Lepton Photon 01

XX International Symposium on
Lepton and Photon Interactions at High Energies

23rd-28th July 2001, Rome Italy

Searches for New Particles

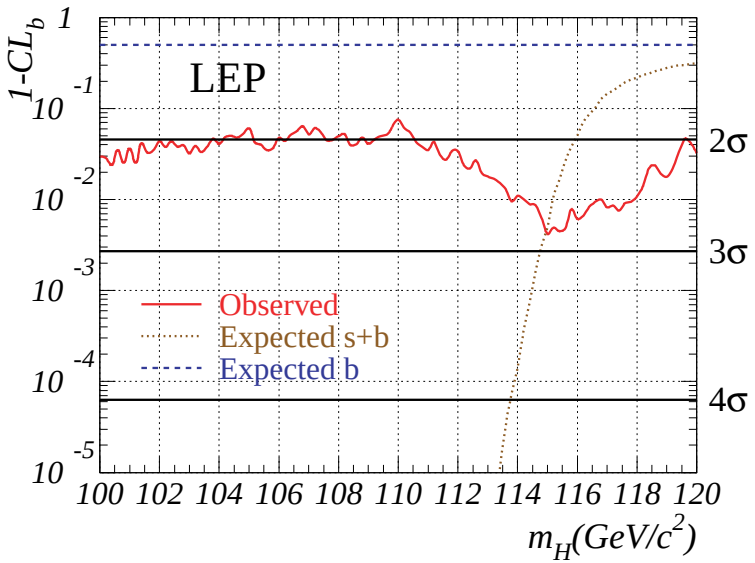
Gail G. Hanson
Indiana University

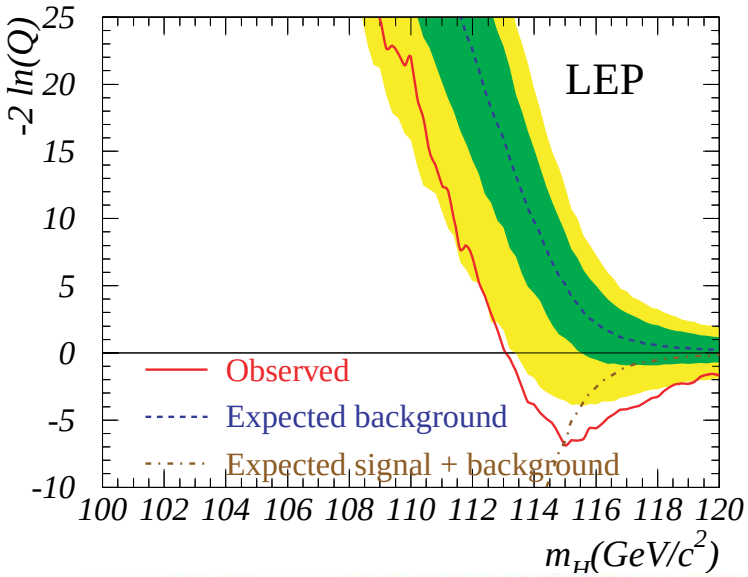
OUTLINE

- Standard Model Higgs Search
- MSSM Higgs Search
- Non-SM Higgs Searches
- Searches for Supersymmetry
- Single Top Quark Production
- Searches for Leptoquarks
- Searches for Excited Fermions
- Technicolor Searches

STANDARD MODEL HIGGS BOSON

November 3, 2000, LEP Experiments Committee (LEPC) presentation:





2.9 s.d. incompatibility with background $(1 - CL_b) = 0.0042$

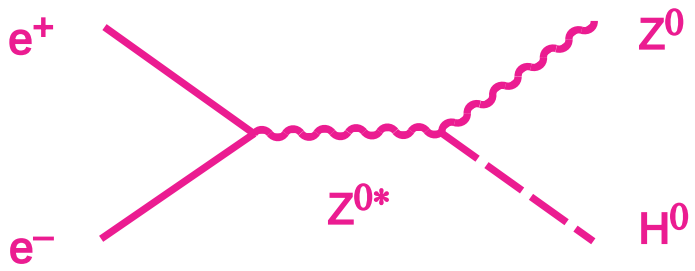
$m_H = 115.0^{+0.7}_{-0.3}$ GeV

$m_H > 113.5$ GeV, 95% C.L.

(115.3 GeV expected)

SM HIGGS SEARCH CHANNELS

Production from Higgsstrahlung $e^+ e^- \rightarrow H^0 Z^0$:



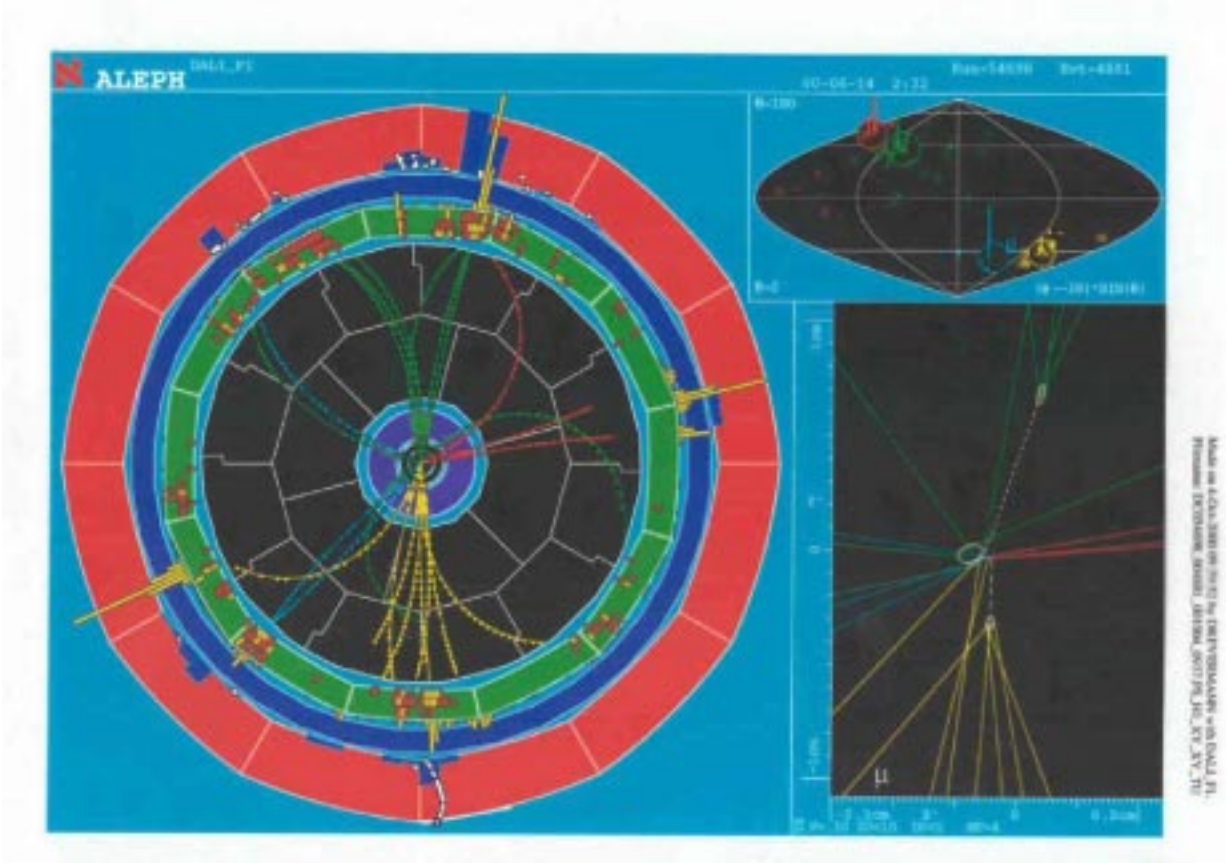
"Four-Jet Channel:" $e^+ e^- \rightarrow H^0 Z^0 \rightarrow b\bar{b}q\bar{q}$

"Missing Energy Channel:" $e^+ e^- \rightarrow H^0 Z^0 \rightarrow b\bar{b}\nu\bar{\nu}$

"Tau Channel:" $e^+ e^- \rightarrow H^0 Z^0 \rightarrow \tau^+\tau^- q\bar{q}$ and $q\bar{q}\,\tau^+\tau^-$

"Lepton Channel:" $e^+ e^- \rightarrow H^0 Z^0 \rightarrow b\bar{b}e^+e^-$ and $b\bar{b}\mu^+\mu^-$

HIGGS CANDIDATE?



