



Search for Physics Beyond the Standard Model at LEP

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For the ALEPH, DELPHI, L3 and OPAL collaborations
Les Rencontres de Physique de la Vallée d'Aoste
La Thuile, Feb.27-Mar.5 2005



New (2004-5) LEP Search Results

Green = New Idea

Yellow = Final Result of Long-Term Effort

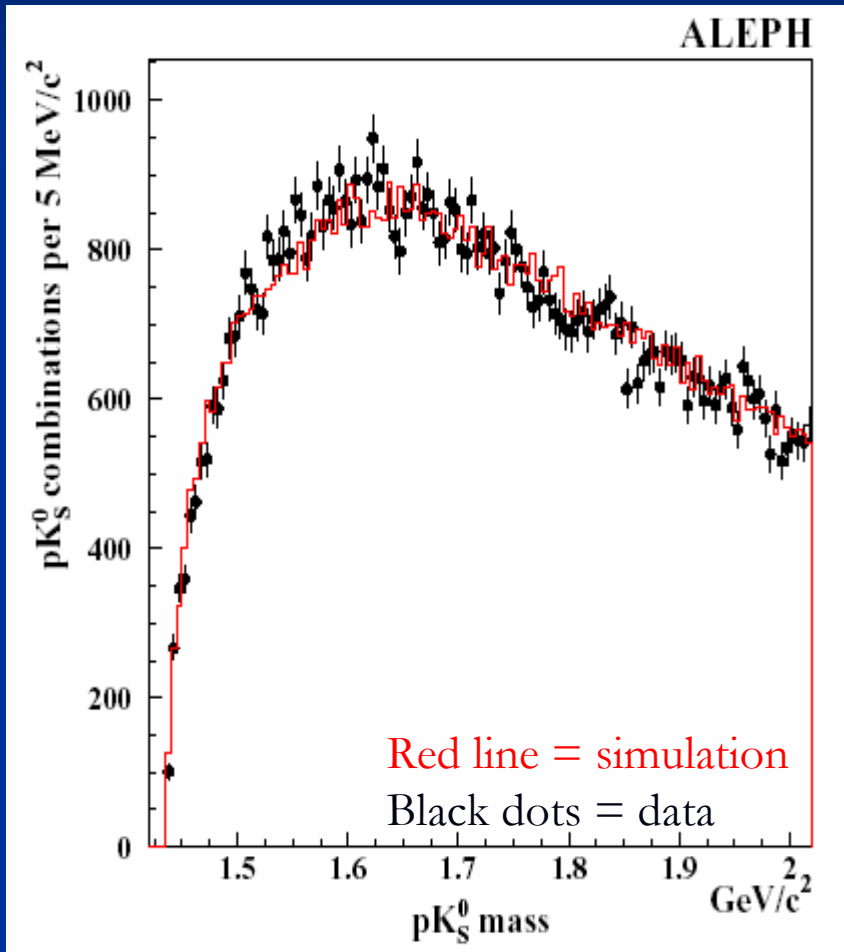
- ALEPH:
 - **Pentaquarks**: Phys.Lett.B599 (2004) 1
 - **LSP limit in MSSM**: Phys.Lett.B583 (2004) 147
 - **Squarks & gluinos**: Euro.Phys.J C31 (2004) 213
- DELPHI:
 - **Excited leptons**: DELPHI-2004-024-CONF-699
 - **Fermiophobic Higgs**: Euro.Phys.J C35 (2004) 313
 - **Neutral Higgs in Extended Models**: Euro.Phys.J C38(2004) 1
 - **Flavour-independent Neutral Higgs searches**: DELPHI-2004-034-CONF-709
 - **Charged Higgs in 2HDM**: Euro.Phys.J C34(2004) 399
- L3:
 - **Branons**: Phys.Lett.B 597 (2004) 145
 - **Anomalous Couplings in Higgs Sector**: Phys.Lett.B 589 (2004) 89
 - **Invisible Higgs**: Hep-ex/0501033 (submitted to Phys.Lett.B)
- OPAL:
 - **Radions**: Hep-ex/0410035 (submitted to Phys.Lett. B)
 - **Photons and Missing Energy**: Phys.Lett.B602 (2004)167
 - **CP-conserving and CP-violating MSSM Higgs**: Hep-ex/0408097 (submitted to Euro.Phys.J C)
 - **Charginos & Neutralinos**: Euro.Phys.J C35(2004)1
- LEP-wide Working Group Combinations:
 - **Large Extra Dimensions**: LEP Exotica WG 2004-03
 - **Neutral MSSM Higgs bosons**: LEP Higgs WG 2004-01
 - **SUSY combinations**: <http://lepsusy.web.cern.ch/lepsusy/>



