Search for 1st and 2nd Generation Scalar Leptoquarks

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Outline

- 2 PRL's out now
  - Comments due by March 25

cdf7529
cdf7530

- Outline of the analyses
- Results
- Combined Limits and Conclusions

1st and 2nd generation scalar LQ only
Lepton signatures!
MET + jets cdf7200 - submitted to PRL

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

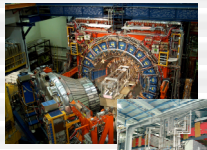
–Yang-Mills coupling: $k_G = \lambda_G = 0$

–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

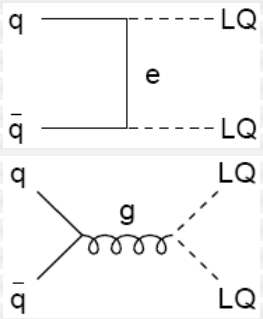


LQ at Hadron Colliders

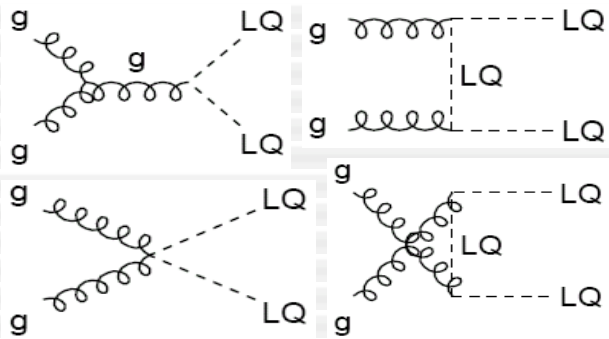
- **Pair production**
  - Practically independent of Yukawa coupling _ (only g-LQ-LQ vertex)
  - Depends mainly on LQ mass

- λ dependent process
- does not contribute significantly to 2nd & 3rd generation

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



$gg \rightarrow LQ\ LQ$



Leptoquark Decay

Each generation can decay into 3 final states:

$\beta = Br(LQ \rightarrow lq)$

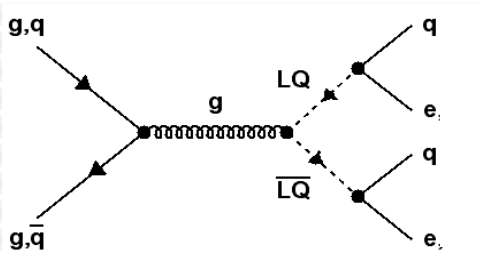
Exclusive to the Tevatron

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

These papers!

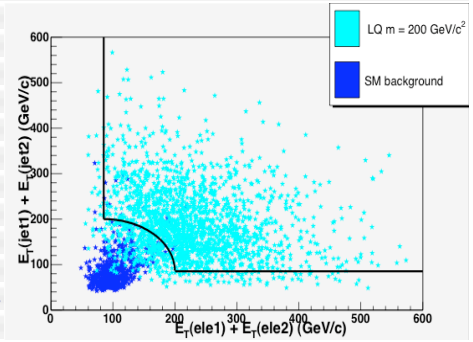
$LQ\,LQ \rightarrow llqq$	2l+2j	$BR = \beta^2$
$LQ\,LQ \rightarrow l\nu qq$	l+MET+2j	$BR = 2\beta(1-\beta)$
$LQ\,LQ \rightarrow \nu\nu qq$	MET+2j	$BR = (1-\beta)^2$

Search for LQ in dileptons + jets (I)



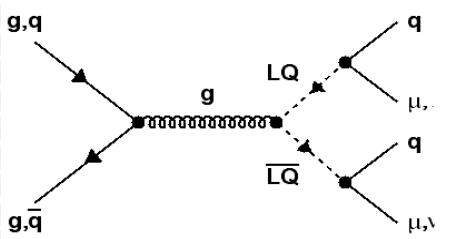
Selection

- ✓ 2 electrons (CC,CF) $E_T > 25$ GeV
- ✓ 2 jets, $E_T(j1) > 30$ GeV, $E_T(j2) > 15$ GeV
- ✓ Z Veto ($76 < M_{\mu\mu} < 110$) GeV
- ✓ Electrons/Jets: $E_T^{j1(e1)} + E_T^{j2(e2)} > 85$ GeV
- ✓ $((E_T(j_1) + E_T(j_2))^2 + (E_T(e_1) + E_T(e_2))^2)^{1/2} > 200$ GeV



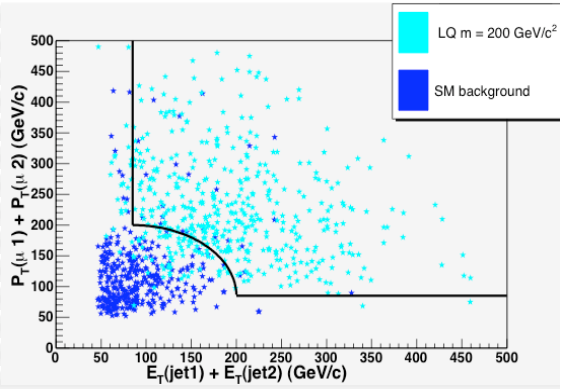
SM background

- Drell-Yan+2jets
- Top ($W \rightarrow e\nu$)
- 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



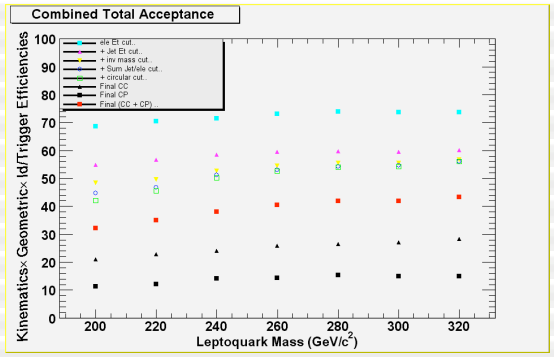
Search for LQ in dileptons + jets(II)

