Di-fermion production at LEP II

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Di-fermion measurements at LEP II

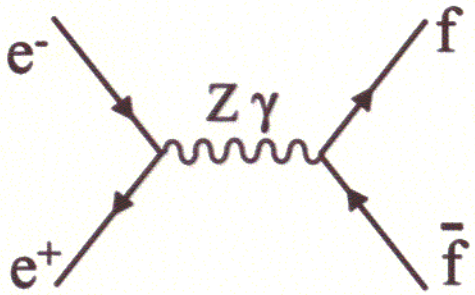
- di-leptons
- $q\bar{q}$, b & c production

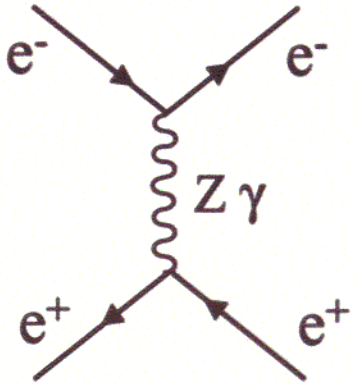
Combination of ADLO results

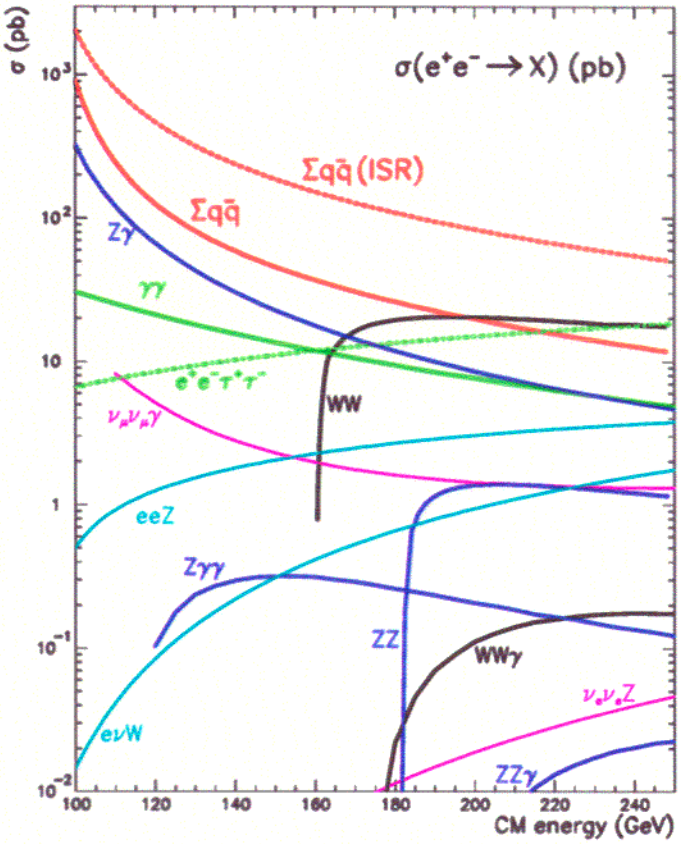
Interpretations Beyond the Standard Model

- Contact interactions
- Gravity in large compactified Extra dimensions
- Leptoquarks
- Z '

fermion pair production







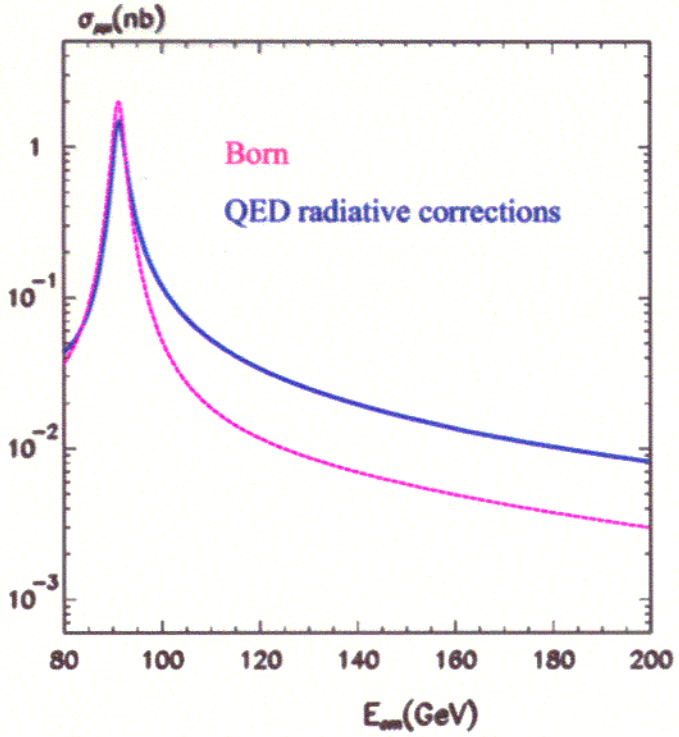
Major backgrounds : WW, Ze^+e^-, ZZ*

for 2 fermions

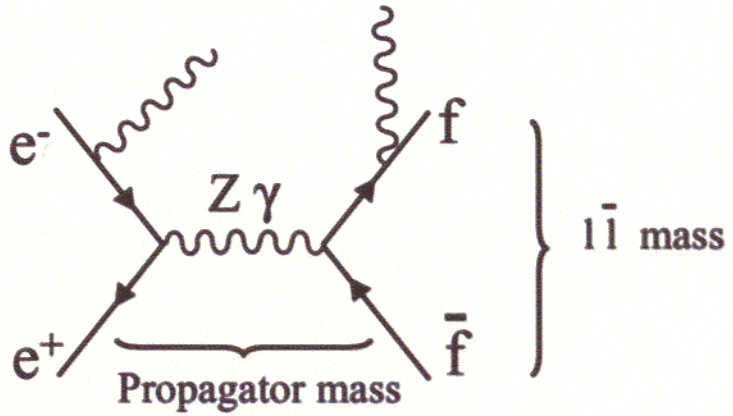
Physics process at high energy

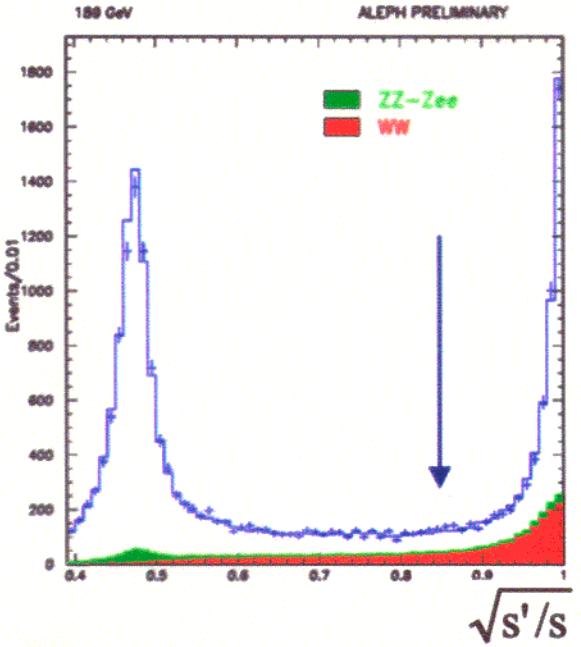
Definition of effective centre of mass energy $\sqrt{s'}$

