Highlights of Higgs Searches at LEP2

Arnulf Quadt

Seminar February 2001

- **Higgs in the Standard Model**
- **SM-Higgs search**
- **MSSM-Higgs search**
- **‘Exotica’**
- **Outlook**

Higgs Mechanism ... SM

Higgs Field	El.magn. field	Weak fields
Complex scalar doublet (4 degrees of freedom)	$U(1)$ symm.	$SU(2)_L$ symm.
Φ^+ Φ^0	B	W^+ W^0 W^-

Higgs mechanism : 3 degrees of freedom from Higgs fields

$\Rightarrow$ Longitudinal polarization of W^+, W^-, Z^0

$\Downarrow$

Massless γ, massive $W^\pm$ and Z^0 bosons

Remaining degree of freedom ...

H^0 neutral scalar boson

Higgs boson mass m_H ... free parameter ... if known

Higgs phenomenology (production/decay) fully

determined

Prof. Peter Higgs

Oct. 1964

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BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
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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 $\varphi_1(x)=0$, $\varphi_2(x)=\varphi_0$:

$$\partial^\mu\{\partial_\mu(\Delta\varphi_1)-e\varphi_0A_\mu\}=0, \qquad (2a)$$

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

$$\partial_\nu F^{\mu\nu}=e\varphi_0\{\partial^\mu(\Delta\varphi_1)-e\varphi_0A^\mu\}. \qquad (2c)$$

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

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

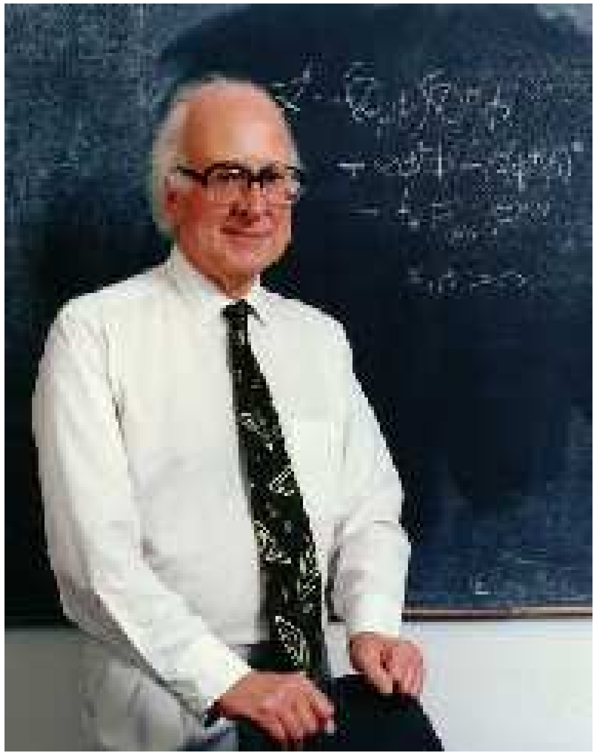
$$G_{\mu\nu}=\partial_\mu B_\nu-\partial_\nu B_\mu=F_{\mu\nu}, \qquad (3)$$

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



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FIND AUTHOR HIGGS,P

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▷ One idea changes the world ...

The Higgs Mechanism

To understand the Higgs mechanism, imagine that a room full of physicists chattering quietly is like space filled with the Higgs field ...

... a well-known scientist walks in, creating a disturbance as he moves across the room and attracting a cluster of admirers with each step ...

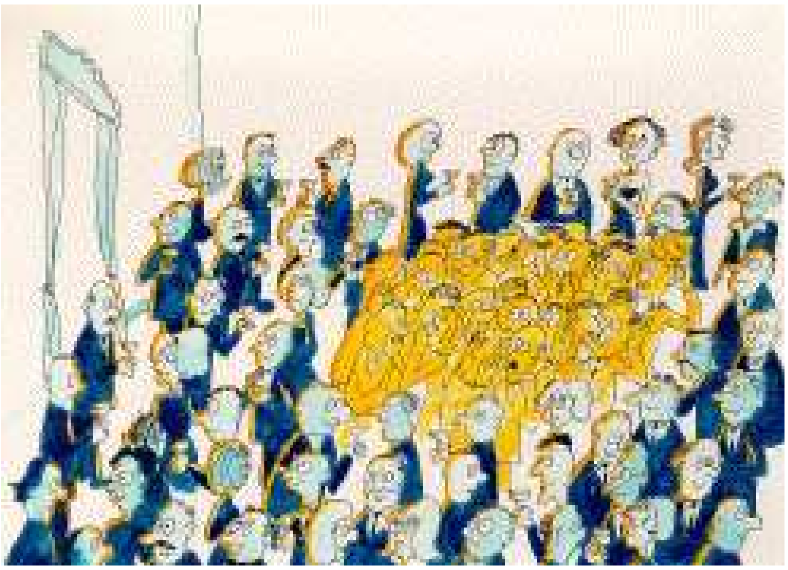
... this increases his resistance to movement, in other words, he acquires mass, just like a particle moving through the Higgs field...

The Higgs Mechanism (cont'd)

.. if a rumor crosses the room, ...

... it creates the same kind of clustering, but this time among the scientists themselves.

In this analogy, these clusters are the Higgs particles.



It cannot be far,
so let's go for it ...

Theoretical Constraints on M_{H^0} (SM)

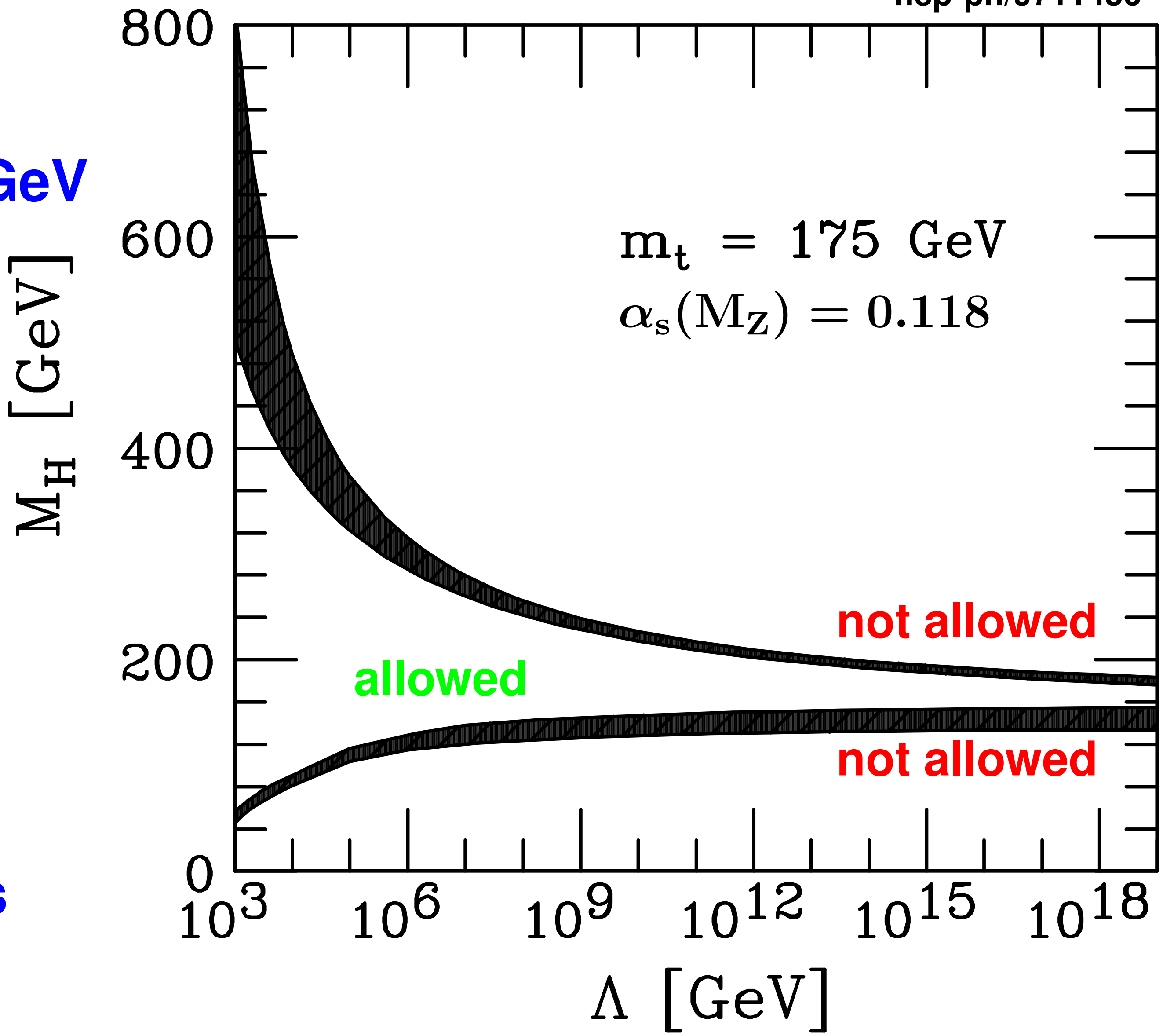
K. Risselmann
hep-ph/9711456

If SM valid up to :

$\Lambda = M_{Planck} = 10^{19}$ **GeV**

130 $< M_{H^0} <$ **180 GeV**

Landau Pole	$\Rightarrow$	**Max.**
Vacuum Stability	$\Rightarrow$	**Min.**

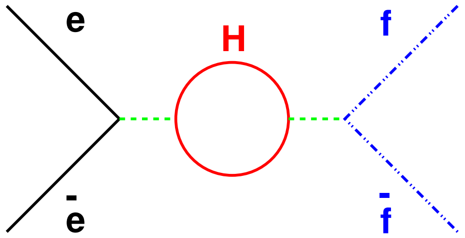


Probing the SM Higgs up to $\sim$ 180 GeV ...

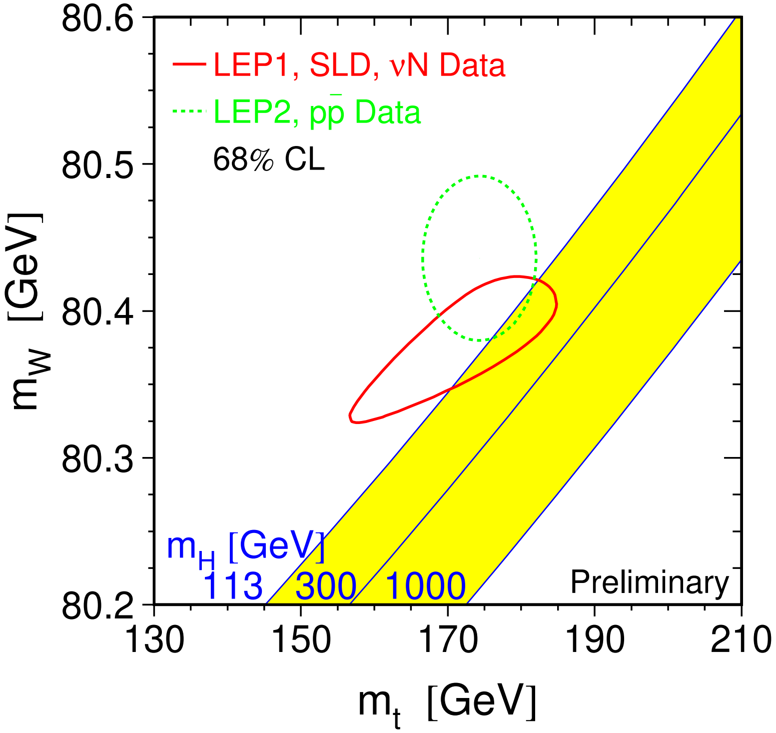
$\Rightarrow$ **Profound implications for $\Lambda_{New\ Physics}$**

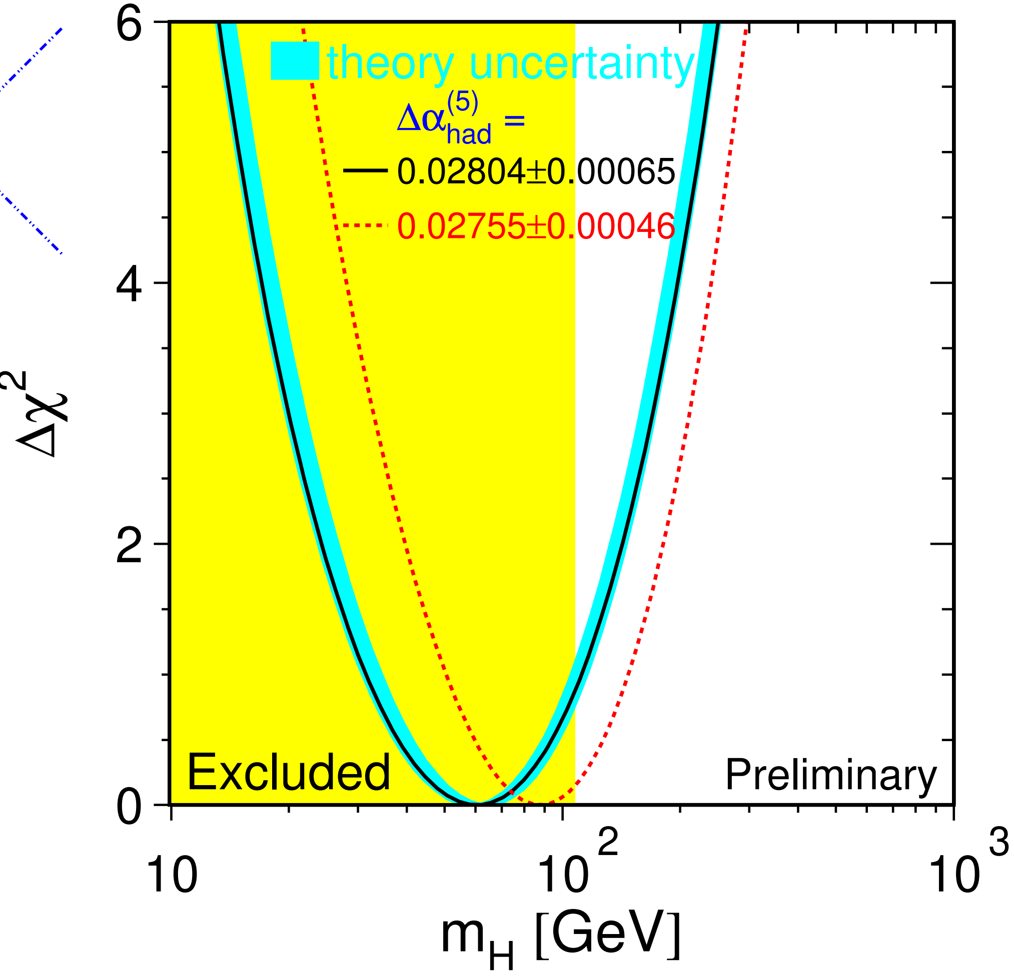
Experimental Constraints on $\mathrm{M_{H^0}}$ (SM)

▷ **EW radiative corr.**
$\sim \ln(m_H^2/\mathrm{GeV}^2)$



LEP-EW group
summer 2000



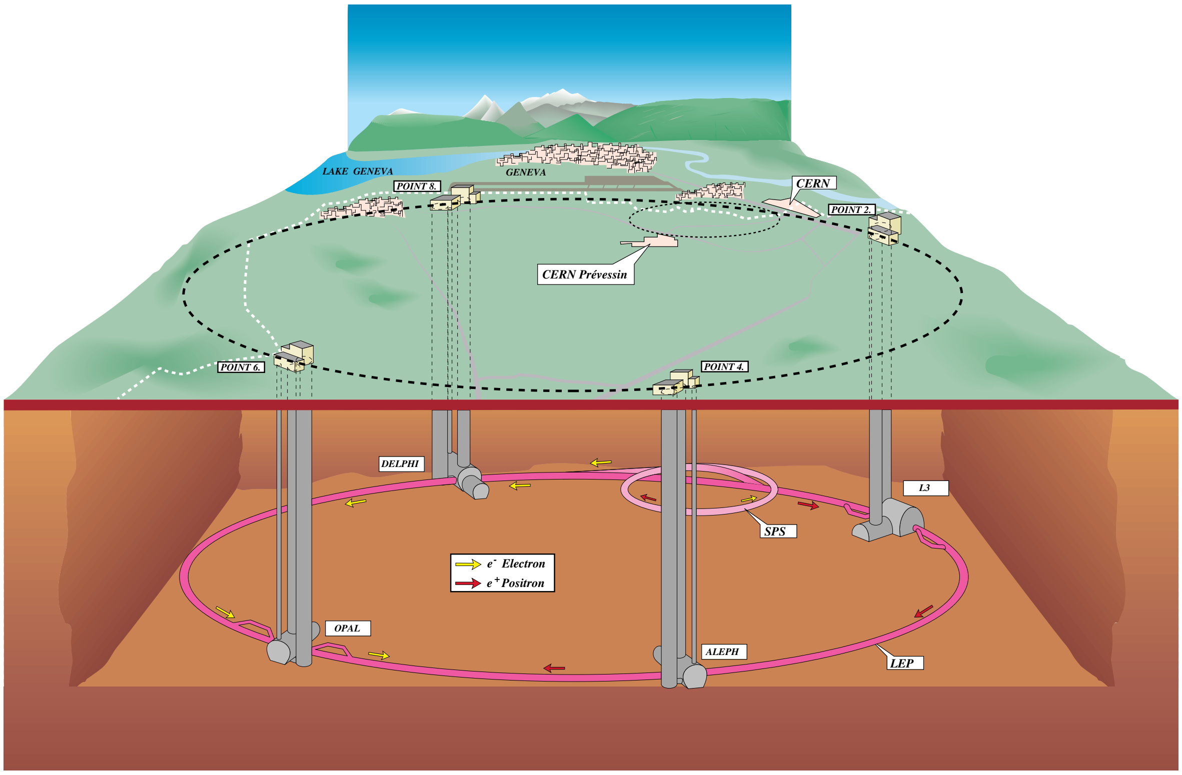


▷ **evidence for a weakly coupled higgs sector ?**

$m_H = 62^{+53}_{-39}$ **GeV** $\Rightarrow m_H < 170$ **GeV 95% CL**

with BES data: $m_H \approx 90$ **GeV** $\Rightarrow m_H < 210$ **GeV 95% CL**

The LEP e^+e^- Collider



Stage	$\sqrt{s}$ (GeV)	Year	$\int \mathcal{L}$/exp. (pb^{-1})
LEP1	$\approx$ 91	1989-95	175
LEP1.5	130-140	1995	5
LEP2	161-172	1996	20
	183	1997	55
	189	1998	180
	192-202	1999	230
	202-209	2000	220

LEP's Final Year

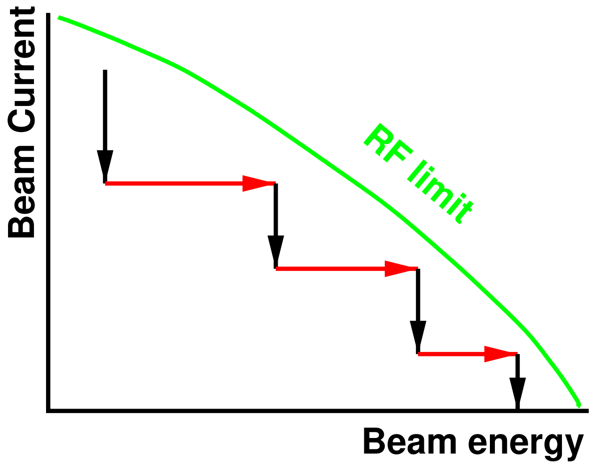
▷ **Optimize energy vs. luminosity**

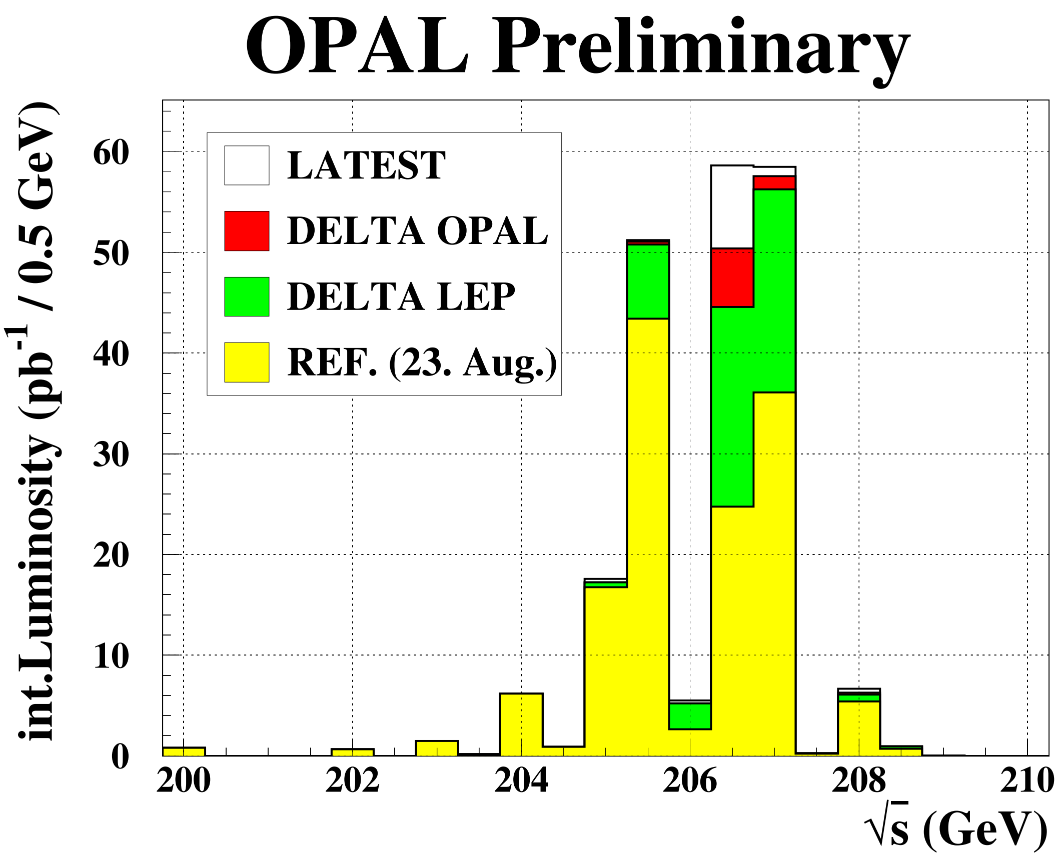
RF power limited:

- **cryogenic load, solved with early LHC cryo plants**
- **RF trips more frequent with energy and current**

▷ **Use mini-ramps:**

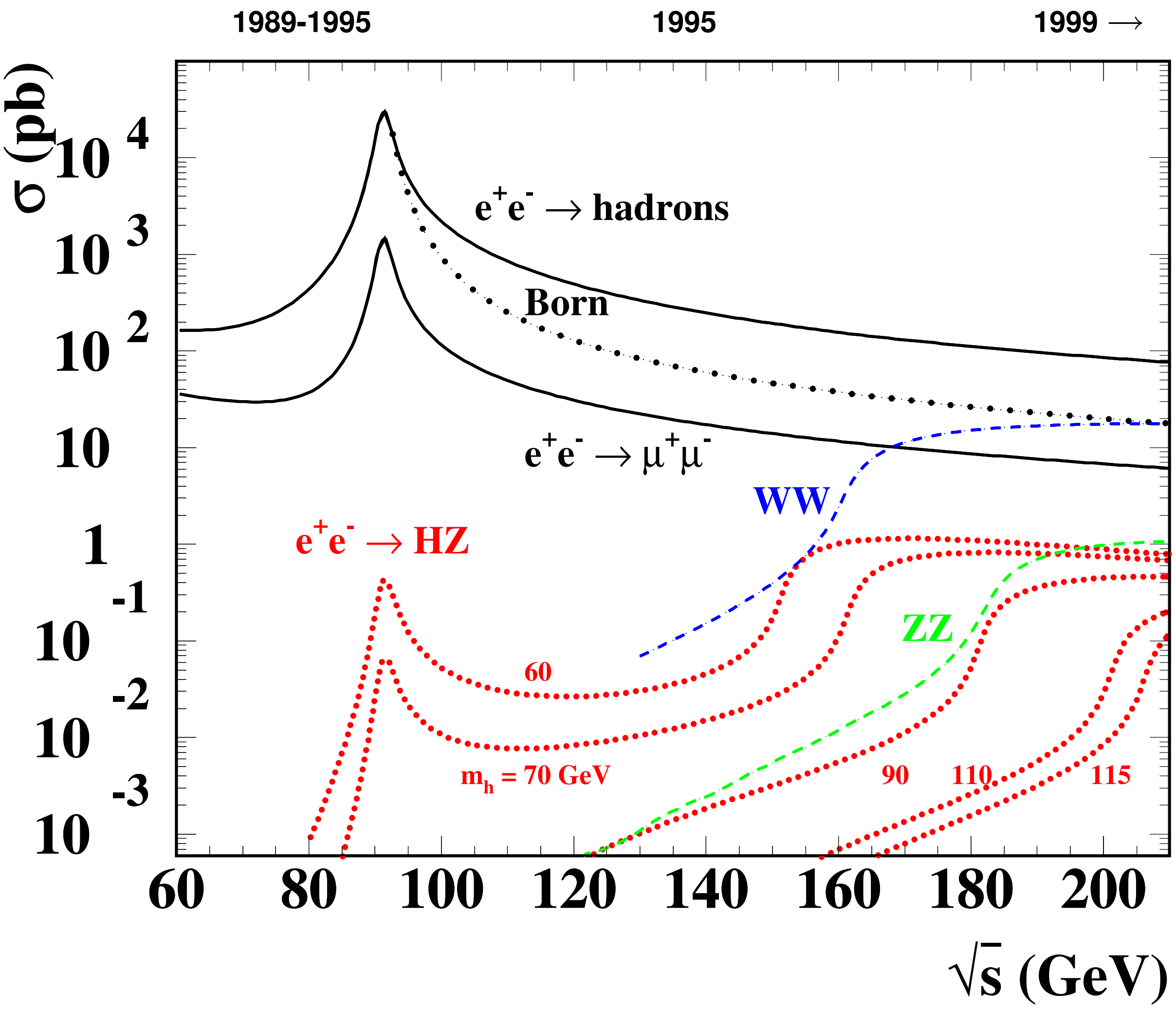
increase energy with decreasing beam current



