SUSY HIGGS AT LEP

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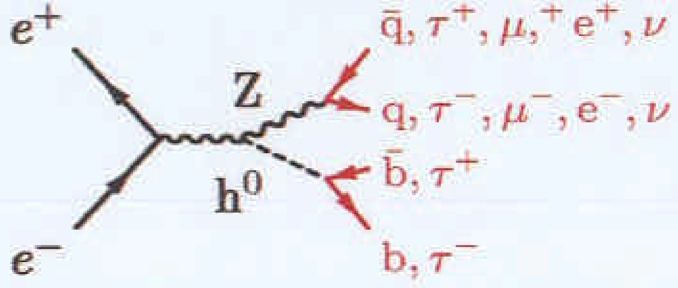
SUSY Higgs at LEP

- Presenting the results on searches for the h and A Higgs bosons of the MSSM and the charged Higgs bosons, H^+ and H^-.
- Results are mainly from the 1998 data at $\sqrt{s}$ =189 GeV and the 1999 data at $\sqrt{s}$ = 192 GeV, 196 GeV, 200 GeV, and 202 GeV from the Aleph, Opal, L3, and Delphi collaborations.
- Together this constitutes a data set of nearly 900 pb^{-1} above 192 GeV and an additional 700 pb^{-1} at 189 GeV giving us a lot of luminosity to probe these processes.
- All results from 1999 should be considered preliminary.

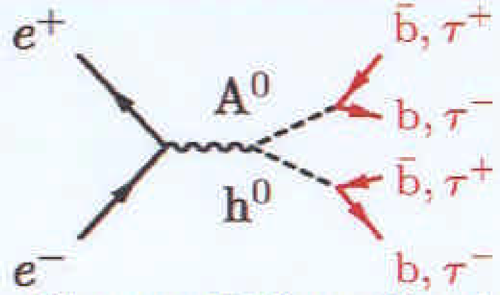
The MSSM Higgs

- In the MSSM there are two Higgs doublets giving rise to 5 Higgs bosons: h, H, H^+, H^-, and A.
- h and A are most often predicted to be producible at LEP. One interesting aspect of the MSSM is that the lightest Higgs is constrained to be fairly light. The LEP program can discover or exclude over a large amount of the available parameter space.
- H^+ and H^- are usually predicted to be heavy and are most often investigated outside the context of the MSSM.

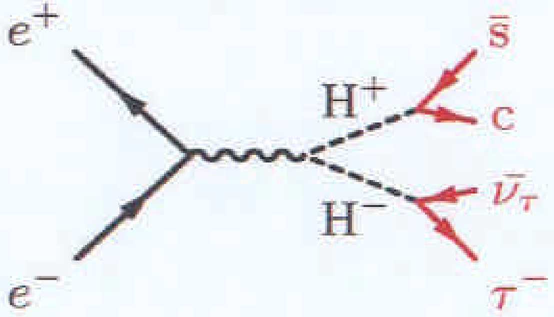
Higgs-strahlung



Pair Production



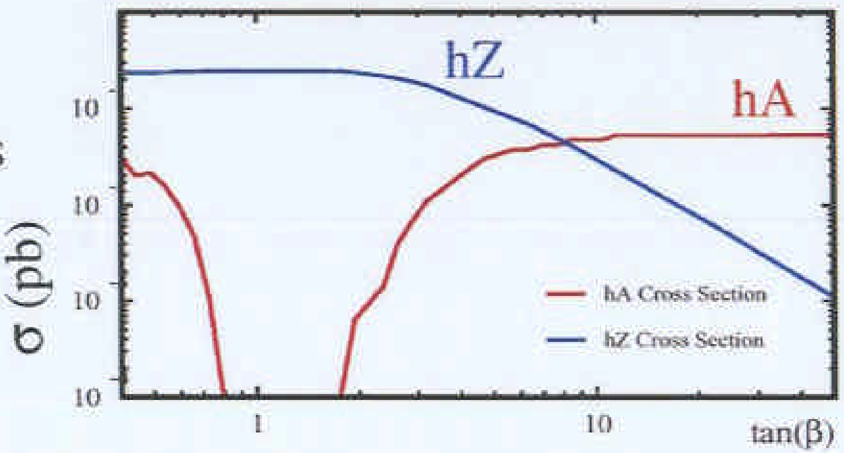
Charged Higgs Production



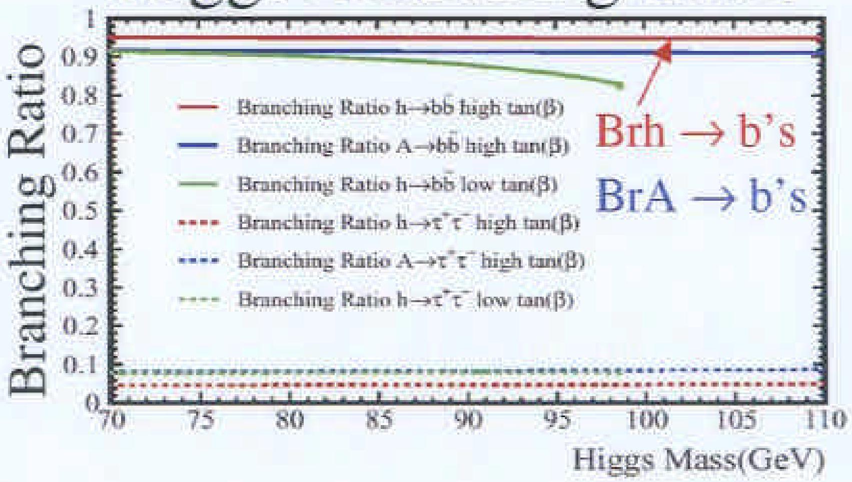
Producing neutral MSSM Higgs

- The Higgs-strahlung process is analogous to the Standard Model Higgs process and dominant for low values of tan(β), the ratio of the Higgs vacuum expectation values and a free parameter of our searches.
- The pair production process is dominant at high tan(β). Clearly in the intermediate region it will be necessary to have searches sensitive to both.
- Both the h and the A decay predominantly to b quarks in most of the mass range accessible to LEP. The ability to identify b decays will be critical.

