Leptoquarks

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Introduction

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
- RPV SUSY

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

•LQ are assumed to couple to same-generation fermions (FCNC and lepton-family number violation constraints)

•**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: $k_G = \lambda_G = 0$

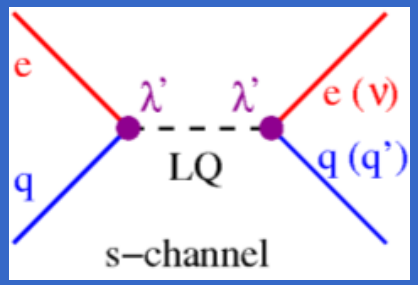
–Minimal coupling: $K_G = 1$, $\lambda_G = 0$

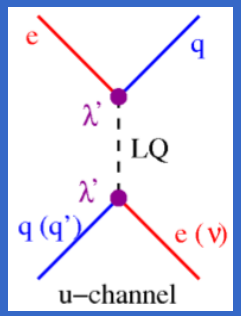
–Decay amplitude proportional to $(1 + \cos\theta^*)^2$

Experimental evidence searched:

- indirectly: LQ-induced 4-fermion interactions
- directly: production cross sections at collider experiments

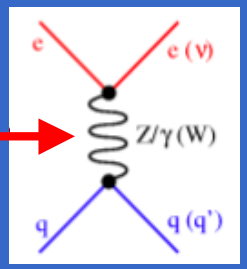
LQ at HERA

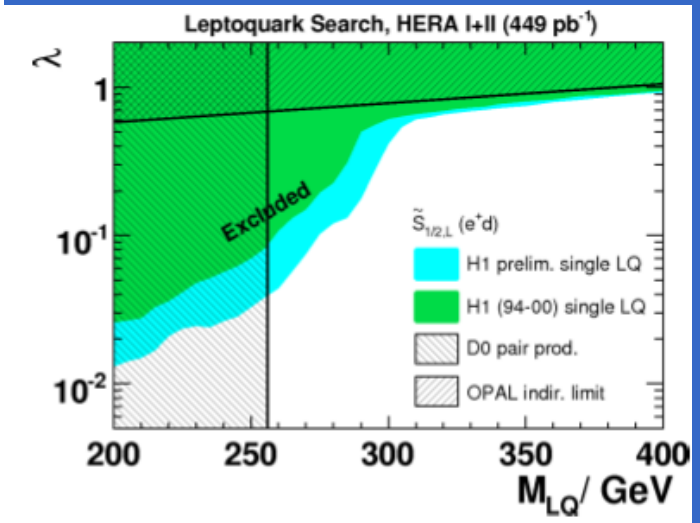




Search for a resonant structure in the LQ mass distribution

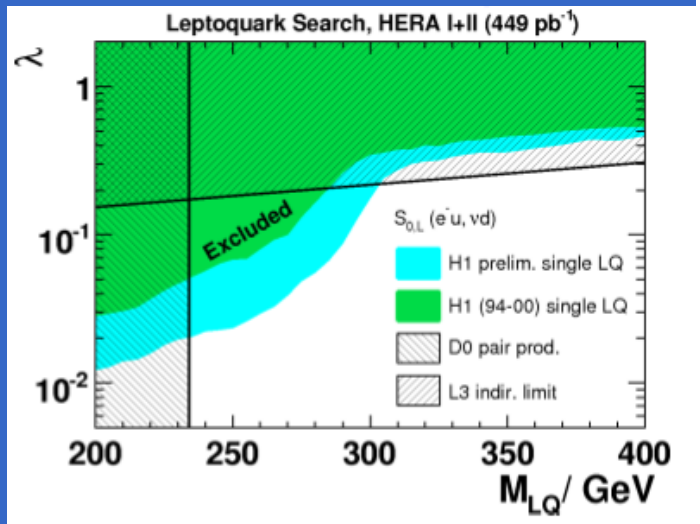
Spectra dominated by SM DIS
No excess observed





U-type squark, decay to ed
Rp-violating coupling λ'_{1j1}

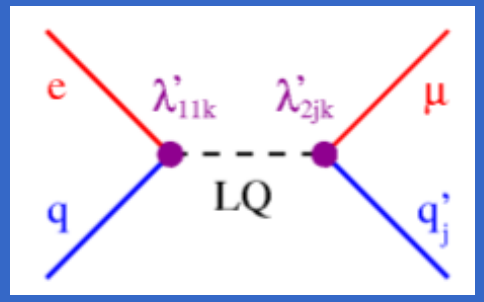
Cross-section is dependent on the Leptoquarks Yukawa coupling λ-mass exclusion plots

