

OPAL SEARCHES

FOR

EXOTIC

PARTICLES

AND



HIGGS

News from  
the Year  
2000

LEP



COMBINATION



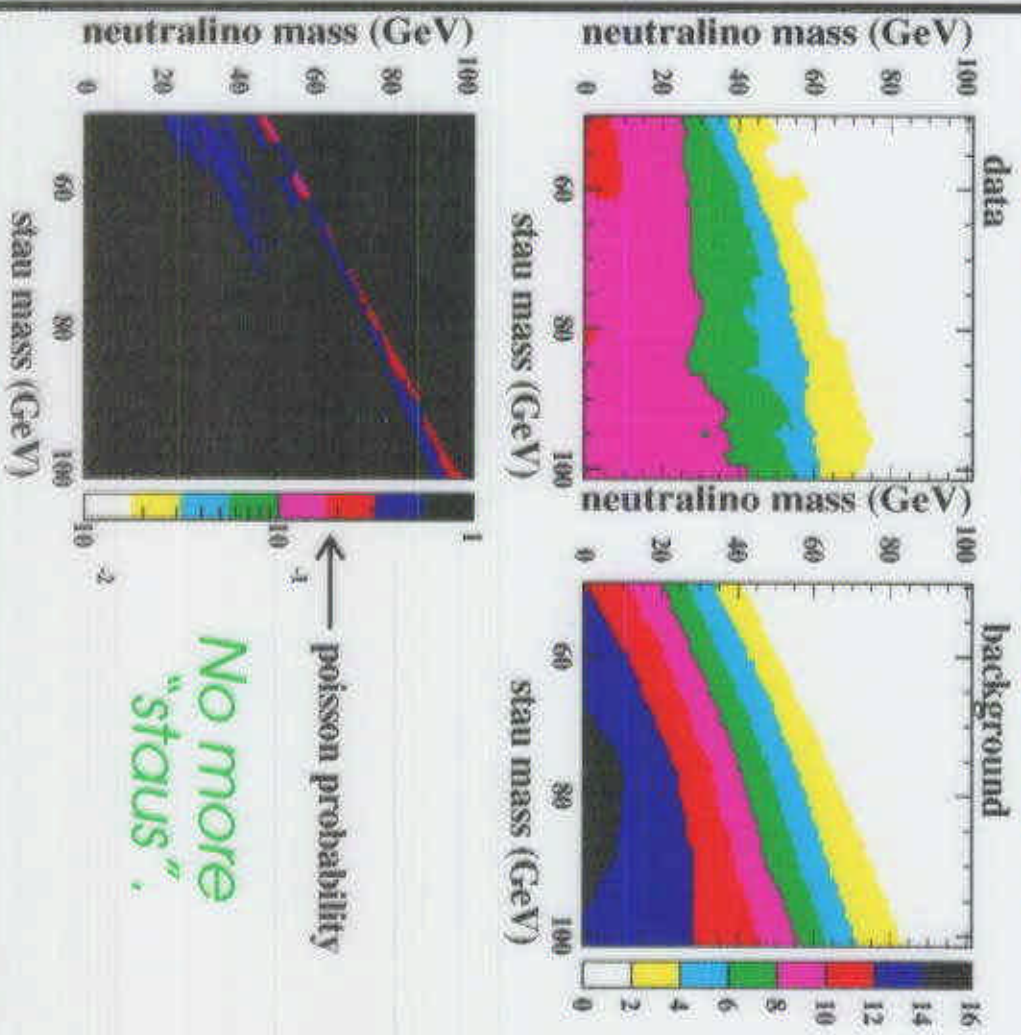
CERN



Kara Hoffmann

# SLEPTONS

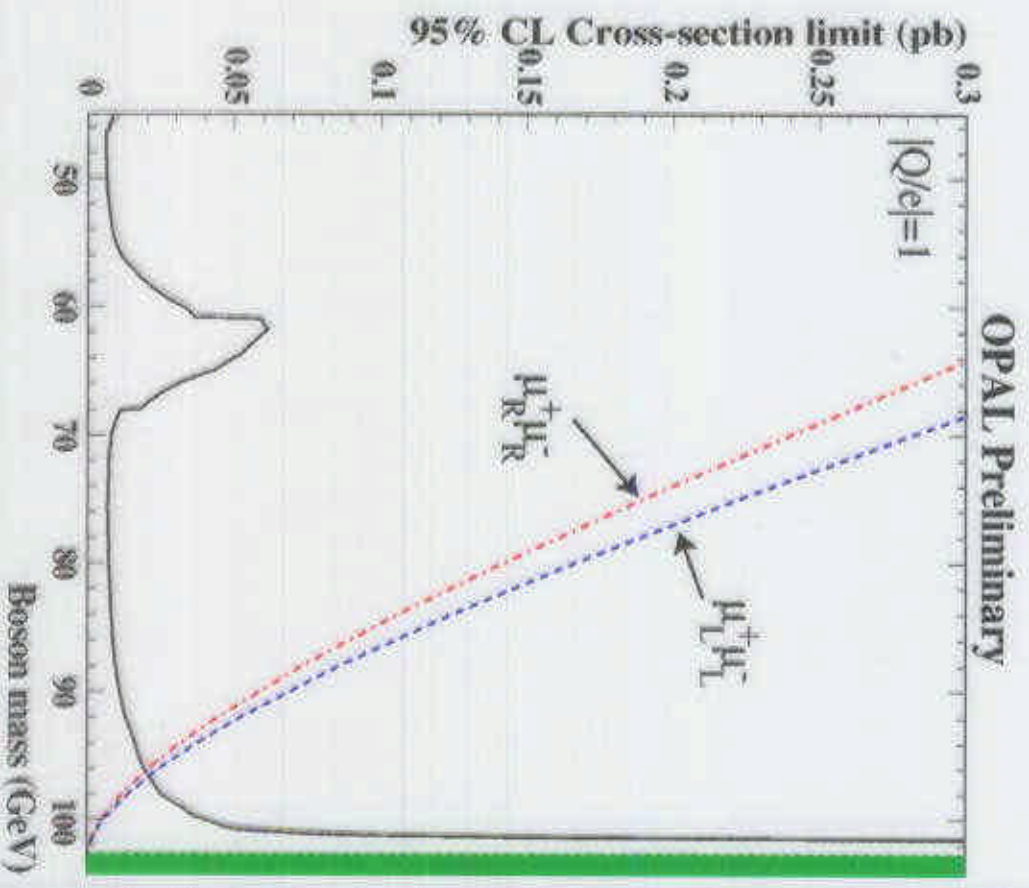
Accoplanar Dileptons  
2000 data agrees with MC.



poisson probability  
No more "staus".

