Search for 2nd Generation Scalar Leptoquarks

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Outline

- One paper to be submitted to PRD-RC
- Outline of the analyses
  - $\mu\mu jj$
    - Blessed in Dec 2003/August 2004
  - $\mu\nu jj$
    - Blessed in March 2004/August 2004
  - Combination
    - Blessed in August 2004/January 2005

cdf7927

Dan Ryan thesis
cdf7425

These analyses : lepton signatures only
Combined with: MET + jets (cdf7200 - published in PRD)

Theoretical Motivation

- **Leptoquarks (LQ) are hypothetical particles which appear in many SM extensions to explain symmetry between leptons and quarks**
  - **SU(5) GUT model**
  - **superstring-inspired models**
  - **'colour' SU(4) Pati-Salam model**
  - **composite models**
  - **technicolor**

•**LQs can have**:

–spin 0 (scalar)

•couplings fixed, i.e., no free parameters

•Isotropic decay

–spin 1 (vector)

•anomalous magnetic (k_G) and electric quadrupole (λ_G) model-dependent couplings

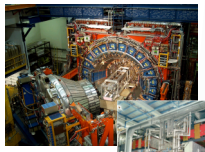
–Yang-Mills coupling: $k_G = \lambda_G = 0$

–Minimal coupling: $K_G = 1, \lambda_G = 0$

–Decay amplitude proportional to $(1 + \cos\theta^*)^2$

•LQs are **coupled to both leptons and quarks** and carry SU(3) color, fractional electric charge, baryon (B) and lepton (L) numbers

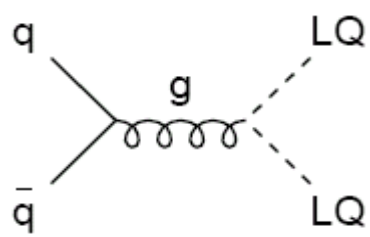
- **Experimental evidence searched:**
  - **indirectly: LQ-induced 4-fermion interactions**
  - **directly: production cross sections at collider experiments**



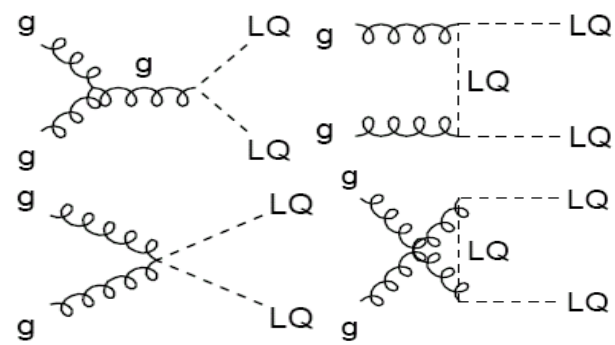
LQ Production

- **Pair production**
  - Practically independent of Yukawa coupling λ (only g-LQ-LQ vertex)
  - Depends mainly on LQ mass

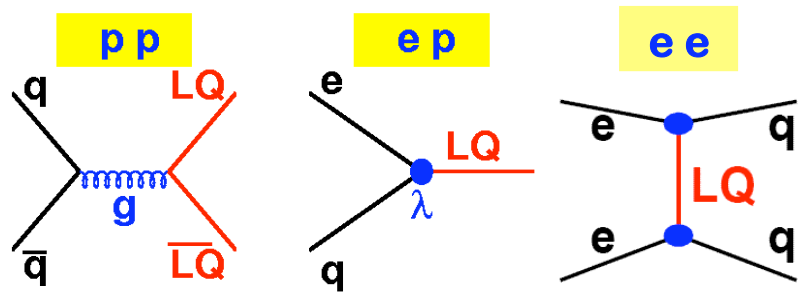
$q\bar{q} \rightarrow LQ\ LQ$



$gg \rightarrow LQ\ LQ$



Comparison with other machines



LQ Decay

b = Br(LQ→lq)

Each generation can decay into 3 final states:

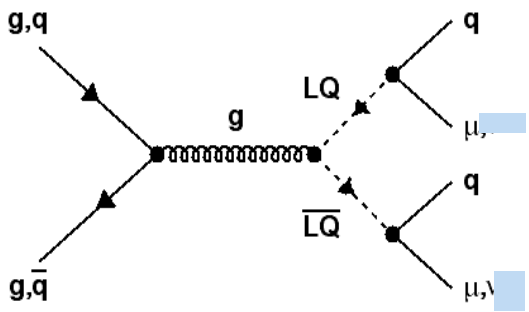
Exclusive to the Tevatron

	1st Generation	2nd Generation	3rd Generation
β = 1	$LQ\,\overline{LQ} \to e^- e^+ q\bar{q}$	$LQ\,\overline{LQ} \to \mu^+ \mu^- q\bar{q}$	$LQ\,\overline{LQ} \to \tau^+ \tau^- q\bar{q}$
β = 0.5	$LQ\,\overline{LQ} \to e^\pm \nu_e q_i q_j$	$LQ\,\overline{LQ} \to \mu^\pm \nu_\mu q_i q_j$	$LQ\,\overline{LQ} \to \tau^\pm \nu\, q_i q_j$
β = 0	$LQ\,\overline{LQ} \to \nu_e \nu_e q\bar{q}$	$LQ\,\overline{LQ} \to \nu_\mu \nu_\mu q\bar{q}$	$LQ\,\overline{LQ} \to \nu_\tau \nu_\tau q\bar{q}$

This paper!

