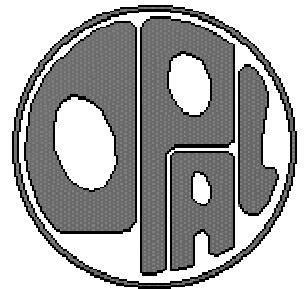
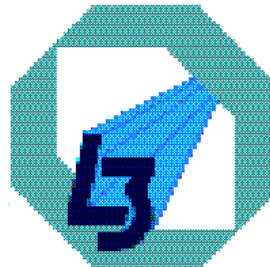
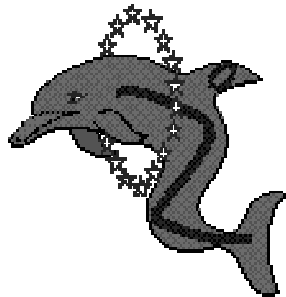
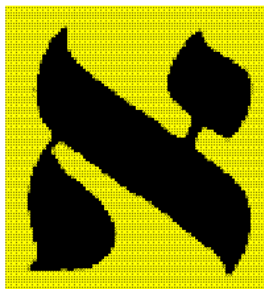


Combined LEP Higgs Searches

Tom Junk

*Carleton University
Ottawa, Canada*

LEP Fest, 10 October 2000



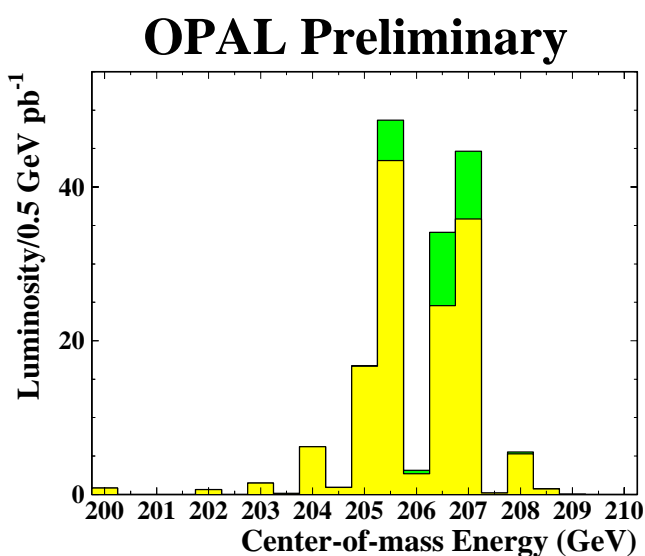
*Preliminary update of the LEP Higgs
Working group, with many thanks to the
ALEPH, DELPHI, L3 and OPAL
Collaborations, and the Accelerator
divisions at CERN.*

Data Sets

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

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

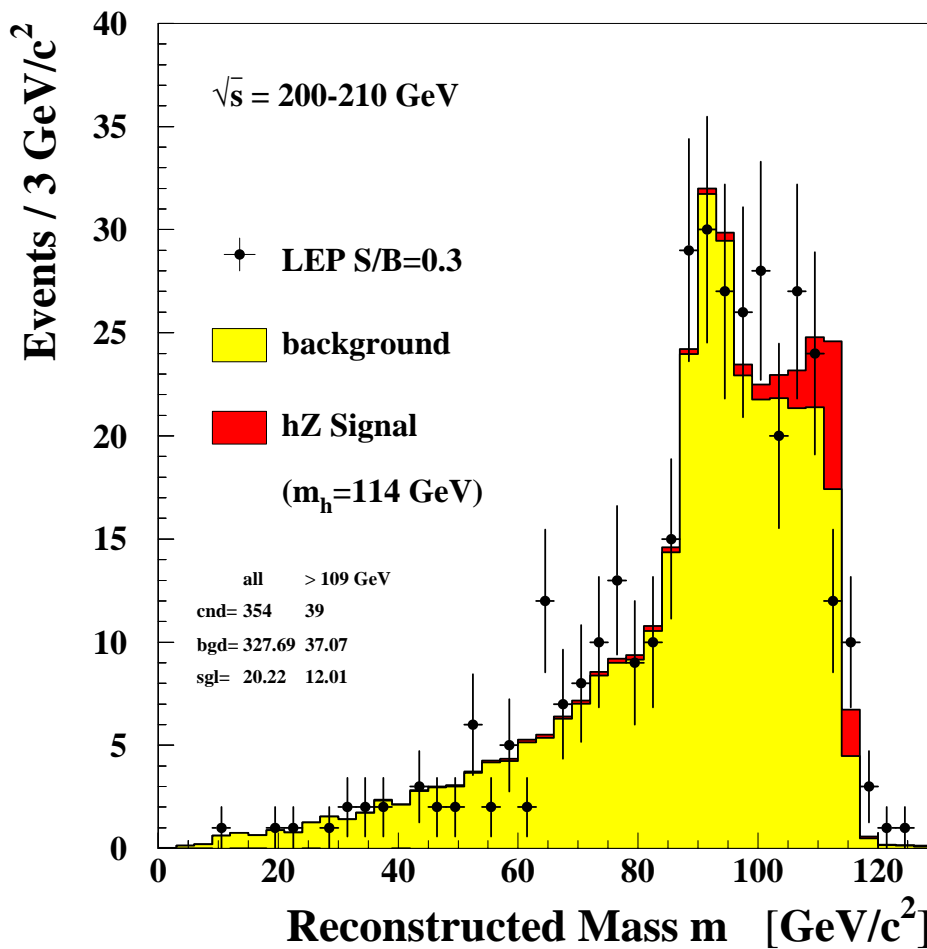
“OLD” Results for September 5 LEPC

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 $m_{\text{rec}} > 109$ GeV
for a 114 GeV Higgs



All
2000
Data

Data Backg Signal

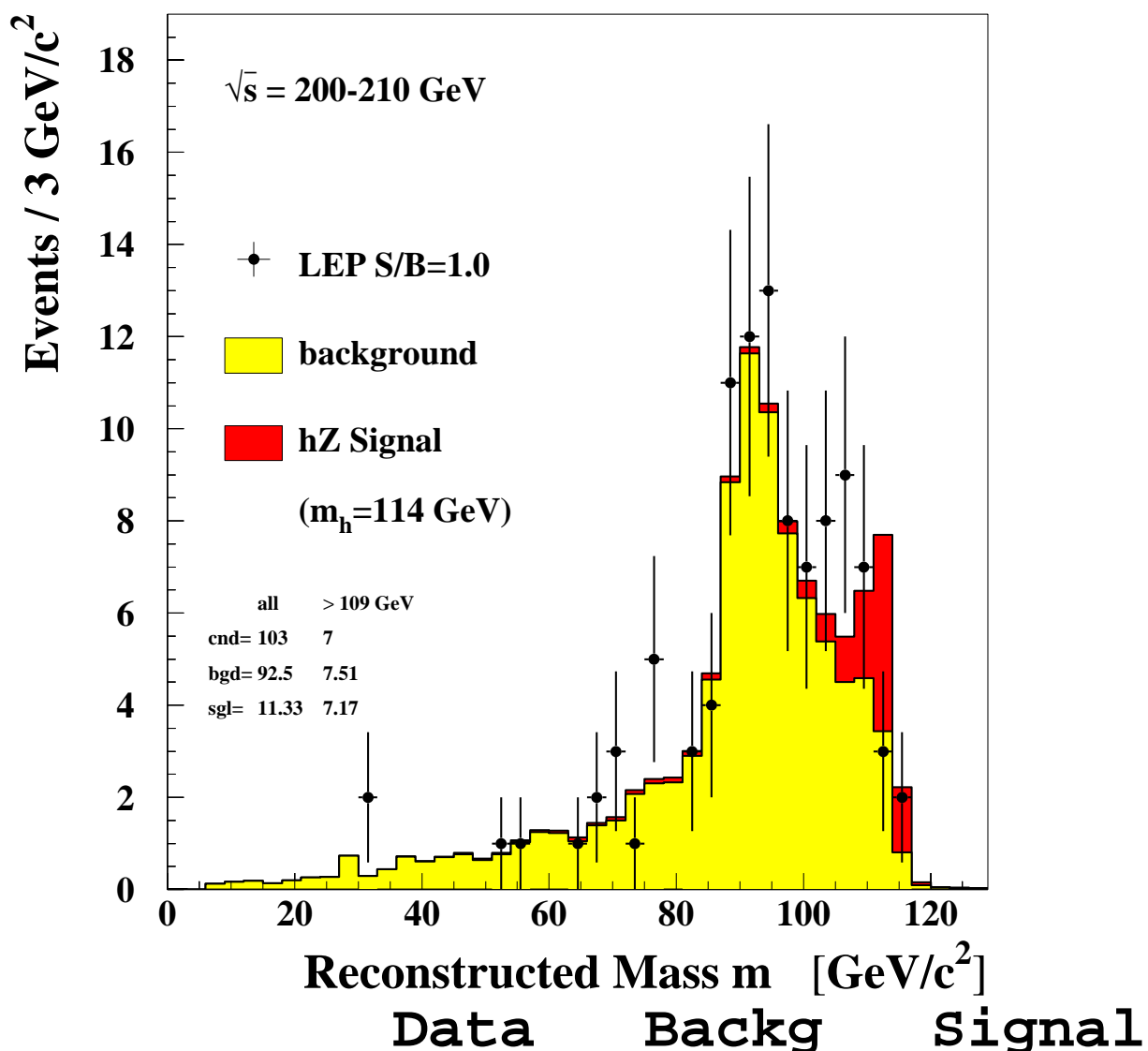
All m_{rec}	354	328	20.2	
$m_{\text{rec}} > 109$ GeV	39	37.1	12.0	

