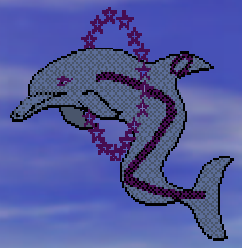
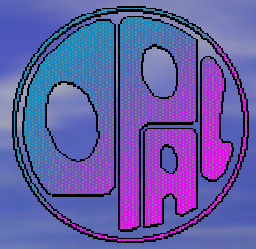


L3


Selected tests of the Physics beyond the SM at LEP

F.-L. Navarria / Bologna

- FCNC via single top production
- Compositeness: searching for excited leptons
- Graviton production/exchange and extra dimensions

Introduction

- ALEPH,DELPHI, L3, OPAL data samples about 2.4 fb^{-1} (~600pb^{-1} per experiment) at $\sqrt{s}$ = 189-209 GeV (1998-2000)
- LEP EXOTICA WG: combination of all non-Higgs and non-SUSY searches at LEP2 – some combinations (single t, excited leptons) available since 2001 (and still preliminary) – new one (extra dimensions) in summer 2004!
- aim: restrict the space of the parameters of some extensions of the SM
- main searches published by all experiments, but some analyses still under way
- statistical procedure adopted for the combination of the different channels (same or different experiments): likelihood ratio method

Flavour-Changing-Neutral-Currents (FCNC) are known to be absent at tree level in the Standard Model. Neutral currents such as $e^+e^- \to t\bar{q}$ can be present at the one loop level, but the rates are severely suppressed.

In SM: Single Top Production is $\mathcal{O}(10^{-9})$ fb at LEP2 Energies

This opens the possibility of using the corresponding FCNC processes to probe for new physics !

Single top

Look for

$e^+e^- \to tc(u)$ at LEP

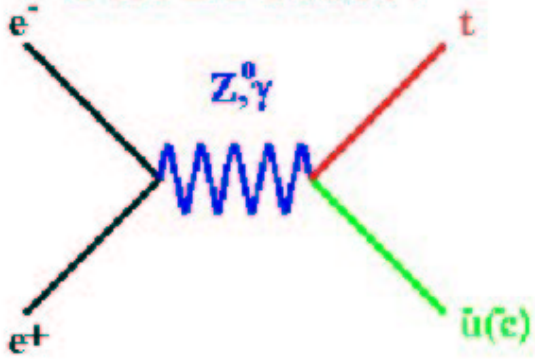
$ep \to teX$ at HERA

$t \to Z(\gamma)c(u)$ at Tevatron

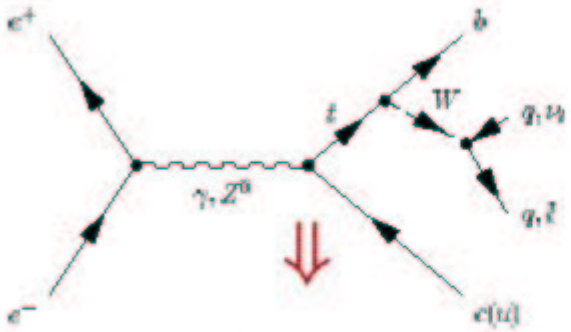
One loop level in SM (GIM)
$BR(t \to (\gamma,g,Z)+c(u)) < 10^{-10}$

- Supersymmetry and multi-Higgs doublet models predict FCNC at tree level
- FCNC coupled singlet quarks, compositeness, or dynamical ew symmetry breaking → BR ~ 10^{-2}

PRODUCTION



Flavour changing vertices are present in many extensions of the SM which could enhance the production of the top quarks.



$$E_t \simeq m_t$$
$$E_W \simeq \frac{m_t^2+m_W^2-m_b^2}{2m_t}$$
$$E_b \simeq \frac{m_t^2-m_W^2+m_b^2}{2m_t}$$
$$E_{c(u)} \simeq \sqrt{s}-m_t$$

Coupling Parameters κ_Z and κ_γ

Analyses use NNW, LHV or DV for h & l channels (b-tag & kinematic variables): no excess above SM bkgd

→ 95% CL excl. lim.

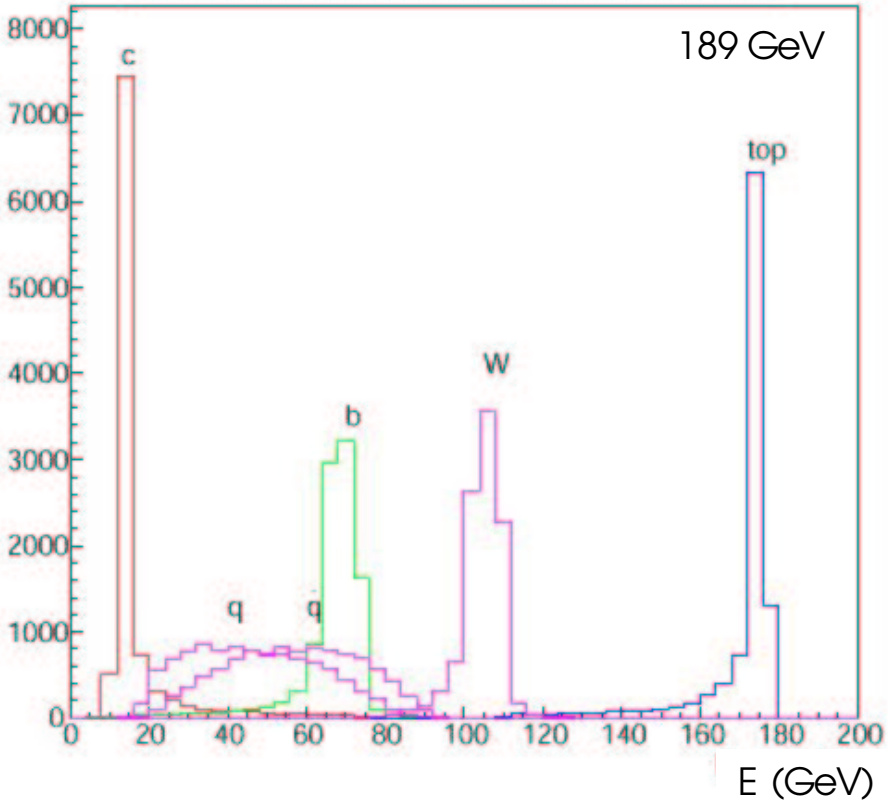
Strength of $\gamma \to ff'$, $Z \to ff'$

$\Gamma^\gamma_\mu = \kappa_\gamma ee_q/\Lambda\ \sigma_{\mu\nu}\ (g_1P_l+g_2P_r)\ q_\nu$

