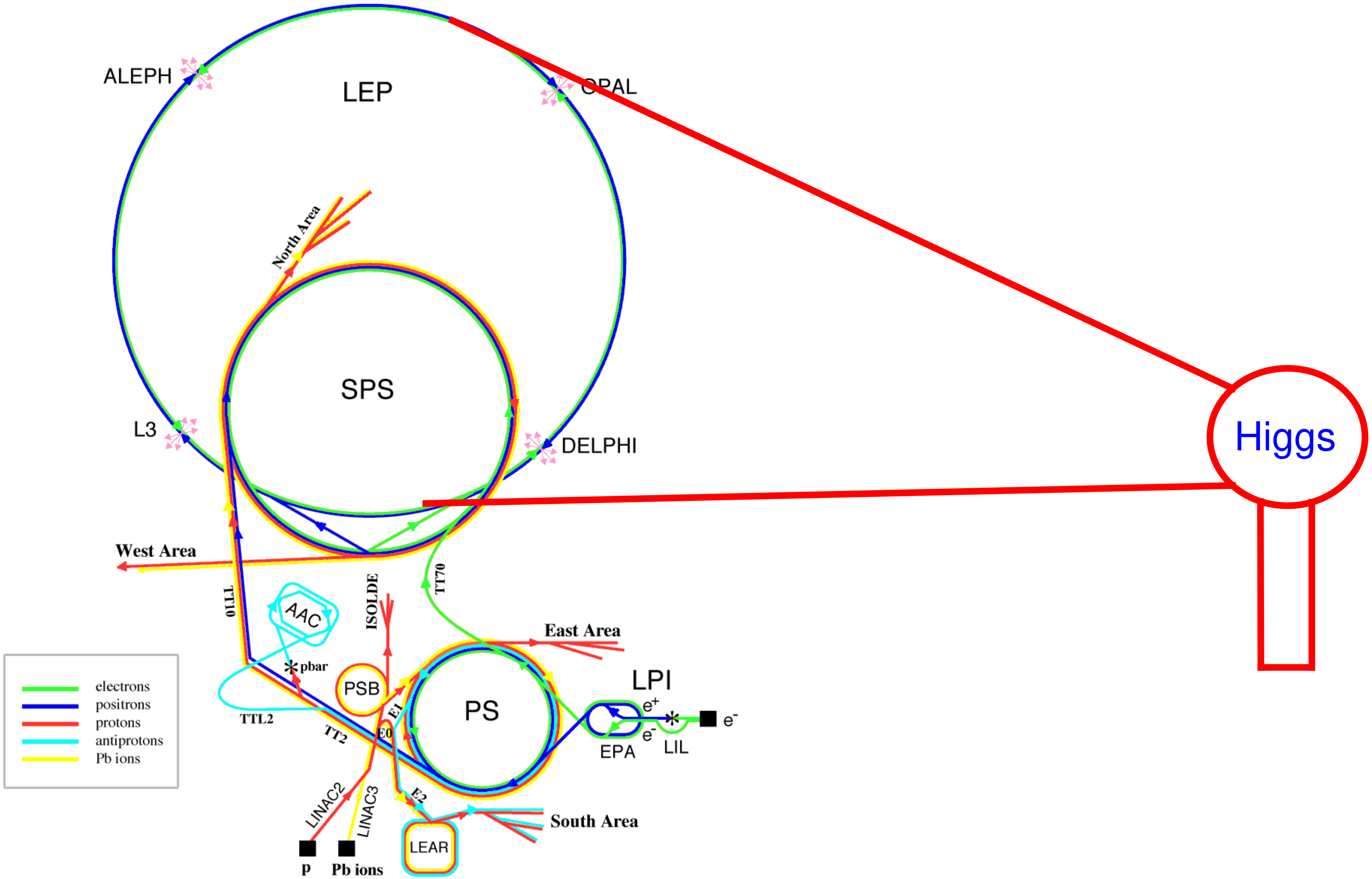
DE ZOEKTOCHT NAAR HET HIGGS BOSON



find a Higgs: 9 papers
find t Higgs: 5099 papers....

VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

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(Received 31 August 1964)

In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these particles (which would be absent if their mass were zero) go over into the Goldstone bosons when the coupling tends to zero. This phenomenon is just the relativistic analog of the plasmon phenomenon to which Anderson[3] has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal plasmon modes of finite mass when the gas is charged.

The simplest theory which exhibits this behavior is a gauge-invariant version of a model used by Goldstone[2] himself: Two real[4] scalar fields φ_1, φ_2 and a real vector field A_μ interact through the Lagrangian density

$$L = -\tfrac{1}{2}(\nabla\varphi_1)^2 - \tfrac{1}{2}(\nabla\varphi_2)^2 - V(\varphi_1^2+\varphi_2^2) - \tfrac{1}{4}F_{\mu\nu}F^{\mu\nu}, \qquad (1)$$

where

$$\nabla_\mu\varphi_1 = \partial_\mu\varphi_1 - eA_\mu\varphi_2,$$

$$\nabla_\mu\varphi_2 = \partial_\mu\varphi_2 + eA_\mu\varphi_1,$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu,$$

e is a dimensionless coupling constant, and the metric is taken as $-+++$. L is invariant under simultaneous gauge transformations of the first kind on $\varphi_1 \pm i\varphi_2$ and of the second kind on A_μ. Let us suppose that $V'(\varphi_0^2)=0$, $V''(\varphi_0^2)>0$; then spontaneous breakdown of U(1) symmetry occurs. Consider the equations [derived from (1) by treating $\Delta\varphi_1$, $\Delta\varphi_2$, and A_μ as small quantities] governing the propagation of small oscillations about the "vacuum" solution $\varphi_1(x)=0$, $\varphi_2(x)=\varphi_0$:

$$\partial^\mu\{\partial_\mu(\Delta\varphi_1) - e\varphi_0 A_\mu\} = 0, \qquad (2a)$$

$$\{\partial^2 - 4\varphi_0^2 V''(\varphi_0^2)\}(\Delta\varphi_2) = 0, \qquad (2b)$$

$$\partial_\nu F^{\mu\nu} = e\varphi_0\{\partial^\mu(\Delta\varphi_1) - e\varphi_0 A_\mu\}. \qquad (2c)$$

Equation (2b) describes waves whose quanta have (bare) mass $2\varphi_0\{V''(\varphi_0^2)\}^{1/2}$; Eqs. (2a) and (2c) may be transformed, by the introduction of new variables

$$B_\mu = A_\mu - (e\varphi_0)^{-1}\partial_\mu(\Delta\varphi_1),$$

$$G_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu = F_{\mu\nu}, \qquad (3)$$

into the form

$$\partial_\mu B^\mu = 0, \quad \partial_\nu G^{\mu\nu} + e^2\varphi_0^2 B^\mu = 0. \qquad (4)$$

Equation (4) describes vector waves whose quanta have (bare) mass $e\varphi_0$. In the absence of the gauge field coupling ($e=0$) the situation is quite different: Equations (2a) and (2c) describe zero-mass scalar and vector bosons, respectively. In passing, we note that the right-hand side of (2c) is just the linear approximation to the conserved current: It is linear in the vector potential, gauge invariance being maintained by the presence of the gradient term.[5]

When one considers theoretical models in which spontaneous breakdown of symmetry under a semisimple group occurs, one encounters a variety of possible situations corresponding to the various distinct irreducible representations to which the scalar fields may belong; the gauge field always belongs to the adjoint representation.[6] The model of the most immediate interest is that in which the scalar fields form an octet under SU(3): Here one finds the possibility of two nonvanishing vacuum expectation values, which may be chosen to be the two $Y=0$, $I_3=0$ members of the octet.[7] There are two massive scalar bosons with just these quantum numbers; the remaining six components of the scalar octet combine with the corresponding components of the gauge-field octet to describe

Higgs Mechanism in the SM:

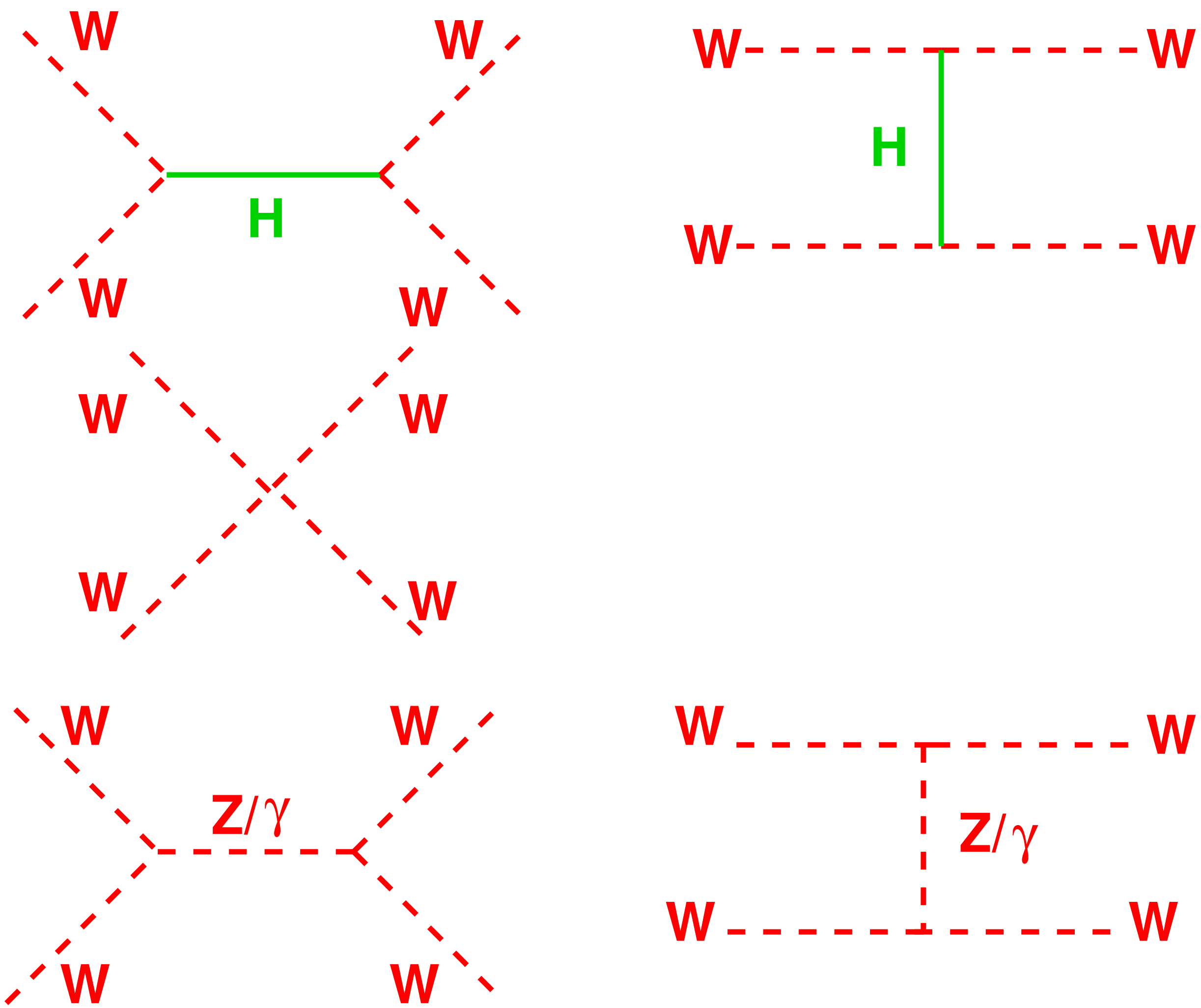
Higgs Field 1 complex scalar doublet	electro- magnetic field U(1) symmetry	weak fields $SU(2)_L$
ϕ^+ ϕ^0	B	W^+ W^- W^0

3 degrees of freedom of the Higgs field become the longitudinal polarisations of the W and Z Bosons

$\gamma, W^+, W^-, Z,$ **H** 4th degree of freedom

Higgs mass free parameter......

Elastic WW scattering at tree level:



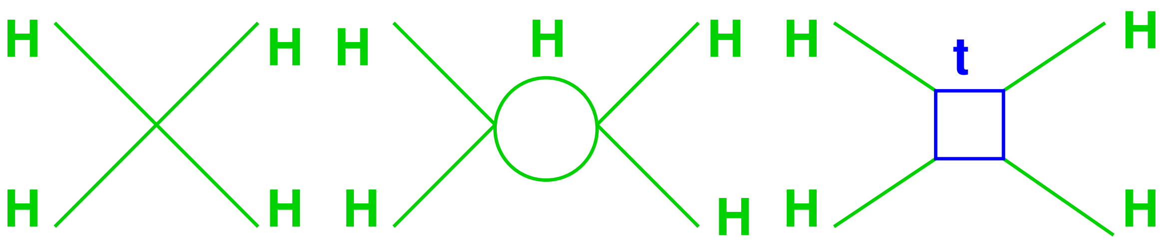
$\sigma_{WW} \rightarrow \infty$

for

$m_H \rightarrow \infty$

Unitarity:

$$m_H^2 \leq \frac{2\pi\sqrt{2}}{G_F} \approx (850\,\mathrm{GeV})^2$$



$\sim\lambda$

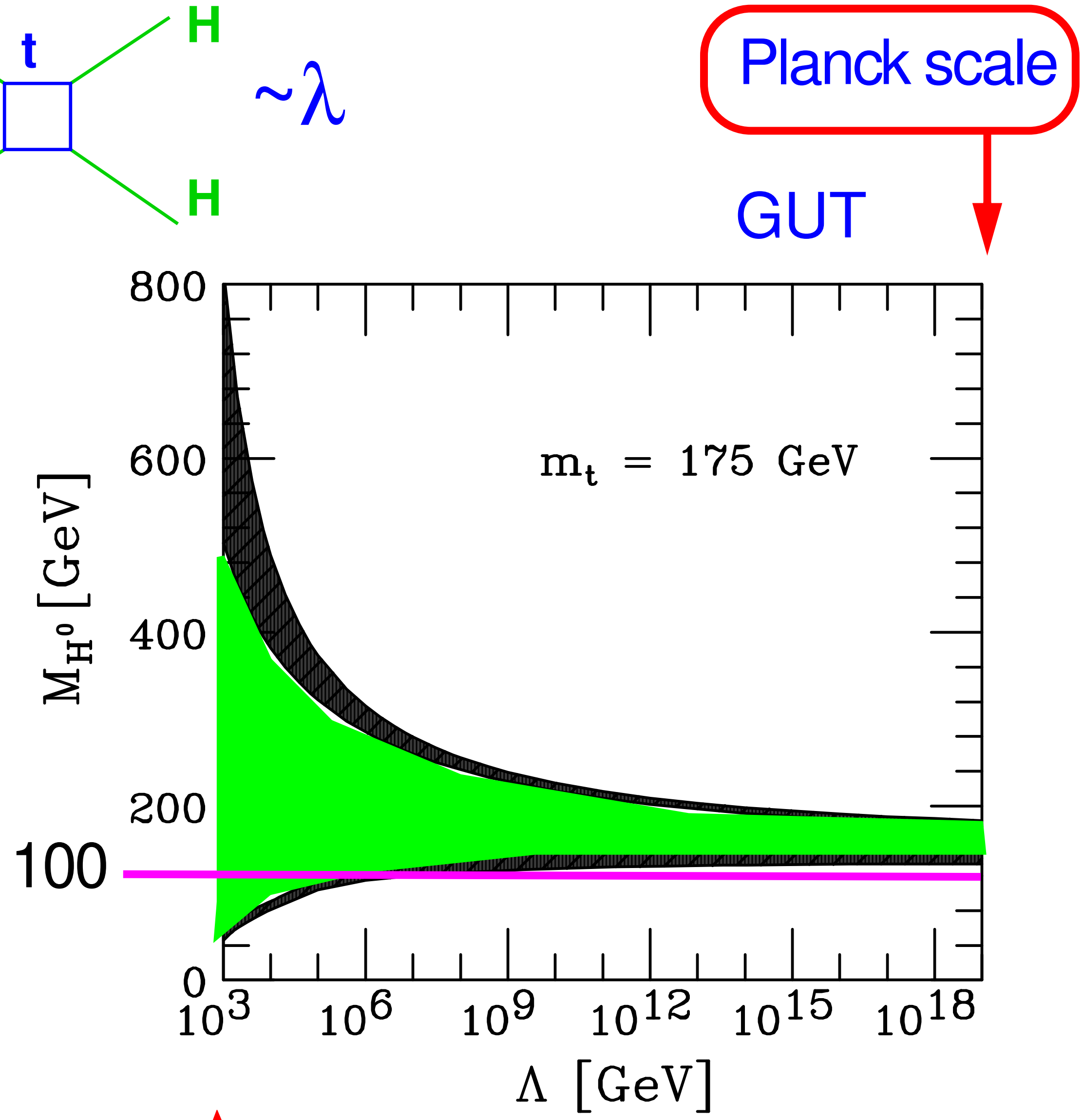
upper boundary:

$$\lambda(\Lambda) < \infty$$

lower boundary:

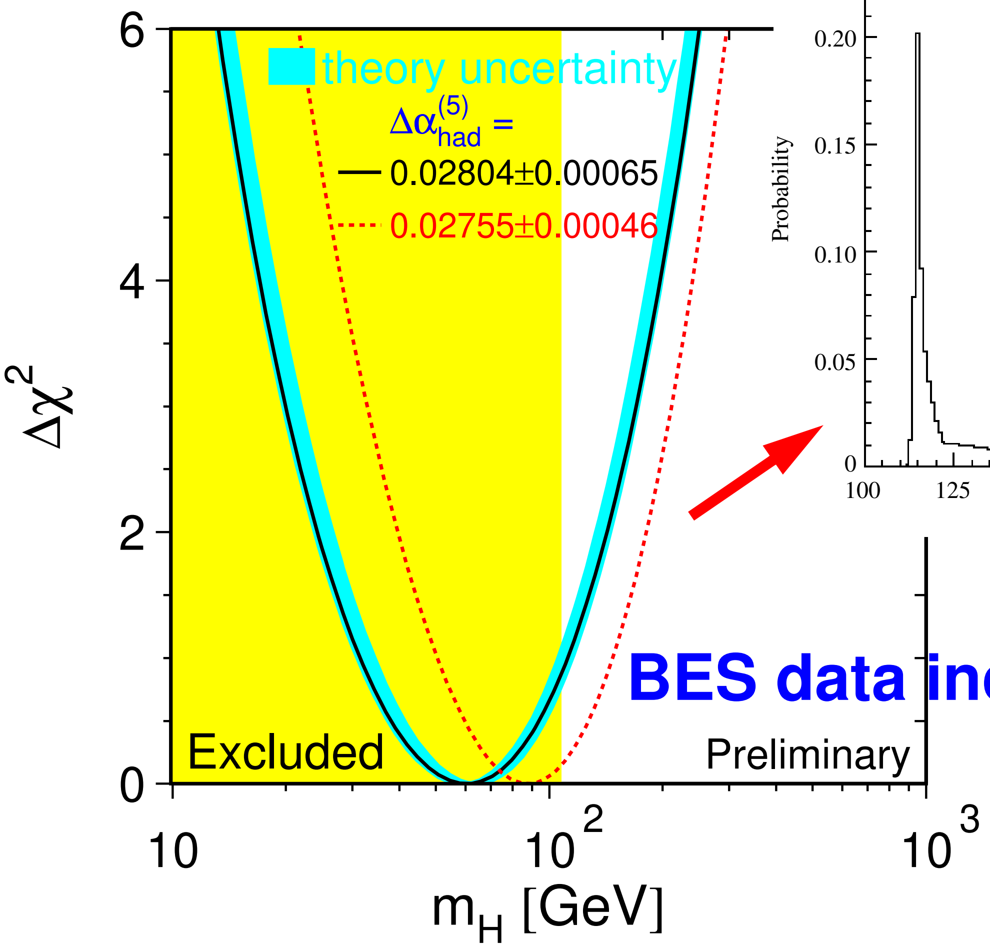
stable el-weak vacuum

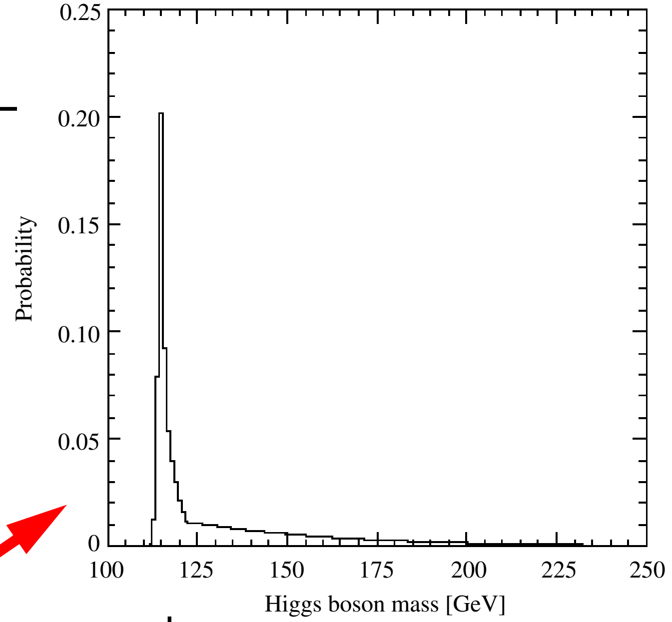
If the Higgs mass lies outside
the region 130-190 GeV,
new physics beyond the SM
exists below the GUT scale



Λ: scale of ‘new physics’

Indirect determination of the Higgs mass



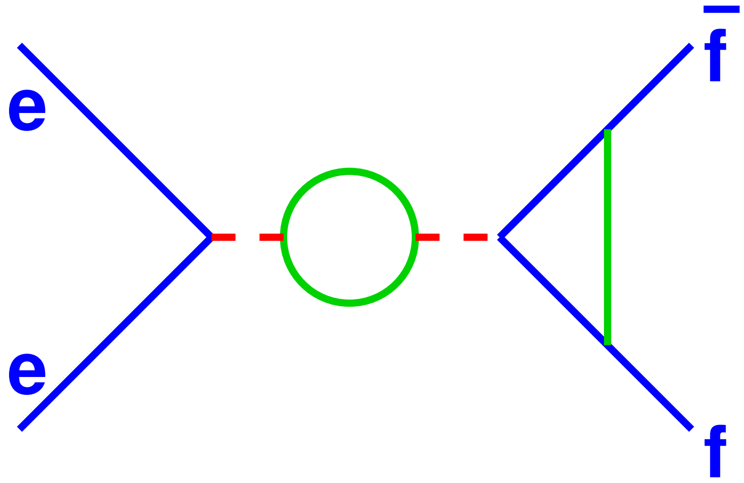


BES data included

electroweak radiative corrections:

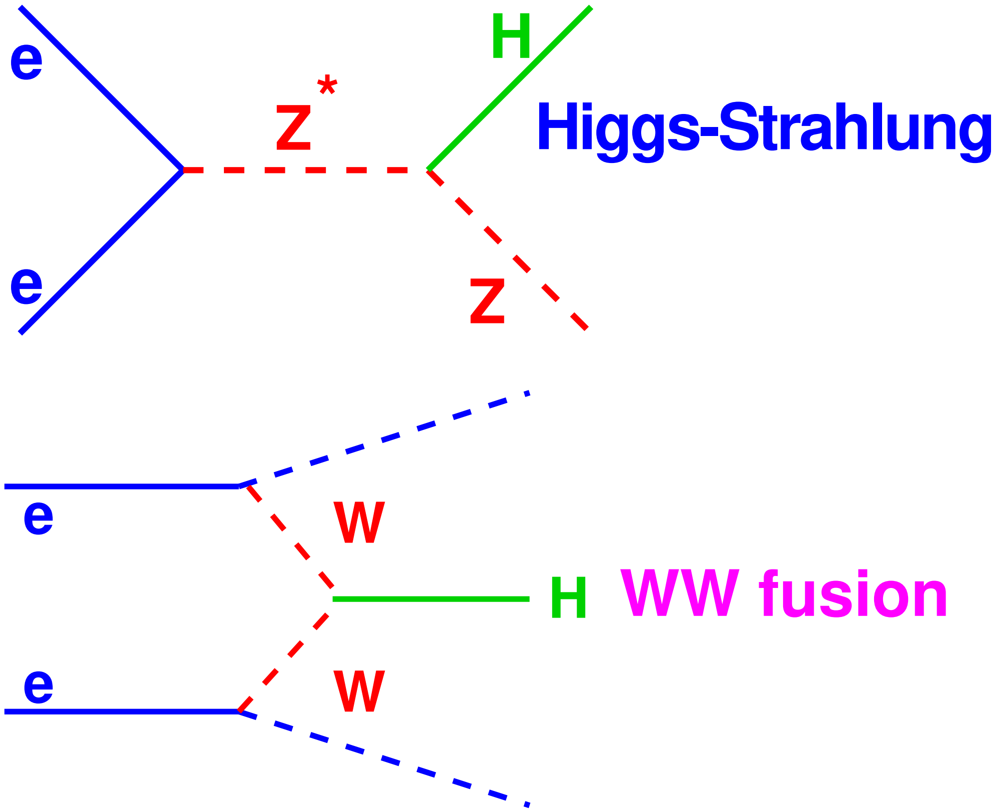
$\sim m_t^2$

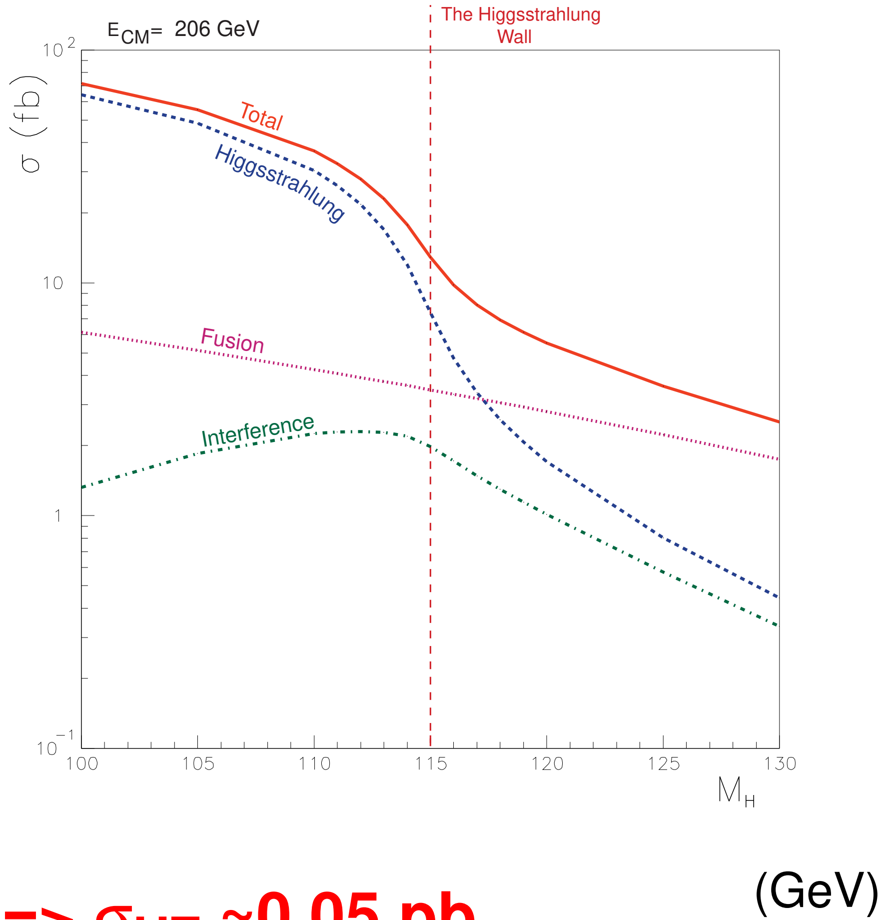
$\sim \ln(m_H^2/\mathrm{GeV}^2)$



Higgs production at LEP

(only Z->νν channel)





E_{cm}=206 GeV m_H=115 GeV => σ_{HZ} ~0.05 pb

$L_{ADLO}(E_{cm}>206\ \text{GeV})\sim 500\ \text{pb}^{-1}$ => 25 signal events

Chronica de una muerte anunciada:

Osaka

- 27 July: ICHEP2000, Osaka:

  no signal (~120 pb^{-1} at E_{cm}>206 GeV)

  LEP run in 'Higgs discovery mode' until beginning of october

- 5 September: LEPC

  ALEPH observes events in 4 jet channel

  (3.9 σ); ADLO: 2.6 σ

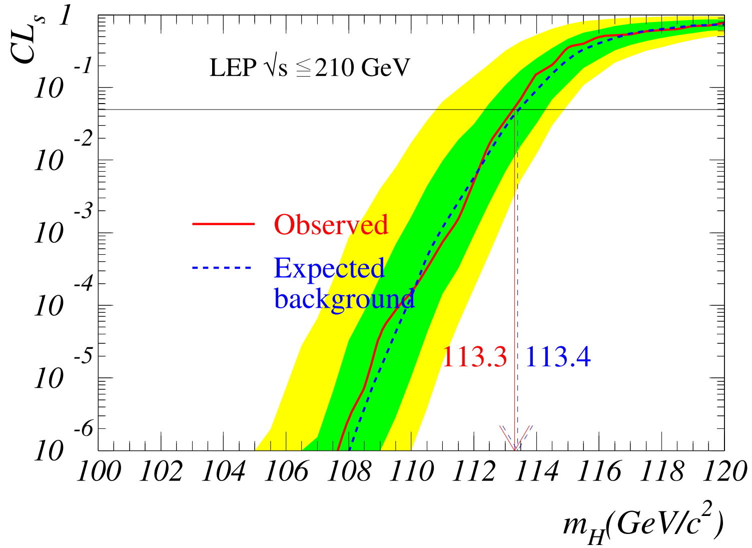
  LEP run extended 3 November

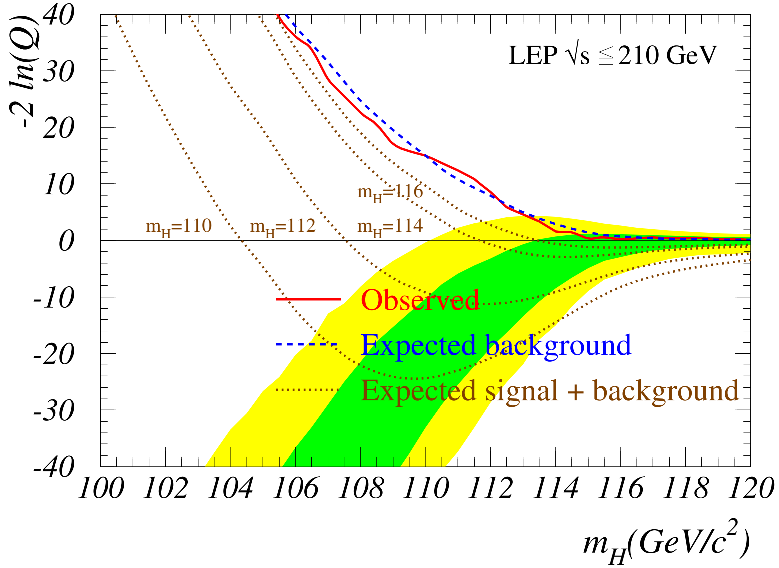
- 3 November: LEPC

  ALEPH: 3.9 σ -> 3.4 σ due to corrections

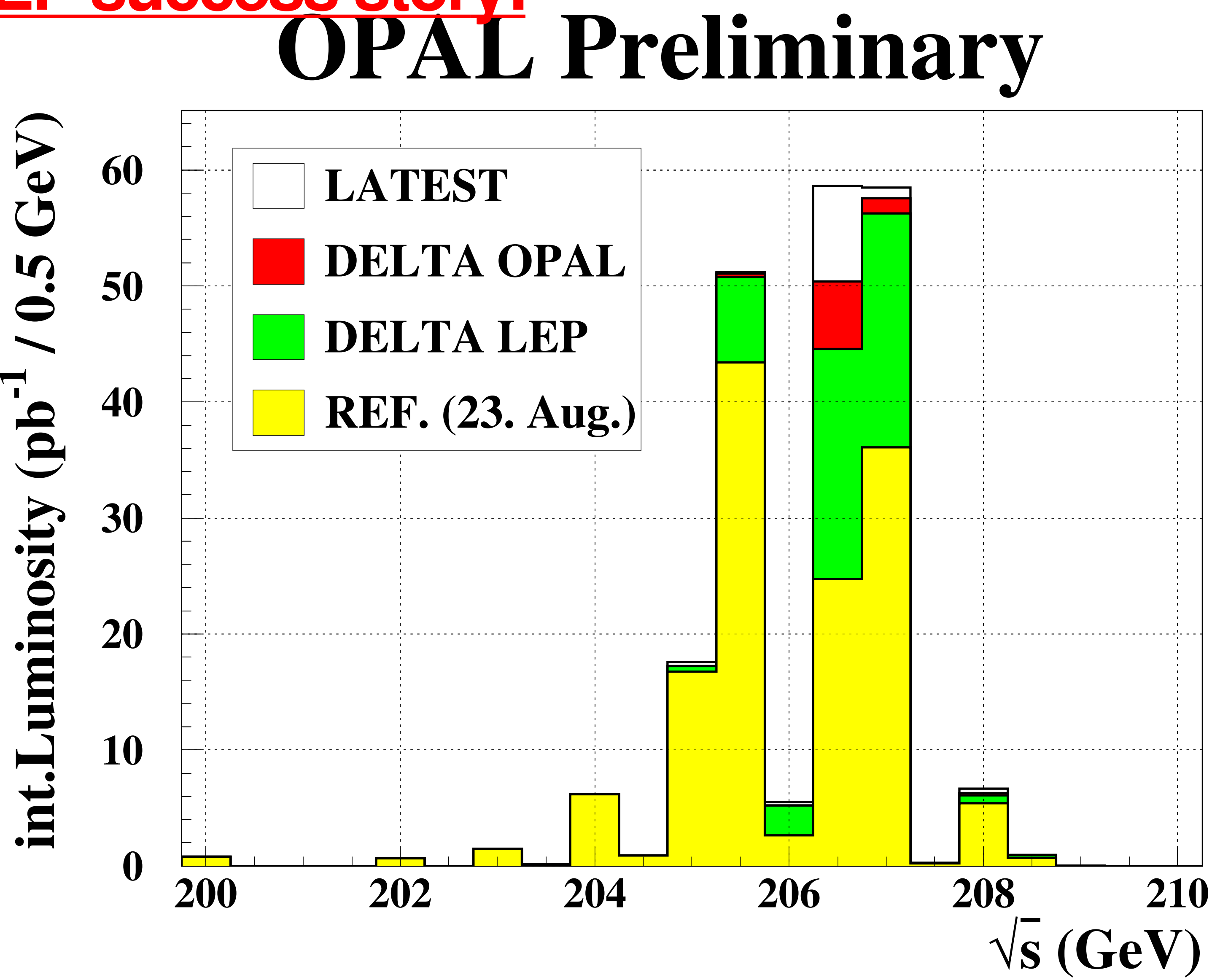
  L3: strong bbνν candidat

  ADLO: 2.9 σ, LEP run in 2001 ?