Hard initial state radiation



Cross-sections enhanced by ~ 5 from QED radiative corrections





$\sqrt{s'} > 0.85\sqrt{s}$

sensitive to new Physics

Di-fermionic measurements at LEP2

for $\sqrt{s'/s} > 0.1$ and for $\sqrt{s'/s} > 0.85$

- Hadronic and leptonic cross-sections $\sigma_{q\bar{q}}$, $\sigma_{l\bar{l}}$

for $\sqrt{s'/s} > 0.85$

- Asymmetries $A^{\mu\mu}_{FB}$, $A^{\tau\tau}_{FB}$
- Leptonic differential cross-sections $\frac{d\sigma_{l\bar{l}}}{d\cos\theta}$
- Measurements on heavy flavour quarks

$$R_b = \frac{\sigma_{b\bar{b}}}{\sigma_{q\bar{q}}} \quad , R_c = \frac{\sigma_{c\bar{c}}}{\sigma_{q\bar{q}}} \quad , A^{cc}_{FB} \, , A^{bb}_{FB}$$

$\sqrt{s}$ (GeV)	130	136	161	172	183	189	192	196	200	202	205	207
$\int$ Ldt (pb^{-1}/exp)	6	6	10	10	55	170	25	75	80	40	85	140

LEP2 : 700 pb^{-1} / experiment

Aleph, Delphi, L3, Opal measurements

- $\sigma_{q\bar{q}}$, $\sigma_{l\bar{l}}$ ADLO $A^{\mu\mu}_{FB}$, $A^{\tau\tau}_{FB}$ ADLO (A:$\sqrt{s'}/s$ 0.9→0.85)
- $\frac{d\sigma_{\mu\mu}}{d\cos\theta}$, $\frac{d\sigma_{\tau\tau}}{d\cos\theta}$ ADLO , $\frac{d\sigma_{ee}}{d\cos\theta}$ ALO

- Measurements on heavy flavour quarks

$\sqrt{s}$ (GeV)	R_b A D L O	R_c A D L O	A^{bb}_{fb} A D L O	A^{cc}_{fb} A D L O
133	F F F F	- - - -	- F - F	- F - F
167	F F F F	- - - -	- F - F	- F - F
183	F P F F	F - - -	F - - F	P - - F
189	P P F F	P - - -	P P F F	P - - F
192 to 202	P P P -	P* - - -	P P - -	- - - -
205 and 207	- P P -	P - - -	P P - -	- - - -

F = Final

P = Preliminary

in red: new preliminary results

* except 192 and 202 GeV

Combination of ADLO measurements

for $\sqrt{s'/s} > 0.85$

Each experiment uses its own $\sqrt{s'/s}$ definition - different angular acceptance

➡ Corrections applied to have common signal definition

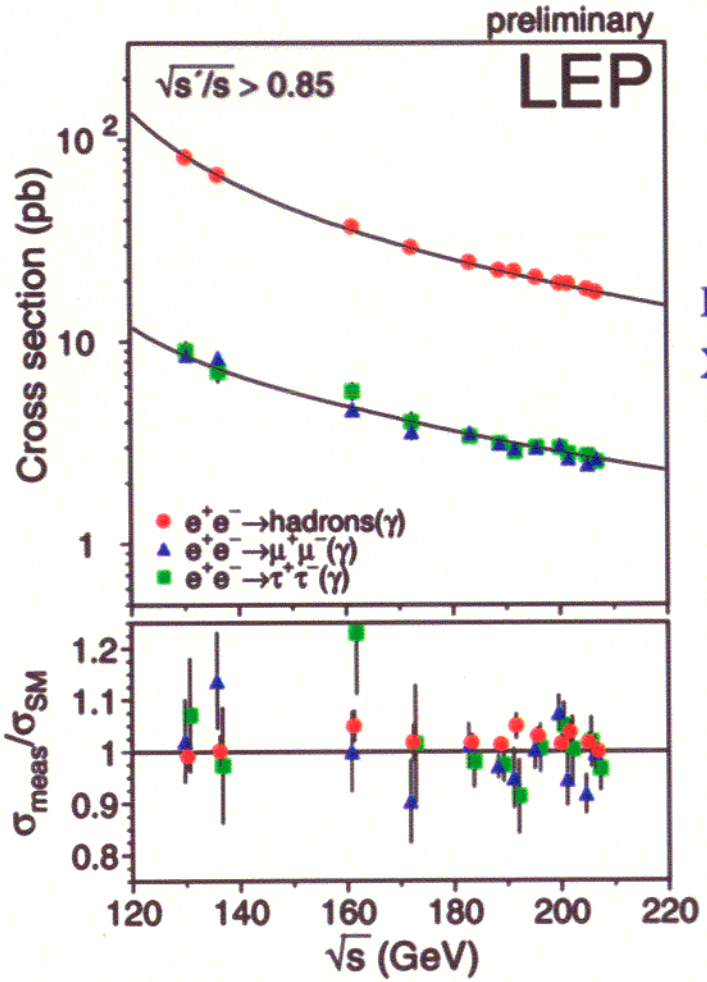
All energies treated together in a single fit

Errors are divided into 6 classes

- Statistical
- Correlated between energies : detectors effects,
  fragmentation, ISR modeling for quark pairs
- Correlated between channels : Luminosity error (exp. & MC statistics)
- Correlated between energies and experiments : ISR/FSR uncertainties
- Correlated between energies, experiments and channels : theoretical luminosity error
- Uncorrelated : MC statistics