Cutting a Little Harder

This time, adjust cuts so that

$$\frac{s_{\text{expected}}}{b_{\text{expected}}} \approx 1.0 \quad \text{For } m_{\text{rec}} > 109 \text{ GeV}$$

for a 114 GeV Higgs

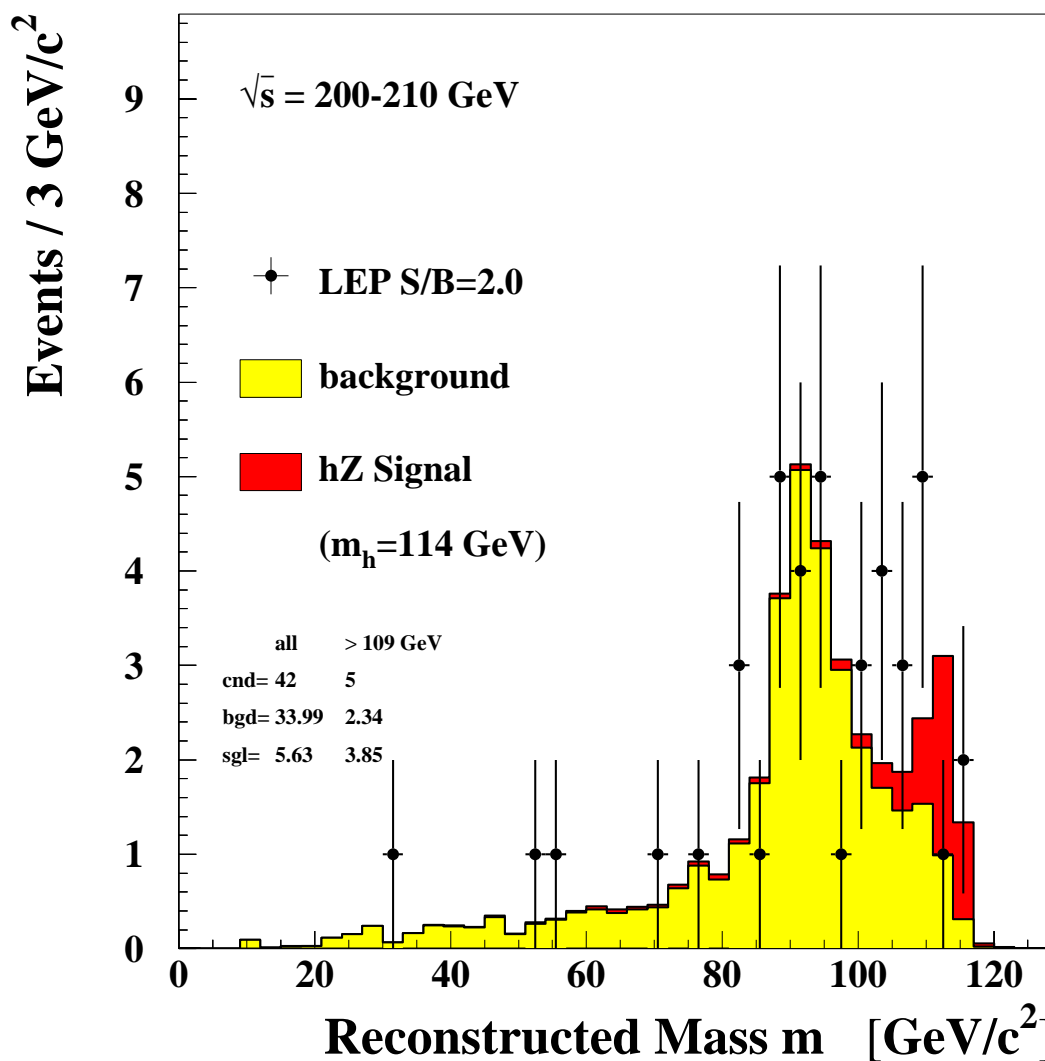


All	m_{rec}	103	92.5	11.3
$m_{\text{rec}} > 109$	GeV	7	7.5	7.2

Very Hard Cuts

$$\frac{S_{\text{expected}}}{b_{\text{expected}}} \approx 2.0 \quad \text{For } m_{\text{rec}} > 109 \text{ GeV}$$

for a 114 GeV Higgs



Losing Efficiency -- but “really good” events kept

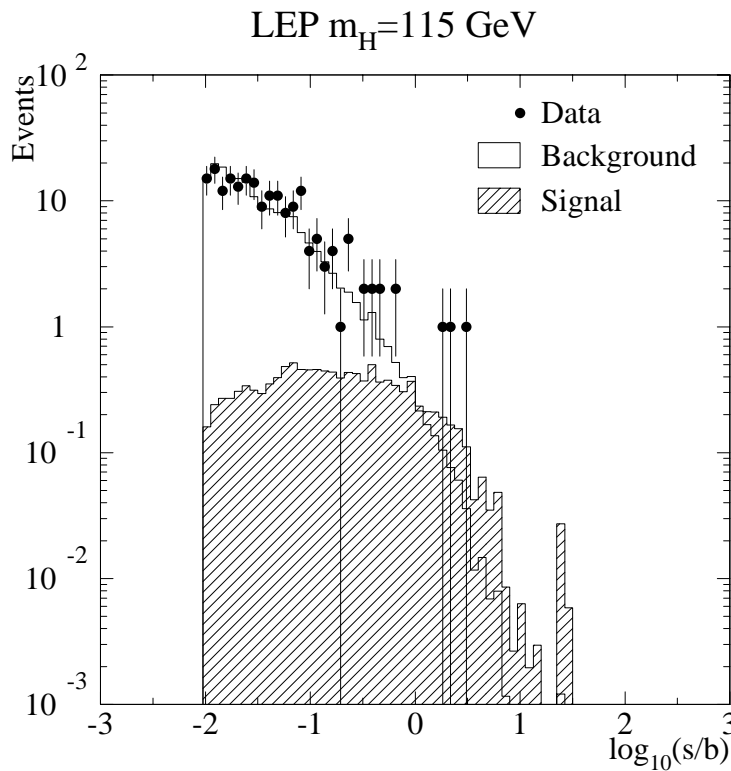
	Data	Backg	Signal
All m_{rec}	42	34.0	5.6
$m_{\text{rec}} > 109 \text{ GeV}$	5	2.3	3.9

