
Tests of the Standard Model and
constraints on new physics from

Fermion-pair production
at LEP2

Georgios Anagnostou

INP Demokritos Athens/Birmingham University

HEP 2003 , Europhysics Conference in Aachen,
Germany, July 2003

Outline

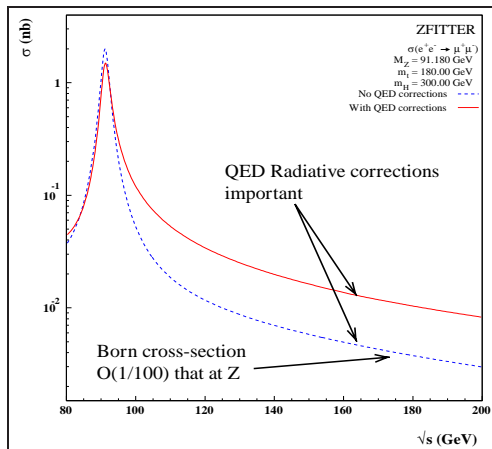
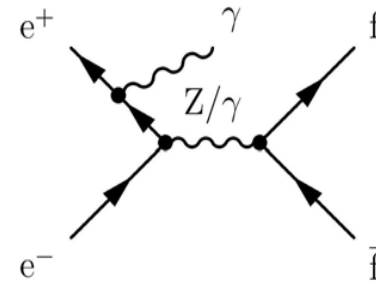
- Photon radiation - signal definition
- Test of the SM - xsections, Afb, Rq's

Constraints on new physics:

- Contact interaction
- Z' bosons
- Low scale gravity

Photon Radiation - Radiative return to Z

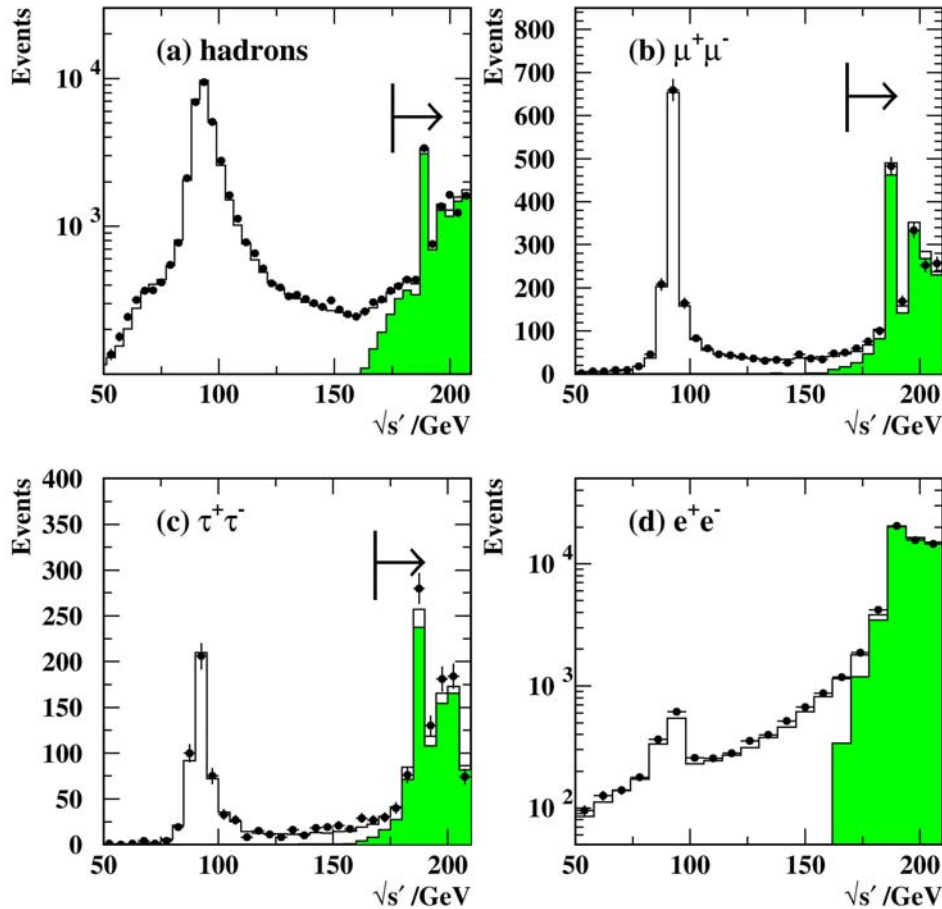
- General feature of $e^+e^- \rightarrow f\bar{f}$: often radiation of an initial state photon decreases effective collision energy \sqrt{s}'
- if \sqrt{s}' close to Z peak more likely to interact \rightarrow significant enhancement of xsection - **Radiative return to Z**.