STATISTICAL PROCEDURE

Each event is assigned a probability density s_i of being a signal at Higgs mass m_H and a probability b_i of being background.

- Each event is then assigned a weight $w_i = (s_i + b_i)/ b_i$
- The likelihood of the sample L is the product of the weights. The logarithm is taken, and then the method is log-likelihood ratio.

Likelihood ratio $Q(m_H) = \dfrac{L(s + b)}{L(b)}$

Two hypotheses:

Background only (CL_b)

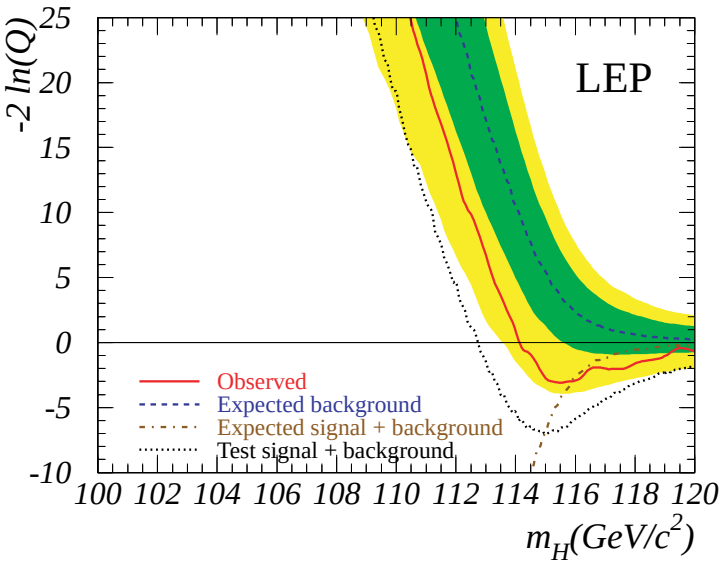
Signal + background ($CL_s = CL_{s+b}/CL_b$)

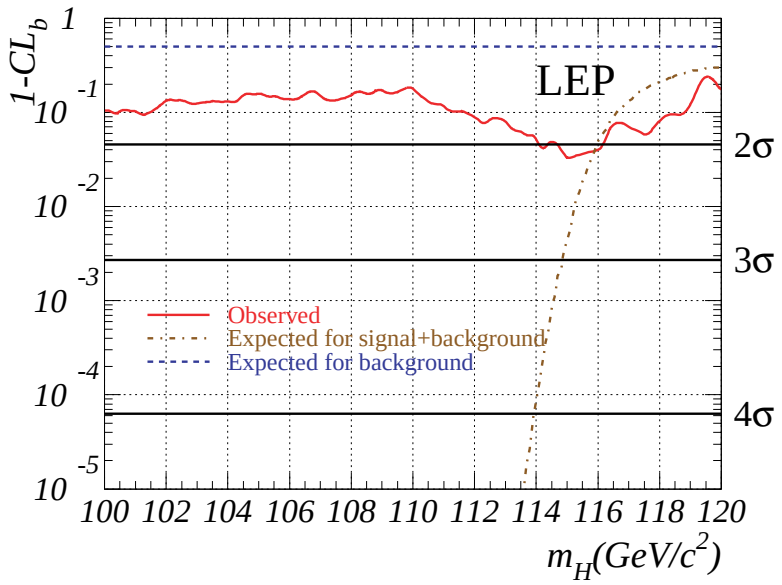
EVENT WEIGHTS AT 115 GeV

	Exp.	Channel	Rec. m_H (GeV)	Nov. 3 *s*/*b*	Current *s*/*b*
1	ALEPH	4-jet	114	4.7	4.7
2	ALEPH	4-jet	113	2.3	2.3
3	ALEPH	4-jet	110	0.9	0.9
4	L3	E-miss	115	2.1	0.7
5	OPAL*	4-jet	111	0.4	0.7
6	DELPHI	4-jet	114	0.5	0.6
7	ALEPH	Lept	118	0.6	0.6
8	ALEPH	Tau	115	0.5	0.5
9	ALEPH	4-jet	114	0.4	0.5
10	OPAL	4-jet	113	0.5	0.5

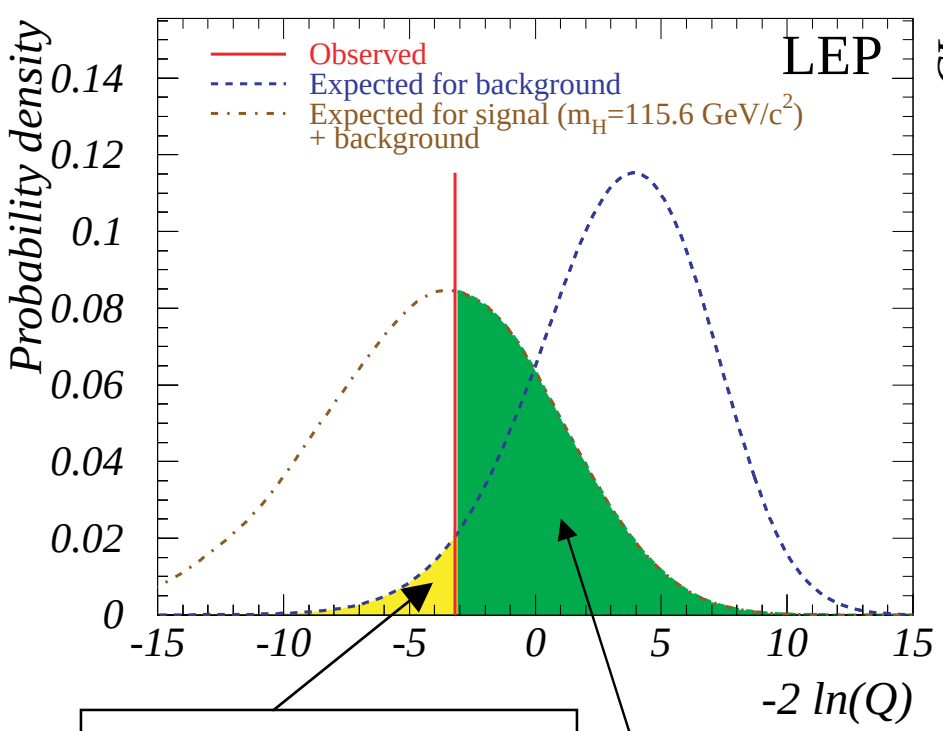
CURRENT COMBINED RESULTS

All four experiments published in 2000. L3 has also published final analysis. New combination:



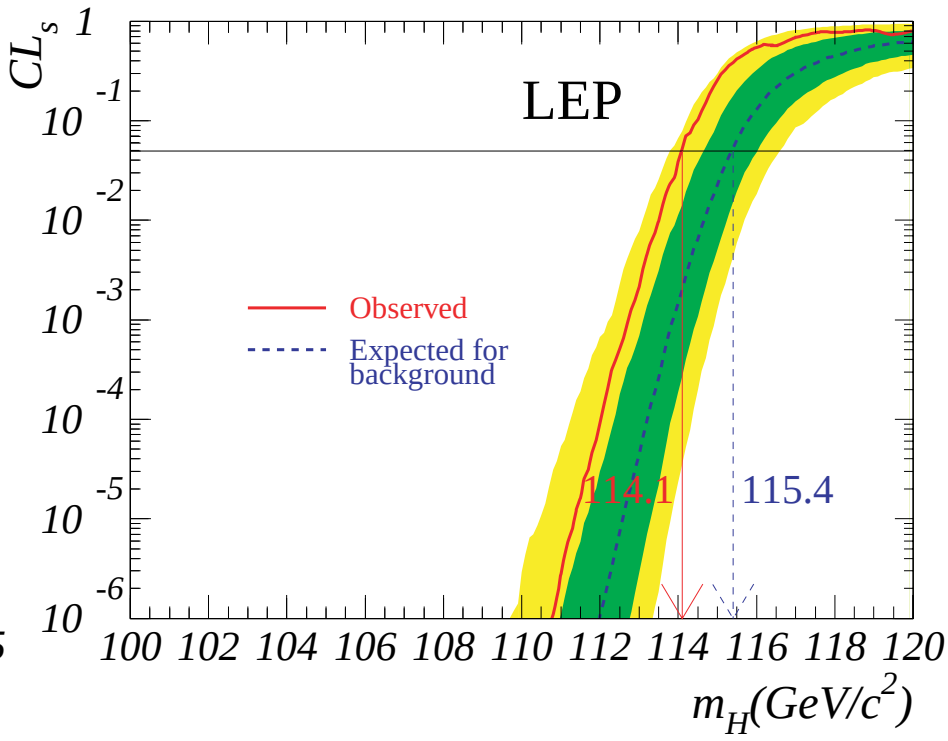


Maximum likelihood ratio at m_H = 115.6 GeV.
Probability of background fluctuation 2.1 s.d.



