Search for New Particles and New Phenomena
Results from e^+e^- Colliders

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... 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

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

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

  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

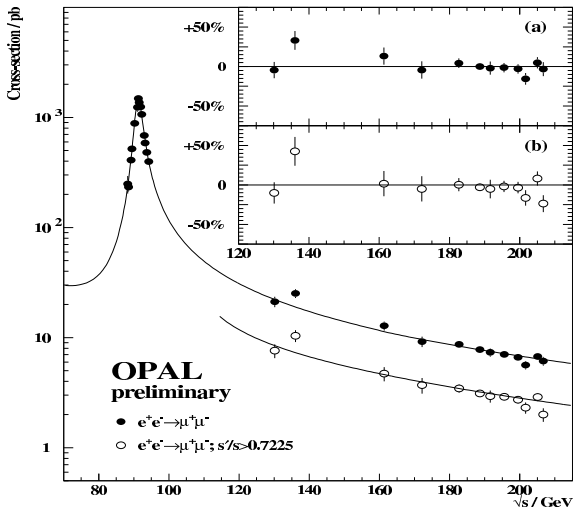
MOST RESULTS ... ... PRELIMINARY !

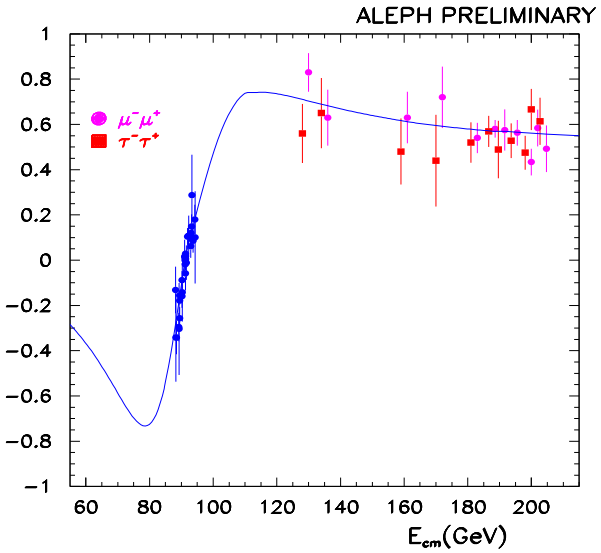
Indirect limits on New Physics

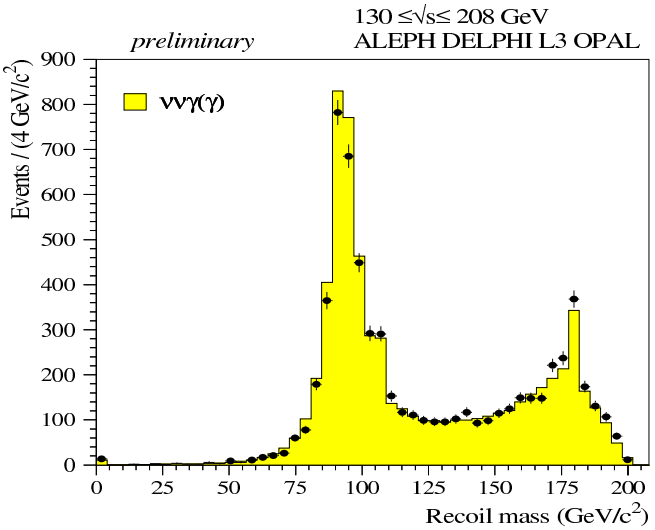
Deviations from SM ? ... **fits to cross-sections**

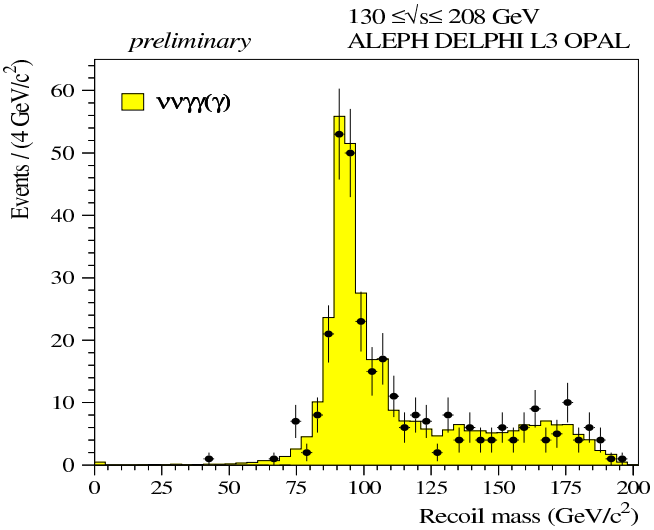
charge asymmetries, angular distributions

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









General agreement with SM ...

$\Rightarrow$ **Little room for 'new physics'**

Four-fermion contact interactions

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

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

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

AA: $\Lambda > 9$ - 15 TeV

(Fermion-sizes ... 2-3 10^{-19} *m)*

- **Sensitivity to s-neutrino or leptoquark exchange**

  $\Rightarrow$ **indirect limits complementing direct searches**

Deviations from QED

$\rm e^+e^- \to \gamma\gamma$ **... almost pure QED process**

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

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

- **Sensitivity to exchange of excited electron**

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

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 $e^+e^- \longrightarrow f\bar{f}$ distributions

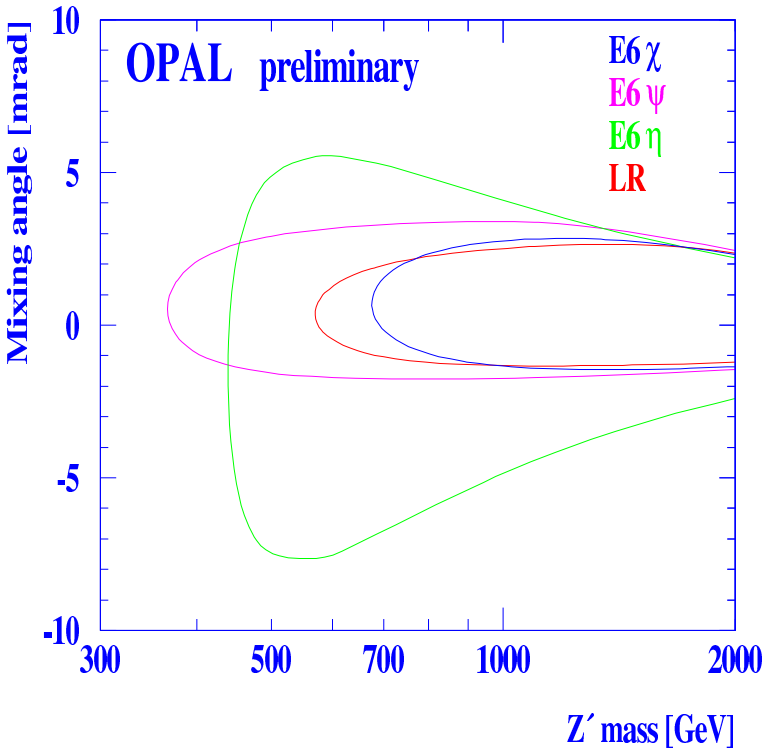
Z-lineshape measurements already exclude large mixing

Limits A, D, L, O

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

A, L ... *Seq-SM Z'*

$M_{Z'}$ >1 TeV



Low-scale Gravity

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 $M_D \approx \Lambda_{ew}$

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

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

  $\delta = 1$ ($R \sim 10^{13}$ cm) **... excluded** ($1/r^2$ **tests)**
  $\delta = 2$ ($R \sim 0.01 - 0.1$ 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 $\quad e^+e^- \to \gamma G \qquad e^+e^- \to (\, Z^0 \to f\bar{f}\,)\, G$

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

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	~0.5 TeV
$M_S >$	1.2 TeV		

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

Direct searches

- **Heavy leptons**
- **Excited leptons**
- **Leptoquarks**
- **Technicolor**
- **Supersymmetry**
- **Higgs**

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

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

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

Most complete recent update: L3 ...

