Inputs on LC/LHC complementarities

- Main avenue: SUSY+light h
- ND>4: several scenarios, KK type signals, Higgs properties modified
- Extended symmetries: Z', new fermions
- Heavy Higgs + new physics to accommodate LEP/SLD

→Variety of scenarios, in some cases combining above 4, for which LC measurements are essential

SUSY

- Numerous SUSY breaking schemes
- LC precision and redundancy needed to solve the puzzle and test GUT
- SUSY-GUT in SU(5) in trouble (Murayama et al hep/0108104) more fermions than MSSM ?
- Difficult experimental scenarios may appear:

➢ Anomalous SSM breaking for which charginos/neutralinos are mass degenerate

➢ SSM breaking in higher dimensions show the same trend

ND>4

- 3 scenarios are proposed:

1. Large extra dimension(ADD) signature γ+miss (towers of gravitons) and graviton resonances
2. TeV extra dimension with KK excitation of γ/Z/W (Antoniadis)
3. Randall-Sundrum with graviton resonances with weak coupling to matter

- String scale also at TeV, hence possible Regge recurrences
- GUT can be recovered but without predictivity on $\sin^2\theta_W$
- SUSY is likely (superstrings) but the argument on hierarchy is lost

ND>4 Signals

- With an effective Planck scale at a few TeV LEP PM compatible with a heavy Higgs (e.g. J.L.Hewett et al hep/0203091)
- Higgs decay widths can be modified (e.g. mixing with radion Hewett-Rizzo hep/0202155)
- KK recurrences γ/Z from scenario 2 to be distinguished from Z' (Rizzo hep/0109179)
- Graviton resonances in ADD or RS to be distinguished (also from γ/Z Regge recurrences) through BR and lineshape at a LC (Rizzo hep/0110202)

