Status of Higgs Boson Searches

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ALEPH, DELPHI, L3, OPAL

and the

LEP Higgs Working Group

—

- Statistics ... definitions
- Data sets ... REF, DELTA, TOTAL
- RESULTS ... REF, DELTA, TOTAL
- Consistency ... btw Experiments / Channels
- Extrapolations ... the “Road map”

Statistics ... Definitions

TASK ... to combine "channels" from four experiments

Data sets @ different E_{cm} and Luminosities

Different decay-channels

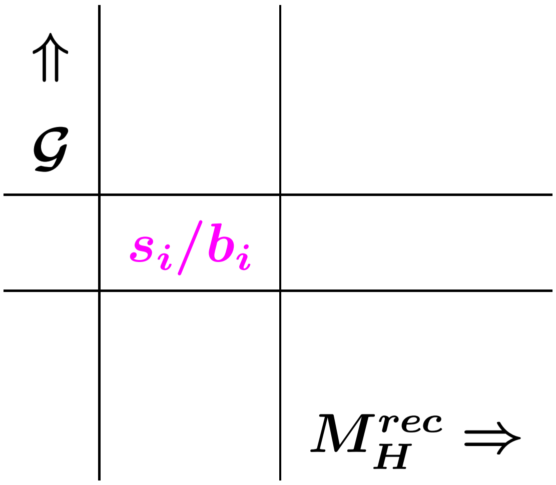
$$e^+e^- \longrightarrow \text{Z H} \longrightarrow b\bar{b},\ \tau^+\tau^-$$
$$\hookrightarrow\ q\bar{q}, \nu\bar{\nu}, e^+e^-, \mu^+\mu^-, \tau^+\tau^-$$

(1) **INPUTS** ... for each "channel" ... binned in two discriminating variables (both contribute to the search sensitivity)

- Reconstructed Higgs mass M_H^{rec}
- Global variable $\mathcal{G}$ ... containing
  b-tag, kinematics, jet-properties ...

In each bin i ...

- Bkgd. (MC) b_i
- Signal (MC) $s_i(m_H)$
  for "test-mass" m_H
- Nbr of candidates N_i



MC estimates of $s_i(m_H)$ and b_i take into account the exp'tal details (e.g. E_{cm}, lumi, signal eff., mass-resol., bkgds ...)

For "test-mass" m_H ...

(2) LIKELIHOOD TEST ... "sig + bkgd" $\Longleftrightarrow$ "bkgd"

$$-2\ln Q(m_H) = 2s_{tot} - 2\sum N_i \ln[1 + s_i(m_H)/b_i]$$

$$Q(m_H) = \mathcal{L}(s+b)/\mathcal{L}(b)$$ **"test-statistic"**

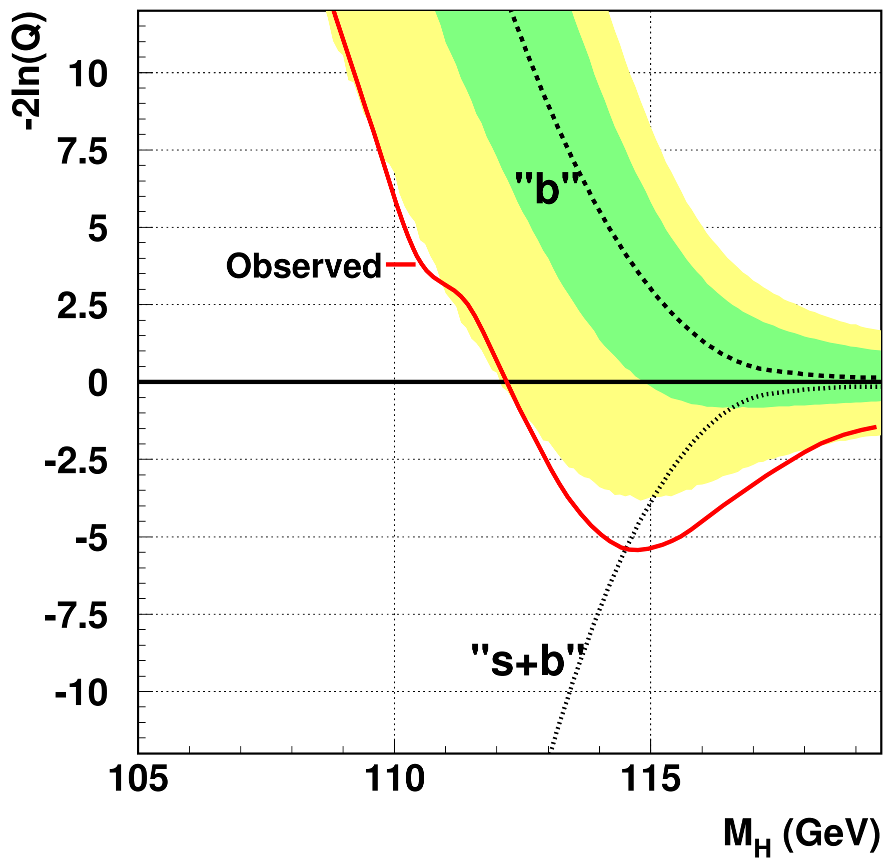
to rank the observed event configuration

between "$s+b$" and "b" hypotheses

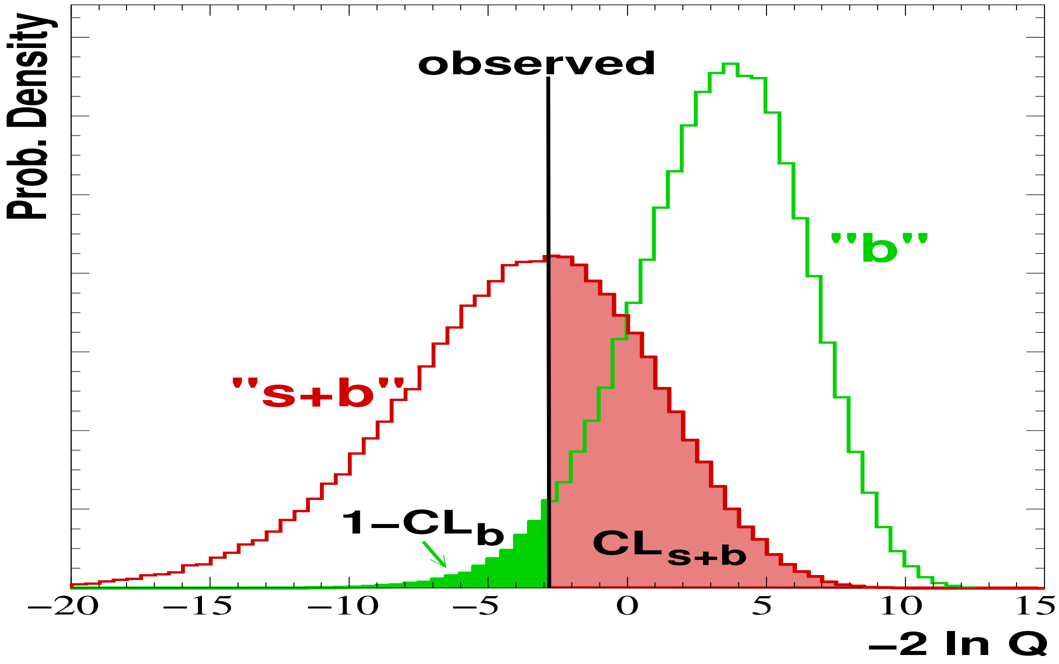
For arbitrary test-mass m_H ... and replacing the data set by

ficticious MC sets of "$s+b$" and "b" configurations

$\Rightarrow$ <u>expected</u> curves ... and statistical spread



(3) CONFIDENCE LEVELS ...