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

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

$L^{\pm} \rightarrow \nu_L W^{\pm}$, $L^0 \rightarrow \ell^{\pm} W^{\pm}$ $(\ell^{\pm} \ldots e^{\pm}, \mu^{\pm}, \tau^{\pm})$

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

$m_{L^0} > 89.0 - 99.5$ GeV *(Dirac)*

$m_{L^0} > 79.6 - 85.7$ GeV *(Majorana)*

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

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

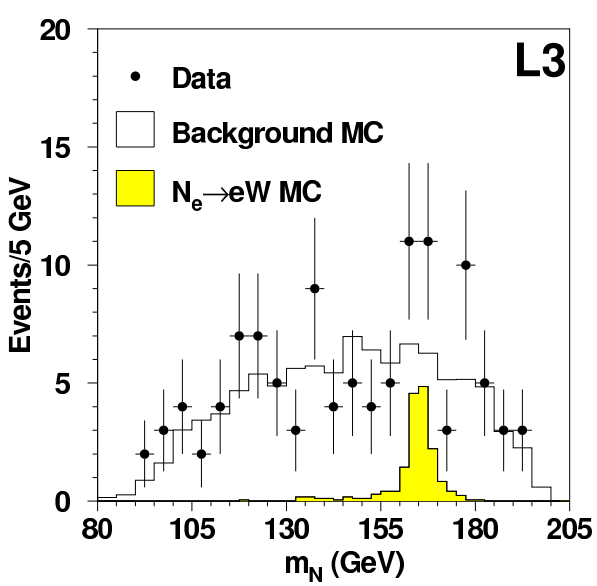
  Production ... by mixing with associated isodoublet neutrino

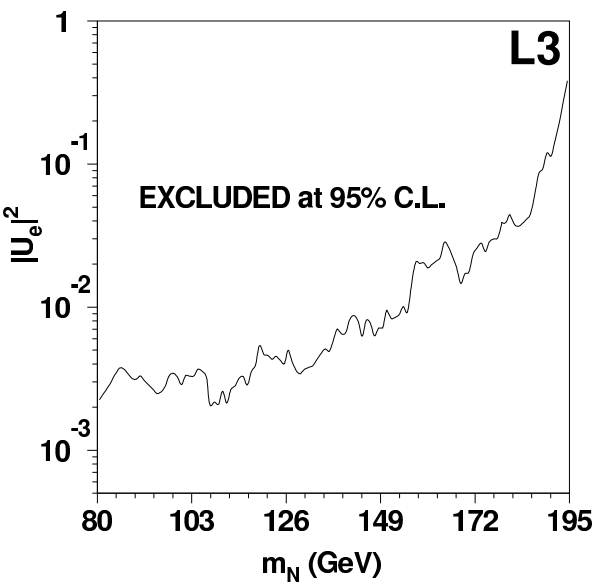
  LEP1, low-E ... mixing amplitude $U_\ell < 0.1$

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

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

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





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

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

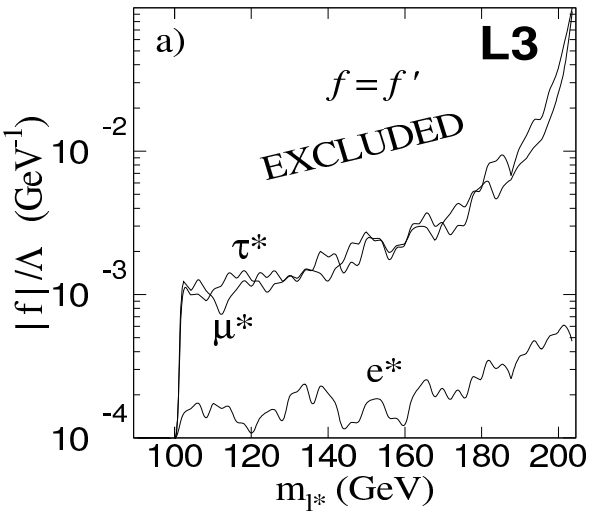
$$\mathcal{L}_{\ell^*\ell} = \frac{1}{2\Lambda}\bar{\ell}^*\sigma^{\mu\nu}[f g \frac{\tau}{2}\mathbf{W}_{\mu\nu} + f' g' \frac{Y}{2}B_{\mu\nu}]\ell_L$$

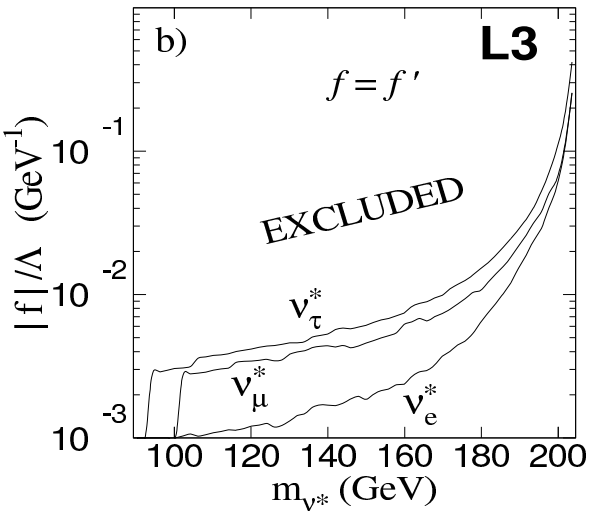
$f,\ f'$ **... control radiative / weak decays**

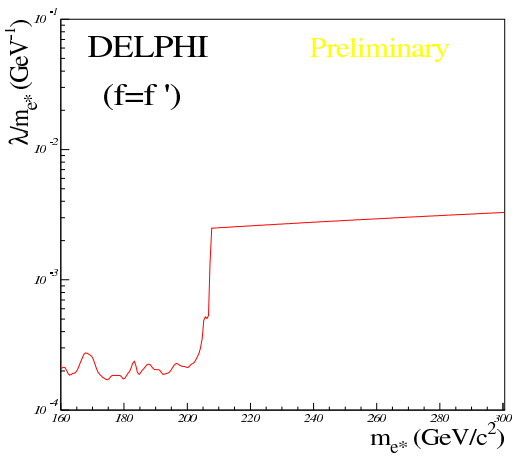
$$\ell^*(\nu^*) \rightarrow \quad \ell(\nu)\gamma,\ \ \nu(\ell)W$$

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

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







$\Leftarrow$

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

Leptoquarks L_q

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

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

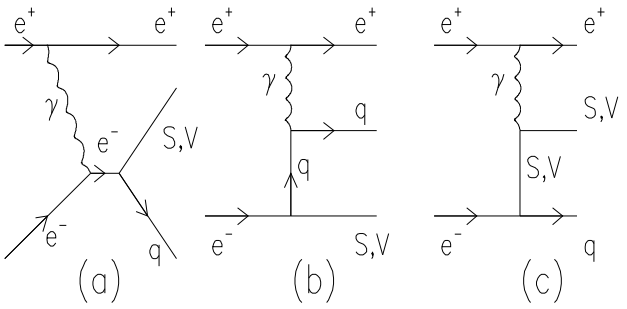
  OPAL ... update

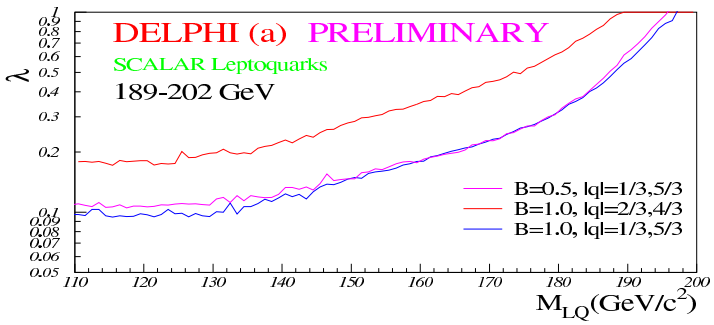
- **Single-production**

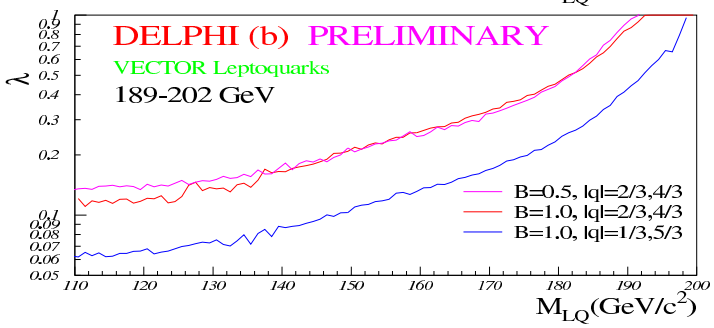
  $e^+e^- \rightarrow eqL_q$

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

  A,D,L,O







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

$m_{L_q} >$ 150 - 185 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 $\tilde{V}_0$ leptoquark of mass $>\approx$ 300 GeV !