New Ideas For Old Data



Pentaquarks

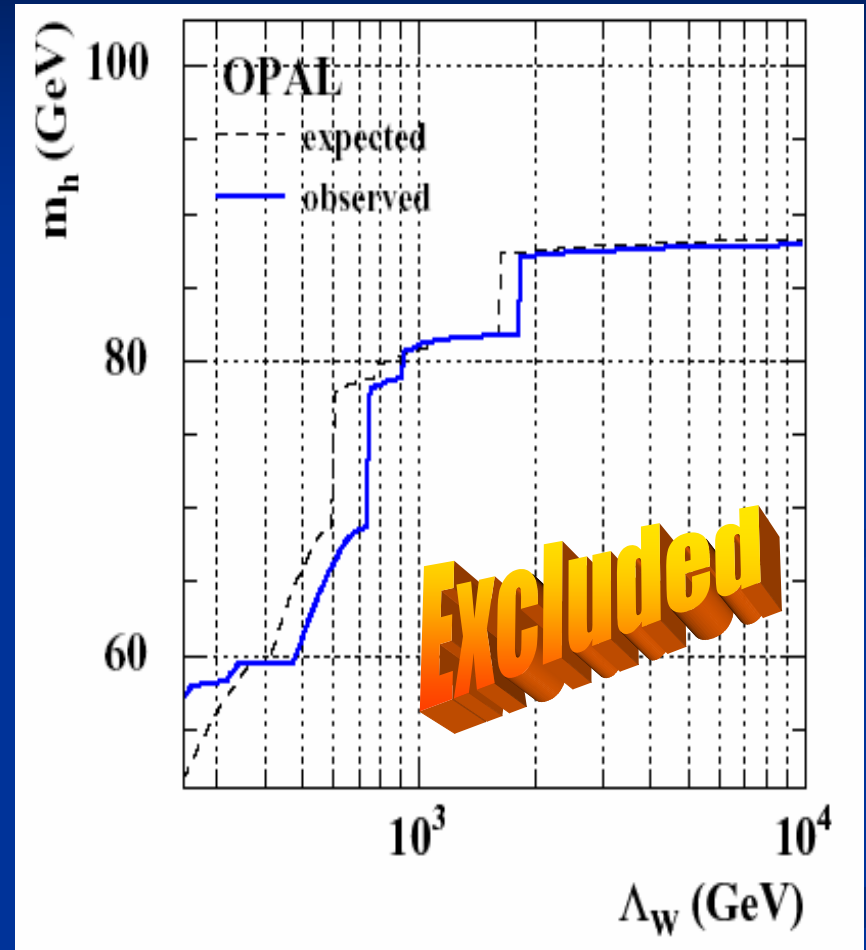


- LEP can still respond rapidly to new challenges
 - Delphi & L3 also showed preliminary results, OPAL investigated sensitivity
- QCD searchers
- Results:
 - $N_{\Theta(1535)^+} \times \text{BR}(\Theta(1535)^+ \rightarrow pK_S^0) < 6.2 \times 10^{-4}$
 - $N_{\Xi(1862)^{-}} \times \text{BR}(\Xi(1862)^{-} \rightarrow \Xi^- \pi^+) < 4.5 \times 10^{-4}$
 - $N_{\Xi(1862)^0} \times \text{BR}(\Xi(1862)^0 \rightarrow \Xi^- \pi^+) < 8.9 \times 10^{-4}$
 - $N_{\Theta_C(3100)^0} \times \text{BR}(\Theta_C(3100)^0 \rightarrow pD^{*-}) < 6.3 \times 10^{-4}$
 - $N_{\Theta_C(3100)^0} \times \text{BR}(\Theta_C(3100)^0 \rightarrow pD^-) < 31 \times 10^{-4}$



Radions

- Re-evaluate SM and flavour-independent Higgs limits in case of **Randall-Sundrum radion**
 - Solution to **EW- M_{Pl} hierarchy problem** with 1 extra warped dim
 - **Radion** is field associated with fluctuation of separation of two branes (all other new KK states could be heavy)
 - Same quantum numbers as **Higgs** \rightarrow **mixes!** Unlike Higgs, **radion couples directly to gluon pairs**
- Limit on mass eigenstate which becomes Higgs if no mixing: **58 GeV**
- Significant **reduction of SM Higgs limit** at small mass scale Λ_{W} values...

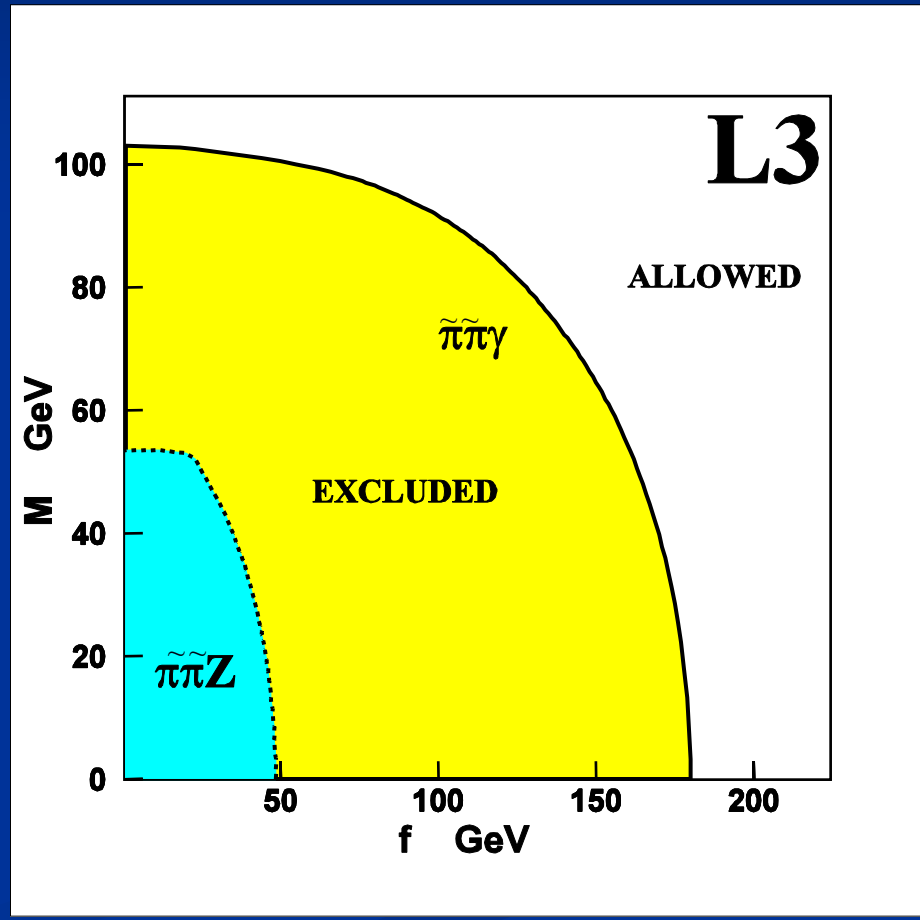


(Exclusion for all allowed mixings ξ ,
radion-like state masses 1 MeV – 1 TeV)