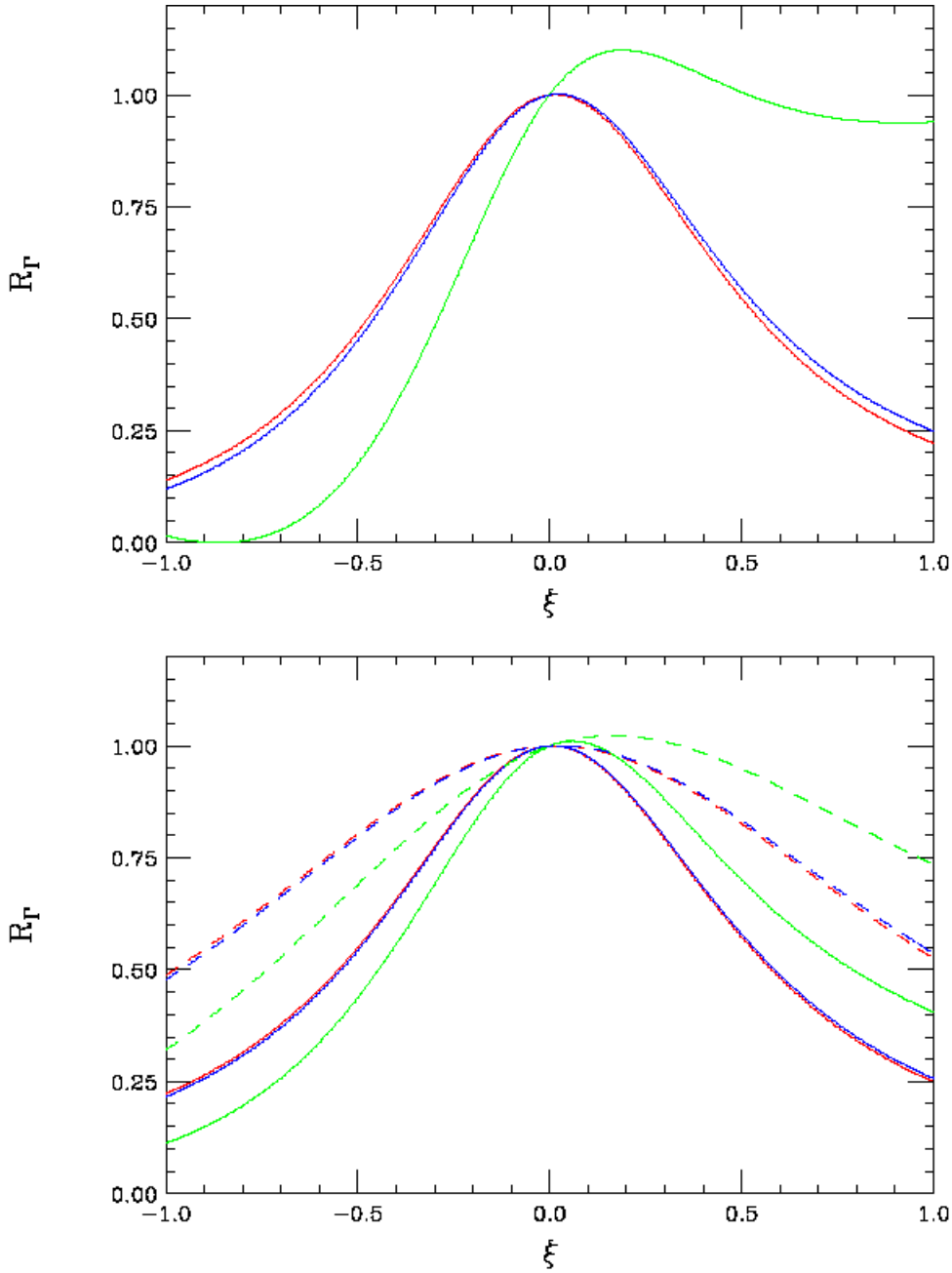
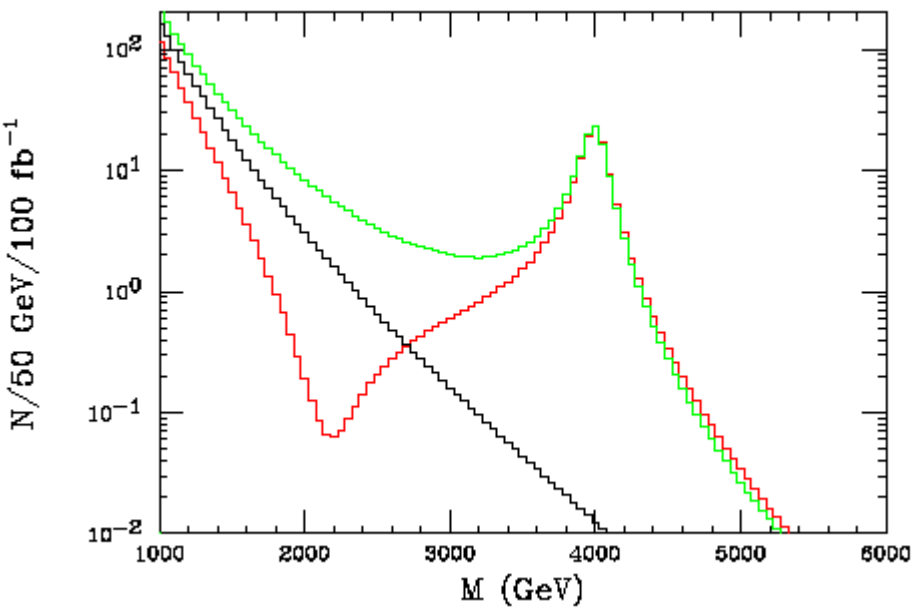


Figure 2: Ratio of Higgs widths to their SM values, R_Γ, as a function of ξ assuming a physical Higgs mass of 125 GeV: red for fermion pairs or massive gauge boson pairs, green for gluons and blue for photons. In the top panel we assume $m_r = 300$ GeV and $v/\Lambda = 0.2$. In the bottom panel the solid(dashed) curves are for $m_r = 500(300)$ GeV and $v/\Lambda = 0.2(0.1)$.