Minimal Supersymmetric Model

Long lived Heavy charged particles  $\tau > 1\mu s$



Kara Hoffmann  
CERN EP Division

# CHARGINO/NEUTRALINO

Minimal Supersymmetric Model

High Cross Section ~ 1pb

Neutralinos  $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \tau^{(*)}$

Charginos  $\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_2^0 W^\mp$

Excess: acoplanar dijet topology Excess: low multiplicity topology

for  $30 < M_{\tilde{\chi}_2^0} - M_{\tilde{\chi}_1^0} \leq 80$  GeV

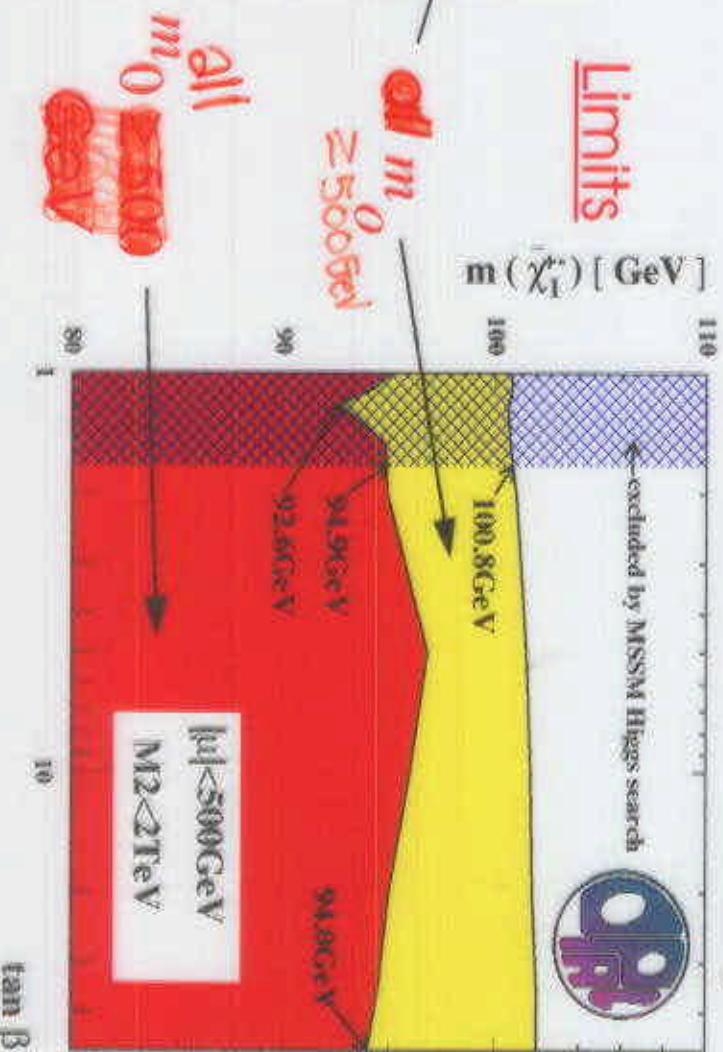
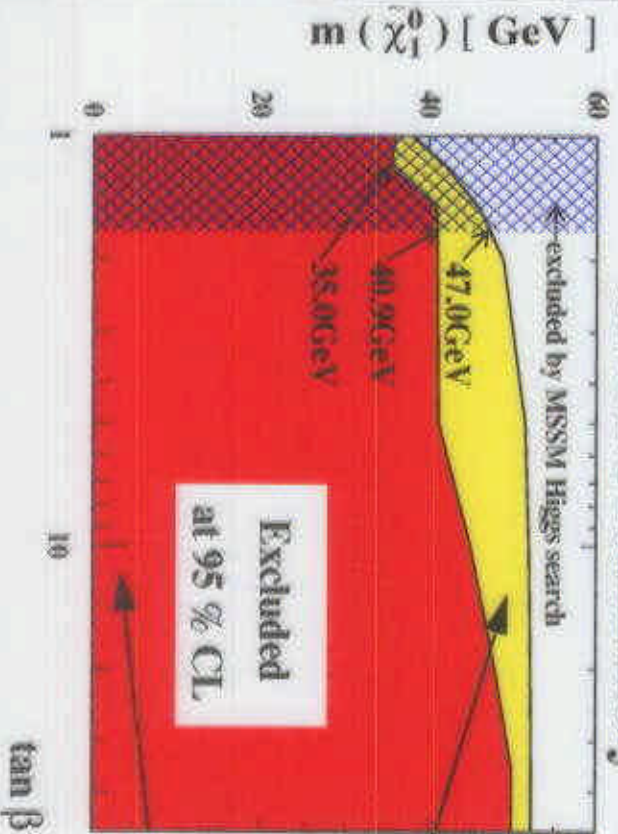
for  $5 < M_{\tilde{\chi}_1^+} - M_{\tilde{\chi}_1^0} \leq 10$  GeV

Expected: 4.9 Data: 11

Expected: 12.9 Data: 21

OPAL Preliminary

OPAL Preliminary



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## Search for 'light sbottom'

- hadronic events with at least 7 tracks
- $s'/s > 0.55$ ,  $T > 0.975$  and  $|\cos(\theta_T)| < 0.9$
- b-tag (a vertex with  $L/\sigma > 2.5$ )
- electron and muon id
- two oppositely charged leptons with  $\Delta\Phi < 8^\circ$

Data: 161-206 GeV, Luminosity=540 pb<sup>-1</sup>

	presel.	b-tag	2 lept	co-planar
data	1454	650	47	15
MC	1491	603	45.7	20.5

Efficiency checked with SM  $b \rightarrow IX$  decays

Also checked with ALEPH

$\bar{b}$  4 vectors

Efficiency for  $\bar{b} \sim 15\%$

No excess over SM expectation

# R-PARITY VIOLATING SUSY

LSP decays to SM particles

Two scenarios probed for slepton search:

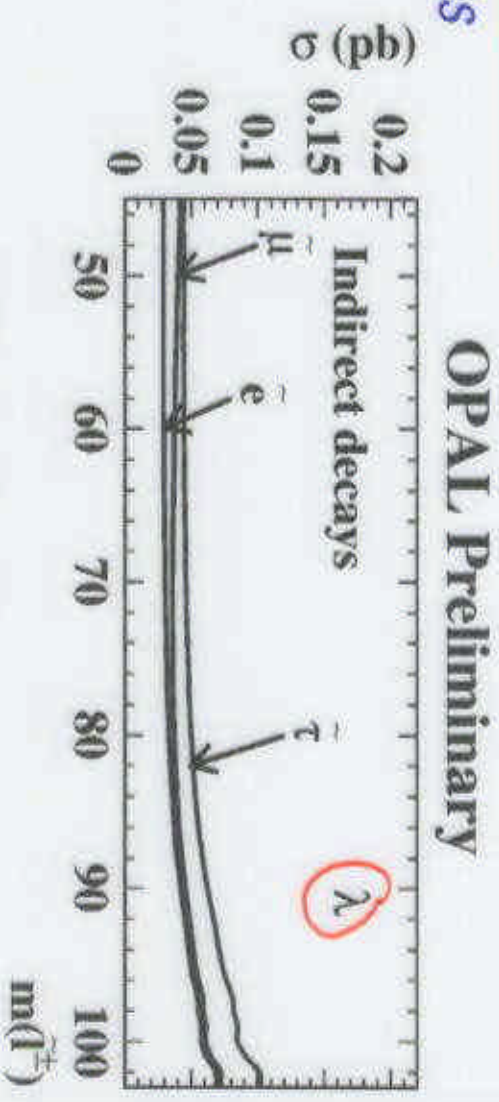
Direct decays to SM particles:

$$\tilde{l}^- \tilde{l}^+ \rightarrow l\nu l\nu$$

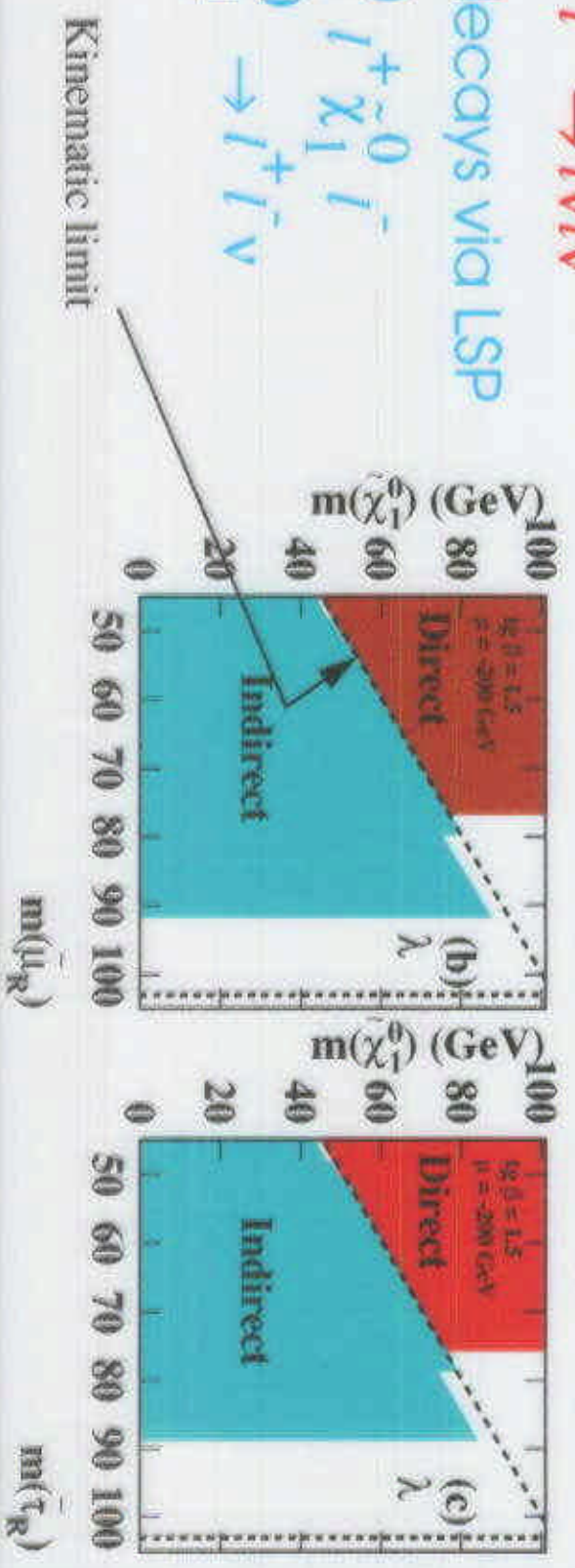
Indirect decays via LSP

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

$$\tilde{\chi}_1^0 \rightarrow l^+ l^- \nu$$



OPAL Preliminary



# LIGHT GRAVITINOS

*gauge mediated SUSY breaking*

GMSB LSP:  $\tilde{G}$  NLSP:  $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$   $\tilde{l}_R \rightarrow l\tilde{G}$

Search for  $\tilde{l}^+\tilde{l}^-$ ,  $\tilde{\chi}_1^0$ ,  $\tilde{\chi}_1^+$ ,  $\tilde{\chi}_1^-$

Excess found in  $l^+l^-\gamma\gamma + B$  from:

$$e^+e^- \rightarrow \tilde{l}^+\tilde{l}^- \rightarrow (\tilde{\chi}_1^0 l^+)(\tilde{\chi}_1^0 l^-) \rightarrow (\tilde{G}\gamma l^+)(\tilde{G}\gamma l^-)$$

for  $\frac{M_{\tilde{l}}}{2} < M_{\tilde{l}} - M_{\tilde{\chi}_1^0} < M_{\tilde{l}}$

Expected:  $1.3 \pm 0.3$

4%

Observed: 4  $\rightarrow$  Probability

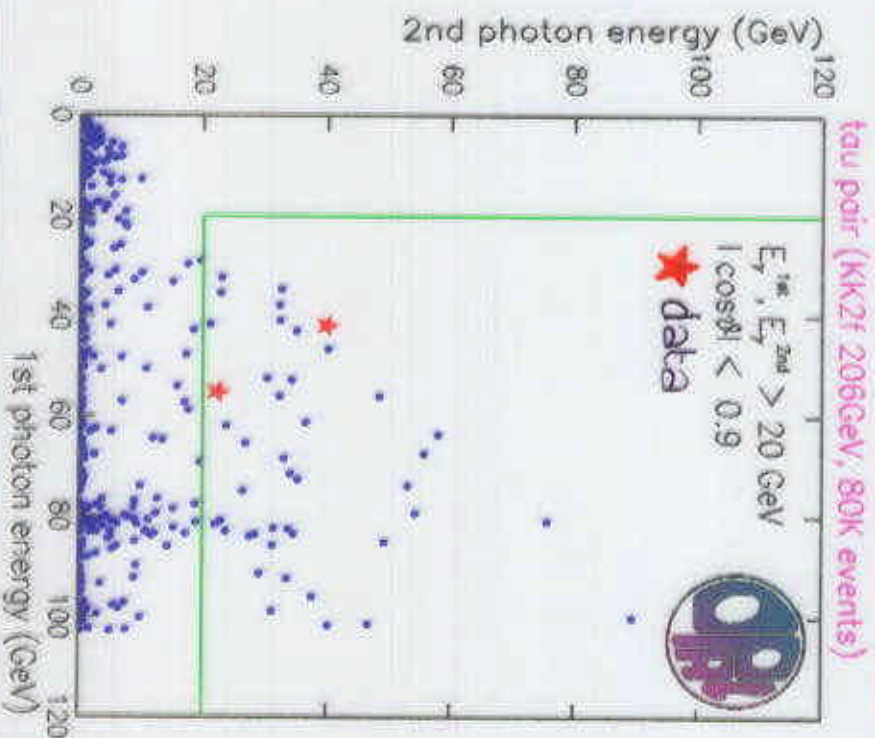
For SM  $\tau\tau\gamma\gamma$  events:

$$E_{\gamma}^1 > 20 \text{ and } E_{\gamma}^2 > 20 \text{ GeV}$$

Probability: very small

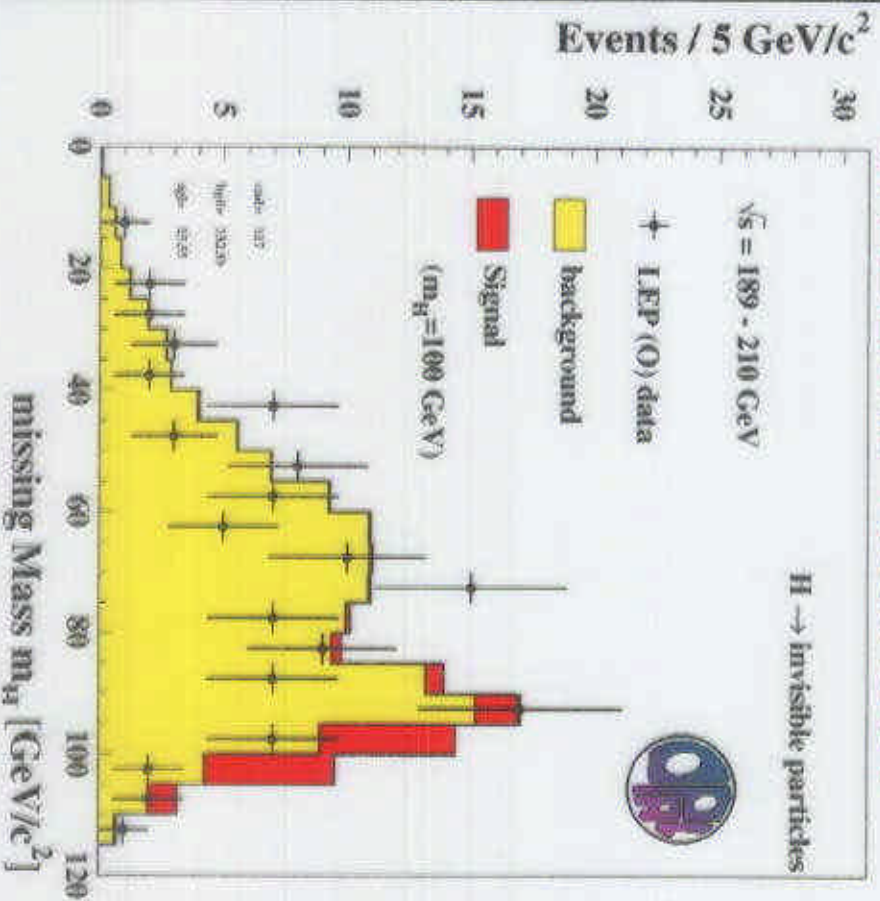
SM background:

$$e^+e^- \rightarrow Z^0\gamma\gamma \rightarrow \tau^+\tau^-\gamma\gamma$$

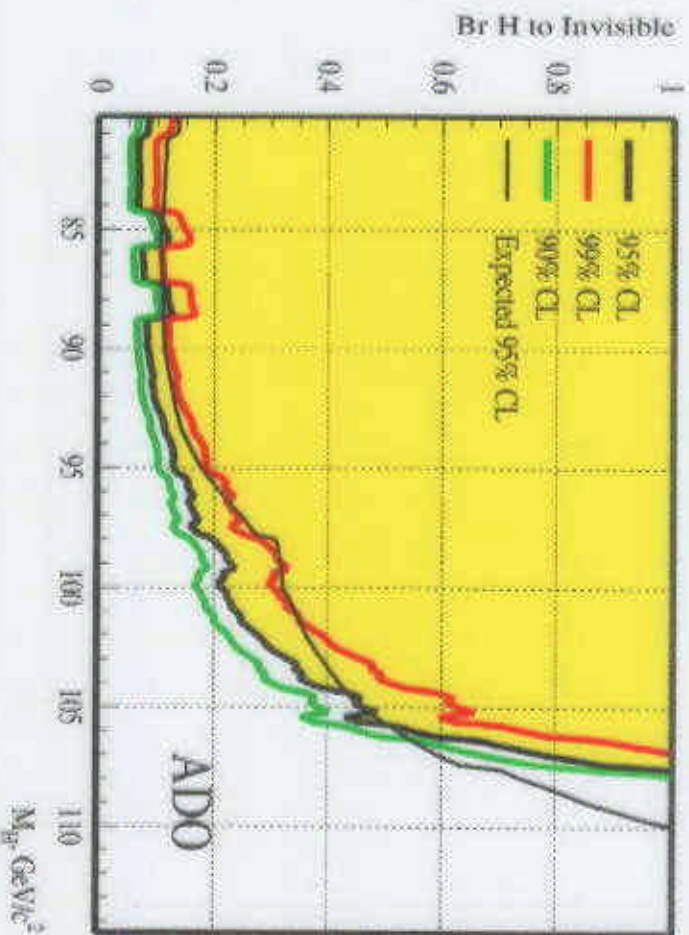


# INVISIBLE HIGGS

$e^-e^+ \rightarrow h^0 Z^0, h^0 \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$   
 $\tilde{\chi}_1^0$  is the lightest neutralino  
 OPAL Limit: 105.8 GeV



*R-parity conserving MSSM*



**LEP Combined**  
 (aleph, delphi, opal)  
 Expected Limit: 110.0 GeV  
 Observed Limit: 107.6 GeV

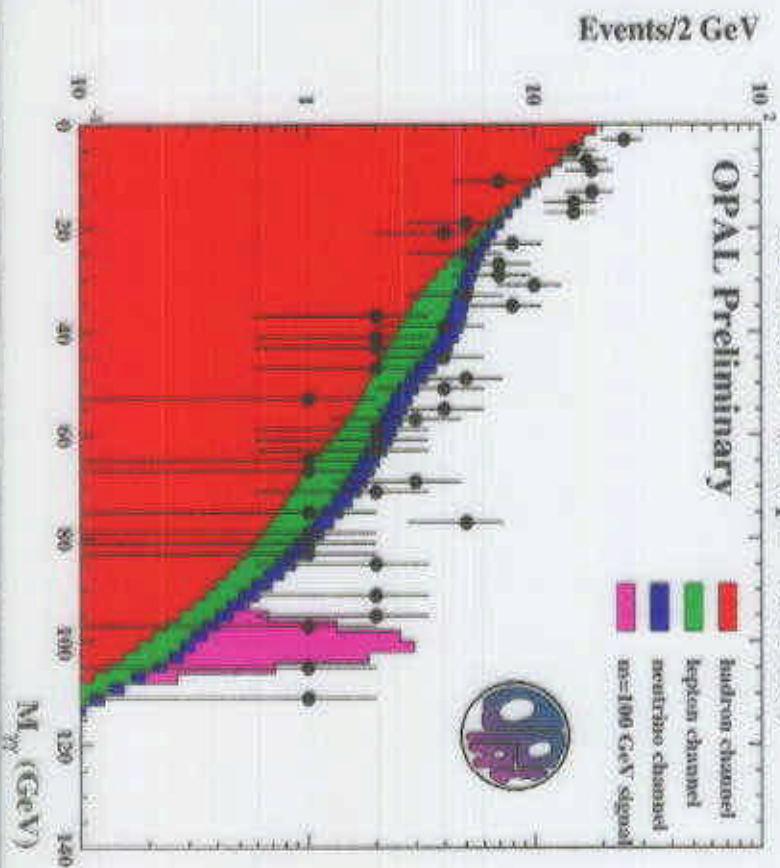


# FERMIOPHOBIC HIGGS

$$e^-e^+ \rightarrow Z^0 h^0, h^0 \rightarrow \gamma\gamma$$

Classified (hadronic, leptonic, neutrino) by Z decay modes.  
 OPAL Limit: 105.1 GeV

88 - 209 GeV (84.6 pb<sup>-1</sup> Y2K data)



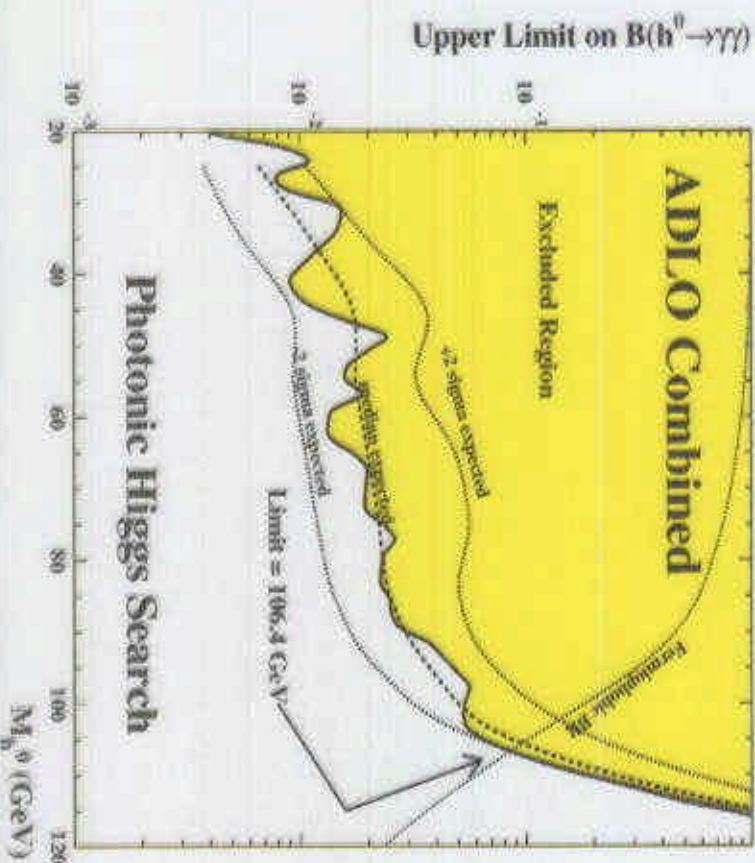
## 2HDM Type I, Bosonic, Higgs Triplets

### LEP Combined

Benchmark: SM  $\sigma$   
 assume fermiophobic

Expected Limit: 105.6 GeV

Observed Limit: 106.4 GeV





# CHARGED HIGGS

non-SUSY two Higgs Doublet Models

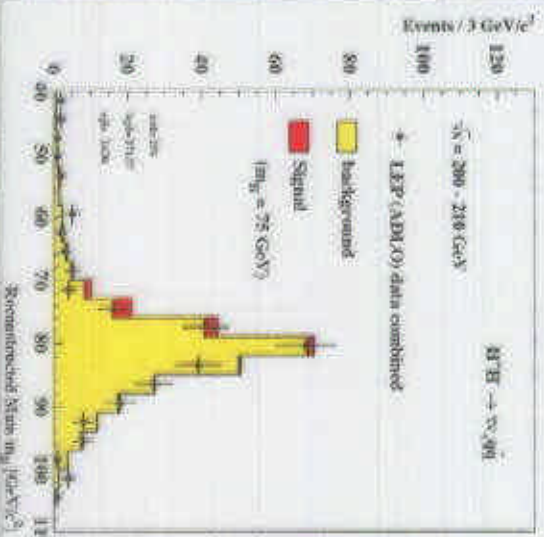
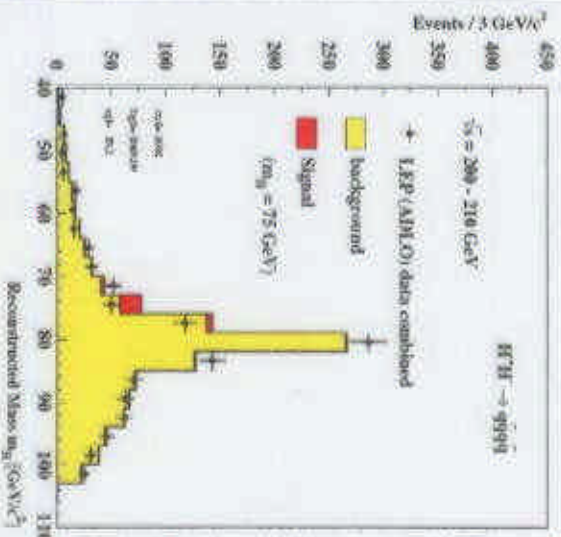
LEP Combined

