17 April, 2001
UCSB

Searches for Signs of an Extended Higgs Sector at LEP

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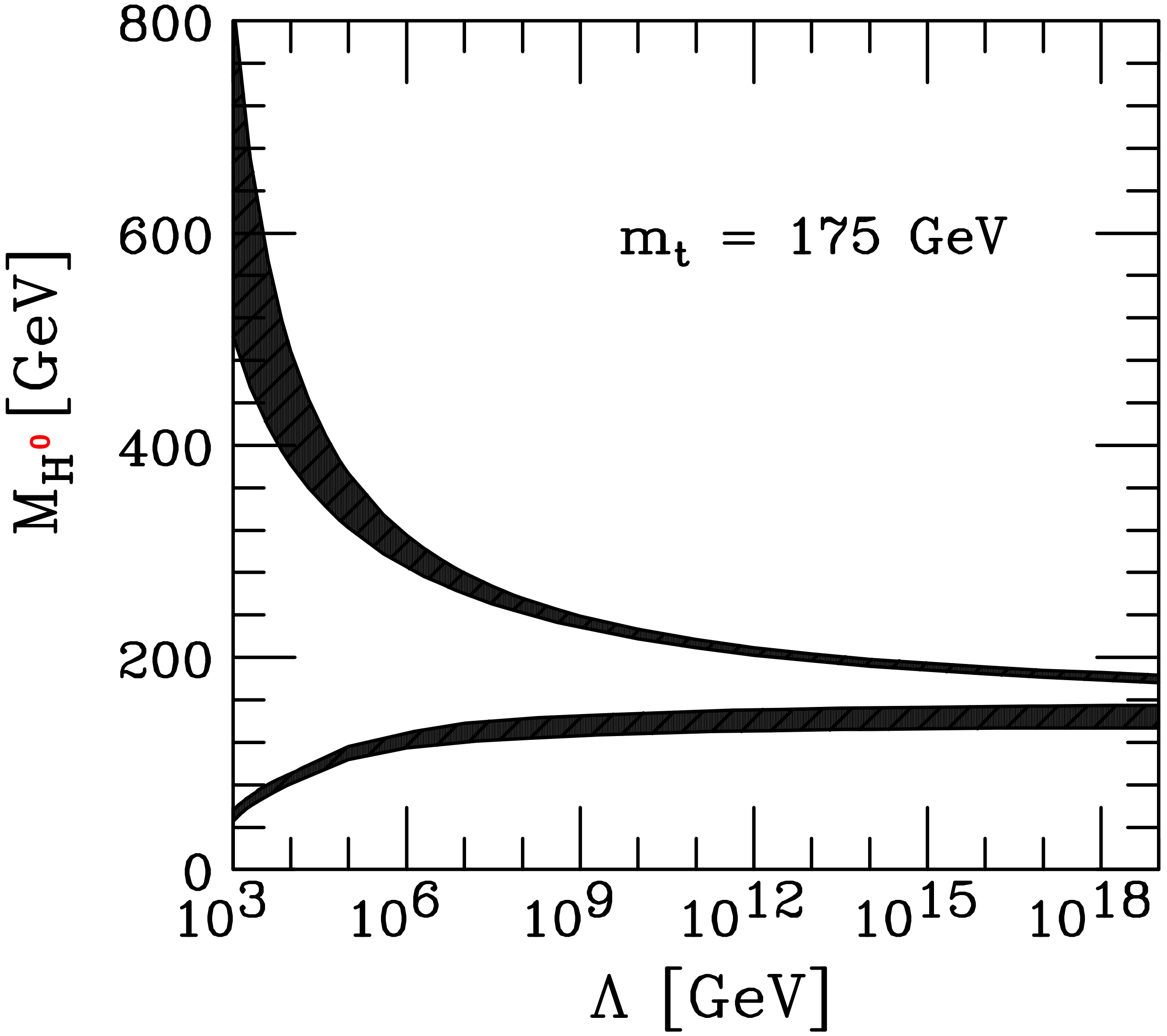
- Motivating Extended Higgs Sectors
- MSSM Searches and Combinations
- Charged Higgs Searches
- $H \rightarrow \gamma\gamma$ Searches
- Invisibly Decaying Higgs Bosons
- Flavor- and Model-Independent Higgs searches

Preliminary, Moriond 2001 Results

Consequences of Believing the Standard Model up to the Planck Scale



hep-ph/9708416 and references therein

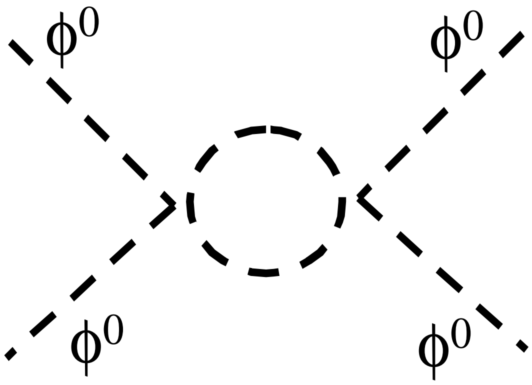
Λ is the scale at which interactions beyond the Standard Model become important

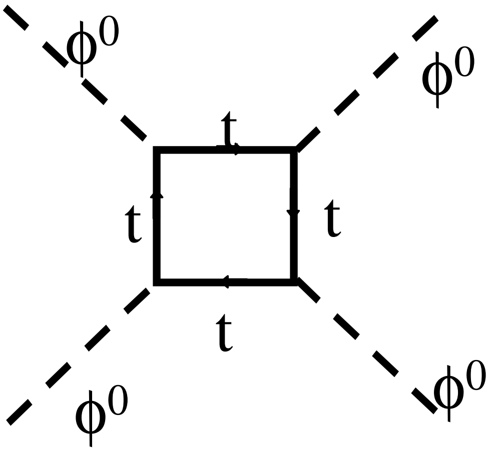
Upper Higgs mass bound -- Landau pole -- Higgs self-coupling grows without bound as the energy scale increases

Lower Higgs mass bound -- vacuum stability

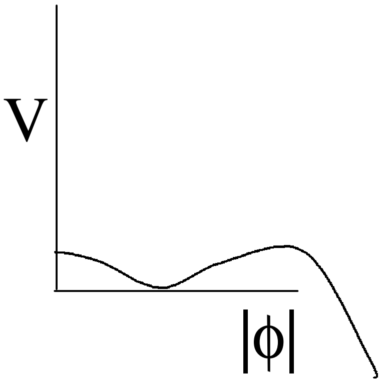
The Vacuum Stability Argument for a lower bound on the Higgs Mass

One-loop correction terms to to the quartic self-coupling:


ϕ^0
ϕ^0
ϕ^0
ϕ^0


ϕ^0
ϕ^0
t
t
t
t
ϕ^0
ϕ^0

Then $V = \frac{1}{2}\mu^2\phi^2 + \frac{1}{4}\lambda\phi^4$ picks up an additional term proportional to $-m_t^4\phi^4$ (among other terms)
V(ϕ) turns negative if m_H is too light:



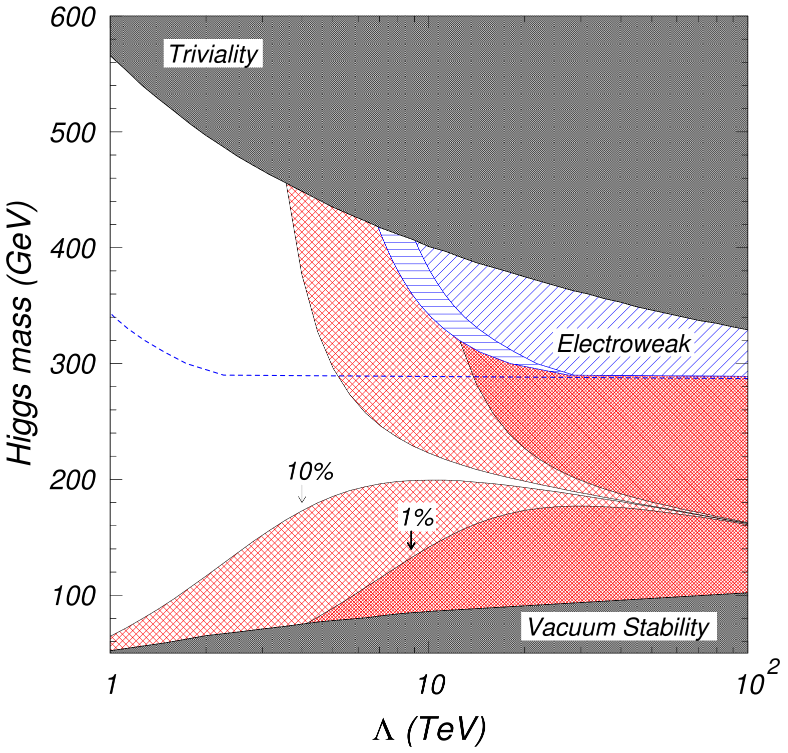
Review: M. Sher, Phys. Rep. 179 (1989) 273.
Calculaitons with measured m_t: Casas, Espinosa, and Quirós

Radiative Corrections and Fine-Tuning

Kolda and Murayama,   hep-ph/0003170

One-loop correction to μ^2 is proportional to Λ^2, which destabilizes the weak scale, unless m_h is exquisitely chosen.

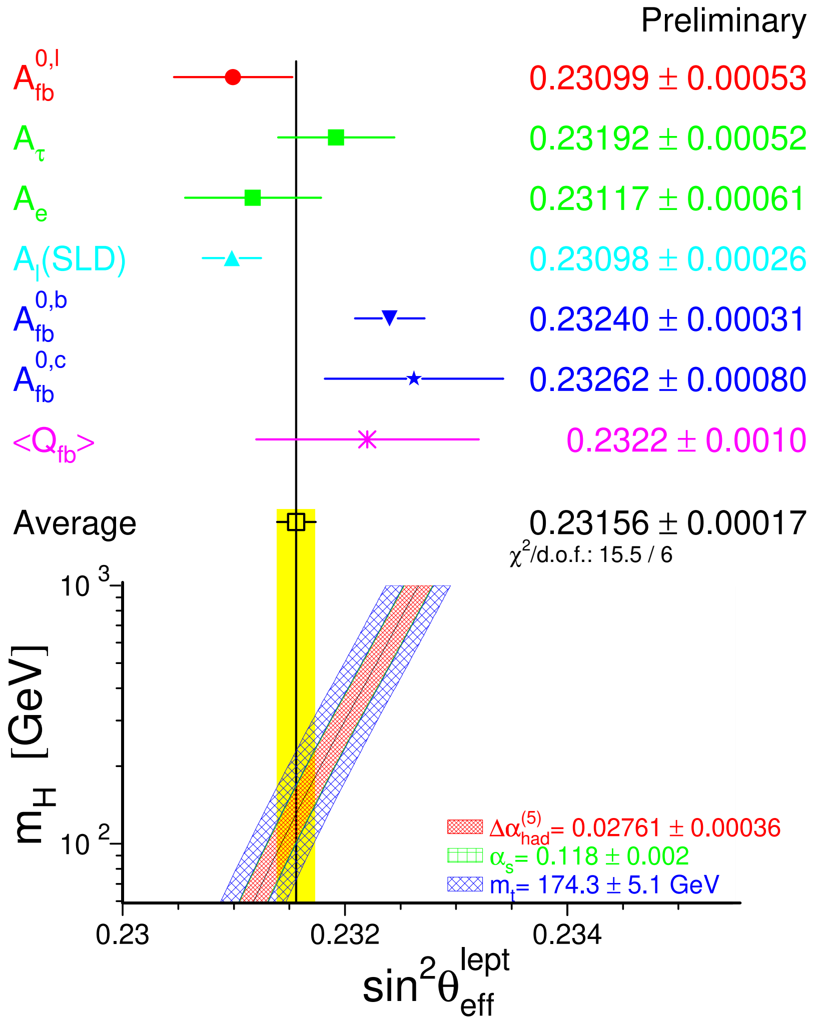
$$\mu^2 \to \mu^2 + \frac{3\Lambda^2}{32\pi^2 v^2}\left(2m_W^2 + m_Z^2 + m_h^2 - 4m_t^2\right)$$



SUSY: boson loops and fermion loops cancel -- but the SUSY breaking scale < 1 TeV for a natural solution.

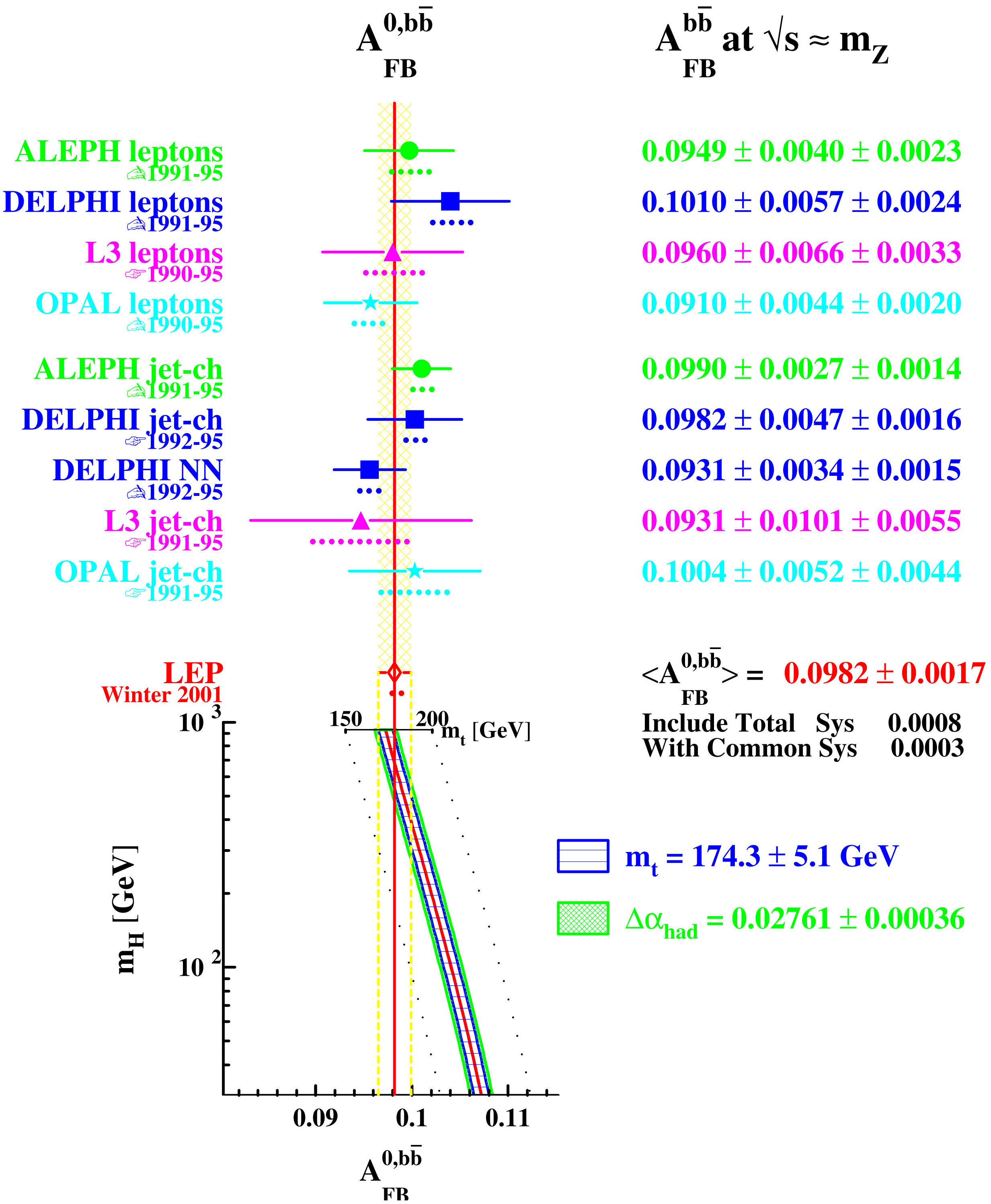
Electroweak Precision Data Sensitivity to m_H

New Measurements of $A_{FB}^{0,b}$ from
ALEPH and DELPHI (Moriond 2001)
Pulls m_H prediction up (and adds χ^2 to the fit)



Central Value of $A_{FB}^{0,b}$ nearly unchanged, but much smaller error.
Comparing avg. leptonic and hadronic measurements of $\sin^2\theta_{W,eff}$ gives a **3.7 sigma discrepancy.**
(Davier, Higgs+SUSY) *Problems in the b sector?*

Summary of A^{b}_{FB} Measurements



	$A^{b\bar{b}}_{FB}$ at $\sqrt{s} \approx m_Z$
ALEPH leptons	$0.0949 \pm 0.0040 \pm 0.0023$
DELPHI leptons	$0.1010 \pm 0.0057 \pm 0.0024$
L3 leptons	$0.0960 \pm 0.0066 \pm 0.0033$
OPAL leptons	$0.0910 \pm 0.0044 \pm 0.0020$
ALEPH jet-ch	$0.0990 \pm 0.0027 \pm 0.0014$
DELPHI jet-ch	$0.0982 \pm 0.0047 \pm 0.0016$
DELPHI NN	$0.0931 \pm 0.0034 \pm 0.0015$
L3 jet-ch	$0.0931 \pm 0.0101 \pm 0.0055$
OPAL jet-ch	$0.1004 \pm 0.0052 \pm 0.0044$

$\langle A^{0,b\bar{b}}_{FB} \rangle = 0.0982 \pm 0.0017$

Include Total Sys 0.0008
With Common Sys 0.0003

Interpretation of A_{FB}

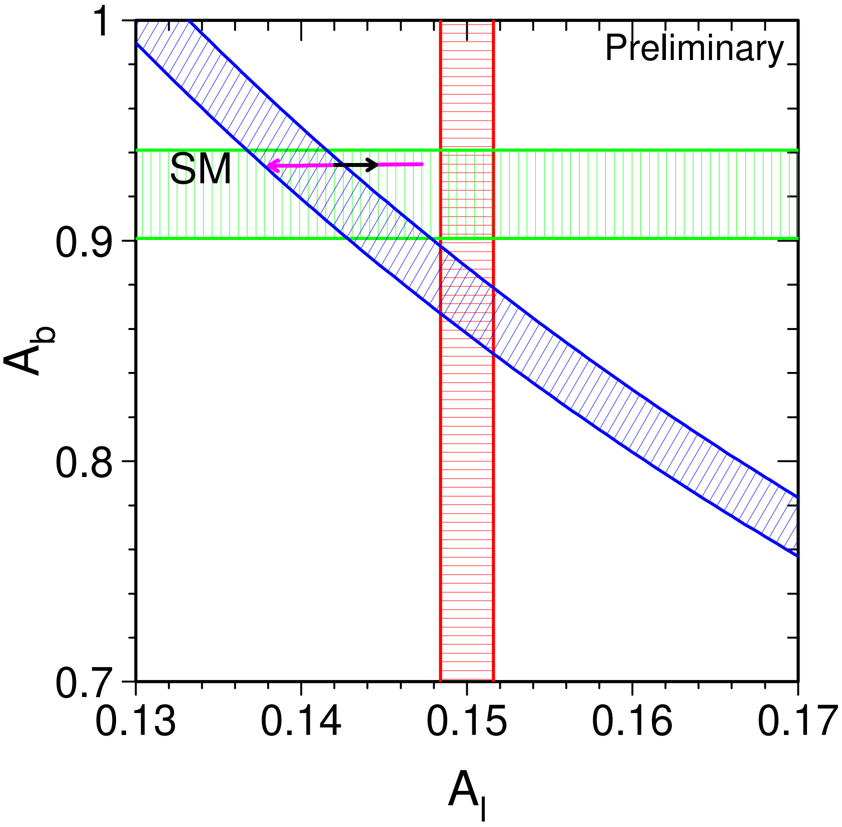
A forward-backward asymmetry of fermions in Z^0 decay requires parity violation at

- the Z^0 production vertex - *polarize the Z*
- the Z^0 decay vertex - *analyze its polarization*

$$A_{FB}^b = \frac{3}{4} A_e A_b$$

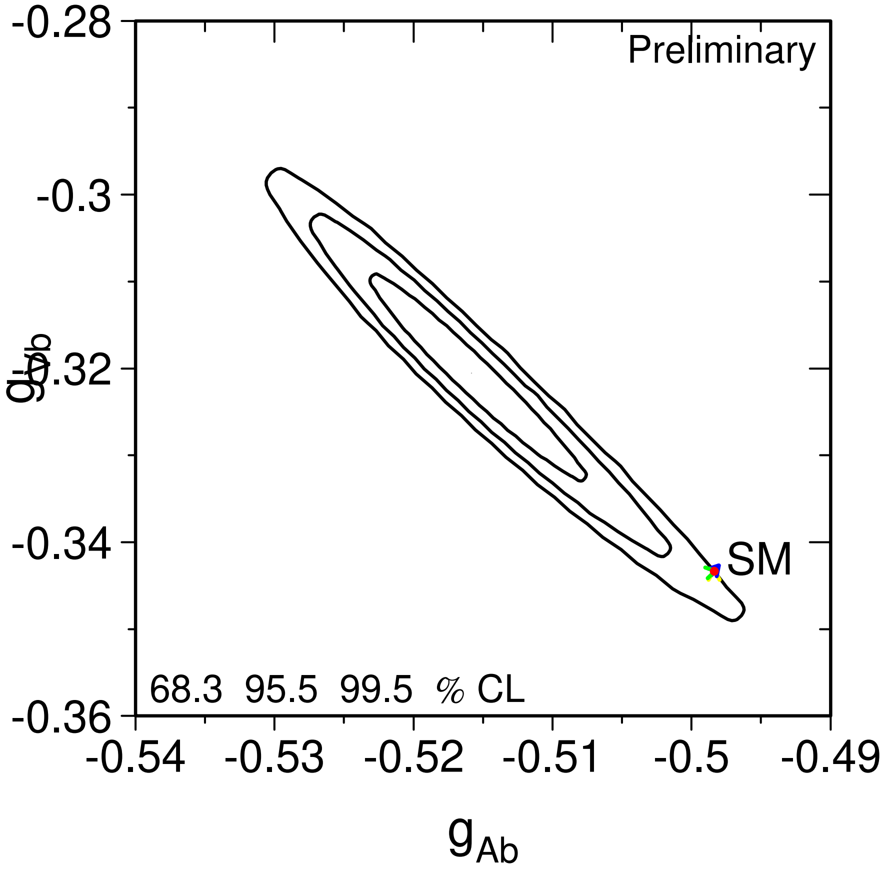
SLD, with a polarized e^- beam can measure A_e and A_b separately.