$\Gamma^Z_\mu = \kappa_Z\ e/\sin 2\Theta_W\ \gamma_\mu\ (z_1P_l+z_2P_r)$

Λ new physics scale (assume $\Lambda = m_t$),
$P_{l,r}$ left, right handed projectors,
$g_1^2 + g_2^2 = 1$, $z_1^2 + z_2^2 = 1$,
conservatively $g_1z_1 + g_2z_2 = -1$

Characteristic Kinematics



Preliminary (2001) combination, all experiments have published final results: A(2002), D(2004), L(2002), O(2001)

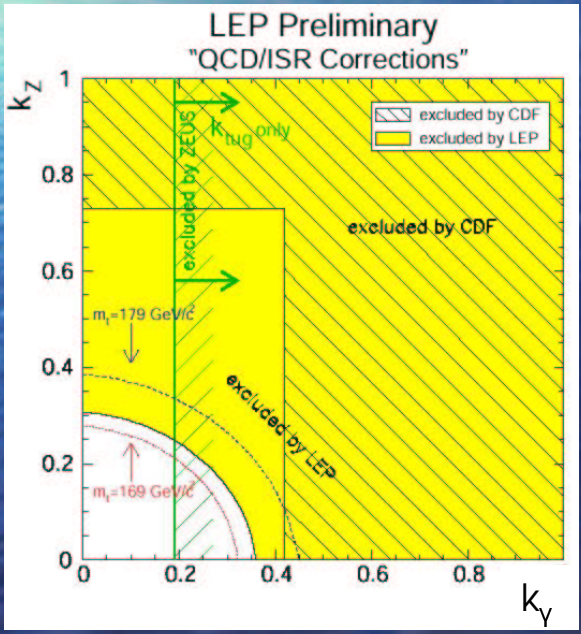
Xsection limit at each C.M energy with signal efficiency ϵ and luminosity $\mathcal{L}$:

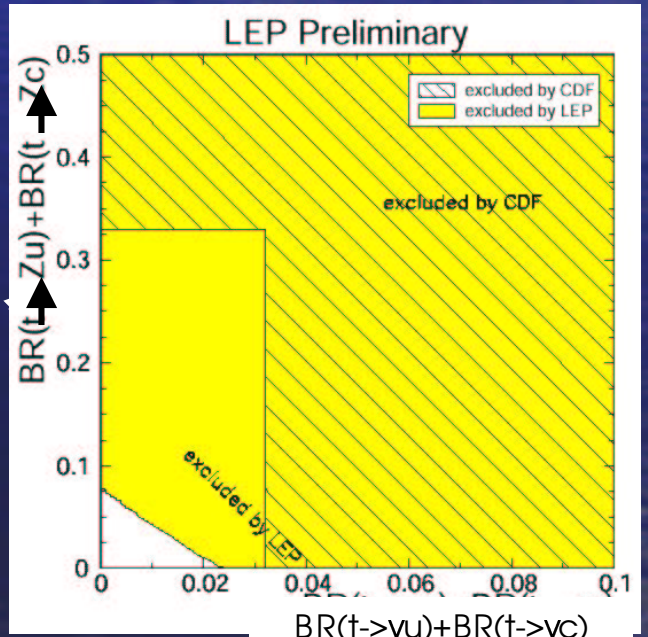
$$CL_s = \prod_{i=1}^{N} \frac{e^{-(s_i+b_i)}(s_i+b_i)^{n_i}}{n_i!} \Big/ \prod_{i=1}^{N} \frac{e^{-b_i} b_i^{n_i}}{n_i!}$$

b_i: MC background events
s_i: Number of signal events
N: Number of data channels

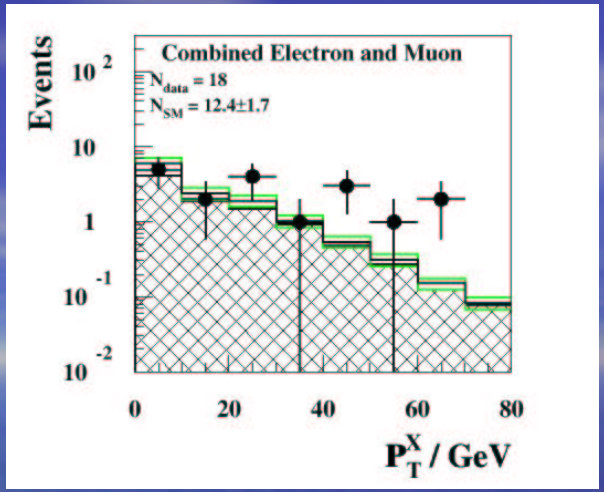
$$\sigma_{95}^{\text{obs.}} = \frac{s_{\text{tot}}/\epsilon}{\mathcal{L}}$$

Combination A+D+L+O [cross-section UL in pb]						
Label (GeV)	$m_{top} = 169\ GeV/c^2$ $\sigma_{95}^{obs.}$	$\sigma_{95}^{exp.}$	$m_{top} = 174\ GeV/c^2$ $\sigma_{95}^{obs.}$	$\sigma_{95}^{exp.}$	$m_{top} = 179\ GeV/c^2$ $\sigma_{95}^{obs.}$	$\sigma_{95}^{exp.}$
189	0.15	0.14	0.11	0.11	0.13	0.13
192	0.41	0.39	0.38	0.33	0.42	0.36
196	0.38	0.24	0.36	0.20	0.39	0.22
200	0.26	0.24	0.21	0.21	0.24	0.20
202	0.31	0.40	0.30	0.35	0.27	0.35
205	0.27	0.28	0.22	0.25	0.23	0.24
207	0.19	0.20	0.17	0.18	0.15	0.17





The most intriguing finding so far in single top production is the H1 leptonic events at HERA (but no evidence in the hadronic channel) or in ZEUS

