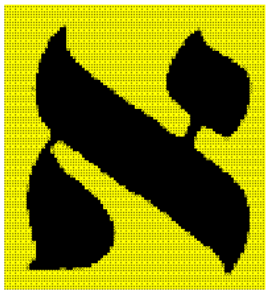
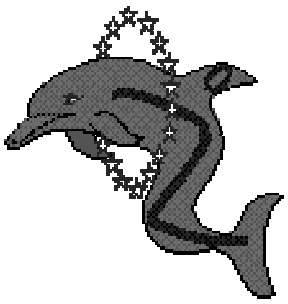
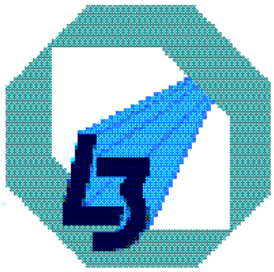
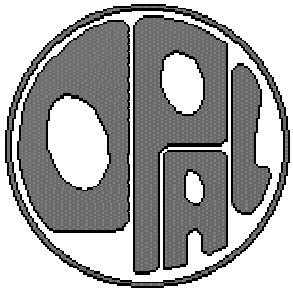
Combined LEP Higgs Searches

Tom Junk
Carleton University
Ottawa, Canada

LEP Fest, 10 October 2000

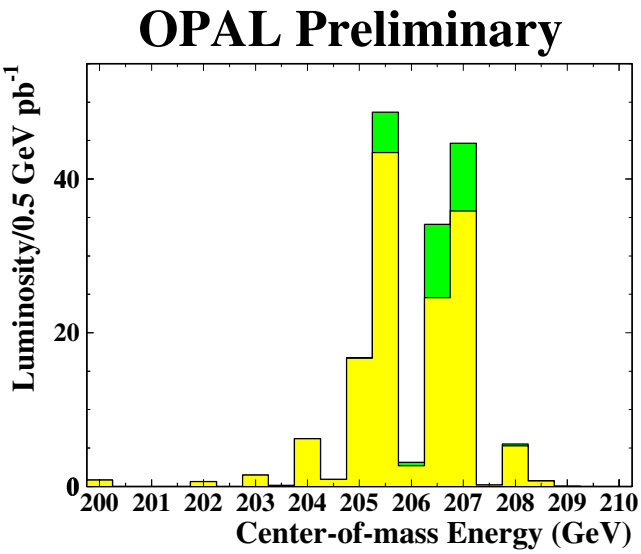
Preliminary update of the LEP Higgs Working group, with many thanks to the ALEPH, DELPHI, L3 and OPAL Collaborations, and the Accelerator divisions at CERN.

Data Sets

$\int L dt \quad [pb^{-1}]$

Experim.	Sept 5	Oct 10	New Lumi
ALEPH	149	178	29
DELPHI	160	160	**
L3	145	170	25
OPAL	140	165	25
Total	594	673	79

**DELPHI suffered from a TPC short. Current data still being calibrated/analyzed.



Average E_{CM} for the year: **206.0 GeV**

New data: mostly 206.6 GeV (a little at 208.x.)

E_{CM} very important to extend sensitivity

Goal from Sep. LEPC: double the lumi >206 GeV

What's also New: Analysis and Reprocessing

Many detailed checks have been carried out since the September 5 LEPC. Some problems found and fixed:

ALEPH: Improved background estimation in the four-jet channel

DELPHI: Improved signal and background estimations in the four-jet channel

L3: Reprocessing of data for TEC
Change to Neutrino channel analysis

OPAL: Reprocessing for better Silicon hit association

Three sets of results to watch:

"NEW" All data up to October 10 LEPC

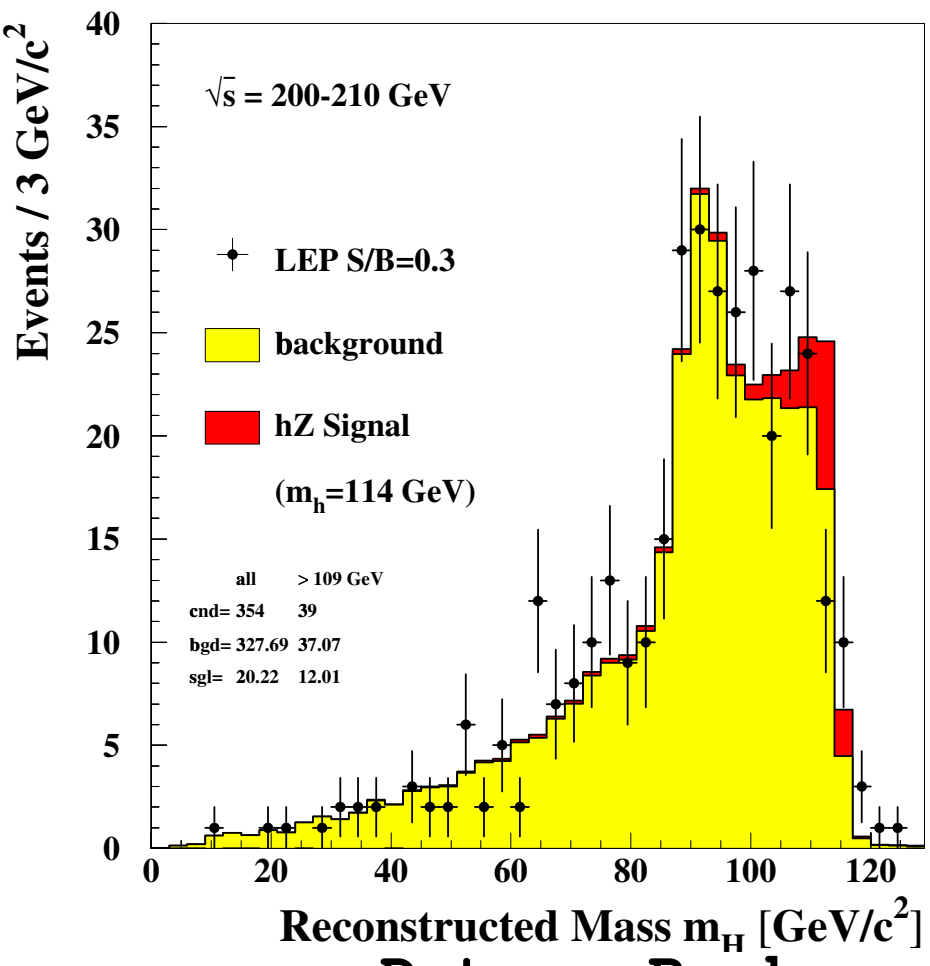
"REFERENCE" Data used for September 5 LEPC but with new analysis

"OLD" Results for September 5 LEPC

Reconstructed m_H of selected candidates

Have to cut somewhere. For illustration only.

Cut on mass independent variables (like b-tags) so that $\frac{s_{\text{expected}}}{b_{\text{expected}}} \approx 0.3$ For m_{rec}>109 GeV for a 114 GeV Higgs