SM fit for m_H effectively constrains A_b to its SM value. (weak dependence on $\sin^2\theta_W$)



Trouble with A_b? Need more Z^0 running! (R_b is now “fine”)

Separate Fit for B Couplings

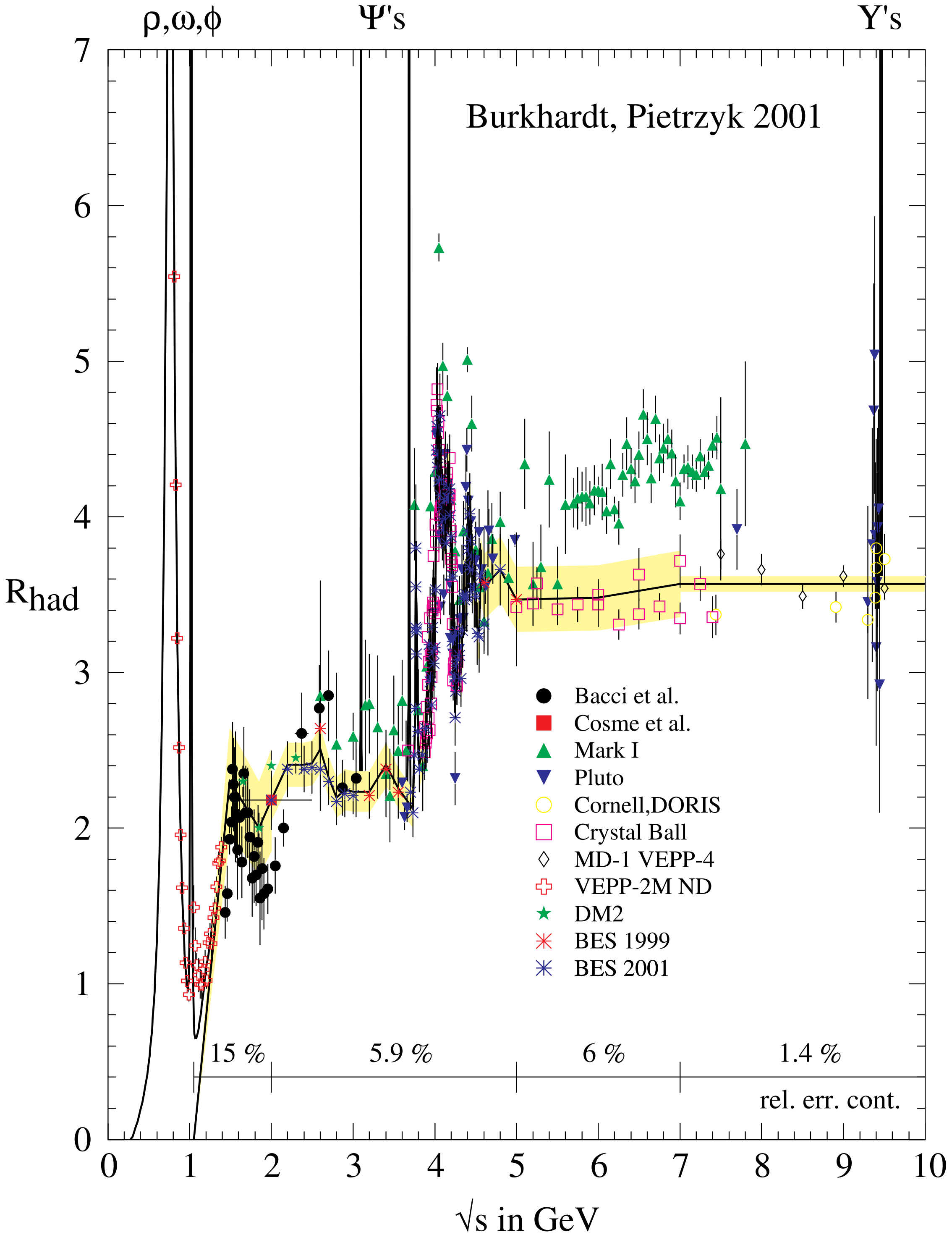


Ingredients: R_b, $A_{FB,b}$, and A_e from leptonic measurements.

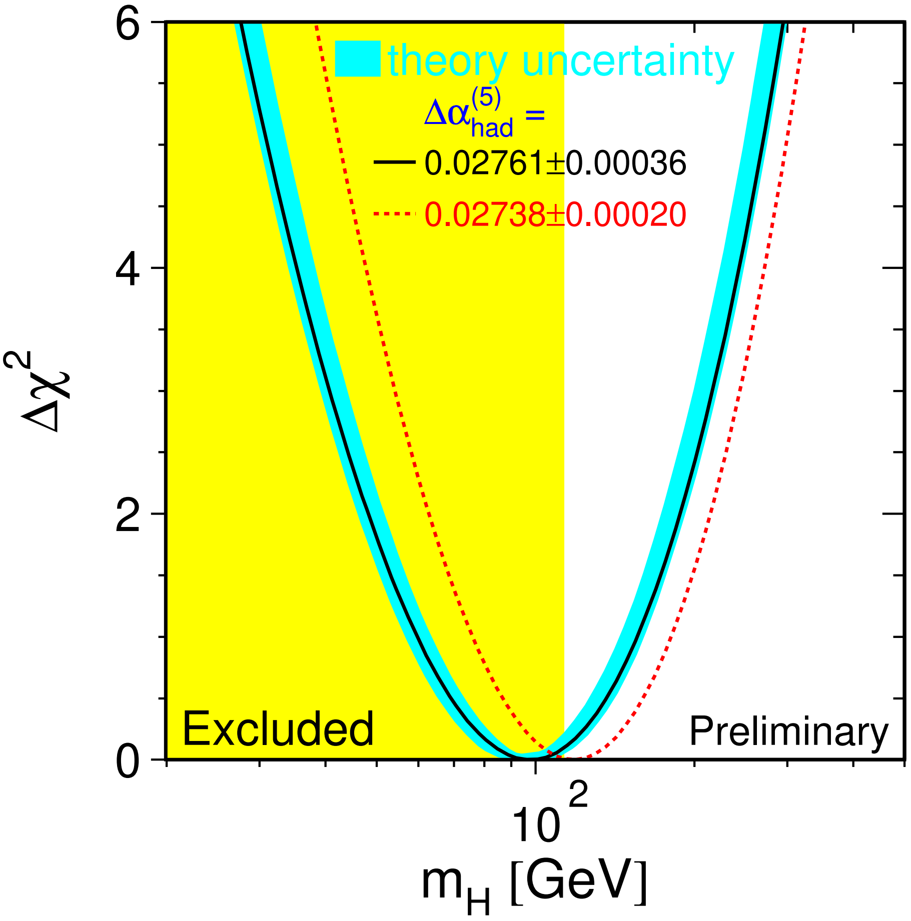
Left-handed Zbb coupling seems okay,
Right-handed one having more trouble.

BES Measurements of R_{had}

- Used to estimate 1-loop QCD vacuum polarization corrections to $\alpha_{EM}(m_Z)$
  Reduced uncertainty in the 2-5 GeV range



Electroweak Fit Constraint on m_H



m_W, m_t msmnts included

- $\sin^2\theta_W$ depends on the logarithm of m_H

Current central value:

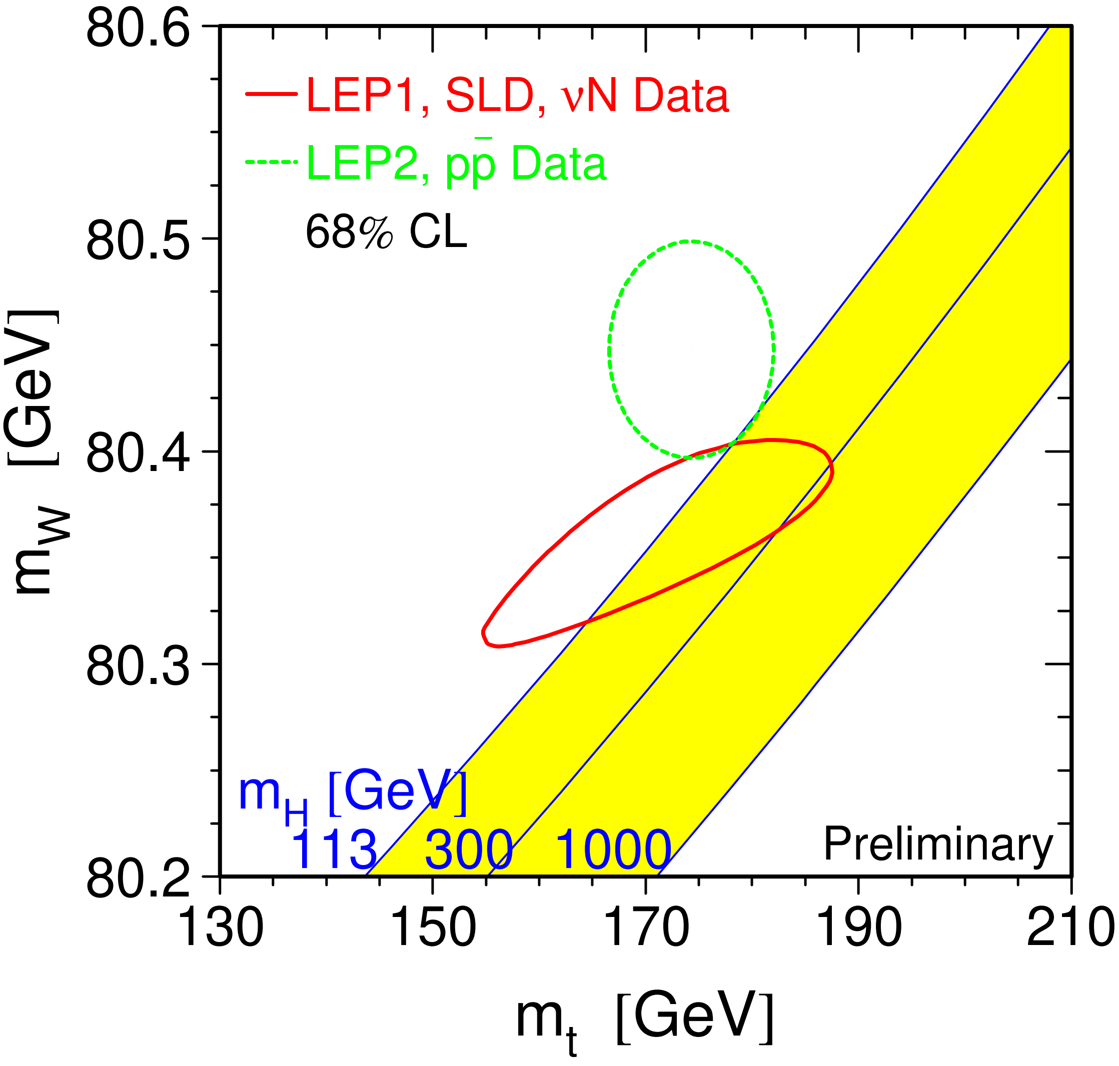
$$\boxed{m_H = 98^{+58}_{-38}\ \text{GeV}}$$

Results as of Moriond 2001

- 95% CL Upper limit

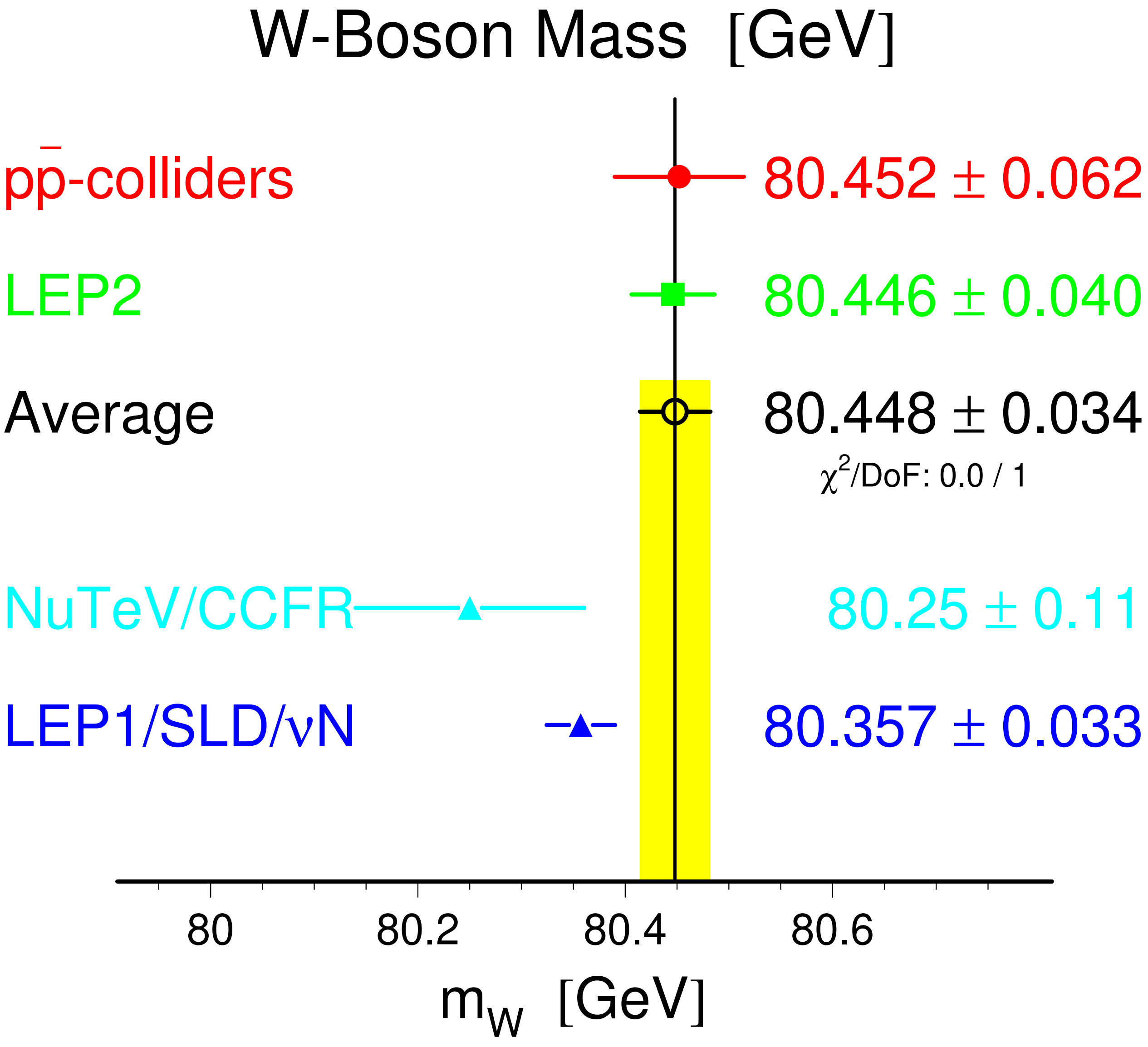
$$m_H < 212\ \text{GeV}$$

Separating the Effects of m_W and m_t from the Z^0 observables



W mass measurements are indicating
a light Higgs boson also
(too light!) -- SM Picture only, however..

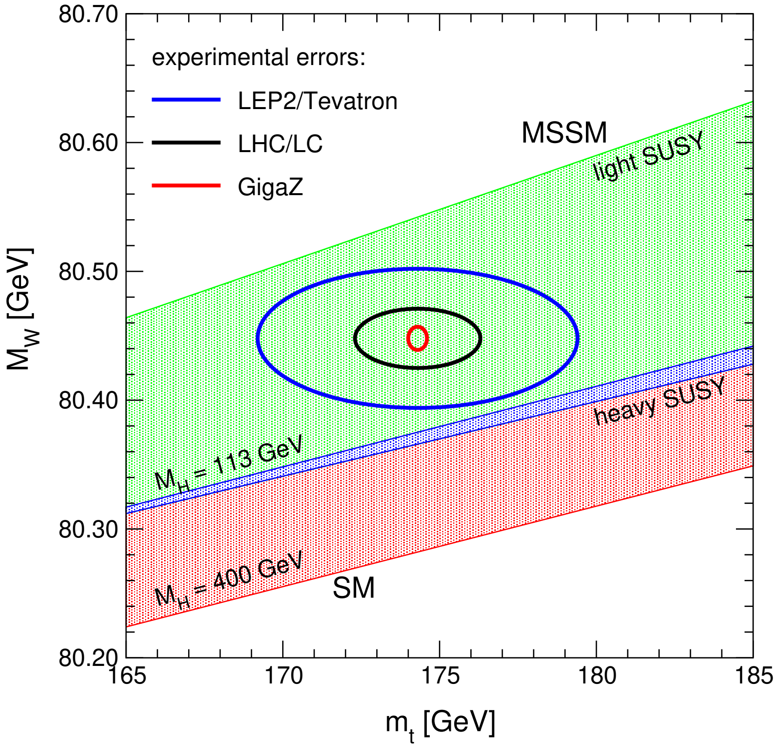
W Boson Mass Measurement Summary



Was: m_W=80.33 GeV in 1998

-- pulling the predicted m_H down!

Higgs Sector is Acutely Sensitive to the Presence of SUSY



Future colliders: only error bars shown.

SM: m_H varied. SUSY: parameters varied

Ref: S. Heinemeyer and G. Weiglein, hep-ph/0012364 (LCWS2000); A. Djouadi, P. Gambino, S. Heinemeyer, W. Hollik, C. Jünger, G. Weiglein hep-ph/9612363, hep-ph/9710438

SM: Lower bound on m_H from theory, experiment.
SUSY: Upper bound on m_h from theory.
Small overlap!

Prediction: some kind of Higgs boson will be found before m_t and m_W get as precise as shown.

