CDFでのレプトクォークの探索

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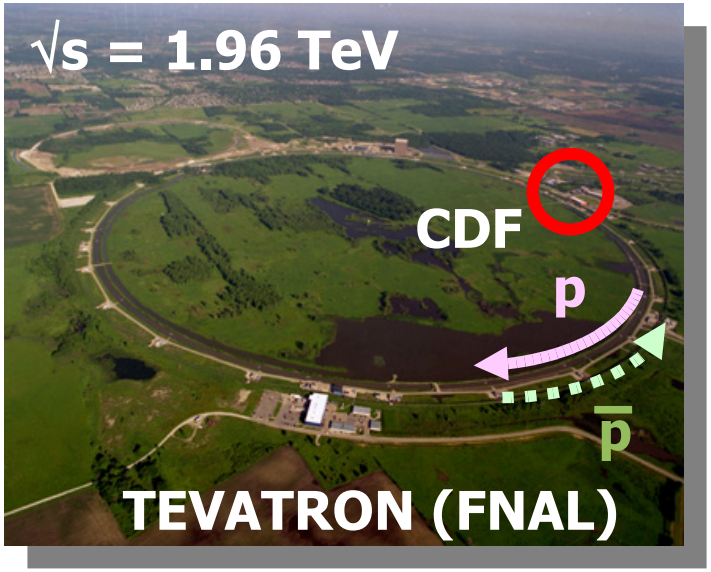
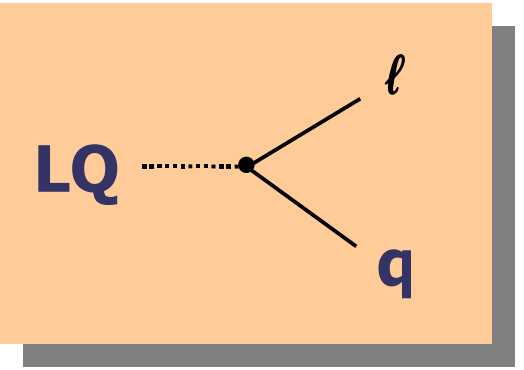


1. Introduction for Leptoquark(LQ)
2. Limits of Scalar LQs
3. 3rd Generation Vector LQs
4. Summary

1.1. The Leptoquark (LQ)

- Symmetry between quark and lepton sectors suggests a possible link at higher energy scales (e.g. > m_{top})
- Theoretical particle which couples to quarks and leptons
  - Carries baryon and lepton numbers
  - Fractional charge
  - Color-triplet boson
  - Two possible spin structures:
    - ➔ Spin 0 (scalar)
    - ➔ Spin 1 (vector)



1.2. Scalar and Vector LQs

Scalar : $$L_S^g = \sum_{scalars} \left[(D_{ij}^{\mu}\Phi^j)^{\dagger}(D_{\mu}^{ik}\Phi_k) - M_S^2 \Phi^{i\dagger}\Phi_i \right]$$

Vector : $$L_V^g = \sum_{vectors} \left[-\frac{1}{2} G_{\mu\nu}^{i\dagger} G_i^{\mu\nu} + M_V^2 \Phi_{\mu}^{i\dagger}\Phi_i^{\mu} - ig_s \left[(1-\lambda)\Phi_{\mu}^{i\dagger} t_{ij}^a \Phi_{\nu}^j \mathcal{G}_a^{\mu\nu} + \frac{\kappa}{M_V^2} G_{\sigma\mu}^{i\dagger} t_{ij}^a G_{\nu}^{j\mu} \mathcal{G}_a^{\nu\sigma} \right] \right]$$

anomalous magnetic moment : $$\mu_V = \frac{g_s}{2M_V}(2+\kappa-\lambda)$$

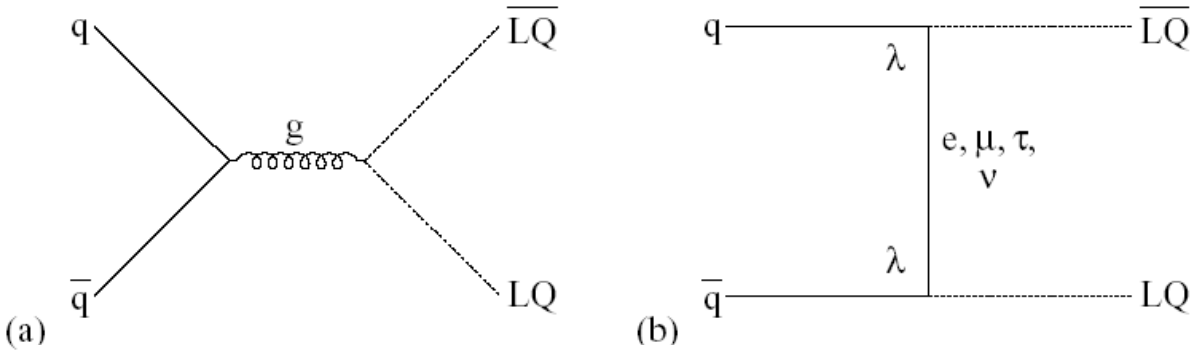
electric quadrupole moment : $$q_V = -\frac{g_s}{M_V^2}(1-\kappa-\lambda)$$

- $\kappa = 0, \lambda = 0$: Yang-Mills coupling
- $\kappa = 0, \lambda = 1$: Minimal vector type coupling

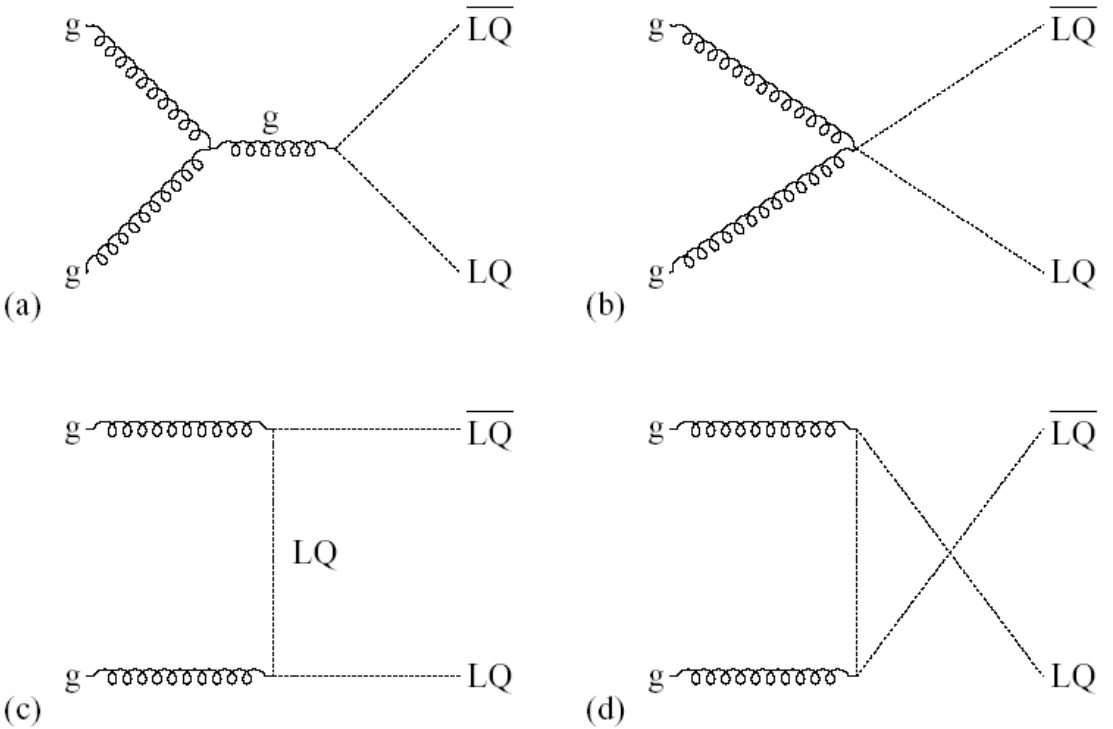
1.3. LQ Pair Production

- Feynman diagrams for leptoquark pair production by $p\bar{p}$ collision.

