Leptoquark Pair Production at ep Colliders

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1. Introduction

ep: DIS

STUDIED SO FOR : e-q($\bar{q}$)-FUSION.

LAGRANGIAN :

$$
\begin{aligned}
\mathcal{L}^f_{|F|=2} &= (g_{1L}\bar{q}^c_L i\tau_2 l_L + g_{1R}\bar{u}^c_R e_R)S_1 \\
&+ \tilde{g}_{1R}\bar{d}^c_R e_R \tilde{S}_1 + g_{3L}\bar{q}^c_L i\tau_2 \vec{\tau} l_L \vec{S}_3 \\
&+ (g_{2L}\bar{d}^c_R \gamma^\mu l_L + g_{2R}\bar{q}^c_L \gamma^\mu e_R)V_{2\mu} \\
&+ \tilde{g}_{2L}\bar{u}^c_R \gamma^\mu l_L \tilde{V}_{2\mu} + h.c.,
\end{aligned}
$$

$$
\begin{aligned}
\mathcal{L}^f_{F=0} &= (h_{2L}\bar{u}_R l_L + h_{2R}\bar{q}_L i\tau_2 e_R)R_2 + \tilde{h}_{2L}\bar{d}_R l_L \tilde{R}_2 \\
&+ (h_{1L}\bar{q}_L \gamma^\mu l_L + h_{1R}\bar{d}_R \gamma^\mu e_R)U_{1\mu} \\
&+ \tilde{h}_{1R}\bar{u}_R \gamma^\mu e_R \tilde{U}_{1\mu} + h_{3L}\bar{q}_L \vec{\tau} \gamma^\mu l_L \vec{U}_{3\mu} + h.c.
\end{aligned}
$$

ALL THE YUKAWA COUPLINGS ABOVE ARE ESSENTIALLY UNPREDICTED EVEN IN GUTS !

MEASURE OR CONSTRAIN THEM EXPERIMENTALLY !

$\longrightarrow$ M_ϕ - λ_ϕ BOUNDS.

WHAT, IF $\lambda_\phi \ll 1$?

$\mathcal{L}_{F=0}$ & $\mathcal{L}_{F=2}$ ALLOWS TO CLASSIFY THE POSSIBLE LEPTOQUARKS COUPLING:

i) FAMILY DIAGONAL

ii) B & L CONSERVING

iii) NON-DERIVATIVE

BUCHMÜLLER, RÜCKL, WYLER '87

Table 1
Quantum numbers and couplings to lepton(anti)quark pairs of the leptoquarks described by the Lagrangians (2) and (3). The particleantiparticle convention is such that $\overline{\Phi}_{F=2} \to lq$ and $\overline{\Phi}_{F=0} \to l\bar{q}$.

Leptoquark (Φ)	Spin	F	Colour	T_3	Q_{em}	$\lambda_L(lq)$	$\lambda_R(lq)$	$\lambda_L(\nu q)$
S_1	0	-2	$\bar{3}$	0	1/3	g_{1L}	g_{1R}	$-g_{1L}$
$\tilde{S}_1$	0	-2	$\bar{3}$	0	4/3	0	$\tilde{g}_{1R}$	0
S_3	0	-2	$\bar{3}$	$+1$	4/3	$-\sqrt{2}g_{3L}$	0	0
				0	1/3	$-g_{3L}$	0	$-g_{3L}$
				-1	$-2/3$	0	0	$\sqrt{2}g_{3L}$
R_2	0	0	3	1/2	5/3	h_{2L}	h_{2R}	0
				$-1/2$	2/3	0	$-h_{2R}$	h_{2L}
$\tilde{R}_2$	0	0	3	1/2	2/3	$\tilde{h}_{2L}$	0	0
				$-1/2$	$-1/3$	0	0	$\tilde{h}_{2L}$
$V_{2\mu}$	1	-2	$\bar{3}$	1/2	4/3	g_{2L}	g_{2R}	0
				$-1/2$	1/3	0	g_{2R}	g_{2L}
$\tilde{V}_{2\mu}$	1	-2	$\bar{3}$	1/2	1/3	$\tilde{g}_{2L}$	0	0
				$-1/2$	$-2/3$	0	0	$\tilde{g}_{2L}$
$U_{1\mu}$	1	0	3	0	2/3	h_{1L}	h_{1R}	h_{1L}
$\tilde{U}_{1\mu}$	1	0	3	0	5/3	0	$\tilde{h}_{1R}$	0
$U_{3\mu}$	1	0	3	$+1$	5/3	$\sqrt{2}h_{3L}$	0	0
				0	2/3	$-h_{3L}$	0	h_{3L}
				-1	$-1/3$	0	0	$\sqrt{2}h_{3L}$

9 VECTORS + 9 SCALARS

BRW

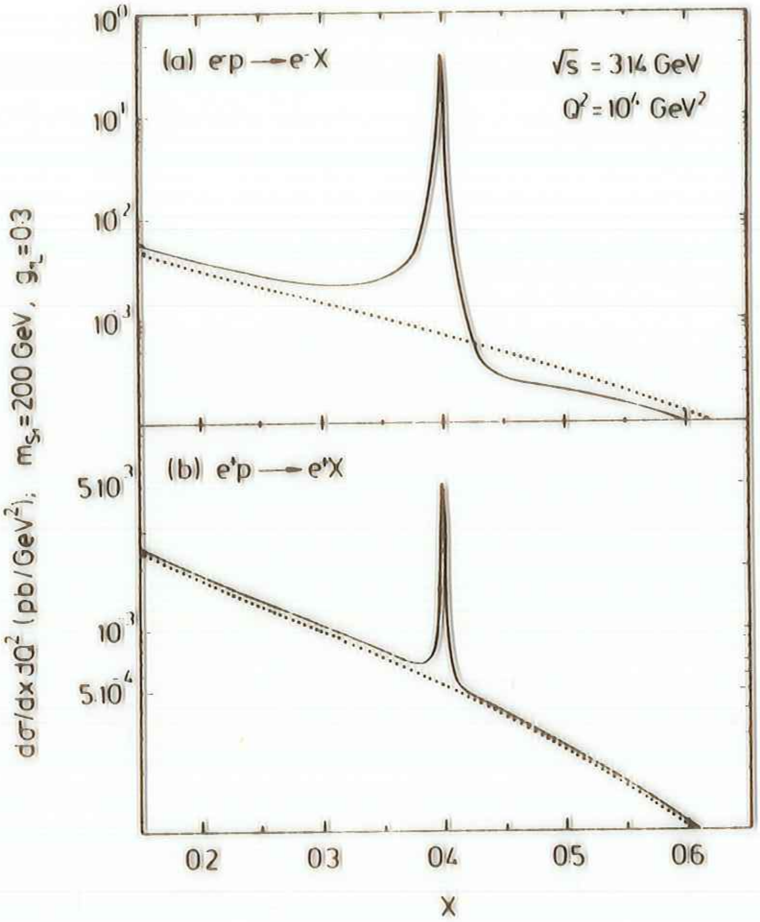
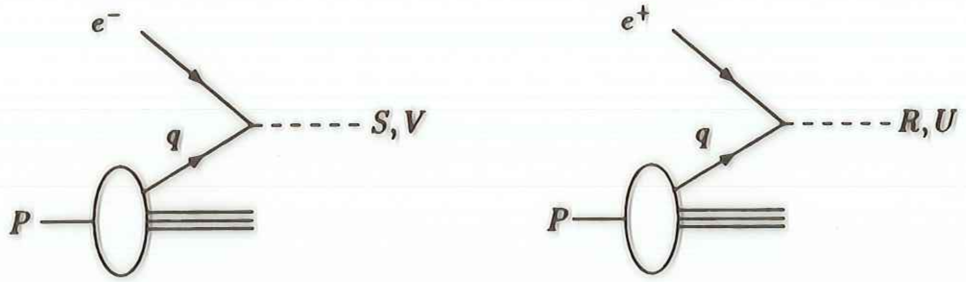
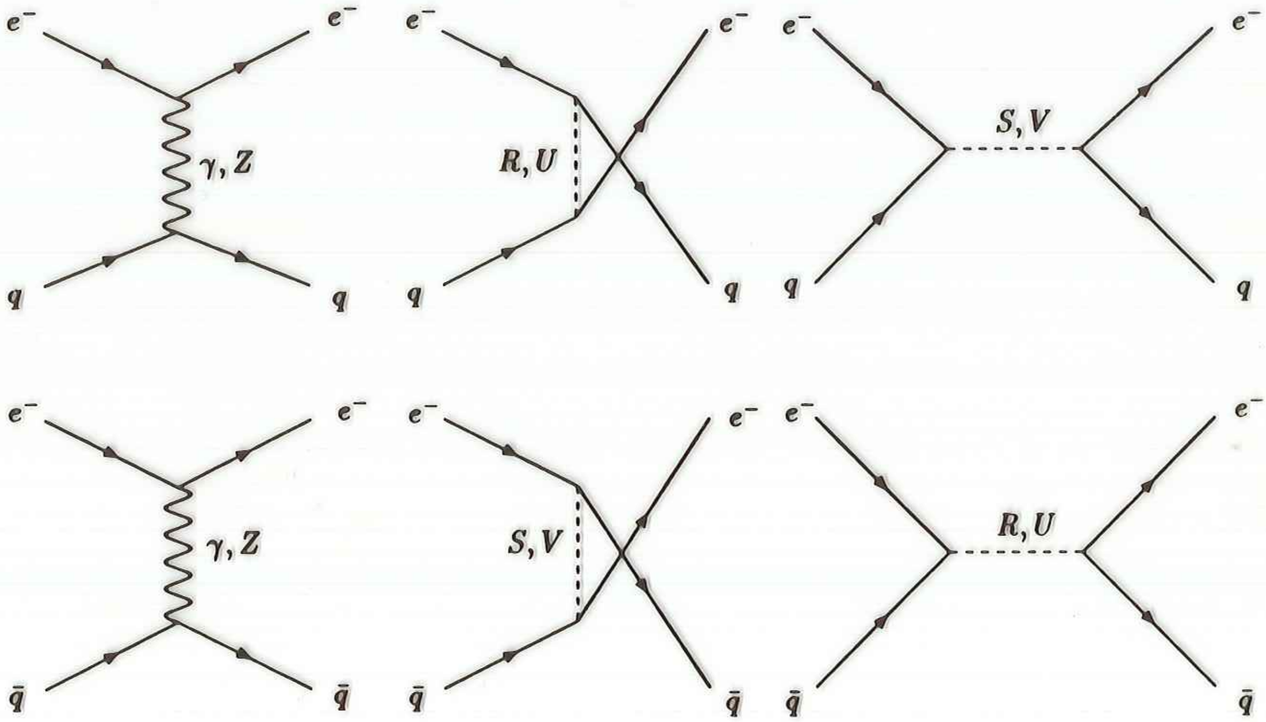