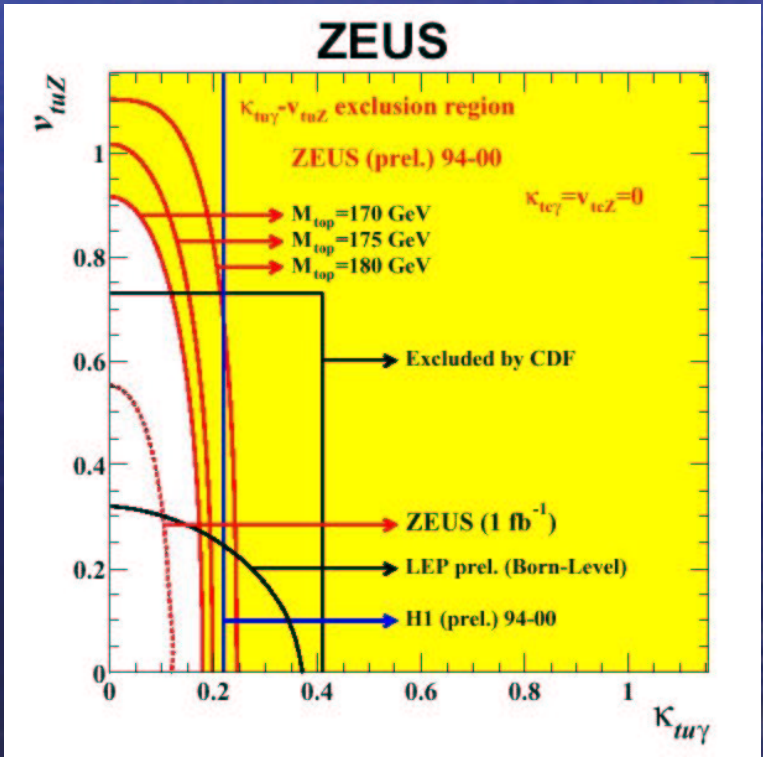


H1

Individual LEP expts – final results

	κ_γ	κ_Z	BR_γ	BR_Z
Aleph	0.49	0.42	.041	.140
Delphi	0.49	0.41		
L3	0.43	0.37	.041	.137
Opal	0.48	0.41		

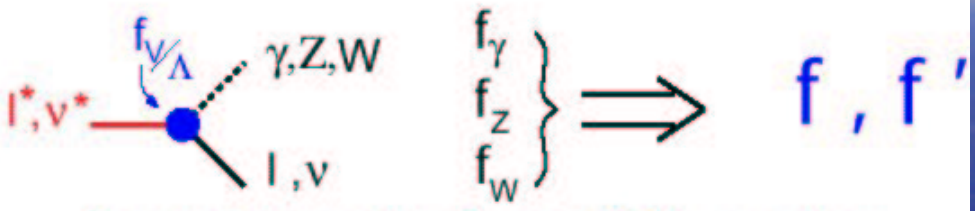
m_t = 175 (174) GeV D,L (A,O)



Compositeness

Substructure at an energy scale Λ $\Longrightarrow$ Excited leptons ℓ^* & ν^*

Decay promptly $\begin{cases} \ell^* \to \ell\gamma, \nu W, \ell Z \\ \nu^* \to \nu\gamma, \ell W, \nu Z \end{cases}$



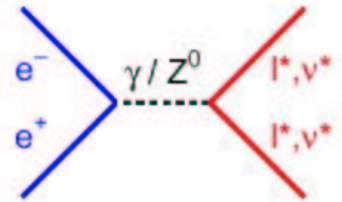
Control strength of weak/EM couplings

(*e.g.* f=f' no $\nu_e^* \to \nu_e\gamma$ f=-f' no $e^* \to e\gamma$)

pair production, σ = σ(m*,s), e.g. 0.6(0.3) pb m=101 GeV, √s=206 GeV for μ*μ*(ν*ν*)

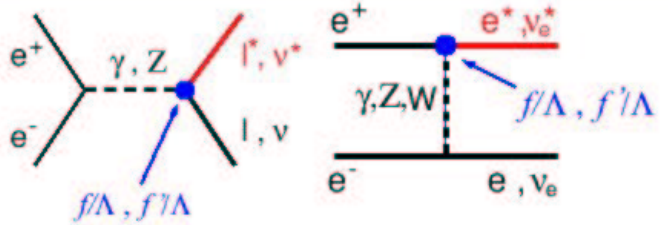
single production, σ depends on f/Λ and f'/Λ