1 - CL_b = 3.4%

CL_{s+b} = 44%



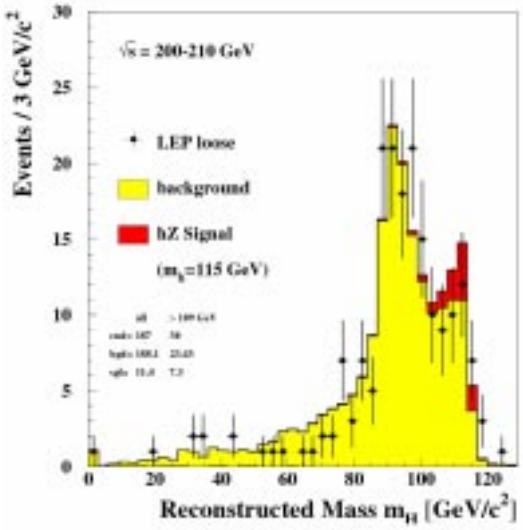
m_H > 114.1 GeV, 95% C.L.

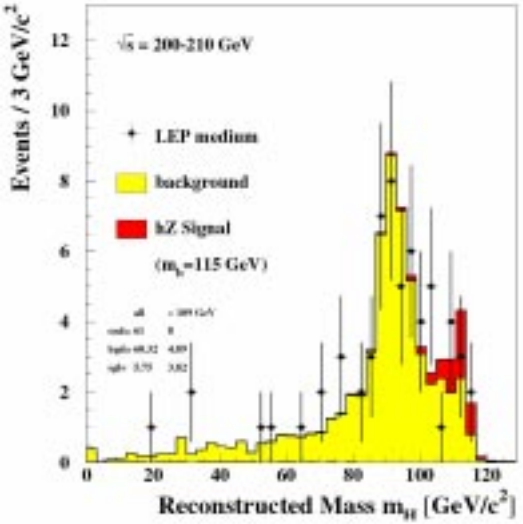
(115.4 GeV expected)

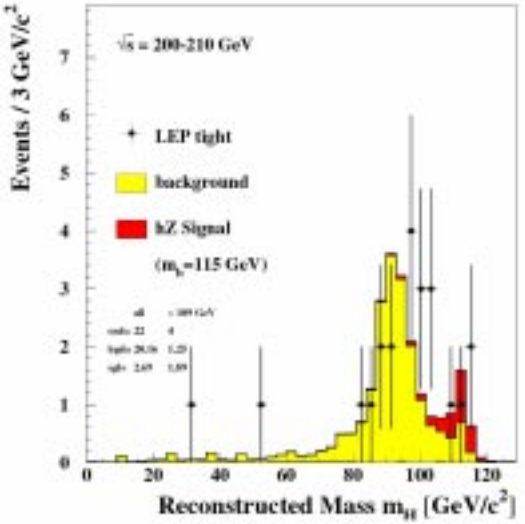
RECONSTRUCTED HIGGS MASS

Purity of selection:

Loose Medium Tight







MSSM HIGGS

Two scalar field doublets resulting in five physical Higgs bosons:

h^0, H^0 CP-even,

A^0 CP-odd

$H^\pm$

At tree level,

$m_h \lesssim m_Z$

$m_A \lesssim m_H$

$m_Z \lesssim m_H$

$m_{H^\pm} \lesssim m_{W^\pm}$

Loop corrections, predominantly from t and $\tilde{t}$,
modify these mass relations, unfortunately for LEP2.

However, $m_h \lesssim$ 135 GeV in MSSM

SUPERSYMMETRY PARAMETERS

MSSM:

$\tan\beta$ v_2 / v_1 = ratio of vacuum expectation values of two scalar fields

μ Higgs mixing parameter

M_1, M_2, M_3 Gaugino masses at EW scale ($\tilde{\chi}^0$, $\tilde{\chi}^{\pm}$, $\tilde{g}$)

Gaugino unification at GUT scale $\rightarrow$ common gaugino mass $m_{1/2}$

$$M_1 = \frac{5}{3}\tan^2\theta_W M_2 \sim 0.5\, M_2$$

A_τ, A_t, A_b Trilinear couplings (third family)

$m_{\tilde{f}}$ Scalar fermion masses

Sfermion mass unification $\rightarrow$ common sfermion mass m_0 at GUT scale

m_A Running mass of CP-odd scalar A^0

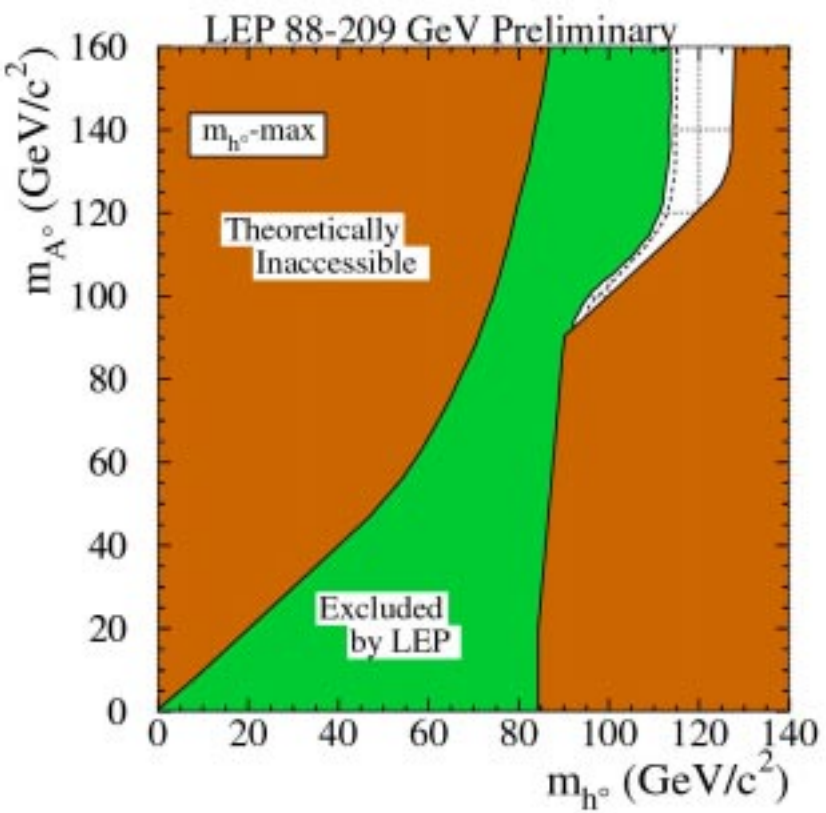
Constrained MSSM (CMSSM): Sfermion and gaugino mass unification

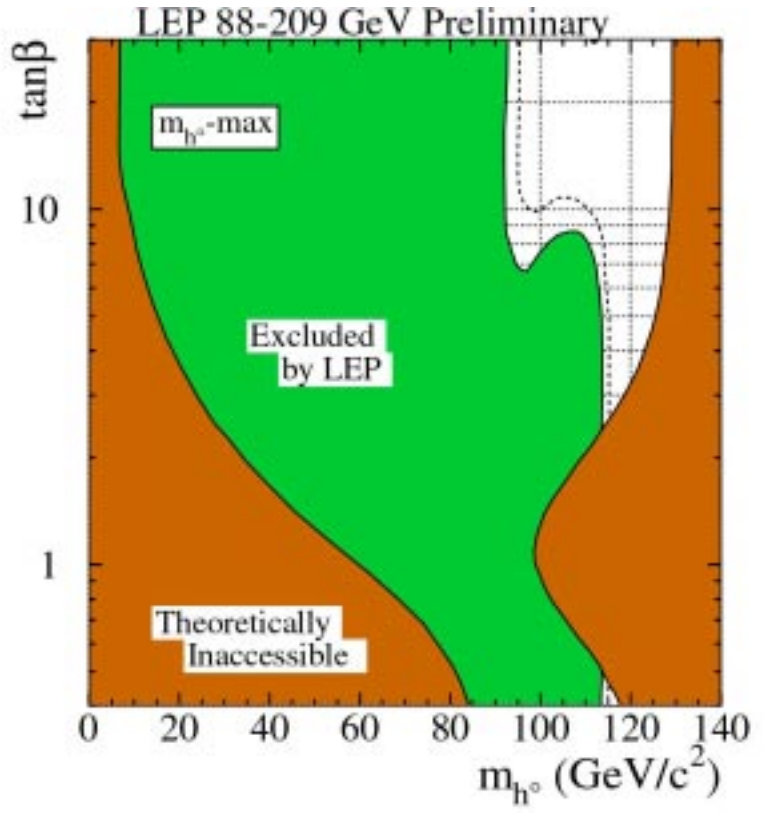
Minimal supergravity-broken MSSM (MSUGRA): Also A_f's equal (A_0), scalar (including Higgs) mass unification, EW symmetry scale $\rightarrow \mu$

