

Search for New Particles and New Phenomena

Results from e^+e^- Colliders

P. Igo-Kemenes

(Heidelberg / CERN)

... towards the end of LEP ... expansion of search activities
(PA11: 120 abstracts from LEP)

- **Physics scope** ... towards more “exotic” models
- **Hidden “corners”** ... not favoured by kinem. or dynam.
- **Model-independence** ... enduring results !

LEP 2 data ... **combined**

$> 2 \text{ fb}^{-1}$ at $E_{cm} > 180 \text{ GeV}$

this year ... $\approx 500 \text{ pb}^{-1}$ at $E_{cm} : 202 - 209 \text{ GeV}$

... still similar amount to come ...

Main directions for physics beyond the SM ...

- More symmetry (e.g. SUSY ...) within GUT scheme
- Substructure, new forces (e.g. LQ, Technicolor ...)

OVERVIEW

- Indirect limits on NEW PHYSICS

Deviations from SM predictions ... ? ... bounds on ...

Contact interactions, QED 'cutoff'

Extra Z'-bosons, Low-scale gravity

5 min

- Direct Searches

Heavy leptons

Excited leptons, Leptoquarks, Technicolor

M.A. FALAGAN W. LOHMANN

5 min

Supersymmetry ... MSUGRA, GMSB, RPV

10 min

- Higgs bosons ... SM, MSSM, 2HDM ... 'exotica'

8 min

Selection ! emphasis on **updated results** (year 2000)
on new physics aspects

ALEPH+DELPHI+L3+OPAL $\Rightarrow$ 'ADLO' results

Limits, limits, limits ... !!! - quoted at **95% CL**

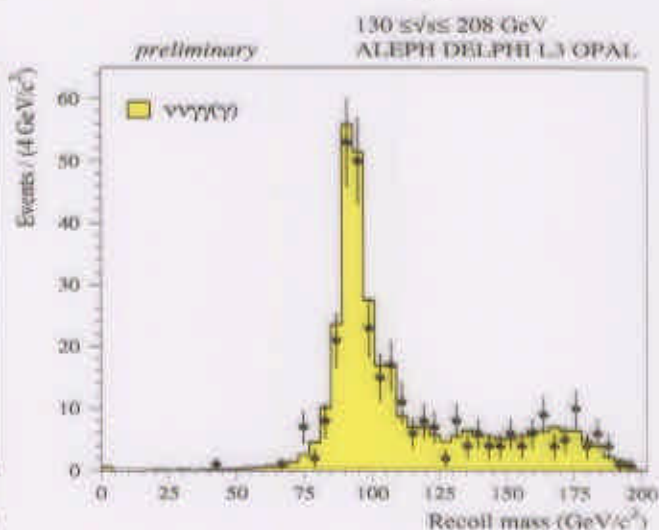
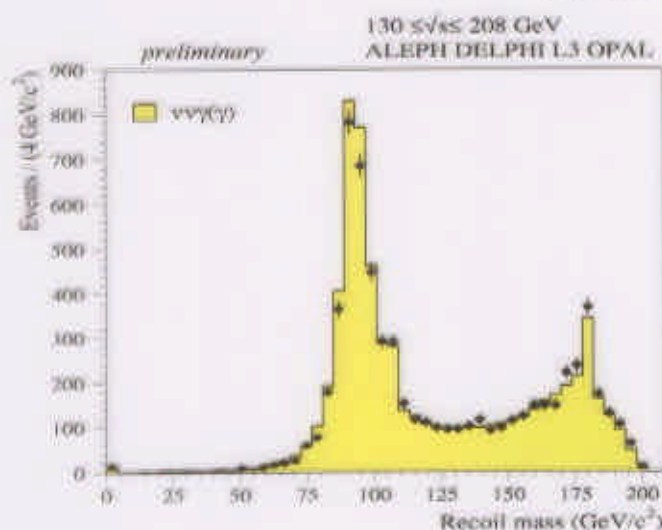
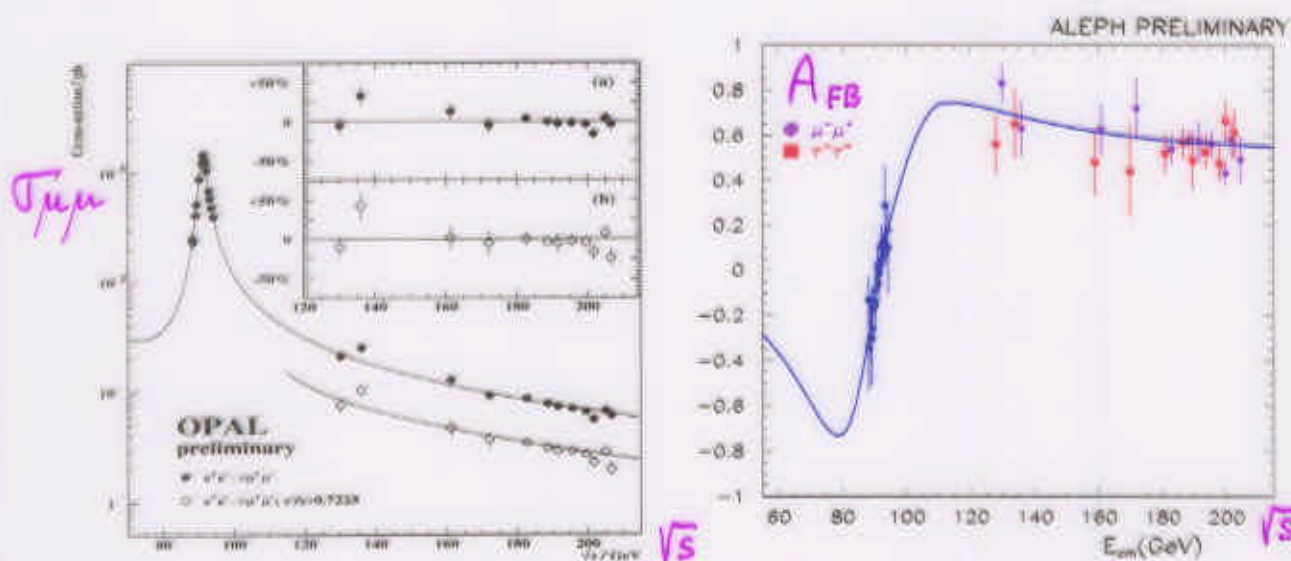
MOST RESULTS ... PRELIMINARY !

Indirect limits on New Physics

Deviations from SM ? ... fits to cross-sections

charge asymmetries, angular distributions

$e^+e^- \rightarrow f\bar{f}, \gamma(\gamma) \dots (+ E_{miss})$



In General, agreement with SM ...

$\Rightarrow$ Little room for 'new physics'

(... Indirect limits)

Four-fermion contact interactions

Generic new physics ... Scale Λ , coupling g , helicity $\eta_{i,j}$

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

Limits ... ($g^2 = 4\pi$) $i, j = VV$: $\Lambda > 11 - 18 \text{ TeV}$

AA : $\Lambda > 9 - 15 \text{ TeV}$

(Fermion-sizes ... $2-3 \cdot 10^{-19} \text{ m}$)

- Sensitivity to **s-neutrino** or **leptoquark** exchange
 $\Rightarrow$ **indirect limits** complementing direct searches

Deviations from QED

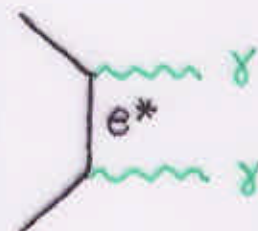
$e^+e^- \rightarrow \gamma\gamma$... almost pure QED process

Deviations ... generic 'UV-cutoff' ...

$$\Lambda_{\pm} > 300 - 330 \text{ GeV}$$

- Sensitivity to exchange of **excited electron**

$$M_{e^*} > 300 - 320 \text{ GeV}$$



(... Indirect limits)

Additional Z-bosons Z'

E(6)-GUT (Z'_ξ, Z'_ψ, Z'_η) L-R symm. , Sequ.-SM

SM-couplings ... modified by **Z - Z' mixing**
affecting $e^+e^- \rightarrow f\bar{f}$ distributions

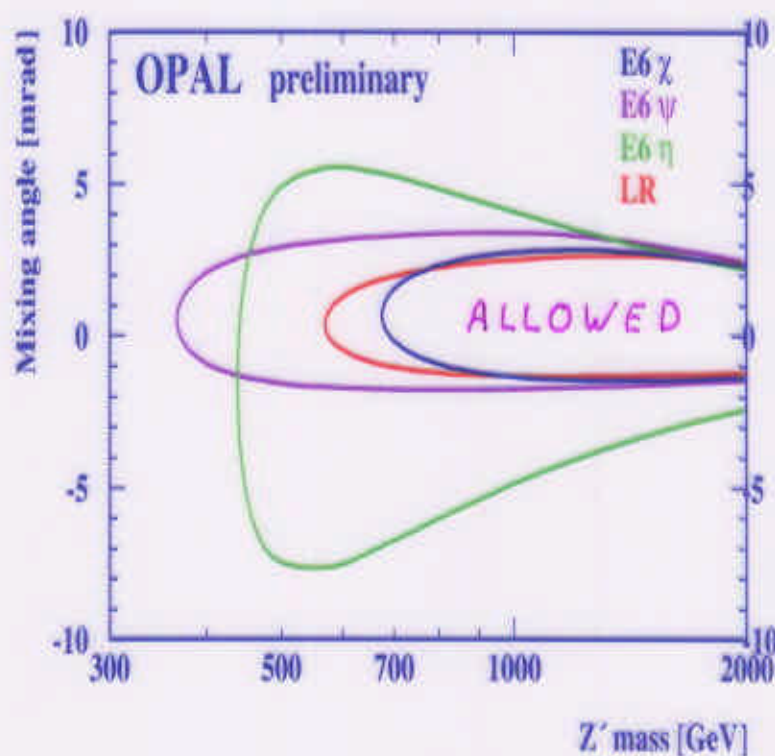
Z-lineshape measurements already exclude large mixing

Limits A, D, L, O

$M_{Z'} > 300-750$ GeV

A, L ... Seq-SM Z'

$M_{Z'} > 1$ TeV



Low-scale Gravity

REV.