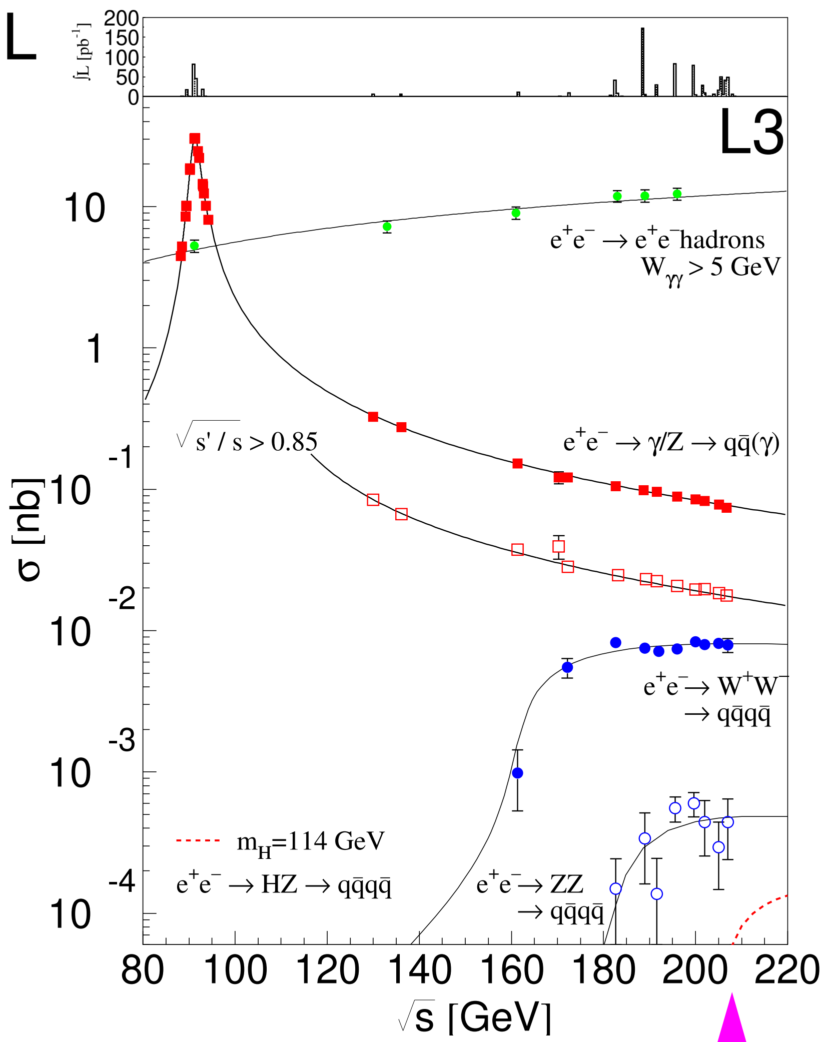
The LEP success story:



only 2000

only OPAL

Background:



γγ–> hadrons

qq

WW

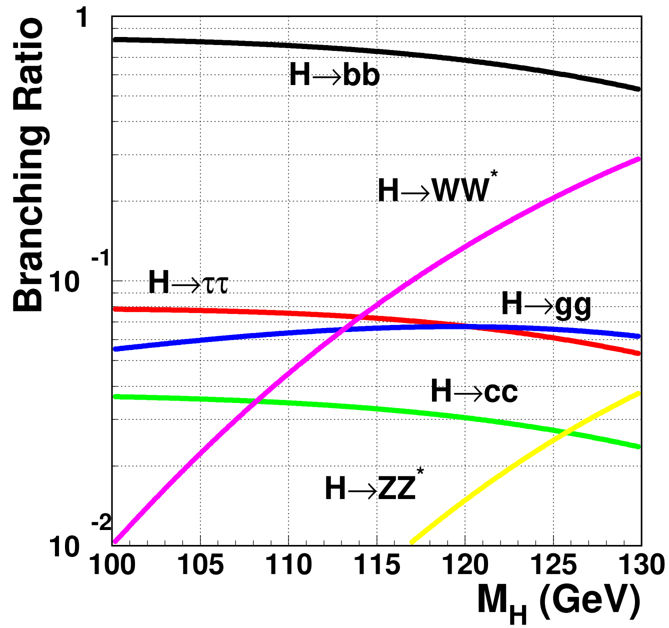
ZZ

H

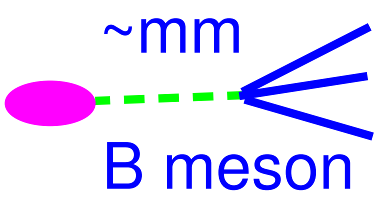
How do I recognise a Higgs ?

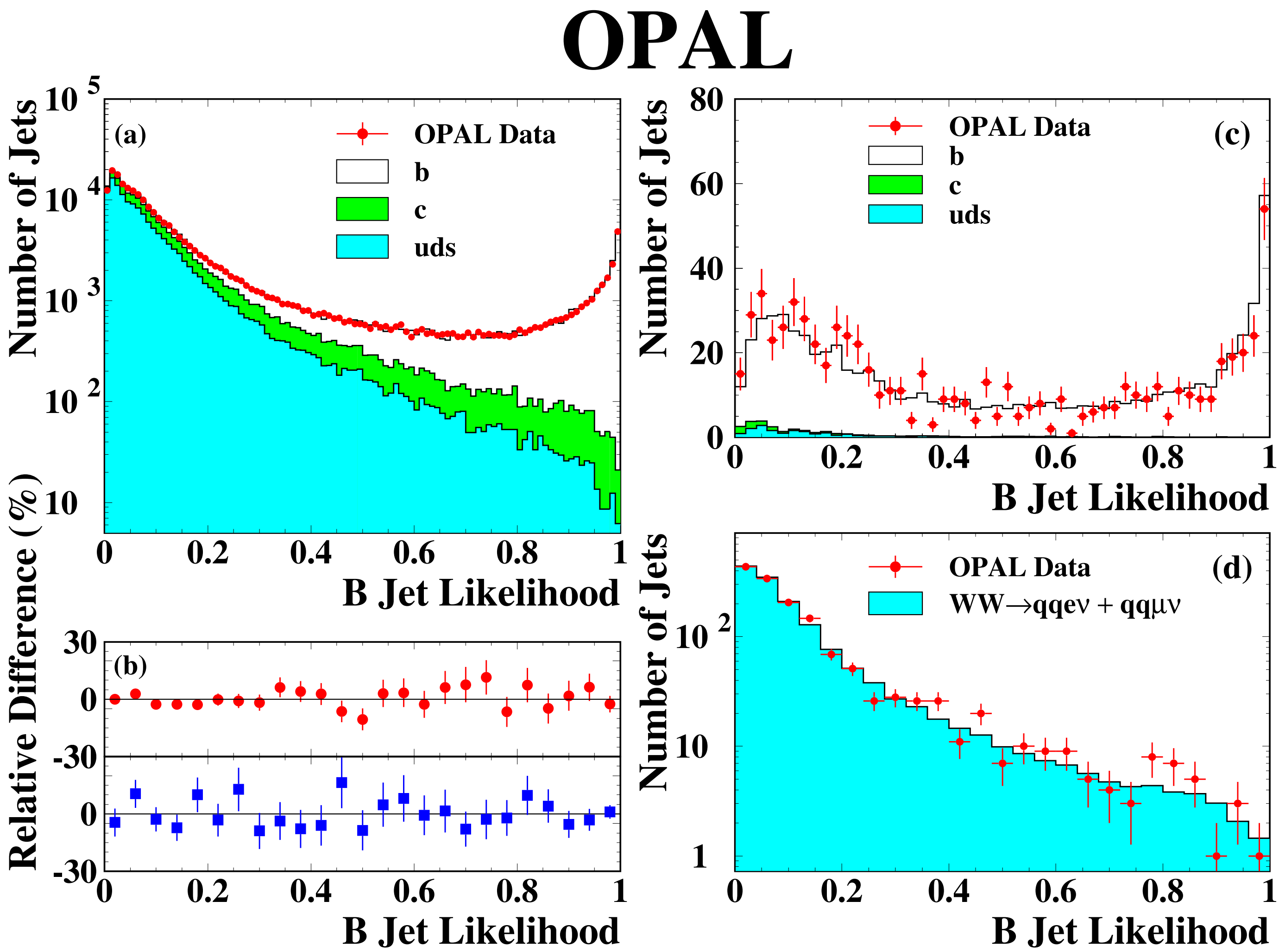
- kinematics (e.g. E_{vis})
- Identification of the final state (b-tagging)

Higgs tagging only possible on statistical basis



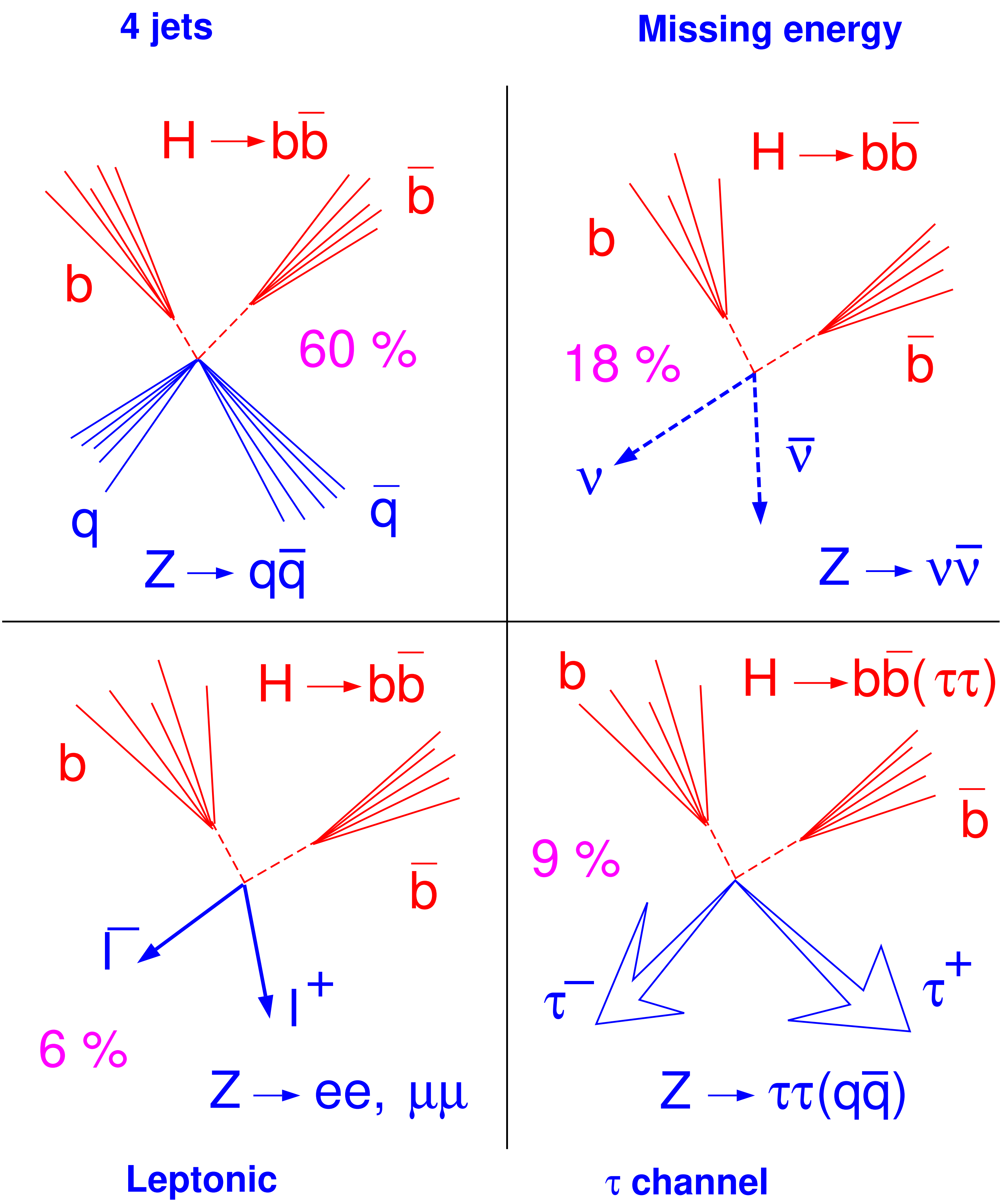
b tagging



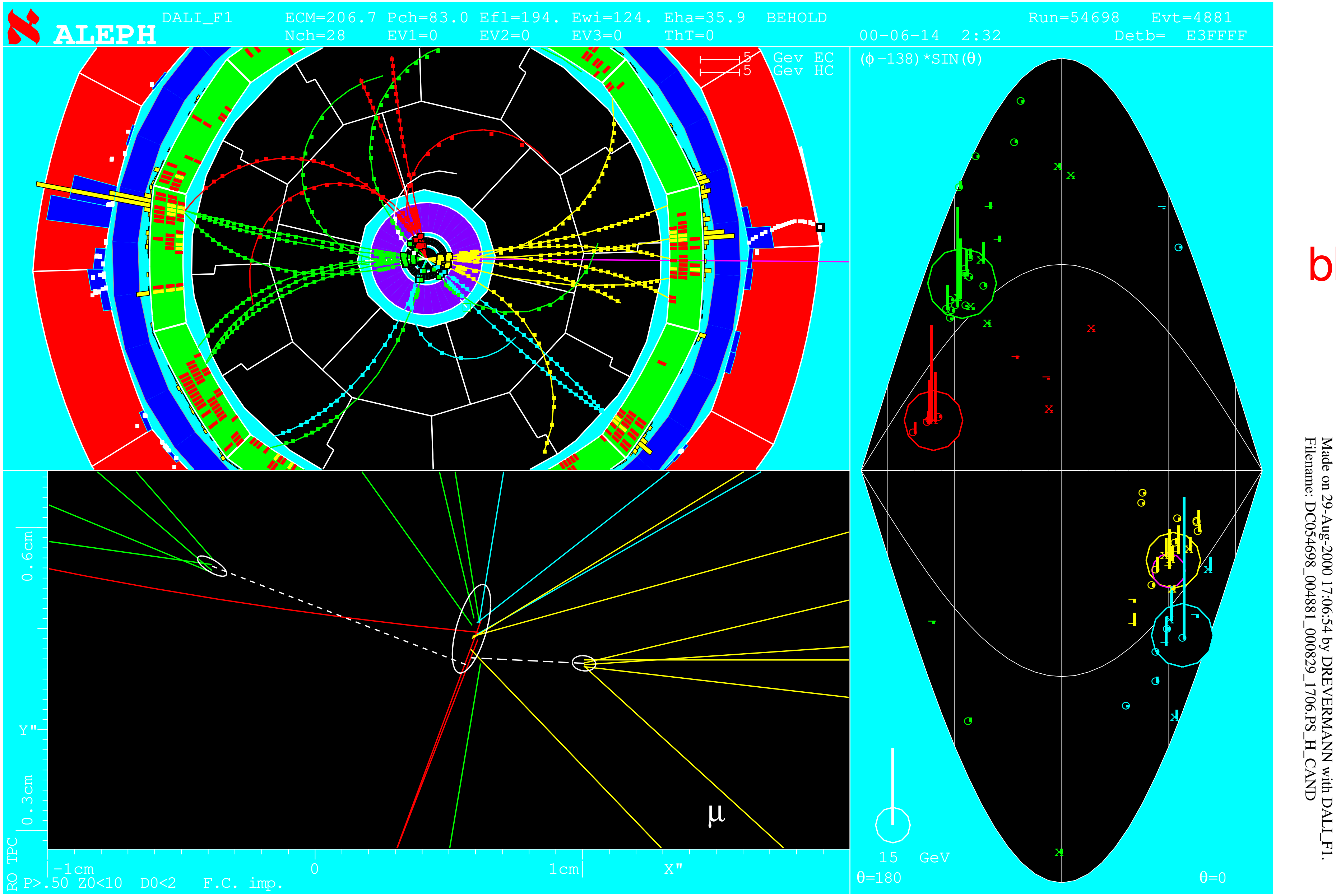


- Secundary vertices (Si tracker) (B lifetime ~ 1.5 ps)
- Tracks with large impact parameters
- Jet properties
- Leptons with large transverse momentum (b->clν)
- syst. error: b-jets ~ 5%, udsc-jets ~2%

e^+e^- -> HZ (Topologies)