All 2000 Data

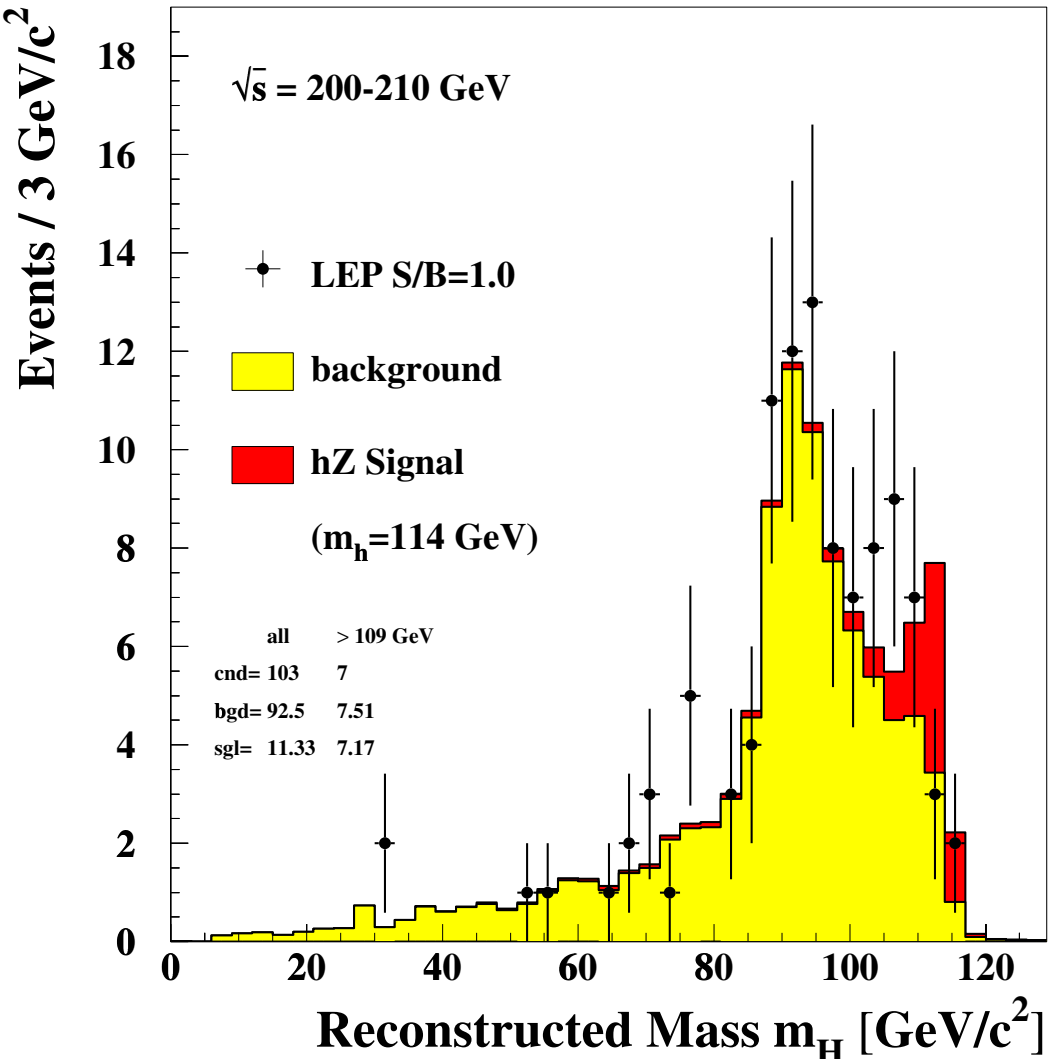
	Data	Backg	Signal
All m_{rec}	354	328	20.2
m_{rec}>109 GeV	39	37.1	12.0

Cutting a Little Harder

This time, adjust cuts so that

$$\frac{s_{\text{expected}}}{b_{\text{expected}}} \approx 1.0$$

For m_{rec}>109 GeV
for a 114 GeV Higgs

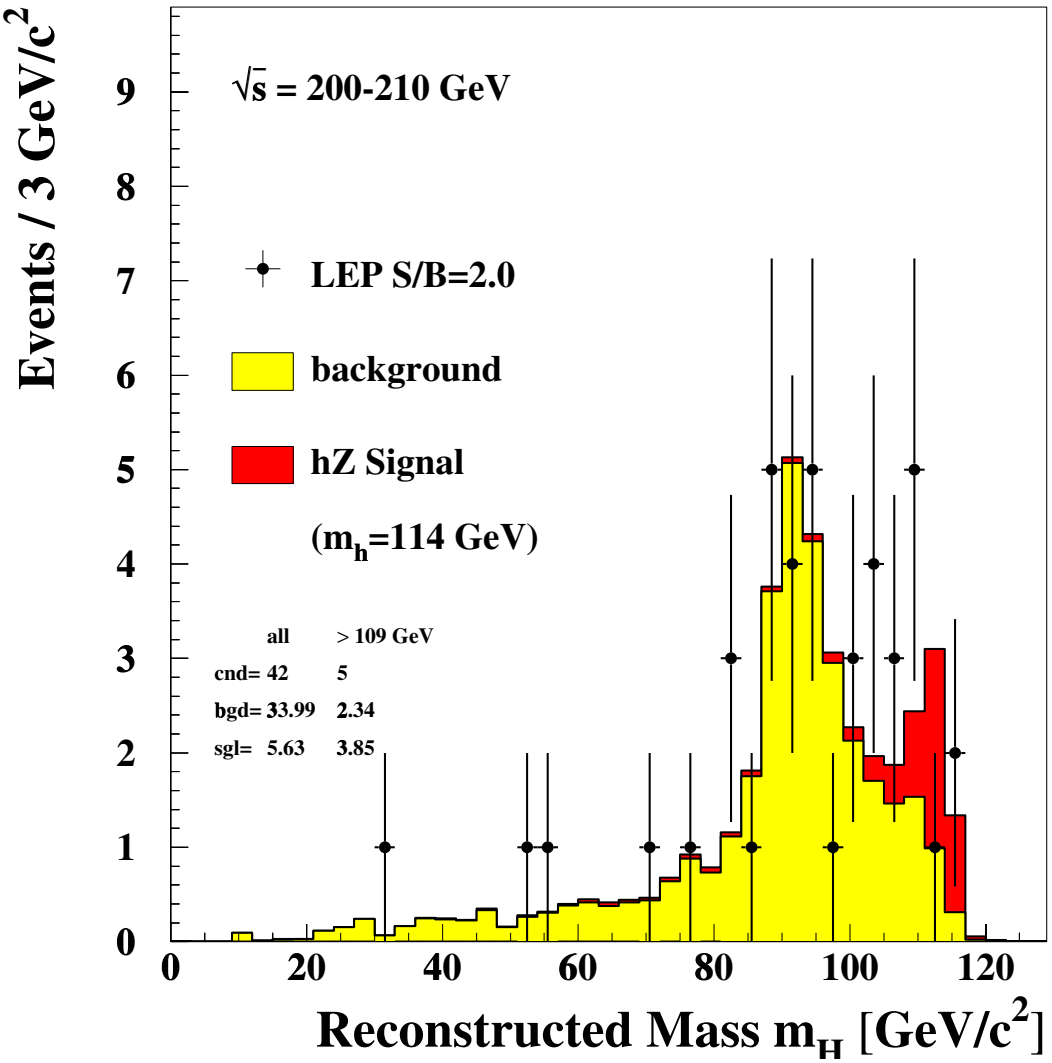


	Data	Backg	Signal
All m_{rec}	103	92.5	11.3
m_{rec}>109 GeV	7	7.5	7.2

Very Hard Cuts

$$\frac{s_{\text{expected}}}{b_{\text{expected}}} \approx 2.0$$

For m_{rec}>109 GeV
for a 114 GeV Higgs



Losing Efficiency -- but "really good" events kept

	Data	Backg	Signal
All m_{rec}	42	34.0	5.6
m_{rec}>109 GeV	5	2.3	3.9

Why Cut at All?

- Need to separate the expected signal
from the expected background

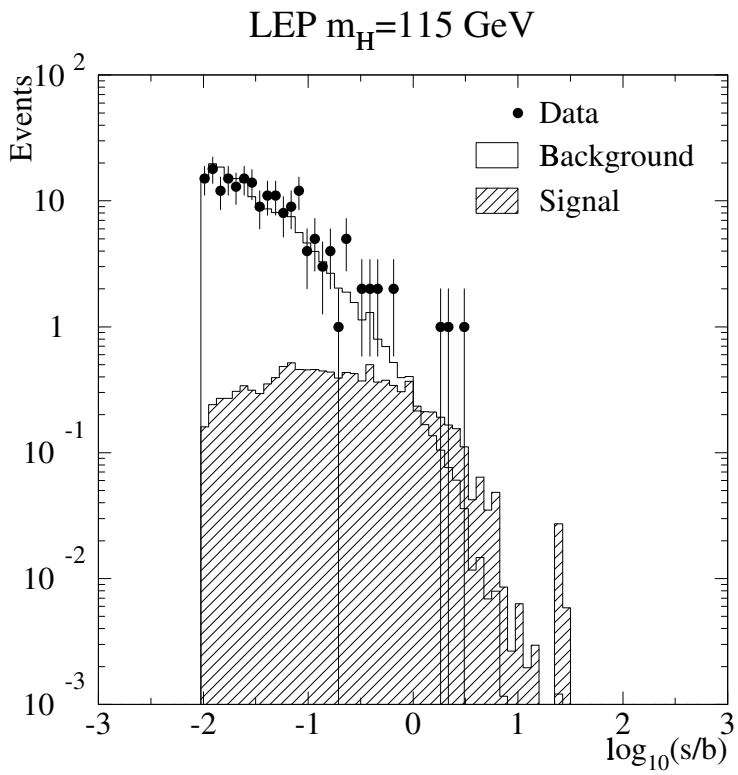
- **Pick good variables to optimize separation**
  - reconstructed m_H
  - b-tags
  - kinematic variables