$\Leftarrow$ "$s+b$" "b" $\Rightarrow$

- $1 - CL_b$ ... a measure of incompatibility with "b"

  Given an ensemble of "b" experiments ...

  probability to obtain an event configuration less bkgd-like

  than the observed event configuration

$1 - CL_b$	0.32	0.046	2.7×10^{-3}	6.3×10^{-5}	5.7×10^{-7}
	1 σ	2 σ	3 σ	4 σ	5 σ

- CL_{s+b} ... a measure of incompatibility with "$s+b$"

  $CL_s = CL_{s+b}/CL_b \Rightarrow$ lower bound on Higgs mass

Data Sets

- **REFERENCE data set ... where it all begun ...**

  data set combined for the Sept 5 LEP seminar ...

  Revisited ... changes within the experiments

  $\Rightarrow$ **Recalibration of data**

  $\Rightarrow$ **Revision of procedures (corrections)**

  $\Rightarrow$ **Improvements ... better sensitivity**

- **DELTA set ... data collected since "REF"**

  (... until the "cutoff date" ... Oct 18-25)

- **TOTAL = REF + DELTA**

Integrated luminosities ... A+D+L+O = "ADLO"

(contributions from single experiments ... within $\pm$5%)

Not included ... latest data ... $\approx$30 pb^{-1}

$\mathcal{L}$ (pb^{-1})	REF	DELTA	TOTAL
$E_{cm} > 200$ GeV	596.6	213.7	810.3
$E_{cm} > 206$ GeV	303.5	184.5	488.0

REFERENCE $\Rightarrow$ TOTAL

No spectacular changes anticipated

(limited additional luminosity)

Relevant question ... the TREND

- **Does the “effect” increase / derease ?**

- **Towards a better distribution ...**

  between experiments ?

  between decay channels ?

RESULTS ... REF, DELTA, TOTAL

- **Derived independently by three people ...**

  same sets of input, differing combination software

- **Results of individual experiments ... reproduced**

  comparisons of $-2\ln Q,\ \ CL_s,\ \ 1 - CL_b$

- **Detailed checking of non-trivial technical details**

  problems fed back to the experiments

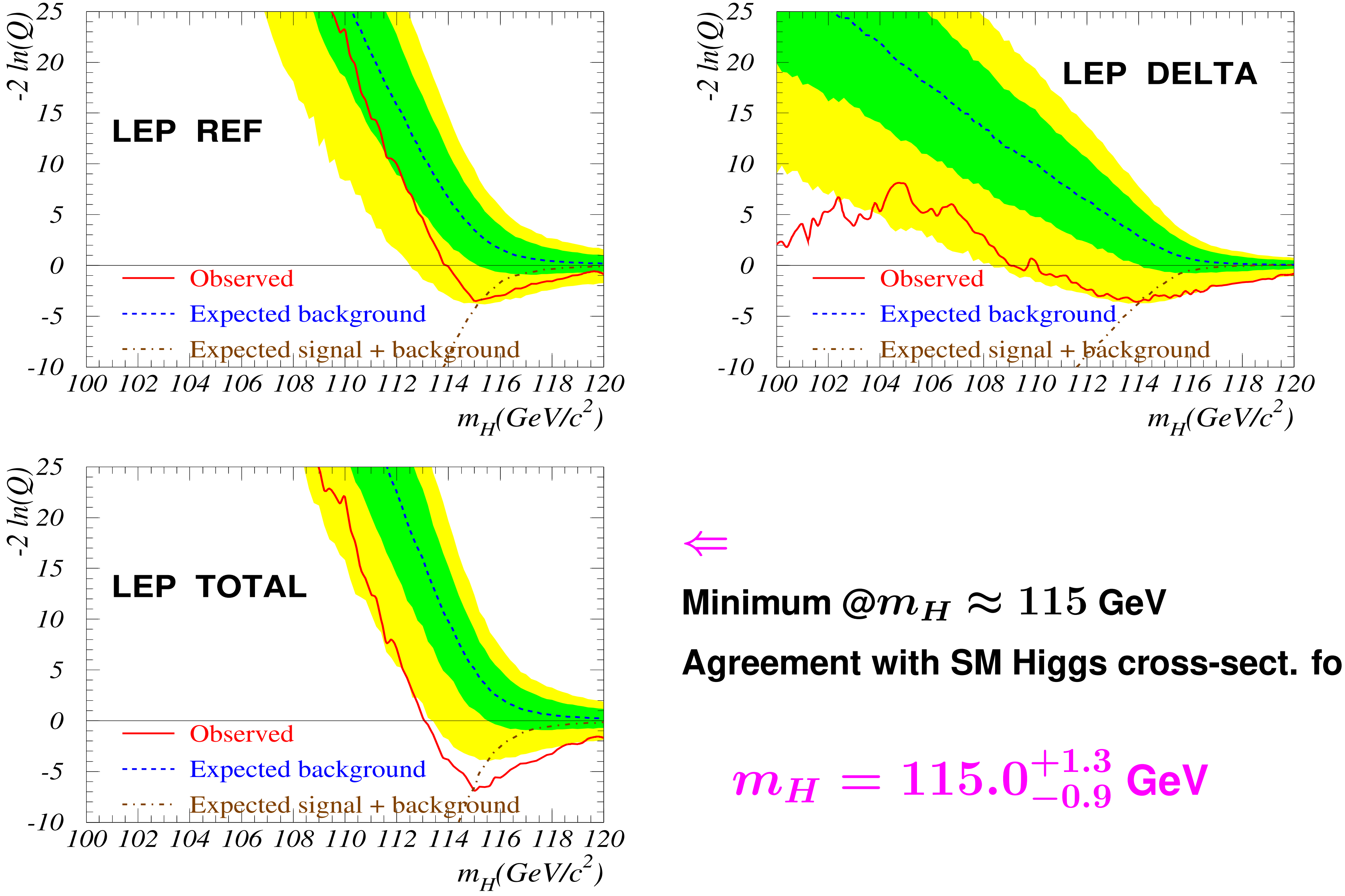
- **Alternative test statistics ...** $\boldsymbol{\Delta = \pm 0.1\,\sigma}$
- **Bypassing the syst. errors ...** $\boldsymbol{\Delta = +0.1\,\sigma}$

$\Rightarrow$ **GLOBAL COMBINATION UNCERTAINTY**

on OBSERVED effect ...

