Contact Interactions at LEP and limits from SM processes

Marco Pieri
INFN Firenze

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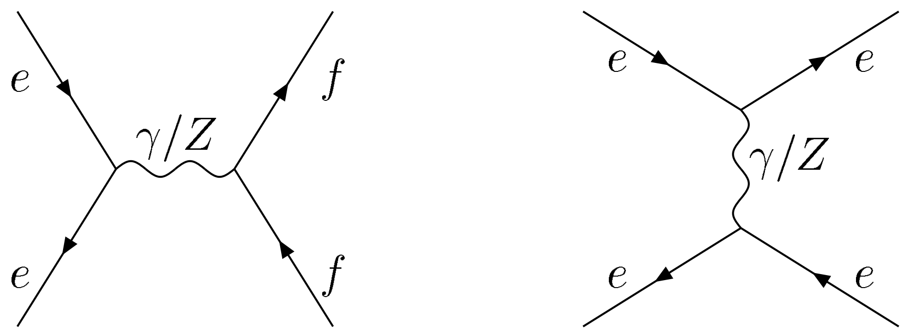
Outline

- Introduction
- Measurements of SM processes at LEP 2
- Search for new physics processes
- Conclusions

Introduction

Two fermion production at LEP



This process would be sensitive to new physics:

- Four fermion contact interactions at a scale $\Lambda >> \sqrt{s}$
- R-Parity violating sneutrino and squark exchange
- Leptoquarks
- Presence of an additional Z'

From the measurements of cross sections and asymmetries, if no signal is found, limits can be derived

Collected Data

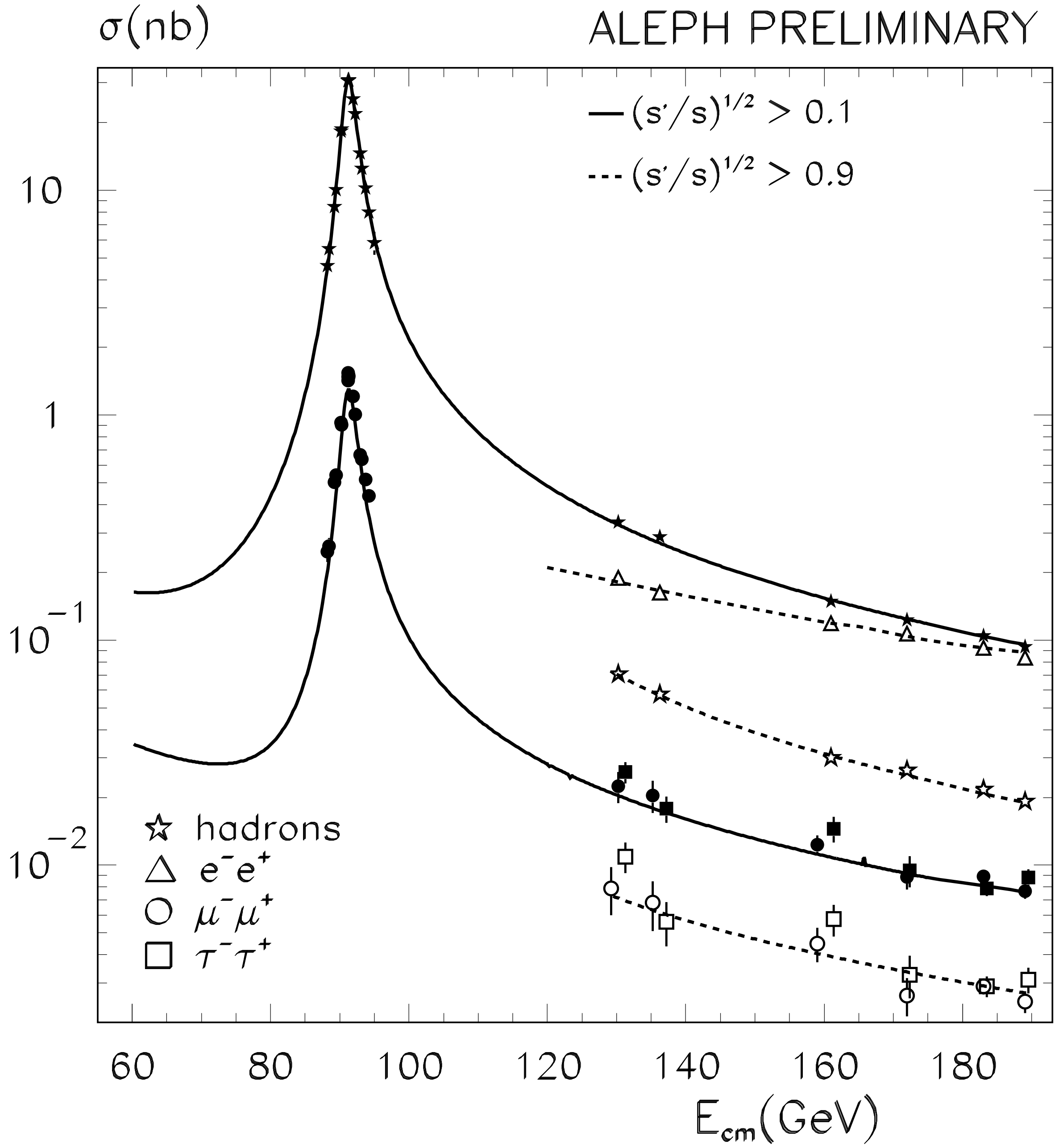
Collected data above the Z peak

$\sqrt{s}(\ \mathrm{GeV})$	$\mathcal{L}$/exp. (pb^{-1})	Year
130	~ 6	1995 + 1997
136	~ 6	1995 + 1997
161	~ 10	1996
172	~ 10	1996
183	~ 55	1997
189	$\sim$ 30–40	1998