Cross Sections for h and A



Higgs Branching Ratio



The MSSM Search Channels

- Searches are performed by all experiments for hZ production investigating approximately 98% of the available decay modes though the $hZ \to q\bar{q}q\bar{q}$ $hZ \to q\bar{q}\tau^+\tau^-$ $hZ \to \tau^+\tau^- q\bar{q}$

  $hZ \to q\bar{q}\nu\bar{\nu}$ $hZ \to q\bar{q}e^+e^-$

  $hZ \to q\bar{q}\mu^+\mu^-$

  which are recycled Standard Model channels
- Specific searches have been performed to investigate h decays to AA for the regions of MSSM parameter space when the A is lighter than half the h.
- Searches are performed by all experiments for hA production, investigating approximately 97% of the available decay modes though $hA \to b\bar{b}b\bar{b}$ $hA \to \tau^+\tau^- b\bar{b}$ $hA \to b\bar{b}\tau^+\tau^-$

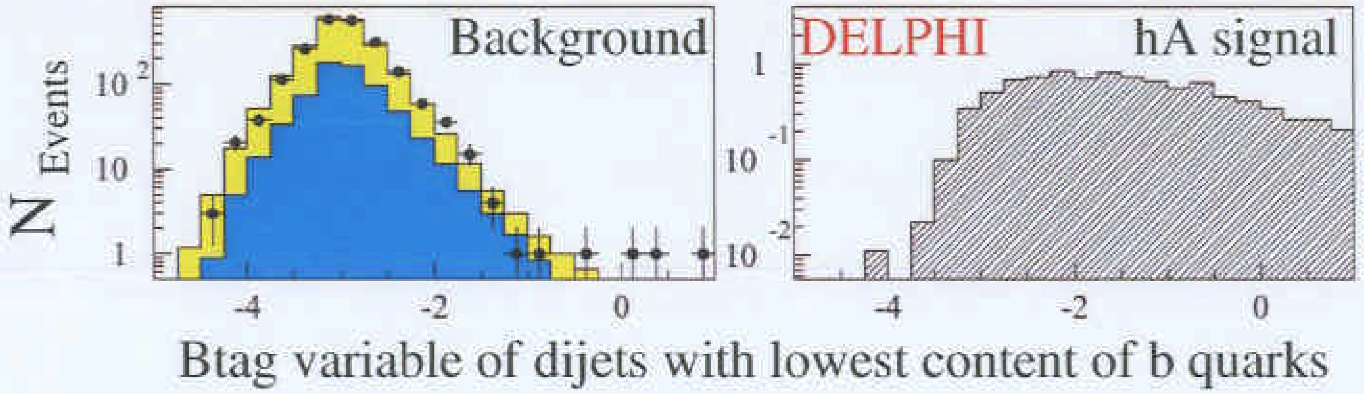
The hA→4-jet Higgs Channel

- Analysis proceeds in similar manner for all 4 LEP experiments.
  - Apply pre-selection to remove easily reduced background.
  - Form a composite variable from other distinguishing variables.
- Either cut on this discriminating variable and make a new distribution to use to evaluate the presence or absence of signal such as reconstructed mass, or just use the composite variable.

Typical Pre-selection Cuts

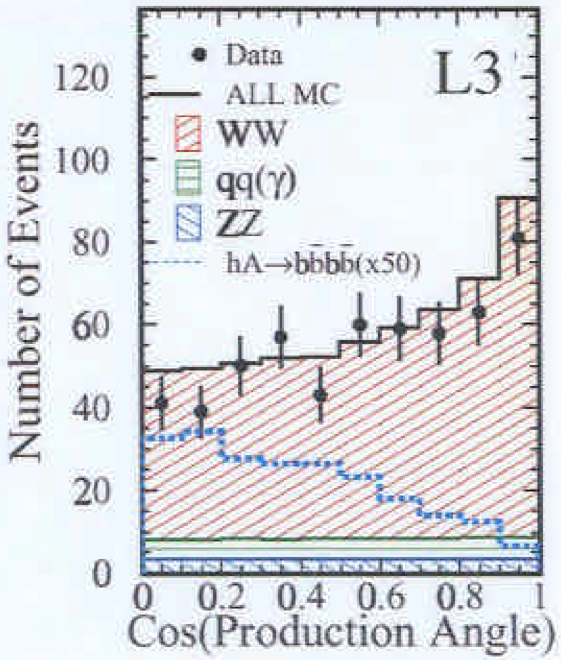
- Track Multiplicity
- Visible Energy
- Ratio of Fox-Wolfram Moments
- Thrust
- χ^2 of 4C kinematic fit
- Y34 Durham
- Maximum photon energy