Cross-section and asymmetries results

for $\sqrt{s'/s} > 0.85$

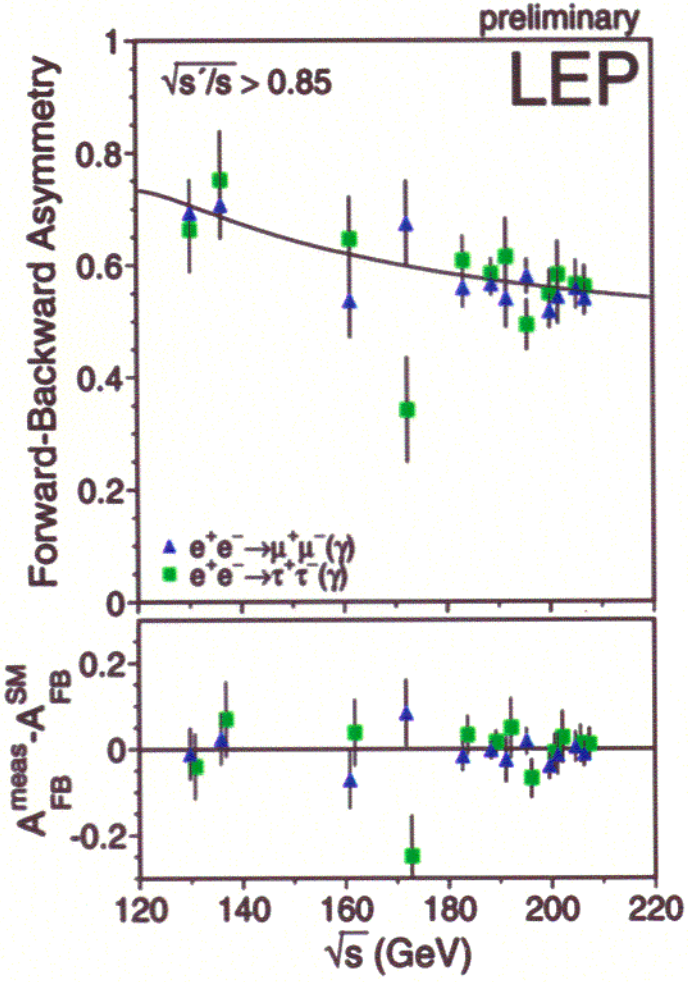


Fit performed on all X-section & Asymmetries

χ^2 ~160/180

Good agreement with SM

(Δ ($q\bar{q}$-SM) averaged over all $\sqrt{s}$ ~1.63σ)



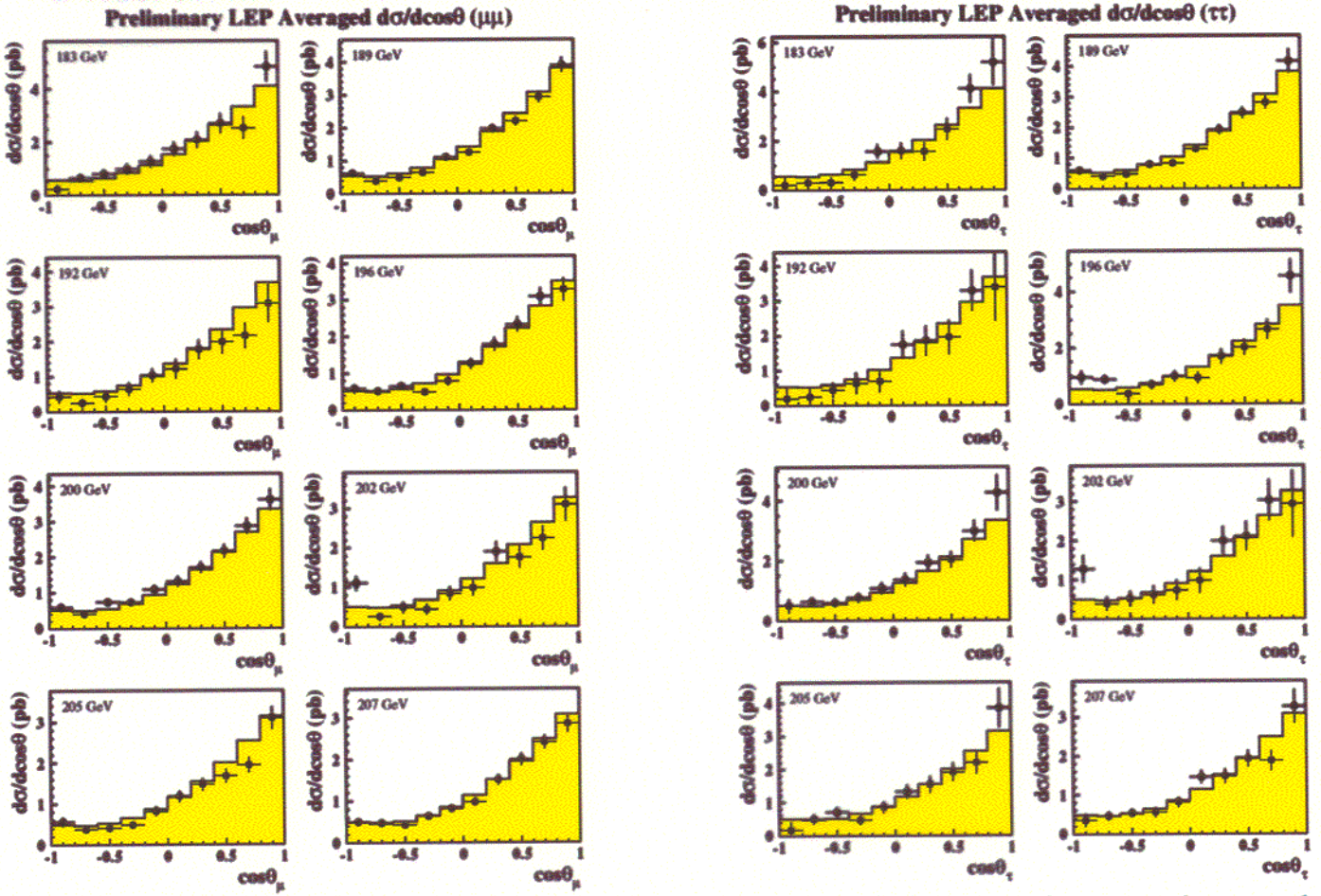
Standard Model Expectations computed with Zfitter 6.36

Theoretical uncertainty (Zfitter-KK2f) on σ : hadrons ~0.3% $\mu^+\mu^-$, $\tau^+\tau^-$ ~0.4%