LQ LQ → llqq	2l+2j	BR = β^2
LQ LQ → lνqq	l+MET+2j	BR = $2\beta(1-\beta)$
LQ LQ → ννqq	MET+2j	BR = $(1-\beta)^2$

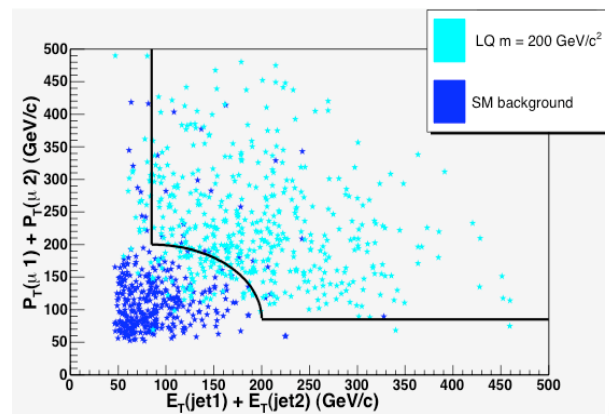
Search for LQ in dimuon + jets



SM background
- Drell-Yan+2jets
- Top ($W \rightarrow \mu\nu$)
- QCD/Fakes

Selection

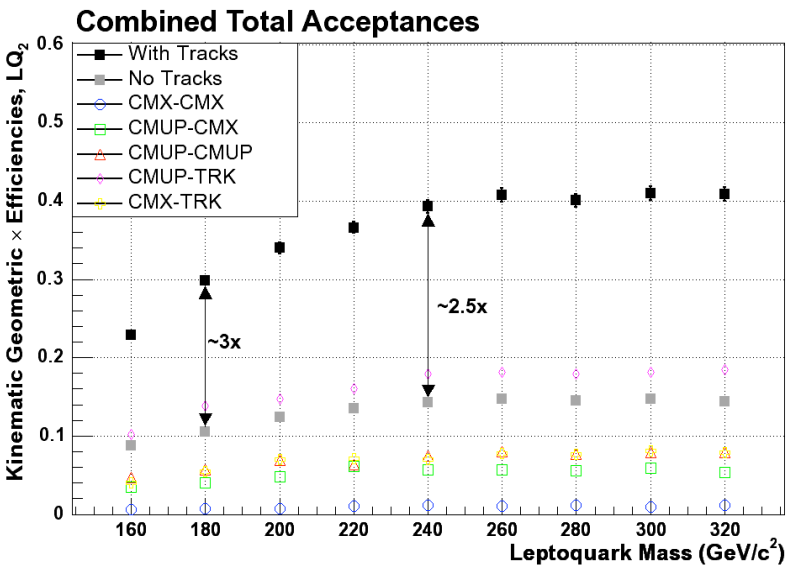
- 2 muons with $P_T > 25$ GeV
- 2 jets with $E_T(j1,j2) > 30,15$ GeV
- Dimuon Mass Veto:
  - $76 < M_{\mu\mu} < 110$, $M_{\mu\mu} < 15$ GeV
- $E_T(j_1) + E_T(j_2) > 85$ GeV and $P_T(\mu_1) + P_T(\mu_2) > 85$ GeV
- $((E_T(j_1) + E_T(j_2))^2 + (P_T(\mu_1) + P_T(\mu_2))^2)^{1/2} > 200$ GeV



Control Sample: Z + 2 jets

	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

Search for LQ in dimuon + jets(II)



Backgrounds:	μμjj
Z + 2 jets (alpgen)	1.7 ± 0.1
ttbar (Pythia)	0.22 ± 0.03
Fakes (data)	1 ± 1
Total	3 ± 1
Observed	2

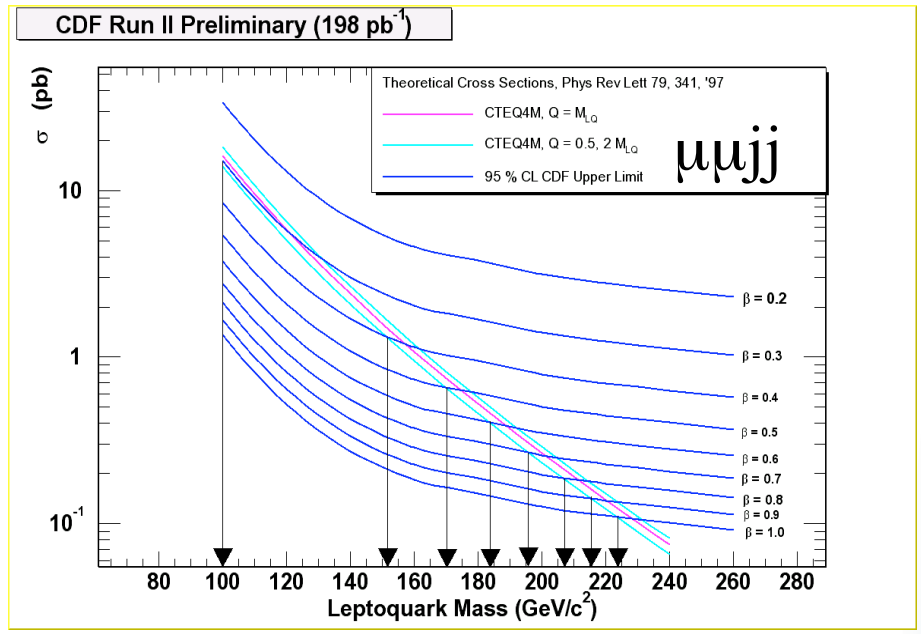
Systematics: signal acceptance and background prediction