The hA→4-jet Higgs Channel

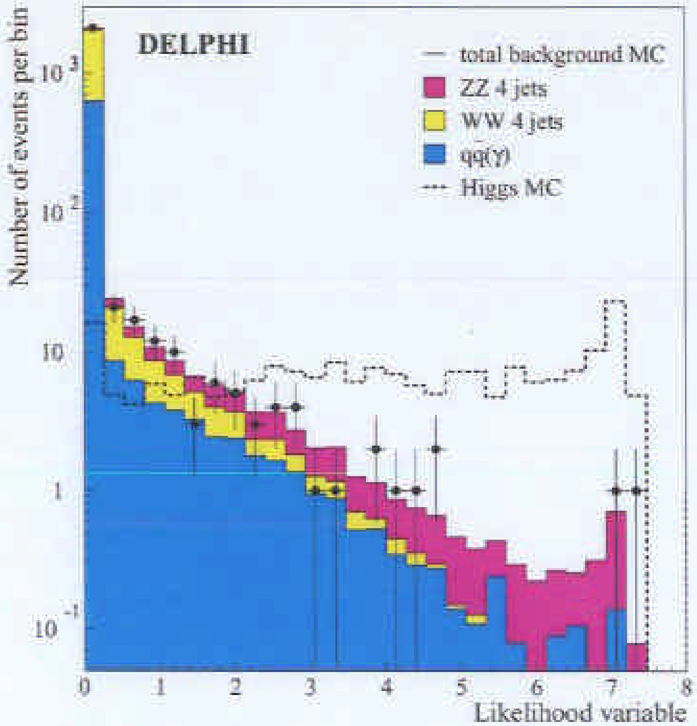


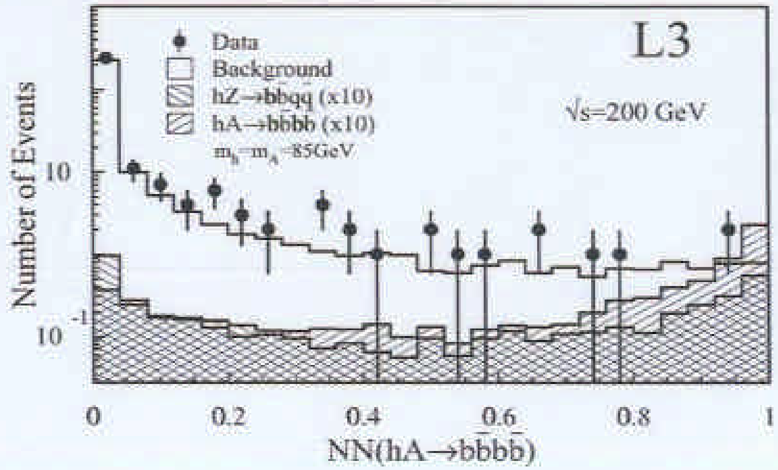
- The most important contribution to the distinguishing power comes from the btag, but other improvements come from adding information from the production angle, imbalance of three jets recoiling against one.

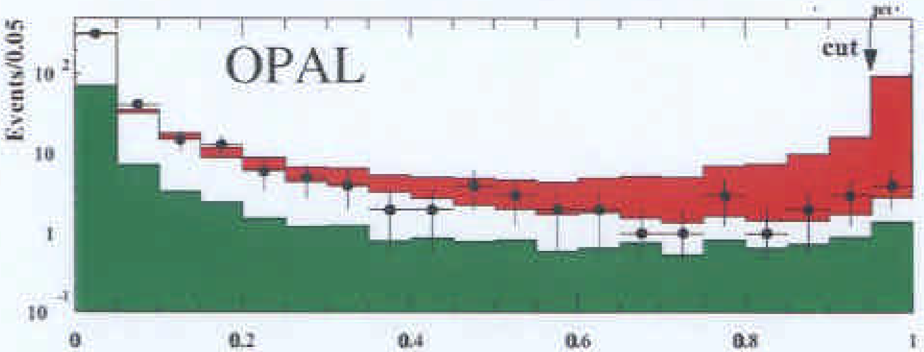
- The information is combined with using likelihood ratio techniques, neural network techniques, combining probabilities, or a series of linear cuts.