- Photon radiation complicates signal definition: Initial/Final state photons cannot be cleanly separated.
- LEP signal definition for reduced collision energy \sqrt{s}' : **mass of s-channel propagator with ISR-FSR interference subtracted so mass is unambiguous.**

Photon Radiation - Signal definition

OPAL 189 - 209 GeV



Data sample divided into

- **non-radiative** $\sqrt{s'}/\sqrt{s} > 0.85$.
- **inclusive** events $\sqrt{s'}/\sqrt{s} > 0.01$.

- LEP combinations and new physics searches only for high energy sample.

- Radioactive events peak at $\sqrt{s'} \sim M_Z$ used for independent beam energy measurement.

LEP combinations

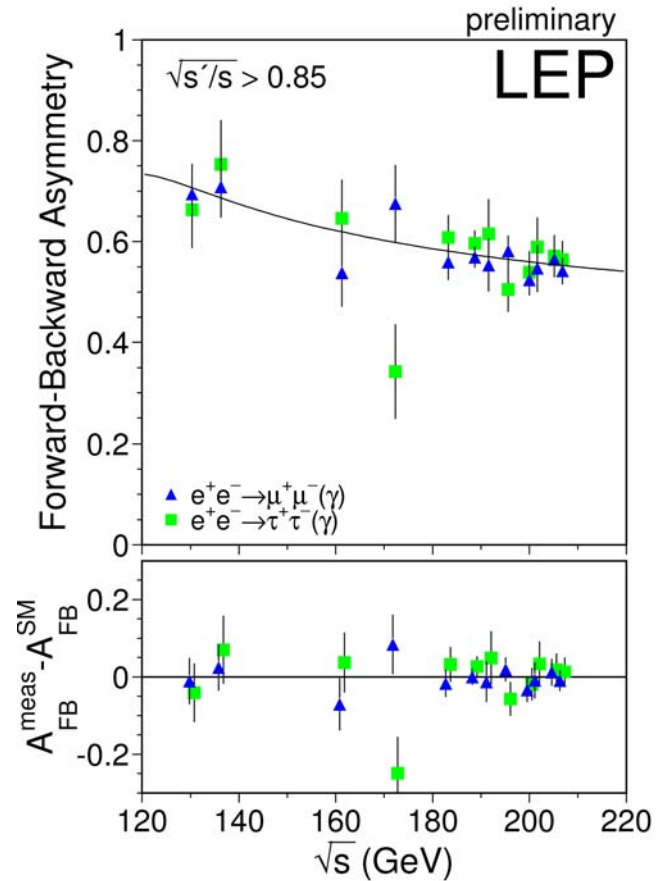
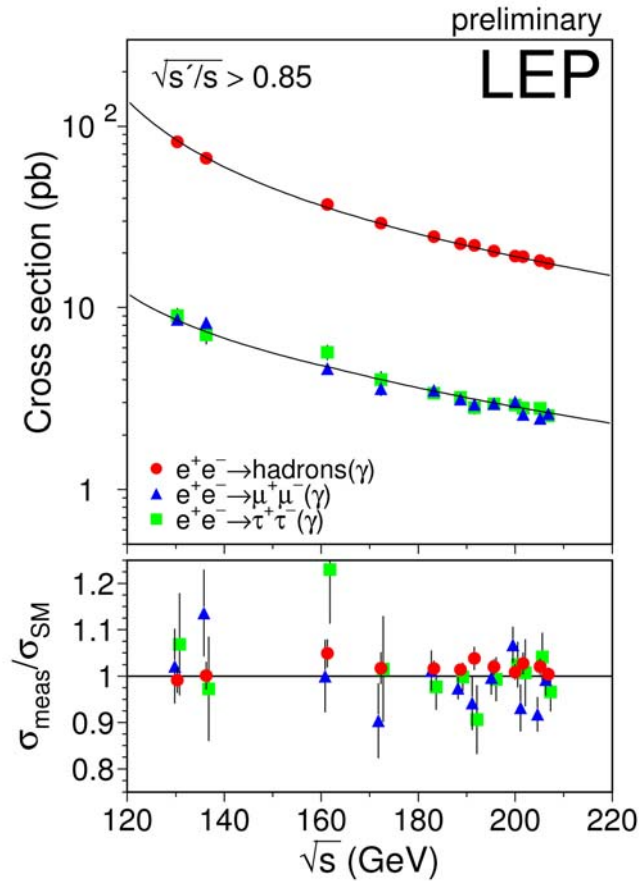
- Preliminary combinations for xsections $\sigma_{\mu\mu}$, $\sigma_{\tau\tau}$, σ_{had} and asymmetries $A_{\text{FB}(\mu\mu)}$, $A_{\text{FB}(\tau\tau)}$ as well as $d\sigma/d\cos\Theta$'s and $R_{b/c}$, $A_{\text{FB}b/c}$.
- Individual measurements performed with slightly different signal definitions → **corrections applied to derive results in common signal definition.**
- **Careful attention to correlated systematics** → systematic error broken down in parts according to correlations between channels, experiments.
- Averaging for xsections-asymmetries performed using **BLUE technique.**



Perhaps you already guess ..

