.5$\pm$1.2	23.2$\pm$0.8$\pm$3.3 (2.1)	0.097/0.097
280	(150,240)	3	3.2$\pm$0.3$\pm$0.6	3.9$\pm$0.1$\pm$0.5 (3.4)	0.043/0.043
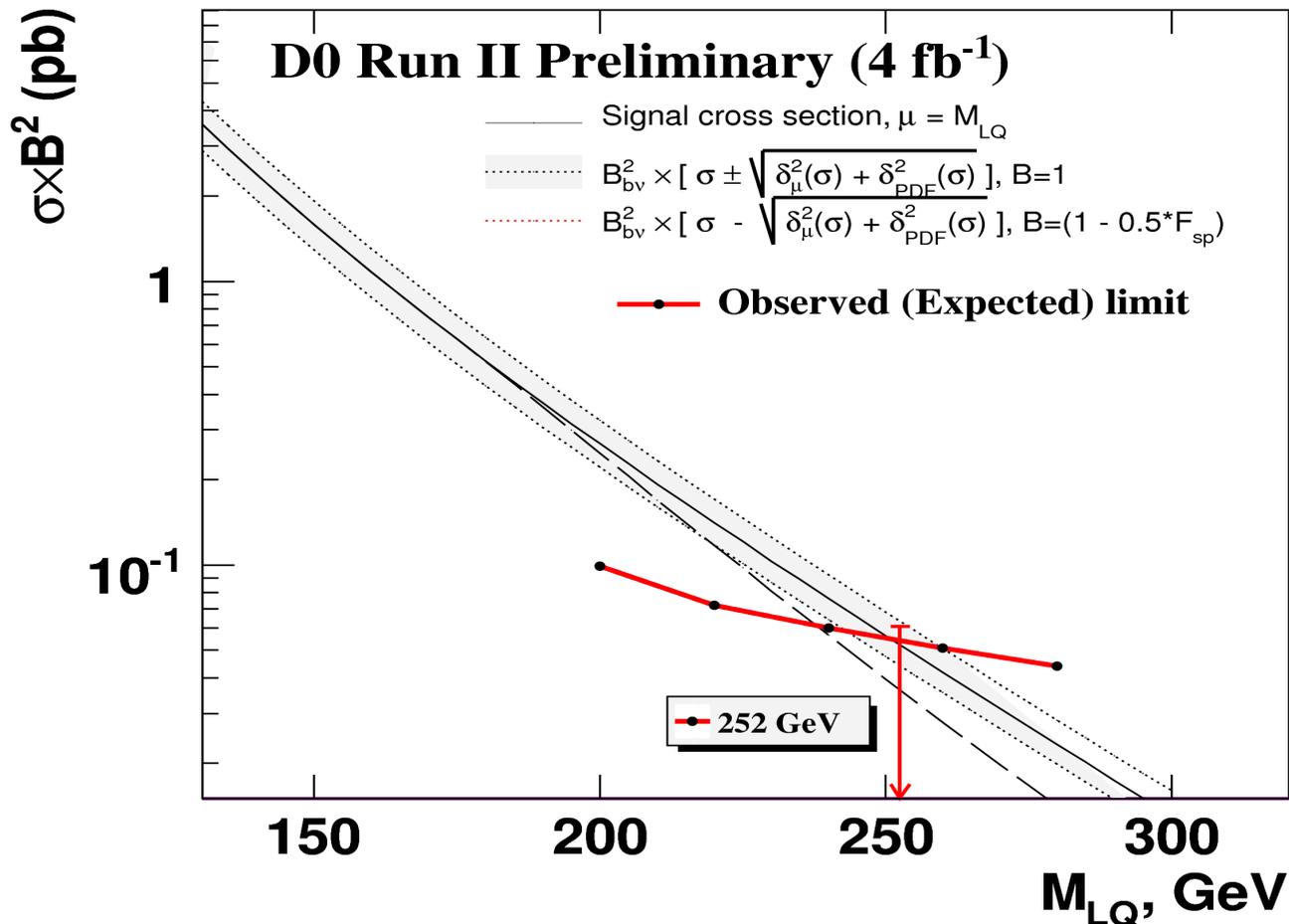
Exclusion: $M_{LQ3} < 252$ GeV