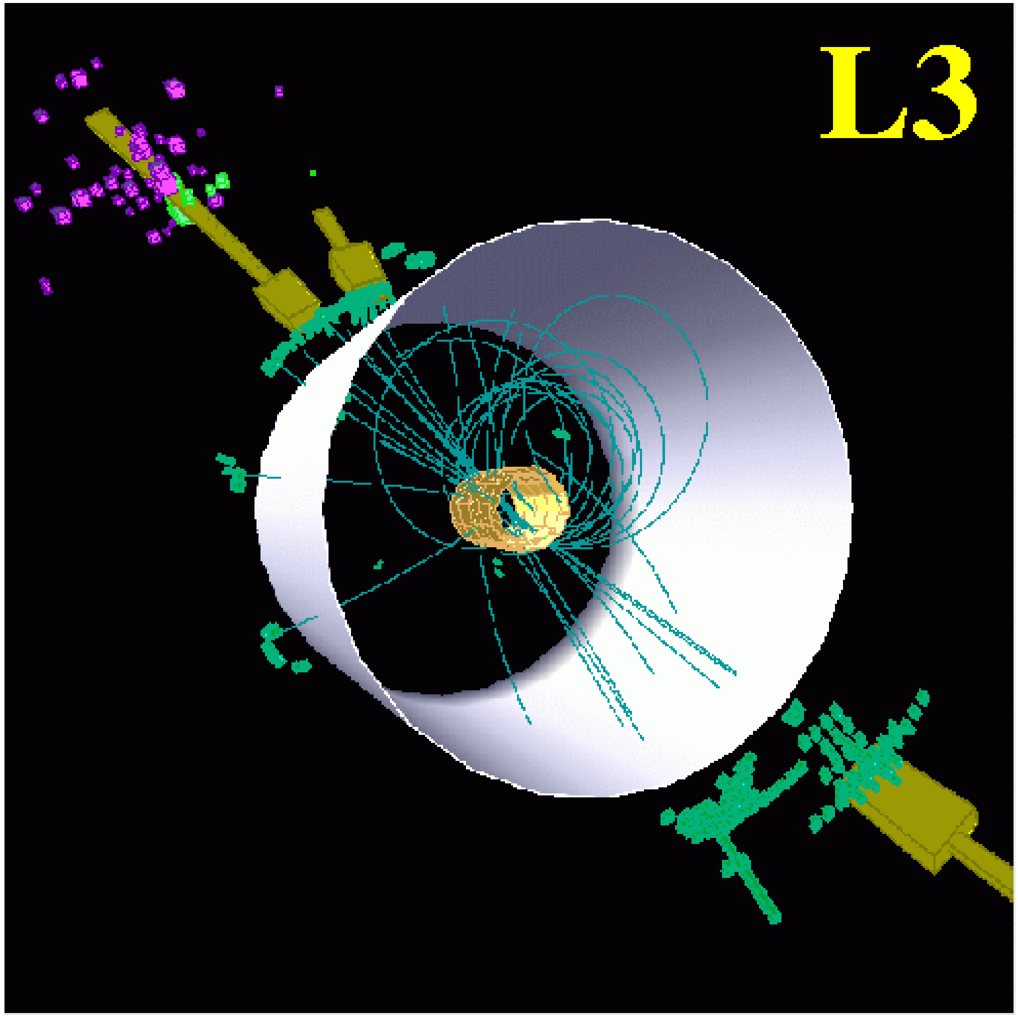


m_h^{rec}=114.3 GeV



bbqq

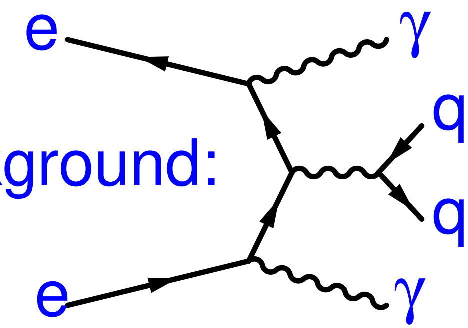
most significant Hνν candidate



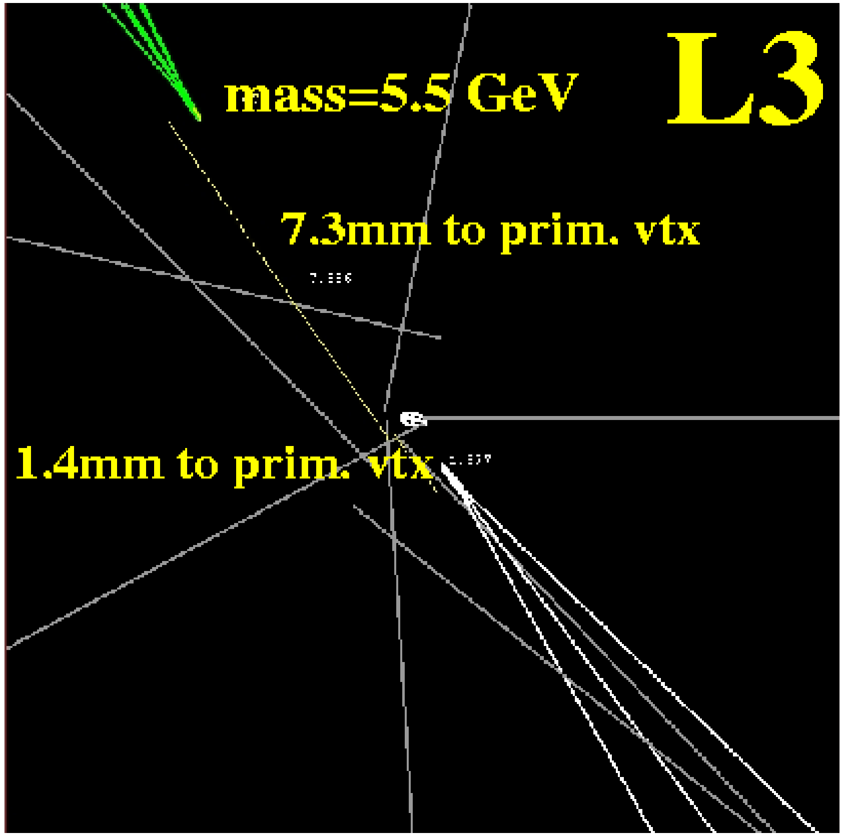
measured H mass=114.4 GeV

H mass resolution ~3 GeV

Background:



Secondary vtx's view



- **Kinematic 5C fit in the 4 jet channel:**

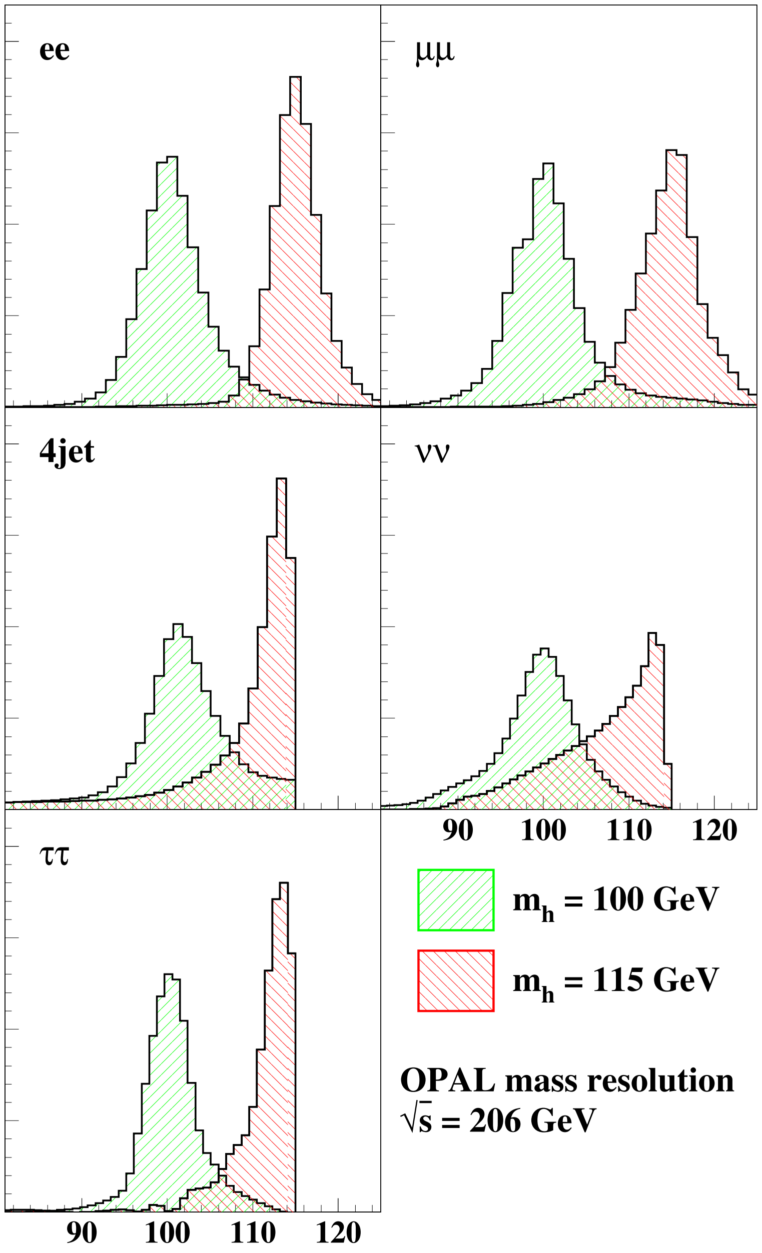
  energy/momentum conservation

  M(jet-jet)=M_Z

- **Best Jet-Jet combination determined with a likelihood method**

- **sharp kinematic edge at**

  m_H=(206-91.2) GeV~115 GeV

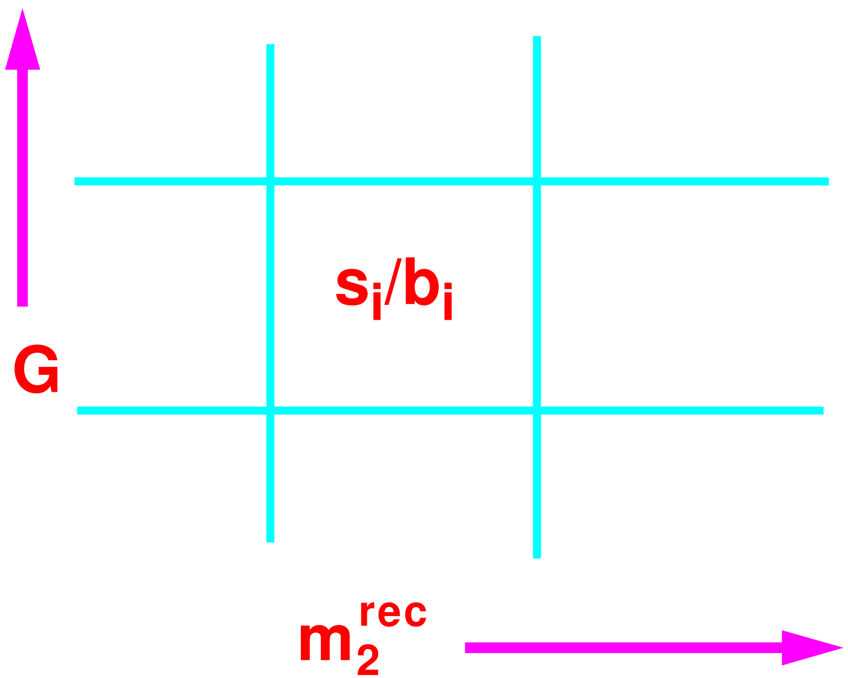


Statistics:

Goal: Combine the data of all 4 LEP experiments for all channels and all cms energies

INPUT:

-reconstructed mass m_2^{rec}
-global variable **G** (b tagging,kinematics)

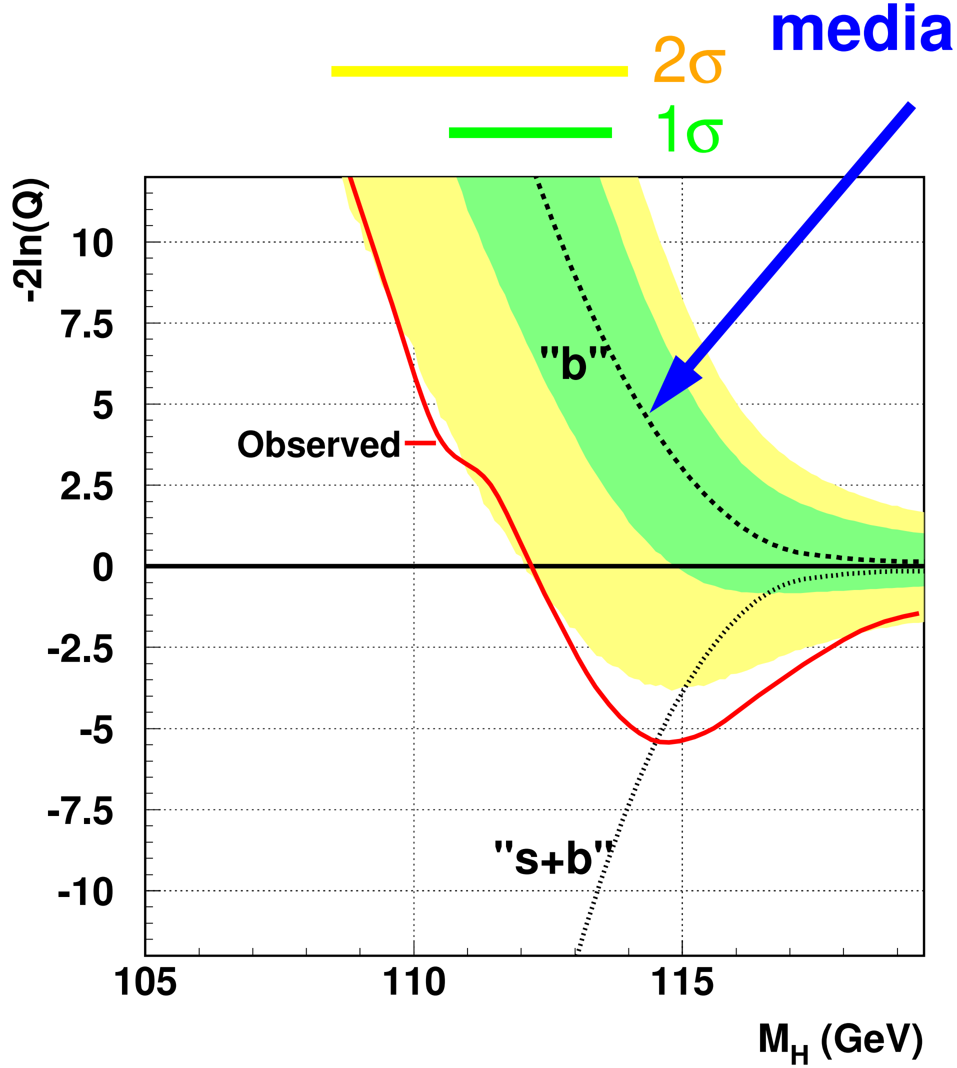


How is the event ranked with respect to the “s+b” and the “only b” Hypothesis ?