$\lesssim \mathbf{0.2}\,\boldsymbol{\sigma}$

$-2\ln(Q)$ ... REF, DELTA, TOTAL



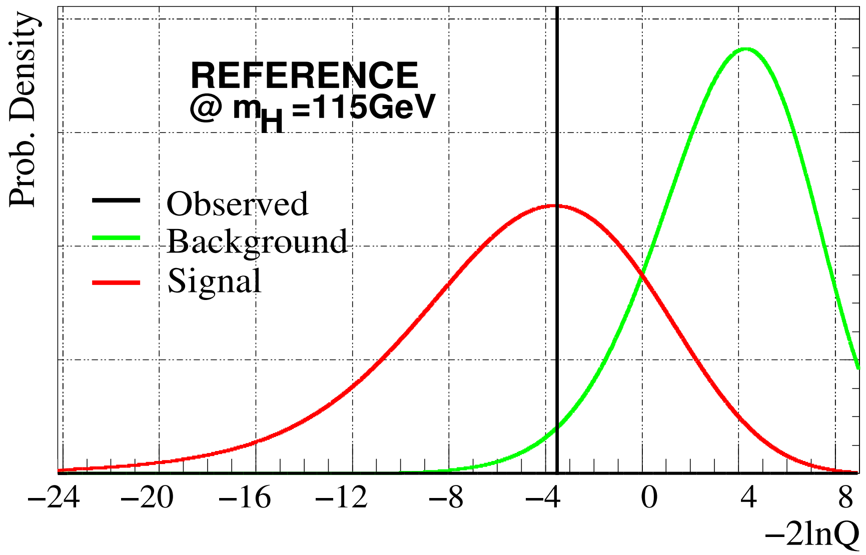
$\Leftarrow$

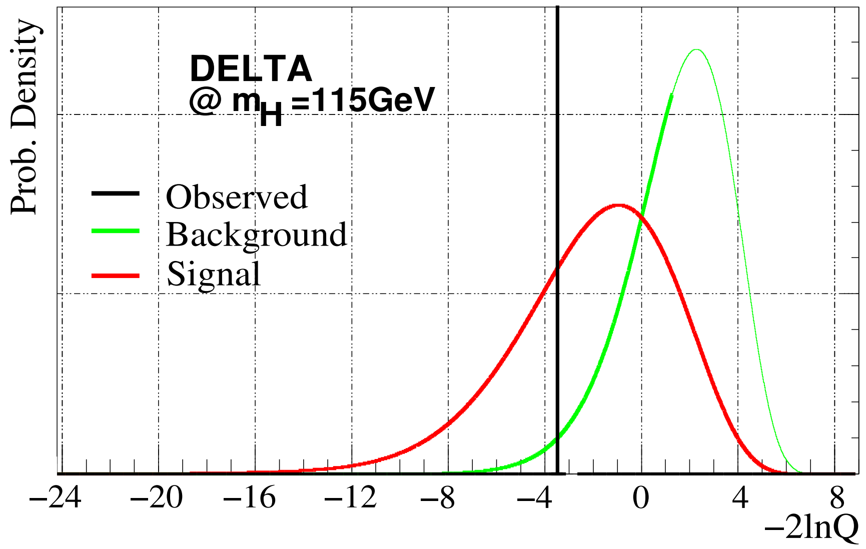
Minimum @$m_H \approx 115$ GeV

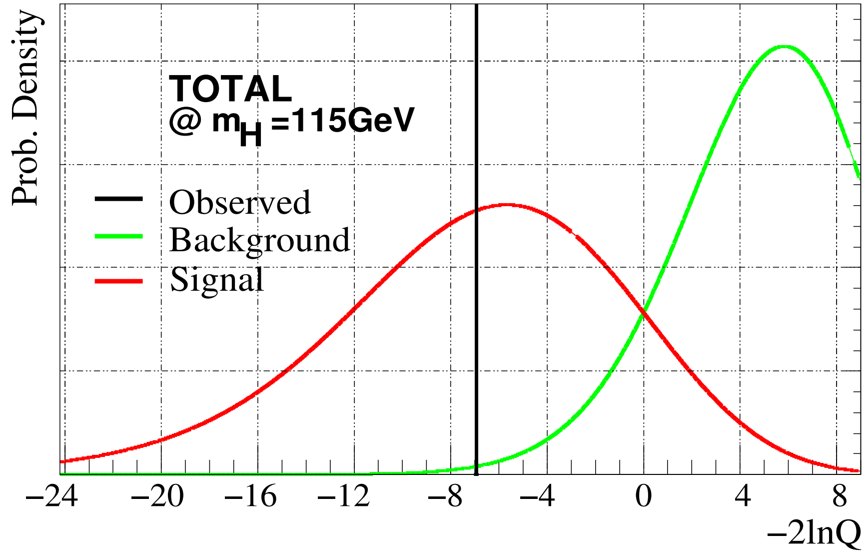
Agreement with SM Higgs cross-sect. for

$$m_H = 115.0^{+1.3}_{-0.9} \text{ GeV}$$

Prob. density $@m_H = 115$ GeV ... REF, DELTA, TOTAL

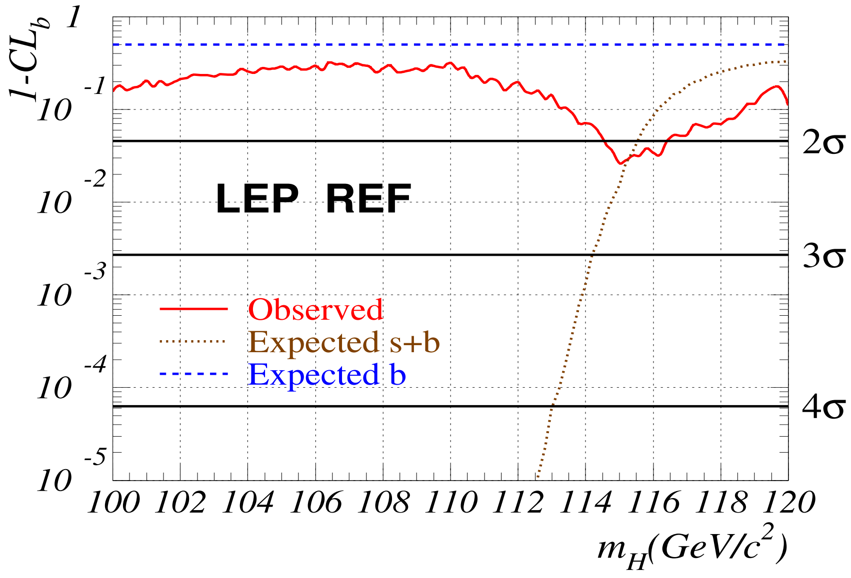


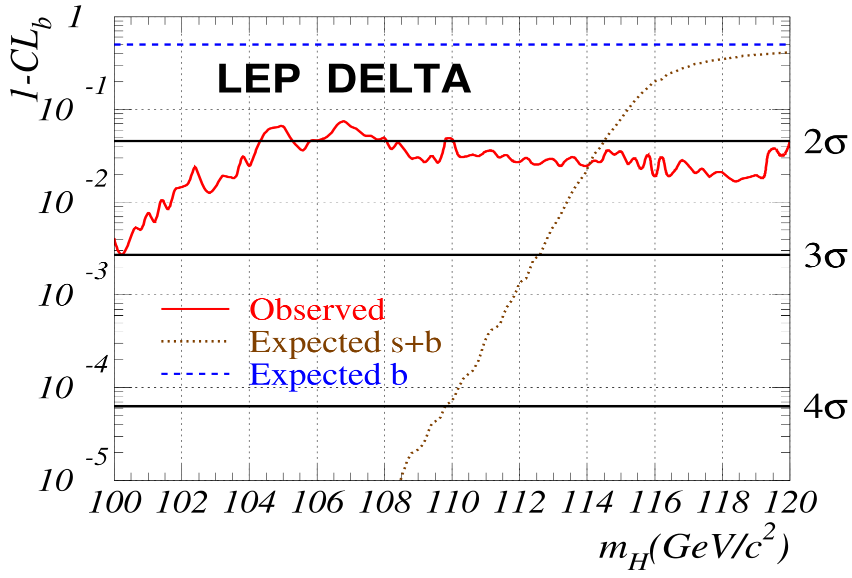