$q\bar{q}$ anihilation

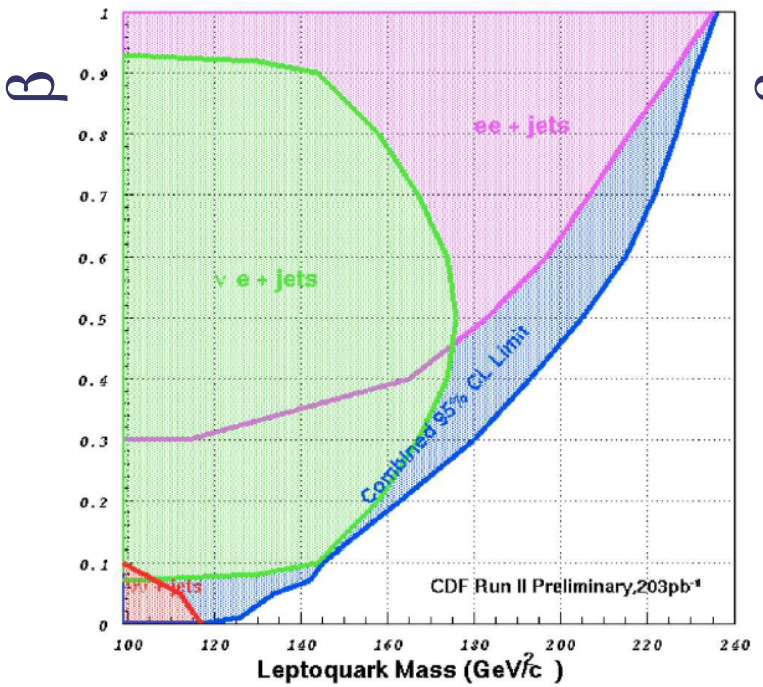


gluon-gluon fusion

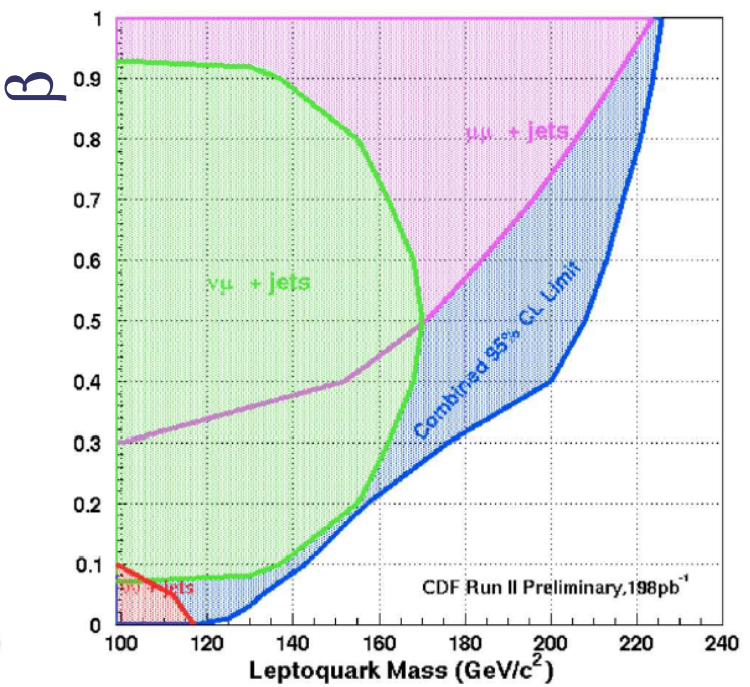


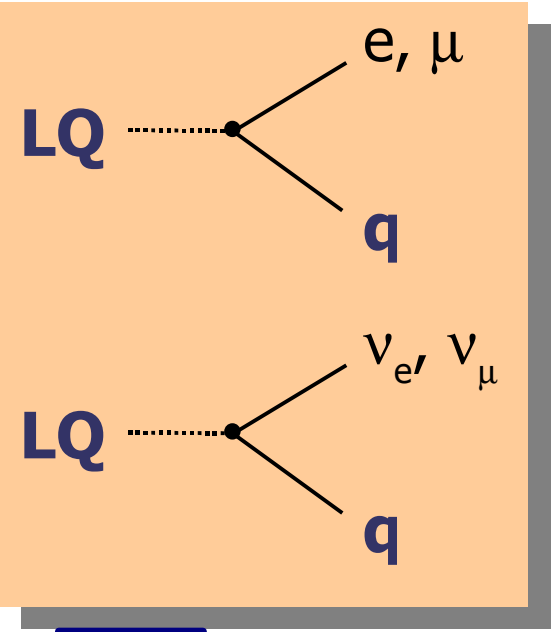
2.1. 1st and 2nd Gen Scalar LQ

1st Generation



2nd Generation



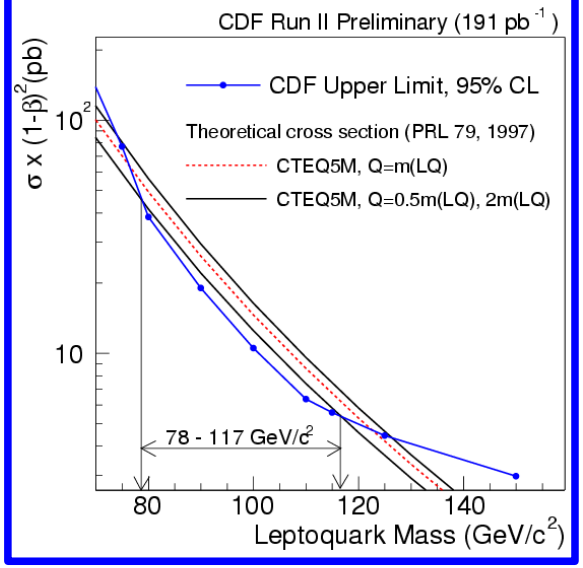


$m_{LQ1} > 235$ GeV/c² (β=1)
$m_{LQ1} > 176$ GeV/c² (β=0.5)

$m_{LQ2} > 224$ GeV/c² (β=1)
$m_{LQ2} > 177$ GeV/c² (β=0.5)

