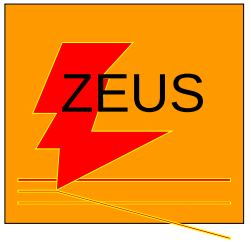
Search for Leptoquark Production and Lepton Flavour Violation

A.F.Żarnecki



Warsaw University

Outline

- Introduction
  Leptoquark model
- Search for leptoquark pair-production
  DØ(#594), CDF(#490), OPAL(#731),
- Search for single leptoquark production
  OPAL(#726), H1(#105), ZEUS(#496)
- Search for effects of virtual leptoquark exchange
  H1(#99), L3(#192)
- Search for Lepton Flavour Violation
  ZEUS(#498), OPAL(#724) $\Leftarrow$ contributions covered in this talk

Introduction

Leptoquarks: bosons (J=0,1) with lepton and baryon numbers

Interactions:

- strong — color
- electroweak — weak isospin and charge
- Yukawa — l-q-LQ coupling λ

Buchmüller-Rückl-Wyler (BRW) model

- $SU(3)_C \times SU(2)_L \times U(1)_Y$ invariance of SM
- lepton and baryon number conservation
- either left- or right-handed couplings (bounds from rare decays)

  $\Rightarrow$ 7 scalar and 7 vector leptoquarks

  fermion number F=0,2, branching ratio to lq: $\beta_{lq} = 0, \frac{1}{2}, 1$

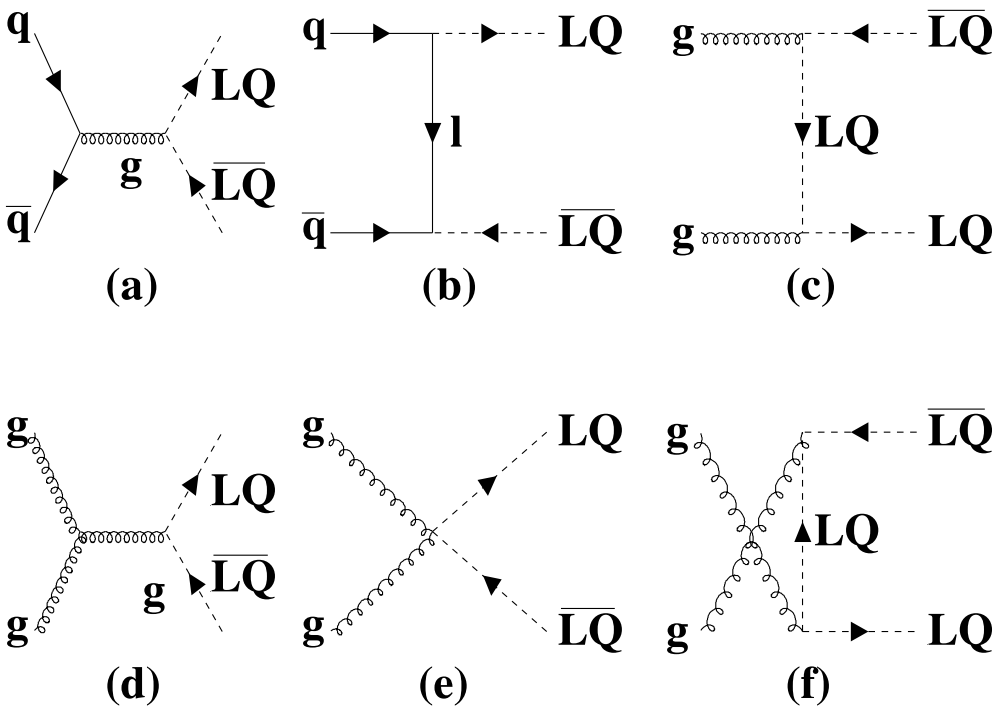
Two parameters for each leptoquark (LQ): mass and Yukawa coupling

Pair-production at Tevatron

Predominantly by gg fusion

$\Rightarrow$ independent of λ

$\Rightarrow$ depends only on spin (scalar or vector) and β_{lq}

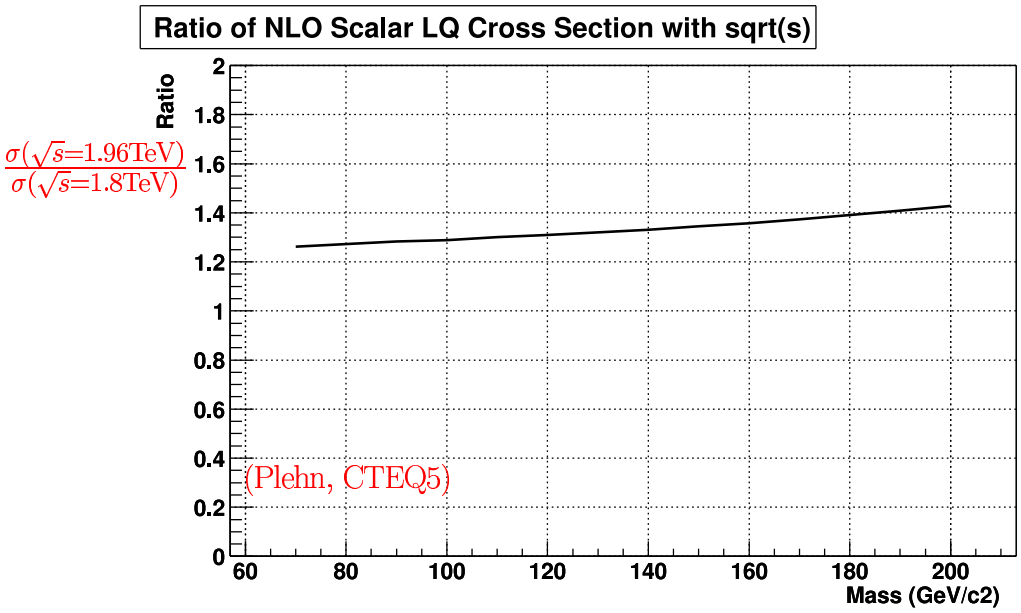


New results from Run II:

- DØ: 41 pb^{-1}
- CDF: 72–76 pb^{-1}

Cross section increase by ∼30–40 %

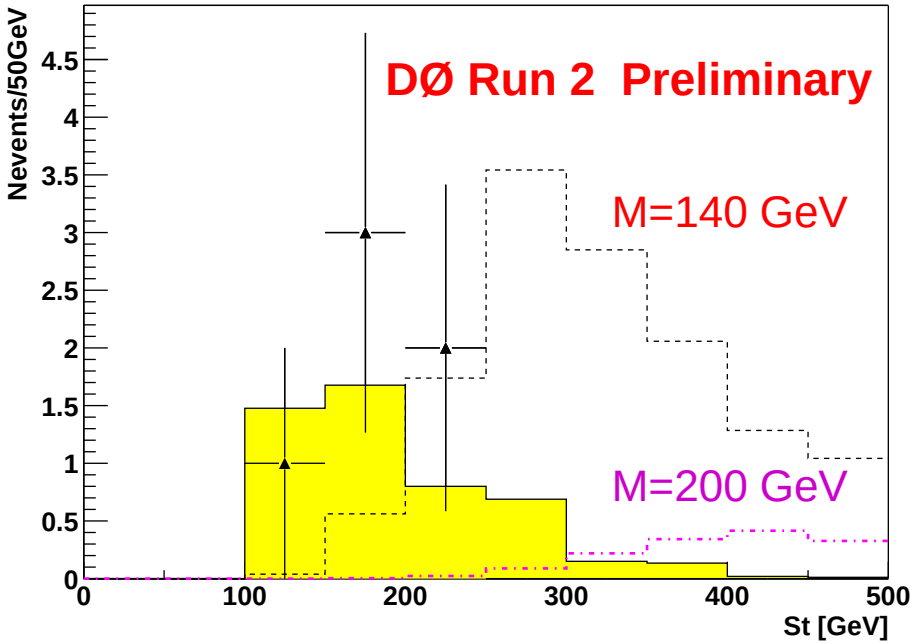
$\sigma(\sqrt{s} = 1.96\text{TeV})/\sigma(\sqrt{s} = 1.8\text{TeV})$ (w.r.t. Run I)



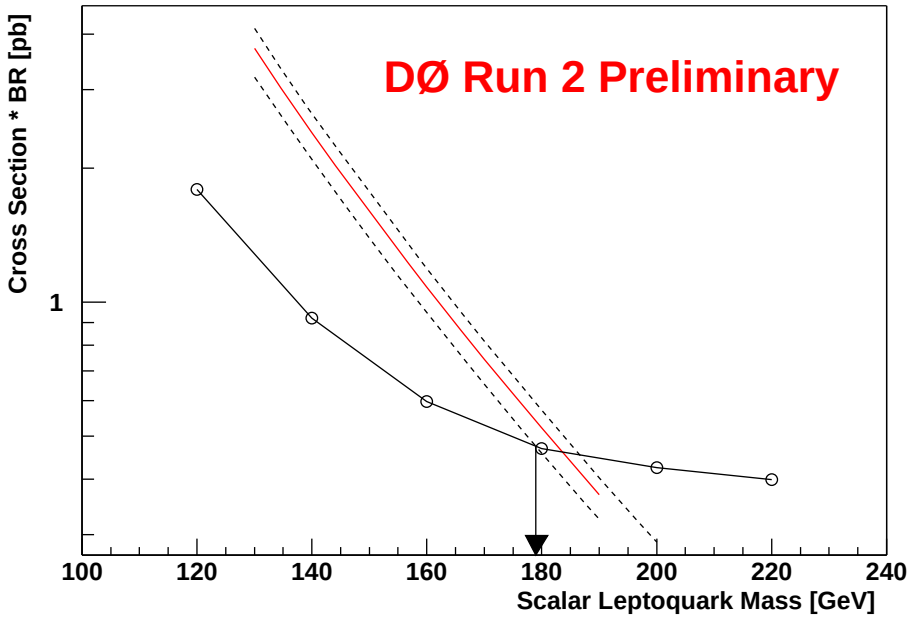
Pair-production at Tevatron

DØ: search for first generation leptoquarks $LQ\ L\bar{Q} \to eejj$

Total transverse energy:



Cross section limit: (41 pb^{-1})



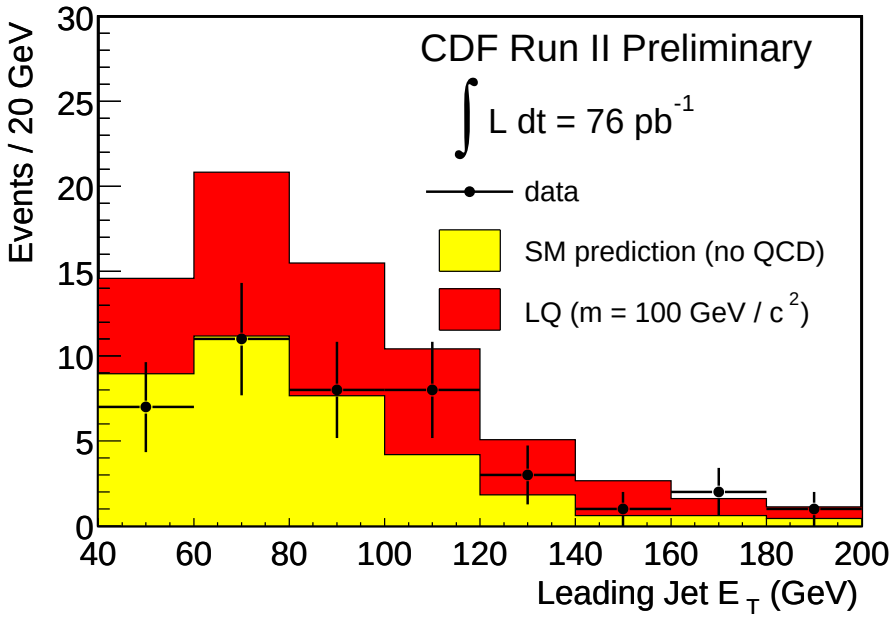
For $\beta_{eq} = 1$ mass limit for scalar leptoquarks is $M >$179 GeV (95%CL)

Second generation LQs ($\mu\mu jj$ channel): $M >$157 GeV ($\beta_{\mu q} = 1$)

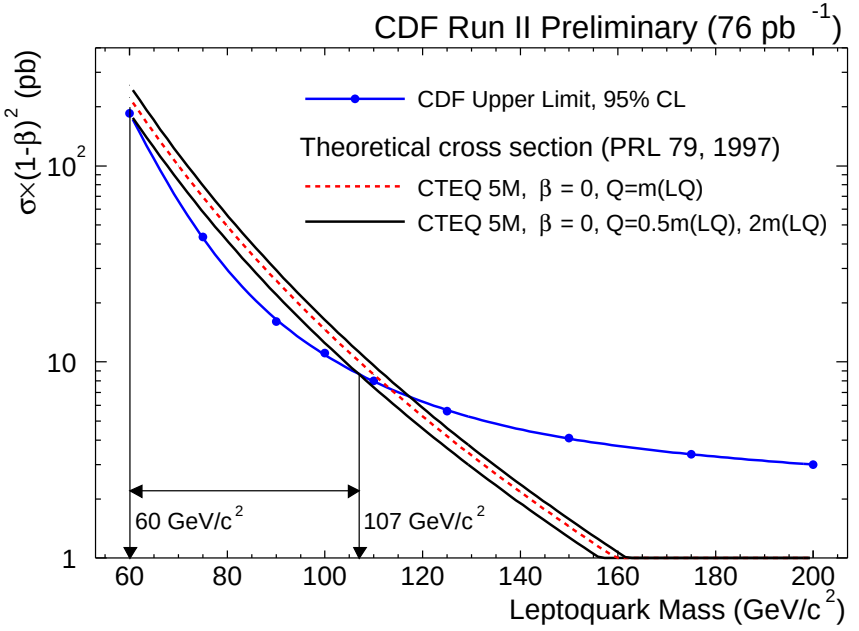
Pair-production at Tevatron

CDF : search for first generation leptoquarks $LQ\ \bar{LQ} \to \nu\nu jj$

Leading jet E_T:



Cross section limit: $(76\ pb^{-1})$



For $\beta_{eq} = 0$ mass limit for scalar leptoquarks is $M >$107 GeV

for $\beta_{eq} = 0.5$ (search in $e\nu jj$ channel): $M >$166 GeV

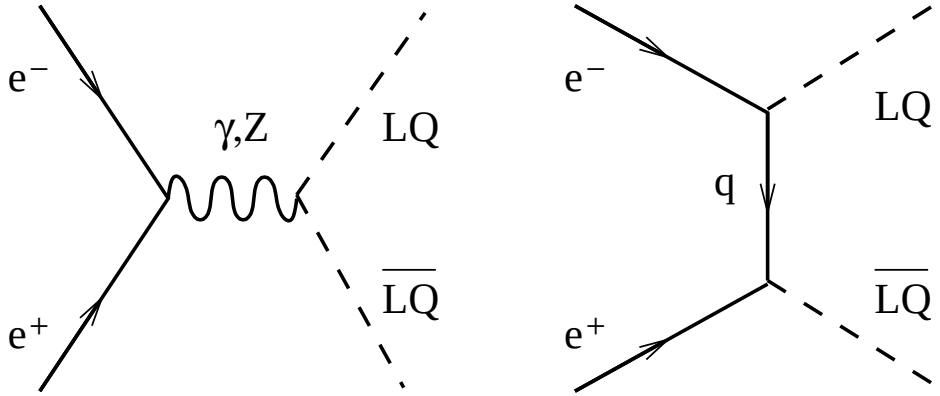
for $\beta_{eq} = 1$ (search in $eejj$ channel): $M >$230 GeV

Pair-production at LEP

New ***OPAL*** results
596 pb^{-1}, $\sqrt{s} = 189 - 209$ GeV

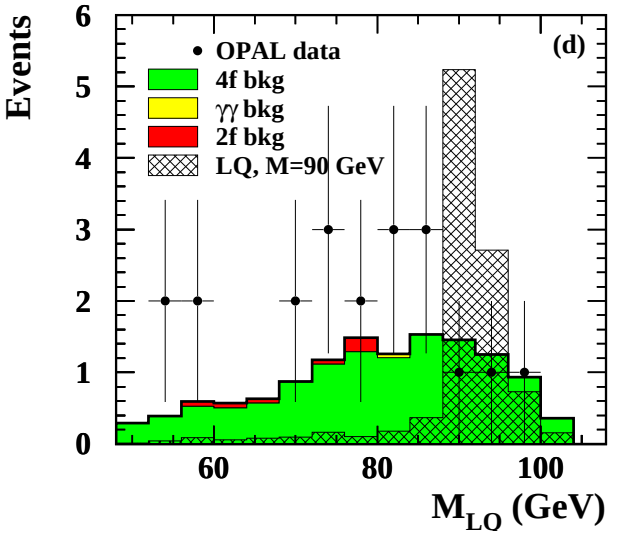
LQ mass
kinematic fit

Pair-production $e^+e^- \to LQ\ \bar{LQ}$:
s-channel γ or Z° exchange

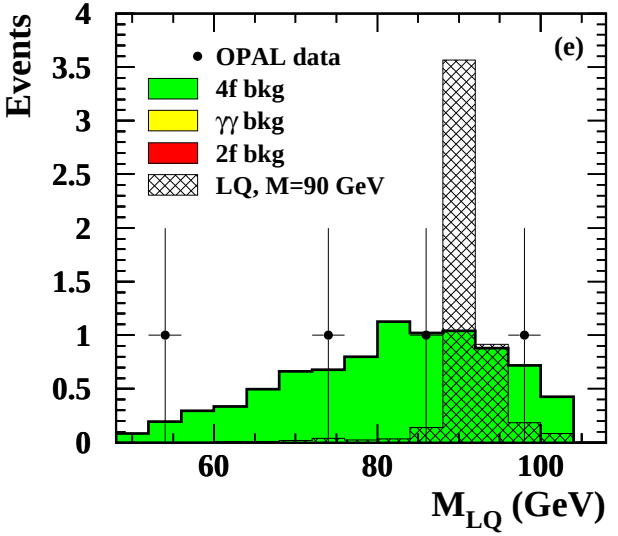


t-channel q exchange (1^{st} gen.)
negligible for small λ

e^+e^-qq
events $\Rightarrow$



$\mu^+\mu^-qq$
events $\Rightarrow$



Pair-production at LEP

Search in l^+l^-qq, $l\nu qq$ and $\nu\nu qq$ channels, for $l = e, \mu, \tau$

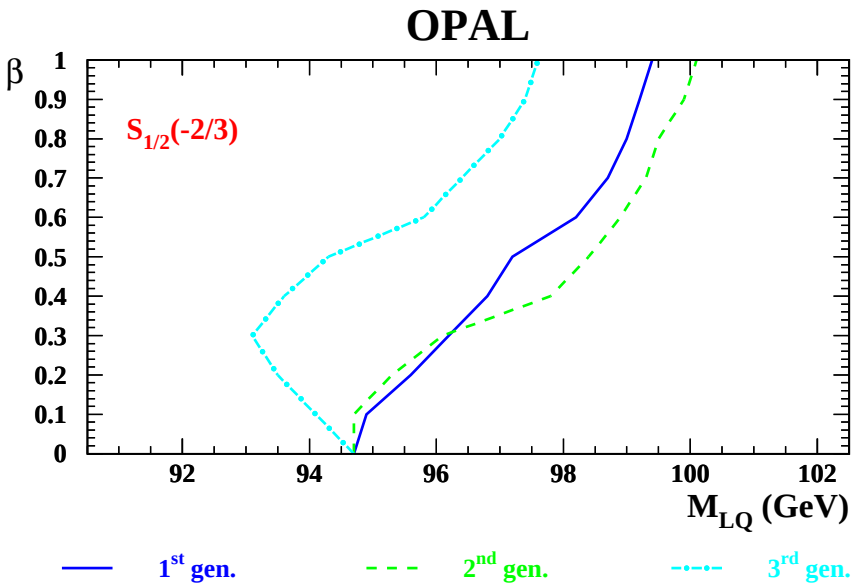
$\Rightarrow$ for $\beta_{lq} = 1$ mass limits between 96 and 102 GeV,

$\Rightarrow$ for $\beta_{lq} = 0$ mass limits between 89 and 101 GeV

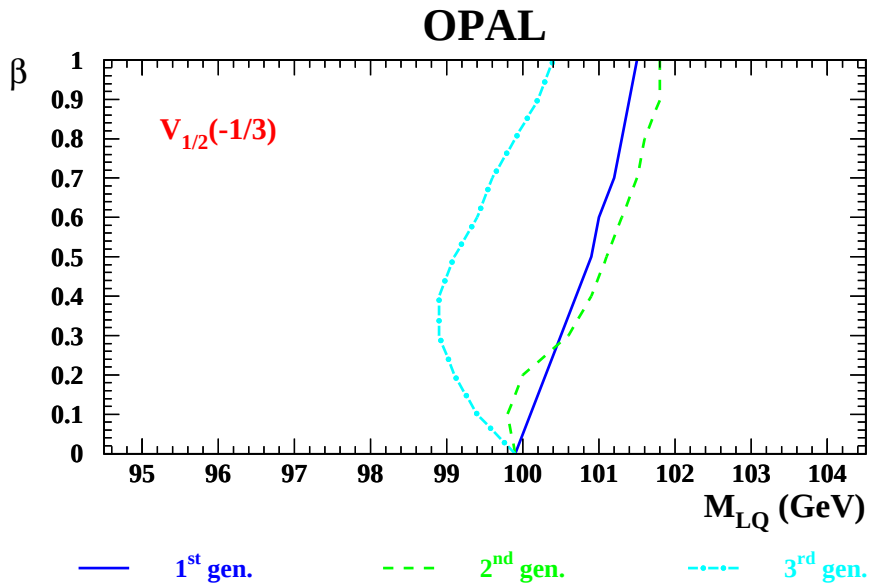
depending on generation and leptoquark type

For leptoquarks with β_{lq} value depending on λ_L and λ_R:

$S_{1/2}$ (scalar LQ with Q=$-2/3$)



$V_{1/2}$ (vector LQ with Q=$-1/3$)

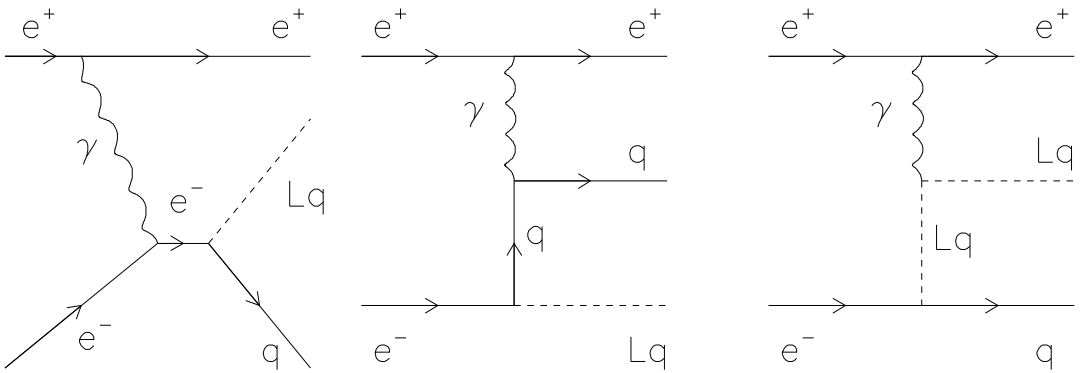


Single-production at LEP

OPAL results for $\sqrt{s} = 189 - 209$ GeV

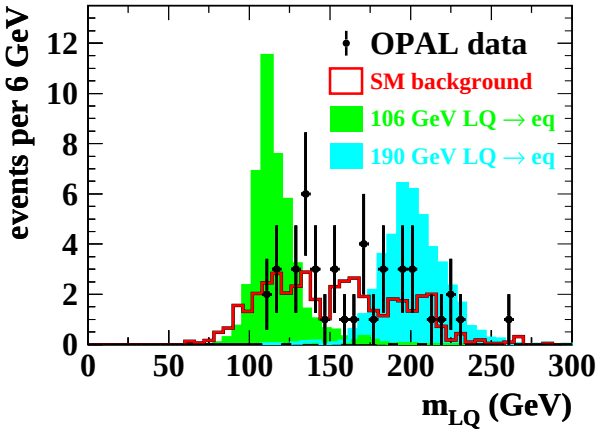
Single leptoquarks can be produced in $e\gamma$ collisions.

Dominant contribution from $\gamma \to q\bar{q}$

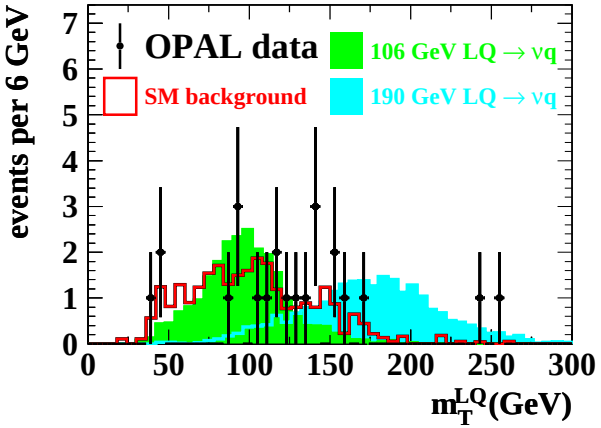


LQ candidate mass

$LQ \to eq$ search



$LQ \to \mu q$ search

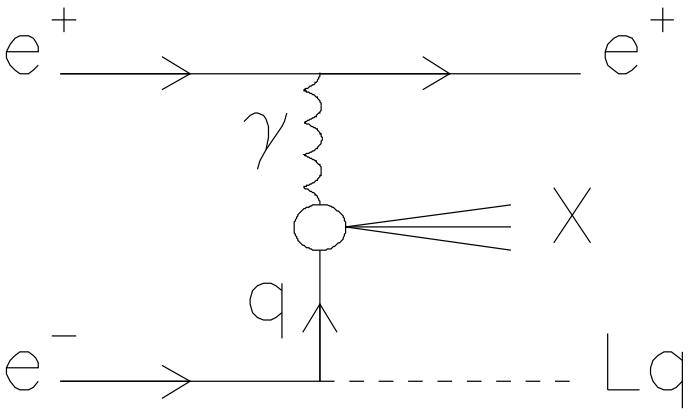


Single-production at LEP

OPAL results for $\sqrt{s} = 189 - 209$ GeV

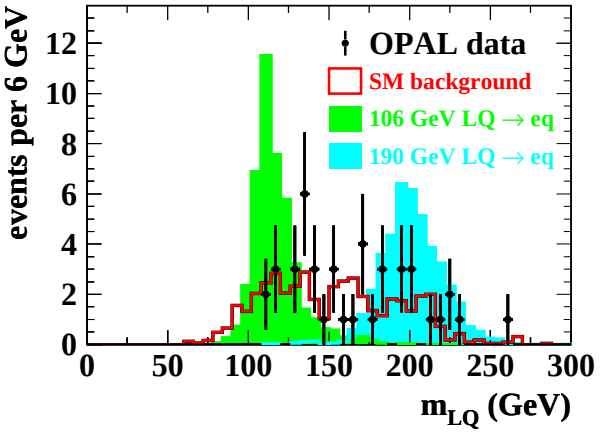
Single leptoquarks can be produced in $e\gamma$ collisions.

