New Physics Phenomena in Fermion-Pair Production

S. Riemann (DESY Zeuthen)

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Outline:

- Contact interaction
- Exchange of leptoquarks
- Exchange of Z'
- Summary

Four-fermion contact interaction (CI)

- general framework to describe interactions beyond the SM at energy scale Λ

$$\mathcal{L}_{eff} \sim \sum_{i,k=L,R} \eta_{ik} \frac{g^2}{\Lambda_{ik}^2} (\bar{e}_i \gamma^\mu e_i)(\bar{f}_k \gamma^\mu f_k)$$

η_{ij} defines C.I. model: $|\eta_{ij}|$=0 or $|\eta_{ij}| = 1$
i, j=L,R helicity;
$g^2/4\pi = 1$ by convention

- Polarization effects:
see ~~also~~ talk of N. Paver in Frascati

$$\frac{d\sigma_{L,R}}{d\cos\theta} = \sum_{i,j=\mathsf{L},\mathsf{R}} \rho_{i,j} |\mathcal{A}_{i,j}|^2$$

with helicity amplitudes

$$\mathcal{A}^{ef}_{i,k} = \left(Q_e Q_f + C^e_i C^f_k \chi + \eta_{i,k} \frac{s}{\alpha} \frac{1}{\Lambda^2} \right) \frac{t}{s};$$

$$i,k = \mathsf{L},\mathsf{R}; \quad i \neq k,$$

$$\mathcal{A}^{ef}_{i,i} = \left(Q_e Q_f + C^e_i C^f_i \chi + \eta_{i,i} \frac{s}{\alpha} \frac{1}{\Lambda^2} \right) \frac{u}{s};$$

$$i = \mathsf{L},\mathsf{R}.$$

$$\chi(s) = \frac{s}{s - m^2_{\mathsf{Z}} + is\Gamma_{\mathsf{Z}}/m_{\mathsf{Z}}}; \quad \chi(t) = \frac{t}{t - m^2_{\mathsf{Z}}},$$

$$C^f_{\mathsf{L}} = v_f + a_f$$

$$C^f_{\mathsf{R}} = v_f - a_f.$$

$$\frac{d\sigma}{d\cos\theta} = \frac{d\sigma^{\mathrm{SM}}}{d\cos\theta} + C_2(s,\cos\theta)\frac{1}{\Lambda^2} + C_4(s,\cos\theta)\frac{1}{\Lambda^4}$$

C.I. models

Model	η_{LL}	η_{RR}	η_{LR}	η_{RL}
LL	± 1	0	0	0
RR	0	± 1	0	0
LR	0	0	± 1	0
RL	0	0	0	± 1
VV	± 1	± 1	± 1	± 1
AA	± 1	± 1	∓ 1	∓ 1
LL+RR	± 1	± 1	0	0
LR+RL	0	0	± 1	± 1
LL−RR	± 1	∓ 1	0	0