Technicolor

- Alternative to Higgs mechanism to generate M_W , M_Z
- New, very strong interaction ... $\Lambda_{TC} >> \Lambda_{QCD}$
- '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

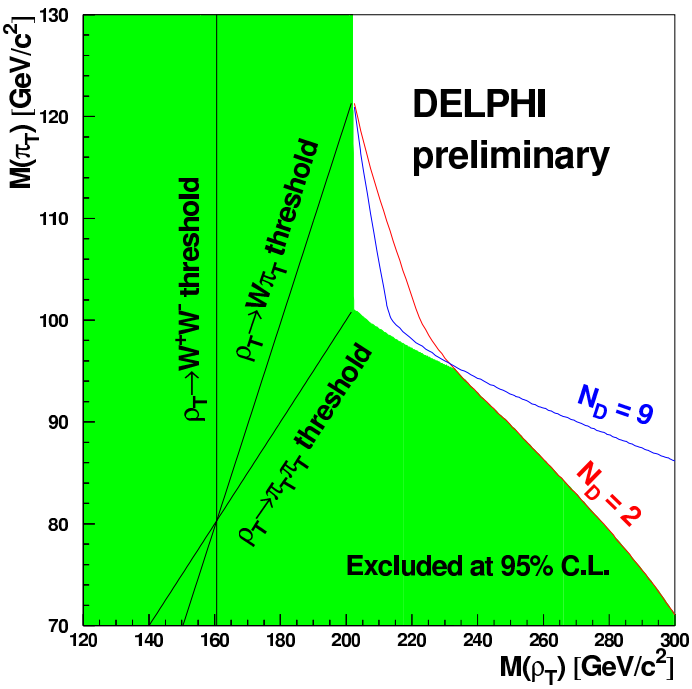
  (Tevatron limits $m >\approx$ 200 GeV)

L3, Delphi ...

$$e^+e^- \rightarrow \pi_T^+\pi_T^-,\ \gamma\pi_T^0,\ \gamma\pi_T^{0\prime},\ W_L\pi_T,\ f\bar{f}, W_LW_L$$
$$\rho_T^{(*)},\ \omega_T^{(*)}$$

Scan of the TC param. space ...

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

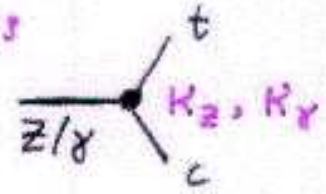


SINGLE TOP PRODUCTION @ LEP

REV: V. OBRAZTSOV

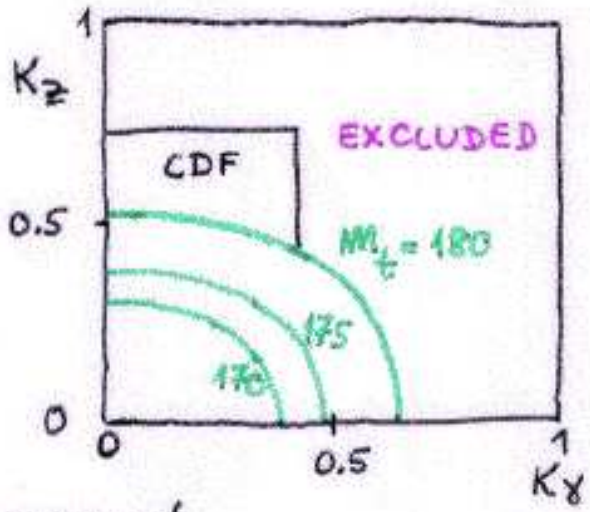
- FOR $\sqrt{s} > 183$ GEV ... $e^+e^- \to t\bar{c}$ $(t\bar{u})$
  kin. possible !

- FCNC ... strongly suppressed in SM
  $\sigma \leq 10^{-3}$ fb
  ⇒ 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 :
  $\sigma < 90$ fb (95 % CL) $\langle E_{cm} \rangle = 194$ GeV



⇒ improvement upon CDF for κ_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 $MSUGRA$	Gauge-mediated $GMSB$
Heavy gravitino ... decoupled	Light gravitino ... $M_{\tilde{G}} \sim \mathcal{O}$(eV)
$\tilde{\chi}^0$ ... LSP ... (or $\tilde{\tau}$)	$\tilde{\mathrm{G}}$ ... LSP
	! NLSP ! ... $\tilde{\chi}^0 \to \gamma\tilde{\mathrm{G}}$ or $\tilde{\ell} \to \ell\tilde{\mathrm{G}}$