Branons

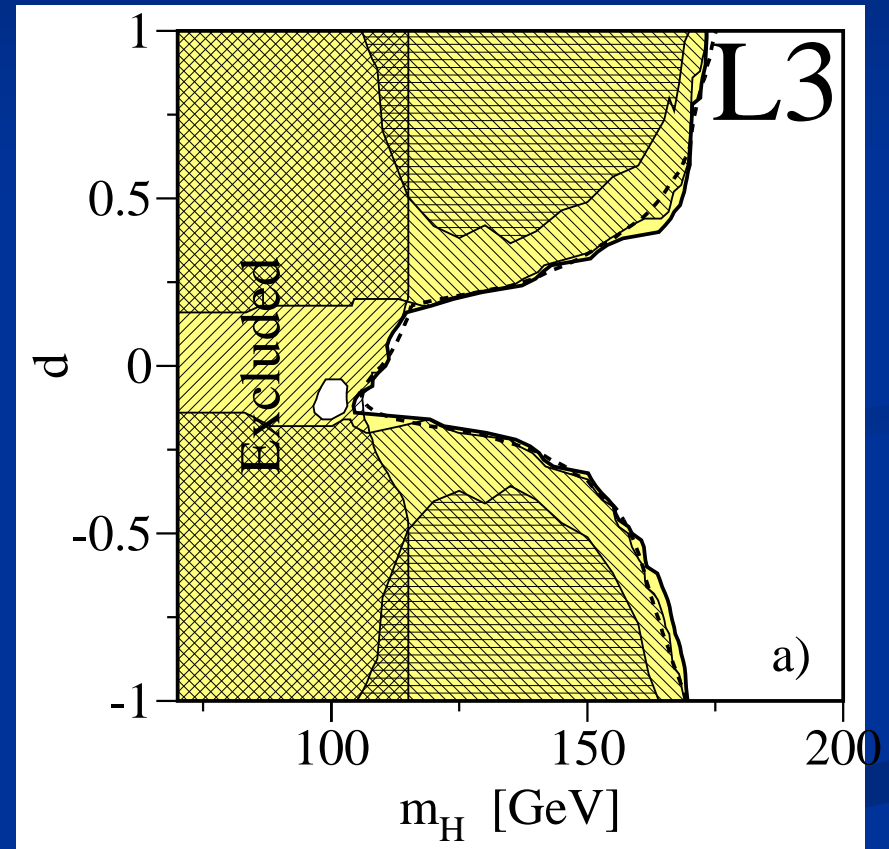
- ADD models
- Branons detectable before gravitons if brane tension $f \ll \ll$ extra dimension scale M_F
 - $e^+e^- \rightarrow \tilde{\pi}\tilde{\pi}Z \rightarrow \tilde{\pi}\tilde{\pi}q\bar{q}$
 - $e^+e^- \rightarrow \tilde{\pi}\tilde{\pi}\gamma$
- Branons: seen as missing energy
- Results:
 - No excess over SM
- 95% CL limits:
 - Branon mass $> 103 \text{ GeV}$
 - (small branon tension assumed)
 - Branon tension $> 180 \text{ GeV}$
 - (light branon assumed)





Search for Anomalous Higgs Couplings

- Study:
 - $e^+e^- \rightarrow H\gamma, e^+e^- \rightarrow HZ, e^+e^- \rightarrow e^+e^- H$
- Decay channels for H:
 - $H \rightarrow ff, H \rightarrow \gamma\gamma, H \rightarrow \gamma Z, H \rightarrow WW$
- Derive limits on couplings $d, d_B, \Delta g_1^Z, \Delta \kappa_\gamma, \xi^2$ and on $H \rightarrow \gamma\gamma, H \rightarrow \gamma Z$ decay rates



Example: d is dimensionless parameter describing $HZZ, H\gamma Z$ and $H\gamma\gamma$ couplings

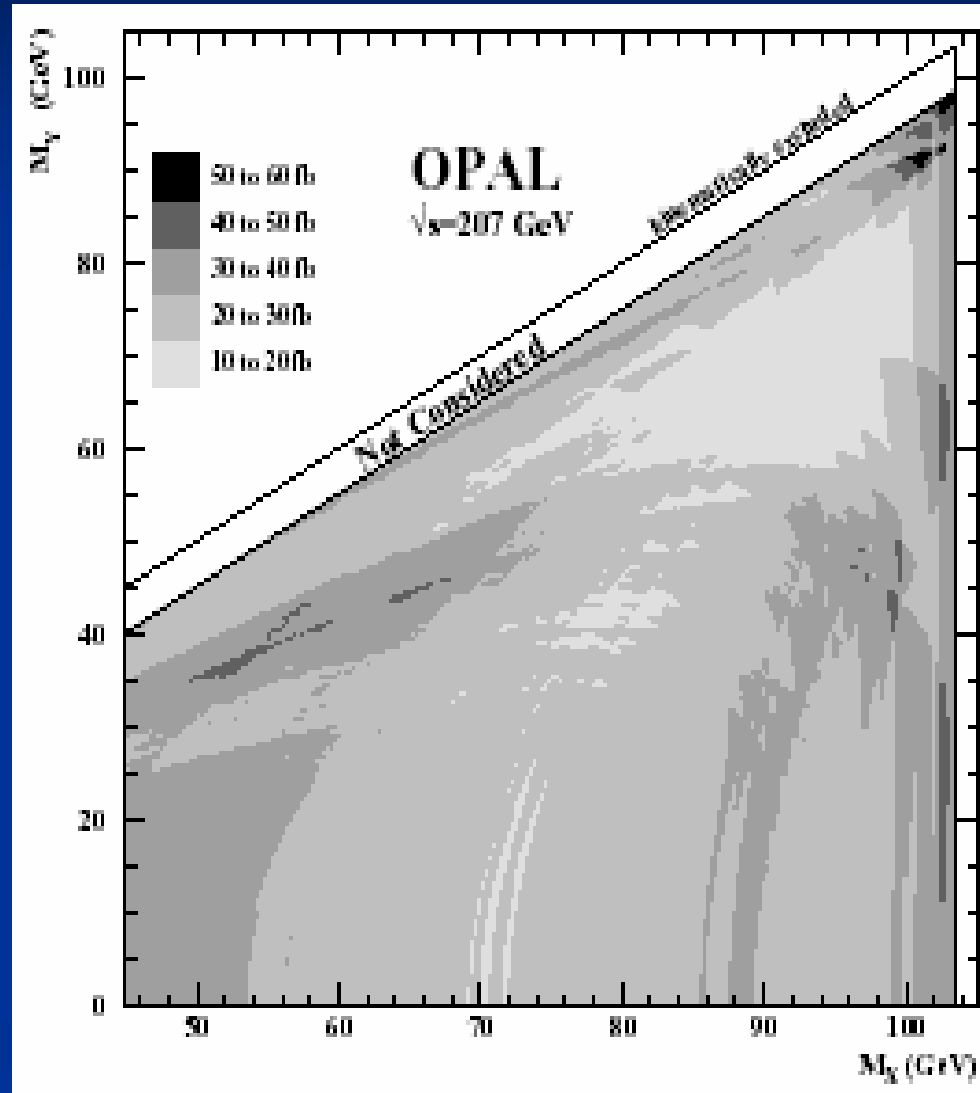
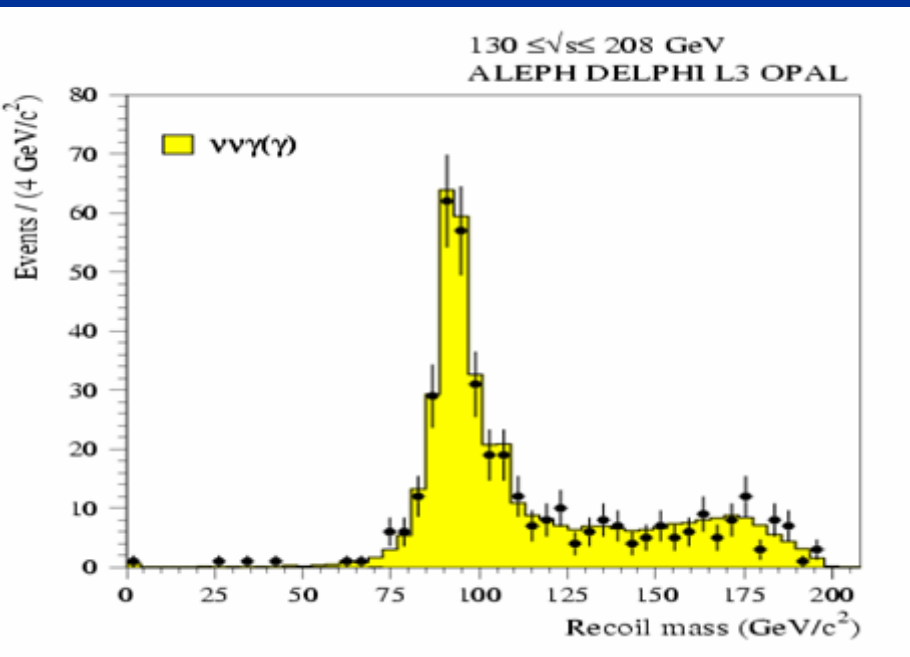
A large, intricate metal cross-shaped structure, likely a telecommunications or weather station, stands prominently on a rocky mountain peak. The structure is composed of a lattice of metal beams. Several people are visible at the base of the structure, providing a sense of scale. The mountain is covered in sparse, low-lying vegetation and large, light-colored rocks. The sky is filled with soft, grey clouds, suggesting an overcast day.