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

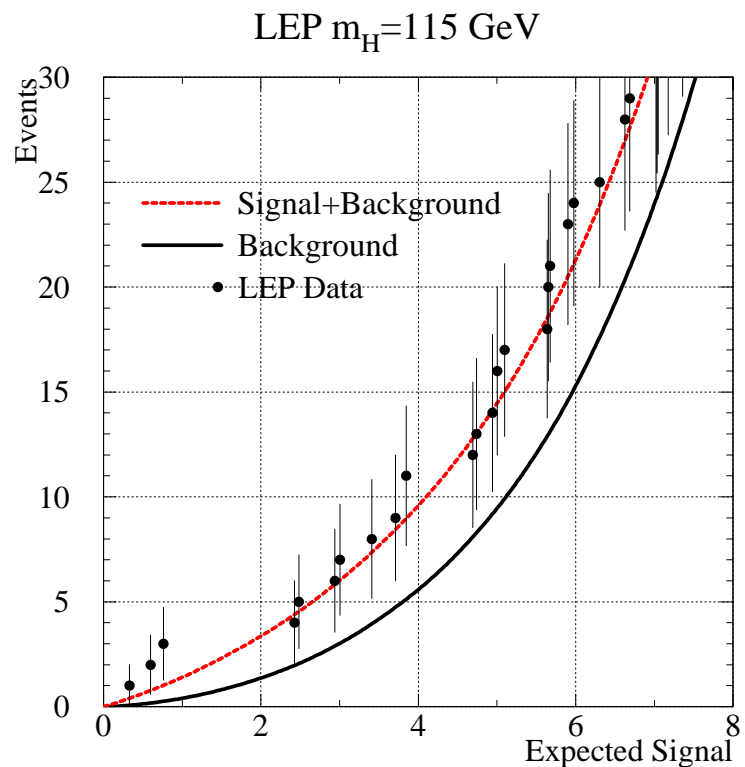
All LEP Data in bins of Expected Signal/Background



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

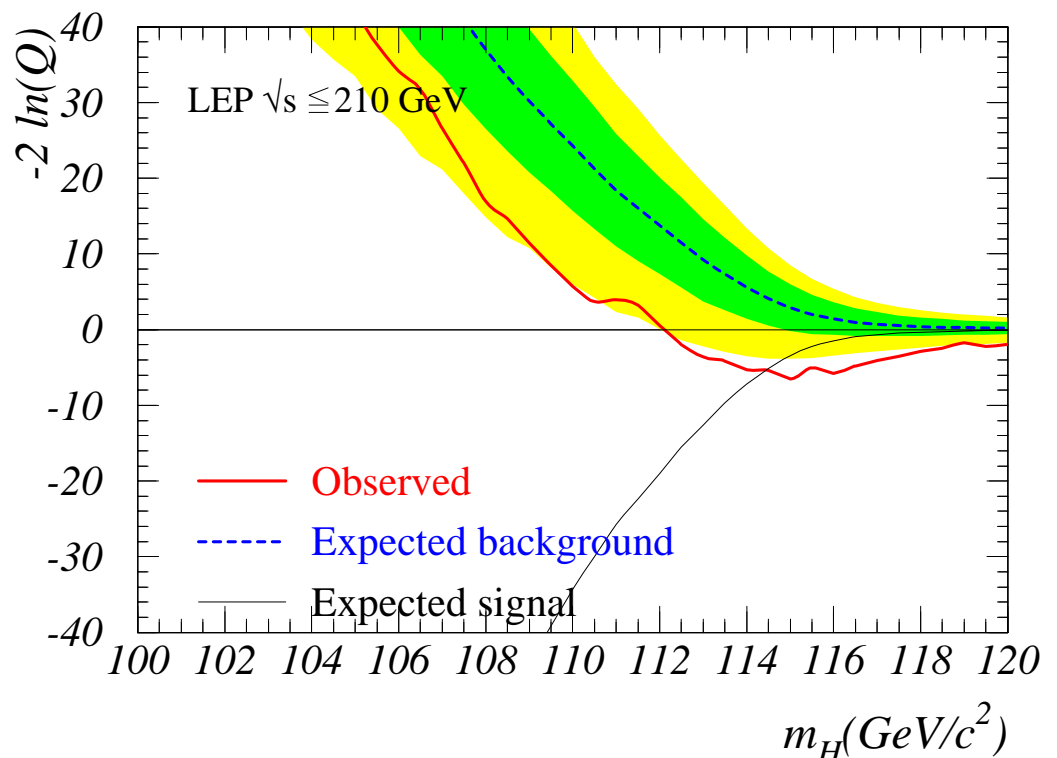
- Construct a parameter that orders outcomes as more signal-like, or less signal-like

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

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



Sep 5 LEPC: “Old”



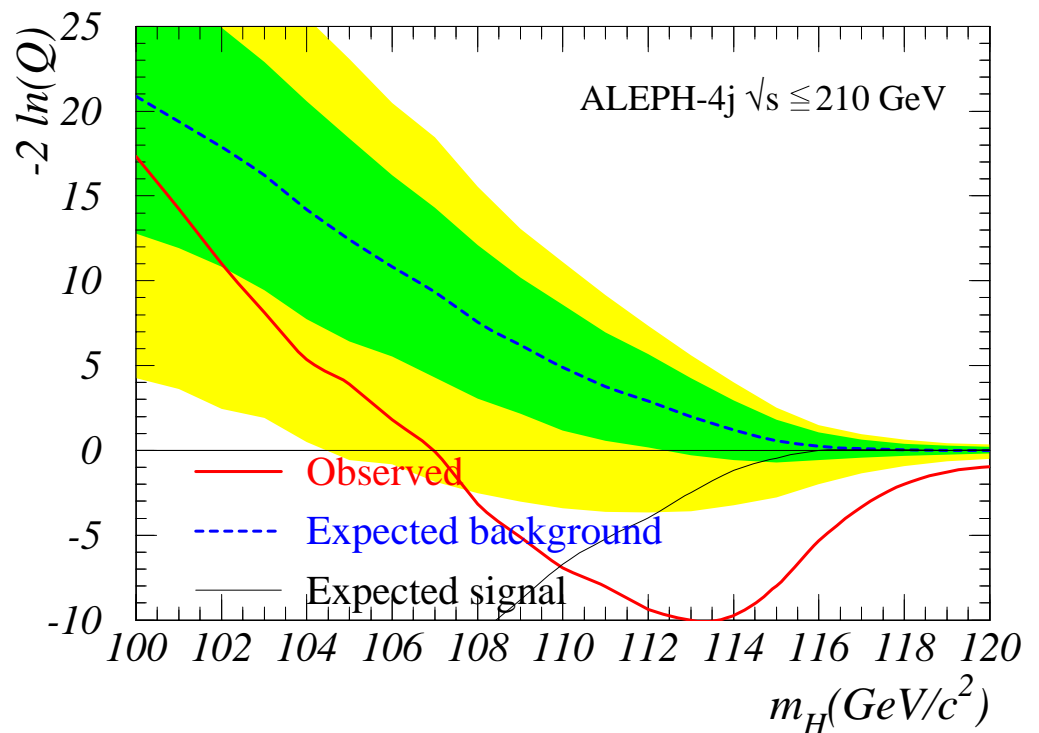
Updated Analysis 1: ALEPH

Four-Jet Channels:

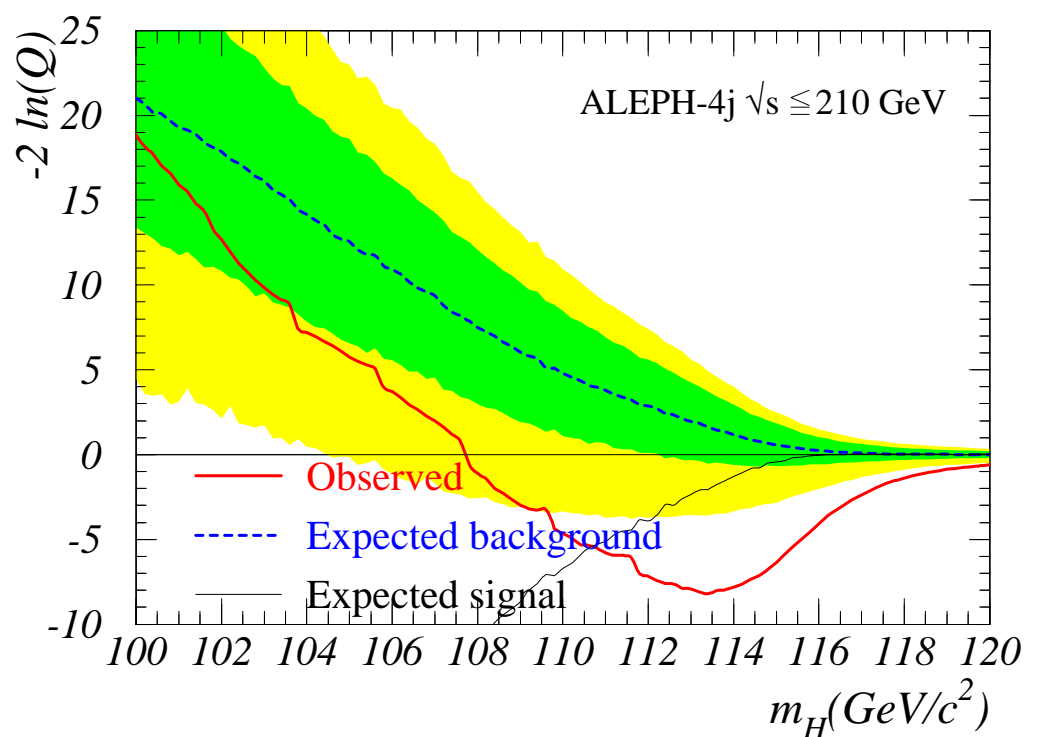
Improved background modeling.

