Search for Leptoquarks in μμ+2jets at 198pb^{-1}

Daniel Ryan, Simona Rolli, Hao Sun

Tufts University

Issues with Pre-Blessing

- Checks via cross-section measurement:
  - $Z \rightarrow \mu^+\mu^-$
    - Historically using Z' Analysis acceptances.
    - Calculated our own from 75k evt. zewk0m MC.
    - Look at window from 75 -105 GeV.
  - DY+2jets
- Estimate Error on Fake Background
- Use stubless muons in the fiducial region? YES

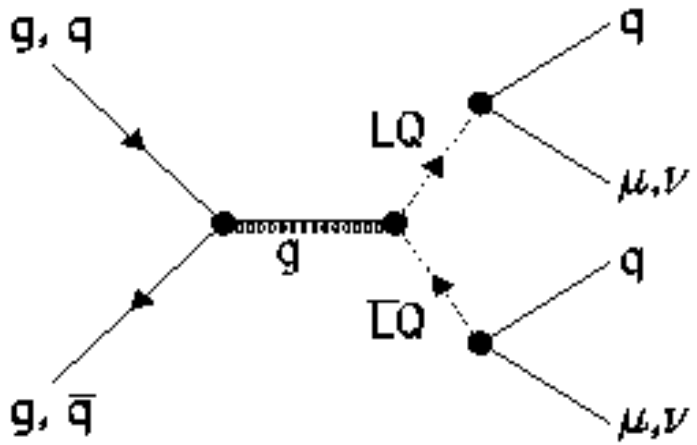
Introduction

2nd Gen. Leptoquarks

LQ→dimuon + dijet

β = Br(LQ→μq)

= 1 in this analysis



Data Sample - Inclusive muons btop1g/j

- Trigger dataset bhmu08/09 using L3 triggers MUON_CMUP18 and MUON_CMX18; reconstructed with offline version 4.8.4 and remade with 4.11.1.
- Good Run List v4 -- 198pb^{-1} (CMUP), 179pb^{-1} (CMX)

Monte Carlo Samples - Generation/Production 4.9.1

LQ Signal – Pythia – 9 masses @ 5000 evts from 160 to 320 GeV

Backgrounds – Alpgen + PS –

- Drell-Yan+2jets, $M_{\mu\mu}$ = (10-75), (75-110), (110-800)
- ttbar ($W \rightarrow \mu\nu$)

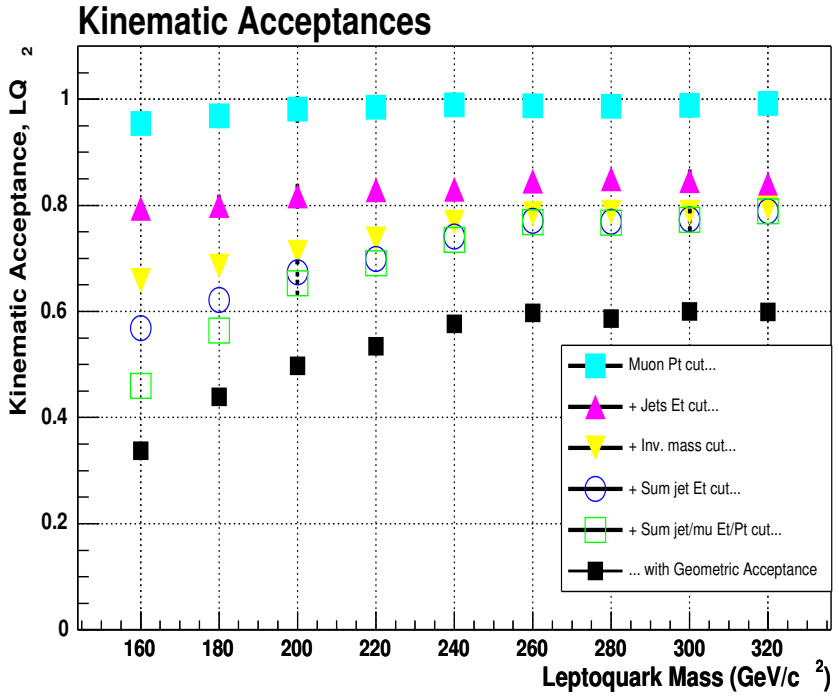
Event Selection

Baseline Cuts

- $P_T(\mu 1) > 20$ GeV
- dx(CMU,CMP,CMX) < 3,5,6cm
- E_{EM}/GeV < 2+max(0,(p-100)*0.0115)
- E_{HAD}/GeV < 6+max(0,(p-100)*0.028)
- $|z_0| < 60$ cm
- r4conet/P_T < 0.1
- COT Di-Cosmic Bit Not Present
- CMX muons must pass COT exit radius cut (>140 cm)