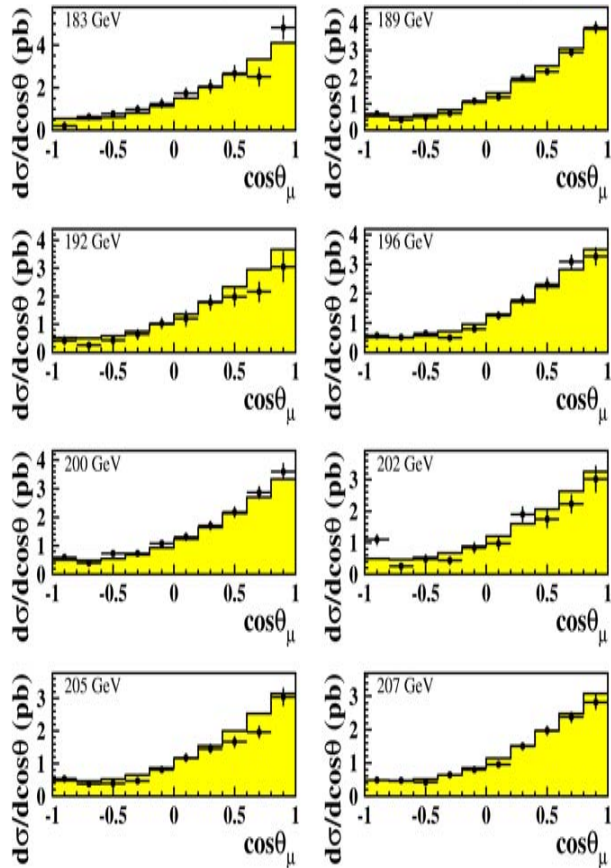
In general good agreement between SM and data ($\chi^2/\text{d.o.f} \sim 160/180$).
Largest difference : Hadronic xsection slightly higher than expectation ($\sim 1.7\sigma$).