Some candidates become less significant

“Old” ---
Sept. 5
Results



“Reference”
Sept. 5 Data
with New
Analysis

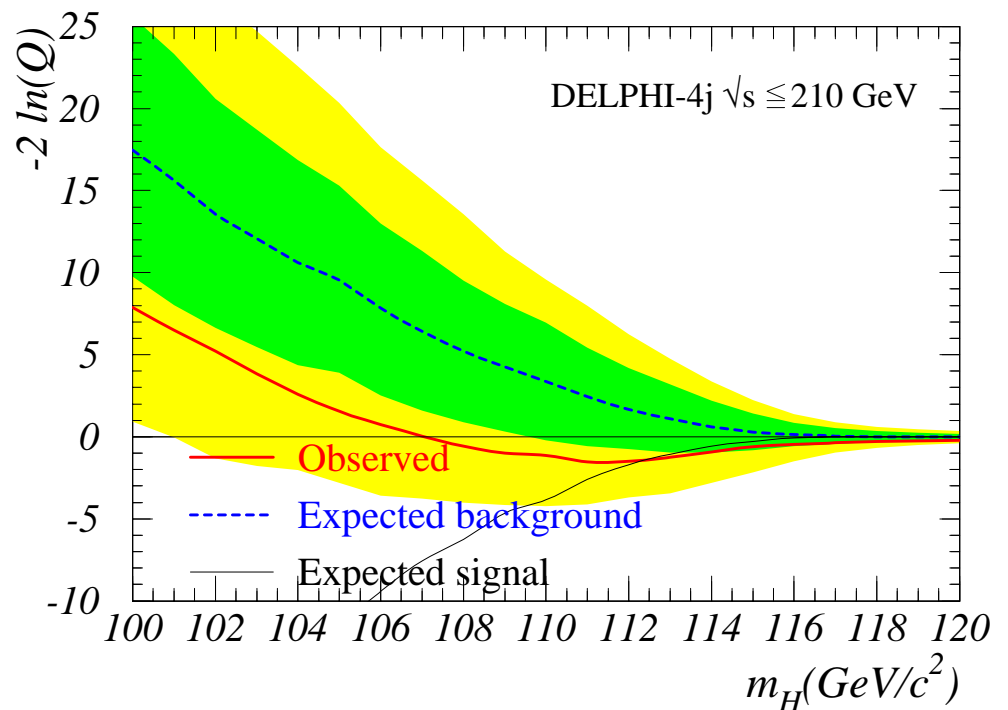


Updated Analysis 2: DELPHI

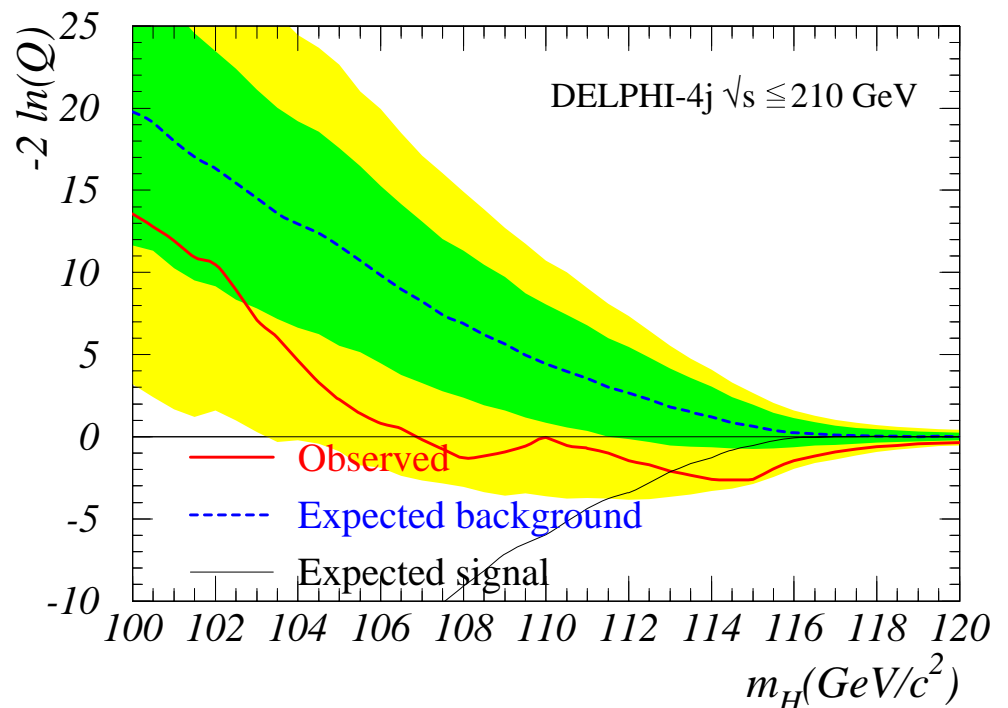
More Monte Carlo -- Better modeling of signal and background.

Increased Sensitivity. Some candidates become more significant.

“Old”

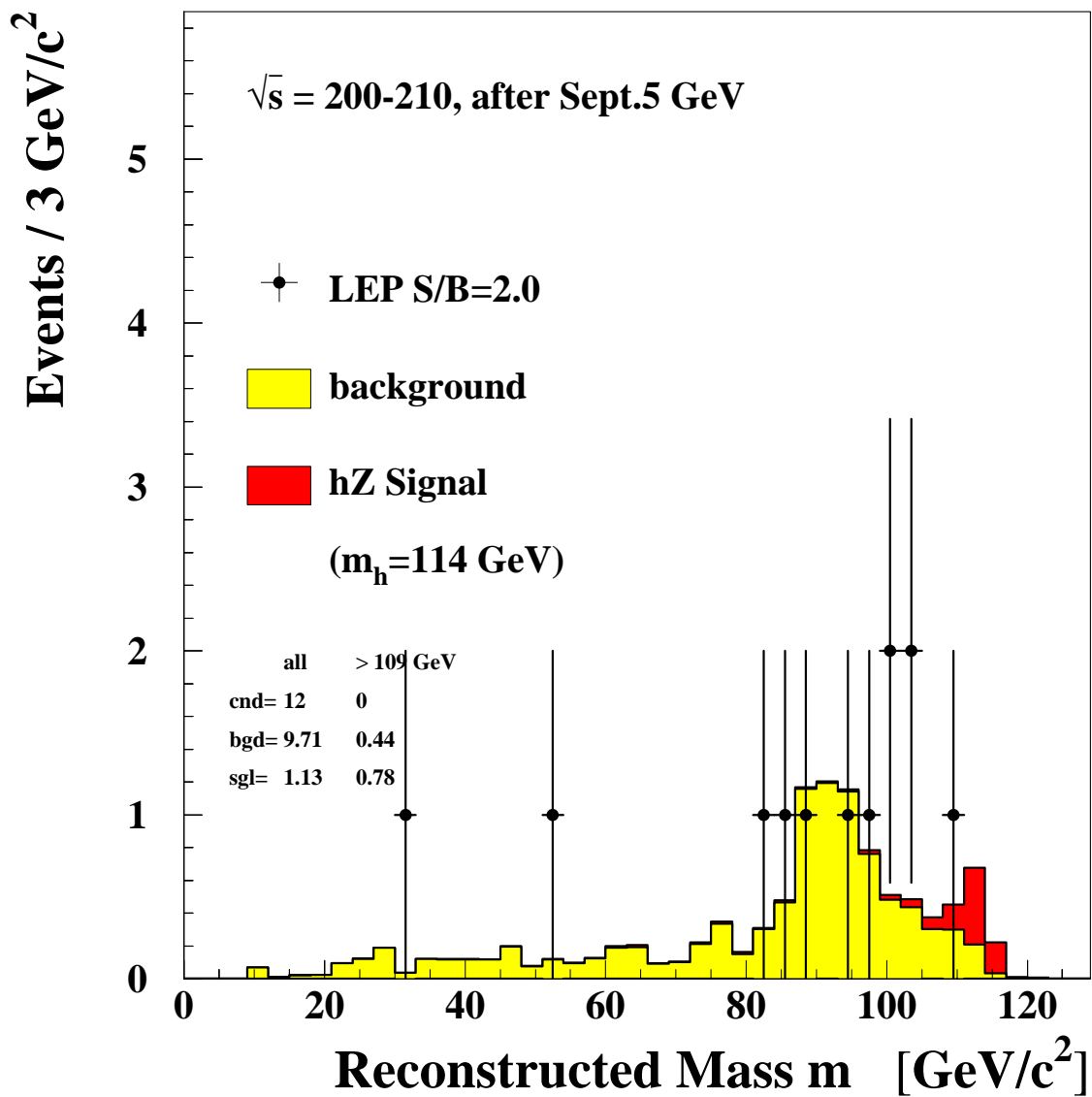


“Reference”