Summary

- **Searches for all 3 LQs generations** were conducted with the D0 detector

- **No signals observed in up to 4 fb^{-1} data samples** – wide range of possible LQ masses conquered from the theory

- **Good understanding of the D0 data** and the developed analysis methods help for searches for new physics in non-leptoquark channels

Backup Slides

The D0 experiment Run II p$\bar{\text{p}}$ @ 1.96 TeV

Forward Mini-drift chambers

Central Scintillator

Forward Scintillator

Shielding

New Solenoid, Tracking System
Si, SciFi, Preshowers

+ New Electronics, Trig, DAQ
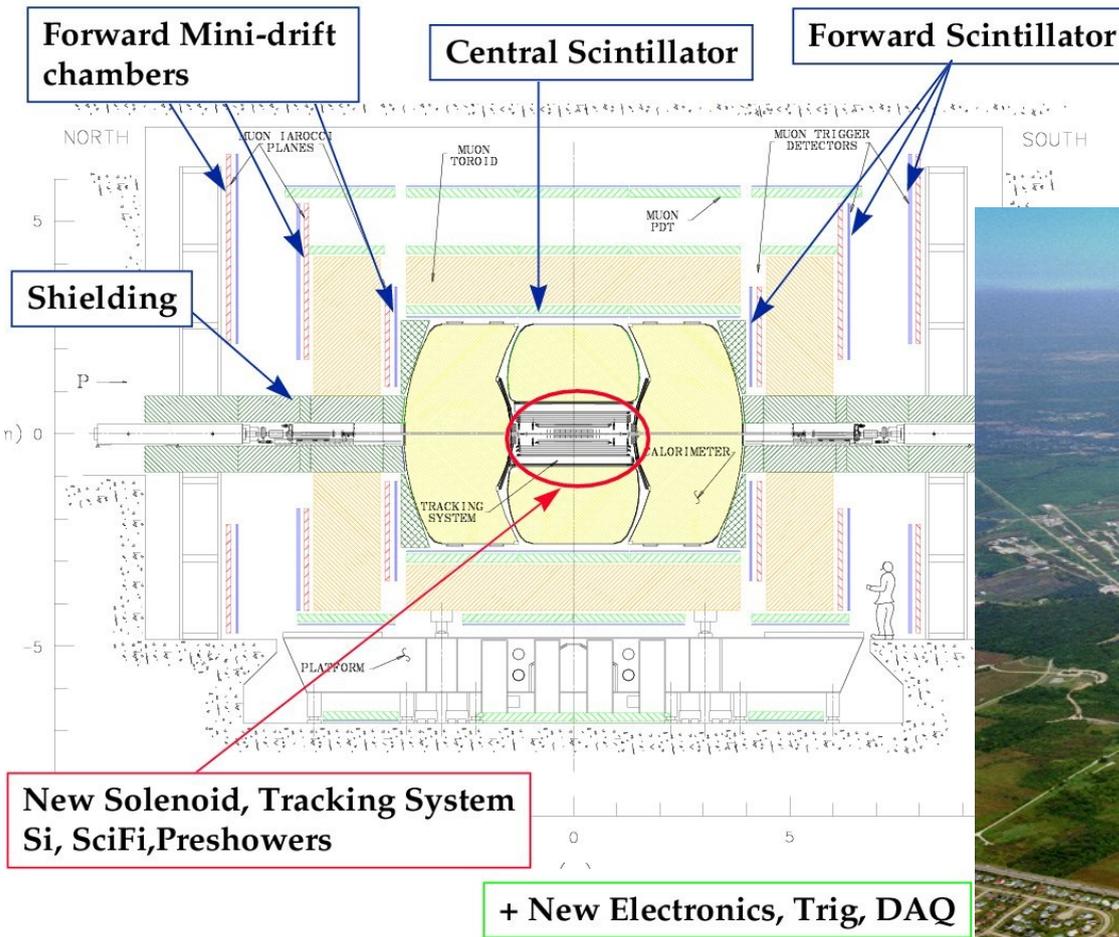
**Run IIa 2001-2005
extended muon and new
tracking system**