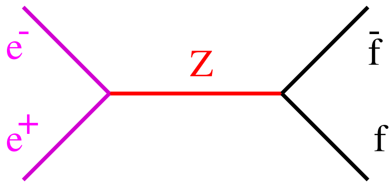


only year 2000

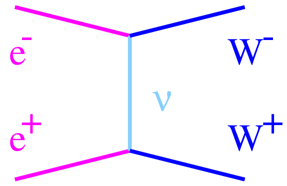
Processes at LEP2



LEP 1



LEP 2



- **Cross section:**

1000 - 10000 pb: $e\gamma$ **and** $\gamma\gamma$ **collisions**

10 - 100 pb: $e^+e^- \to f\bar{f}$ **(EW, QCD)**

1 - 15 pb: **W-physics**

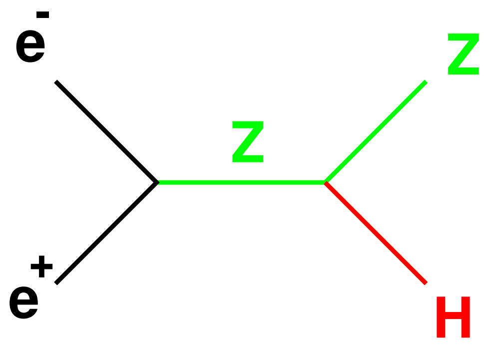
1 pb: **ZZ-physics**

0.1 - 1 pb: **search sensitivity**

SM Higgs Production at LEP

Higgs-Strahlung

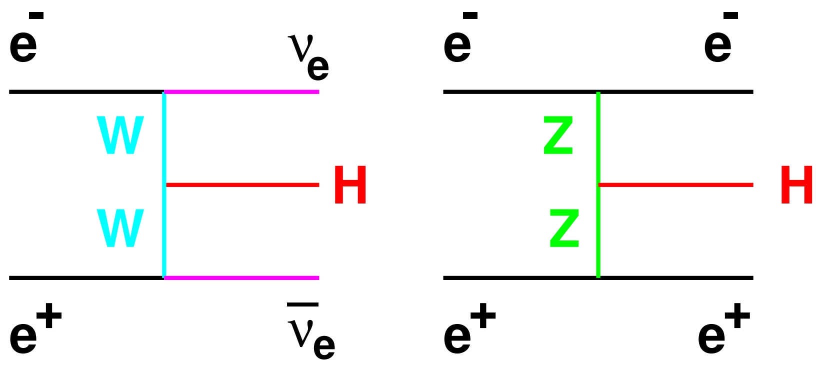
(dominant mode)



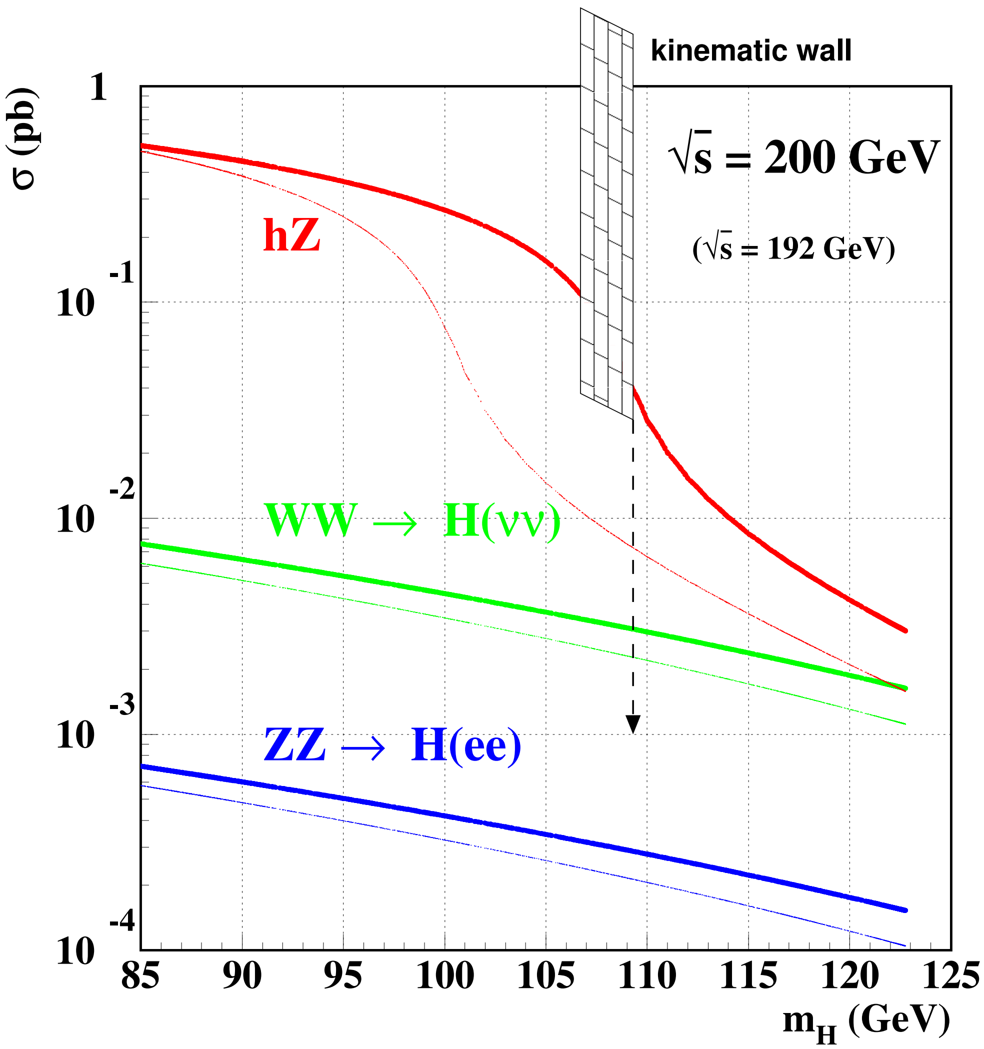
$m_h \simeq \sqrt{s} - m_Z$

WW and ZZ fusion

(small contribution)



Possibility to go beyond kinematic limit



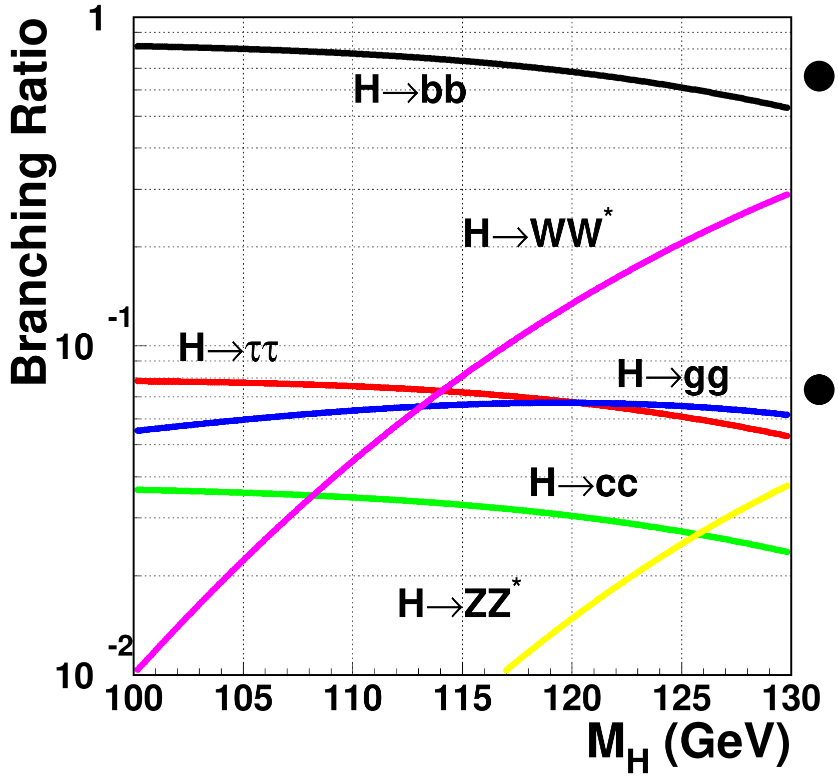
$\sqrt{s}$ = 206 GeV and

m_h = 115 GeV

$\sigma_{hZ} \sim$ 0.05 pb

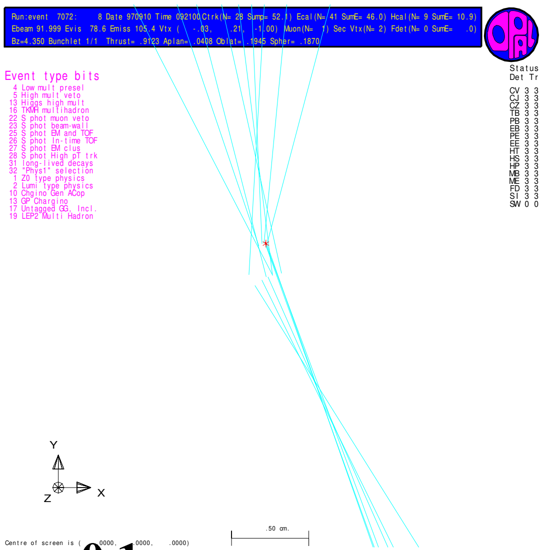
$$\int \mathcal{L} \,(^{\sqrt{s}>206\,\mathrm{GeV}}_{\mathrm{ADLO}}) \simeq 500\ \mathrm{pb}^{-1} \Rightarrow 25\ \mathrm{HZ\text{-}events}$$

SM Higgs Decays

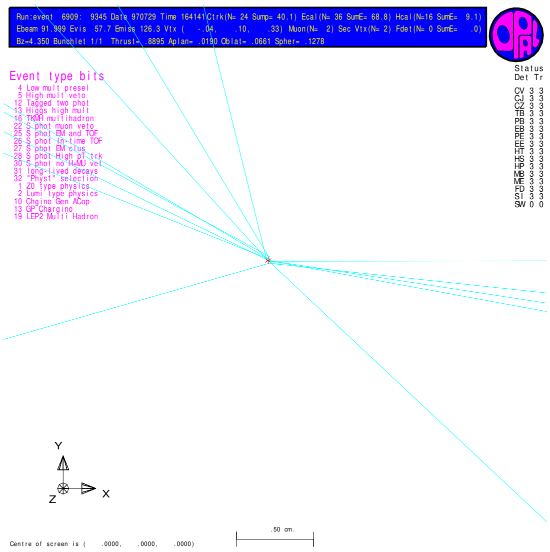


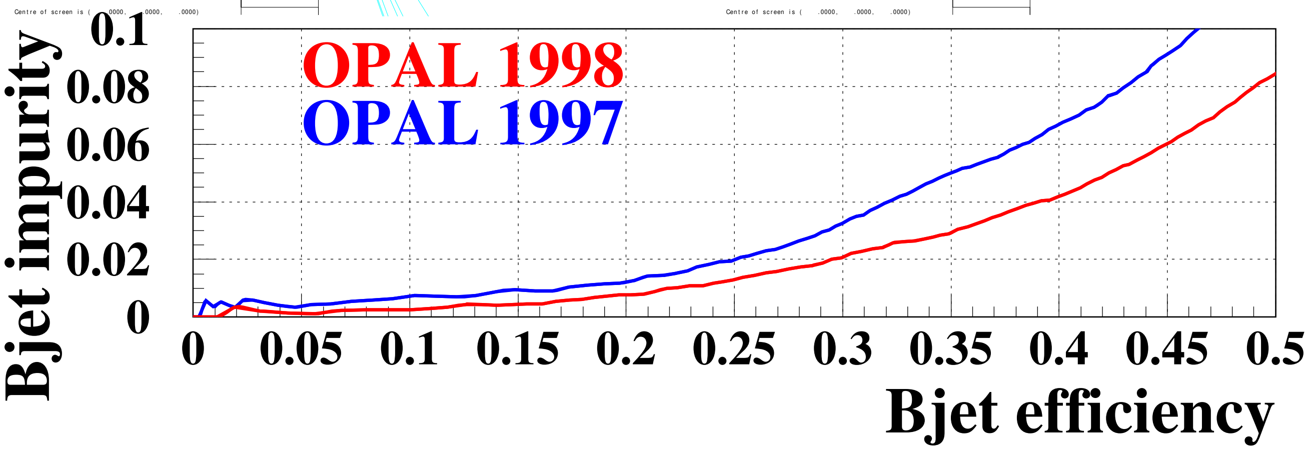
- **A SM Higgs boson decays** $>$ **83% to** $\mathrm{b\bar{b}}$
- **b-tag is essential to tag Higgs in the mass range accessible at LEP**

$$e^+e^- \longrightarrow ZH \longrightarrow \nu\bar{\nu}b\bar{b}$$

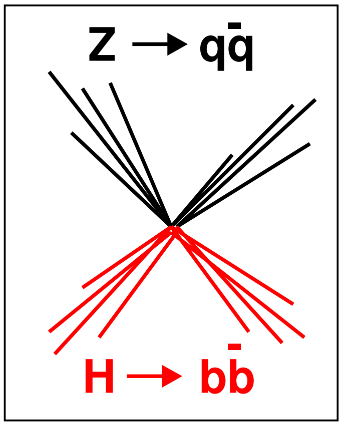


$$e^+e^- \longrightarrow ZZ \longrightarrow \nu\bar{\nu}q\bar{q}$$

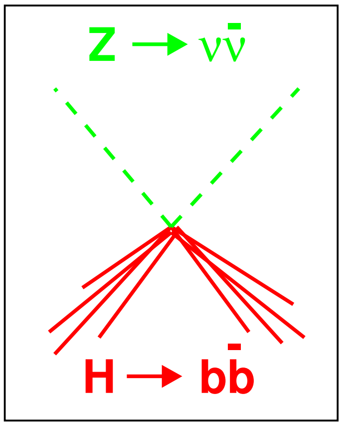




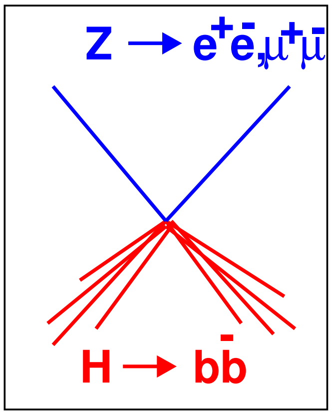
Higgs Search Topologies at LEP



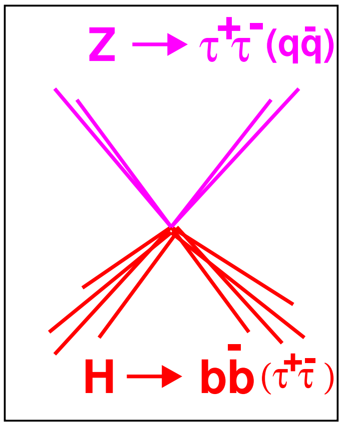
- **Four Jets :** (58% in SM)
  - ▷ Energy-momentum conservation
  - ▷ The 2 most probable b-tagged jets recoil against a di-jet compatible with a Z-boson
  - ▷ eff 40-50 %



- **Missing Energy :** (17% in SM)
  - ▷ The recoil mass of the 2 b-tagged jets is compatible with a Z-boson
  - ▷ eff 30-40 %

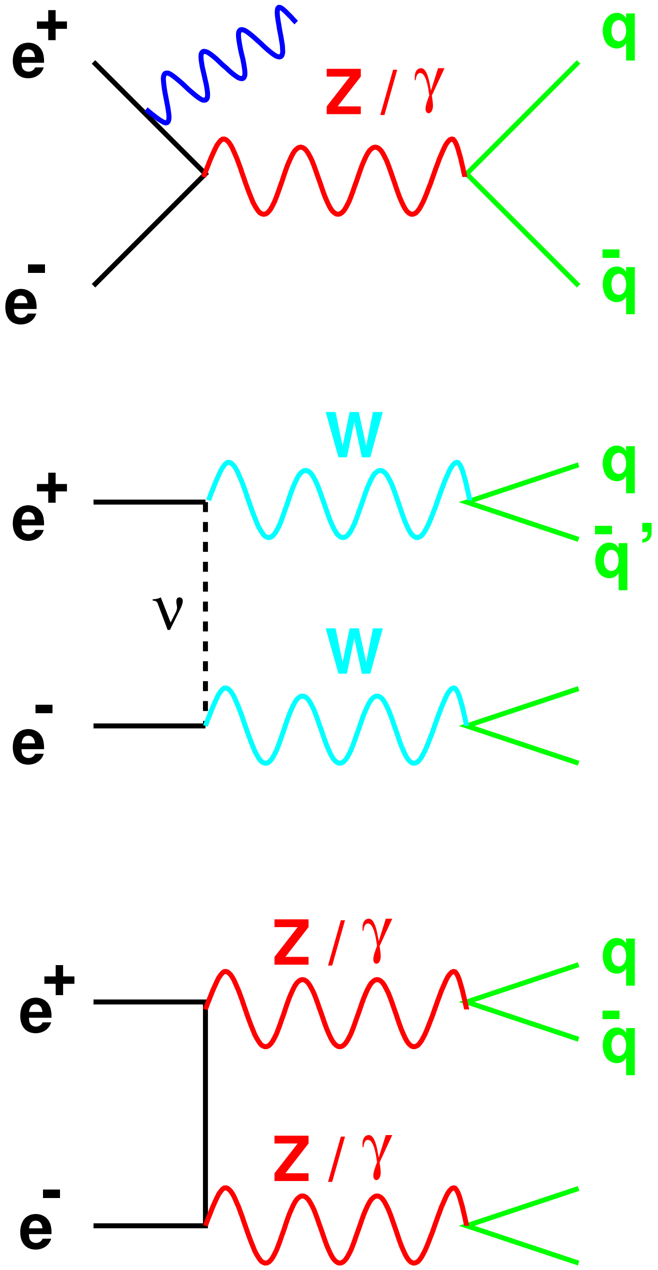


- **Leptons :** (6% in SM)
  - ▷ 2 high energetic leptons with a mass compatible with a Z-boson recoil against 2 jets
  - ▷ eff 50-60 %, clean channel



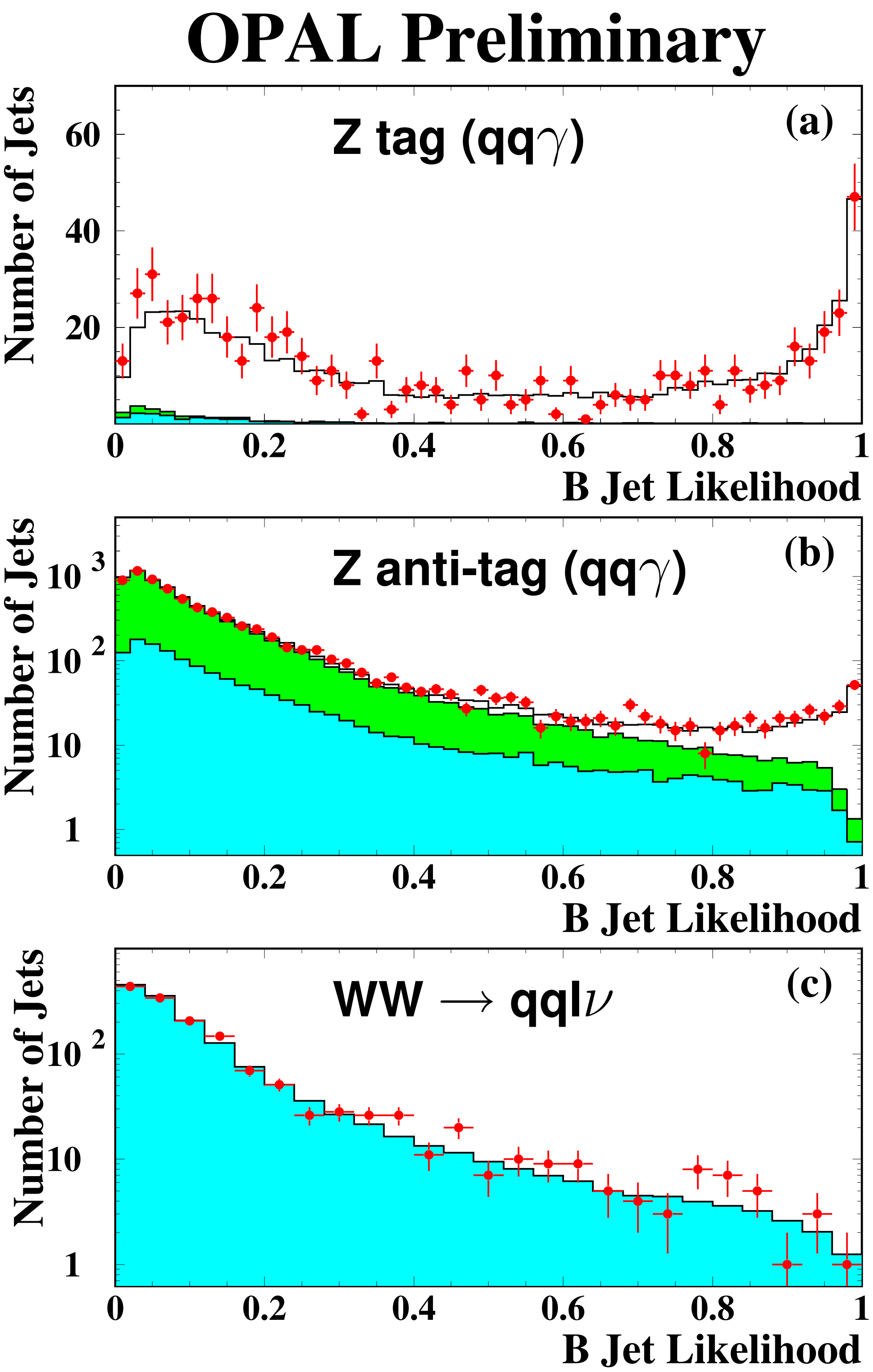
- **τ's :** (10% in SM)
  - ▷ 2 low multiplicity jets compatible with a Z-boson and 2 b-tagged jets
  - ▷ eff 35 %

Backgrounds: ZZ, WW & qq



- The most severe background is the Higgs-like irreducible ZZ production, at high masses also qq

- SM Higgs decays to b-quarks $>$ 83% of the time. Only good b-tag will reduce ZZ and WW bgds



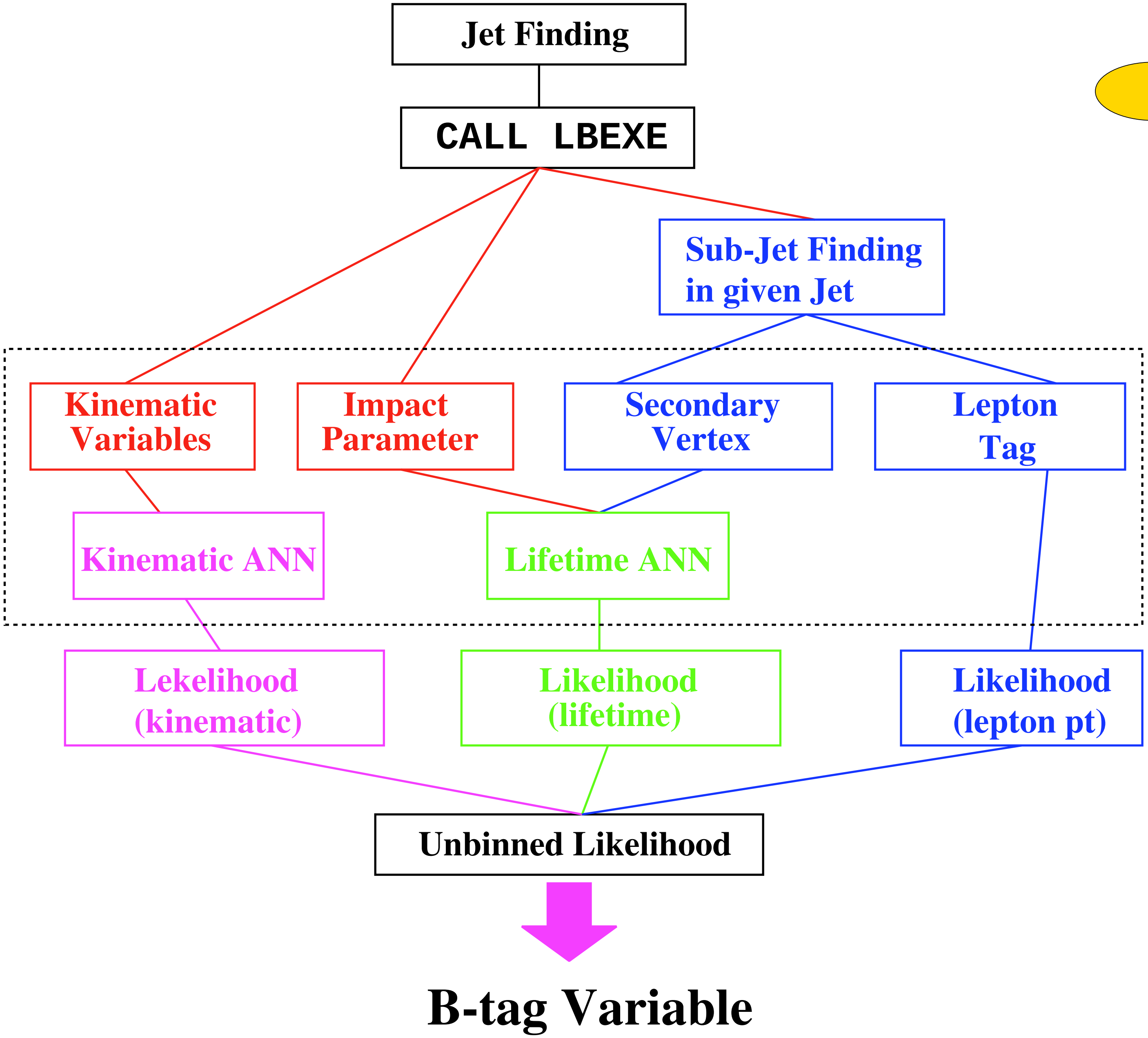
Signal Efficiency
$\Rightarrow$ **ok**

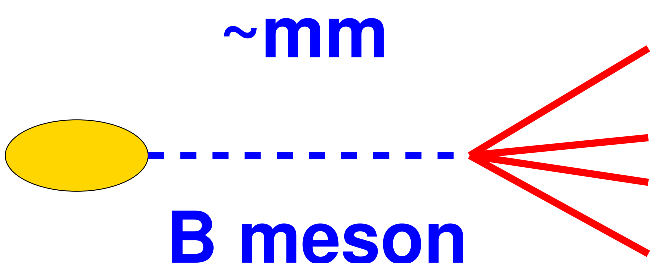
Signal & Backgrd Fakes
$\Rightarrow$ **ok**