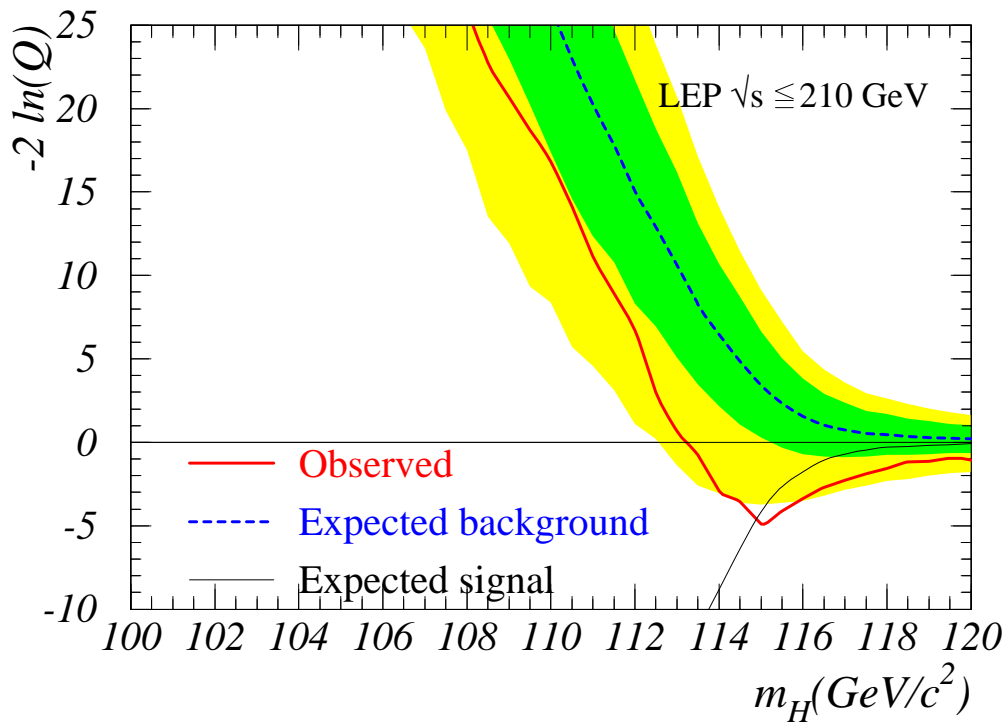
Just the New Data

Hard cuts, only the best candidates shown.

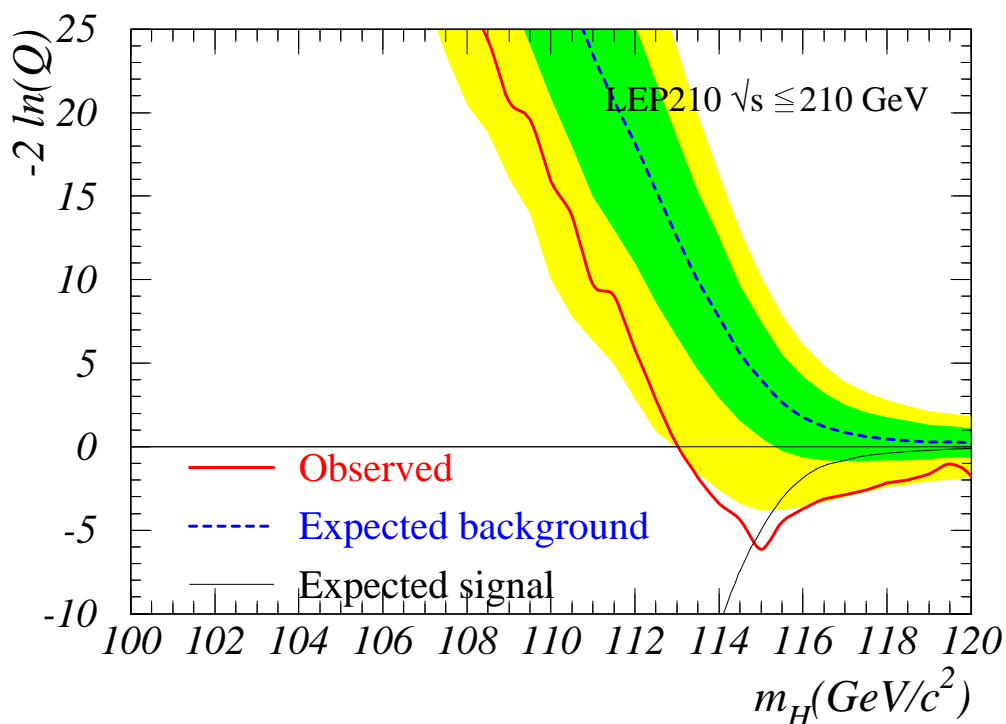


The Effect of New Data

“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-CL_b < 5.7×10⁻⁷ is a 5σ discovery

CL calculations cross-checked by several people:

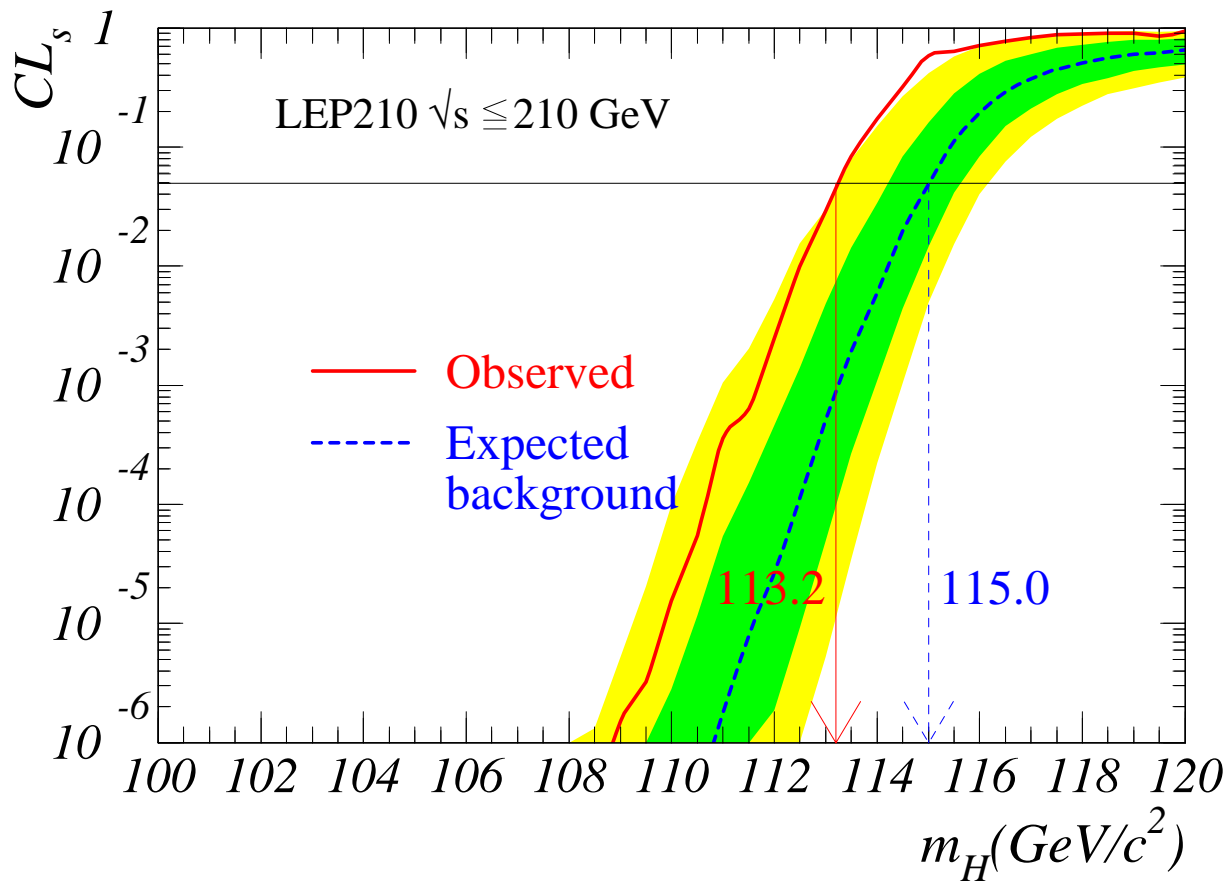
- MC ensemble
- Folding of probabilities
- FFT
- Different test-statistics (LR or others)

Systematic errors can be treated in more than one way.