Fig. 4. Differential cross sections of unpolarized e^-p (a) and e^+p (b) scattering versus x at $\sqrt{s} = 314$ GeV and fixed $Q^2 = 10^4$ GeV^2. The full curves represent the theoretical distributions if a S_1 leptoquark exists with $m_{S_1} = 200$ GeV and $g_{1L} = 0.3$, $g_{1R} = 0$, while the dashed curves show the standard model predictions for $m_Z = 92$ GeV and $\sin^2\theta_w = 0.229$.

DIS :





2. Production Cross Sections

γ & g COUPLINGS OF ϕ_{S_i} & ϕ_{V_i} :

$$\mathcal{L} = \mathcal{L}_s + \mathcal{L}_v \tag{1}$$

with

$$\mathcal{L}_s = \sum_{scalars} \left[(D_\mu \Phi)^\dagger (D_\mu \Phi) - M_s^2 \Phi^\dagger \Phi \right] \tag{2}$$

and

$$\begin{aligned} \mathcal{L}_v \;=\; \sum_{vectors} \Big[& -ie \left(\kappa_{\gamma} \Phi_\mu^\dagger \Phi_\nu F^{\mu\nu} + \frac{\lambda_A}{M_v^2} \Phi_{\sigma\nu}^\dagger \Phi_\nu^\mu F^{\nu\sigma} \right) + (D_\mu\Phi_\nu - D_\nu\Phi_\mu)(D_\mu\Phi_\nu - D_\nu\Phi_\mu) \\ & - ig_s \frac{\lambda^a}{2} \left(\kappa_g \Phi_\mu^\dagger \Phi_\nu G_a^{\mu\nu} + \frac{\lambda_G}{M_v^2} \Phi_{\sigma\nu}^\dagger \Phi_\nu^\mu G_a^{\nu\sigma} \right) + M_v^2 \Phi_\mu^\dagger \Phi^\mu \Big] \end{aligned} \tag{3}$$

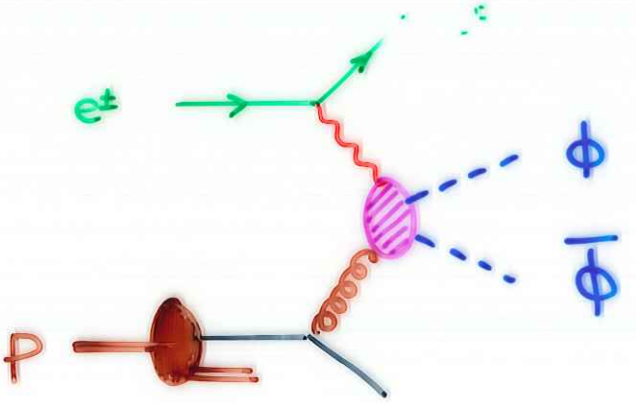
Here, the field strenth tensors of the photon–, gluon–, and vector leptoquark fields are

$$\begin{aligned} F_{\mu\nu} &= \partial_\mu A_\nu - \partial_\nu A_\mu, \\ G_{\mu\nu}^a &= \partial_\mu G_\nu^a - \partial_\nu G_\mu^a + i f^{abc} G_{\mu b} G_{\nu c}, \\ \Phi_{\mu\nu} &= D_\mu \Phi_\nu - D_\nu \Phi_\mu. \end{aligned} \tag{4}$$

The parameters $\kappa_{A,G}$ and $\lambda_{A,G}$ are assumed to be real numbers. They are related to the anomalous 'magnetic' moment[2] μ_Φ and 'electric' quadrupole moment q_Φ

$$\begin{aligned} \mu_{\Phi,a} &= \frac{g_a}{2M_\Phi}(1 + \kappa_a + \lambda_a) \\ q_{\Phi,a} &= -\frac{g_a}{M_\Phi^2}(\kappa_a - \lambda_a) \end{aligned} \tag{5}$$

$a = \gamma, g$



also:
PHOTOPRODUCTION.

WE CONSIDER THE DIRECT TERMS FOR THE MOMENT; RESOLVED CONTR. WILL ENLARGE THE SIGNAL FURTHER!

$KA = 1 - K_\gamma$

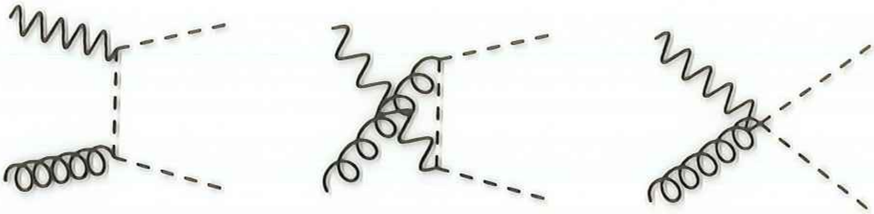
$KG = 1 - K_g$

$KA = KG = 1, \lambda_A = \lambda_G = 0 \Rightarrow$ Min

$KA = KG = 0, \lambda_A = \lambda_G = 0 \Rightarrow$ Y-M

2

'SEA-GULL'



$$\sigma_{s,v}(S, M_\Phi^2) = \int_0^1 dy \int_0^1 dx \phi_\gamma(y) G_{g/p}(x, \mu^2) \hat{\sigma}_{s,v}(\hat{s}, \beta) \theta(\hat{s} - 4M_\Phi^2) \tag{9}$$

with $\beta = \sqrt{1 - 4M_\Phi^2/\hat{s}}$.