Luminosity	6%
pdf	2.1%
statistics of MC	~1.2%
Jet Energy Scale	<1%
ele id	<1%
Z vertex cut	0.5%

Search for LQ in dimuon + jets (III)

TABLE III: 95% C.L. lower limits on the second generation scalar leptoquark mass (in GeV/c^2), as a function of β.The limit from CDF[4] ($\mu\mu jj$) Run I ($\sim 120pb^{-1}$) is also given.

β	$\mu\mu$ jj	$\mu\nu jj$	$\nu\nu jj$	Combined	CDF Run I
0.01	-	-	114	125	-
0.05	-	-	110	133	-
0.1	-	137	-	143	-
0.2	-	155	-	157	-
0.3	100	162	-	176	-
0.4	152	168	-	200	-
0.5	171	170	-	208	-
0.6	184	168	-	213	-
0.7	196	162	-	217	-
0.8	206	155	-	221	-
0.9	215	137	-	224	-
1.0	224	-	-	226	202

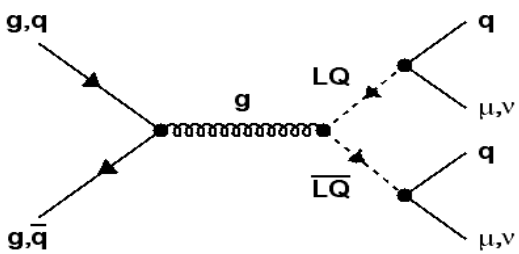


Other β limits are obtained using partial information on the acceptance

This analysis is optimized for β = 1

Exclude at 95% CL M_{LQ}<224 GeV/c^2

Search for LQ in muon + MET + jets



SM background

- W +2jets
- Top (l + jets and dilepton)
- QCD/Fakes

Selection

Z veto (tight/loose pair)

No 2nd muon (CMUP, CMX, or stubless)

$P_T(\mu) > 25$ GeV

$\not{E}_T > 60$ GeV

2 jets, @ E_T>30GeV

$\Delta\phi(\mu,\not{E}_T)<175^\circ$, $\Delta\phi(\not{E}_T,\text{jets})>5^\circ$

$E_T(\text{jet1})+E_T(\text{jet2}) > 80$ GeV

$M_T(\not{E}_T,\text{Muon}) > 120$ GeV/c^2

Mass Cut

Mass Cut

$|M(\mu,j_1) - M_{LQ}| < 2\sigma_1$

or

$|M(\mu,j_2) - M_{LQ}| < 2\sigma_2$

$M_T(\not{E}_T,j_1) > T_1(\text{min})$

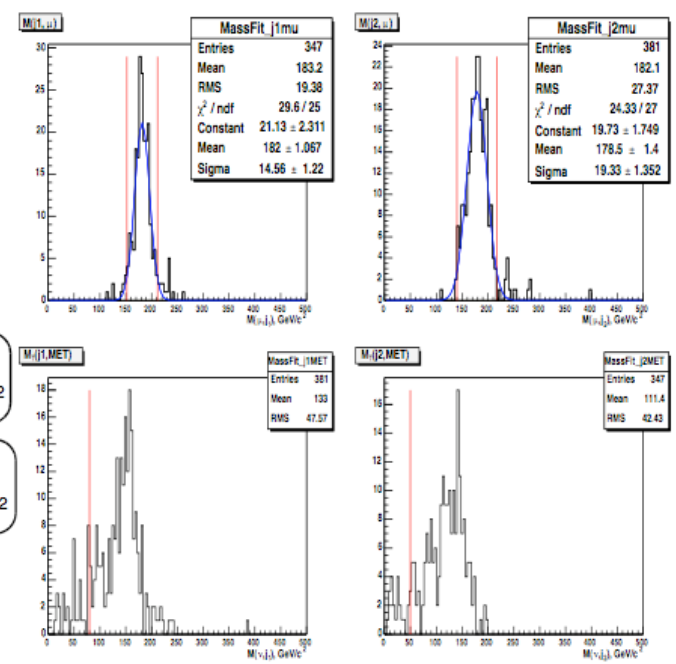
or

$M_T(\not{E}_T,j_2) > T_2(\text{min})$

$T_1(\text{min}) = 20 + (M_{LQ} - 120)$ GeV/c^2

$T_2(\text{min}) = 20 + (M_{LQ} - 120)/2$ GeV/c^2

Sigma's determined from generator-level matched reconstructed objects.