Differential cross-sections μ & τ pairs

θ angle between final lepton l^- and incoming e^- in the laboratory

Differential cross-sections are fitted from the 4-LEP measurements

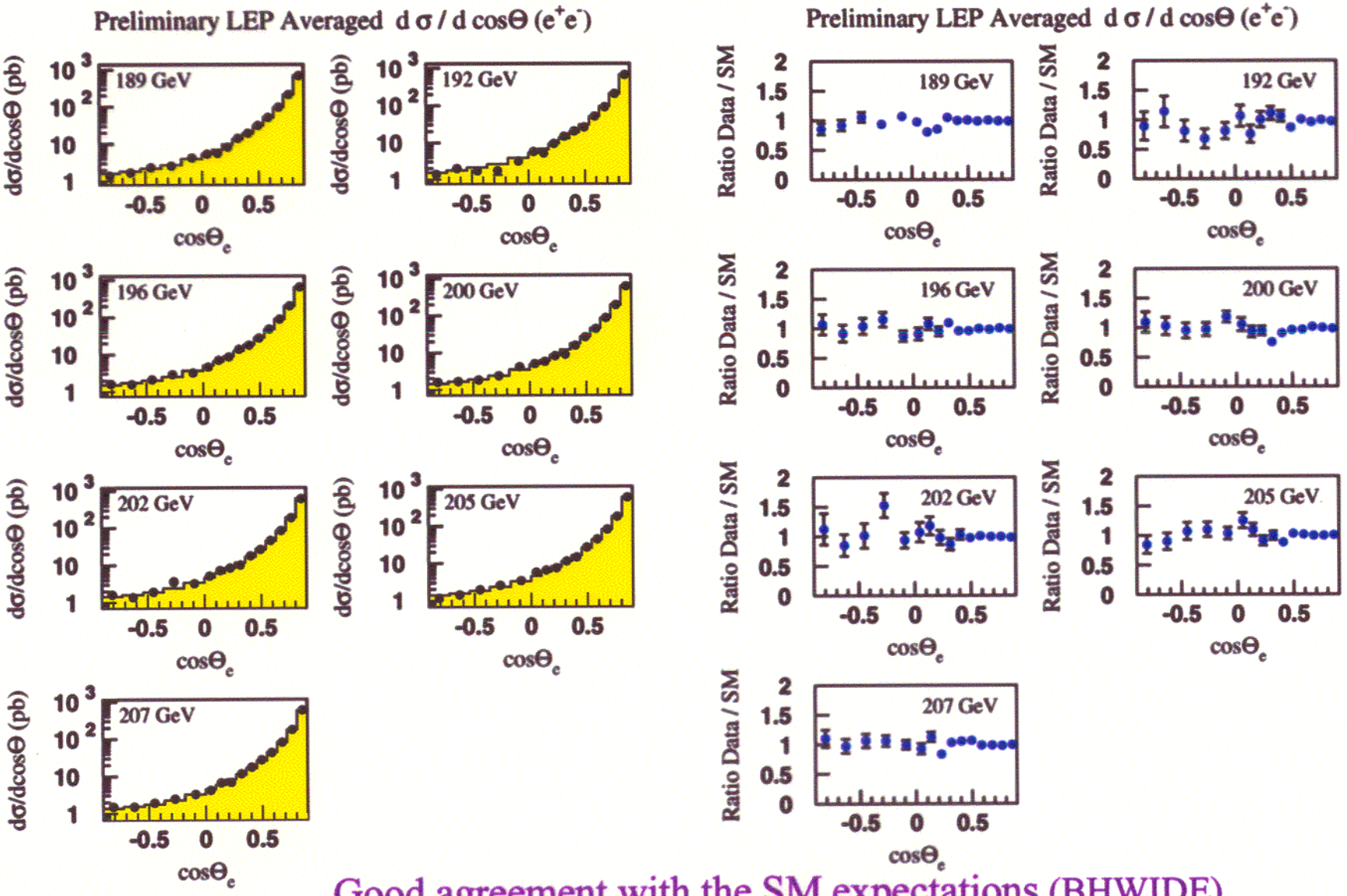


Correlations between bins are less 2% of the total error in each bin

Good agreement with the SM expectations

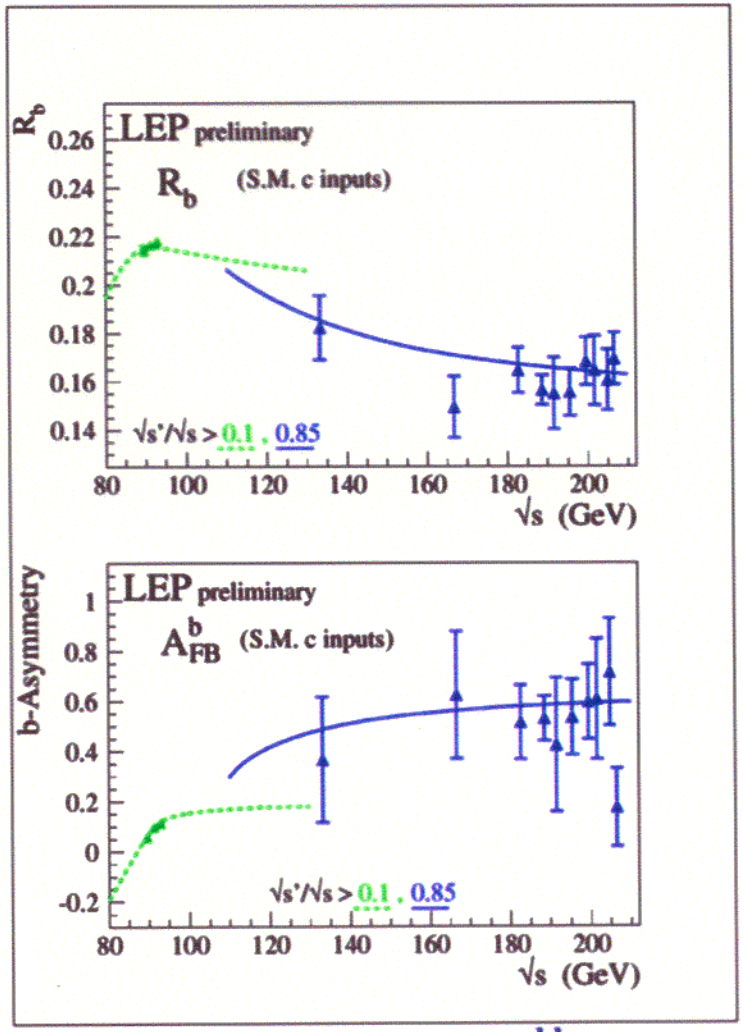
Differential cross-sections for electrons pairs (ALO)