G. LANDSBERG

Theory ... with δ extra space dimensions of range R
 escaping the 'scale-hierarchy' problem ... no SUSY, no
 compositeness (Arkani-Hamed, Dimopoulos, Dvali)

- M_{Planck} ... 'effective' scale in 3-dim space

The fundamental scale in $3 + \delta$ -dim. space is $M_D \approx \Lambda_{ew}$

$$M_{Planck} = R^\delta M_D^{\delta+2}$$

- $M_D \approx \Lambda_{ew} \Rightarrow R \approx 10^{30/\delta - 17} \text{ cm}$

$\delta = 1$ ($R \sim 10^{13} \text{ cm}$) ... excluded ($1/r^2$ tests)

$\delta = 2$ ($R \sim 0.01 - 0.1 \text{ cm}$) ... possible for large M_D (SN1987)

- **Graviton** ... many massive spin-0,1,2 excitations in 3-dim space

Searches in e^+e^- ... A, D, L, O

Direct $e^+e^- \rightarrow \gamma G$ $e^+e^- \rightarrow (Z^0 \rightarrow f\bar{f}) G$

Virtual effects $e^+e^- \rightarrow f\bar{f}, \gamma\gamma, W^+W^-, Z^0Z^0$

Parametrizations ... $M_S, \Lambda_T^\pm, G^\pm \sim M_D$ same $\mathcal{O}$

	$\delta = 2$	$\delta = 4$	$\delta = 6$
$M_D >$	1.0-1.3	0.7-0.8	$\sim 0.5 \text{ TeV}$
$M_S >$	1.2 TeV		

Scale close to Λ_{ew} ... NOT FAVOURED !

Direct searches

- Heavy leptons
- Excited leptons
- Leptoquarks → REV. : M.A. FALAGAN
- Technicolor → REV. : W. LOHMANN
- SINGLE TOP PROD → REV. : V. OBRAZTSOV
- Supersymmetry
- Higgs

Heavy leptons $L^\pm, L^0$

Renewed interest ... since possibly $m_\nu \neq 0$!

... e.g. See-saw mechanism ... $m_{L^0_\ell} = m_\ell^2 / m_{\nu_\ell} \sim 100 \text{ GeV}$

Most complete recent update: **L3** ...

Sequential / vector / mirror $L^\pm, L^0$... 'Dirac' / 'Majorana' L^0

$$e^+e^- \rightarrow L^+L^-, L^0L^0$$

$$L^\pm \rightarrow \nu_L W^\pm, L^0 \rightarrow \ell^\pm W^\pm \quad (\ell^\pm \dots e^\pm, \mu^\pm, \tau^\pm)$$

$$m_{L^\pm} > 98.7 - 99.1 \text{ GeV}$$

$$m_{L^0} > 89.0 - 99.5 \text{ GeV} \quad (\text{Dirac})$$

$$m_{L^0} > 79.6 - 85.7 \text{ GeV} \quad (\text{Majorana})$$

(Sequence of limits ... vector > sequential $\approx$ mirror ... $\mu \approx e > \tau$)

● Isosinglet neutrino N_ℓ ... GUT, superstring, LR-symm ...

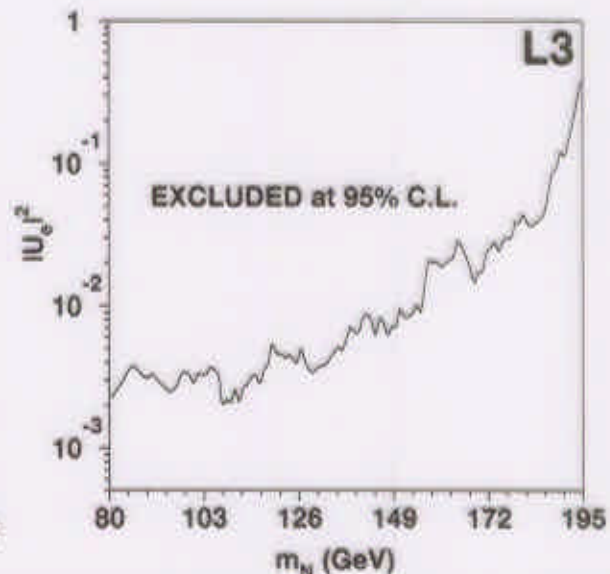
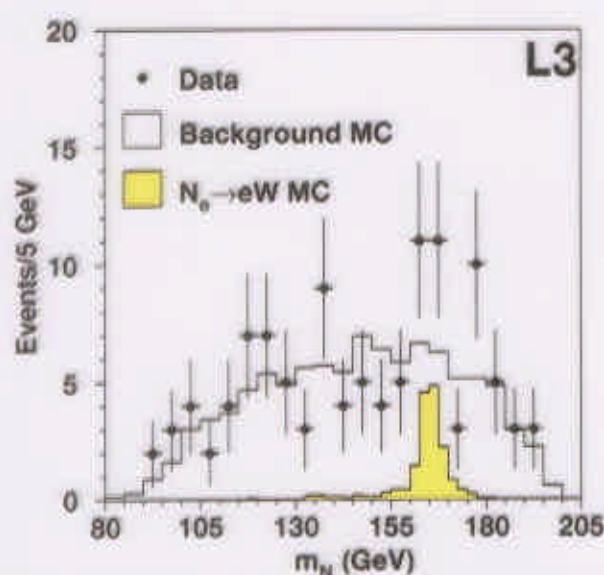
Production ... by mixing with associated isodoublet neutrino

LEP1, low-E ... mixing amplitude $U_\ell < 0.1$

1-st gen ... *t-channel enhancement* ...

L3 search $e^+e^- \rightarrow N_e + \nu_e$ (m_{N_e} fully reconstructed)

$$\hookrightarrow e^\pm + W^\mp \dots (W^\mp \rightarrow q\bar{q})$$



Excited leptons ... $\ell^{\pm*}, \nu_\ell^*$

REV: M.A. FALAGAN

Compositeness ... *substructure* ... scale Λ

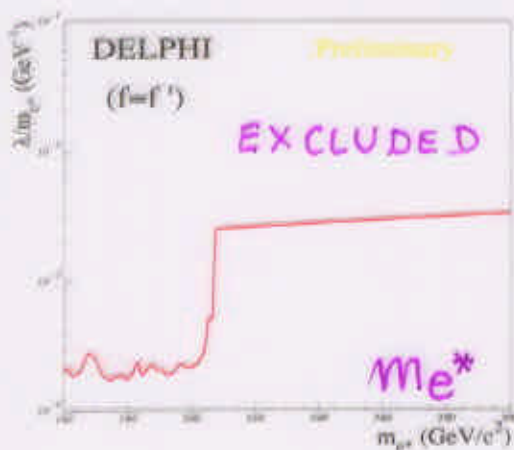
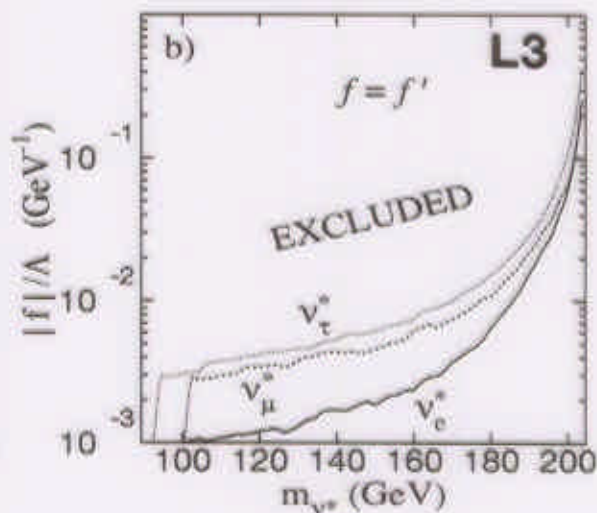
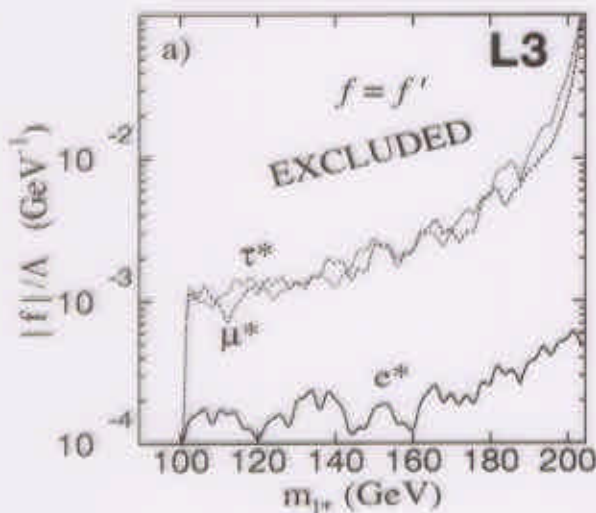
$$\mathcal{L}_{\ell^*\ell} = \frac{1}{2\Lambda} \bar{\ell}^* \sigma^{\mu\nu} [f g \frac{\tau}{2} W_{\mu\nu} + f' g' \frac{Y}{2} B_{\mu\nu}] \ell_L$$

f, f' ... control radiative / weak decays

$$\ell^*(\nu^*) \rightarrow \ell(\nu) \gamma, \nu(\ell) W$$

Parameters $f/\Lambda, f'/\Lambda$... $\lambda/m^* = f/\Lambda\sqrt{2}$

Emphasis on single prod. ... $e^+e^- \rightarrow \ell^*\ell, \nu^*\nu \Rightarrow \dots \sqrt{s}$



Combining direct searches
with indirect limits
from $e^+e^- \rightarrow \gamma\gamma$

Leptoquarks L_q

REV:

M. A. FALAGAN

Coloured particles ... spin 0 and 1, $B, L \neq 0$

$$|Q| = 1/3, 2/3, 4/3, 5/3$$

GUT, Technicolor, Composite models ...