- **Express in bins**
  - Experimental Data
  - Monte Carlo Signal Expectation
  - Monte Carlo Background Expectation

- **Systematic Uncertainties**
  - By search channel, on signal and background
  - Signed errors, labeled by source name
  - Correlated errors properly treated

Need a language: classical confidence levels

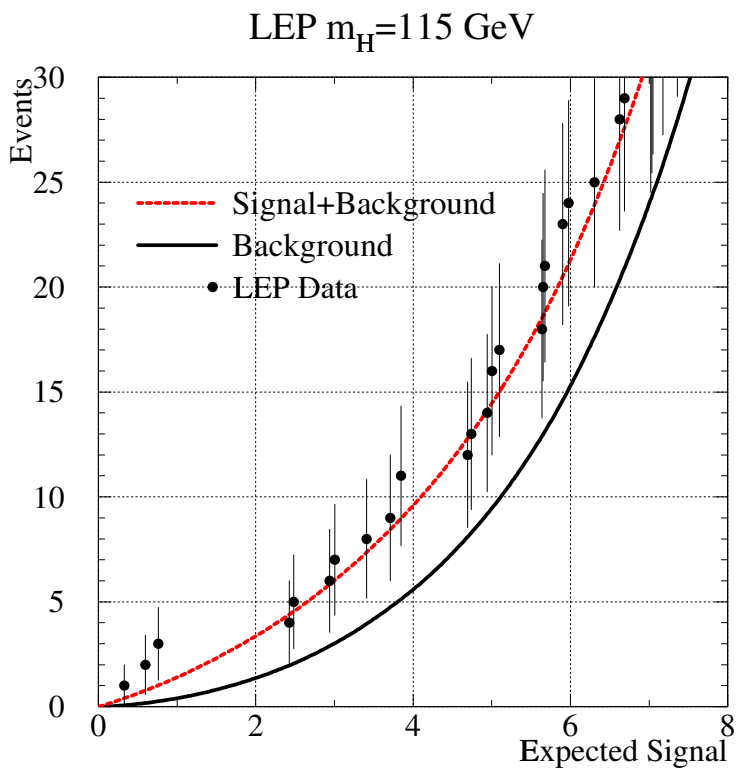
All LEP Data in bins of Expected Signal/Background



Important Candidates stand out

And the integral -- the optimal answer to the questions:

"How many did you see? How many did you expect? Where did you cut?"



Comparing Signal and Background Hypotheses

- Construct a parameter that orders outcomes as more signal-like, or less signal-like

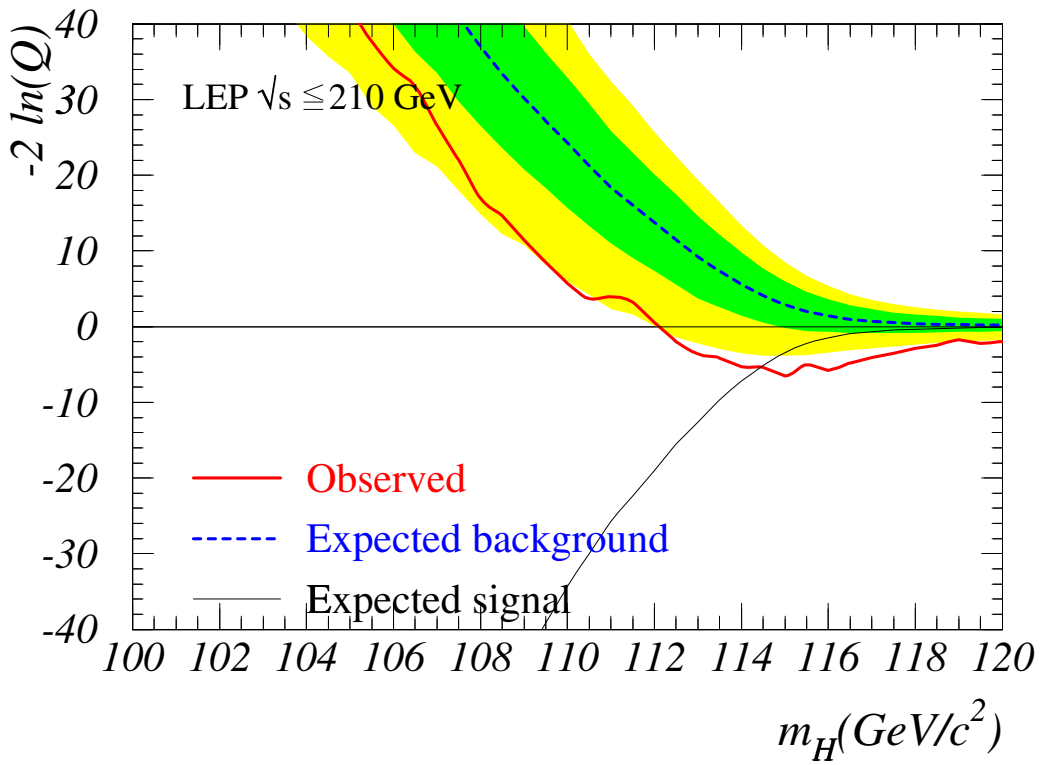
$$Q = \frac{P_{poiss}\left(data \,|\, signal + background\right)}{P_{poiss}\left(data \,|\, background\right)}$$

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

Background-like

Signal-like

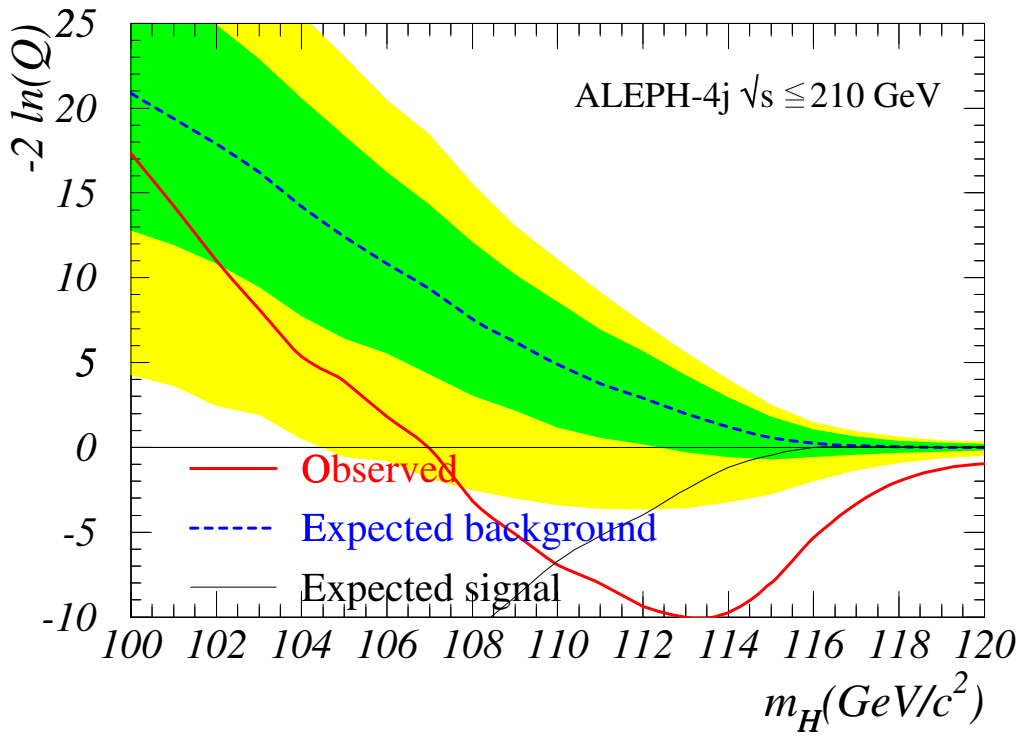
Sep 5 LEPC: "Old"