IMPROVED WWA:

$$\phi_\gamma(y) = \frac{\alpha}{2\pi}\left[2m_e^2 y\left(\frac{1}{Q^2_{max}} - \frac{1}{Q^2_{min}}\right) + \frac{1+(1-y)^2}{y}\log\frac{Q^2_{max}}{Q^2_{min}}\right] \tag{7}$$

with

$$Q^2_{min} = \frac{m_e^2 y^2}{1-y} \qquad Q^2_{max} = yS - 4M_\Phi^2 - 4M_\Phi m_p \tag{8}$$

FRIXIONE et al. '93

- POSSIBILITY TO SEARCH FOR 2^{nd} & 3^{rd} GENERATION LQ's [μc]
  [τb] etc.
- SEARCH FOR $\begin{pmatrix} \text{JET} + \nu \\ \text{JET} + \ell \end{pmatrix} \otimes \begin{pmatrix} \text{JET} + \nu \\ \text{JET} + \ell \end{pmatrix}$ SIGNATURE.

HAS FERMILAB <u>ALL THESE</u> POSSIBILITIES DEFINITELY RULED OUT YET? (WINDOWS ...)

→ NO (COMPARABLE) FORMULAE FOR VECTORS YET!

2.1. Scalar Leptoquarks

$$\frac{d\hat{\sigma}_s}{d\cos\theta} = \frac{\pi\alpha\alpha_s(\mu^2)}{\hat{s}} T_R Q_\Phi^2 \beta \left\{1 - \frac{2(1-\beta^2)}{1-\beta^2\cos^2\theta} + \frac{2(1-\beta^2)^2}{(1-\beta^2\cos^2\theta)^2}\right\} \tag{10}$$

and

$$\hat{\sigma}_s(\hat{s},\beta) = \frac{\pi\alpha\alpha_s(\mu^2)}{\hat{s}} T_R Q_\Phi^2 \left\{2(2-\beta^2)\beta - (1-\beta^4)\log\left|\frac{1+\beta}{1-\beta}\right|\right\} \tag{11}$$

X- SECT. KNOWN SINCE
$\sim$ 1940 (UK)

$\rightarrow$ • NO UNITARITY VIOLATION FOR $s \to \infty$

• PARAM. DEPENDENCE:

$|Q_{em}(\Phi)|$ & M_Φ ONLY.

$= \frac{1}{3}, \frac{2}{3}, \frac{4}{3}, \frac{5}{3}$.

$\rightarrow$ NO λ_i DEPENDENCE

$\rightarrow$ CLEAN MASS BOUNDS CAN BE DERIVED.

2.2. Vector Leptoquarks

$$
\begin{aligned}
\frac{d\hat{\sigma}_v}{d\cos\theta} &= \frac{\pi\alpha\alpha_s(\mu^2)}{M_v^2} Q_\Phi^2 T_R \Big\{ F_0 + (\kappa_A + \kappa_G)F_1 + (\kappa_A^2 + \kappa_G^2)F_2 + \kappa_A\kappa_G F_3 \\
&+ \kappa_A\kappa_G(\kappa_A + \kappa_G)F_4 + \kappa_A^2\kappa_G^2 F_5 + (\lambda_A + \lambda_G)F_6 \\
&+ (\lambda_A^2 + \lambda_G^2)F_7 + \lambda_A\lambda_G F_8 + \lambda_A\lambda_G(\lambda_A + \lambda_G)F_9\lambda_A^2\lambda_G^2 F_{10} \\
&+ (\kappa_A\lambda_A + \kappa_G\lambda_G)F_{11} + (\kappa_A\lambda_G + \kappa_G\lambda_A)F_{12} \\
&+ \lambda_A\lambda_G(\kappa_A + \kappa_G)F_{13} + (\kappa_A^2\lambda_G + \kappa_G\lambda_A^2)F_{14} \\
&+ (\lambda_A\lambda_G(\kappa_A\lambda_G + \kappa_G\lambda_A)F_{15} + (\kappa_A^2\lambda_G + \kappa_G^2\lambda_A)F_{16} \\
&+ (\lambda_A^2\lambda_G^2 + \kappa_G^2\lambda_A^2)F_{17} + \kappa_A\kappa_G(\lambda_A + \lambda_G)F_{18} \\
&+ \kappa_A\kappa_G\lambda_A\lambda_G F_{19} + \kappa_A\kappa_G(\kappa_A\lambda_G + \kappa_G\lambda_A)F_{20}\Big\} \frac{1}{(1-\beta^2\cos^2\theta)^2}
\end{aligned}
\tag{12}
$$

The integrated cross section reads

$$
\hat{\sigma}_v = \frac{2\pi\alpha\alpha_s(\mu^2)}{M_v^2} Q_\Phi^2 T_R \sum_{j=0}^{20} \chi_j(\kappa_{A,G}, \lambda_{A,G}) \tilde{F}_j(\hat{s}, \beta) \;, \tag{13}
$$

$\kappa_A = 1 - \kappa_\gamma$
$\kappa_G = 1 - \kappa_g$
$\lambda_A = \lambda_\gamma ; \lambda_G = \lambda_g$

Here, the coefficients χ_j denote the respective combinations of $\kappa_{A,G}$ and $\lambda_{A,G}$ listed in (12) and

$$
\tilde{F}_j = \int_{-1}^{1} d\cos\theta \frac{F_j(\cos\theta)}{(1-\beta^2\cos^2\theta)^2} \tag{14}
$$

- A BIT MORE INVOLVED FORMULAE.
- EFFECTIVE LAGRANGIAN FOR LOW ENERGIES, FORMALLY UNITARITY VIOL. TERMS PRESENT

→ NOT CRITICAL FOR $s \sim 4M_\Phi^2$.
(THRESHOLD)

→ TO BE SUPPLEMENTED BY HIGGS etc. TERMS IN THE HE-LIMIT (REN. GUT).

$\boxed{\text{20 TERMS DUE TO } \kappa_{A,G}, \lambda_{A,G} \text{ COMBINATIONS}}$