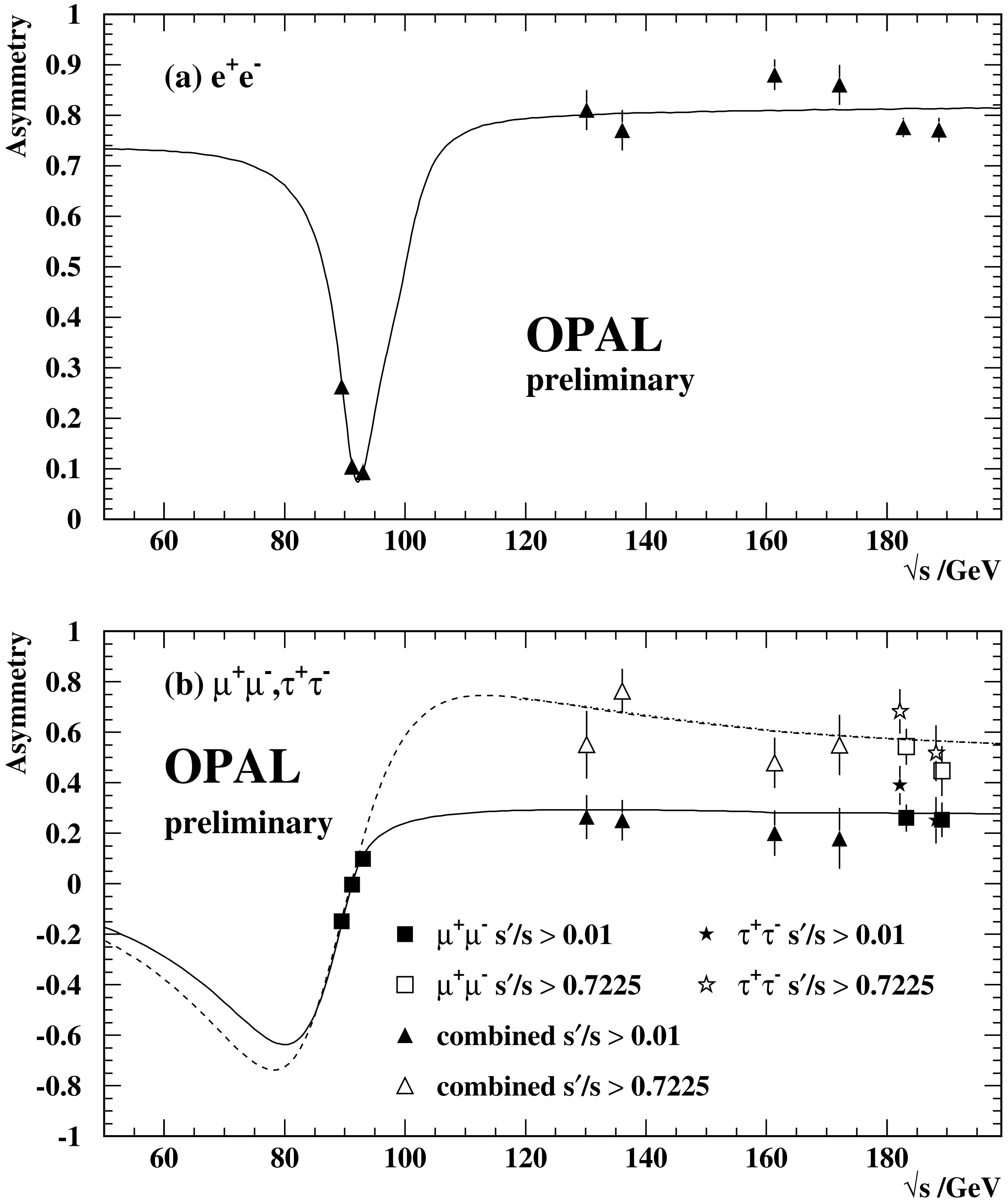
189 GeV preliminary results on cross section and asymmetry measurements from all LEP experiments

189 GeV preliminary results on searches for new phenomena from DELPHI and L3

Cross Section Measurements

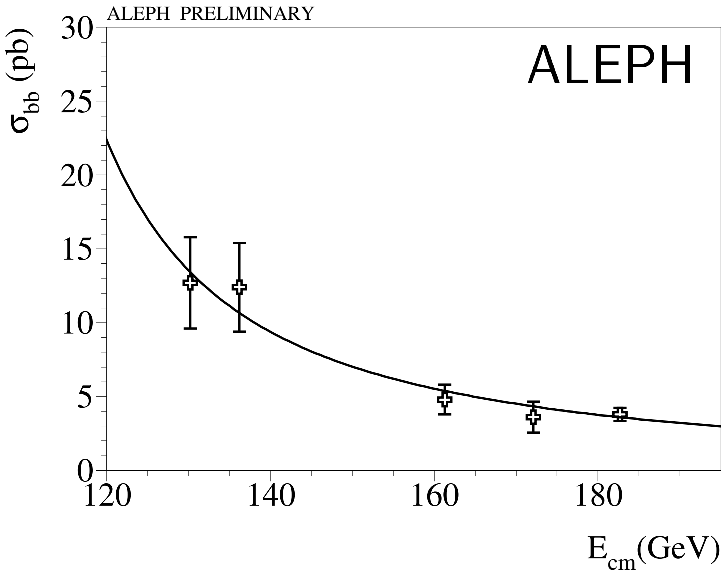


Asymmetry Measurements

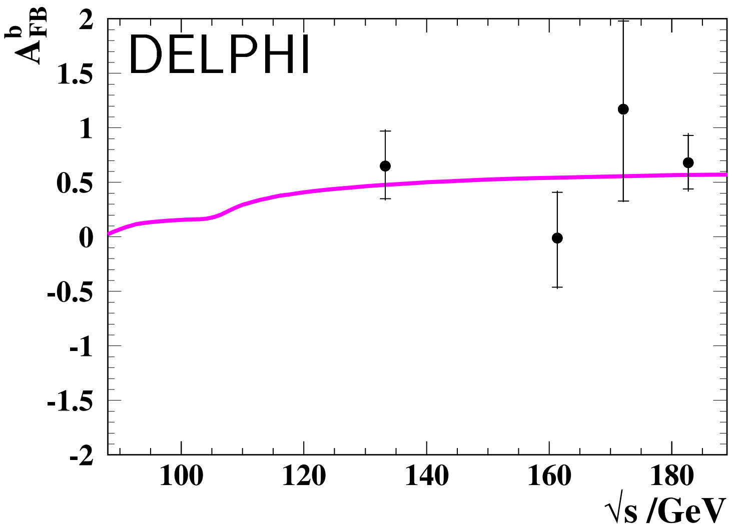


ALEPH, DELPHI and OPAL also measured cross sections and asymmetries for the different quark flavours (no update for 189 GeV data)

$\sigma_{b\bar{b}}(\text{pb})$



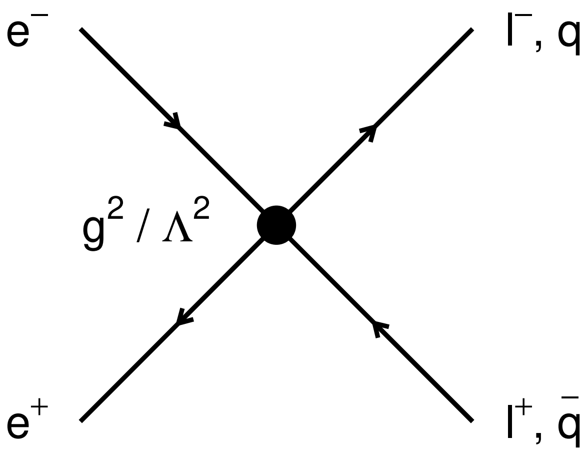
A_{FB}^{b}



All measurements in agreement with the Standard Model predictions

Contact Interactions

Contact interactions provide a general description of new physics at a higher energy scale.