MSSM Parameters

"Low-energy effective SUSY (CP-conserving)"

Seven Parameters to specify it:

M_2: EW scale SU(2) Gaugino mass. Assume Gaugino masses unified at GUT scale

M_{SUSY}: Soft SUSY-Breaking mass scale (common masses for squarks, sleptons, sneutrinos at the EW scale, modulo squark mixing splitting the L and R states)

$\tan\beta$: Ratio of the VEV's of the two Higgs doublets

μ: Higgs mass/mixing parameter

A_0: Common trilinear coupling (parameterizes squark mixing)

M_A: Mass of the CP-odd Higgs Boson

$m_{\tilde{g}}$: Gluino mass -- only important via loops

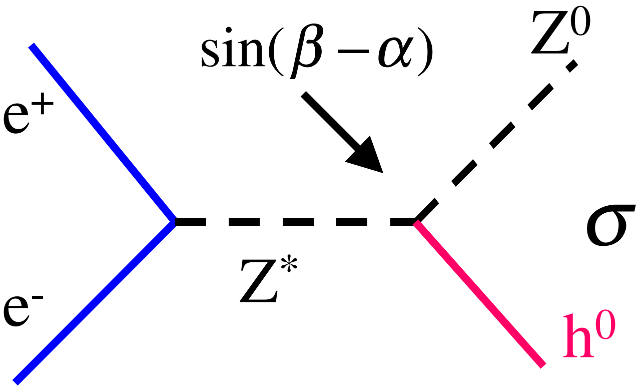
Can derive: m_h, m_H, α: mixing angle between two doublets for the neutral Higgses

The Neutral Higgses of the MSSM

Two Higgs Doublets: 5 Higgses

h^0	light CP-even Higgs
H^0	heavy CP-even Higgs
A^0	CP-odd Higgs
H^+, H^-	Charged Higgs

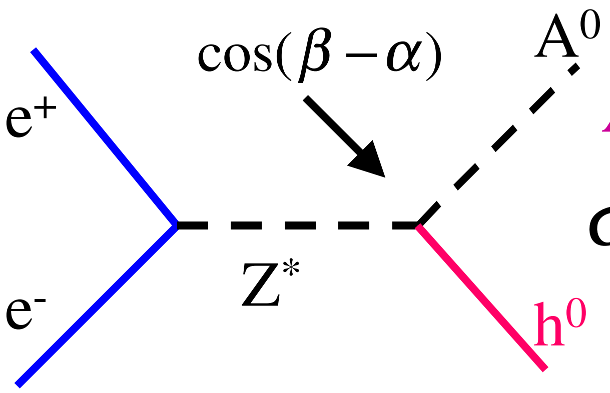
$$\boxed{m_{h^0} < \sim 135 \text{ GeV}}$$


$\sin(\beta-\alpha)$
Z^0
e^+
e^-
Z^*
h^0

Higgs-strahlung

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

And fusion processes too!


$\cos(\beta-\alpha)$
A^0
e^+
e^-
Z^*
h^0

Associated Production

$$\sigma_{hA} = \cos^2(\beta-\alpha)\bar{\lambda}\sigma_{hZ}^{SM}$$

$\bar{\lambda}$: kinematic factor $(m_h, m_A, \sqrt{s})$

Decay Modes of MSSM Higgses

Tree-level couplings of the MSSM
Higgses to Fermions

Up-type quarks

Down-type quarks
(and charged leptons)

$$h^0 t\bar{t} \propto \frac{\cos\alpha}{\sin\beta} \qquad h^0 b\bar{b} \propto \frac{-\sin\alpha}{\cos\beta}$$

$$A^0 t\bar{t} \propto \cot\beta \qquad A^0 b\bar{b} \propto \tan\beta$$

For tanβ>1 $Br(h^0 \to b\bar{b}) \approx 90\%$

Increases with tanβ, most of remainder goes to $\tau^+\tau^-$.

- Low tanβ: charm+gluons!
- Low mA, **$h^0 \to A^0 A^0$ can be dominant**

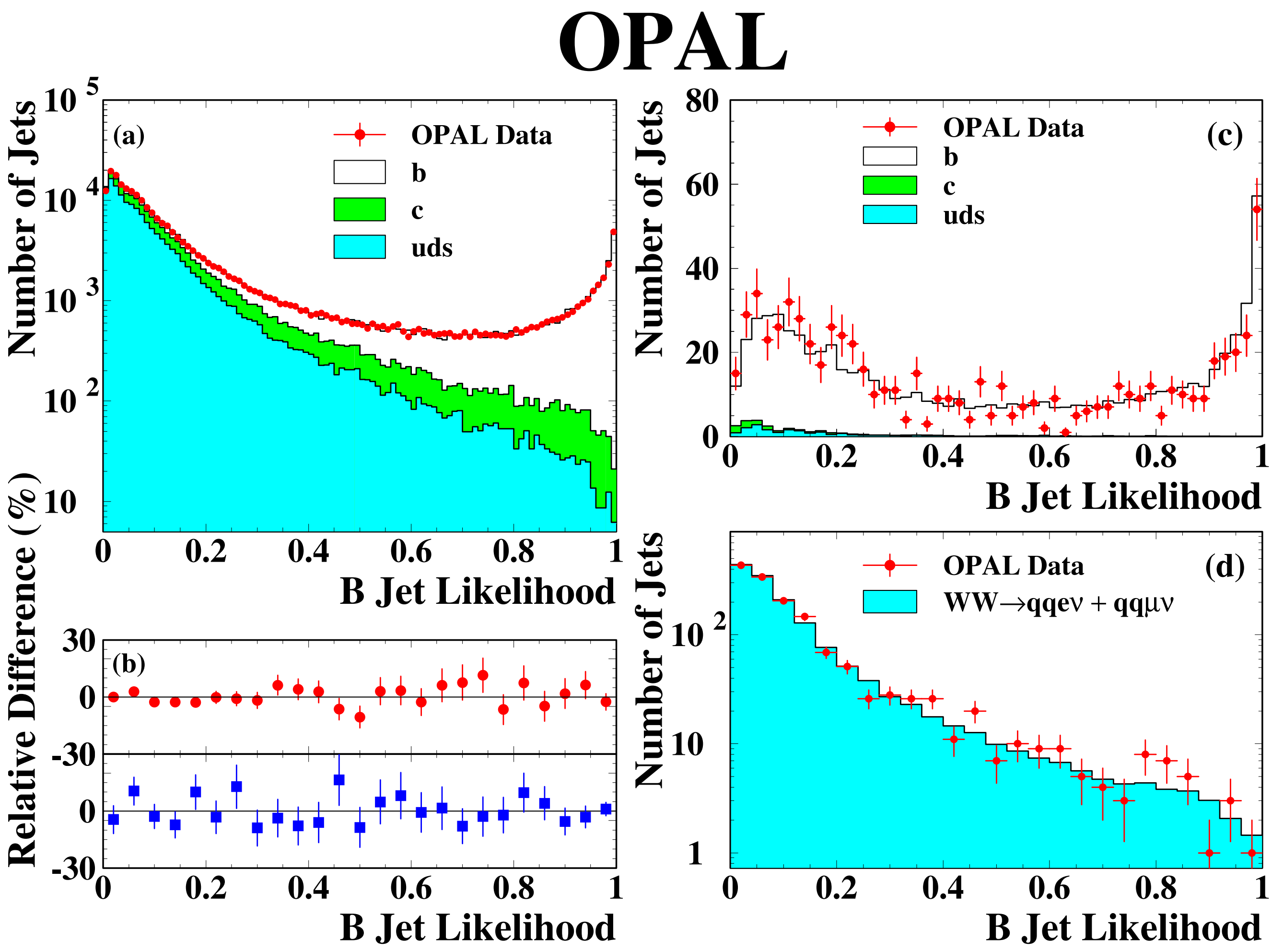
for $m_h > 2m_A$

Searches Neutral Higgs Bosons of the MSSM

- h^0Z^0 Searches
  - Reuse SM H^0Z^0 analyses
  - Find Efficiency for processes with $h^0 \to A^0A^0$ with $A^0 \to bb$

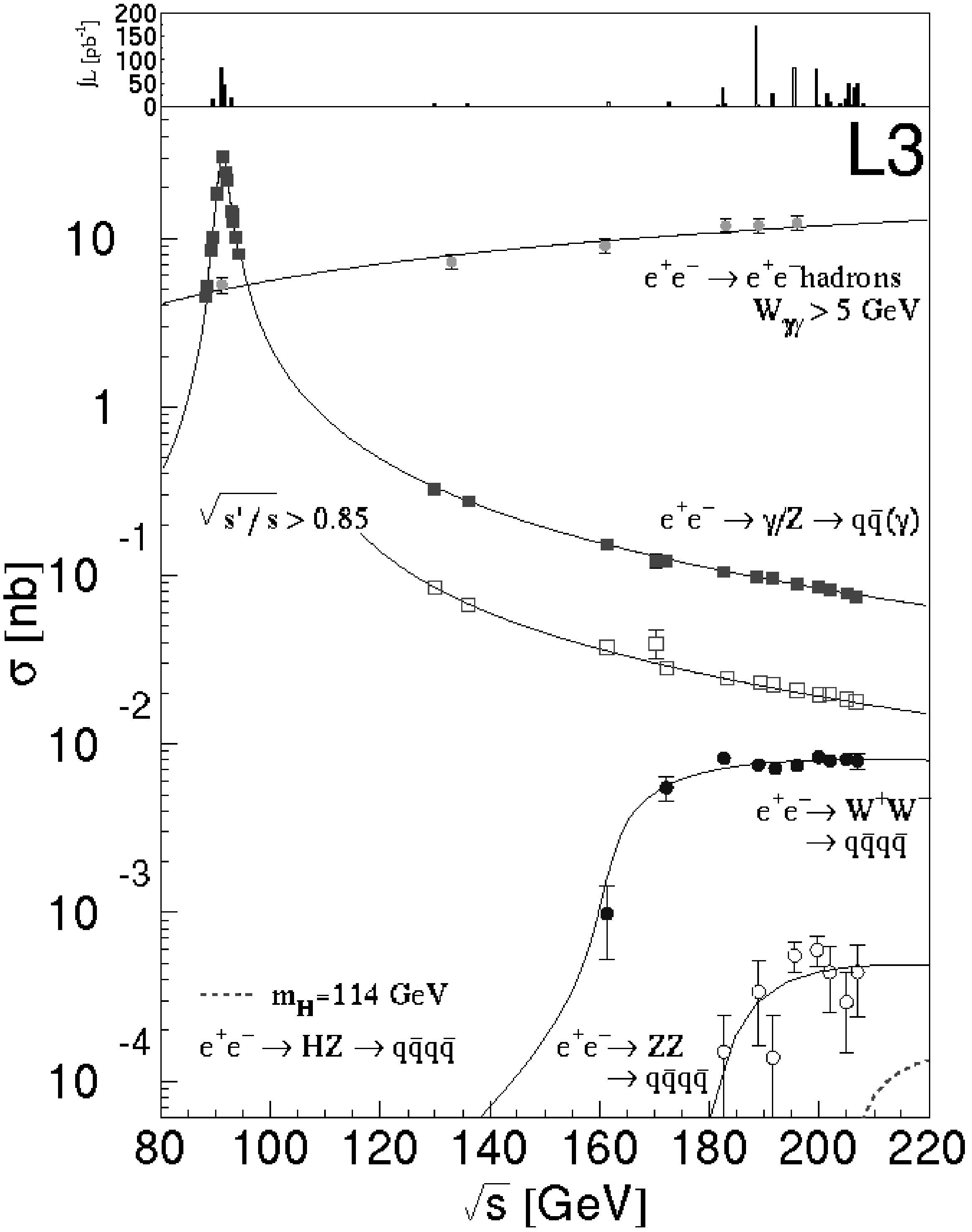
- h^0A^0 Searches
  - No Z^0 mass constraint! Rely more on the b-tag: bbbb and $bb\tau\tau$ are main channels.
  - Six combinations in 4-jet
    Two combinations in $bb\tau\tau$
  - Also a dedicated $A^0A^0A^0 \to 6b$ search
  - Use H^0A^0 production when allowed

Checking the B-tag Simulation



- Z^0 Calibration Data (four sets in 2001)
- "Radiative Returns" to the Z^0 (boosted)
- $W^+W^- \rightarrow qql\nu$ events (almost no real b's -- test of the mistag rate)

SM Background Processes



At LEP, SM processes are well-understood, measured electroweak interactions. Measuring luminosity is no problem.

Confidence Levels and the Likelihood Ratio

First: Select a hypothesis of new physics to test.

One parameter to order experimental outcomes

Does the experiment look

Signal-like: more candidates

Background-like: fewer candidates

or Somewhere in Between?

- Constructed from binned search results:
- Each bin has
  - **Estimated number of signal events**
    (depends on m_H, x-sec., branching ratios)
  - **Estimated number of background events**
  - **Number of events observed in the data**
- Systematic errors included by channel by error source.

$$Q = \frac{P_{poiss}(data \,|\, signal + background)}{P_{poiss}(data \,|\, background)}$$

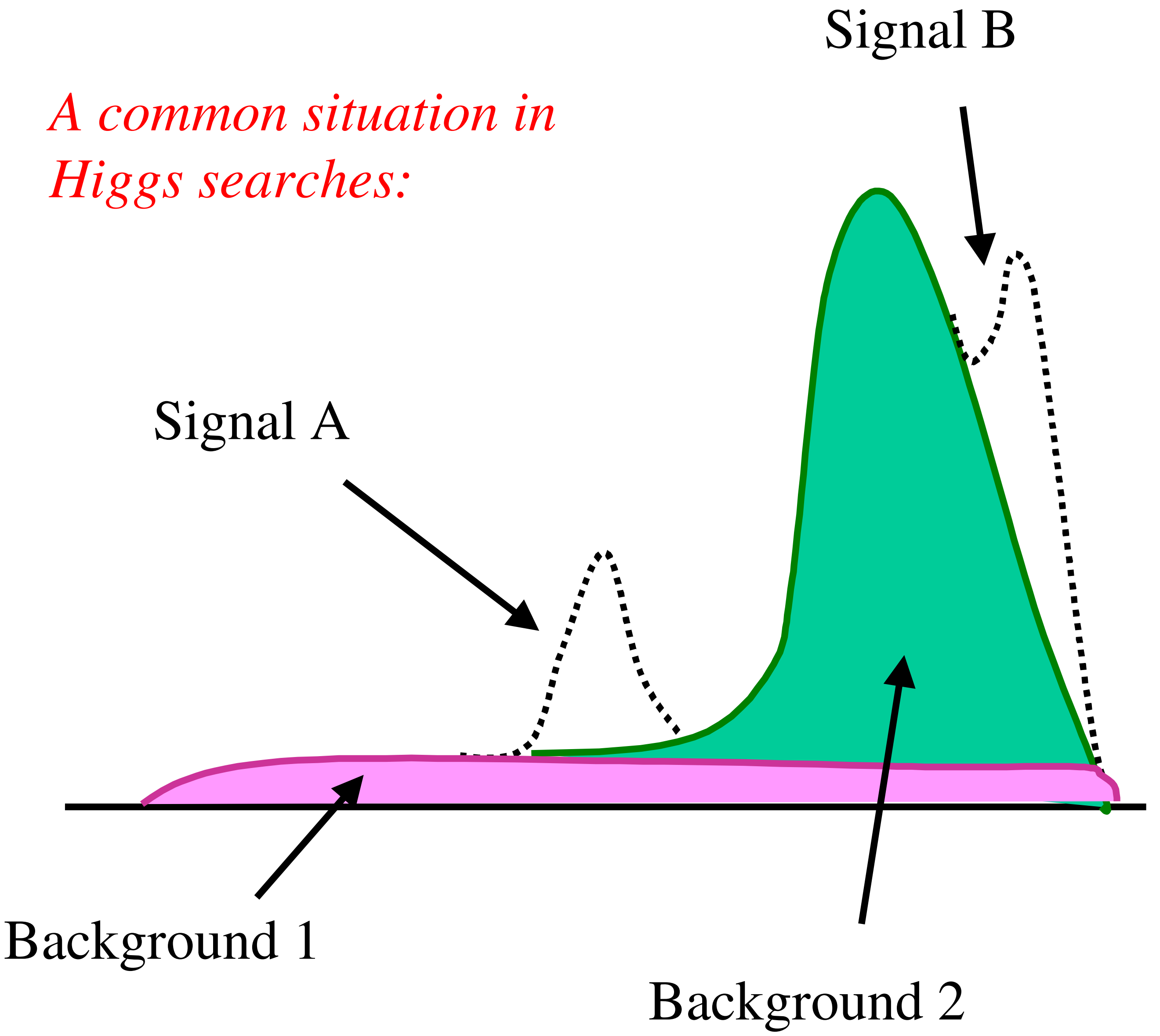
Exchanging Errors on the Signal and Background Estimations

- For each search analysis channel:
  - **signed relative error on the signal and background** itemized *by named source*
  - examples: B decay modeling, ZZ x-sect, MC comparisons
  - Errors typically 5% (signal), 10-20% (bkg)

- Effect of including errors
  - Uncorrelated: Almost no effect on limits
  - 100% Correlated: 200-300 MeV lower expected SM limit
  - Properly correlated: ~100 MeV lower expected SM limit
  - **We were prepared in advance for a discovery!**

Not Included Yet
-- Shape Errors

A common situation in Higgs searches:


Signal B
Signal A
Background 1
Background 2

Depending on the Higgs mass, the background could come mainly from source #1 or source #2 and have different uncertainty. Reporting errors on each bin is a lot of overhead. Can weight error by its importance, or divide the search into two or more channels.

The Likelihood Ratio

Treat each bin as an independent counting experiment.

$$Q = \prod_i \frac{\dfrac{(s_i + b_i)^{n_i^{data}} e^{-(s_i + b_i)}}{n_i^{data}\,!}}{\dfrac{b_i^{n_i^{data}} e^{-b_i}}{n_i^{data}\,!}}$$

$$\log Q = -s_{tot} + \sum_{bins} n_i^{data} \log\left(1 + \frac{s_i}{b_i}\right)$$

- Combination is very easy -- logQ’s add linearly
- Contribution of an event depnds on the *local* s/b ratio. -- in the bin in which the candidate is observed.

Events are classified by their s/b ratios.

s/b depends on m_H (x-sec, branching ratios)

Confidence Levels

Use MC or analytic techniques to find the PDF of log$Q$, given the results of all bins.

The probability of missing a signal if it is there:

$$CL_{s+b} = P\left(Q \le Q_{obs} \mid signal + background\right)$$

The probability of seeing the candidates we got (or more) if there were only background.

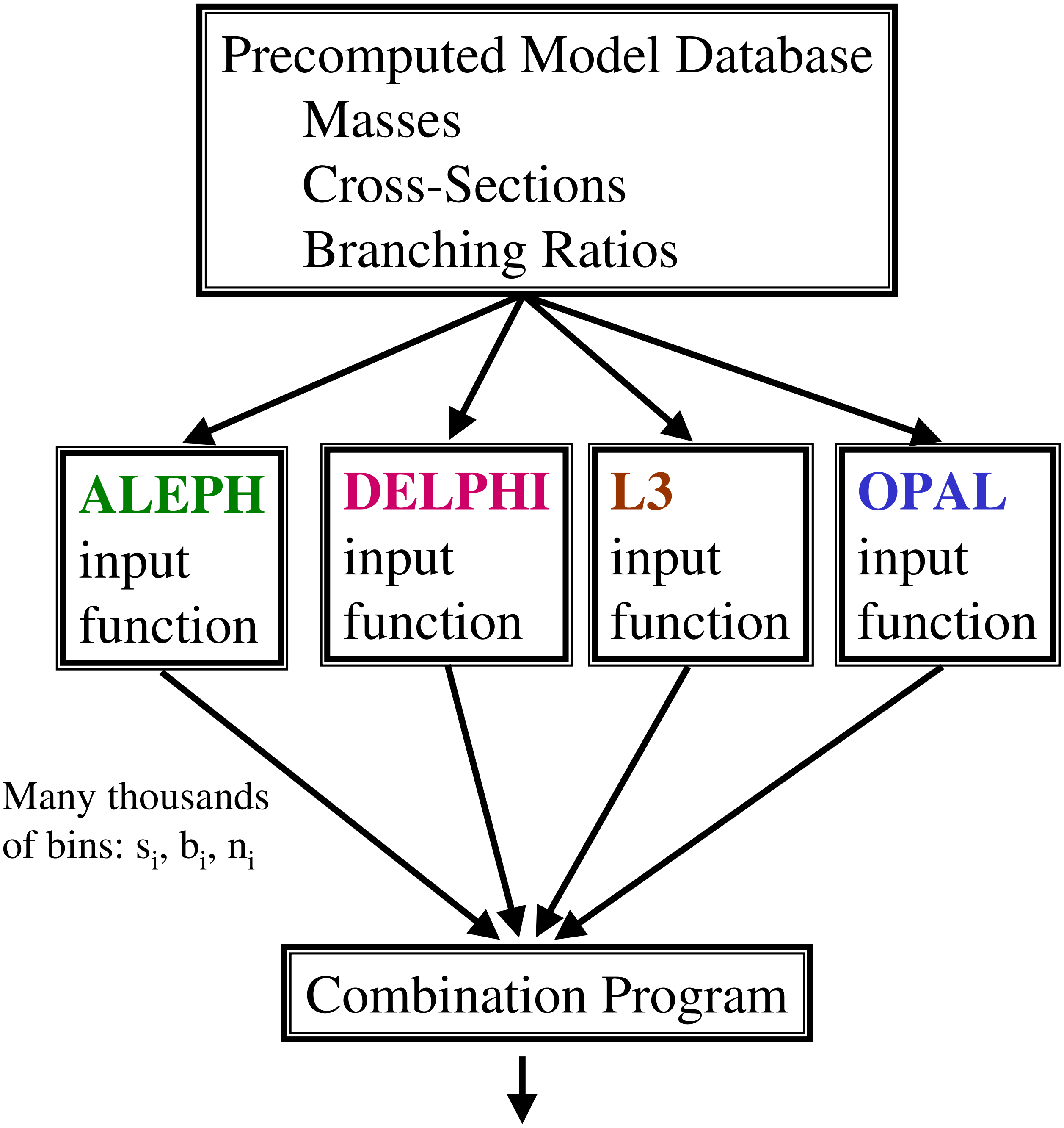
$$1 - CL_b = P\left(Q > Q_{obs} \mid background\right)$$

Discovery Criterion: $1\text{-}CL_b < 5.7 \times 10^{-7}$

Regulated CL_{s+b} so fluctuations in bg do not exclude models we are not sensitive to.

$$CL_s = CL_{s+b} / CL_b$$

Combination Map



Precomputed Model Database
Masses
Cross-Sections
Branching Ratios

ALEPH input function

DELPHI input function

L3 input function

OPAL input function

Many thousands of bins: s_i, b_i, n_i

Combination Program

$-2\ln Q$, CL_s, CL_b, ...