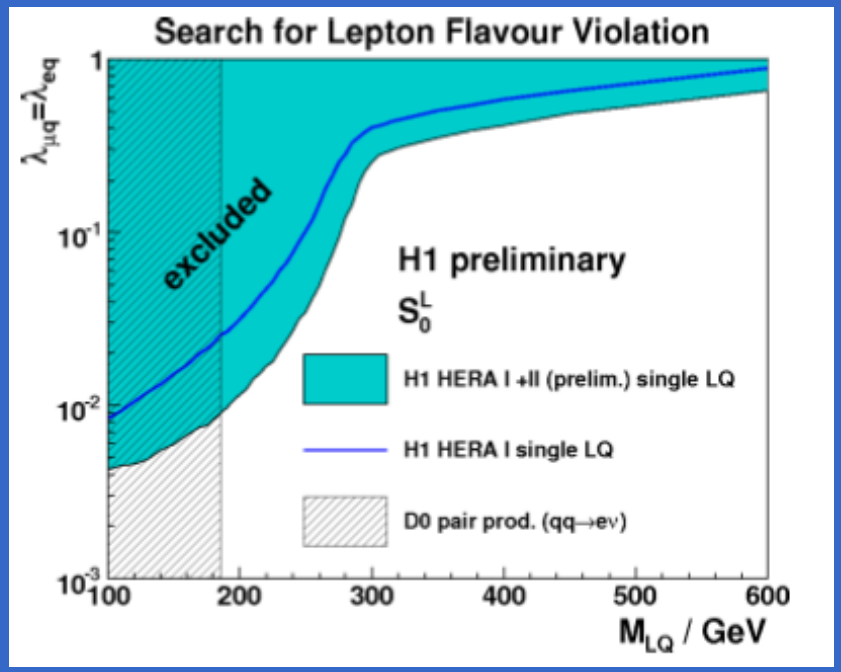


D-type squark, decay to eu, νd
Rp-violating coupling λ'_{11k}

Leptoquarks at HERA

- Lepton flavor violating LQ
- Study of the LQ decay to μ-jet
- Limits on $\lambda'_{11k'}$ and $\lambda'_{2jk'}$
- Unpublished HERA result





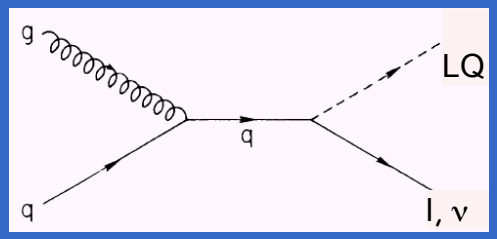
S.Schmitt, SUSY08

LQ at Hadron Colliders: Production

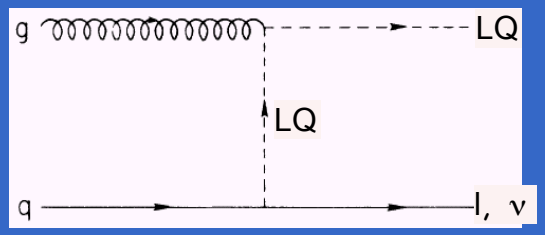
Single production

- strongly depends on λ
- possible signatures:
  - l^+l^- + jet
  - $l\nu$ + jet
  - $\nu\,\nu$ + jet
- Main background: Zjet & tt

$qg \to l\,LQ$,



$qg \to \nu\,LQ$

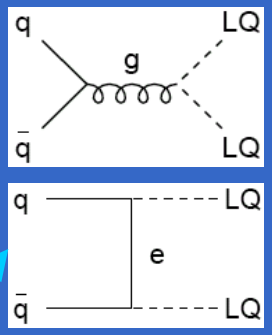


Generally negligible for m(LQ) < 1 TeV

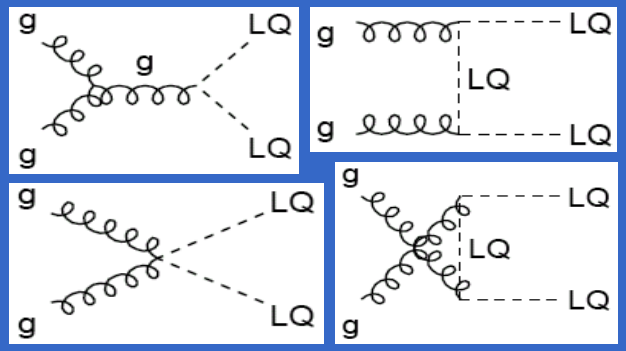
Pair production

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

$q\bar{q} \to LQ\,LQ$

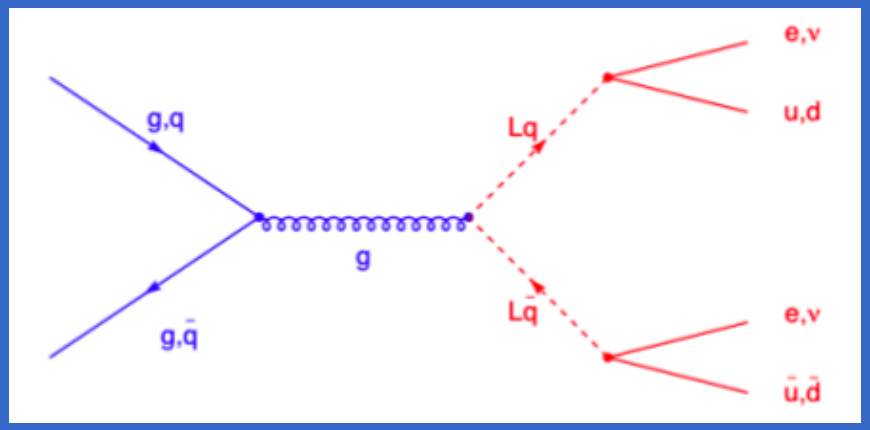


$gg \to LQ\,LQ$



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

LQ at Hadron Colliders: Decay



Decay

- Each generation can decay into 3 final states:

β = Br (LQ→lq)