Backgrounds:	eejj	μμjj
Z + 2 jets (alpgen)	1.89 ± 0.44	1.7 ±0.1
ttbar (Pythia)	0.35 ± 0.03	0.22 ±0.03
Fakes (data)	3.96 ± 2.01	1±1
Total	6.24 ± 2.16	3.0 ±1
Observed	4	2

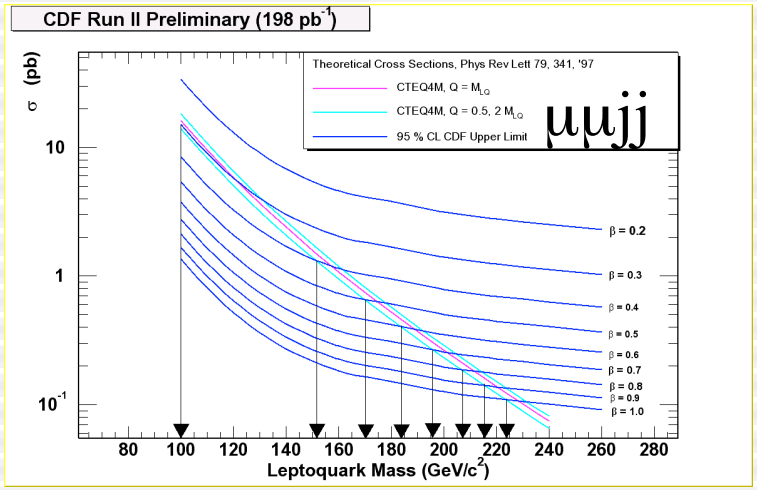
Systematics: signal acceptance and background prediction

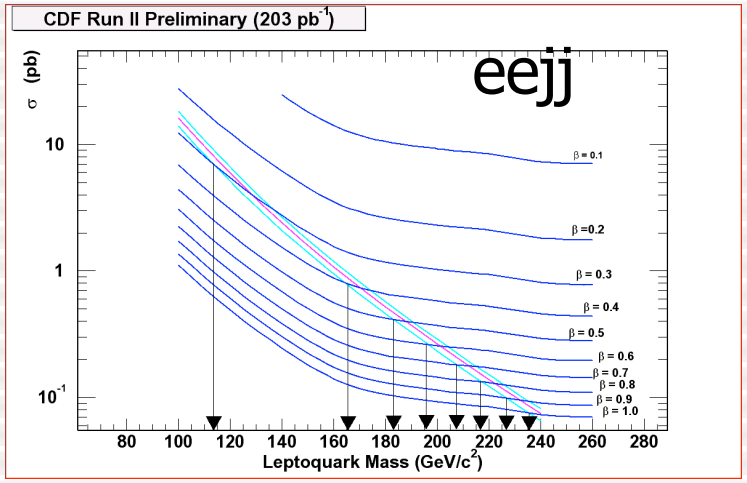
Luminosity	6%
pdf	2.1%
statistics of MC	~1.2%
Jet Energy Scale	<1%
muon reco/ele id	<1%
Z vertex cut	0.5%

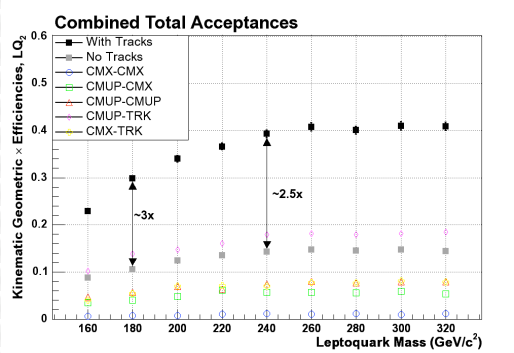
Search for LQ in dileptons + jets (III)



Exclude at 95% CL M_{LQ}<224 GeV/c^2 for β = 1.0







Exclude at 95% CL M_{LQ}<235 GeV/c^2 for β = 1.0

Search for LQ in dileptons + jets (III)

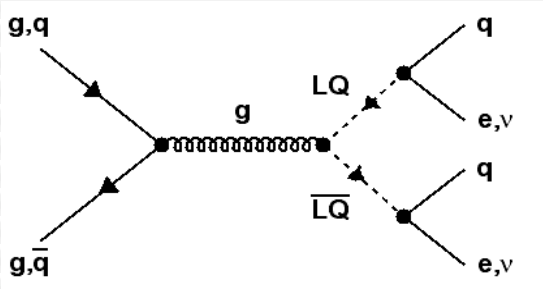
TABLE I: Efficiencies after all cuts, relative errors and 95% C.L. upper limits on the production cross section × branching fraction Br, as a function of M_{LQ}, for the two channels.

$M_{\mathrm{LQ}}(\mathrm{GeV}/c^2)$	$eejj$		$e\nu jj$	
	ϵ	$\sigma\times$Br(pb)	ϵ	$\sigma\times$Br(pb)
100	0.07 ± 0.07	1.11	0.02 ± 0.13	5.71
140	0.12 ± 0.04	0.25	0.08 ± 0.09	0.69
160	0.21 ± 0.04	0.14	0.08 ± 0.09	0.65
200	0.32 ± 0.05	0.09	0.16 ± 0.08	0.37
220	0.35 ± 0.05	0.08	0.19 ± 0.08	0.24
240	0.38 ± 0.04	0.07	0.20 ± 0.08	0.23
260	0.40 ± 0.04	0.07	0.22 ± 0.08	0.22

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.