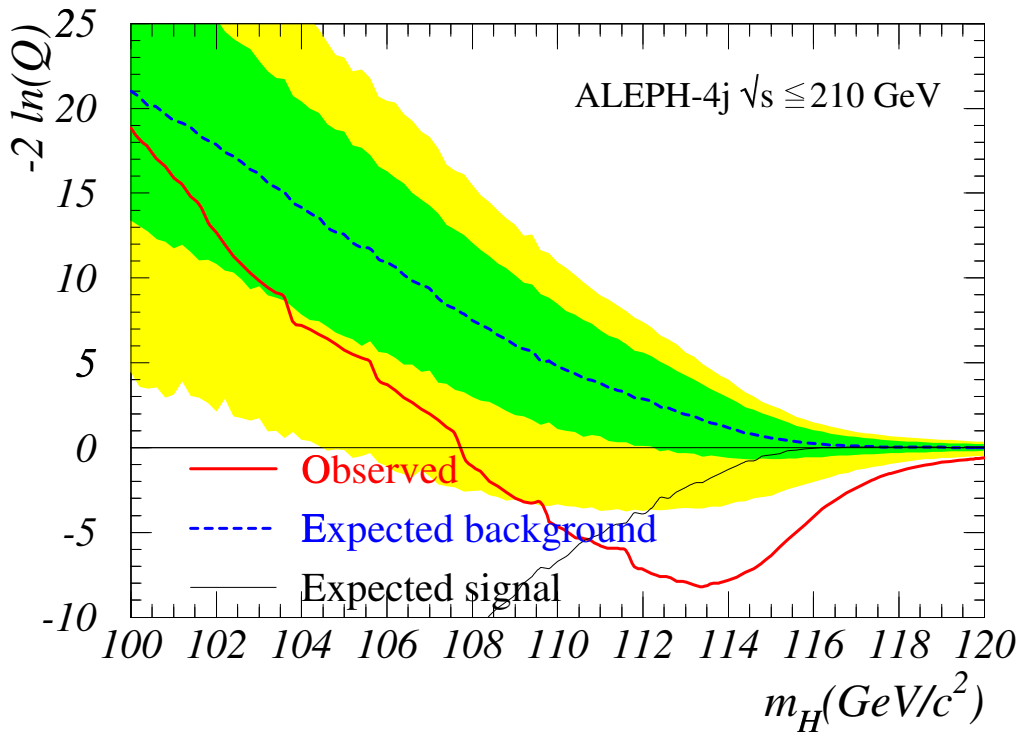
Updated Analysis 1: ALEPH

Four-Jet Channels:
Improved background modeling.
Some candidates become less significant

"Old"---
Sept. 5
Results



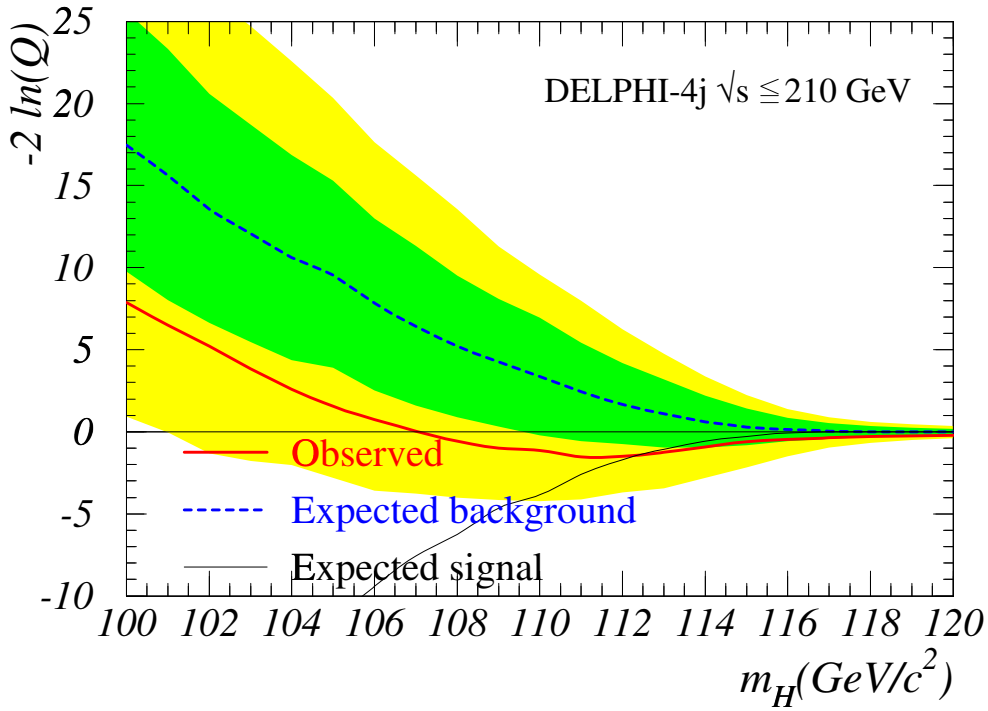
"Reference"
Sept. 5 Data
with New
Analysis



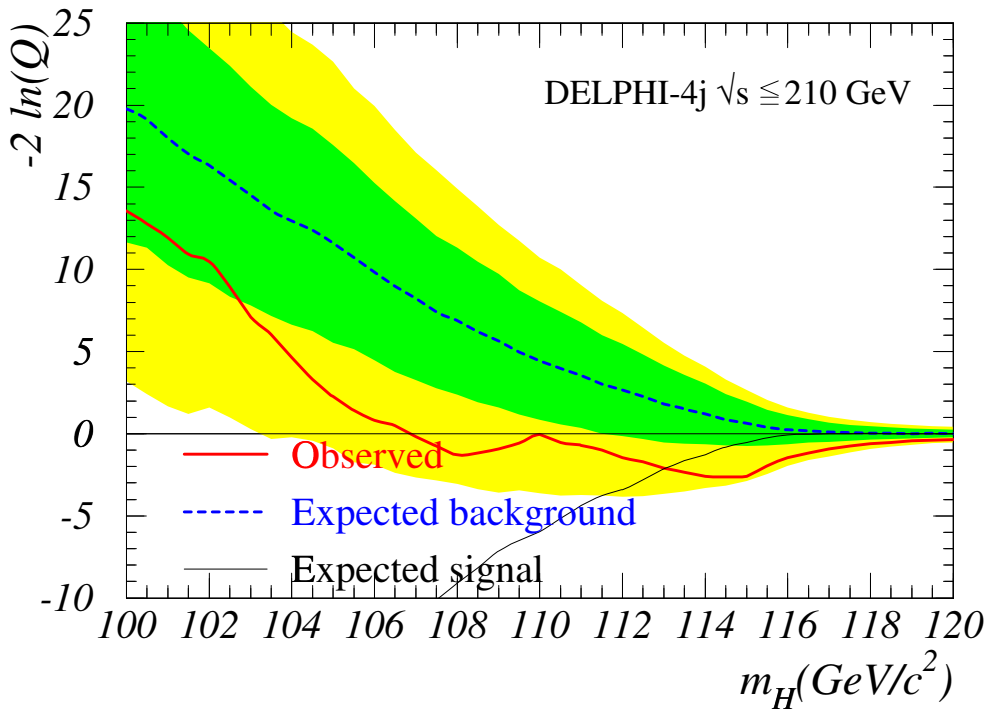
Updated Analysis 2: DELPHI

More Monte Carlo -- Better modeling of signal and background.
Increased Sensitivity. Some candidates become more significant.

"Old"