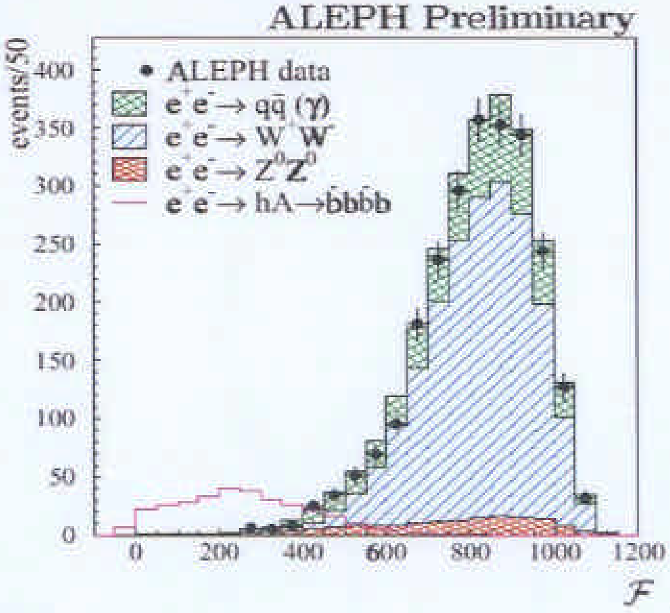


Examples of the combined variable



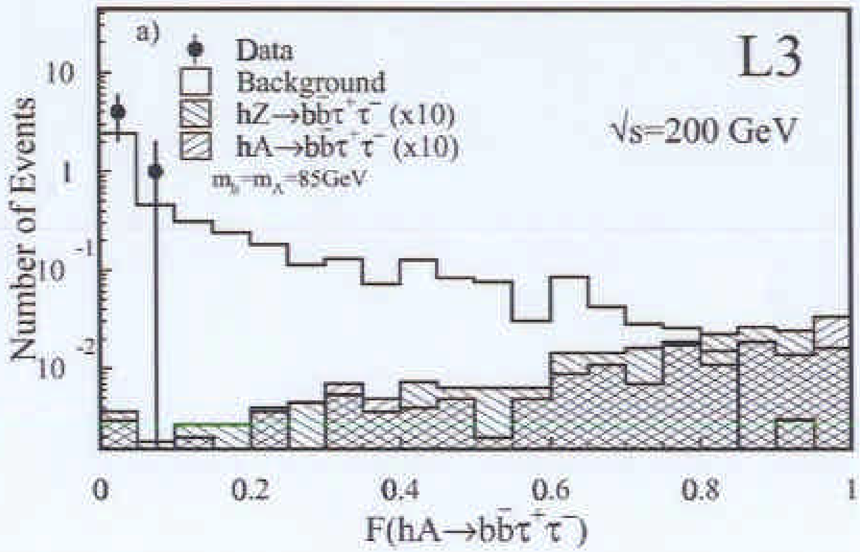






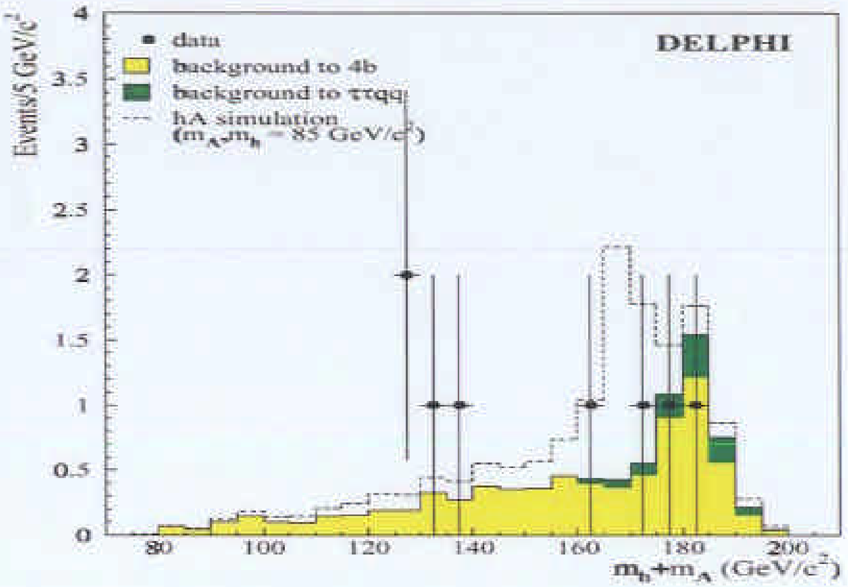
hA→bbττ and ττbb

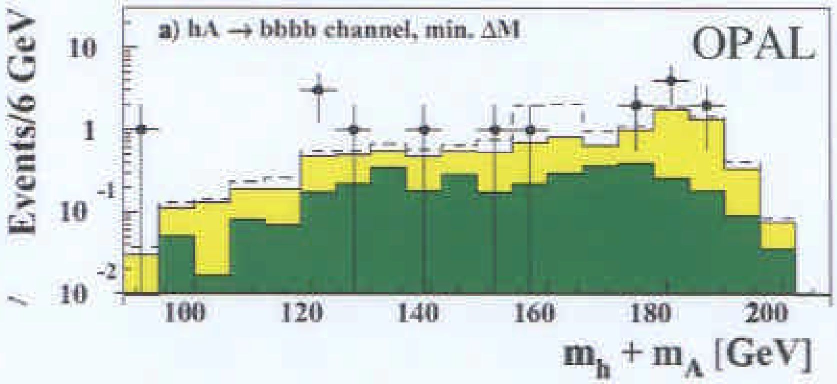
- Second Highest branching fraction.
- The analysis relies heavily on the identification of two τ's.
- Btag continues to be useful to distinguish signal and background.

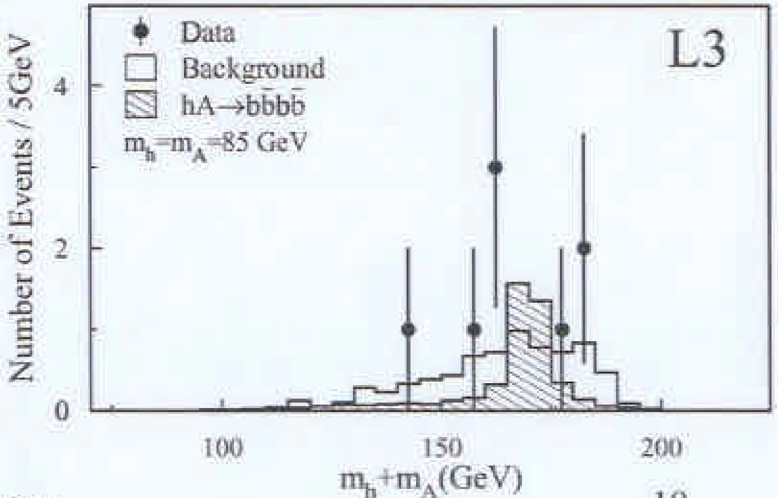


Analyzing the Results

- Once a final set of events has been selected it is necessary to find some way to examine them to determine the presence or absence of a signal in the collected data.
- Combine all contributing channels.
- Apply statistical procedure comparing signal and signal + background hypotheses to determine the Confidence Level.