Cross-sections & Asymmetries

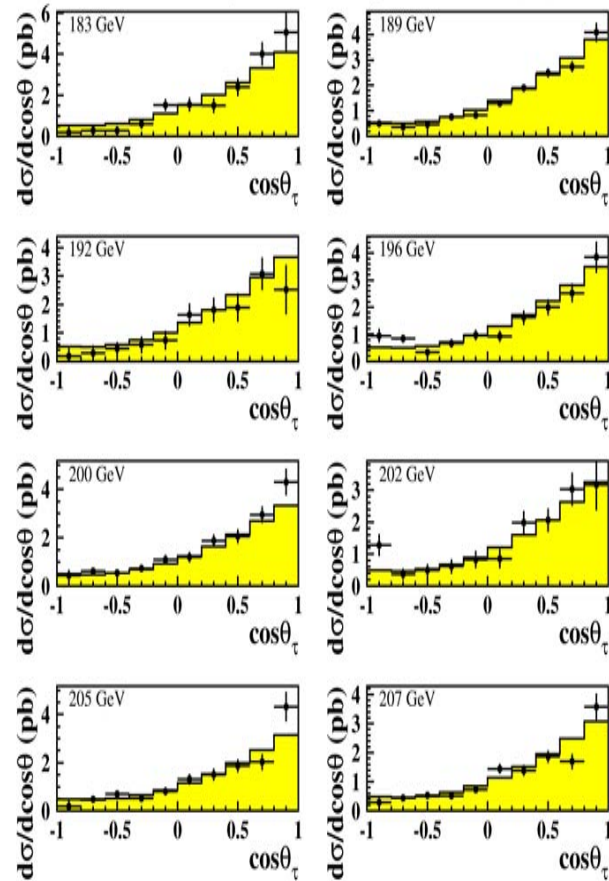


Differential cross-sections - $\mu\mu$, $\tau\tau$

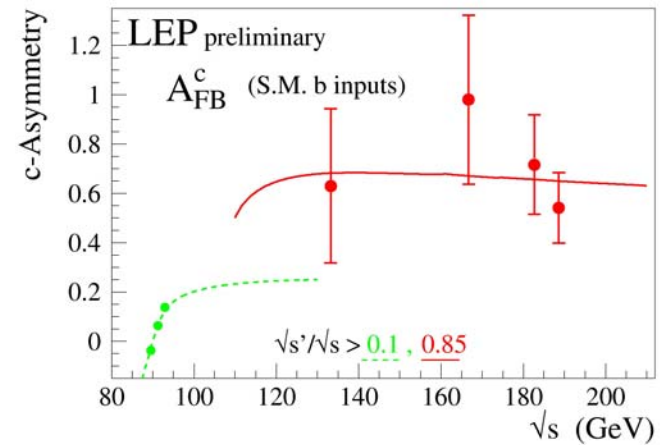
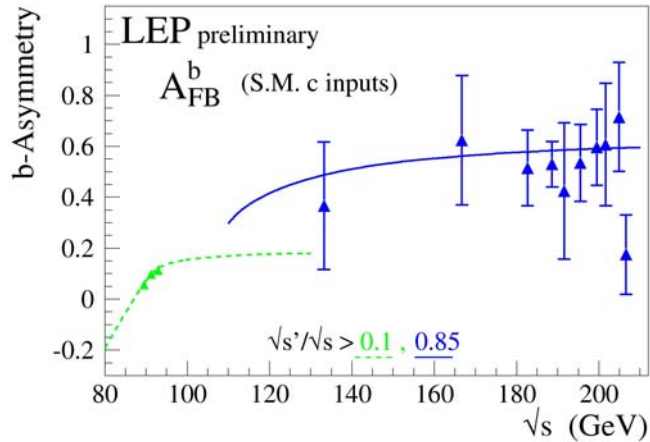
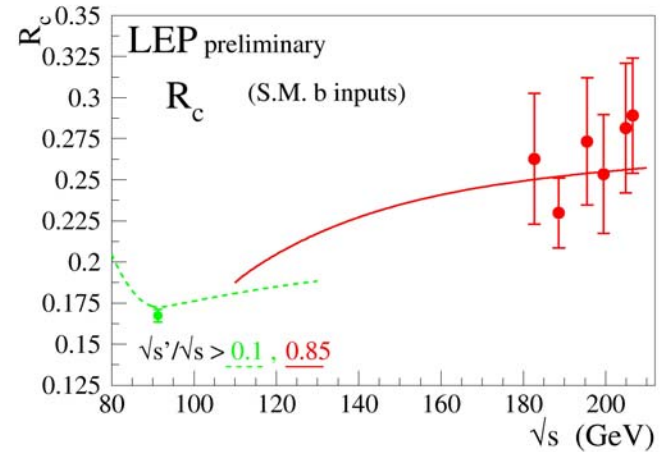
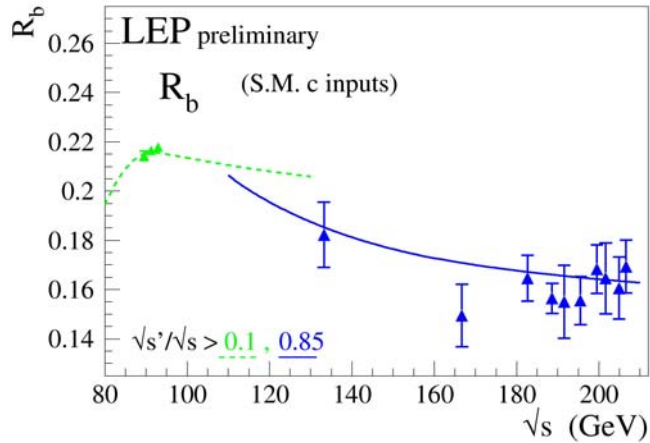
Preliminary LEP Averaged $d\sigma/d\cos\theta$ ($\mu\mu$)



Preliminary LEP Averaged $d\sigma/d\cos\theta$ ($\tau\tau$)



Heavy Flavours: R_b , $A_{\text{FB}b}$, R_c , $A_{\text{FB}c}$



Contact Interactions (I)

- Convenient parameterisation of new physics due to composite quark & leptons OR due to the exchange of heavy boson with $m_\chi \gg \sqrt{s}$.