$$
\begin{aligned}
\tilde{F}_0 &= \beta\left(\frac{11}{2}-\frac{9}{4}\beta^2+\frac{3}{4}\beta^4\right)-\frac{3}{8}\left(1-\beta^2-\beta^4+\beta^6\right)\ln\left|\frac{1+\beta}{1-\beta}\right| \qquad \text{YANG-MILLS}\\
\tilde{F}_1 &= -4\beta-\frac{3}{4}\left(1-\beta^2\right)\log\left|\frac{1+\beta}{1-\beta}\right| \qquad \propto \kappa_A+\kappa_G\\
\tilde{F}_2 &= \frac{1}{16}\beta\frac{\hat{s}}{M_\Phi^2}+\frac{3-\beta^2}{4}\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_3 &= 3\beta+\frac{1}{8}\beta\frac{\hat{s}}{M_\Phi^2}+\left(2-\frac{3}{2}\beta^2\right)\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_4 &= -\frac{1}{8}\beta\frac{\hat{s}}{M_\Phi^2}+\left(-1+\frac{3}{8}\beta^2\right)\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_5 &= -\frac{1}{96}\beta+\frac{5}{48}\beta\frac{\hat{s}}{M_\Phi^2}+\frac{4-\beta^2}{16}\log\left|\frac{1+\beta}{1-\beta}\right| \qquad \propto \lambda_A+\lambda_G\\
\tilde{F}_6 &= -\frac{1}{2}\left(1-\beta^2\right)\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_7 &= \frac{7}{12}\beta\frac{\hat{s}}{M_\Phi^2}+\frac{1}{24}\beta\frac{\hat{s}^2}{M_\Phi^4}-\frac{5+\beta^2}{4}\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_8 &= -\frac{1}{6}\beta+\frac{1}{4}\beta\frac{\hat{s}}{M_\Phi^2}-\frac{1}{12}\beta\frac{\hat{s}^2}{M_\Phi^4}+\left(-\frac{1}{2}+\frac{1}{2}\frac{\hat{s}}{M_\Phi^2}\right)\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_9 &= -\frac{1}{2}\beta+\frac{11}{12}\beta\frac{\hat{s}}{M_\Phi^2}-\frac{1}{6}\beta\frac{\hat{s}^2}{M_\Phi^4}-\frac{3+\beta^2}{8}\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_{10} &= -\frac{1}{96}\beta+\frac{59}{80}\beta\frac{\hat{s}}{M_\Phi^2}-\frac{113}{320}\beta\frac{\hat{s}^2}{M_\Phi^4}+\frac{43}{960}\beta\frac{\hat{s}^3}{M_\Phi^6}+\left(-\frac{1}{2}-\frac{1}{16}\beta^2+\frac{1}{8}\frac{\hat{s}}{M_\Phi^2}\right)\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_{11} &= \frac{1}{2}\left(1+\beta^2\right)\log\left|\frac{1+\beta}{1-\beta}\right| \qquad \propto \kappa_A\lambda_A+\kappa_G\lambda_G\\
\tilde{F}_{12} &= \beta+\frac{1}{2}\log\left|\frac{1+\beta}{1-\beta}\right| \qquad \propto \kappa_A\lambda_G+\kappa_G\lambda_A\\
\tilde{F}_{13} &= \beta-\frac{5}{12}\beta\frac{\hat{s}}{M_\Phi^2}+\frac{1}{24}\beta\frac{\hat{s}^2}{M_\Phi^4}+\left[-\frac{1}{4}\frac{\hat{s}}{M_\Phi^2}+\left(\frac{3}{8}+\frac{1}{4}\beta^2\right)\right]\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_{14} &= -\frac{11}{24}\beta\frac{\hat{s}}{M_\Phi^2}-\frac{1}{24}\beta\frac{\hat{s}^2}{M_\Phi^4}\frac{9+3\beta^2}{8}\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_{15} &= \frac{1}{48}\beta-\frac{59}{96}\beta\frac{\hat{s}}{M_\Phi^2}+\frac{5}{64}\beta\frac{\hat{s}^2}{M_\Phi^4}+\frac{5+\beta^2}{8}\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_{16} &= -\frac{1}{2}\beta-\frac{1}{8}\beta^2\log\left|\frac{1+\beta}{1-\beta}\right| \qquad \propto \kappa_A^2\lambda_G+\kappa_G^2\lambda_A\\
\tilde{F}_{17} &= -\frac{1}{96}\beta+\frac{1}{48}\beta\frac{\hat{s}}{M_\Phi^2}+\frac{1}{48}\beta\frac{\hat{s}^2}{M_\Phi^4}-\frac{2+\beta^2}{16}\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_{18} &= -\frac{1}{4}\beta\frac{\hat{s}}{M_\Phi^2}-\frac{1-6\beta^2}{8}\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_{19} &= -\frac{1}{24}\beta+\frac{7}{96}\beta\frac{\hat{s}}{M_\Phi^2}+\frac{3}{64}\beta\frac{\hat{s}^2}{M_\Phi^4}+\left[\frac{1}{8}\frac{\hat{s}}{M_\Phi^2}-\frac{2+\beta^2}{4}\right]\log\left|\frac{1+\beta}{1-\beta}\right|\\
\tilde{F}_{20} &= \frac{1}{48}\beta+\frac{1}{6}\beta\frac{\hat{s}}{M_\Phi^2}-\frac{1}{8}\left(1-\beta^2\right)\log\left|\frac{1+\beta}{1-\beta}\right|
\end{aligned}
\tag{16}
$$

ZEUS

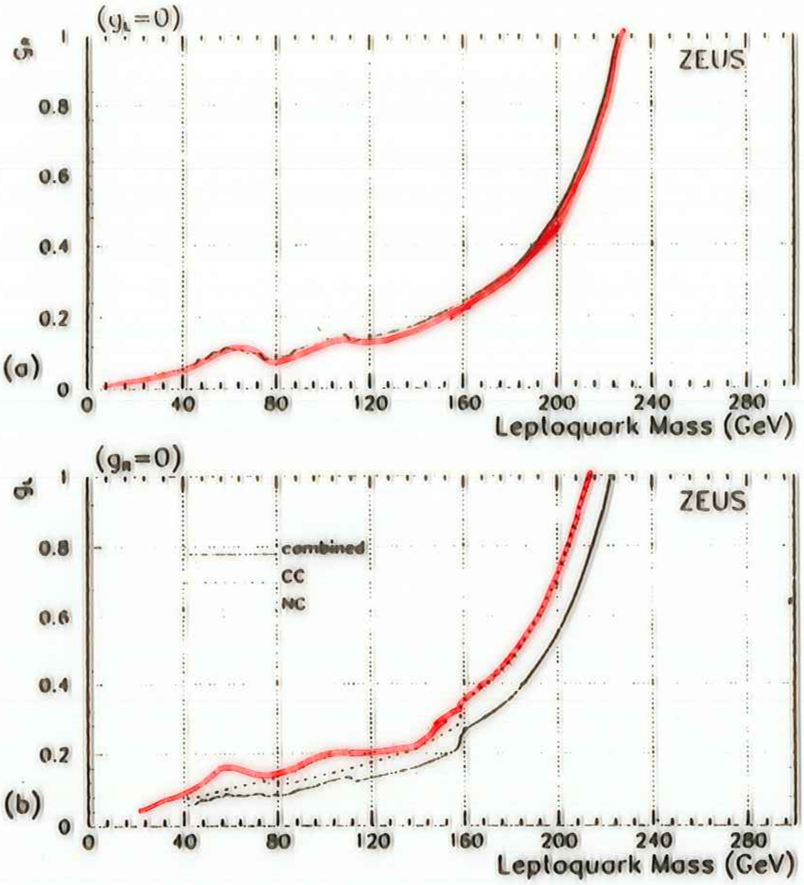


Fig. 2. The 95% confidence upper limits on the couplings of scalar leptoquarks with zero weak isospin and fermion number $F = -2$ versus the leptoquark mass in GeV. (a) The right-handed coupling limit from the NC decay mode with $b = 1$. (b) Assuming $b = \frac{1}{2}$, the left-handed coupling calculated from the NC data sample (dotted), from the CC data sample (dashed), and from the combined samples (solid). To obtain the limit for other branching fraction assumptions, the ordinate of the NC (CC) curve should be multiplied by $\sqrt{0.5/b}$ [$\sqrt{0.5/(1-b)}$]. Because the limits from NC and CC are similar at larger masses, the combined left-handed coupling limit at large mass is largely independent of b.