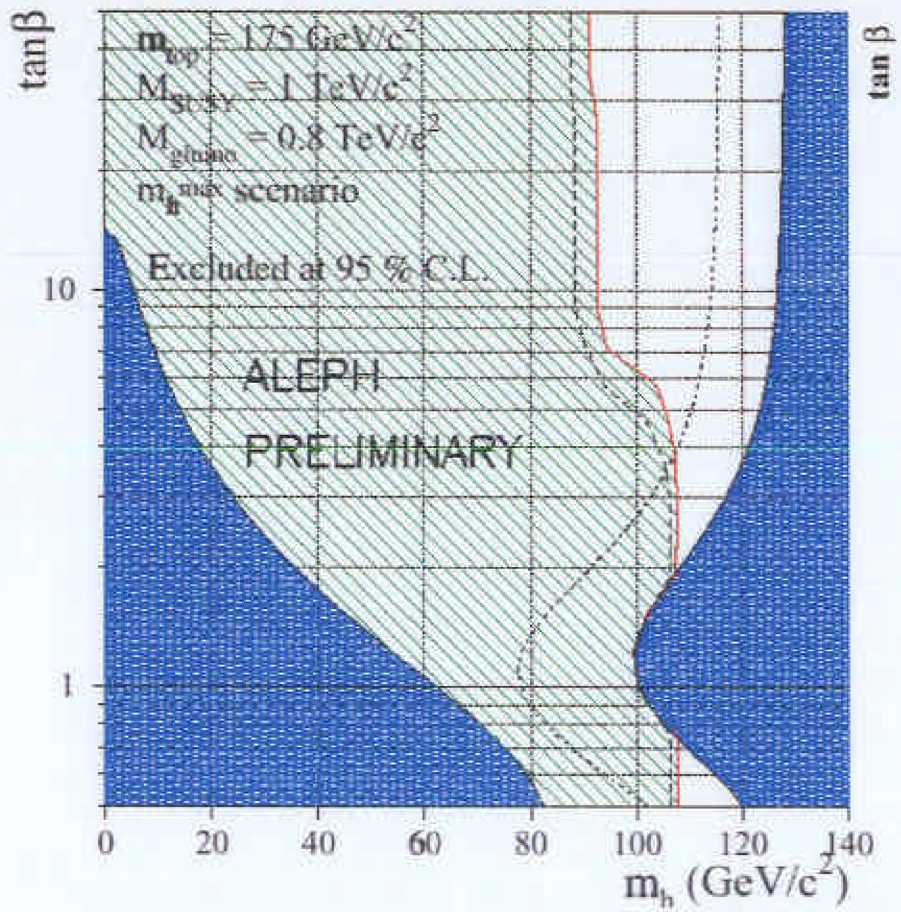
Analyzing The Results

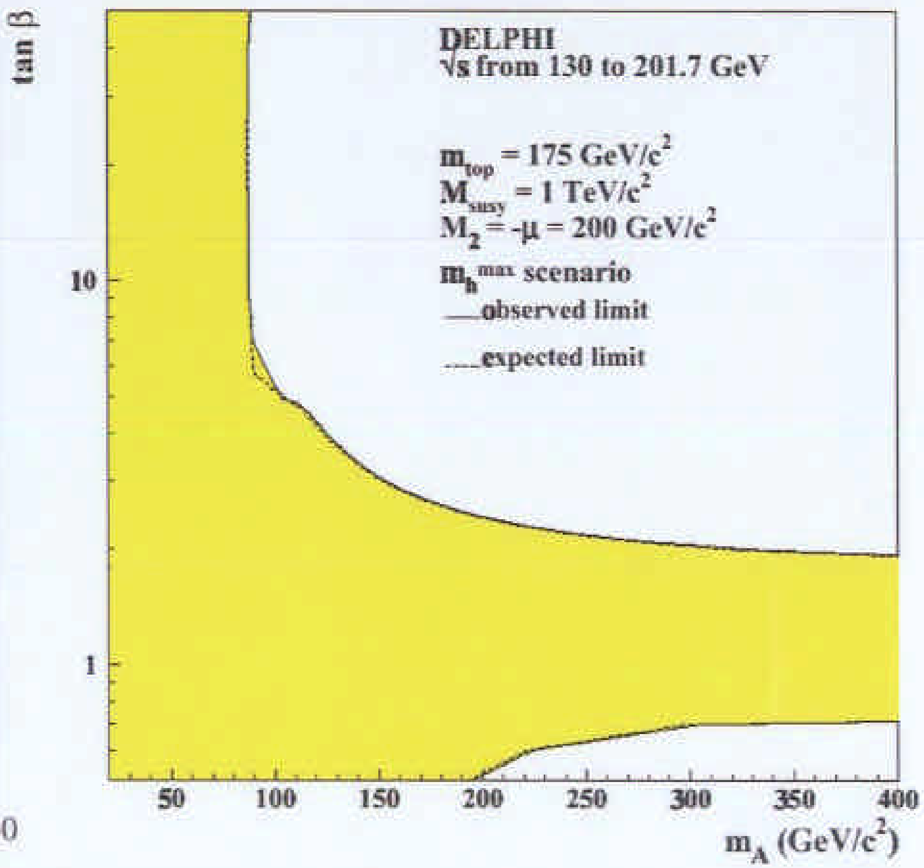
Events Observed and Expected in the MSSM channels

Experiment	ALEPH	DELPHI	L3	OPAL
Total Luminosity (pb-1)	237	228.2	233.1	214-217
$hA \to b\bar{b}b\bar{b}$				
Background Expected	46.4	51.1	13.7	10.5
Events Observed	30	47	10	16
$hA \to \tau^+\tau^- b\bar{b}$ $hA \to b\bar{b}\tau^+\tau^-$				
Background Expected	2.7	7.1	1.3	7.7
Events Observed	1	6	0	6
Limits				
Limit Observed m_h (GeV)	91.5	86.1	83.5	79.2
Limit Expected m_h (GeV)	87.7	85.8	85.5	83.7
Limit Observed m_A (GeV)	91.9	87.2	83.7	80.2
Limit Expected m_A (GeV)	88.1	87.3	85.7	85.4