Final results from long-term efforts



Photons & Missing Energy

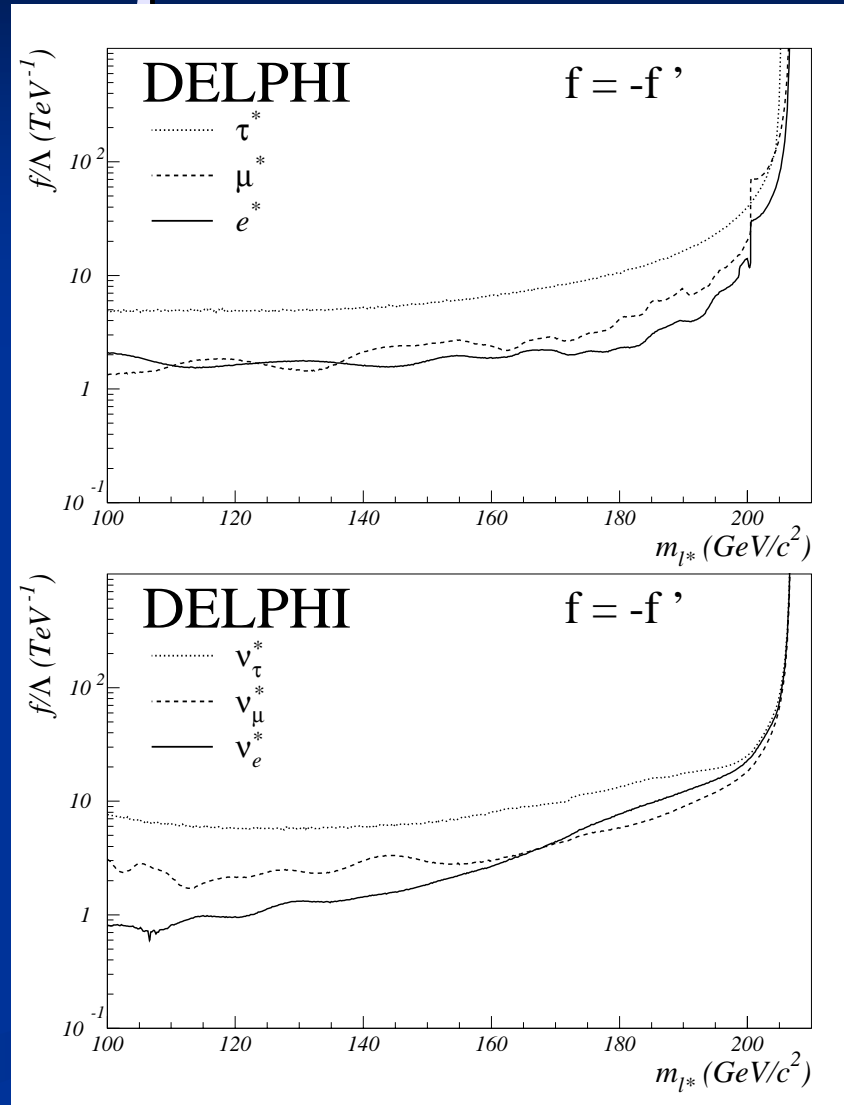
- Topological search for $e^+e^- \rightarrow XX$, $X \rightarrow Y\gamma$ (Y escapes undetected)
- Interpretations in models with
 - massive Y: $X = \chi^0_2$, $Y = \chi^0_1$: Limits 10-60 fb
 - massless Y: $X = \chi^0_1$, Y=light gravitino (GMSB); $X = \nu^*$, $Y = \nu$: Limits 20-40 fb