Indirect limits on masses and couplings from SM fits ...

assuming $\lambda = \sqrt{4\pi\alpha_{em}} \approx 0.3 \dots m_{L_q} > 60 - 600 \text{ GeV}$

• Pair-prod. $e^+e^- \rightarrow L_q \bar{L}_q$... limited to $m_{L_q} < \sqrt{s}/2$

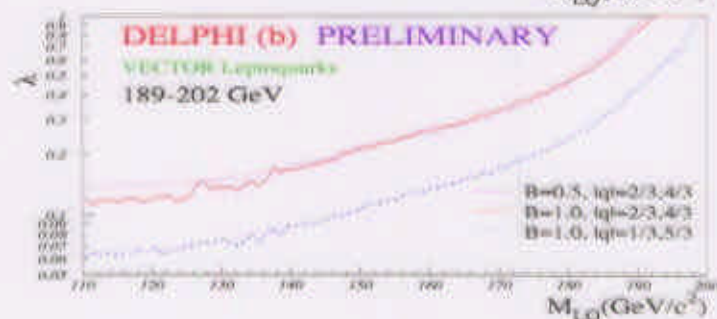
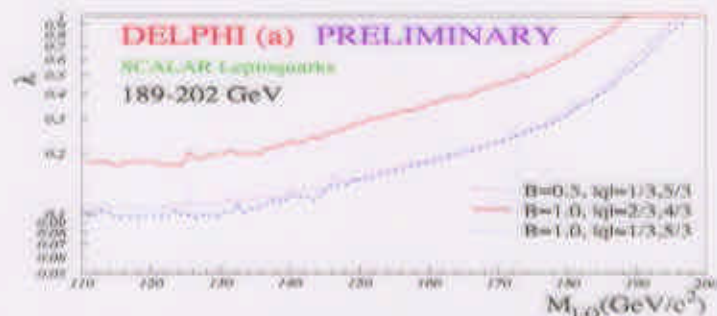
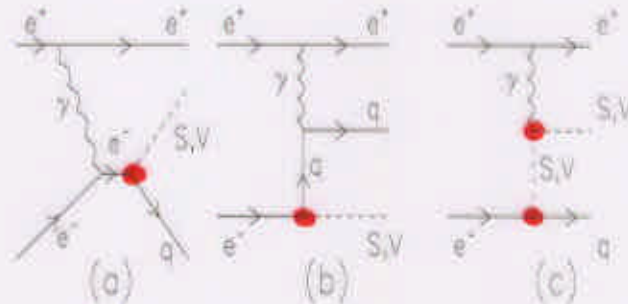
OPAL ... update

• Single-production

$$e^+e^- \rightarrow eqL_q$$

$$m_{L_q} \Rightarrow \sqrt{s}$$

A,D,L,O



For $\lambda \approx \lambda_{em}$

$$m_{L_q} > 150 - 185 \text{ GeV}$$

A.F. Zarnecki ... Abstr.213 ...

Global fit to Hera, LEP, Tevatron data + low-E constraints ... Data seem to favour models incl. an S_1 or $\bar{V}_0$ leptoquark of mass $> \approx 300 \text{ GeV}$!

Technicolor

REV: W. LOHMANN

- Alternative to Higgs mechanism to generate M_W , M_Z
- New, very strong interaction ... $\Lambda_{TC} \gg \Lambda_{QCD}$
- 'Standard' TC ... (QCD-like 'running') $\Rightarrow \Leftarrow$ LEP1 data
... more elaborate models ... 'walking' TC ... seem viable
- Additional scalars π_T, π_T' and vectors ρ_T, ω_T
(Tevatron limits $m > \approx 200$ GeV)

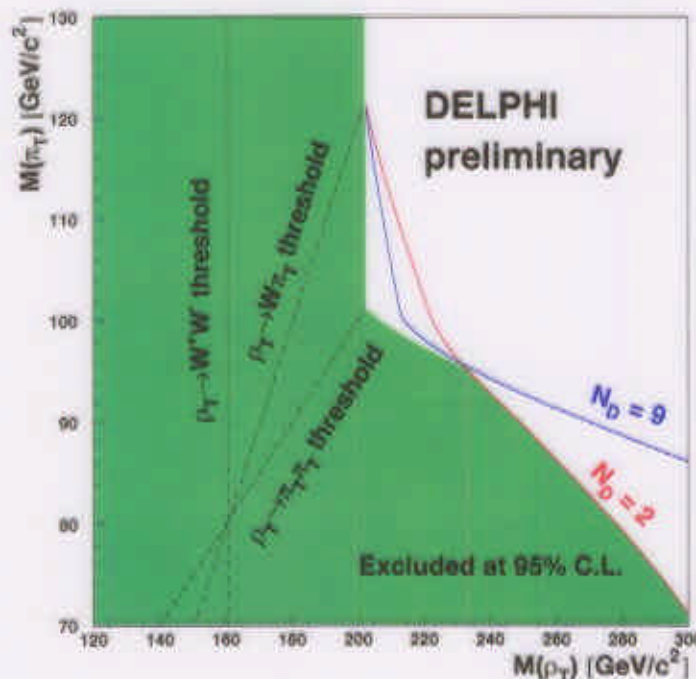
L3, Delphi ...

$$e^+e^- \rightarrow \pi_T^+ \pi_T^-, \gamma \pi_T^0, \gamma \pi_T'^0, W_L \pi_T, f\bar{f}, W_L W_L$$

$$\rho_T^{(*)}, \omega_T^{(*)}$$

Scan of the TC param. space ...

$\Rightarrow$ Limit in (M_{π_T}, M_{ρ_T}) plane ... for N_D TC-q doublets

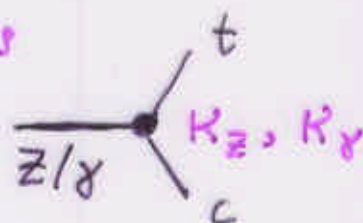


SINGLE TOP PRODUCTION @ LEP

REV: V. OBRATSOV

- For $\sqrt{s} > 183$ GeV ... $e^+e^- \rightarrow t\bar{c}$ ($t\bar{u}$)
kin. possible!

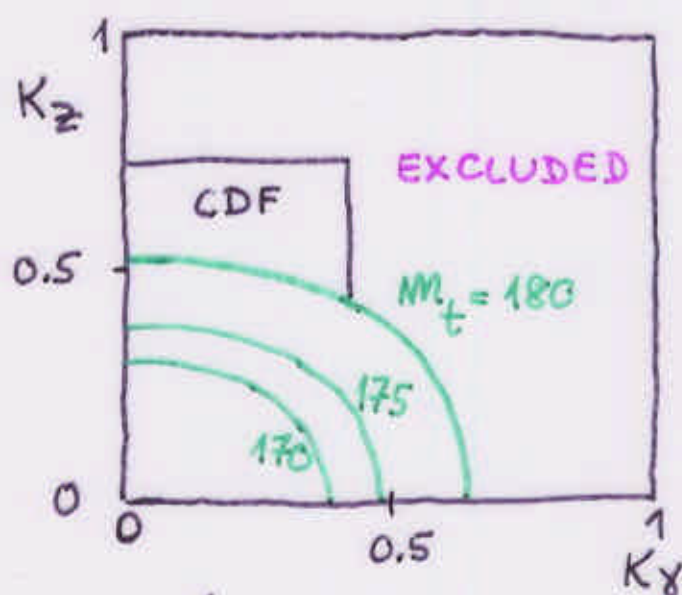
- FCNC ... strongly suppressed in SM
 $\sigma \lesssim 10^{-9}$ fb
 $\Rightarrow$ good place to look for NEW PHYSICS
with anomalous couplings



- A, D, L ... $\sqrt{s} = 189 \div 202$ GeV
O ... $\sqrt{s} = 189$ GeV

- LEP - Combined results:

$$\sigma < 90 \text{ fb (95\% CL)} \quad \langle E_{\text{cm}} \rangle = 194 \text{ GeV}$$



$\Rightarrow$ improvement
upon CDF for K_Z

Supersymmetry

SUSY ... within *GUT* ... *fermions* $\Leftrightarrow$ *bosons*

- particles $\Leftrightarrow$ sparticles
solution to “scale-hierarchy” problem”
- Masses / couplings unified at Λ_{GUT}
 $m_0, m_{1/2}, A_0, \tan \beta, \mu$
- “Soft” SUSY breaking ... $M_{soft} \sim M_W$...
 $\Rightarrow$ “messenger interaction”

Gravity-mediated *MSUGRA*

Heavy gravitino ... decoupled

$\tilde{\chi}^0$... LSP ... (or $\tilde{\tau}$)

Gauge-mediated *GMSB*

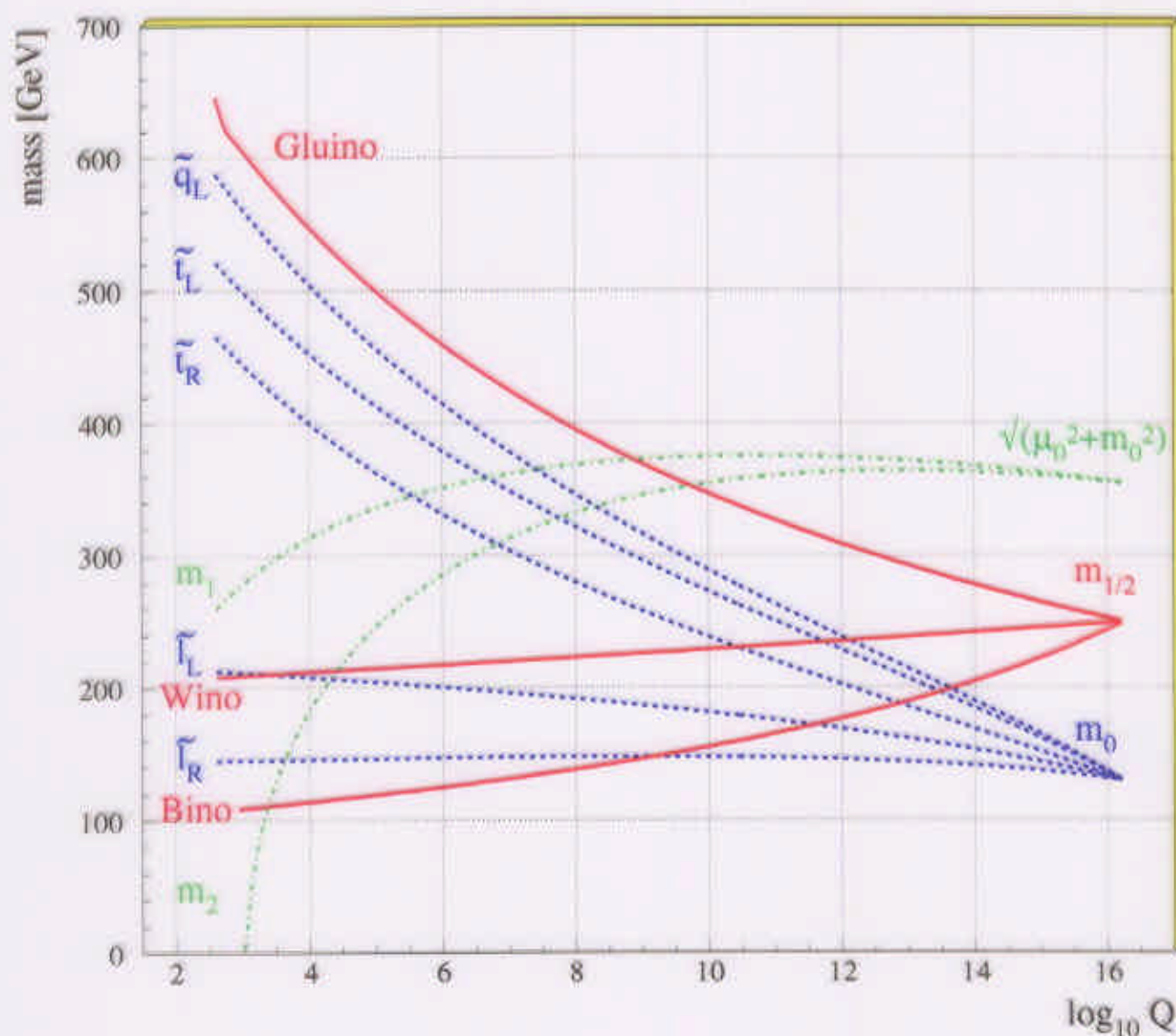
Light gravitino ... $M_{\tilde{G}} \sim \mathcal{O}(\text{eV})$

$\tilde{G}$... LSP

! NLSP ! ... $\tilde{\chi}^0 \rightarrow \gamma \tilde{G}$ or $\tilde{\ell} \rightarrow \ell \tilde{G}$

R-parity : $P_R = (-1)^{3B+L+2s}$

- Conserved ... RPC
LSP is stable ... $\tilde{\chi}^0$ “dark matter” candidate
- Violated ... RPV
LSP unstable ... $\rightarrow \ell^\pm, q$... No “dark matter” candidate



EW scale

← RGE

Λ_{GUT}

- $\tilde{W}, \tilde{Z}, \tilde{\gamma}, \tilde{H}$ mixing $\Rightarrow \tilde{\chi}^0, \tilde{\chi}^\pm$
- L-R mixing
- Yukawa couplings (3d generation)

Additional complexity ... small m_0

$$m_{\tilde{e}} \approx m_{\tilde{\chi}}$$

$\Rightarrow$ interferences ...

