BEYOND THE STANDARD MODEL with LEP

SM $\subset$???

G.G.Ross, LEP FEST 2000

Parameters :

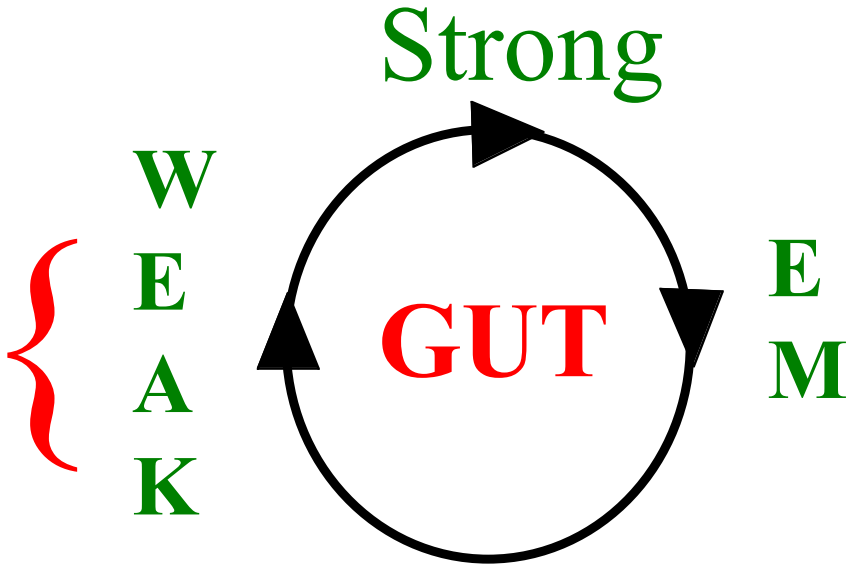
g, $M_{W,Z}$, M_H , M_{q_i} , M_{l_i}, _i, _

Structures :

SU(3)%SU(2) % U(1)

$N_f = 3$

Multiplet Structure



1 Family $\subset$ **16**$_{SO(10)}$

BEYOND THE STANDARD MODEL with LEP

SM ⊂ ???

G.G.Ross, LEP FEST 2000

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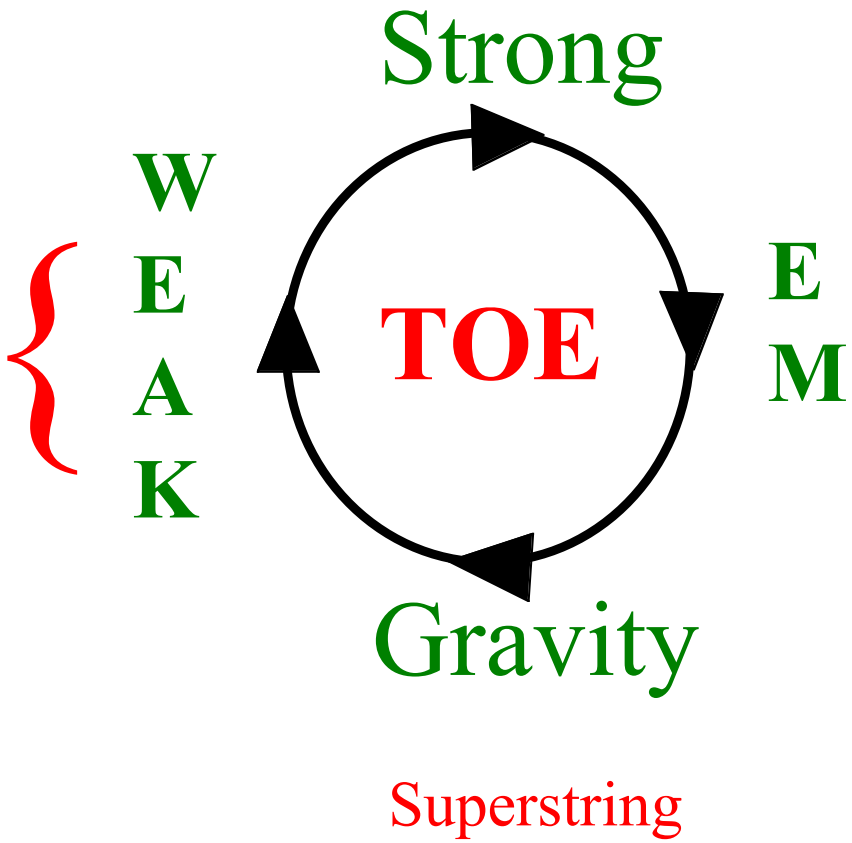


Superstring

BEYOND THE STANDARD MODEL with LEP

SM ⊂ T.O.E. ?