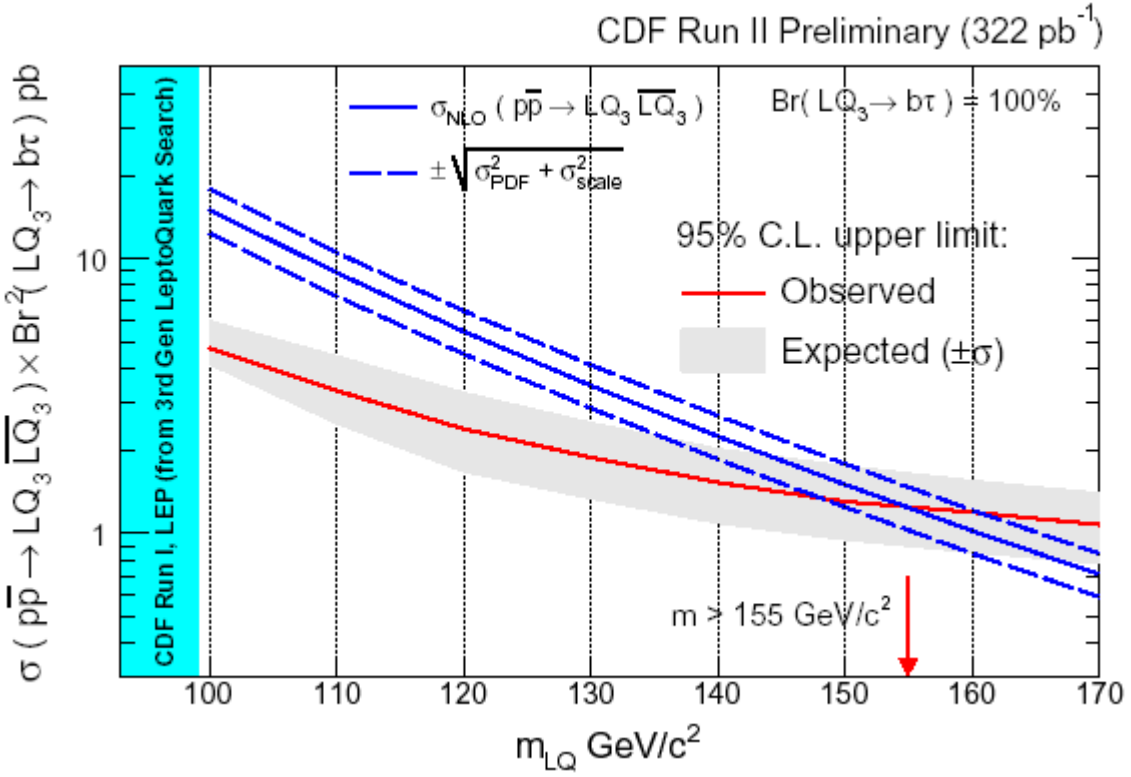
$m_{LQ1,2} < 78$ GeV/c², $m_{LQ1,2} > 117$ GeV/c² (β=0)

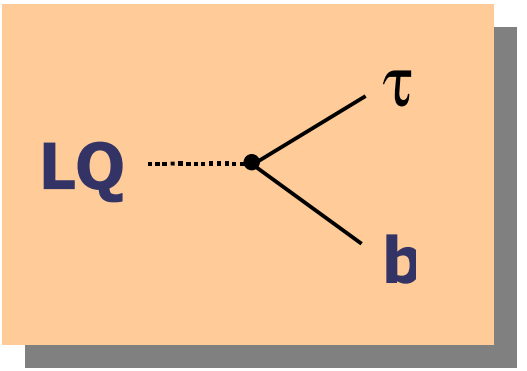
νν jj



2.2. 3rd Gen Scalar LQ

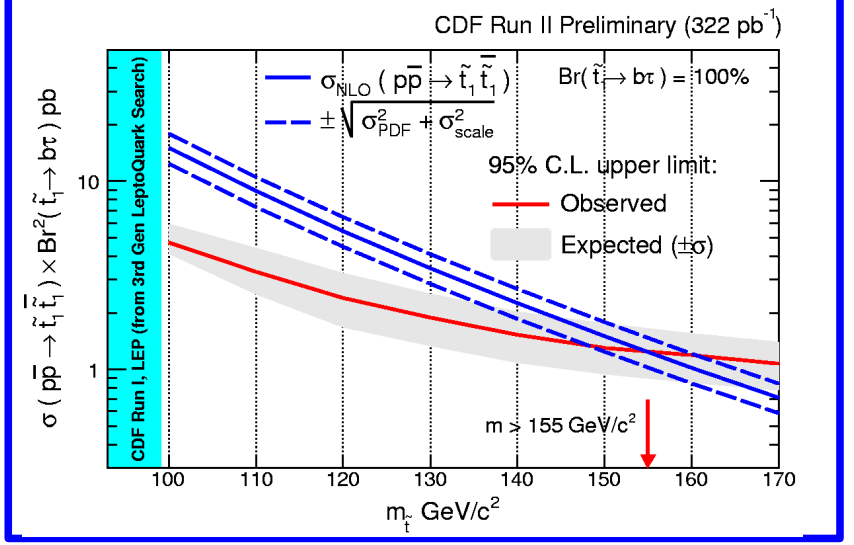
3rd Generation Scalar LQ limit is fully applicable to RPV stop case.





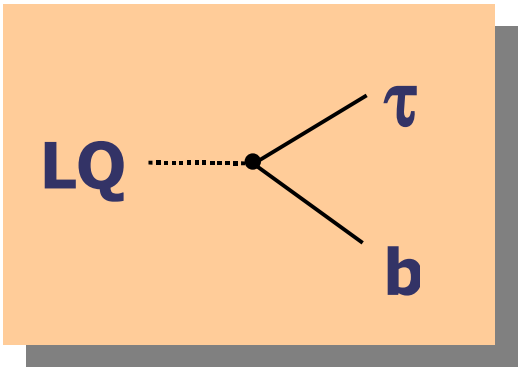
m_{LQ3} > 155 GeV/c² (β=1)

RPV stop



3.1. 3rd Gen LQs

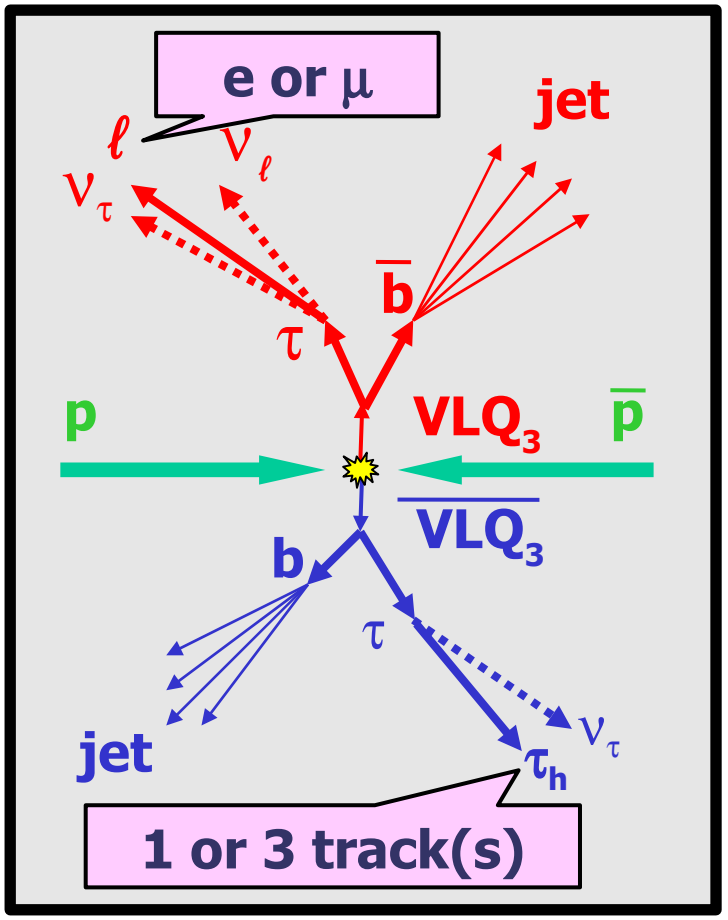
- Various species of LQ3s
- 3rd generation decays:
  - Define: β = Br(LQ3$\rightarrow \tau$b)



We search for β=1 case.