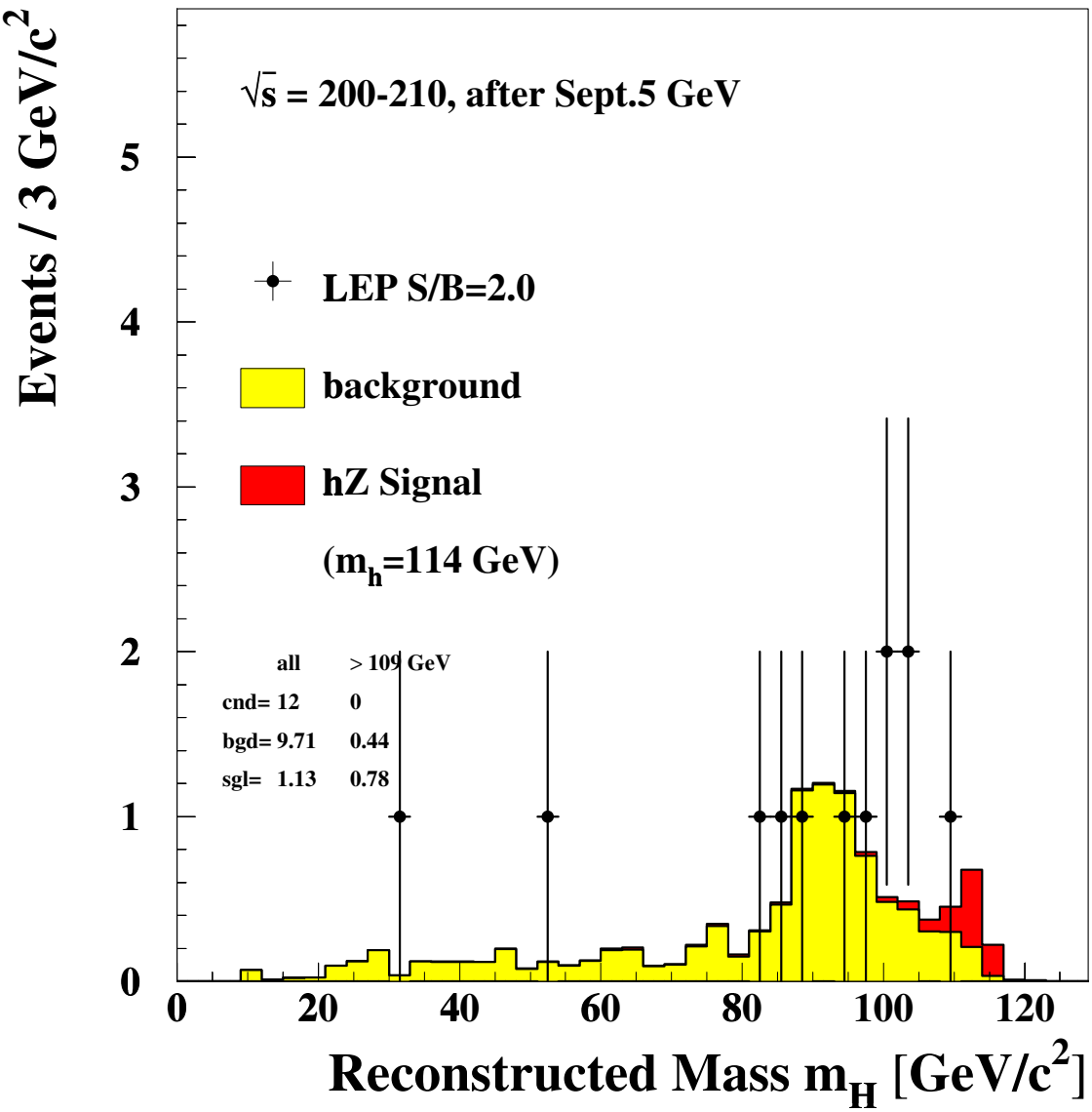


"Reference"



Just the New Data

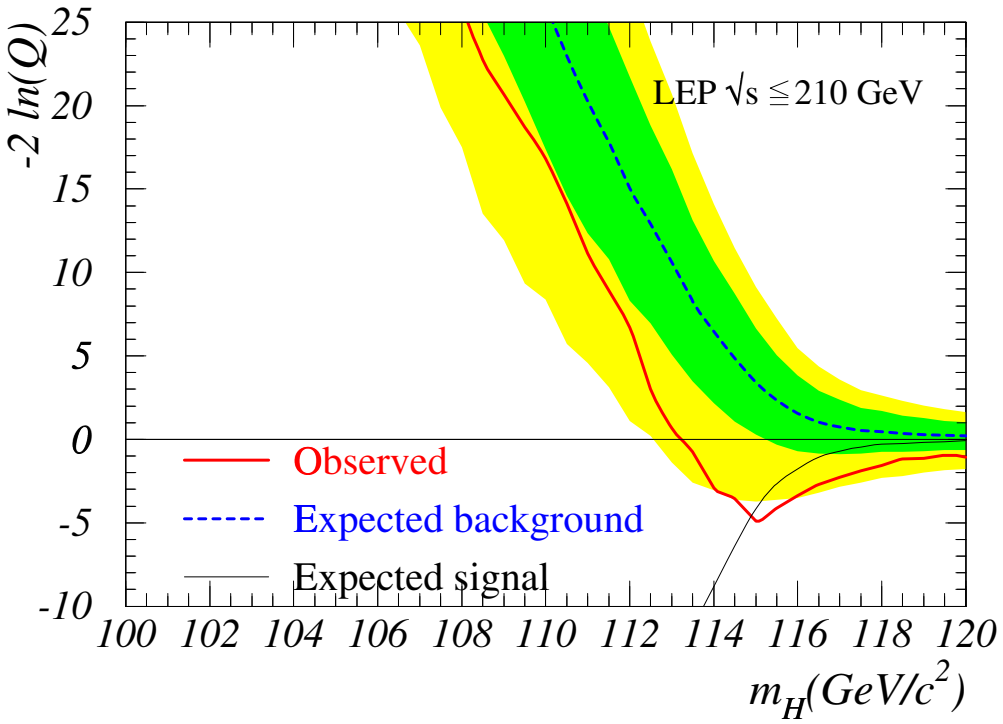
Hard cuts, only the best candidates shown.



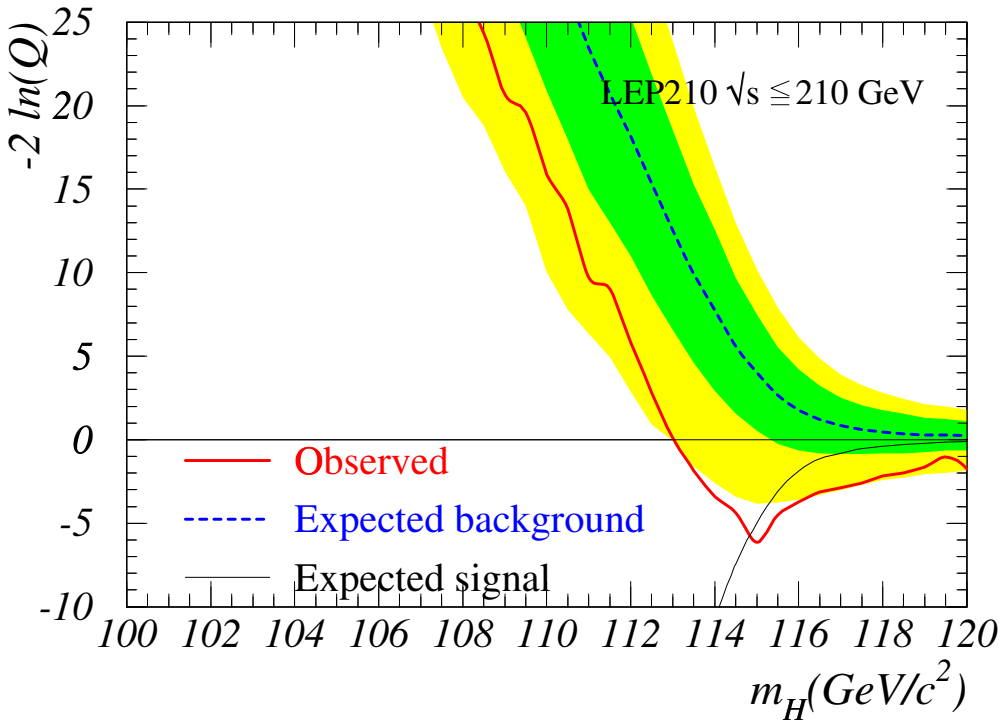
Highest-mass candidate: L3 4-jet candidate

The Effect of New Data

"Reference" Set



New data for October 10. Same procedures as reference set:



How Significant is it?
→ Confidence Levels

- **CL_s** -- compatibility with signal hyp.
  $CL_s < 0.05$: Signal hypothesis ruled out at the 95% CL.

- **CL_b** -- compatibility with background hyp.
  $1\text{-}CL_b < 5.7\times10^{-7}$ is a 5σ discovery

CL calculations cross-checked by several people:

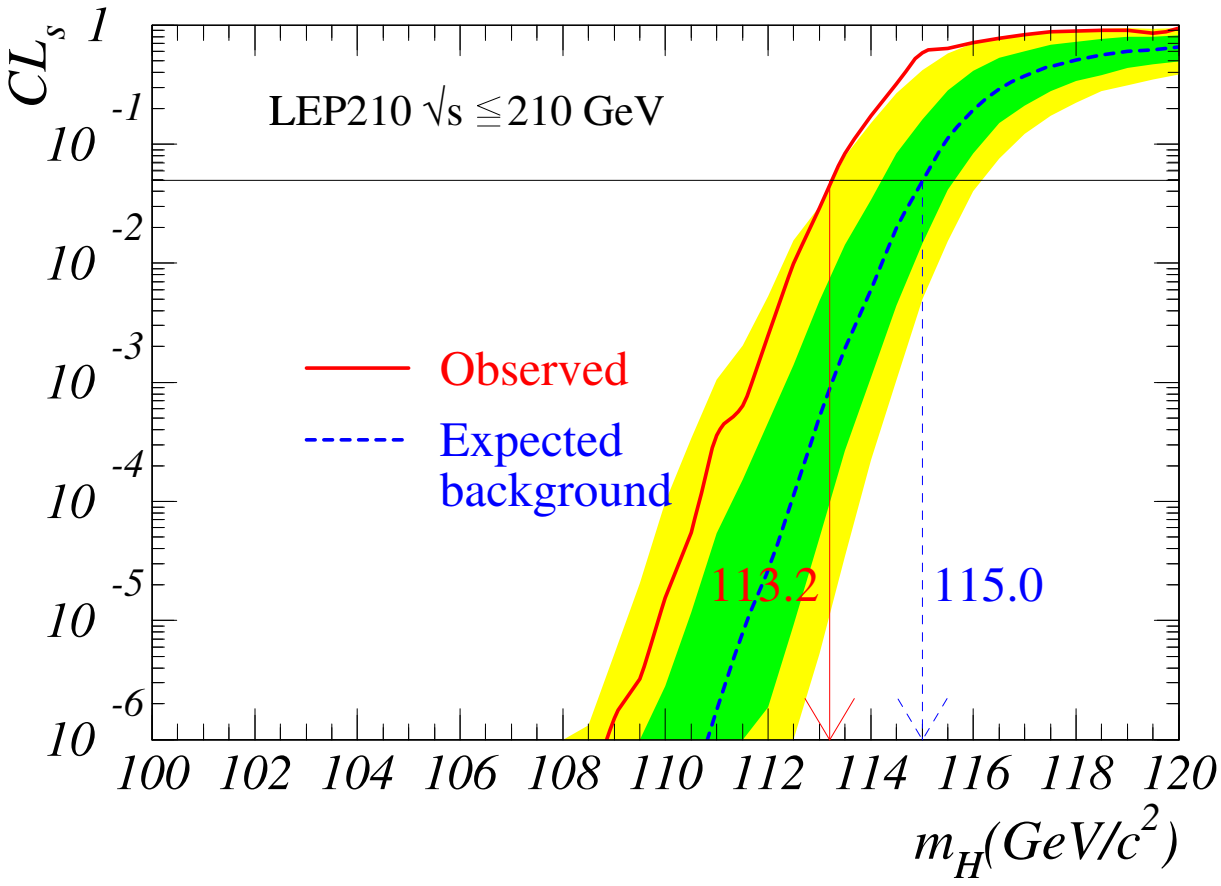
- MC ensemble
- Folding of probabilities
- FFT
- Different test-statistics (LR or others)

Systematic errors can be treated in more than one way.

Spread in CL significances: $\pm0.2\sigma$

Preliminary!

Lower Limit on m_H in Combination



Observed limit: m_H>113.2 GeV @95% CL

Median Expected: 115.0 GeV,

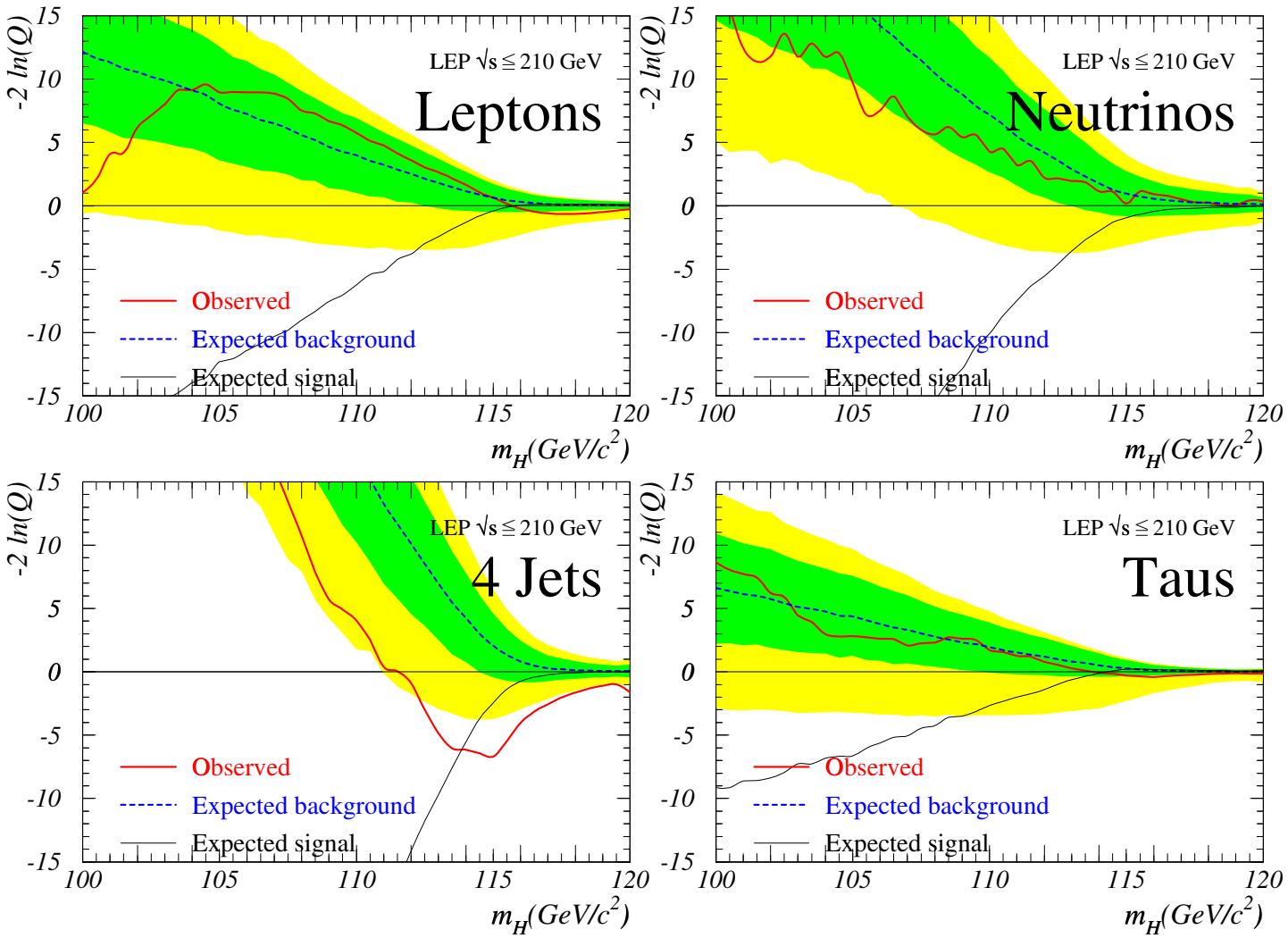
in many experiments with only background present

Reference set: new analyses, data for Sep. 5: observed limit: m_H>113.2 GeV, expected 114.8 GeV