Pair production of Excited Leptons



Discovery up to $M_{\ell^*} \sim \sqrt{s}/2$

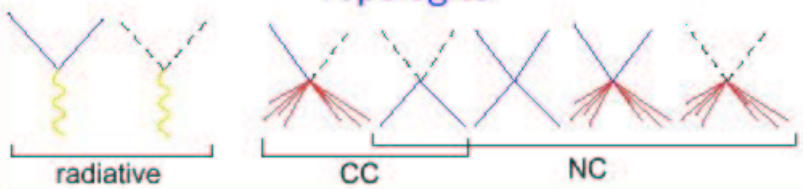
Single production of Excited Leptons



Discovery up to $M_{\ell^*} \sim \sqrt{s}$

Direct Searches

Topologies

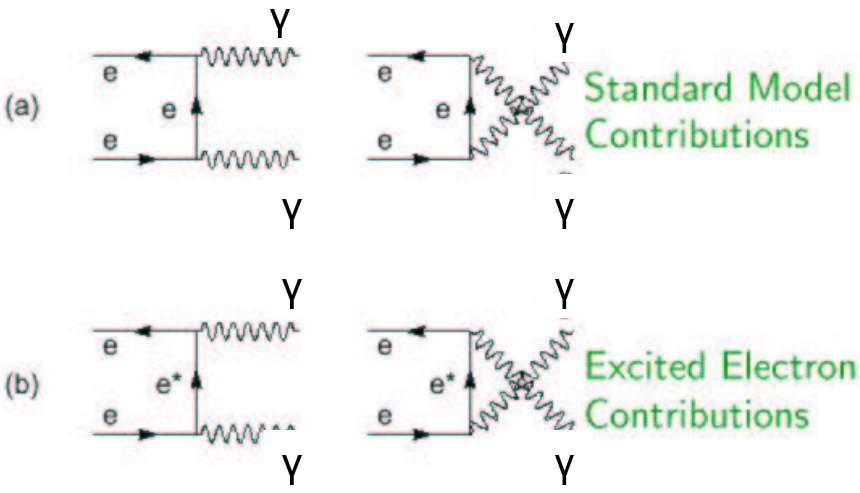


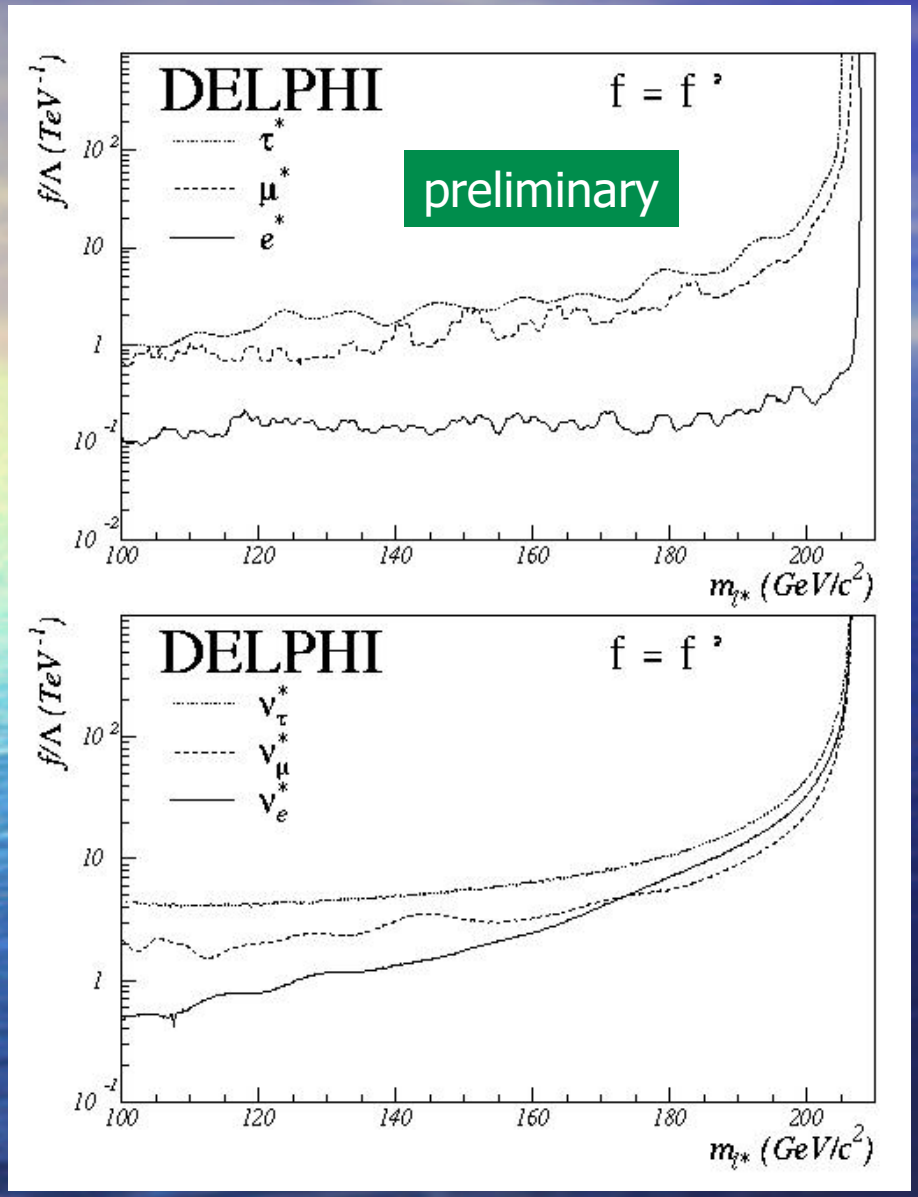
Single production

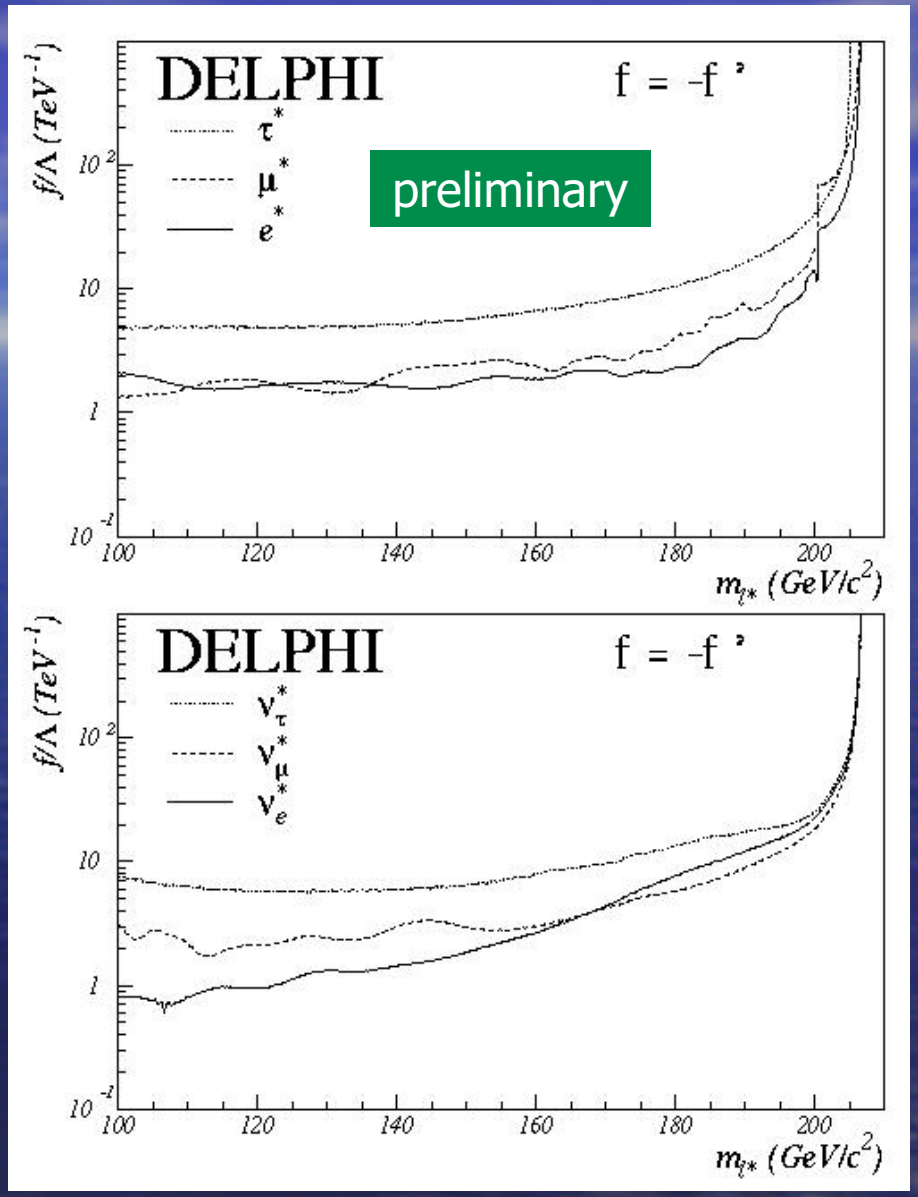
$e^+e^- \rightarrow \gamma\gamma$

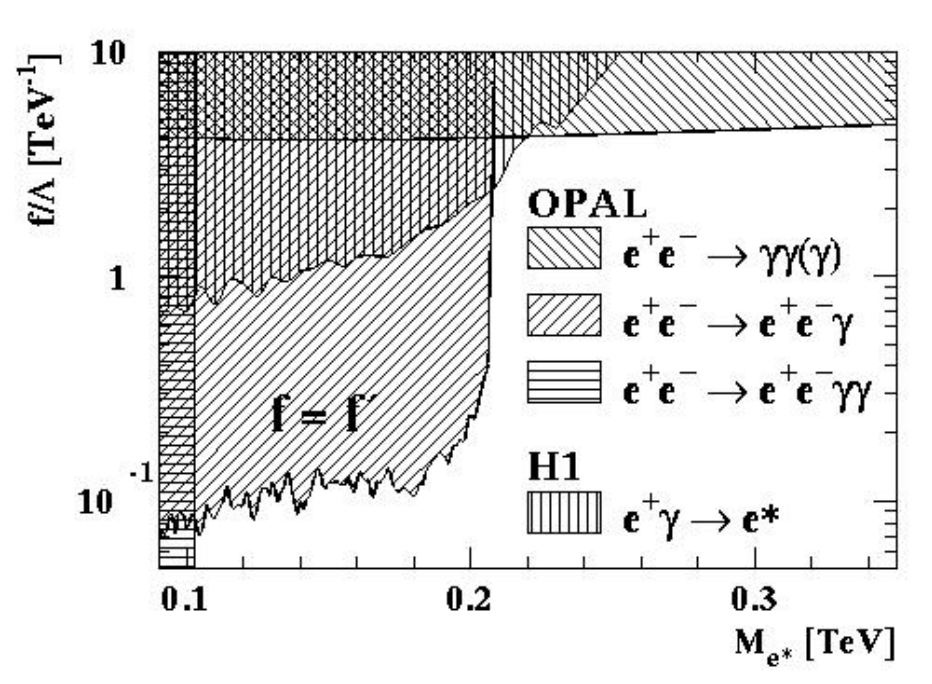
$f/\Lambda = \sqrt{2\lambda}/m_{e^*}$

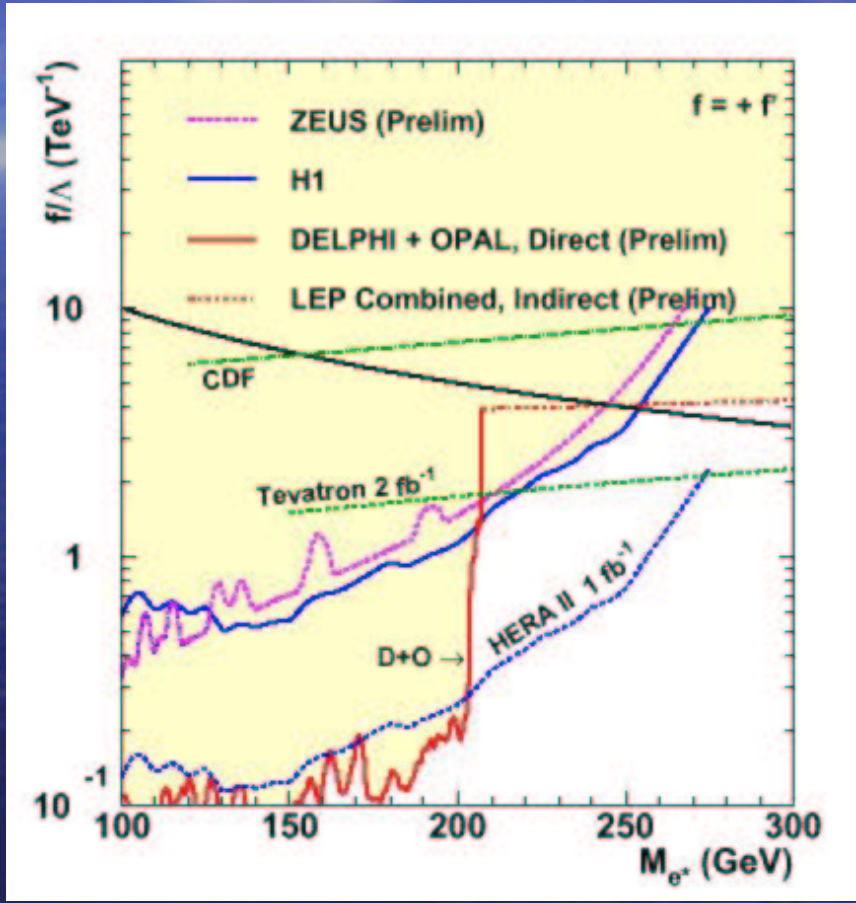
Indirect Searches




DELPHI
f = f '
preliminary
τ*
μ*
e*
f/Λ (TeV⁻¹)
m_f* (GeV/c²)
DELPHI
f = f '
ν*τ
ν*μ
ν*e
f/Λ (TeV⁻¹)
m_f* (GeV/c²)


DELPHI
f = -f '
preliminary
τ*
μ*
e*
f/Λ (TeV⁻¹)
m_f* (GeV/c²)
DELPHI
f = -f '
ν*τ
ν*μ
ν*e
f/Λ (TeV⁻¹)