Experiment input routines handle:

- interpolation (E_{CM} and masses)
- selection of which analyses to apply
- correct lumi*b.r.*cross-section and binning

MSSM Combinations

- An important ingredient -- Model calculations -- masses, b.r.'s, and production cross sections
- SM is easy -- just one unknown parameter: m_H. Agreed calculations with fusion and interference.
- MSSM more involved. Seven parameters in our model.
- Need to combine data rapidly, so need a precomputed, shared model database

Three Scenarios

- No stop-quark mixing scenario
  generous exclusion
- m_h-max scenario
  conservative limits on tanβ
- Large-μ scenario
  branching to b quarks suppressed
  "pathological" points

Some Recent Progress on the Theory Front

- Two-loop calculation of m_h in the MSSM:
  Weiglein, Heinemeyer, Hollik hep-ph/9909540

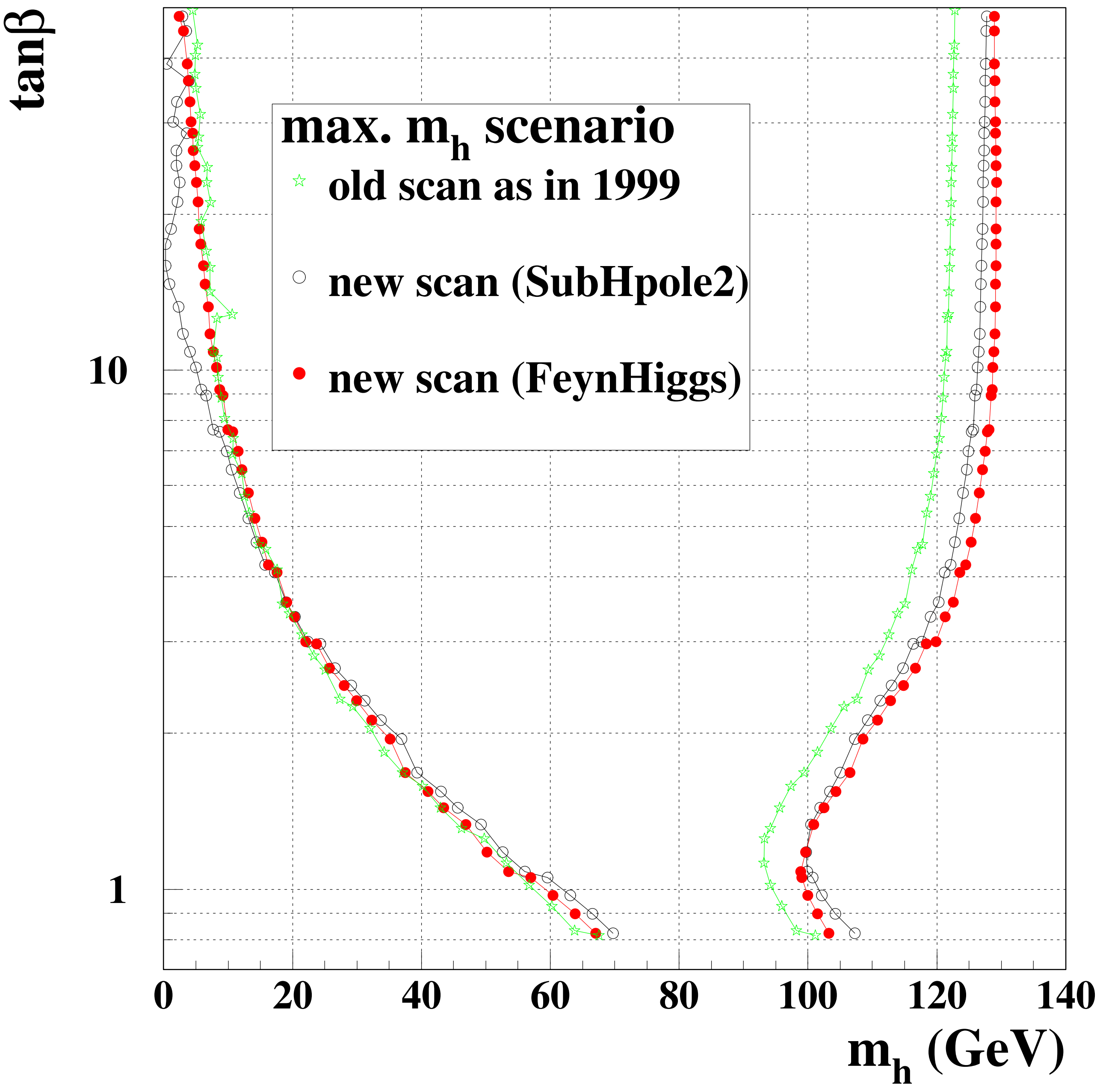
- One-loop renormalization-group improved
  calculation: Carena, Quiros, Wagner
  Nucl. Phys. **B461** (1996) 407.

- Reconciliation of differences in
  calculation hep-ph/0001002 --
  Carena, Haber, Heinemeyer,
  Hollik, Wagner, Weiglein

- Outcome is the best of all worlds
  - Genuine 2-loop terms computed
  - Resummation of higher-order effects
  - Differences absorbed in the running
    top quark mass at the apropriate scale.

- Two-loop calculation used for no-mixing
  and max-m_h scenarios -- conservative
  limits on tanβ. RG-improved
  1-loop more stable for the large-μ scenario

Two-Loop Allowed Regions vs. Old Models

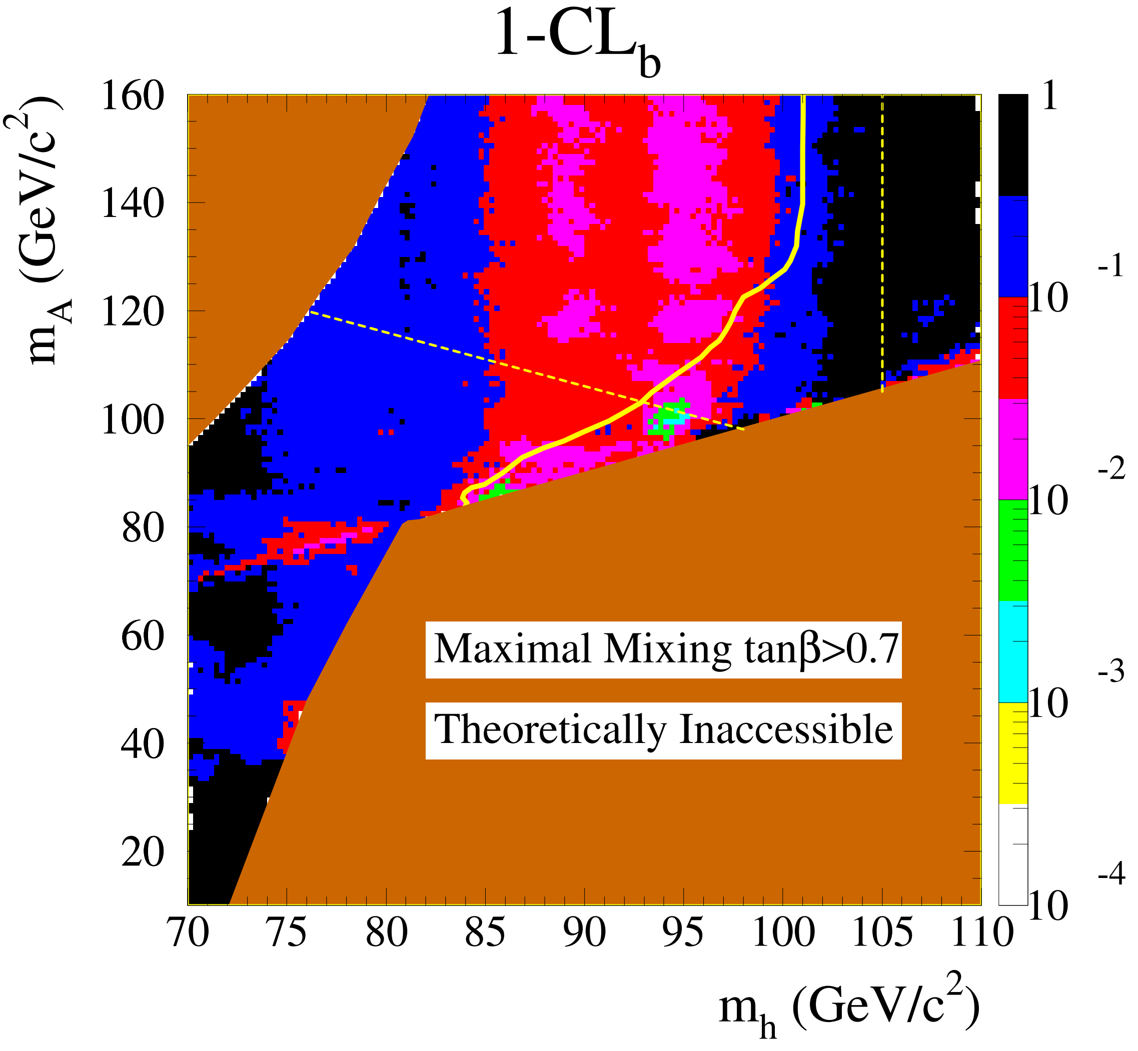


Experimental hA Results from Around the LEP Ring

	ALEPH	DELPHI	L3	OPAL
$h^0A^0 \rightarrow 4b$ channel				
Data	10	5	12	11
SM Bg	5.5	6.5	7.8	10.3
Eff'y	47%	47%	42%	48%
Sig.	3.5	3.6	3.2	3.4
$h^0A^0 \rightarrow bb\tau\tau$ channel				
Data	3	5	2	5
SM Bg	3.0	6.0	3.2	4.5
Eff'y	41%	25%	33%	43%
Sig.	0.6	0.4	0.4	0.6
Limits (GeV)				
m_h	89.6	89.8	83.7	79.3
expct	91.7	89.0	88.1	85.1
m_A	90.0	90.8	83.9	80.6
expct	92.1	90.0	88.3	86.9

210 - 220 pb^{-1} of data per expt in 2000

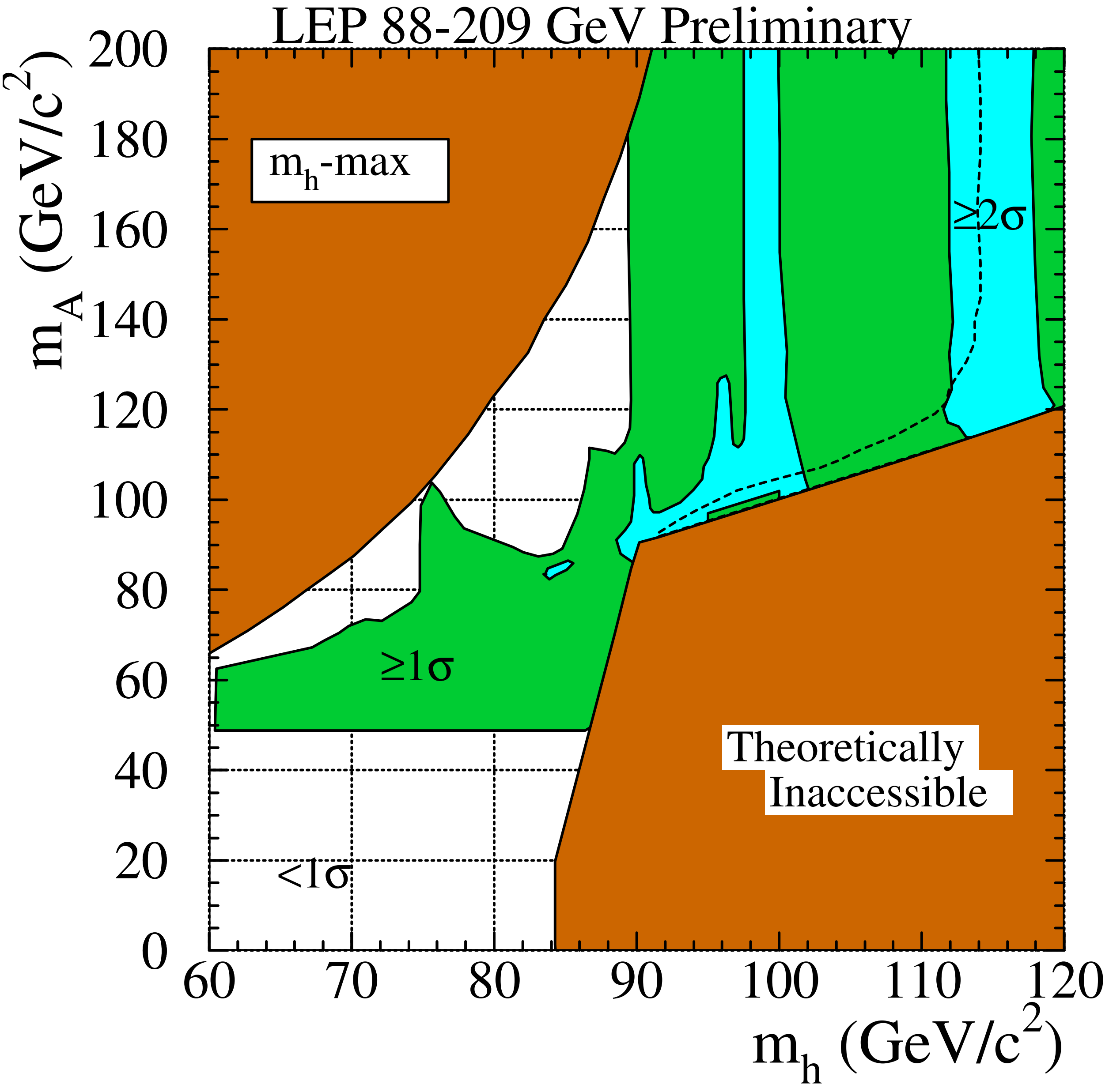
A Hint of Something from Summer 1999?



m_h=m_A=83 GeV: 2 events in OPAL 1998 data
in the hA→bbττ channel -- not repeated.

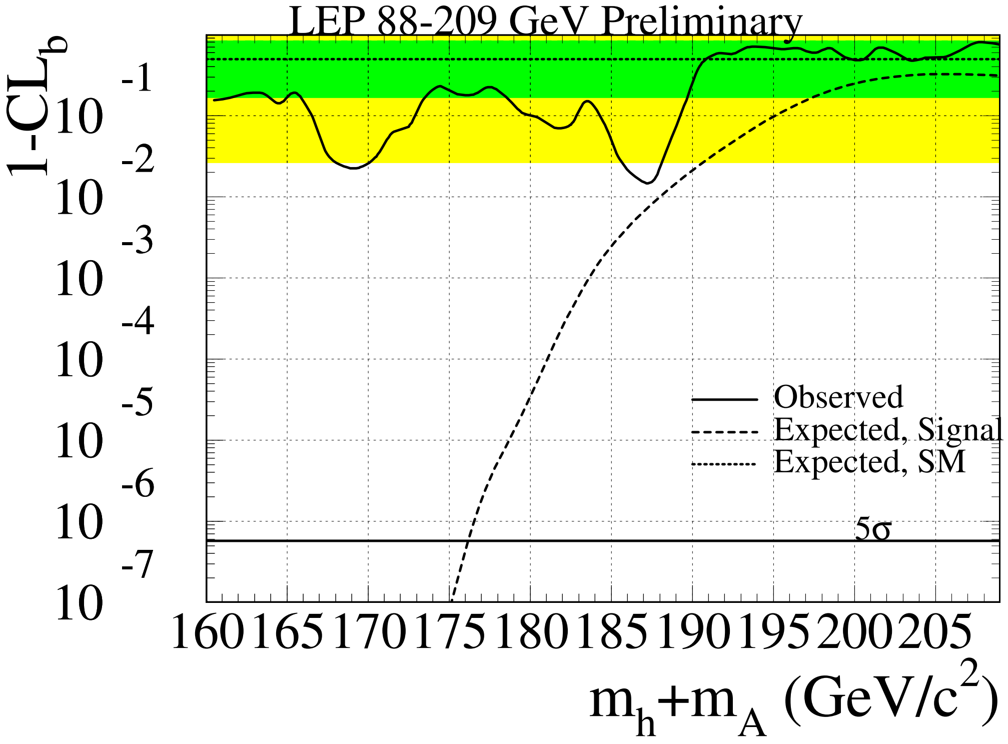
m_h=95 GeV, m_A=100 GeV -- slight excess seen in all four experiments *but* -- almost no hA signal expected (<1 event) -- mostly hZ events.
+large “Anywhere factor”

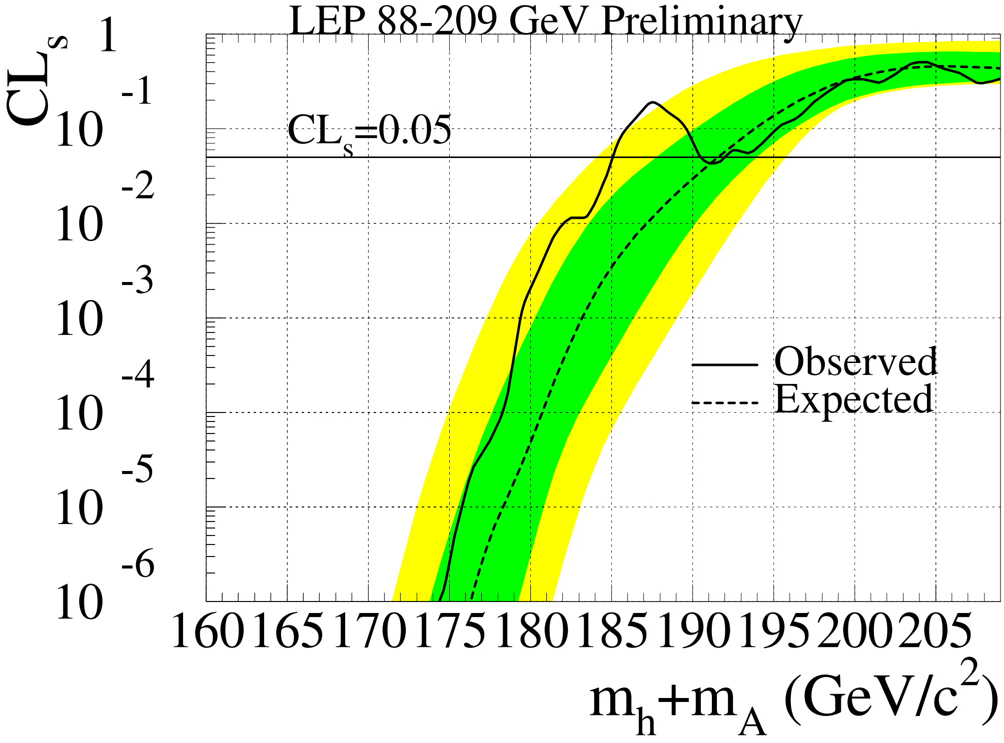
1-CL_b Significance in in the m_h-max Scenario