Chicago

CDF

D0

$\bar{\text{p}}$ Tevatron   p

Main Injector & Recycler
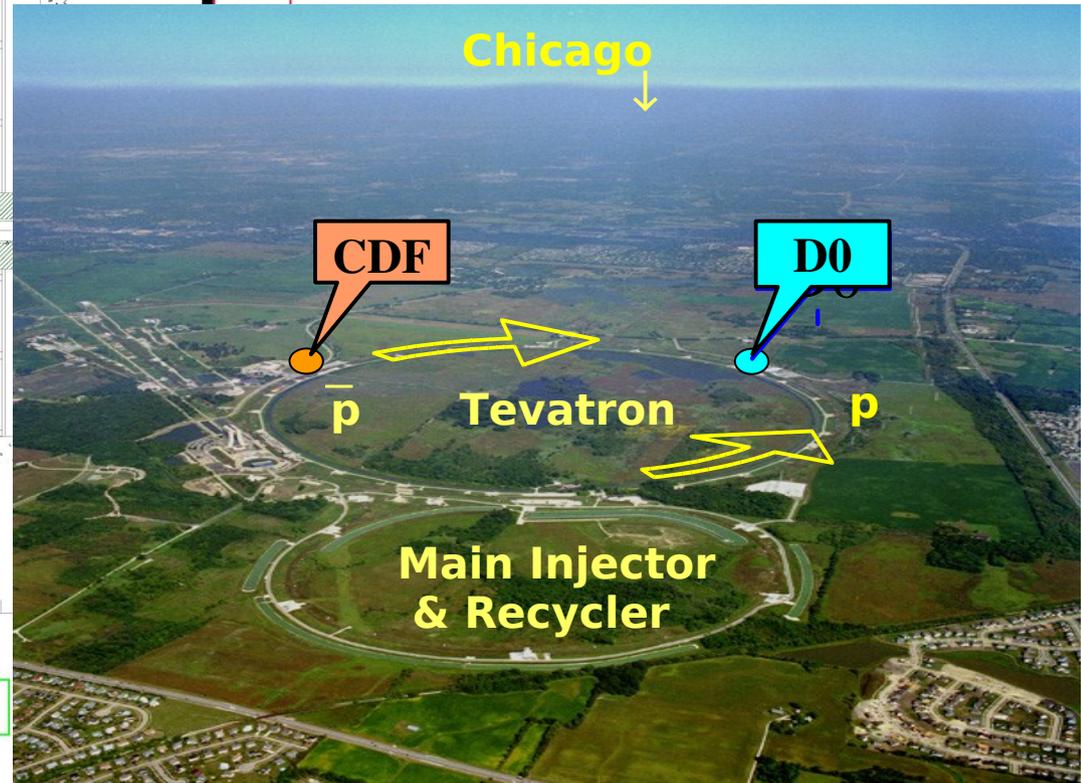
**RunIIb - started 2006
tracking and trigger
systems upgrade**