$\beta = 1$

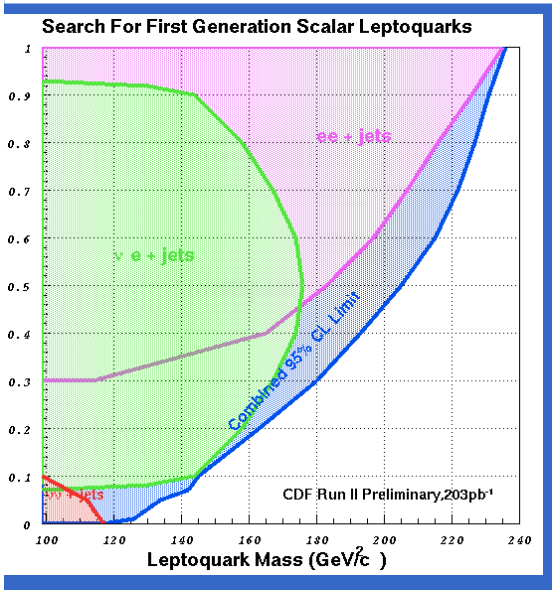
$\beta = 0.5$

$\beta = 0$

Exclusive to hadron colliders

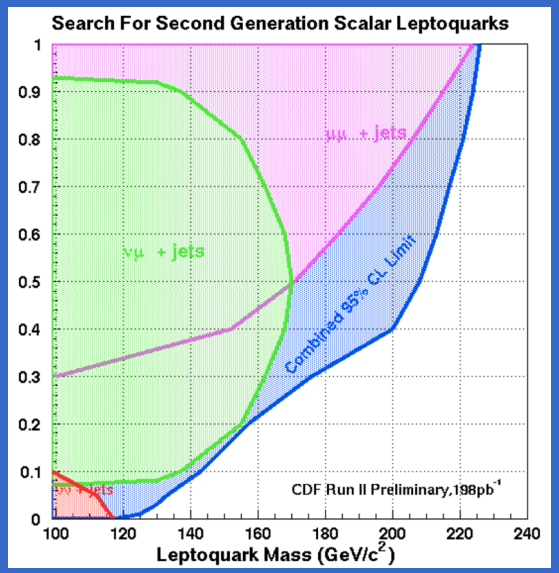
1st Generation	2nd Generation	3rd Generation
$LQ\,\overline{LQ} \to e^- e^+ q\bar{q}$	$LQ\,\overline{LQ} \to \mu^+ \mu^- q\bar{q}$	$LQ\,\overline{LQ} \to \tau^+ \tau^- q\bar{q}$
$LQ\,\overline{LQ} \to e^\pm \nu_e q_i q_j$	$LQ\,\overline{LQ} \to \mu^\pm \nu_\mu q_i q_j$	$LQ\,\overline{LQ} \to \tau^\pm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

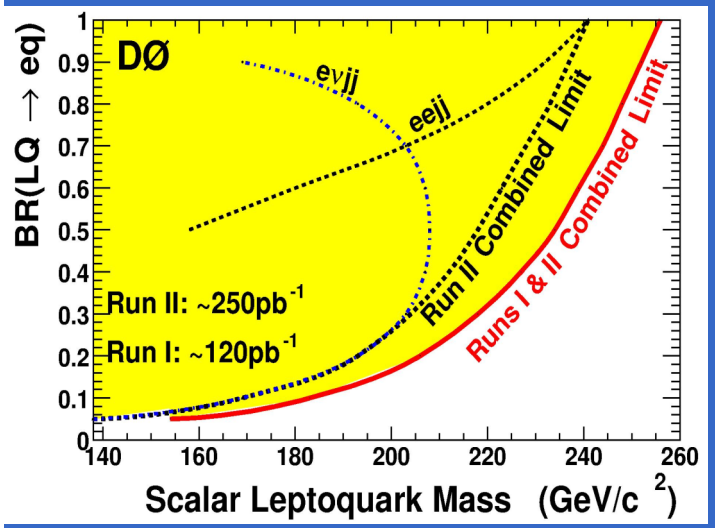
LQ at the Tevatron



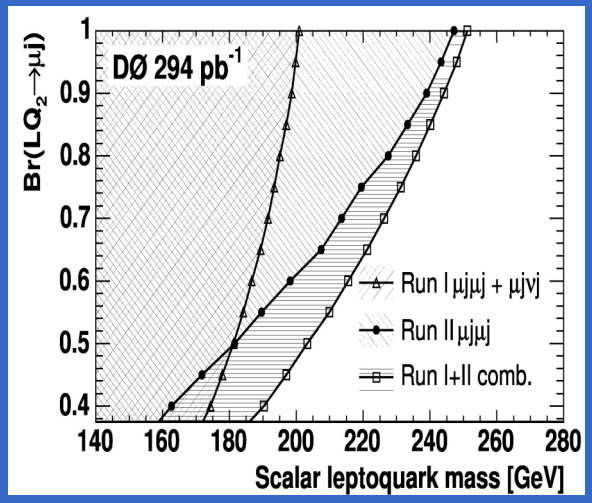
Phys Rev D 72, 2005

Phys Rev D 73, 2006



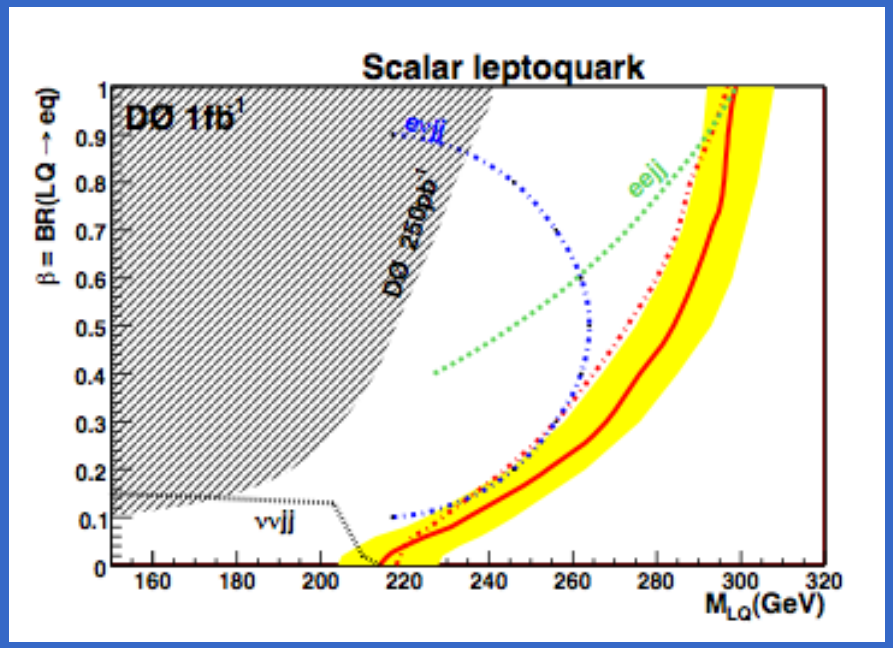


Phys. Rev. D **71**, 071104 (2005)