Observations by Channel

Lepton
Neutrino
Tau

Combined they are as sensitive as the four-jet channels



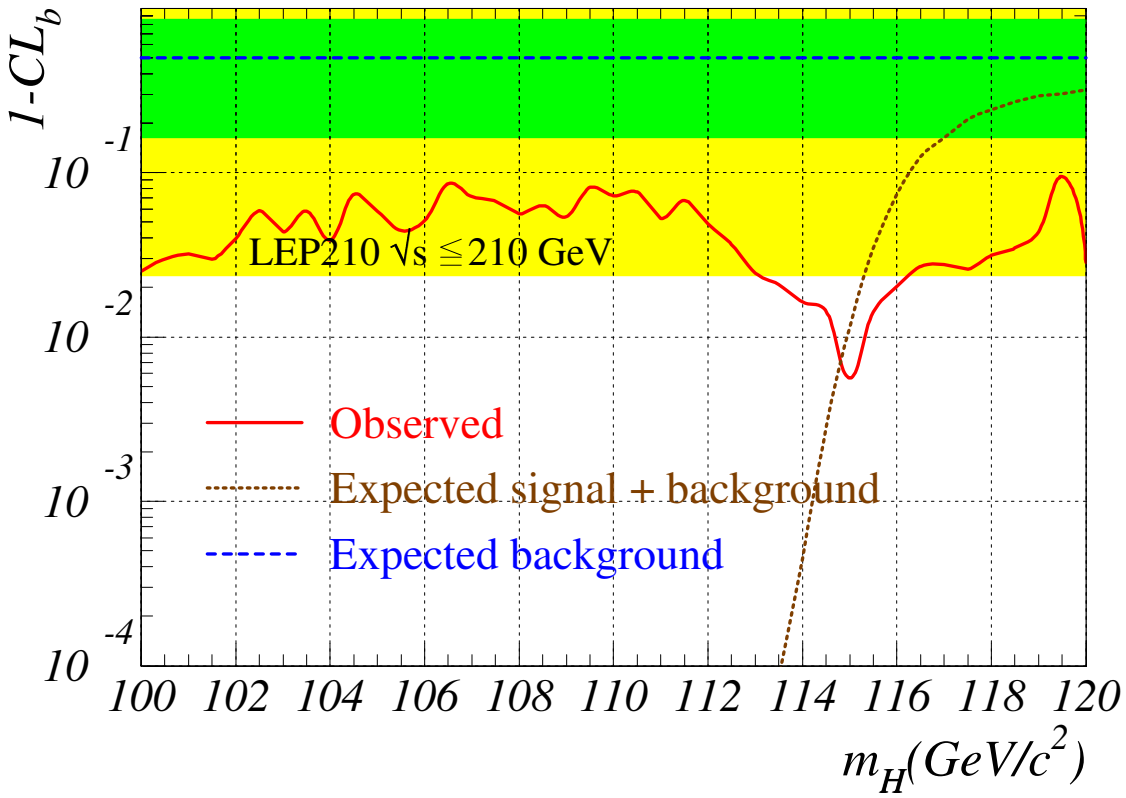
SM Higgs Limit Summary

Experiment	Observed	Expected
ALEPH	**110.2**	**113.0**
DELPHI	**111.2**	**112.3**
L3	**113.0**	**110.9**
OPAL	**109.3**	**112.2**
LEP 4J	**111.8**	**114.1**
LEP Neutrinos	**110.9**	**112.1**
LEP Tau	**103.7**	**105.7**
LEP Lepton	**110.6**	**110.0**
LEP	**113.2**	**115.0**

- All limits are preliminary
- Limits are quoted at 95% CL
- All computed consistently with the same test-statistic, error handling, etc. and may differ from the experiments' limits esp. when CL curves are near the 5% edge.

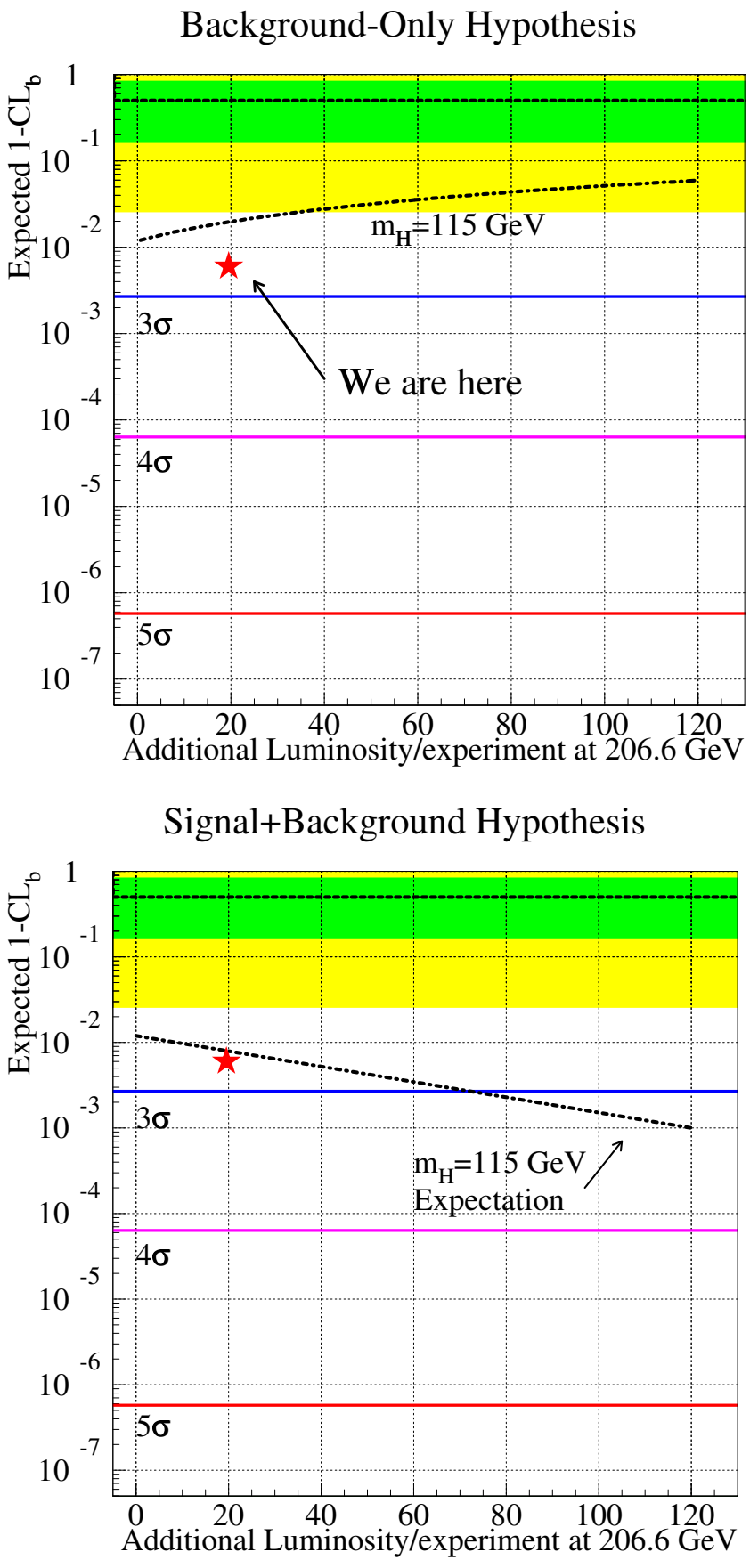
Background Confidence Level Evolution: Reanalysis and New Data

Oct 10 data



Situation	Significance of $1\text{-}CL_b$ Minimum
Sept. LEPC	2.6σ
"Reference"	2.2σ
October 10:	2.5σ

Current Status of 1-CL_b on the Roadmap

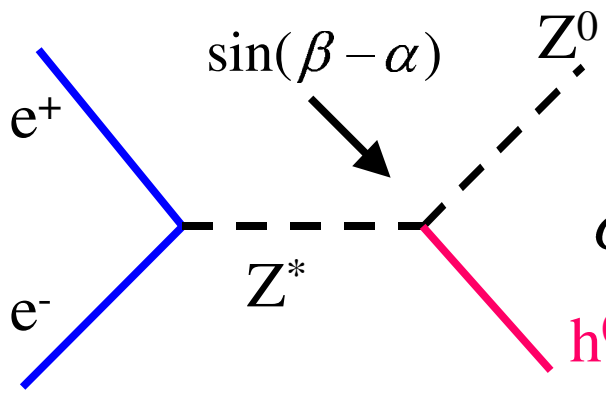


The Neutral Higgses of the MSSM

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

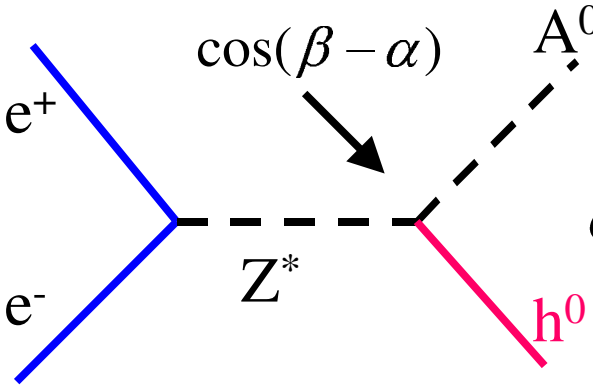
$$m_{h^0} < \sim 135 \ \text{GeV}$$



Higgs-strahlung

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

And fusion processes too!