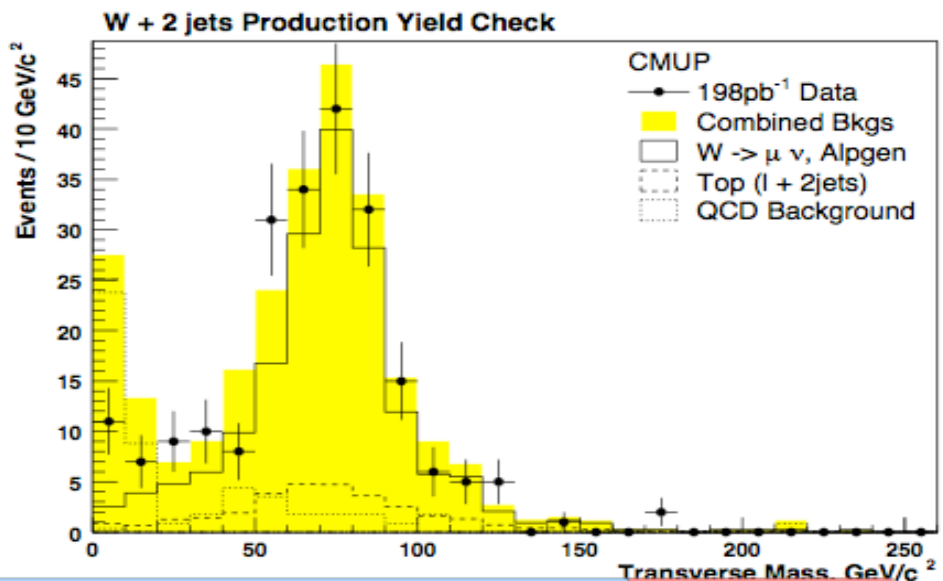


Search for LQ in muon + MET + jets

W+2jet Check

$N(W) = \sigma \times BR(W \rightarrow \mu\nu jj) \times A(W) \times \varepsilon \times L$

Theory = 295 pb
$\not{E}_T > 20$,
Muon $P_T > 25$
2 Tight Jets,
Jet Topology Cuts

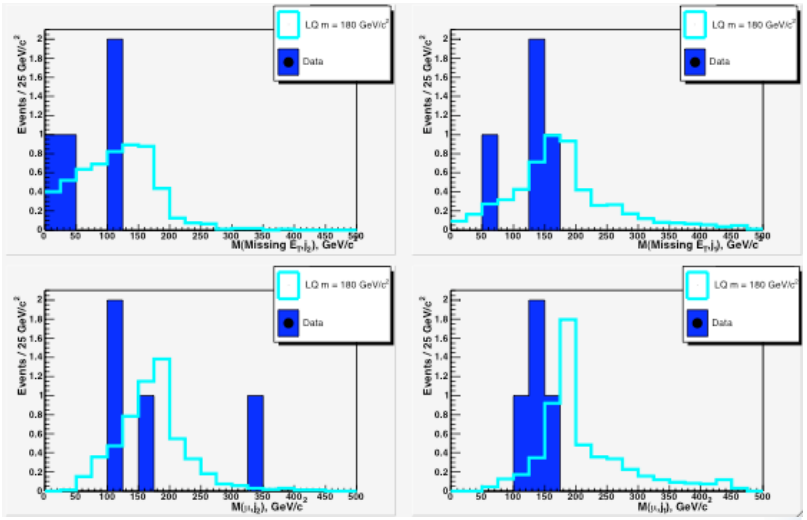


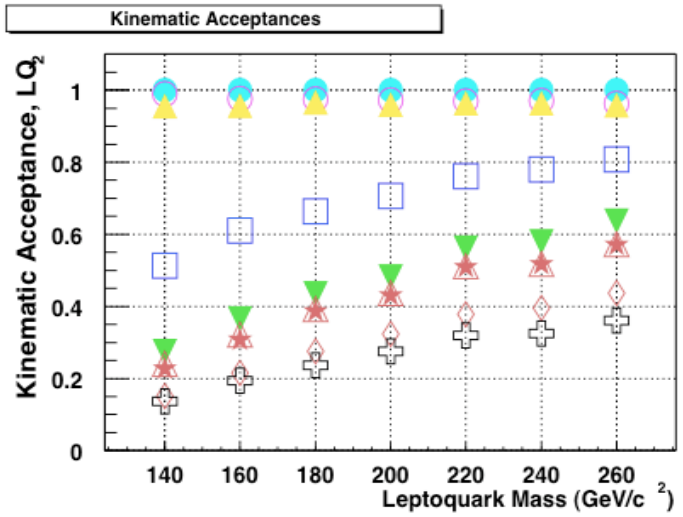
TYPE	A(W)	Lumi	Eff	N_{bkg}	N_{W+2j}	N_{obs}-N_{bkg}
CMUP	0.37	197.9	0.695	84 ± 12	152 ± 10	133 ± 27
CMX	0.16	179.2	0.835	42 ± 7	69 ± 5	70 ± 16

Search for LQ in muon ,MET + jets (II)

TABLE II: Number of events surviving all cuts in the muon, missing energy and jets topology, compared with background expectations, as function of the LQ mass (in GeV/c^2). The number for the individual contributions have been multiplied by 10.