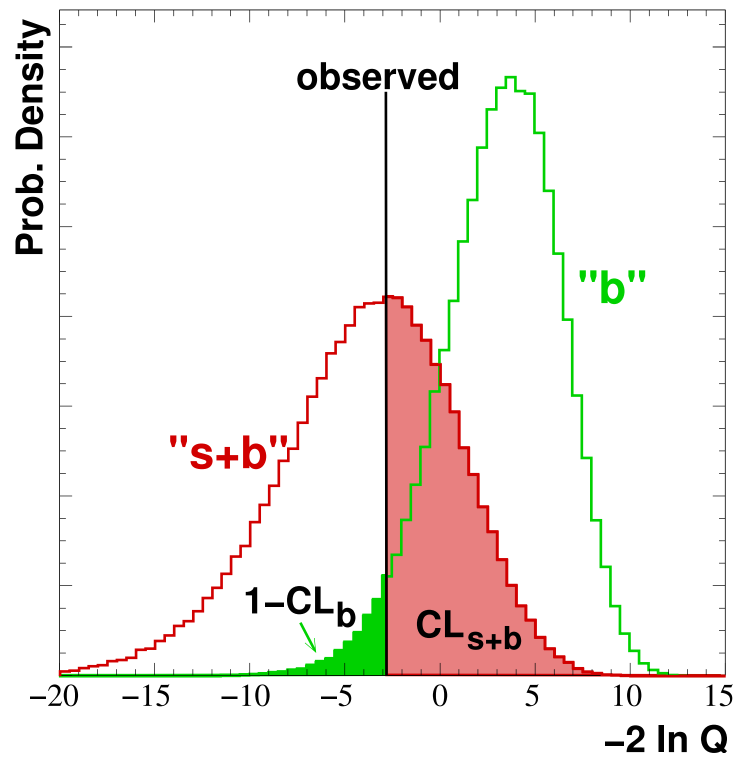
$$Q(m_H) = \frac{L(s+b)}{L(b)}$$

$$-\ln Q(m_H) = \Sigma s - \Sigma N_i \ln\left(1 + \frac{s_i(m_H)}{b_i}\right)$$

median expected

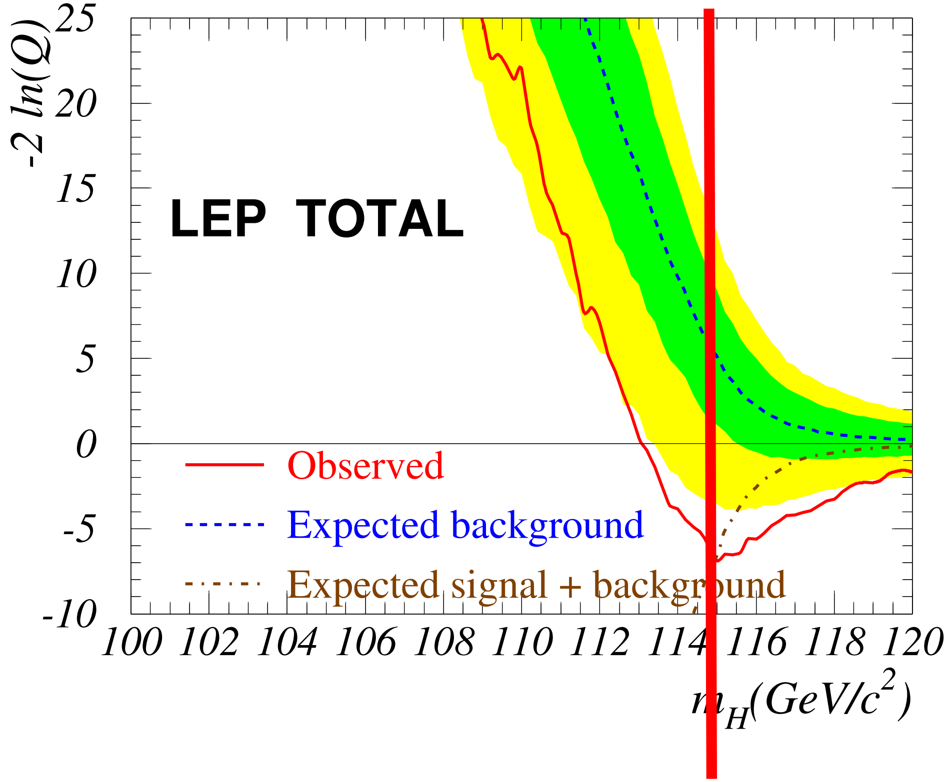


test mass

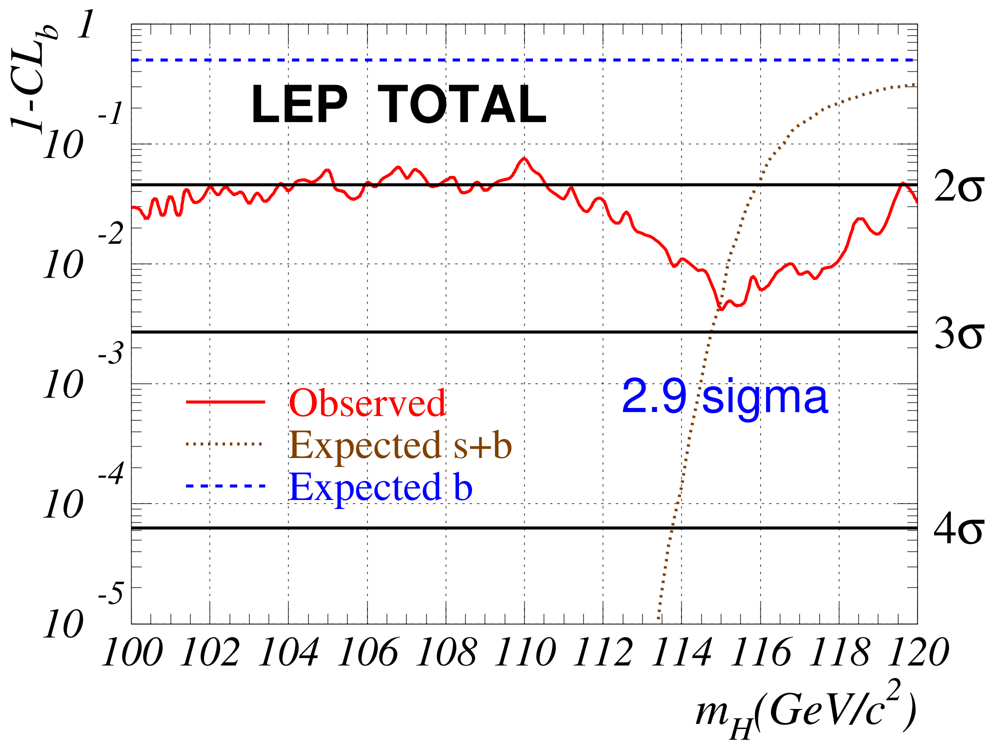


1-CL$_b$: Inconsistency with ‘b’ hypothesis

1-CL$_{S+B}$: Inconsistency with ‘s+b’ hypothesis

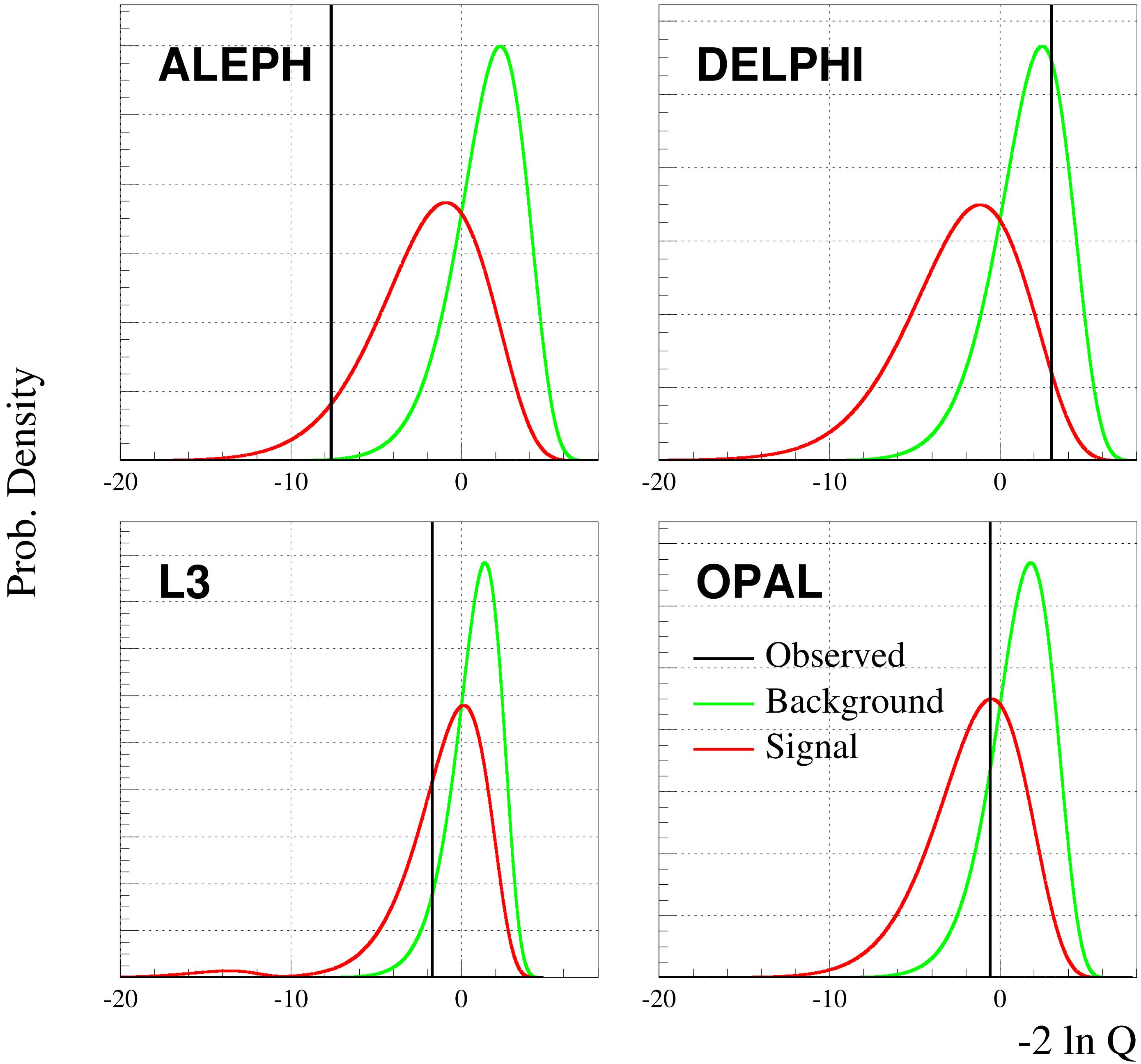


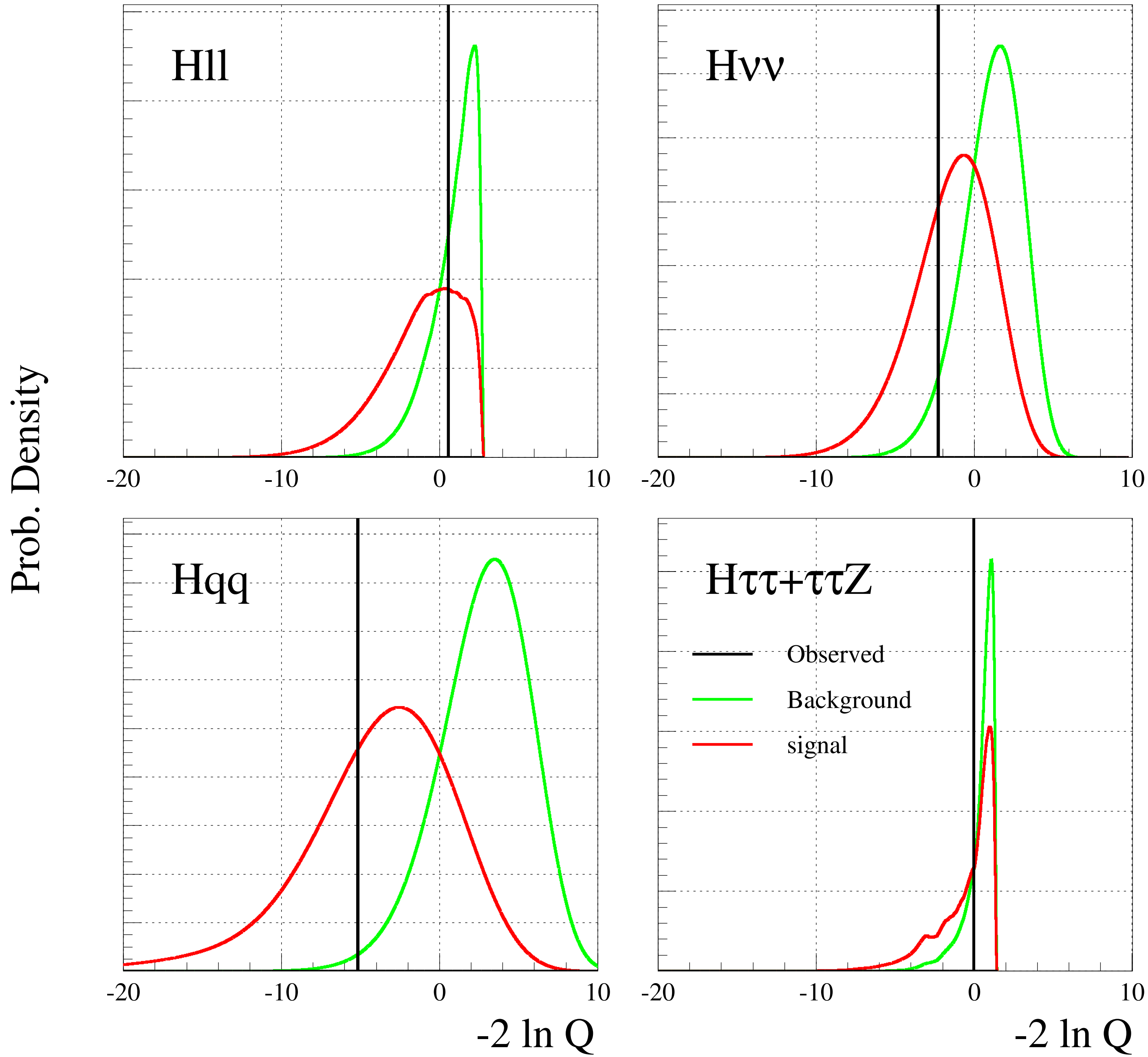
P.Igo-Kemenes, LEPC-Seminar, 3.11.2000



$$m_H = 115^{+1.3}_{-0.9}\ \text{GeV}$$

ist consistent with SM cross-section

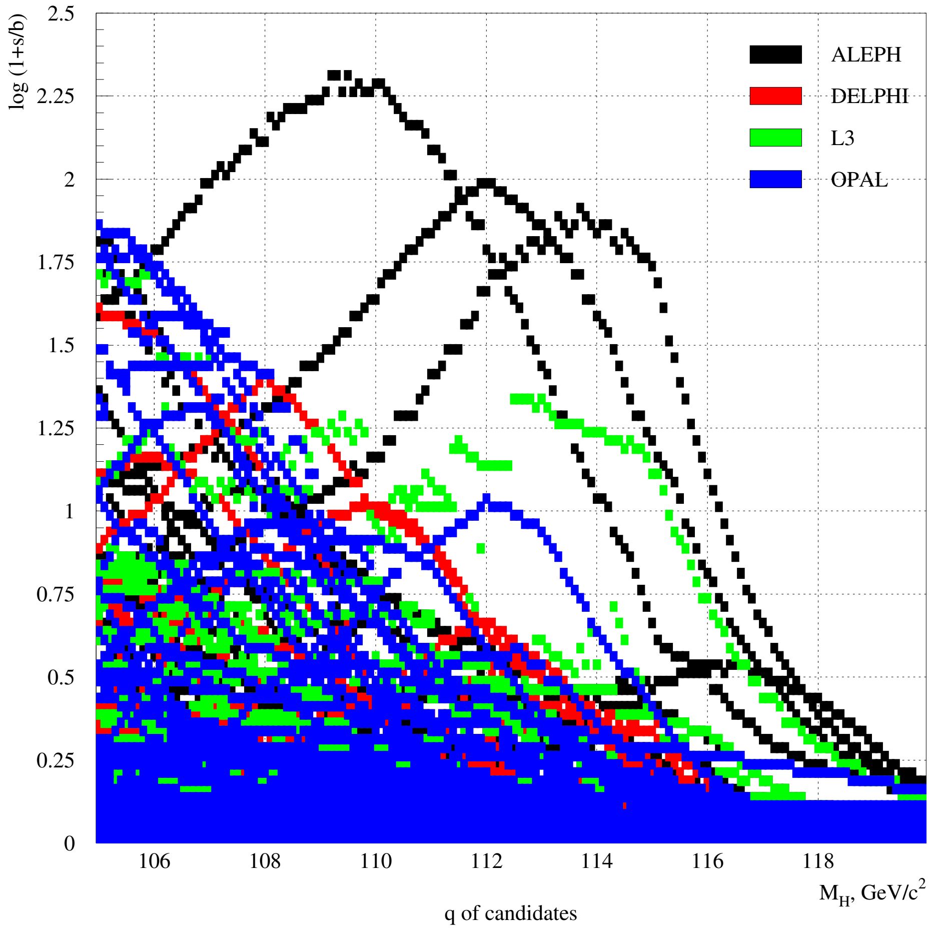

ALEPH
DELPHI
L3
OPAL
Prob. Density
-20
-10
0
Observed
Background
Signal
-2 ln Q


Prob. Density
Hll
Hνν
Hqq
Hττ+ττZ
Observed
Background
signal
-20
-10
0
10
-2 ln Q

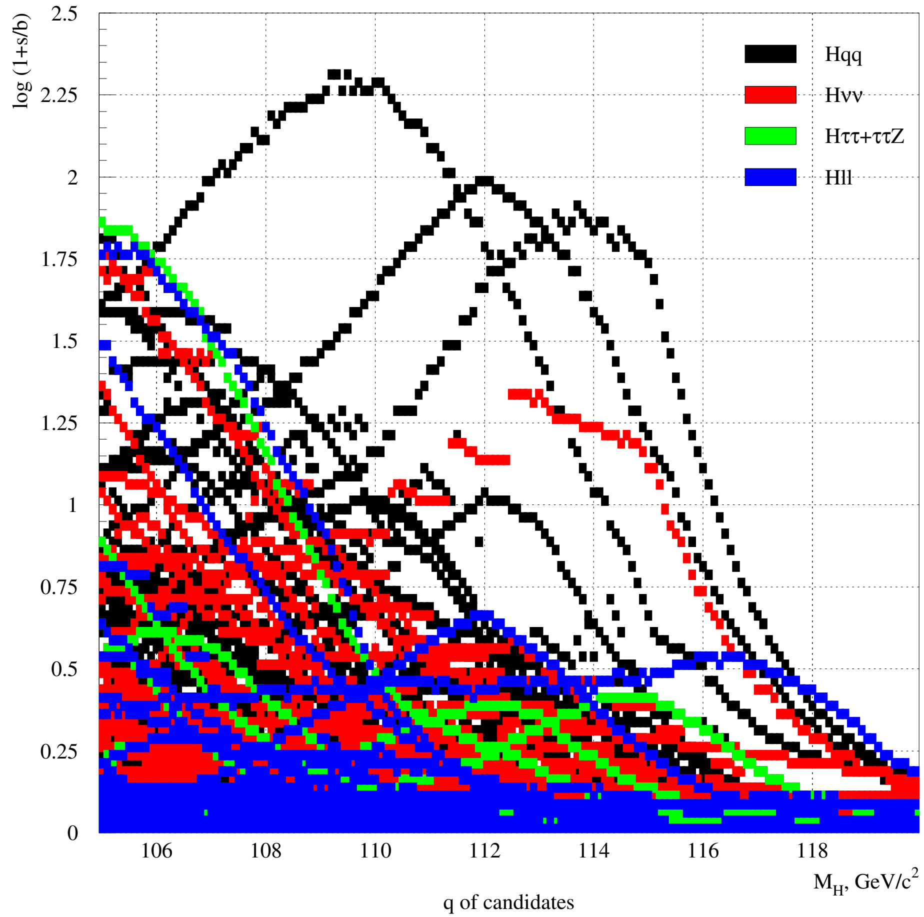
contributions from single candidates:

$-2\ln(Q) \sim \Sigma \ln(1+s_i/b_i)$ 'weight'

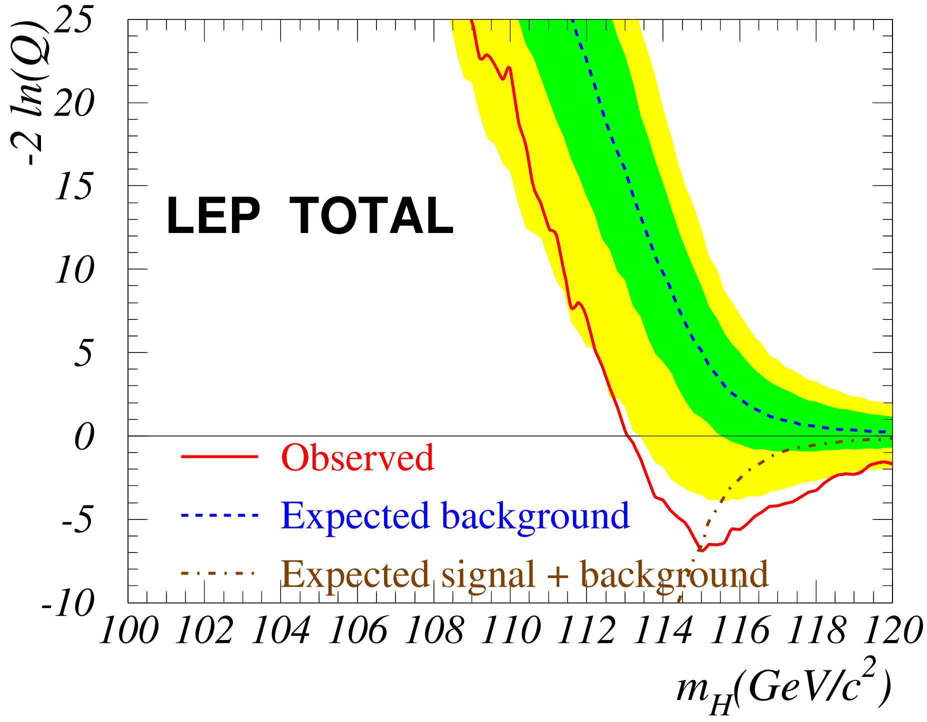
per experiment



per channel

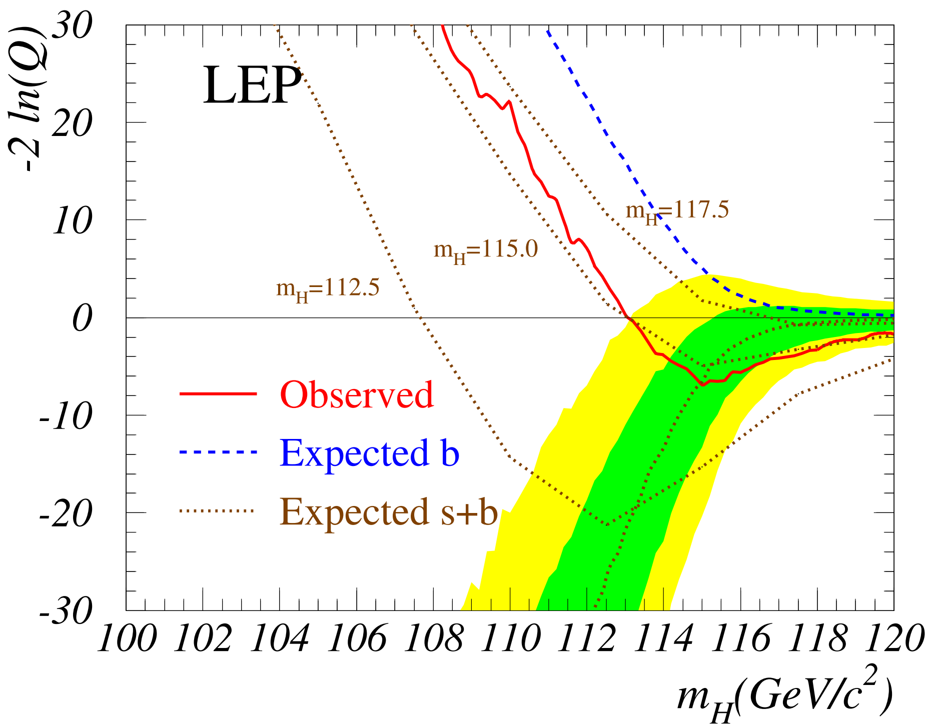


What is expected for a Higgs mass of 115 GeV ?