Hewett-Rizzo hep/0202155

Rizzo hep/0109179



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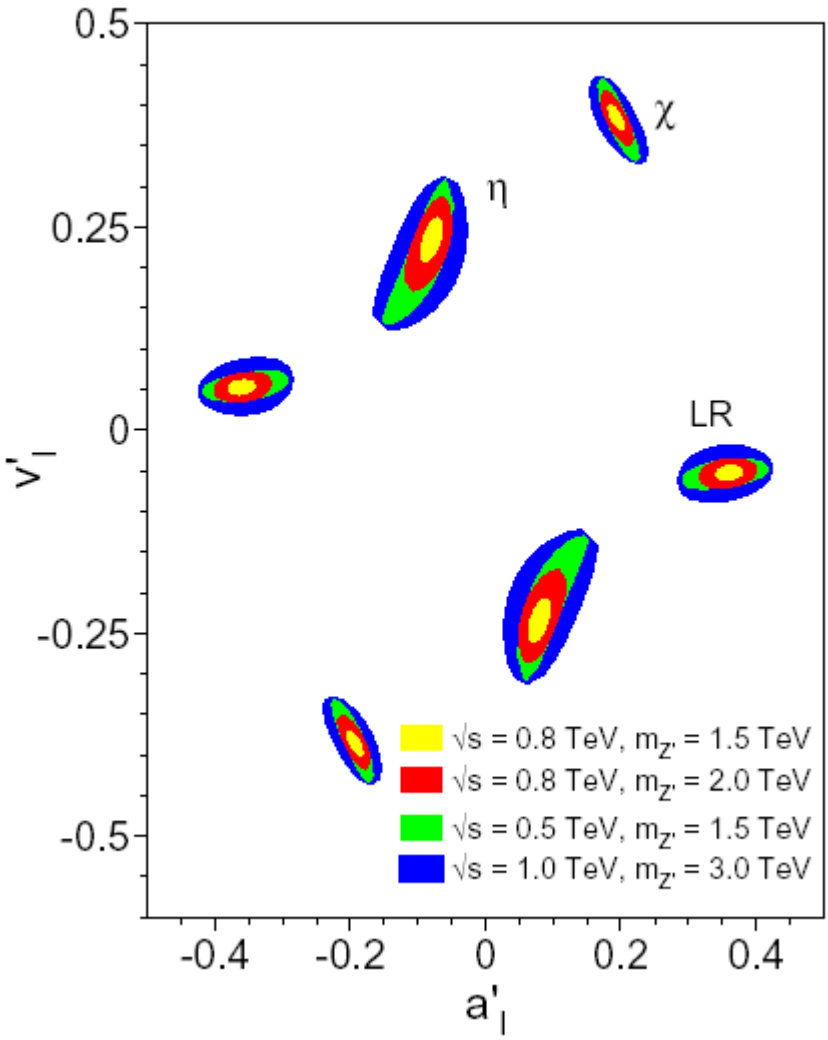
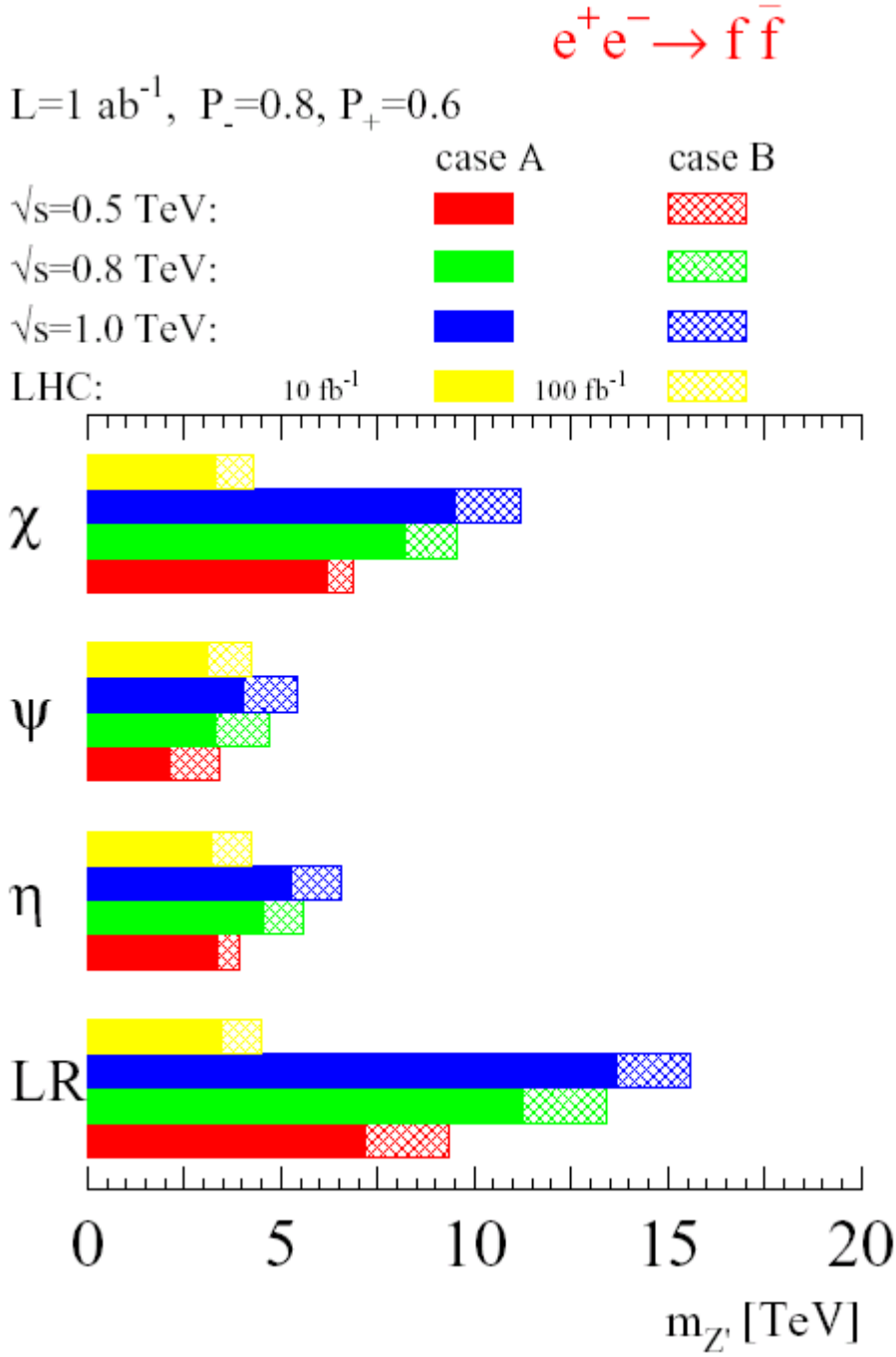
TeV ND>4 γ+Z