LL-RR $\Longleftrightarrow$ worst case

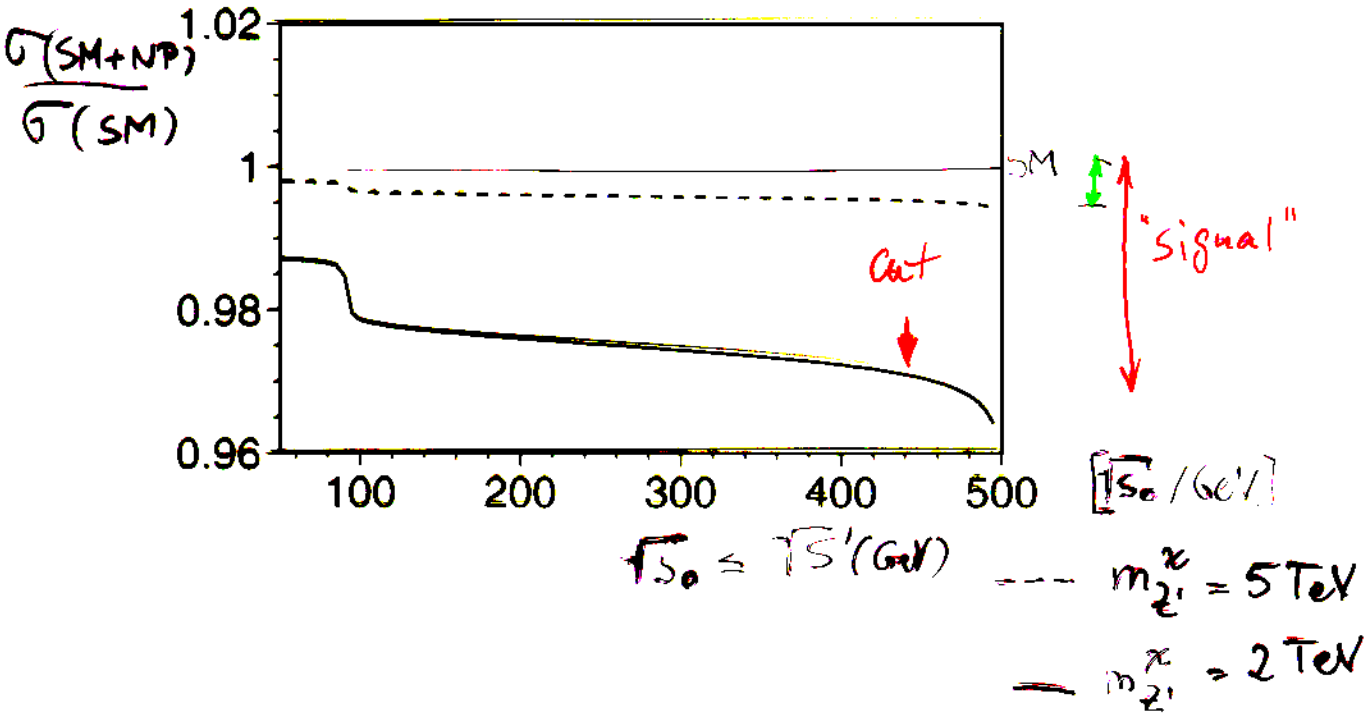
In the following:

- Λ_+ gives limits related to 'upper' sign of η
- Λ_- gives limits related to 'lower' sign of η

APV NOT sensitiv to parity conserving models

Sensitivity to New Physics Effects

- return to the $\bar{Z}$ peak due to ISR (acollinear events)



- non–radiative events – sensitive to NP

$$\frac{\sqrt{s'}}{\sqrt{s}} = \left(1 - \frac{E_\gamma}{E_{beam}}\right) > \frac{m_Z^2}{s}$$

LC: $\sqrt{s'} > 0.9\sqrt{s}$

More details on QED: see talk of M. Jack, T. Riemann

Consider:

- $\sqrt{s} = 0.5$ TeV
- $\mathcal{L}_{int} = 50$ fb^{-1}
- experimental errors:
  - ee $\rightarrow \mu\mu$:
    $\epsilon = 0.95$
    $\Delta sys = 0.5\%$
  - ee $\rightarrow$ bb:
    $\epsilon = 0.65$
    $\Delta sys = 1.0\%$
  - ee $\rightarrow$ cc:
    $\epsilon = 0.35$
    $\Delta sys = 1.5\%$
- Perform χ^2 fit

$\sqrt{s} = 0.5\,\text{TeV}$

$\alpha_{int} = 50\,\text{fb}^{-1}$

Expected Limits for Four-Fermion Contact Interaction

95% Lower Limits on Λ in TeV) $(P=0)$

	LL	RR	RL	LR
ee→ $\mu\mu$	27	26	18	18
	35	33	23	23
ee→ bb	23	13	12	11
	44	30	23	22
ee→ cc	20	17	10	12
	33	28	15	20

$\sqrt{s'} = 0.1\sqrt{s}$

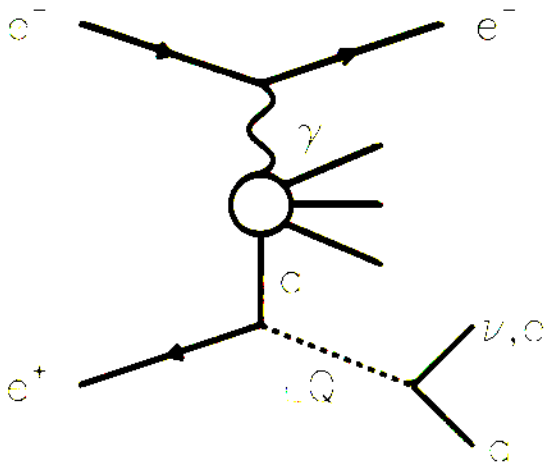
$\sqrt{s'} = 0.9\sqrt{s}$

Expect limits on $\Lambda > (30 \ldots 90) \cdot \sqrt{s}$

Direct Search for Leptoquarks

LQ pair production: $m_{LQ} > \sqrt{s}/2$ if not seen (or find them)
see Blümlein