Dominant contribution from $\gamma \to q\bar{q}$ and "resolved photon" diagram:

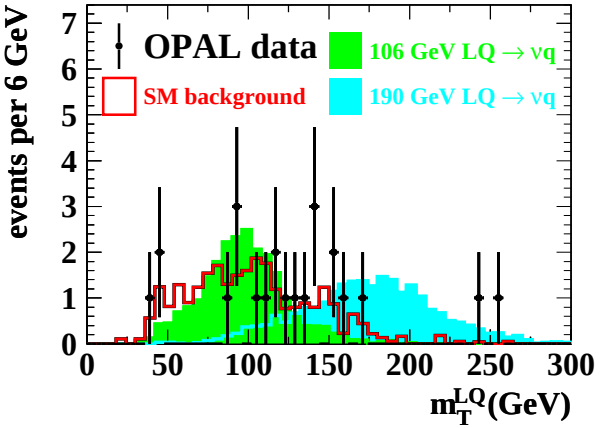


LQ candidate mass

$LQ \to eq$ search



$LQ \to \mu q$ search

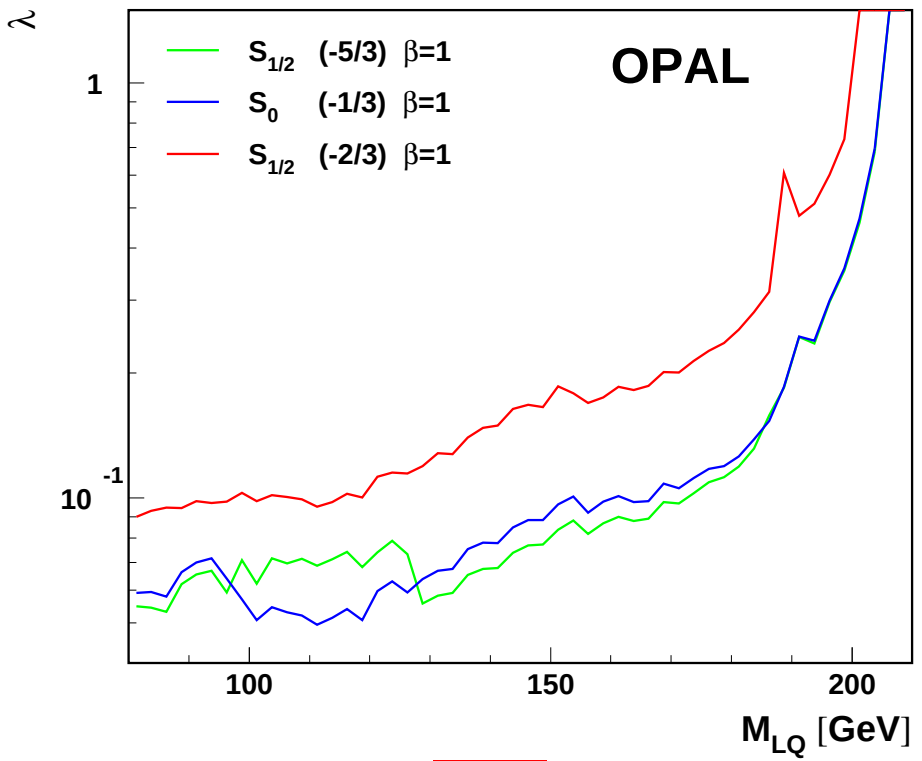


Single-production at LEP

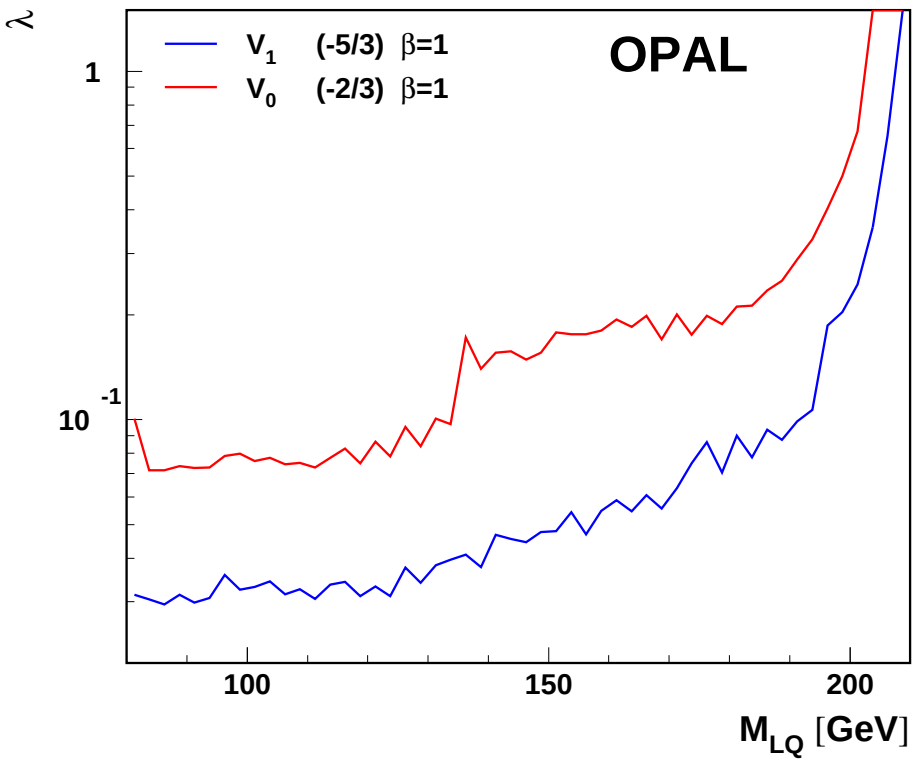
Mass dependent λ limits from OPAL

Strongest limits for $|Q| = 1/3, 5/3,$ weakest limits for $|Q| = 2/3$

Scalar



Vector



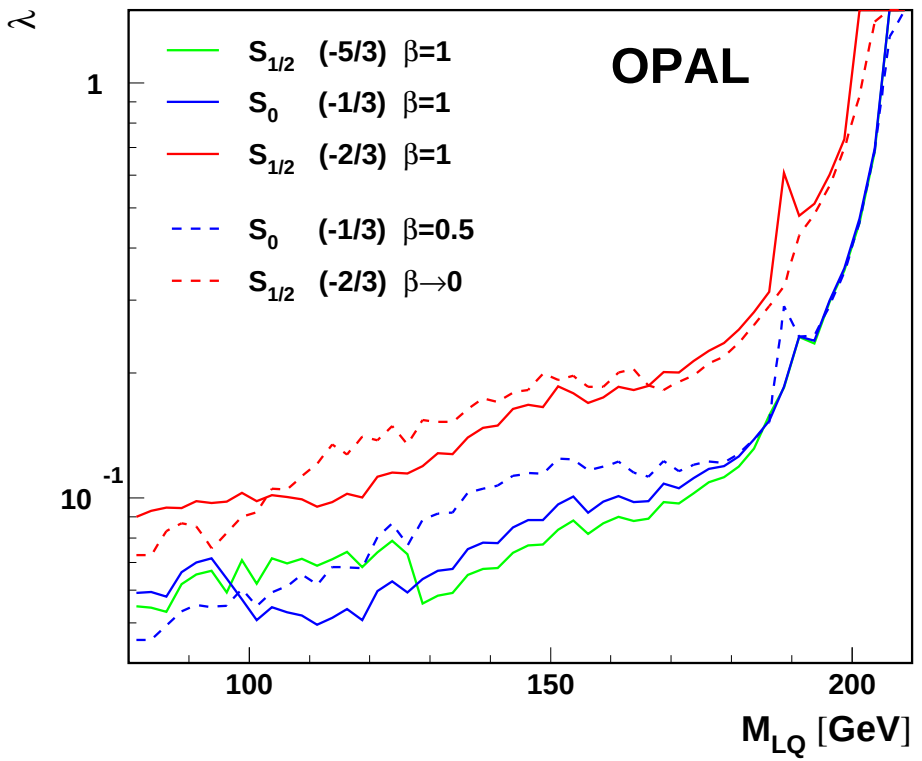
For $\lambda = \sqrt{4\pi\alpha}$: $M_{LQ} > 183 - 202$ GeV

Single-production at LEP

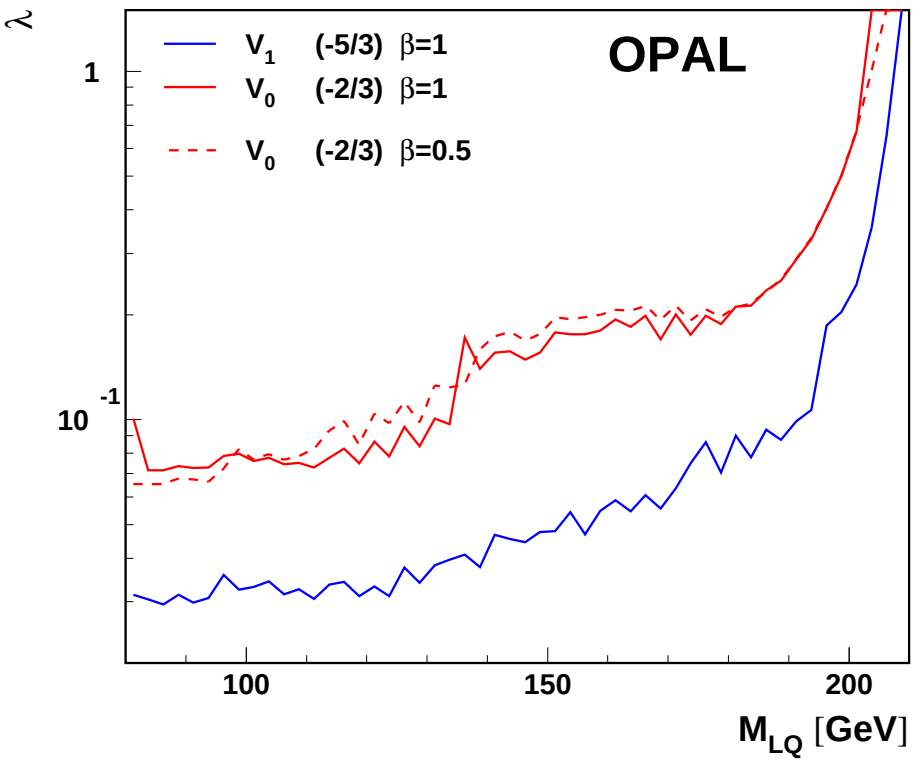
Mass dependent λ limits from OPAL

Strongest limits for $|Q| = 1/3, 5/3,$ weakest limits for $|Q| = 2/3$

Scalar



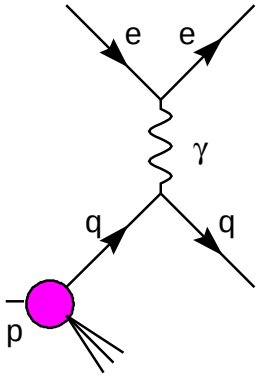
Vector



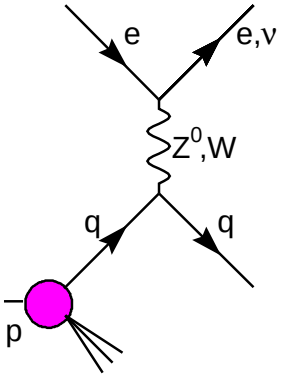
Both eq and νq decay channels $\Rightarrow$ limits weakly depend on β

Single-production at HERA

Direct eq interactions:



(a)

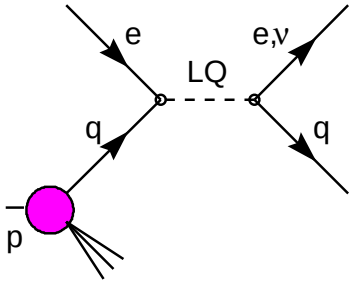


(b)