Backgrd Efficiency
$\Rightarrow$ **ok**

▷ **B-tag well described by MC and reliable !**
sys.error.: b-jets $\sim$ 5%, udsc-jets $\sim$ 2%

B-Tagging

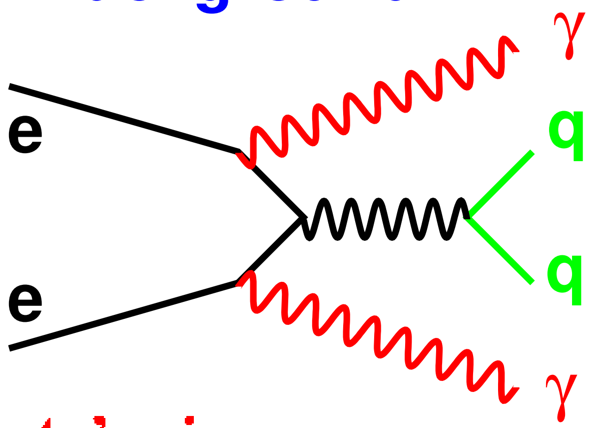




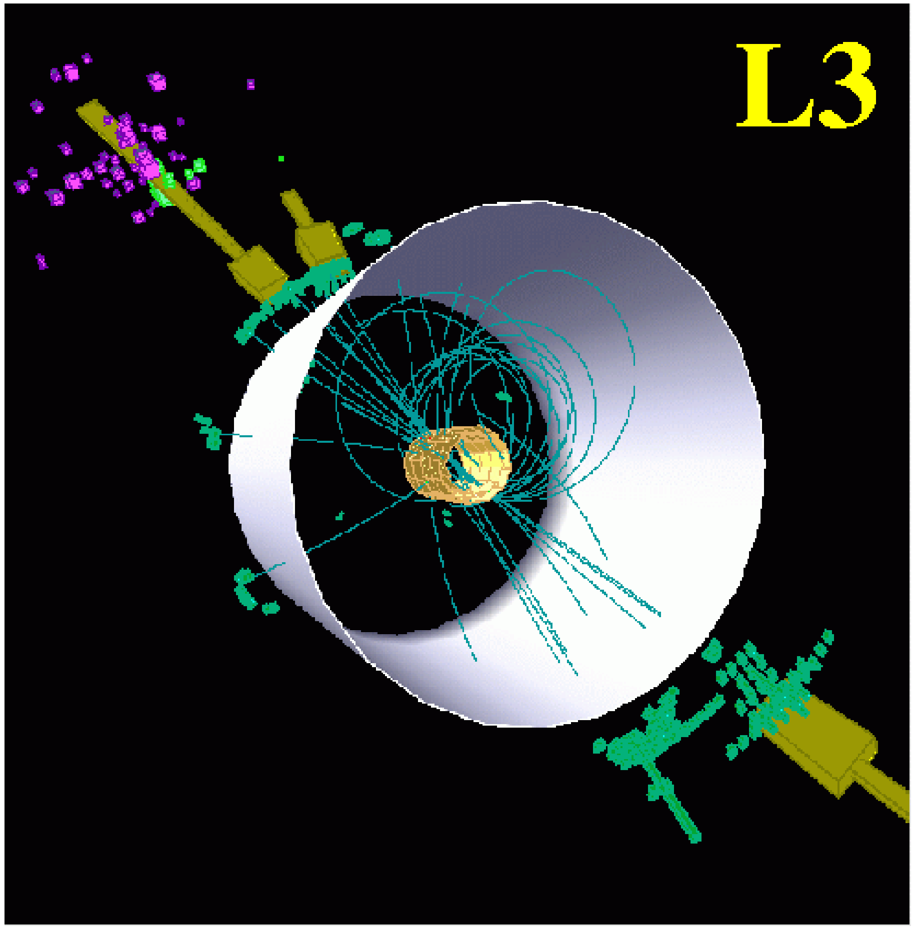
(B lifetime $\sim$ 1.5 ps)

L3: Higgs Candidate

Background :

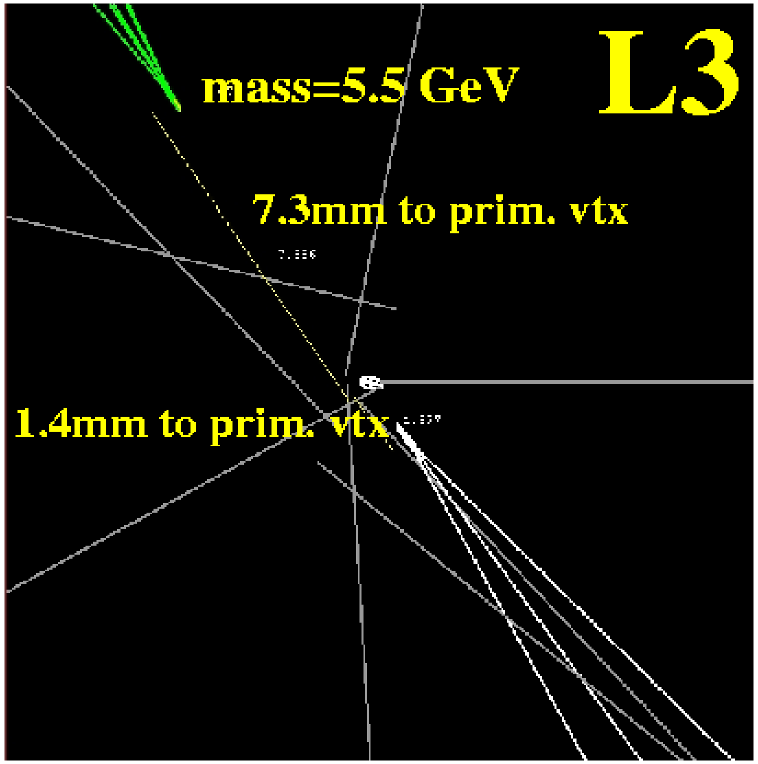


most significant Hνν candidate

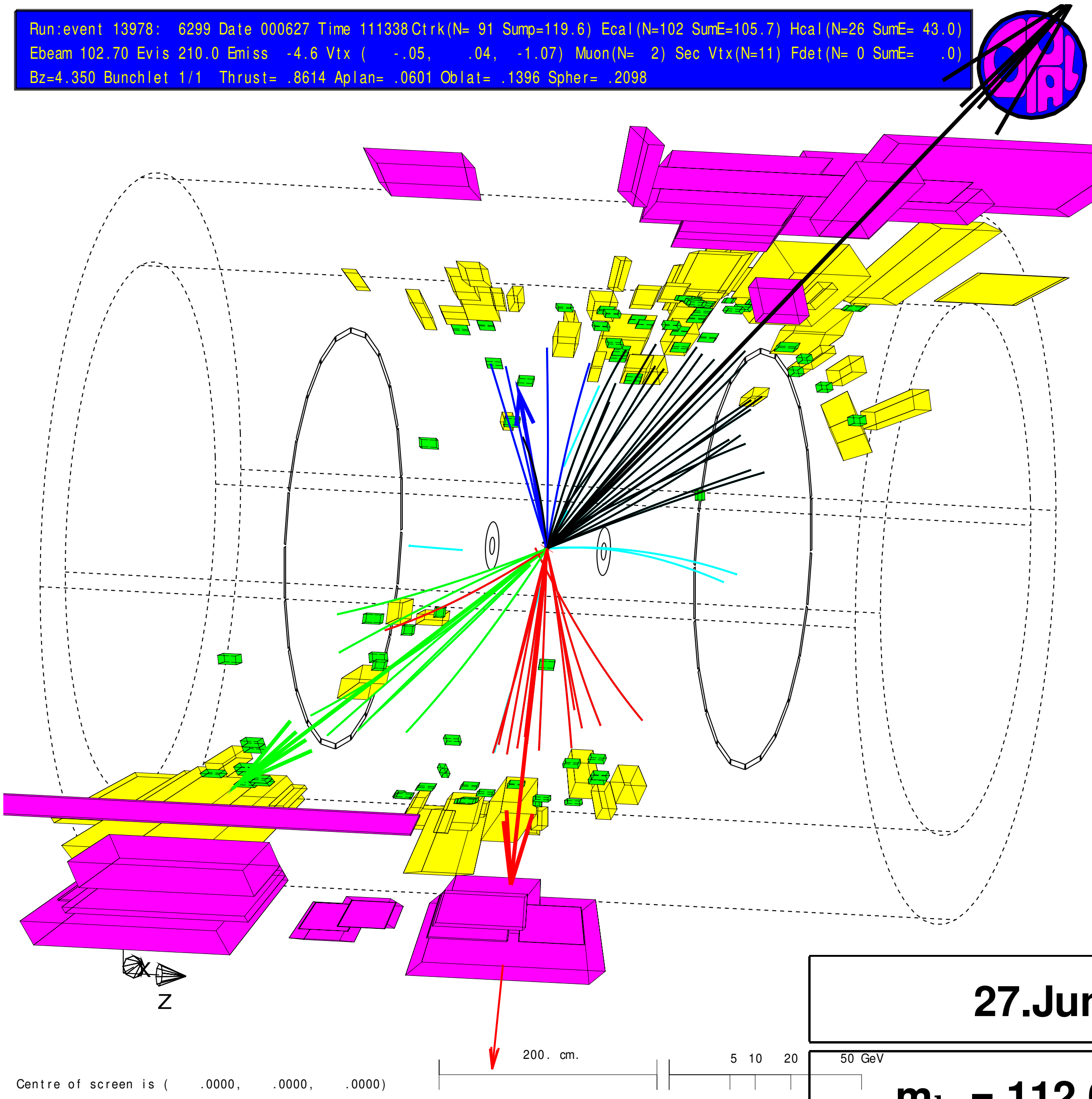


measured H mass=114.4 GeV
H mass resolution ~3 GeV

Secondary vtx's view



OPAL: Higgs Candidate



27.June

m_h = 112.6 GeV

B-tag(1) = 0.345

B-tag(2) = 0.960

$\sqrt{s}$ = 205.4 GeV

$\mathcal{L}$ = 0.999

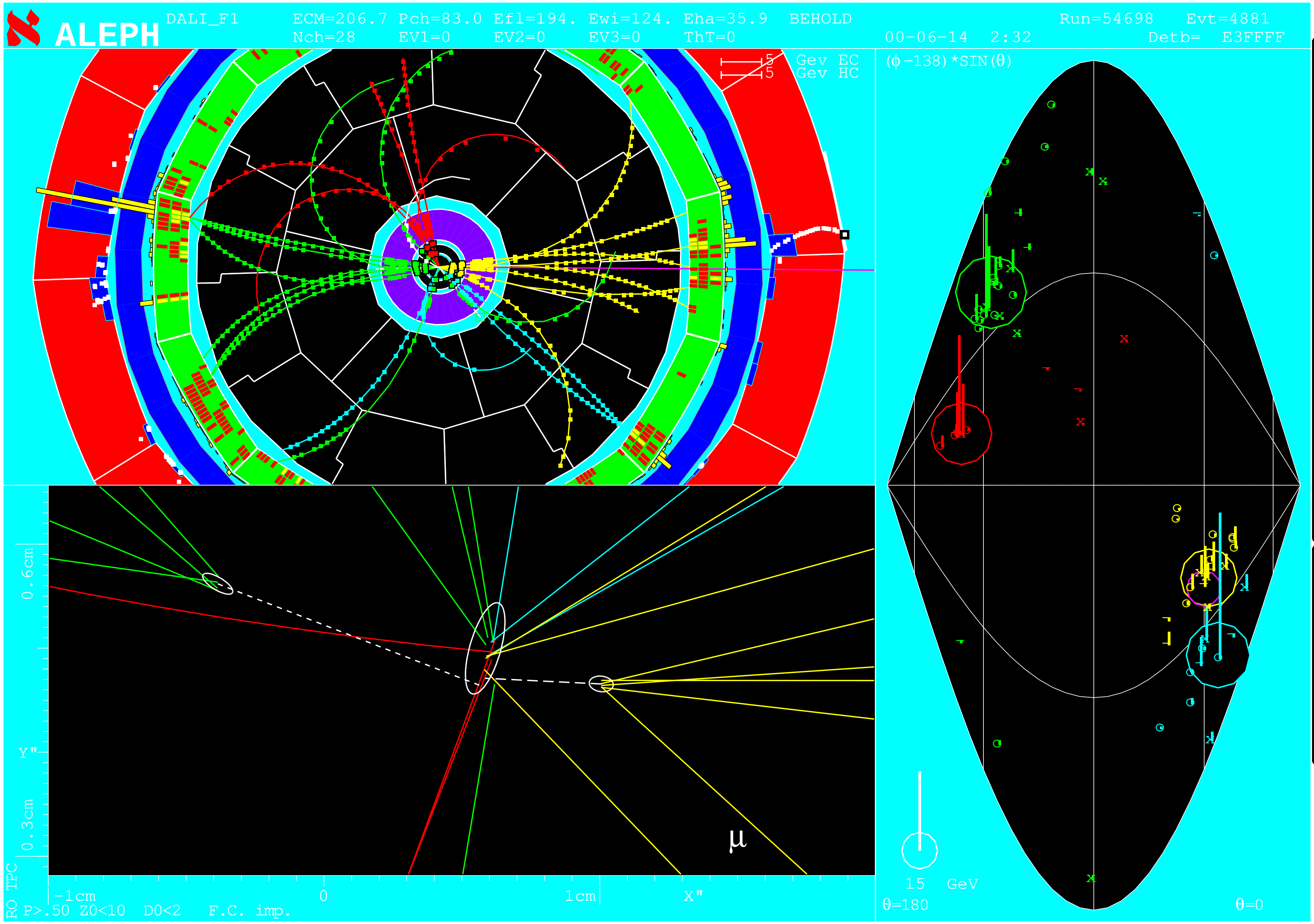
s/b(105 GeV) = 0.2844

s/b(110 GeV) = 1.1355

s/b(115 GeV) = 0.5234

▷ Highest weight OPAL candidate (4-jet)

ALEPH: Higgs Candidate (4-jet)



m_h = 114 $\pm$ 3 GeV

BH1 = 0.99

BH2 = 0.99

BZ1 = 0.14

BZ2 = 0.01

$\sqrt{s}$ = 206.7 GeV

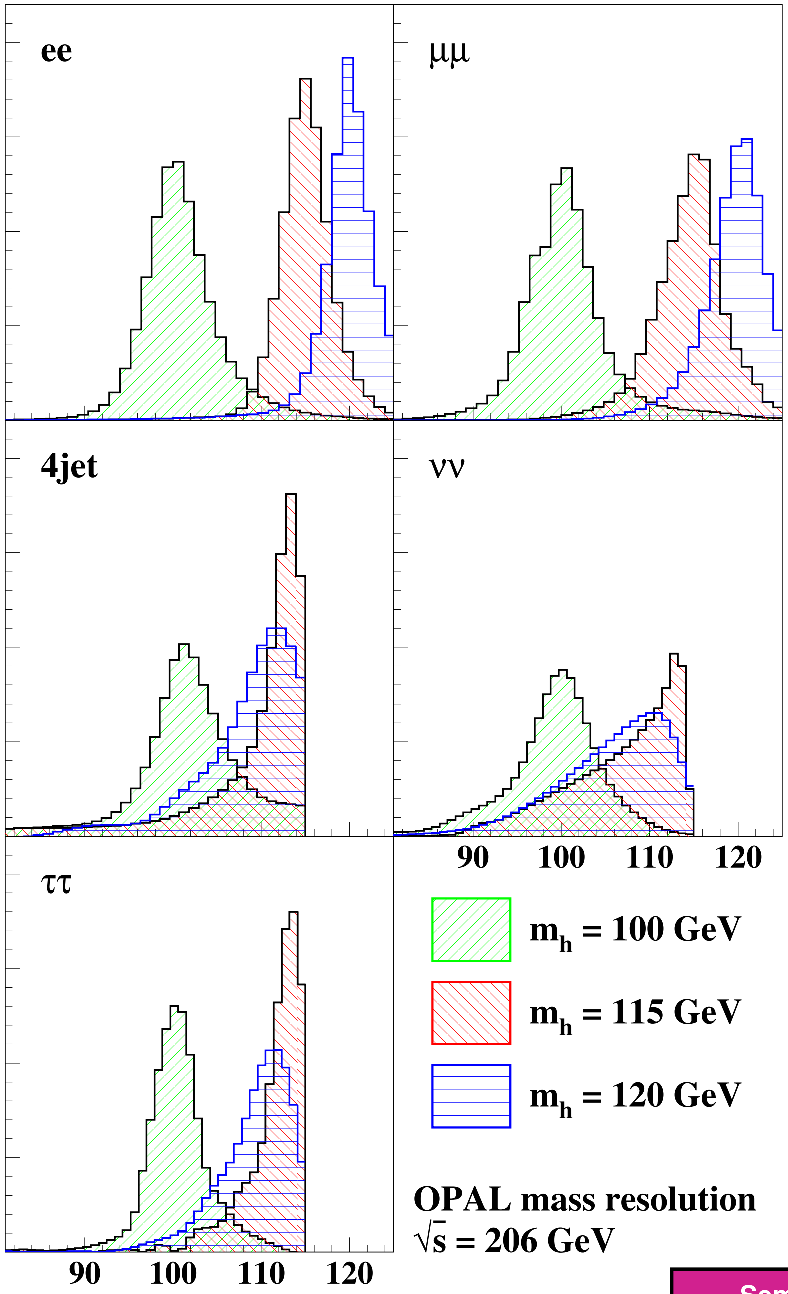
$\mathcal{L}$ = 0.996

kin. mass fit:

m_h = 112.4 GeV

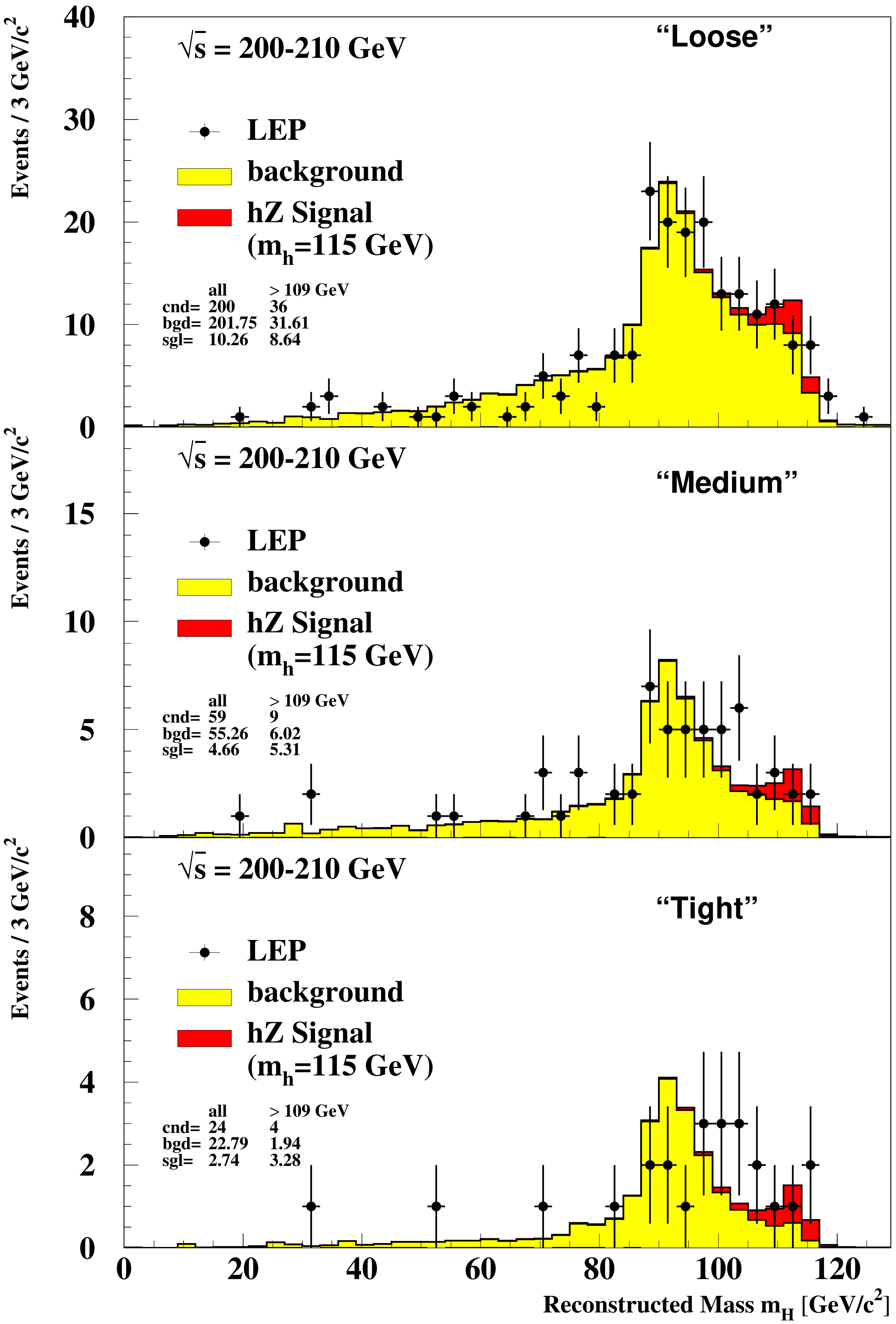
m_Z = 93.3 GeV

Mass Reconstruction



- ▷ **Recoil mass in ee and $\mu\mu$ channels**
- ▷ **Kinematic 5C fit in the 4jet channel:**
  - **energy and momentum conservation**
  - **M(jet-jet) = M_Z**
  - **Best Jet-Jet combination chosen with likelihood method**
  - **Sharp kinematic edge at m_H = (206 - 91.2) GeV $\sim$ 115 GeV**

Distributions of Reconstructed Mass



Special selection ...not biasing the mass distribution

$\Rightarrow M^{rec}_{H^0}$ **not the whole story ...**

Statistical Channel Combination

TASK : Combination of results from ...

- 5 decay modes
- 4 LEP experiments
- all $\mathrm{E_{CM}}$

$\Rightarrow \mathcal{O}$(100) 'channels' with different sensitivity

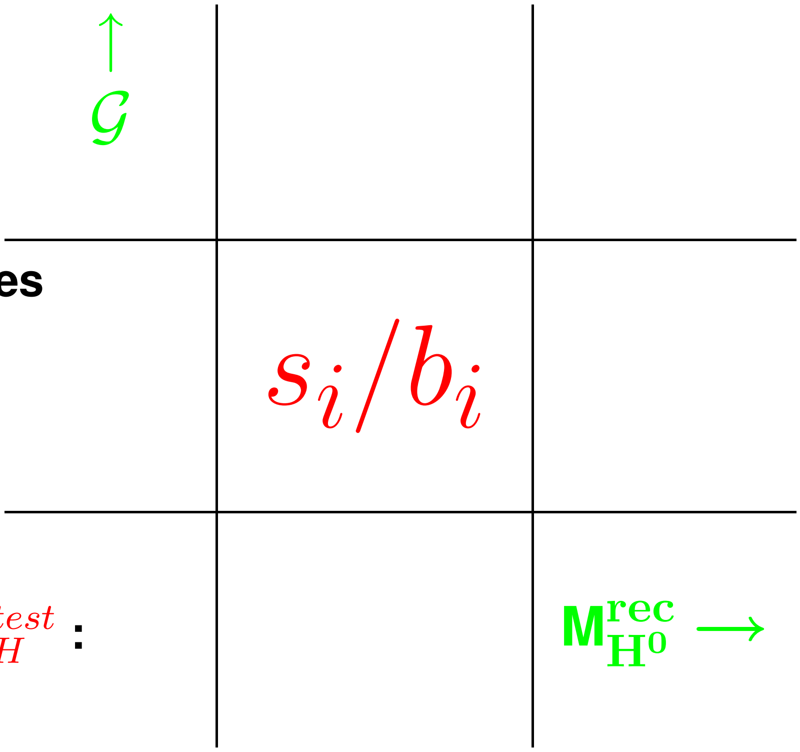
For each event in each channel define:

$\mathrm{M}_{\mathrm{H^0}}^{\mathrm{rec}}$: Reconstructed Higgs mass

$\mathcal{G}$: Global discrimination variable (b-tag, kinematics ...)