Production of single LQ



Signature:

- 1 high E_T jet recoiling against electron
- 1 monojet

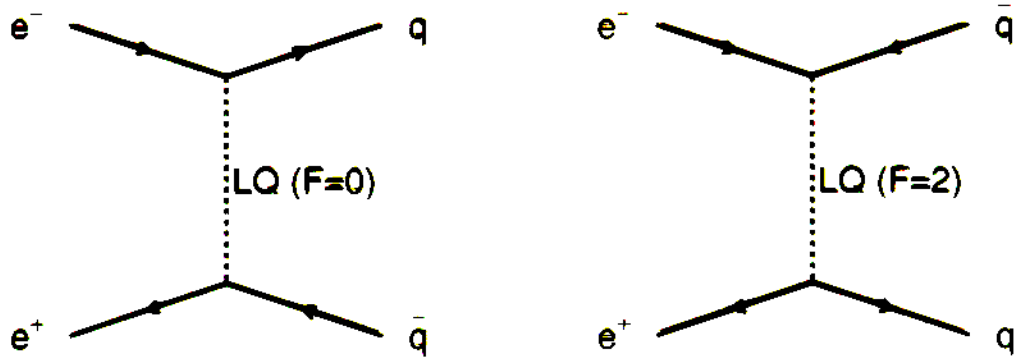
Assume: $g_{LQ} = \sqrt{4\pi\alpha_{em}}$

At LEP2: limits competetive with indirect searches
At LC: expect ~~1~~ 450 Gev (see Snowmass '96)

If no LQ is found → indirect searches in e^+e^- → hadrons

Exchange of Leptoquarks

- LQ's could be exchanged in ee→hadrons in u-channel ($F = L + 3B = 2$) and in t-channel ($F = 0$):



Details see Kalinowski et al., Consider:

- S_o, S_1, $\tilde{S}_o$, $S_{1/2}$, $\tilde{S}_{1/2}$
- V_o, V_1, $\tilde{V}_o$, $V_{1/2}$, $\tilde{V}_{1/2}$