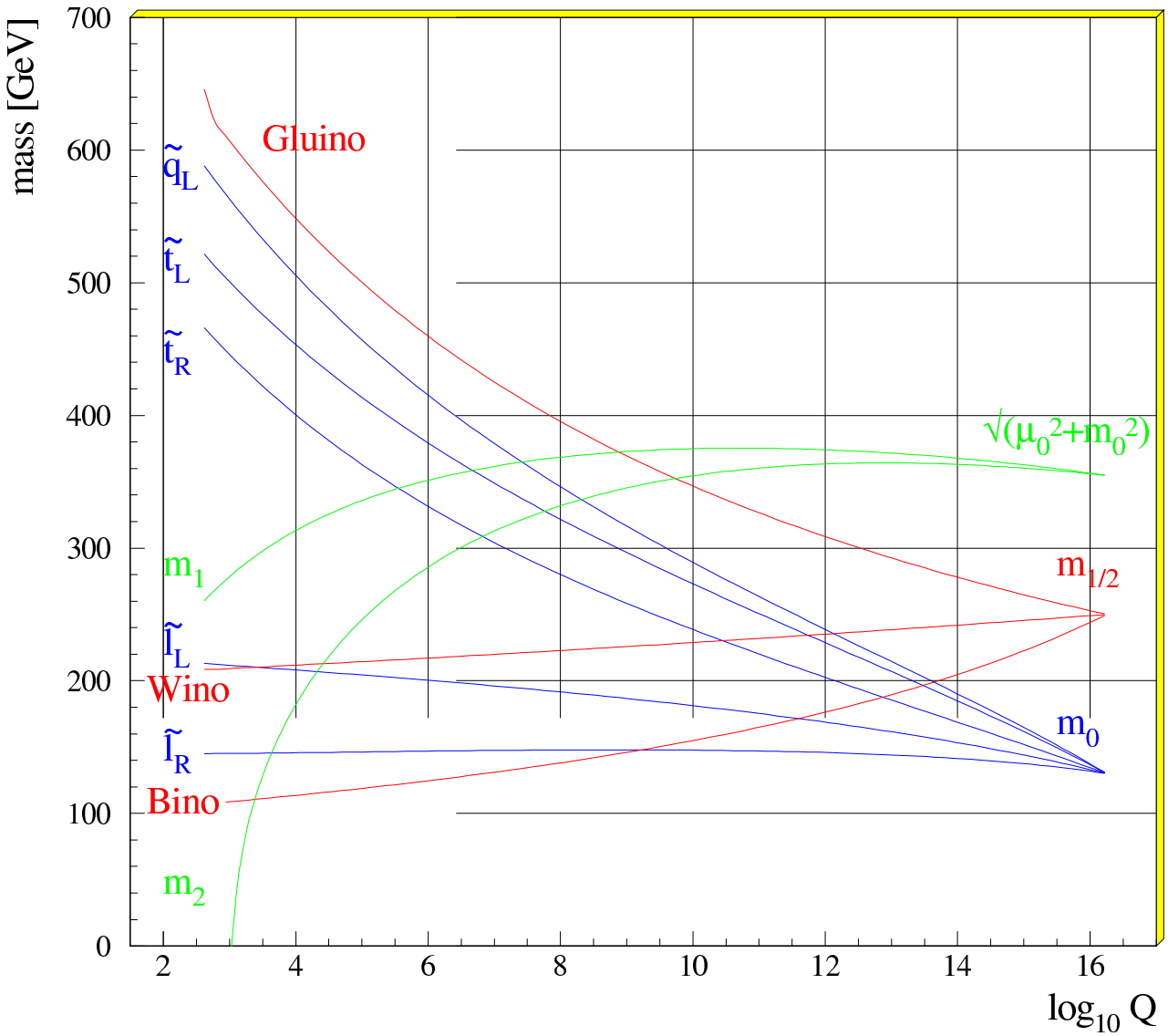
R-parity : $P_R = (-1)^{3B+L+2s}$

- Conserved ... RPC

  LSP is stable ... $\tilde{\chi}^0$ "dark matter" candidate

- Violated ... RPV

  LSP unstable ... $\longrightarrow \ell^{\pm}$, q ... No "dark matter" candidate



EW scale $\Leftarrow$ **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

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

$\Rightarrow$ **interferences ...**

Searches ... interpreted in MSUGRA

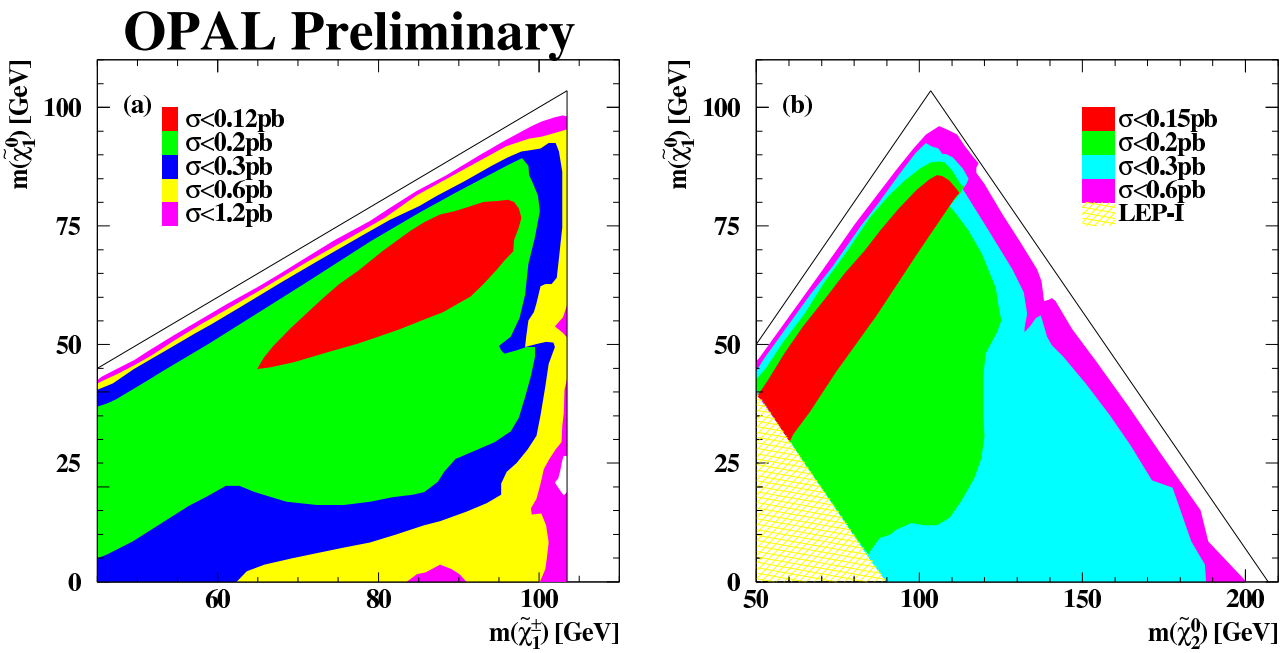
A, D, L, O have updated ... year 2000 data

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

- Small $\Delta m = m - m_{LSP}$ < 10 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

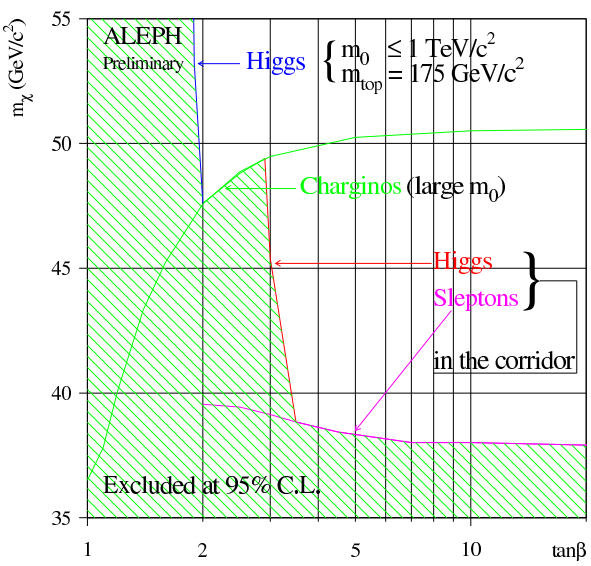
$e^+e^- \to \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \to \tilde{\chi}_1^0 W^\mp$	$q\bar{q}\, q\bar{q}$ + E_{miss}
$\hookrightarrow \tilde{\chi}_1^0 W^\pm$	$\ell^\pm q\bar{q}$ + E_{miss}
$e^+e^- \to \tilde{\chi}_2^0 \tilde{\chi}_1^0$	$q\bar{q}$ + E_{miss}
$\hookrightarrow \tilde{\chi}_1^0 Z^0$	$\ell^+\ell^-$ + E_{miss}

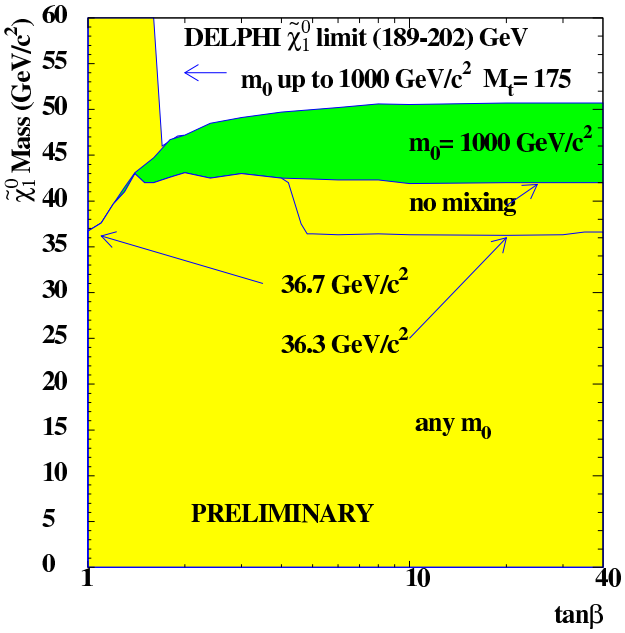


Interpretation ...

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

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



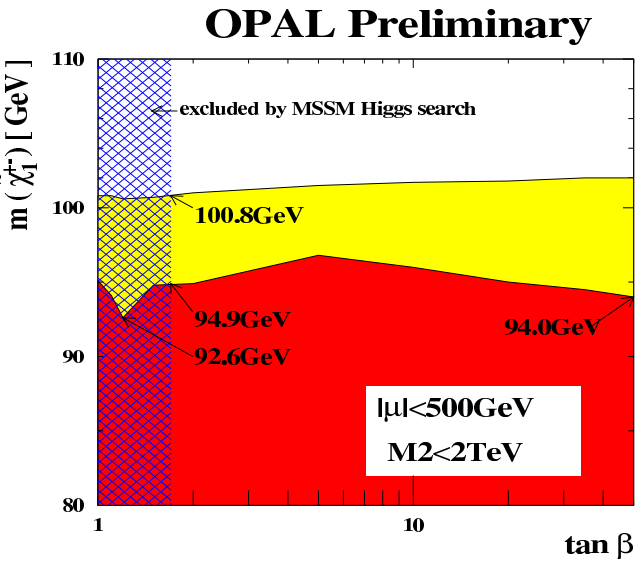


$\tilde{\chi}^0$ - LSP mass ... $m_{\tilde{\chi}^0} > 36$ - 38 GeV

(... stonger ... using constraint on $\tan\beta$ from Higgs searches)

Chargino ...

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



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Heavy $\tilde{g}$ assumed

$\Rightarrow$ **weak decay**

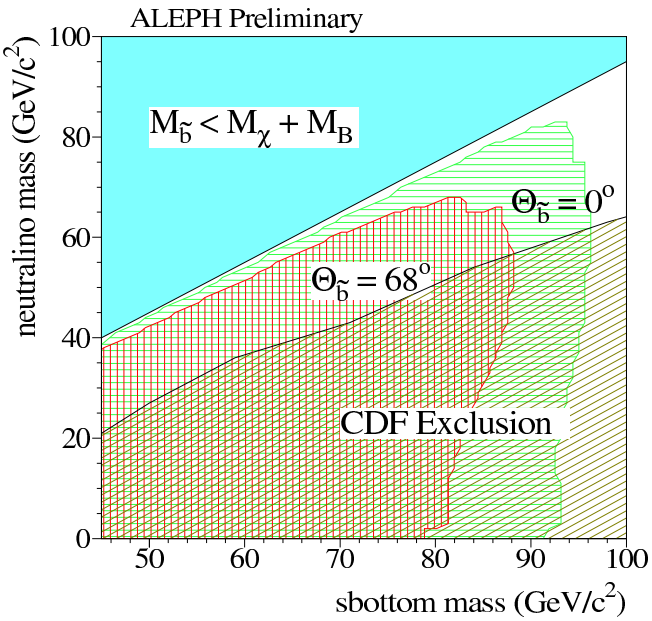
ADLO ... 202 GeV data

(least favourable mixing)