MSSM HIGGS SEARCHES

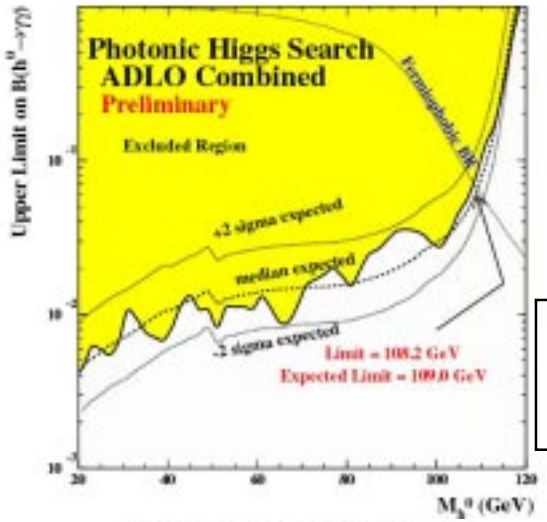
Combined LEP Experiments: $m_{h^0} > 91.0$ GeV, $m_{A^0} > 91.9$ GeV, 95% C.L.

$0.5 < \tan\beta < 2.4$ excluded m_h-max, $m_t < 174.3$GeV



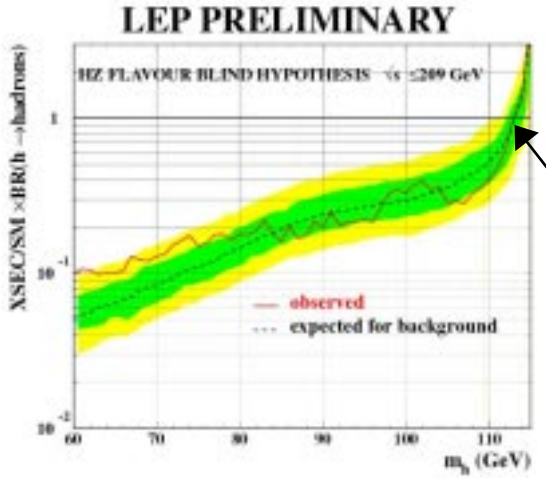


HIGGS SEARCHES IN EXTENDED MODELS



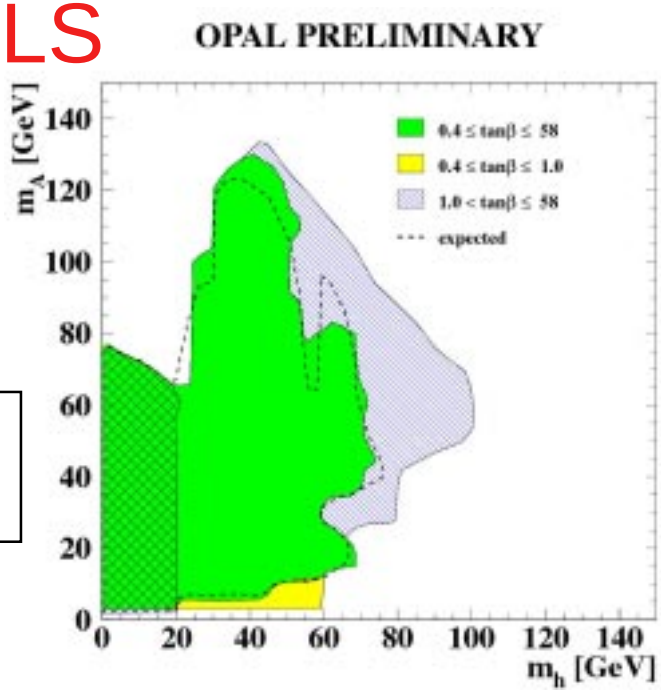
$h \rightarrow \gamma\gamma$

$m_h > 108.2$ GeV
ADLO comb.



Flavour Independent

$m_h > 112.9$ GeV
ADLO comb.



2HDM(II):

α= Higgs mixing angle
$1 \leq m_{h^0} \leq 58$ GeV and

$10 \leq m_{A^0} \leq 65$ GeV
excluded at 95% C.L.
for all α, tanβ

SEARCHES FOR SUPERSYMMETRIC PARTICLES

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

B baryon number
L lepton number
S spin

R-parity conservation:

- SUSY particles are produced in pairs
- The lightest SUSY particle (LSP) is stable

Gravity mediated supersymmetry breaking:

Gravitino $\tilde{G}$ heavy ; $\tilde{\chi}_1^0$ is the lightest SUSY particle (LSP)

Gauge mediated supersymmetry breaking:

$\tilde{G}$ very light (LSP); $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$ for example

R-parity violating supersymmetry decays

SUSY MAP

FERMIONS		SUSY PARTNER (SCALARS)	
LEPTONS			
	e	Selectron	$\tilde{e}$
	μ	Smuon	$\tilde{\mu}$
	τ	Stau	$\tilde{\tau}$
	ν_e, ν_μ, ν_τ	Sneutrinos	$\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$
QUARKS			
	u, c, t	Squarks	$\tilde{u}, \tilde{c}, \tilde{t}$
	d, s, b		$\tilde{d}, \tilde{s}, \tilde{b}$
GAUGE PARTICLES (BOSONS)		**SUSY PARTNER (FERMIONS)**	
	$W^\pm, H^\pm$	Charginos	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$
	$\gamma, Z^0, h^0, H^0, A^0$	Neutralinos	$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$
	g_i	Gluinos	$\tilde{g}_i$
	Graviton G	Gravitino	$\tilde{G}$

SEARCHES FOR SLEPTONS

$e^+e^- \to \tilde{\ell}^+\tilde{\ell}^-$

$\tilde{\ell}^- \to \tilde{\chi}_1^0 \ell^-$, $\tilde{\chi}_1^0$ = LSP

Topology: acoplanar $\ell^+\ell^-$

$\Delta M = M_{\tilde{\ell}^-} - M_{\tilde{\chi}^0}$

Note: $\tilde{\ell}_R^-, \tilde{\ell}_L^-$ are the scalar partners of the right-handed, left-handed ℓ^-.

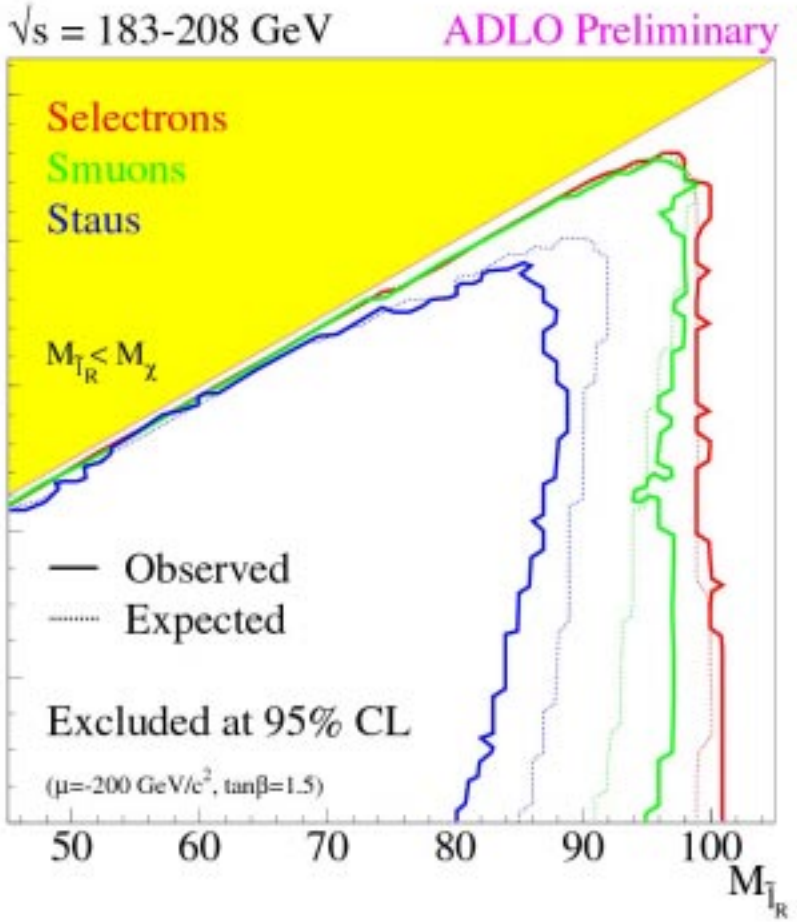
$\sigma(e^+e^- \to \tilde{\ell}_R^+\tilde{\ell}_R^-)$ is smaller than $\sigma(e^+e^- \to \tilde{\ell}_L^+\tilde{\ell}_L^-)$.