G.G.Ross, LEP FEST 2000

Numerical :

g, $M_{W,Z}$, M_H , M_{q_i} , M_{l_i}, _i, _

Structural :

$SU(3) \otimes SU(2) \otimes U(1) \xrightarrow{V} SU(3) \otimes U(1)_{EM}$

$V/M_{Planck} \sim 10^{-17}$…

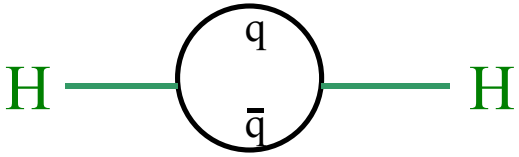
hierarchy problem

$N_f=3$

Multiplet Structure

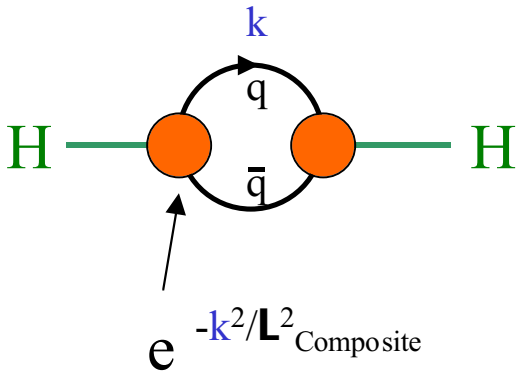
<H>=V

SU(3) % SU(2) % U(⇒ SU(3) % $U(1)_{EM}$, V/M_{Planck} À 10^{-17}…



Hierarchy problem

⇒ **Composite Higgs** (New strong interactions)



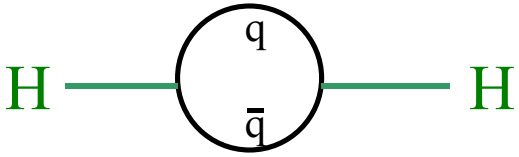
H = $\bar{Q}_{TC}Q_{TC}$

$L^2_{Composite}$ [1TeV

Technipions, additional Higgs…

<H>=V

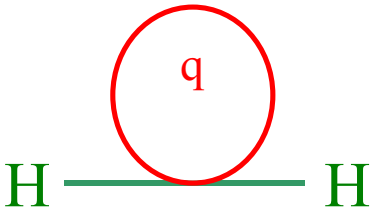
SU(3)%SU(2) % U(1) ⇒ SU(3) % $U(1)_{EM}$, V/M_{Planck} À 10^{-17}…



Hierarchy problem

⇒ **Composite Higgs**

⇒ **Supersymmetry**



New SUSY states :

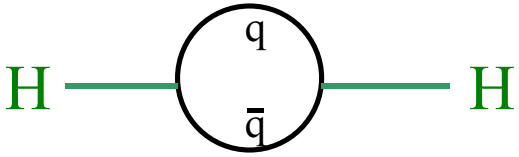
$\tilde{g}$, $\tilde{W}$, $\tilde{Z}$, $\tilde{\ }$, $\tilde{q}$, $\tilde{l}$, H_1, H_2

M^2_H À $a_H(m^2_q - m^2_q)$

m_q î TeV

<H>=V

SU(3) % SU(2) % U(1) ⇒ SU(3) % $U(1)_{EM}$, V/M_{Planck} À 10^{-17}…



Hierarchy problem

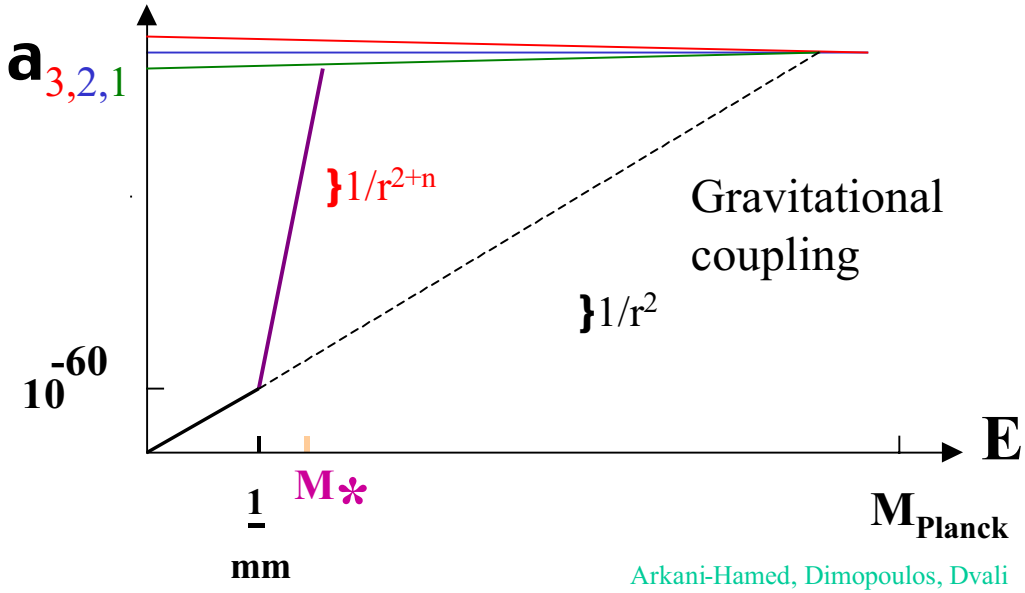
$V/M_* À 1$, M_* À TeV

- **Composite Higgs**
- **Supersymmetry**
- **Large new dimensions**

Kaluza Klein tower of gravitons …

Dm À 10^{-3}eV, 20keV, 7MeV, 100Mev

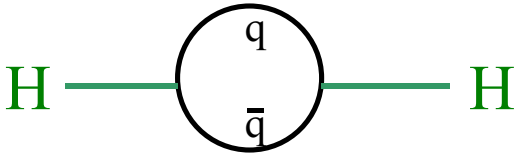
n = 2, 4, 6, 8



Arkani-Hamed, Dimopoulos, Dvali

<H>=V

SU(3) % SU(2) % U(1) ⇒ SU(3) % $U(1)_{EM}$, V/M_{Planck} À 10^{-17} …



Hierarchy problem

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Dm À 10^{-3}eV, 20keV, 7MeV, 100Mev
n = 2, 4, 6, 8