H1

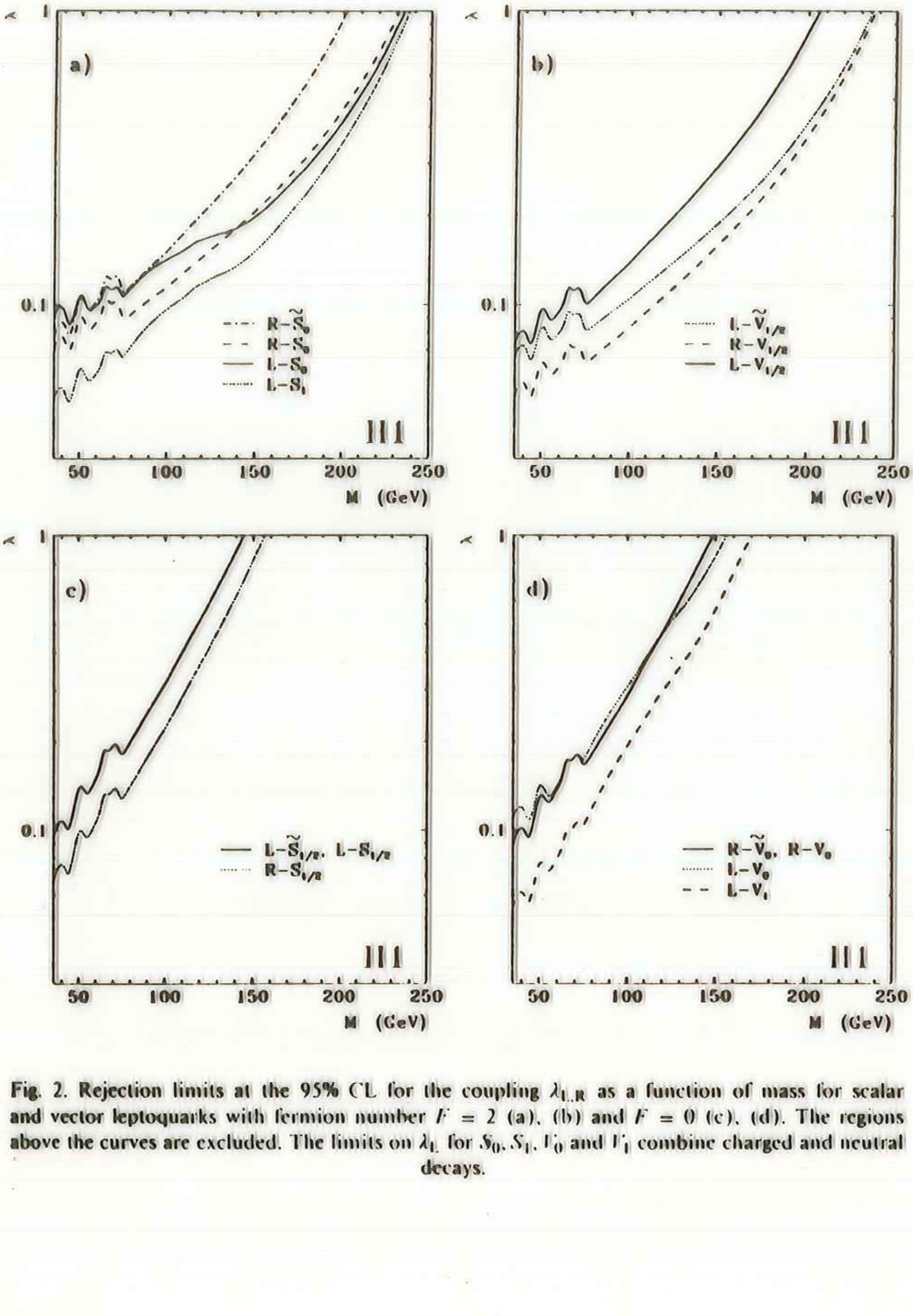


Fig. 2. Rejection limits at the 95% CL for the coupling $\lambda_{L,R}$ as a function of mass for scalar and vector leptoquarks with fermion number $F = 2$ (a), (b) and $F = 0$ (c), (d). The regions above the curves are excluded. The limits on λ_L for S_0, S_1, V_0 and V_1 combine charged and neutral decays.

3. Numerical Results

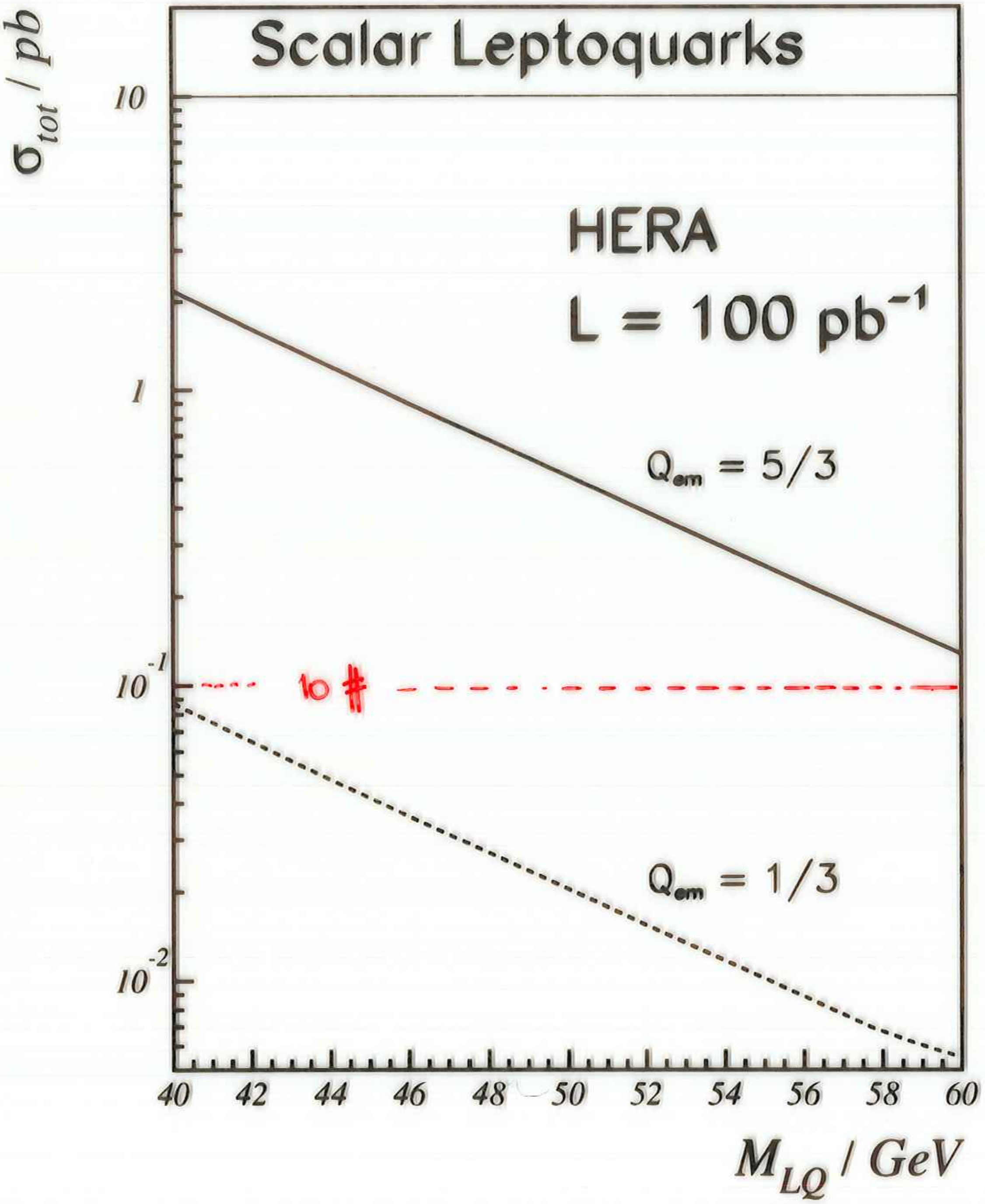
- PHOTOPRODUCTION
  - DIRECT TERMS γ-g-fusion , LO
  - CTEQ2 + IMPROVED WWA.

- HERA , $\mathcal{L} = 100\ pb^{-1}$
- LEP1 x LHC , $\mathcal{L} = 1\ fb^{-1}$

VECTORS : 'MINIMAL COUPLING'

(EXAMPLE)

$$\kappa_{A,G} \equiv -1$$
$$\lambda_{A,G} \equiv 0$$



Scalar Leptoquarks
HERA
L = 100 pb⁻¹
$Q_{em} = 5/3$
$Q_{em} = 1/3$
10 #
σ_{tot} / pb
10
1
10^{-1}
10^{-2}
40
42
44
46
48
50
52
54
56
58
60
M_{LQ} / GeV