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

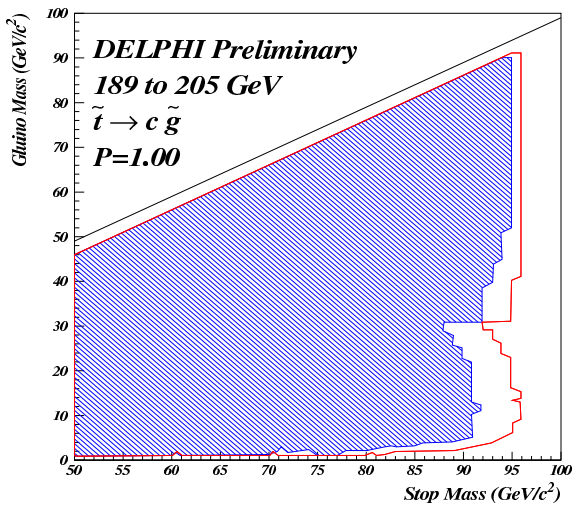
$\tilde{t} \rightarrow b\tilde{\chi}^{\pm}$ ...$m_{\tilde{t}} > 89$ GeV

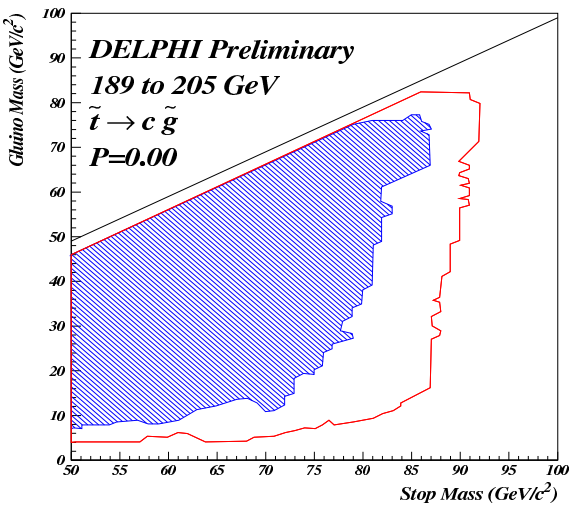
$\tilde{b} \rightarrow b\tilde{\chi}^0$ ... $m_{\tilde{b}} > 85$ GeV



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

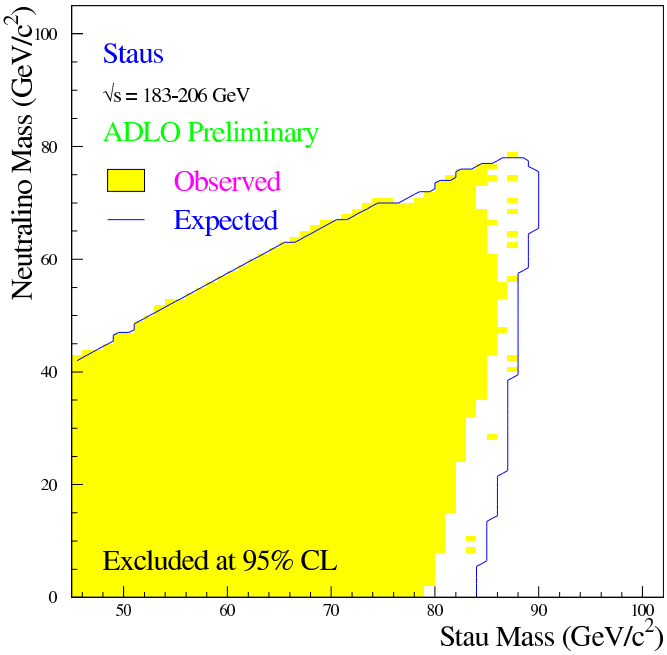
  Gluino fragmentation $\Rightarrow$ heavy stable hadrons $R^{\pm}$, R^0





Sleptons

$e^+e^- \to \tilde{\ell}^+\tilde{\ell}^-$ ... $\tilde{\ell}^\pm \to \ell^\pm \tilde{\chi}_1^0$ ... $\ell^+\ell^- + E_{miss}$



ADLO ... year 2000 data

($\Delta m > 15$ GeV)

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

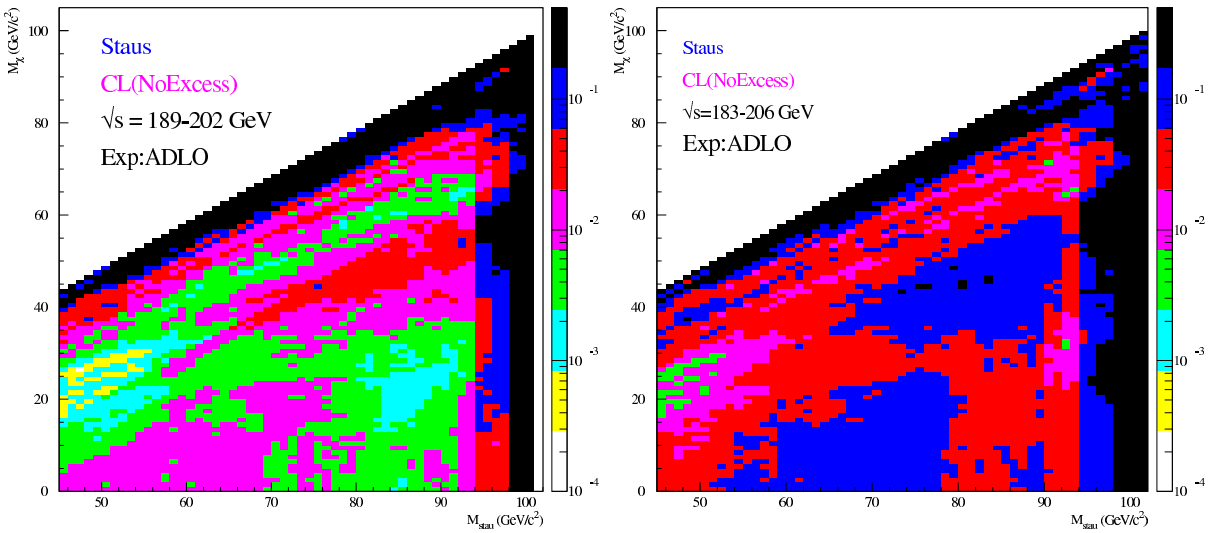
$m_{\tilde{\mu}} > 94$ GeV

$m_{\tilde{\tau}} > 79$ 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)

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

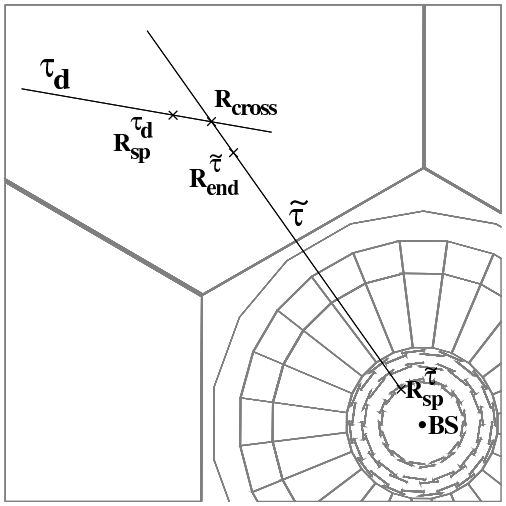
Phenomenology depends on the NLSP ...

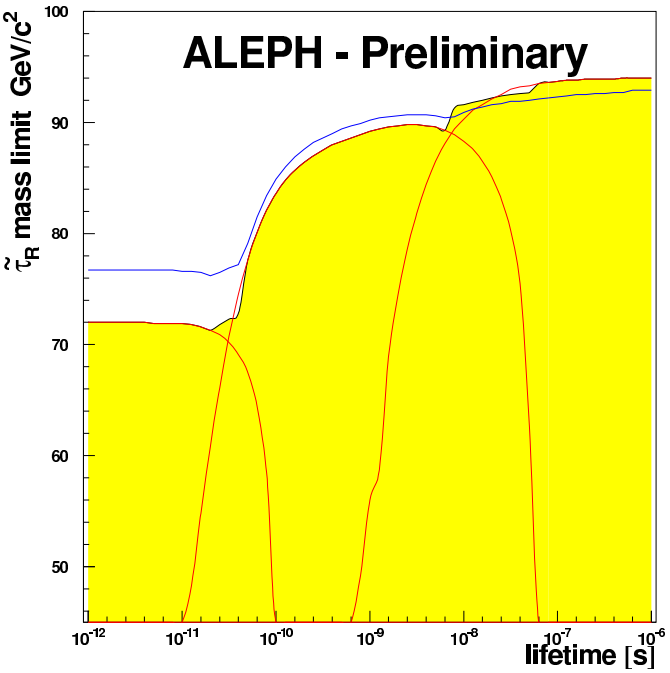
- $\tilde{\chi}_1^0$ ... NLSP ... $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$ ... $\gamma + E_{miss}$
- $\tilde{\tau}_R$ ... NLSP ... $\tilde{\tau}_R \rightarrow \tau^{\pm}\tilde{G}$ ... $\tau^{\pm} + E_{miss}$

$\Rightarrow$ 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





Interpretation in GMSB ...