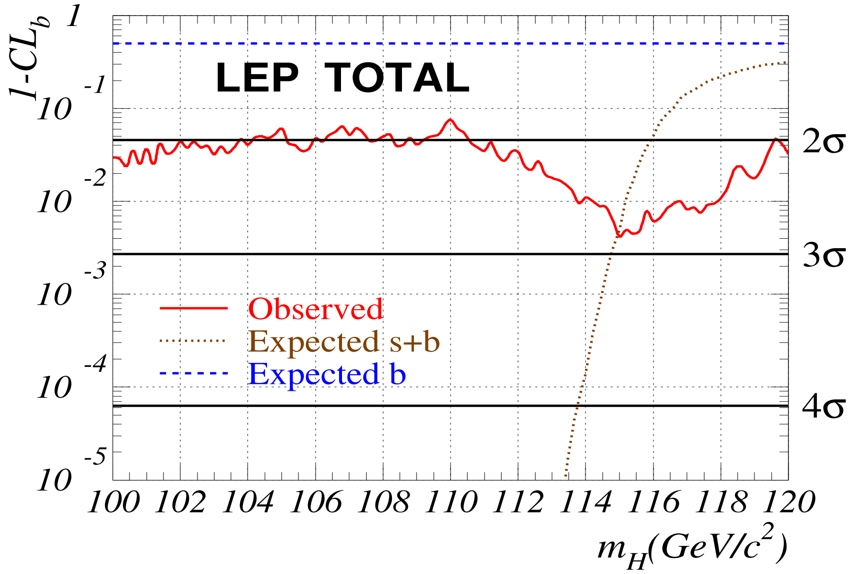


ADLO	Observed $-2\ln(Q)$
REF	-3.5
DEL	-3.5
TOT	-7.0

$1 - CL_b$ ... REF, DELTA, TOTAL







ADLO	$1 - CL_b$	
REF	2.5×10^{-2}	2.2σ
DEL	2.2×10^{-2}	2.3σ
TOT	4.2×10^{-3}	2.9σ

EVOLUTION ... BY EXPERIMENT

(values quoted @ $m_H = 115$ GeV)

ALEPH	$1 - CL_b$	
REF	1.6×10^{-4}	3.8σ
DEL	0.43	bkgd-like
TOT	6.5×10^{-4}	3.4σ

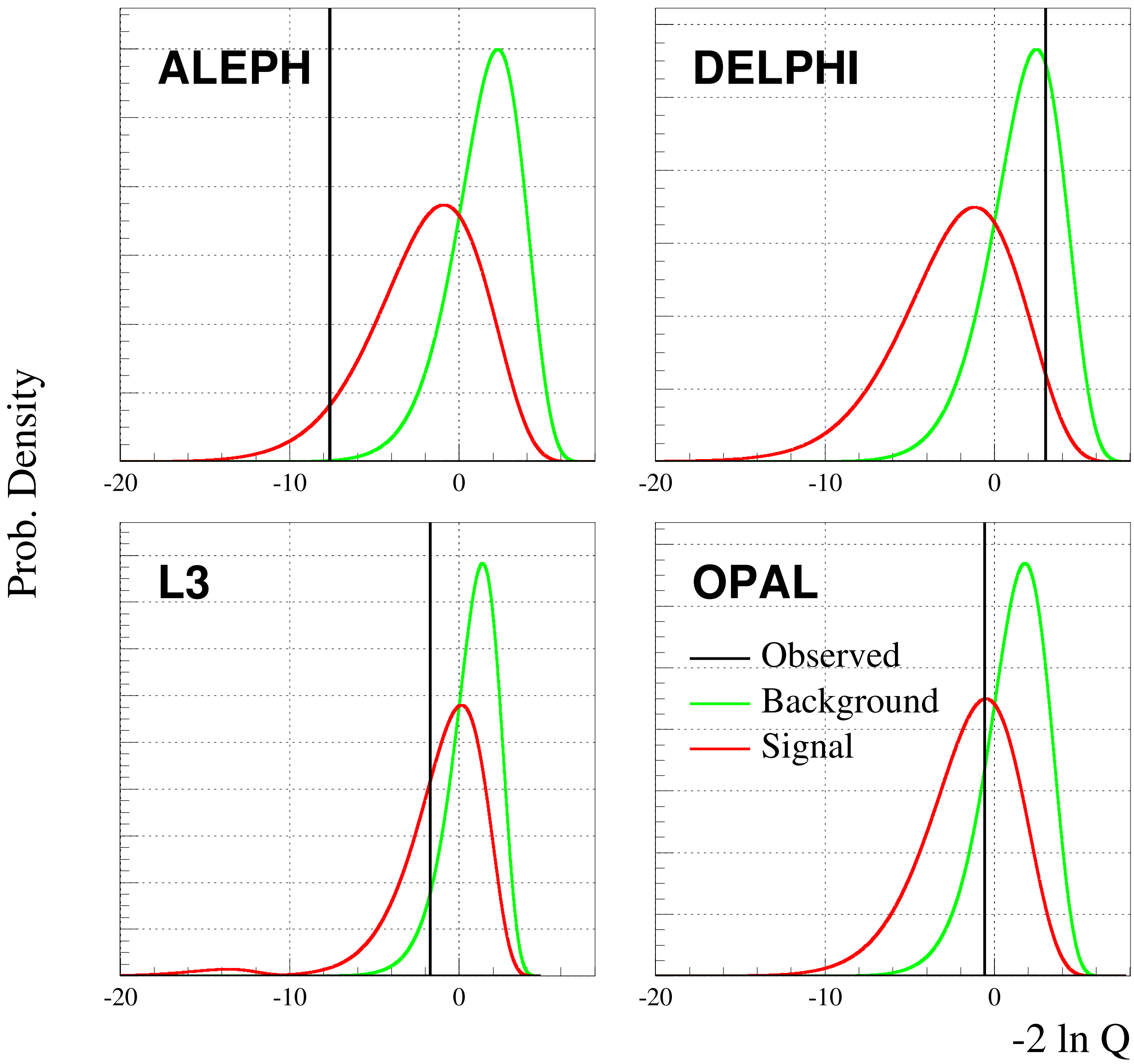
DELPHI	$1 - CL_b$	
REF	0.67	bkgd-like
DEL	0.52	bkgd-like
TOT	0.68	bkgd-like