Energy scale Λ equivalent to the mass of the exchanged particle

- g strength of the coupling
- Λ values quoted assuming $g^2/4\pi = 1$

Contact interactions would affect cross sections and asymmetries at lower energies.

Contact Interactions

Effective Lagrangian for contact interactions in the $\mathrm{e^+e^-\to f\bar{f}}$ process:

$$\mathcal{L} = \frac{1}{1+\delta_{\mathrm{e}f}} \sum_{i,j=\mathrm{L,R}} \eta_{ij} \frac{g^2}{\Lambda^2} (\bar{\mathrm{e}}_i \gamma^\mu \mathrm{e}_i)(\bar{f}_j \gamma^\mu f_j)$$

$\delta_{\mathrm{e}f} = 1$ for $\mathrm{e^+e^-}$ final state, else 0

η_{ij} define the helicity amplitudes which contribute

Assume $|\eta_{ij}| = 0, 1$

Differential cross section:

$$\frac{d\sigma}{d\cos\theta} = \frac{d\sigma^{\mathrm{SM}}}{d\cos\theta} + c_2(s,\cos\theta)\frac{1}{\Lambda^2} + c_4(s,\cos\theta)\frac{1}{\Lambda^4}$$

c_2 interference between SM and new physics

c_4 pure contact interaction term

Models Considered

Model	$\eta_{\rm LL}$	$\eta_{\rm RR}$	$\eta_{\rm LR}$	$\eta_{\rm RL}$
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

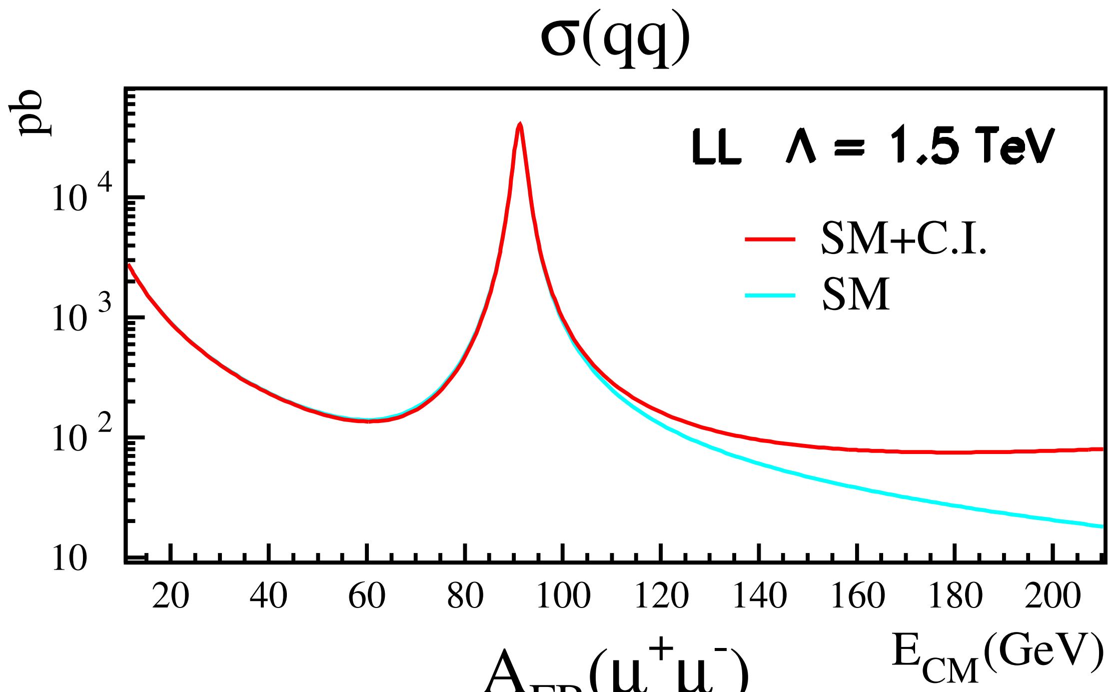
Λ_+ (Λ_-) corresponds to the upper (lower) sign

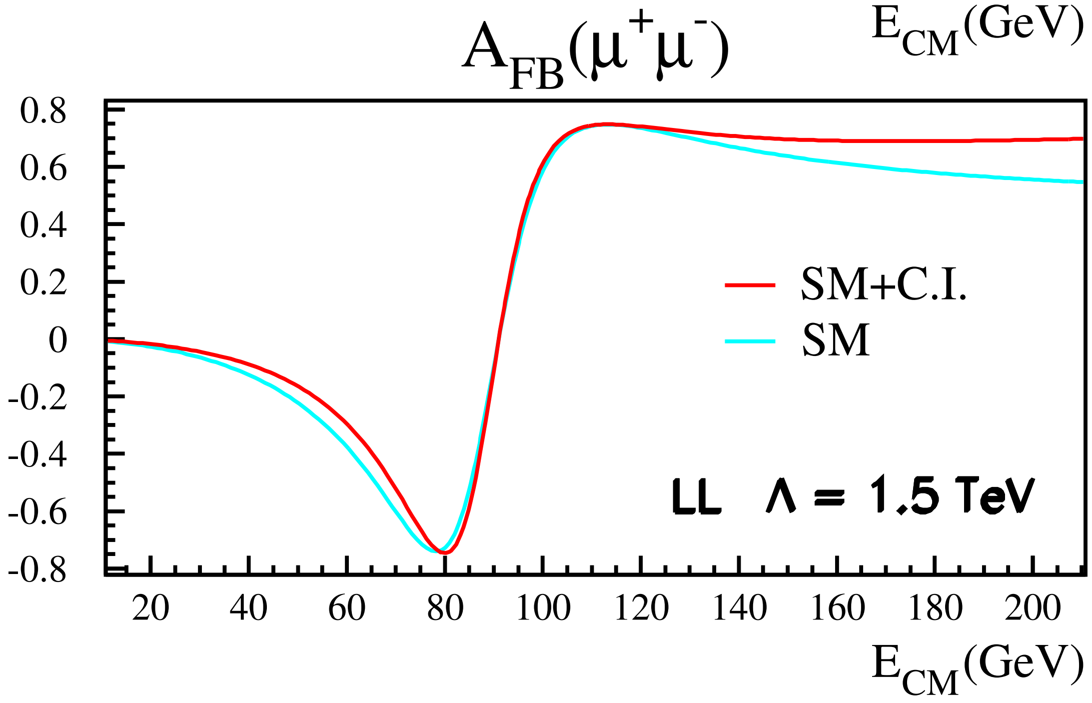
Models VV, AA, LL+RR, and LR+RL are parity conserving,
not subject to limits from atomic parity violation ($\Lambda \gtrsim 15 \mathrm{TeV}$)