In each bin i ...

- b_i = Bkgd. (MC)
- $s_i(m_H^{test})$ = Signal (MC)
- N_i = Nr. of candidates



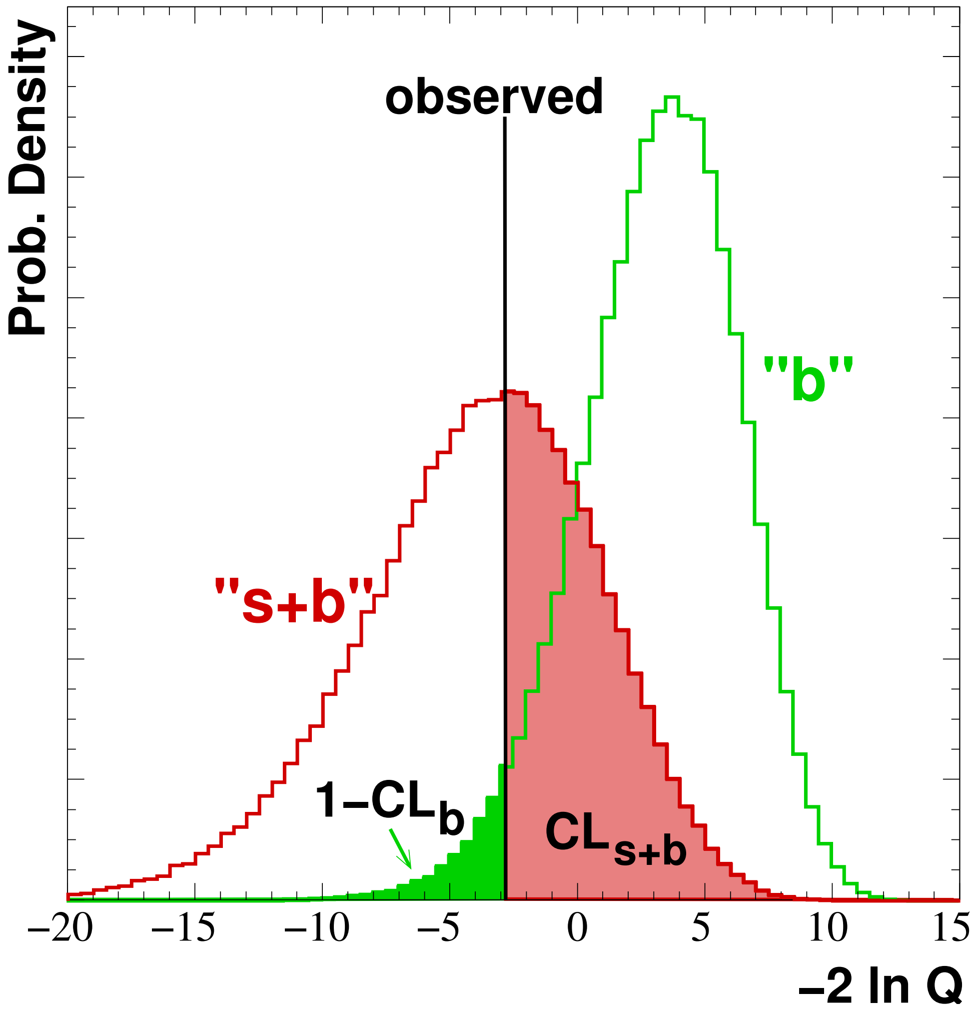
Test for mass hypothesis m_H^{test} :

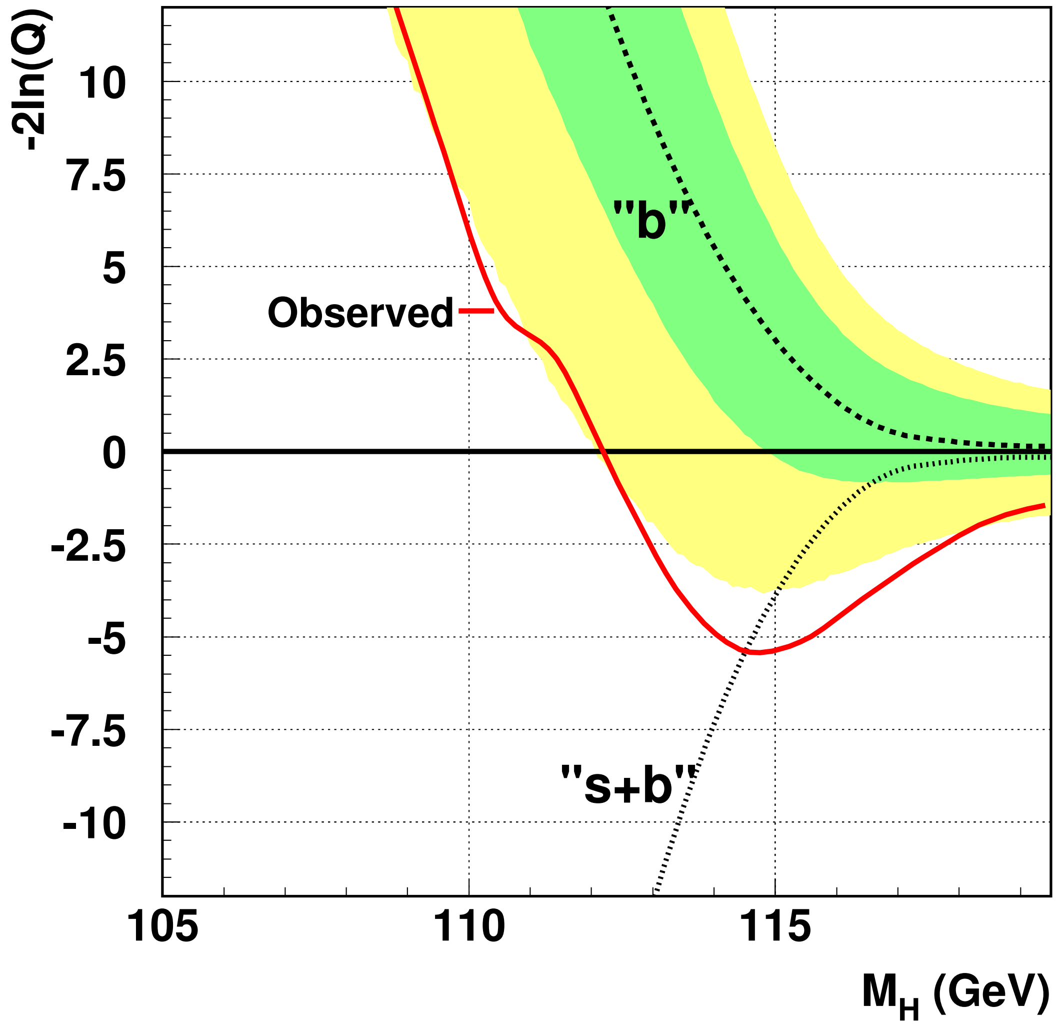
'sig + bkgd' $\Leftrightarrow$ 'bkgd'

Use *Likelihood Ratio* :

$$
\begin{aligned}
Q(m_H^{test}) &= \mathcal{L}(s+b)/\mathcal{L}(b) \\
-2\ln Q(m_H^{test}) &= 2\, s_{tot}(m_H^{test}) \\
&\quad -2\sum N_i \ln\left[1 + s_i(m_H^{test})/b_i\right]
\end{aligned}
$$

Statistics cont'd





$1 - CL_b$: compatibility with 'b' hypothesis

CL_{s+b} : compatibility with 's+b' hypothesis

'expected' curves from MC experiments

Likelihood Ratio

N	number of observed candidates
$\tilde{s}_i$	expec. nr. of sgl events in local bin of (mass, discriminant)
$\tilde{b}_i$	expec. nr. of bgd events in local bin of (mass, discriminant)
s	total number of expected signal events
b	total number of expected background events

Likelihood for signal + background hypothesis

$$L_{s+b} = \frac{(s+b)^N}{N!} e^{-(s+b)} \prod_{i=1}^{N} \frac{(\tilde{s}_i + \tilde{b}_i)}{s+b}$$

Likelihood for background only hypothesis

$$L_b = \frac{b^N}{N!} e^{-b} \prod_{i=1}^{N} \frac{\tilde{b}_i}{b}$$

$$Q = \frac{L_{s+b}}{L_b} = \frac{e^{-(s+b)}}{e^{-b}} \prod_{i=1}^{N} \left(\frac{\tilde{s}_i + \tilde{b}_i}{\tilde{b}_i} \right)$$

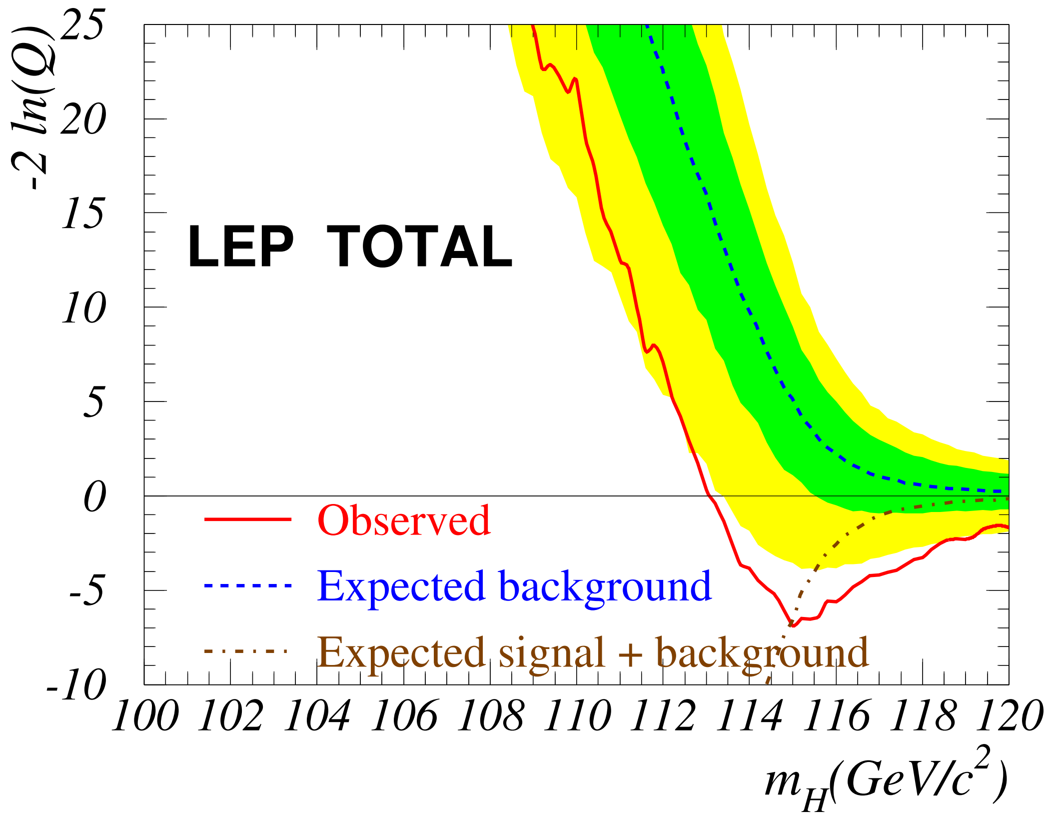
$$= e^{-s} \prod_{i=1}^{N} \left(1 + \frac{\tilde{s}_i}{\tilde{b}_i} \right)$$

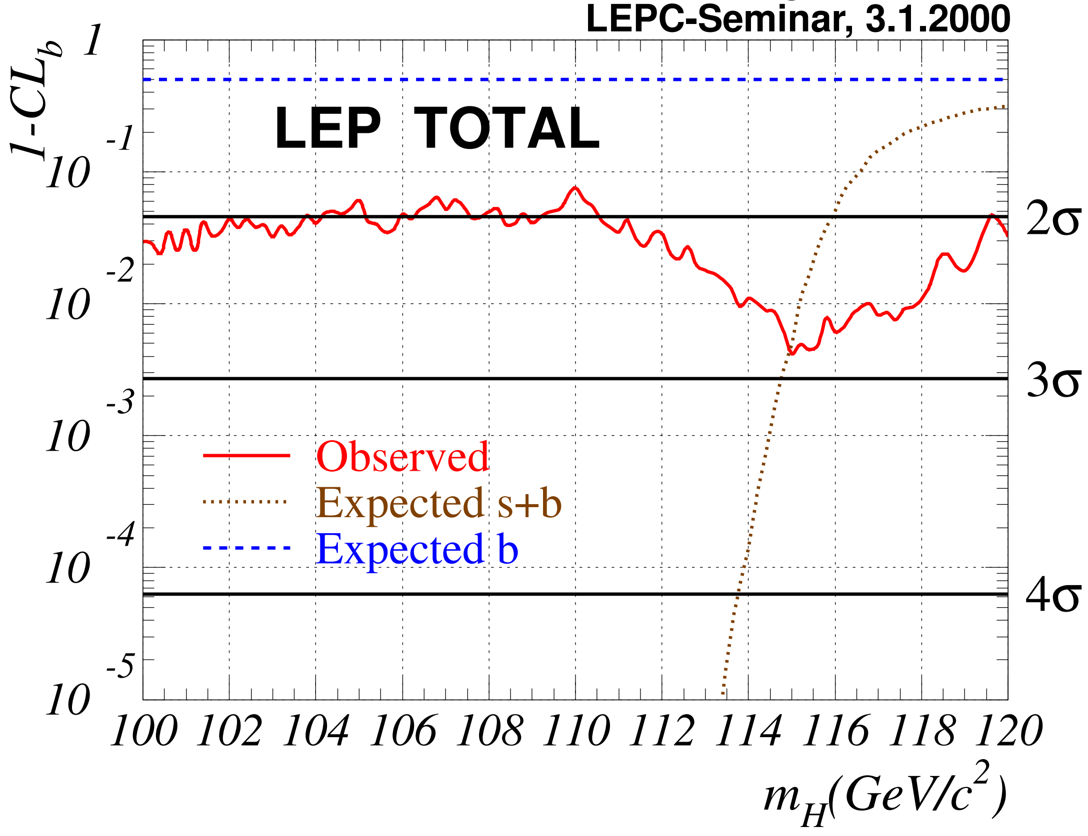
$$\Rightarrow \boxed{-2 \ln Q = 2 \left(s - \sum_{i=1}^{N} \omega_i \right)}$$

with weight $\omega_i = \ln \left(1 + \frac{\tilde{s}_i}{\tilde{b}_i} \right)$

LEP Result

P. Igo-Kemenes
LEPC-Seminar, 3.1.2000





Minimum @ $m_H \approx$ 115 GeV

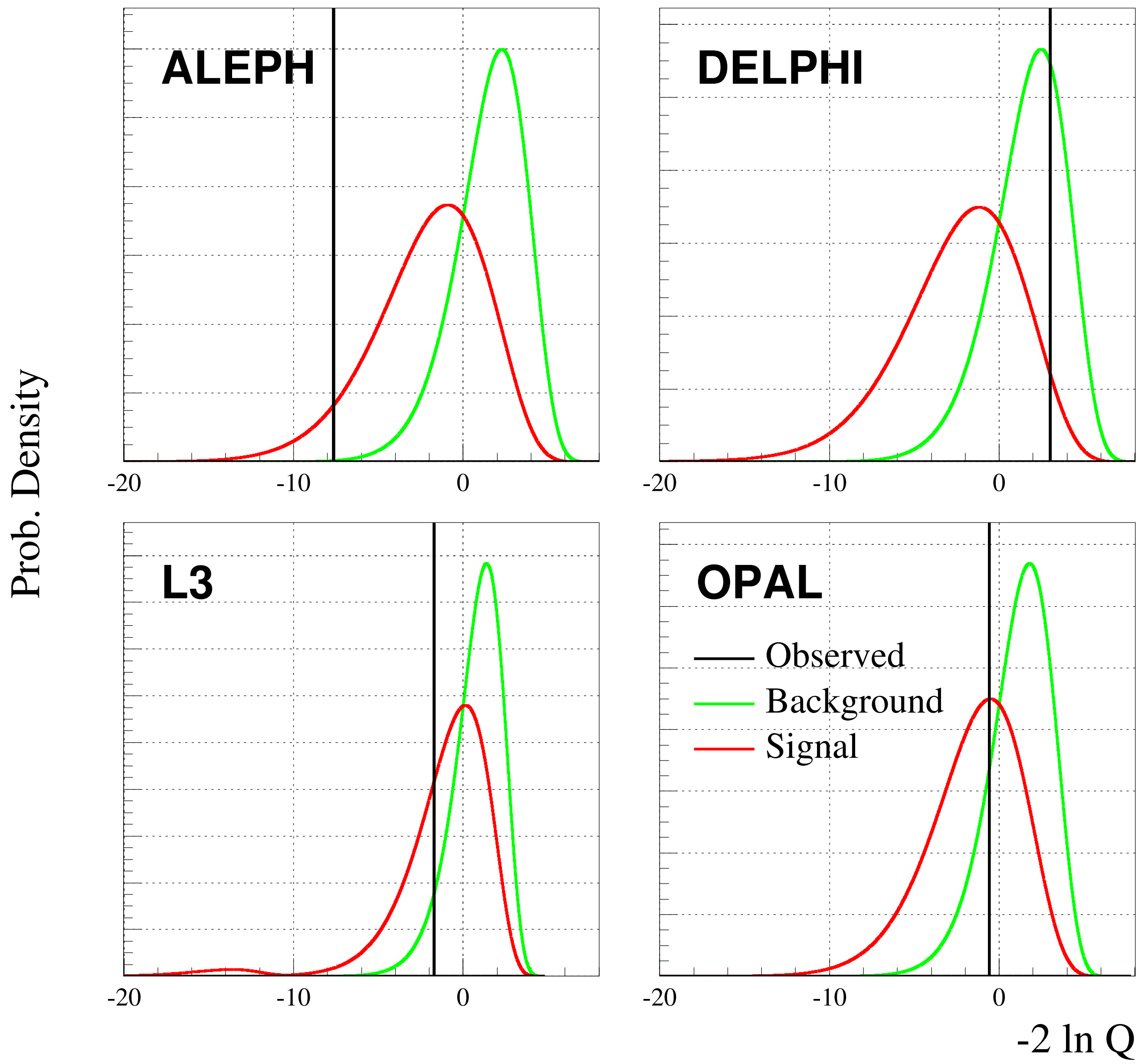
Agreement with SM Higgs cross-sect. for

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

$\boxed{1-CL_b = 2.9\ \sigma}$

LEP Result by Experiment

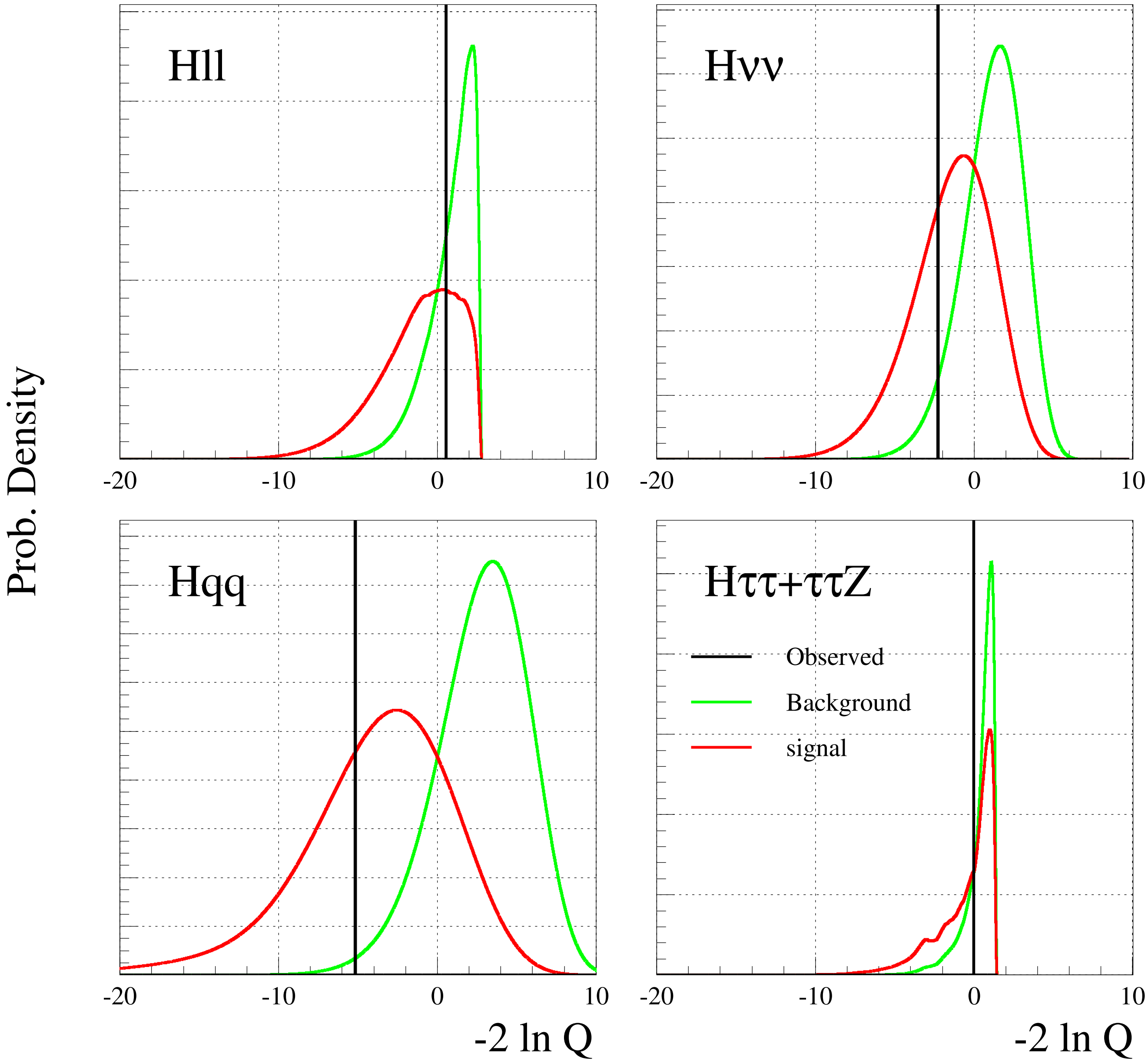
$@\ m_H^{test}$ = 115 GeV



▷ **ALEPH, L3 and OPAL 's+b' like**

LEP Result by Decay Channel

@ m_H^{test} = 115 GeV

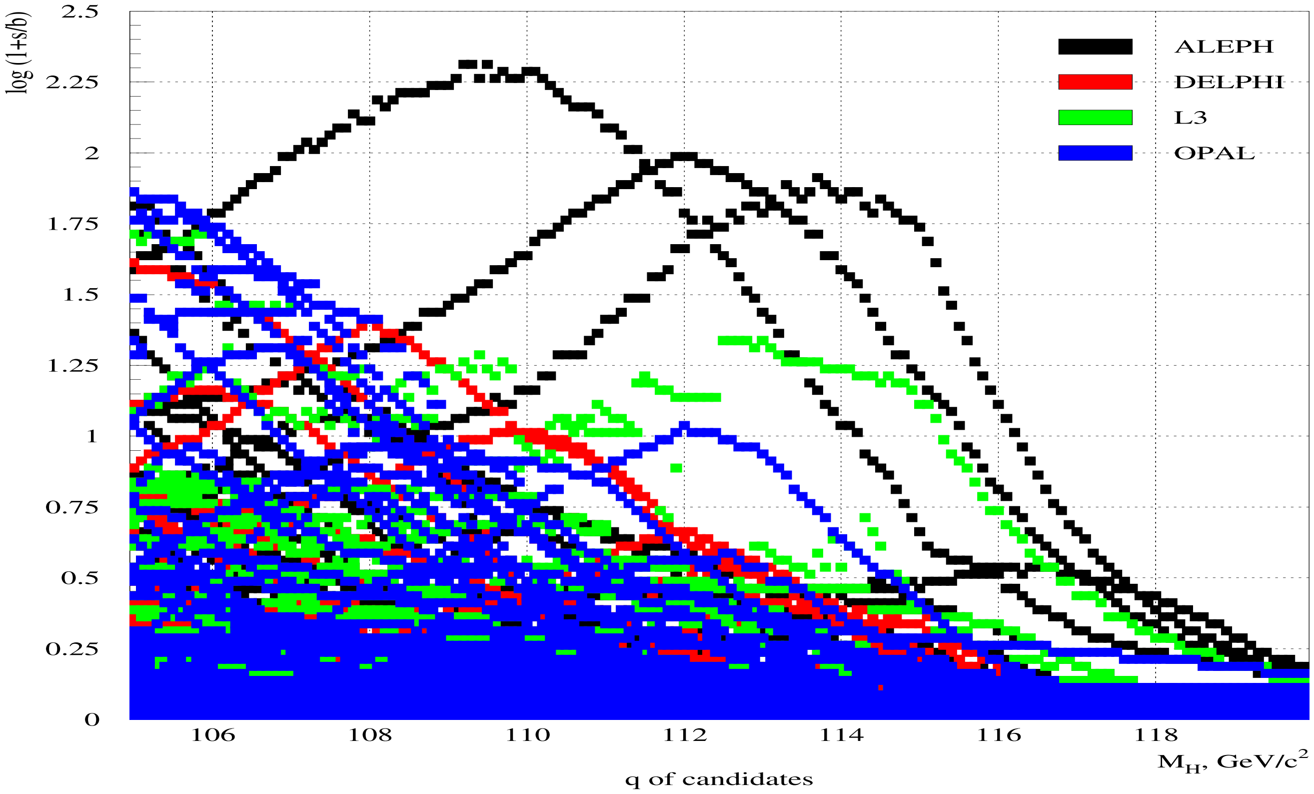


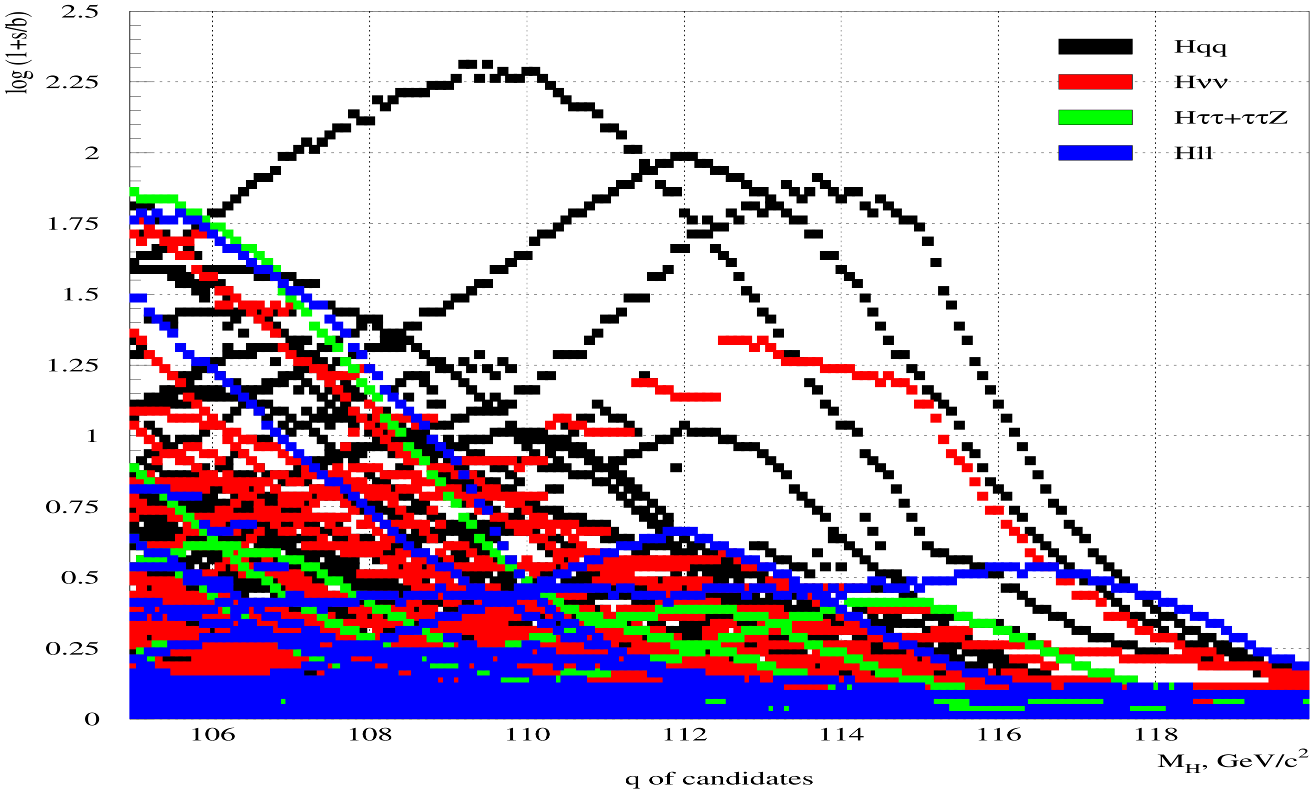
▷ **4-jet and E-misss channel 's+b' like**