L3	$1 - CL_b$	
REF	0.84	bkgd-like
DEL	9.0×10^{-3}	2.6σ
TOT	6.8×10^{-2}	1.8σ

OPAL	$1 - CL_b$	
REF	0.47	bkgd-like
DEL	6.2×10^{-2}	1.9σ
TOT	1.9×10^{-1}	1.3σ

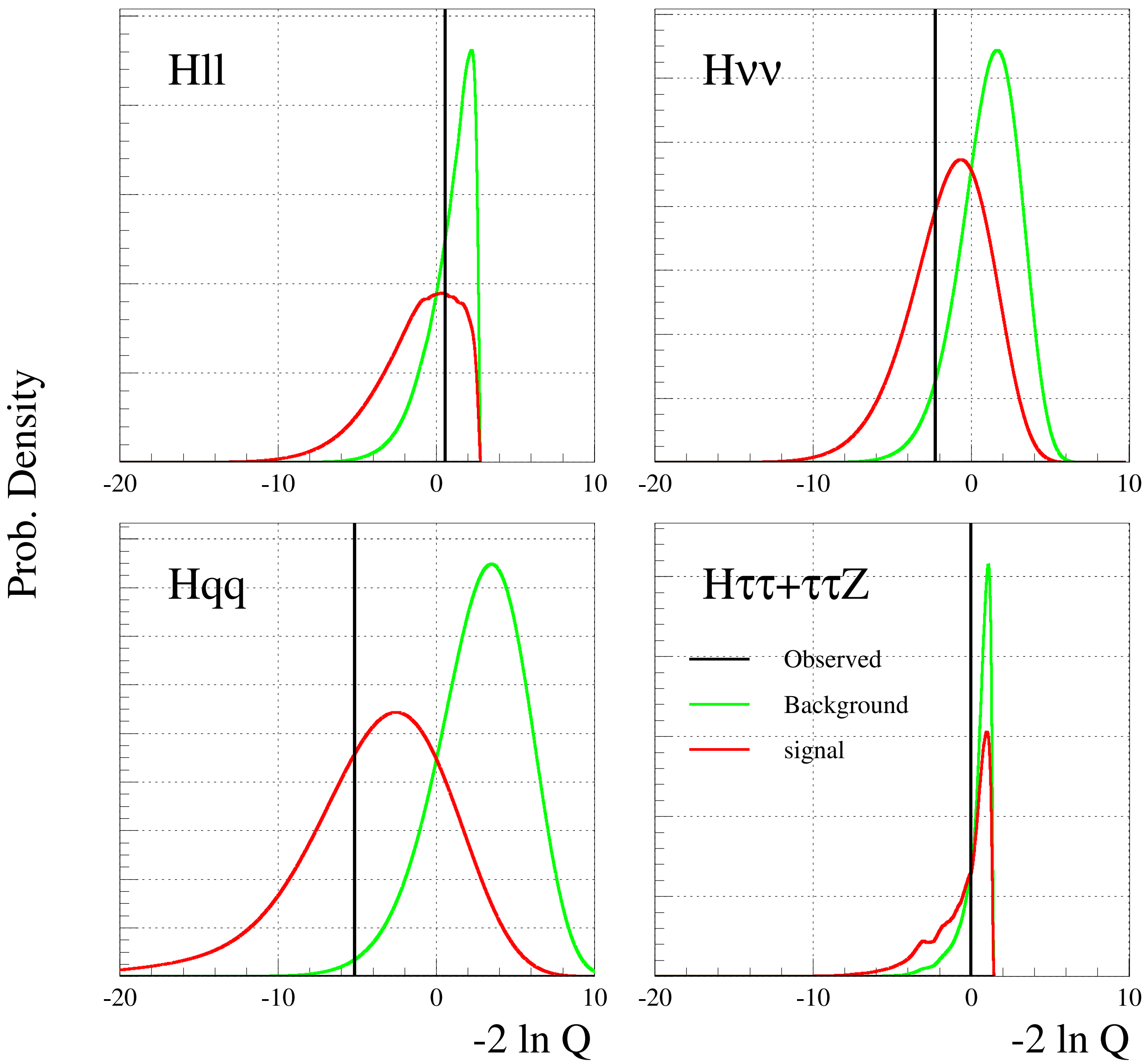
Results by Experiments

for TOTAL data set, @ $m_H = 115$ GeV



Results by Decay-Channel

for TOTAL data set, @ $m_H = 115$ GeV

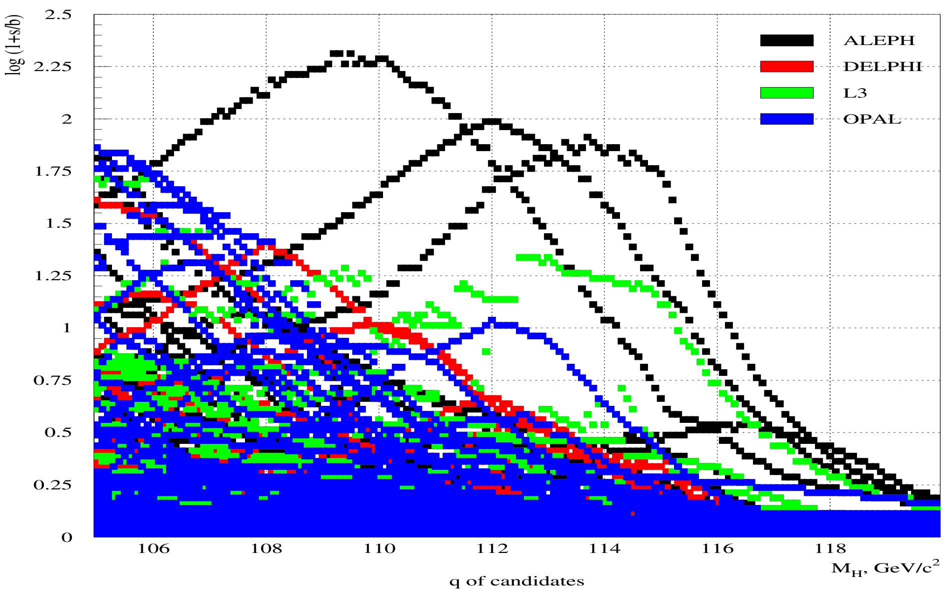


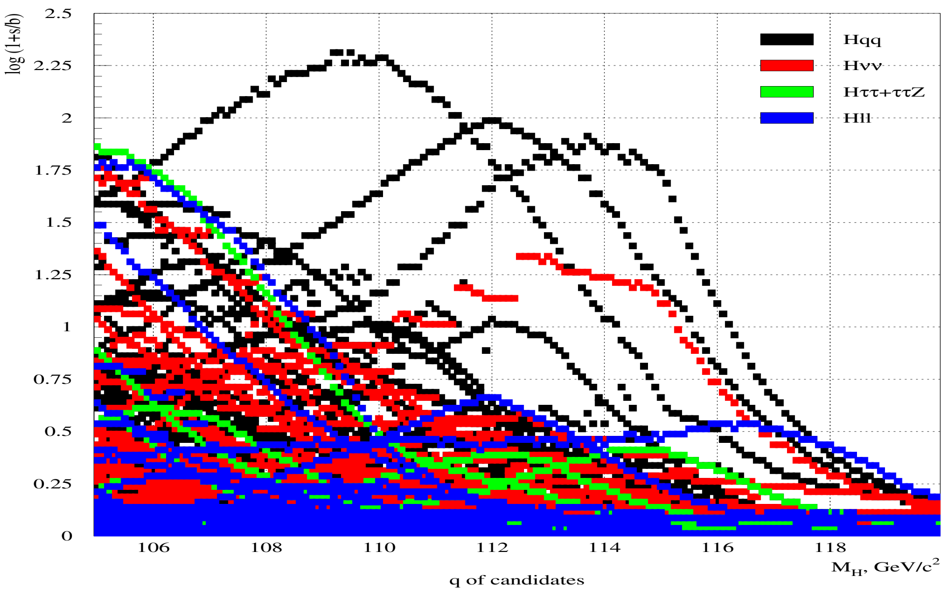