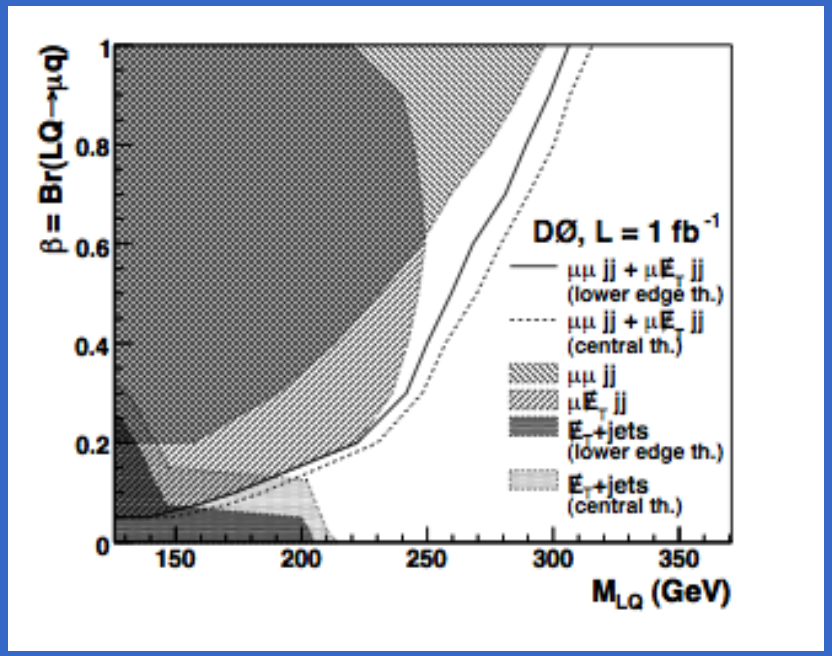


Phys. Lett. B **636**, 183 (2006)

New Results

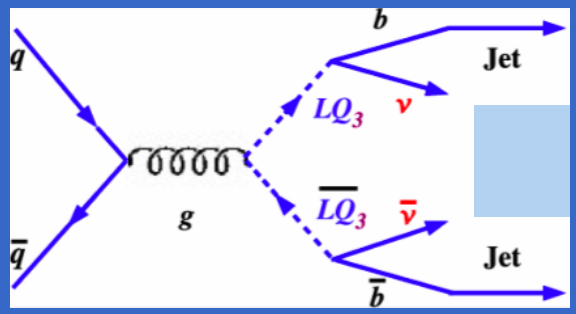


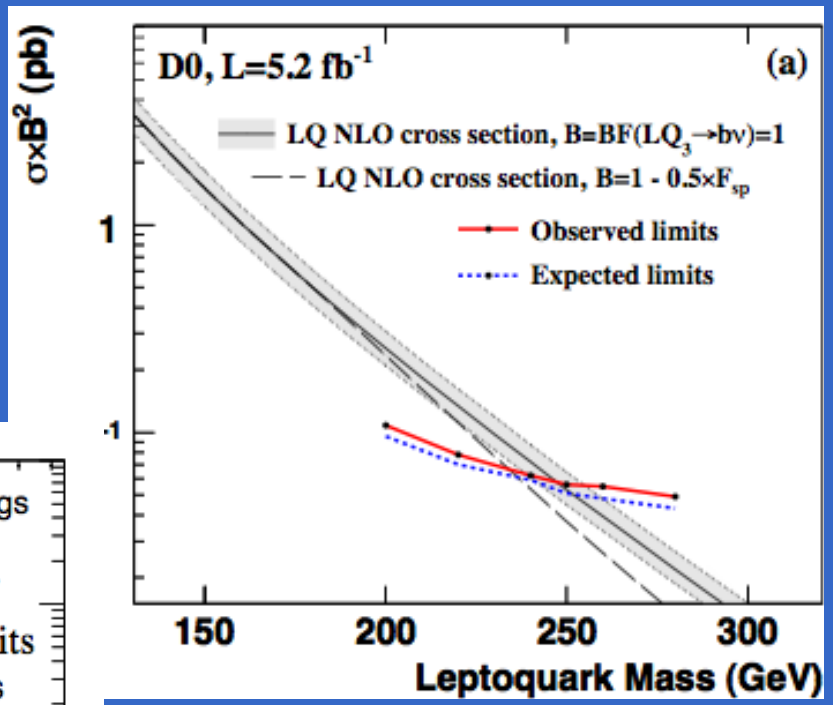
Phys. Lett. B **681**, 224 (2009)