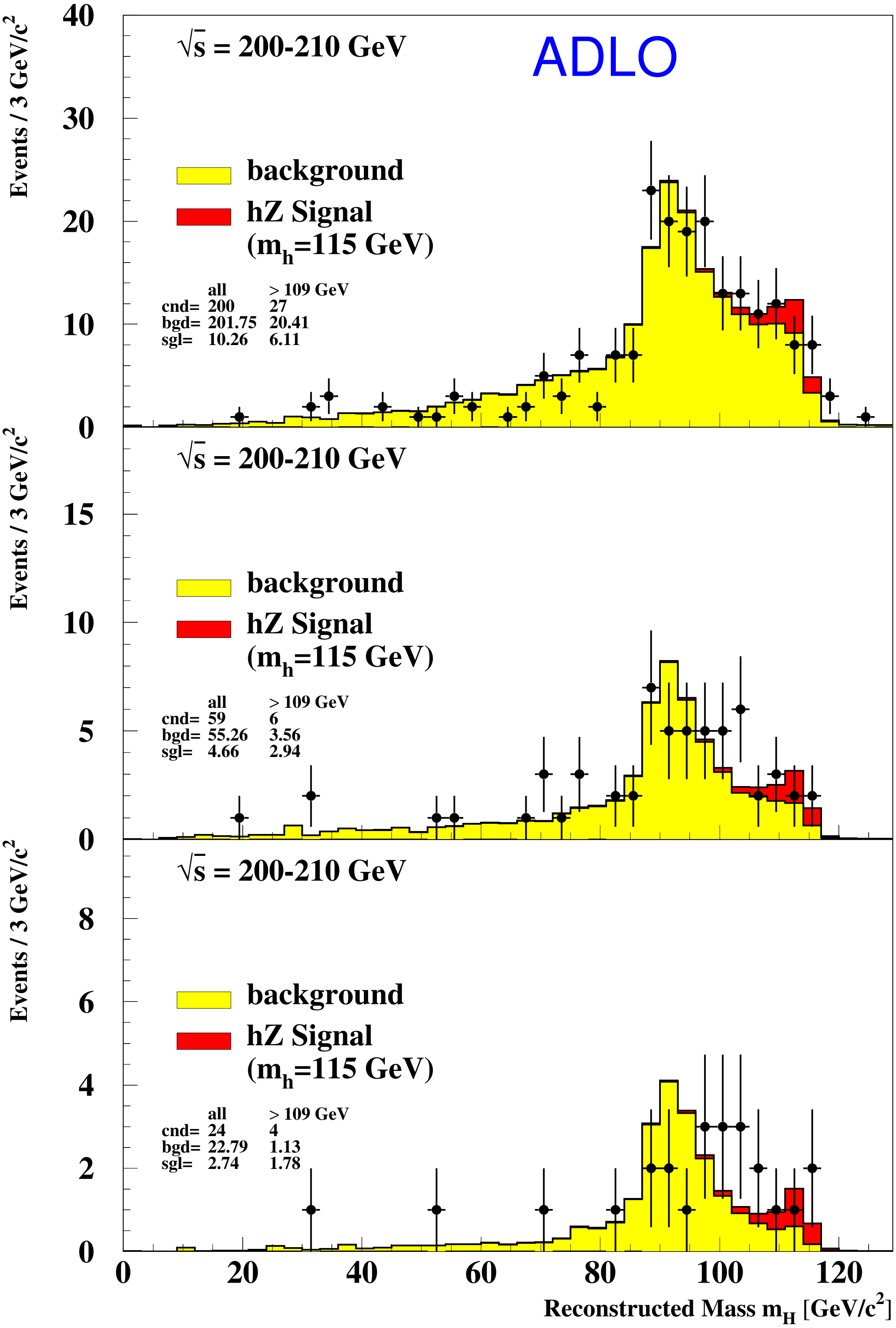
ADLO=4xDELPHI

A Higgs at 115 GeV influences smaller test masses !



Also no bias expected due to kinematic limit.

Mass distributions...



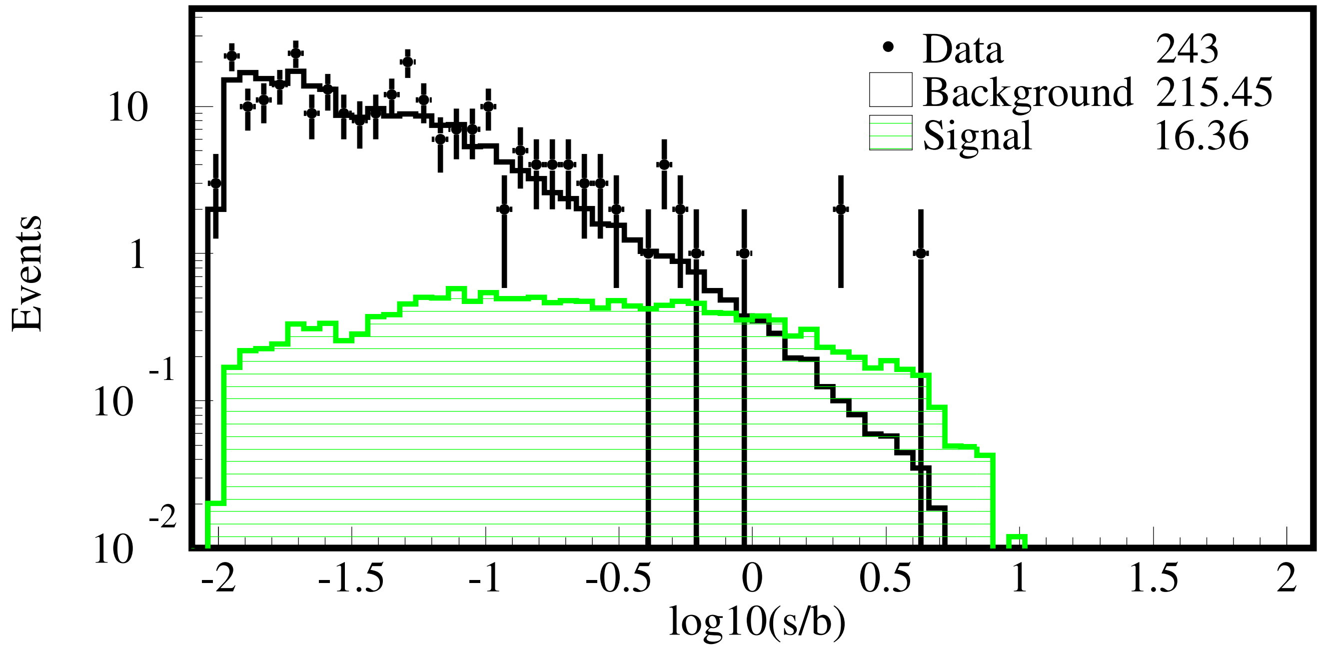
Selection:

loose

medium

hard

only contain part of the information.

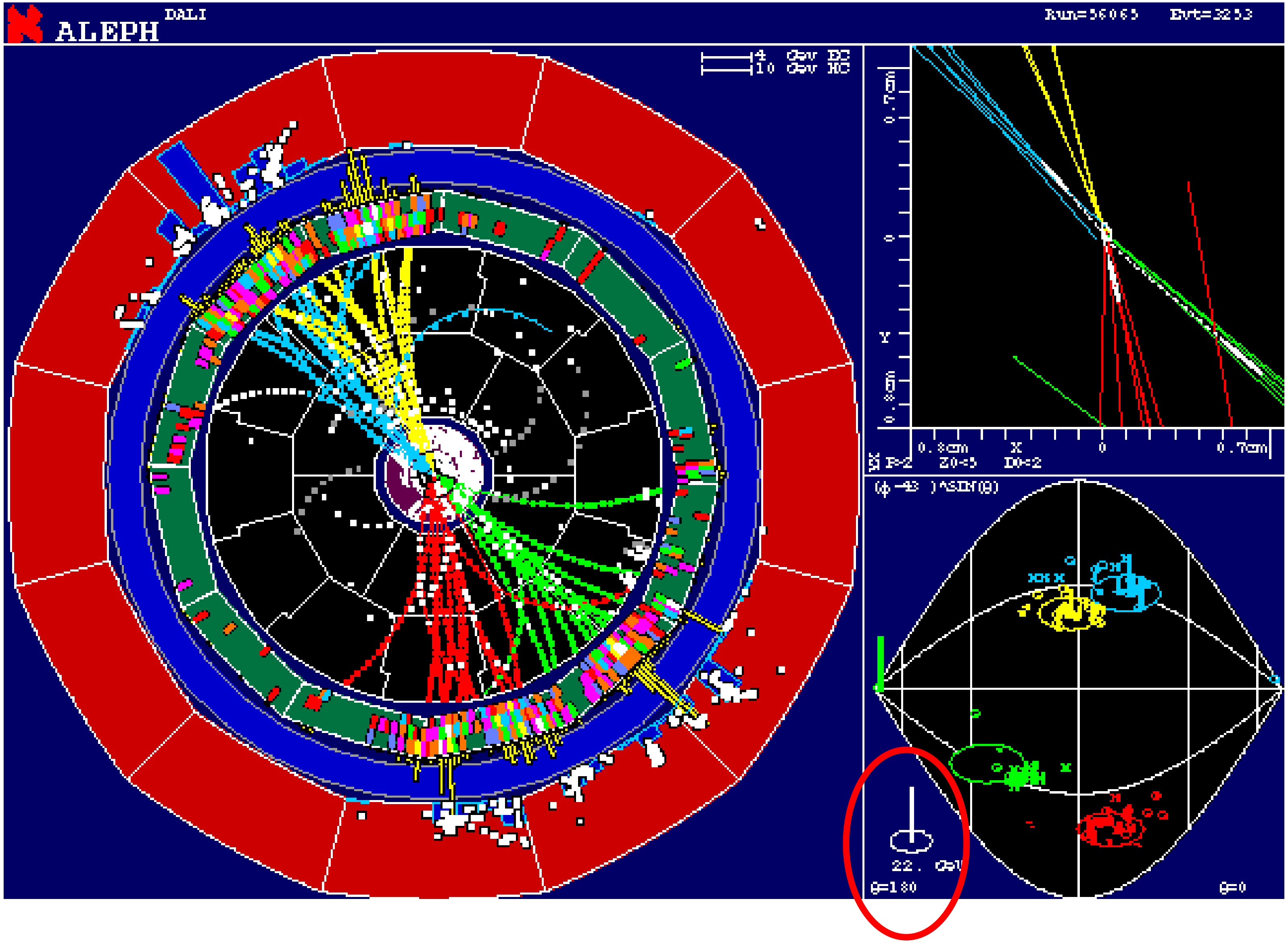


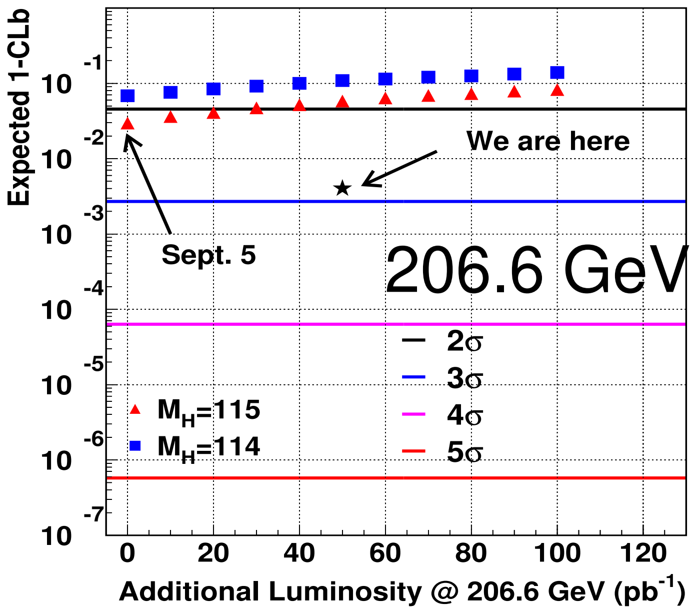
Comparable contribution to signal from events with s/b>1 und s/b<1 !

ADLO expectation for s/b>1:

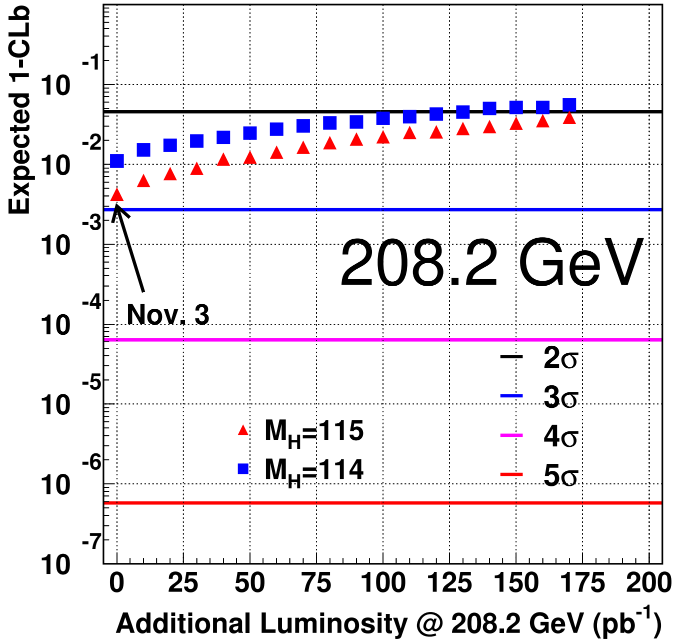
	Background	Signal
4 Jets	0.93	1.60
E_{miss}	0.30	0.46
Lepton	0.35	0.68
Tau	0.14	0.29

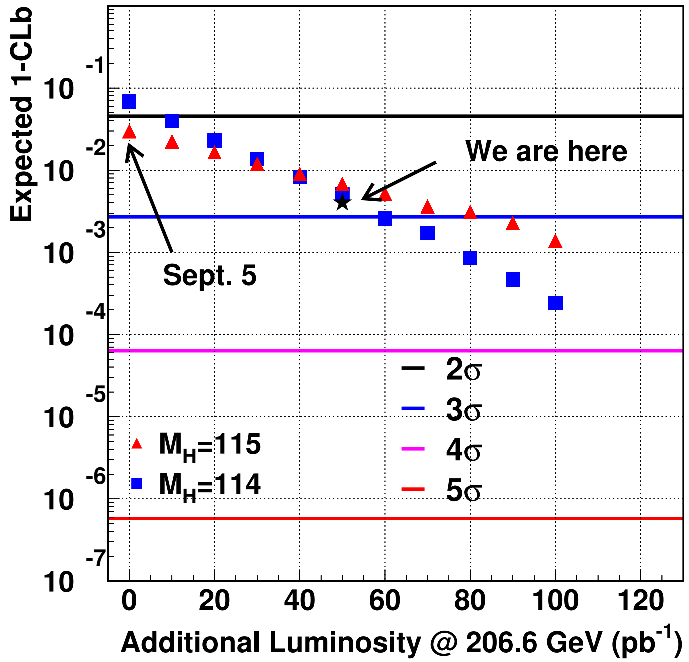
3 b tags, m_h^{rec}=112.9 GeV



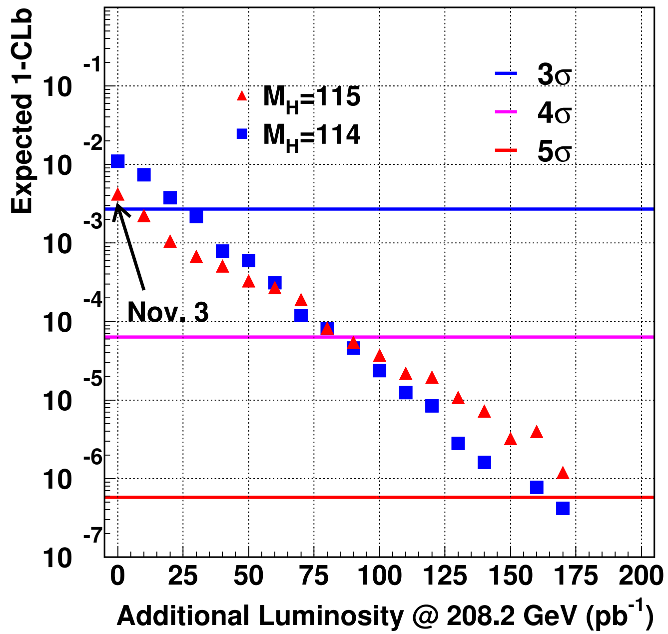


only background





signal plus background



Press Release of the Director General:

8. November 2000:

After extended consultation with the appropriate scientific committees, CERN's Director-General Luciano Maiani announced today that the LEP accelerator has been switched off for the last time.

..tantalising signs of possible new physics led to LEP's run being extended until 2 November.

At the end...LEP ..had produced a number of collisions compatible with the production of Higgs particles...These events were also compatible with other known processes.