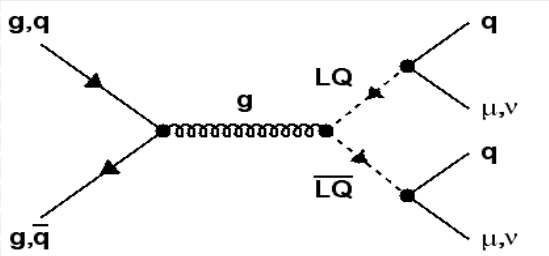
$M_{\mathrm{LQ}}(\mathrm{GeV}/c^2)$	$\mu\mu jj$		$\mu\nu jj$	
	ϵ	$\sigma\times$Br(pb)	ϵ	$\sigma\times$Br(pb)
100	0.02 ± 0.17	1.35	0.005 ± 0.10	-
120	0.05 ± 0.09	0.52	0.07 ± 0.07	0.86
160	0.13 ± 0.08	0.18	0.07 ± 0.08	0.73
200	0.19 ± 0.08	0.13	0.11 ± 0.07	0.41
220	0.21 ± 0.08	0.11	0.13 ± 0.08	0.24
240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

Search for LQ in lepton + MET + jets



SM background

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



Selection

- 1central electrons with E_T > 25 GeV
- MET > 60 GeV
- Veto on 2nd electron, central loose or Plug
- 2 jets with E_T > 30 GeV
- $\Delta\phi$ (MET-jet) > 10°
- $E_T(j1) + E_T(j2)$ > 80 GeV
- $M_T(e\text{-}\nu)$ > 120
- LQ mass combinations

Selection

Z veto (tight/loose pair)

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

$P_T(\mu) > 25$ GeV

$\not{E}_T > 60$ GeV

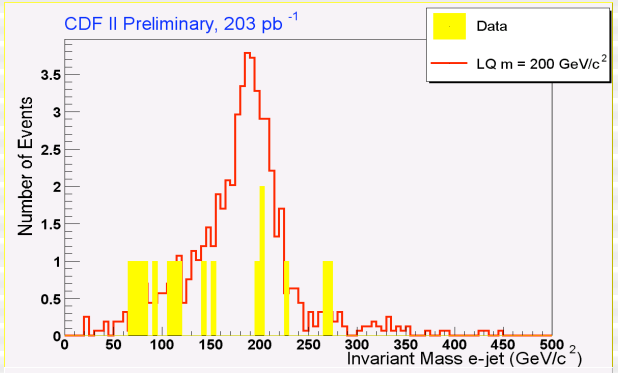
2 jets, @ E_T>30GeV

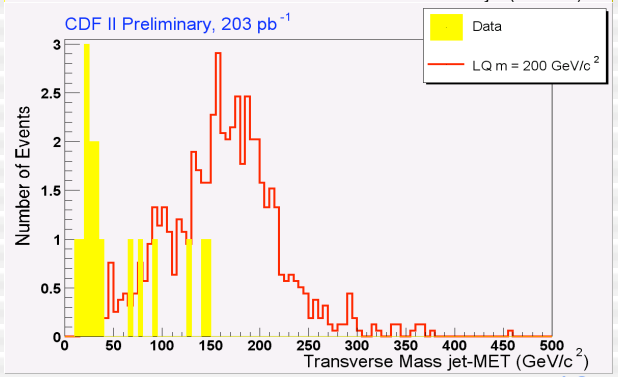
$\Delta\phi(\mu,\not{E}_T)<175°$, $\Delta\phi(\not{E}_T,\text{jets})>5°$

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

$M_T(\not{E}_T,\text{Muon}) > 120$ GeV/c²

Mass Cut

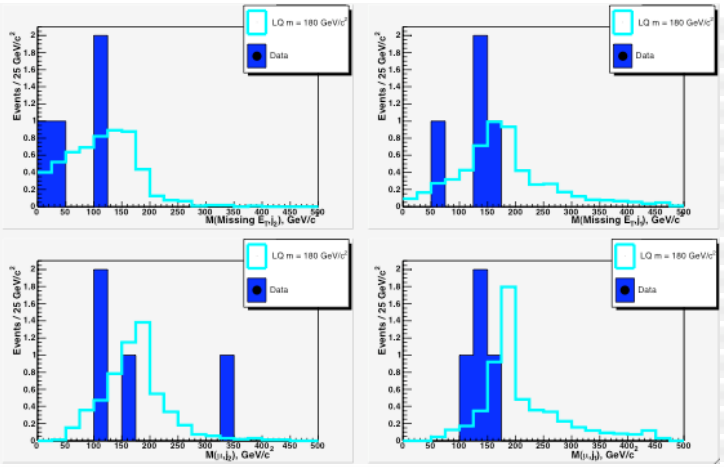




Search for LQ in lepton,MET + jets (II)

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



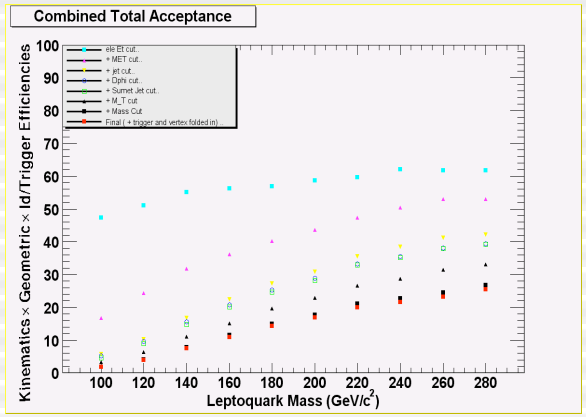
Systematics: signal acceptance and background estimate

Luminosity	6%
pdf	2.1%
Statistics of MC	~1.2%
Jet energy scale	<1%
Muon reco/ele id	<1%
Z vertex cut	0.5%