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

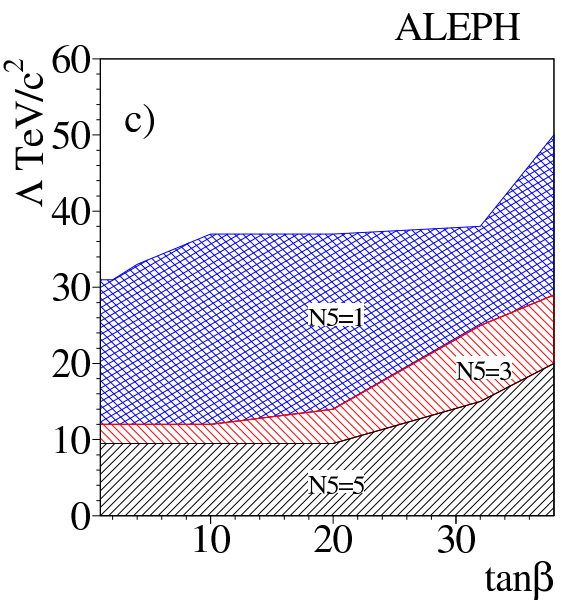
  ... prompt / delayed

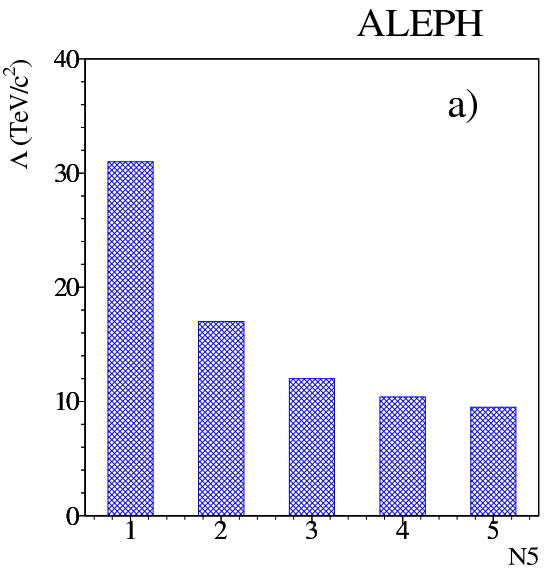
$\Rightarrow$ **NLSP mass limits** ... $m_{\tilde{\chi}^0} > 95$ GeV

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

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

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





$\Rightarrow$ $\Lambda > 30$ TeV / 10 TeV ... for N_5 = 1 / 5

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

R-parity violation (RPV)

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

$\lambda\, LL\bar{E}$	+	$\lambda'\, LQ\bar{D}$	+	$\lambda''\, \bar{U}\bar{D}\bar{D}$
$\tilde{\nu} \to \ell\ell$		$\tilde{q} \to q\ell$		$\tilde{q} \to qq$
$\tilde{\ell} \to \ell\nu$		$\tilde{\ell} \to qq$		

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

  $\tilde{f} \to f\tilde{\chi}^0 \to f(\tilde{\chi}^0 \to f f f)$

  (RPC) *(RPV)*

- **LSP is unstable !**
- **Exp'tal signature ...**

  Topologies with many leptons and quark-jets from LSP decay

... Most are covered at LEP

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

- Only one coupling (λ, λ', λ") $\neq 0$ at a time
- Decay ... within 1 cm

$\Rightarrow$ sensitive to couplings $> 10^{-4}/10^{-7}$ (indirect / direct)

Charged sleptons ...

$m_{\tilde{e}} > 80$ GeV
$m_{\tilde{\mu}} > 75$ GeV
$m_{\tilde{\tau}} > 75$ GeV

Stop / sbottom

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

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

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

Typically ...

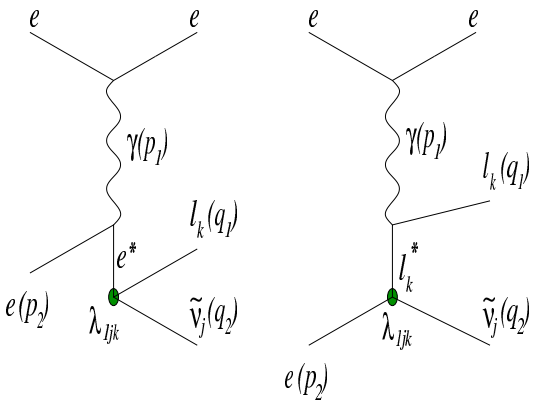
$m_{\tilde{\chi}^\pm} > 100$ -102 GeV
$m_{\tilde{\chi}^0} > 36$ - 38 GeV

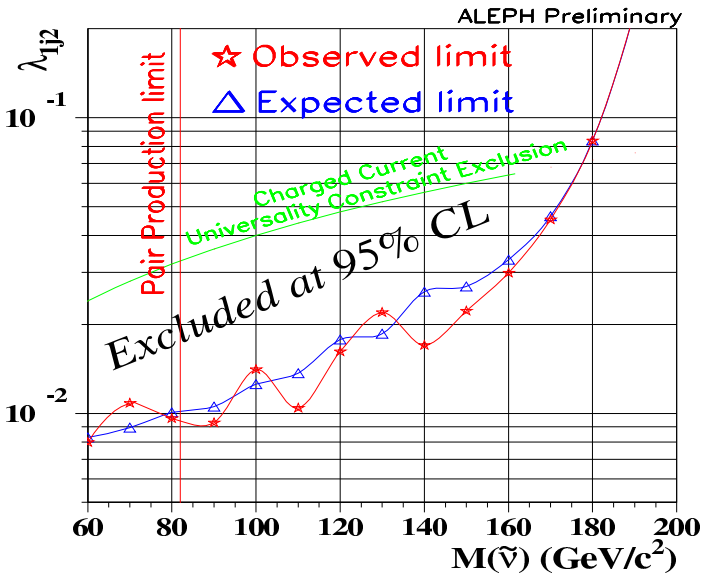
RPV does not "destroy" the RPC limits !

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

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

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





... Impovement upon the low-E constraints

- **Spontaneous breaking of RPV** ... bilinear term ϵLH

  DELPHI ...

  $\tilde{\chi}^\pm \rightarrow \tau^\pm J \Rightarrow$ acoplanar taus

  $m^\pm_{\tilde{\chi}} > 95$ GeV... (for $m_{\tilde{\nu}} > 300$ GeV)

Searches for Higgs bosons

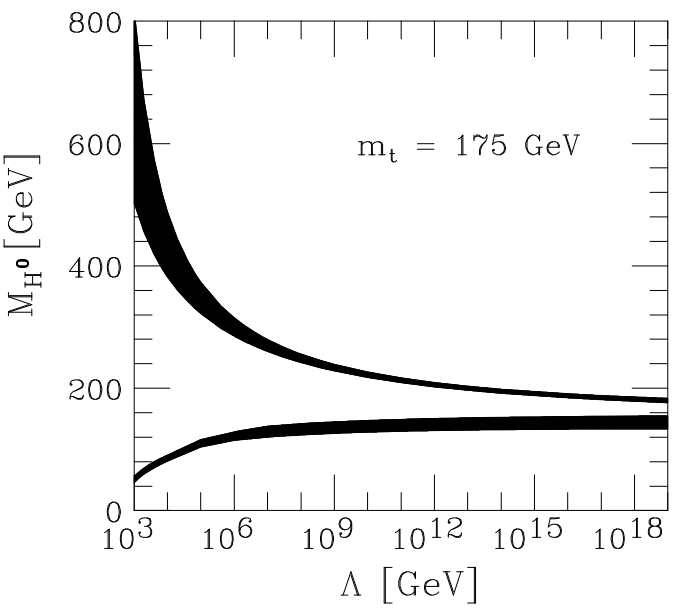
SM Higgs - H^0_{SM} MSSM - h^0, A^0 2HDM - $H^\pm$

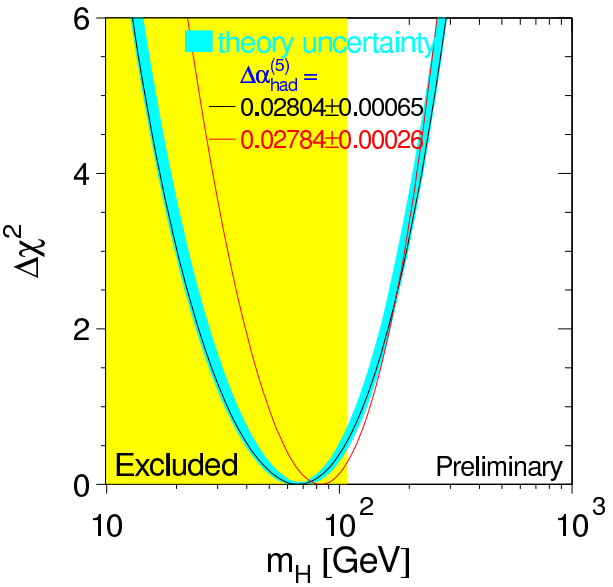
More "exotic" ... $H^0 \to \gamma\gamma$, 'invisible' , ...