Kinematic Cuts

- $P_T(\mu 1)$ and $P_T(\mu 2)$>25 GeV
- E_T j1, j2 > 15,30 GeV
- Veto Mμμ<15 and 76<Mμμ<106
- $\sum P_T(\mu^i)$ and $\sum P_T(j^i)$ > 85 GeV
- Sqrt(Sumμ^2+Sumj^2) > 200 GeV



Event-Type Efficiencies

- *At least one* muon must have an attached **CMUP** or **CMX** stub. The second leg can be CMUP, CMX, or TRK (anything not CMUP,CMX)
- Efficiencies combined (trigger/z0/ID/reco/iso) according to muon type and applied to MC acceptance.

5 Event Types
CMUP/CMUP
CMUP/CMX
CMX/CMX
CMUP/TRK
CMX/TRK

$$\varepsilon^{PP} = (\varepsilon^{P} \times (2-\varepsilon^{P}))_{trig} \times (\varepsilon^{P}_{reco})^2 \times \varepsilon_{z0} \times (\varepsilon^{P}_{ID})^2 \times (\varepsilon^{P}_{iso})^2$$

$$\varepsilon^{XX} = (\varepsilon^{X} \times (2-\varepsilon^{X}))_{trig} \times (\varepsilon^{X}_{reco})^2 \times \varepsilon_{z0} \times (\varepsilon^{X}_{ID})^2 \times (\varepsilon^{X}_{iso})^2$$

$$\varepsilon^{PX} = (\varepsilon^{P} + \varepsilon^{X} - (\varepsilon^{P} \times \varepsilon^{X}))_{trig} \times (\varepsilon^{P} \times \varepsilon^{X})_{iso} \times (\varepsilon^{P} \times \varepsilon^{X})_{reco} \times \varepsilon_{z0} \times (\varepsilon^{P} \times \varepsilon^{X})_{ID}$$

$$\varepsilon^{PT} = \varepsilon^{P}_{trig} \times (\varepsilon^{P} \times \varepsilon^{T})_{iso} \times \varepsilon^{P}_{reco} \times \varepsilon_{z0} \times (\varepsilon^{P} \times \varepsilon^{T})_{ID}$$

$$\varepsilon^{XT} = \varepsilon^{X}_{trig} \times (\varepsilon^{X} \times \varepsilon^{T})_{iso} \times \varepsilon^{X}_{reco} \times \varepsilon_{z0} \times (\varepsilon^{X} \times \varepsilon^{T})_{ID}$$

TRK ID/Isolation Efficiency

1-leg method

Both tracks pass:

- 1 tight CMUP or CMX
- $80 < M_{\mu\mu} < 100$ GeV
- $P_T > 20$ GeV
- |z0| < 60cm

TRK (DefTrks)- 179pb^{-1}	
Cut Variable	***MIXED-TYPE***
COT: 16(ST) and 20(AX)	0.988 +/- 0.000
$E_{HAD} < 6+\max(0,(p-100)*0.0280)$ GeV	0.982 +/- 0.000
$E_{EM} < 2+\max(0,(p-100)*0.0115)$ GeV	0.970 +/- 0.000
ID (all above)	0.929 +/- 0.000
ISO (r4conet < 0.1 Pt)	0.978 +/- 0.000