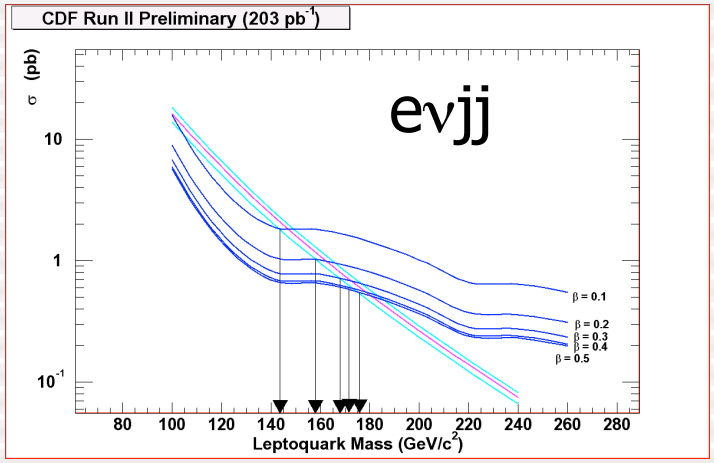
TABLE II: Final number of events surviving all cuts in the electron, missing energy and jets topology, compared with background expectations, as function of the LQ mass (in GeV/c^2).

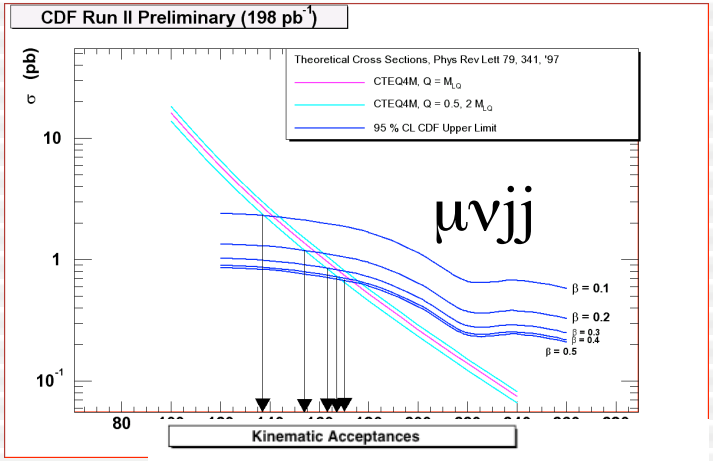
Mass	W + 2 jets	top	Z + 2 jets	Total	Data
120	1.5 ± 0.9	3.3 ± 0.5	0.06 ± 0.01	4.9 ± 1.0	6
140	1.5 ± 0.9	3.1 ± 0.6	0.08 ± 0.02	4.7 ± 1.0	4
160	2.5 ± 1.1	2.8 ± 0.6	0.08 ± 0.02	5.4 ± 1.2	4
180	2.5 ± 1.1	2.4 ± 0.5	0.08 ± 0.02	5.0 ± 1.2	4
200	2.5 ± 1.1	2.0 ± 0.5	0.07 ± 0.02	4.6 ± 1.2	4
220	2.0 ± 1.0	1.6 ± 0.3	0.06 ± 0.02	3.7 ± 1.1	2
240	2.0 ± 1.0	1.1 ± 0.3	0.06 ± 0.02	3.1 ± 1.0	2
260	1.5 ± 1.0	0.8 ± 0.3	0.04 ± 0.02	2.4 ± 0.9	2

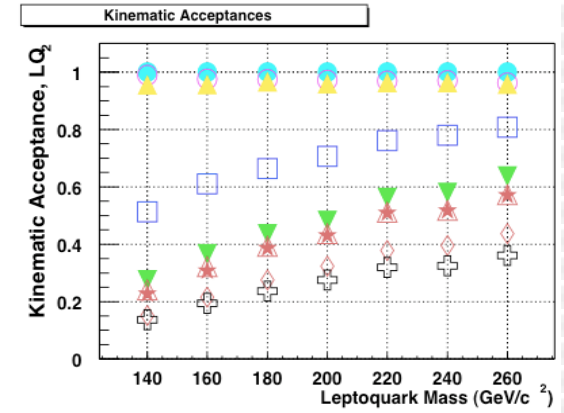
Search for LQ in lepton,MET + jets (III)



Exclude at 95% CL M_{LQ}<170 GeV/c^2 for β = 0.5







Exclude at 95% CL M_{LQ}<176 GeV/c^2 for β = 0.5

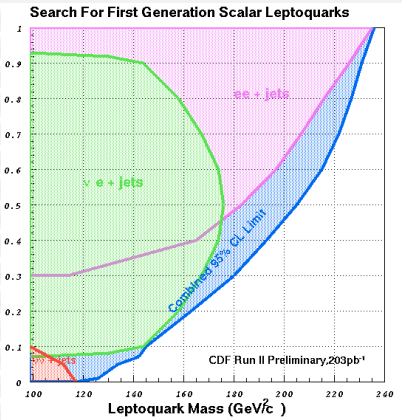
Final Combined Limits

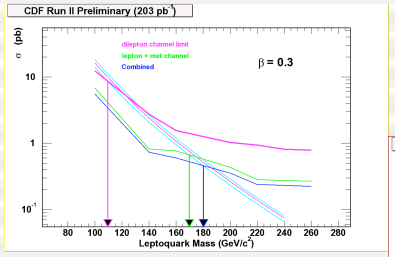
Joint likelihood formed from the product of the individual channels likelihood.
The searches in the dileptons and lepton + MET channels use common criteria and sometime apply the same kind of requirements (for example on lepton identification) so the uncertainties in the acceptances have been considered 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)