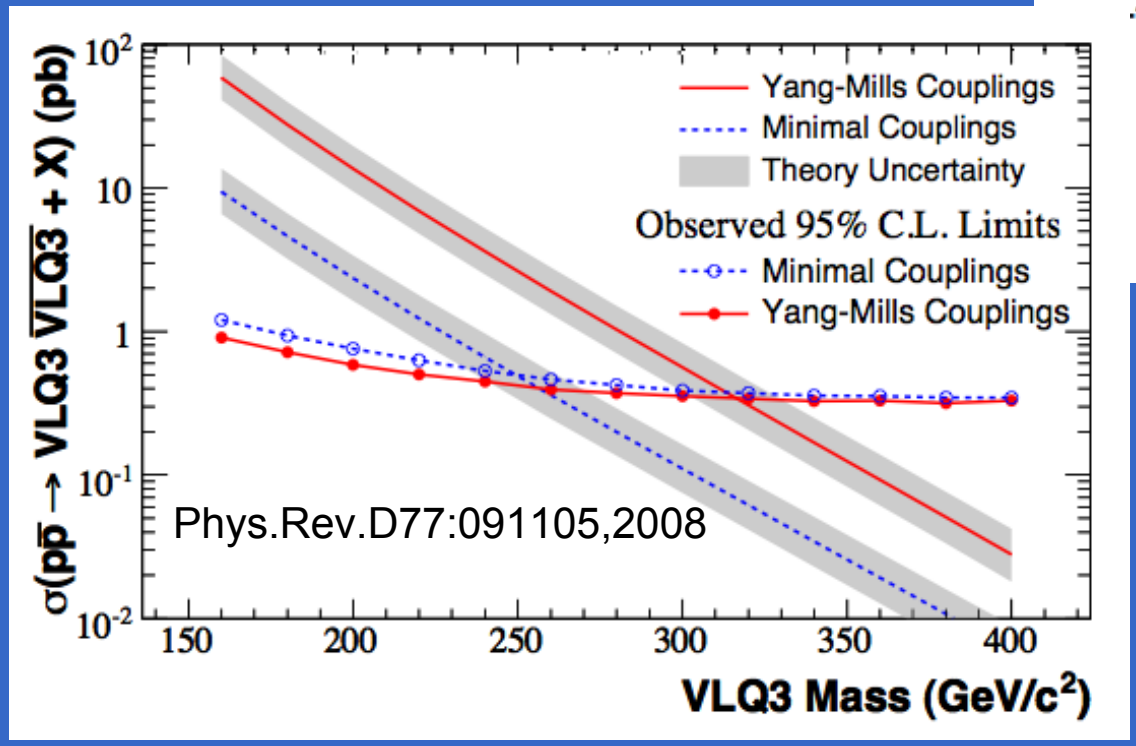
Phys. Lett. B **671**, 224 (2009)

Third Generation LQ



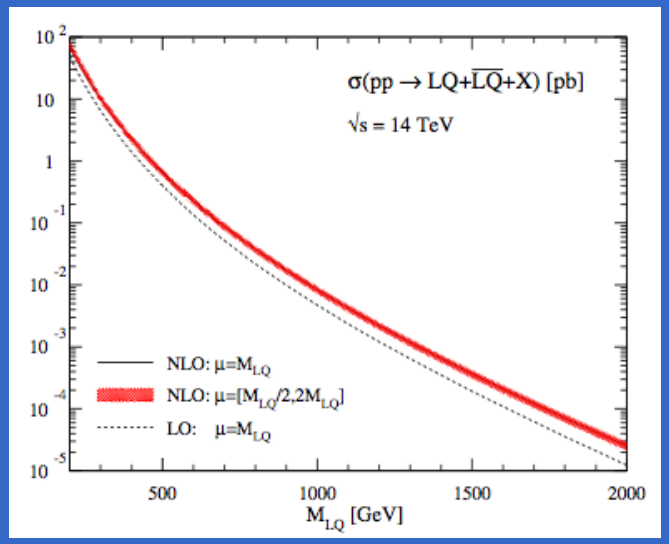


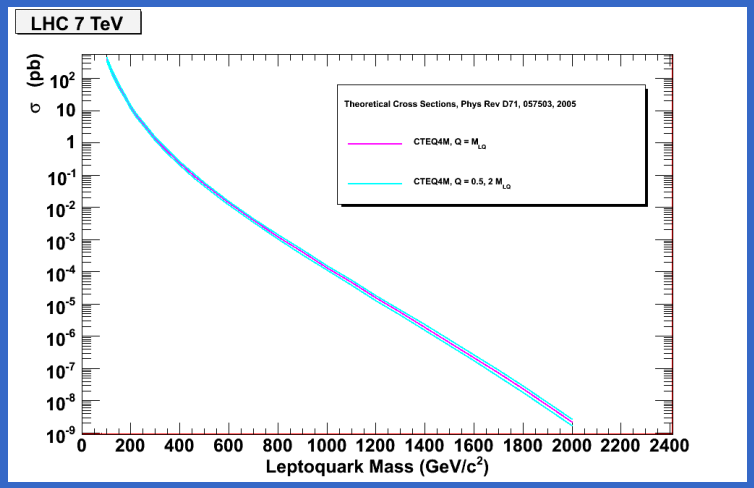
Phys. Lett. B **693**, 95 (2010)

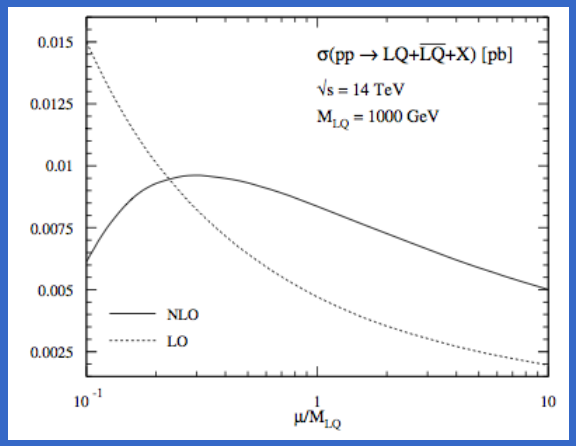


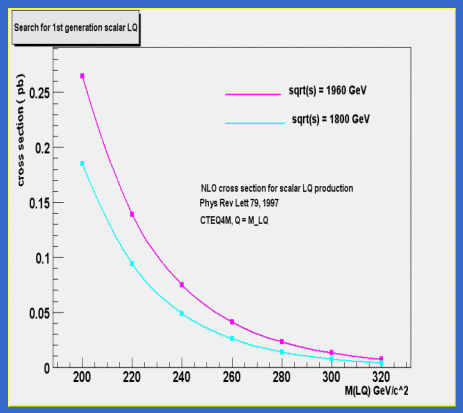
LHC

NLO predictions available in M.Kramer, T. Plehn, M.Spira, P.M. Zerwas Phys Rev D **71,** 057503 (2005)