m_f* (GeV/c²)


f/Λ [TeV^{-1}]
10
1
10^{-1}
0.1
0.2
0.3
M_{e^*} [TeV]
OPAL
$e^+e^- \to \gamma\gamma(\gamma)$
$e^+e^- \to e^+e^-\gamma$
$e^+e^- \to e^+e^-\gamma\gamma$
f = f'
H1
$e^+\gamma \to e^*$


f/Λ (TeV^{-1})
f = + f'
ZEUS (Prelim)
H1
DELPHI + OPAL, Direct (Prelim)
LEP Combined, Indirect (Prelim)
CDF
Tevatron 2 fb^{-1}
HERA II 1 fb^{-1}
D+O →
10
1
10^{-1}
100
150
200
250
300
M_{e^*} (GeV)

Large extra dimensions

Hierarchy problem $M^2_{ew} << M^2_{Pl}$

$(\sim 10^3\ GeV)^2 << (\sim 10^{19}\ GeV)^2$

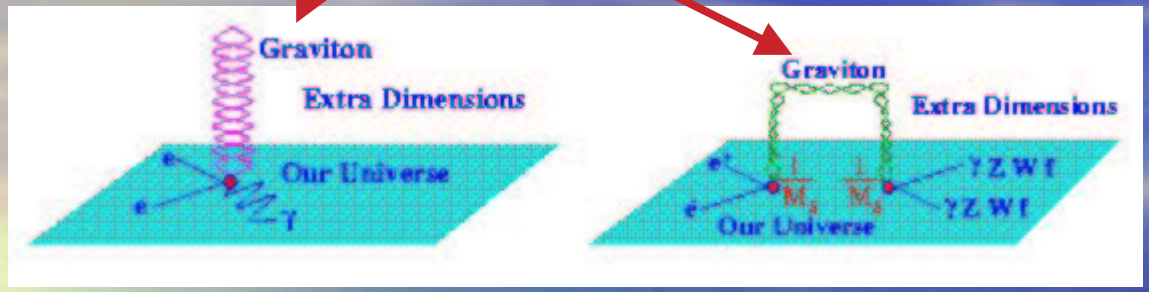
Solution (ADD) – D = 3+n+1 dimensional space-time

$M^2_{Pl} \sim R^n M^{2+n}_D$

with $M_D \sim 1$ TeV → R = 0.3 mm, 10 pm, 30 fm for n-dim = 2,4,6
(compactification on a torus (flat ed) $G_N^{-1} = 8\pi R^n M_D^{n+2}$)