$Br(H^+ \rightarrow \tau^+ \nu)$	Expected	Observed
0.0	79.6 GeV	80.8 GeV
1.0	90.5	87.7
Any	78.8	<del>77.4</del> 77.4

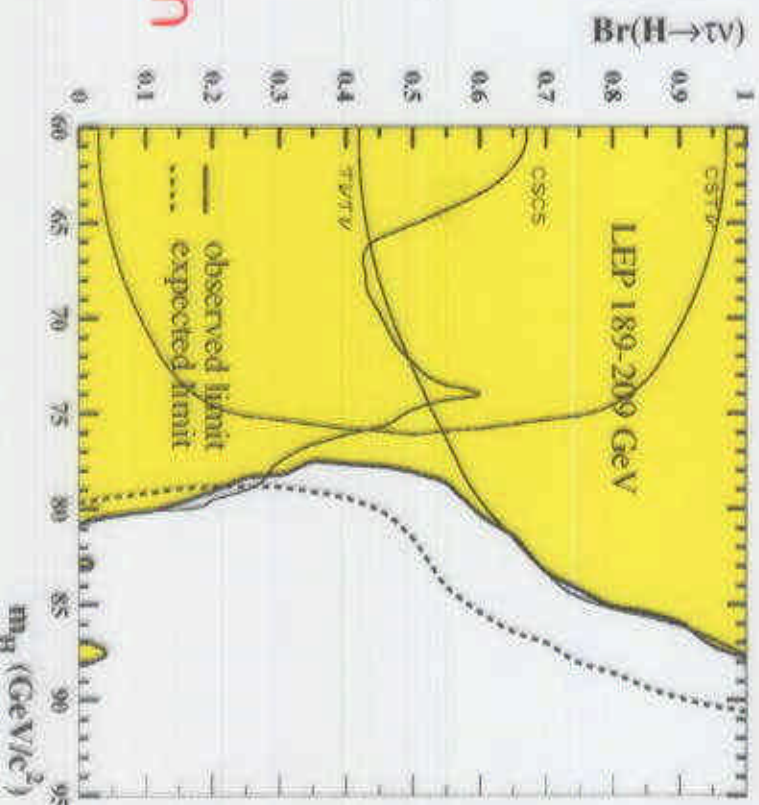
Assuming:

$$Br(H^+ \rightarrow \tau^+ \nu) +$$

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



No mass reconstruction for  $\tau\nu\tau\nu$  channel



# OPAL HIGGS-STRAHLUNG

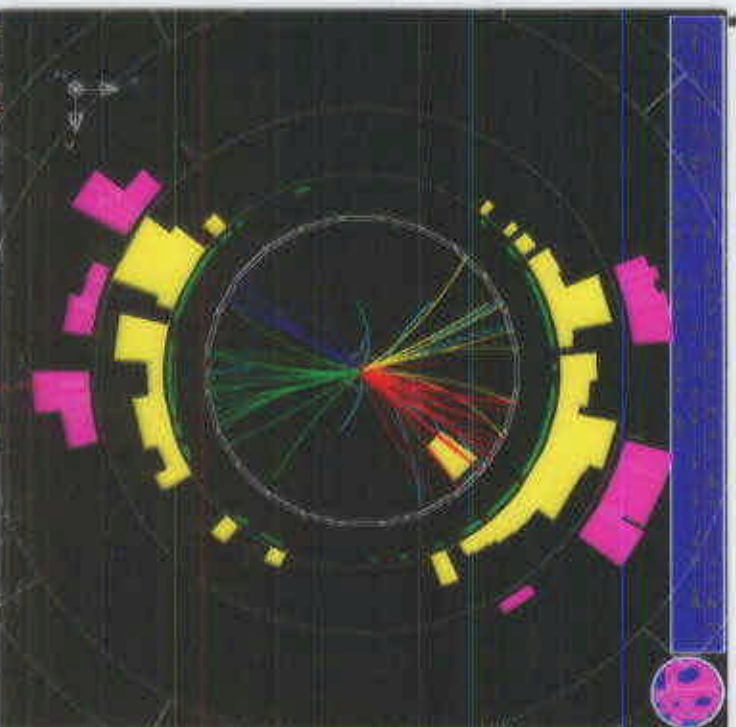
Standard Model, MSSM

$$e^-e^+ \rightarrow Z^0 H^0$$

$Z^0 H^0 \rightarrow q\bar{q}b\bar{b}$  "4 jet"  
 $\nu\bar{\nu}b\bar{b}$  "missing energy"  
 $e^-e^+b\bar{b}, \mu^-\mu^+b\bar{b}$  "leptonic"  
 $\tau^+\tau^-b\bar{b}, q\bar{q}\tau^+\tau^-$  "tau"