LQ	Spin	3B+L	$SU(3)_C$	$SU(2)_W$	$U(1)_Y$	Q_{EM}	Channel(s) [couplings(s)]
S_1	0	-2	3^*	1	$\frac{1}{3}$	$-\frac{1}{3}$	$\tau_{L,R}^- t$ [$g_{1L,R}$], $\nu_L b$ [$-g_{1L}$]
$\tilde{S}_1$	0	-2	3^*	1	$\frac{4}{3}$	$-\frac{4}{3}$	$\tau_R^- b$ [$\tilde{g}_{1R}$]
S_3	0	-2	3^*	3	$\frac{1}{3}$	$\frac{2}{3}$ $-\frac{1}{3}$ $-\frac{4}{3}$	$\nu_L t$ [$\sqrt{2}g_{3L}$] $\tau_L^- t$ [$-g_{3L}$], $\nu_L b$ [$-g_{3L}$] $\tau_L^- b$ [$-\sqrt{2}g_{3L}$]
V_2	1	-2	3^*	2	$\frac{5}{6}$	$-\frac{1}{3}$ $-\frac{4}{3}$	$\tau_R^- t$ [g_{2R}], $\nu_L b$ [g_{2L}] $\tau_{L,R}^- b$ [$g_{2L,R}$]
$\tilde{V}_2$	1	-2	3^*	2	$-\frac{1}{6}$	$\frac{2}{3}$ $-\frac{1}{3}$	$\nu_L t$ [$\tilde{g}_{2L}$] $\tau_L^- t$ [$\tilde{g}_{2L}$]
R_2	0	0	3	2	$\frac{7}{6}$	$-\frac{2}{3}$ $-\frac{5}{3}$	$\tau_R^- \bar{b}$ [$-h_{2R}$], $\nu_L \bar{t}$ [h_{2L}] $\tau_{L,R}^- \bar{t}$ [$h_{2L,R}$]
$\tilde{R}_2$	0	0	3	2	$\frac{1}{6}$	$\frac{1}{3}$ $-\frac{2}{3}$	$\nu_L \bar{b}$ [$\tilde{h}_{2L}$] $\tau_L^- \bar{b}$ [$\tilde{h}_{2L}$]
U_1	1	0	3	1	$\frac{2}{3}$	$-\frac{2}{3}$	$\tau_{L,R}^- \bar{b}$ [$h_{1L,R}$], $\nu_L \bar{t}$ [h_{1L}]
$\tilde{U}_1$	1	0	3	1	$\frac{5}{3}$	$-\frac{5}{3}$	$\tau_R^- \bar{t}$ [$\tilde{h}_{1R}$]
U_3	1	0	3	3	$\frac{2}{3}$	$\frac{1}{3}$ $-\frac{2}{3}$ $-\frac{5}{3}$	$\nu_L \bar{b}$ [$\sqrt{2}h_{3L}$] $\tau_L^- \bar{b}$ [$-h_{3L}$], $\nu_L \bar{t}$ [h_{3L}] $\tau_L^- \bar{t}$ [$\sqrt{2}h_{3L}$]

3.2. Event Selection



Lepton	Hadronic Tau
e: E_T>10 GeV μ: p_T>10 GeV/c separated from a jet	p_T>15 GeV/c separated from a jet

Event Selection

Opposite sign charge ($Q(\ell)*Q(\tau_h) = -1$)

Conversion / Cosmic removal

DY removal using mass window cut
(veto if $76 < m_{\ell\ell} < 106$ GeV/c^2)

$\not\!\!E_T$ > 10 GeV

H_T > 400 GeV (*)

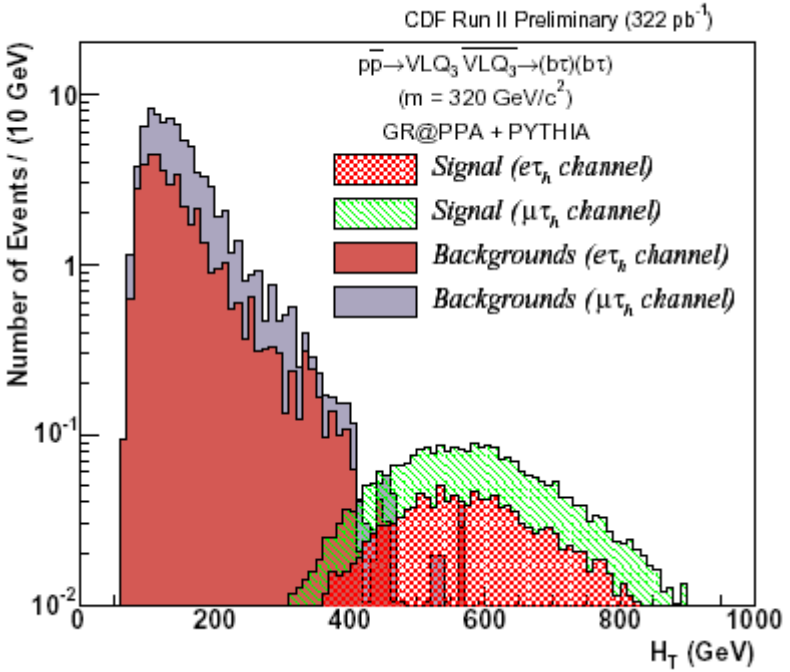
$N_{jets} \geq 2$ (E_T > 15 GeV)

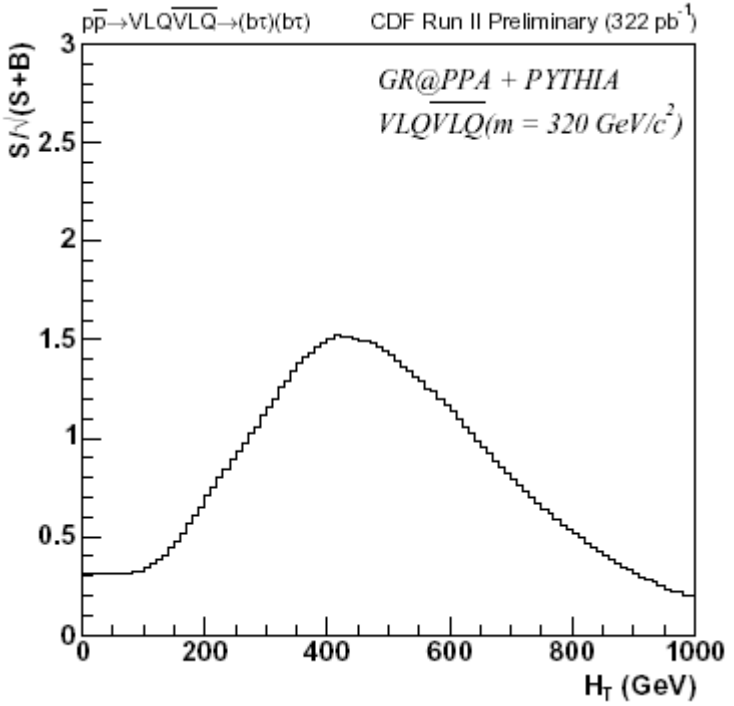
$$*H_T = E_T(\ell) + E_T(\tau_h) + \not\!\!E_T + \Sigma E_T(\text{jets})$$