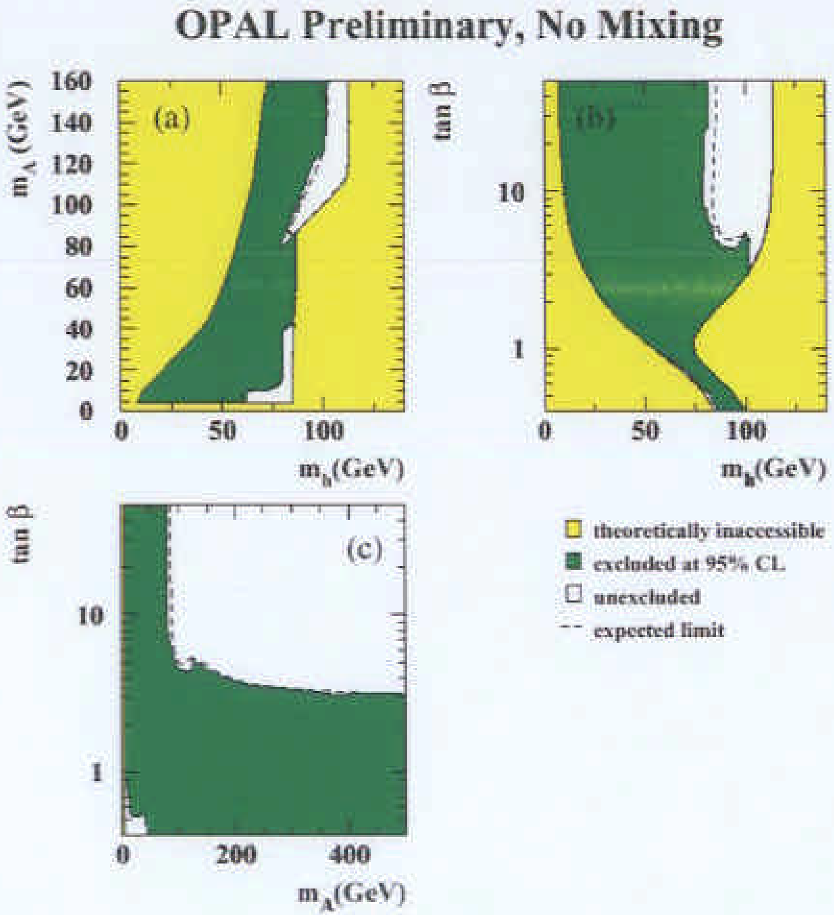
- SUSY has a number of free parameters, but making about scalar fermion masses and unification reduces this to a reasonable level. We typically leave only two parameters, tan(β) and the mass of the A, free and form benchmark scenarios.
- Scan over the allowed values of tan(β) and Higgs mass to determine
- The scenarios are chosen to investigate the largest h mass for a given tan(β) and A mass, minimal squark mixing, and recently a model when the A and h decay more frequently to τ's.