Strings at a Tev

Antoniadis, Lykken

BSM in the light of LEP

- **Direct Searches**

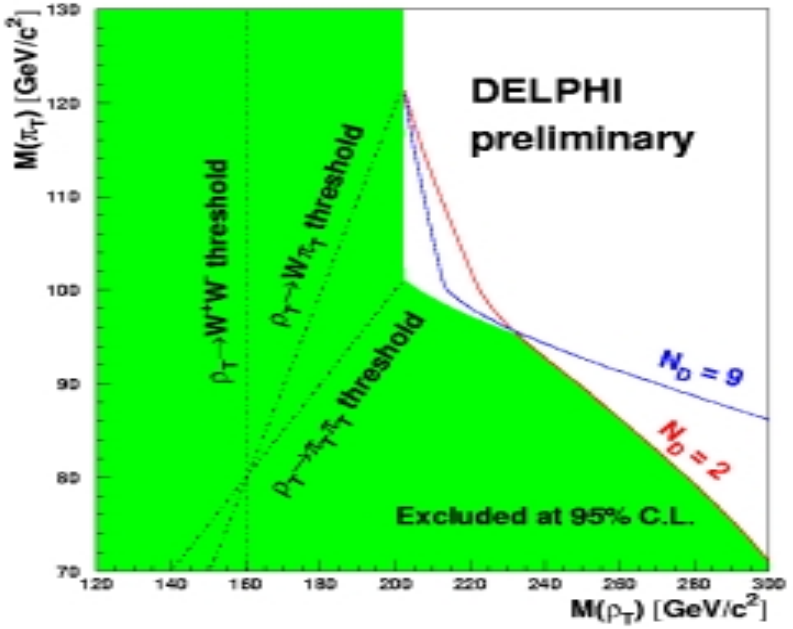
- Technicolour

Additional scalars o_T, o'_T, q_T, z_T

L3, Delphi ..

$e^+e^- \to o^+_T o^-_T$, $c o^0_T$, $W_L o_T$, $W_L W_L$, $f\bar{f}$

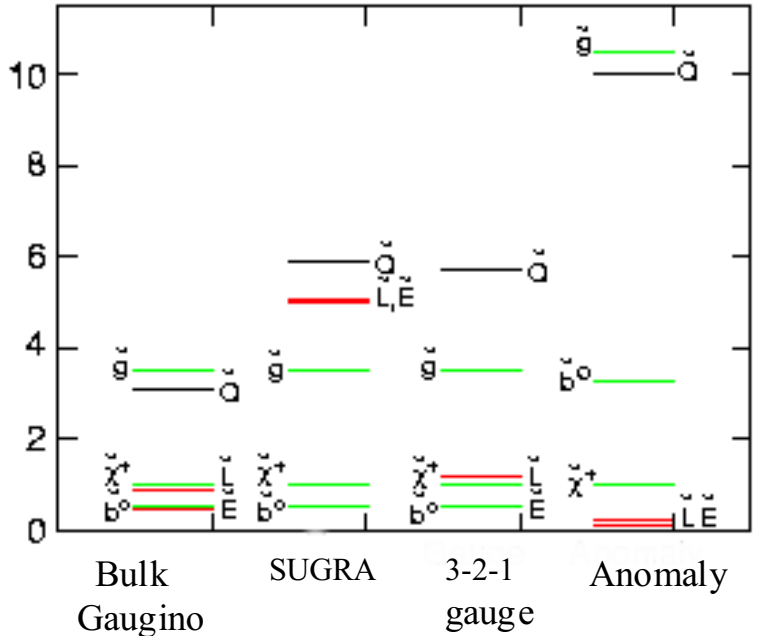
Limit for N_D Technicolour quark doublets



Supersymmetry

Spectrum determined by soft SUSY breaking

…many possibilities



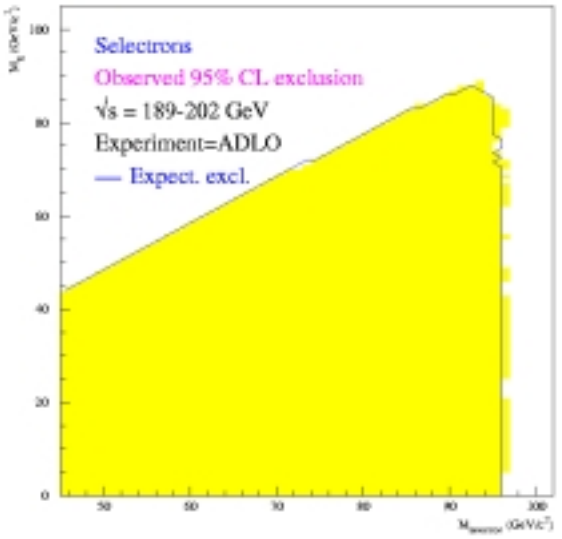
ADLO mass limits in the MSSM :