Cross Check with CDF 6825

CMUP (DefTrks) - 179pb^{-1}				
Cut Variable	***SAME-TYPE***	***MIXED-TYPE***	***COMBINED***	***CDF 6825***
COT: 16(ST) and 20(AX)	1.000 +/- 0.000	1.000 +/- 0.001	1.000 +/- 0.001	-
dx (CMU) < 3 cm	0.950 +/- 0.005	0.963 +/- 0.001	0.956 +/- 0.005	0.954 +/- 0.004
dx (CMP) < 5 cm	0.979 +/- 0.004	0.976 +/- 0.001	0.977 +/- 0.004	0.980 +/- 0.003
E_{HAD} < 6+max(0,(p-100)*0.028) GeV	0.984 +/- 0.003	0.987 +/- 0.001	0.985 +/- 0.003	0.982 +/- 0.002
E_{EM} < 2+max(0,(p-100)*0.0115) GeV	0.963 +/- 0.005	0.966 +/- 0.001	0.964 +/- 0.005	0.968 +/- 0.002
ID	0.882 +/- 0.007	0.895 +/- 0.001	0.888 +/- 0.007	0.889 +/- 0.006
ISO (r4conet < 0.1 Pt)	0.988 +/- 0.003	0.976 +/- 0.000	0.982 +/- 0.003	0.980 +/- 0.003

CMX (DefTrks) – 179pb^{-1}				
Cut Variable	***SAME-TYPE***	***MIXED-TYPE***	***COMBINED***	***CDF 6825***
COT: 16(ST) and 20(AX)	1.000 +/- 0.000	1.000 +/- 0.001	1.000 +/- 0.001	-
dx (CMX) < 6 cm	0.971 +/- 0.007	0.971 +/- 0.001	0.971 +/- 0.007	0.995 +/- 0.002
E_{HAD}<6+max(0,(p-100)*0.028) GeV	0.984 +/- 0.005	0.979 +/- 0.001	0.981 +/- 0.004	0.980 +/- 0.003
E_{EM}<2+max(0,(p-100)*0.0115) GeV	0.977 +/- 0.006	0.979 +/- 0.001	0.978 +/- 0.004	0.976 +/- 0.004
ID (all above)	0.933 +/- 0.010	0.930 +/- 0.001	0.932 +/- 0.010	0.952 +/- 0.005
ISO (r4conet < 0.1 Pt)	0.979 +/- 0.006	0.976 +/- 0.000	0.977 +/- 0.006	0.976 +/- 0.004