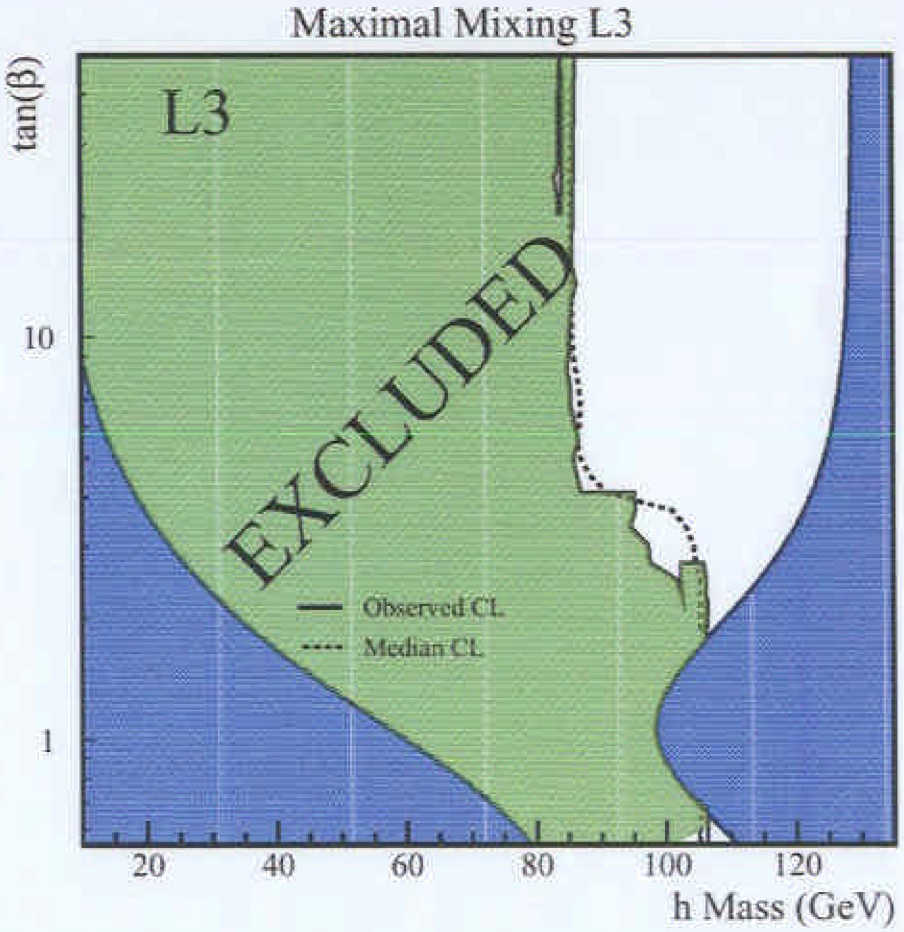
Final Results of the MSSM Higgs Search



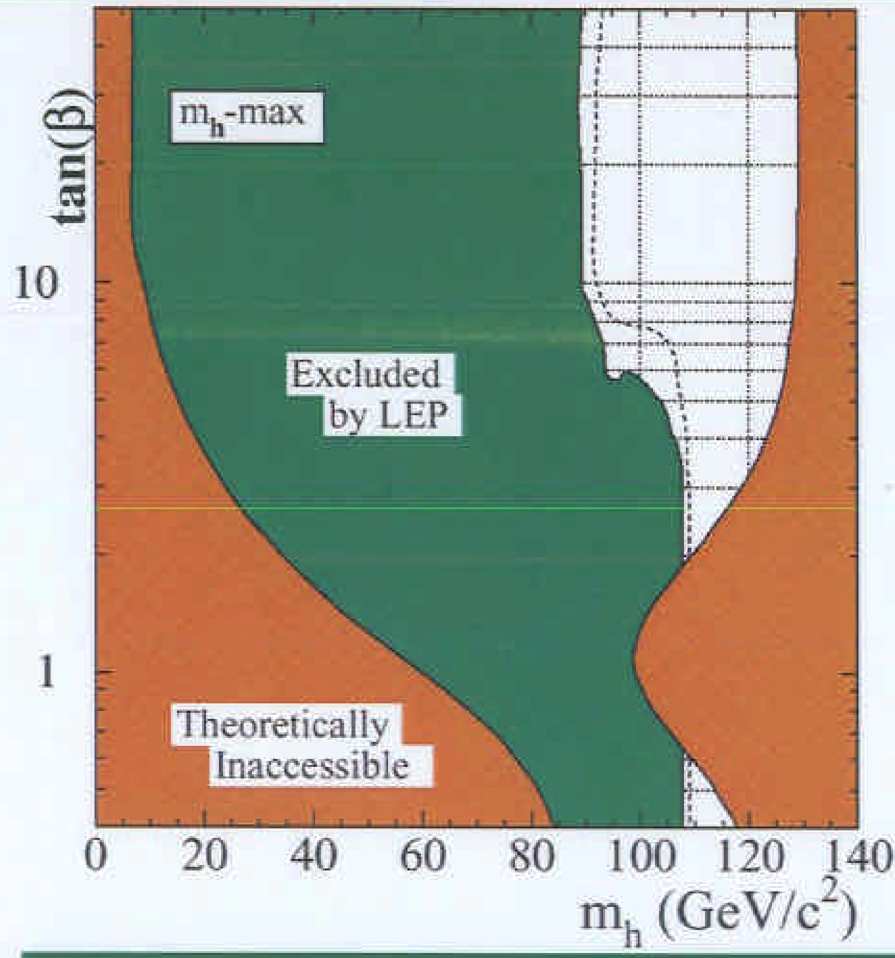


Final Results of MSSM Higgs Search

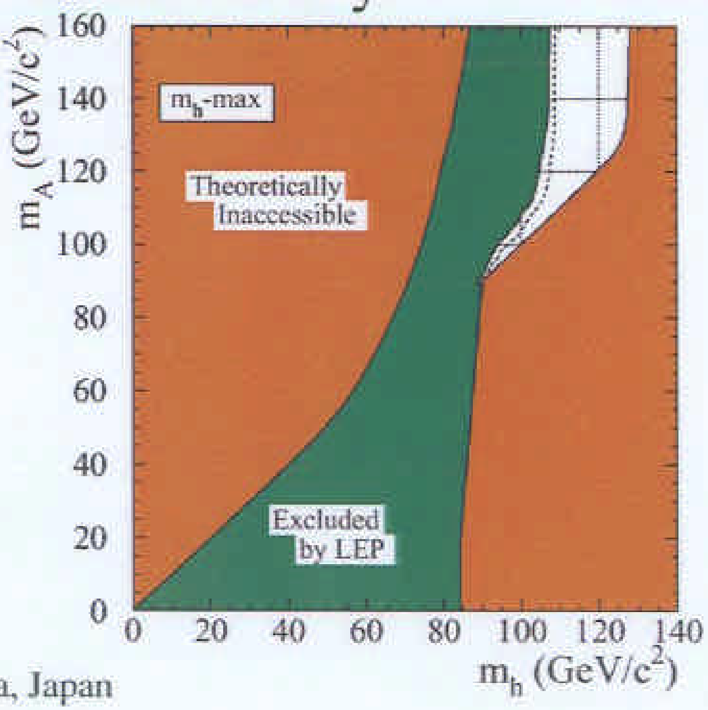




Combining Results



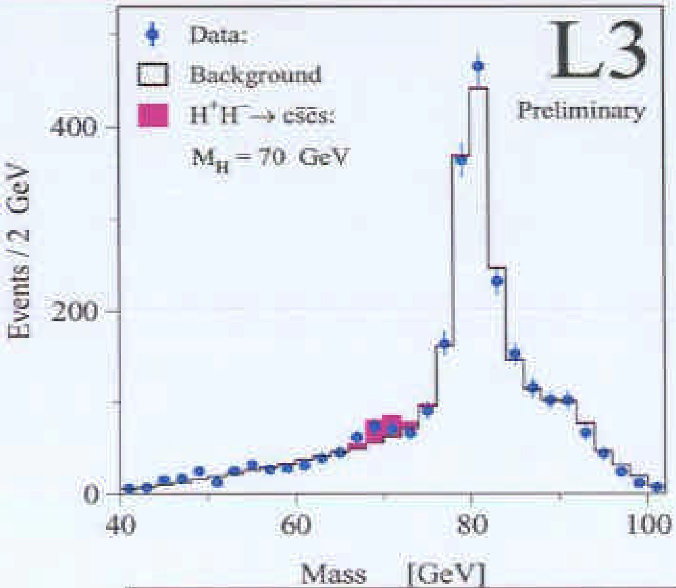
- Real Power comes from combining the results of the 4 LEP experiments.
- At high tan(β) the limit of sensitivity is heavily dependent on luminosity.