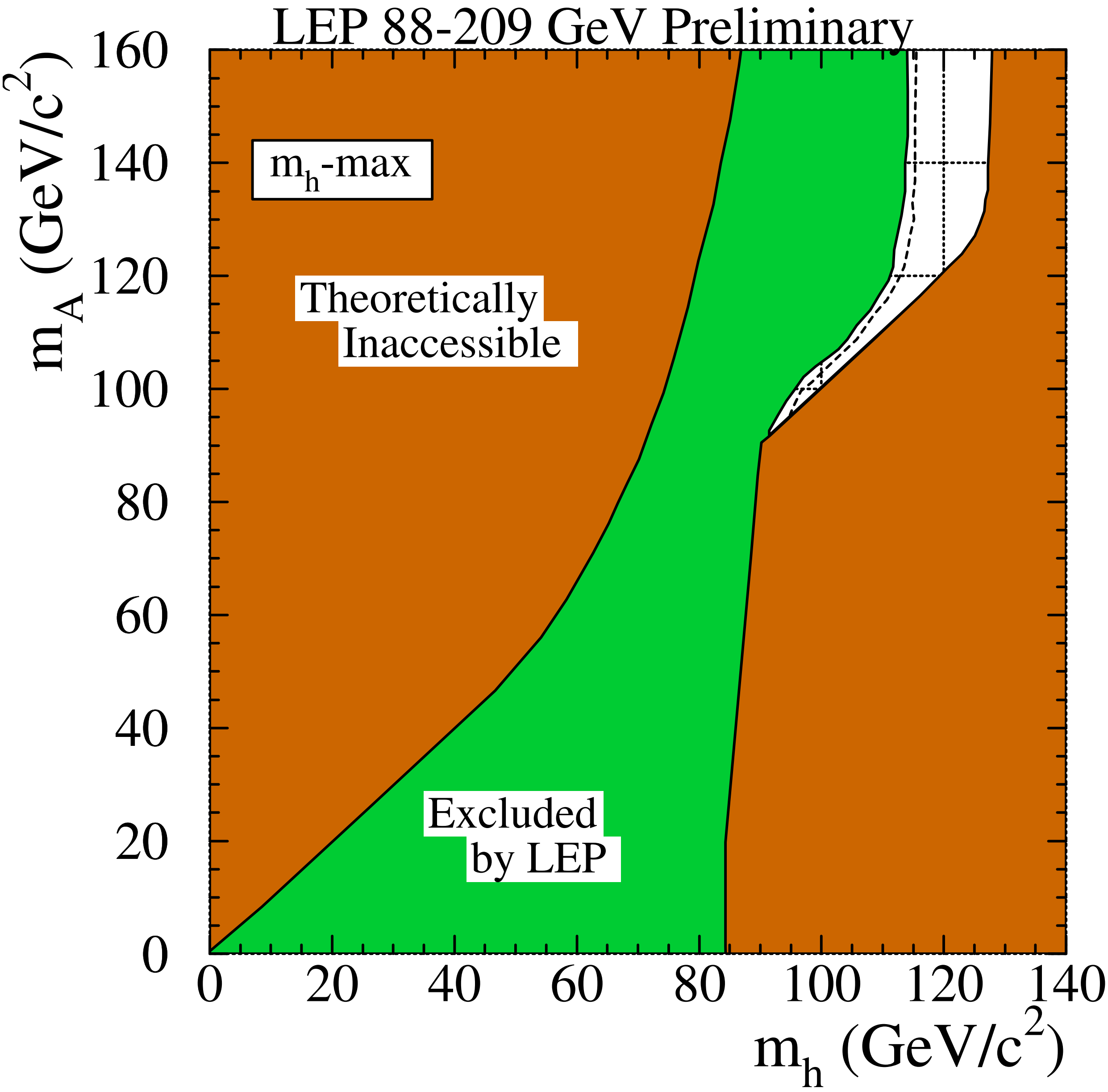
- Results as of Moriond 2001
- SM Features reproduced
- “Anywhere” factor -- 35-60

Combined 1-CL_b and CL_s On the Diagonal





Exclusions in the m_h-max Scenario



Exclusion limits at the 95% CL

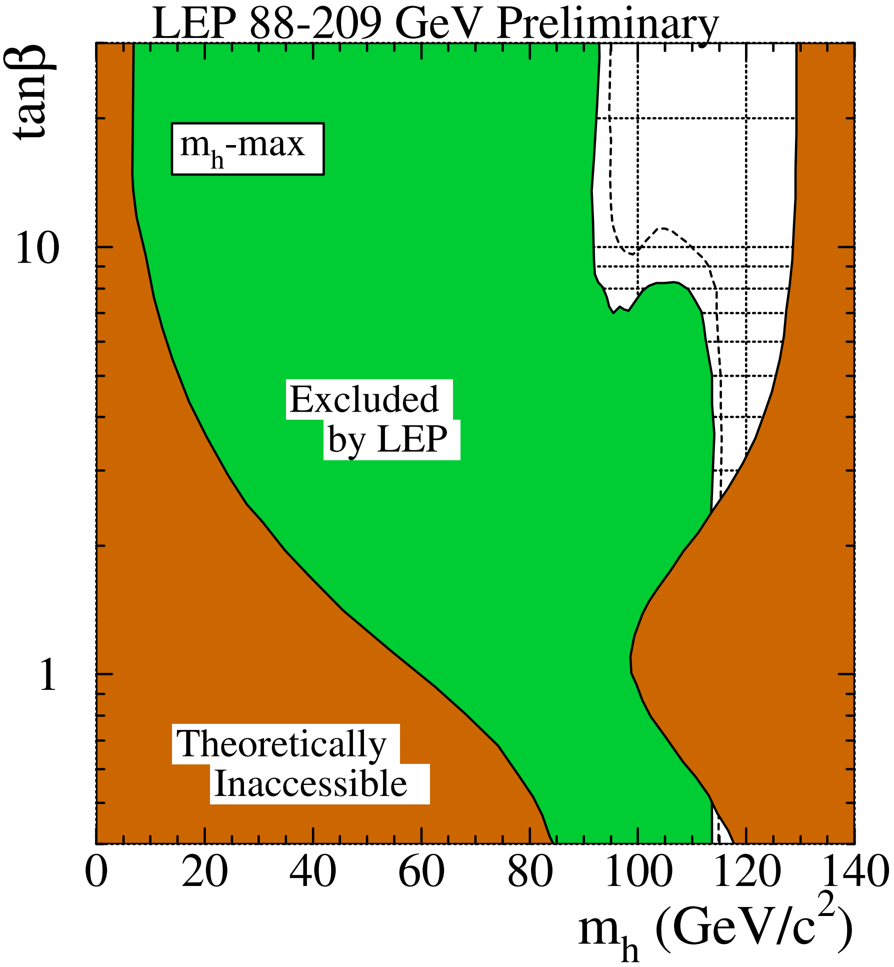
$m_h > 91.0$ GeV

expected (bg): 94.6 GeV

$m_A > 91.9$ GeV

expected (bg): 95.0 GeV

Excluded tanβ in the m_h-max Scenario



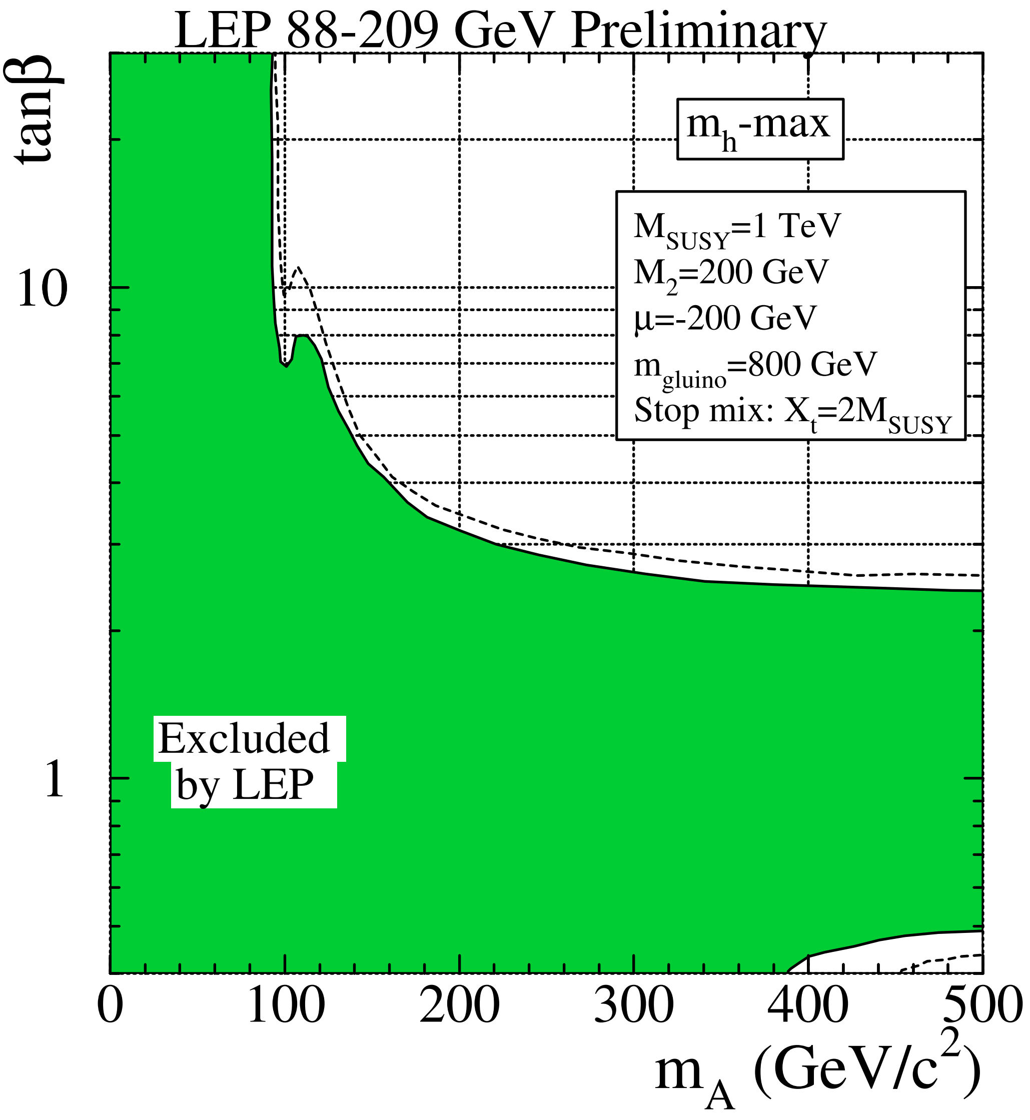
MSSM Parameters chosen so that m_h has a maximal value for different tanβ. m_{top}=174.3 GeV

0.5 < tanβ < 2.4 Excluded

(expected if only background: 0.5 < tanβ < 2.6)

m_h, and also the tanβ exclusion depend on m_{top}
For m_{top}=179 GeV, 0.6<tanβ<1.9 excluded

Exclusions in the (m_A , tanβ) Plane



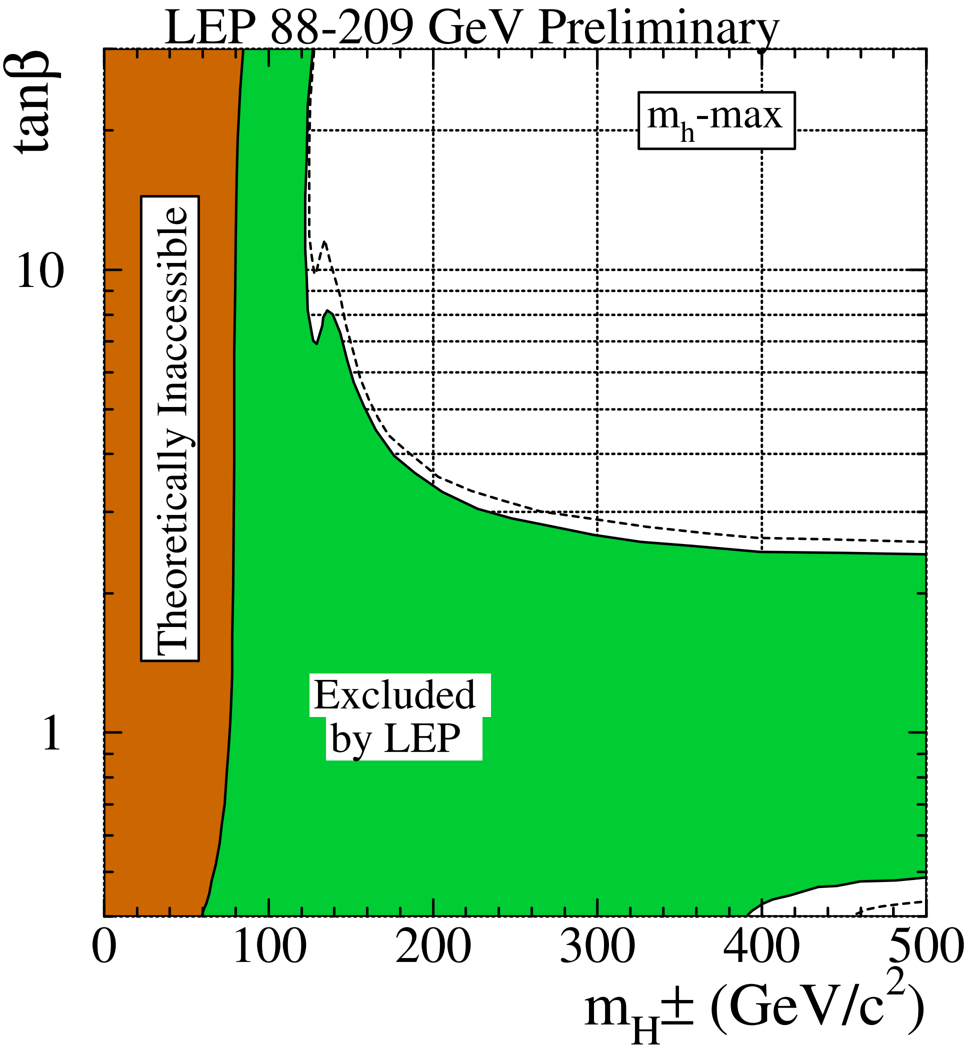
Low tanβ: $e^+e^- \to h^0Z^0$ searches more sensitive. Higher tanβ: $e^+e^- \to h^0A^0$ searches are more sensitive.

tanβ<30 to keep decay widths <3 GeV

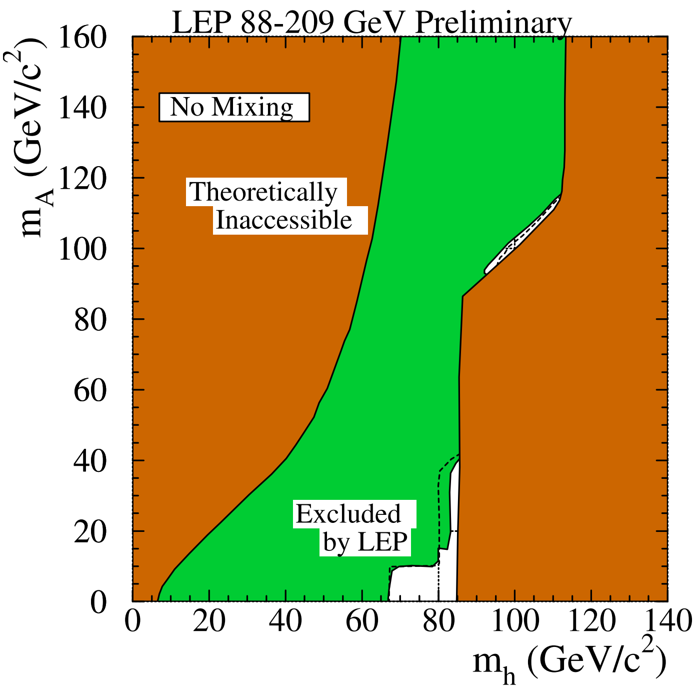
And a New Projection

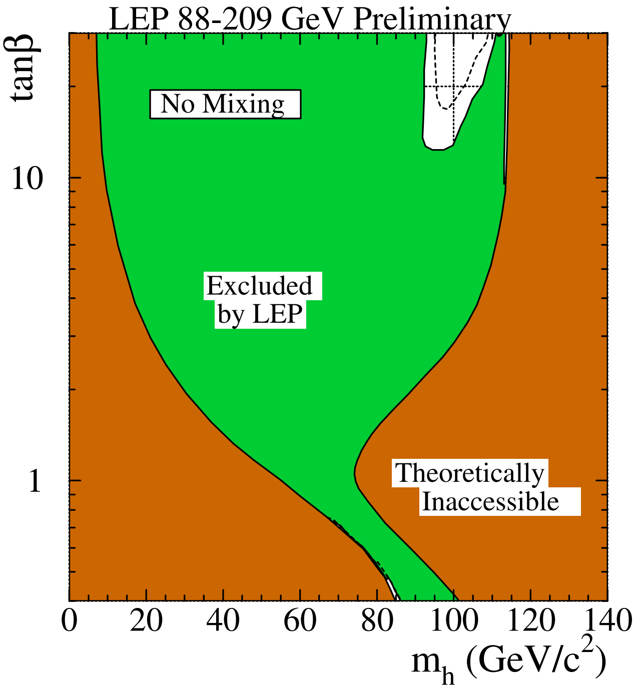
Charged Higgs mass vs. tanβ.

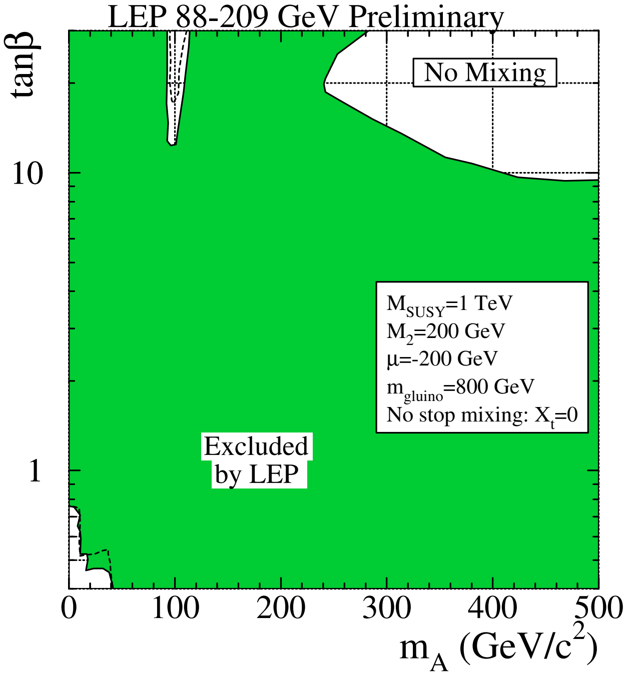
- Necessary to make progress in CP-violating MSSM models (no CP-odd Higgs boson any more!) *but*
- Neither tanβ nor the charged Higgs are observable in the neutral Higgs searches -- derived quantities.