Mass	Wjj	top	Z jj	multijets	Total	Data
140	9 ± 1	17 ± 2	2 ± 0.1	3 ± 3	3.1 ± 0.3	3
160	14 ± 1	18 ± 2	2 ± 0.2	3 ± 3	3.7 ± 0.4	4
180	14 ± 1	14 ± 2	2 ± 0.1	3 ± 3	3.2 ± 0.3	2
200	16 ± 1	10 ± 4	2 ± 0.1	3 ± 3	3.1 ± 0.3	0
220	16 ± 1	8 ± 3	2 ± 0.1	3 ± 3	2.9 ± 0.3	0





<u>Systematics: signal acceptance and background estimate</u>

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Statistics of MC	~1.2%
Jet energy scale	<1%
reco/ele id	<1%
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Search for LQ in muon,MET + jets (III)

TABLE III: 95% C.L. lower limits on the second generation scalar leptoquark mass (in GeV/c^2), as a function of β.The limit from CDF[4] ($\mu\mu jj$) Run I ($\sim 120pb^{-1}$) is also given.

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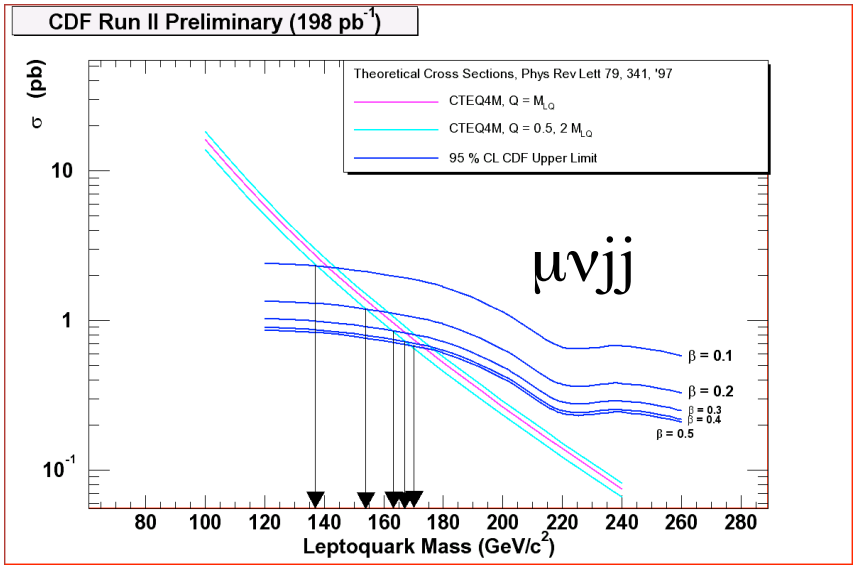

This analysis is optimized for β = 0.5

Other β limits are obtained using partial information on the acceptance

Exclude at 95% CL M_{LQ}<170 GeV/c^2

Combined Limit

Joint likelihood formed from the product of the individual channels likelihood. The searches in the dileptons and lepton + MET channels use common criteria and sometime apply the same kind of requirements (for example on lepton identification) so the uncertainties in the acceptances have been considered completely correlated (which gives the most conservative limit).
When calculating the limit combination including also the $\nu\nu jj$ channel the uncertainties in the acceptances have been considered uncorrelated.A correlation factor of 0.5 has also been considered (no difference)

$$\sigma_{LIM} = N_{LIM}/(\varepsilon_{average} \times \mathcal{L})$$

$$\varepsilon_{average} = (\beta^2 \varepsilon(\mu\mu jj) + 2\beta(1-\beta)\varepsilon(\mu\nu jj) + (1-\beta)^2 \varepsilon(\nu\nu jj) + \beta^2 \varepsilon(\mu\mu \text{ as } \mu\nu))$$

This is the correct efficiency for ALL β

Single channel limits are obtained using efficiency optimal ONLY for β = 1 and β = 0.5. All other β values are extrapolations in the absence of complete information

Conclusions

- We have performed a search for first generation scalar letpoquarks using Run II data.
  - All β channels have been included (Run I only the β =1 result was published)
  - All channels have been combined (no Run I analogous result)
- No LQ's observed …
- 95% CL mass limits for as a function of β

TABLE III: 95% C.L. lower limits on the second generation scalar leptoquark mass (in GeV/c^2), as a function of β.The limit from CDF[4] ($\mu\mu jj$) Run I ($\sim 120pb^{-1}$) is also given.