Searches ... interpreted in MSUGRA

A, D, L, O have updated ... year 2000 data

Emphasis on 'difficult' kinematic and dynamic domains ...

- Small $\Delta m = m - m_{LSP} < 10 \text{ GeV}$... small visible mass ...
backgd from $\gamma\gamma$ processes ... special analyses ... ISR-photon tag
- Finite decay-length ... tracks or photons non-pointing to IP
- Small m_0 ... $m_{\tilde{\ell}} \sim m_{\tilde{\chi}}$... interference ... complicated decays

Chargino / Neutralino

REV: K. NAGAI

$$e^+e^- \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \rightarrow \tilde{\chi}_1^0 W^\mp$$

$$\hookrightarrow \tilde{\chi}_1^0 W^\pm$$

$$e^+e^- \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^0$$

$$\hookrightarrow \tilde{\chi}_1^0 Z^0$$

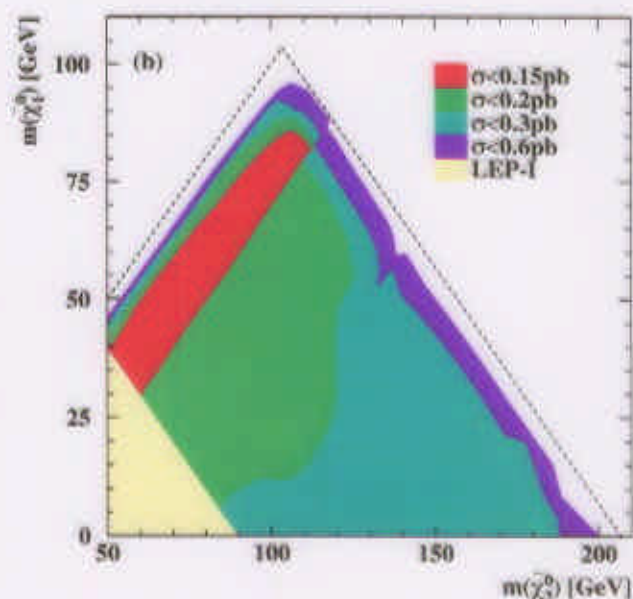
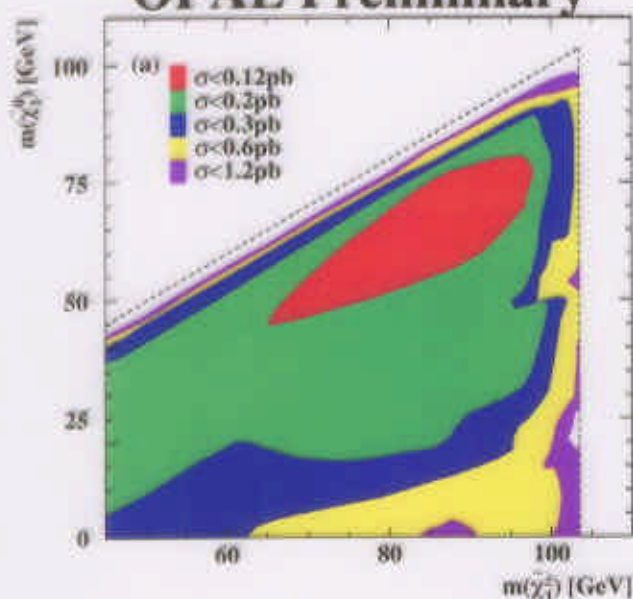
$$q\bar{q} q\bar{q} + E_{\text{miss}}$$

$$\ell^\pm q\bar{q} + E_{\text{miss}}$$

$$q\bar{q} + E_{\text{miss}}$$

$$\ell^+\ell^- + E_{\text{miss}}$$

OPAL Preliminary

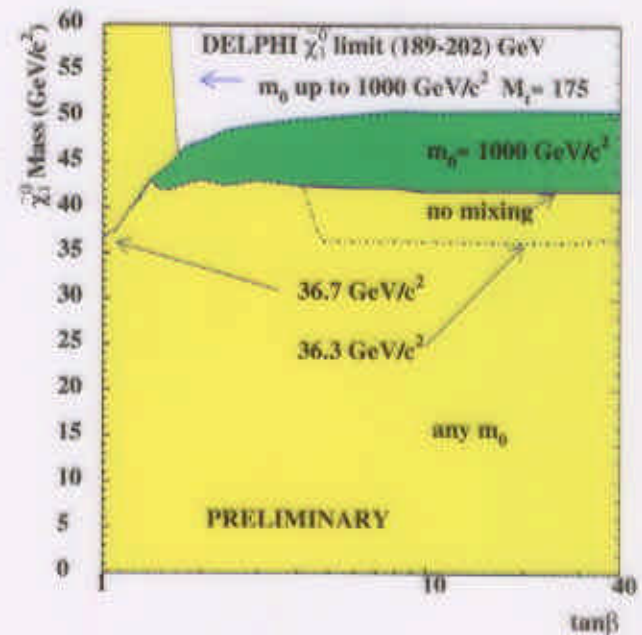
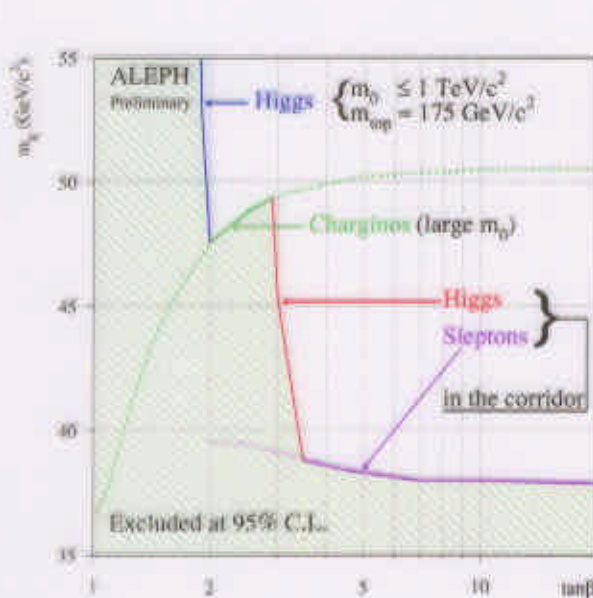


(... MSUGRA)

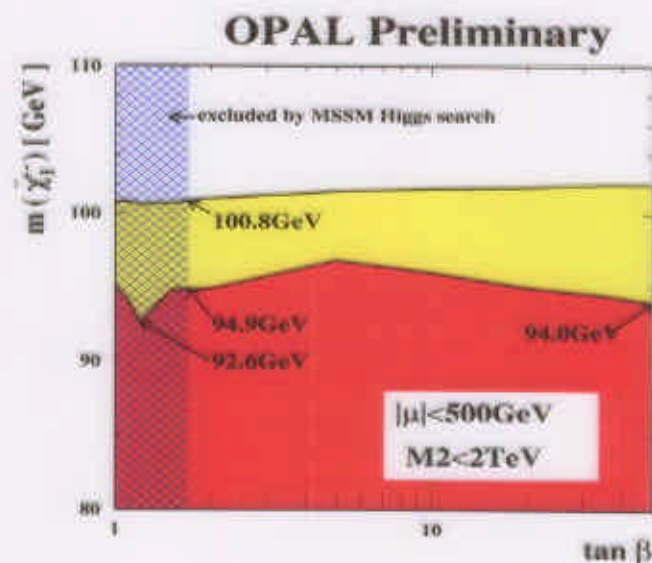
Interpretation ...

 $\Rightarrow$ Mass limits ... valid for any m_0

- Combination of searches for $\tilde{\chi}^\pm$, $\tilde{\chi}^0$, $\tilde{e}$

 $\tilde{\chi}^0$ - LSP mass ... $m_{\tilde{\chi}^0} > 36 - 38 \text{ GeV}$ (... stronger ... using constraint on $\tan\beta$ from Higgs searches)

Chargino ...