Exclusions in the No Stop Mixing Scenario



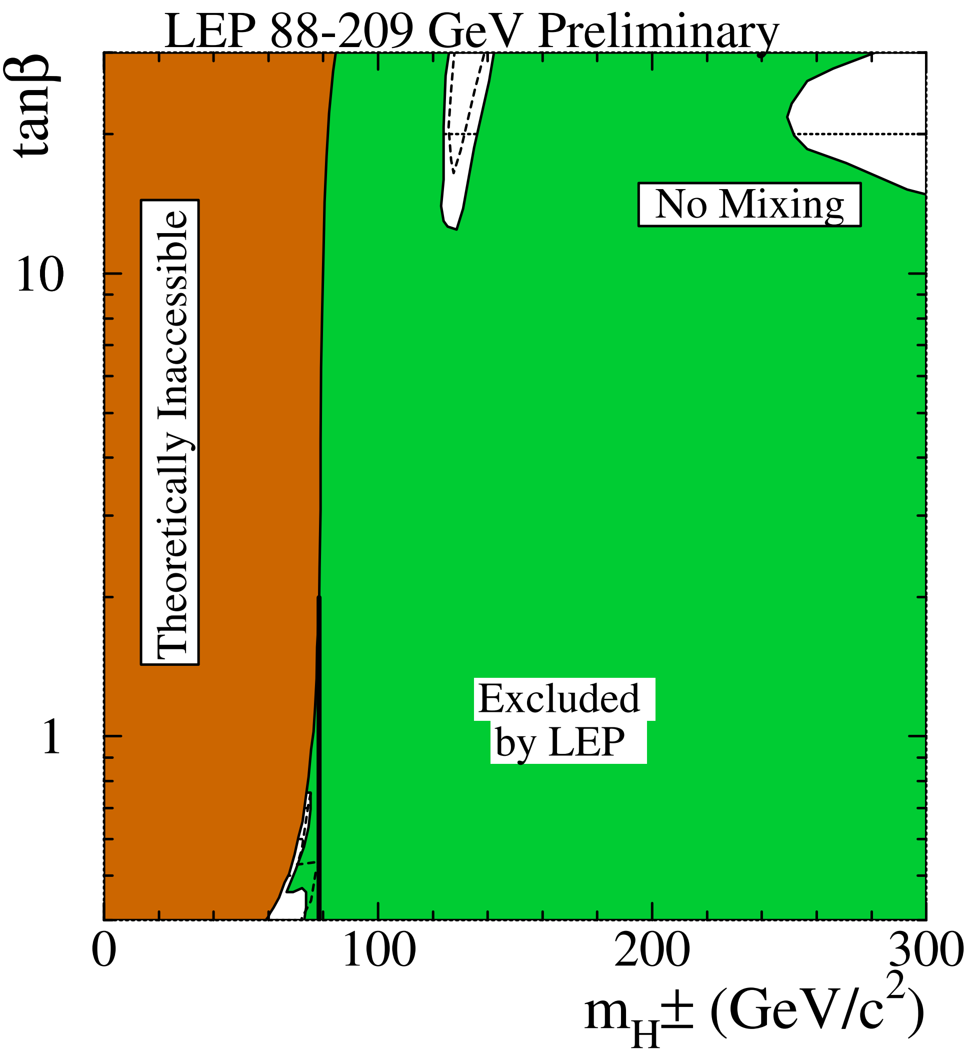




Exclusion limits at the 95% CL

m_h>91.5 GeV
(exp. 95.0 GeV)
m_A>92.2 GeV
(exp. 95.3 GeV)
0.8 < tanβ < 9.6
Excluded
(exp 0.8 < tanβ < 17)

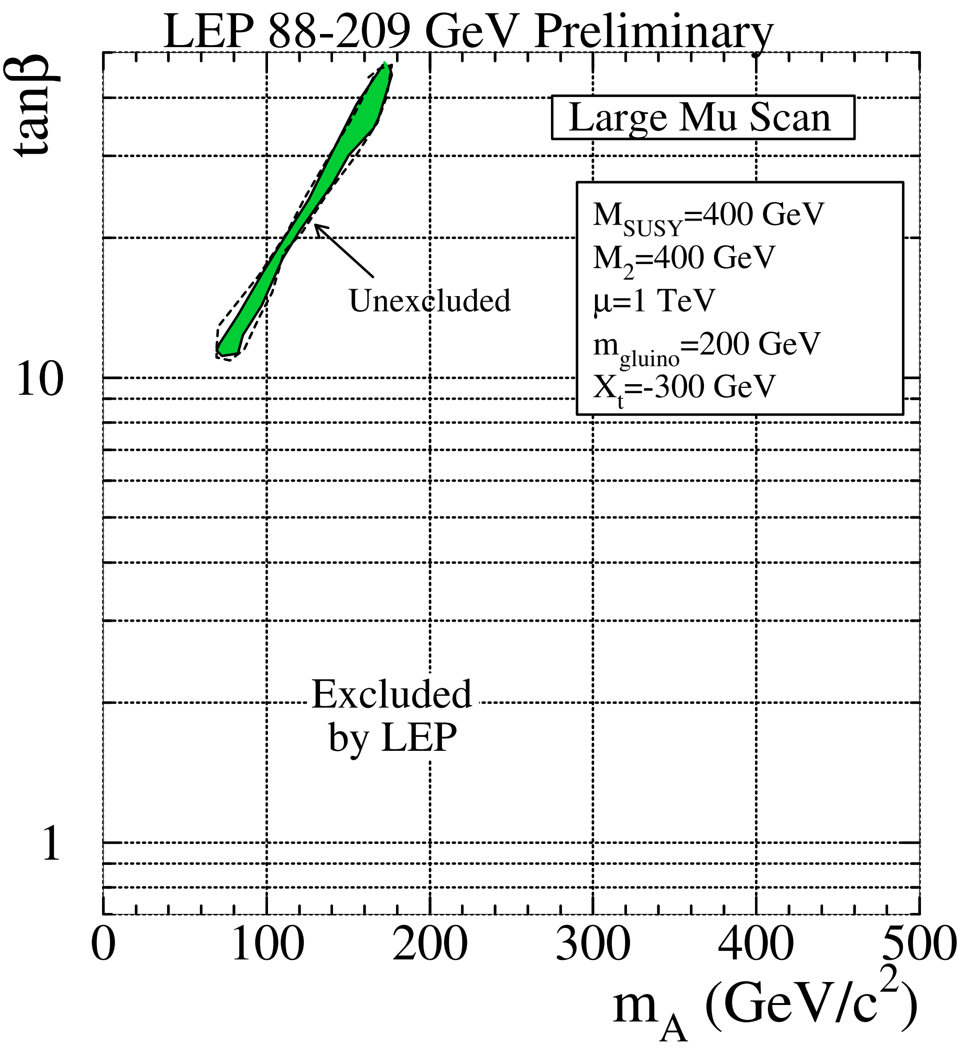
Charged Higgs Search Constraints on the MSSM No-Mixing scenario



LEP Charged Higgs limit: $m_{H^\pm} > 78.5\ \mathrm{GeV}$
assuming $Br(H^+ \to c\bar{s}) + Br(H^+ \to \tau^+\nu_\tau) = 1$

But $Br(H^\pm \to W^{(*)\pm} A^0)$ *can be sizeable.* X-sec limits are stronger for lower charged Higgs mass, but this has to be done right.

Exclusions in the Large-μ Scenario



SUSY-QCD and electroweak corrections become large if μtanβ is large -- suppressed branching ratios to b quarks and tau pairs
Charm, gluons, W^+W^- make up the difference

Parameters chosen so the maximum m_h (m_H) is about 107 GeV -- within reach!

To do: include flavor-independent search results.

Work Plans for the LEP MSSM Higgs Searches

- **No Stop Mixing Scenario** -- some unexcluded model points with either low tanβ, low m_A, or both.

  h→AA, and A does not decay to b-bbar
  because either it is too light or tanβ is too small
  A→charm or gluons or other particles

  - ALEPH flavor-blind search helps, but is not enough (excludes at 85% CL)
  - OPAL search targeted at these points is done (no excesses found) and will be combined next iteration

- **Large-μ Scenario** -- also include the flavor-blind searches.

- **All Scenarios -- large tanβ** → large decay widths reduced *s/b* if the decay width is comparable to or larger than the mass resolution

CP-Violating MSSM Higgs Sector

- Very interesting possibility -- the states h, A, and H are CP eigenstates and do not have meaning in a CP-violating model.
  -- call the neutral states h_1, h_2, h_3

- "A-strahlung" is forbidden, but when the CP states are mixed, strahlung of all neutral Higgs states is possible.

- Possible processes (neutral Higgs production):
  h_1Z h_2Z h_3Z
  h_1h_2 h_1h_3 h_2h_3

- All of these may be simultaneously present in the data

- Complicated to reuse the SM analyses --
  separately optimized at each value of m_H --
  even the background is a function of m_H --
  one cannot just add the signal components of Zh_i together

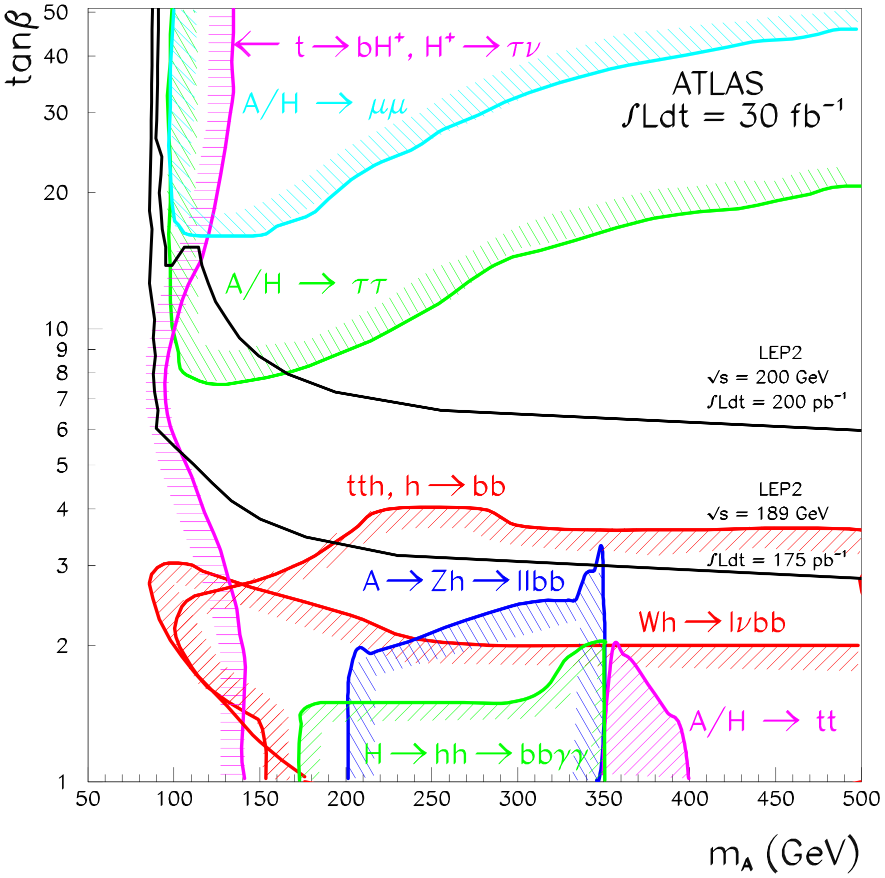
CP-Violating MSSM Higgs Sector

- Decays to b-bbar pairs can be suppressed with appropriate choices of parameters -- need to put in the flavor-blind searches

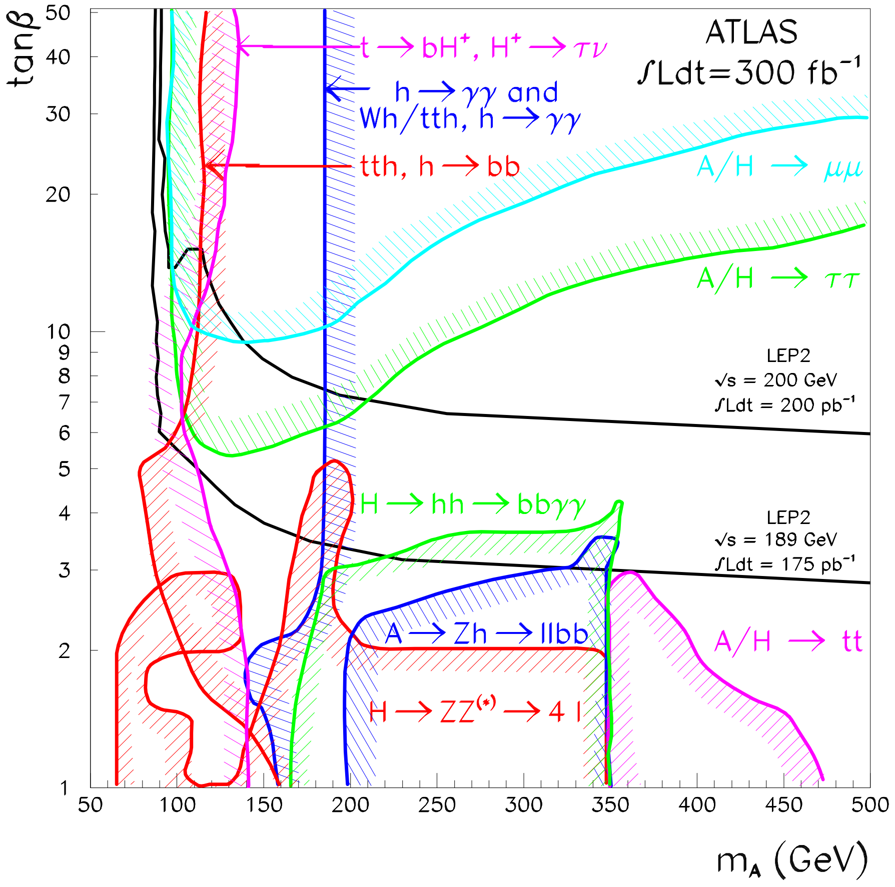
- Interpretation of candidates is ambiguous, especially in the four-jet case (or if any of the h_i have a mass near m_Z)
  - Alternative jet pairings can make the same event an hZ or hA candidate (already taken into account). Now it can be one of six processes.
  - Even in the tau case h_iZ and h_ih_j candidates can have multiple interpratations

- Flavor-blind searches select a superset of the b-tagged search candidates. Each experiment needs to keep track of the overlap for the signal, background, and candidates (or just switch between one search or the other depending on x-section and branching ratios)

MSSM Higgs Reach at the LHC



30 fb^{-1} still leaves a hole



Complete coverage with 300 fb^{-1}

Charged Higgs Searches at LEP

Production via s-channel γ/Z^0 exchange.

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

and provide results as a function of

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

Three search channels:

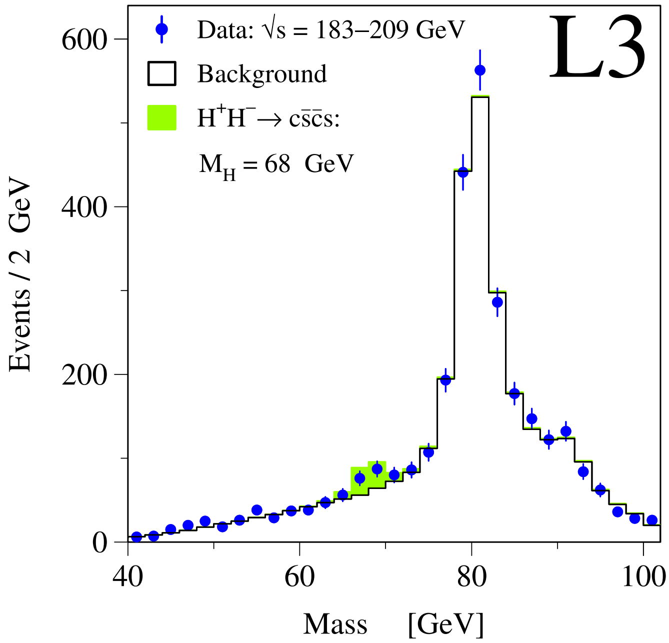
"Hadronic"	four-jets, no b-tagging
"Semileptonic"	two jets, lepton, missing energy
"Leptonic"	two leptons + missing energy -- Acoplanar dilepton searches used to look for $H^\pm$

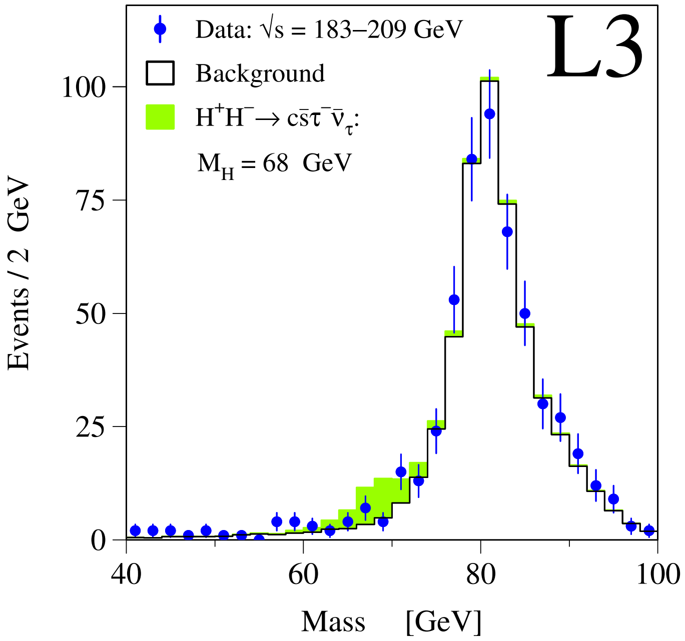
Main Background: W^+W^- production

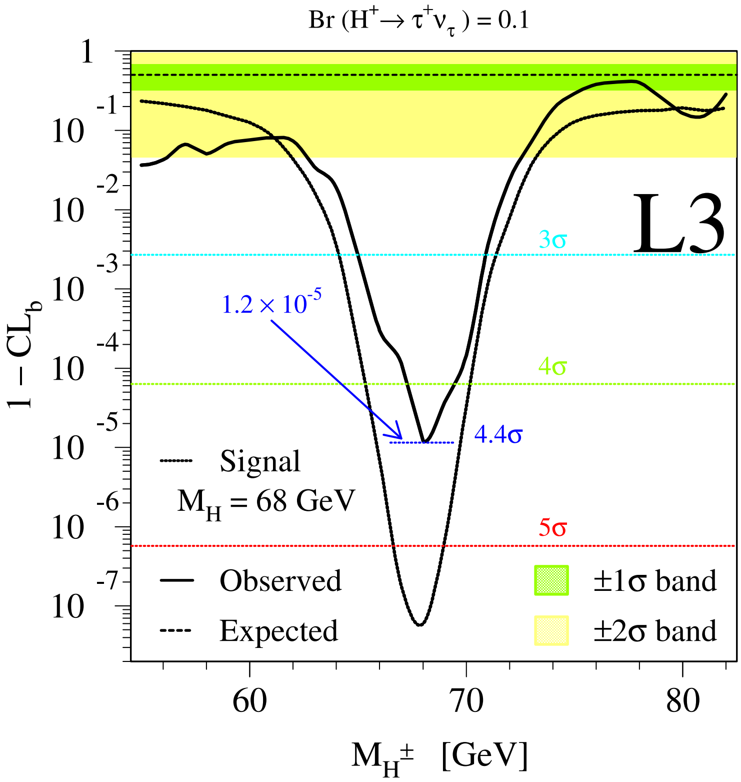
Can exploit kinematic distributions, known W^+W^- production and decay.