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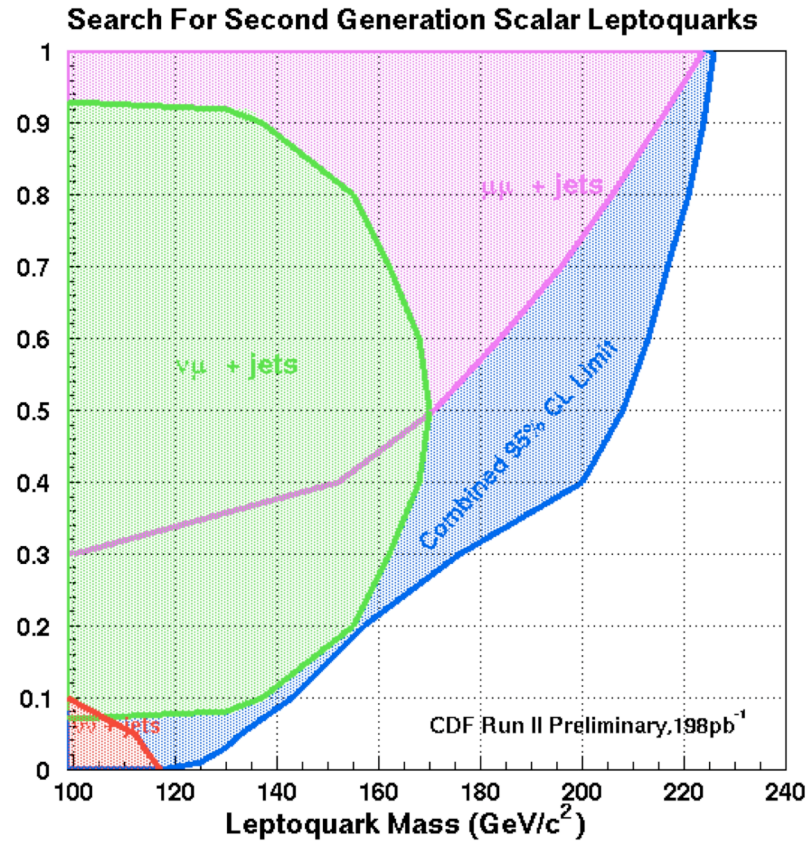


Aknowledgments

Thanks to the Exotic Conveners, especially Stephan Lammel!

Thanks to the GP's, Frank Chlebana, Allan Clark and Lucio Cerrito!

Thanks to the Run I predecessors:
Carla Gross-Pilcher, Federica Strumia and Lorenzo Moneta !

Thanks to the reading institutions!

Thanks for all the other comments and suggestions!
http://fcdfwww.fnal.gov/internal/physics/lq_search/

Backup Slides

GP's and references

GP's are:
Frank Chlebana (FNAL, chair)
Allan Clark (Geneva)
Lucio Cerrito (Oxford)

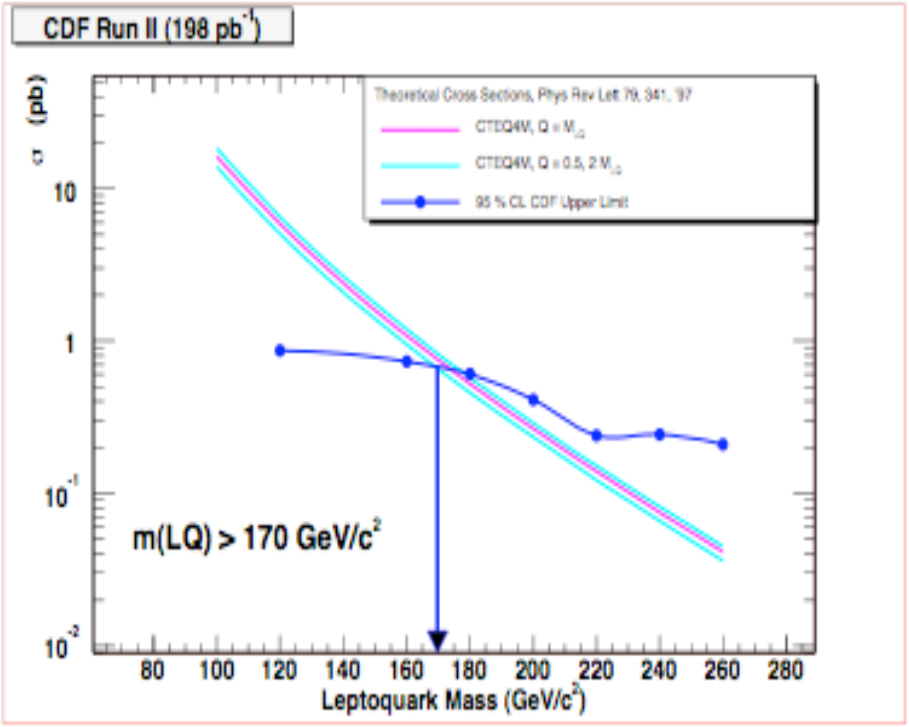
Web page at:
http://fcdfwww.fnal.gov/internal/physics/lq_search/