Spread in CL significances: ±0.2σ

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*

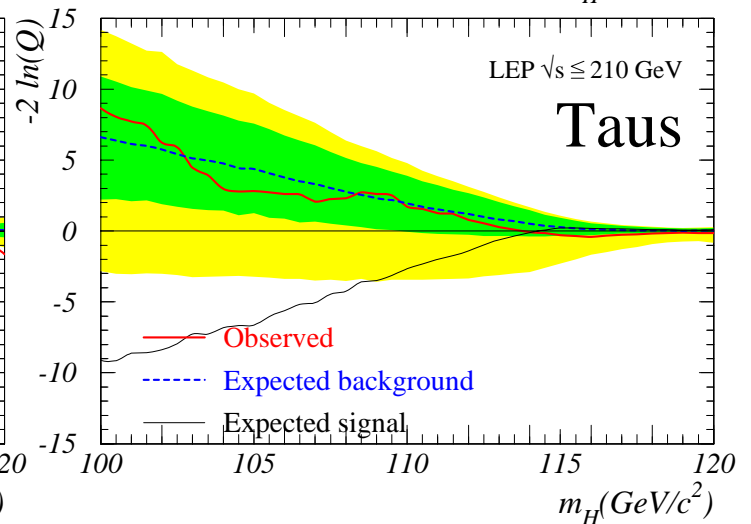
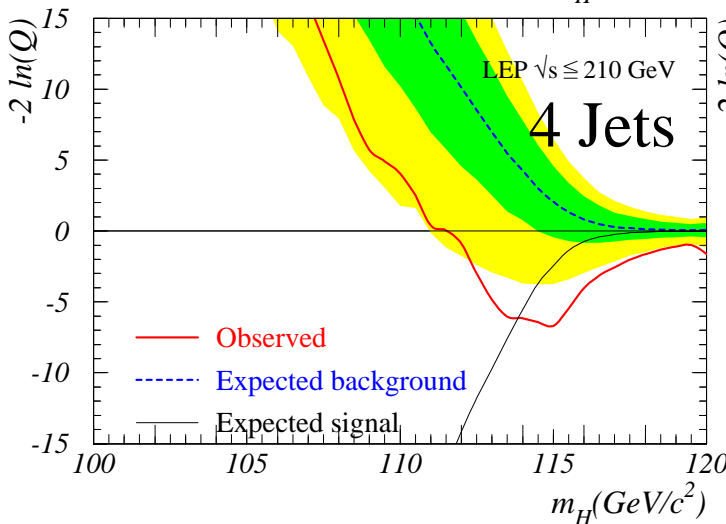
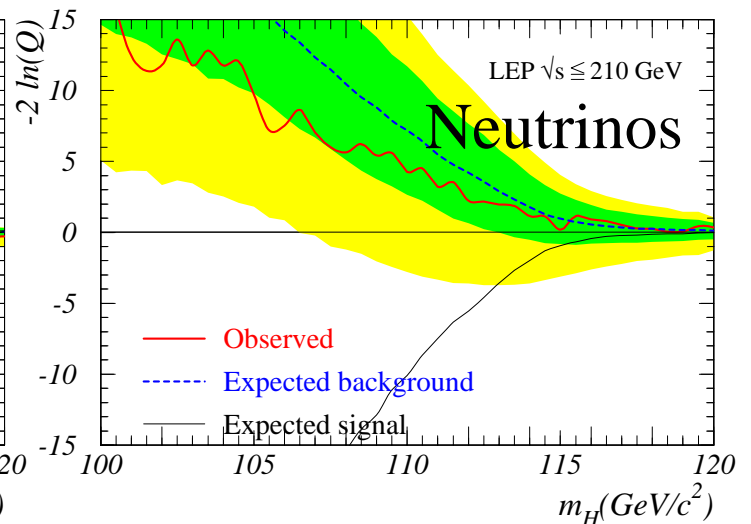
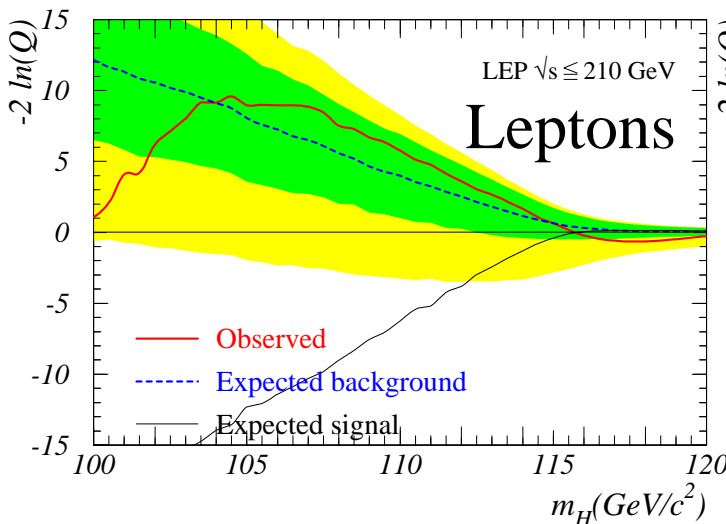
Reference set: new analyses, data for Sep. 5:

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



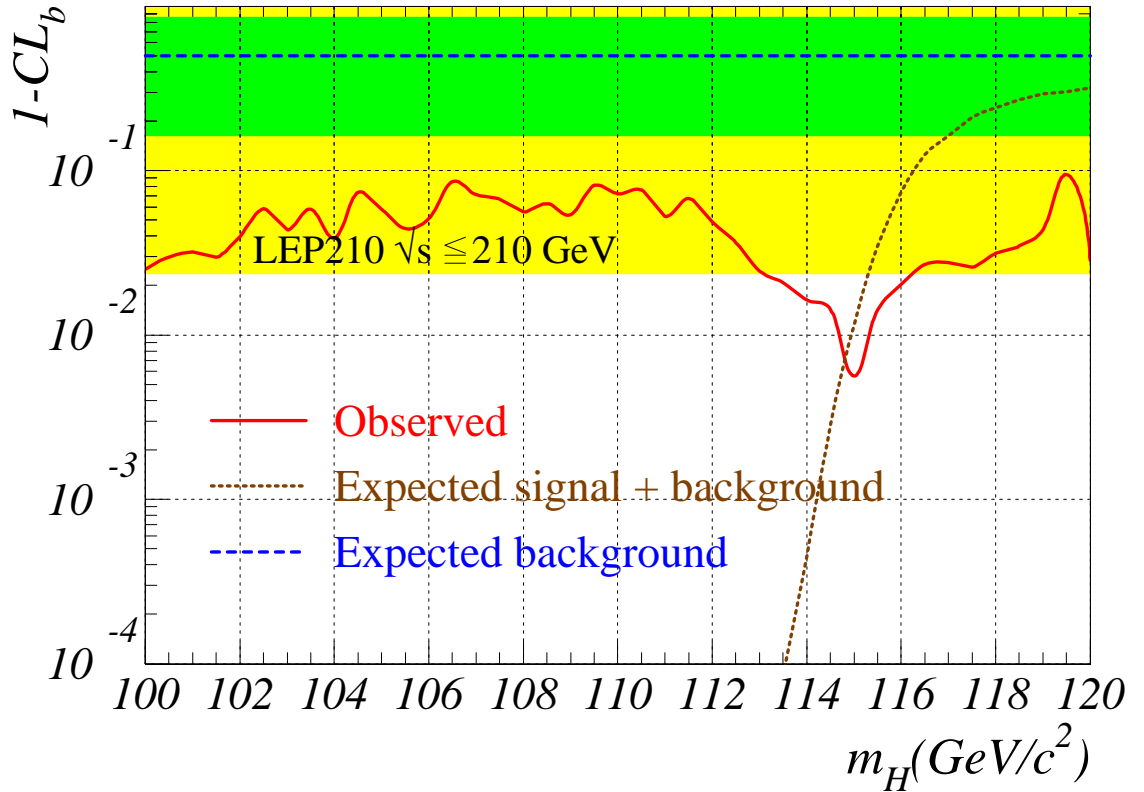
SM Higgs Limit Summary

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
 $1-CL_b$ Minimum

Sept. LEPC

2.6σ

“Reference”