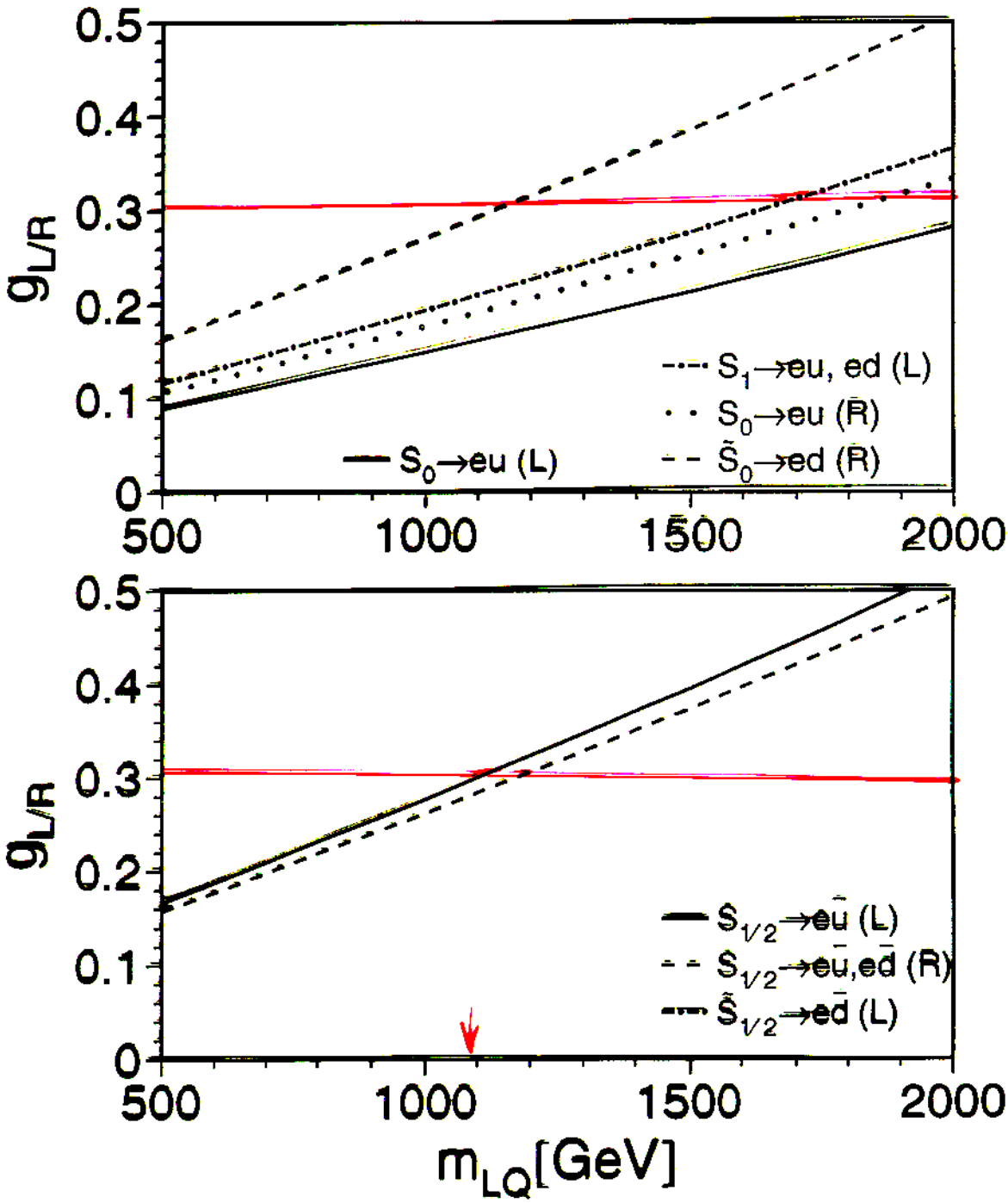
$g_L \neq 0$; $g_R = 0$
$g_R \neq 0$; $g_L = 0$

Remark:

- Bounds on g_L (g_R) of S_o ($\tilde{S}_o$) exchange agree with bounds on λ'_{1jk} from exchange of scalar down-type (up-type) quarks in u-channel (t–channel)

Expected Limits on Scalar Leptoquarks

($\sqrt{s} = 0.5$ TeV , $\mathcal{L}_{int} = 50 fb^{-1}$, $P = 0$)