Effect of contact interactions in the LL model for:

$e^+e^- \to q\bar{q}$ cross section

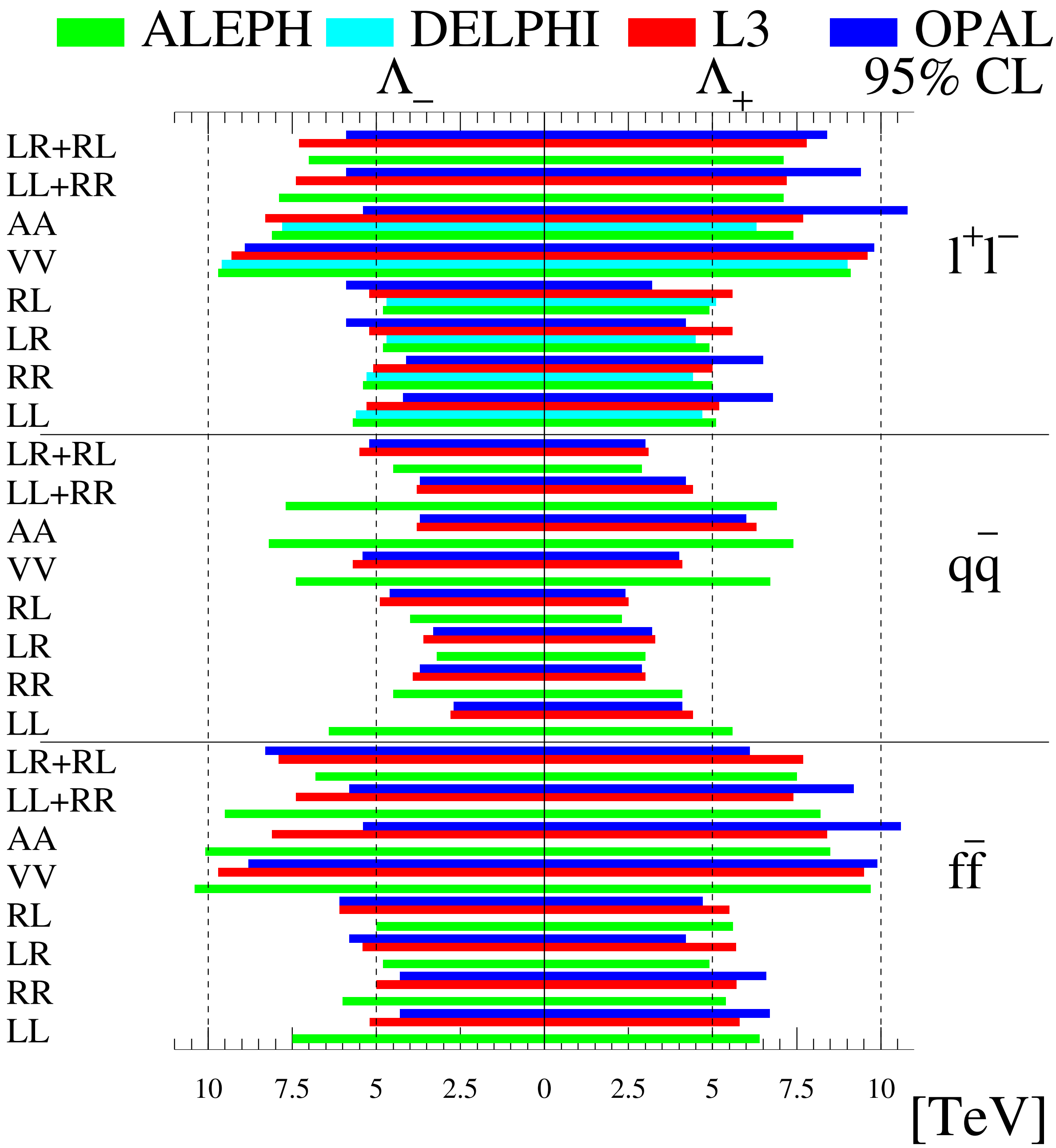
$e^+e^- \to \mu^+\mu^-$ asymmetry





Limits on Λ

95% lower limits on Λ



R-Parity Breaking Scalar Fermions

In Supersymmetric theories with R-parity breaking the superpotential contains L and B violating trilinear Yukawa couplings:

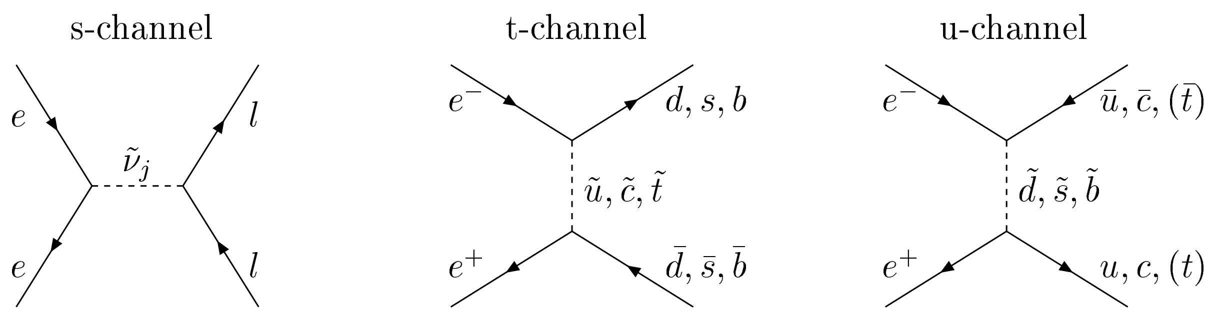
$$W^{lll}_{\not R} = \lambda_{ijk} L^i_L L^j_L \bar{E}^k_R + \lambda'_{ijk} L^i_L Q^j_L \bar{D}^k_R$$

L,Q — left-handed doublets of leptons, quark
E,D — right-handed singlets of charged leptons, down-type quarks
ijk — generation indices

$\lambda_{ijk} \neq 0$ only for $i < j$.