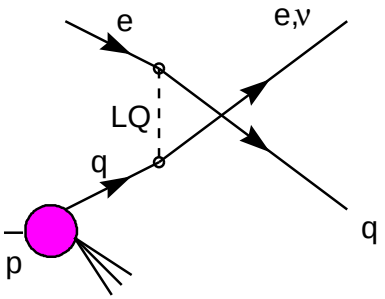
Large SM background from NC and CC DIS

eq invariant mass vs scattering angle $\Rightarrow$

$y = \frac{1}{2}(1 - \cos\theta^{\star})$

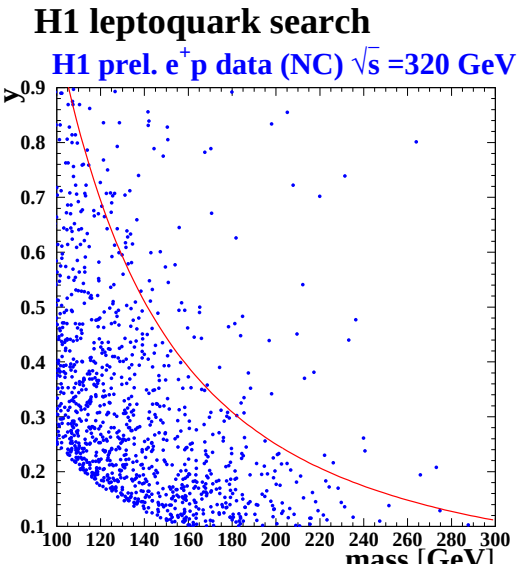


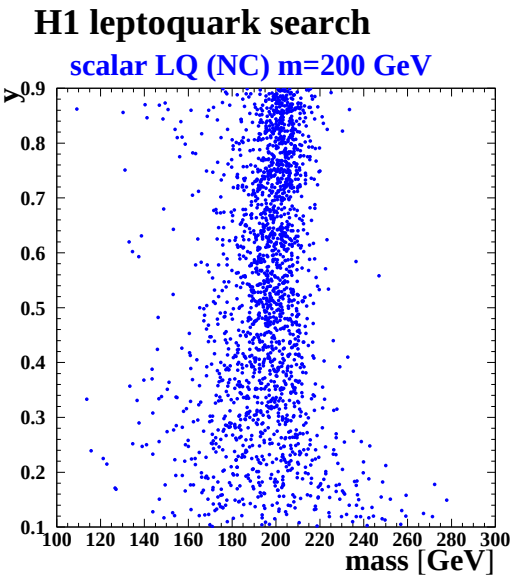
(c)



(d)

LQ signal can be extracted from 2-dimensional event distribution





Single-production at HERA

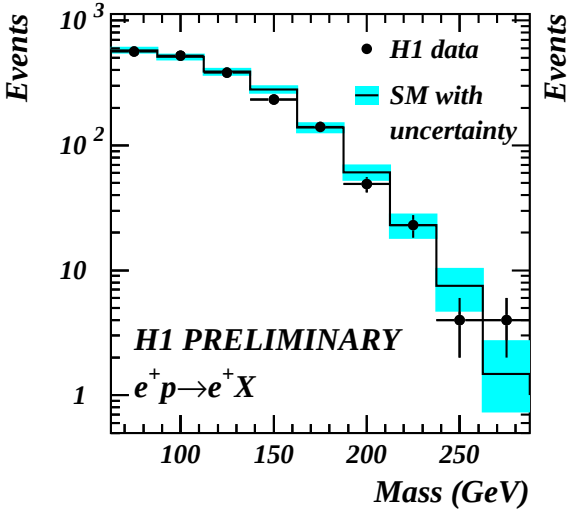
H1 and ***ZEUS*** results based on analysis of 1994-2000 HERA data

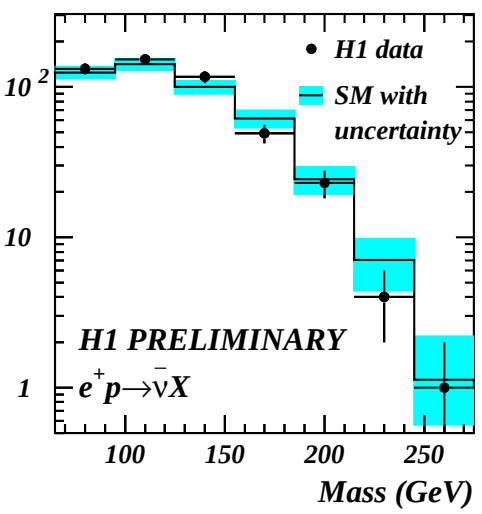
e^+p and e^-p DIS at $\sqrt{s}$ = 300-318 GeV