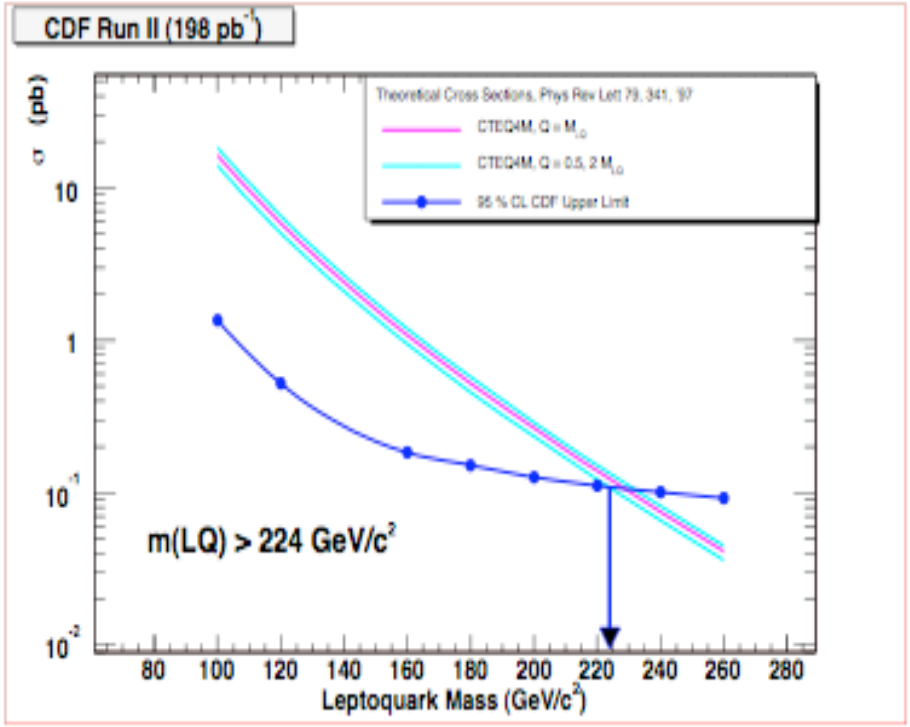
Efficiencies

TABLE I: Efficiencies after all cuts, relative errors and 95% C.L. upper limits on the production cross section × branching fraction Br, as a function of M_{LQ}, for the two channels.

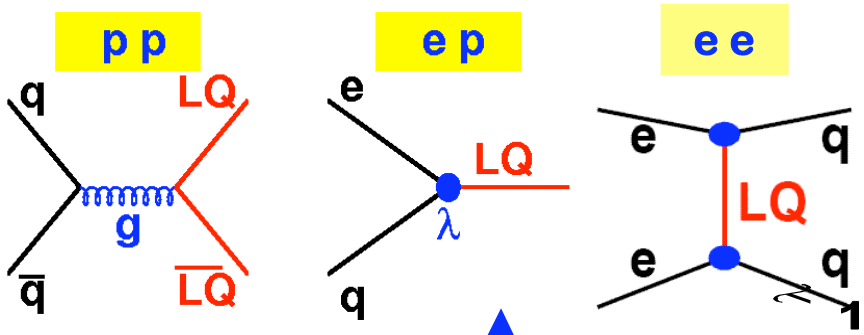
$M_{\mathrm{LQ}}(\mathrm{GeV}/c^2)$	$\mu\mu jj$		$\mu\nu jj$	
	ϵ	$\sigma\times\mathrm{Br(pb)}$	ϵ	$\sigma\times\mathrm{Br(pb)}$
100	0.02 ± 0.17	1.35	0.005 ± 0.10	-
120	0.05 ± 0.09	0.52	0.07 ± 0.07	0.86
160	0.13 ± 0.08	0.18	0.07 ± 0.08	0.73
200	0.19 ± 0.08	0.13	0.11 ± 0.07	0.41
220	0.21 ± 0.08	0.11	0.13 ± 0.08	0.24
240	0.24 ± 0.08	0.10	0.13 ± 0.07	0.24
260	0.26 ± 0.08	0.09	0.14 ± 0.07	0.21