Excited Leptons

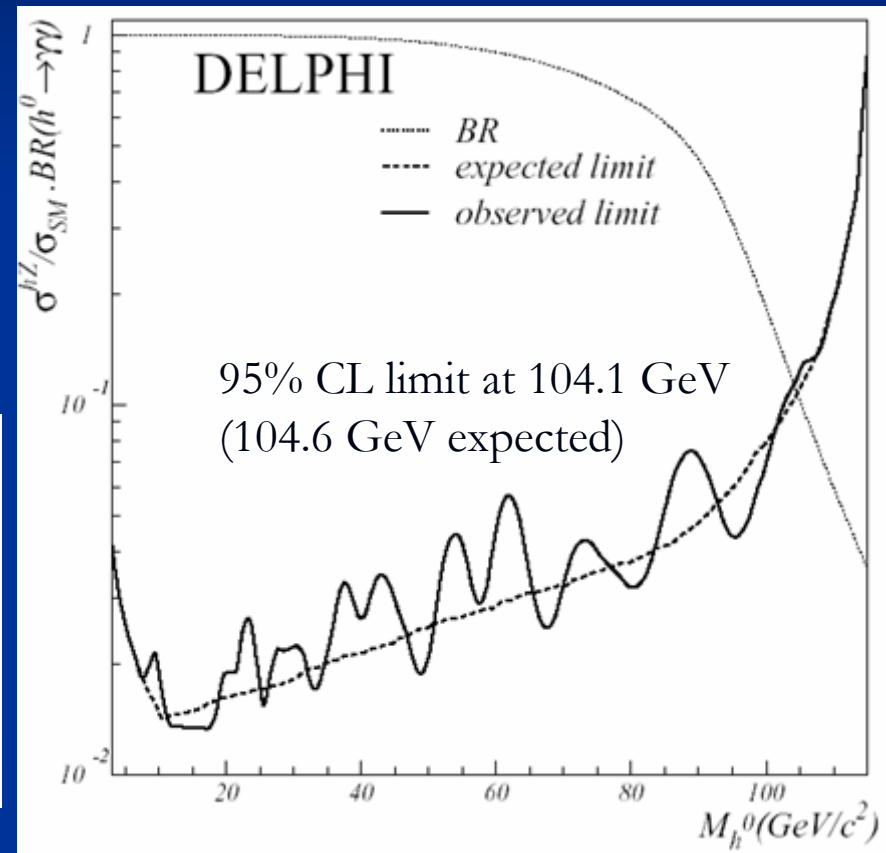
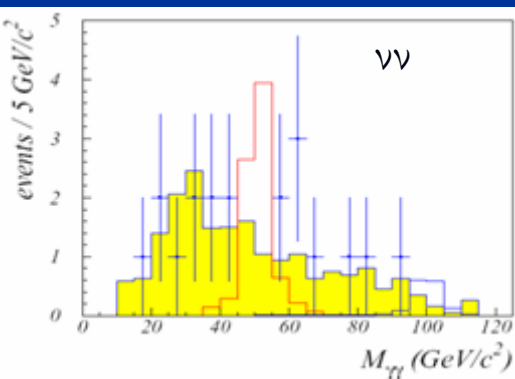
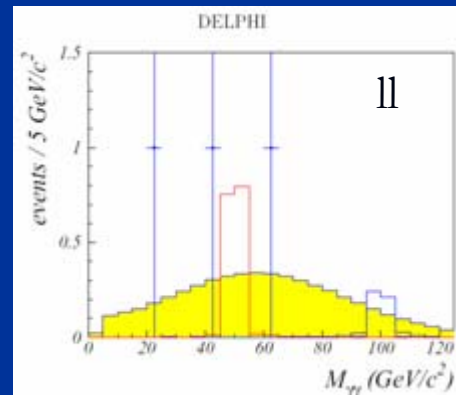
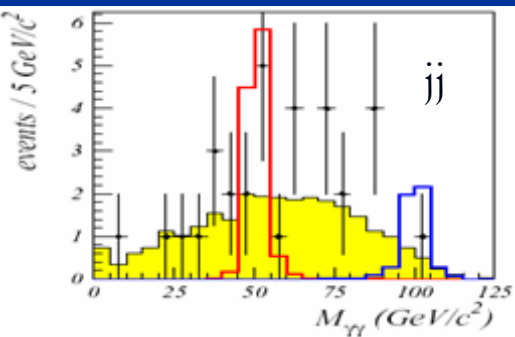
- l^*, ν^* ($l=e, \mu, \tau$)
- Single & pair production
- Decays: $l^* \rightarrow l\gamma, \nu W, lZ$;
 $\nu^* \rightarrow \nu\gamma, lW, \nu Z$
- Parameters:
 - Λ is compositeness scale
 - f, f' : weight factors associated with SU(2), U(1) gauge groups
 - Assume $f=f'$ (no $\nu^* \rightarrow \nu\gamma$)
 - or $f=-f'$ (no $l^* \rightarrow l\gamma$)
- Plots are example for single production with $f=-f'$...





Fermiophobic Higgs

- Assume large $h^0 \rightarrow \gamma\gamma$ BR
- $qq\gamma\gamma$, $ll\gamma\gamma$, $\nu\nu\gamma\gamma$ final states

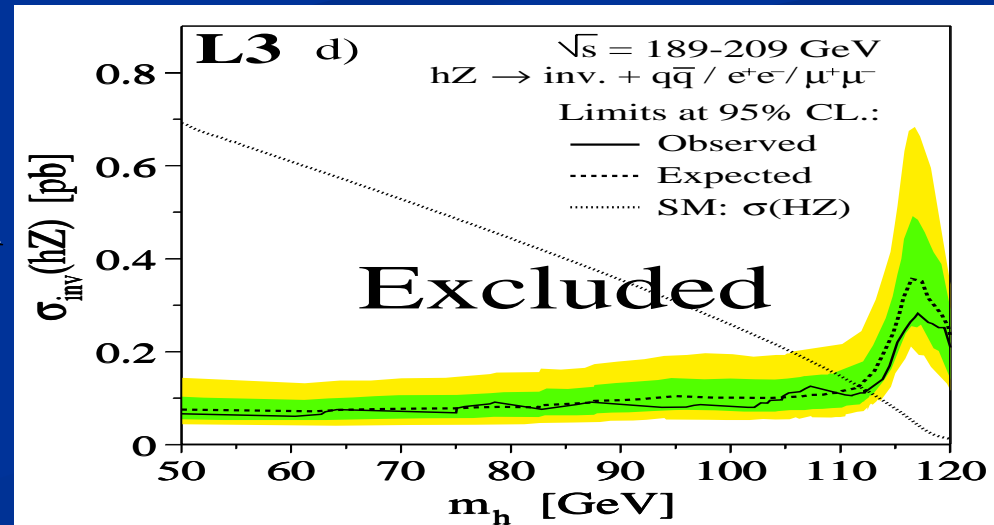
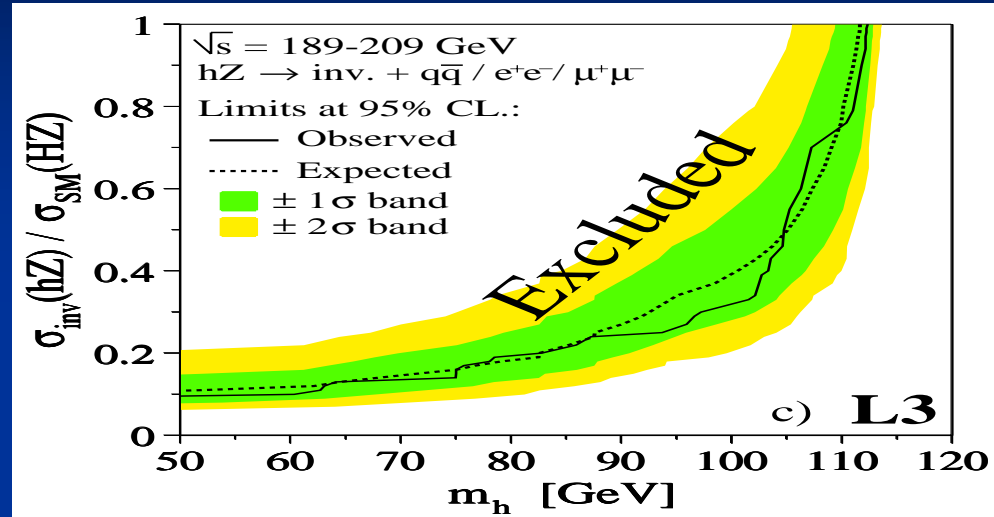