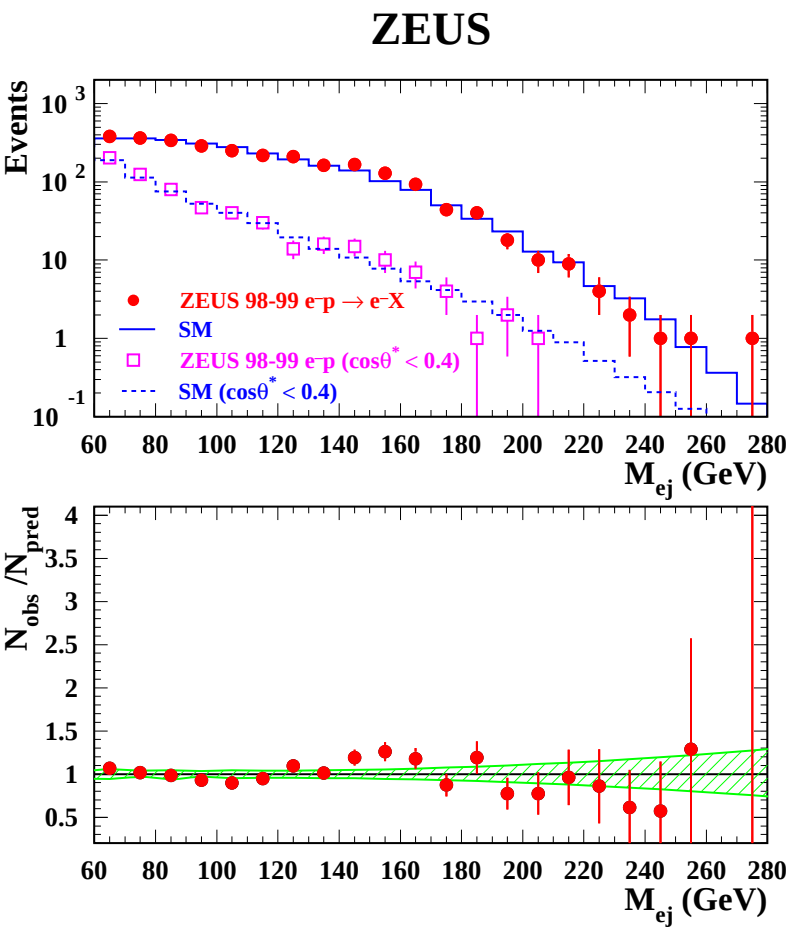
ZEUS: $e^-p \to e^-X$

Comparison of observed and expected invariant mass distributions

H1: $e^+p \to e^+X$ $\quad$ $e^+p \to \bar{\nu}_e X$





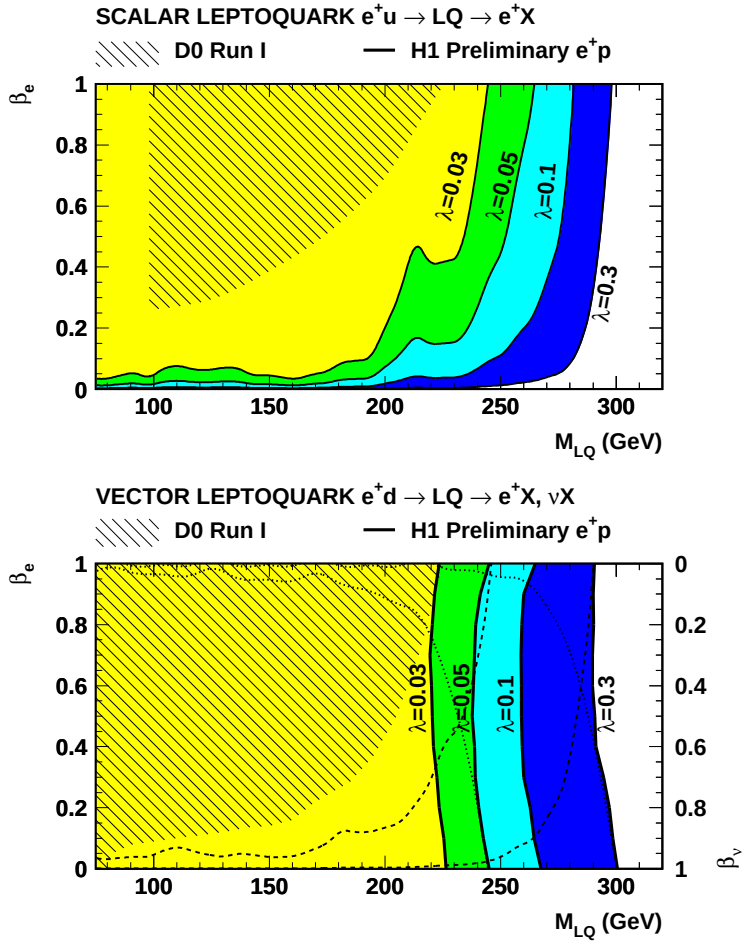


Single-production at HERA

Combined analysis of NC and CC DIS events

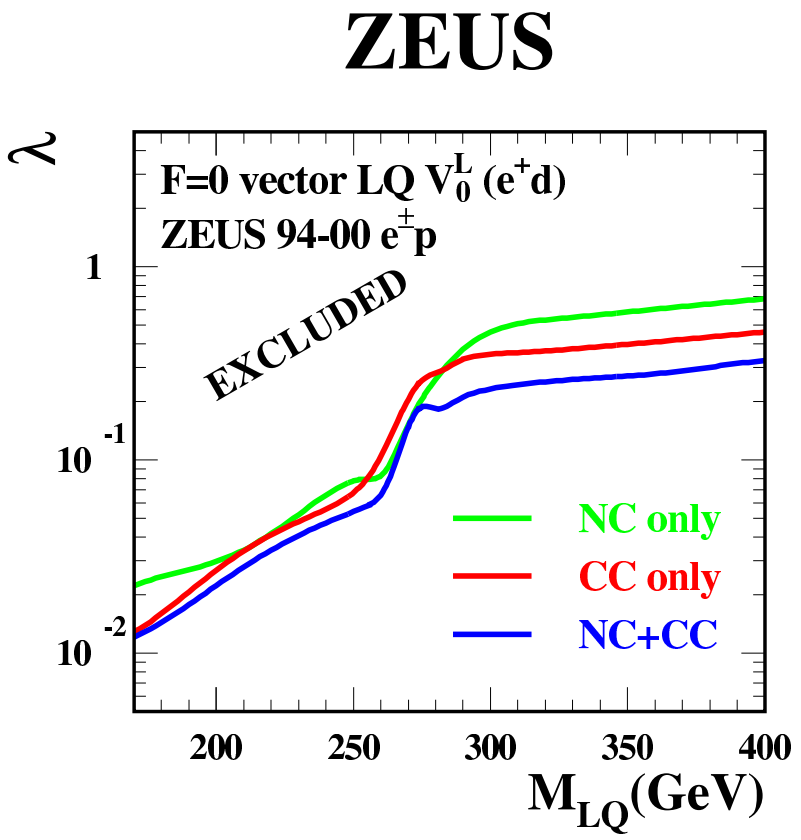
Generic model

$\Rightarrow \beta$ vs M_{LQ} limits



BRW model

Improved limits for $\beta = 0.5$ leptoquarks

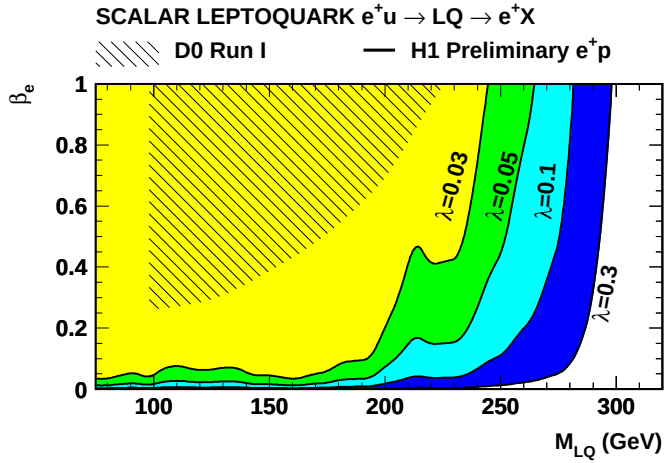


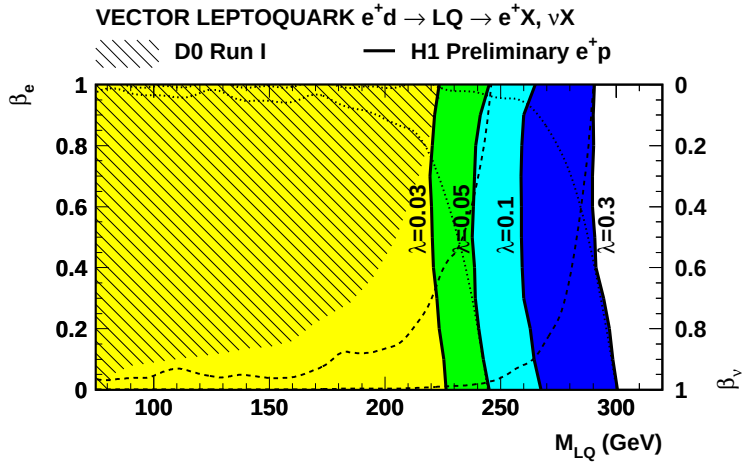
Single-production at HERA

Combined analysis of NC and CC DIS events

Generic model

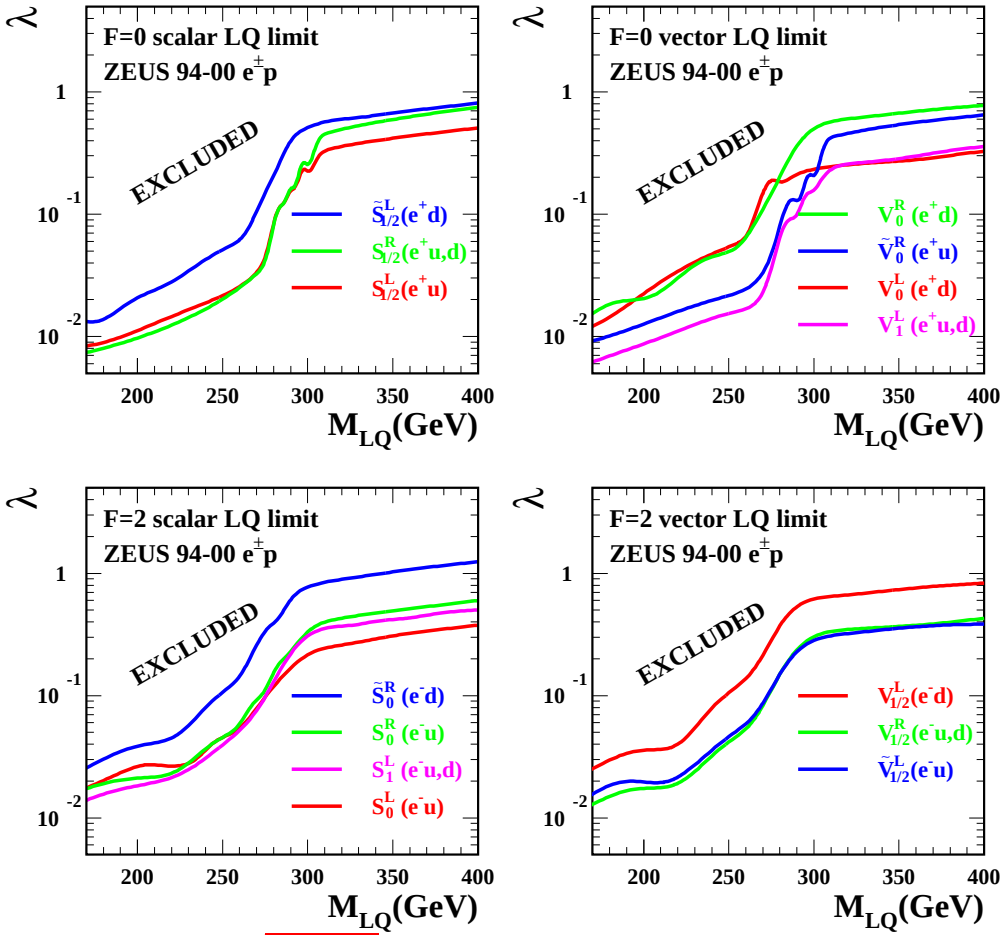
$\Rightarrow \beta$ vs M_{LQ} limits





BRW model

ZEUS



For $\lambda = \sqrt{4\pi\alpha}$: $M_{LQ} > 273 - 386$ GeV

Search for virtual effects

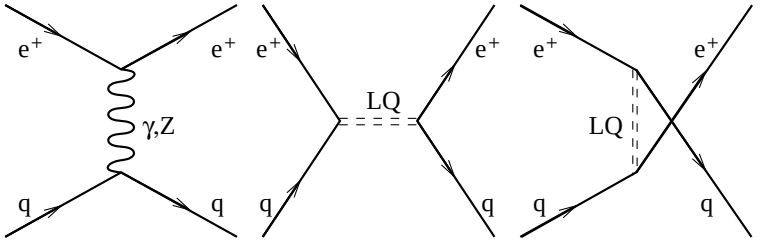
Virtual LQ exchange can affect HERA, LEP and Tevatron measurements even for $M_{LQ} \gg \sqrt{s}$

HERA

$e^+q \longrightarrow e^+q$

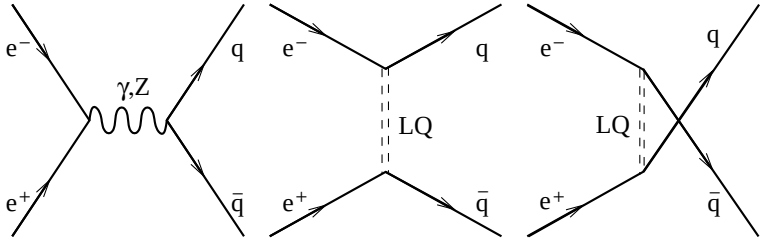
or

$e^-\bar{q} \longrightarrow e^-\bar{q}$



LEP

$e^+e^- \longrightarrow q\,\bar{q}$

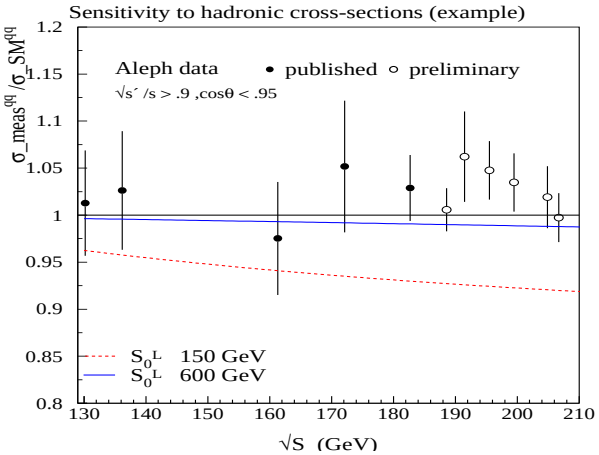


Tevatron

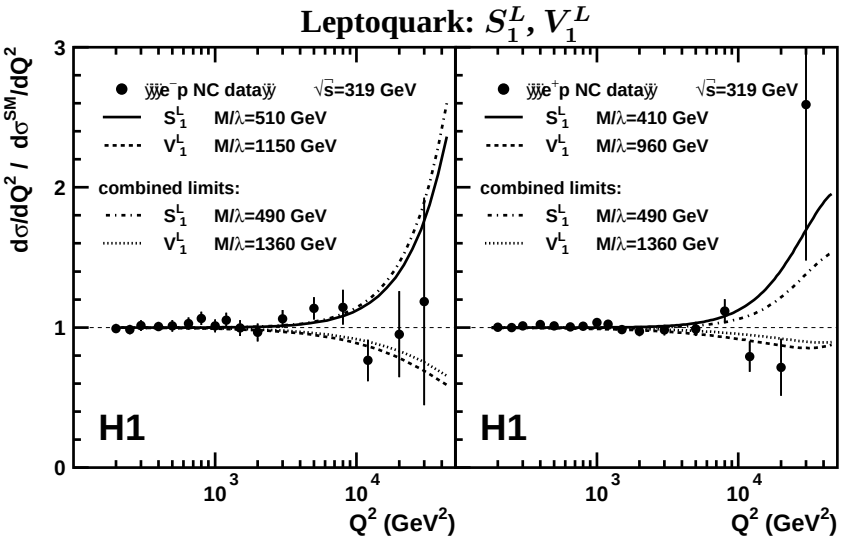
$q\,\bar{q} \longrightarrow l^+l^-$

Interference with SM processes important

σ_{had} at LEP:

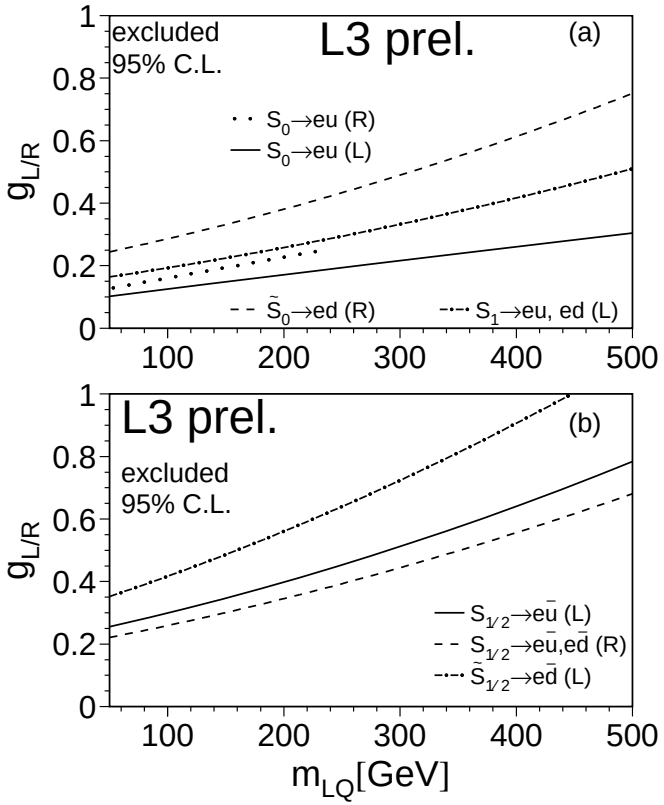


NC DIS at HERA:



Search for virtual effects

L3 limits on λ



For $\lambda = \sqrt{4\pi\alpha}$:

$M > 112 - 375$ GeV (scalar)

$M > 159 - 557$ GeV (vector)

M_{LQ}/λ limits [TeV] (1^{st} generation)

LQ	H1	L3⋆	ZEUS	ALEPH⋆	LEP2⋆
S_0^L	0.71	1.24	0.75	2.13	2.16
S_0^R	0.64	0.88	0.69	0.41	1.72
$\tilde{S}_0^R$	0.33	0.40	0.31	0.57	0.67
$S_{1/2}^L$	0.85	0.37	0.91	0.53	0.59
$S_{1/2}^R$	0.37	0.52	0.69	0.61	0.77
$\tilde{S}_{1/2}^L$	0.43	-	0.50	-	-
S_1^L	0.49	0.89	0.55	1.48	1.19
V_0^L	0.73	1.84	0.69	2.59	3.03
V_0^R	0.58	0.53	0.58	0.49	0.55
$\tilde{V}_0^R$	0.99	1.25	1.03	1.29	1.62
$V_{1/2}^L$	0.42	0.84	0.49	0.81	1.00
$V_{1/2}^R$	0.95	0.71	1.15	0.68	0.75
$\tilde{V}_{1/2}^L$	1.02	0.55	1.26	0.55	0.58
V_1^L	1.36	1.73	1.42	1.98	2.18