Contributions from Single Candidates

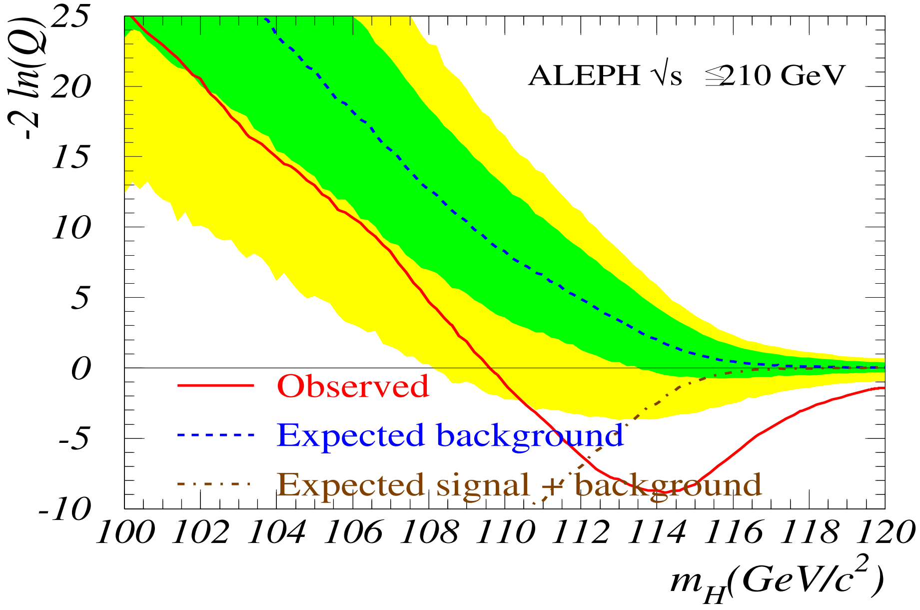
$$-2\ln(Q) \sim \sum \underbrace{\ln(1+s_i/b_i)}$$

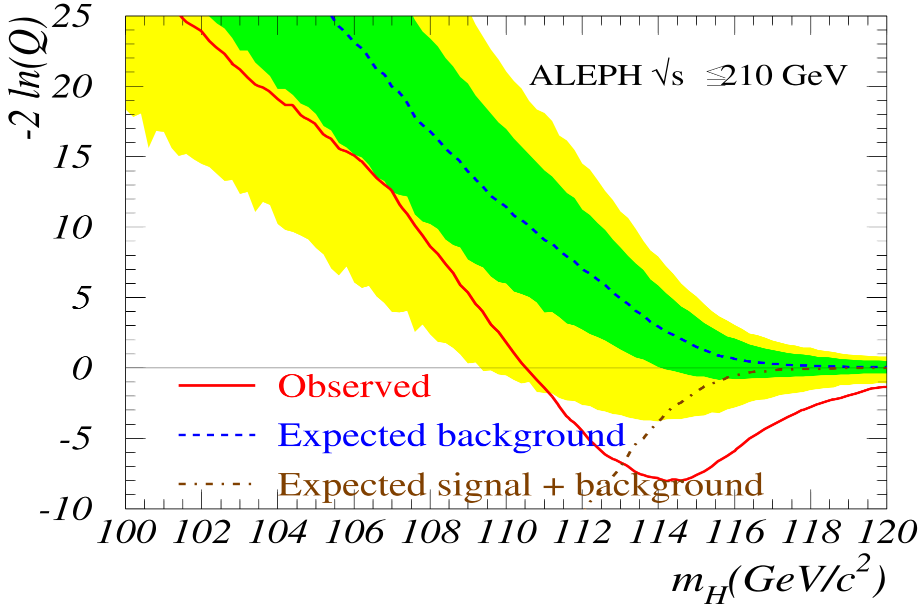
indicator of event weight



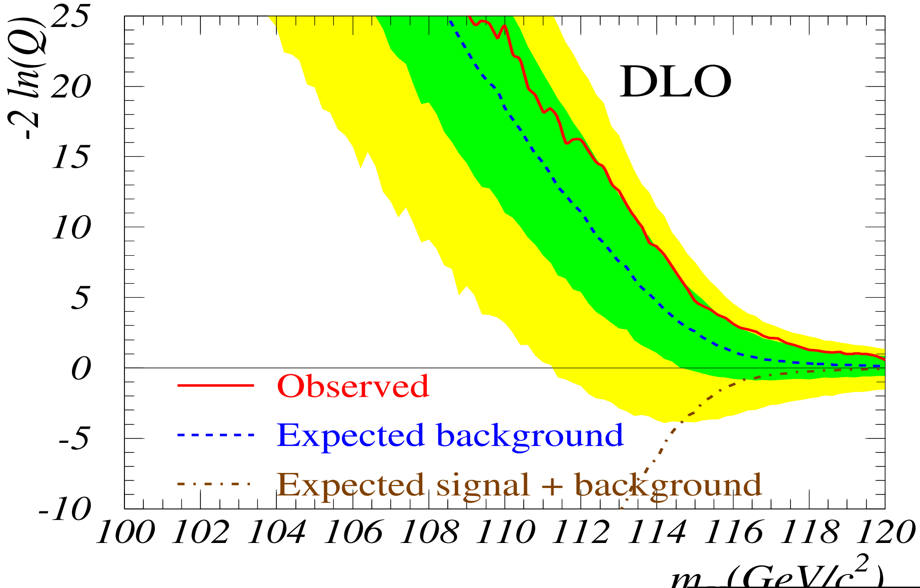


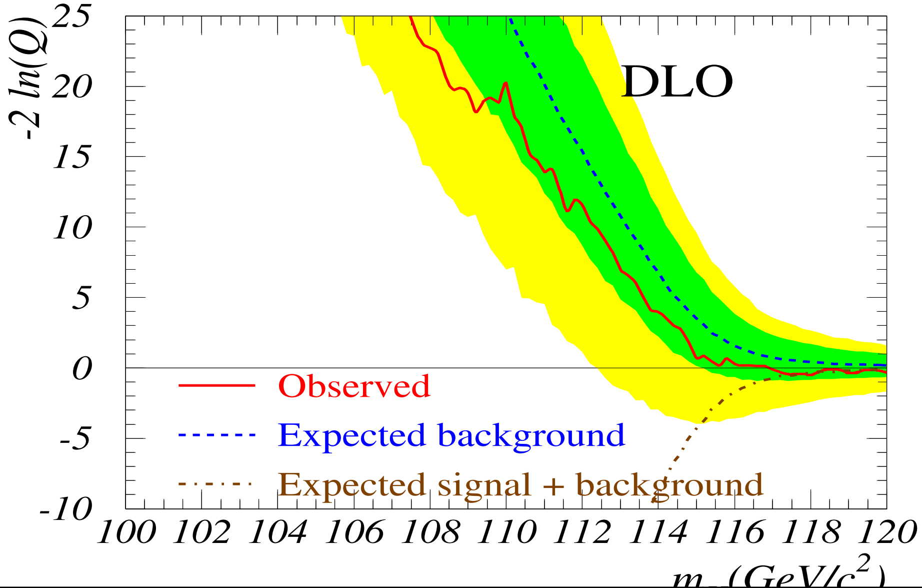
ALEPH ⇔ DLO





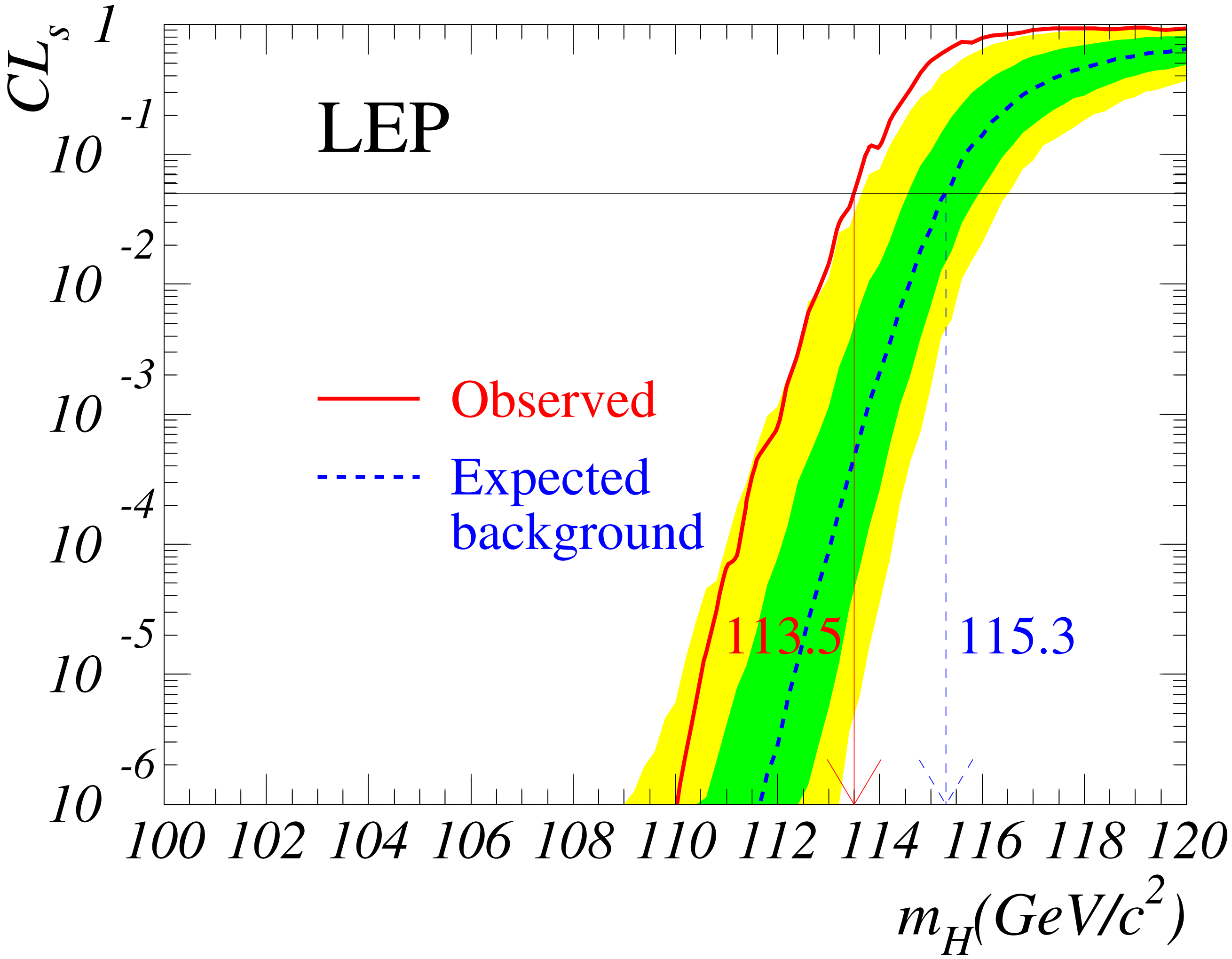
REFERENCE (Sept.5) ⇒ **TOTAL**





SM Higgs Mass Limit

(Nov.3, 2000 ... 'TOTAL' data sample)



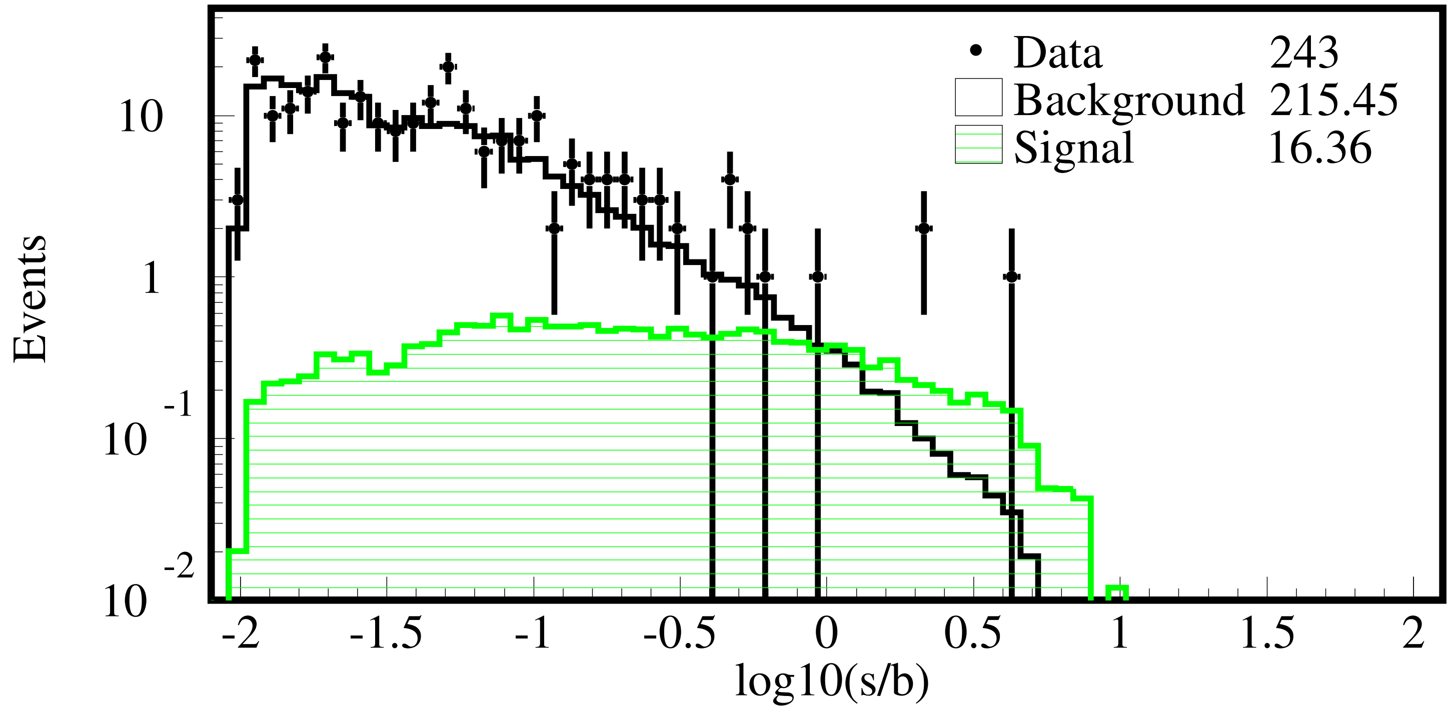
obs: $m_H > 113.5$ **GeV** @ 95% CL

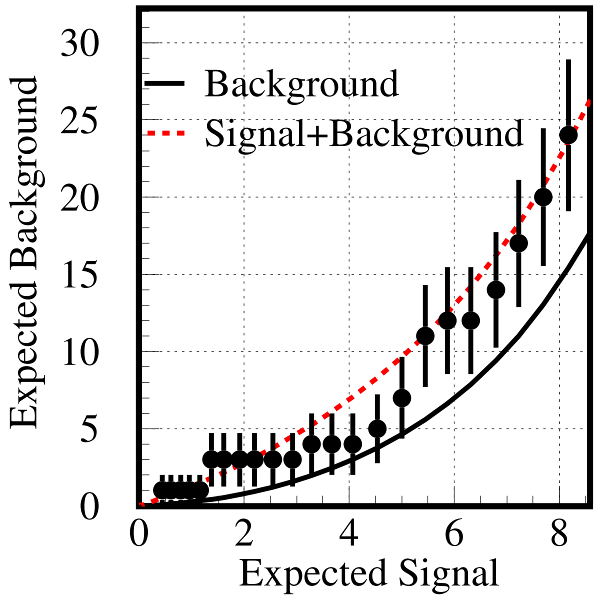
exp: $m_H > 115.3$ **GeV**

Distribution of Event 'Weights'

@ $\mathrm{m}_{\mathrm{H}}^{\mathrm{test}}$ = 115 GeV

'Bkgd'-like or 'Signal+ Bkgd'-like ?





'Signal' significance ...

equally split between

5 events with highest weights

$\Leftrightarrow$

rest of the events

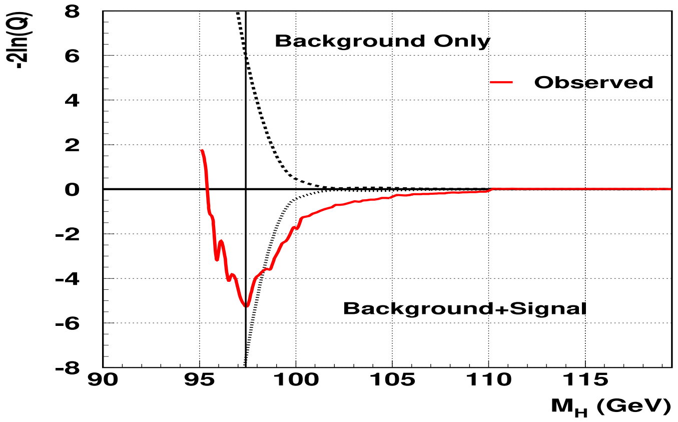
for $s/b \geq 0.7$

ADLO	Bkgd	Signal	Cand.
4-jet	0.93	1.60	3
E-miss	0.30	0.46	1
e,μ	0.35	0.68	0
τ	0.14	0.29	0
TOTAL	1.72	3.03	4

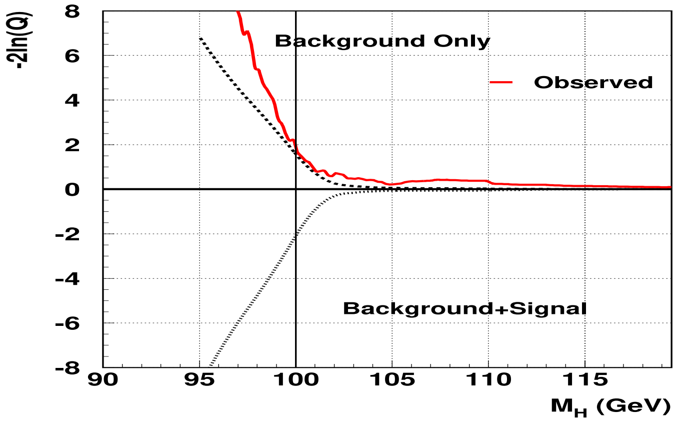
Systematic Effect Close to Kinematic Limit ?