Charged Higgs Excess in L3

Excess in L3 published data near 67 GeV, getting bigger with addition of 202--209 GeV data

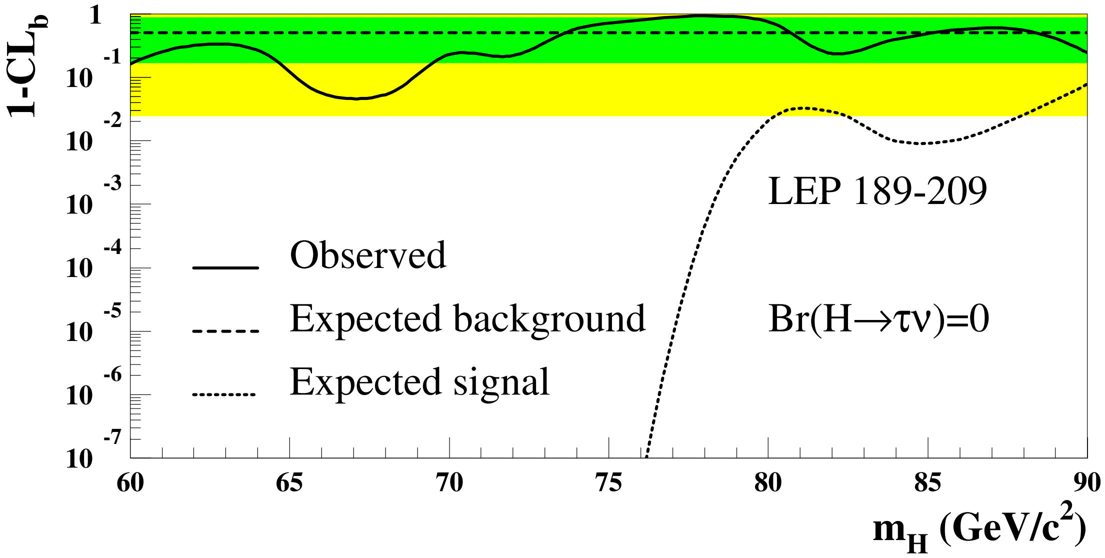




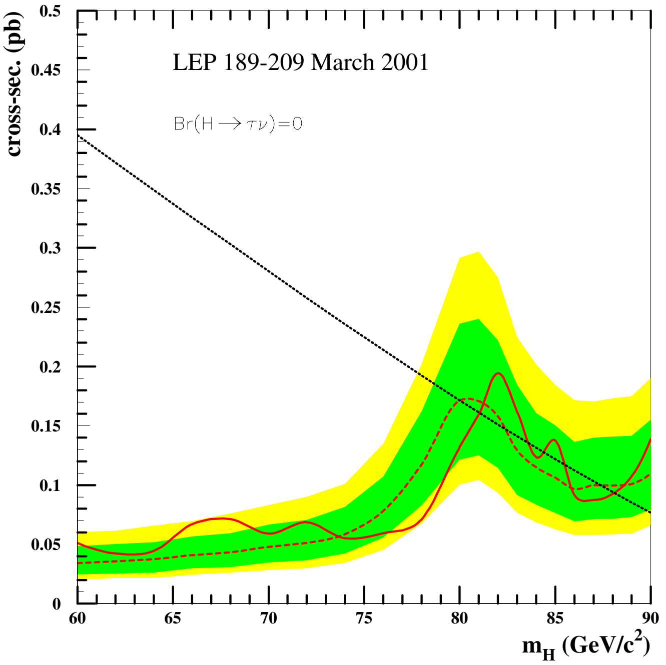


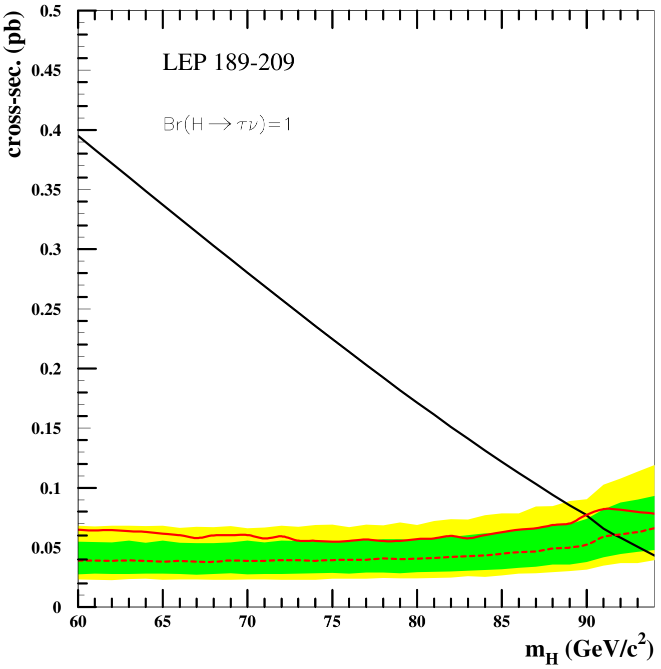
From: S. Wynhoff, LEP Jamboree 27 Feb. 2001

Combining L3 with ALEPH, DELPHI, and OPAL



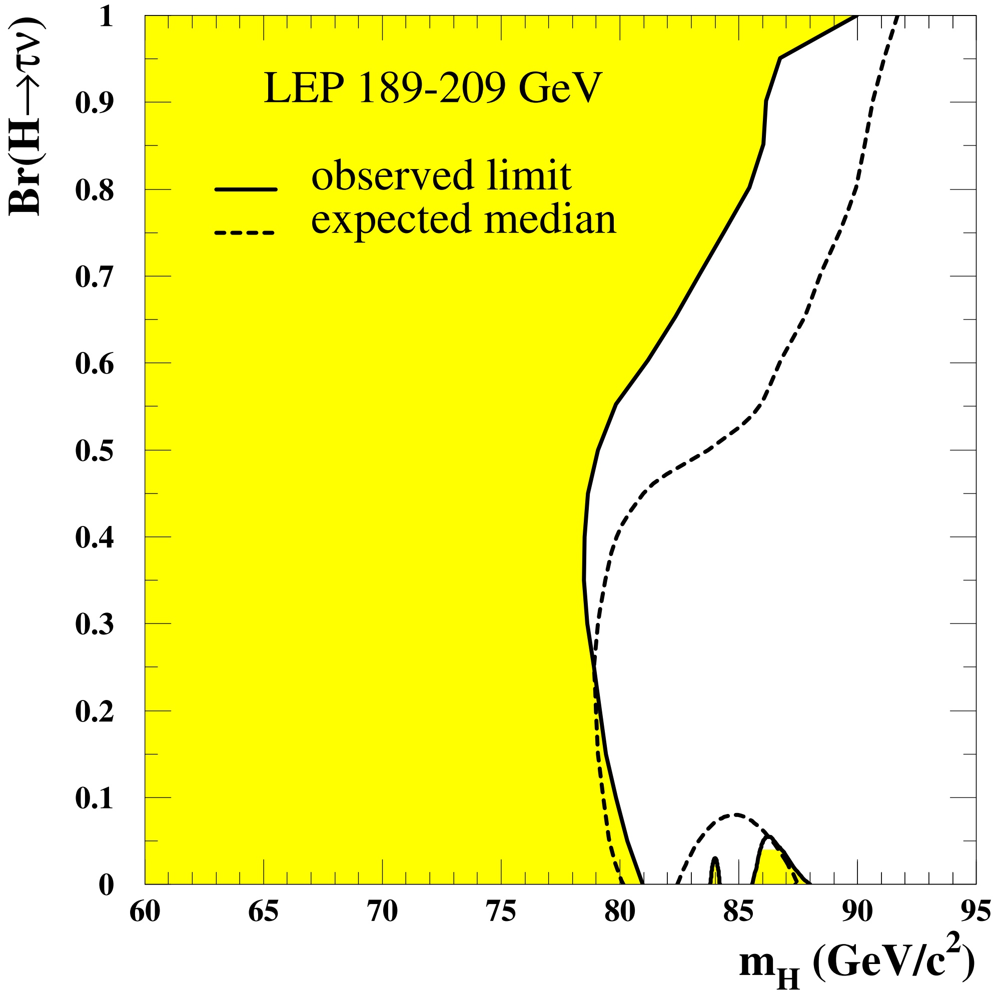
ALEPH has a bit of a deficit at 70 GeV
-- no significant excess seen in combination.





Charged Higgs Mass limits -- Combined

Large background from W^+W^- production -- easiest to overcome in the $\tau\nu\tau\nu$ channel.



Observed (median expected) Limits (GeV)

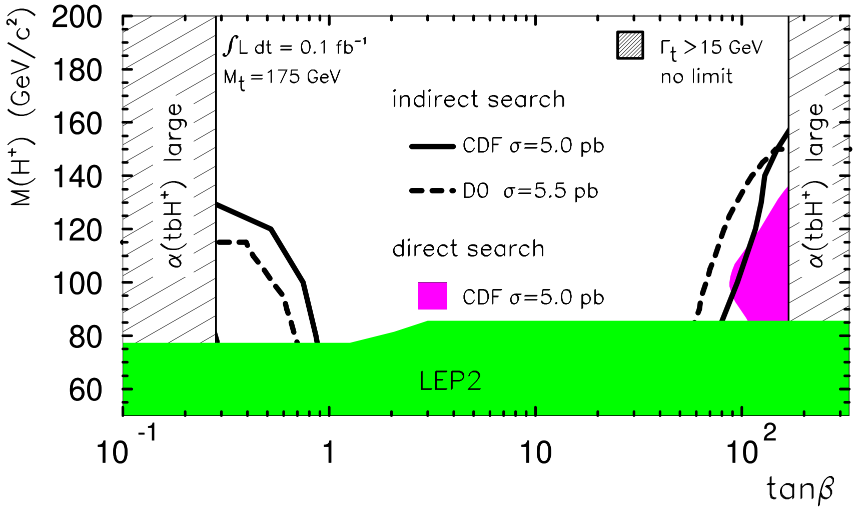
vs. $Br\left(H^+ \rightarrow \tau^+\nu_\tau\right)$

Br = 0	Br = 1	Any Br
81.0 (80.1)	90.0 (91.7)	78.5 (78.9)

Complementarity with the TeVatron

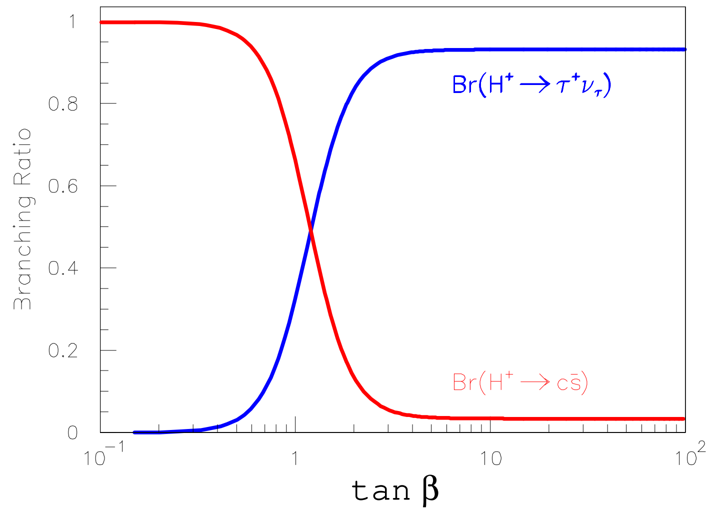
CDF and D0 Search for t→H$^+$b via the *disappearance* of t→W$^+$b -- search for the wrong mixture of leptonic and hadronic decays of the boson.

LEP sensitivity depends on the b.r. to qq.



(LEP limits as of March 2000 for this plot)

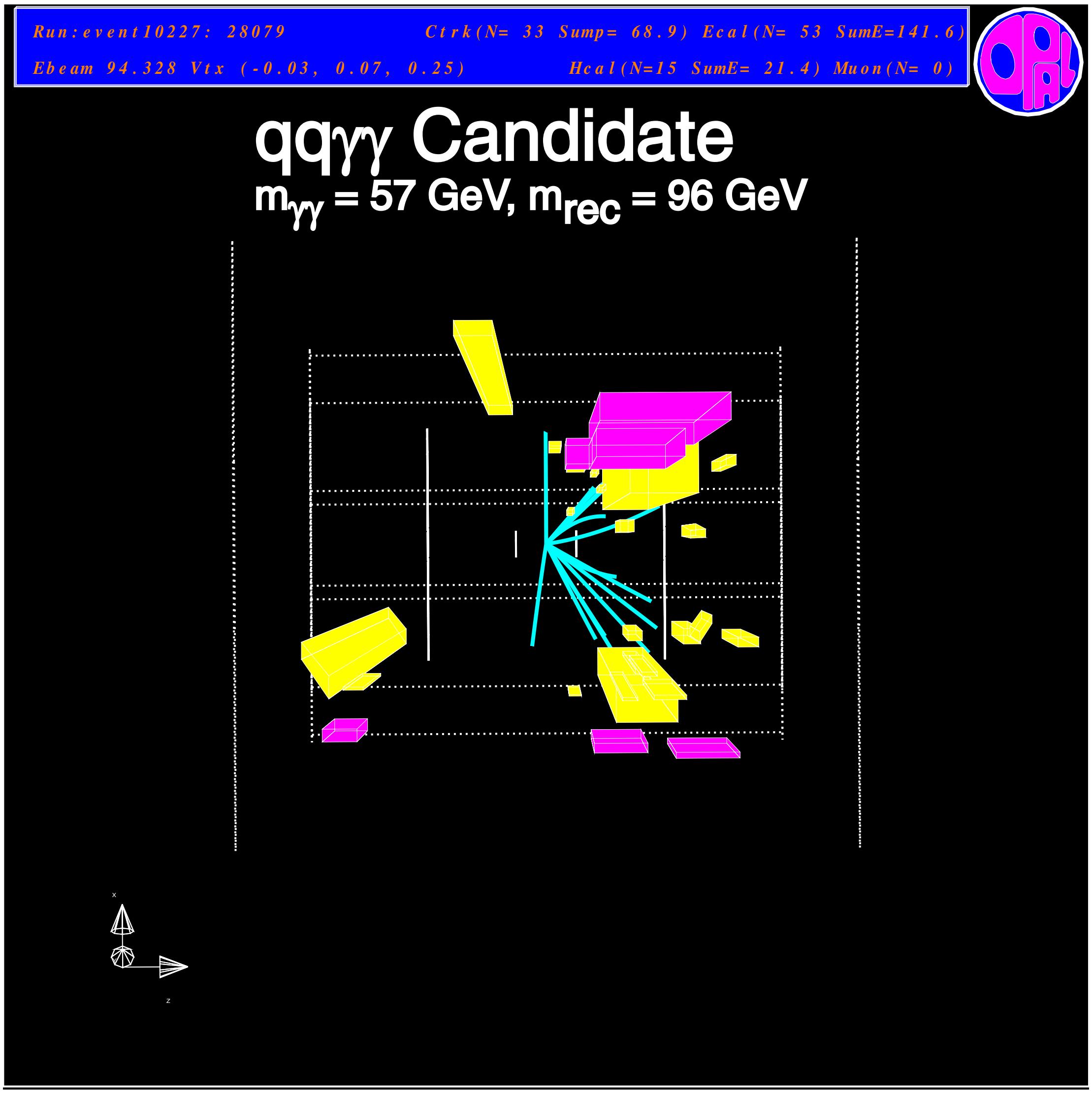
Branching ratios vs. tanβ:



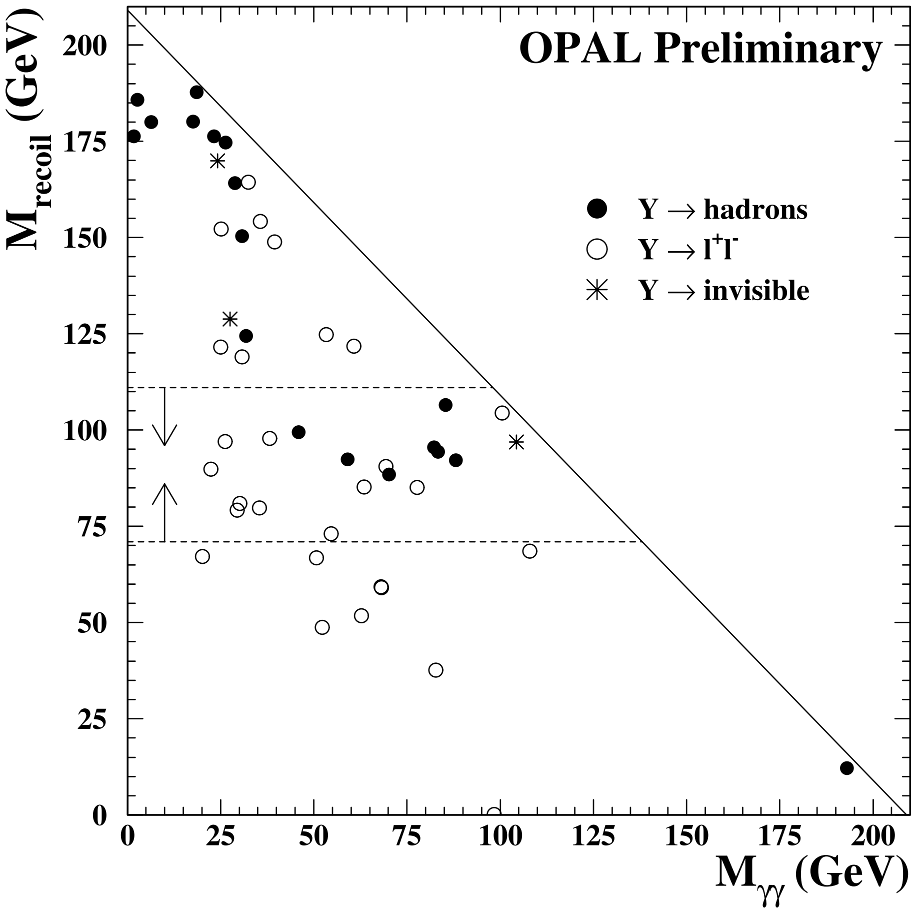
Searches for $H^0 \rightarrow \gamma\gamma$

- Typical scenario: SM cross-section for $e^+e^- \rightarrow Z^0H^0$, with $H^0 \rightarrow \gamma\gamma$. Search modes depend on the decays of the Z^0: qq, l^+l^-, or $\nu\nu$.

- Photon Identificicication easy -- large ECAL clusters with no associated track


Run:event 10227: 28079
Ctrk(N= 33 Sump= 68.9) Ecal(N= 53 SumE=141.6)
Ebeam 94.328 Vtx (-0.03, 0.07, 0.25)
Hcal(N=15 SumE= 21.4) Muon(N= 0)
qqγγ Candidate
mγγ = 57 GeV, mrec = 96 GeV
x
z

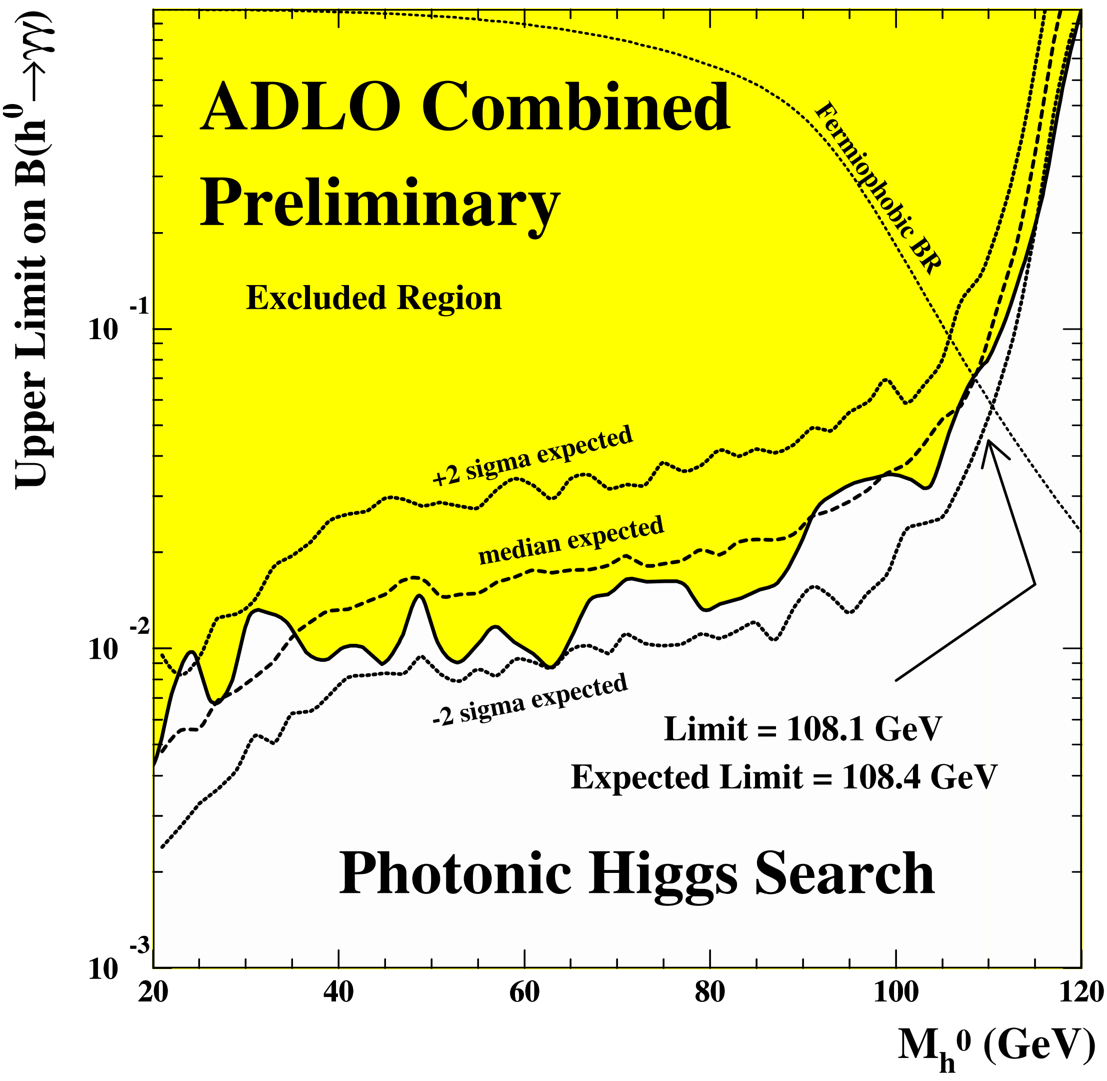
Reconstructed Masses in OPAL H→$\gamma\gamma$ Searches