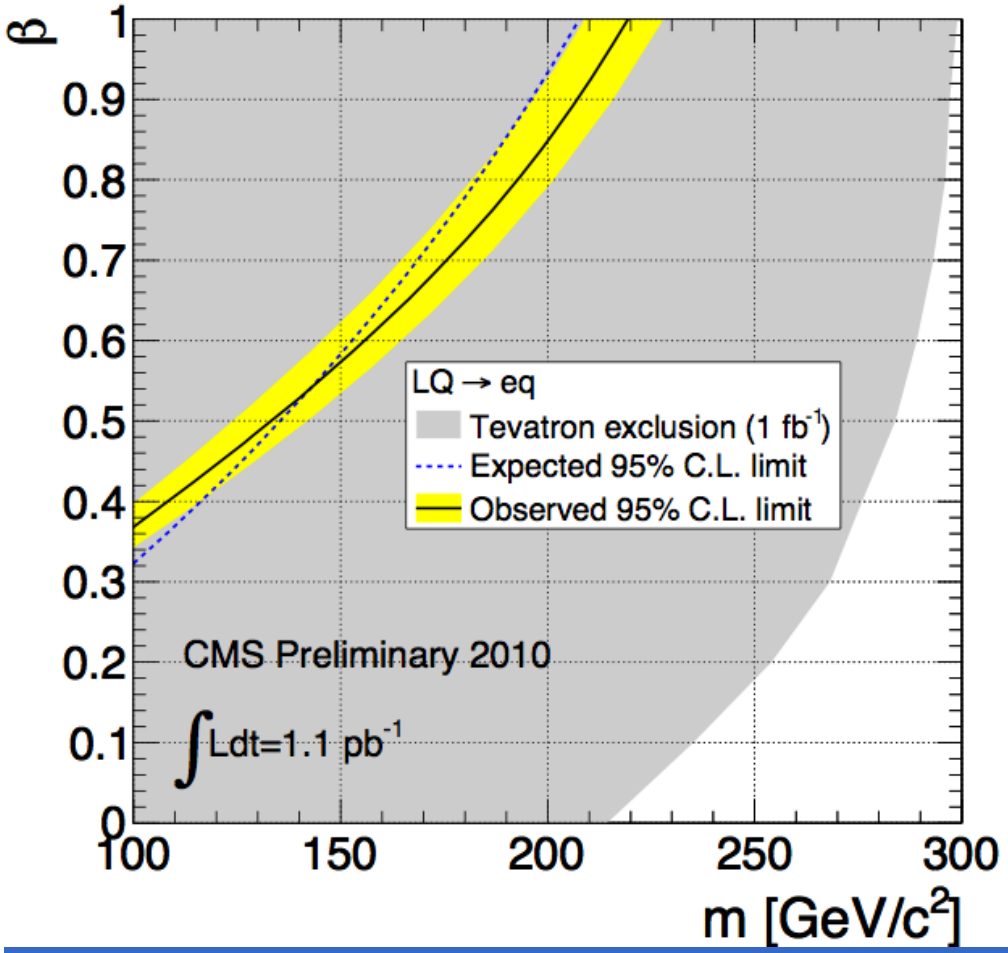




Big jump in the cross section compared to Tevatron!!

LHC Preliminary Results

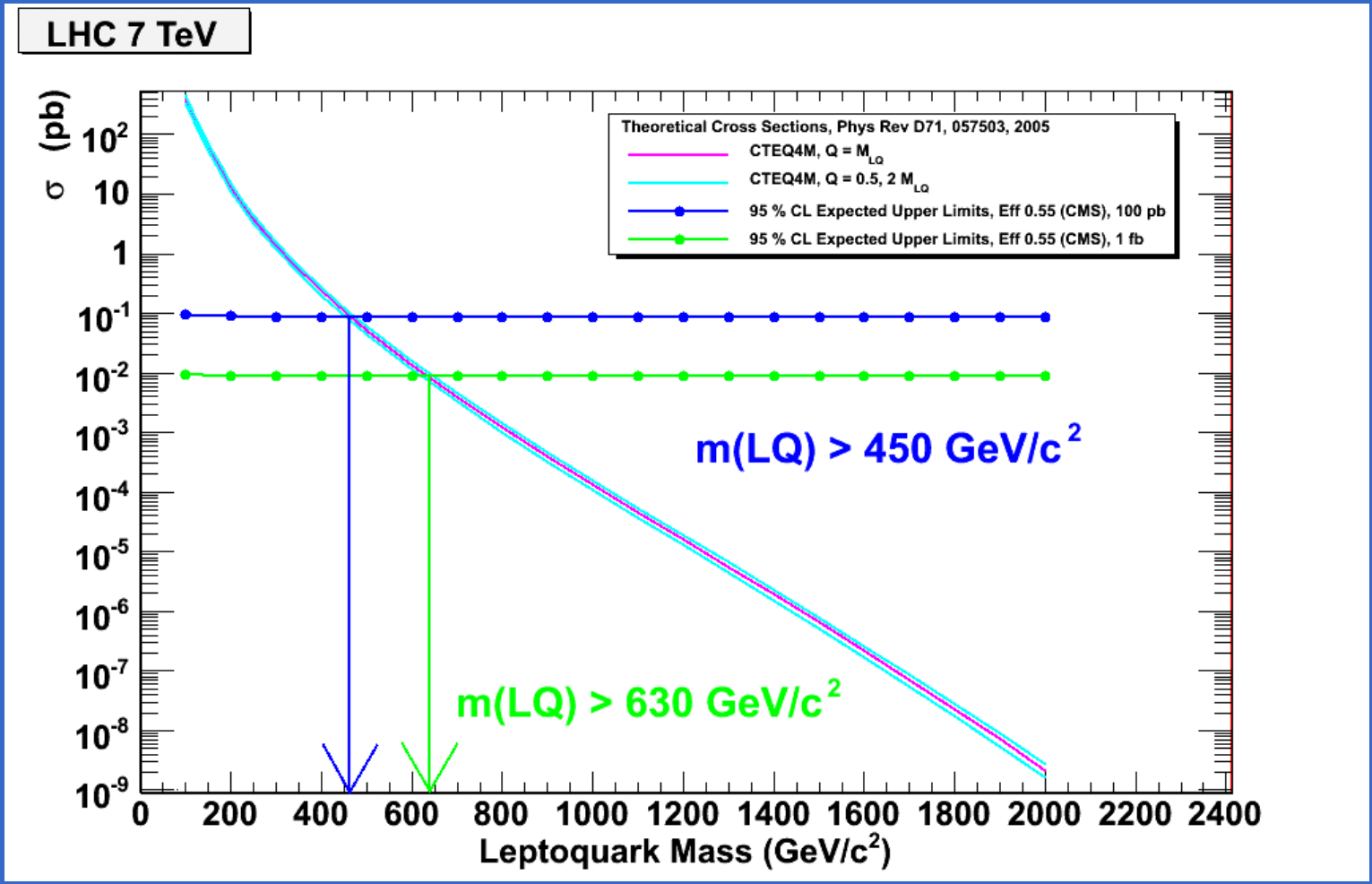
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO10005