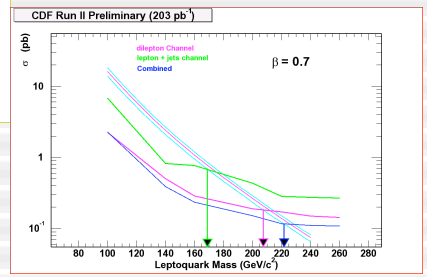
$$\sigma_{LIM} = N_{LIM}/(\varepsilon_{average} \times \mathcal{L})$$

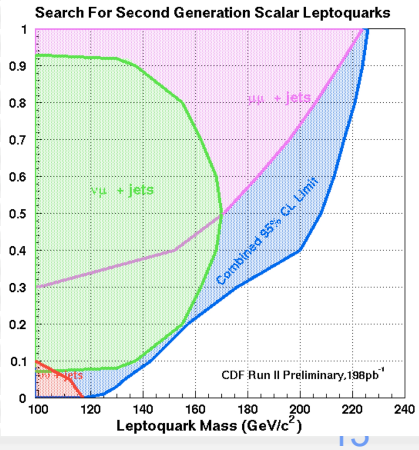
$\varepsilon_{average} = (\beta^2\varepsilon(eejj) + 2\beta(1-\beta)\varepsilon(e\nu jj) + \beta^2\varepsilon(ee \text{ as } e\nu))$ for the 2 channels case and

$\varepsilon_{average} = (\beta^2\varepsilon(eejj) + 2\beta(1-\beta)\varepsilon(e\nu jj) + (1-\beta)^2\varepsilon(\nu\nu jj) + \beta^2\varepsilon(ee \text{ as } e\nu))$ for the 3 channels case.









Final Results

TABLE III: 95% C.L. lower limits on the first generation scalar leptoquark mass (in GeV/c^2), as a function of β.The limit from CDF[7] ($eejj$) Run I ($\sim 120pb^{-1}$) is also given.

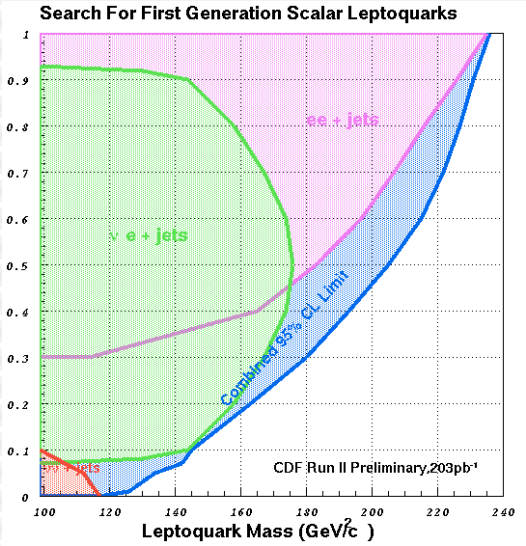
β	ee jj	$e\nu jj$	$\nu\nu jj$	Combined	CDF Run I
0.01	-	-	116	126	-
0.05	-	-	112	134	-
0.1	-	144	-	145	-
0.2	-	158	-	163	-
0.3	114	167	-	180	-
0.4	165	174	-	193	-
0.5	183	176	-	205	-
0.6	197	174	-	215	-
0.7	207	167	-	222	-
0.8	216	158	-	227	-
0.9	226	144	-	231	-
1.0	235	-	-	236	213

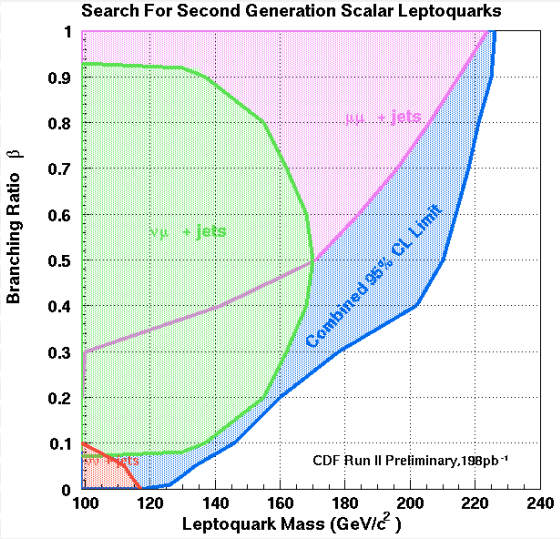
TABLE III: 95% C.L. lower limits on the second generation scalar leptoquark mass (in GeV/c^2), as a function of β.The limit from CDF[4] ($\mu\mu jj$) Run I ($\sim 120pb^{-1}$) is also given.

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

Conclusions

- We have performed the combination of all the CDF searches for first and second generation scalar letpoquarks using Run II data.
- The results are combined using a procedure based on a Bayesian approach which takes into account the correlations in the systematic uncertainties.
- We set 95% CL mass limits for scalar leptoquarks as function of β:





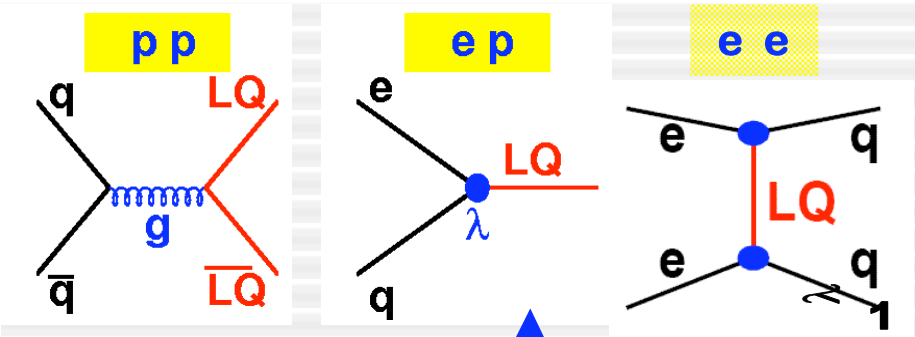
Backup Slides

GP's and references

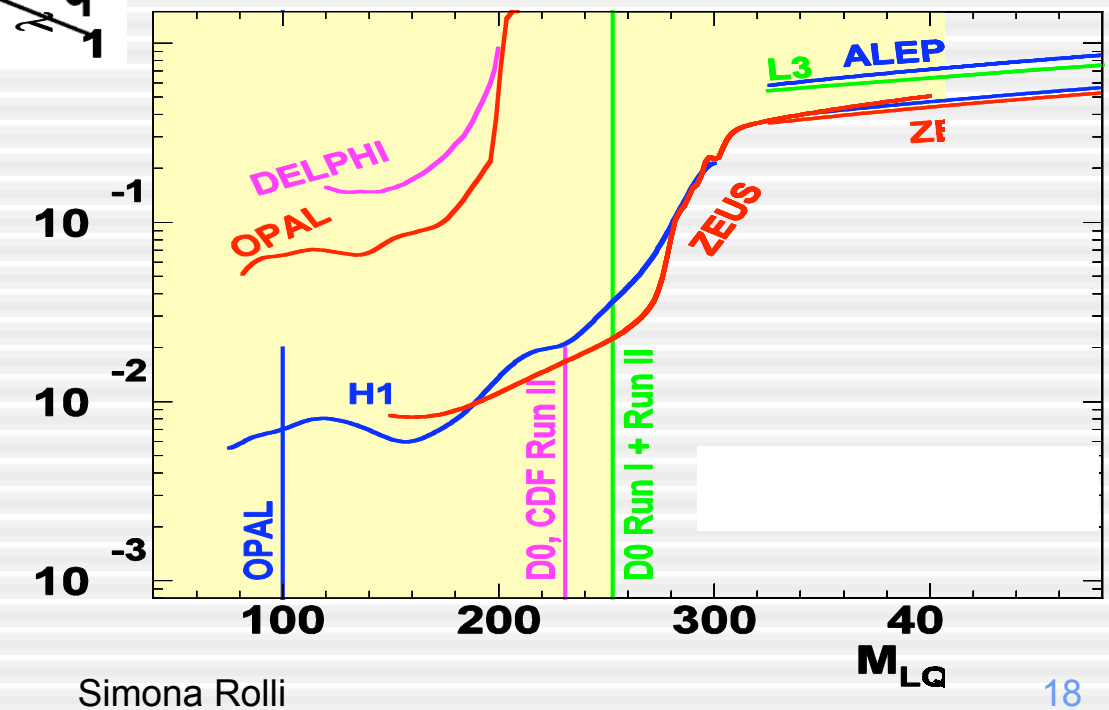
GP's are:
Frank Chlebana (FNAL, chair)
Allan Clark (Geneva)
Lucio Cerrito (Oxford)