- Lagrangian has additional term:

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



$$\frac{d\sigma}{d\cos\theta} = A(s,t) + B(s,t) \varepsilon + C(s,t) \varepsilon^2, \quad \varepsilon = \frac{1}{\Lambda^2}$$

Model	LL	RR	LR	RL	VV	AA	V0	A0
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



- η_{ij} describes chiral structure of the model

- Λ energy scale of new physics

- g unknown coupling

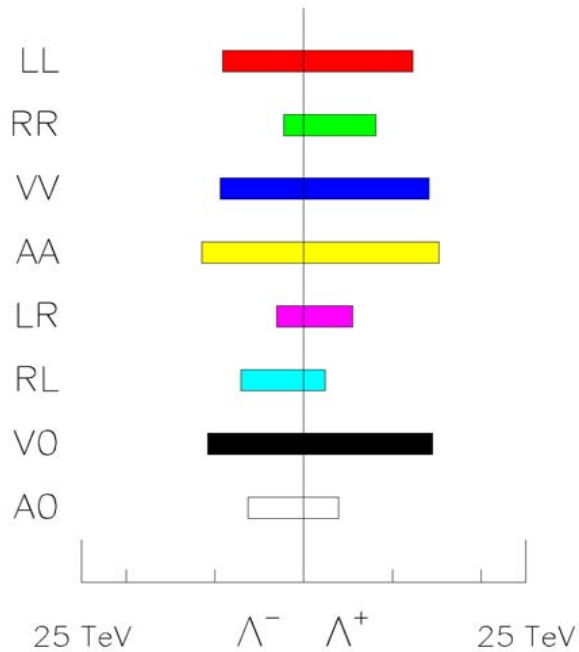
$$\delta = \begin{cases} 1 & \text{for } e^-e^+ \rightarrow e^-e^+ \\ 0 & \text{otherwise} \end{cases}$$

- Fit ε (having set $g^2/4\pi=1$)

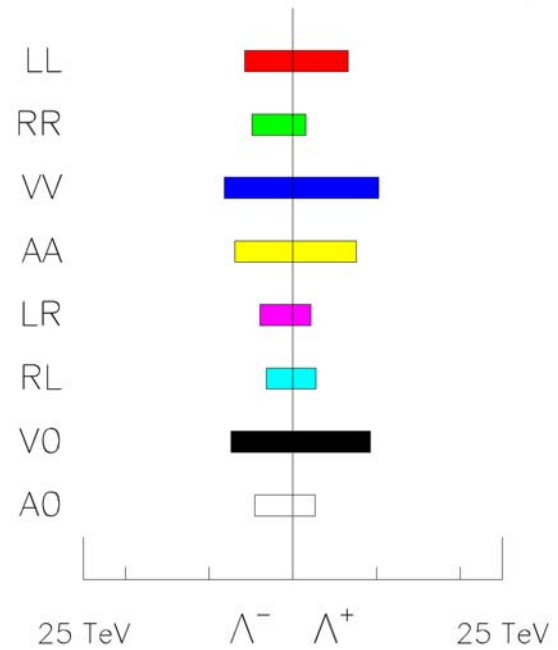
- limits Λ^+ , Λ^- correspond to constructive, destructive interference with SM.

Contact Interactions (II)

bb – LEP Preliminary



cc – LEP Preliminary



Extra Z' Boson

- If SM embedded into a larger gauge group \rightarrow new heavy gauge boson, some of which will be neutral $\rightarrow Z'$.
- In general Z' could mix with Z^0 , mixing parameterized by angle Θ_E :

$$\begin{pmatrix} Z \\ Z' \end{pmatrix} = \begin{pmatrix} \cos \Theta_E & \sin \Theta_E \\ -\sin \Theta_E & \cos \Theta_E \end{pmatrix} \begin{pmatrix} Z^0 \\ Z^{0'} \end{pmatrix}$$