OPAL limit: obs 109.5 GeV exp. 109.5 GeV

Background	Data
$8.9 \pm 1.1$	7
$13.6 \pm 1.4$	6
$3.4 \pm 0.4$	8
$1.3 \pm 0.2$	0



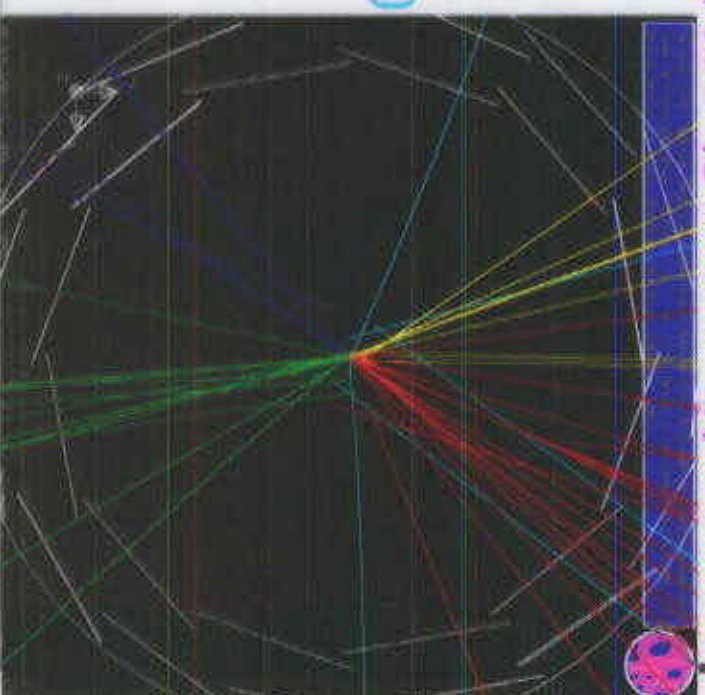
## Candidate

from June 27, 2000

4 jet channel

mass = 113 GeV

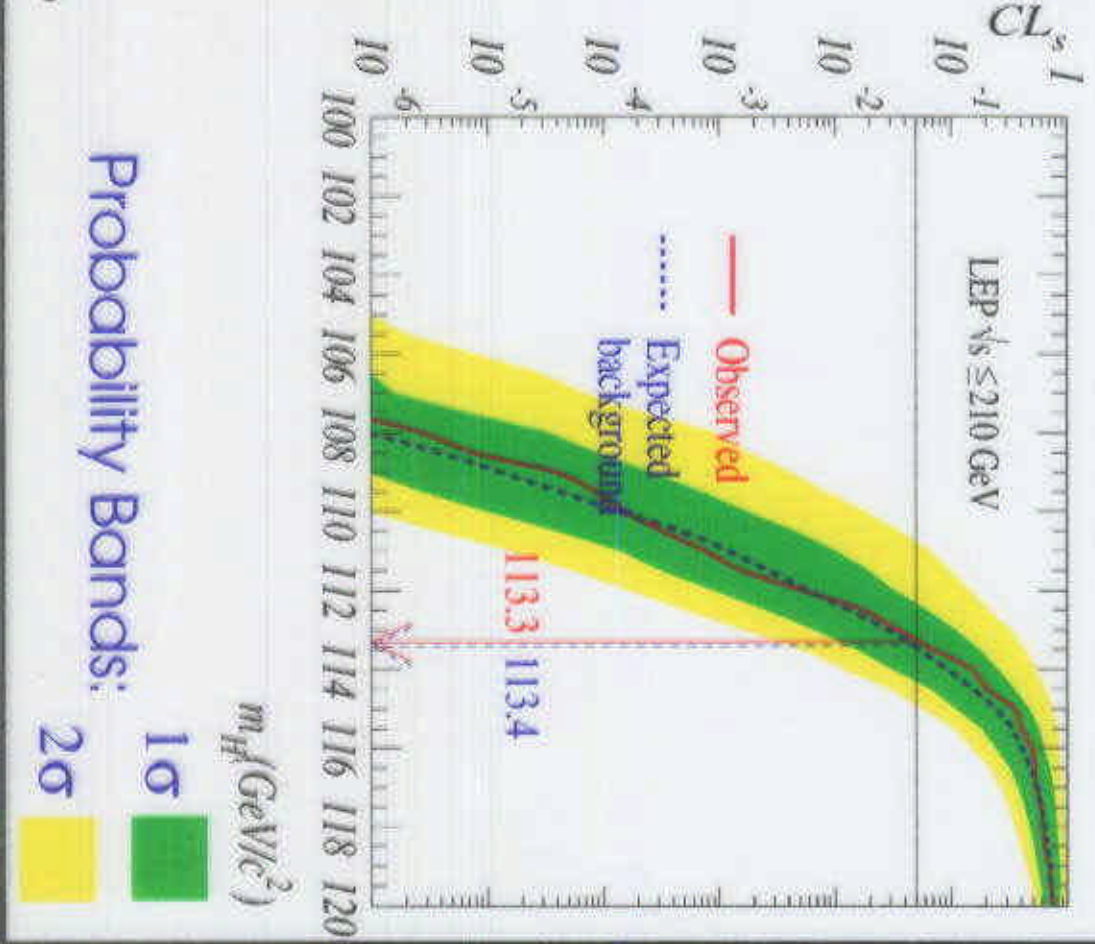
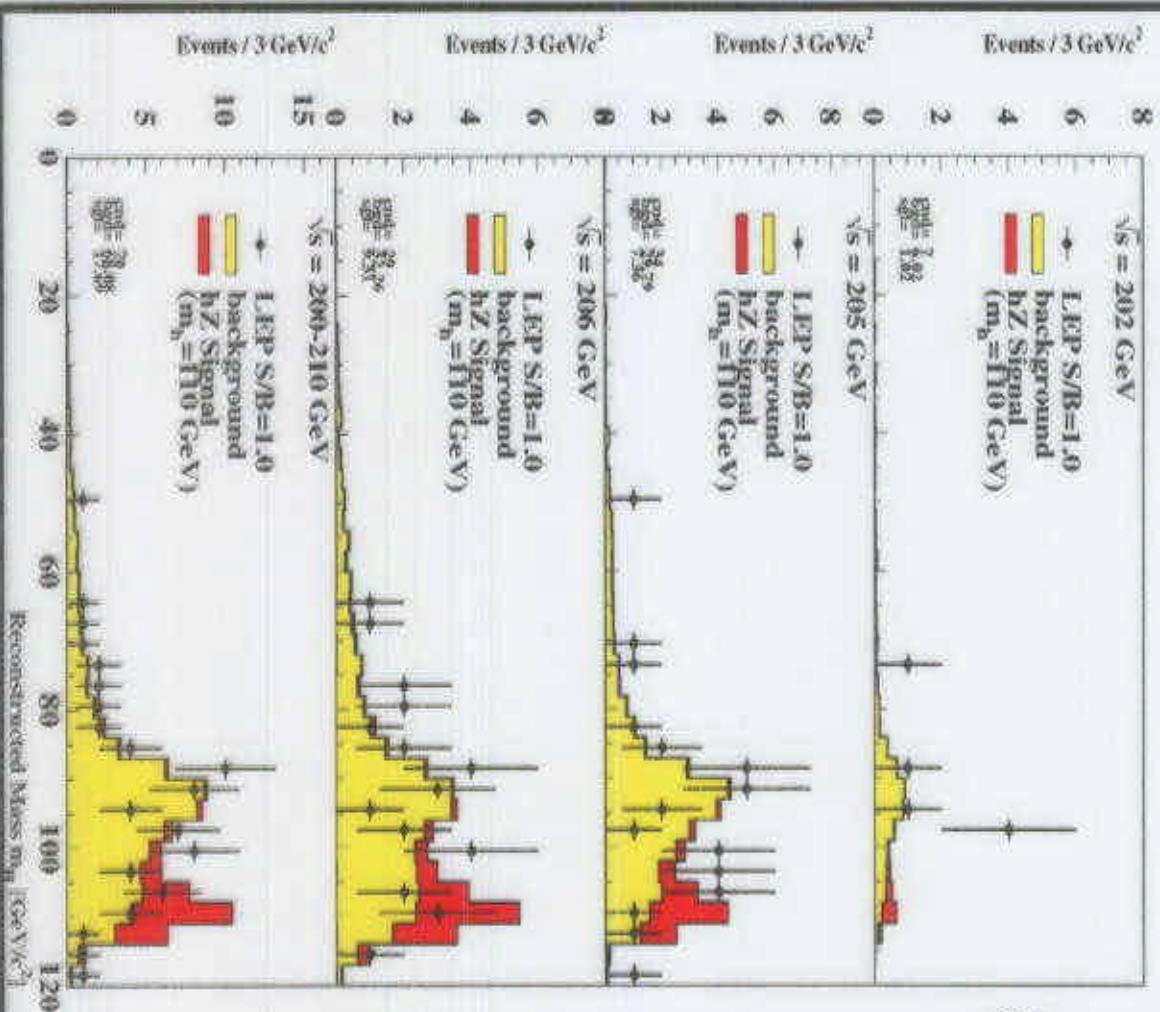
@  $\sqrt{s} = 205.4$  GeV



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# THE STANDARD MODEL HIGGS

LEP Combined



Probability Bands:



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# HIGGS ASSOCIATED PRODUCTION

2HDM's

$$e^- e^+ \rightarrow A^0 h^0$$

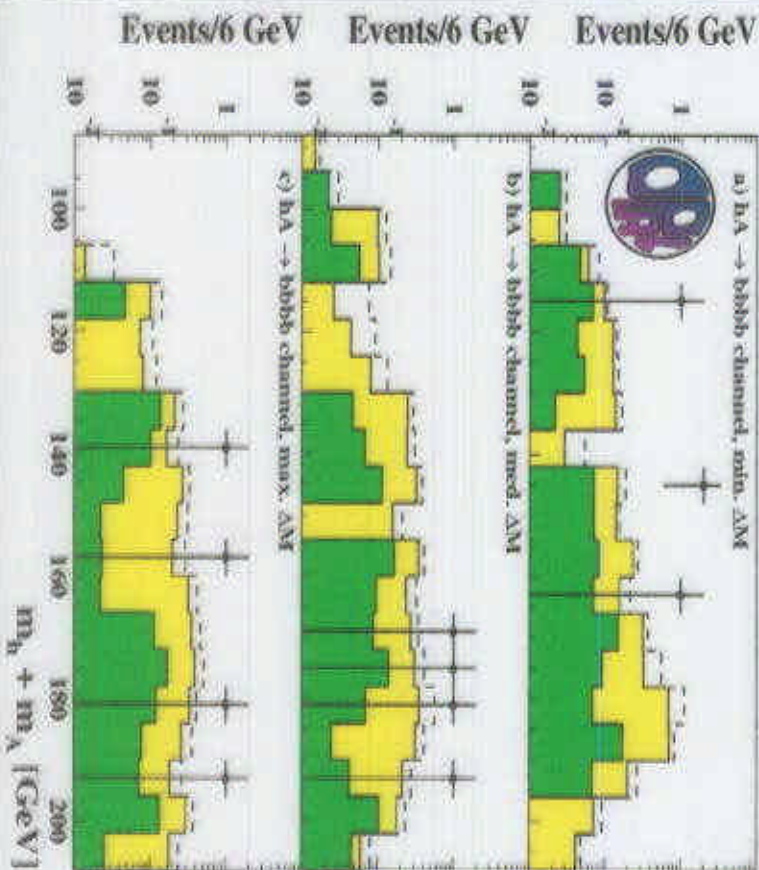
No Z mass constraint:

Candidates

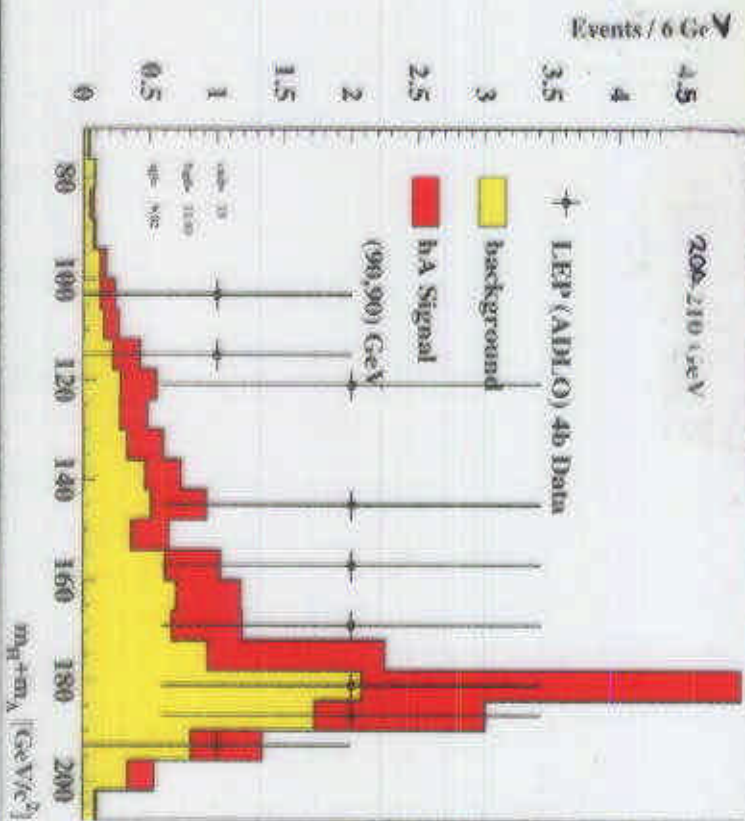
- $A^0 h^0 \rightarrow \tau^- \tau^+ b \bar{b}$
- $A^0 h^0 \rightarrow b \bar{b} b \bar{b}$

Year 2000	1999
<u>expect</u>	<u>expect</u>
<u>data</u>	<u>data</u>
1.7 ± 0.2	7.2
3.7 ± 0.4	10.2
4	16

## OPAL preliminary



## LEP Combined



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# NEUTRAL MSSM HIGGS

Higgs-strahlung:

$$e^+ e^- \rightarrow Z^0 h^0$$

$$\sigma = \sin^2(\beta - \alpha) \sigma_{SM}$$

→ reinterpret above SM searches

Associated production:

$$e^+ e^- \rightarrow A^0 h^0$$

$$\sigma \propto \cos^2(\beta - \alpha) \sigma_{SM}$$

→ apply Model assumption to 2HDM Higgs

LEP Combined

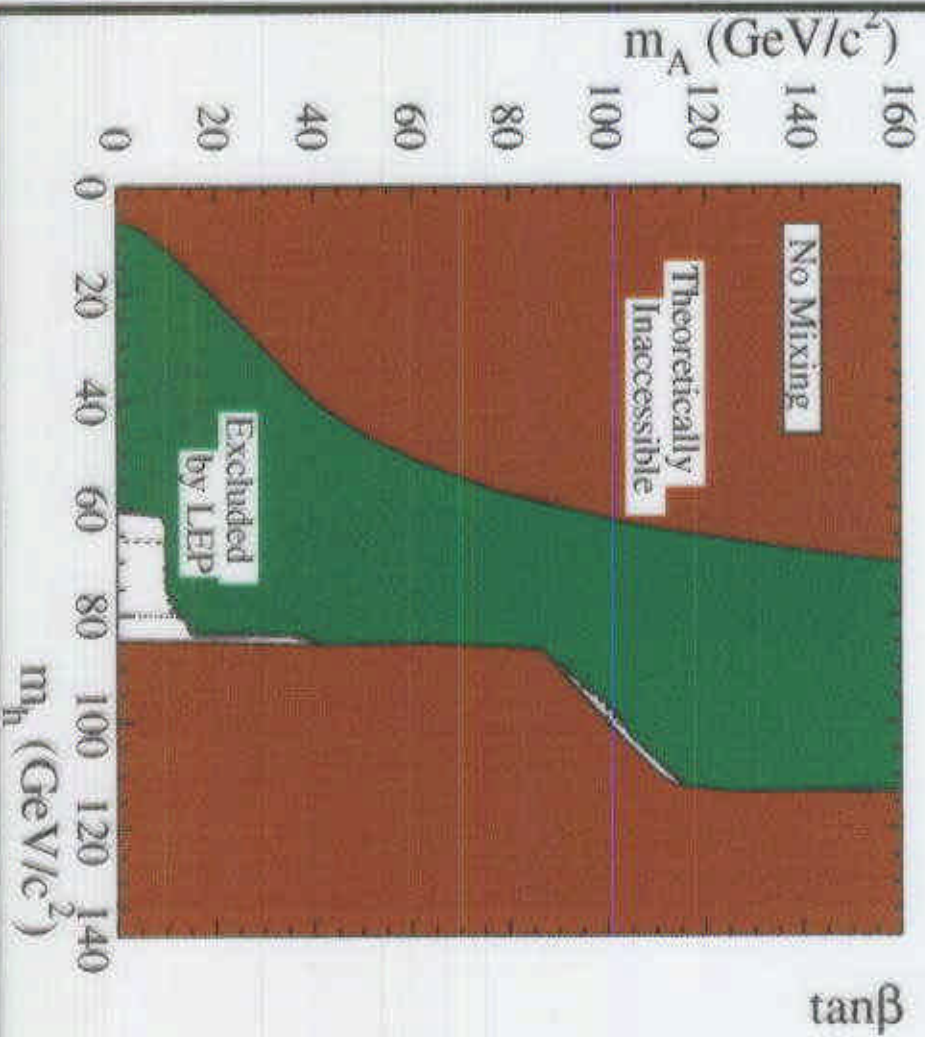
Benchmark	$m_h$ (GeV)	$m_A$ (GeV)	$\tan\beta$
Maximize allowed $m_h$	90.5	90.5	0.53-2.27
No stop mixing	90.4	90.5	0.9-7.7
Large $\mu$ $Br(h^0 \rightarrow b\bar{b}) \rightarrow 0$	-	-	-