$$m_{limit} = \sqrt{s} - m_{Z^0} - 1\ \text{GeV}$$

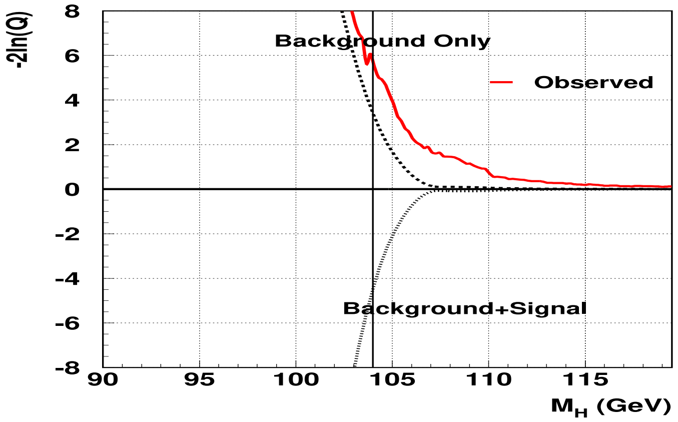
$\sqrt{s} = 189$ GeV



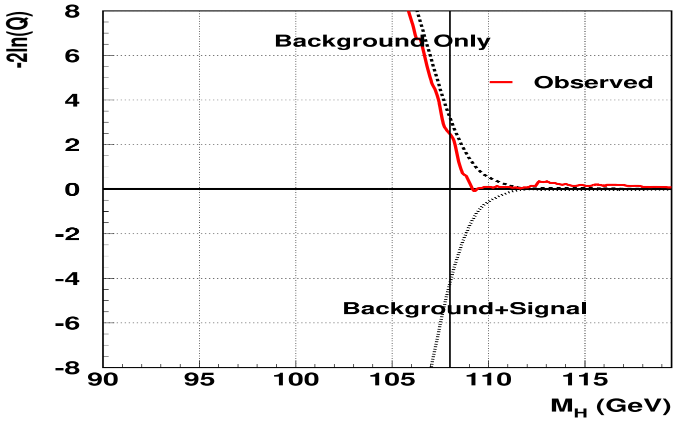
$\sqrt{s} = 192$ GeV



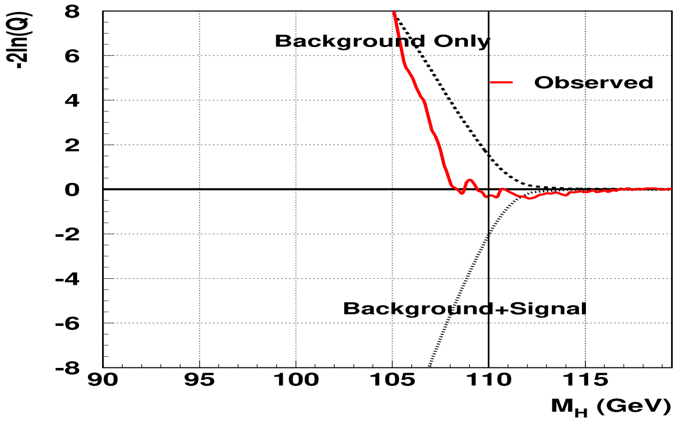
$\sqrt{s} = 196$ GeV



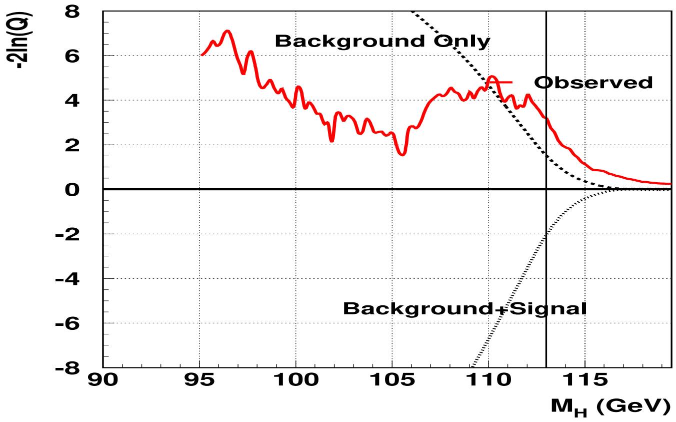
$\sqrt{s} = 200$ GeV



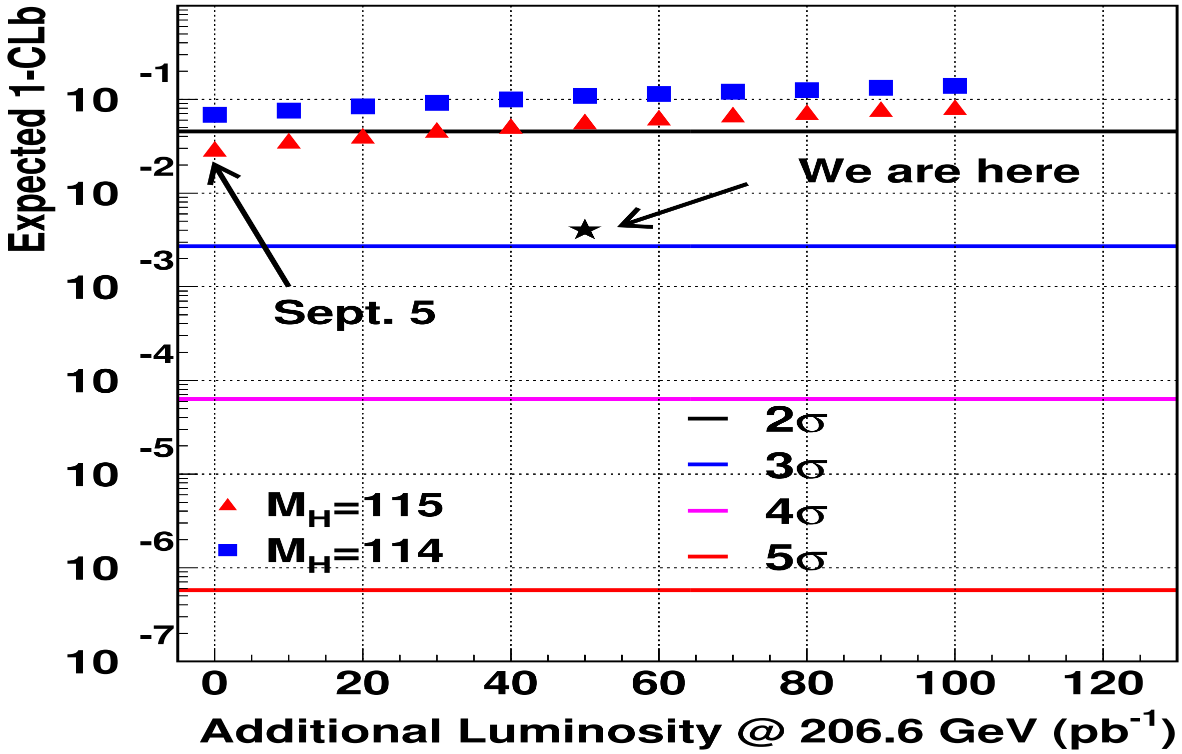
$\sqrt{s} = 202$ GeV



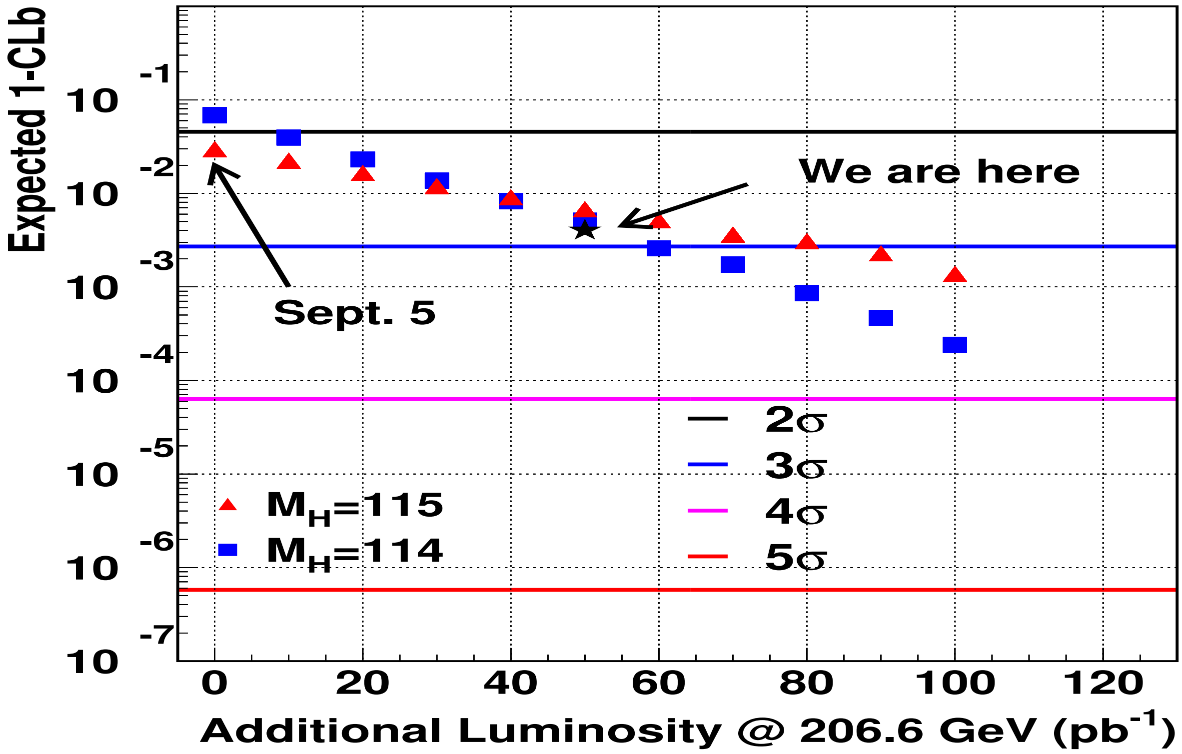
$\sqrt{s} = 205$ GeV



If accumulating background only ...

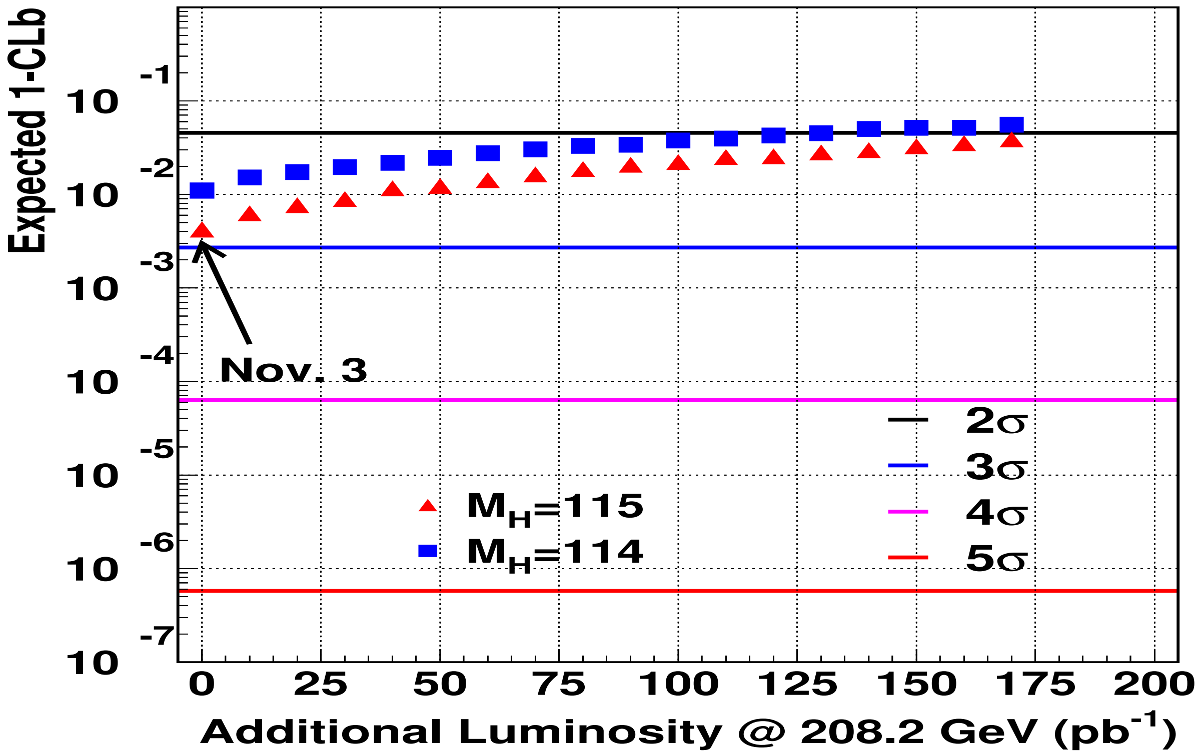


If accumulating signal + background ...

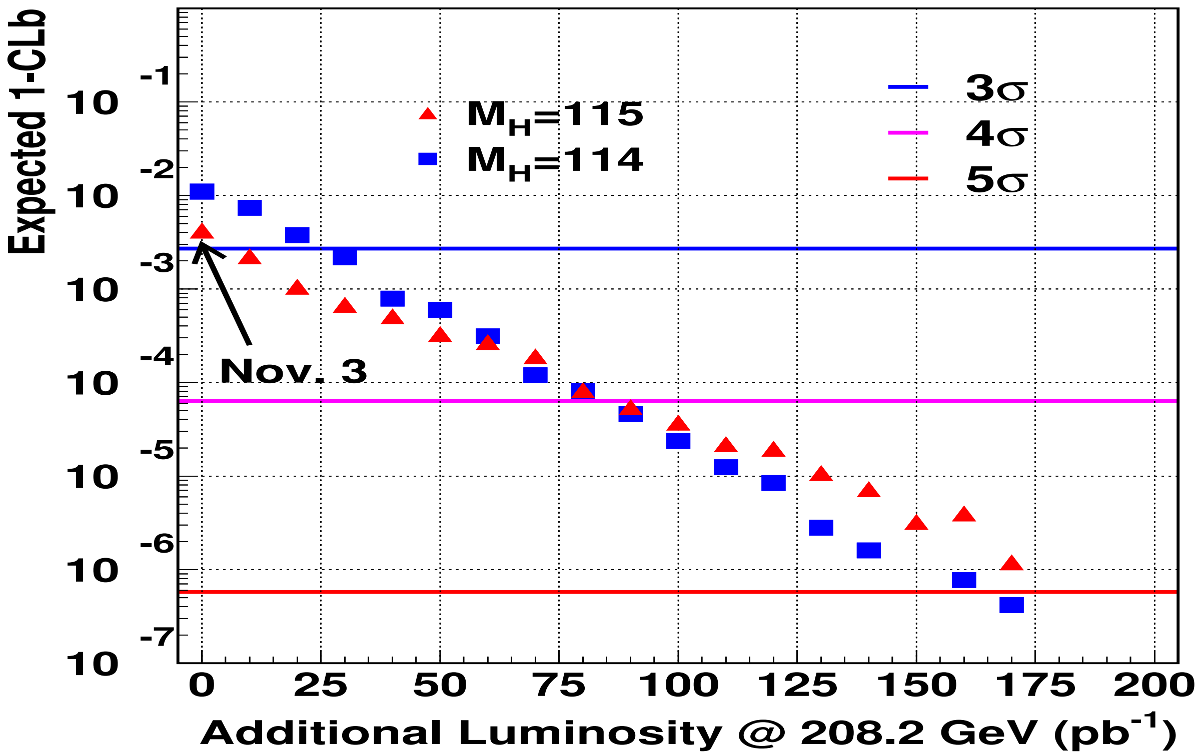


The 'Road-Map' ... Running at $\sqrt{s}$ = 208.2 GeV

If accumulating background only ...



If accumulating signal + background ...



SM Higgs Summary

ADLO (3.Nov.2000)

2.9 σ excess

Three expts 's+b'-like

4-jet, E-miss 's+b'-like

Compatibility with

SM Higgs cross section

for

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

Individual expts publication:

Submitted Nov./Dec.2000 ...

ALEPH	PLB 495 (2000) 1
DELPHI	PLB 12.Jan. (2001)
L3	PLB 495 (2000) 18
OPAL	PLB 12.Jan. (2001)

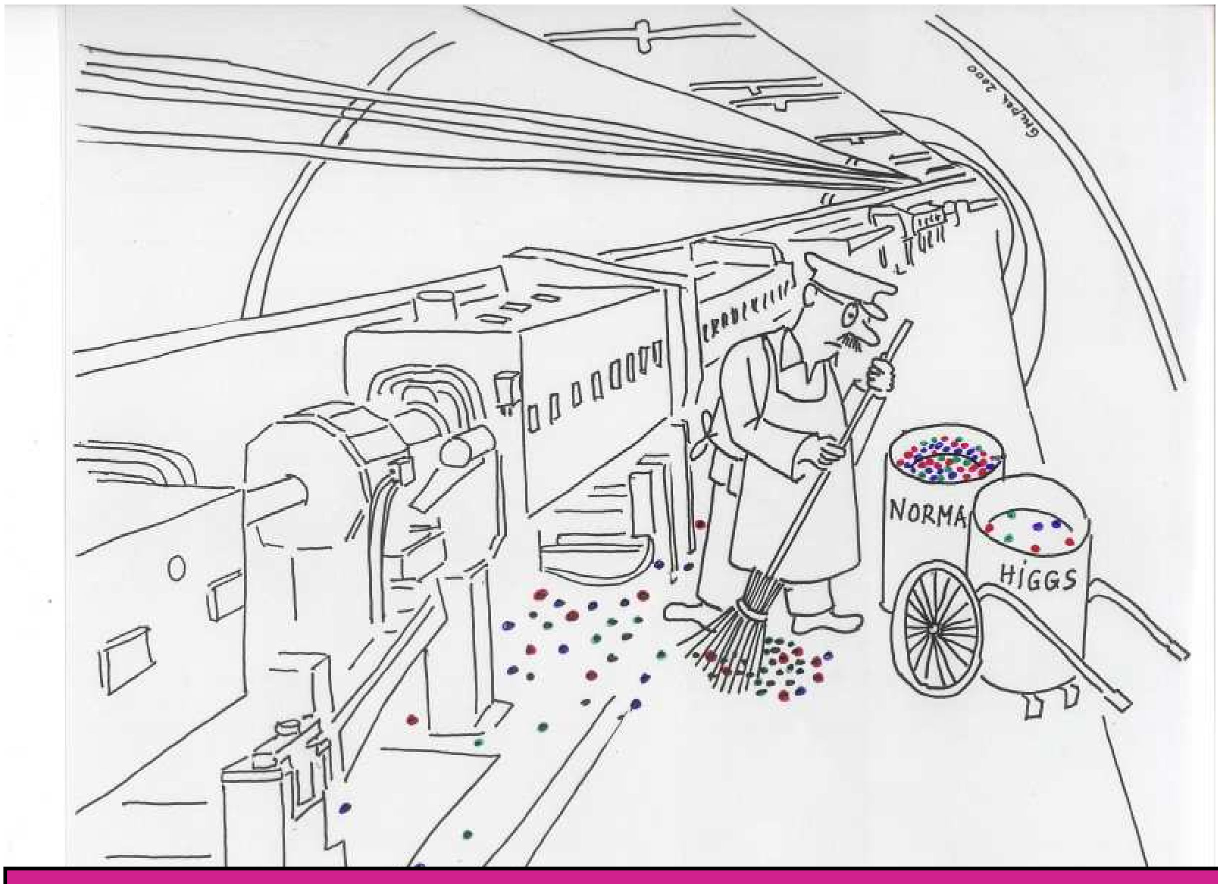
New ADLO combination ...

LEP-HWG publication imminent

Current mass bounds @ 95% CL :

obs: $m_H > 113.5$ GeV

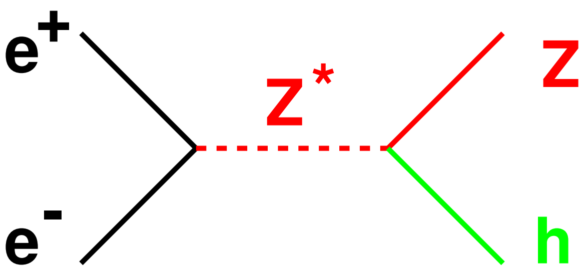
exp: $m_H > 115.3$ GeV

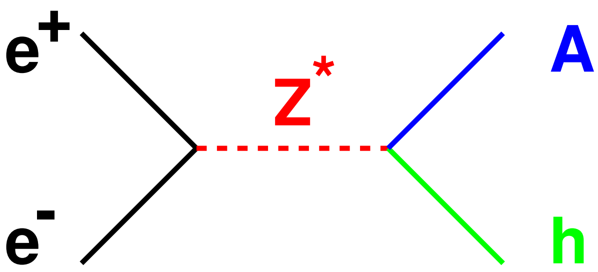


The Higgs Sector in the MSSM

Two Higgs Doublets $\mathcal{H}_1$, $\mathcal{H}_2$ and 5 physical states

2 CP-even neutral Higgses	$\mathrm{h^0, H^0}$	$\mathrm{m_h < m_H}$
1 CP-odd neutral Higgs	$\mathrm{A^0}$	
2 charged Higgses	$\mathrm{H^\pm}$	
Free parameters:	$\tan\beta = v_2/v_1$	(VEV ratio)
	α	(mixing angle of h, H)
	μ	Higgs mass parameter
	A_0	common trilinear Higgs-sfermion coupling
tree level:	$\mathrm{m_h < m_Z < m_H}$	
rad.corrected:	$\mathrm{m_h < 130}$ GeV	





"Higgsstrahlung"

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

- largest at small $\tan\beta \approx 1.4$
- SM topologies
- recycle SM searches

"Associated Production"

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

- largest at $\tan\beta > 15$
- typically $\mathrm{m_A \approx m_h}$
- new topologies
- dedicated searches:

$\mathrm{hA \rightarrow b\bar{b}b\bar{b}, hA \rightarrow \tau^+\tau^-b\bar{b}}$

- also $\mathrm{h^0 \rightarrow A^0A^0}$ and $\mathrm{h^0, A^0 \rightarrow \chi^0\chi^0}$ (invisible)

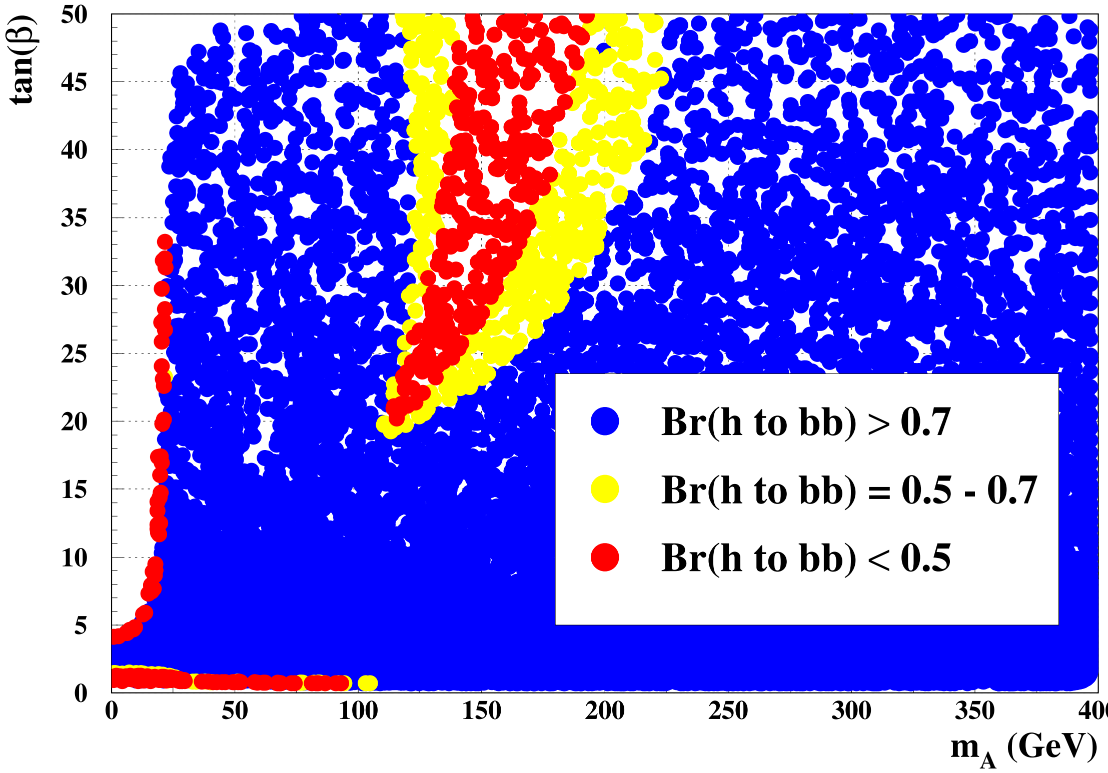
The Benchmark Scans

m_A and $\tan\beta = v_2/v_1$ varied ...
other parameters fixed or related to each other
$m_h(m_A, \tan\beta)$ calculated ...

(A) 'No mixing' ... in $\tilde{t}_L - \tilde{t}_R$ sector
$X_t = A - \mu \cot\beta = 0$
... reduced parameter space

(B) 'Max m_h' ... large mixing ... $X_t \approx 1$ TeV
... extended parameter space
$\Rightarrow$ Conservative limits

(C) 'Large μ'
... pathological points with $Br(h \longrightarrow b\bar{b}) \ll 1$
$\Rightarrow$ Flavour independent analyses



M. Carena,
S. Heinemeyer,
C. Wagner,
G. Weiglein

(hep-ph/9912223)

The Benchmark Scans (cont'd)

Comparison of :

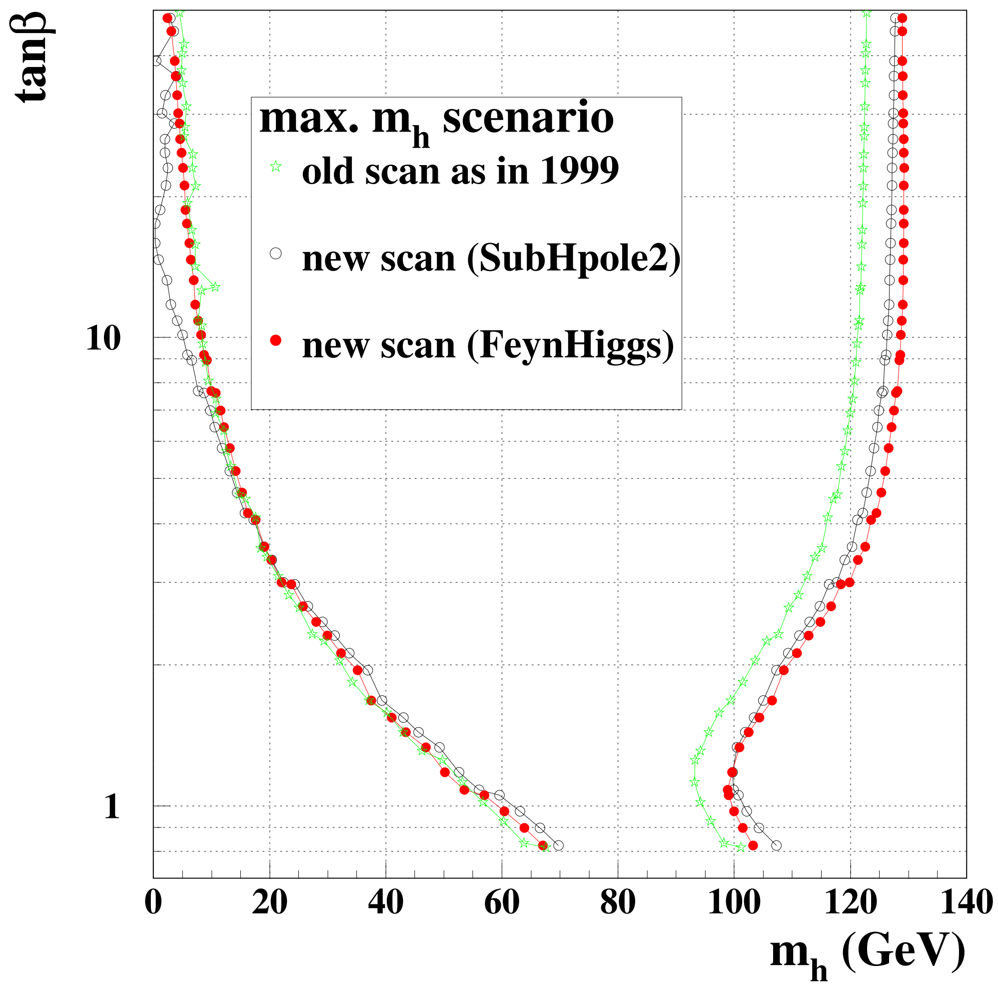
SubHpole2 **by M. Carena, M. Quiros and C.E.M. Wagner**