54 events selected, 52 ± 1 expected for $h^0 Z^0$ final states
25 events selected, 25.5 ± 0.4 expected for $h^0 A^0$ final states ($A \rightarrow bb$)



Invisible Higgs

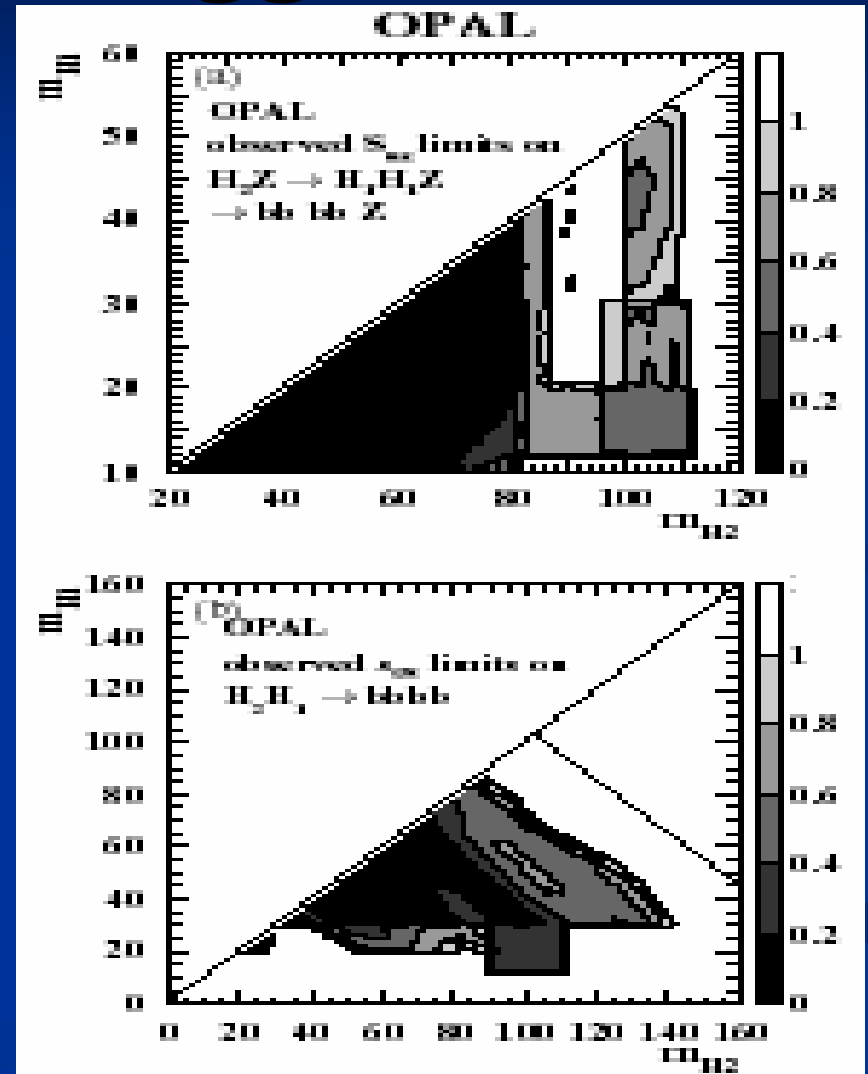
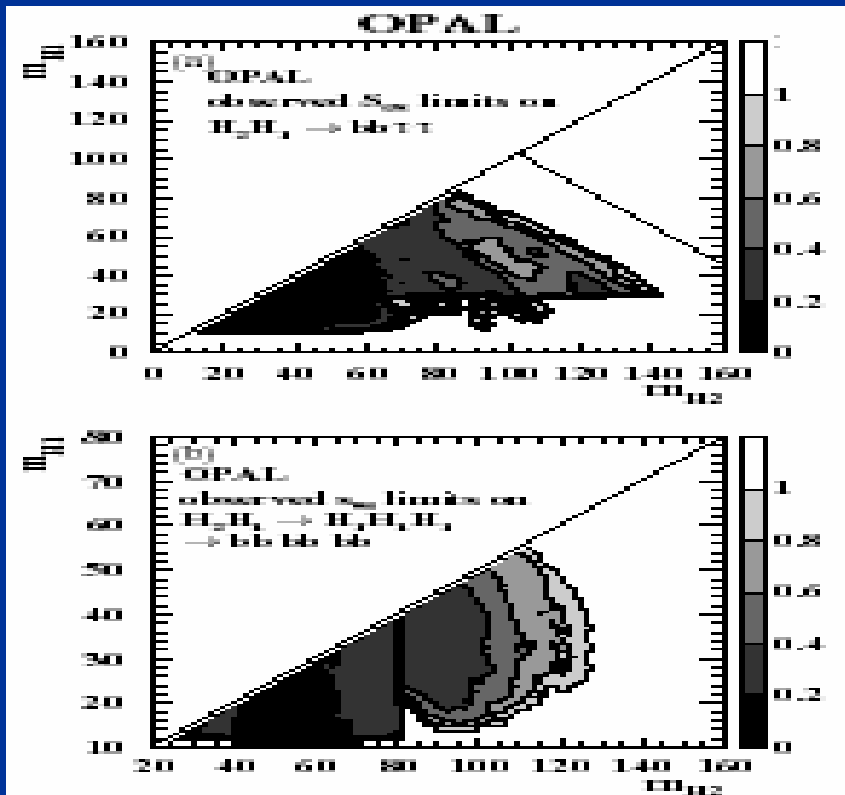
- $e^+e^- \rightarrow HZ$
 - $Z \rightarrow hh, ee, \mu\mu$
 - $H \rightarrow \text{LSPs}, 4^{\text{th}} \text{ gen } \nu, \text{ extra dim, majorons, etc.}$
- Exclusion to **112.1 GeV** in hadrons channel (111.4 GeV expected)
- Exclusion to **91.3 GeV** in leptons channels (88.4 GeV expected)
- Combined 95% CL exclusion to **112.3 GeV** if SM production cross-section assumed