At least two different generations are coupled in the purely leptonic vertices

Sparticles can be exchanged in the s, t or u channels



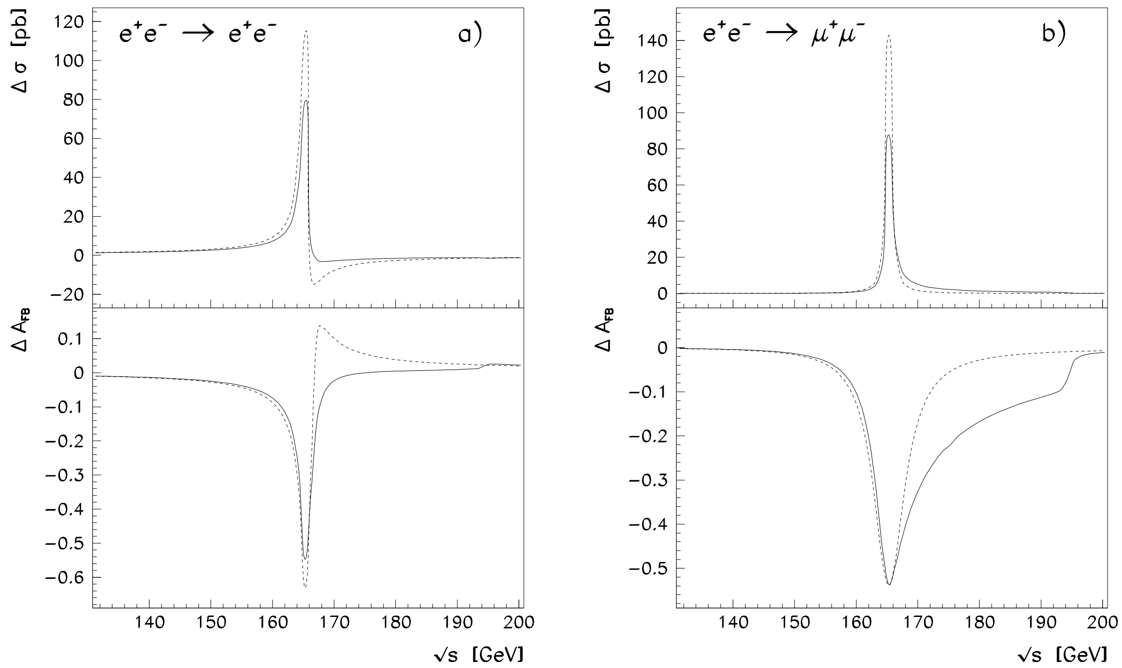
Scalar Neutrinos

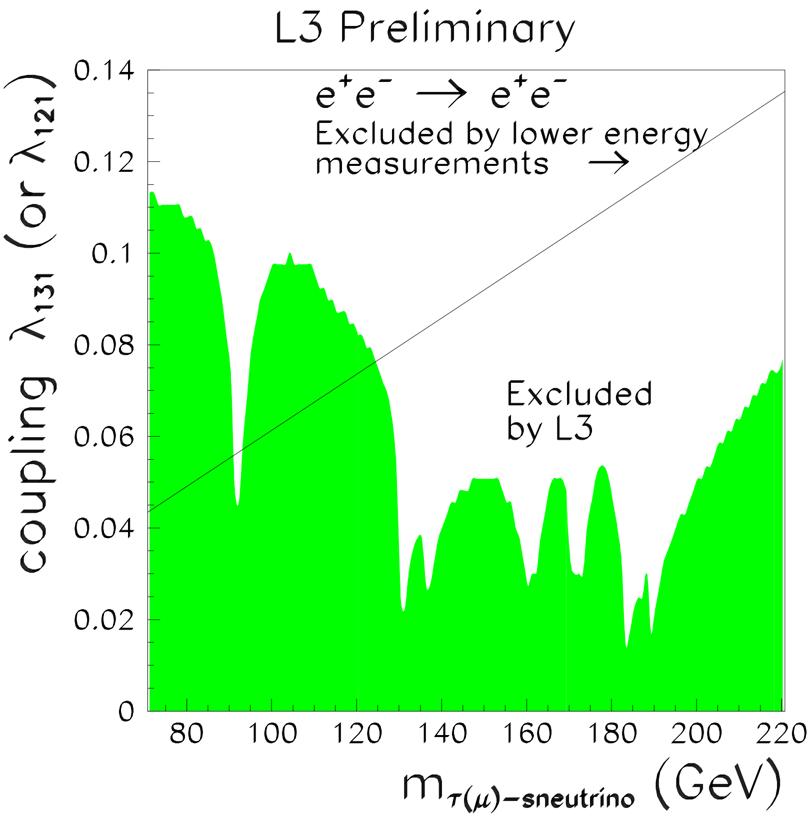
Sneutrinos which contribute to the different processes

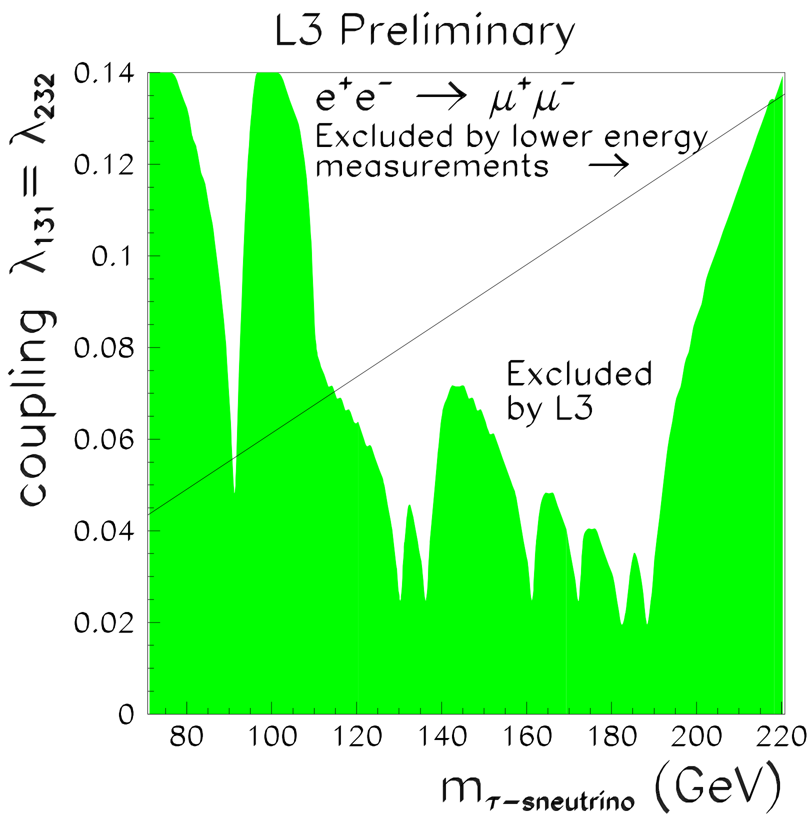
Assume 1 or 2 couplings $\neq 0$

λ^2	e^+e^-	$\mu^+\mu^-$	$\tau^+\tau^-$
λ^2_{121}	$\tilde{\nu}_\mu$ (t,s)	$\tilde{\nu}_e$ (t,s)	
λ^2_{131}	$\tilde{\nu}_\tau$ (t,s)		$\tilde{\nu}_e$ (t)
$\lambda_{121}\lambda_{233}$			$\tilde{\nu}_\mu$ (s)
$\lambda_{131}\lambda_{232}$		$\tilde{\nu}_\tau$ (s)	