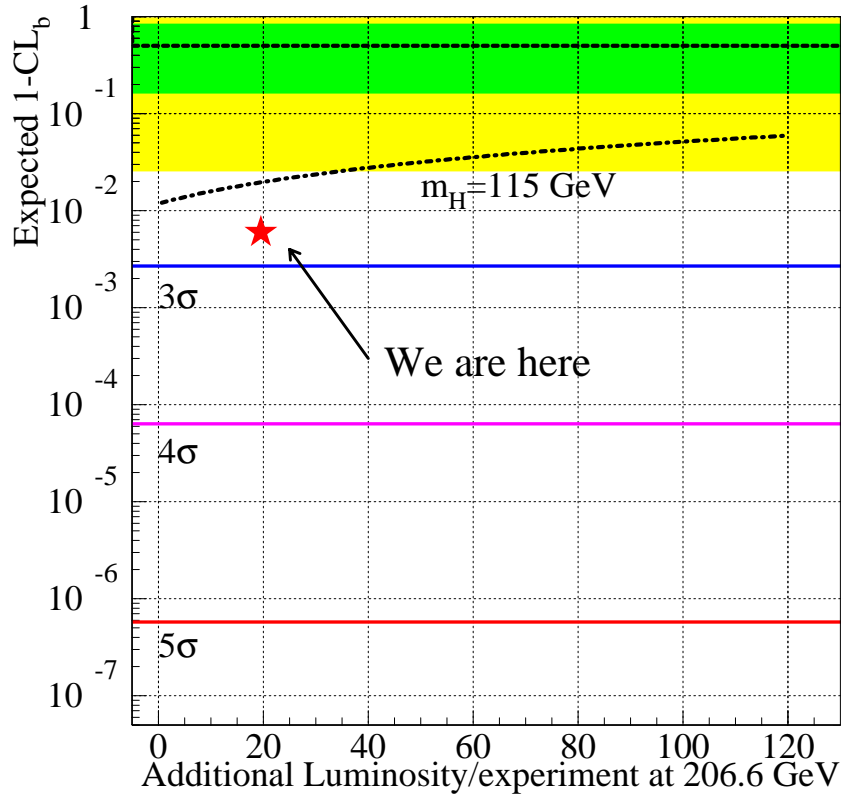
2.2σ

October 10:

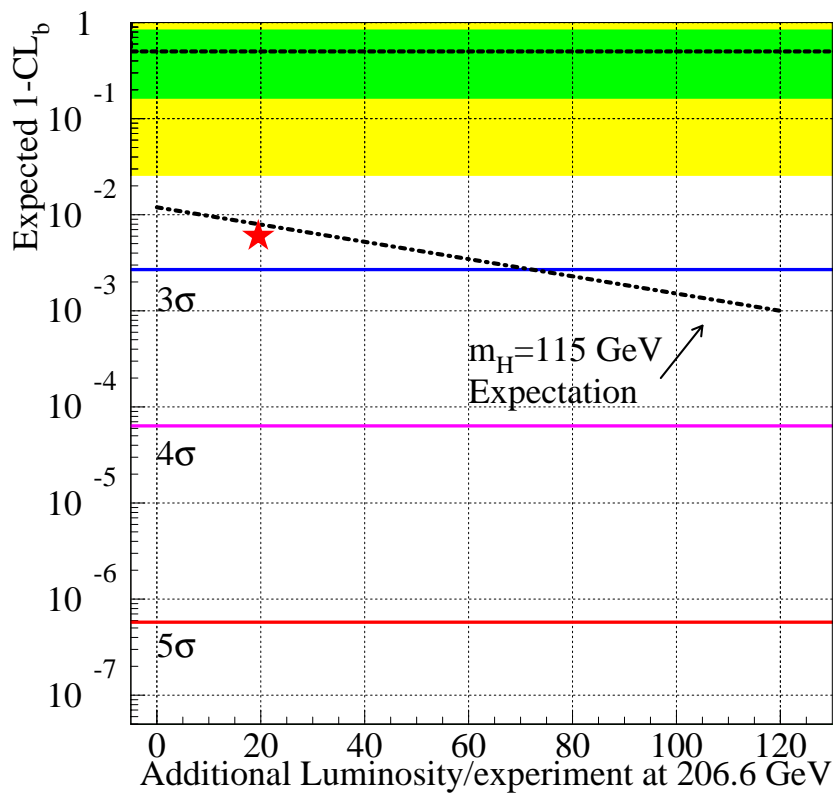
2.5σ

Current Status of $1-CL_b$ on the Roadmap

Background-Only Hypothesis



Signal+Background Hypothesis

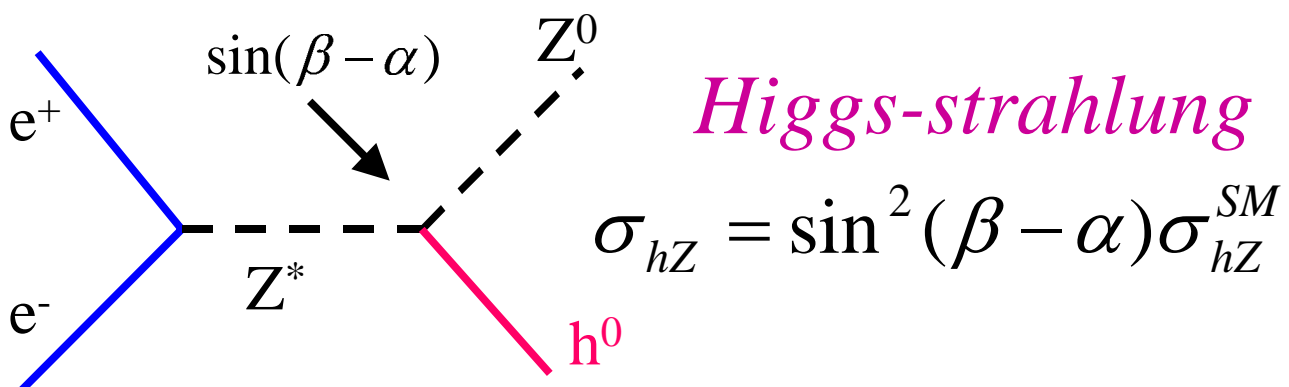


The Neutral Higgses of the MSSM

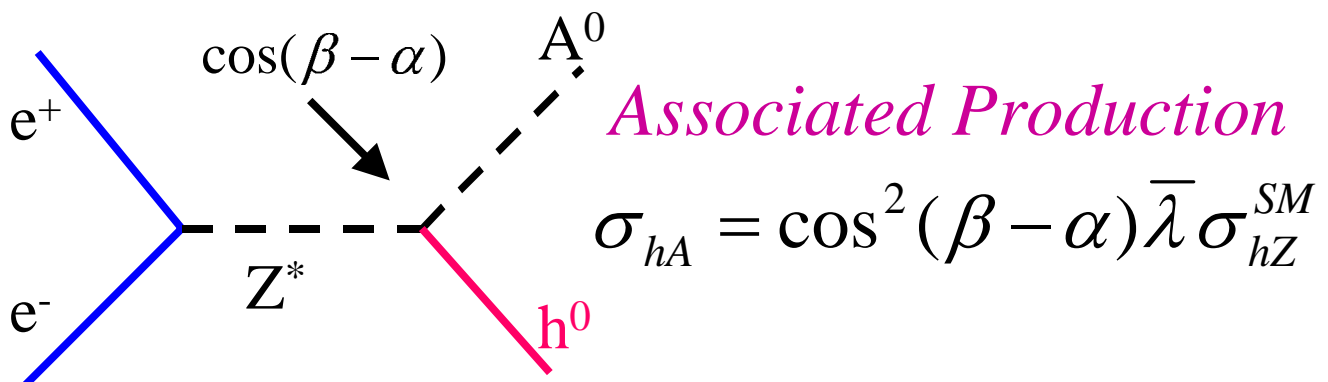
Two Higgs Doublets: 5 Higgses

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

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



And fusion processes too!