- n = 1 excluded by behaviour of Newton's law at solar-system scales
- ew & strong tested to $\sim (100\ GeV)^{-1} \approx 10^{-15}$ mm, but gravity tested only to ~ 1 mm → deviation (?) from 3-dim at small distances
- SM fields on the 3-dim brane, graviton propagates in the bulk → weakness of gravity, coupling ~ 1/MPl, graviton expanded in KK tower of massive states, m ~1/R

i) Graviton emission
ii) Graviton exchange

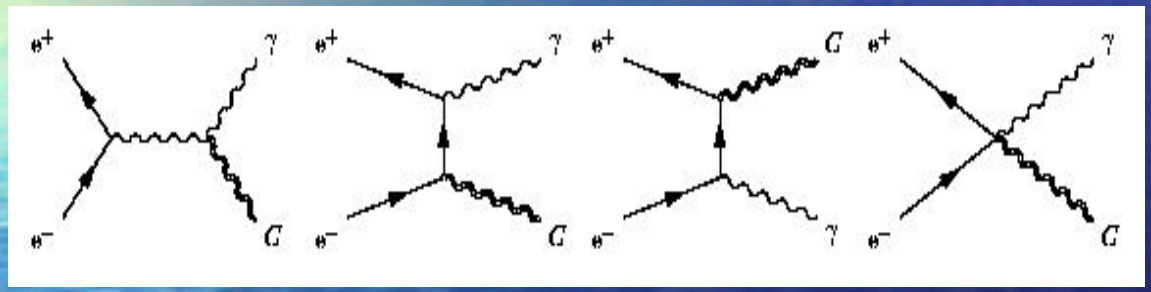


Angular & E_γ distribution for $e^+e^- \rightarrow G\gamma$

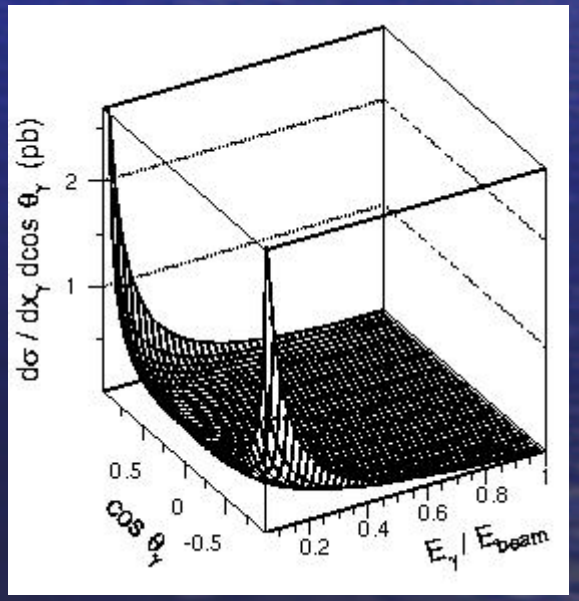
$$\frac{d^2\sigma}{dx_\gamma d\cos\theta_\gamma} = \frac{\alpha}{32s}\frac{\pi^{n/2}}{\Gamma(n/2)}\left(\frac{\sqrt{s}}{M_D}\right)^{n+2} f(x_\gamma, \cos\theta_\gamma),$$

$$f(x,y) = \frac{2(1-x)^{\frac{n}{2}-1}}{x(1-y^2)}\left[(2-x)^2(1-x+x^2)\right.$$

$$\left. - 3y^2x^2(1-x) - y^4x^4\right]$$

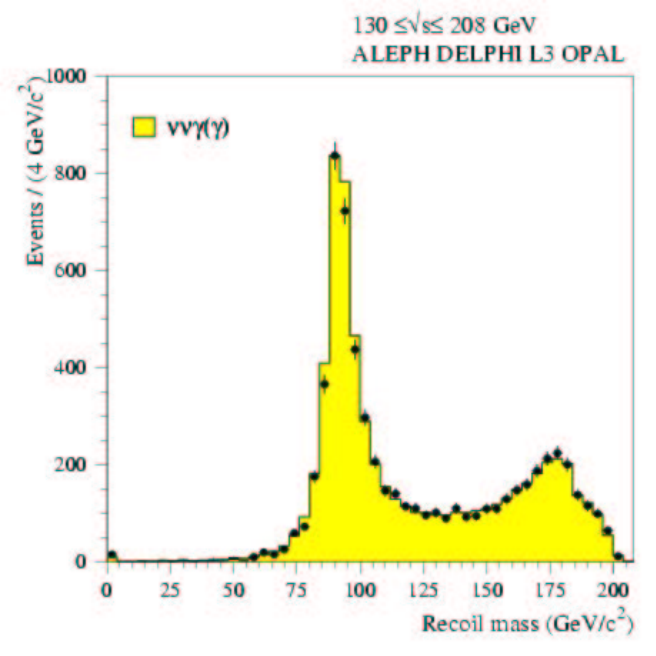


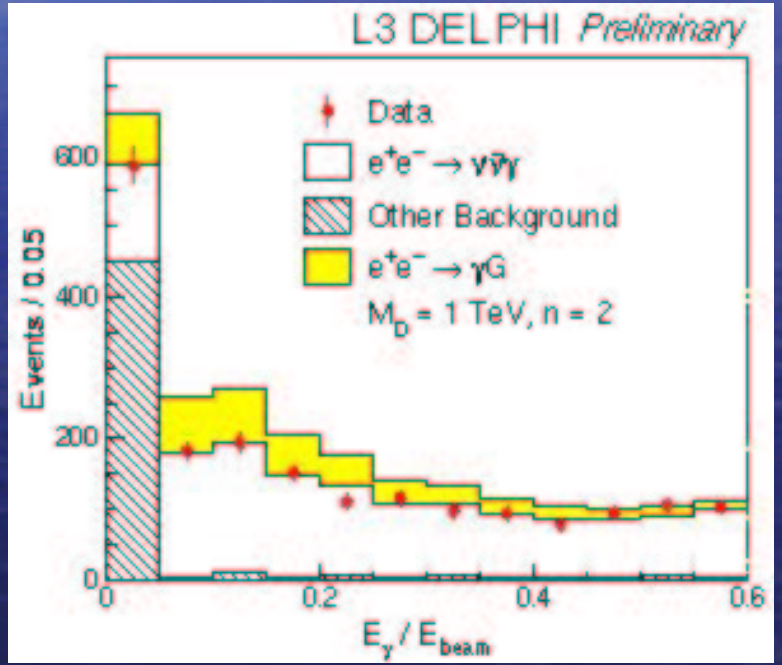
$e^+e^- \rightarrow$ single γ + graviton



principal SM background
$e^+e^- \rightarrow \nu\bar{\nu}\gamma$

- no deviation is observed wrt SM background
- preliminary combination DELPHI+L3 (with ALEPH included via likelihoods reconstructed from fitted M_D's vs n) – OPAL published results up to 189 GeV