DELPHI '93

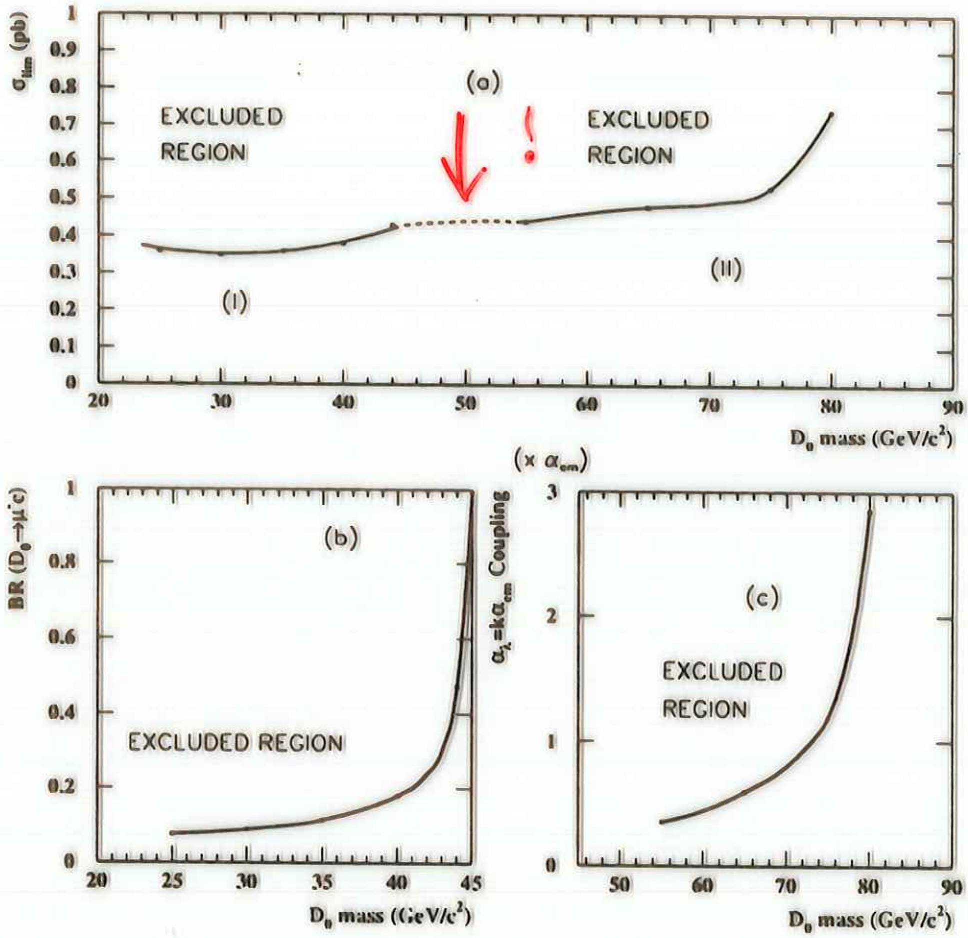
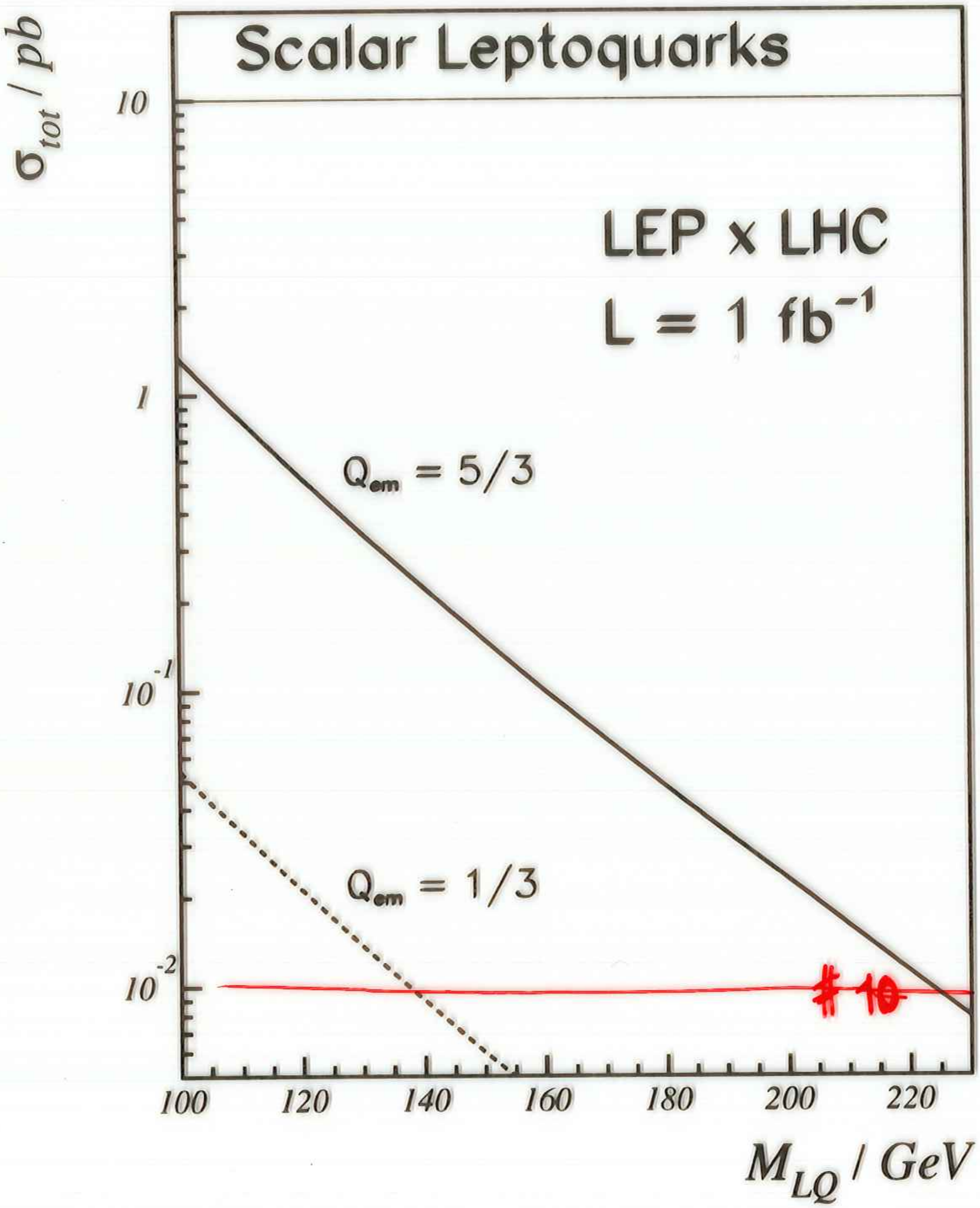
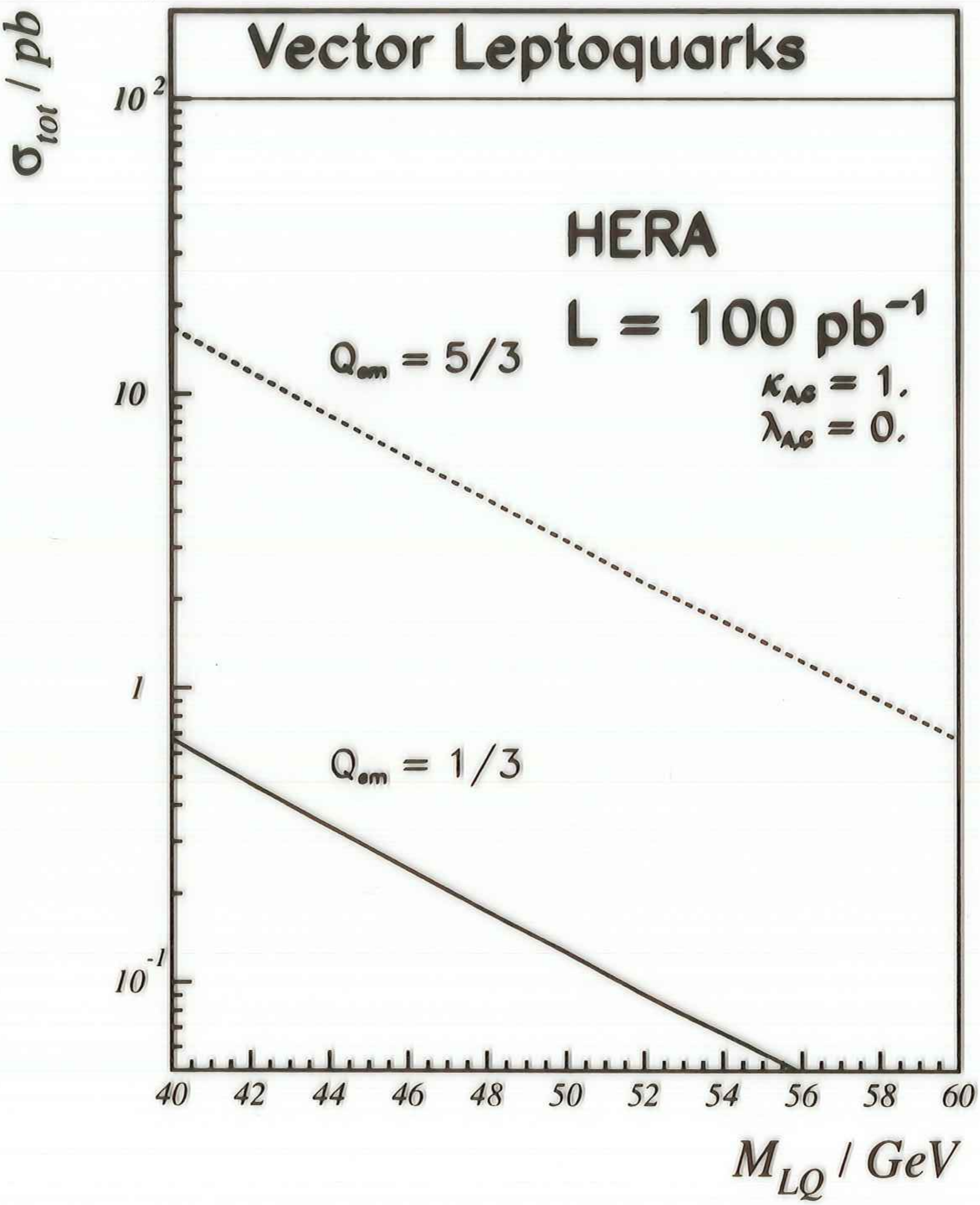