# NEUTRAL MSSM HIGGS

**Benchmark: No stop mixing**

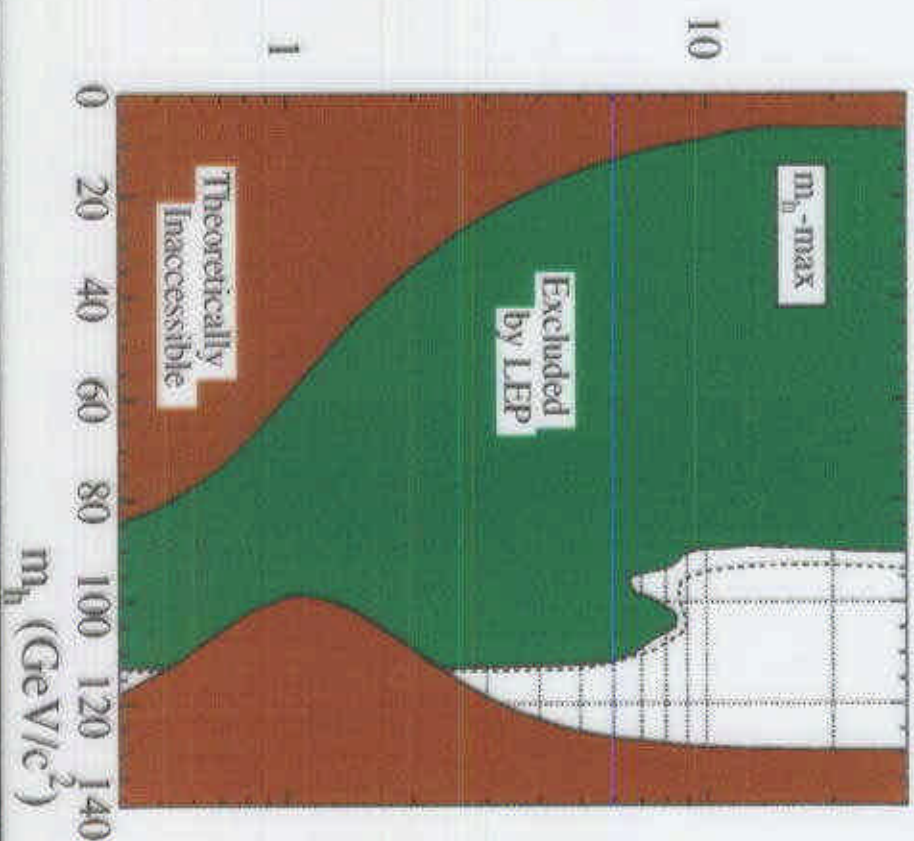
Excluded:  $m_A < 90.5$   $m_h < 90.4$   
 $0.9 < \tan\beta < 7.7$



**LEP Combined**

**Maximize allowed  $m_h$**

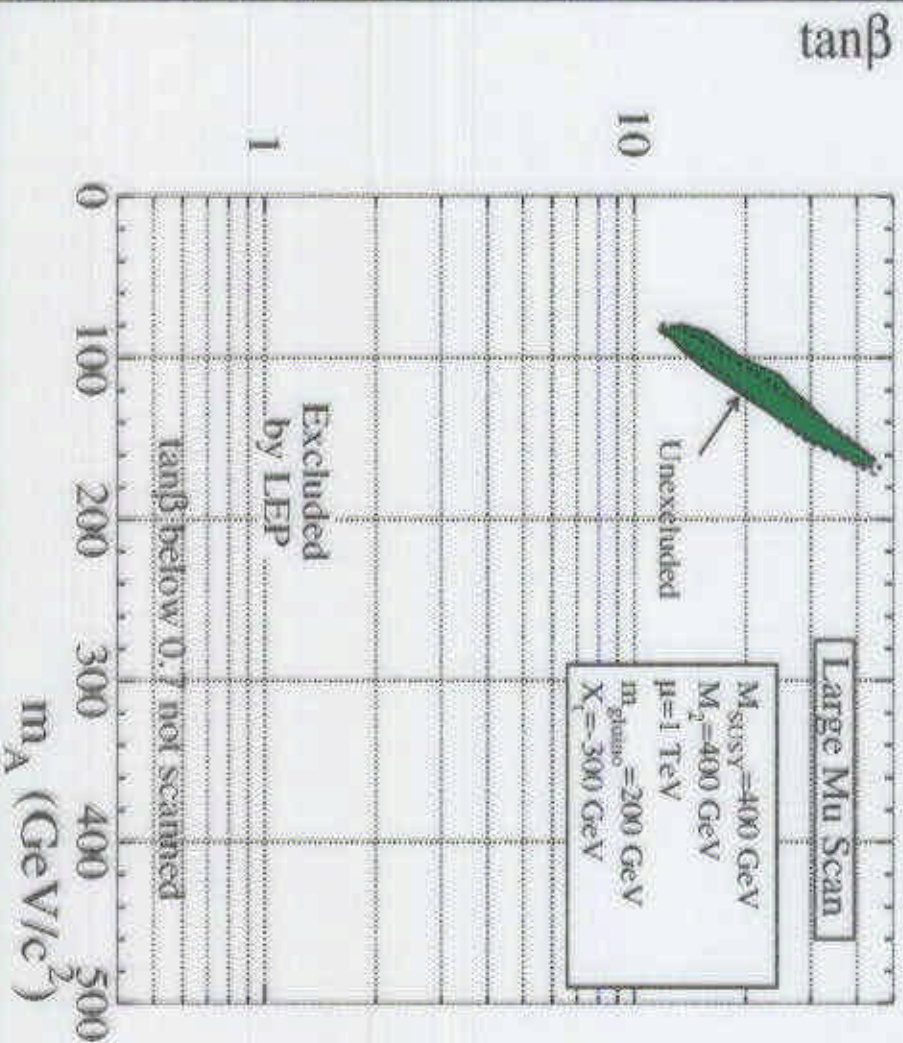
Excluded:  $m_A < 90.5$   $m_h < 90.5$   
 $0.5 < \tan\beta < 2.3$



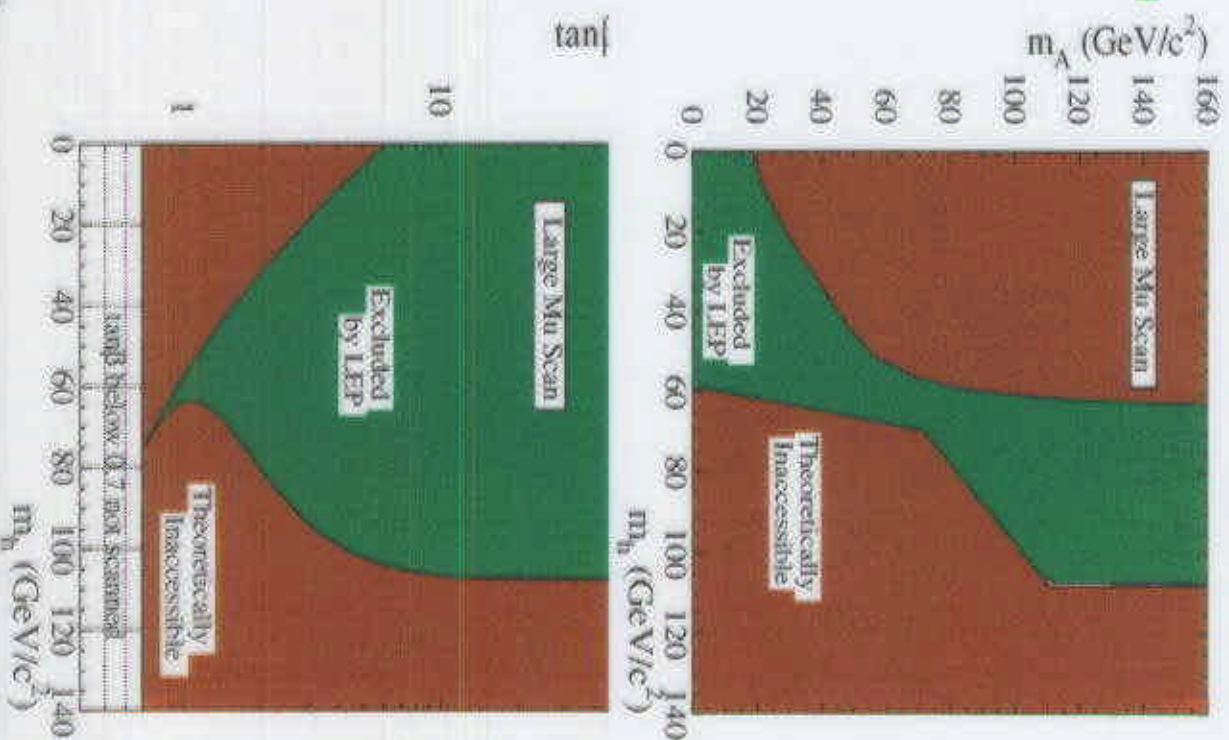
# NEUTRAL MSSM HIGGS

Benchmark: Large- $\mu$   $Br(h^0 \rightarrow b\bar{b}) \rightarrow 0$   
 due to loop cancellations

Use flavor-independent channels.



LEP Combined



# CONCLUSIONS

A wide range of scenarios actively (tirelessly!) sought.  
Too many to show here! Read our note!

Some “curiosities” but no compelling evidence  
of new physics...yet.

The Higgs remains elusive.

Time is running out...

We will continue until they send the  
wrecking ball.