Combined ALEPH, DELPHI, L3, OPAL (ADLO) limits for $\Delta M > 10$ GeV:

$M_{\tilde{e}_R} > 99$ GeV

$M_{\tilde{\mu}_R} > 95$ GeV

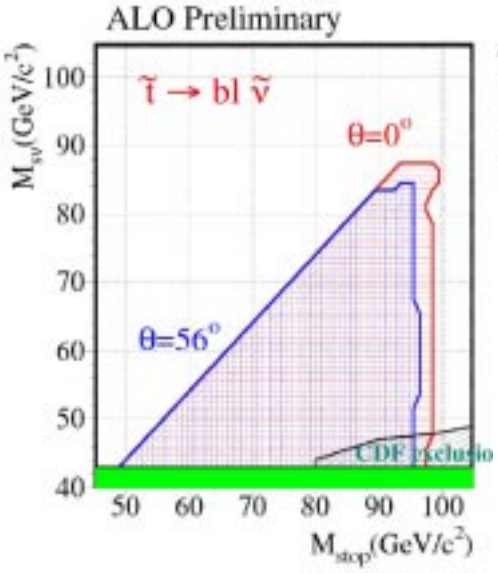
$M_{\tilde{\tau}_R} > 80$ GeV

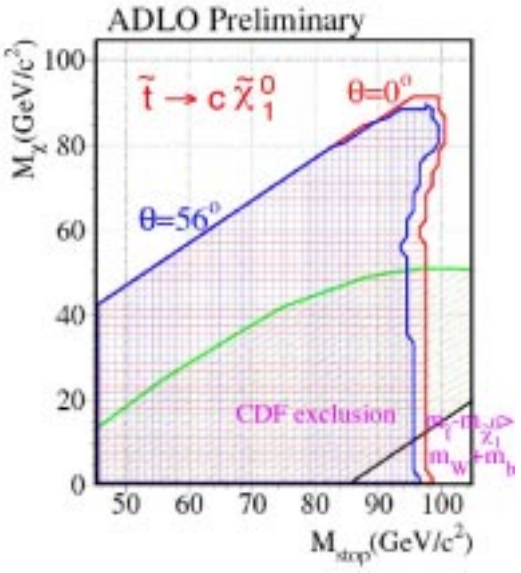


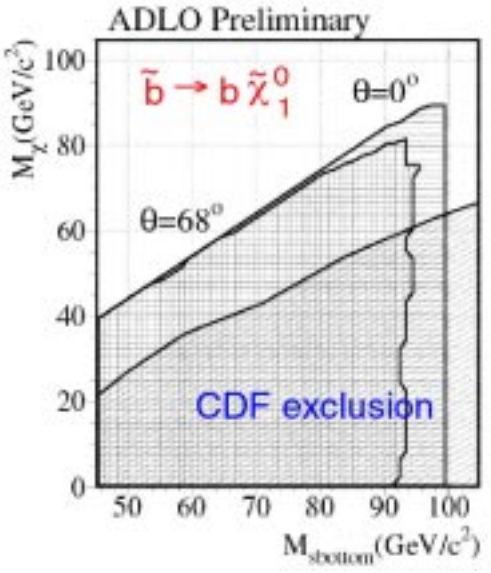
STOP AND SBOTTOM

Limit for $\Delta M > 10$ GeV		
θ	$\tilde{t}_1 \to c\tilde{\chi}^0_1$	$\tilde{t}_1 \to bl\tilde{\nu}$
0^o	97 GeV	97 GeV
56^o	95 GeV	95 GeV

Limit for $\Delta M > 10$ GeV	
θ	$\tilde{b}_1 \to b\tilde{\chi}^0_1$
0^o	100 GeV
68^o	92 GeV



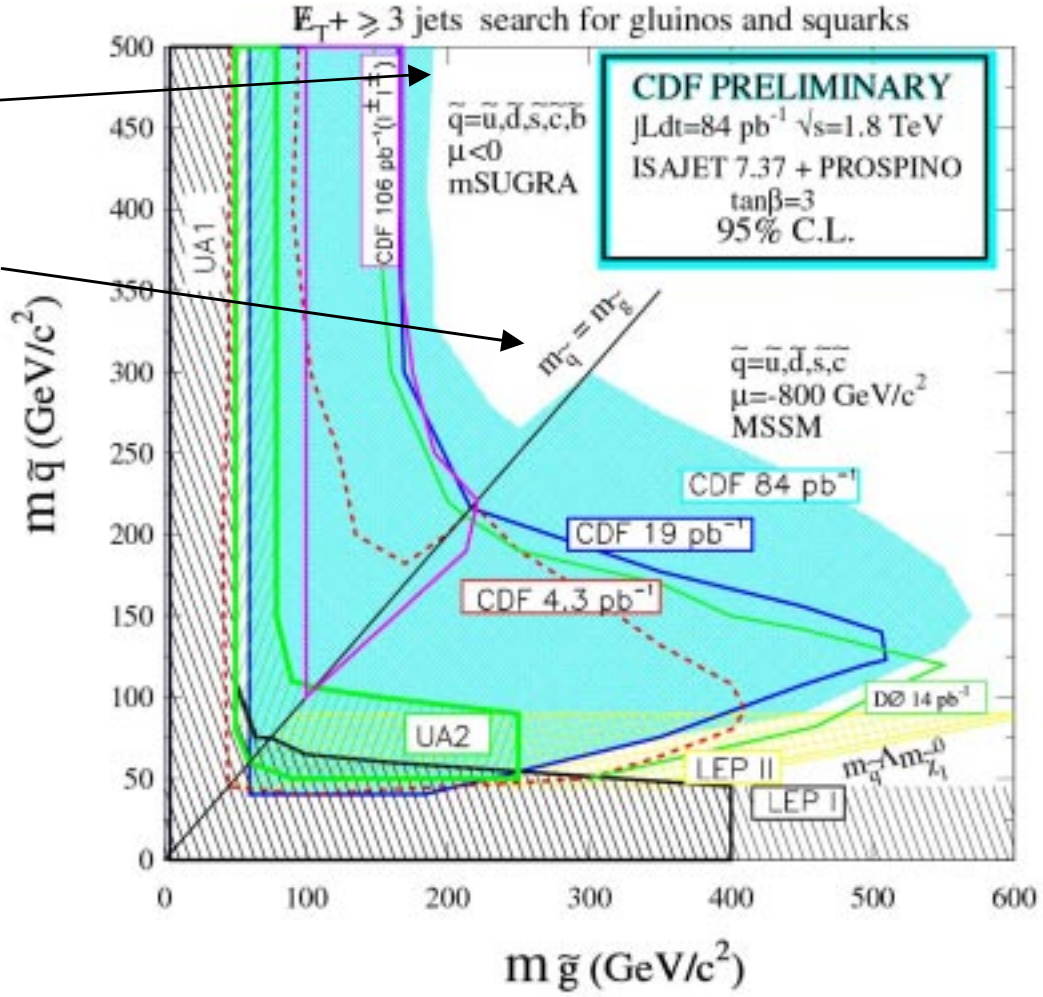




SQUARKS AND GLUINOS

$m_{\tilde{g}} > 195$ GeV

$m_{\tilde{g}} \approx m_{\tilde{q}} > 300$ GeV



CHARGINOS

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

$\tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 W^* \rightarrow \tilde{\chi}_1^0 \ell^+ \nu$ or $\tilde{\chi}_1^0 q\bar{q}'$