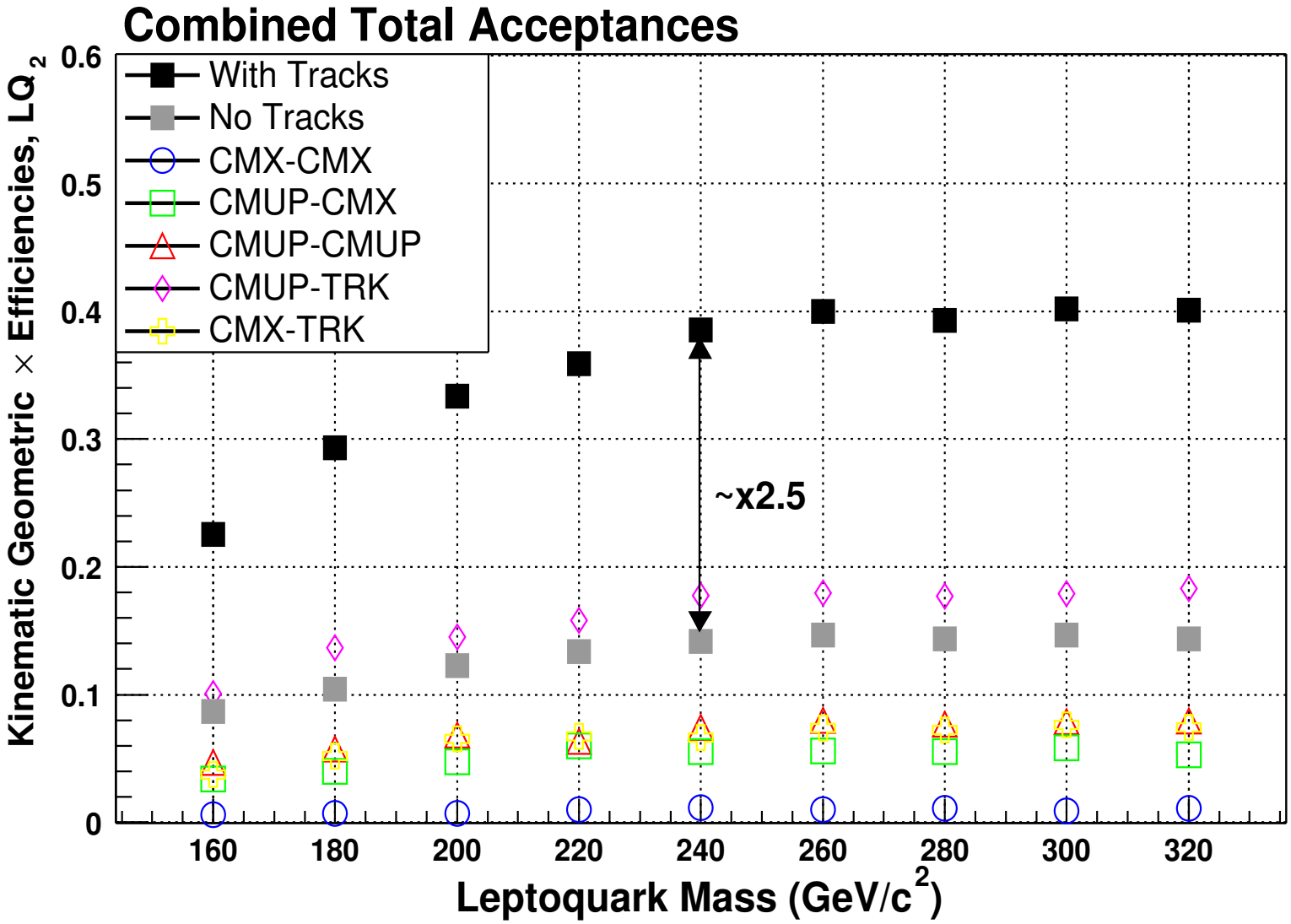
Efficiencies Breakdown

	CMUP*	CMX*	TRK
Vertex*	95.2 ± 0.1%	95.2 ± 0.1%	95.2 ± 0.0%
Reco	94.5 ± 0.6%	99.2 ± 0.3%	
ID	88.9 ± 0.6%	95.2 ± 0.5%	92.9 ± 0.0%
Trig	88.7 ± 0.7%	95.4 ± 0.6%	
Iso	98.0 ± 0.3%	97.6 ± 0.4%	97.8 ± 0.0%

CMUP-CMUP	$\varepsilon^{PP} = 63.7 \pm 1.1\%$	63.7 ± 1.7% - CDF 6733
CMUP-CMX	$\varepsilon^{PX} = 71.9 \pm 1.1\%$	73.0 ± 1.7%
CMX-CMX	$\varepsilon^{XX} = 80.7 \pm 1.6\%$	82.7 ± 1.6%
CMUP-TRK	$\varepsilon^{XX} = 63.2 \pm 0.8\%$	
CMX-TRK	$\varepsilon^{XX} = 76.1 \pm 0.7\%$	

*CDF Note 6331

*CDF Note 6825


Combined Total Acceptances
With Tracks
No Tracks
CMX-CMX
CMUP-CMX
CMUP-CMUP
CMUP-TRK
CMX-TRK
~x2.5
Kinematic Geometric × Efficiencies, LQ$_2$
Leptoquark Mass (GeV/c^2)
0
0.1
0.2
0.3
0.4
0.5
0.6
160
180
200
220
240
260
280
300
320

Backgrounds in 198pb^{-1}

Drell-Yan	**σ(NLO)**	**$N_{Expected}$**
$10 < M_{\mu\mu} < 75$	65.5 ± 1.7 pb	0.38 ± 0.02
$75 < M_{\mu\mu} < 105$	31.4 ± 1.0 pb	0.56 ± 0.04
$105 < M_{\mu\mu} < 800$	1.09 ± 0.01 pb	0.88 ± 0.06
DY-Combined		1.81 ± 0.12

ttbar	**σ(LO) × Br(W→ μν)**	
both $W \rightarrow \mu\nu$	0.074 ± 0.01 pb	0.34 ± 0.05

QCD/Fakes

Kinematic Cut	*Same-Sign Evts*
$P_T(\mu 1)$ and $P_T(\mu 2)$>25 GeV	220
E_T j1, j2 > 15,30 GeV	3
Mμμ > 15 and 76 > Mμμ > 106	2
$\sum P_T(\mu^i)$ and $\sum P_T(j^i)$ > 85 GeV	0
Sqrt(Sumμ^2+Sumj^2) > 200 GeV	0