Sleptons

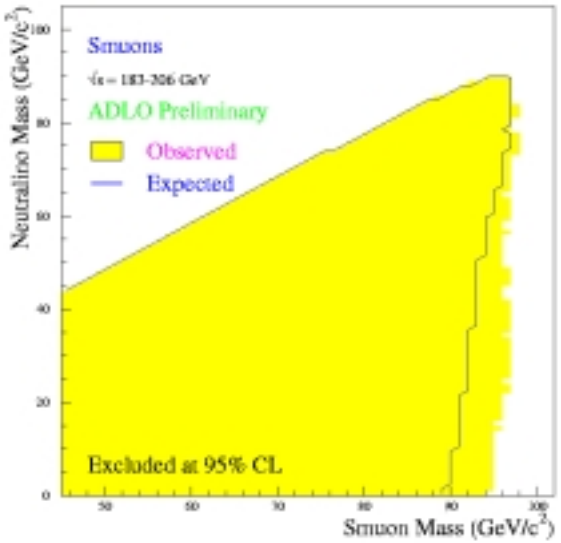
$e^+e^- \to \tilde{l}^+\tilde{l}^- \to (l^+\chi^0)(l^-\chi^0)$

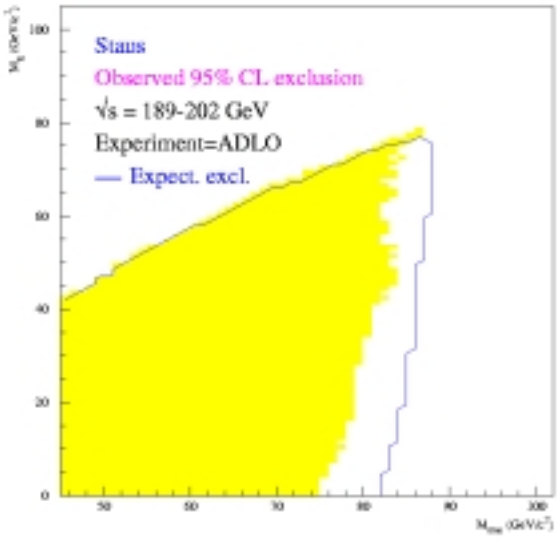
For a mass difference M(slepton)-M(LSP) > 15 GeV, the exclusion limits from 189-202 GeV data are:

$M_{\tilde{e}} < 95$GeV



$M_{\tilde{l}} < 95$GeV

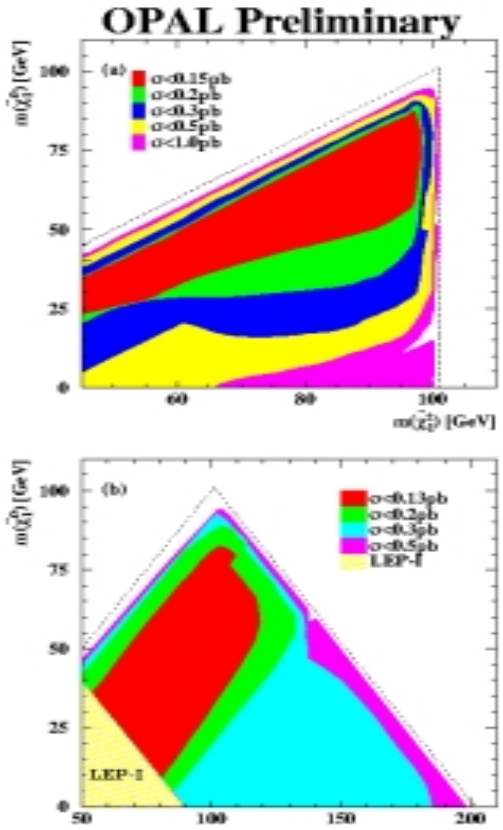




Charginos, Neutralinos

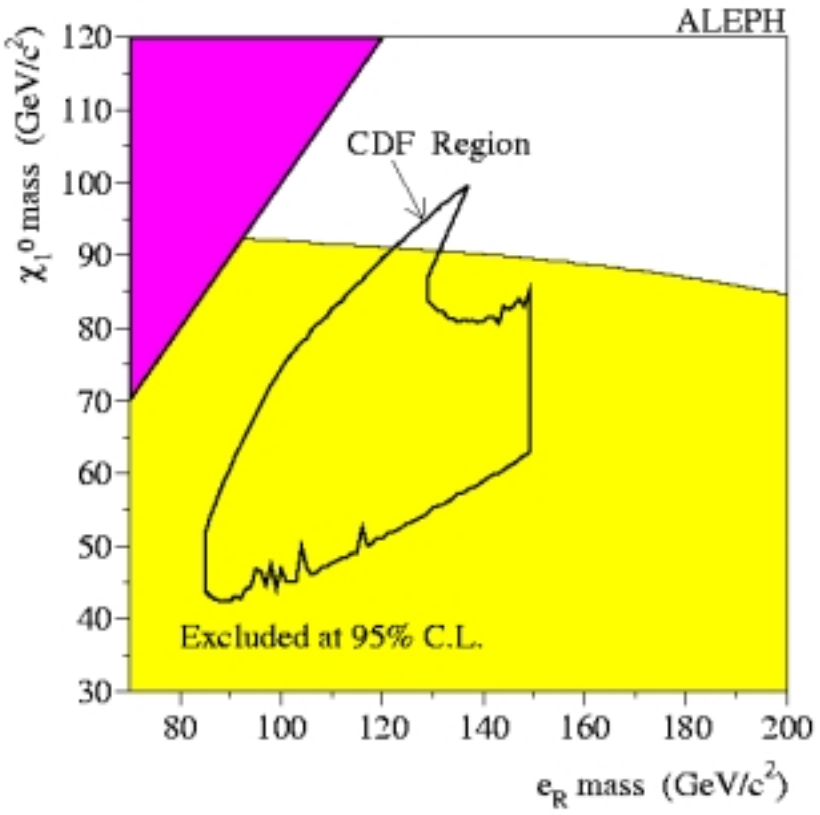
$e^+e^- \to \tilde{\chi}^+_1\tilde{\chi}^-_1$, $\quad \tilde{\chi}^+_1 \to \tilde{\chi}^0_1 W^{(*)+}$