3.2. Event Selection

H_T > 400 GeV

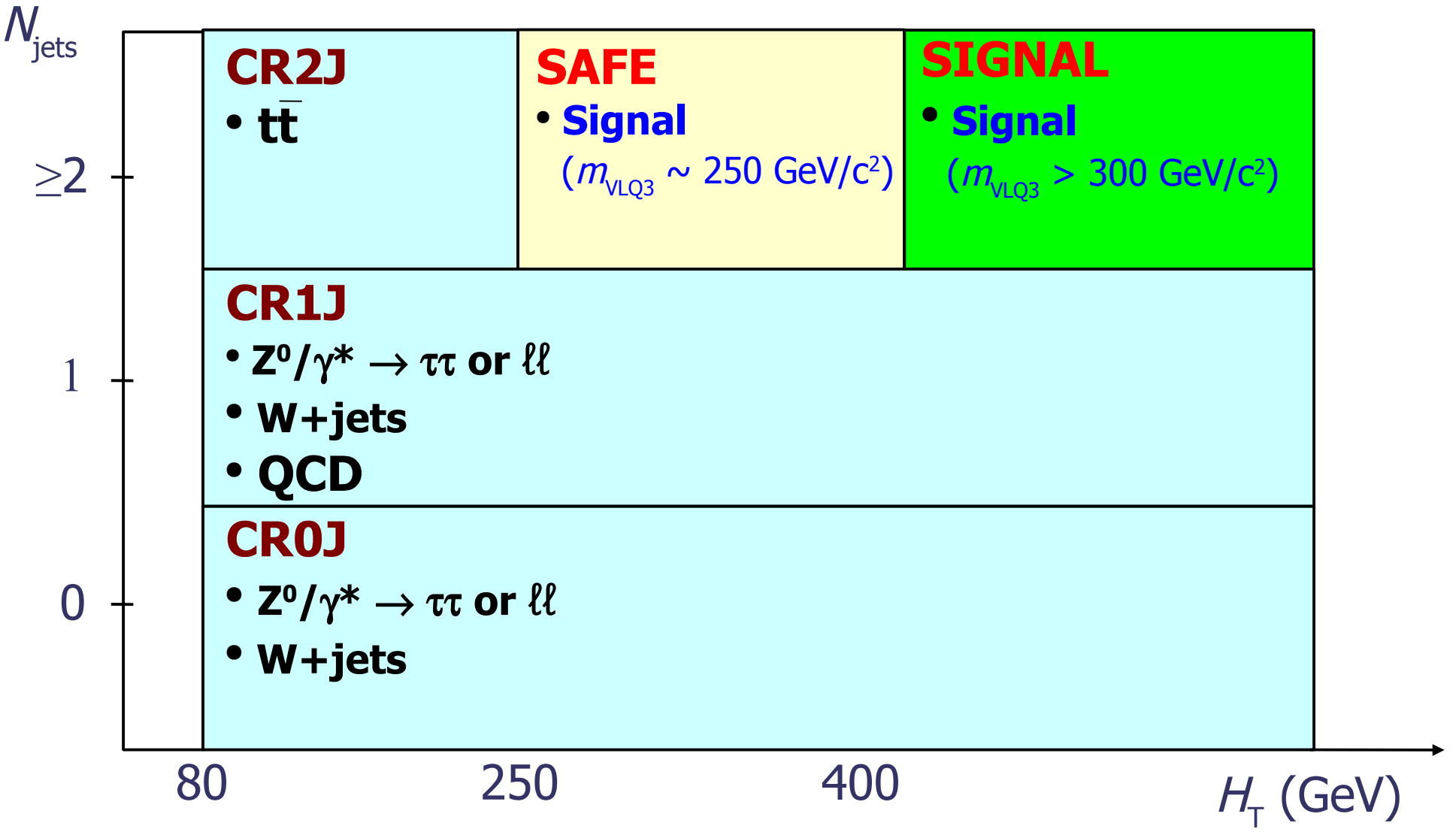
$$H_T = E_T(e,\mu) + E_T(\tau_h) + \not{E}_T{}^{\mathrm{corr}} + \sum E_T(\mathrm{jets})$$





H_T cut is very strong event selection cut.

3.3. Signal and Control Regions



*** Existing limit is m_{VLQ3} > 225 GeV/c^2 and H_T > 250 GeV is sensitive region. So it was blind until cuts finalized**

3.4. Systematic Uncertainties

- Systematic uncertainties on signal, for 160, 260, 360 GeV/c^2

$e\tau_h$ channel

Systematics (%) for $e\tau_h$ Channel			
	m_{LQ3}		
Source	160	260	360
PDF	2.4	1.1	0.7
ISR	3.6	3.6	3.6
FSR	3.7	3.7	3.7
Jet Scale	7.5	2.8	0.9
$\not\!\!E_T$	0.1	0.1	0.1
Acceptance	1.7	1.7	1.7
Lepton ID	1.0	1.0	1.0
Tau ID	3.0	3.0	3.0
Isolation	3.0	3.0	3.0
Total	10.5	7.6	7.1

$\mu\tau_h$ channel

Systematics (%) for $\mu\tau_h$ Channel			
	m_{LQ3}		
Source	160	260	360
PDF	2.7	1.0	0.5
ISR	3.7	3.7	3.7
FSR	3.6	3.6	3.6
Jet Scale	6.9	2.7	0.8
$\not\!\!E_T$	0.0	0.1	0.0
Acceptance	1.0	1.0	1.0
Lepton ID	3.0	3.0	3.0
Tau ID	3.0	3.0	3.0
Isolation	3.0	3.0	3.0
Total	10.4	7.9	7.5

Syst. = 10% ~ 7%

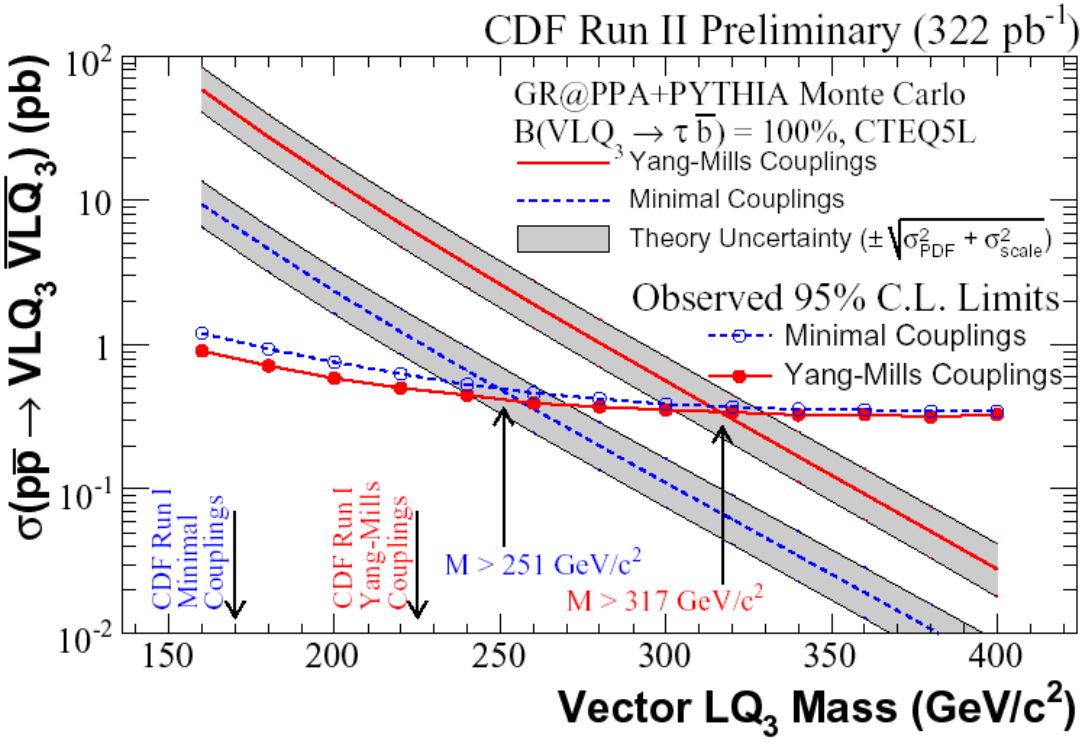
3.5. Event Yields ($e\tau_h$)