Neutral Higgs

- CP-conserving and CP-violating
- $h^0, A^0, H^0 \rightarrow H_1, H_2, H_3$
- Interpreted at many benchmark points
- Model-independent σ limits

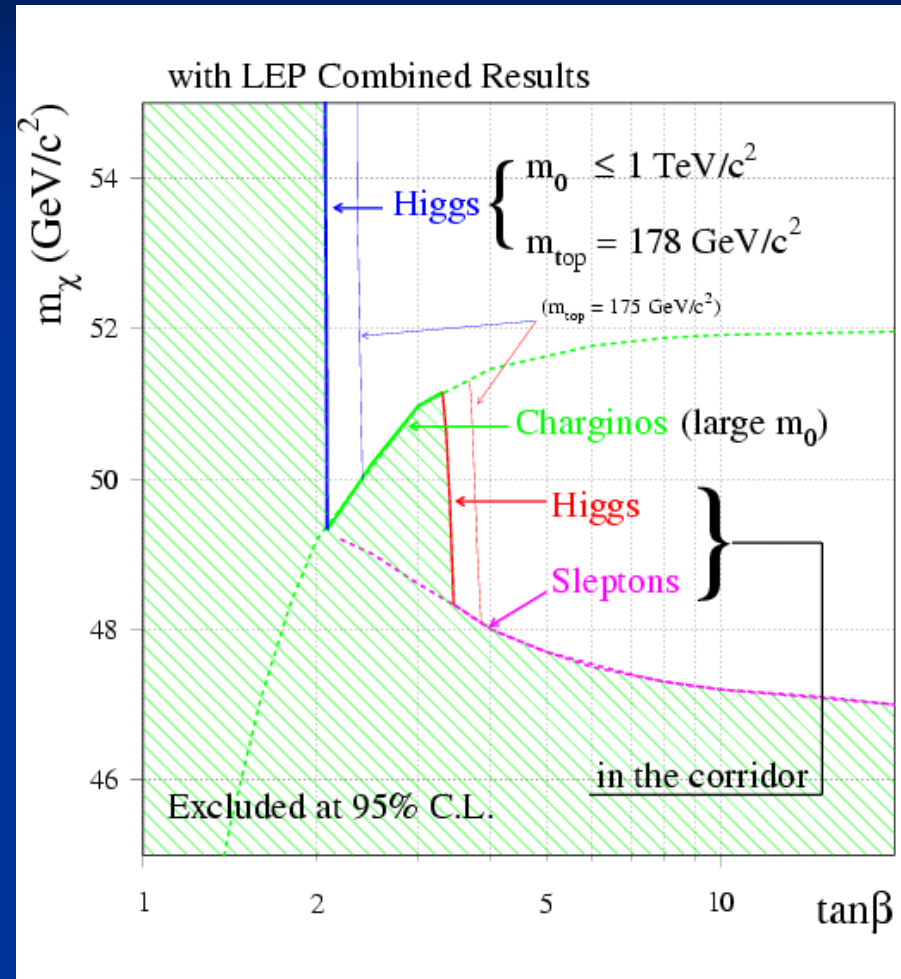


Final LEP Combinations

LEP Combination

MSSM LSP Limit

- Grand combination of χ^\pm, χ^0 , squark, slepton, Higgs searches in MSSM
 - R-parity conserved
 - GUT-scale gaugino, sfermion mass unification
- No stau mixing:
 - $M_{\text{LSP}} > 43.1 \text{ GeV}$ (Aleph alone)
 - $M_{\text{LSP}} > 47 \text{ GeV}$ (LEP comb.)
- Stau mixing allowed:
 - $M_{\text{LSP}} > 42.4 \text{ GeV}$ (Aleph alone)
- mSUGRA:
 - $M_{\text{LSP}} > 50 \text{ GeV}$ (Aleph alone, $m_{\text{top}} = 175 \text{ GeV}$, any A_0)

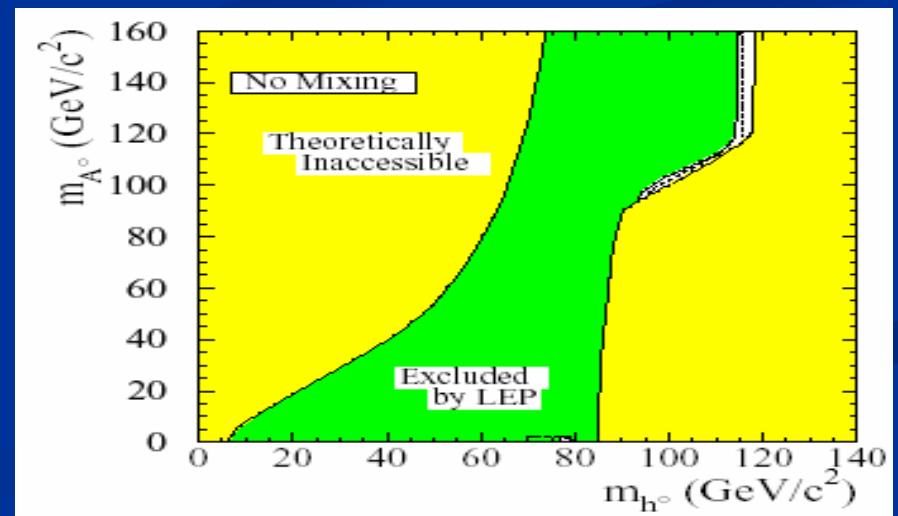
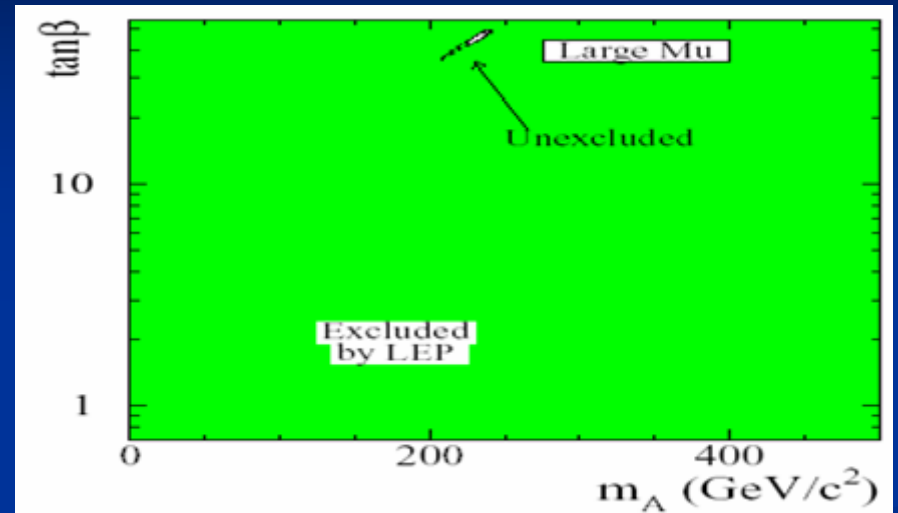