**Recorded Luminosity:
(June'09) : 6 fb^{-1}**

Run II Integrated Luminosity

19 April 2002 - 31 May 2009

Daily Data Taking Efficiency

19 April 2002 - 31 May 2009

- Delivered
- Recorded

6.81

6.01
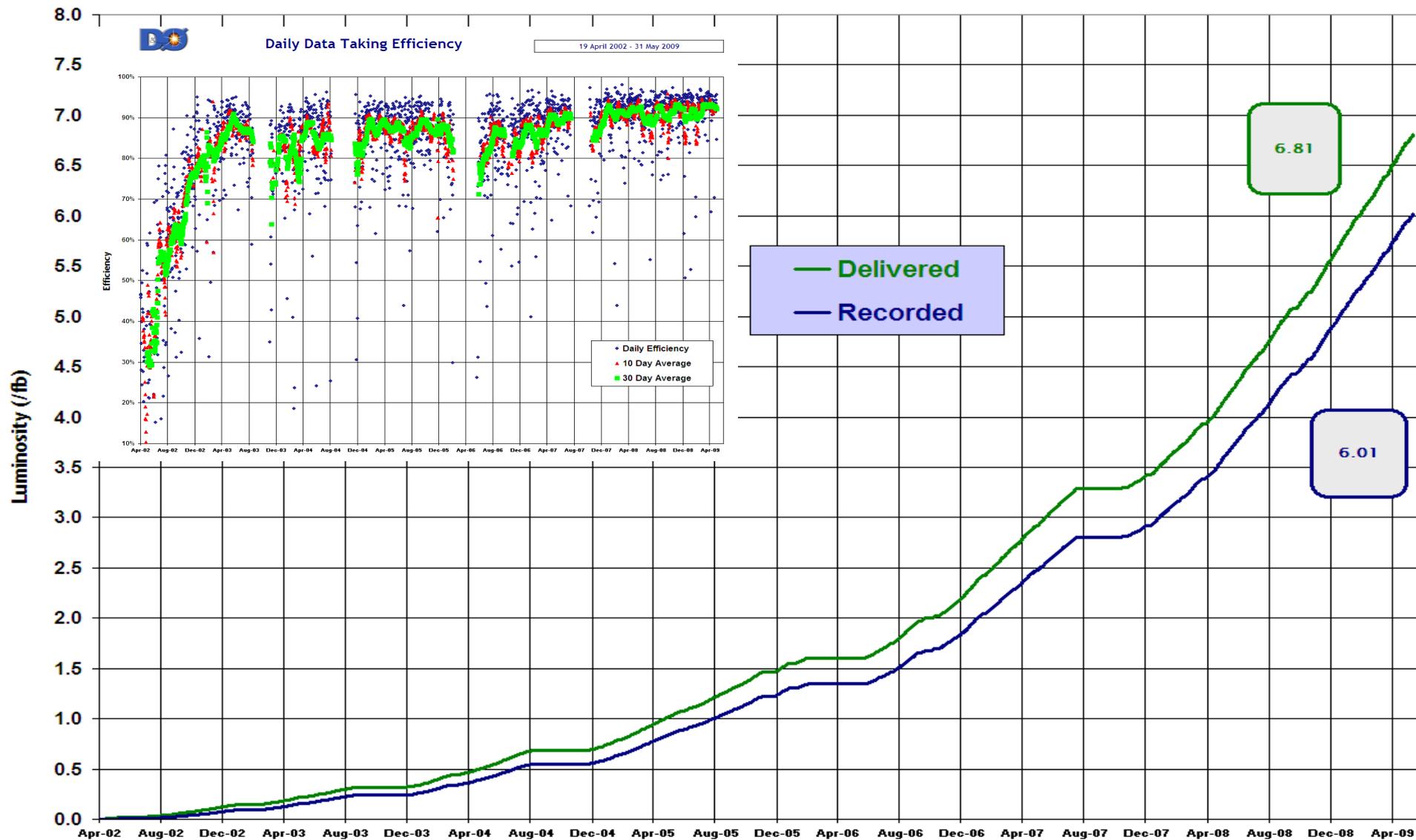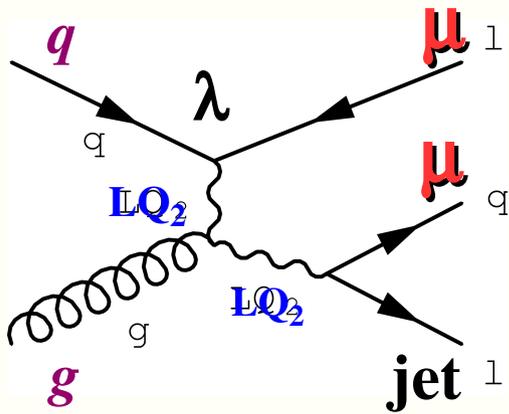
Backgrounds: Z($\mu\mu$)+jets, W(lμ)+jets, QCD

Signal selections

- $\geq$ **1jet** E_T > 50 GeV, | η |< 2.4 ; **2 muons** p_T>15 GeV

- **M$_T$($\mu\mu$) > 110 GeV**, veto against Z

- **Bins in** $\hat{E}$=(M($\mu\mu$) − 110) x (E$_T$(j)-50)>500,1000,2500,5000

Selected data could be SM+ [**a)** single LQ or **b,c)** single+pairs (β=0.5,1)

Result (λ^2=1): M$_{LQ}$>226 GeV (β=0.5), M$_{LQ}$>274 GeV (β=1)