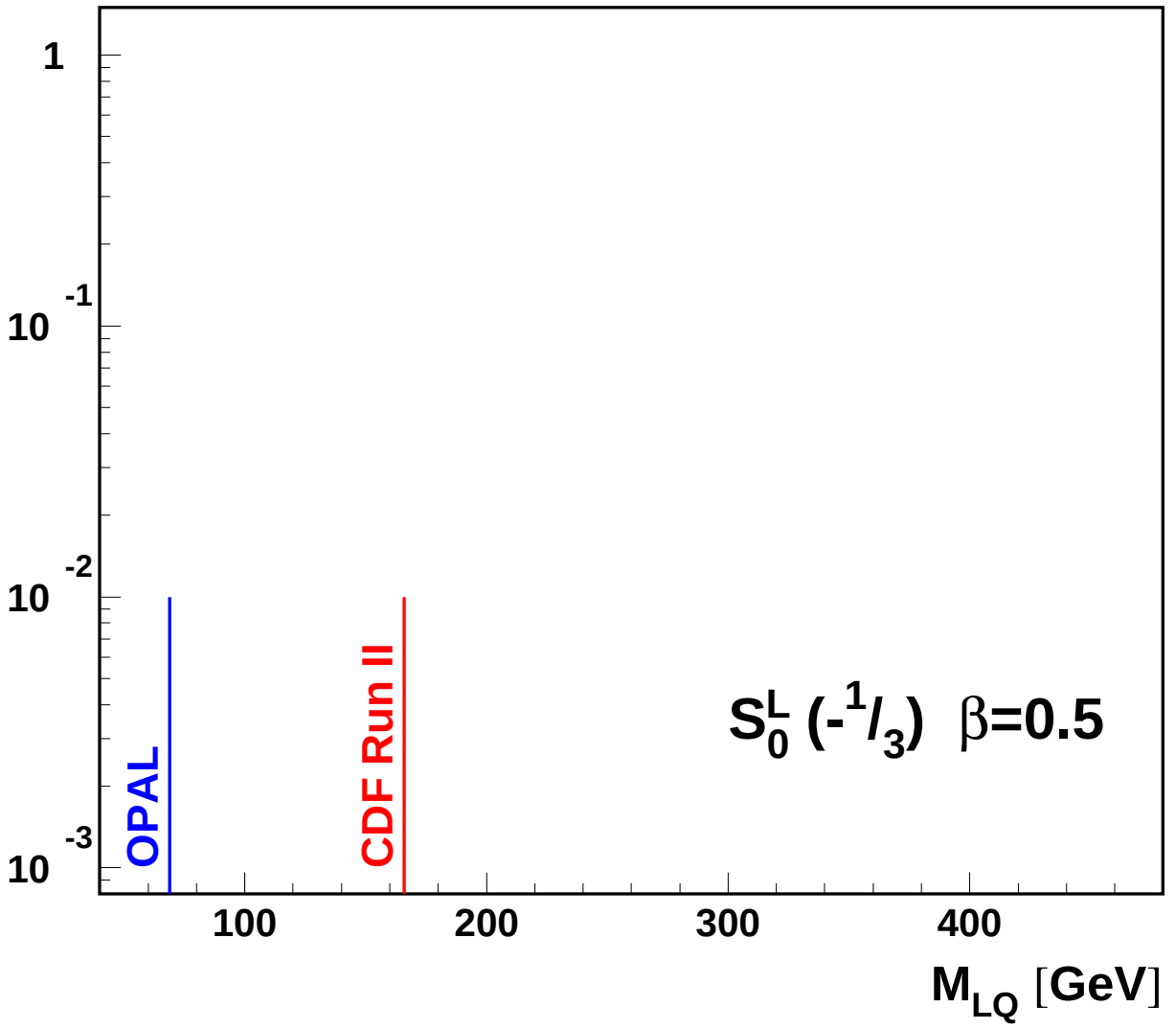
⋆ - calculated from M_{LQ} limits for $\lambda = \sqrt{4\pi\alpha(0)}$

Comparison of leptoquark limits

Limits on S_0^L (1^{st} gen.)

Best constraints:

pair prod. $\Rightarrow$ Tevatron

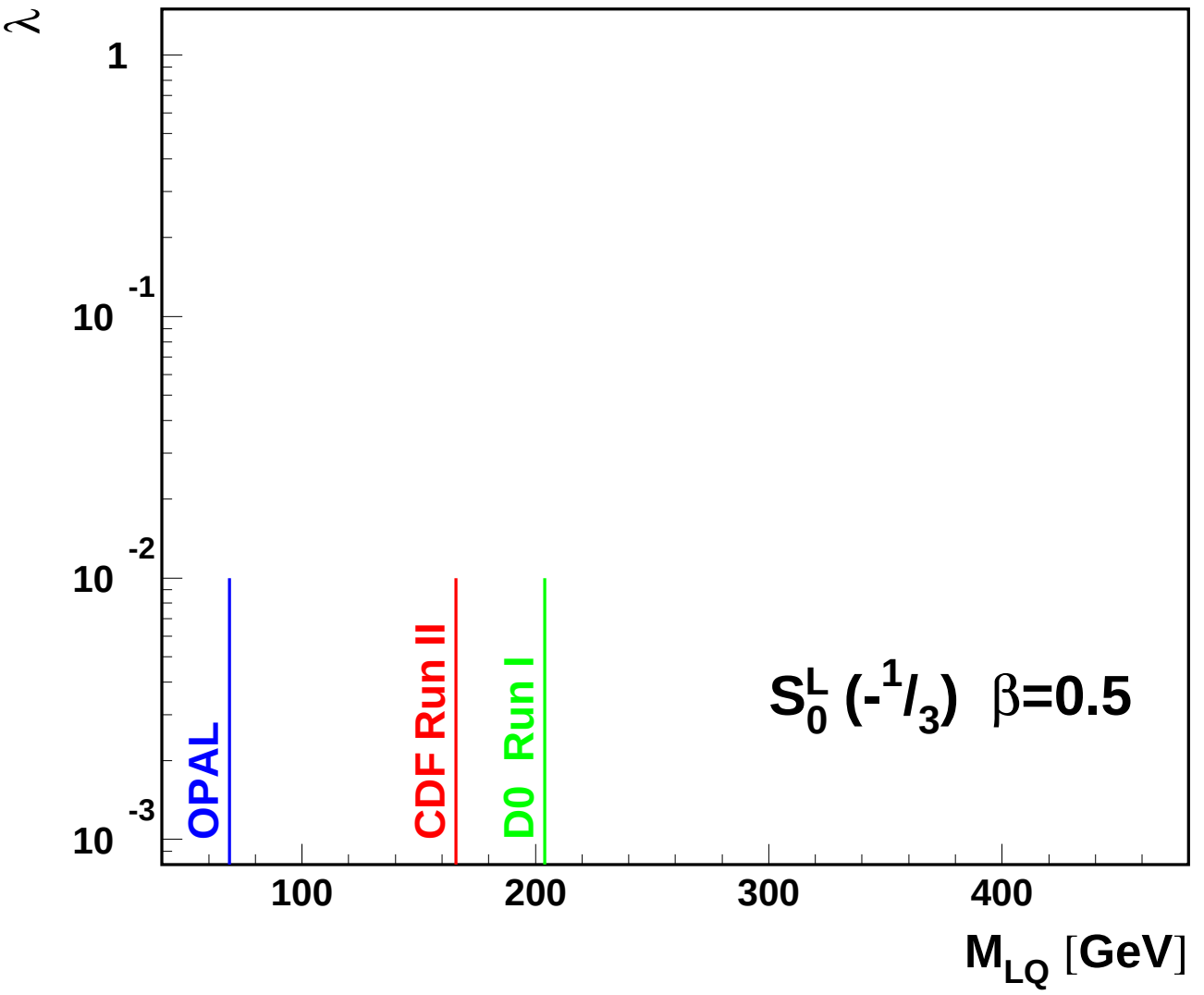


Comparison of leptoquark limits

Limits on S_0^L (1^{st} gen.)

Best constraints:

pair prod. $\Rightarrow$ Tevatron Run I



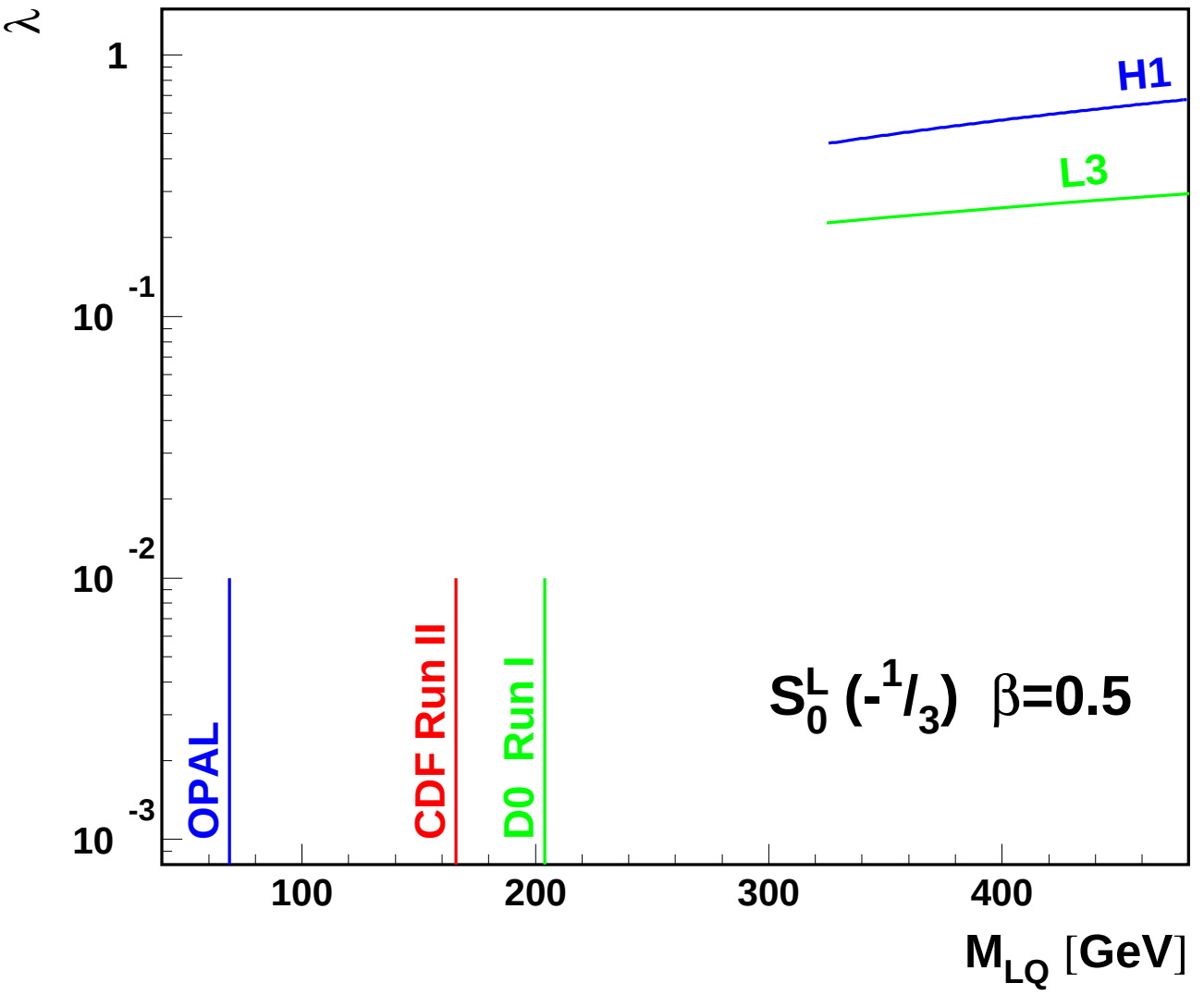
Comparison of leptoquark limits

Limits on S_0^L (1^{st} gen.)

Best constraints:

pair prod. $\Rightarrow$ Tevatron Run I

virtual effects $\Rightarrow$ LEP



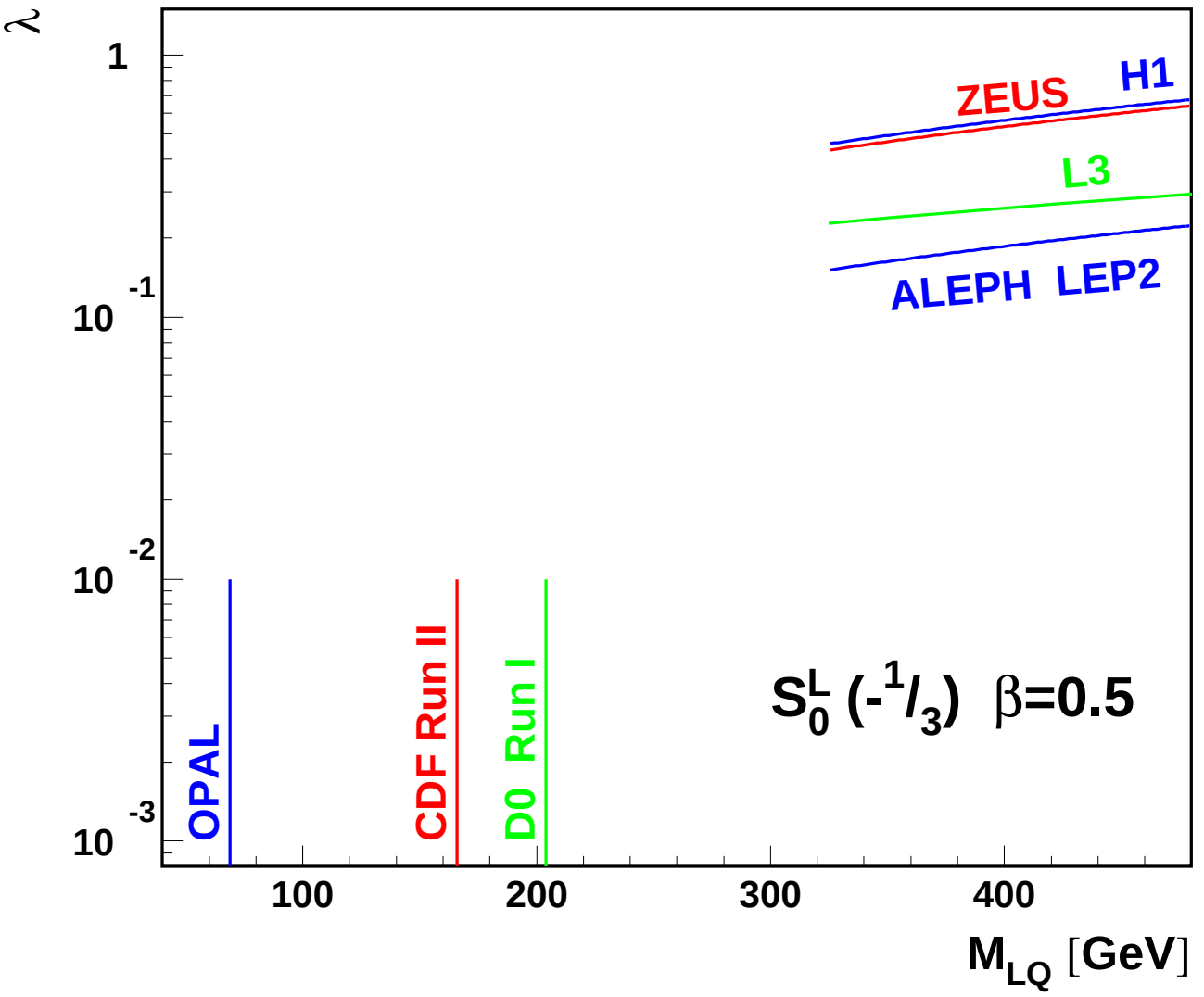
Comparison of leptoquark limits

Limits on S_0^L (1^{st} gen.)