CMS results with muons coming out soon with 15 pb^{-1} most likely superseding TeV results

ATLAS is planning on releasing results by Winter Conferences 2011

LHC Projected Sensitivity



Conclusions and Plans

So far PDG has reported on HERA/Tevatron limits

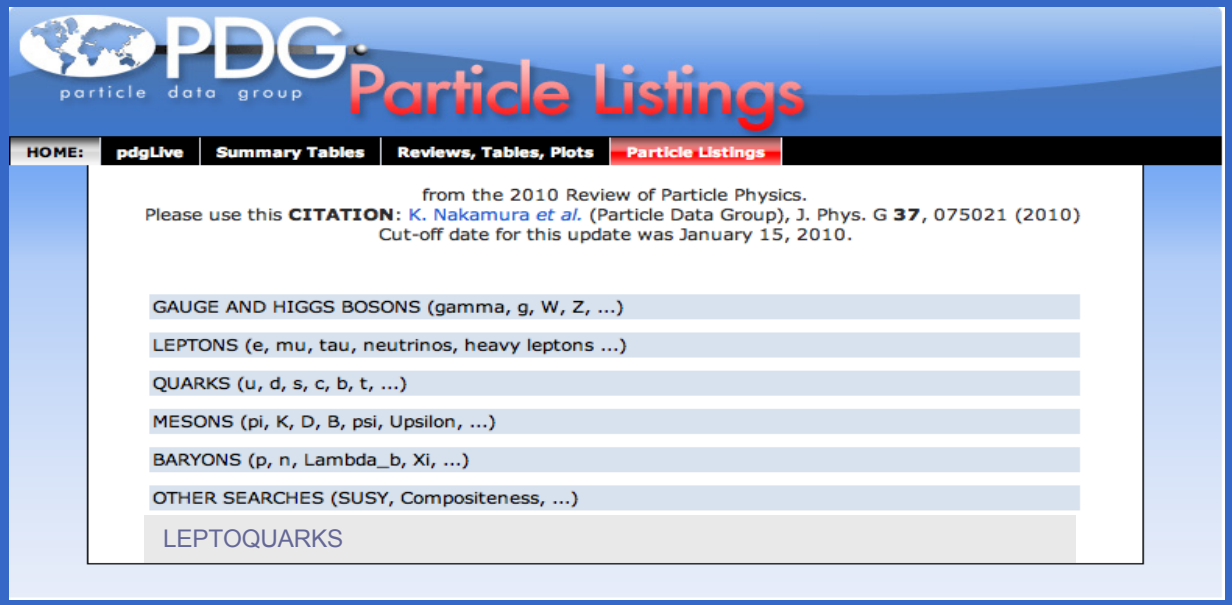
most stringent up-to-date

By Spring/Summer 2011 CMS and ATLAS should surpass the Tevatron limits

update the review accordingly…

If something is observed….

….well then, it's an entire new business (and a change of section!)



Backup

TABLE 1 Leptoquark classification according to electroweak quantum numbers

Type	Q	Coupling	β	F
S_0^L	$-1/3$	$\lambda_L(e_L u)$, $-\lambda_L(\nu_e d)$	1/2	2
S_0^R	$-1/3$	$\lambda_R(e_R u)$	1	2
$\tilde{S}_0^R$	$-4/3$	$\lambda_R(e_R d)$	1	2
S_1^L	$-4/3$	$-\sqrt{2}\lambda_L(e_L d)$	1	2
	$-1/3$	$-\lambda_L(e_L u)$, $-\lambda_L(\nu_e d)$	1/2	2
	$+2/3$	$\sqrt{2}\lambda_L(\nu_e u)$	0	2
$V_{1/2}^L$	$-4/3$	$\lambda_L(e_L d)$	1	2
	$-1/3$	$\lambda_L(\nu_e d)$	0	2
$V_{1/2}^R$	$-4/3$	$\lambda_R(e_R d)$	1	2
	$-1/3$	$\lambda_R(e_R u)$	1	2
$\tilde{V}_{1/2}^L$	$-1/3$	$\lambda_L(e_L u)$	1	2
	$+2/3$	$\lambda_L(\nu_e u)$	0	2
$S_{1/2}^L$	$-5/3$	$\lambda_L(e_L \bar{u})$	1	0
	$-2/3$	$\lambda_L(\nu_e \bar{u})$	0	0
$S_{1/2}^R$	$-5/3$	$\lambda_R(e_R \bar{u})$	1	0
	$-2/3$	$-\lambda_R(e_R \bar{d})$	1	0
$\tilde{S}_{1/2}^L$	$-2/3$	$\lambda_L(e_L \bar{d})$	1	0
	$+1/3$	$\lambda_L(\nu_e \bar{d})$	0	0
V_0^L	$-2/3$	$\lambda_L(e_L \bar{d})$, $\lambda_L(\nu_e \bar{u})$	1/2	0
V_0^R	$-2/3$	$\lambda_R(e_R \bar{d})$	1	0
$\tilde{V}_0^R$	$-5/3$	$\lambda_R(e_R \bar{u})$	1	0
V_1^L	$-5/3$	$\sqrt{2}\lambda_L(e_L \bar{u})$	1	0
	$-2/3$	$-\lambda_L(e_L \bar{d})$, $\lambda_L(\nu_e \bar{u})$	1/2	0
	$+1/3$	$\sqrt{2}\lambda_L(\nu_e \bar{d})$	0	0