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}

  $130 < m_H < 190$ GeV

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

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

SM Higgs ...

$$e^+e^- \to Z^0H^0 \to b\bar{b}$$
$$\hookrightarrow q\bar{q},\ \nu\bar{\nu},\ e^+e^-,\ \mu^+\mu^-,\ \tau^+\tau^-$$

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

Essential tool ... b-tagging **(Si-μvertex 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

  $CL_s < 0.05 \quad \Rightarrow \quad m_H$ **excluded at 95% CL**

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

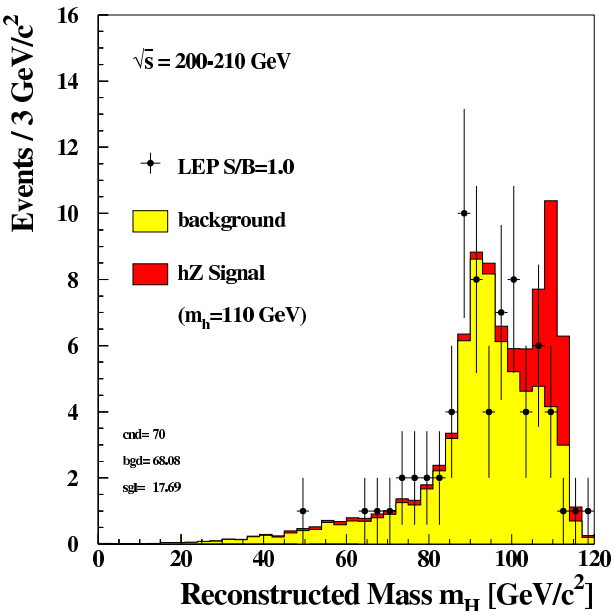
Including this year's data ... up to July 10 !

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*

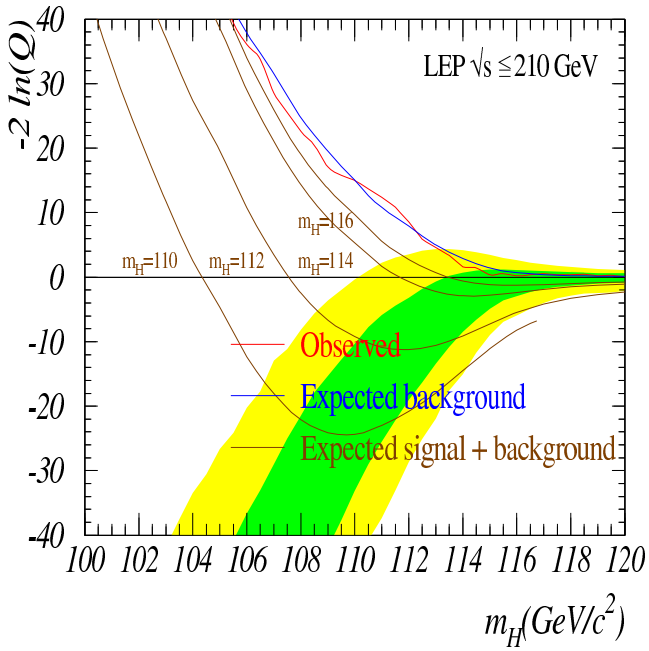
LEP-combined results

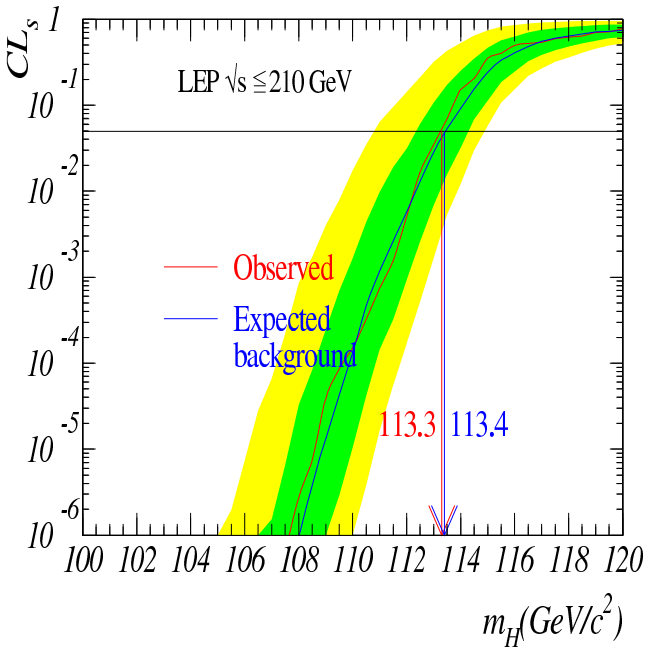


Data: 70 events

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

- $\mathcal{H}_1$, $\mathcal{H}_2$ $\Rightarrow$ $\mathrm{h^0, H^0, A^0, H^{\pm}}$

  $m_h < 135$ GeV

- " Constrained MSSM " ... unification @ Λ_{GUT}

- $\mathrm{e^+e^- \to h^0 Z^0}$ $\quad \sigma_{hZ} = \sin^2(\beta - \alpha)\ \sigma_{HZ}^{SM}$

  $\mathrm{e^+e^- \to h^0 A^0}$ $\quad \sigma_{hA} = \cos^2(\beta - \alpha)\ \bar{\lambda}\ \sigma_{HZ}^{SM}$

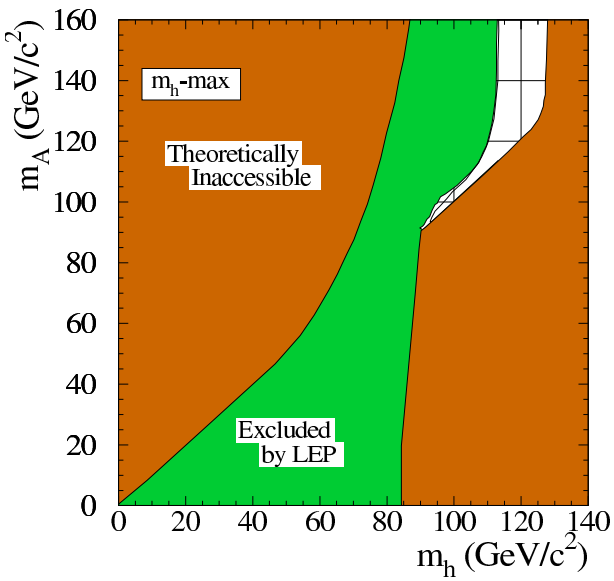
- "Benchmark" parameter scans ...

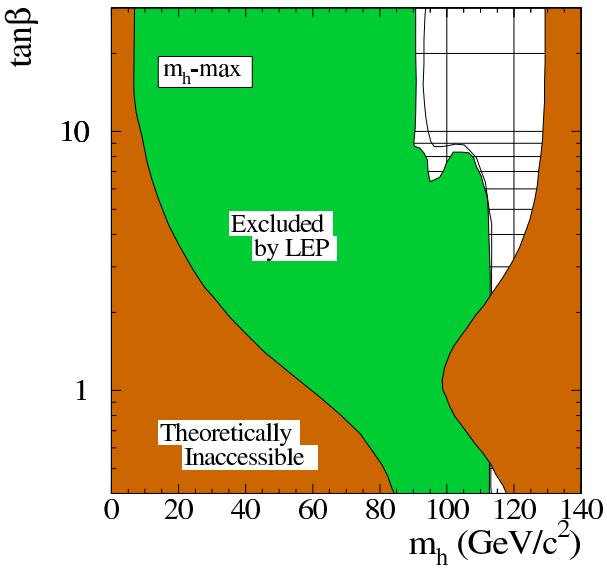
  $\Rightarrow$ No stop mixing

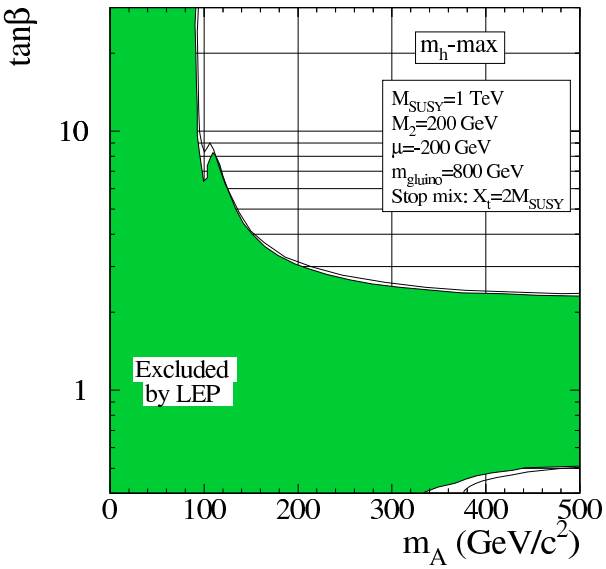
  $\Rightarrow$ "m_h-max scenario" ... large mixing,

  maximizes m_h $\Rightarrow$ conservative limits (e.g.$\tan\beta$)

LEP-combined results ... Max-m_h scenario







Mass limits at 95% CL ... m_h , m_A > 90.5 GeV (any mixing)

Exclusion in tan β ... 0.5 - $\approx$ 2.3 (m_{top} =175 GeV)

Charged Higgs bosons

Two Higgs Doublet Models - Type II ...