 $m_{\tilde{\chi}^\pm} > 90 - 95 \text{ GeV}$ 

Stop / sbottom

Heavy $\tilde{g}$ assumed

⇒ weak decay

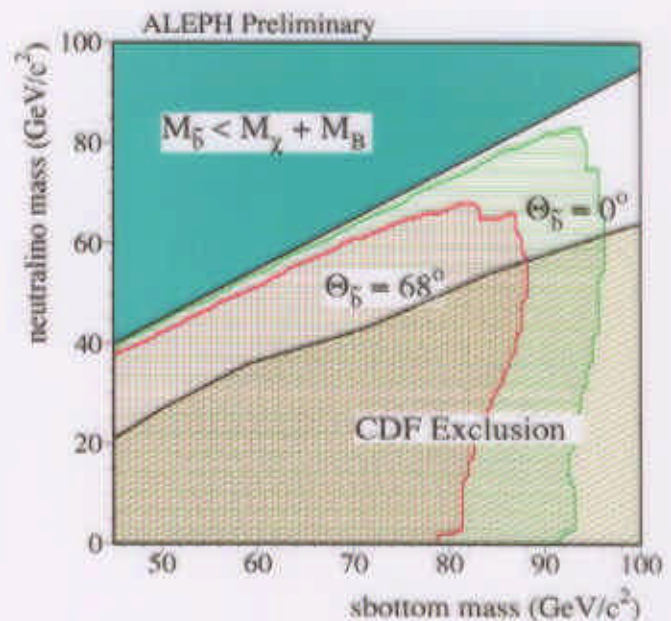
ADLO ... 202 GeV data

(least favourable mixing)

$$\tilde{t} \rightarrow c\tilde{\chi}^0 \dots m_{\tilde{t}} > 95 \text{ GeV}$$

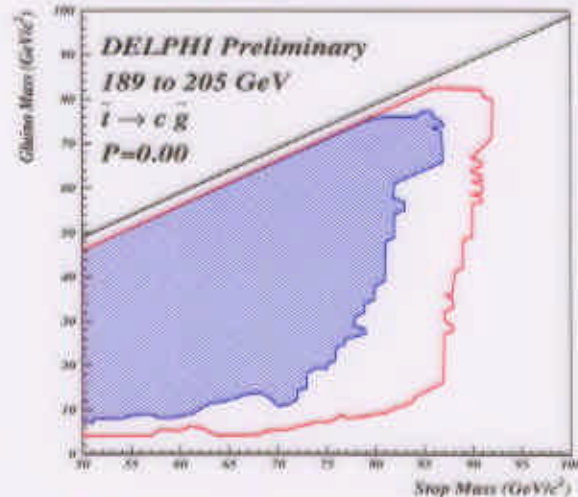
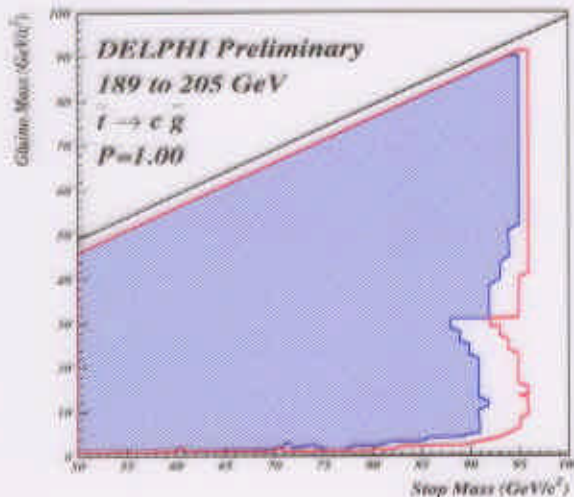
$$\tilde{t} \rightarrow b\tilde{\chi}^\pm \dots m_{\tilde{t}} > 89 \text{ GeV}$$

$$\tilde{b} \rightarrow b\tilde{\chi}^0 \dots m_{\tilde{b}} > 85 \text{ GeV}$$



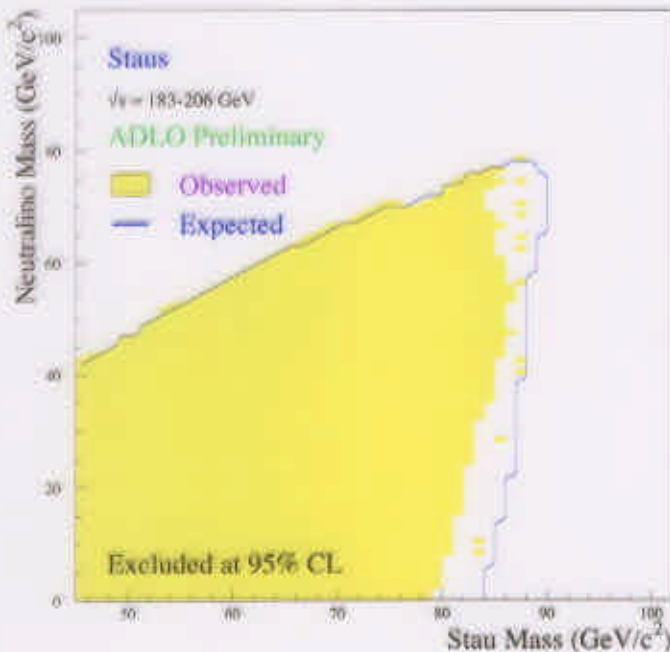
- DELPHI ... Search for $\tilde{t} \rightarrow c\tilde{g}$... assuming light gluino LSP

Gluino fragmentation ⇒ heavy stable hadrons $R^\pm, R^0$



Sleptons

$$e^+e^- \rightarrow \tilde{\ell}^+\tilde{\ell}^- \quad \dots \quad \tilde{\ell}^\pm \rightarrow \ell^\pm \tilde{\chi}_1^0 \quad \dots \quad \ell^+\ell^- + E_{\text{miss}}$$



ADLO ... year 2000 data
 $(\Delta m > 15 \text{ GeV})$

$$m_{\tilde{e}} > 98 \text{ GeV}$$

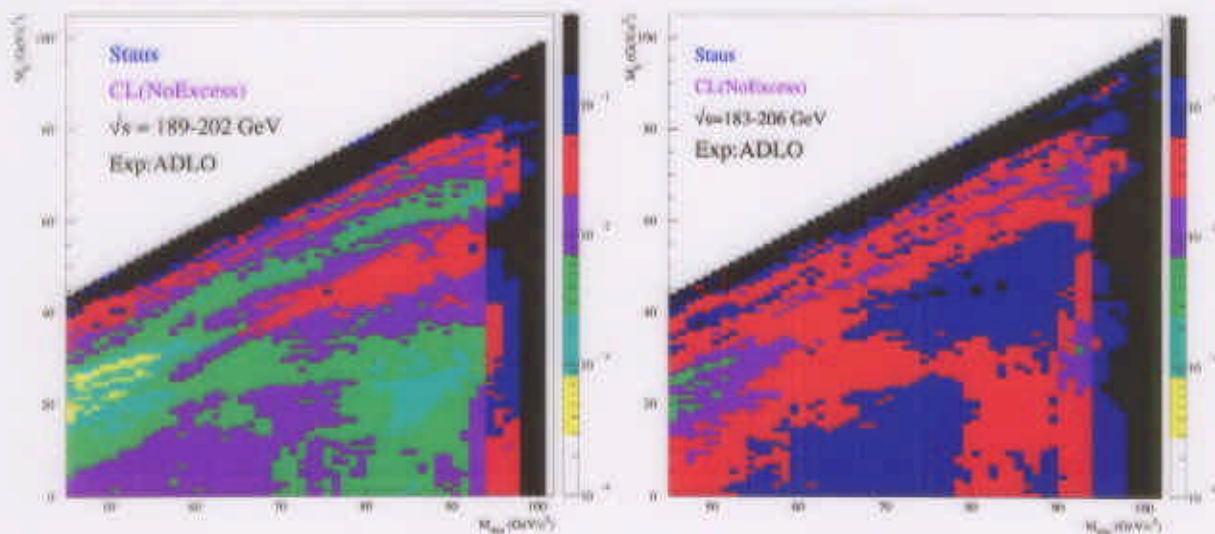
$$m_{\tilde{\mu}} > 94 \text{ GeV}$$

$$m_{\tilde{\tau}} > 79 \text{ GeV}$$

Stau ... signal ? ... slight excess in 189-202 GeV data ... A,D,L,O

CL for 'no signal' ... $\approx 10^{-3}$

ADLO ... Not confirmed by year 2000 data



⇒ Most likely ... statistical fluctuation of the background

Gauge-mediated SUSY breaking (GMSB)

Rev: V. HEDBERG

Mean feature : $m_{\tilde{G}} \dots \mathcal{O}(\text{eV}) \dots \tilde{G}$ is the LSP !

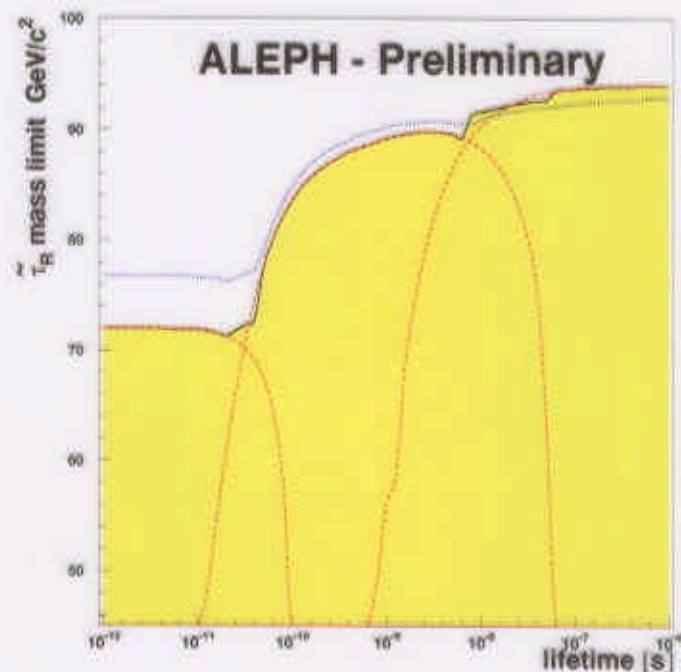
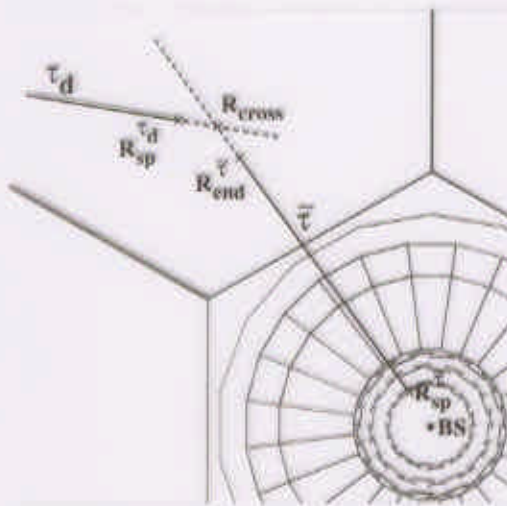
Phenomenology depends on the NLSP ...

- $\tilde{\chi}_1^0 \dots \text{NLSP} \dots \tilde{\chi}_1^0 \rightarrow \gamma \tilde{G} \dots \gamma + E_{\text{miss}}$
- $\tilde{\tau}_R \dots \text{NLSP} \dots \tilde{\tau}_R \rightarrow \tau^\pm \tilde{G} \dots \tau^\pm + E_{\text{miss}}$

$\Rightarrow$ Supplementary exp'tal signature ... good signal 'visibility' !