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

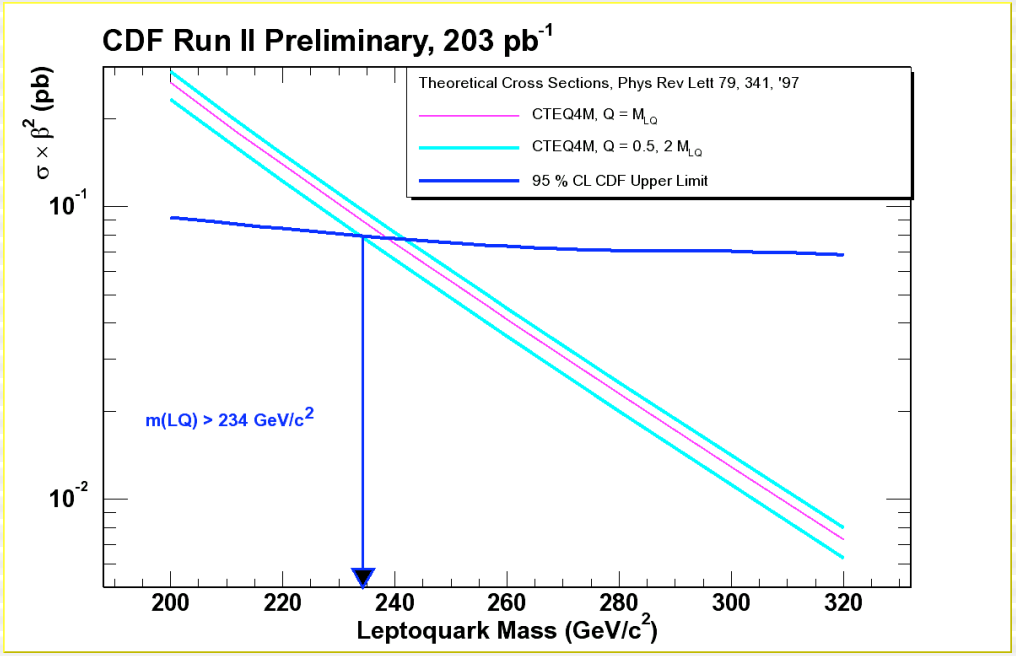
Comparison with Other Colliders



λ dependence



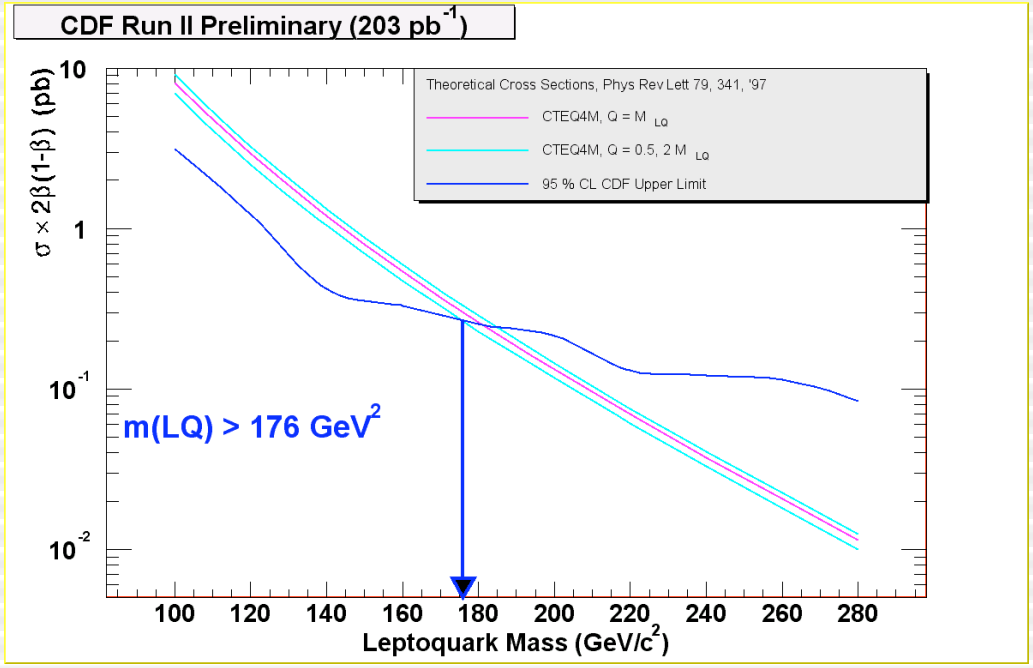
CDF - ee channel



Luminosity 203pb^{-1}

Exclude at 95% CL M_{LQ}<235 GeV/c^2

CDF – eνjj Channel



Luminosity 203pb^{-1}

Exclude at 95% CL M_{LQ}<176 GeV/c^2

eνjj - Mass combination

The peak of the *ej* histogram is fitted with a gaussian

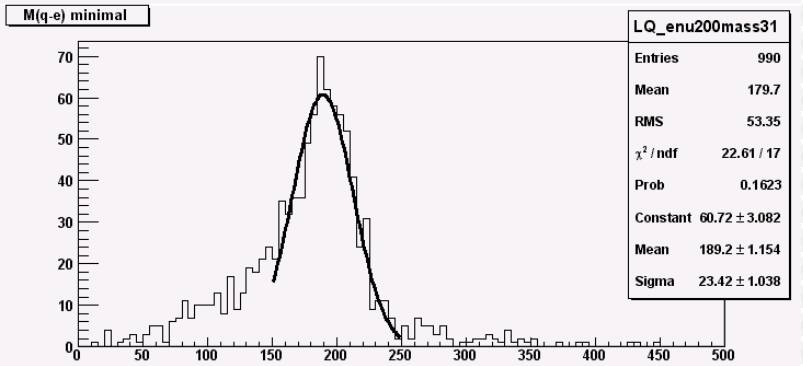
rough estimate of the spread of the distribution in the signal region.

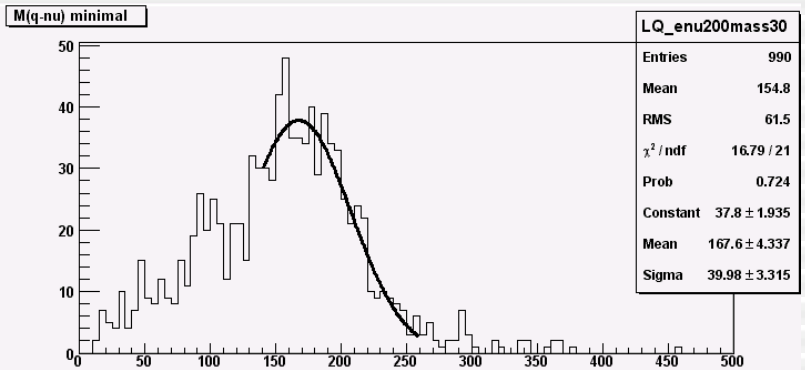
Several masses (120-160-200-240-280) tested:

σ_e ~ 15%.

The ν-*q* transverse mass distribution is fitted including the high mass tail end, with a Gaussian to estimate the signal spread.

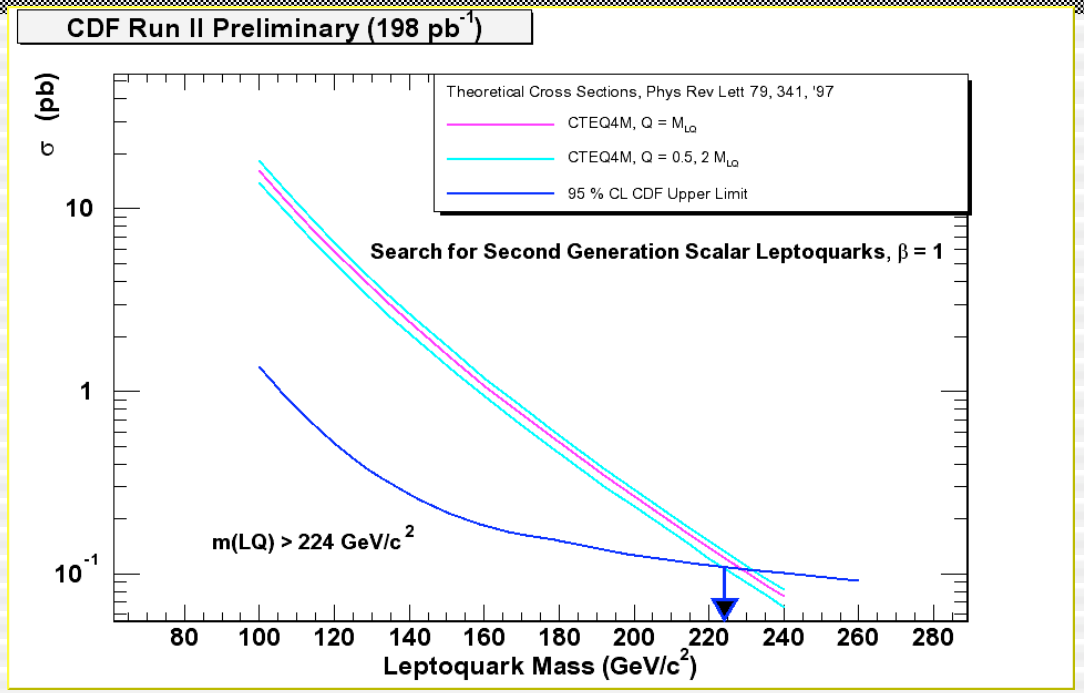
σ_ν ~ 25%.