Contributions from Single Candidates

(for TOTAL data set)

$$-2\ln(Q) \quad \sim \quad \sum \ln(1+s_i/b_i)$$

$1 + s/b$ ... an indicator of of event "weight"

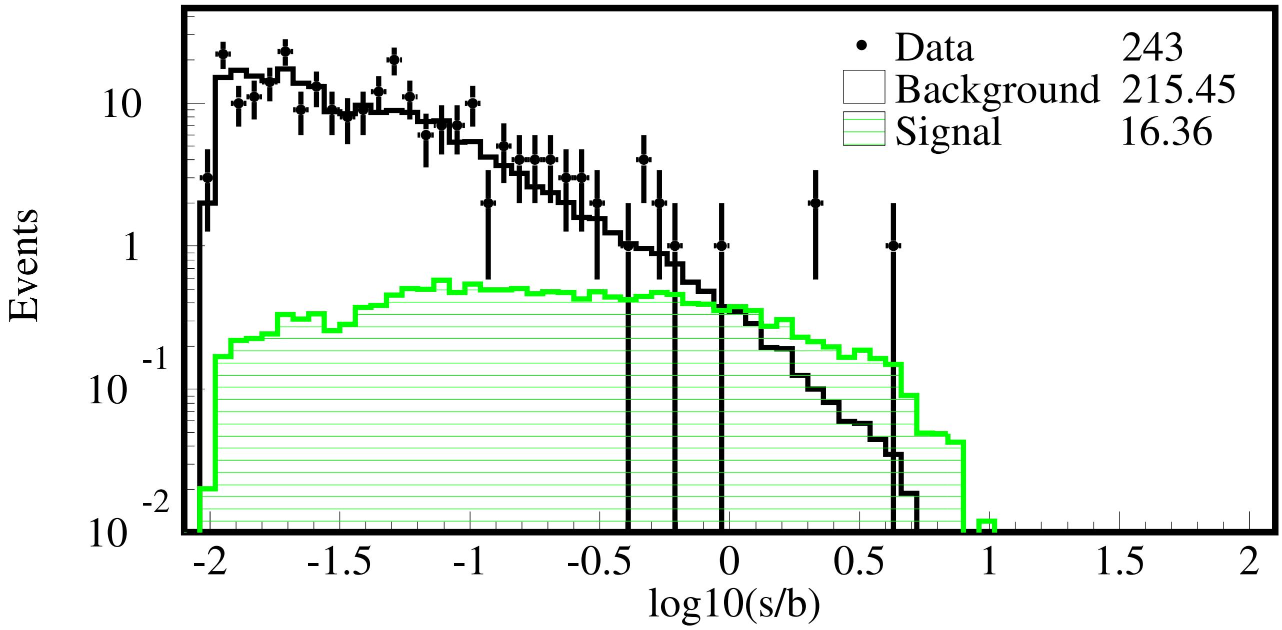


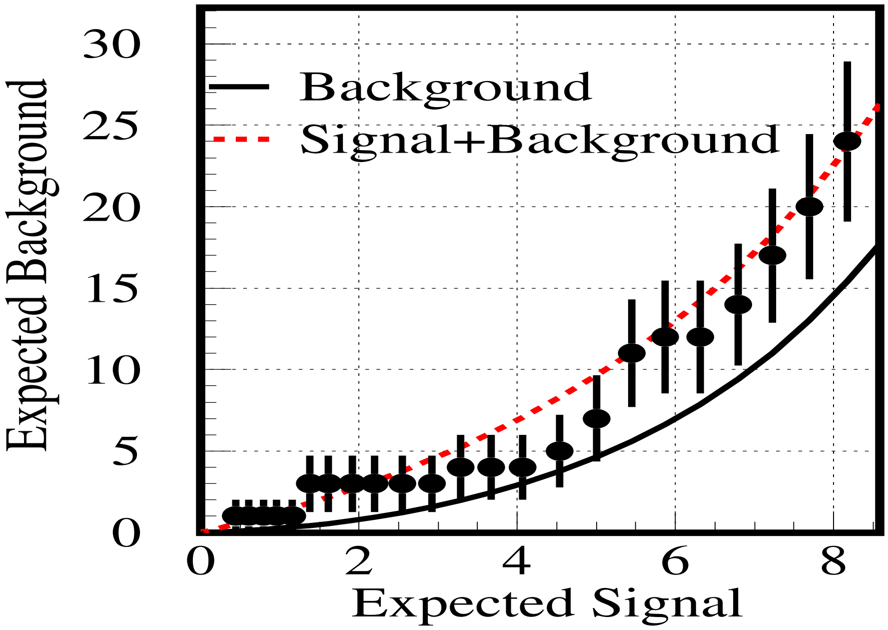


Distributions of Event “weights”

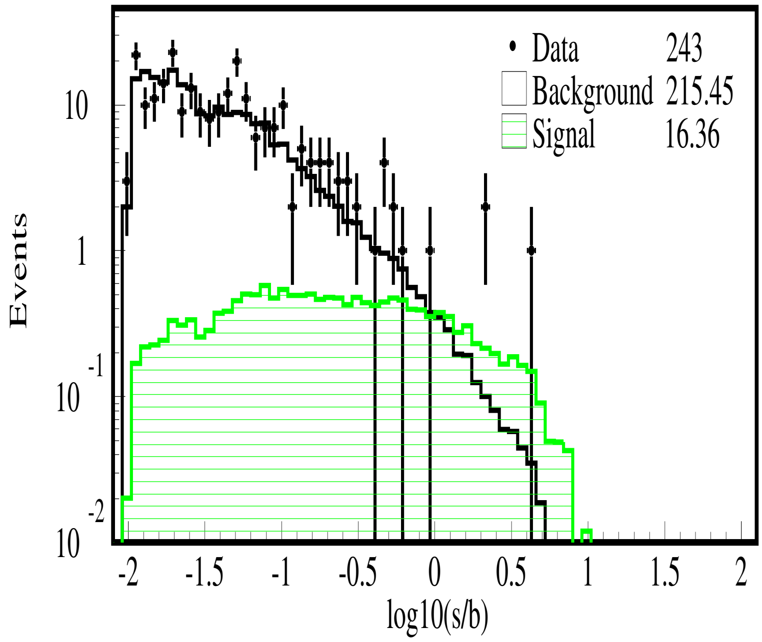
(for TOTAL data set @ $m_H = 115$ GeV)

“Bkgd”-like or “Signal+bkgd”-like ?