Model	Mixing
χ	$\Theta_E = 0$
ψ	$\Theta_E = \pi/2$

- Example: E(6) GUT

$$E(6) \rightarrow SO(10) \times U(1)_X$$

$$\hookrightarrow SU(5) \times U(1)_Y$$

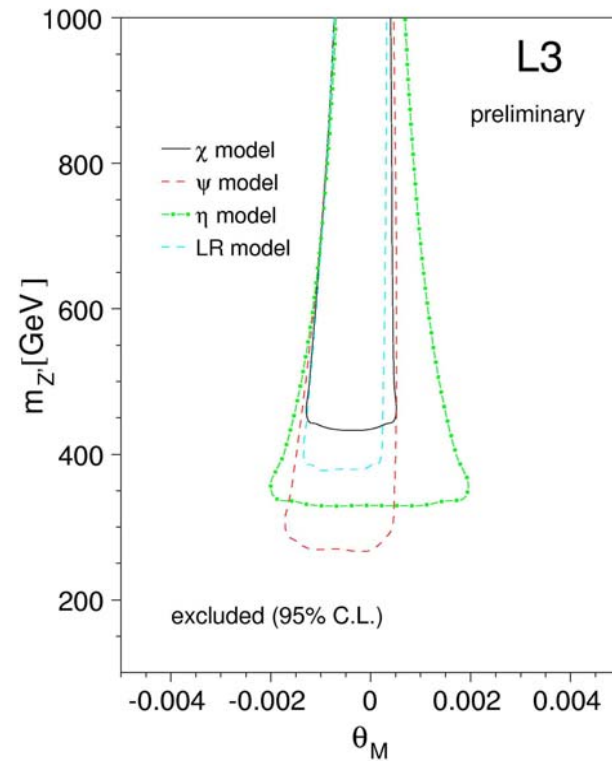
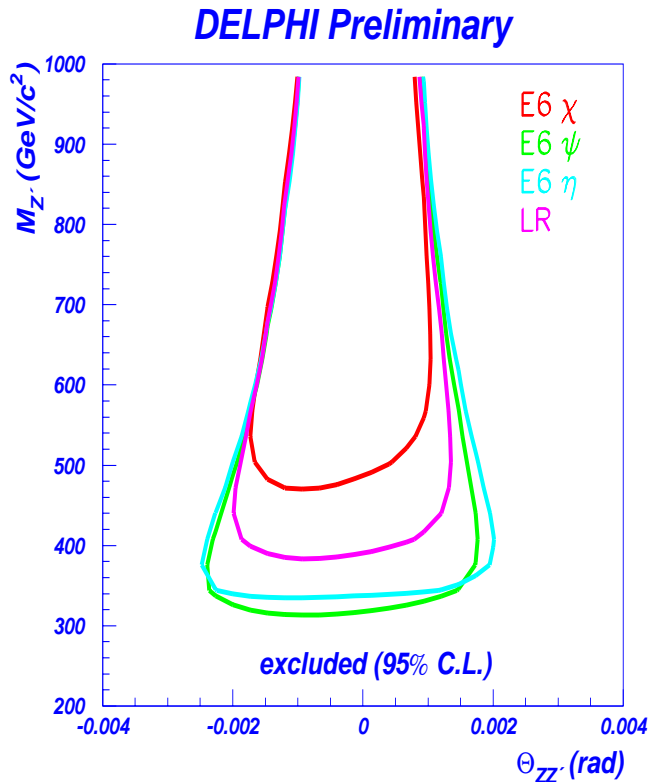
$$\hookrightarrow SU(3)_C \times SU(2)_L \times U(1)$$

- Two additional gauge groups introduced.
- In general $Z^{0'}$ will be a mixed state of Z_X, Z_Y

$$Z^{0'} = Z_\Psi \sin \Theta_{E6} + Z_X \cos \Theta_{E6}$$

- Also Sequential SM $\rightarrow Z'$ has same couplings to fermions as Z .
- Left Right symmetric model (LR) \rightarrow introduce additional $SU(2)_R$ symmetry.

Extra Z' Boson (II) - Exclusion contours



Extra Dimensions - Low scale Gravity (I)

The two seemingly fundamental energy scales in nature M_{EW} and $M_{Pl} \sim G_N^{-1/2}$ have a ratio of $10^{-15} \rightarrow$ hierarchy problem.

- While ElectroWeak interactions have been tested experimentally at distances $\sim M_{EW}^{-1}$, gravity tested only in the \sim mm range.

- Assumption: M_{EW} is the only fundamental short range scale in nature, even for gravity.

Assume, $M_{Pl(4+n)} \sim M_{EW} (10^3 GeV)$

$n=1 \rightarrow R \sim 10^{13} cm$

$n=2 \rightarrow R \sim 100 \mu m - 1 mm$

$n=3..$

$$1. (D=4) \quad V(r) = G_N \frac{m_1 m_2}{r}, \quad G_N = M_{Pl(4)}^{-2}$$



$$2. (D=n+4) \quad a) \quad V(r) \sim \frac{m_1 m_2}{M_{Pl(n+4)}^{n+2}} \frac{1}{r^{n+1}}, \quad r \ll R$$

$$b) \quad V(r) \sim \frac{m_1 m_2}{M_{Pl(n+4)}^{n+2} R^n} \frac{1}{r}, \quad r \gg R$$



(1) & (2b) must look the same

$$\leftarrow M_{Pl(4)}^2 \sim M_{Pl(n+4)}^{n+2} R^n$$

Extra Dimensions - Low scale Gravity (II)

- SM interactions tested accurately up to M_{EW} scale \rightarrow experimental constraint for SM particles not to propagate in extra dimensions \rightarrow only gravity does.