The new data was not sufficiently conclusive to justify running LEP in 2001, which would have inevitable impact on LHC construction...

final decision by CERN council: 17. November

All 4 LEP experiments have published:

- OPAL, accepted by PLB 12 Jan 2001

  Search for the Standard Model Higgs Boson in e^+e^- collisions at sqrt(s)=192-209 GeV

- DELPHI, accepted by PLB 12 Jan 2001

  Search for the Standard Model Higgs Boson at LEP in the year 2000

- ALEPH, Phys. Lett. B495 (2000) 1

  Observation of an Excess in the Search for the Standard Model Higgs Boson at ALEPH

- L3, Phys. Lett. B495 (2000) 18

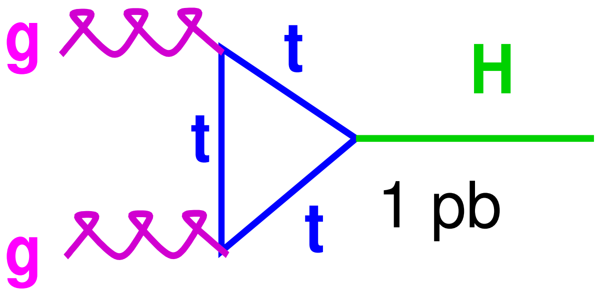
  Search for the Standard Model Higgs Boson in e^+e^- Collisions at sqrt(s) up to 202 GeV

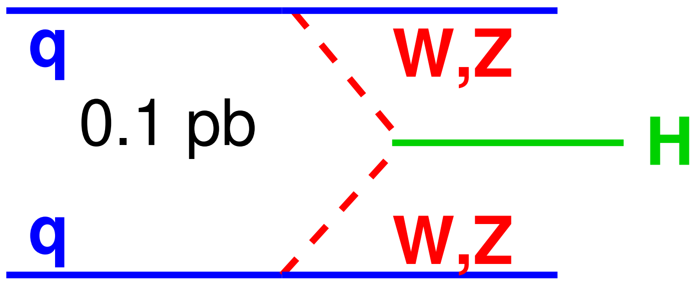
Main Changes wrt preliminary results:

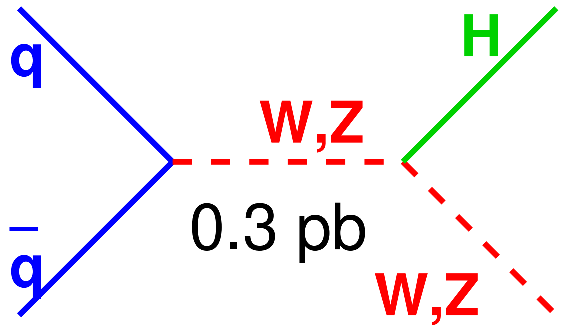
ALEPH significance slightly reduced due to additional luminosity and 2-dim correlations

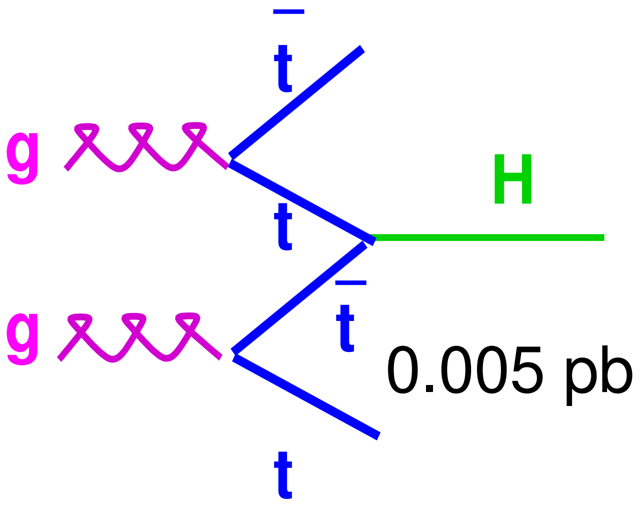
L3 has published candidates but reprocessing needed for LEP Higgs combination paper

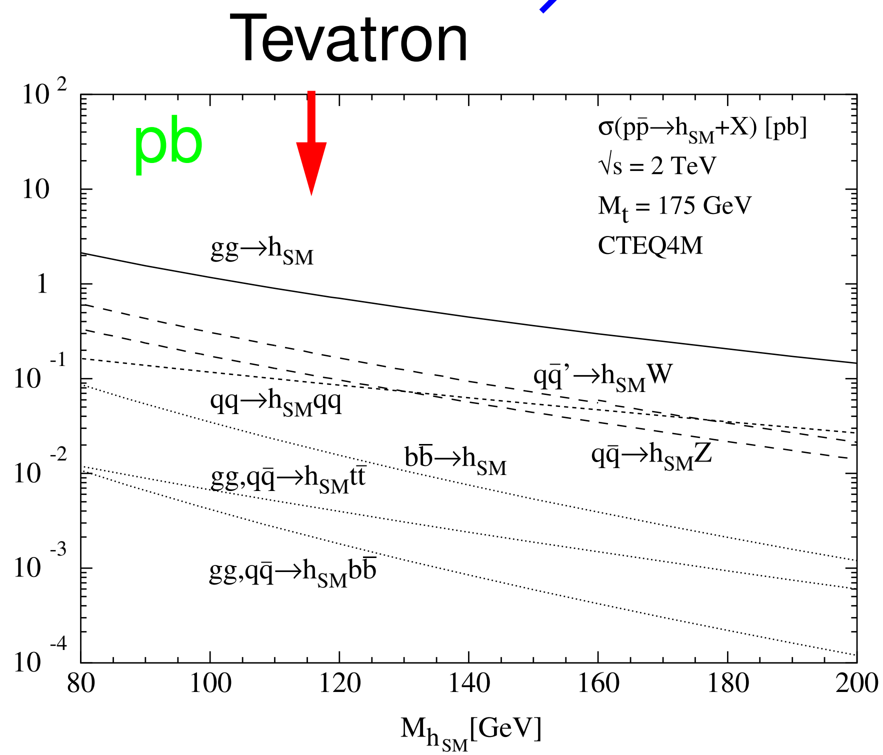
Higgs production in pp/$\overline{p}$p scattering:



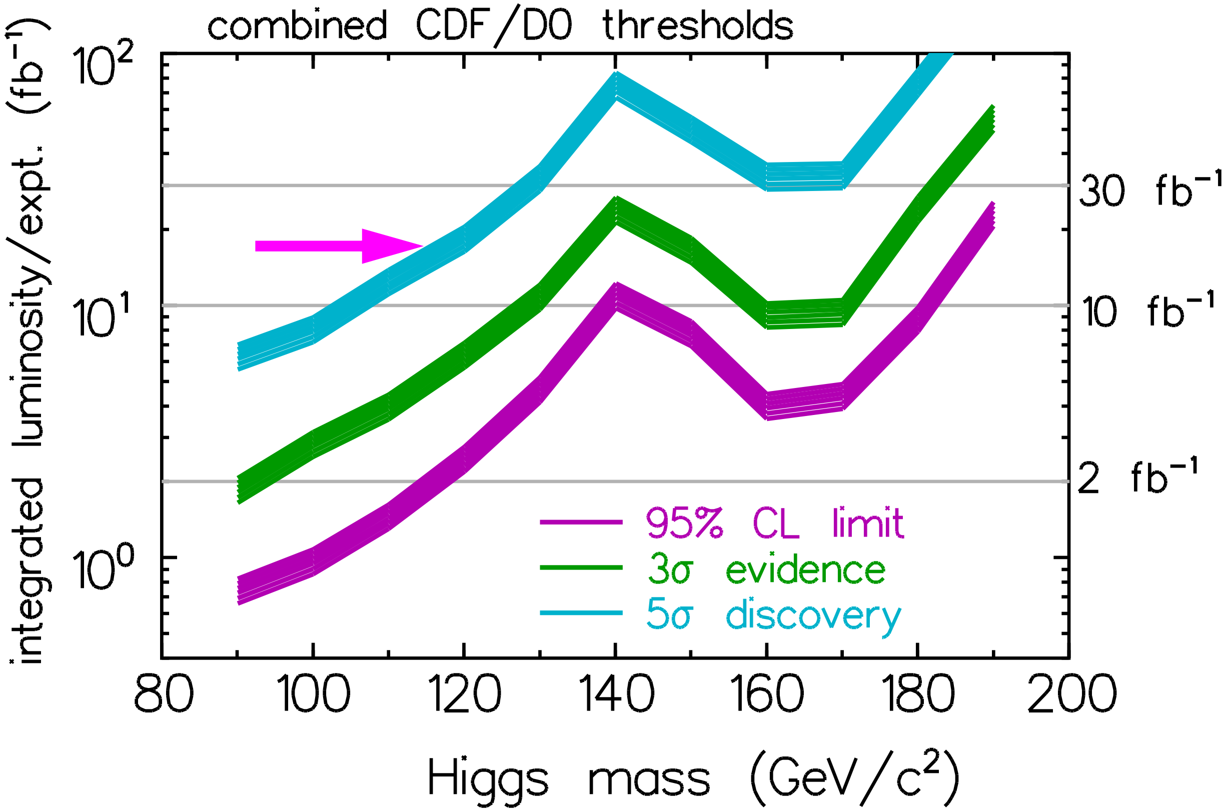








Discovery of the Higgs boson at the Tevatron ?

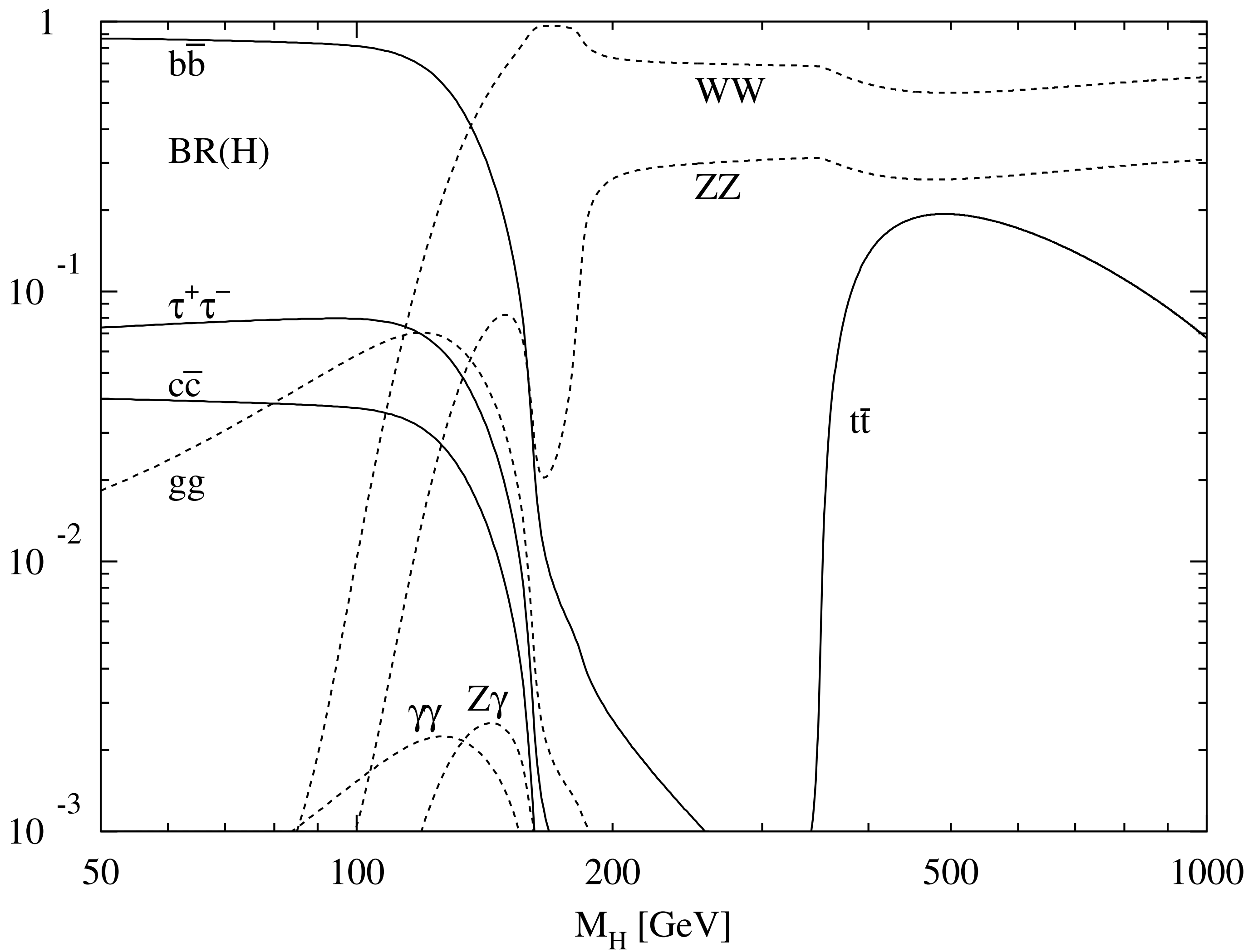


expected luminosity:

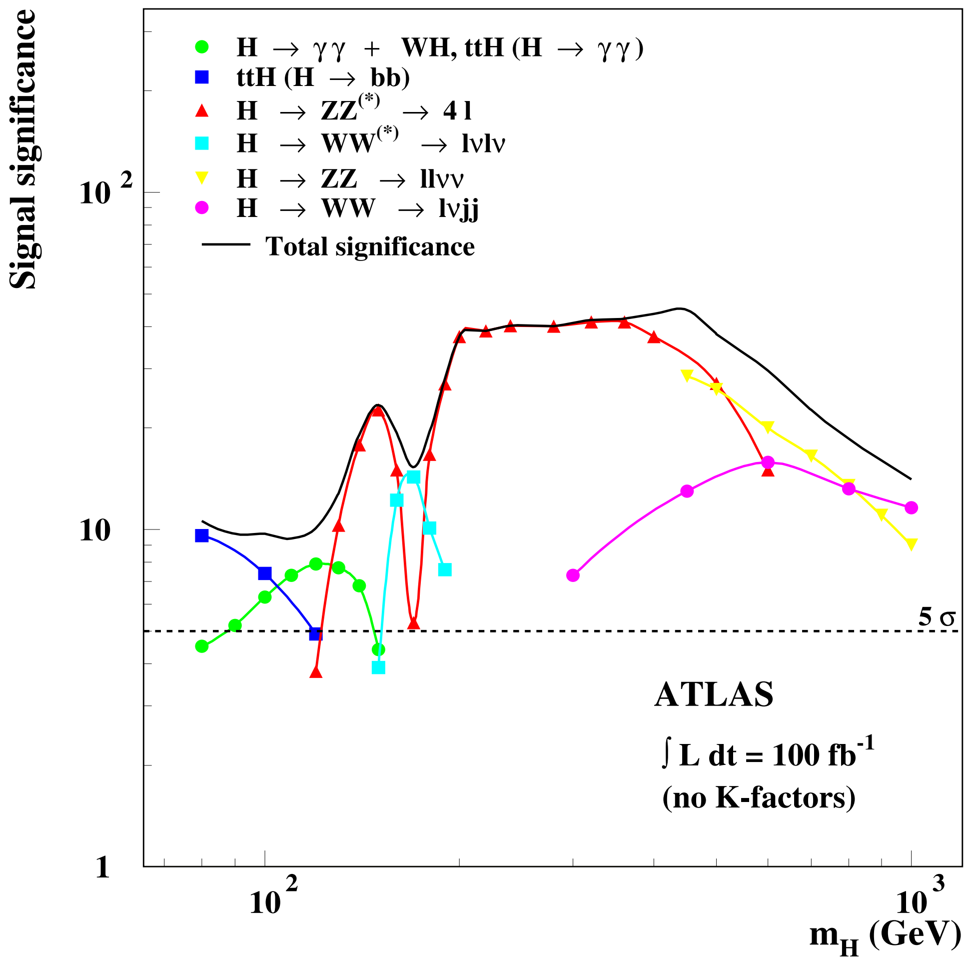
(S. Holmes, ICFA seminar 1999):

- End of 2006: ~11 fb-1
- End of 2007: ~15 fb-1

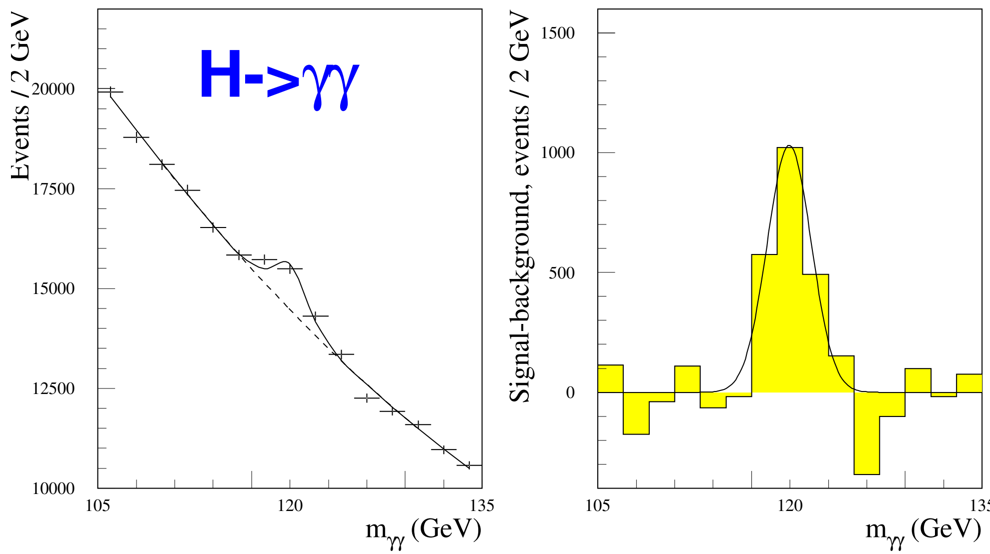
Branching ratios:



Discovery of the Higgs boson at the LHC ?