The number of fake events could still be > 0…

Backgrounds in 198pb^{-1} -- continued

- **QCD/Fakes**

	P_T >25 GeV		P_T >20 GeV	
Kinematic Cut	*Events*	*SS Evts*	*Events*	*SS Evts*
After P_T >25 GeV	8027	220	8632	298
E_T j1, j2 > 15,30 GeV	144	3	171	5
Mμμ > 15 and 76 > Mμμ > 106	25	2	37	3
$\sum P_T(\mu^i)$ and $\sum P_T(j^i)$ > 85 GeV	3	0	6	1
Sqrt(Sumμ^2+Sumj^2) > 200 GeV	2	0	4	1

$$B_T = (S_T/S_L) \times B_L = (2/4) \times 1 = 0.5$$

QCD/Fakes	1.0 ± 1.0
Top ($W \rightarrow \mu\nu$)	0.34 ± 0.05
DY+2jets	1.81 ± 0.12
Combined Expected Background	3.15 ± 1.17
Events Surviving Selection	**2**

Z Cross-Check – 198pb^{-1}

$$\sigma \times Br(pp \rightarrow \mu\mu) = (N(Z) - N(bkg))/(A(Z) \times \varepsilon^{ii} \times L)$$

	CMUP/ CMUP	*CMX/ CMX*	*CMUP/ CMX*	*CMUP/ TRK*	*CMX/ TRK*
A(Z) (%)	3.2 ± 0.1	0.73 ± 0.04	2.8 ± 0.1	10.4 ± 0.1	4.8 ± 0.1
A(Z) Z' Analysis	2.7± 0.1	0.76± 0.01	2.7± 0.1	10.2± 0.4	4.7± 0.1
efficiency	0.64 ± 0.01	0.81 ± 0.01	0.72 ± 0.01	0.63 ± 0.01	0.76 ± 0.01
N(Obs.)	881 ± 30	267± 16	879 ± 30	3268 ± 57	1546 ± 39
N(Bkg.)	0.7	2.6	0.1	45.0	22.3
Luminosity (pb^{-1})	197.9 ± 11.6	179.2 ± 10.6	179.2 ± 10.6	197.9 ± 11.6	179.2 ± 10.6
Sigma(Z->mumu)	239.1 ± 14.6	252.8 ± 20.2	239.1 ± 15.9	246.7 ± 15.2	234.6 ± 14.8

DY + 2jets Cross-Check – 198pb^{-1}

	CMUP/ CMUP	***CMX/ CMX***	***CMUP/ CMX***	***CMUP/ TRK***	***CMX/ TRK***
A(Z) (%)	3.0 ± 0.3	.90 ± 0.17	3.0 ± 0.3	9.7 ± 0.5	5.0 ± 0.4
efficiency	0.64 ± 0.01	0.81 ± 0.01	0.72 ± 0.01	0.63 ± 0.01	0.76 ± 0.01
Luminosity (pb^{-1})	197.9 ± 11.6	179.2 ± 10.6	179.2 ± 10.6	197.9 ± 11.6	179.2 ± 10.6
N(Obs.)	16 ± 4	1± 1	9 ± 3	60 ± 8	25 ± 5
N(exp)	12.4 ± 1.4	4.1 ± 1.2	12.3 ± 2.1	38.1 ± 3.2	21.4 ± 2.2