A'=-1.08 V'=-1.81

For leptons




$e^+e^- \to f\bar{f}$
L=1 ab^{-1}, P$_-$=0.8, P$_+$=0.6
case A
case B
√s=0.5 TeV:
√s=0.8 TeV:
√s=1.0 TeV:
LHC:
10 fb^{-1}
100 fb^{-1}
χ
ψ
η
LR
0
5
10
15
20
m$_{Z'}$ [TeV]

Rizzo hep/0110202

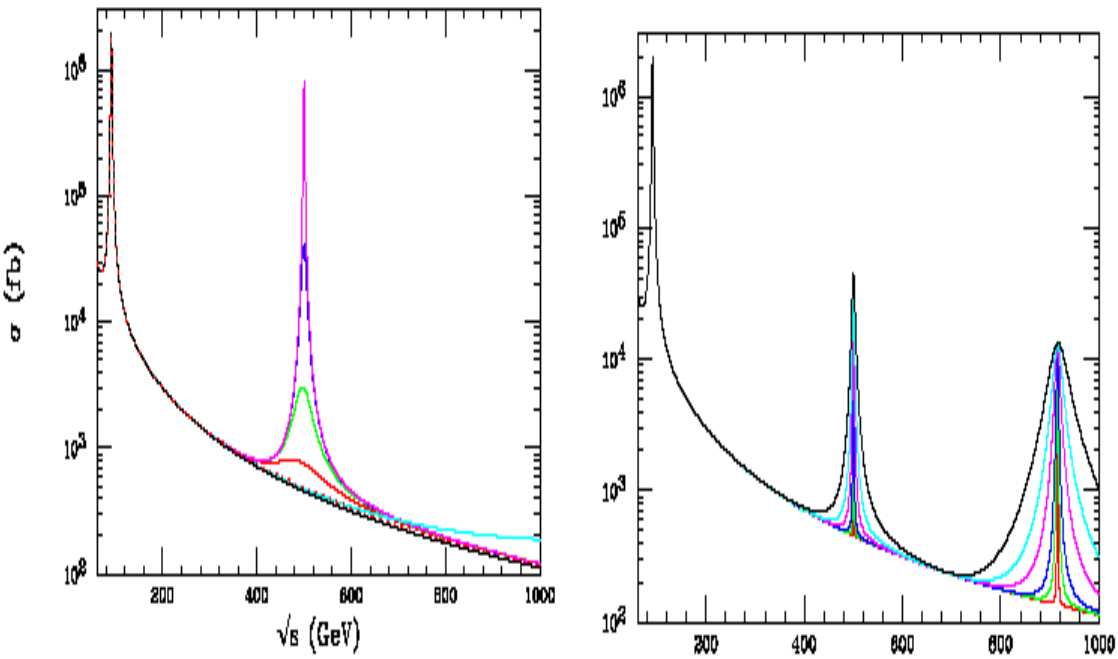


FIG. 1: $e^+e^- \to \mu^+\mu^-$ in the Dvali *et al.*(left) and RS(right) models. For the Dvali *et al.* case we assume $M_* = 3$ TeV with $d = 2$(red dots) and $d = 3, 4, 5$ and 6(solid red, green, blue and magenta curves). The cyan curve is the ADD model prediction with constructive interference. For the RS model the sample curves are for the parameter $c = k/\overline{M}_{Pl}$ in the range 0.01-0.1.