similar fitting procedure

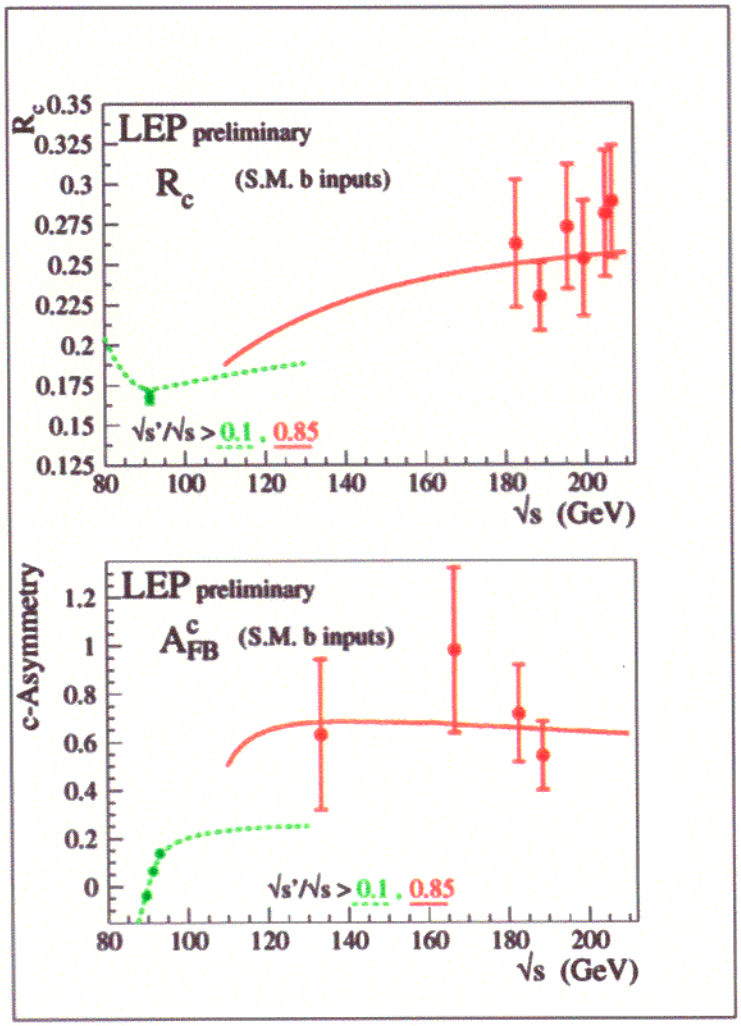


Good agreement with the SM expectations (BHWIDE)

Heavy Flavour results



Simultaneous fit

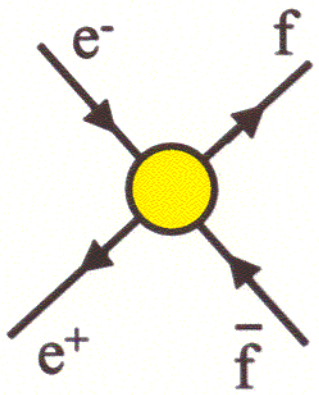


$\Delta_{SM}(R_b) = -2.1\sigma$ $\Delta_{SM}(A^{bb}_{FB}) = -1.6\,\sigma$ averaged over all $\sqrt{s}$

$\Delta_{SM}(R_c) = +0.3\sigma$ $\Delta_{SM}(A^{cc}_{FB}) = -0.2\,\sigma$ averaged over all $\sqrt{s}$

Contact interactions

$$L_{eff} = \frac{1}{1+\delta_e} \frac{g^2}{\Lambda^2} \sum_{i,j=L,R} \eta_{ij} (\bar{e}_i \gamma_\mu e_i)(\bar{f}_j \gamma^\mu f_j)$$



$g^2 = 4\pi$ η_{ij} : helicity $\delta_e = 1$ (electron) or 0 (other)

Λ : energy scale of new physics

Different helicity coupling between initial and final currents ➡ different models

New parameter $\varepsilon = 1/\Lambda^2$ ➡ fit contact interaction using

$$\frac{d\sigma}{d\cos\theta} = SM(s,t) + \varepsilon\, C_{inter}(s,t) + \varepsilon^2 C_{NewPhysics}(s,t)$$