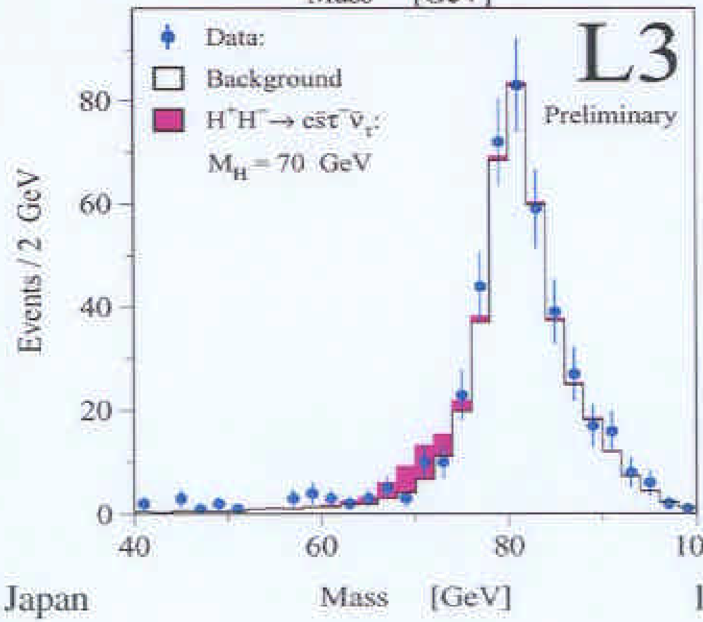


$m_h > 88.3$ GeV and $m_A > 88.4$ GeV
$\tan(\beta) < 0.7$ or $\tan(\beta) > 1.8$

Charged Higgs

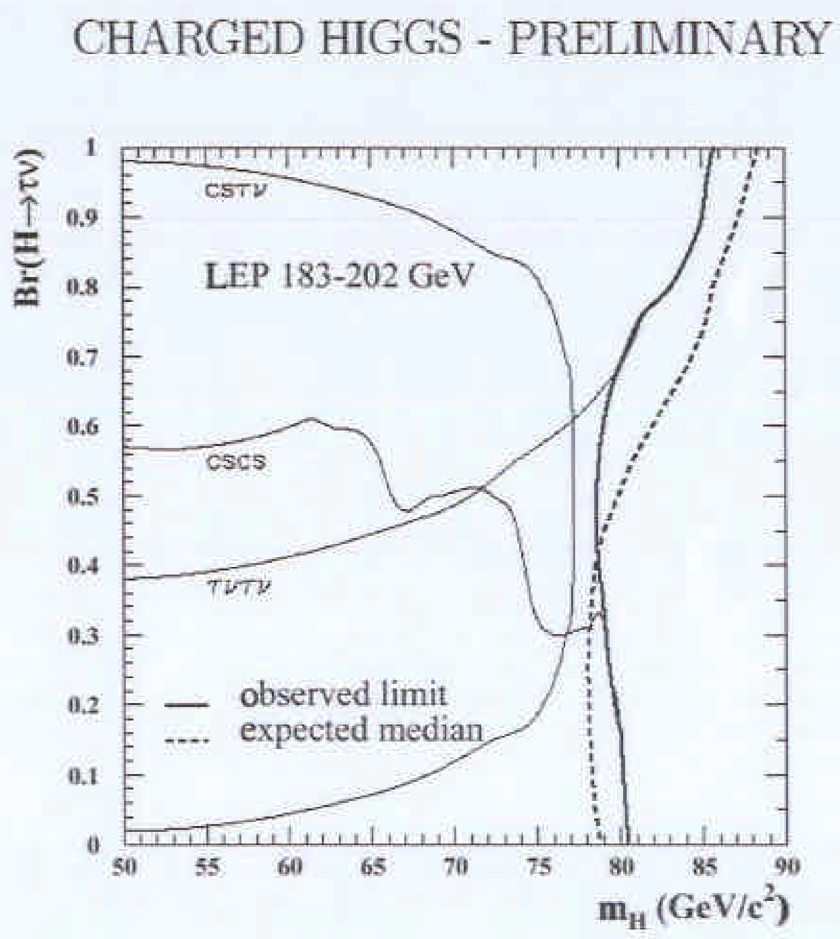
- The charged Higgs is more difficult because the btag is no longer useful.
- In mass regions visible at LEP the W pair background is very large.
- The charged Higgs is not predicted to be light in the MSSM so it is probed in the context of two doublet model searches.
- No prediction of branching ratio.





Combined Results of Charged Higgs

- The charged Higgs exclusion is generally plotted as a function of branching fraction to $\tau\nu$.
- The fully leptonic, semi-leptonic, and fully hadronic all contribute.
- In the fully leptonic where the background is lower it is easier to exclude past the W mass.
- Combining increases sensitivity.



Conclusions

- Combining the 4 LEP experiments using data up to $\sqrt{s}$=202GeV. Limits on
  - $m_A > 88.4$ GeV
  - $m_h > 88.3$ GeV
  - $0.7 < \tan(\beta) < 1.8$ Excluded (top mass < 174.3GeV)
  - $m_{H+-} > 78.6$ GeV
- The allowed parameter space of the MSSM is disappearing, but there is still room.