Individual Limits

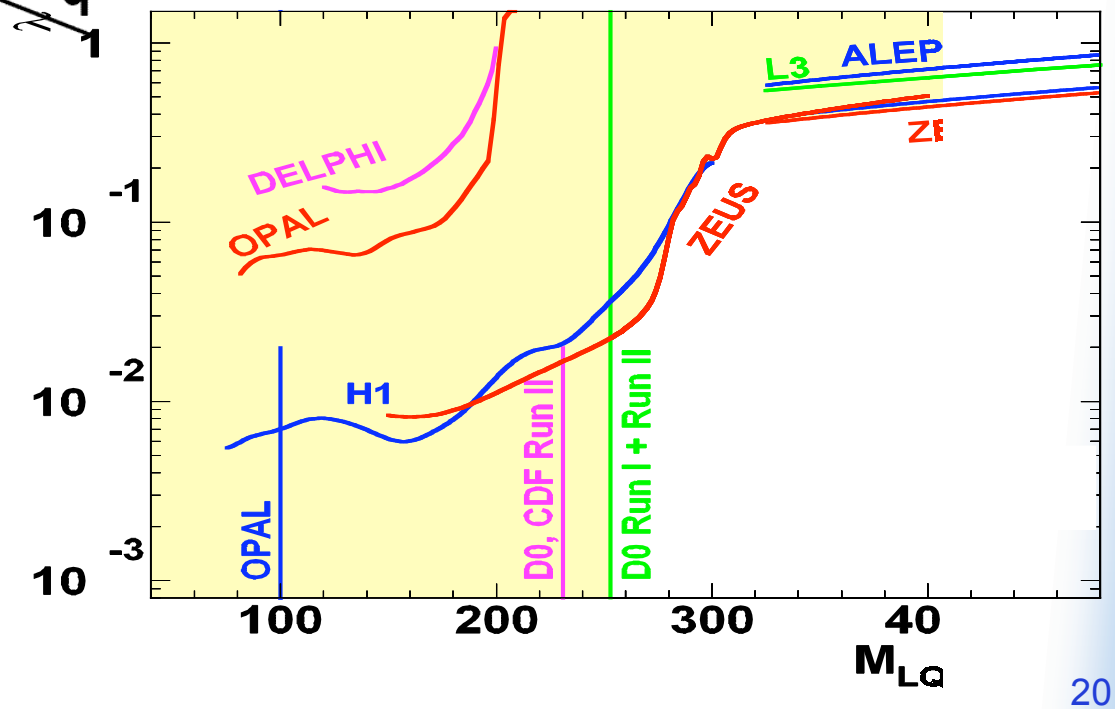




Comparison with Other Colliders



λ dependence



At the End of TeVatron Run II

Assumptions:

Same acceptances as now

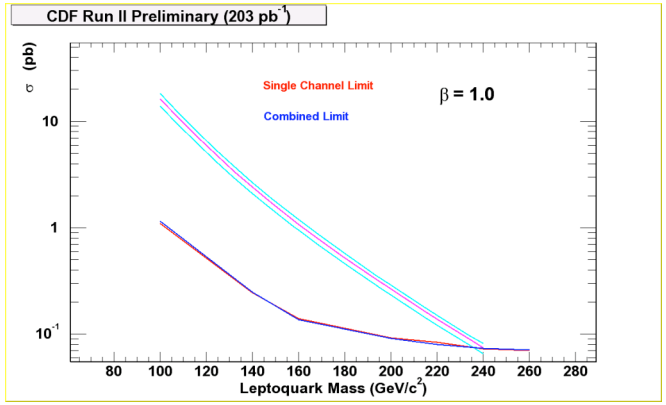
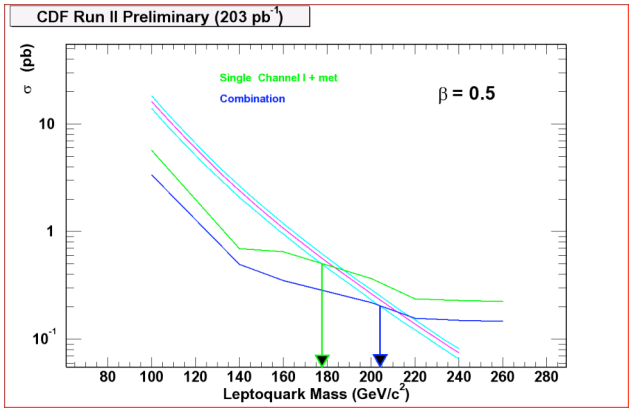
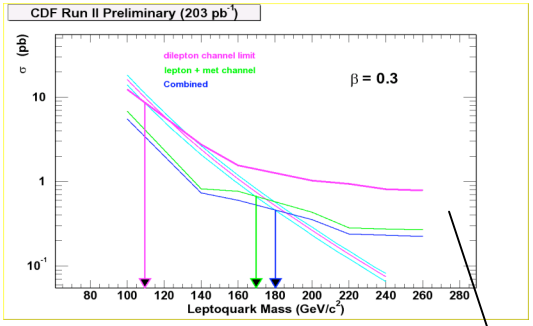
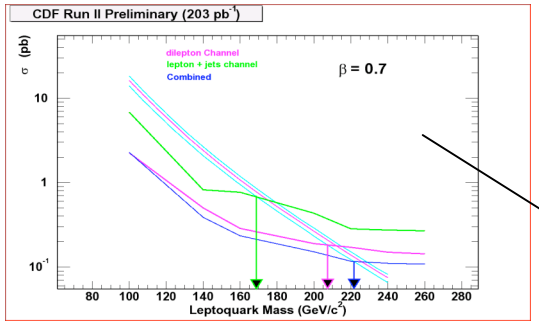
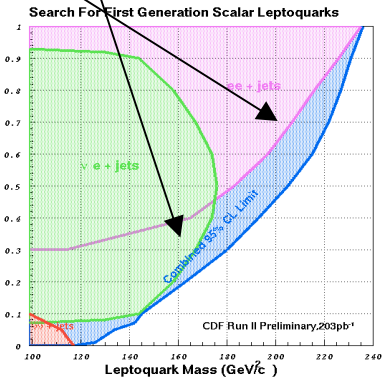
Number of events observed = number of predicted background

Same errors

$\beta = 1$ mass limit up to 250-300 GeV/c^2

$\beta = 0.5$ mass limit up to 230-280 GeV/c^2

Preliminary

New analysis strategy
(not counting experiment anymore?)
might be necessary.....

Combined Limit (II)