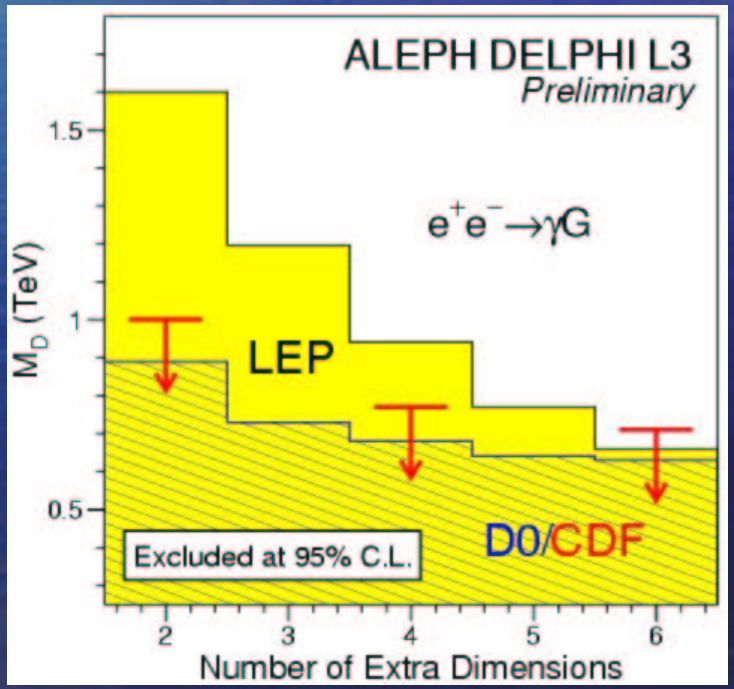


individual experiments

n	M_D (TeV)			
	ALEPH [7]	DELPHI [8]	L3 [9]	OPAL [10]
2	1.26	1.31	1.50	1.09
3	0.95	1.02	1.14	0.86
4	0.77	0.82	0.91	0.71
5	0.65	0.67	0.76	0.61
6	0.57	0.58	0.65	0.53

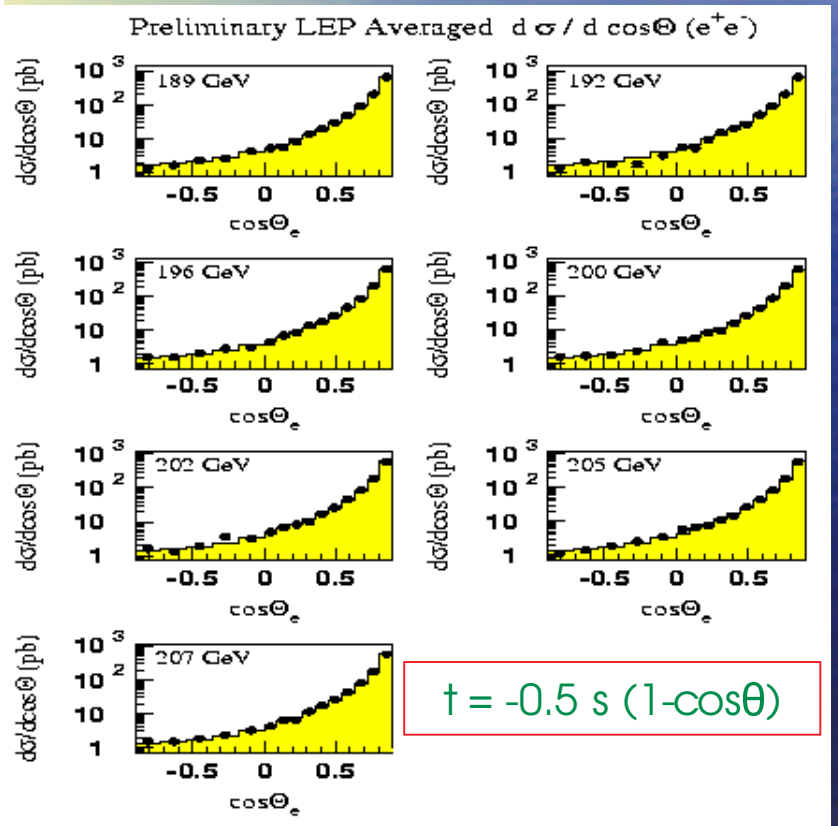
combined

n	$(1/M_D)^{n+2}$	M_D (TeV)	R (mm)
2	-0.02 ± 0.08 TeV^{-4}	> 1.60	< 0.19
3	-0.09 ± 0.22 TeV^{-5}	> 1.20	$< 2.6 \times 10^{-6}$
4	-0.3 ± 0.8 TeV^{-6}	> 0.94	$< 1.1 \times 10^{-8}$
5	-0.9 ± 3.3 TeV^{-7}	> 0.77	$< 4.1 \times 10^{-10}$
6	-4.8 ± 15.2 TeV^{-8}	> 0.66	$< 4.6 \times 10^{-11}$



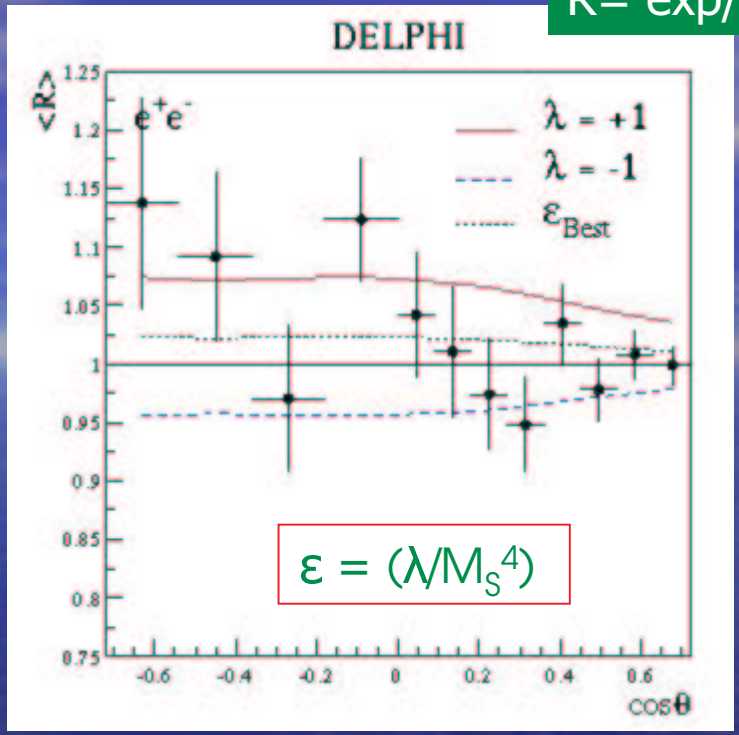
Graviton exchange in boson and fermion pair production