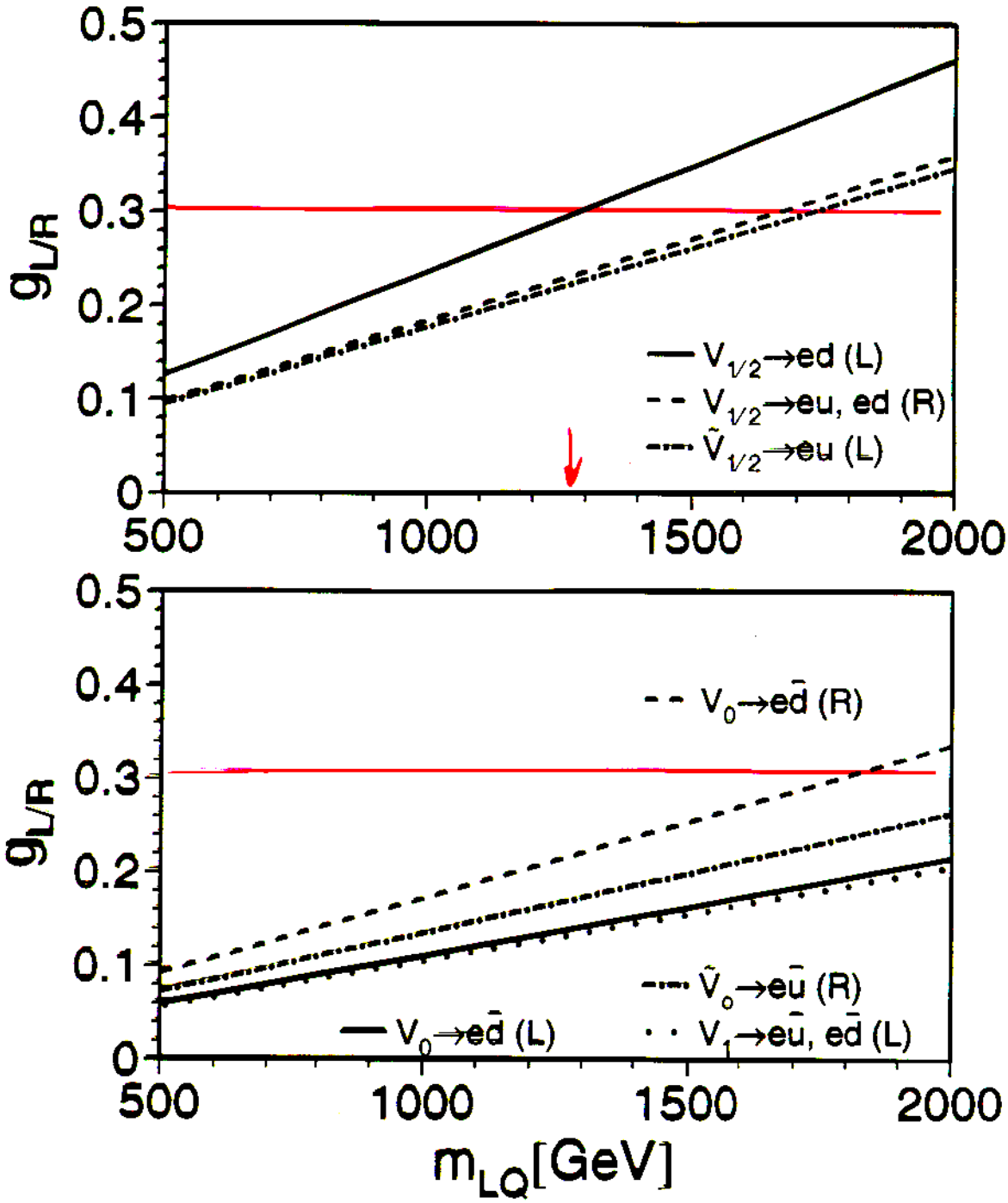


With $g = \sqrt{4\pi \alpha_{em}} \approx 0.3$

$m_{LQ} > 1.1$ TeV

Expected Limits on ~~Scalar~~ Vector LQ's

($\sqrt{s} = 0.5$ TeV
$\mathcal{L}_{int} = 50\ fb^{-1}$, $P = 0$)



With $g = \sqrt{4\pi\,\alpha_{em}} \approx 0.3$

$m^{S}_{LQ} > 1.3$ TeV

Search for Extra Z Bosons

$$\mathcal{L} = eA_\mu J^\mu_\gamma + g Z^0_\mu J^\mu_{Z^0} + g' Z'^0_\mu J^\mu_{Z'^0}$$

Z′ couplings to fermions:

- defined by GUT models (model-dependent Z′ search), mass limits can be derived
- model-blind Z′ search; Sensitivity only to normalizd couplings,

$$a^f_N = a' \sqrt{s/m^2_{Z'} - s} \qquad v^f_N = v' \sqrt{s/m^2_{Z'} - s}$$

(see contributions to earlier workshops)

SR, A. Leike, A. Pankov, V. Paver

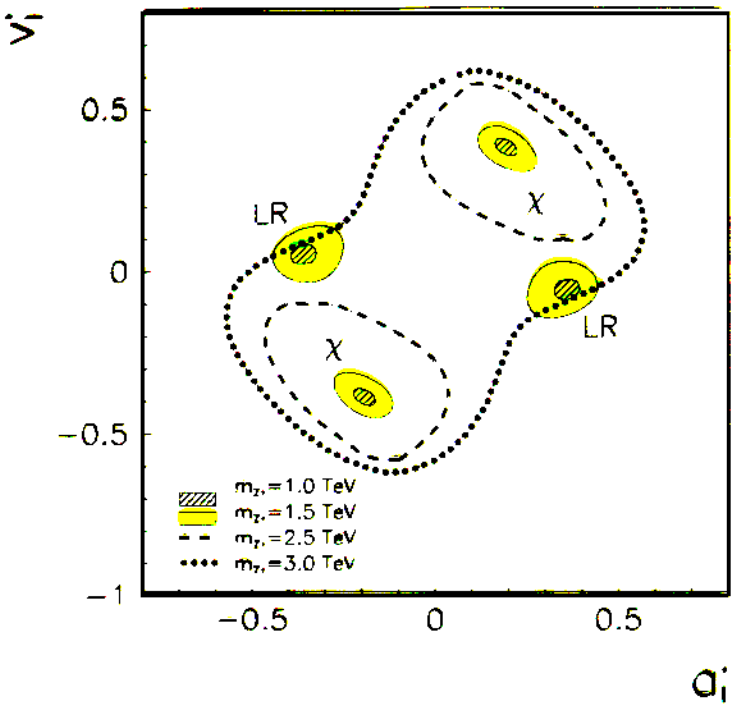
Are we able to identify the Z′ at future LC?