Interference

Contact interactions

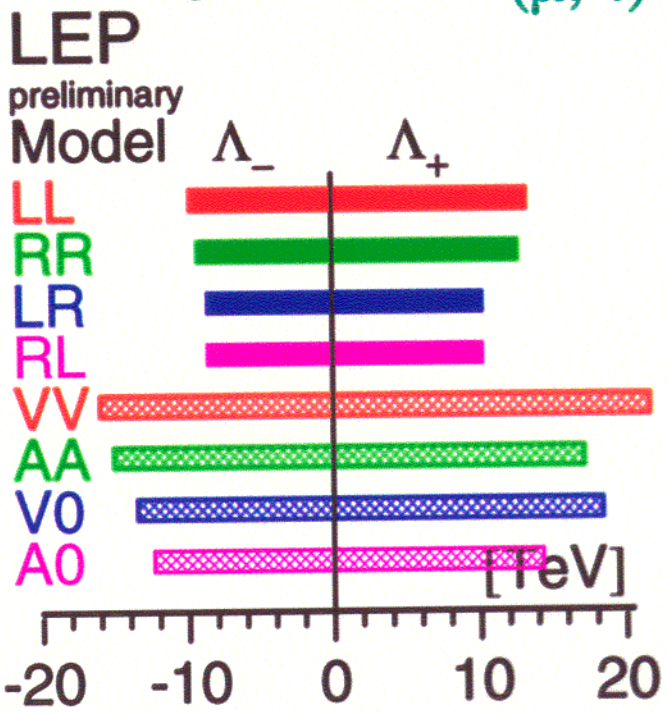
LEPTONS

95% confidence limits on Λ scale

Λ^- : destructive interference

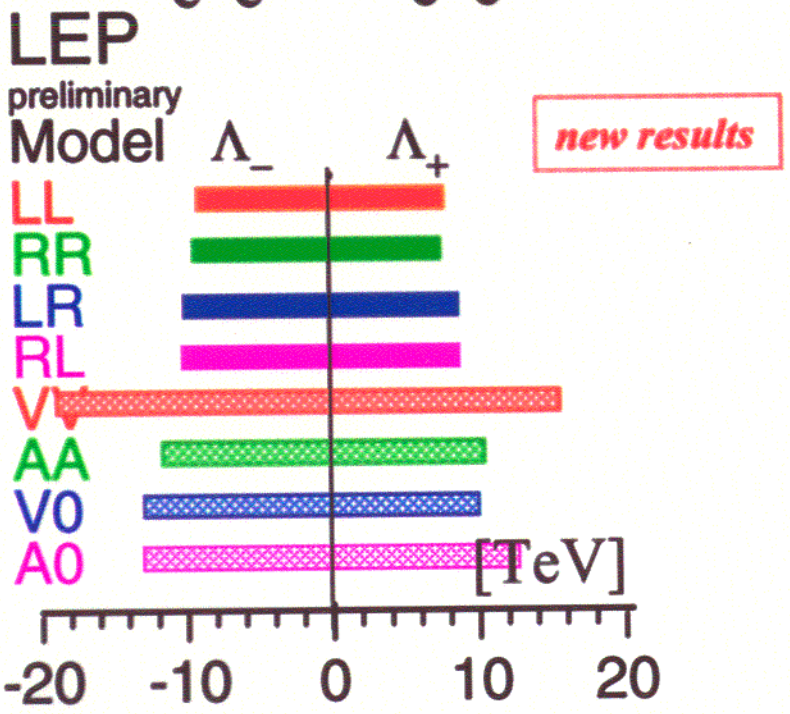
Λ^+ : constructive interference

$e^+e^- \rightarrow l^+l^-$ (μ, τ)



$g^2 = 4\pi$

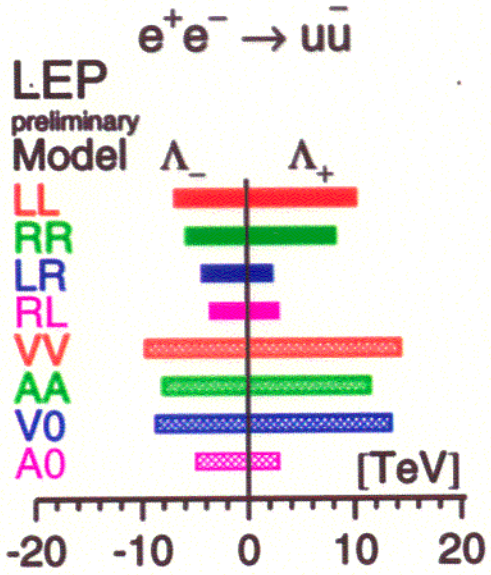
$e^+e^- \rightarrow e^+e^-$



Contact interactions

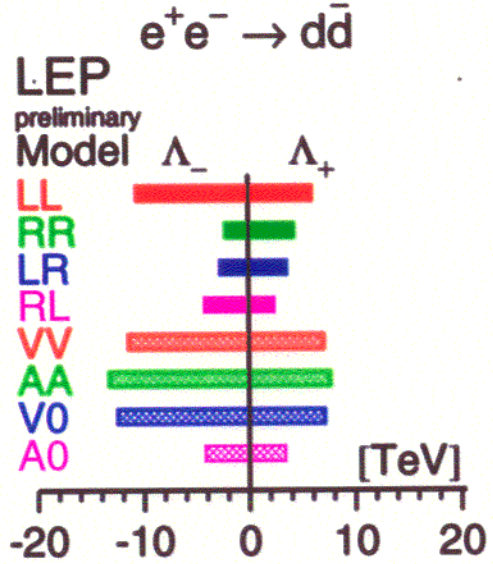
QUARKS

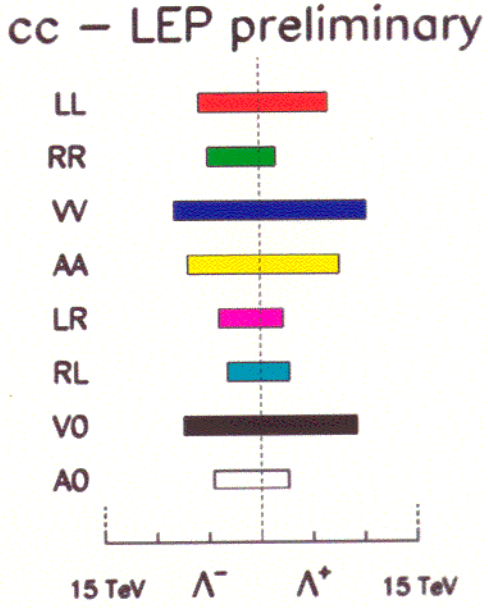
new results



$\sigma_{q\bar{q}}$

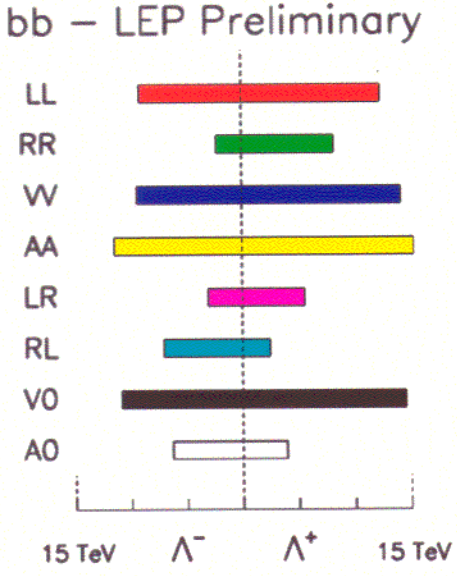
Assuming no deviation for all 4 other flavours





R_c
A^{cc}_{FB}

R_b
A^{bb}_{FB}



$g^2 = 4\pi$

Gravity in large Compactified Extra dimensions

Arkani-Hamed Dimopoulos and Dvali model

Possible solution to the Hierarchy Problem $M_{Plank} >> M_{Weak}$

space : δ extra dimension compactified to a radius R

Quantum gravity mass scale $M_D \sim 1$ TeV $\quad M^2_{Plank} \approx R^{\delta} M_D^{\delta+2}$