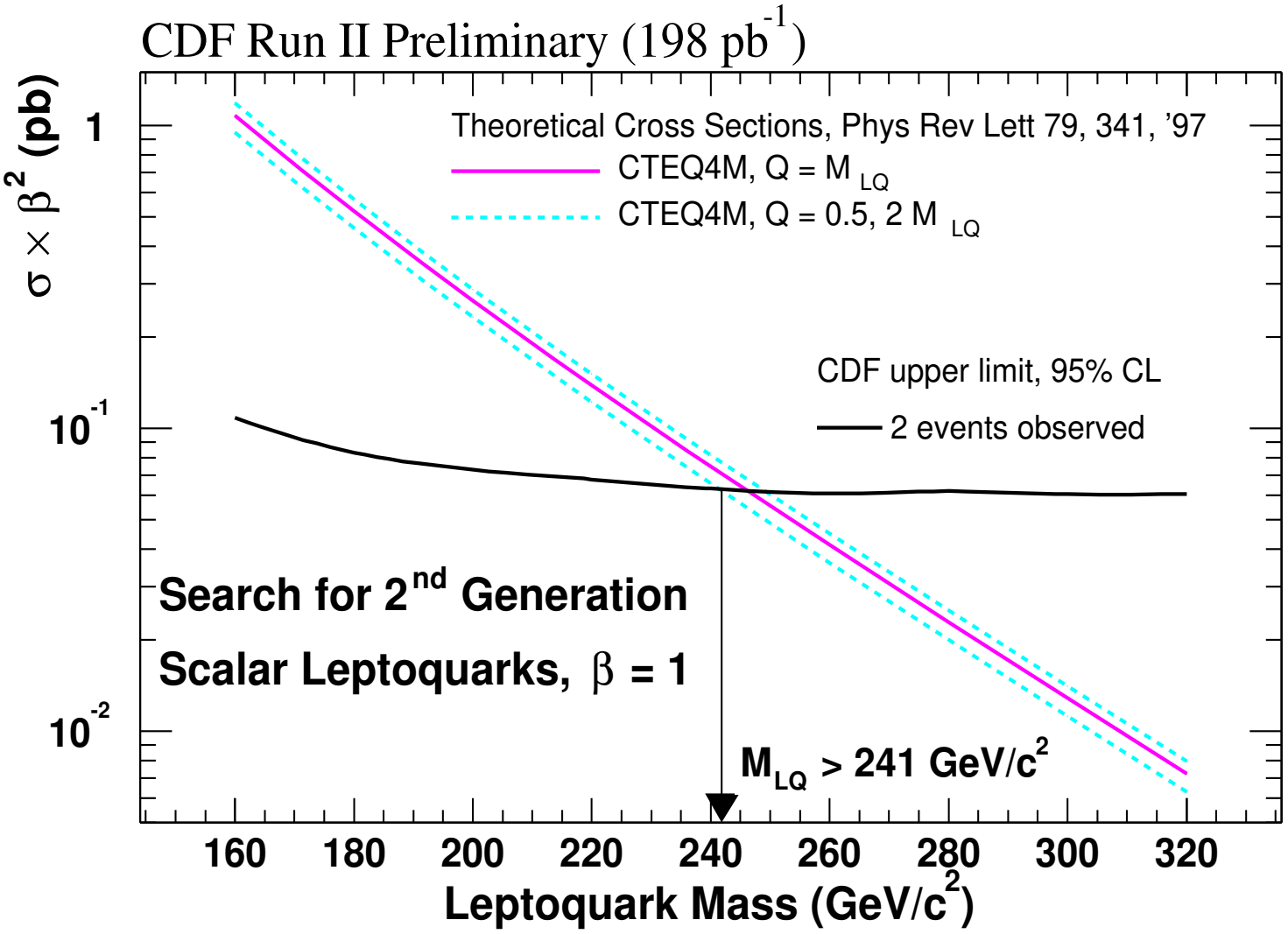
Systematics and Combined Relative Error

Jet Corr..... 0.1 – 0.8%
Muon ID* ... 1.6%
Lumi 6%
MC ..... 1.6 - 1.7%
PDF* 4%
Vertex 0.5%

Mass (GeV/c^2)	*A(LQ)*	*(stat)*	*(sys)*	*Combined Relative*
160	0.225	± 0.003	± 0.018	0.0828
180	0.293	± 0.004	± 0.023	0.0780
200	0.333	± 0.004	± 0.025	0.0768
220	0.359	± 0.005	± 0.027	0.0761
240	0.385	± 0.005	± 0.029	0.0760
260	0.400	± 0.005	± 0.030	0.0757
280	0.393	± 0.005	± 0.029	0.0759
300	0.402	± 0.005	± 0.030	0.0756
320	0.401	± 0.005	± 0.030	0.0756

**from Z' analysis*

Cross Section Limit



Summary

- Increased geometric acceptance by ~x2.5 by loosening stub requirement on second muon leg.
- Increased statistics by including summer data (198pb^{-1}).
- Cross checked DefTrk muon ID/ISO efficiencies with B.C. COT and calculated TRK ID/ISO using 1-leg method.
- We calculate 3.15 ± 0.17 background events from DY+2jets, Top, and QCD/Fakes.
- We observe 2 events in 198pb^{-1} of 4.11.1 data. We exclude second generation scalar leptoquarks at 95% CL below mass of 241 GeV/c^2 for beta = 1.