	CR0J	CR1J	CR2J	SAFE	SIGNAL
Backgrounds:					
$Z^0 \to \tau\tau \to e\tau_h$	$39.86^{+0.85}_{-0.85} \pm 3.22$	$43.02^{+0.88}_{-0.88} \pm 3.80$	$9.09^{+0.41}_{-0.41} \pm 1.06$	$0.67^{+0.11}_{-0.11} \pm 0.15$	$0.04^{+0.04}_{-0.02} \pm 0.00$
$Z^0 \to ee$	$5.45^{+0.55}_{-0.55} \pm 1.12$	$6.62^{+0.61}_{-0.61} \pm 1.47$	$1.22^{+0.26}_{-0.26} \pm 0.33$	$0.45^{+0.19}_{-0.13} \pm 0.10$	$0.00^{+0.06}_{-0.00} \pm 0.00$
QCD	$2.83^{+0.47}_{-0.47} \pm 0.32$	$22.66^{+1.32}_{-1.32} \pm 5.63$	$15.23^{+1.08}_{-1.08} \pm 3.85$	$0.08^{+0.12}_{-0.05} \pm 0.00$	$0.00^{+0.08}_{-0.00} \pm 0.00$
$t\bar{t}$	$0.01^{+0.01}_{-0.0} \pm 0.01$	$0.30^{+0.06}_{-0.06} \pm 0.07$	$0.81^{+0.09}_{-0.09} \pm 0.22$	$1.35^{+0.12}_{-0.12} \pm 0.39$	$0.15^{+0.04}_{-0.04} \pm 0.04$
$W(e+\nu)+\text{jets}$	$53.06^{+1.13}_{-1.13} \pm 9.82$	$20.29^{+0.79}_{-0.79} \pm 4.87$	$3.51^{+0.35}_{-0.35} \pm 1.72$	$0.60^{+0.15}_{-0.15} \pm 0.29$	$0.07^{+0.07}_{-0.04} \pm 0.03$
$W(\tau+\nu)+\text{jets}$	$20.68^{+1.43}_{-1.43} \pm 4.43$	$14.90^{+1.37}_{-1.37} \pm 3.73$	$2.87^{+0.64}_{-0.64} \pm 1.99$	$0.14^{+0.23}_{-0.09} \pm 0.08$	$0.00^{+0.14}_{-0.00} \pm 0.00$
$\gamma+\text{jets}$	$0.18^{+0.18}_{-0.09} \pm 0.00$	$1.44^{+0.36}_{-0.36} \pm 0.29$	$0.66^{+0.07}_{-0.00} \pm 0.18$	$0.00^{+0.09}_{-0.00} \pm 0.00$	$0.00^{+0.09}_{-0.00} \pm 0.00$
Total Background	$122.08^{+2.14}_{-2.14} \pm 11.31$	$109.23^{+2.35}_{-2.35} \pm 9.27$	$33.39^{+1.40}_{-1.39} \pm 4.80$	$3.28^{+0.40}_{-0.27} \pm 0.52$	$0.25^{+0.21}_{-0.06} \pm 0.05$
Data	129	110	36	5	0

3.5. Event Yields ($\mu\tau_h$)

	CR0J	CR1J	CR2J	SAFE	SIGNAL
Backgrounds:					
$Z^0 \to \tau\tau \to \mu\,\tau_h$	$42.03^{+0.87}_{-0.87} \pm 2.91$	$40.10^{+0.85}_{-0.85} \pm 2.22$	$8.34^{+0.39}_{-0.39} \pm 0.70$	$0.59^{+0.10}_{-0.10} \pm 0.06$	$0.09^{+0.05}_{-0.03} \pm 0.03$
$Z^0 \to \mu\mu$	$27.06^{+1.19}_{-1.19} \pm 8.45$	$8.39^{+0.66}_{-0.66} \pm 2.74$	$2.20^{+0.34}_{-0.34} \pm 0.73$	$0.10^{+0.10}_{-0.05} \pm 0.04$	$0.00^{+0.05}_{-0.00} \pm 0.00$
QCD	$2.30^{+0.56}_{-0.56} \pm 0.39$	$16.54^{+1.50}_{-1.50} \pm 2.91$	$11.58^{+1.25}_{-1.25} \pm 2.05$	$0.00^{+0.13}_{-0.00} \pm 0.00$	$0.00^{+0.13}_{-0.00} \pm 0.00$
$t\bar{t}$	$0.04^{+0.03}_{-0.02} \pm 0.00$	$0.32^{+0.06}_{-0.06} \pm 0.07$	$0.67^{+0.08}_{-0.08} \pm 0.13$	$1.24^{+0.11}_{-0.11} \pm 0.29$	$0.15^{+0.04}_{-0.04} \pm 0.05$
$W(\mu+\nu)+\text{jets}$	$56.60^{+1.59}_{-1.59} \pm 7.98$	$21.99^{+1.12}_{-1.12} \pm 4.23$	$4.36^{+0.53}_{-0.53} \pm 1.74$	$0.31^{+0.18}_{-0.11} \pm 0.11$	$0.00^{+0.06}_{-0.00} \pm 0.00$
$W(\tau+\nu)+\text{jets}$	$19.11^{+1.37}_{-1.37} \pm 2.71$	$13.13^{+1.28}_{-1.28} \pm 2.56$	$3.44^{+0.70}_{-0.70} \pm 2.53$	$0.00^{+0.14}_{-0.00} \pm 0.00$	$0.00^{+0.14}_{-0.00} \pm 0.00$
Total Background	$147.13^{+2.62}_{-2.62} \pm 12.29$	$100.46^{+2.51}_{-2.51} \pm 6.74$	$30.58^{+1.62}_{-1.62} \pm 3.83$	$2.25^{+0.32}_{-0.20} \pm 0.32$	$0.24^{+0.22}_{-0.05} \pm 0.05$
Data	129	79	26	3	0