s channel $\tilde{\nu}_\tau$ exchange ($m_{\tilde{\nu}_\tau} = 165.3$ GeV, $\Gamma_{\tilde{\nu}_\tau} = 1$ GeV, $\lambda_{131} = \lambda_{232} = 0.08$)




L3 Preliminary
$e^+e^- \rightarrow e^+e^-$
Excluded by lower energy measurements $\rightarrow$
Excluded by L3
coupling λ_{131} (or λ_{121})
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
80
100
120
140
160
180
200
220
$m_{\tau(\mu)-\mathrm{sneutrino}}$ (GeV)


L3 Preliminary
$e^+e^- \rightarrow \mu^+\mu^-$
Excluded by lower energy measurements $\rightarrow$
Excluded by L3
coupling $\lambda_{131} = \lambda_{232}$
0.14
0.12
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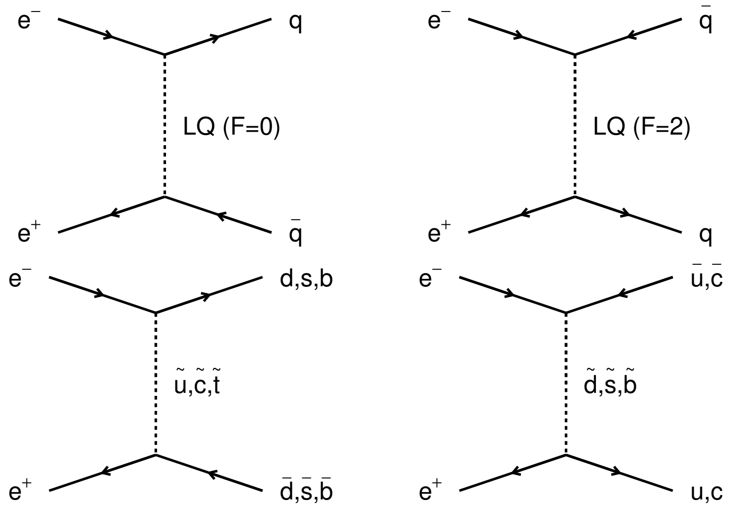
$m_{\tau-\mathrm{sneutrino}}$ (GeV)

Leptoquarks and Squarks

t-channel | *u*-channel



t–channel associated with $\mathrm{e}^- \rightarrow \mathrm{q}\ (F=0)$
u–channel associated with $\mathrm{e}^- \rightarrow \bar{\mathrm{q}}\ (F=2)$

$$\frac{d\sigma}{d\cos\theta} = \frac{N_c}{128\pi s} \sum_{i,k=L,R} \rho_{ik} |f_{ik}|^2$$

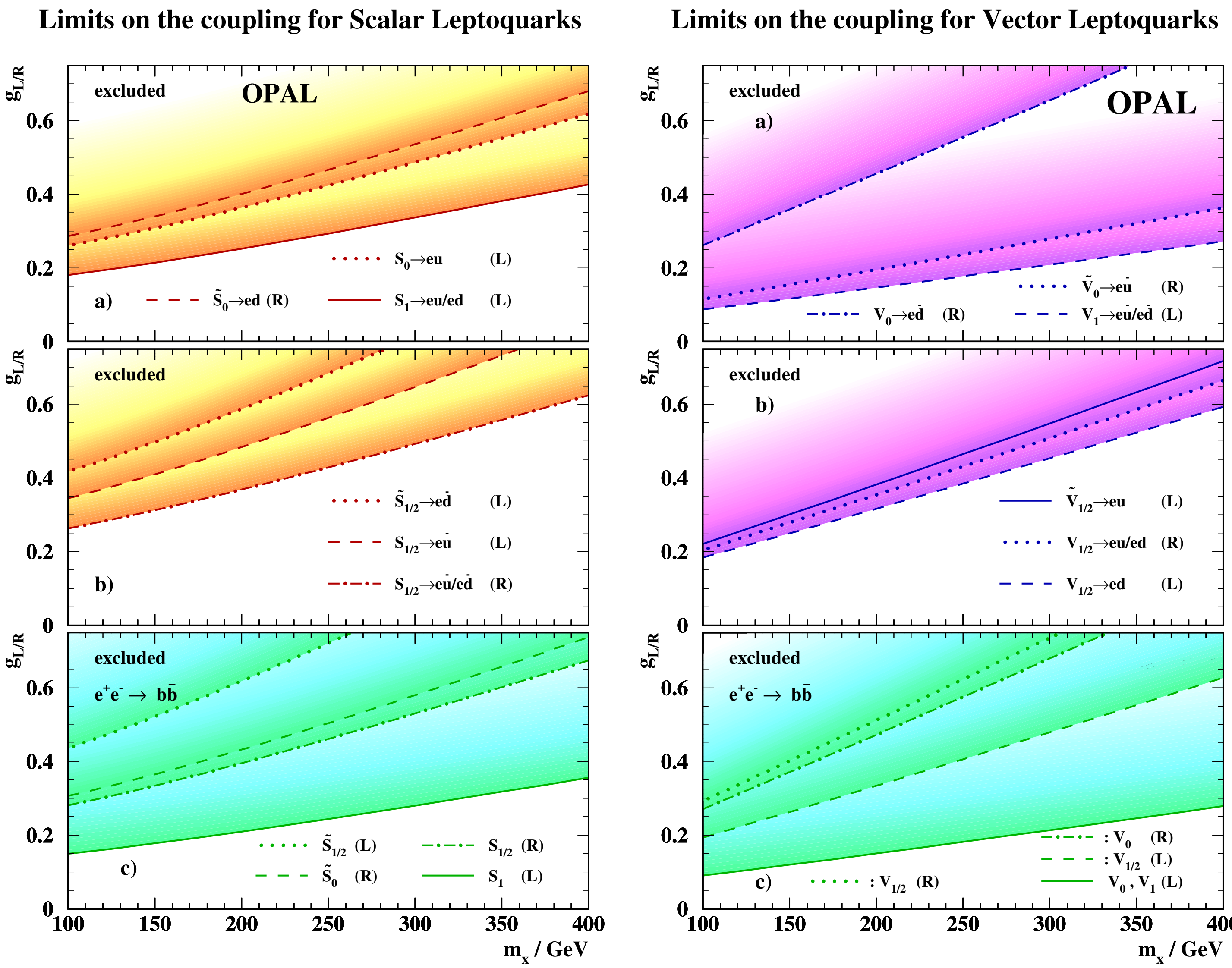
f_{ik} helicity amplitudes
ρ_{ik} spin density matrix elements