Expect a concentration at a particular $m_{\gamma\gamma}$ for m_{recoil} near m_Z.

qq channel: obs: 7 SM bg: 7.9±0.7 events
ll channel: obs: 11, SM bg: 9.8±2.0 events
νν channel: obs: 1, SM bg: 6.5±0.3 events

Combination of LEP $H\to\gamma\gamma$ Searches



Really the cross-section limits assuming $Br(H\to\gamma\gamma)=1$, normalized to the SM x-sect

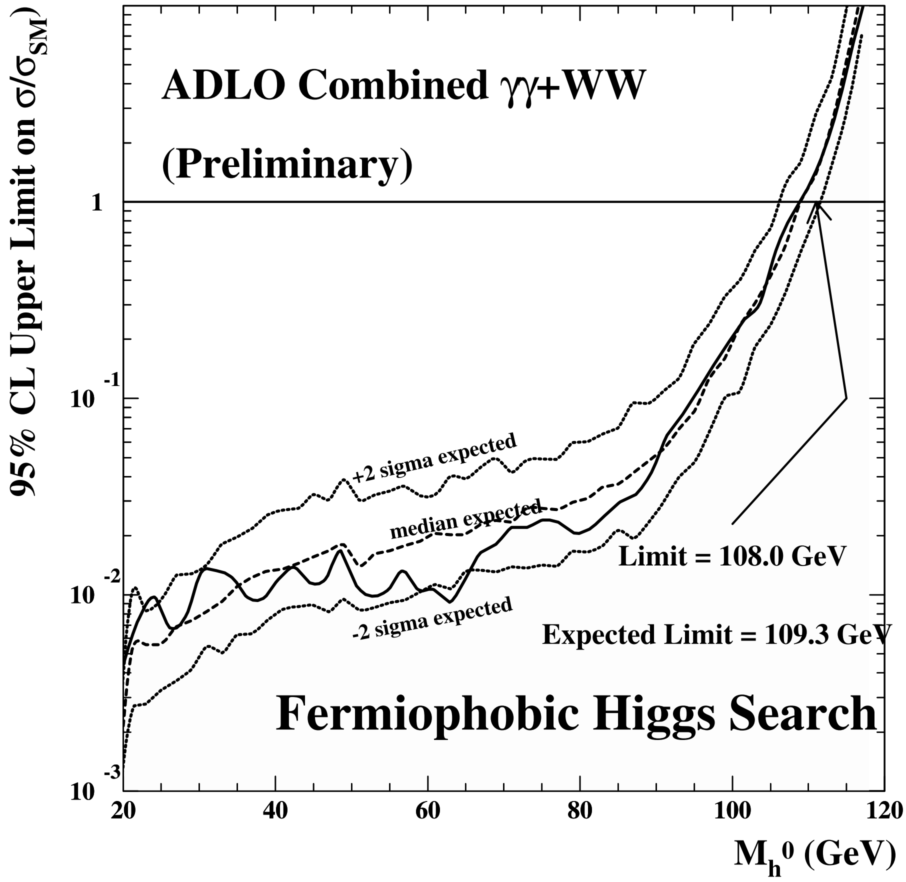
Can derive a mass limit assuming
$Br(H\to fermions)=0$

Observed limit: 108.1 GeV
Median expected: 108.4 GeV

Fermiophobia above m_h=105 GeV

- The decay $h^0 \to W^{(*)\pm}W^{\mp}$
  Starts to become important (one W is resonant)

- Searches are difficult -- many final states in the $Z^0W^+W^-$ system -- 6-fermion final states with quarks, leptons, or neutrinos…
- L3 has started with these searches, others to come. *PRELIMINARY!*

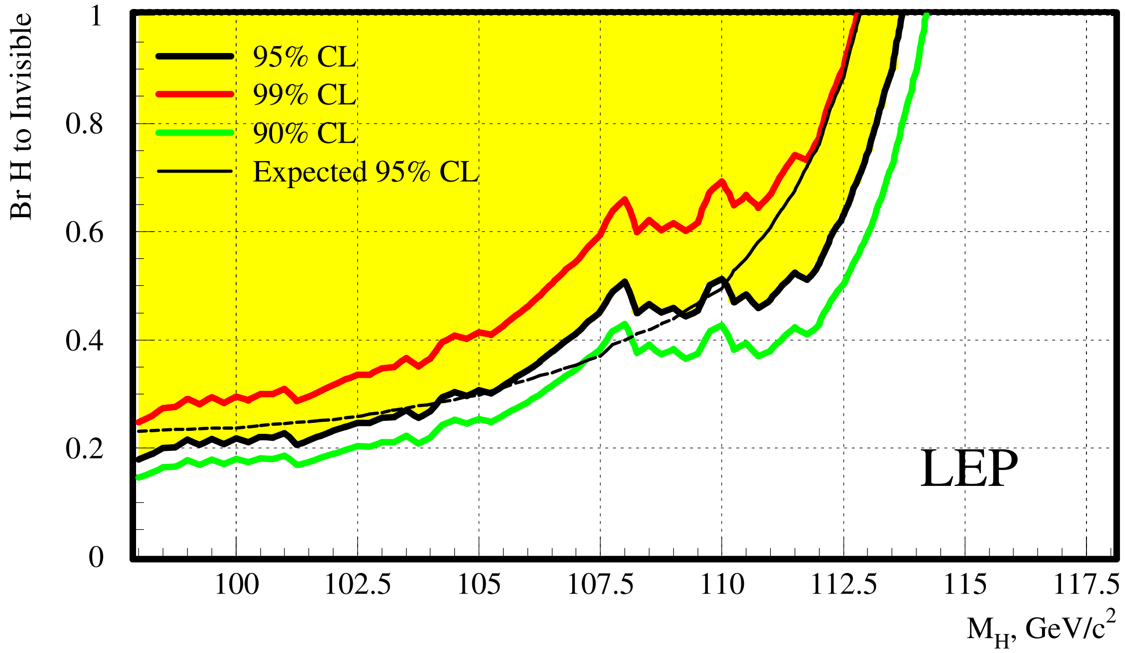


Searches for $H^0 \to$ Invisible Particles

$$\text{e.g.,}\quad h^0 \to \chi_1^0 \chi_1^0 \quad \text{with} \quad \chi_1^0 = \text{LSP}$$

but no restrictions on the model.
Search: similar to the SM missing-energy channel, but the visible system has mass M_Z.

Can use the beam constraint for powerful reconstruction of the invisible decay mass!



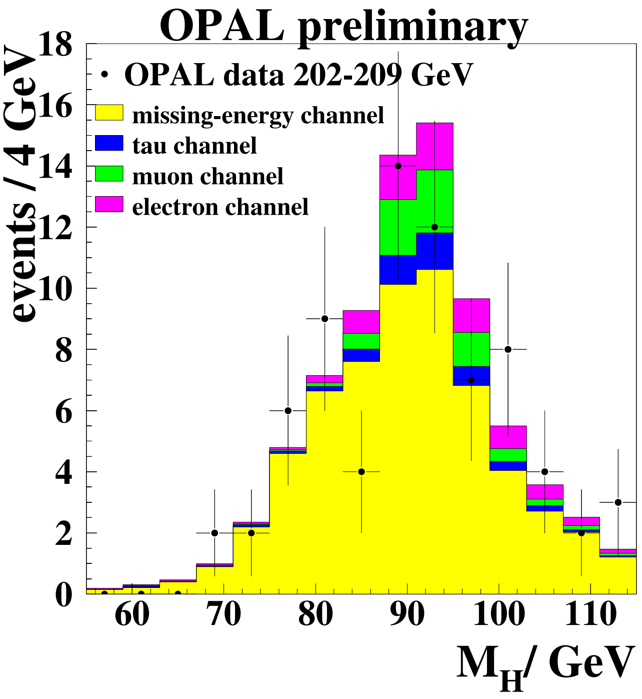
Assuming SM production x-section and 100% invisible decays, obtain the limits

Observed Limit: 113.7 GeV
Median Expected: 112.8 GeV

Flavor-Independent Searches (OPAL)

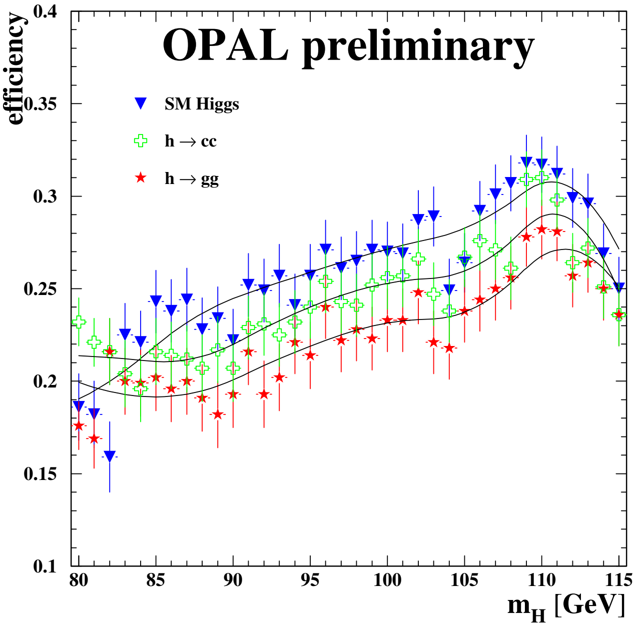
- Motivation:
  - Some parameter choices in the MSSM do not have large $Br(h^0 \to b\bar{b})$ (e.g., large μ models) or MSSM: h→AA, but the A does not decay t b's
  - Higgs search results get reinterpreted as searches for other scalars (e.g. technicolor particles)

- Procedure: Redo SM channels without b-tagging
  - Some channels need extra care. W^+W^- background very large in the four-jet case -- test-mass dependent analysis. Others still dominated by ZZ background.



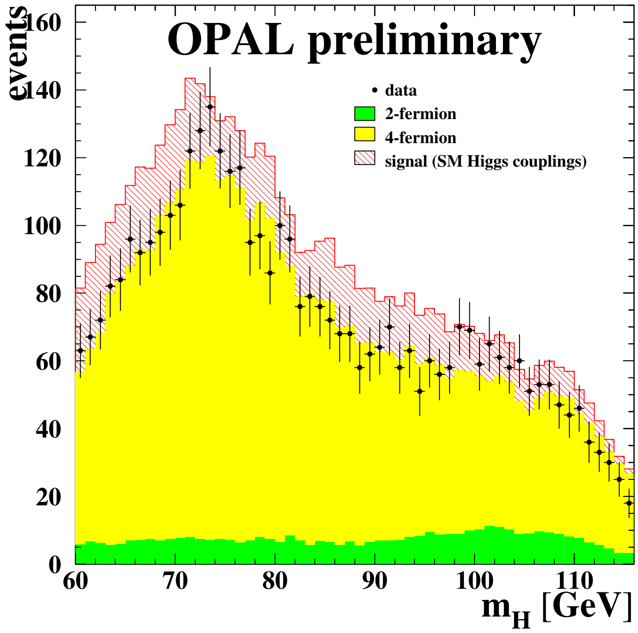
Flavor-Independent Four-Jet Search

- W^+W^- Background is large -- develop a separate search for each value of m_H (on a grid) -- use kinematic variables for separation of s from b



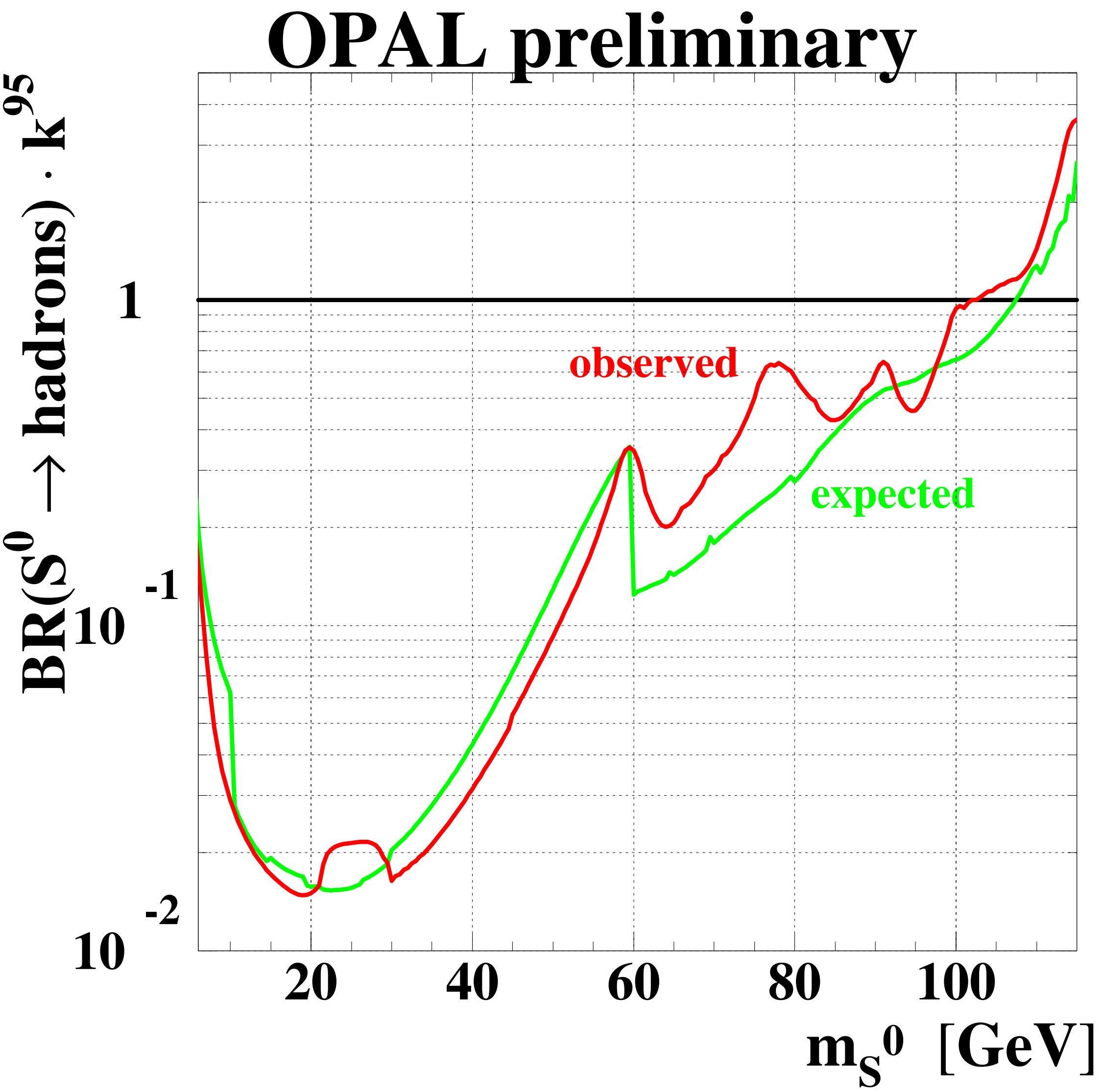
Check flavor-dependence of the efficiency -- choose the lowest (most conservative) efficiency

Selected event counts vs. m_H



Flavor-Independent Cross-Section Limits

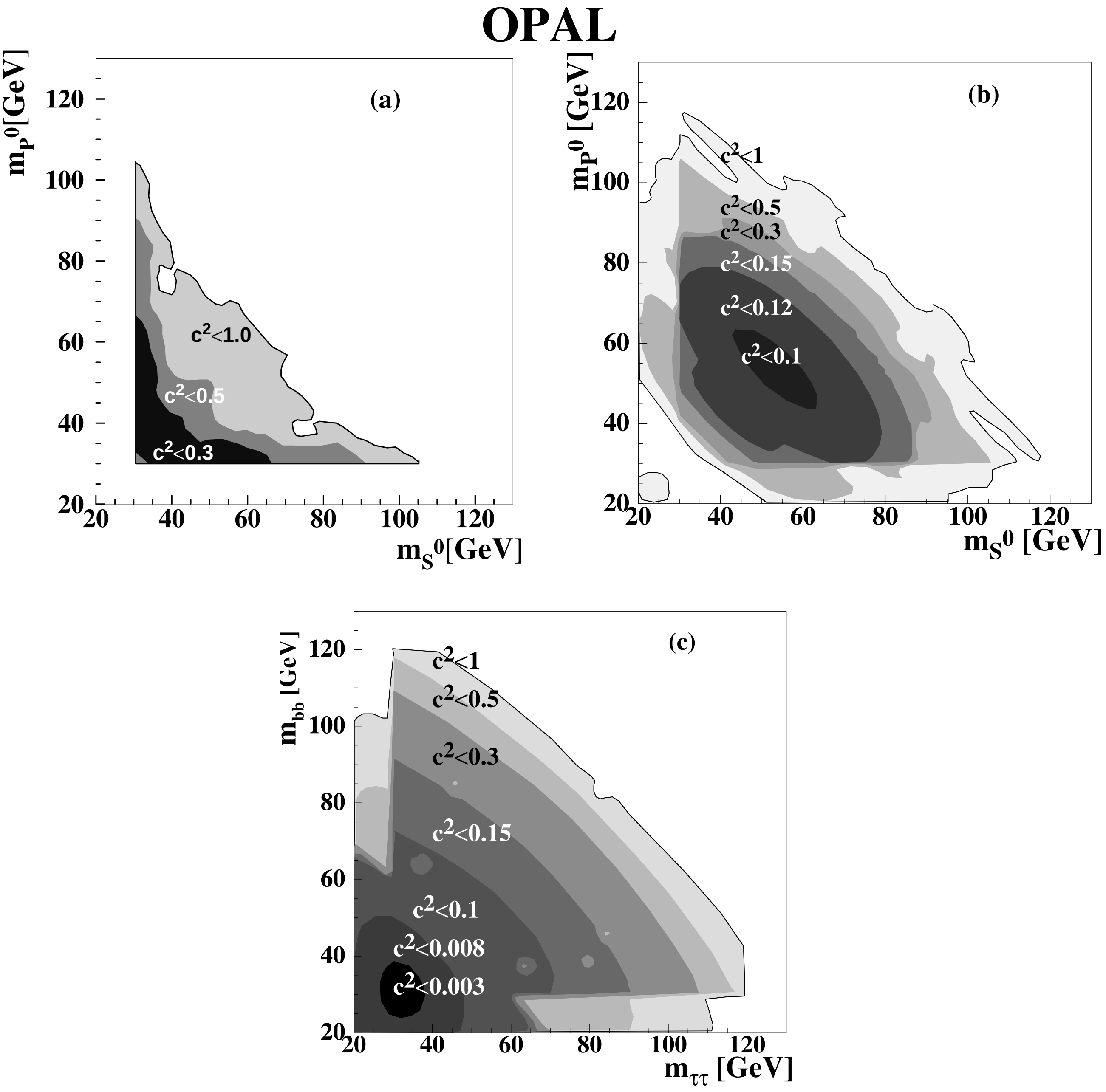
OPAL, all LEP2 data included.



Really a limit on the cross-section assuming 100% hadronic decays.

Mass limit assuming SM x-sec and hadronic decays: 101.8 GeV (obs) 107.3 GeV (expected)

2HDM General Search for hA Producition



OPAL 189 GeV -- Published

Separately for searches for

$$h^0A^0 \to b\bar{b}b\bar{b},\ b\bar{b}\tau^+\tau^-,\ \text{and}\ q\bar{q}q\bar{q}$$

Summary

- MSSM motivated to keep radiative corrections to m_H under control -- max m_h is 135 GeV

- Light Higgs favored by electroweak measurements, hint of something at m_h=115 GeV. EW: $m_H = 98^{+58}_{-38}$ GeV (SM, or MSSM assuming decoupling)

- MSSM getting constrained, but still alive and well. m_h>91.0 GeV,
  m_A>91.9 GeV
  "room to maneuver"

- Charged Higgs Search: excess seen by L3 in the hadronic search with a mass of ~67 GeV -- ruled out in combination. Under investigation.

Summary (Cont'd)

- Charged Higgs direct searches rule out masses below 78.5 GeV if

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

- No Evidence seen for $H^0 \to \gamma\gamma$; fermiophobic limit $m_H > 108.1$ GeV

- $H^0 \to$ invisible particles possible due to beam constraint. $m_H > 113.7$ GeV if H^0 decays invisibly 100% of the time.

- Flavor-Blind H^0Z^0 search: OPAL limit: 101.8 GeV. To be combined. Also limits on h^0A^0 production with fewer model constraints.