Searches

Direct

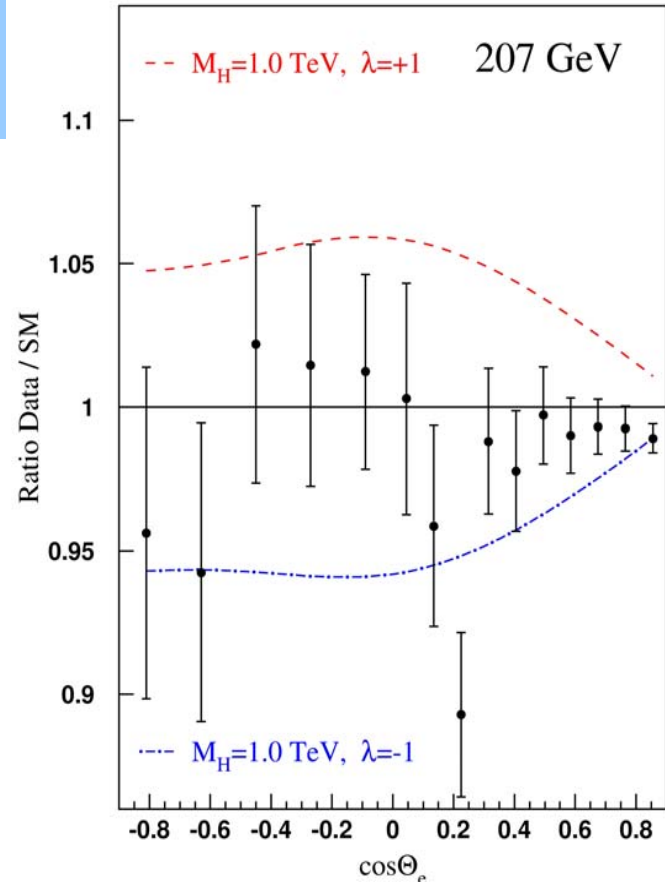
$$e^+e^- \rightarrow G\gamma$$

Indirect

$$e^+e^- \rightarrow G^* \rightarrow f\bar{f}$$

$$d\sigma/d\Omega = A(s,t) + \frac{\lambda}{M_s^4} B(s,t) + \frac{\lambda^2}{M_s^8} C(s,t)$$

Preliminary LEP Averaged $d\sigma/d\cos\Theta(e^+e^-)$



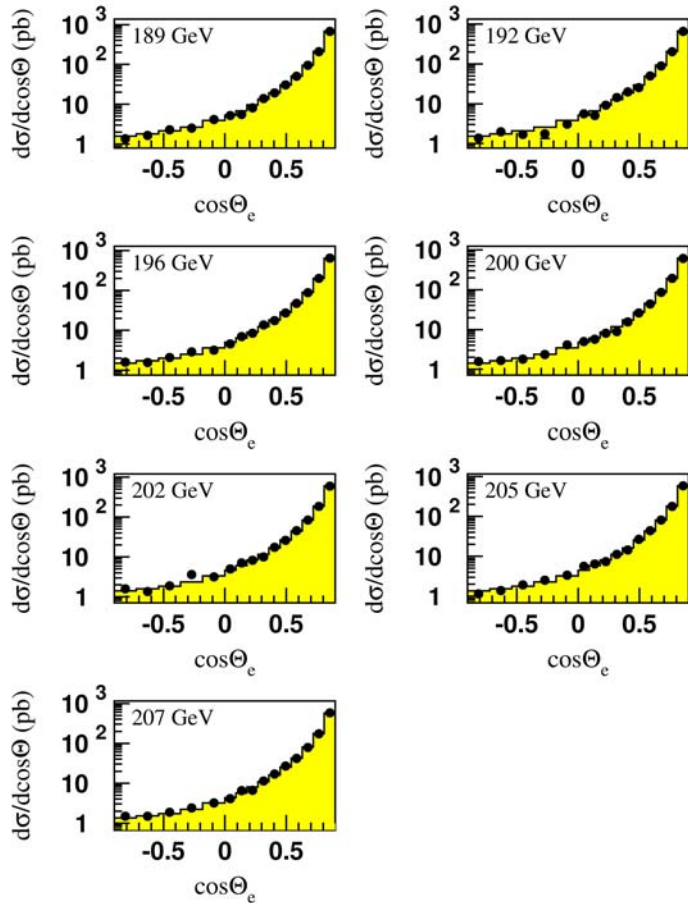
Conclusions

- Results from 4 LEP experiments consistent and in good agreement with each other.
- Preliminary combined results for xsections, asymmetries and R_q 's are in good agreement with SM expectations.
- Used to set limits to new physics depending on the model:
 - contact interactions in the range 1.5-19.7 TeV.
 - Z' from 0.34-1.787 TeV.
 - low scale gravity $M_s > 1.2$ TeV ($\lambda=+1$), 1.09 TeV ($\lambda=-1$).
- Final results now starting to appear. When available perform combinations and limit's extraction again using same methods.