Scalar left-handed up-type quark $\approx \tilde{S}_{1/2}$
Scalar right-handed down-type quark $\approx S_0$

When $m_{LQ} >> \sqrt{s}$ this process is equivalent to contact interactions with:

$$\frac{g^2_{L,R}}{m^2_{LQ}} \sim \frac{1}{\Lambda^2_{ij}}$$

Limits on Leptoquark Couplings



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INFN Firenze

Indirect search for Z'

$M_{Z'}$, Z–Z' mixing angle, Z' couplings

Z' couplings are defined in GUT theories or can be left free in a model independent search

Neutral current Lagrangian becomes:

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

E_6 Models

$$J^\mu_{Z'} = J^\mu_\chi \cos\theta_6 + J^\mu_\psi \sin\theta_6$$

- χ model; $\theta_6 = 0$
- ψ model; $\theta_6 = \pi/2$
- η model; $\theta_6 = -\arctan\sqrt{5/3}$

Left-right symmetric models

$$J^{LR} = \alpha_{LR} J^\mu_{3R} - \frac{1}{2\alpha_{LR}} J^\mu_{B-L}$$

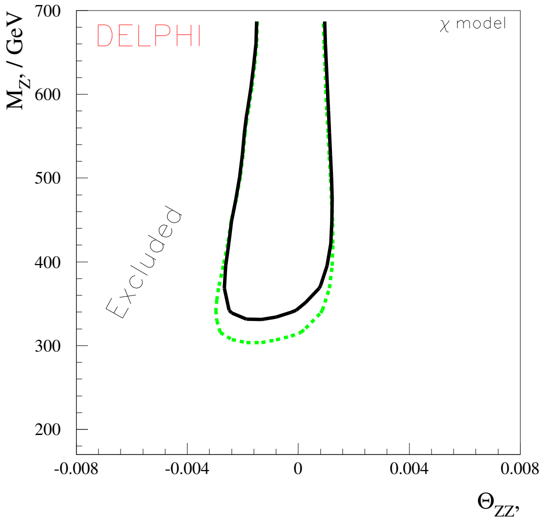
- LR model; $\alpha_{LR} = 1.53$

Sequential Standard Model (SSM)

