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Contact interactions at Hera, LEP and Tevatron

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Abstract. Current experimental limits on 4-fermions Contact Interactions at Hera, LEP and Tevatron are reviewed.

1 Introduction

Four fermions Contact Interactions (CI) parametrise interactions beyond the Standard Model by an effective energy scale Λ. The new Lagrangian is of the form [1]:

$$\mathrm{L}^{\mathrm{CI}} = \frac{4\pi}{\Lambda^2_{\mathrm{ef}}} \sum \eta_{\mathrm{ij}} (\mathrm{e}^{\mathrm{i}} \gamma^{\mu} \mathrm{e}_{\mathrm{i}})(\mathrm{f}^{\mathrm{j}} \gamma_{\mu} \mathrm{f}_{\mathrm{j}})$$

where parameters η_{ij}'s specify the relative contributions of the helicity states of the initial (e) and final (f) fermions involved in the new interaction, defining several models. The most commonly referenced models are listed in the Table 1. The new current can have a constructive or destructive interference with the Standard Model, and limits are labelled Λ^+ and Λ^-.

Table 1. Definition of the most common CI models

	LL	RR	LR	RL	VV	AA	V0 (X3)	A0 (X4)
η_{LL}	1	0	0	0	1	1	1	0
η_{RR}	0	1	0	0	1	1	1	0
η_{LR}	0	0	1	0	1	-1	0	1
η_{RL}	0	0	0	1	1	-1	0	1

Experiments operating on the colliders Hera, LEP and Tevatron are sensitive to couplings between different initial and final state fermions.

2 Hera

Hera is sensitive to e-q interactions and due to the parton distribution inside the proton, essentially to e-u and e-d couplings. Limits are derived from the differential cross-section of the neutral current $d\sigma^{NC}/dQ^2$ and exploit data taken in the configurations e^-p at $\sqrt{s} = 319$ GeV and e^+p at $\sqrt{s}$ 301 GeV and 319 GeV, cumulating a total luminosity close to 120 pb^{-1} per experiment. H1 has finalised its analysis [2] of the Neutral Current and from the absence of deviation with respect to the predictions, limits ranging between 1.6 to 5.5 TeV on Λ^- and between 2.8 to 5.3 TeV on Λ^+ are obtained. Figure 1 details the limits for several models.

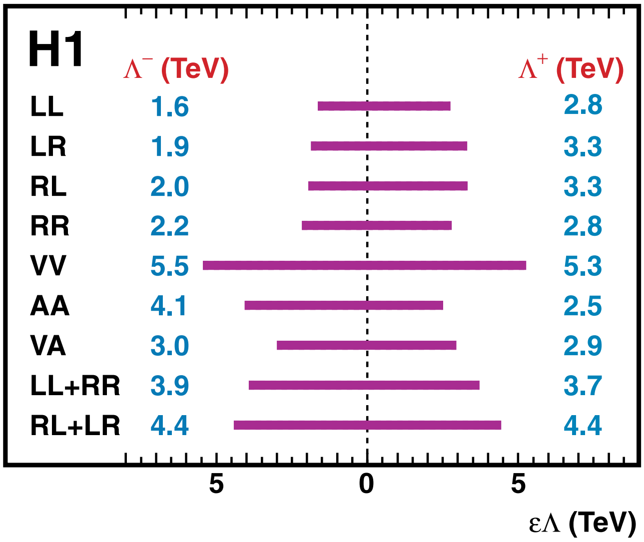

Fig. 1. Final limits from H1 on several models of Contact Interactions [2]

3 Tevatron

CDF and D0 have a unique sensitivity to 4 quarks and $q-\mu$ couplings, involving essentially valence quarks. With a luminosity of 110 pb^{-1} per experiment taken at Run I at $\sqrt{s} = 1.8$ TeV, limits of the order of 2 to 5 TeV [3],[4] could be set on Λ, using the di-jet or di-muons mass distributions.