100fb^{-1}



2005: pilot run

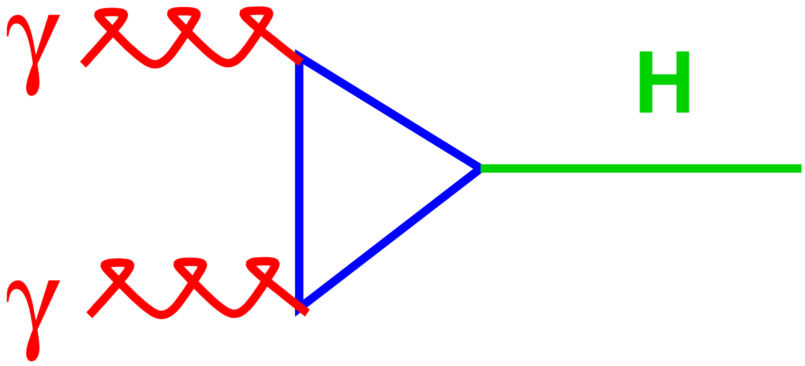
2006: ~1 fb^{-1}

2007: ~10 fb^{-1}

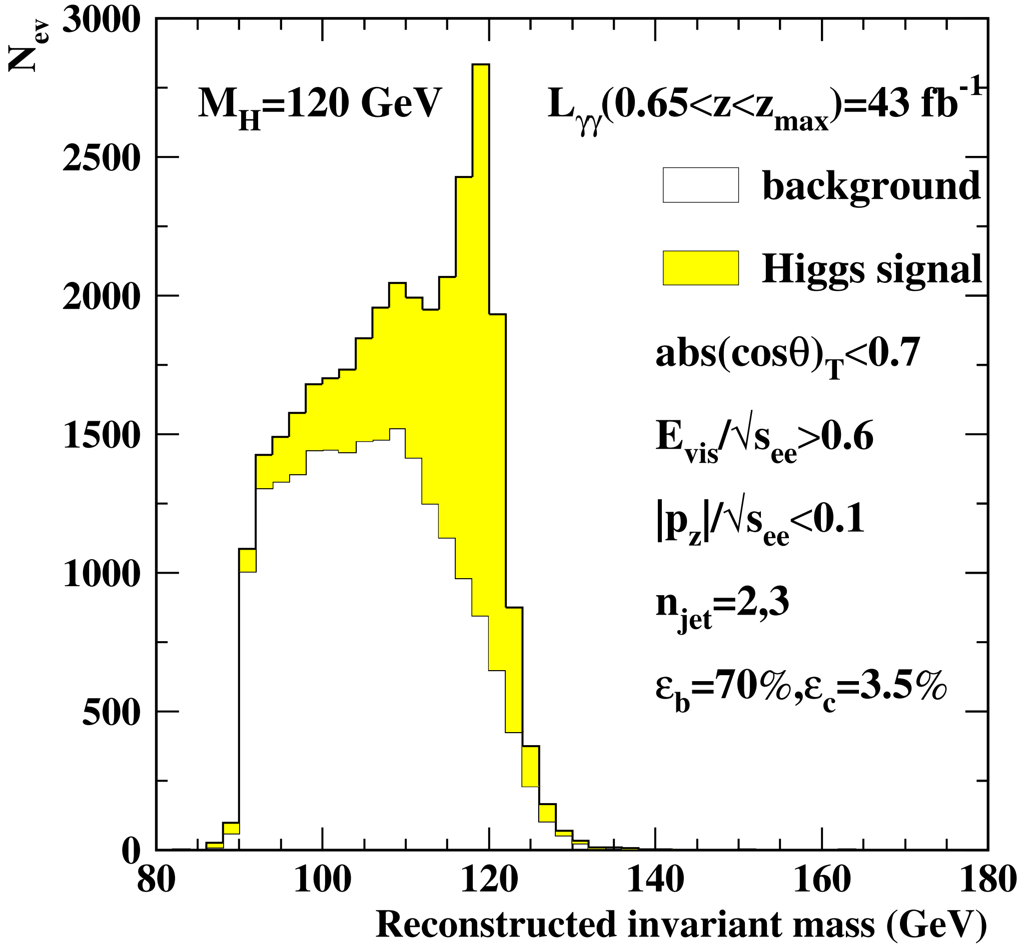
ATLAS+CMS: 5 σ for 10 fb^{-1}/expt.

Light Higgs at the Compton Collider:

G. Jikia, SSR, Nucl.Phys.Proc.Suppl.82 (2000) 373



any massive & charged particle in the loop



~2 % precision on two-photon width

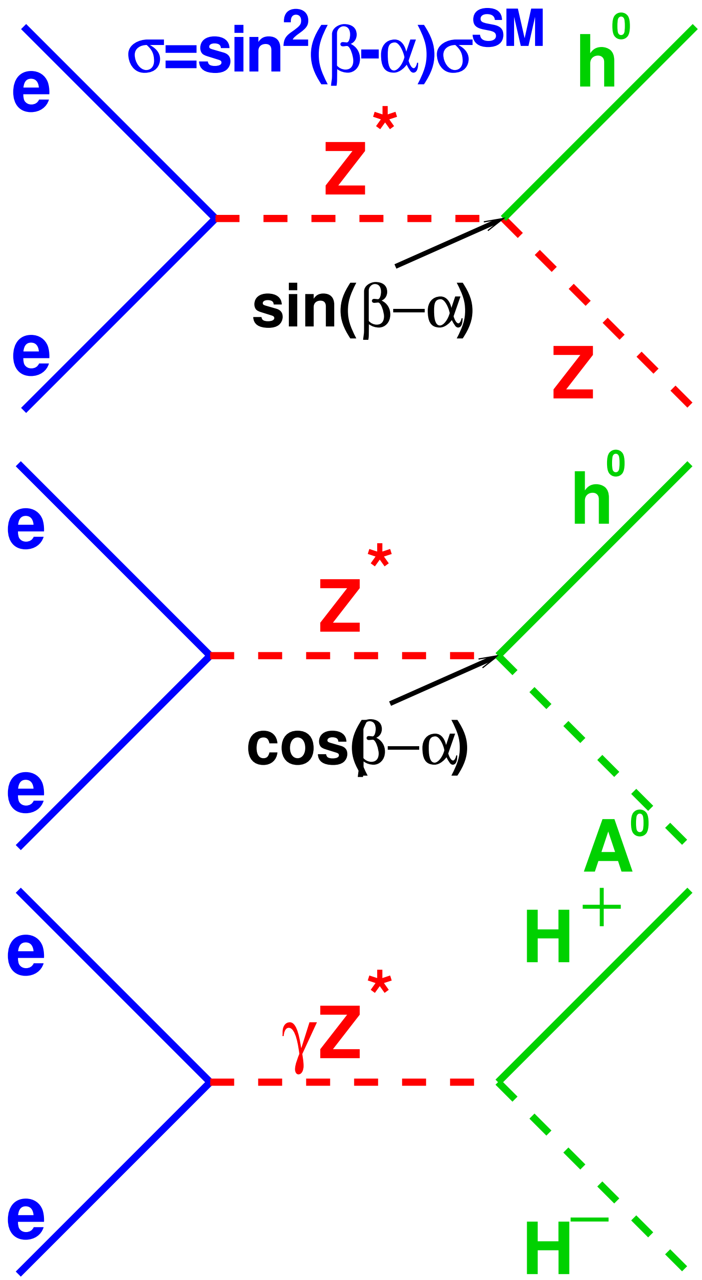
MSSM Higgs bosons:

Two Higgs doublets=>
5 Higgs particles

- h_0: light CP-event Higgs
- H_0: heavy CP-odd Higgs
- A_0: CP-odd Higgs
- H^+,H^-: charged Higgs

m_{h0}<~135 GeV

tan $\beta = v_1/v_2$ (vacuum expectation value)
α: mixing parameter

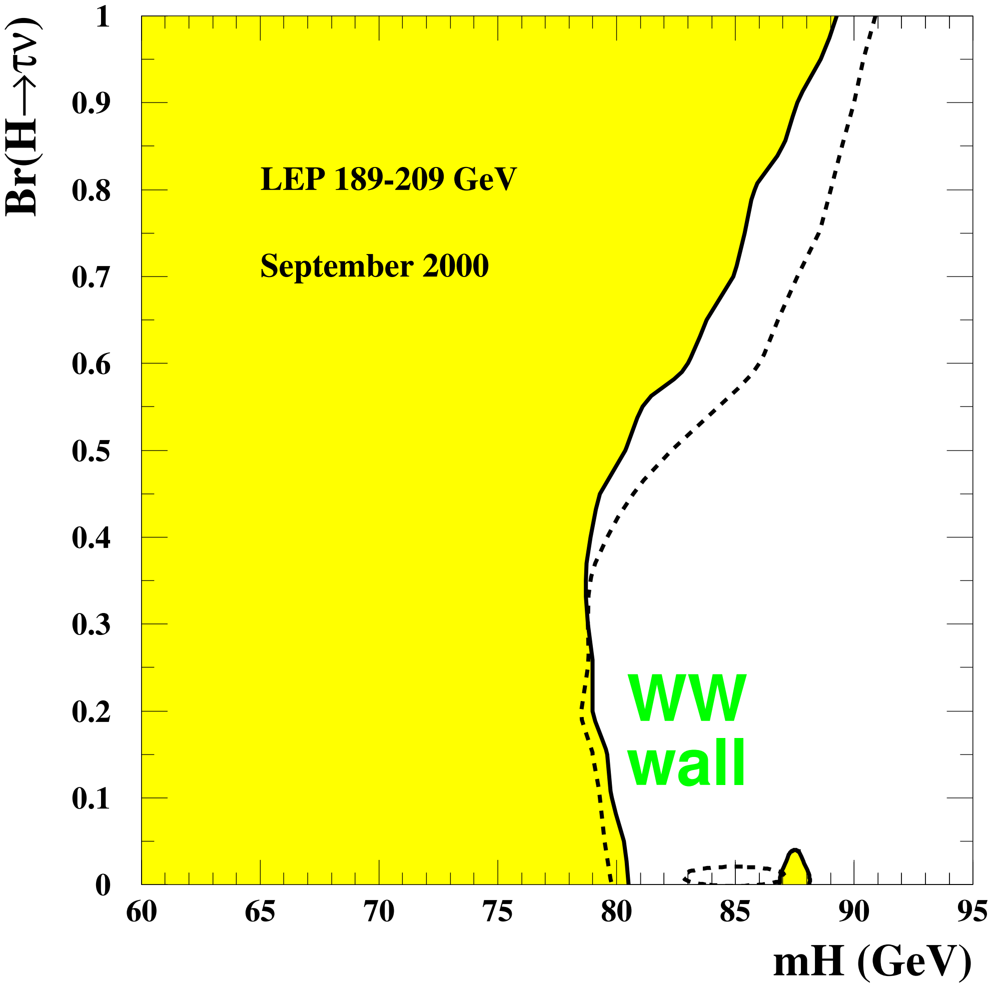


$BR(H^+ \to \tau^+\nu_\tau) + BR(H^+ \to cs) = 1$

$\tau\nu\tau\nu$

$\tau\nu$cs

cscs



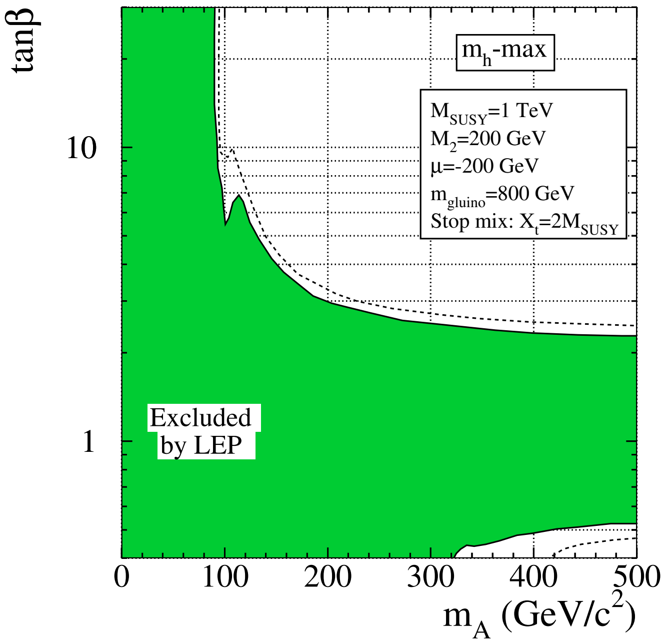
2 leptons + E_{miss}

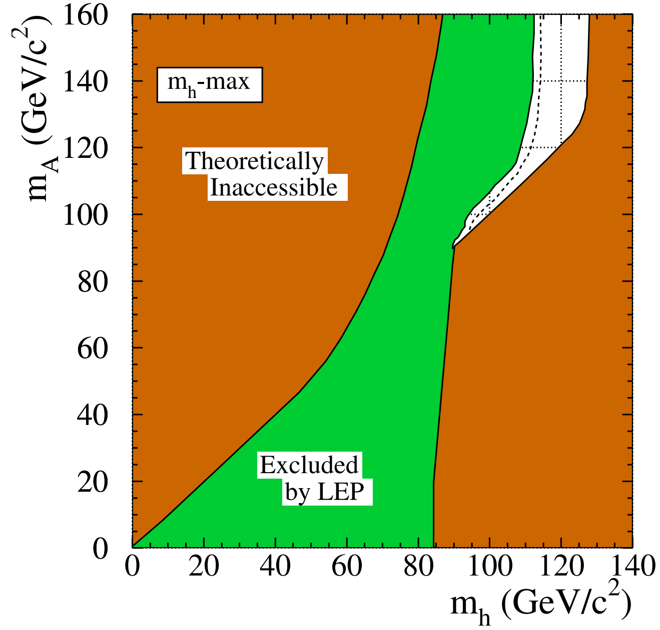
2 jets, 1 lepton + E_{miss}

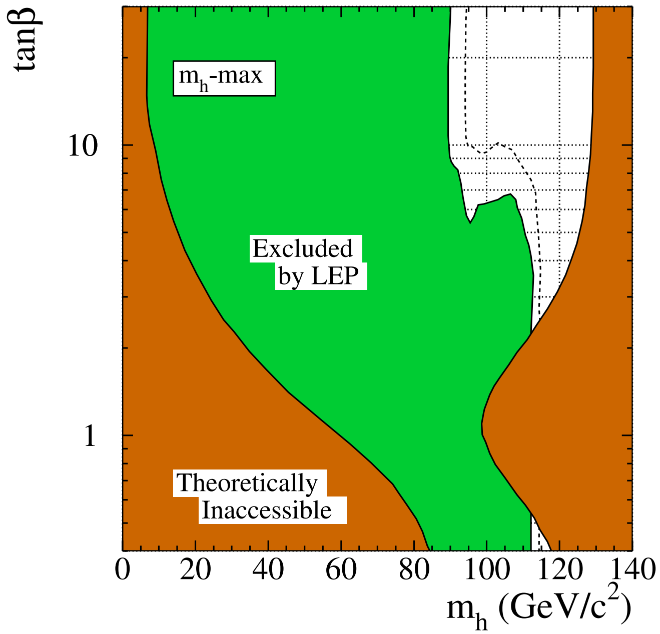
4 jets

L3 discrepancy around 70 GeV under investigation..

Max-m_h Scenario..







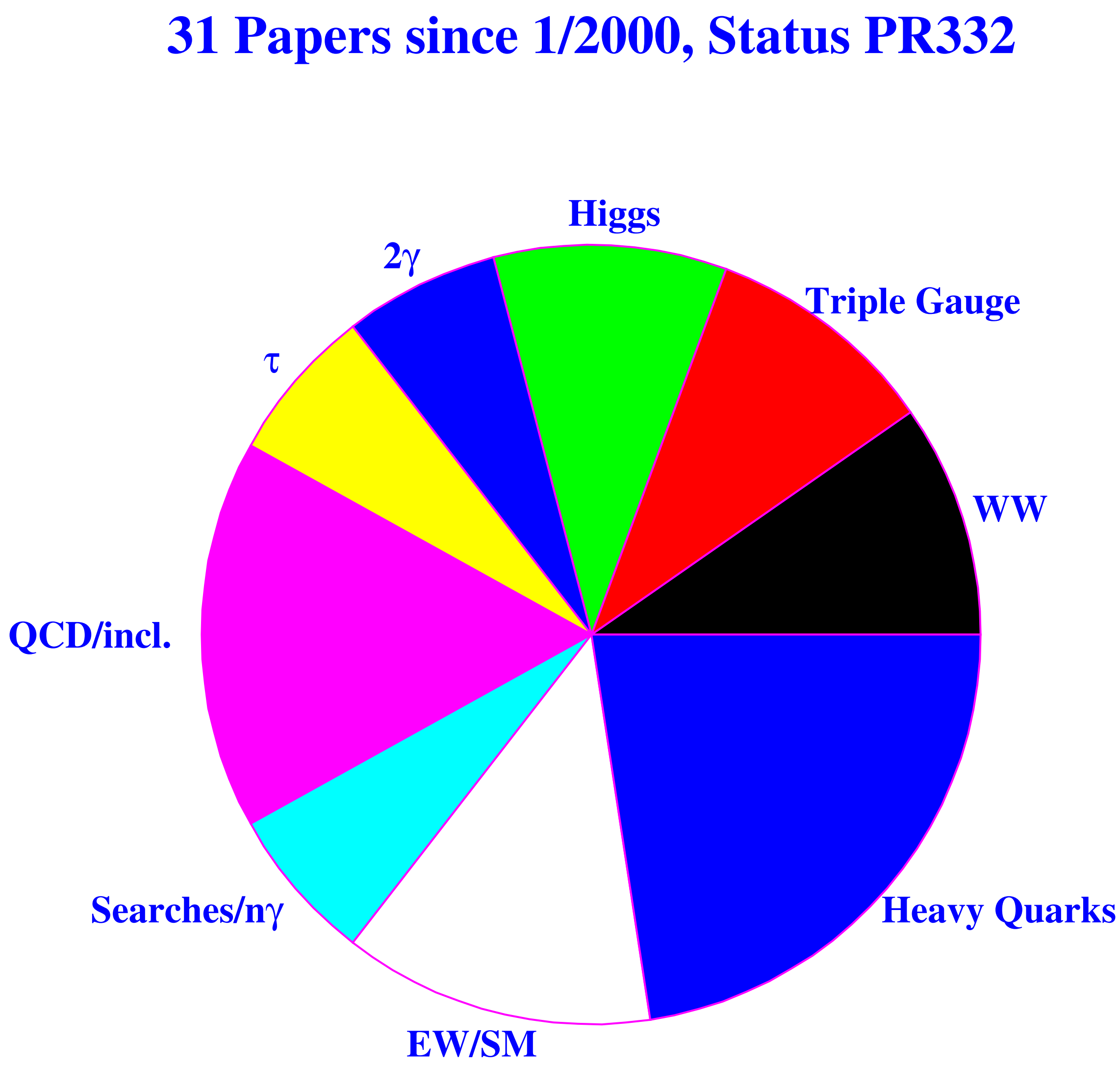
m_h>89.9 GeV (expected 93.8 GeV)

m_A>90.5 GeV (expected 94.1 GeV)

0.52<tanβ<2.25

also studied:
“invisible”, fermiophobic...

Not everything is Higgs....



Summary

- LEP observes a 2.9 σ indication for the production of a Standard Model Higgs bosons with a mass of about 115 GeV.
- 3/4 experiments (ALO) and 2/4 channels (4 jet, E_{miss}) are “s+b” like
- All four LEP experiments have published their results before Christmas. The LEP Higgs publication is expected in February.
- The race between the Tevatron and LHC has started, confirming or disproving the LEP observation until 2006/2007.
- Higgs properties or alternative scenarios without Higgs can be tested at TESLA (also interesting for $\gamma\gamma$ mode)