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Rizzo hep/0110202

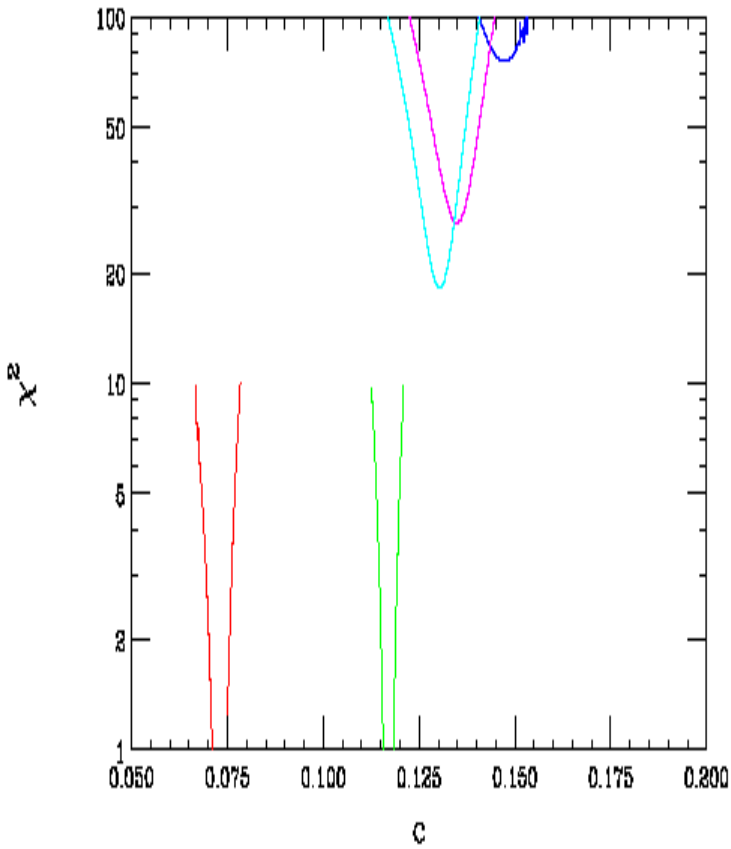

FIG. 3: Sample fits to different resonances in $e^+e^- \to \mu^+\mu^-$ assuming the validity of the RS model. The resonance mass is taken to be 1 TeV and a total integrated luminosity of $500 fb^{-1}$ is assumed as described in the text. The red(green) curves are for RS gravitons with $c = k/\overline{M}_{Pl} = 0.073(0.117)$ are used as tests of our fitting method. The blue(magenta,cyan) curves are the corresponding fits for the Dvali *et al.* model with $M_s = 5.0(5.5, 5.7)$ TeV.

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ND>4 Signals II

J.L.Hewett et al hep/0203091 within RS model:

- Several motivations (neutrino masses) to put fermions in the bulk
- Cannot put the 3d generation in the bulk to avoid mixing with KK
- With 1st 2 generations in the bulk one gets reasonable $\delta\rho$ contributions which would allow a Higgs mass up to 500 GeV
- LC can detect the presence of KK beyond LHC with PM on fermion pair production and/or at GigaZ