3σ cut around the nominal mass to select LQ candidates of a given mass

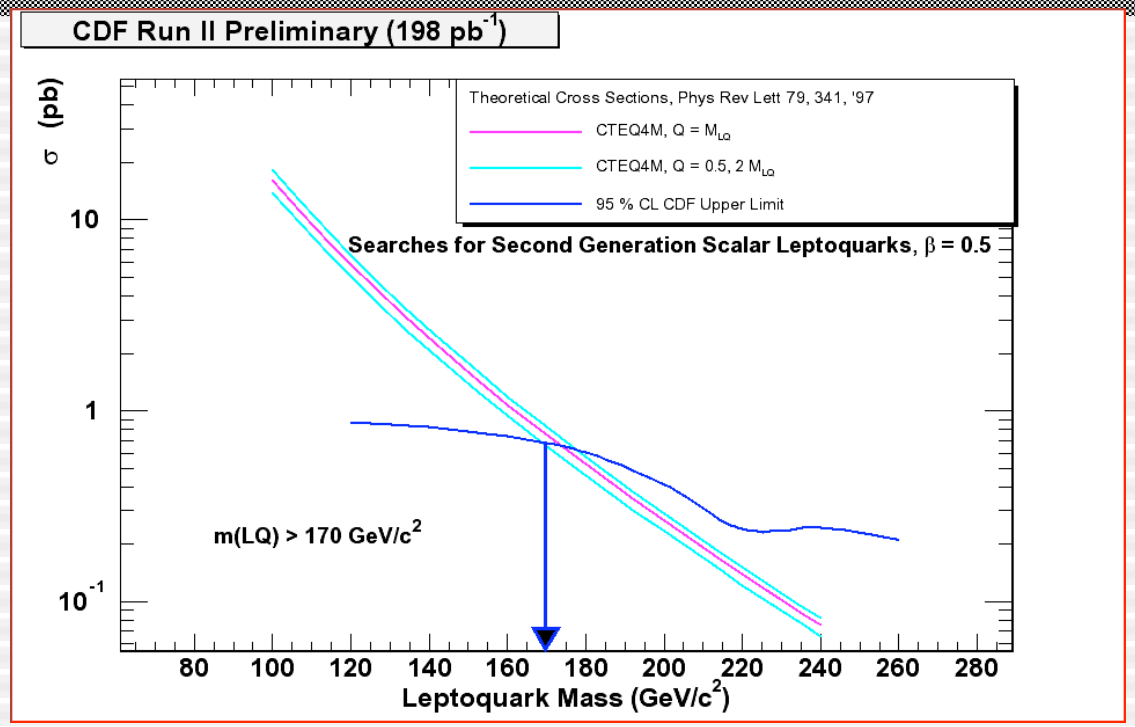
CDF - μμ Channel



Luminosity 198pb^{-1}

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

CDF - $\mu\nu jj$ Channel



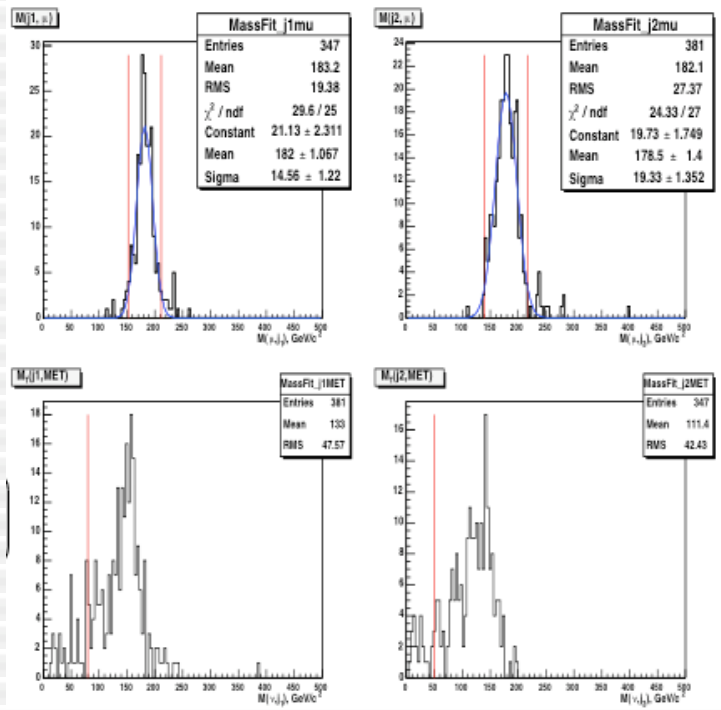
Luminosity 198pb^{-1}

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

μνjj - Mass Cut

$$|M(\mu,j_1) - M_{LQ}| < 2\sigma_1$$
or
$$|M(\mu,j_2) - M_{LQ}| < 2\sigma_2$$

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



$$M_T(\not{E}_T, j_1) > T_1(\min)$$
or
$$M_T(\not{E}_T, j_2) > T_2(\min)$$

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

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

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.....