NLSP lifetime ... arbitrary ... related to $m_{\tilde{G}}$

- Prompt decay ... MSUGRA searches recycled
- Delayed ... new analyses ... non-pointing photons, large-IP tracks, anomalous ionization



(... GMSB)

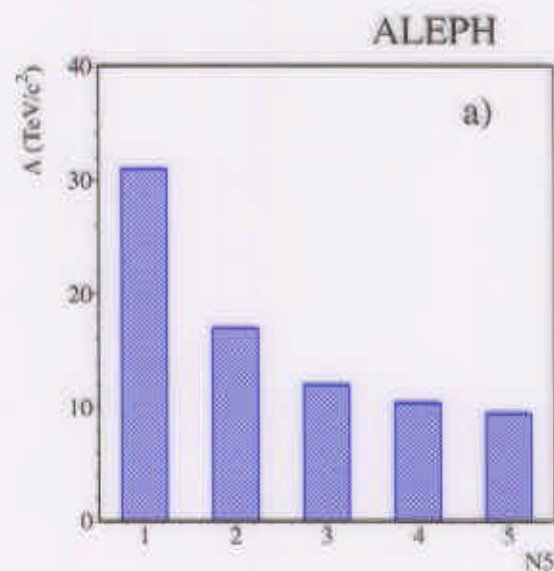
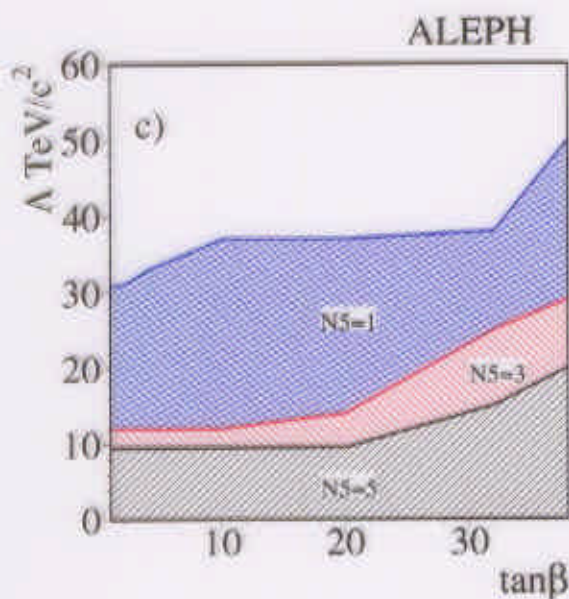
Interpretation in GMSB ...

- Combination of all searches ... **photonic / leptonic**
... **prompt / delayed**

⇒ NLSP mass limits ... $m_{\tilde{\chi}^0} > 95 \text{ GeV}$
 $m_{\tilde{\tau}} > 75 \text{ GeV}$

- Scan over **messenger sector parameters** ... **ALEPH, OPAL**

Scale Λ , Nbr. of SU(5)-multiplets: N_5



⇒ $\Lambda > 30 \text{ TeV} / 10 \text{ TeV}$... for $N_5 = 1 / 5$

$m_{\tilde{G}} > 0.20 \text{ eV} / 0.02 \text{ eV}$

R-parity violation (RPV)

REV: I. FLECK

RPV ... 45 new 'interactions' ... ***L* / *B*** violating !

$$\lambda LL\bar{E} + \lambda' LQ\bar{D} + \lambda'' \bar{U}\bar{D}\bar{D}$$

$$\tilde{\nu} \rightarrow \ell\ell \quad \tilde{q} \rightarrow q\ell \quad \tilde{q} \rightarrow qq$$

$$\tilde{\ell} \rightarrow \ell\nu \quad \tilde{\ell} \rightarrow qq$$

- Proton lifetime, low-E data ... $\lambda, \lambda', \lambda'' < 0.01$

$$(\lambda_{em} = \sqrt{4\pi}\alpha_{em} \approx 0.3)$$

$\Rightarrow$ Associated production and decay mainly via **RPC** couplings

$\Rightarrow$ **RPV** only in last stages of decay !

- If $\tilde{f}$ LSP $\Rightarrow$ 'direct' RPV-decay $\tilde{f} \rightarrow ff'$

- If $\tilde{\chi}^0$ LSP $\Rightarrow$ 'indirect' RPV-decay

$$\tilde{f} \xrightarrow{(RPC)} f\tilde{\chi}^0 \xrightarrow{(RPV)} f(\tilde{\chi}^0 \rightarrow fff)$$

- LSP is unstable !**

- Exp'tal signature ...

Topologies with **many leptons and quark-jets** from LSP decay

... Most are covered at LEP

(... RPV)

RPV searches in e^+e^- ... assume ...

- Only **one coupling** ($\lambda, \lambda', \lambda''$) $\neq 0$ at a time
 - Decay ... within **1 cm**
- $\Rightarrow$ sensitive to couplings $> 10^{-4}/10^{-7}$ (indirect / direct)

Charged sleptons ...

$$m_{\tilde{e}} > 80 \text{ GeV}$$

$$m_{\tilde{\mu}} > 75 \text{ GeV}$$

$$m_{\tilde{\tau}} > 75 \text{ GeV}$$

Stop / sbottom

- $\lambda' LQ\bar{D}$... direct ... $m_{\tilde{t}}, m_{\tilde{b}} > \approx 90 \text{ GeV}$
- $\lambda'' \bar{U}\bar{D}\bar{D}$... indirect ... $m_{\tilde{t}}, m_{\tilde{b}} > \approx 70 \text{ GeV}$

($\Delta m = m - m_{LSP} > 20 \text{ GeV}$, worst case mixing)

Charginos / Neutralinos ... studied separately for $\lambda, \lambda', \lambda'' \neq 0$

Typically ...

$$m_{\tilde{\chi}^\pm} > 100 - 102 \text{ GeV}$$

$$m_{\tilde{\chi}^0} > 36 - 38 \text{ GeV}$$

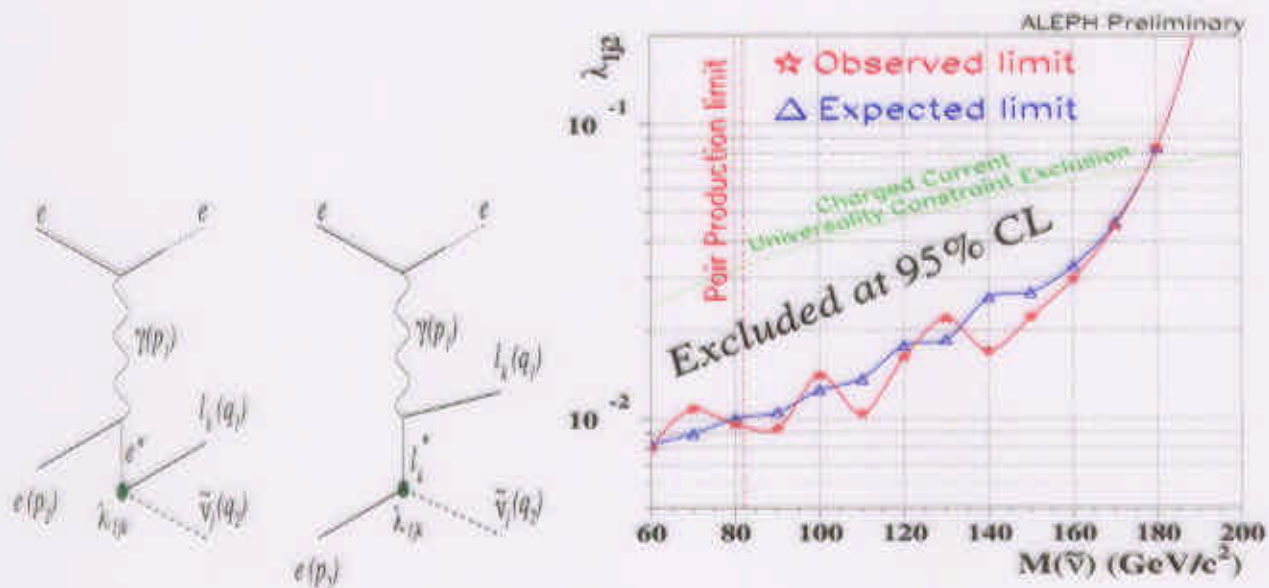
RPV does not “destroy” the RPC limits !

(... RPV)

Sneutrino single production ... $\lambda LL\bar{E}$... Lept. nbr. violating

... extending the searches to $m \approx \sqrt{s}$

- $e^+e^- \rightarrow \tilde{\nu} \rightarrow e^+e^-, \mu^+\mu^-, \tau^+\tau^- \dots$ **A, D, L, O**
- $e^+e^- \rightarrow \tilde{\nu} \rightarrow \tilde{\chi}^0\nu, \tilde{\chi}^0\mu^\pm \dots$ **ALEPH**
- $e\gamma \rightarrow \ell^\pm (\tilde{\nu} \rightarrow e^\pm\mu^\mp) \dots$ **ALEPH**



... Improvement upon the low-E constraints

- Spontaneous breaking of RPV ... bilinear term ϵLH

DELPHI ...

$\tilde{\chi}^\pm \rightarrow \tau^\pm J' \Rightarrow$ *massless Majoron* acoplanar taus

$m_{\tilde{\chi}^\pm} > 95 \text{ GeV} \dots$ (for $m_{\tilde{\nu}} > 300 \text{ GeV}$)

Searches for Higgs bosons

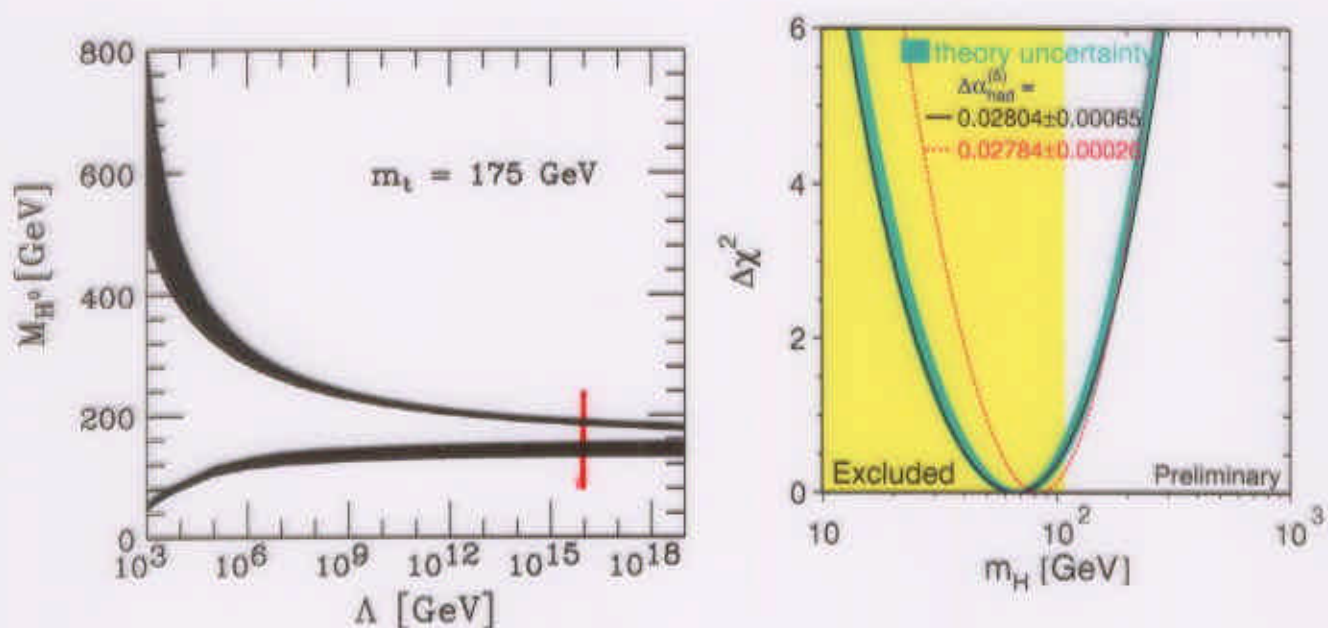
SM Higgs - H_{SM}^0 MSSM - h^0, A^0 2HDM - $H^\pm$

More "exotic" ... $H^0 \rightarrow \gamma\gamma$, 'invisible', ...