Expected rates @$m_H = 115$ GeV ..... TOTAL



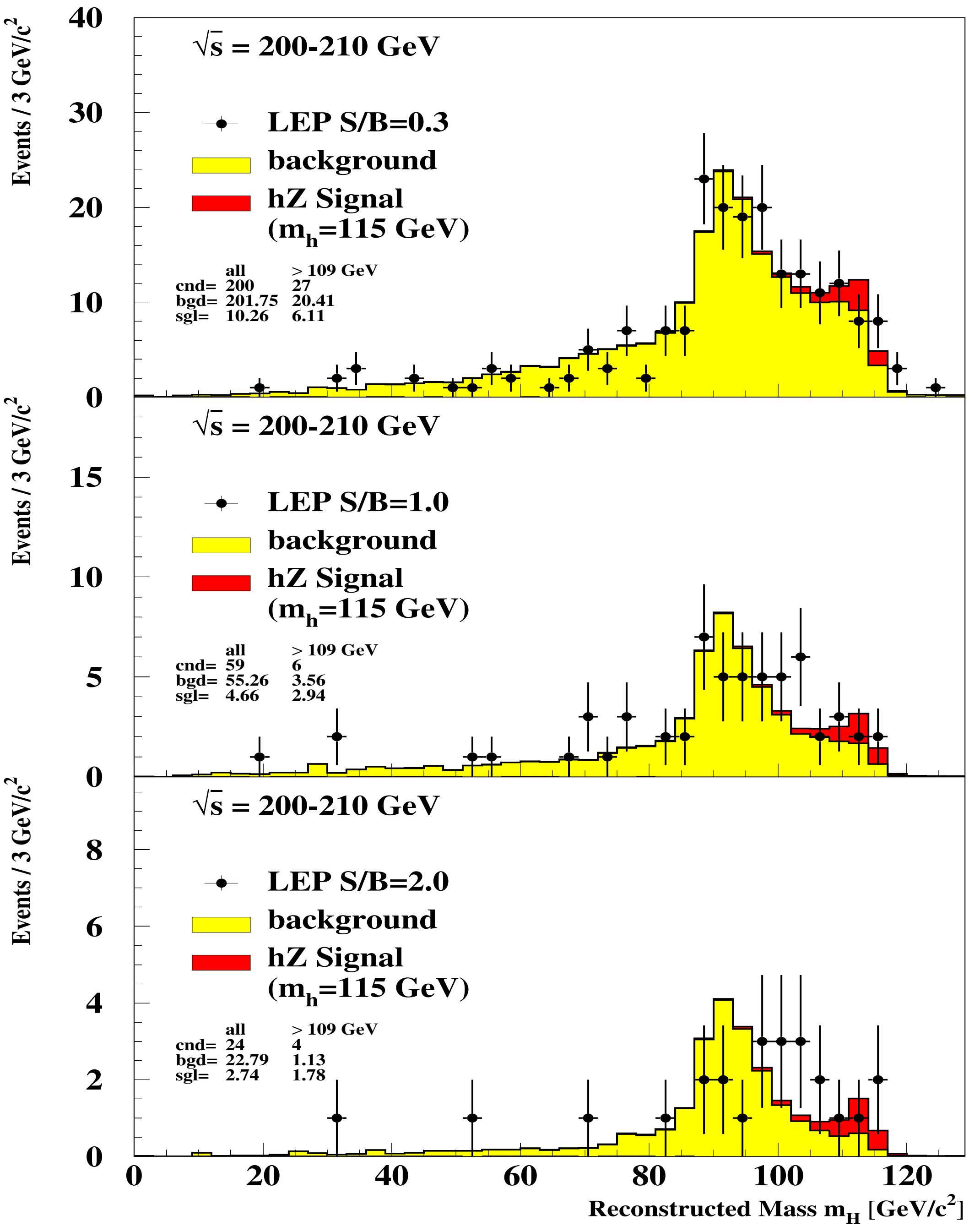
Integrating bkgd, signal and data ...

for $s/b \gtrsim 1$

		Backgd	Signal	Candidates
ADLO	4-jet	0.93	1.60	3
	E-miss	0.30	0.46	1
	Lept	0.35	0.68	0
	Taus	0.14	0.29	0
ADLO	All chan.	1.72	3.03	4

Distributions of Reconstructed Mass

Sequence: "Loose", "Medium" and "Tight" selection (*)



(*) Special selection ... not biasing the mass distribution

SUMMARY

REFERENCE	$\Rightarrow$	TOTAL
2.2σ	$\Rightarrow$	2.9σ
One expt "s+b"-like	$\Rightarrow$	Three expt "s+b"-like
4-jet "s+b"-like	$\Rightarrow$	4-jet, E-miss "s+b"-like

Perfect compatibility with SM Higgs cross section

for

$m_H = 115.0^{+1.3}_{-0.9}$ **GeV**

! ALL THIS IS VERY EXCITING !