Best constraints:

pair prod. $\Rightarrow$ Tevatron Run I

virtual effects $\Rightarrow$ LEP



Comparison of leptoquark limits

Limits on S_0^L (1^{st} gen.)

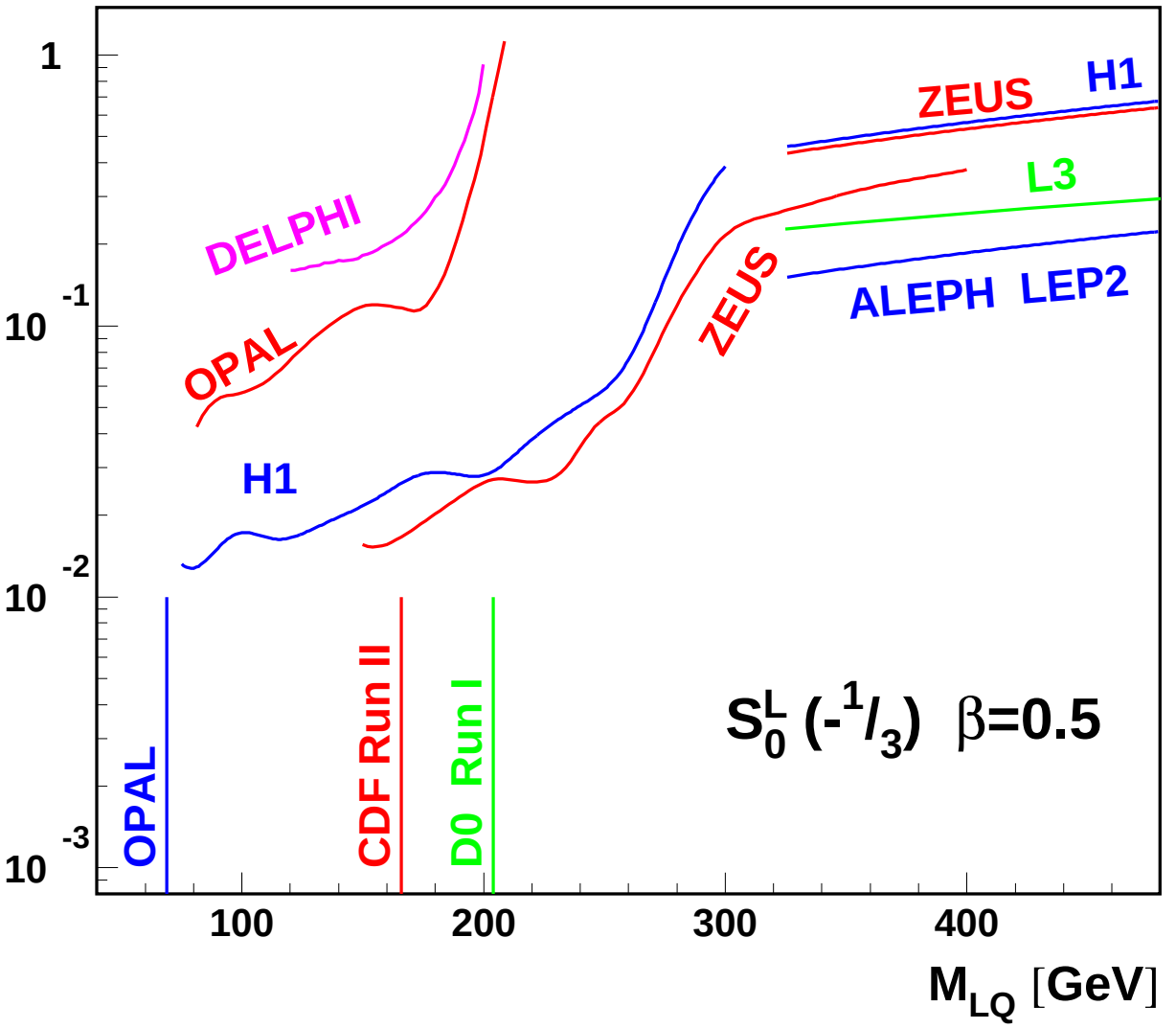
Best constraints:

pair prod. $\Rightarrow$ Tevatron Run I

virtual effects $\Rightarrow$ LEP

single prod. $\Rightarrow$ HERA

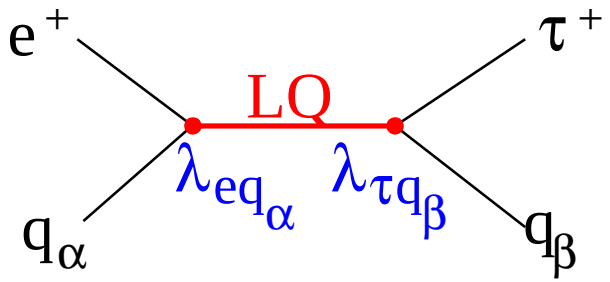
Complementary constraints from different machines



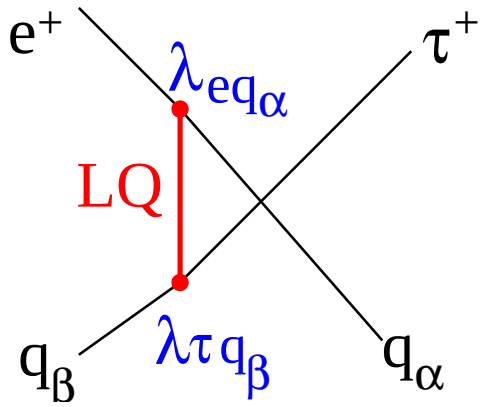
LFV at HERA

Leptoquarks could also mediate lepton flavour violation:

a)



b)



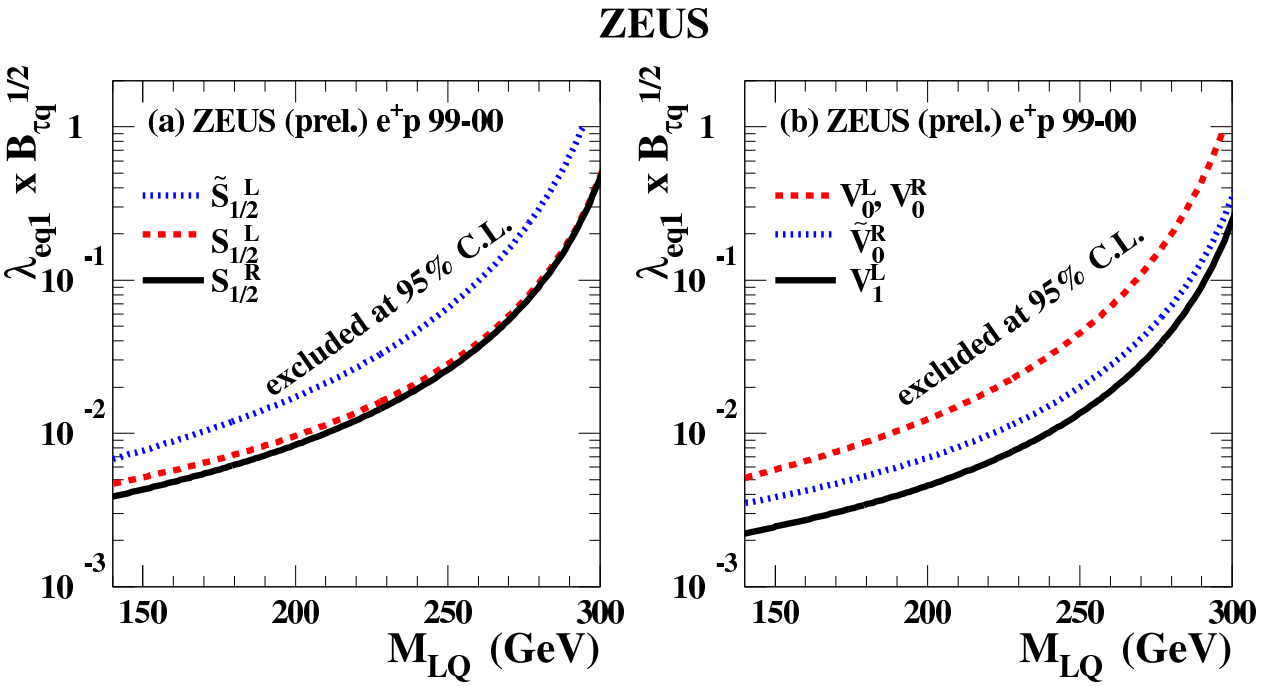
assuming $\lambda_{eq_\alpha} \times \lambda_{lq_\beta} \neq 0$

ZEUS search for $e^+p \to \tau\ X$

66 pb^{-1} of e^+p data 1999-2000

No events found

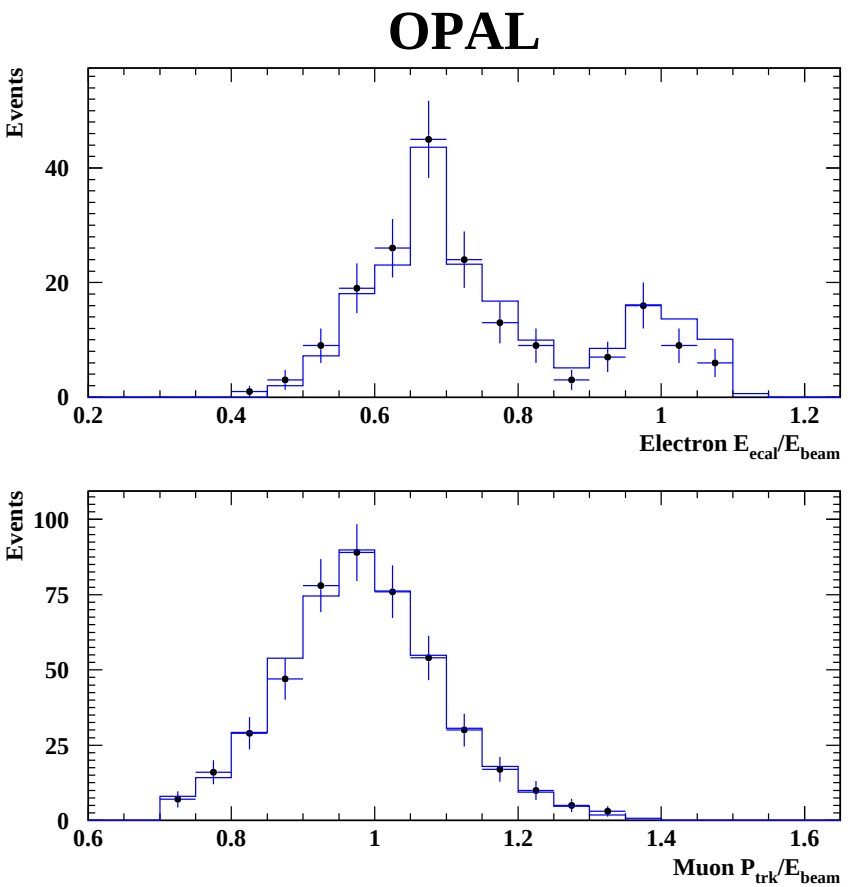
$\Rightarrow$ limits on $\lambda_{eq_1} \times \sqrt{BR(LQ \to \tau q)}$



LFV at LEP

OPAL analysis of LEP2 data (189-209 GeV)

Electron and muon candidates



Search for lepton flavour violating processes:

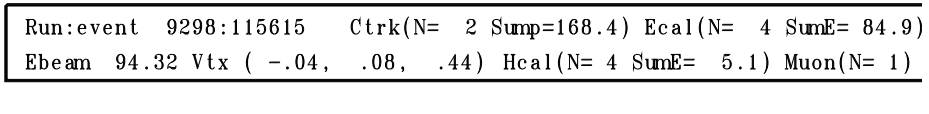
	SM exp.	Observed
$e^+e^- \to e\mu$	0.019	1
$e^+e^- \to e\tau$	5.01	5
$e^+e^- \to \mu\tau$	14.3	11