$e^+ e^- \longrightarrow f\bar{f}$ affected by the exchange of virtual gravitons

Fit with $\varepsilon = 1/M_s^4$ with $M_S \sim M_D$ and $\delta = 2$

$$\frac{d\sigma}{d\cos\theta} = A(\cos\theta) + \varepsilon\lambda B(\cos\theta) + \varepsilon^2 \lambda^2 C(\cos\theta)$$

$\lambda = \pm 1 \Rightarrow$ interference with SM

Limits on extra dimensions from e+e- channel

new results

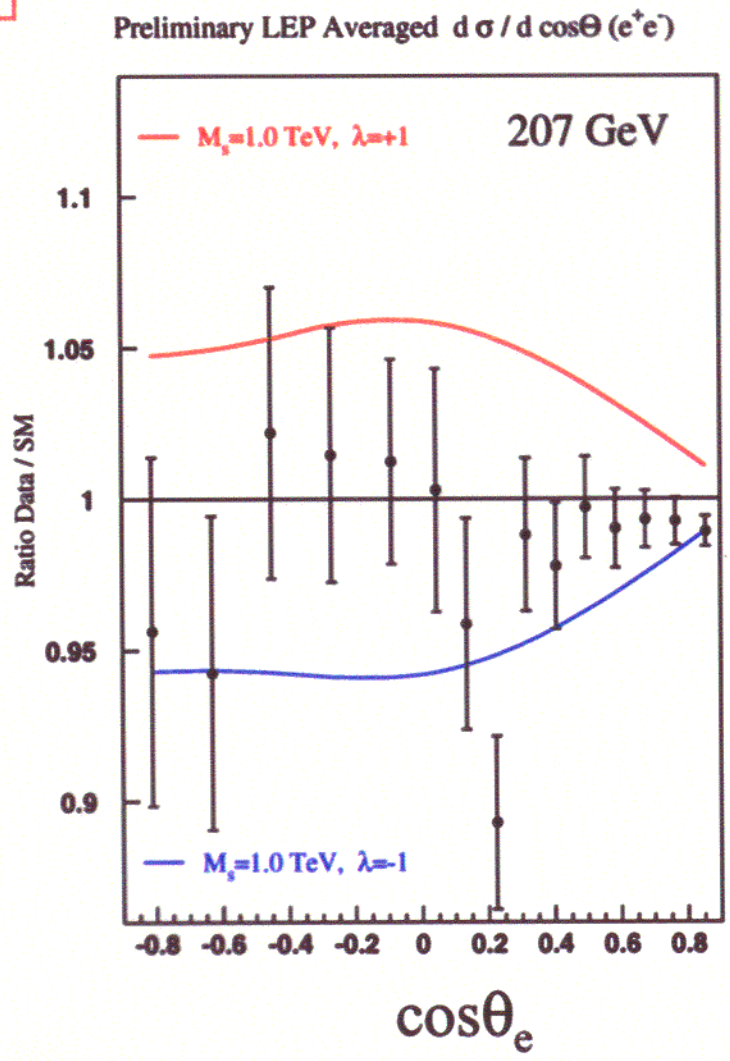
ALO combined result

e+e- production is most sensitive for quantum gravity effects

95 % confidence limits on M_S

$\lambda = +1$ 1.20 TeV

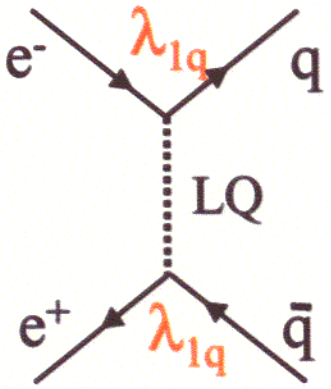
$\lambda = -1$ 1.09 TeV



Leptoquarks

Büchmuller-Rückl-Wyller model

LEP



LQ coupling to a lepton and a quark

10 leptoquarks..... 14 couplings λ_{1q}

5 scalars S_0, $S_{1/2}$ …	5 vectors V_0, $V_{1/2}$ …

3 generations of couplings :

coupling to e,u or e,d	coupling to e,c or e,s	coupling to e,b or e,t (t not accessible to LEP)

Access to $\lambda_{1q}\lambda_{1\bar{q}}$ ➡ Limits on $\frac{\lambda^2_{1q}}{M_{LQ}^2}$ using

$\sigma_{q\bar{q}}$	$\sigma_{q\bar{q}}$, R_c , A^{cc}_{FB}	R_b , A^{bb}_{FB}
⬇	⬇	⬇
1st generation	2nd generation	3rd generation

Leptoquarks

new results

Indirect limits on m_{LQ}

Assume: $\lambda_{L,R} = \sqrt{4\pi\alpha_{em}}$

LQ type	m_{LQ} [GeV/c^2]
$S_0(L) \rightarrow eu$	655
$S_0(R) \rightarrow eu$	520
$\tilde{S}_0(R) \rightarrow ed$	202
$S_1(L) \rightarrow eu, ed$	361
$S_{1/2}(L) \rightarrow e\bar{u}$	178
$S_{1/2}(R) \rightarrow e\bar{u}, e\bar{d}$	232
$\tilde{S}_{1/2}(L) \rightarrow e\bar{d}$	-
$V_{1/2}(L) \rightarrow ed$	303
$V_{1/2}(R) \rightarrow eu, ed$	227
$\tilde{V}_{1/2}(L) \rightarrow eu$	176
$V_0(L) \rightarrow e\bar{d}$	917
$V_0(R) \rightarrow e\bar{d}$	165
$\tilde{V}_0(R) \rightarrow e\bar{u}$	489
$V_1(L) \rightarrow e\bar{u}, e\bar{d}$	659