$e^+e^- \to \tilde{\chi}^0_2\tilde{\chi}^0_1$, $\quad \tilde{\chi}^+_1 \to \tilde{\chi}^0_1 Z^{(*)0}$



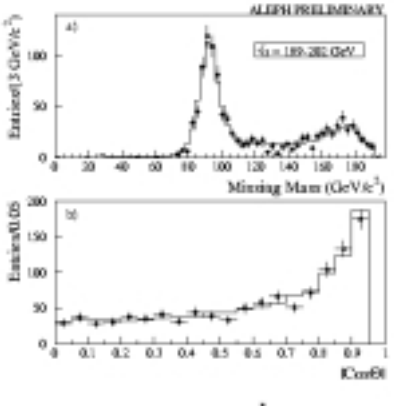
Light gravitino (GMSB)

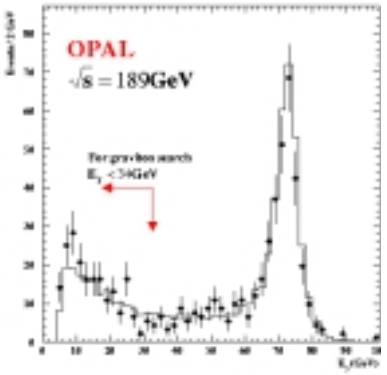
$\bar{q}q\mathbf{t}e^{+}_{R}e^{-}_{R}\ \mathbf{t}e^{+}e^{-}\mathbf{xx}\ \mathbf{t}e^{+}e^{-}GG\mathbf{cc}$

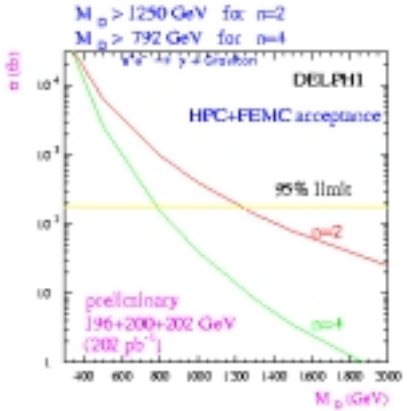


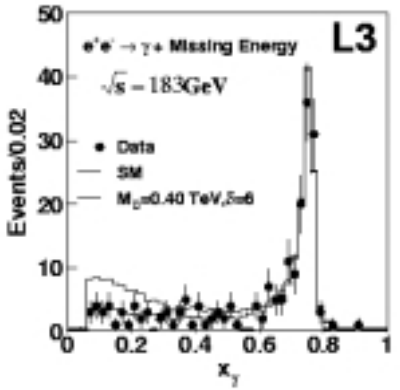
⇨ Large new dimensions

LEP searches for $e^+e^- \to tG_{KK}c$









Efficiencies for signal from $e^+e^- \to \nu\bar{\nu}\gamma$ reweighted to expected signal differential cross-section

	$\sqrt{s}$ (GeV)	$\int L\,(pb^{-1})$	n = 2	3	4	5	6	7
A	189-202	410	1.10	0.86	0.70	0.60	0.52	
D	196-202	202	1.25		0.79			
L	189	176	1.02	0.81	0.67	0.58	0.51	0.45
O	189	177.3	1.09	0.86	0.71	0.61	0.53	0.47

M_*(TeV)