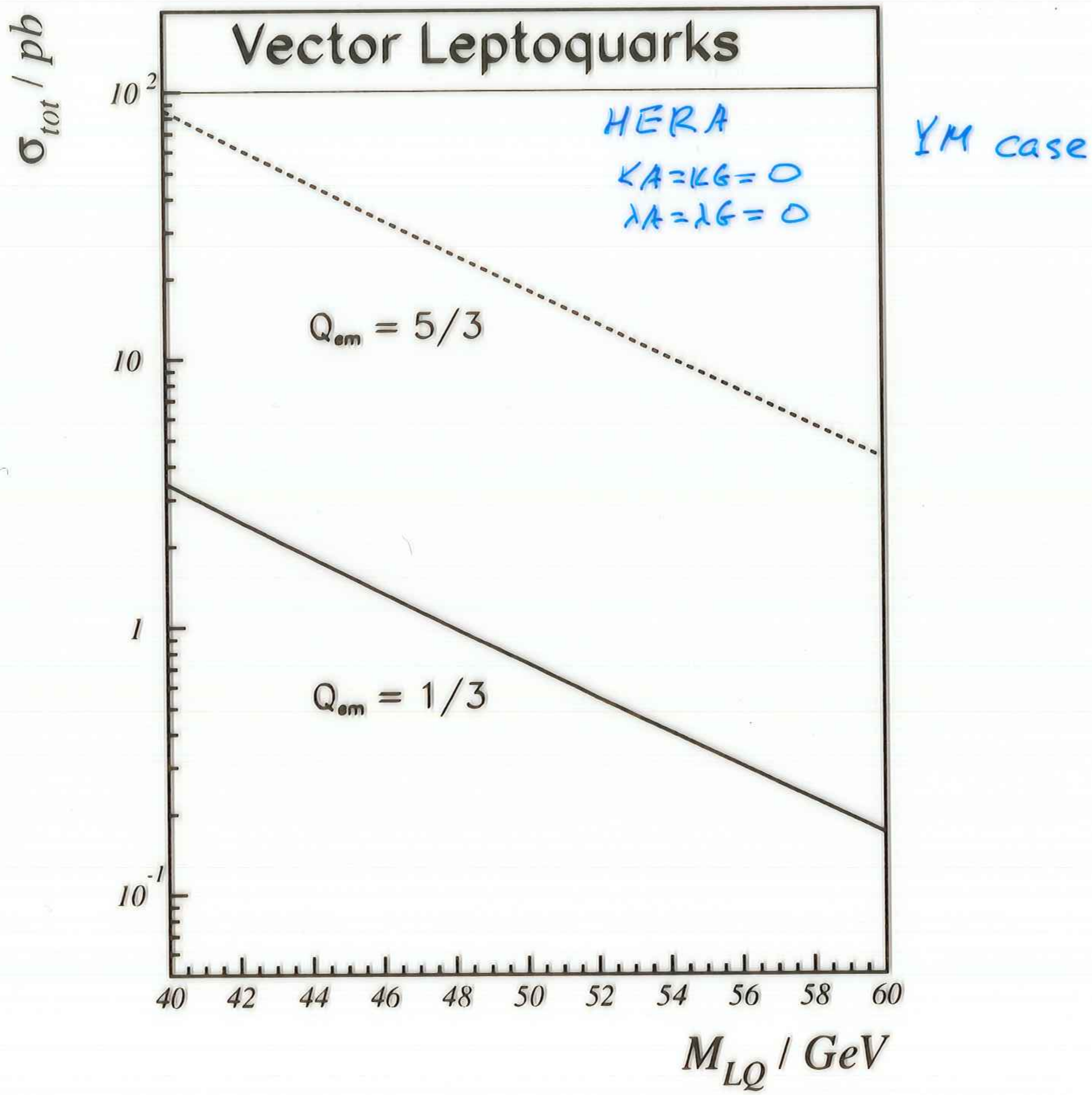
Fig. 3. Limits at 95% CL for a scalar leptoquark with charge $Q = -\frac{1}{3}$: (a) Model-independent cross-section limits as a function of the mass for a leptoquark of the second generation $D_0 \to \mu^- c$) with BR = 100% for (I) pair and (II) single production. (b) The contour in the plane of mass and branching ratio for the second generation ($D_0 \to \mu^- c$) pair produced leptoquarks. (c) Limits on the $D_0 l q$ Yukawa coupling as a function of the mass for the second generation single leptoquark production of the E_6 inspired model with $Q = -\frac{1}{3}$ and BR = $\frac{2}{3}$.