3.6. Limits of Vector LQ3s



	σ < 344 fb	m_{VLQ3} > 317 GeV/c²
1 σ varied	σ < 354 fb	m_{VLQ3} > 303 GeV/c²

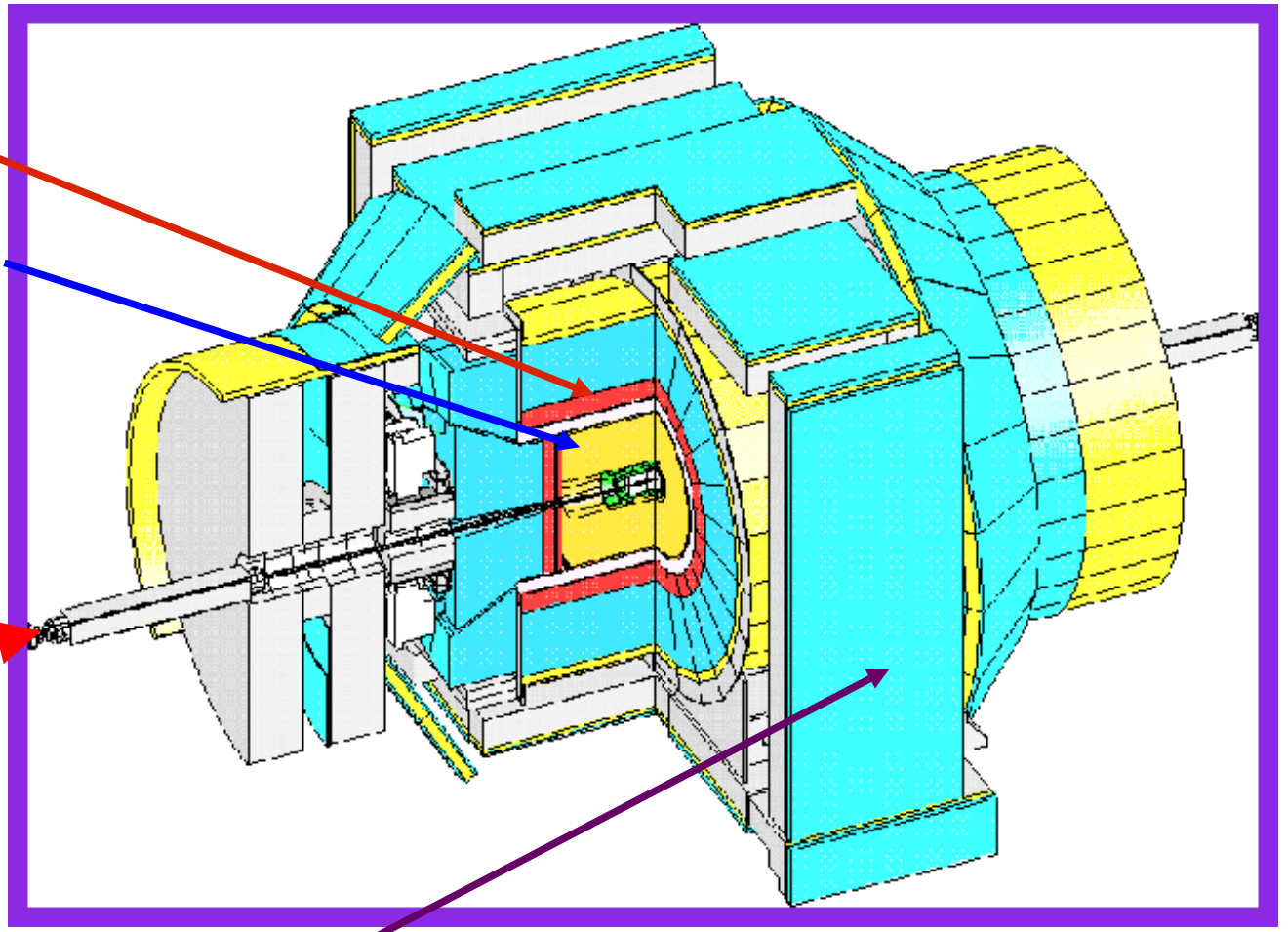
	σ < 493 fb	m_{VLQ3} > 251 GeV/c²
1 σ varied	σ < 555 fb	m_{VLQ3} > 235 GeV/c²

3. Summary

- List of CDF Run II results for Leptoquarks search.

Spin	Decay	Generation	Mass Limit (95% C.L.)	Int. $\mathcal{L}$
0	$\beta=1$	1^{st}	> 235 GeV/c^2	203 pb^{-1}
		2^{nd}	> 224 GeV/c^2	198 pb^{-1}
		3^{rd}	> 155 GeV/c^2	322 pb^{-1}
	$\beta=0.5$	1^{st}	> 176 GeV/c^2	203 pb^{-1}
		2^{nd}	> 177 GeV/c^2	198 pb^{-1}
	$\beta=0$	1^{st}, 2^{nd}	< 78 GeV/c^2, > 117 GeV/c^2	191 pb^{-1}
1	$\beta=1$	3^{rd}	> 317 GeV/c^2(Yang-Mills) > 251 GeV/c^2(Minimal)	322 pb^{-1}