RGE approach

FeynHiggs **by S. Heinemeyer, W. Hollik, G. Weiglein**

Diagramatic approach,

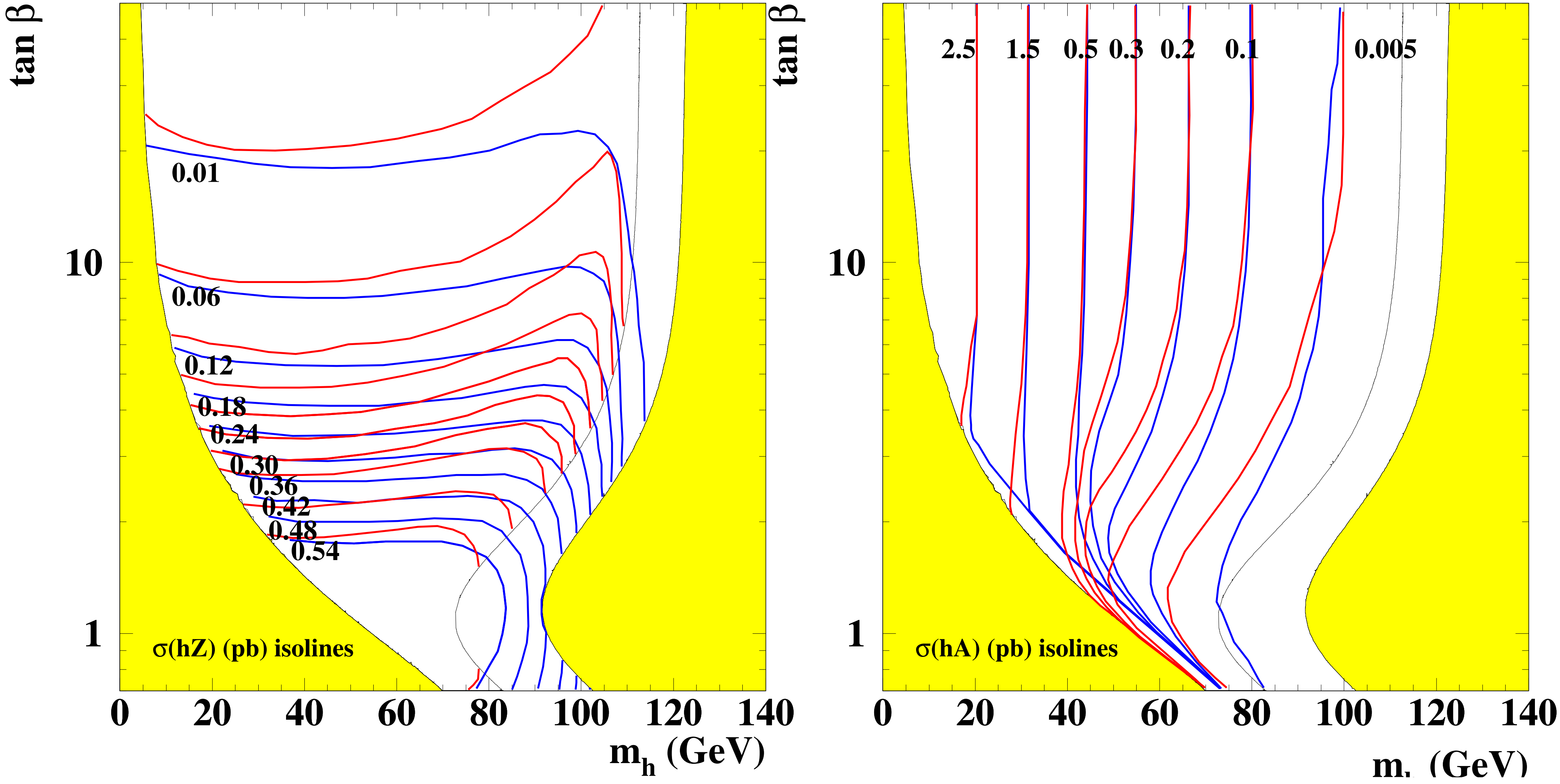
more generic 2-loop terms



⇒ Use FeynHiggs in HZHA3.0 for scans (A) and (B)

⇒ Conservative $\tan\beta$ exclusion

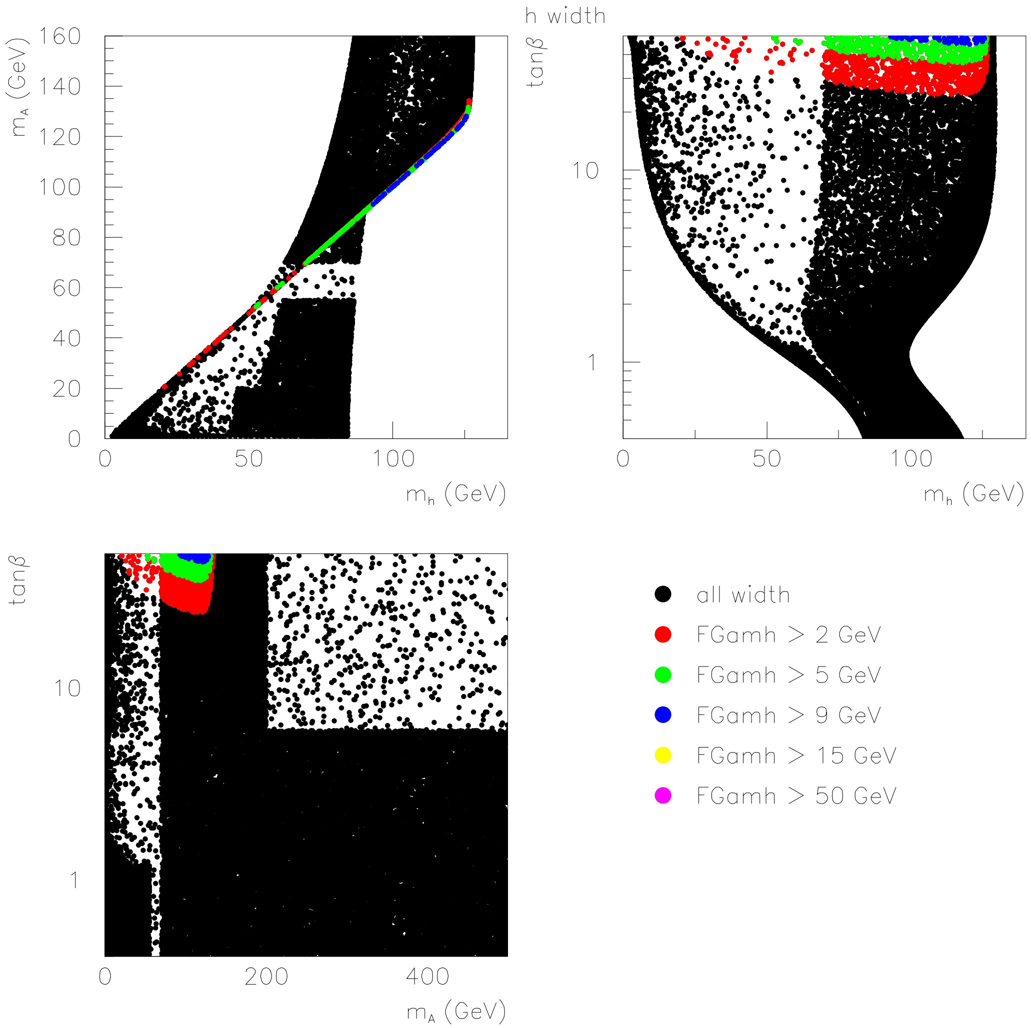
Cross-Section Isolines



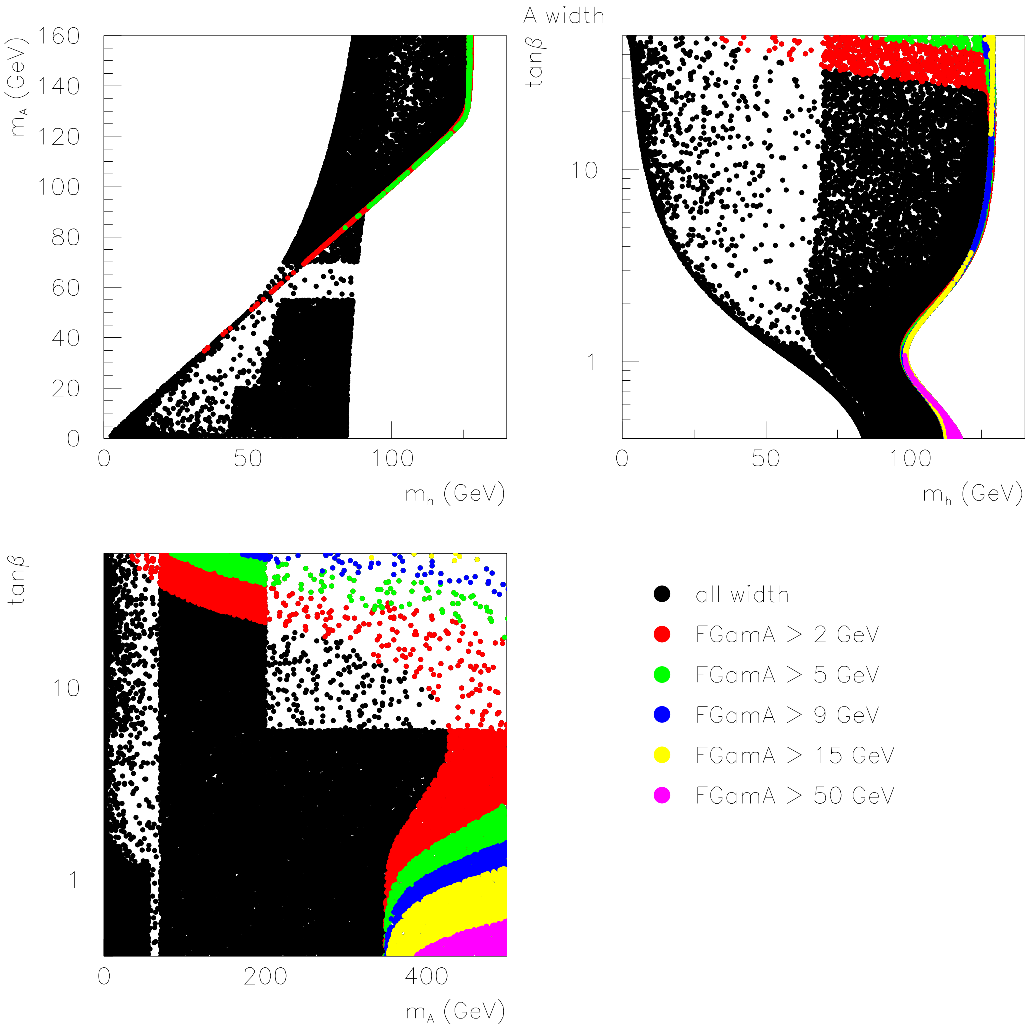
▷ hZ- and hA-production complementary

Higgs Width

h width



A width



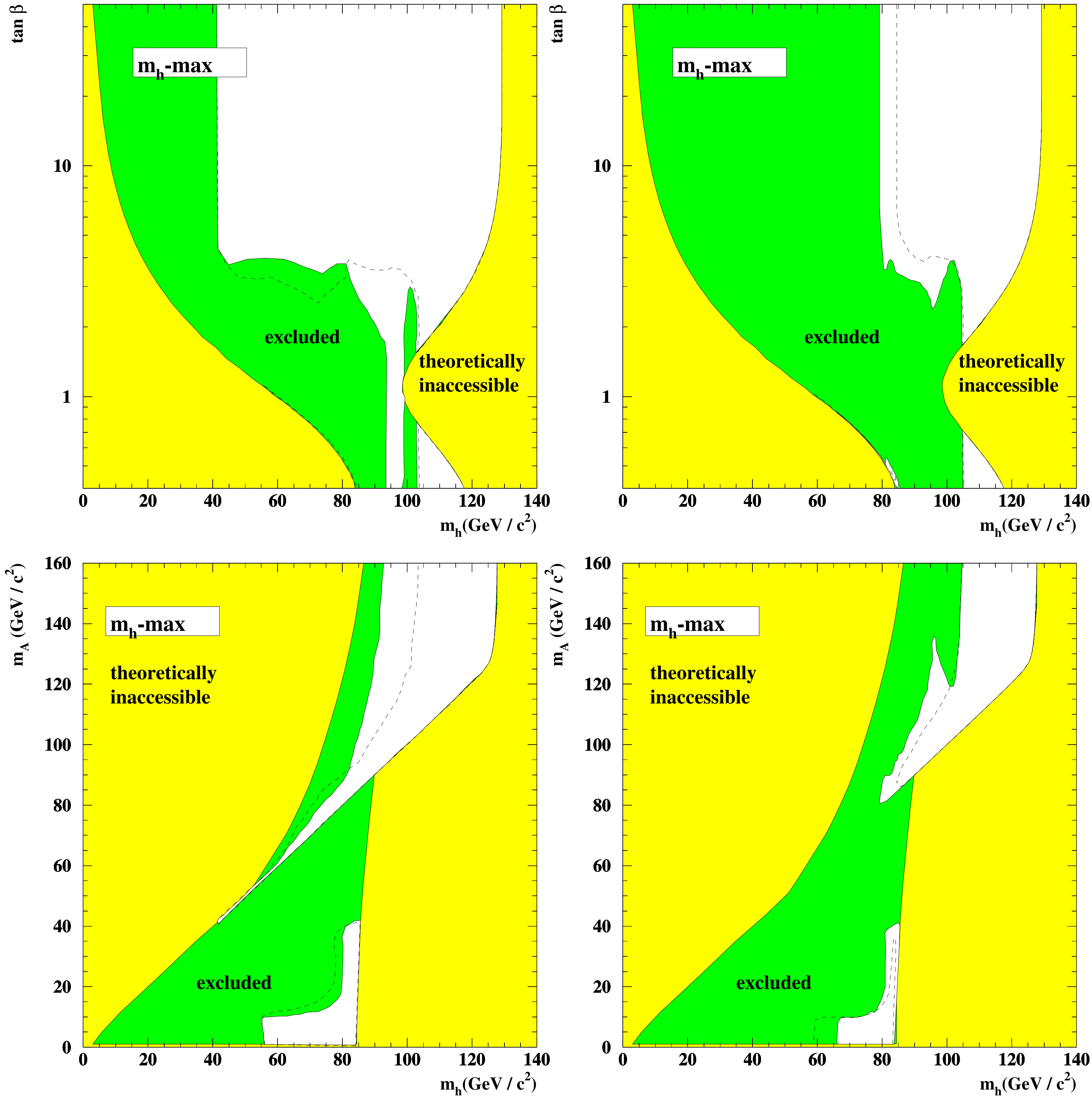
▷ **widths to be considered for scans at $\tan\beta > 30$ or large m_A**

Single Channels in the MSSM

OPAL data up to 1999 ($\sqrt{s} \leq 202$ GeV)

... only for demonstration ...

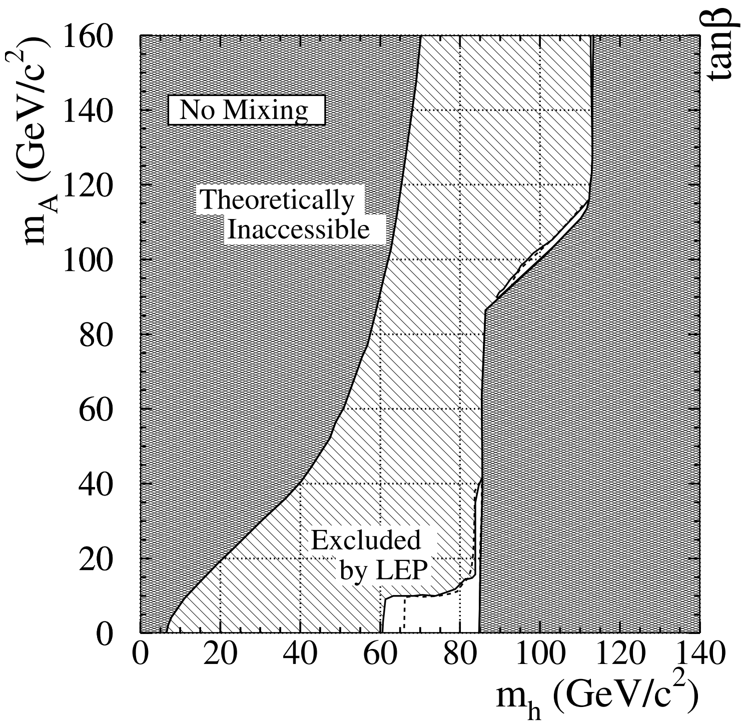
4jet-ZH only | **all channels**

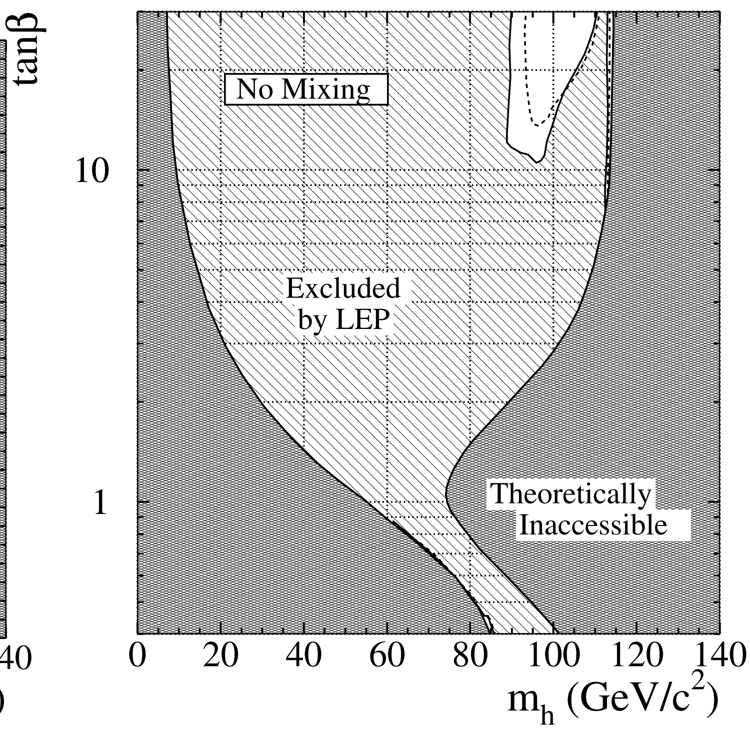


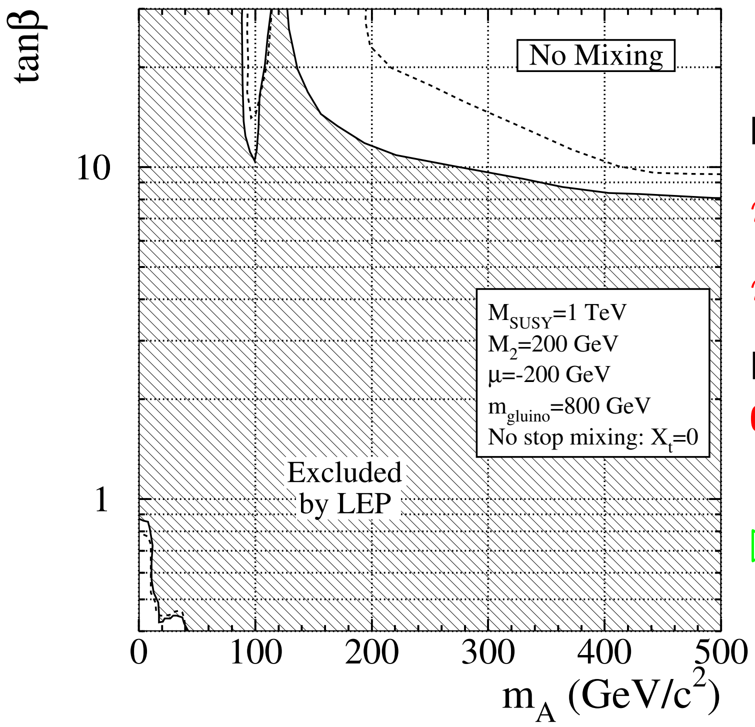
▷ need all channels in combination !

LEP Results : No-Mixing scenario

LEP-HWG, Osaka 2000







Mass limits at 95% Cl ...

$m_h > 90.4$ **GeV** $\quad (\tan\beta > 0.9)$

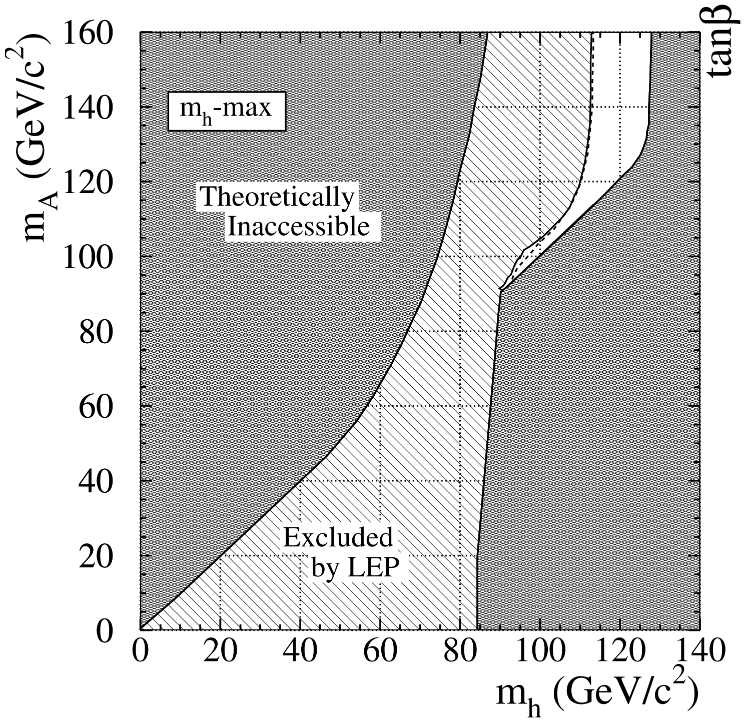
$m_A > 90.5$ **GeV** $\quad$ **(... ... ...)**

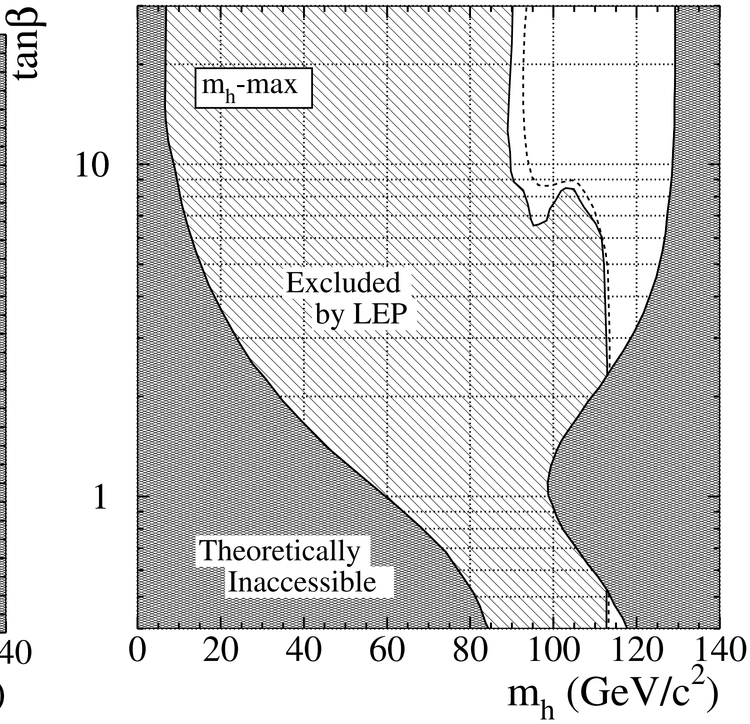
Exclusion in $\tan\beta$ ...

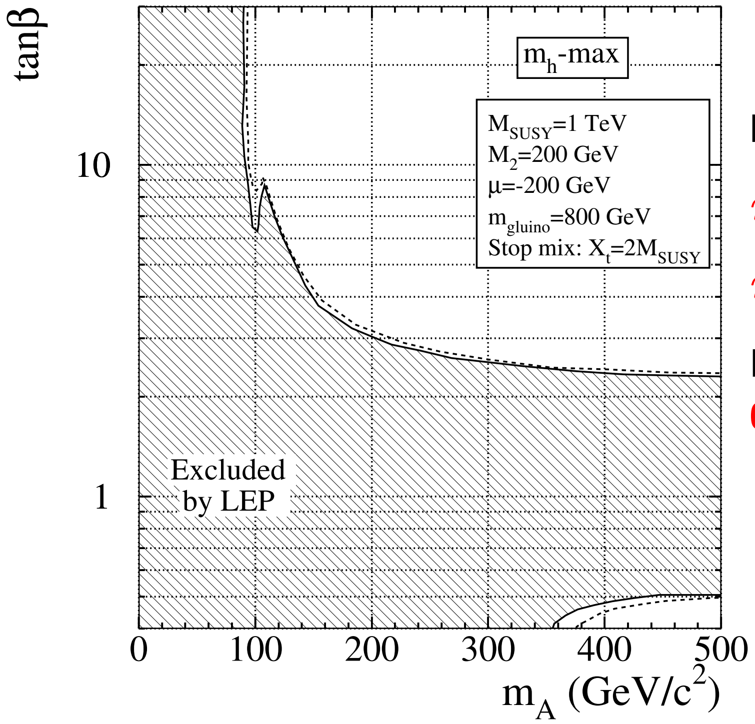
0.9 - 7.7 $\quad (m_{top} = 174.3$ **GeV)**

▷ **Almost entirely excluded**

LEP Results : Max-m_h scenario







Mass limits at 95% CI ...