J.L.Hewett et al hep/0203091

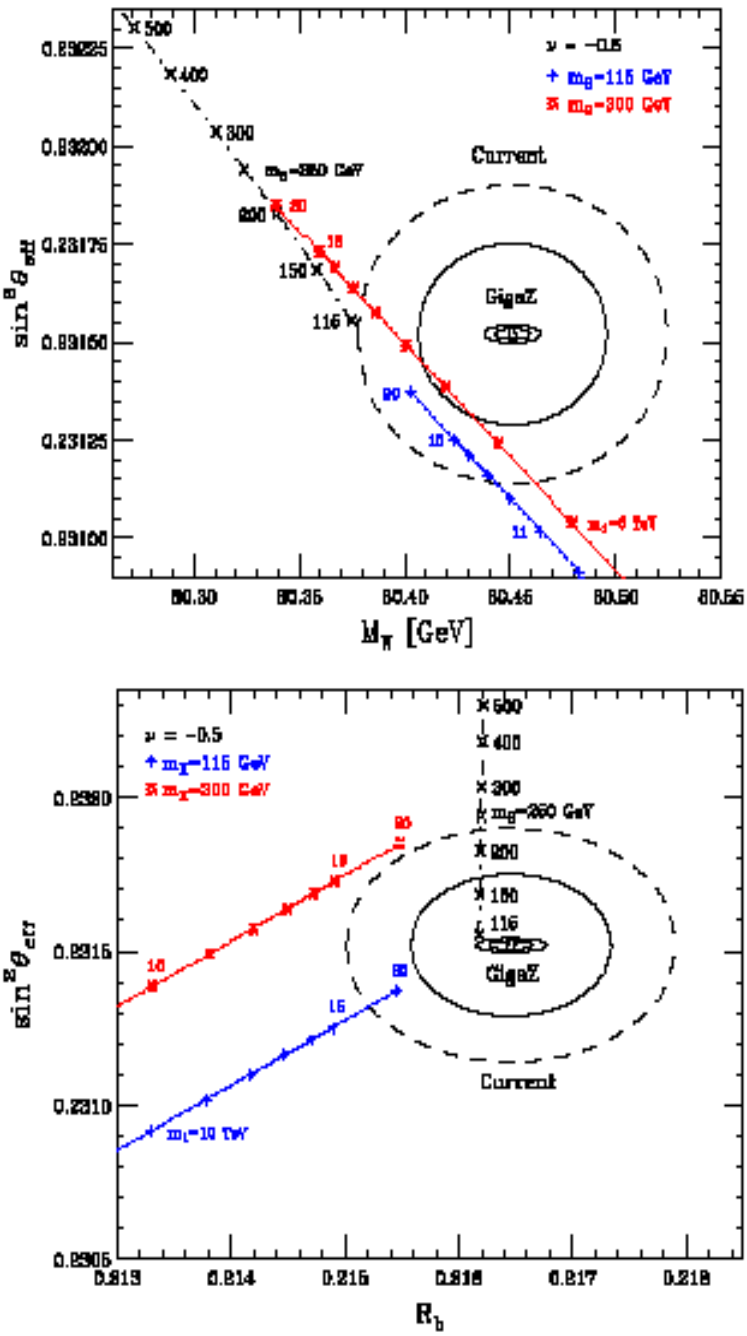


Figure 10: Plots of the $\sin^2\theta_{eff}$ versus M_W plane (top) and $\sin^2\theta_{eff}$ versus R_b plane (bottom) showing current and future sensitivities, SM predictions, and RS model predictions. The diamonds show the current measured values. The large solid and dashed ellipses represent respectively the 68% and 95% CL regions from current sensitivities, while the smaller solid ellipses anticipate the same after operation of GigaZ. The black dashdot lines show the SM predictions for different Higgs boson masses, while the three solid colored lines show the RS model results for varying m_1 and for two Higgs masses satisfying the current EW constraints.