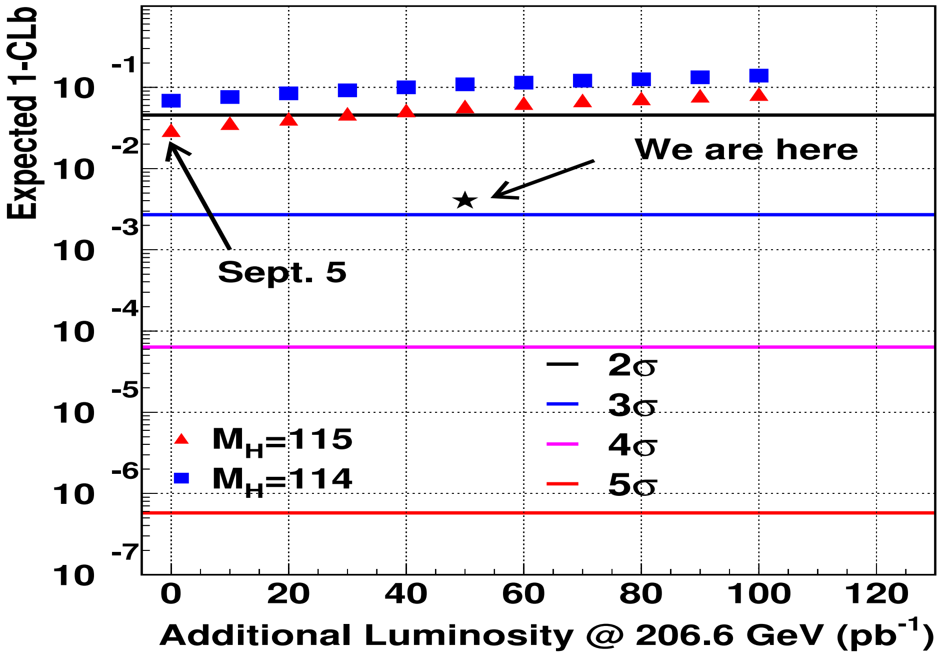
Current bound on Higgs boson mass

$m_H > 113.5$ **GeV @95% c.l.**

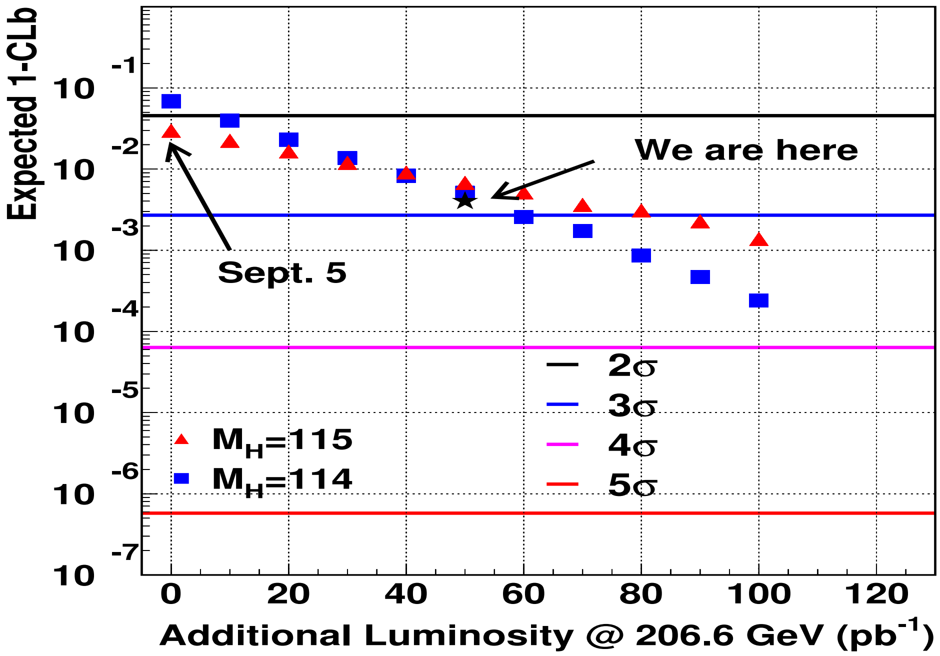
for 115.3 GeV expected

The "Road-Map" ... Since Sept' 2000

If accummulating background only ...

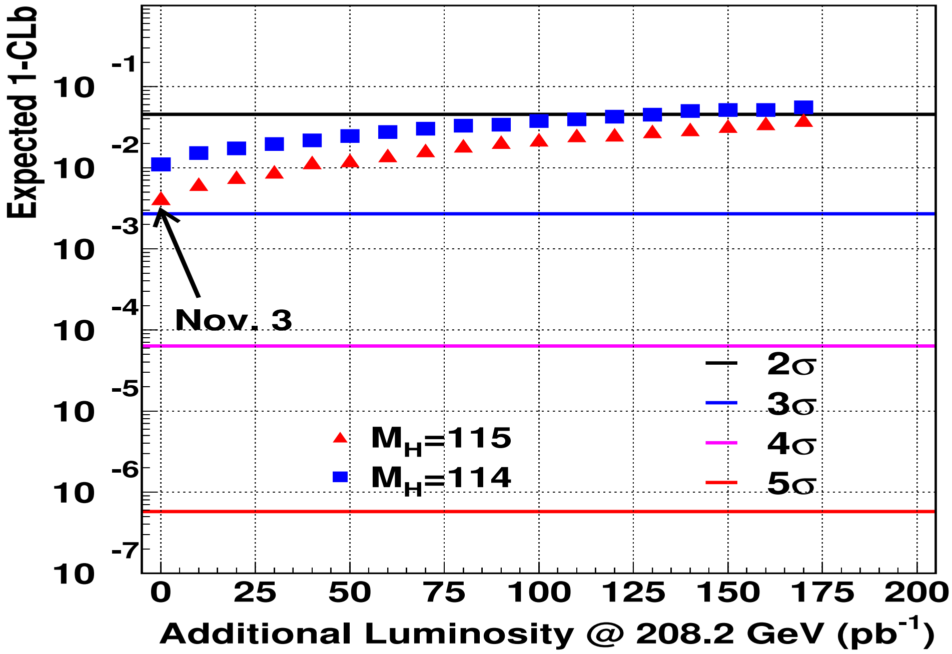


If accummulating signal + background ...

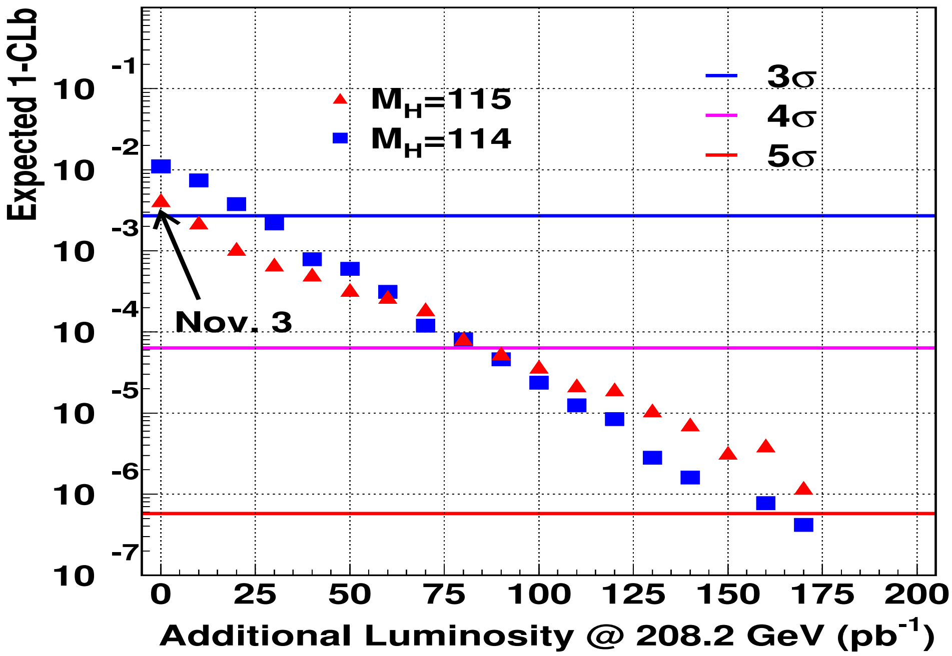


The "Road-Map" ... Running at $E_{cm} = 208.2$ GeV

If accummulating background only ...



If accummulating signal + background ...



RECOMMENDATION

Given the consistency for the combined results with the hypothesis of the production of a SM Higgs boson with a mass of 115 GeV, and an observed excess in the combined data set of 2.9σ, a further run with 200 pb^{-1} per experiment at 208 GeV would enable the four experiments to establish a 5σ discovery.

The four experiments consider the search for the SM Higgs boson to be of the highest importance, and CERN should not miss such a unique opportunity for a discovery.

Therefore, we request to run LEP in 2001 to collect $\mathcal{O}$(200 pb^{-1}) at $\sqrt{s} \geqq 208$ GeV.

ALEPH, DELPHI, L3, OPAL

The LEP Higgs Working Group