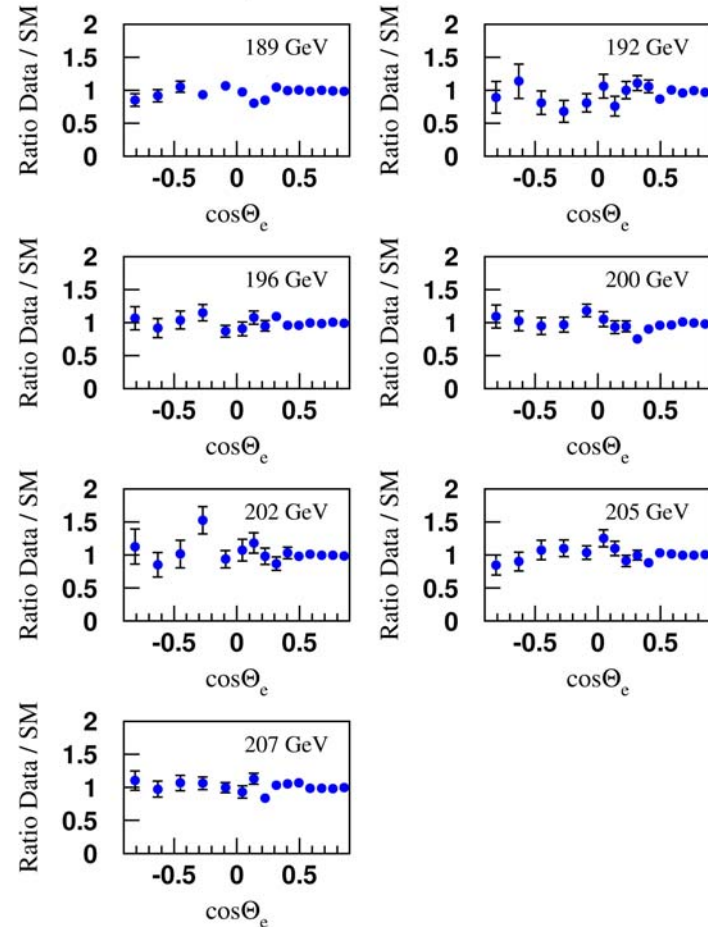
Back-up slides

Differential cross-sections - Bhabhas

Preliminary LEP Averaged $d\sigma/d\cos\Theta(e^+e^-)$

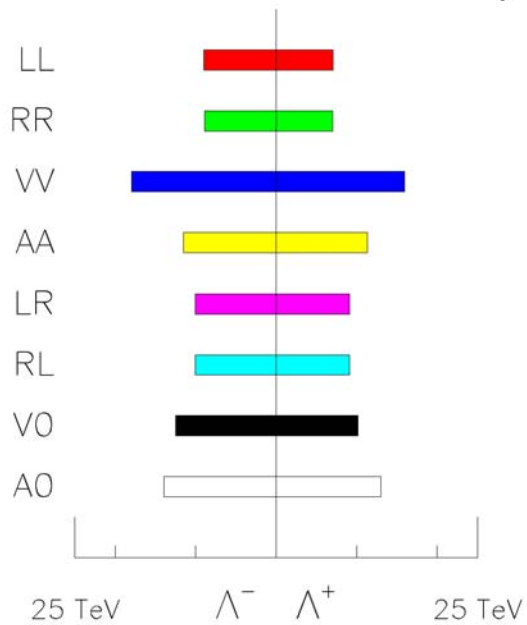


Preliminary LEP Averaged $d\sigma/d\cos\Theta(e^+e^-)$

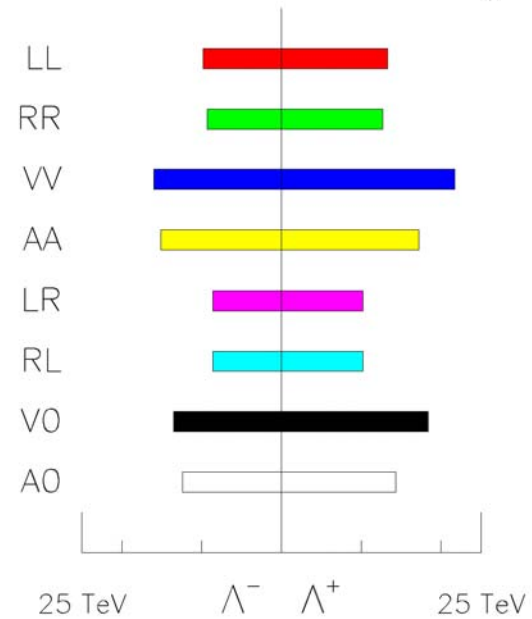


Contact Interactions (III)

ee – LEP Preliminary



ll – LEP Preliminary



Extra Dimensions - Low scale Gravity (III)