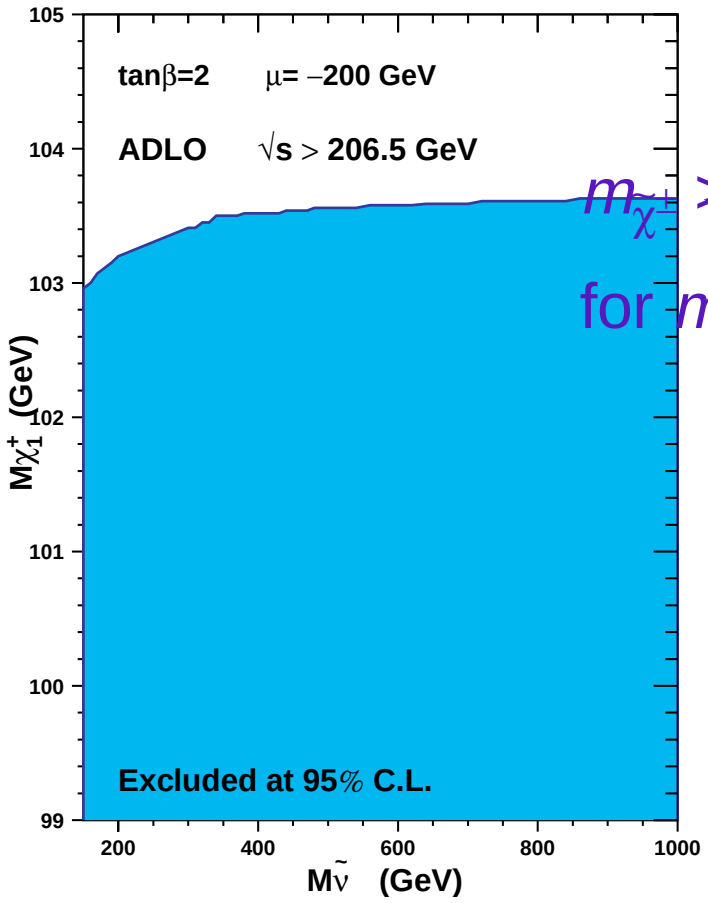
→ Signature is large missing energy and large missing transverse momentum

$\Delta M = M_{\tilde{\chi}_1^+} - M_{\tilde{\chi}_1^0}$

Several topologies:

- Hadronic, large multiplicity
- Large multiplicity with isolated lepton
- Low multiplicity (acoplanar leptons)

At large m_0 (heavy scalar leptons) cross section is largest.→ $M_{\tilde{\chi}_1^+}$ is at kinematical limit.

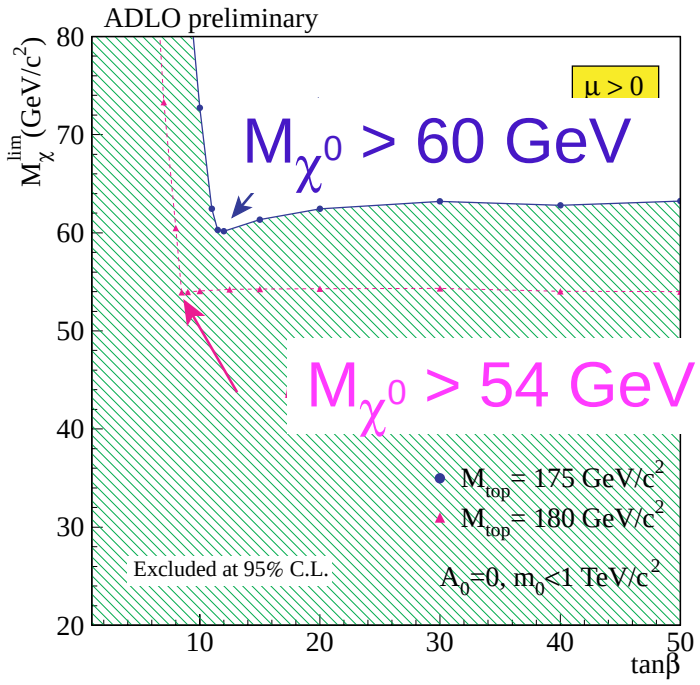


$m_{\tilde{\chi}^\pm} > 103.5$ GeV

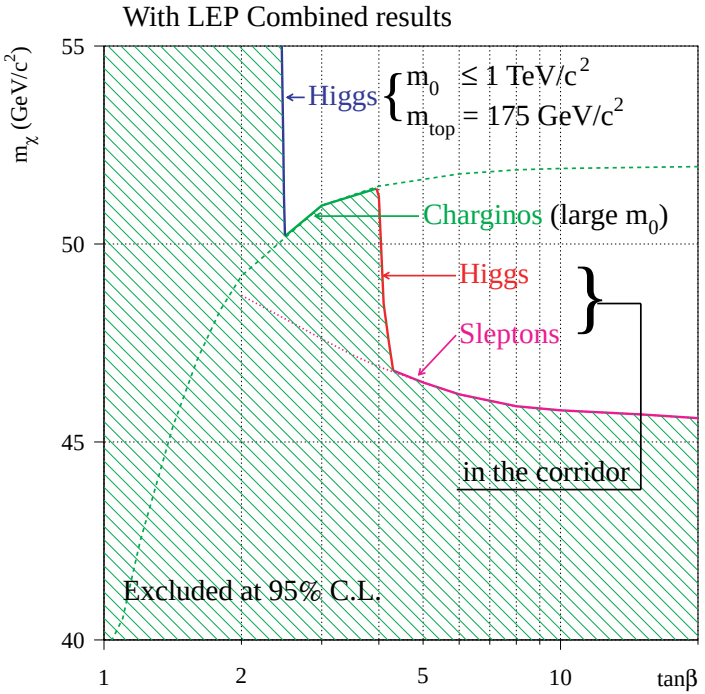
for $m_{\tilde{\nu}} > 300$ GeV

LIMIT ON THE LSP MASS

$\tilde{\chi}_1^0$ Neutralino LSP Constraints in MSUGRA



χ_1^0 Neutralino LSP Constraints in MSSM
Unification at GUT Scale (CMSSM)



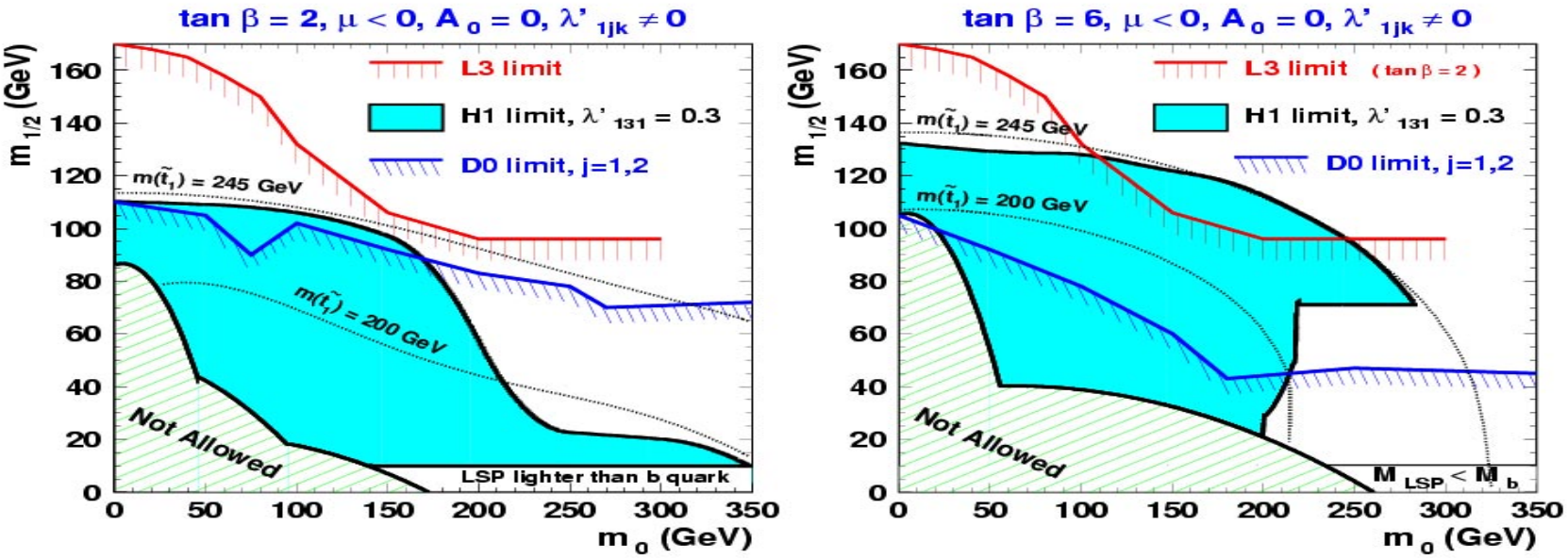
$M_{\tilde{\chi}^0}$ > 45.6 GeV

R-PARITY VIOLATION

$\tilde{q}$'s are produced through an *R*-parity violating λ'_{1jk} coupling.