P.Kreiger, SUSY2000

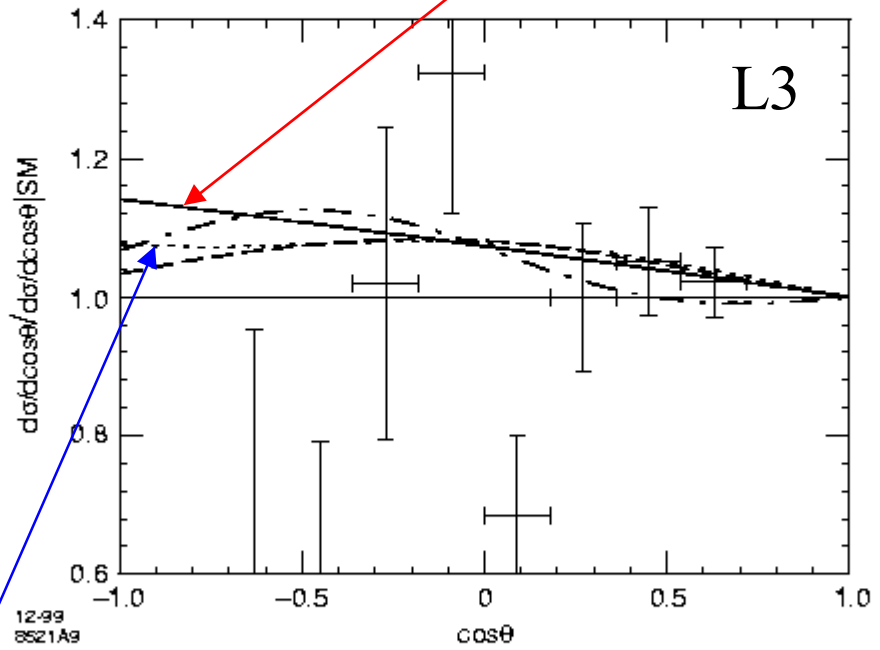
⇨ TeV Strings

String Regge contribution may dominate over KK contribution

TeV Strings

Bhabha scattering

String model
M_S=410 GeV



Cullen, Perelstein, Peskin

KK exchange M_H=830 GEV (M_H>1.2 TeV)

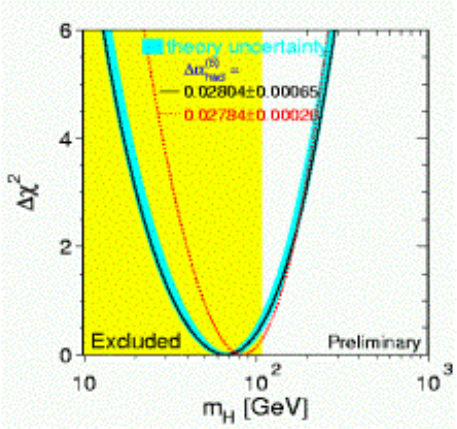
BSM in the light of LEP

⇨ Indirect searches – precision tests

New families
(G_ZeN$_m$=2.984!0.008),

Z', btsc, …

M_{higgs} light



	Measurement	Pull
m_Z [GeV]	91.1875 ± 0.0021	.05
Γ_Z [GeV]	2.4952 ± 0.0023	-.42
σ^0_{had} [nb]	41.540 ± 0.037	1.62
R_l	20.767 ± 0.025	1.07
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.75
A_c	0.1498 ± 0.0048	.38
A_τ	0.1439 ± 0.0042	-.97
$\sin^2\theta^{lept}_{eff}$	0.2321 ± 0.0010	.70
m_W [GeV]	80.427 ± 0.046	.55
R_b	0.21653 ± 0.00069	1.09
R_c	0.1709 ± 0.0034	-.40
$A^{0,b}_{fb}$	0.0990 ± 0.0020	-2.38
$A^{0,c}_{fb}$	0.0689 ± 0.0035	-1.51
A_b	0.922 ± 0.023	-.55
A_c	0.631 ± 0.026	-1.43
$\sin^2\theta^{lept}_{eff}$	0.23098 ± 0.00026	-1.61
$\sin^2\theta_W$	0.2255 ± 0.0021	1.20
m_W [GeV]	80.452 ± 0.062	.81
m_t [GeV]	174.3 ± 5.1	-.01
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02804 ± 0.00065	-.29

SUSY P

Technicolour

Precision measurements severely constrain possibilities

$\mathbf{e}_3$ S : Weak Isospin conserving

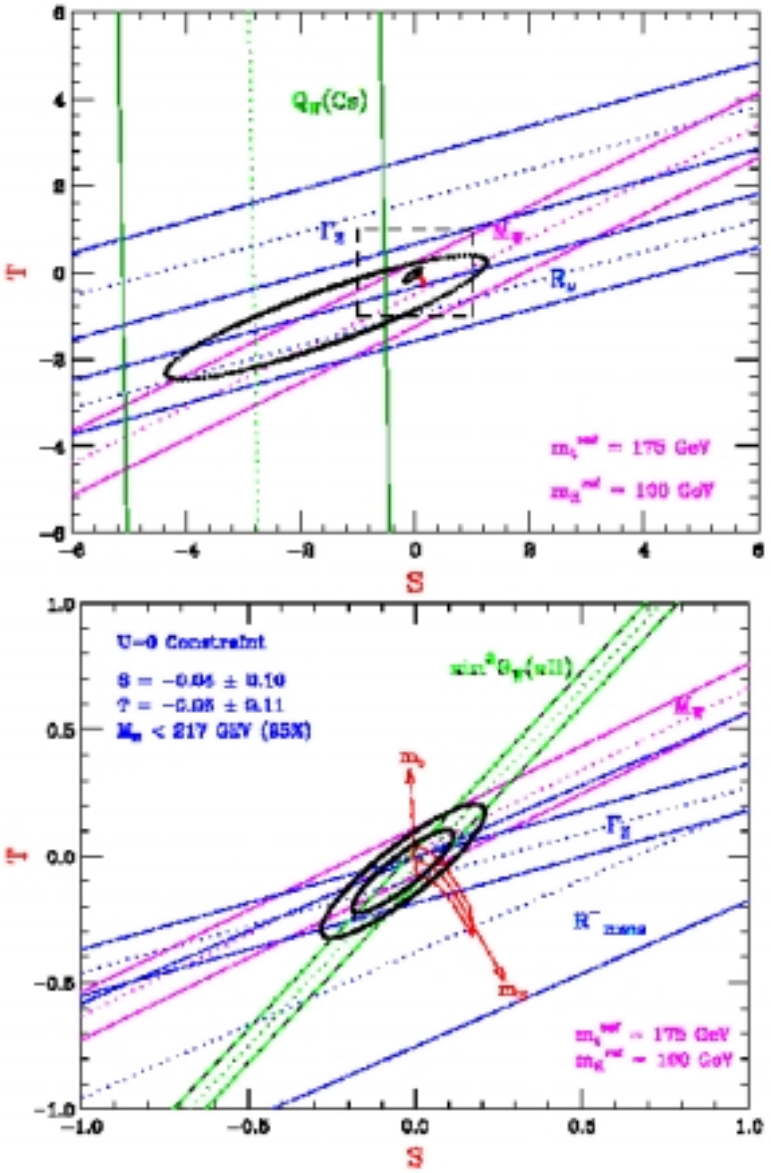
$\mathbf{e}_1$ T : Weak Isospin violating