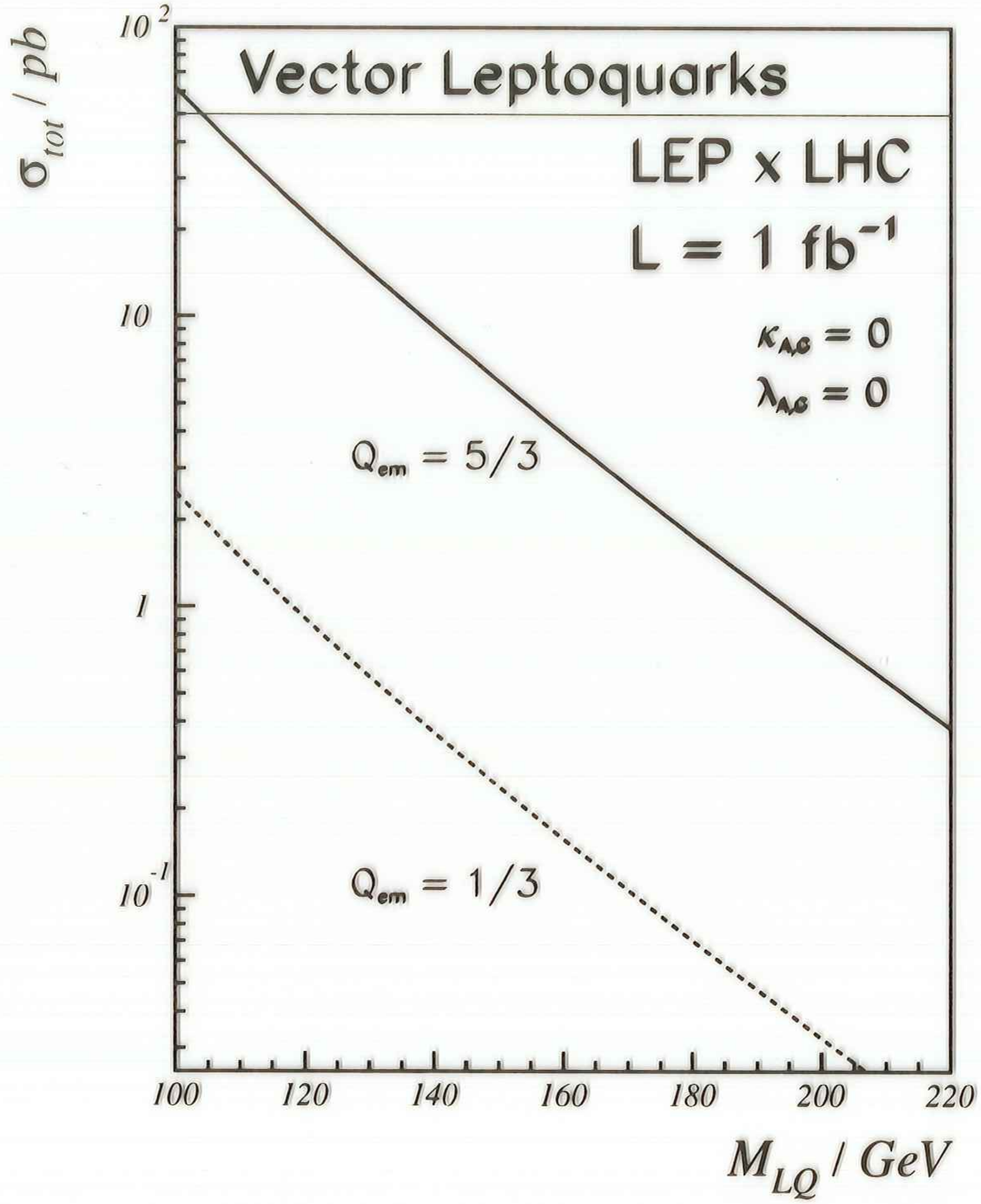


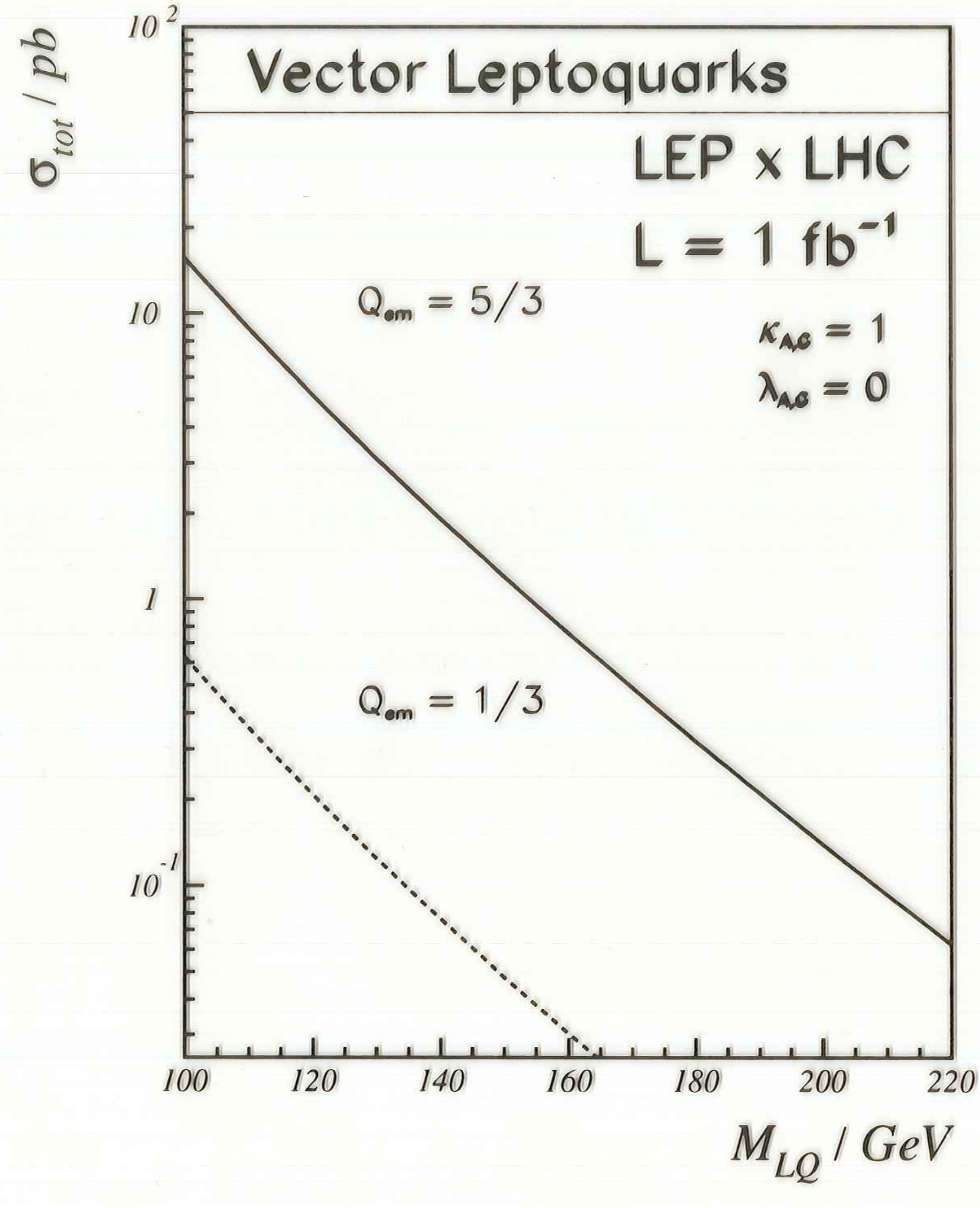
Scalar Leptoquarks
LEP x LHC
L = 1 fb^{-1}
Q_{em} = 5/3
Q_{em} = 1/3
10
σ_{tot} / pb
10
1
10^{-1}
10^{-2}
100
120
140
160
180
200
220
M_{LQ} / GeV



Minimal case


Vector Leptoquarks
HERA
κA=κG=0
λA=λG=0
YM case
Qem = 5/3
Qem = 1/3
σtot / pb
10 2
10
1
10 -1
40
42
44
46
48
50
52
54
56
58
60
MLQ / GeV


Vector Leptoquarks
LEP x LHC
L = 1 fb^{-1}
$\kappa_{A,G} = 0$
$\lambda_{A,G} = 0$
$Q_{em} = 5/3$
$Q_{em} = 1/3$
σ_{tot} / pb
10^2
10
1
10^{-1}
100
120
140
160
180
200
220
M_{LQ} / GeV



Vector Leptoquarks
LEP x LHC
L = 1 fb^{-1}
Q_{em} = 5/3
$\kappa_{A,G}$ = 1
$\lambda_{A,G}$ = 0
Q_{em} = 1/3
σ_{tot} / pb
10^2
10
1
10^{-1}
100
120
140
160
180
200
220
M_{LQ} / GeV

4. Conclusions

1) THE STUDY OF LQ-PAIR PRODUCTION IN ep-PHOTOPRODUCTION ALLOWS TO DERIVE MASS-BOUNDS AND NOT ONLY $M_\phi - \lambda_{\phi i}$-LIMITS.

2) ONE MAY TEST AND/OR CONSTRAIN THE COLOR & CHARGE (EM.) STRUCTURE OF VECTOR LQ'S. → $\kappa_i - \lambda_i$ - LIMITS.

3) IF HERA REACHES $\mathcal{L} = 100\,pb^{-1}$ BEFORE LEP-2 OPERATES FULLY OPEN (YET) MASS WINDOWS MAY BE CLOSED.

- The resolved photon contribution has to be calculated
- Simulation of all backgrounds has to be done