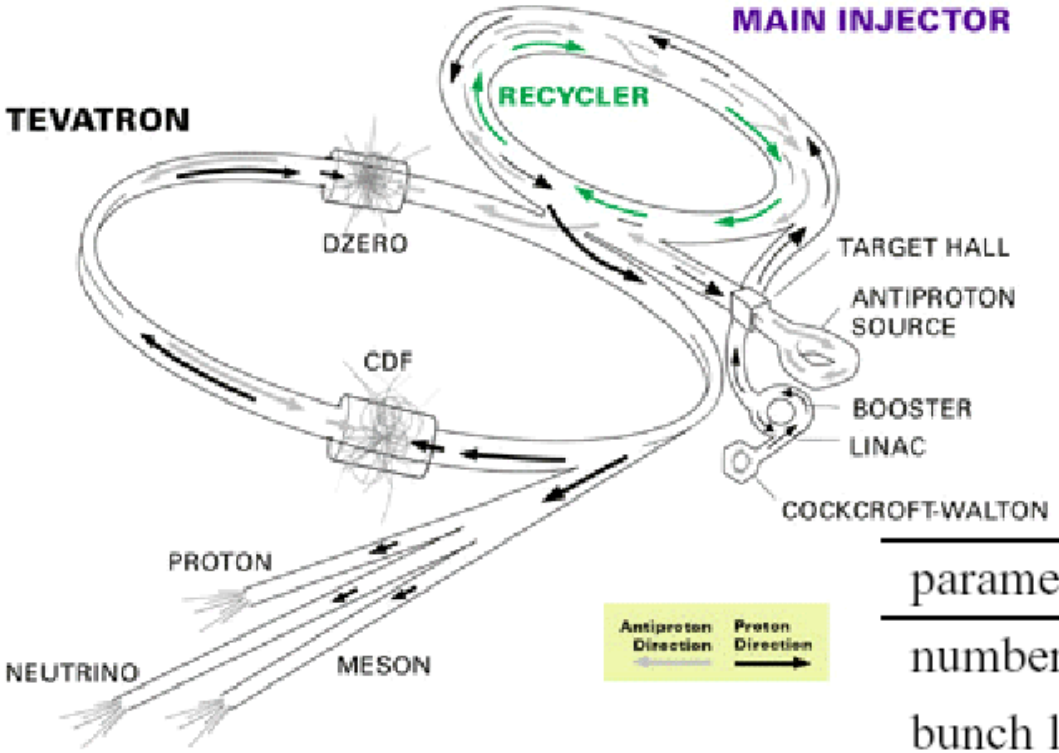
CDF

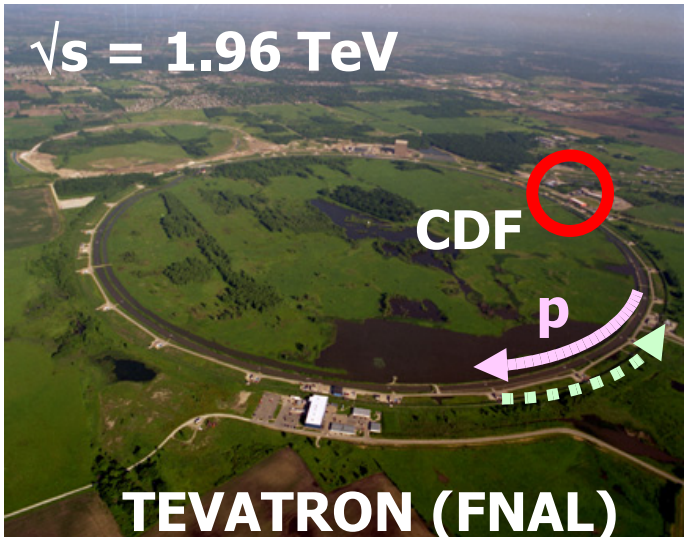


pseudorapidity

$$\eta \equiv -\ln\tan\left(\frac{\theta}{2}\right)$$

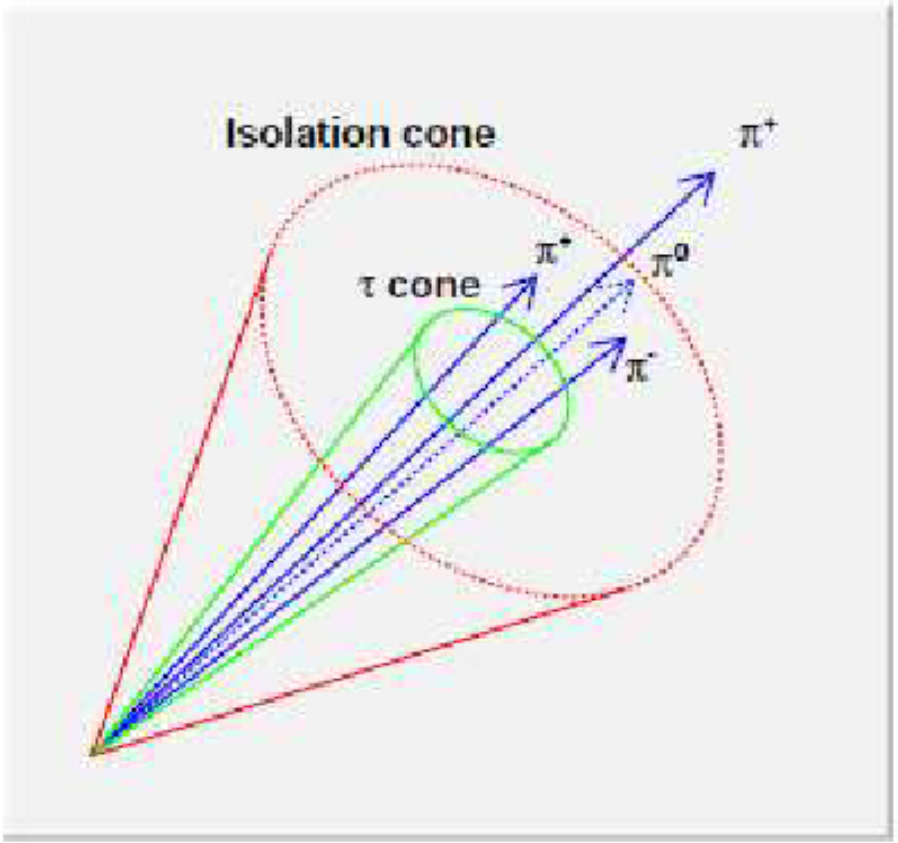
TEVATRON





parameter	Run I	Run II
number of bunches (N_B)	6	36
bunch length [m]	0.6	0.37
bunch spacing [ns]	3500	396
protons/bunch (N_p)	2.3×10^{11}	2.7×10^{11}
antiprotons/bunch ($N_{\bar{p}}$)	5.5×10^{10}	3.0×10^{10}
total antiprotons	3.3×10^{11}	1.1×10^{12}
β^* [cm]	35	35
interactions/crossing	2.5	2.3
integrated luminosity [pb^{-1}]	112	450
peak luminosity [$\text{cm}^{-2}\text{s}^{-1}$]	2×10^{31}	1.2×10^{32}

Shrinking Cone Algorithm



Signal Cone (Shrinking Cone)

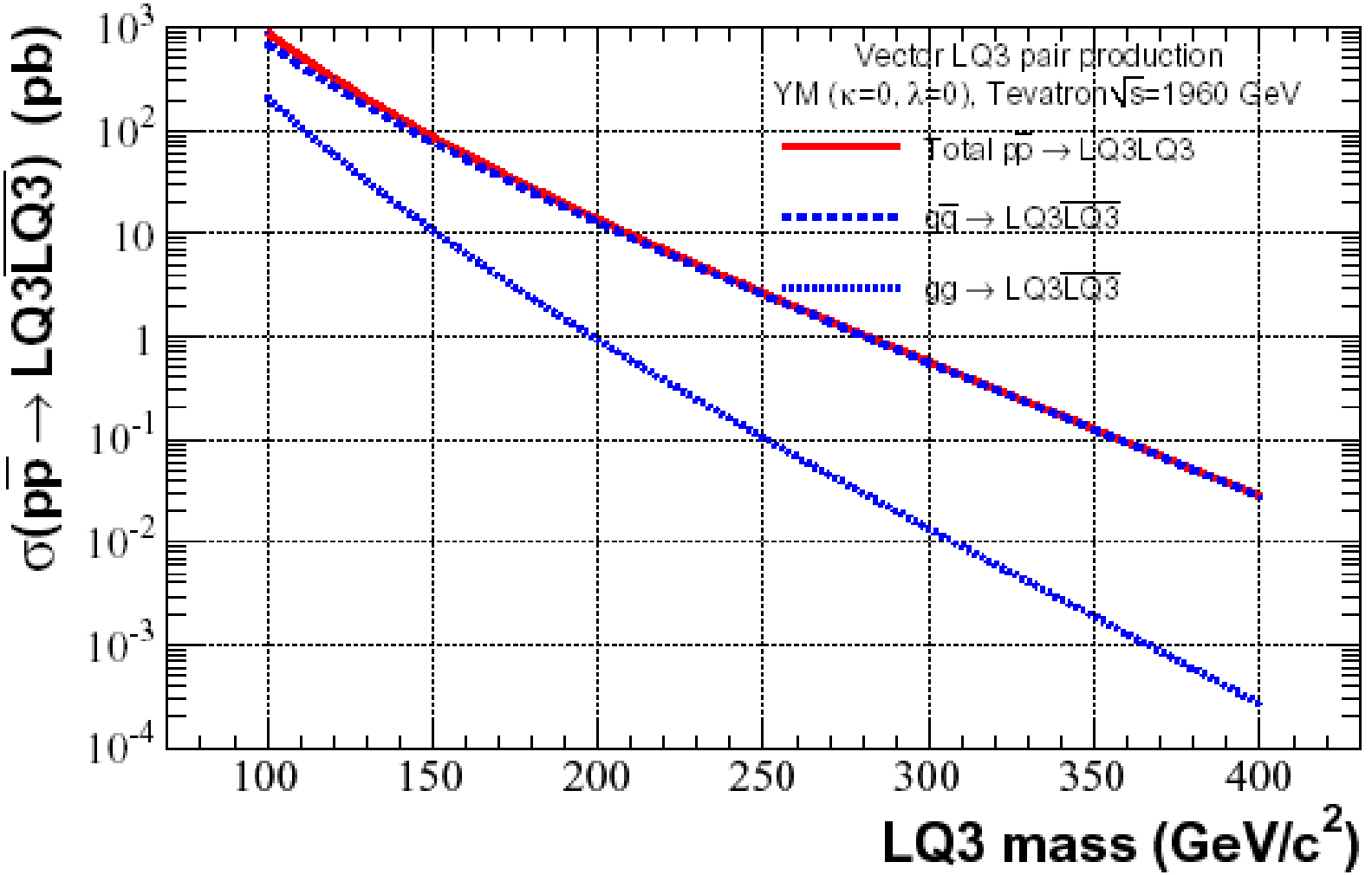
$\theta < \alpha_{trk}$ (~2.9° - ~10°)

$$\alpha_{trk} = min[0.175, max(5\ \ \mathrm{GeV}/E^{cal}, 0.05)]$$

Isolation Cone (Fixed Cone)

$\alpha_{trk} < \theta < 0.52$ (~30°)

Production Cross Section



VLQ_3 signal MC was produced by GR@PPA + PYTHIA