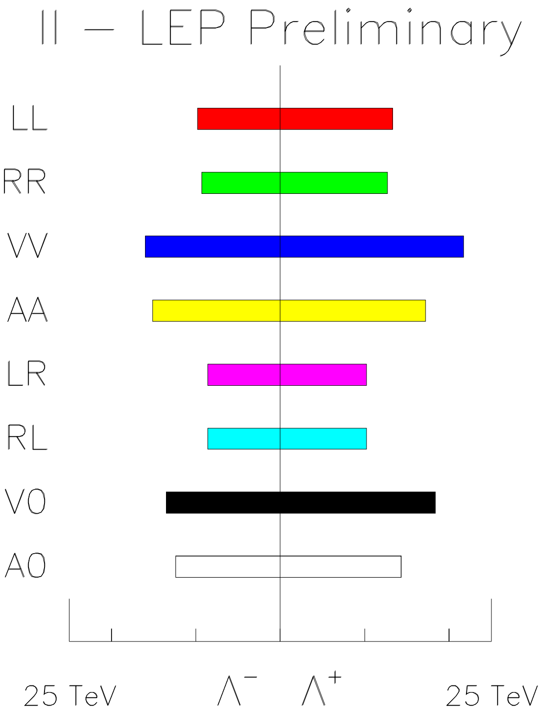

Fig. 2. Limits on the scale of CI in $e^+e^- \to \mu^+\mu^- + \tau^+\tau^-$ using LEP combined measurements from 130 to 209 GeV

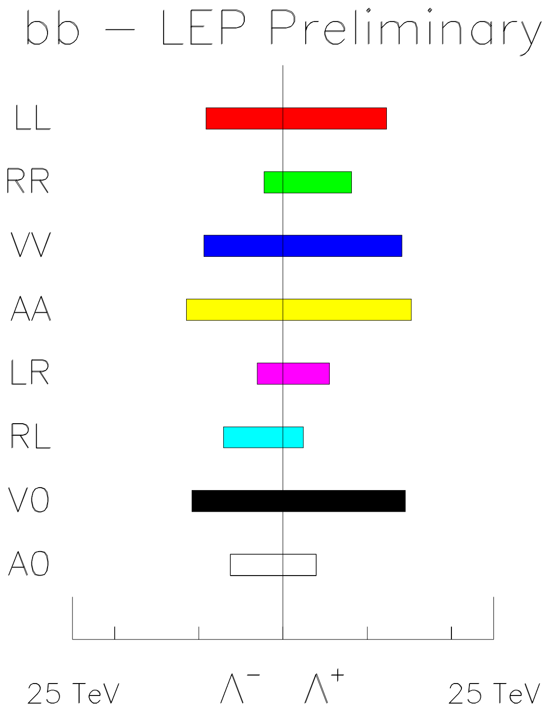

Fig. 3. Limits on the scale of CI in $e^+e^- \to b\bar{b}$ using LEP combined measurements from 130 to 209 GeV

4 LEP

The LEP experiments are sensitive to 4 leptons interaction, heavy quarks final state and neutrinos final state. Contact Interactions indirect effects could be seen in total and differential hadronic and leptonic cross-sections, leptonic asymmetries or heavy flavours observables R_b, R_c, A^b_{FB} and A^c_{FB}. The 4 LEP experiments cumulated a total luminosity close to 2.8 fb^{-1} taken at centre-of-mass energies ranging between 130 to 209 GeV.

The preliminary LEP-combined measurements [5] of the electroweak observables did not show any deviation from the Standard Model predictions. Therefore limits on Λ^+ and Λ^- were derived. Some results are shown in Fig. 2 for the combined $\mu^+\mu^-$ and $\tau^+\tau^-$ final state and in Fig. 3 for the bb final states.

LEP is also sensitive to CI with neutrino final state through the single photon topology. Delphi has performed such an interpretation [6] using the parametrisation $\varepsilon \times G_F$ ($\approx 4\pi/2\sqrt{2}\Lambda^2$ [7]) The exclusion contours obtained in 3 different hypothesis for the final state ($\nu_e\overline{\nu_e}, \nu_\tau\overline{\nu_\tau}, \nu_\alpha\nu_\beta$) are shown in Fig. 4.

Finally, the Single Top production would inevitably sign New Physics since the production in the Standard Model is smaller than 10^{-9} fb [8]. The absence of signal was interpreted in terms of CI by Delphi [9] and L3 [10]. The Non Standard cross-section can include tensor, vectorial and scalar contributions [11]. Limits ranging between 0.5 to 1.3 TeV are obtained depending on the models.