"down" fermions couple to $\mathcal{H}_1$

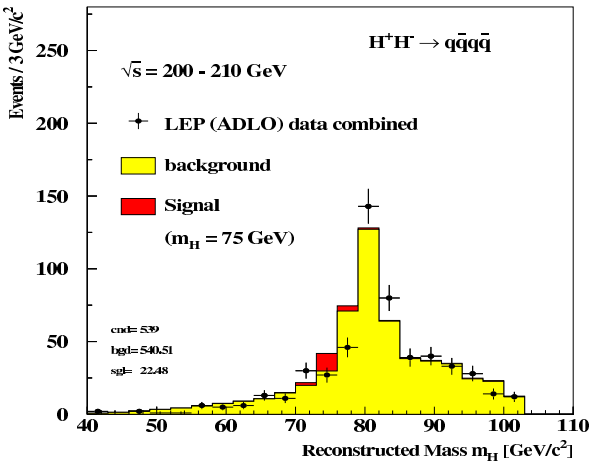
"up" fermions couple to $\mathcal{H}_2$

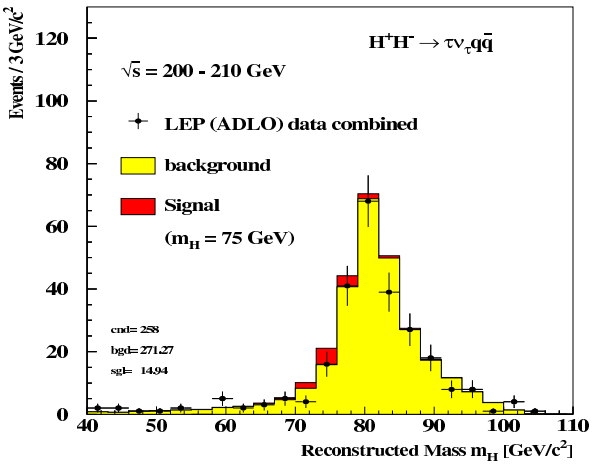
$e^+e^- \rightarrow H^+H^-$

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

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

LEP-combined results

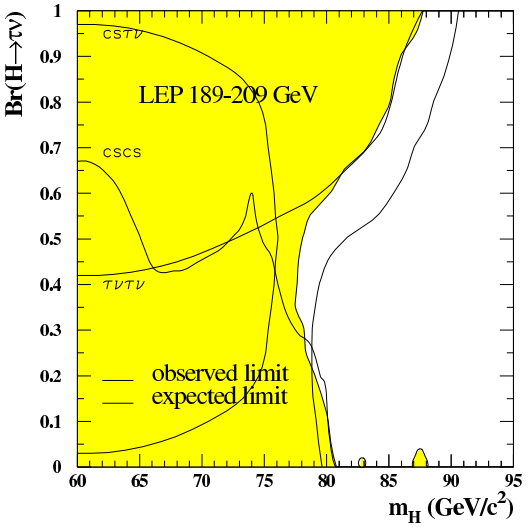




Mass limit @ 95% CL

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

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

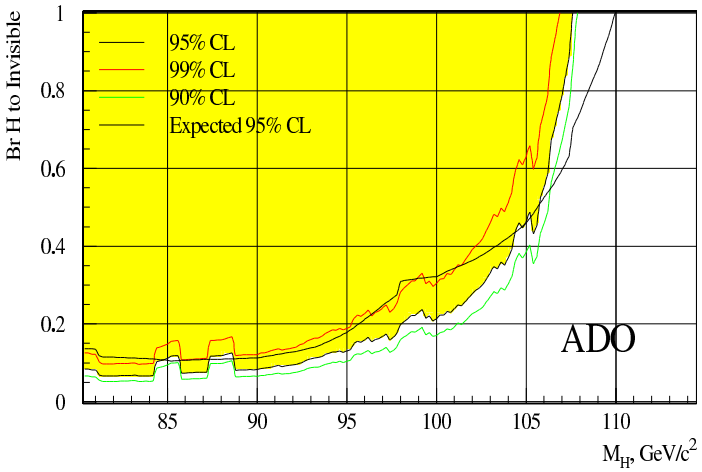


Higgs search "exotica"

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

$e^+e^- \to Z^0\, h^0$ $\quad\quad$ m_h : **mass recoiling against the** Z^0

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



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

ADO ... $m_h > 107.6$ **GeV**

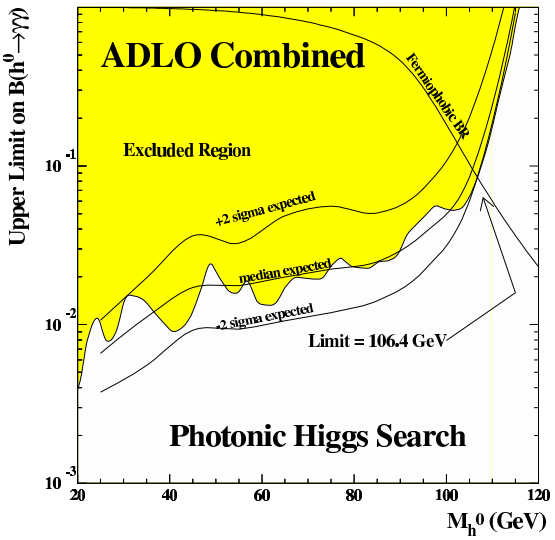
(for R_{inv}**=1)**

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

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

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

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



"Fermiophobic" limit...

ADLO ... $m_h > 106.4$ **GeV**

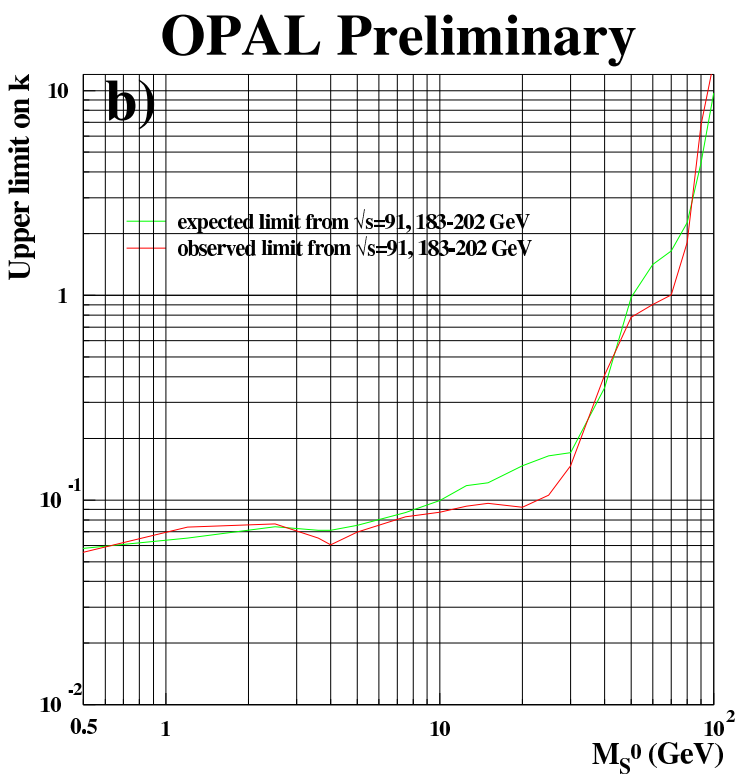
... Further Higgs "exotica"

- **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
- **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

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



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

Model-independent indelible result !

SUMMARY

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

  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 ... ?