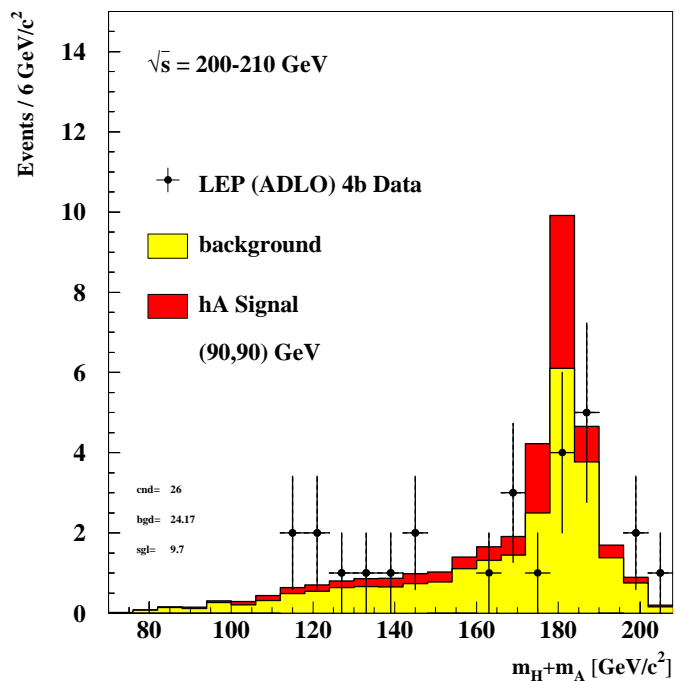


$\bar{\lambda}$: kinematic factor (m_h, m_A, \sqrt{s})

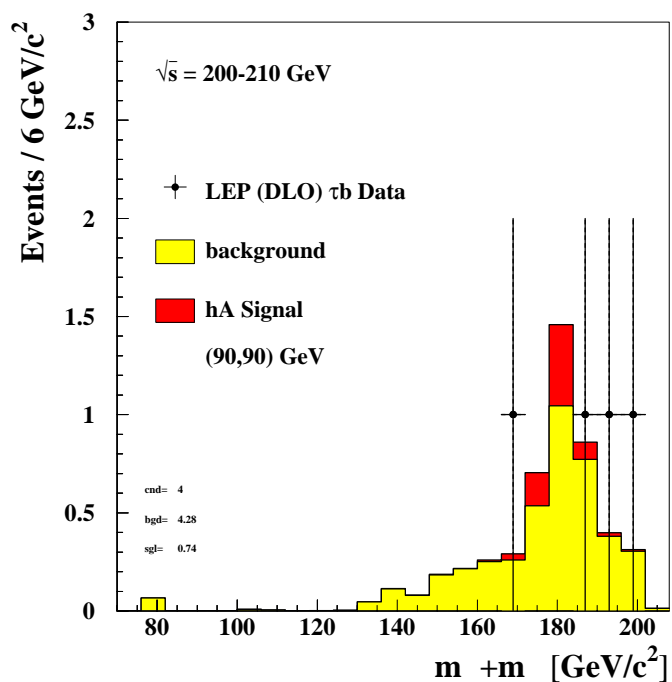
Reconstructed Mass Distribution of hA Search Candidates

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).

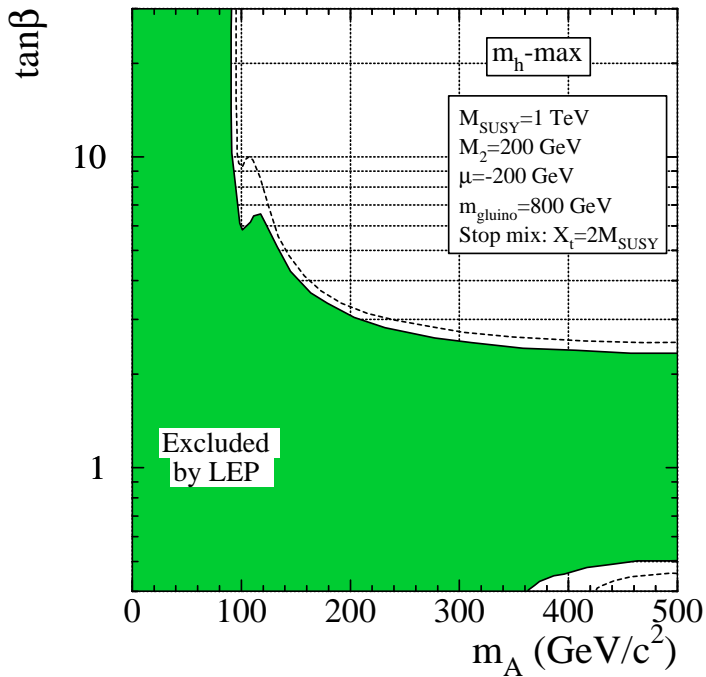
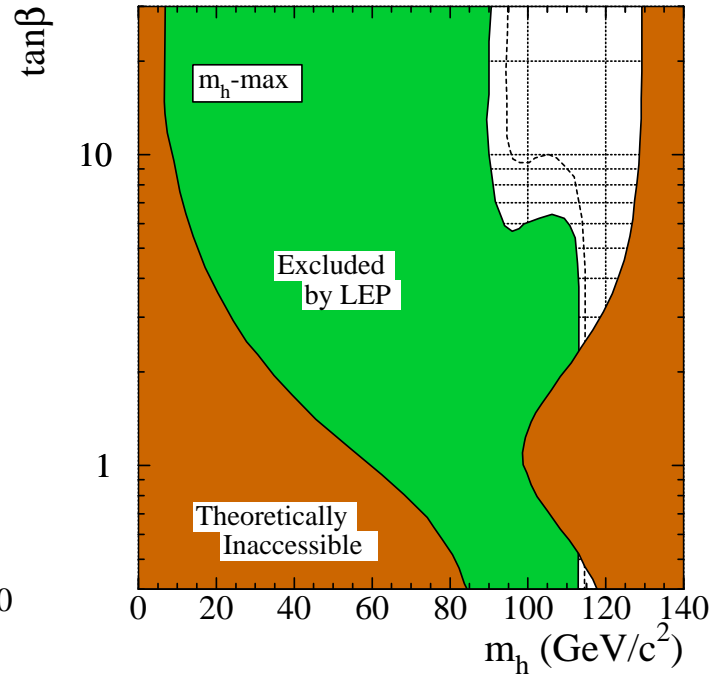
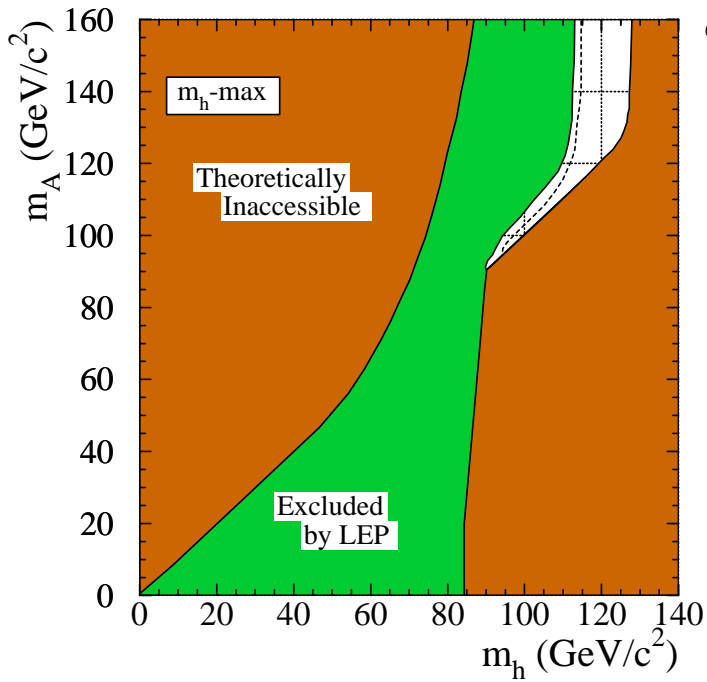
Four-b channel:



bb $\tau\tau$ 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

$\tan\beta$ 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
- **2.5 σ excess persists at $m_H = 115$ GeV.**

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

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.**