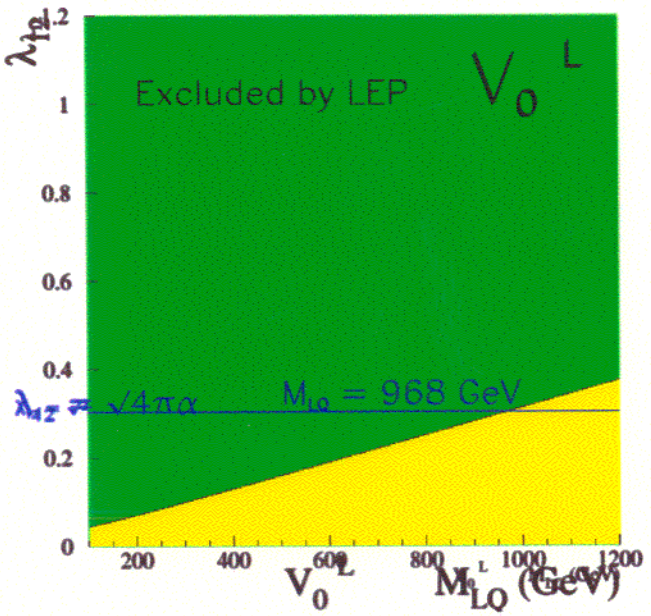
1st generation

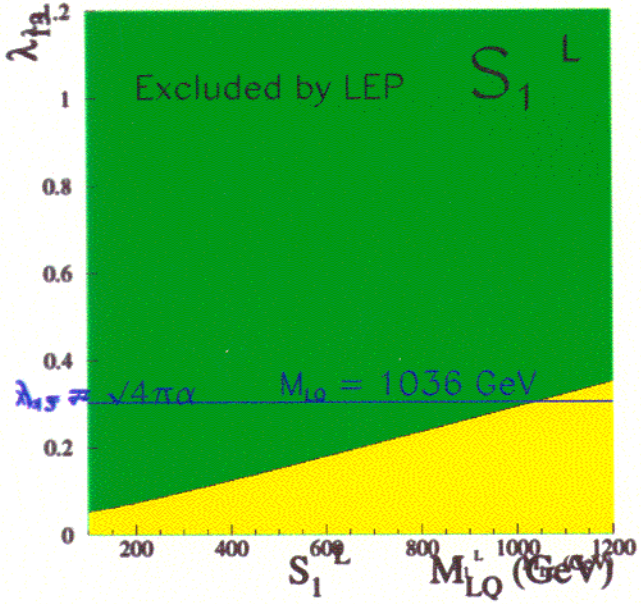
2nd generation

$V_0(L) \rightarrow ec, es$

3rd generation

$S_1(L) \rightarrow eb$



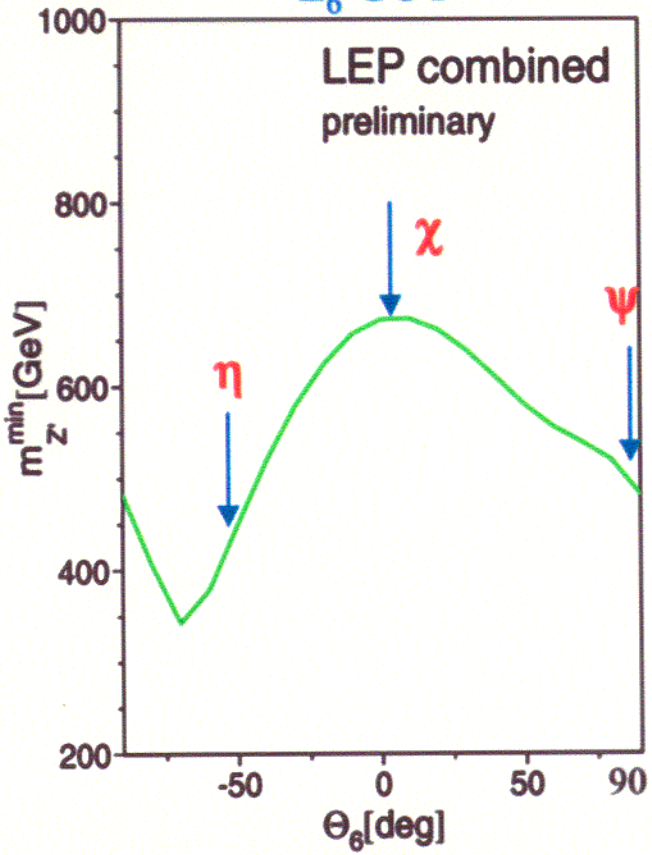


Extra Z ’

ZZ ’ mixing angle set to 0

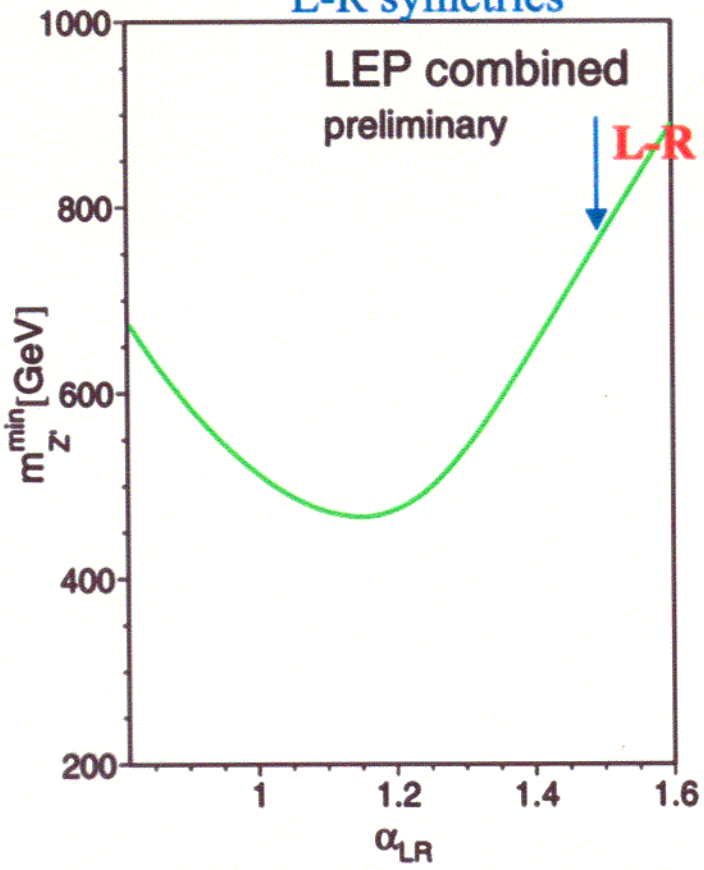
Z ’ model	χ	ψ	η	L-R	SSM
$M_{z'}$ (GeV/c²)	673	481	434	804	1787

E_6 GUT



$$J_{z'} = J_\chi \cos\theta_6 + J_\psi \sin\theta_6$$

L-R symetries



Summary

- The LEP2 di-fermion data are in good agreement with Standard Model predictions, at the % level

- Constraints have been put on several models:

- For instance:
  - contact interactions
  - compactified extra-dimensions
  - leptoquarks
  - Z '

- In next 6 months, the 4 LEP experiments will have hopefully final results.

  LEP data will be combined.