J.L.Hewett et al hep/0203091

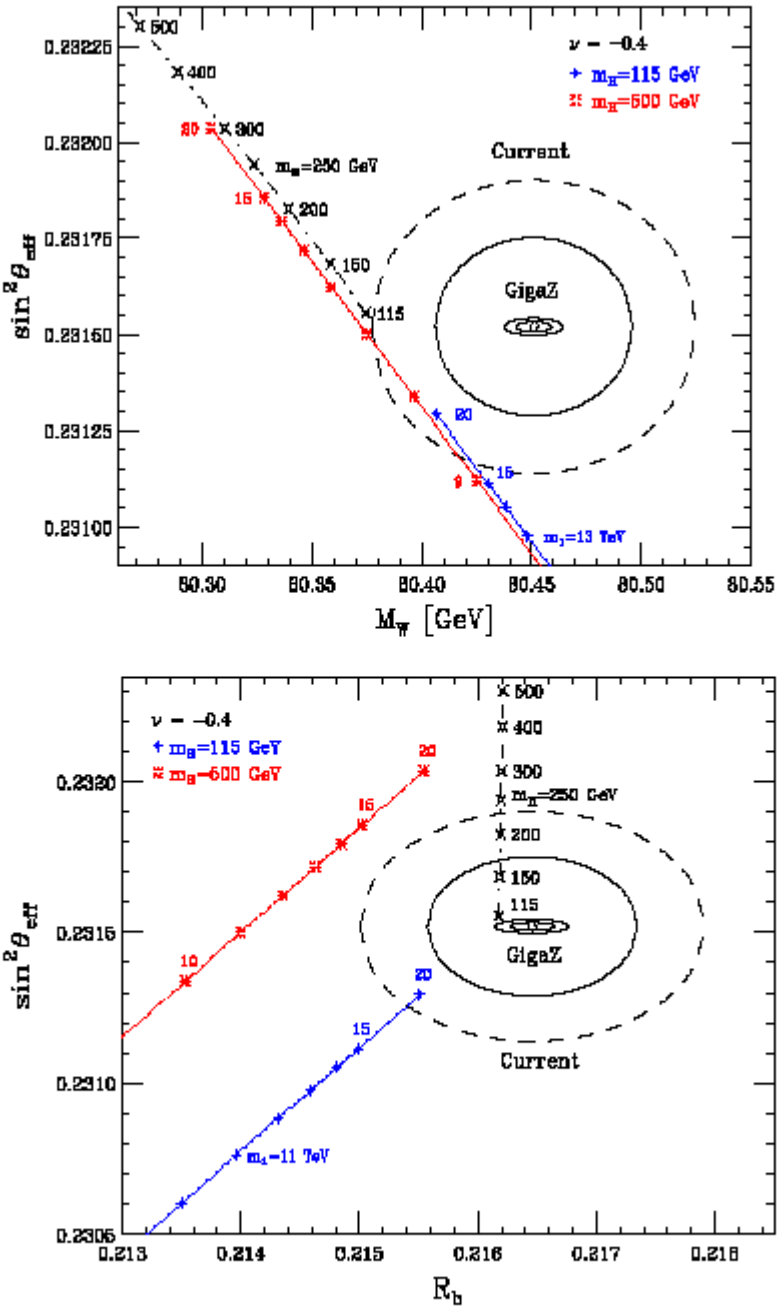


Figure 11: Same as the previous figure for $\nu = -0.4$, and different m_H choices.

GUT at 1 TeV

S. Dimopoulos et al
hep/0202136

- $\sin^2\theta_W = 1/4$ undelying SU(3) (instead of 3/8 in SU(5))due to some undelying symmetry
- GUT occurs much earlier, at 1 TeV, as suggested by ND>4 avoiding any hierarchy problem
- New phenomenology described in

S. Dimopoulos et al
hep/0203001

Extended Symmetries

- Motivated by superstrings (E6), neutrino masses, unification at GUT scale
- Z' and vector-like fermion multiplets could appear at TeV
- Higgs with mass > 200 GeV possible
- Precise measurements at LC provide crucial informations

SO(10)

K.S. Babu J.C. Pati hep/0203029 propose an extended SUSY with 2 vector-like fermion families of SO(10) with masses from 200 GeV to 2TeV

- Neutrino masses and mixings , interfamily hierarchy are OK
- Keeps all SUSY advantages + better GUT properties
- Claims some correlated indications from NuTeV (3σ) and LEP neutrino counting (2 σ)
- GigaZ+direct searches for new fermions (single production of heavy neutrinos at LC?) open new prospects for LC and LHC

E6

- E6 group 'superstring inspired' can lead to new U(1) with a Z' mass + additional fermions at the same scale (Hewett-Rizzo Phys. Rept. 183, 193 1989)
- Recently Hambye et al hep 0011197 have shown that this low-energy E6 models pass well leptogenesis, neutrino pattern constraints

Model	χ	ψ	L-R
LEP2	678	463	800
Atomic Parity	730	-	790

95% confidence level lower limit on the Z' mass

Heavy Higgs Models

- New physics is needed to accommodate LEP/SLD:
  - Topcolor model
  - Two Higgs doublet extension
  - Randall-Sundrum with fermions on the brane (top) and in the bulk (light)….
- No Higgs with S.I. WW + a new scale revealed by LC precision measurements