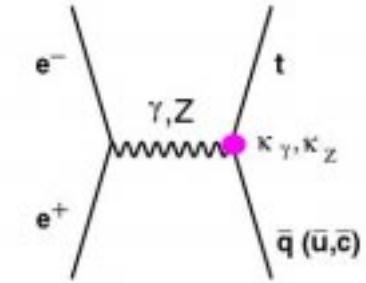
They decay either through the same coupling or through an *R*-parity conserving gauge decay into a $\tilde{\chi}^{\pm}$, a $\tilde{\chi}^0$, or a $\tilde{g}$.

Minimal Supergravity + R_p Violation

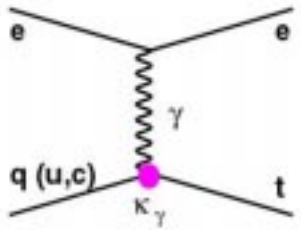


SINGLE TOP QUARK PRODUCTION

Flavor Changing Neutral Currents (FCNC)



LEP $e^+e^- \to t\bar{q} \to bW\bar{q}$



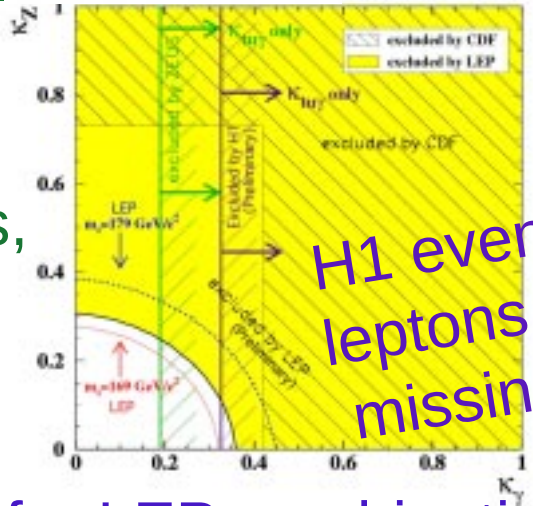
HERA $e^{\pm}p \to e^{\pm}bWX$

$W \to l\bar{\nu}_l$ or $q\bar{q}'$

CDF searched for

$t \to \gamma c(u)$ or $Zc(u)$

FCNC suppressed at tree level in SM (GIM mechanism). Small contributions at one-loop level. In e^+e^- $\sigma_{SM} \sim 10^{-9}$ fb. Extended models, e.g. SUSY and multi-Higgs, can allow FCNC at tree level.



H1 events with isolated leptons with large missing p_T

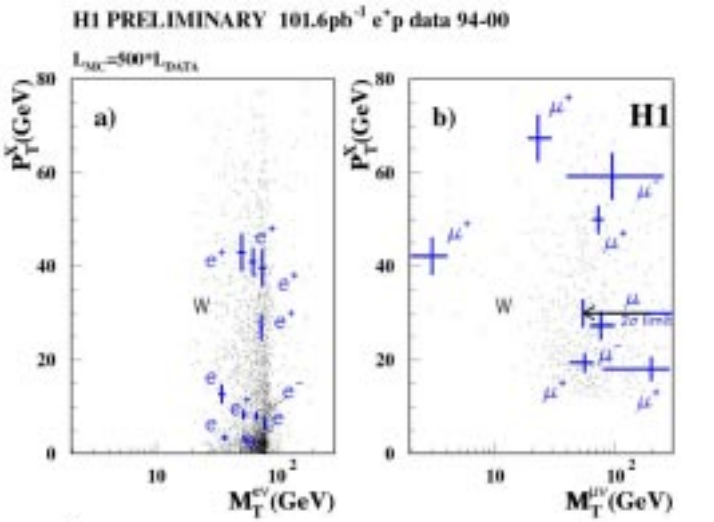
ISR and QCD corrections for LEP combination.

EVENTS WITH ISOLATED LEPTONS AND LARGE MISSING p_T

Primary Standard Model process is single W production

H1	electron		muon	
	obs.	exp.	obs.	exp.
P_T^X<25 GeV	6	6.6	2	1.0
P_T^X>25 GeV	4	1.3	6	1.5

ZEUS	electron		muon	
	obs.	exp.	obs.	exp.
P_T^X>25 GeV	1	1.1	1	1.3



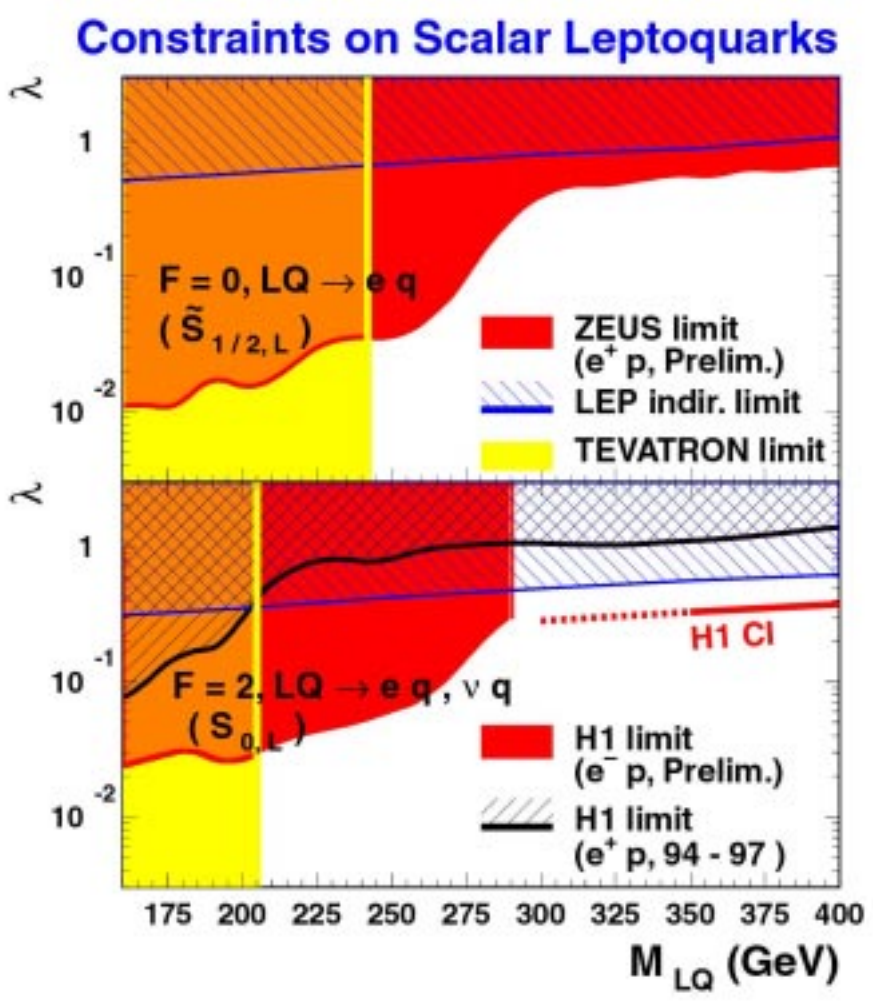
LEPTOQUARKS

Leptoquarks carry baryon and lepton number. Scalar or vector.