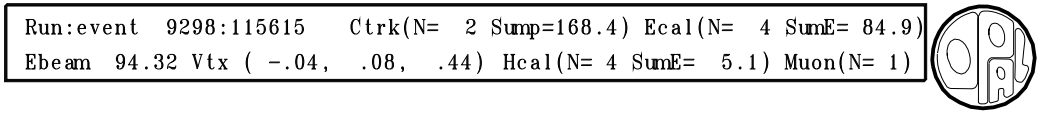
Upper cross section limits:

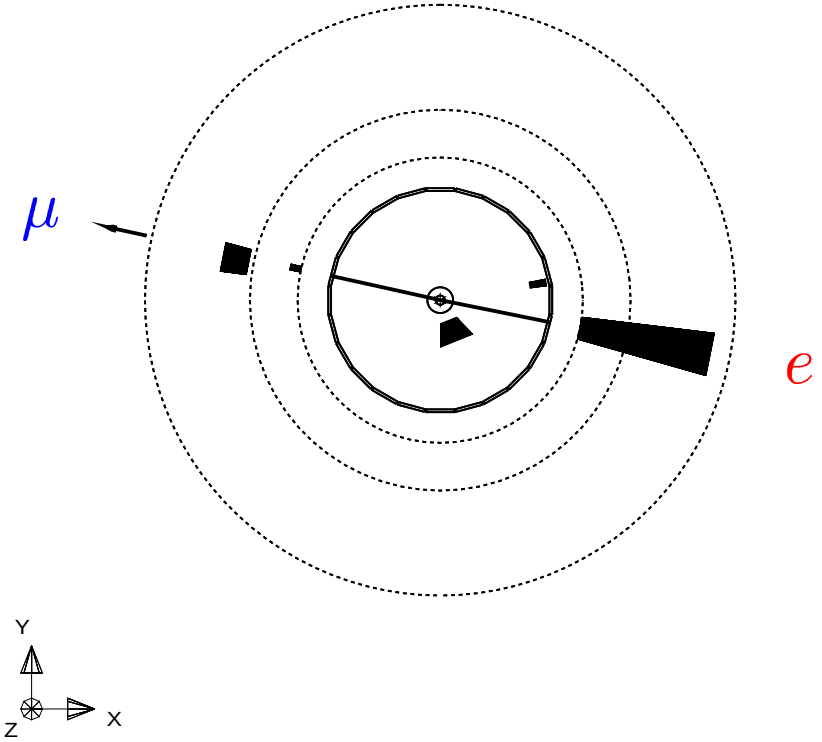
- 22 to 58 fb for $e\mu$
- 78 to 144 fb for $e\tau$
- 64 to 166 fb for $\mu\tau$

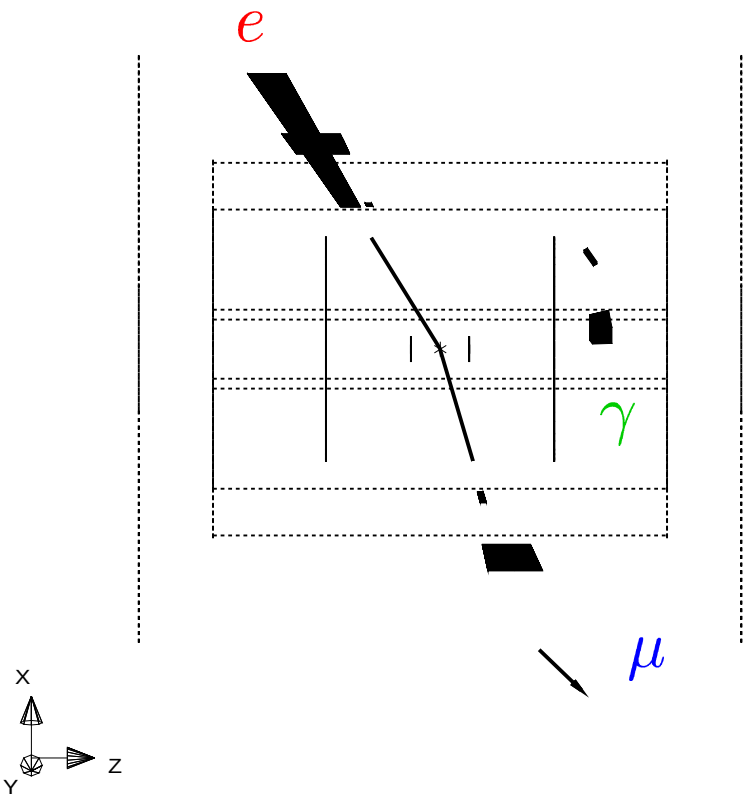
Lepton Flavour Violation

OPAL $e^+e^- \to e\mu$ event









Summary

New results from leptoquark searches at LEP, HERA and Tevatron

No signal of LQ production observed

Complementary limits from different processes and experiments

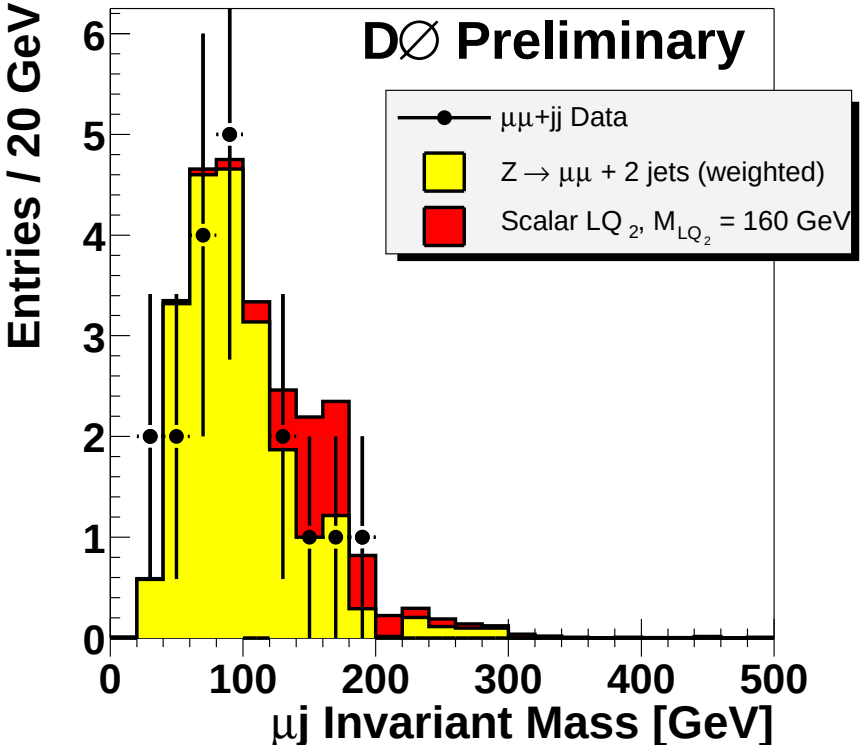
No signal of lepton flavour violation for charged leptons

Single $e^+e^- \to e\mu$ event from OPAL:
interesting, but not a discovery yet...

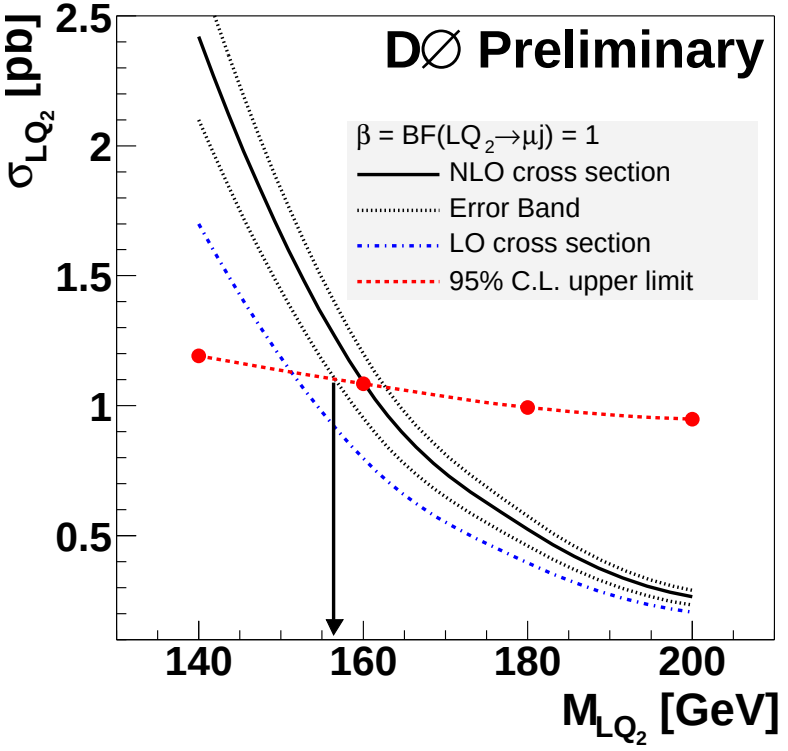
Pair-production at Tevatron

DØ: search for second generation leptoquarks $LQ\ \bar{LQ} \to \mu\mu jj$

Reconstructed mass:



Cross section limit: $(41\ pb^{-1})$

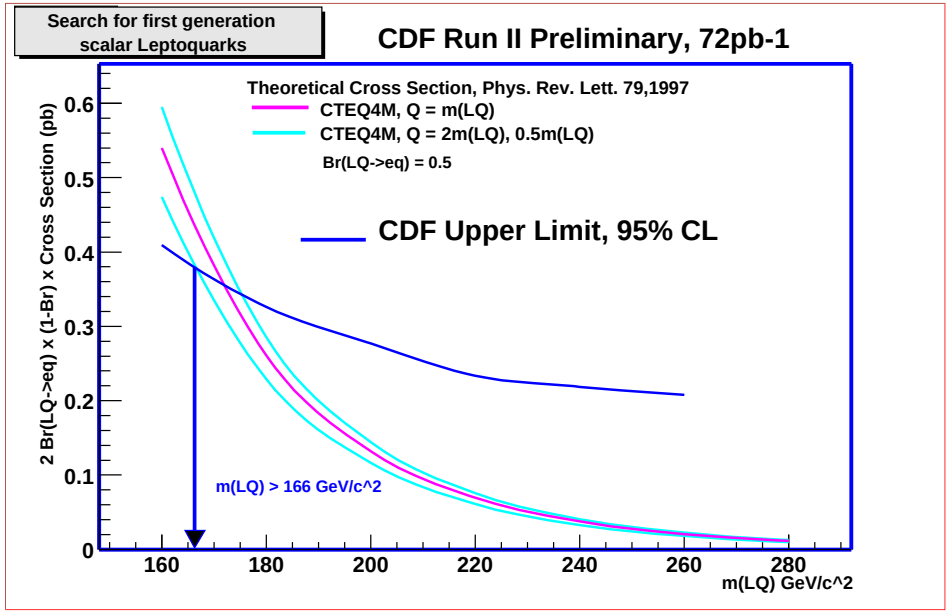


For $\beta_{\mu q} = 1$ limit for scalar leptoquarks is $M >$157 GeV (95% CL)

Pair-production at Tevatron

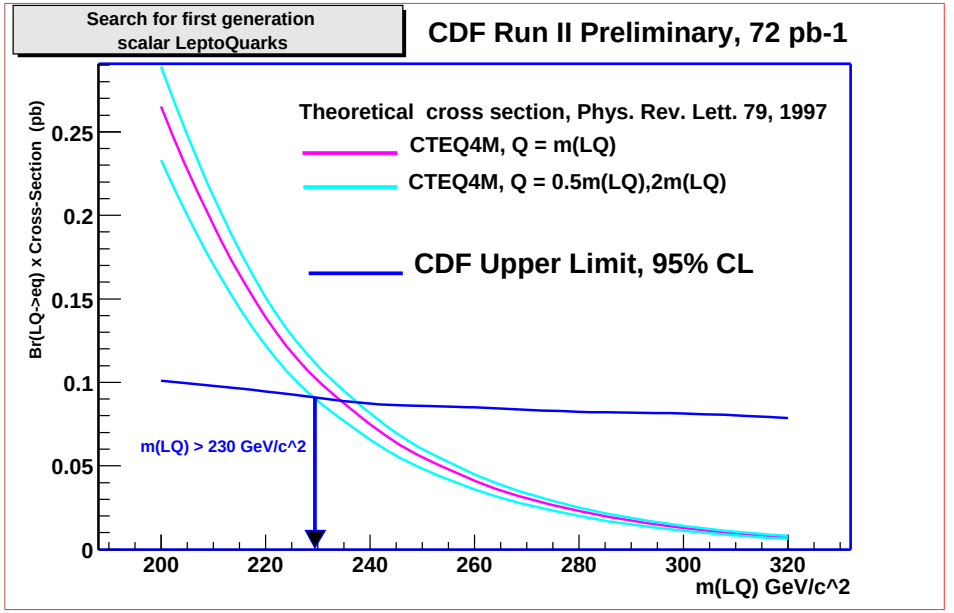
CDF : search for first generation leptoquarks

$LQ\ \bar{LQ} \to e\nu jj$



$\beta_{eq} = 0.5 \Rightarrow M >$166 GeV

$LQ\ \bar{LQ} \to eejj$



$\beta_{eq} = 1 \Rightarrow M >$230 GeV

Comparison of leptoquark limits

Limits on $S^L_{1/2}$ (1^{st} gen.)