ALEPH, DELPHI, L3, OPAL ... incl. year 2000 data

ADLO ... combined up to July 10 !

The SM Higgs boson



- Perturbativity and vacuum-stability up to Λ_{GUT}

$$130 < m_H < 190 \text{ GeV}$$

- Indirect constraints from precision ew measurements ($\log M_H$)

$$m_H = 62_{-39}^{+53} \text{ GeV} \quad m_H < 170 \text{ GeV (95\% CL)}$$

SM Higgs ...

$$e^+e^- \rightarrow Z^0 H^0 \rightarrow b\bar{b}$$

$$\hookrightarrow q\bar{q}, \nu\bar{\nu}, e^+e^-, \mu^+\mu^-, \tau^+\tau^-$$

... more than 90% of 'signal' cross-section

Essential tool ... **b-tagging** (Si- μ vertex detectors)

Analyses ... **A, D, L, O** ... optimized

Procedures to **combine** data ...

... A+D+L+O = **ADLO** ... established

● Testing two hypotheses :

"signal + background" or "SM background only"

● Corresponding confidence levels ... CL_s , CL_b

$$CL_s < 0.05 \quad \Rightarrow \quad m_H \text{ excluded at 95\% CL}$$

$$1 - CL_b < 5.7 \cdot 10^{-7} \quad \Rightarrow \quad 5\sigma \text{ discovery}$$

Including this year's data ... up to July 10 !

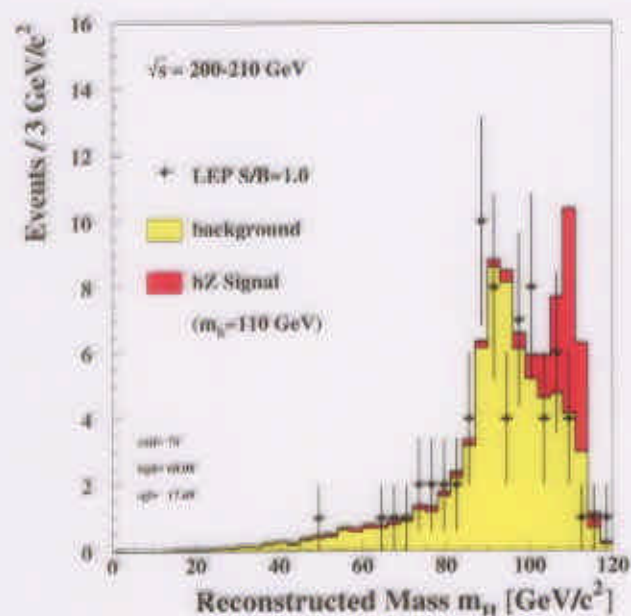
No claim for a signal by any single experiment !

	ALEPH ^(*)	DELPHI	L3	OPAL	ADLO
Mass limit [GeV]	110.8	109.0	107.6	109.5	113.3

(*) ... using its own test statistic

(... SM Higgs)

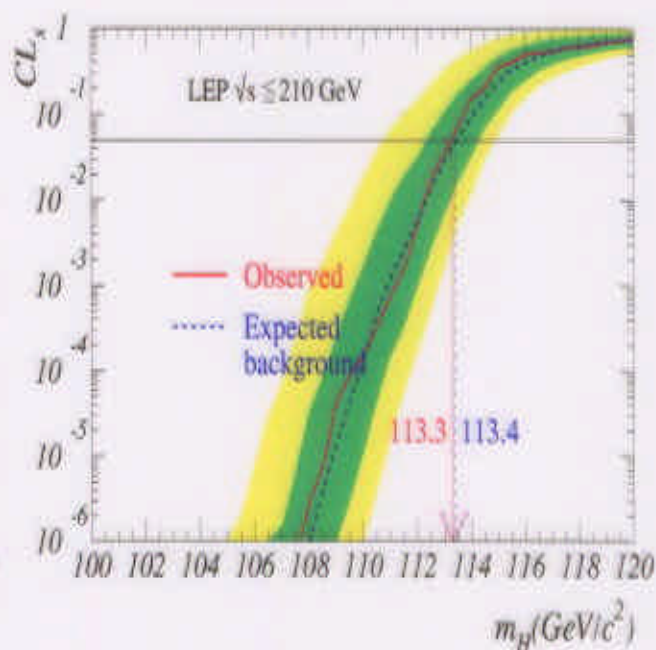
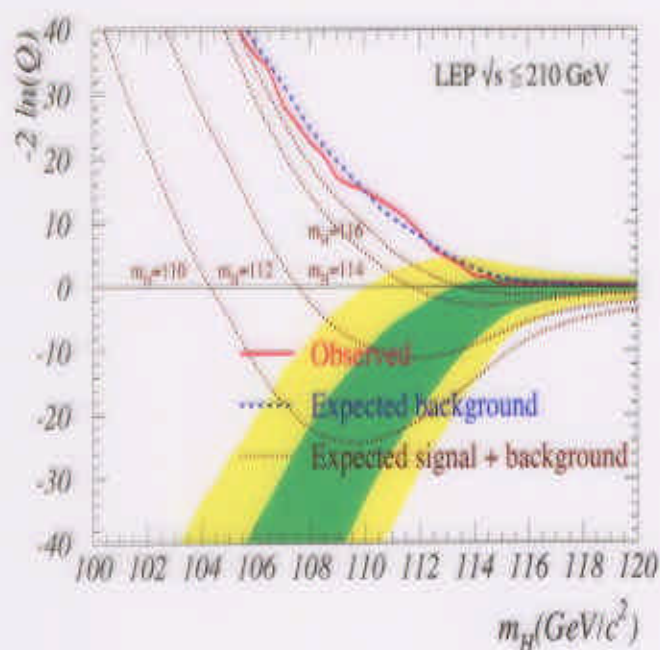
LEP-combined results



Data: 70 events

Bgd: 68.1 expected

Sig (110 GeV): 17.7 expected



Data compatible with SM expectation for **NO HIGGS** !

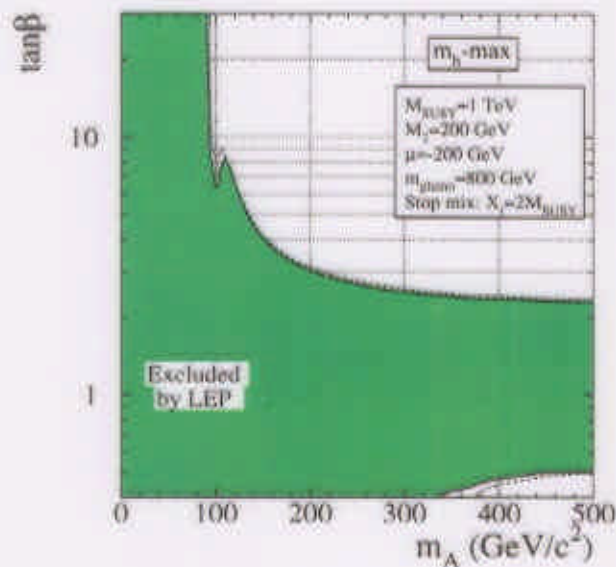
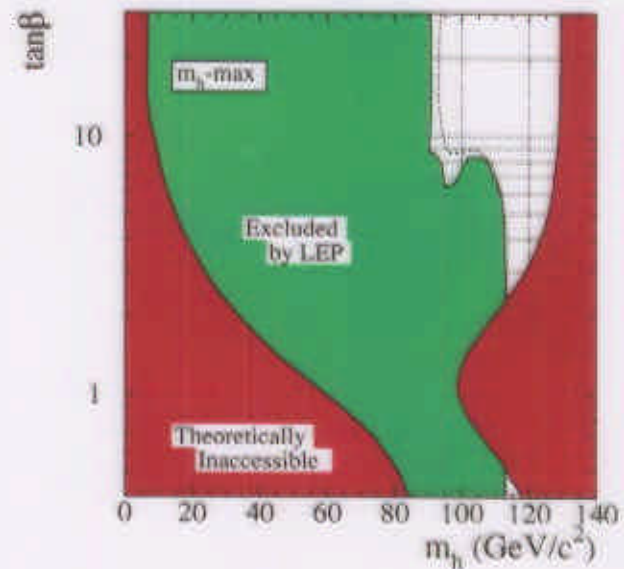
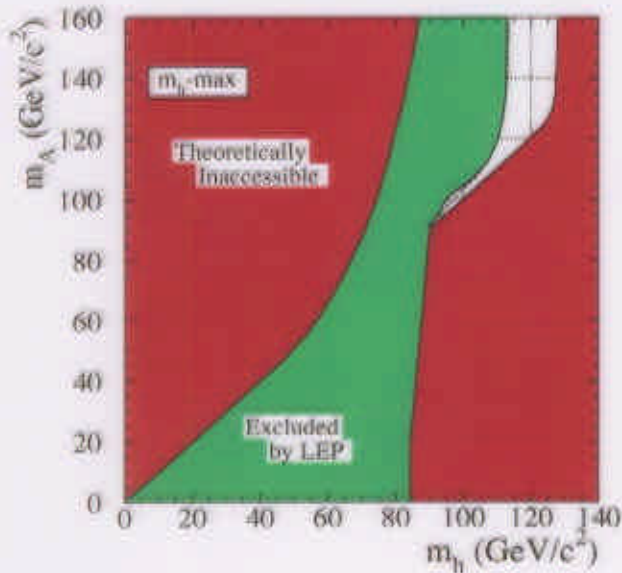
Limit expected ... $m_H > 113.4$ GeV

Limit observed ... $m_H > 113.3$ GeV @ 95% CL

MSSM Higgs bosons

- $\mathcal{H}_1, \mathcal{H}_2 \Rightarrow h^0, H^0, A^0, H^\pm$
 $m_h < 135 \text{ GeV}$
- “Constrained MSSM” ... unification @ Λ_{GUT}
- $e^+e^- \rightarrow h^0 Z^0 \quad \sigma_{hZ} = \sin^2(\beta - \alpha) \sigma_{HZ}^{SM}$
 $e^+e^- \rightarrow h^0 A^0 \quad \sigma_{hA} = \cos^2(\beta - \alpha) \bar{\lambda} \sigma_{HZ}^{SM}$
- “Benchmark” parameter scans ...
 - $\Rightarrow$ No stop mixing
 - $\Rightarrow$ “ m_h -max scenario” ... large mixing,
 maximizes $m_h \Rightarrow$ conservative limits (e.g. $\tan \beta$)

(... MSSM Higgs)

LEP-combined results ...Max- m_h scenarioMass limits at 95% CL ... $m_h, m_A > 90.5 \text{ GeV}$ (any mixing)Exclusion in $\tan\beta$... $0.5 - \approx 2.3$ ($m_{\text{top}} = 175 \text{ GeV}$) $0.7 - 1.9$ (- " - 180 GeV)

Charged Higgs bosons

Two Higgs Doublet Models - Type II ...