$F = L + 3B$ is preserved

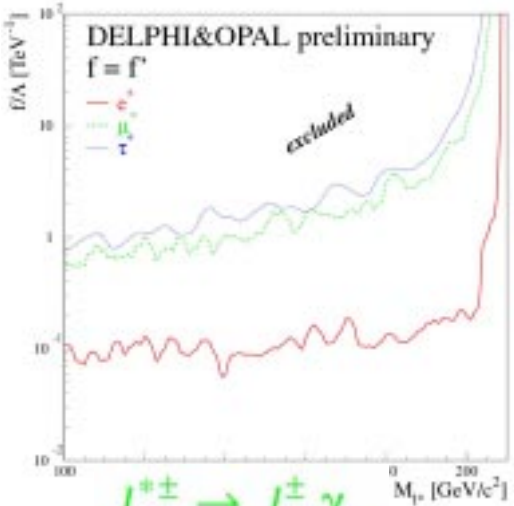
$$e^{\pm} q \rightarrow LQ$$

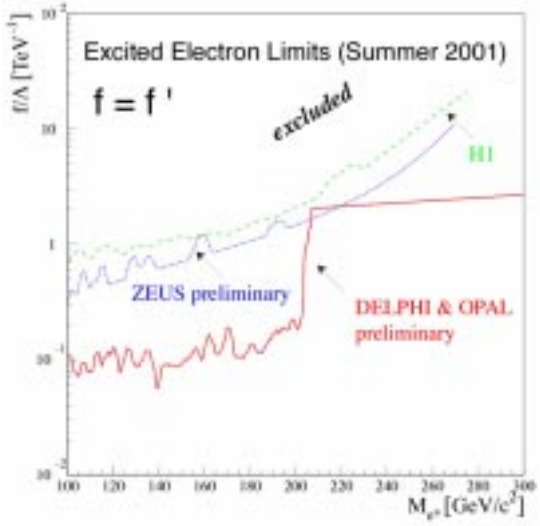
$$q\bar{q} \rightarrow LQ\,LQ$$

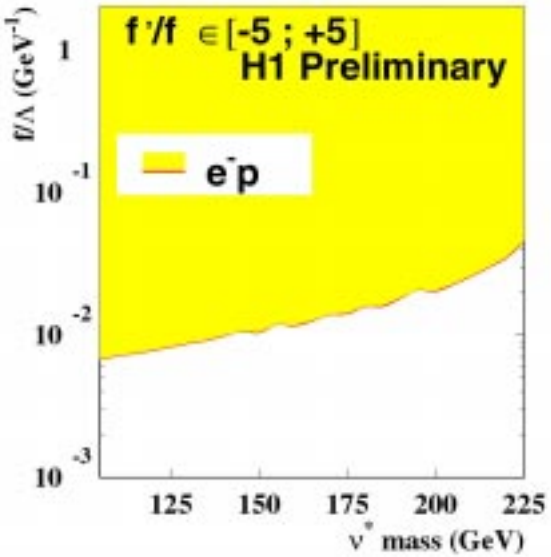


EXCITED FERMIONS

$$\mathcal{L}_{ll^*} = \frac{1}{2\Lambda}\bar{l}^*\sigma^{\mu\nu}\left[gf\frac{\tau}{2}W_{\mu\nu} + g'f'\frac{Y}{2}B_{\mu\nu}\right]l_L + h.c.$$







$l^{*\pm} \rightarrow l^{\pm}\gamma$

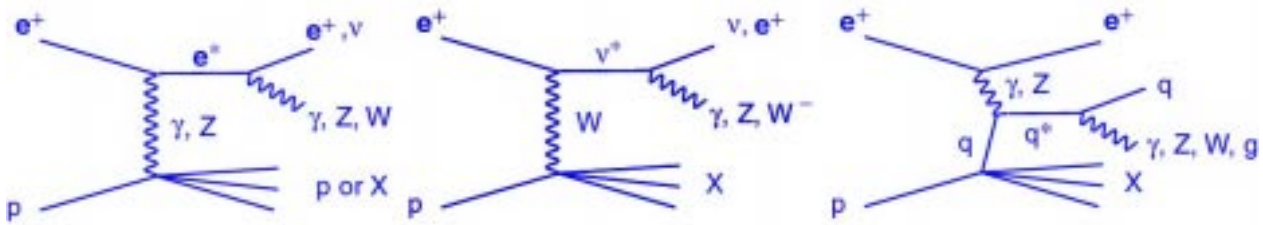
$l^{*\pm} \rightarrow \nu W^{\pm}$

$l^{*\pm} \rightarrow l^{\pm} Z^0$

$\nu^* \rightarrow \nu\gamma$

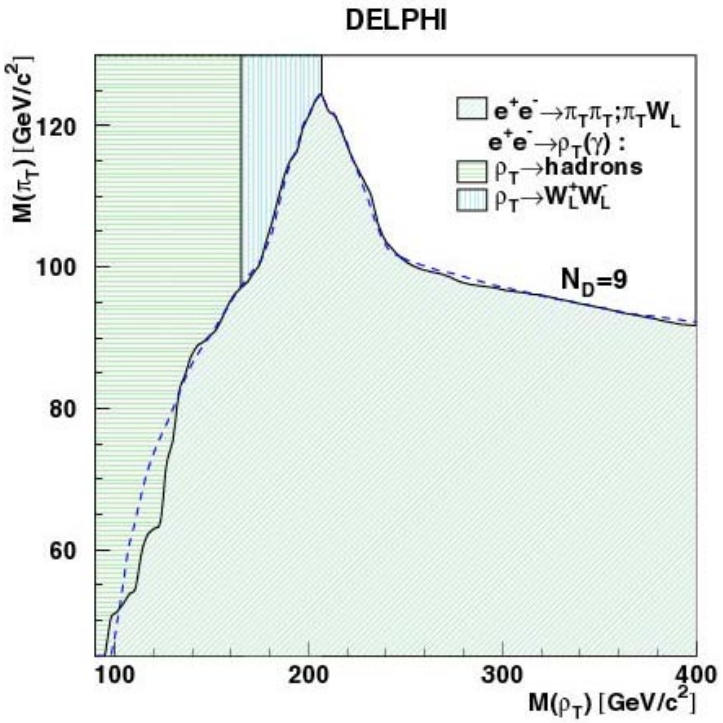
$\nu^* \rightarrow l^{\mp} W^{\pm}$

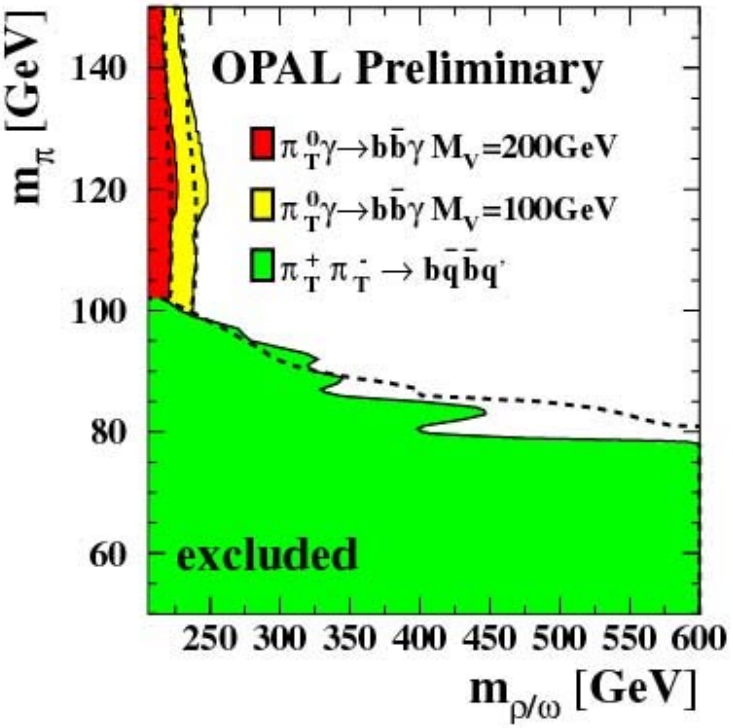
$\nu^* \rightarrow \nu Z^0$



EXCITED FERMION PRODUCTION AT HERA

TECHNICOLOR





m_{π_T} > 89.1 (79.8) GeV for N_D = 9 (2)

m_{π_T} > 77 (62) GeV for N_D = 9 (2)

SUMMARY AND CONCLUSIONS

- m_H > 114.1 GeV, 95% C.L., from direct search.
- "Hint" of 2 s.d. signal at m_H = 115.6 GeV

Is there a light Higgs boson?

Will have to wait until ~ 2007 to find out

Is there another mechanism for electroweak symmetry breaking?

Will we find supersymmetry? Technicolor?

Still only questions!…..