Assume: Z′ mass is known (LHC)

Consider: $\sqrt{s}$=500 GeV, $\mathcal{L}_{int}$=50 fb^{-1}
P_{e^-}=80%, P_{e^+}=0

Input: χ model (LR model)

Determine: Z′$l\bar{l}$ couplings

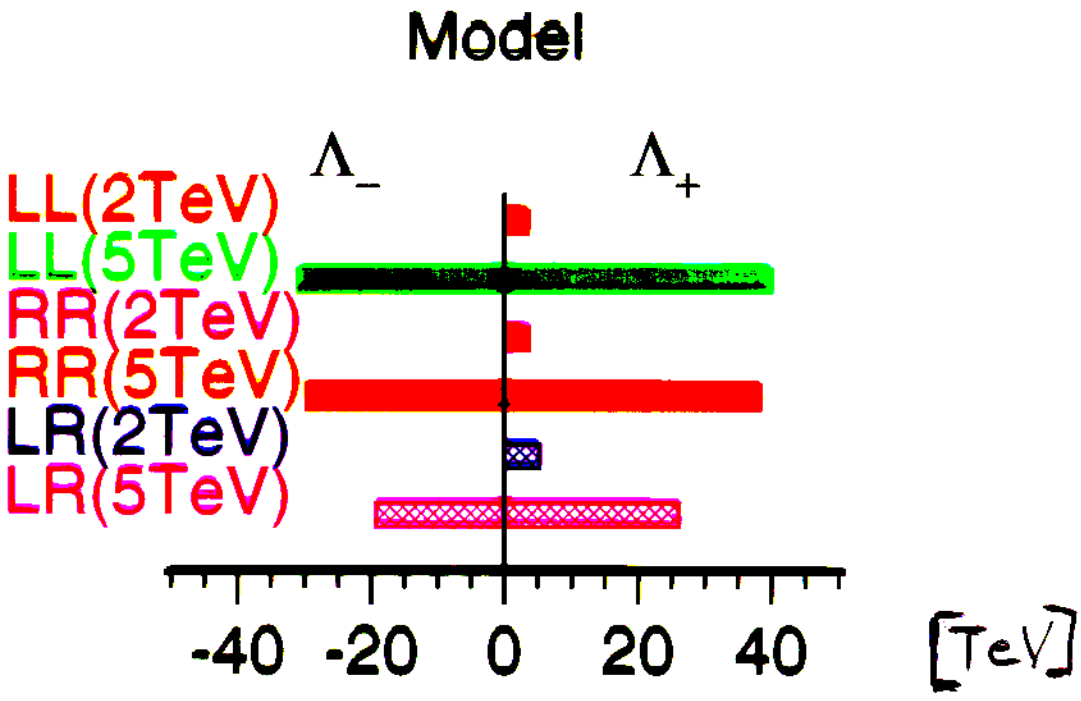


- Distinction between Z′ models possible for $m_{Z'} < 3\sqrt{s}$
- 2-fold ambiguity

Assume:

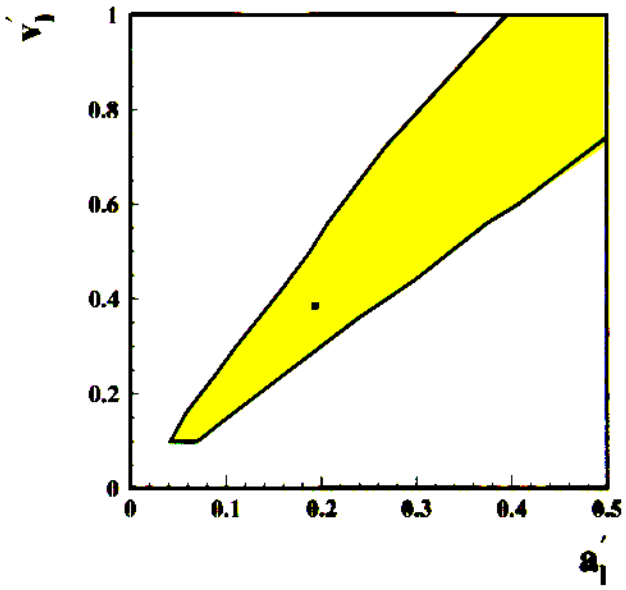
- Z′ with $m_{Z'} = 2$ (5) TeV exists, χ model is realized
- What will we see ????

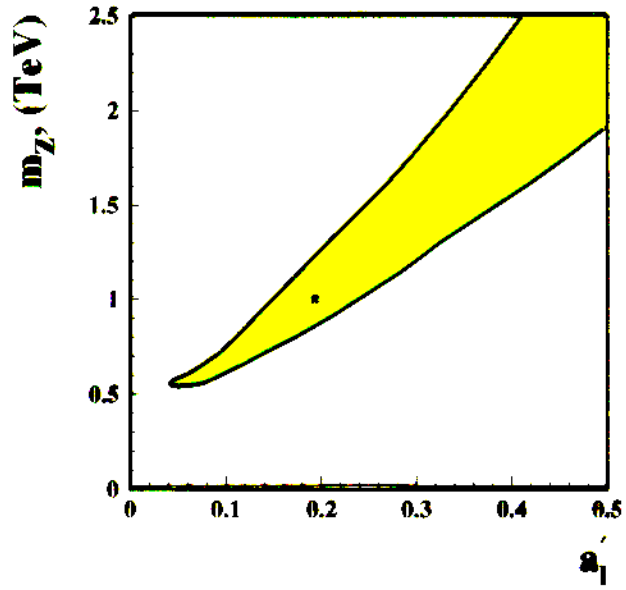
$$e^+e^- \Rightarrow \mu^+\mu^-$$



m_{Z_1} is unknown

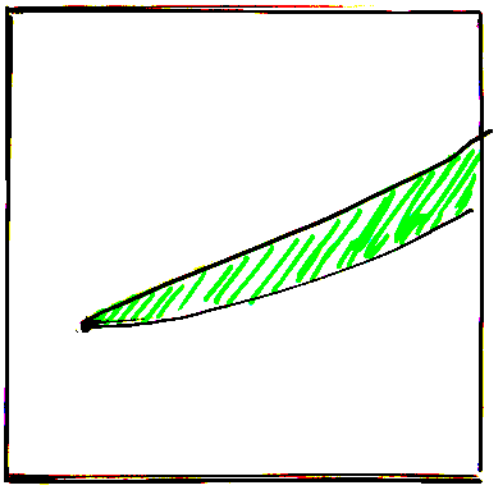
→ limits on v'_1, a'_1 depend on m_{Z_1}





Upper limit on m_{Z_1} can be found if

- second measurement at $\overline{S_2} > \overline{S_1}$
- $$\frac{S_2}{\overline{S_1}} < \frac{a_2^N + \Delta a_2^N}{a_1^N - \Delta a_1^N}$$



$$\alpha^N = \alpha' \sqrt{s/(m_2^2 - s)}$$

SUMMARY

- Fermion-pair production is a process with interesting physics potential (not less interesting than WW, ZZ, $t\bar{t}$ ...)
- sensitive to new physics at energies $> \sqrt{s}$
- Expected sensitivity:

$$\Lambda > (30 \ldots 90)\sqrt{s} \qquad (P=0)$$

But Λ is only a scale. If nothing will be found Λ is not very attractive without new ideas what it could be

- expect

$$m_{LQ} > (2 \ldots 6)\sqrt{s} \qquad (P=0)$$

for $g = \sqrt{4\pi\alpha}$

- $m_{Z'} > (5 \ldots 10)\sqrt{s}$
- Scaling between different collider parameters:

$$\Lambda \sim \frac{m_X}{g} \sim \left(\mathcal{L}_{int} \cdot s\right)^{1/4}$$