$M_D^4 = 2/(\pi\lambda)\, M_S^4$ M_S cut-off $|\lambda| \sim 1$



$t = -0.5\ s\ (1-\cos\theta)$

R= exp/SM



$\varepsilon = (\lambda/M_S^4)$

SM

$d\sigma/d\cos\theta = A(s,t) + (\lambda/M_S^4)\, B(s,t) + (\lambda/M_S^4)^2\, C(s,t)$

inter

G exch

most sensitive is Bhabha scattering

$M_S > 1.20(1.09)$ TeV for $\lambda = +1(-1)$ @ 95% CL

Extra Dimensions: beyond rigidity & flatness

L3: $e^+e^- \rightarrow \tilde{\pi}\tilde{\pi}\gamma$ & $\tilde{\pi}\tilde{\pi}Z$, branons, new scalars <-> brane fluctuations along ED (natural candidate for DM) – coupling ~f, brane tension,

-search complements G production:

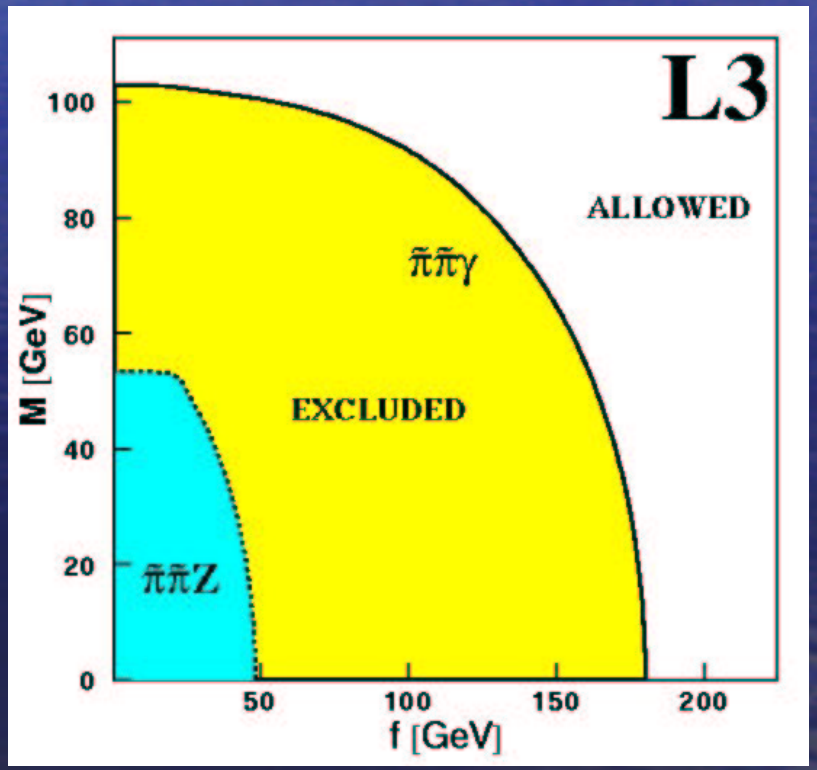
$f >> M_F$, gravity scale => G's accessible 1st;

$f << M_F$ => π, f ~

-look for E miss., no signal above SM background

elastic brane $f \rightarrow 0$ M>103GeV

massless brane M=0 f>180GeV



OPAL: within RS model ("warped" geometry) spinless inter-brane fluctuation $r_0 \rightarrow r_0 + \Delta r$ - since radion r & SM H can mix (same q.n.), at LEP2

$e^+e^- \rightarrow Zr$ or Zh with r,h mass eigenstates

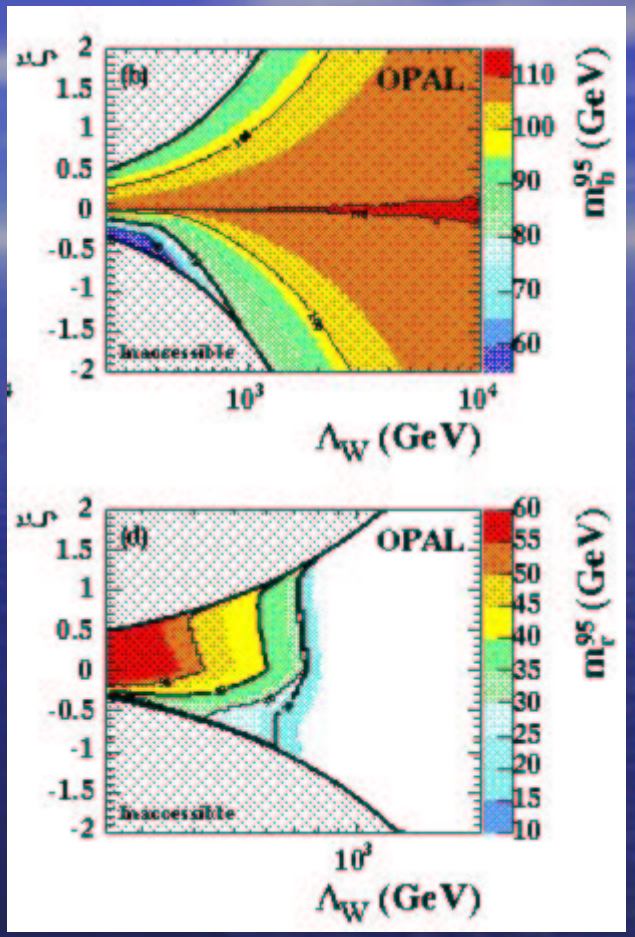
- use σ limits from SM H, flavour indep. had. decaying H & decay mode indep. H searches

-> restrict RS parameter space

- m_r, m_h, Λ_W ~O(1TeV), mass scale on SM brane, ξ, mixing parameter (ξ=0, h = SM H)

- r couplings ∝ m_{part} (reduced by $v/(\sqrt{6}\,\Lambda_W)$ wrt SM H) but r couples to g

=> BR of h particle to HQ & leptons may be reduced ($h \rightarrow gg$)



- ξ=0 → SM H mass limit
- ξ≠0 → mass limit generally lower & decreasing with decreasing Λ_W (lowest for $m_r > m_h$)
- for all ξ, m_r, Λ_W

m_h > 58 GeV @ 95% CL (54 GeV)

Conclusions

- LEP2 analyses have addressed new phenomena beyond the SM and searched for new particles
- no new phenomenon/particle has been found, and exclusion limits have been set at 95% CL for FCNC, compositeness, extra dimensions etc.
- final results of the individual experiments are now available on the main topics, but combinations and some particular analyses are still preliminary