Heavy Higgs Models II

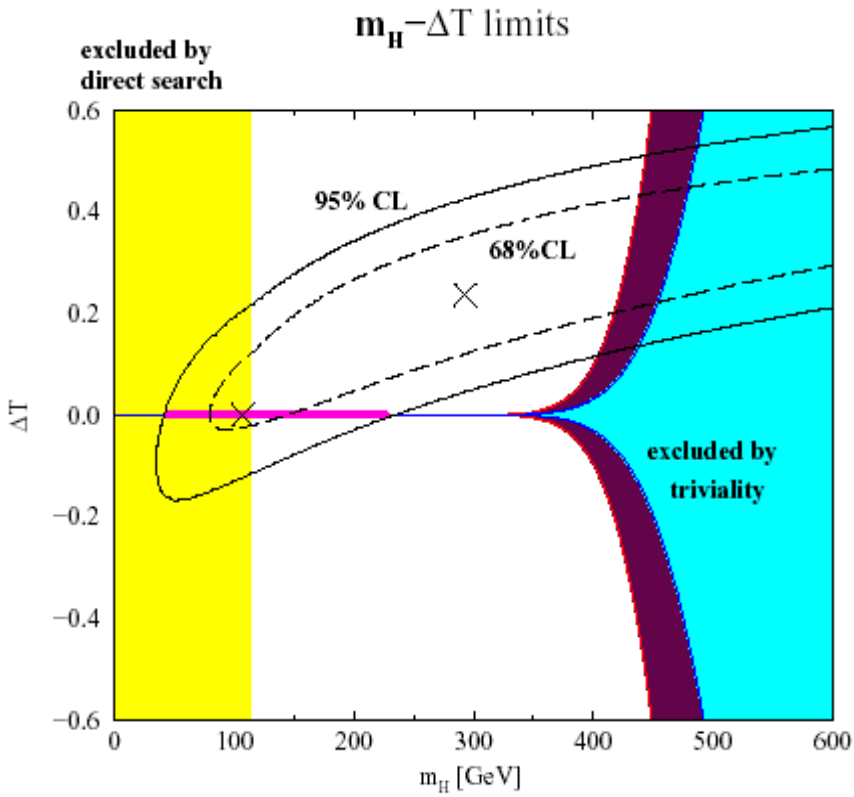
Choudhury et al hep/0202162

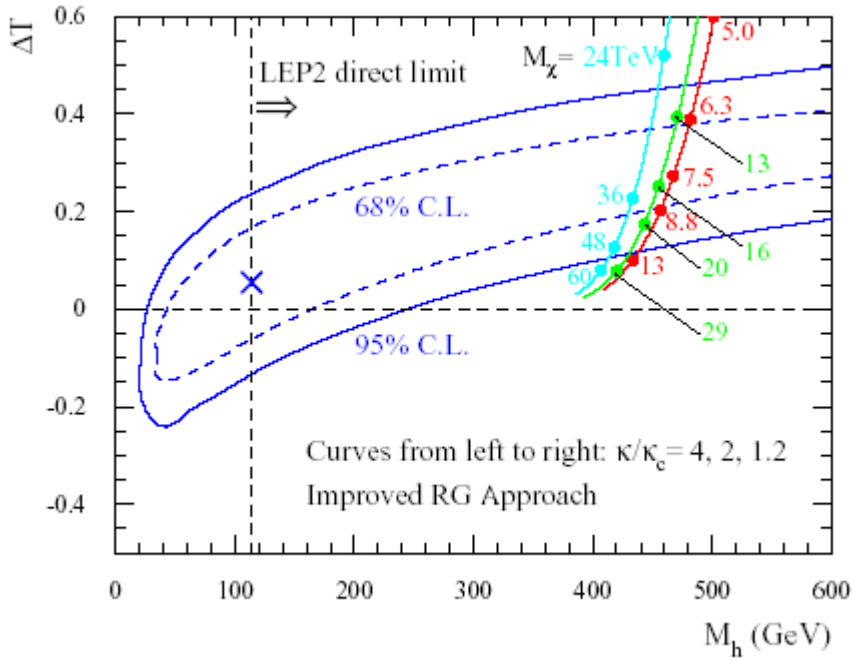
- Top seesaw model with a heavy singlet fermion χ(4 to 7 TeV) gives an EWSB scheme consistent with a heavy Higgs(non elementary). Top coupling to Z boson is affected 1 to 5%. No obvious direct signal at LC/LHC
- Two Higgs doublet model can mimic an apparent light Higgs
- Vector-like quarks, top-like χ and bottom-like ω can be introduced with masses below 300 GeV which allow a heavier Higgs+improve the b asymmetry measurement (mixing with ω)

Heavy Higgs Models III

T.Barklow et al hep/0201243

- Non-elementary Higgs scenarios (bound state system of new fermions)
- 'Conspiracy' (see Chivukula et al hep/0110214) to pass LEP/SLD precision measurements
- Technicolor, top condensate with obsevable new particles at LC/LHC
- Enhanced gauge-boson couplings and fermion compositeness due to some new strong dynamics hidding at non-accessible energy scale. LC has a sensitivity > LHC for this type of scenario





Chivukula et al hep/0110214

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Conclusions

- A clear goal for LC will be, after investigating the EW scenario, to search for signs of new physics beyond the SM
- These signs could be seen directly through production of new particles, in which case the LC is needed for precision and for interpretation e.g. :
  - spin 1 resonance at LHC, Z' or ND>4, which type of Z' ?
  - spin 2 resonance at LHC which ND>4 ?
- If no direct sign of new physics can be observed, precision measurement of the GigaZ type and/or high energy precision measurements can provide answers beyond LHC e.g. : if a heavy Higgs is found, which underlying mechanism is operating ?