Associated Production

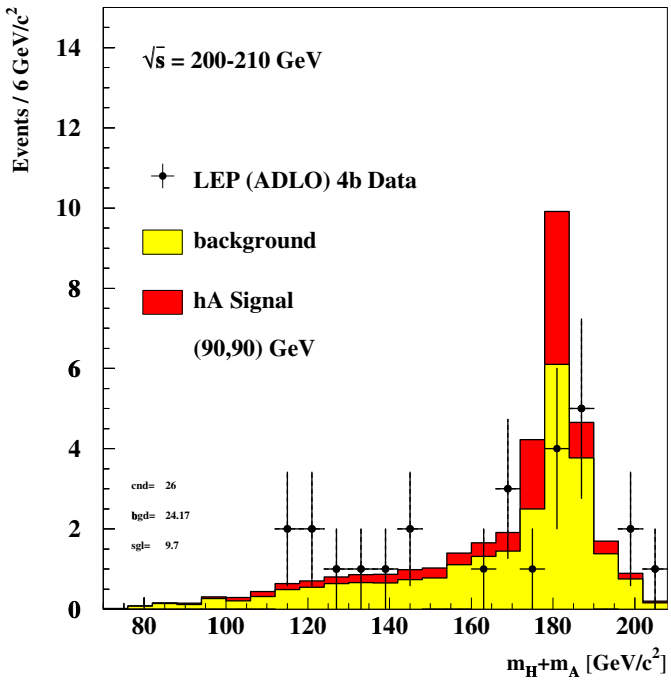
$$\sigma_{hA} = \cos^2(\beta-\alpha)\bar{\lambda}\,\sigma_{hZ}^{SM}$$

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

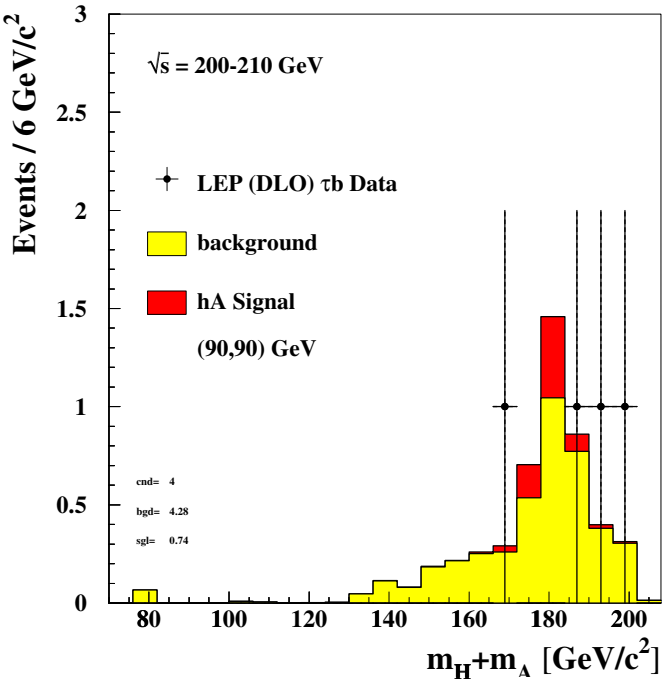
Reconstructed Mass Distribution of hA Search Candidates

MSSM constraint: cross-section is large only for $m_h \approx m_A$. So plot $m_h + m_A$ for the minimum mass difference (4jet).

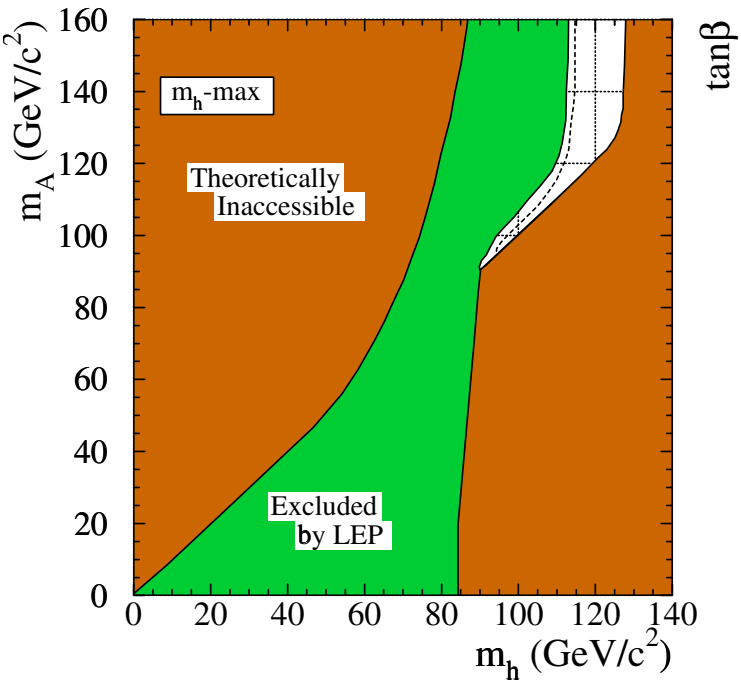
Four-b channel:

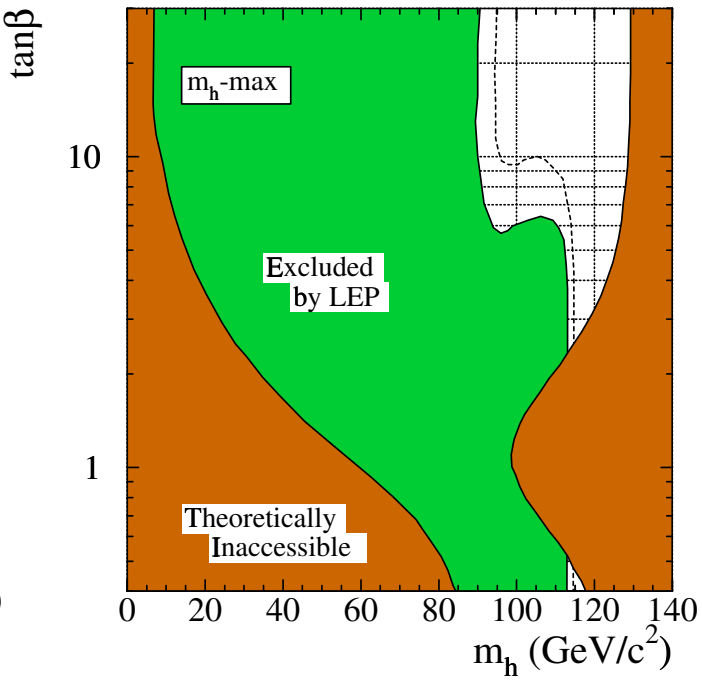


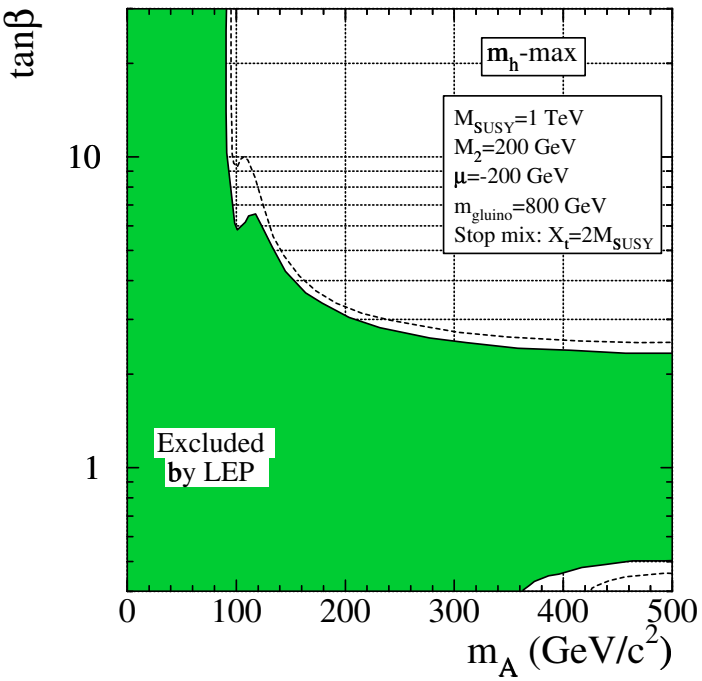
bbττ channel:



MSSM Exclusions in the Max-m_H Scenario







Mass Limits:

	obs	expected
m_H >	89.9	93.8
m_A >	90.5	94.1

tanβ excluded from
0.52 to 2.25 obs.
0.48 to 2.48 expected

Summary and Plans for the LEP Higgs WG

- Much progress for one month:
  - 79 pb^{-1} of data added in combination
  - Detailed systematic checks
    - Excess is robust under scrutiny
    - Excess is more consistent -- two experiments see excess candidates

- Minimal SM Higgs excluded for m_H<113.2 GeV
  -- but we expected to exclude up to 115.0 GeV

- 2.5σ excess persists at m_H=115 GeV.

September LEPC:	2.6σ
Same data with new analysis:	2.2σ
With new data:	2.5σ

  Actual history of CL_b will depend on the discrete arrival of candidates.
  Sawtooth CL_b vs. time (if there is a signal)

- Another combination planned for the **3 November LEPC**.