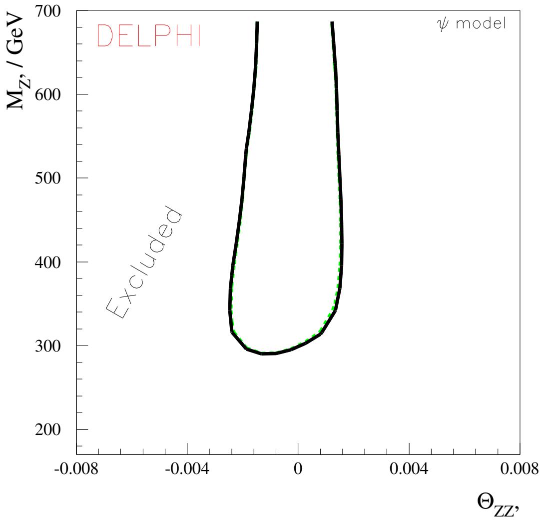
Z' same as Z, only heavier

New results using 189 GeV data from DELPHI and L3

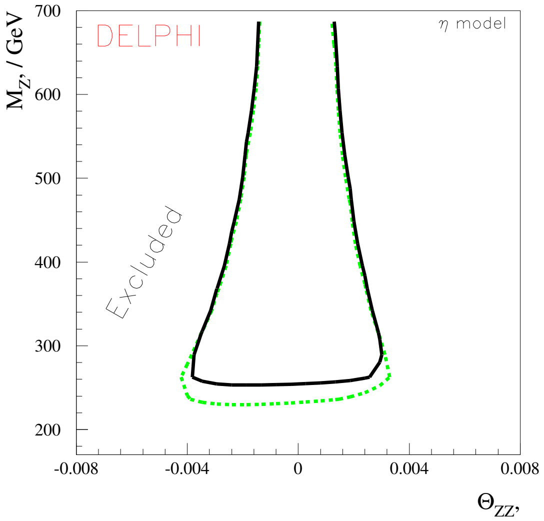
χ model



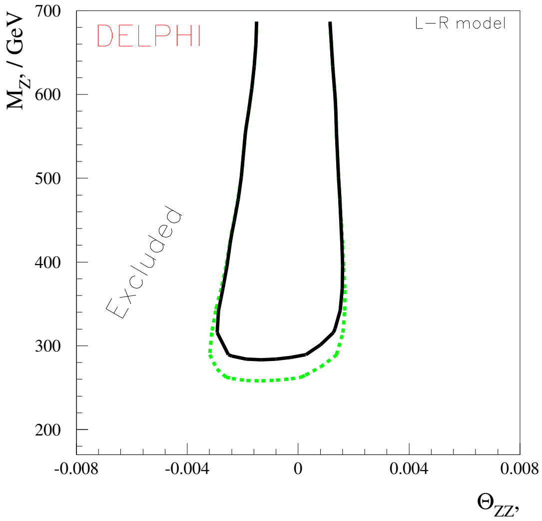
ψ model



η model



LR model

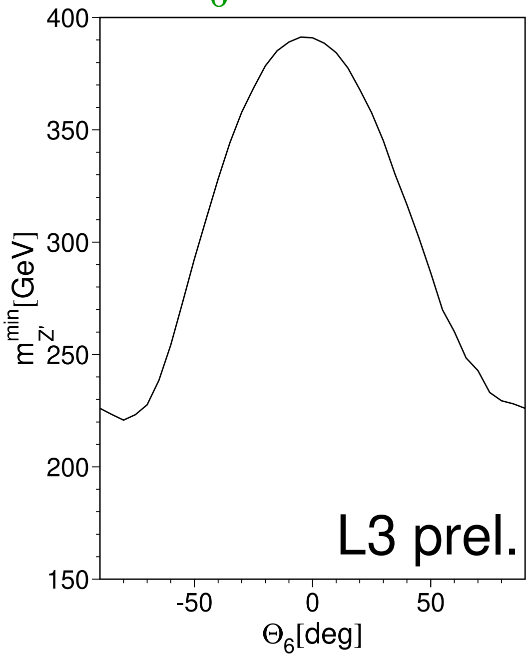


— without 189 GeV data

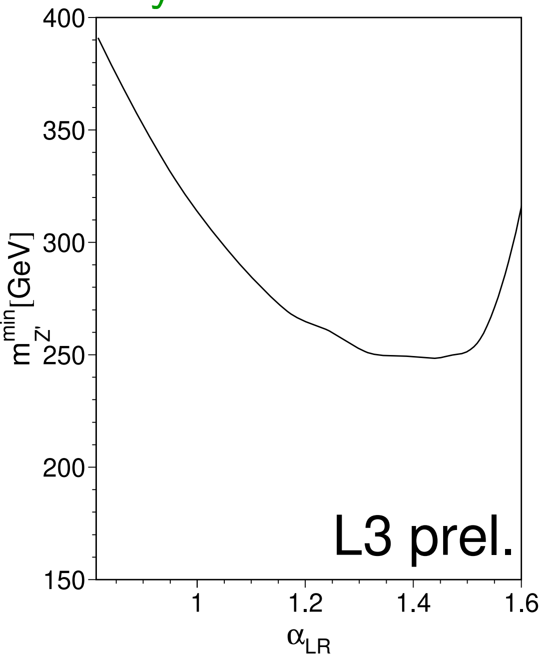
— including 189 GeV data

95% lower limits on Z' mass for no mixing

E_6 Models



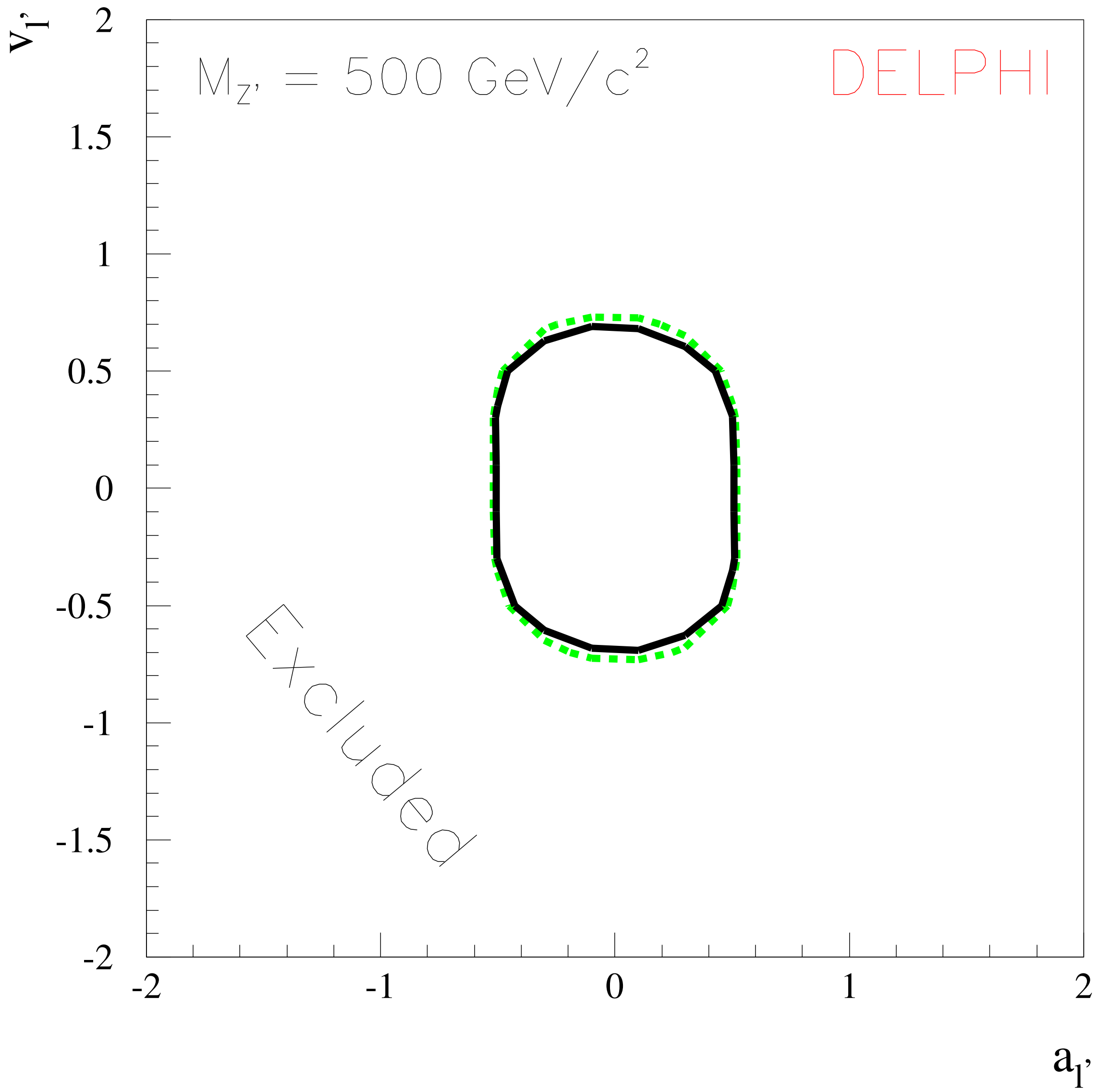
LR Symmetric models



Z' model	$m_{Z'}$ (GeV)
χ	390
ψ	230
η	285
LR	250
SSM	820

Model independent limits

95% limits on Z' couplings to leptons



— without 189 GeV data

— including 189 GeV data

Conclusions

- New preliminary results from all LEP experiments on the measurements of $e^+e^-\rightarrow f\bar{f}$ cross sections and asymmetries based on $\approx$ 30–40 pb^{-1}/exp.
- All measurements agree with the SM predictions
- Improved limits on new physics derived from 1998 data by DELPHI and L3
  - Lower limits on contact interaction scale 2 – 10 TeV
  - Improved limits on R-parity violating s-particle and leptoquark couplings
  - Lower limit on $m_{Z'}$ in SSM of 820 GeV