(Plot includes Aleph χ^\pm result + LEP combined sleptons & Higgs)

LEP Combination

Neutral Higgs in the MSSM

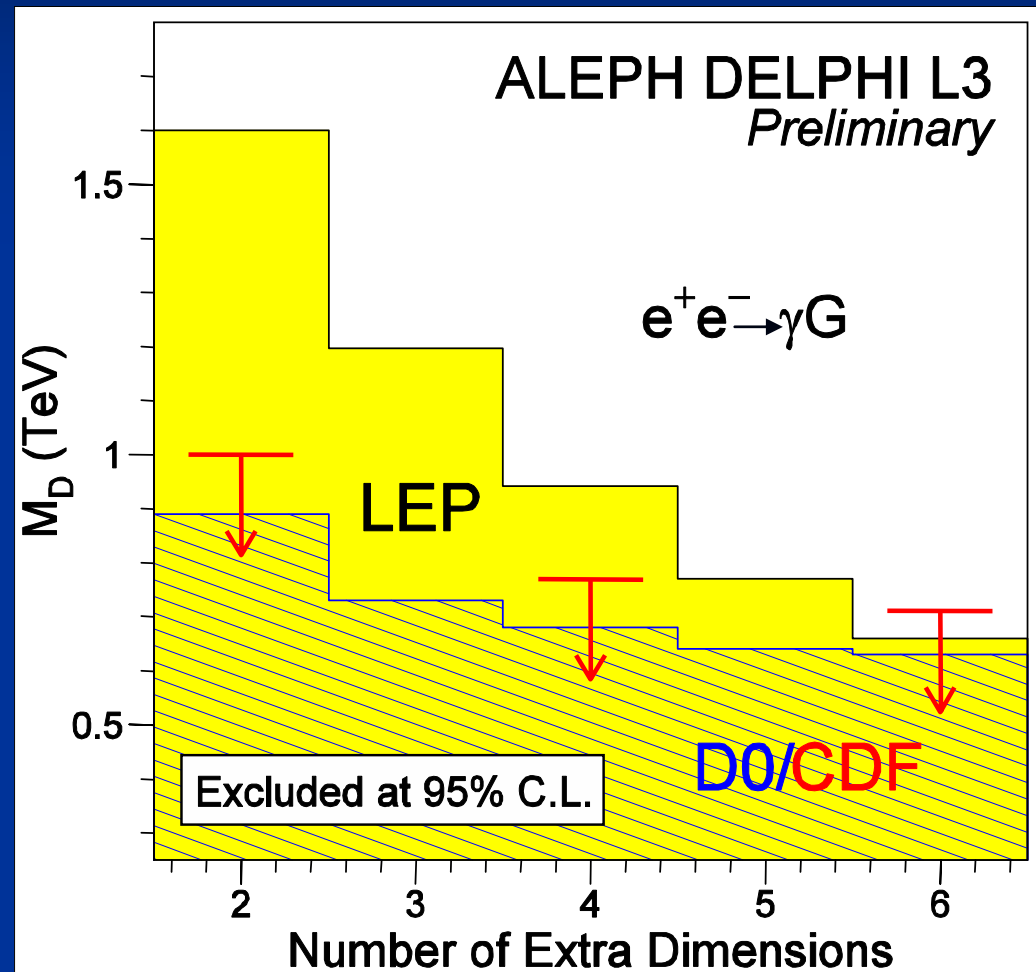
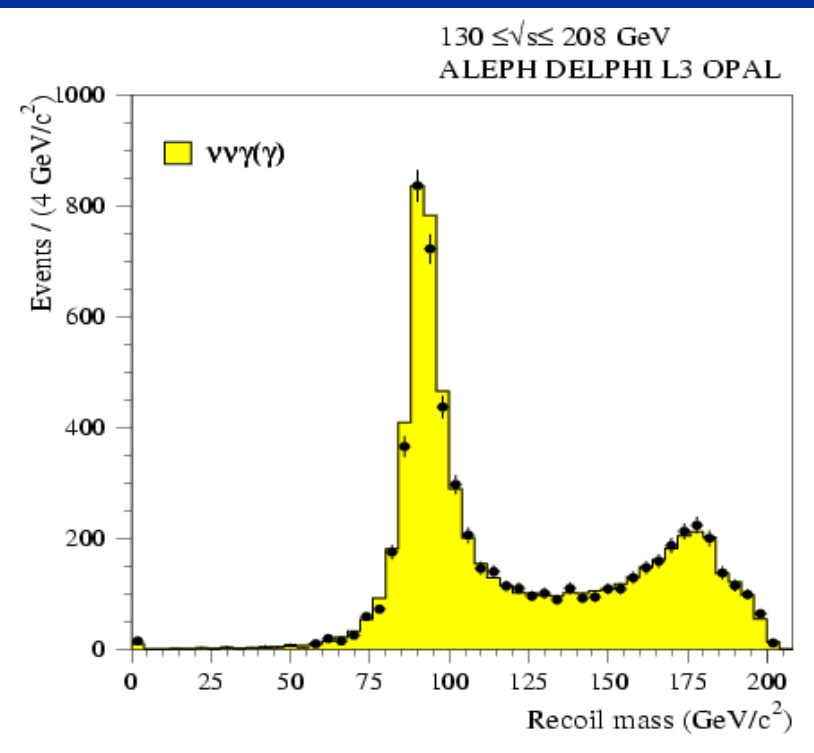
- 95% CL exclusion in the various parameter spaces for benchmark scenarios
- Combine exclusions from HZ , H_1H_2 analyses (including CP-violating), many final states
- Some benchmarks very close to totally excluded!



LEP Combination

Large Extra Dimensions

- Direct search for graviton in $e^+e^- \rightarrow G\gamma$
- M_D : fundamental gravity scale



So... What can we conclude?

- Final LEP2 search results mostly published
 - *New initiatives still possible*, especially for non-traditional search signatures (e.g. QCD-like)
 - But surprises seem unlikely at this stage
- LEP BSM search results can be summarized:
 - *“no significant excess”* – disappointing?
- What can we conclude from LEP about the *viability* of SUSY models, technicolour, extra dimensions?
- *LEP searches have excluded* some LHC benchmarks
 - Now also look to the SM fits for where to search at the LHC and beyond...