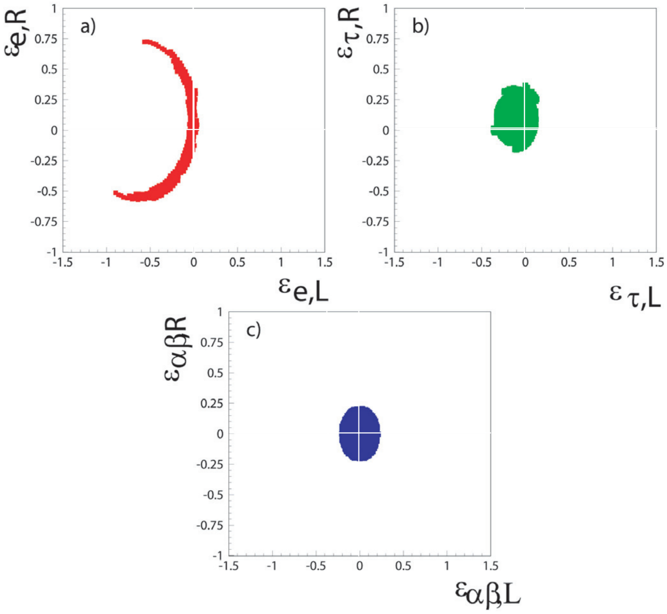

Fig. 4. DELPHI PRELIMINARY: Exclusion contour for CI involving neutrinos final state where L/R refers to the helicity of the incoming electrons. a) The region in the $\varepsilon_{eL} - \varepsilon_{eR}$ plane which is not excluded b) The region in the $\varepsilon_{\tau L} - \varepsilon_{\tau R}$ plane which is not excluded. c) The region in the $\varepsilon_{\alpha\beta L} - \varepsilon_{\alpha\beta R} (\alpha \neq \beta)$ plane which is not excluded

5 Interpretations in terms of specific models

Although Contact interactions were initially formulated in the scope of compositeness, they can be interpreted in other specific extensions of the Standard Model. A selection are reviewed in the following subsections.

5.1 Extra Z bosons

Additional heavy gauge bosons, Z', are predicted by many theories. Indirect effects could be seen at LEP in the combined hadronic and leptonic cross-sections and asymmetries. Table 2 presents lower limits on the Z' mass for some specific models χ, ψ, η from the E6-GUT group, for L-R extension group and for a Sequential Standard Model (SSM) Z'.

Table 2. 95% confidence level lower limits on the Z' mass and $\mathrm{E}_6(\chi), E_6(\psi), E_6(\eta)$, L-R and SSM models [5]

Model:	χ	ψ	η	L-R	SSM
$\mathrm{m}^{l}_{Z'}im$ (GeV)	673	481	434	804	1787

5.2 Extra dimensions

Recently, theories of quantum gravity with extra spatial dimensions have suggested a way to go around the hierarchy problem [12]. The graviton would propagate in 4 + n compactified spatial dimensions resulting in a Kaluza-Klein tower, whereas the SM particles stay in the usual dimensions. This results in an effective Planck scale which could as low as the electroweak scale. At colliders, the KK graviton could be exchanged between fermions pairs. Within the "Hewett" scheme [13], preliminary limits on the cut-off M_s using the LEP combined di-electron differential cross-sections [5] is 1.2 TeV (resp. 1. TeV) supposing negative (resp. positive) interference. Final H1 limits [2] in the "GRW" scheme [14] are respectively 0.780 and 0.820 TeV.

5.3 Leptoquarks

Leptoquarks would mediate lepton-quark transitions. Within the effective model [15], 14 types are identified, distinguishing coupling to either L or R leptons exclusively. Following the basis in [16], leptoquarks could be exchanged in the processes $\mathrm{e}^+e^- \longrightarrow q\bar{q}$ at LEP and $\mathrm{e}^\pm(u/d) \longrightarrow e^\pm(u/d)$ at Hera. Limits on the mass of the leptoquark over its coupling are given in Table 3. It should be noted that LEP and Hera provide complementary limits.

Table 3. 95% confidence level lower limits on $M_{LQ}(GeV)/g$. A - indicates that no limits could be set. NB: The quoted LEP numbers are extrapolated from limits given for a coupling $\sqrt{4\pi\alpha}$

LQ type	H1 Final limits [2]	LEP Prelim. [5]
$S_0(L)$	710	2150
$S_0(R)$	640	1700
$\tilde{S}_0(R)$	330	660
$S_1(L)$	490	1190
$S_{1/2}(L)$	850	590
$S_{1/2}(R)$	370	770
$\tilde{S}_{1/2}(L)$	430	-
$V_0(L)$	730	3020
$V_0(R)$	580	540
$\tilde{V}_0(R)$	990	1610
$V_1(L)$	1360	2170
$V_{1/2}(L)$	420	1000
$V_{1/2}(R)$	950	750
$\tilde{V}_{1/2}(L)$	1020	580

6 Conclusion

Indirect searches did not reveal New Physics so far. Tevatron with its upgraded energy and Hera with its specific polarisation program will probe the Standard Model further.

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