Decoupling : S, T ~ $M_Z^2/4\pi M^2$, $M \gg M_Z$ **P**

e.g. SUSY

Non-decoupling : Technicolour, 4th generation, q,l composite

…difficult ?



Swartz, Altarelli,Barbieri, Peskin, Takaheuc

⇨ Large new dimensions : KK exchange modifies SM processes

Summary of Limits from Indirect Searches

Krieger SUSY2000

$\sqrt{s} \leq 189$ GeV published

$\sqrt{s} \leq 189$ GeV preliminary

$\sqrt{s} \leq 202$ GeV preliminary

$$\frac{|\lambda|}{M_*^4} = \frac{\pi}{2}\frac{1}{\Lambda_T^4}$$

	$\Lambda_T^+ / \Lambda_T^-$	M_s $(\lambda = +1/-1)$		
Channel	ALEPH	OPAL	DELPHI	L3
$\mu^+\mu^-$	680/630	600/630	725/592	690/560
$\tau^+\tau^-$	590/570	630/500	645/557	540/580
$q\bar{q}$	610/660	---	---	490/490
e^+e^-	1030/800	---	---	994/911
Fermions combined	1040/820	680/610	755/598	1000/840
$\gamma\gamma$	920/910	641/629 *	713/691	790/800
WW	---	---	---	790/680
ZZ	---	---	---	770/760
Bosons combined	890/770	641/629	713/691	890/820
Bosons + fermions	1120/840	---	---	1070/870

Best limits from Bhabha scattering in which interference terms contributes significantly

* (OPAL limits from $\gamma\gamma$ are on $\left(\frac{2}{\pi}\right)^{1/4} M_s$)