“down” fermions couple to $\mathcal{H}_1$

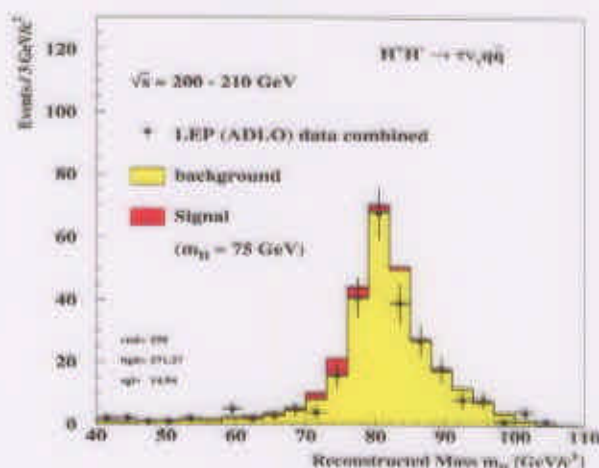
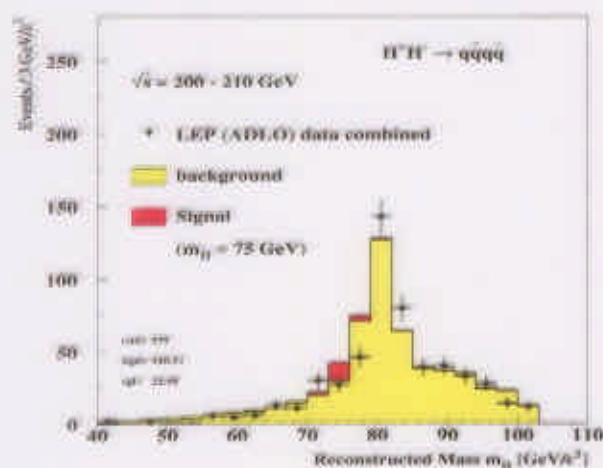
“up” fermions couple to $\mathcal{H}_2$

$$e^+e^- \rightarrow H^+H^-$$

$$\dots Br(H^+ \rightarrow c\bar{s}) + Br(H^+ \rightarrow \tau^+\nu_\tau) = 1$$

$\Rightarrow$ Exclusion limits ... in the $m_{H^\pm}, Br(\tau\nu)$ plane

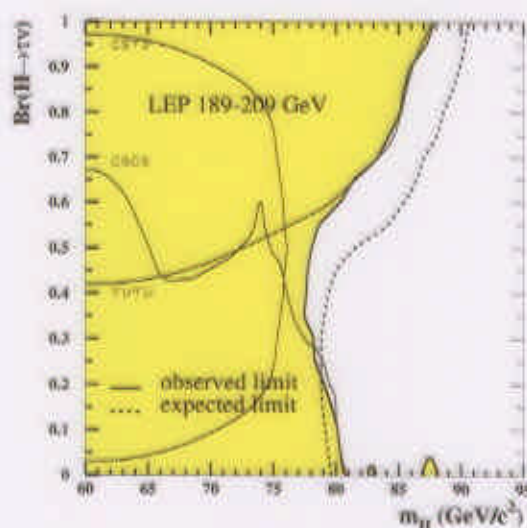
LEP-combined results



Mass limit @ 95% CL

for any $Br(\tau\nu)$...

$$m_{H^\pm} > 77.5 \text{ GeV}$$

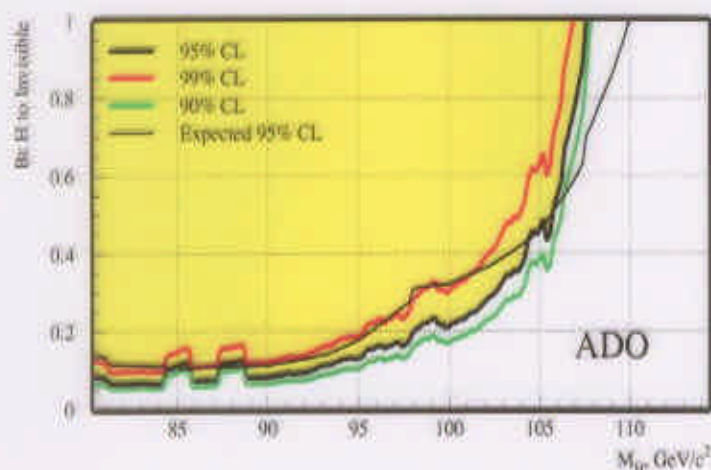


Higgs search "exotica"

- "Invisible" Higgs decay ... e.g. $h^0 \rightarrow \tilde{\chi}^0 \tilde{\chi}^0$

$$e^+e^- \rightarrow Z^0 h^0 \quad m_h : \text{mass recoiling against the } Z^0$$

$$\hookrightarrow q\bar{q}, \ell^+\ell^-$$



$$R_{inv} = BR \times \sigma / \sigma_{HZ}^{SM}$$

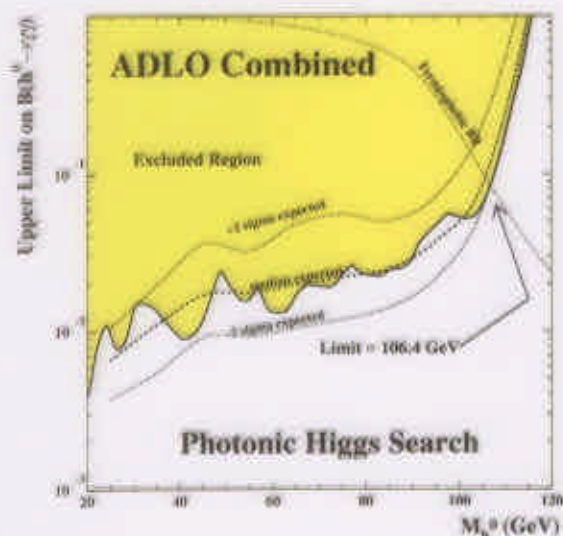
ADO ... $m_h > 107.6 \text{ GeV}$
(for $R_{inv}=1$)

- "Fermiophobia" ... 2HDM - Type I

All fermions couple to $\mathcal{H}_1$... can be "tuned away"

$\Rightarrow$ Enhancement of bosonic decays ... $h^0 \rightarrow \gamma\gamma$

$\Rightarrow$ SM : loop level ... Sensitivity to new loop contributions



"Fermiophobic" limit...

ADLO ... $m_h > 106.4 \text{ GeV}$

... Further Higgs "exotica"

- Anomalous Higgs-gauge couplings (photonic events)

DELPHI, L3

- $H^+ \rightarrow W^+ A^0$... (2HDM - Type I) ... OPAL

- $h^0 \rightarrow W W^*$... (2HDM - Type I) ... L3

- $H^{++} \rightarrow \tau^+ \tau^+$... L-R symmetric models ... OPAL $m > 93 \text{ GeV}$

- Neutral Higgs in 2HDM - Type II ... (no b-tag !)

$\Rightarrow$ q-flavour independent bounds on masses, $\sigma \times Br$

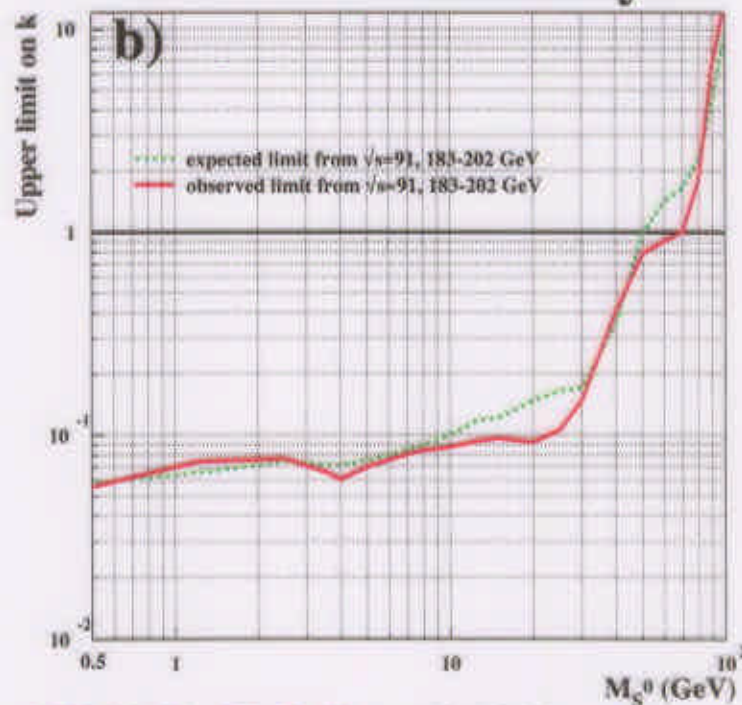
OPAL, DELPHI, L3

$e^+e^- \rightarrow Z S^0$... (scalar) ... OPAL ... LEP1 + LEP2

S^0 decay ... any comb. of hadrons, leptons, photons, invisible ...

unstable or stable

OPAL Preliminary



$$k = \sigma / \sigma_{HZ}^{SM}$$

For $k = 1$... M_{S^0} ... 500 MeV - 70 GeV excluded

Model-independent Indelible result !

SUMMARY

- No Higgs ! $m_H > 113 \text{ GeV}$
- No sign for SUSY ! $m_{LSP} > 38 \text{ GeV}$

MSUGRA, GMSB, RPV investigated ...

bounds are similar

However ...

- Rich harvest of important bounds
- Still work to do ... LEP-combined results
... "Loopholes" ... ?
- More data to come ! ...

Last minute surprise ... ?