Leptoquarks classification
(Buchmuller-Ruckl-Wyler)

F = L + 3B

β = Br (LQ $\rightarrow$ lq)

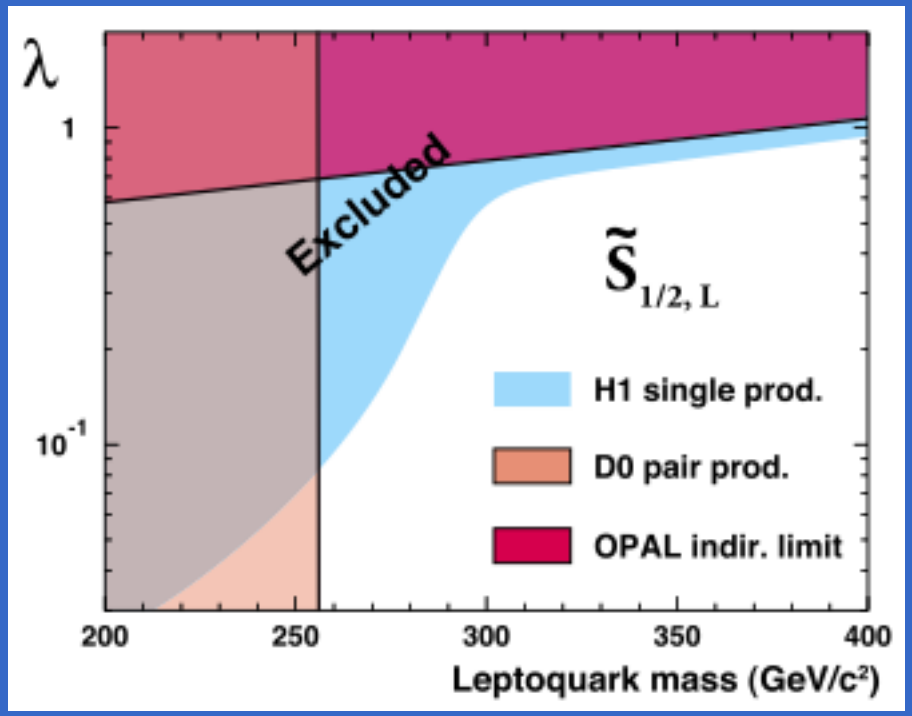
V/S: vector or scalar

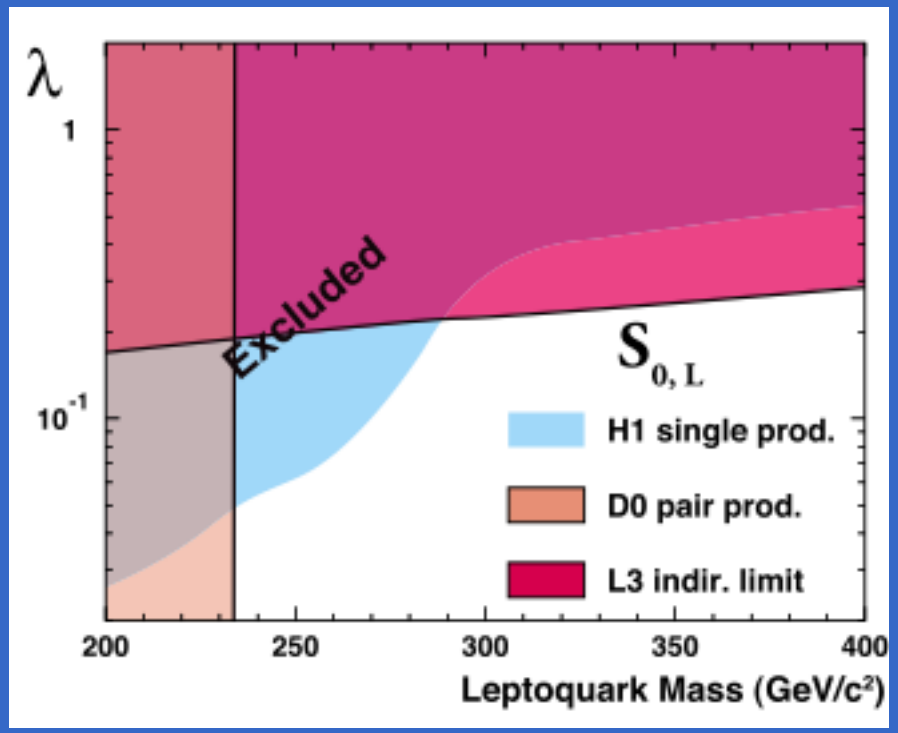
Subscript : weak isospin

Superscript: coupling to left-handed or right-handed fermions

At the Tevatron/LHC LQ production does not depend explicitly on EW quantum numbers

PDG Summary


λ
1
10^{-1}
Excluded
$\tilde{S}_{1/2, L}$
H1 single prod.
D0 pair prod.
OPAL indir. limit
200
250
300
350
400
Leptoquark mass (GeV/c²)


λ
1
10^{-1}
Excluded
$S_{0, L}$
H1 single prod.
D0 pair prod.
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200
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Leptoquark Mass (GeV/c²)