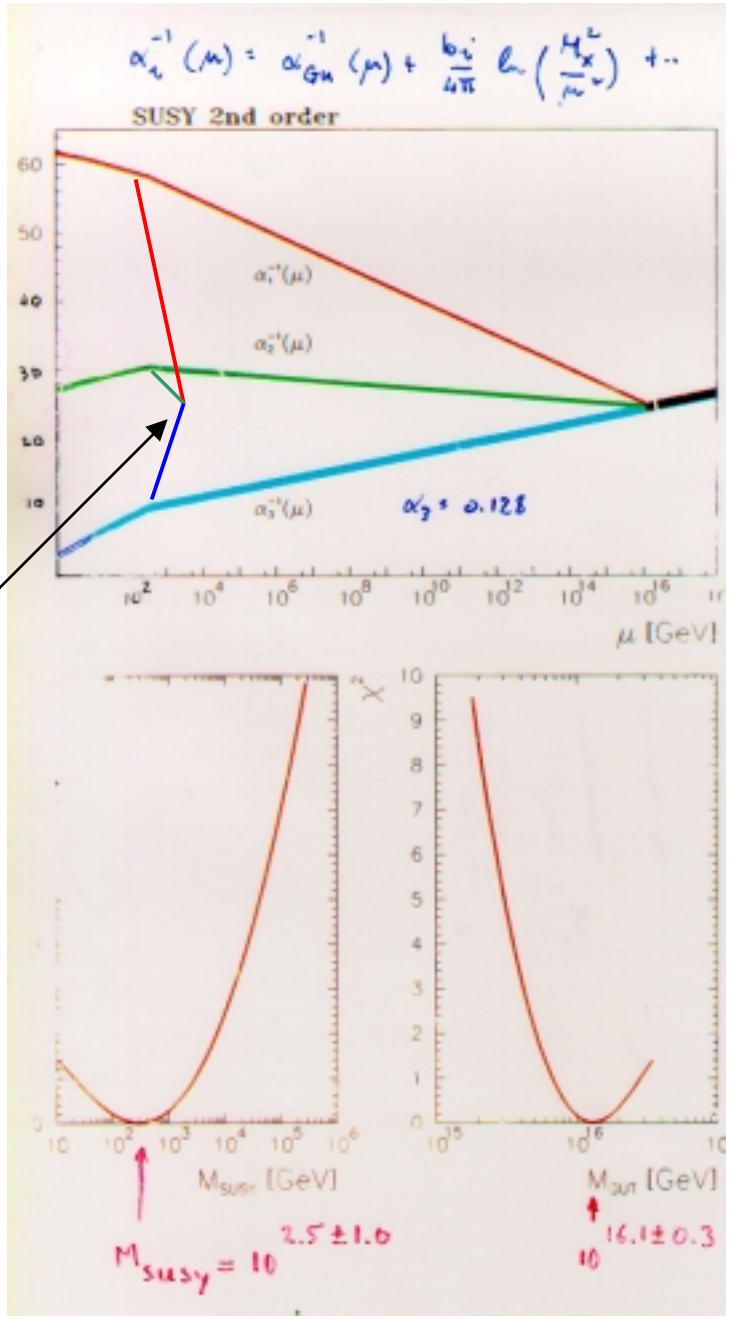
Unification Hints

MSSM

Large New Dimensions

Unification at a TEV???

Dienes, Dudas, Ghergetta,

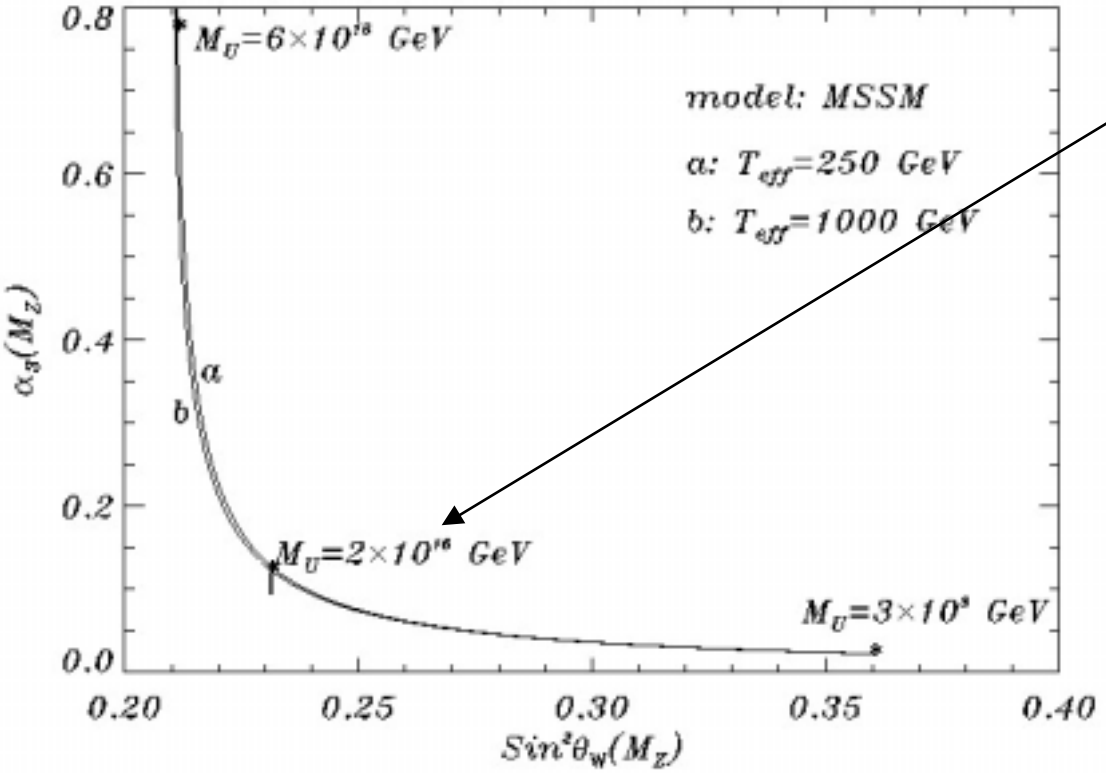


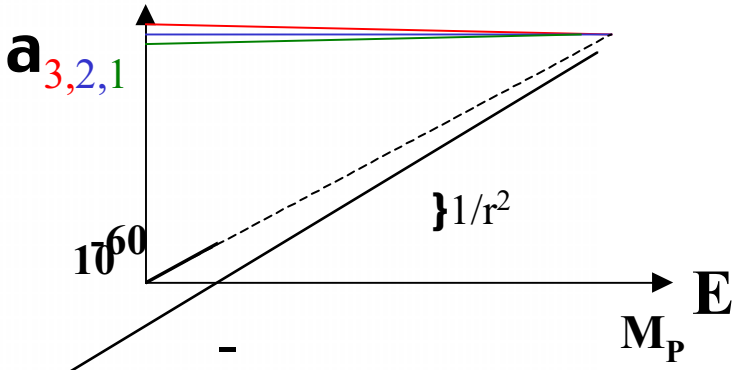
Amaldi, de Boer, Furstenau

See also :
Ellis, Kelley, Nanopoulos;
Langacker, Luo

Dimopoulos, Raby, Wilczek
Ibanez, GGR

Unification Hints





Unification at a TEV?

D.Ghilencea

LEPilogue

	Technicolour	Large Extra Dimensions	SUSY
Gauge Unification	?	🔔	P
Light Higgs	🔔	?	P
Indirect : Decoupling	🔔	?	P
V/M	P	P	P
SU(2) 🔔 U(1)tU(1)$_{EM}$	P	?	P
Direct searches	🔔?	🔔?	🔔?