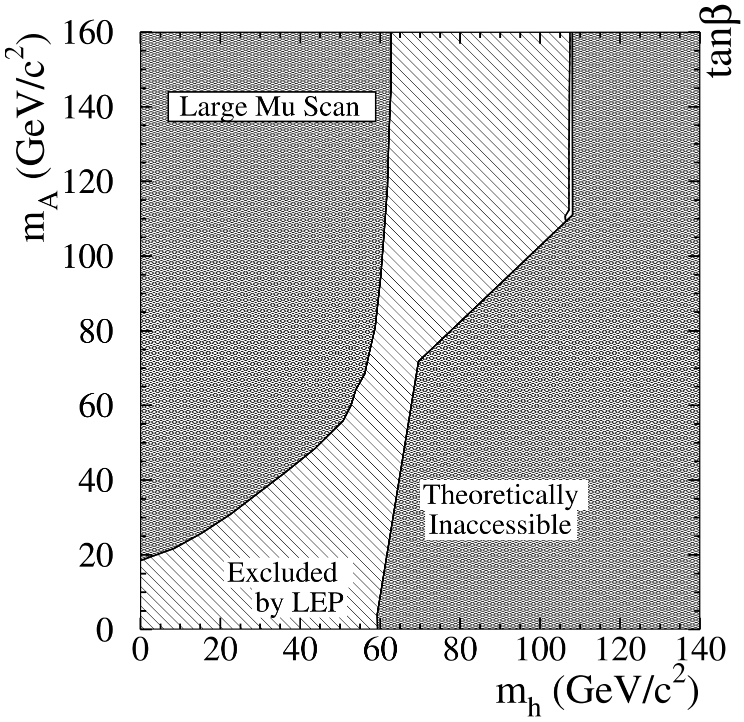
$m_h > 90.5$ **GeV** $(\tan\beta > 0.9)$

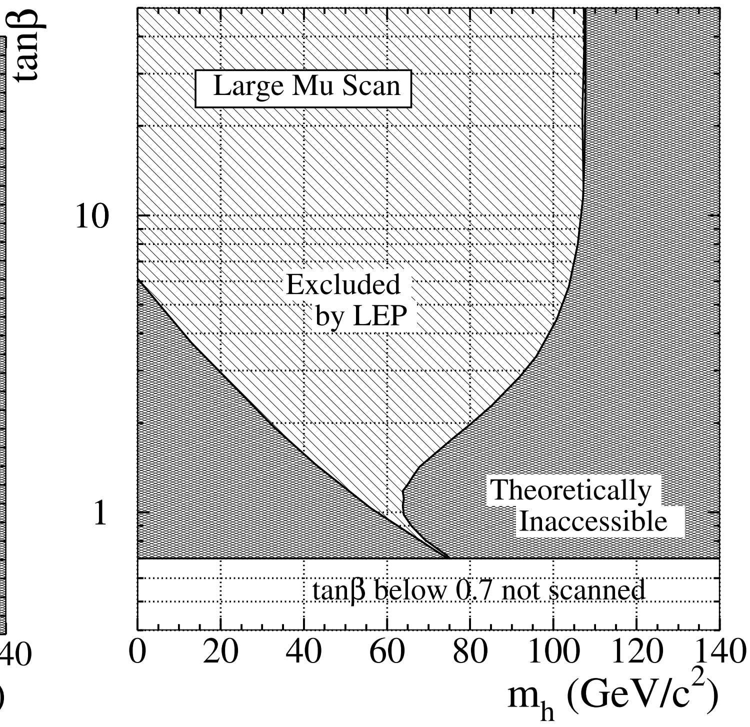
$m_A > 90.5$ **GeV** **(... ... ...)**

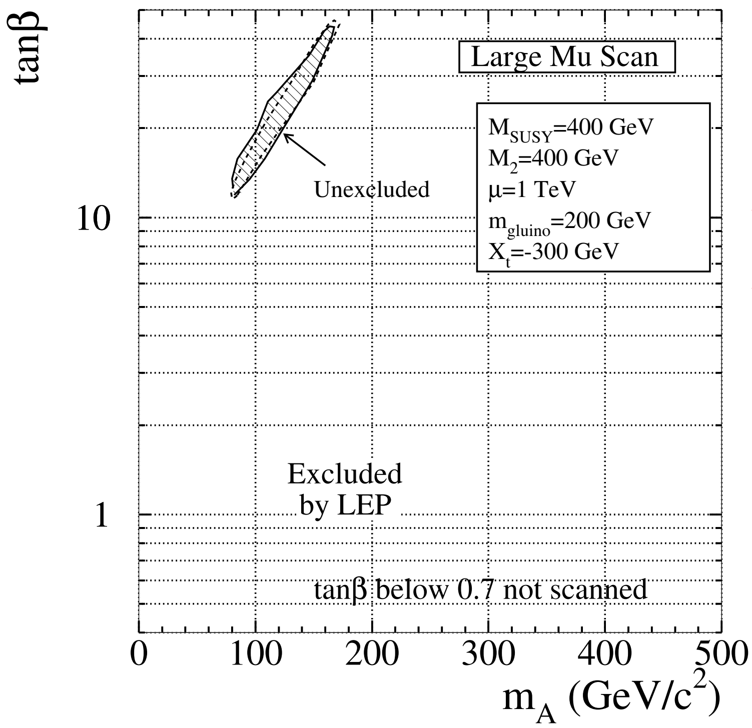
Exclusion in $\tan\beta$ ...

0.5 - 2.3 ($m_{top} = 174.3$ **GeV)**

LEP Results : Large-μ scenario







Mass limits at 95% Cl ...

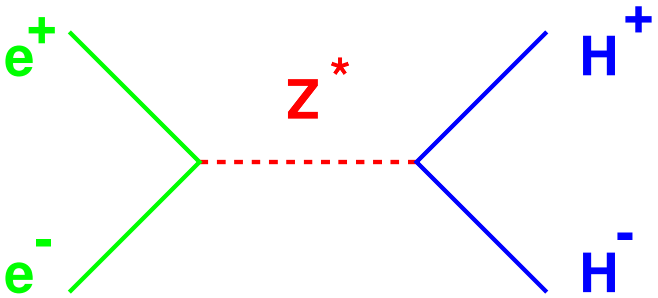
$m_h \not\simeq 108$ **GeV**

$m_A \not\simeq 90 - 170$ **GeV**

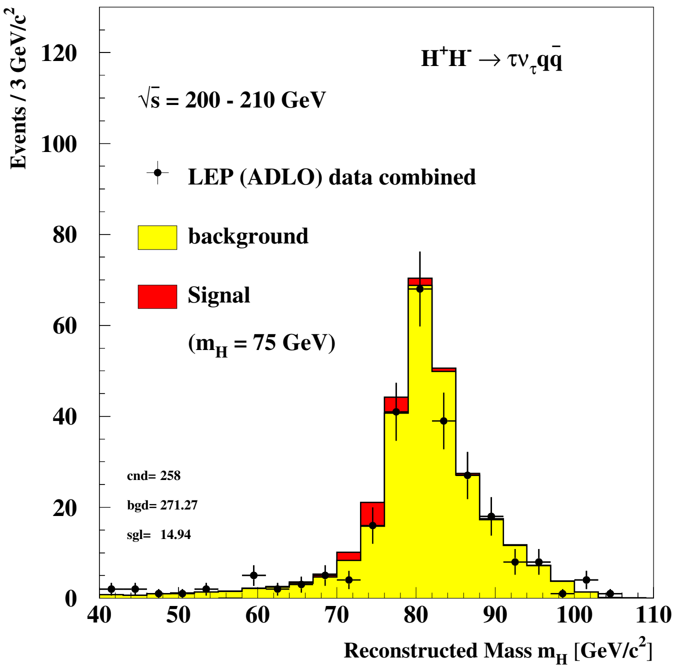
Need flavour independent analyses

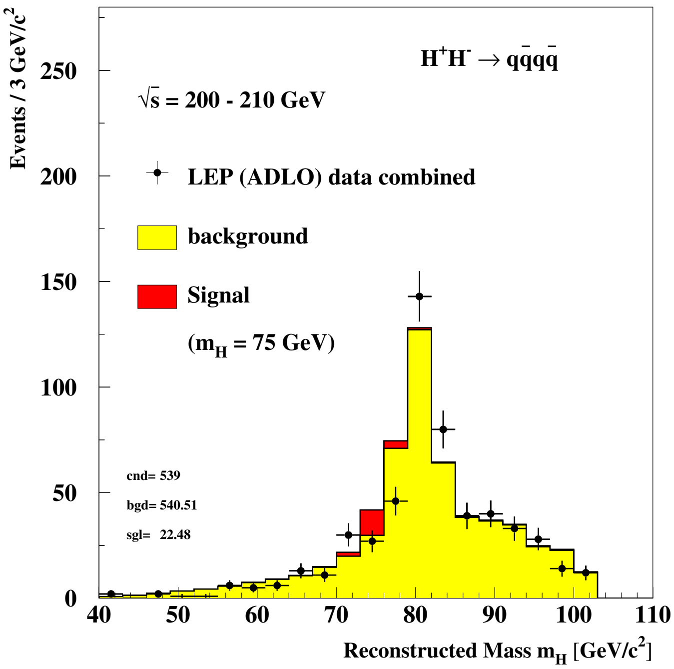
Charged Higgs at LEP

- Two Higgs Doublet Models - **Type II** ...
  down / up fermions couple to $\mathcal{H}_1$ / $\mathcal{H}_2$



- in the MSSM at tree-level: $\mathrm{m_{H^\pm}} > \mathrm{m_{W^\pm}}$
- rad. corrections can yield $\mathrm{m_{H^\pm}} < \mathrm{m_{W^\pm}}$
- decays to $\mathrm{H}^\pm \longrightarrow \tau^\pm\nu, \mathrm{c\bar{s}}$
- Background from $e^+e^- \longrightarrow W^+W^-$
- Assume: $Br(H^+ \longrightarrow \tau\nu_\tau) +$
  $$Br(H^+ \longrightarrow c\bar{b}) = 1$$

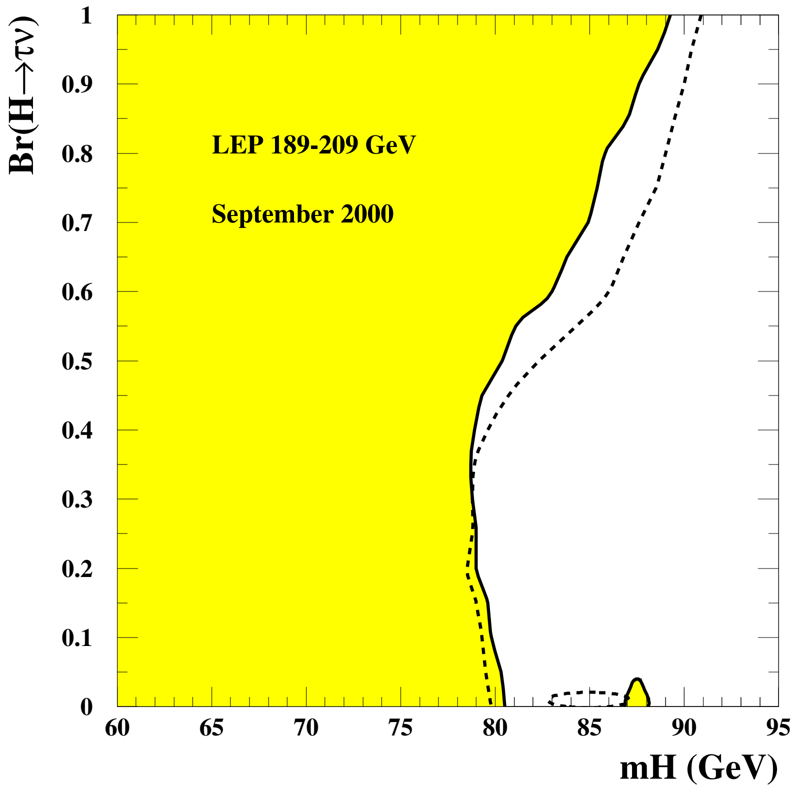




Charged Higgs Search Results

ADLO : Mass limit @ 95% CL for any Br($\tau\nu$) ...

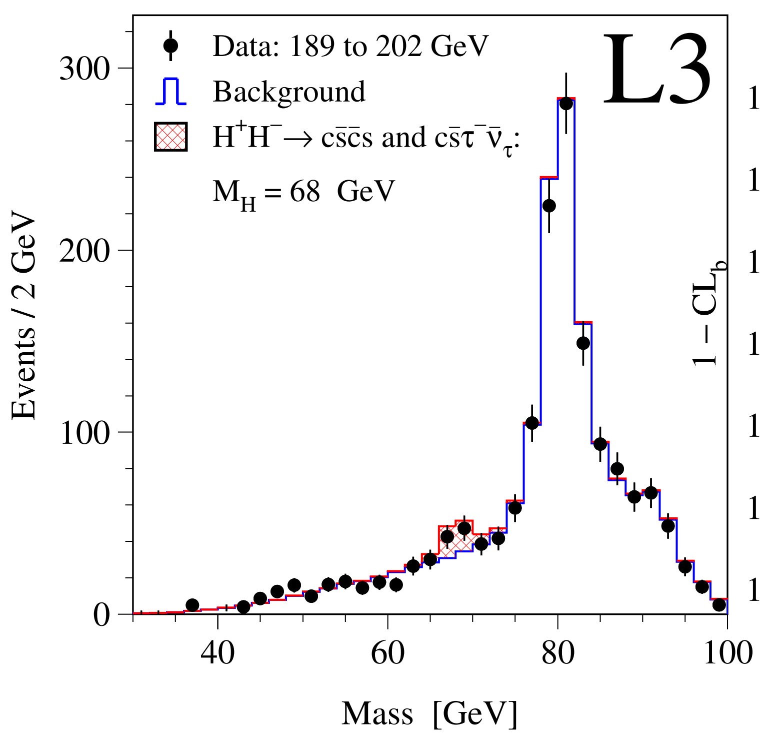
$m_{H^\pm} > 78.7$ **GeV**

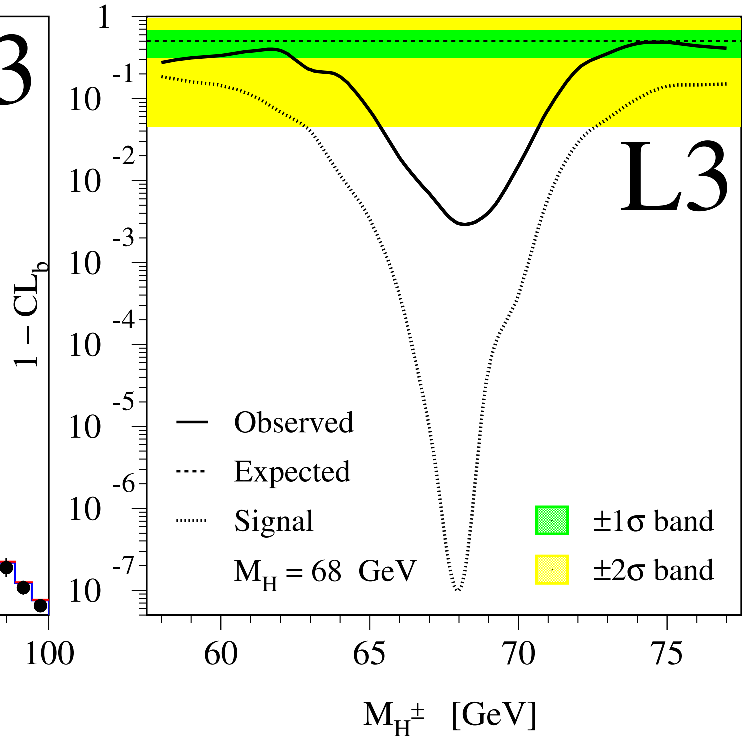


But ...

L3 sees in all data with

$\sqrt{s} > 189$ **GeV :**





▷ **Effect under investigation in all LEP experiments ...**

Fermiophobic Higgs

- Two Higgs Doublet Model - Type I ...

  all fermions couple to $\mathcal{H}_1$

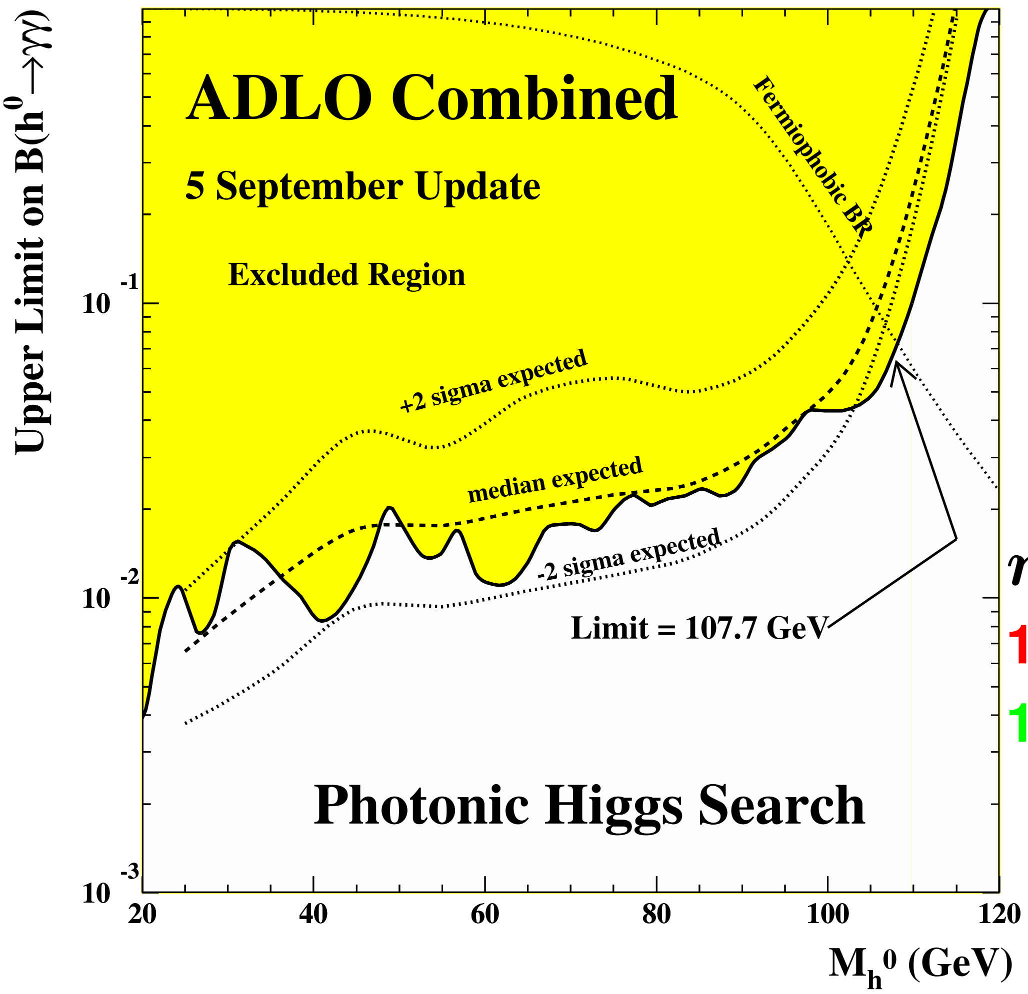
  $g_{Hf\bar{f}} \sim \cos\alpha \Rightarrow$ fermiophobic for $\alpha = \pi/2$

  ▷ Enhancement of bosonic decays ... $h^0 \rightarrow \gamma\gamma$

  (In SM Br($h^0 \rightarrow \gamma\gamma$) $\sim 0.1\%$ for m_h = 90 GeV)

- Search for 2 energetic γ + all decay modes of the Z

- Assume SM σ_{hZ}, SM partial width for $h \rightarrow \gamma\gamma$ with Br($h \rightarrow f\bar{f}$) = 0



$m_h >$
107.7 GeV (obs.)
105.8 GeV (exp.)

Invisible Higgs Decays

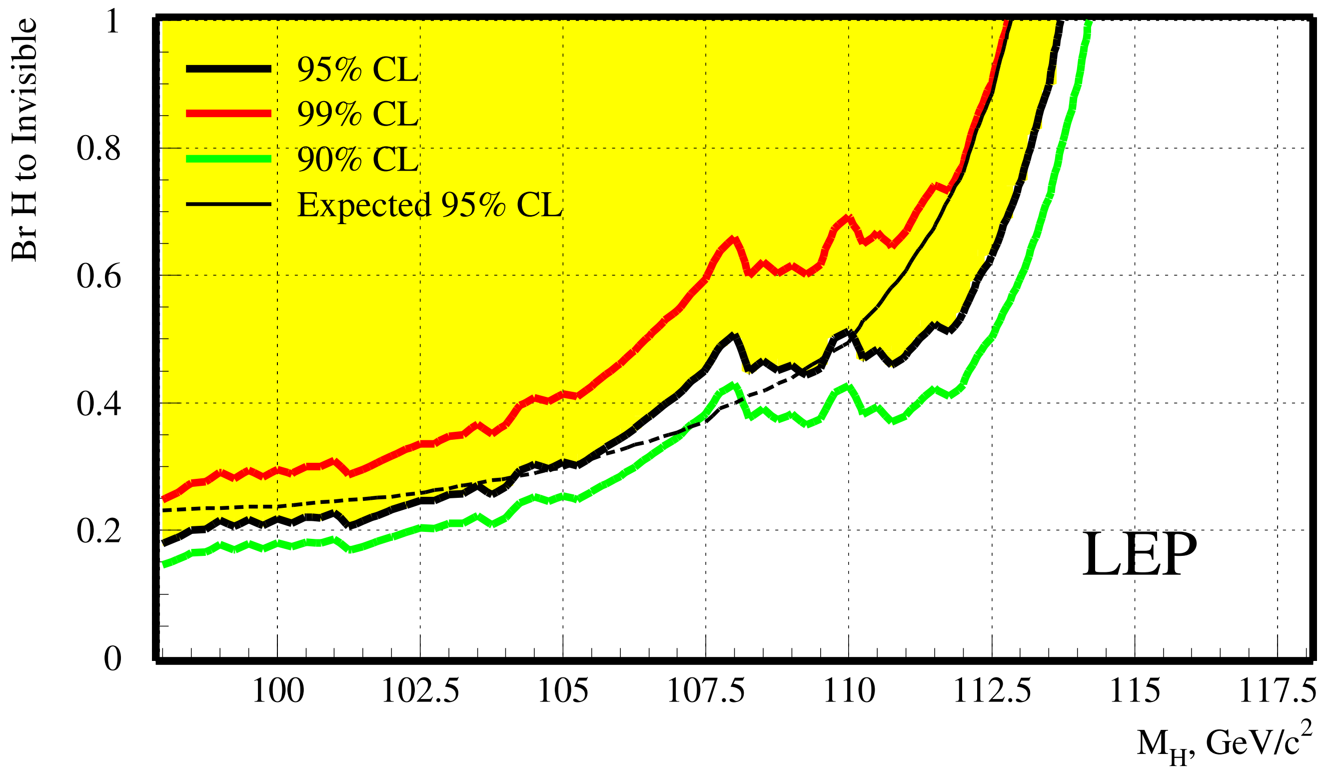
- Invisible Higgs decay ... $h^0 \rightarrow \tilde{\chi}^0 \tilde{\chi}^0$

$$e^+e^- \longrightarrow Z^0 h^0$$
$$\hookrightarrow q\bar{q},\ l^+l^-$$

$\Rightarrow$ Search for acoplanar leptons or jets

assuming $\sigma = \sigma_{hZ}^{SM}$ for Br($h \longrightarrow invis$) = 1

$m_h >$ 113.7 GeV (obs.)
112.8 GeV (exp.)



CP Violating MSSM Higgs Bosons

M. Carena, J. Ellis, A. Pilaftsis and C.E.M. Wagner **(hep-ph/0003180)** **(hep-ph/0009212)**

CP parities of neutral Higgses may be mixed by rad. effects due to CP-violating interactions of Higgs bosons to t - and b - quarks

$\Rightarrow$ **neutral Higgses H_1, H_2, H_3 mixed CP parities**

$\Rightarrow$ **modified Yukawa couplings to t - and b - quarks**

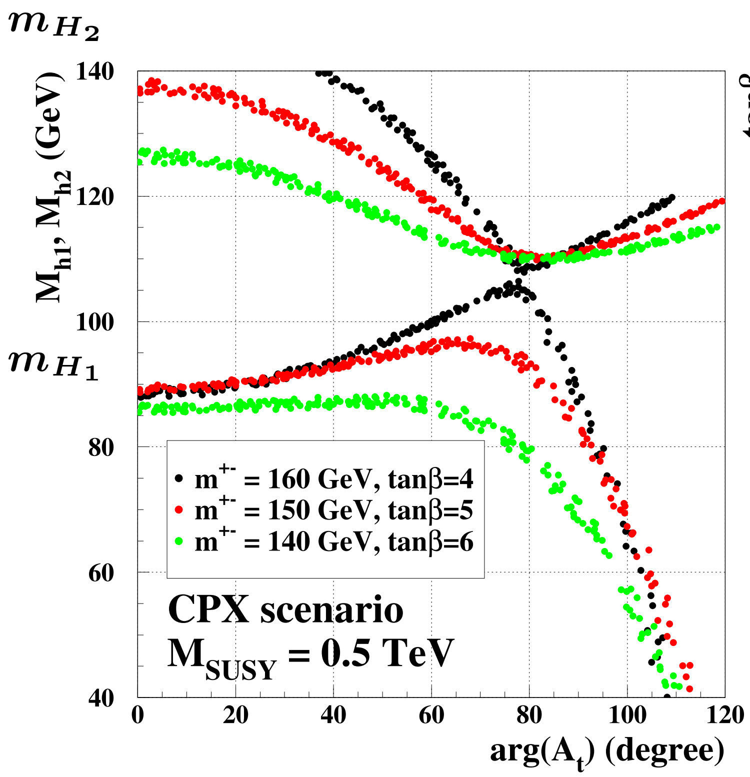
$\Rightarrow$ **parametrize MSSM Higgs sector in terms of M_H^+ and $\tan\beta$**

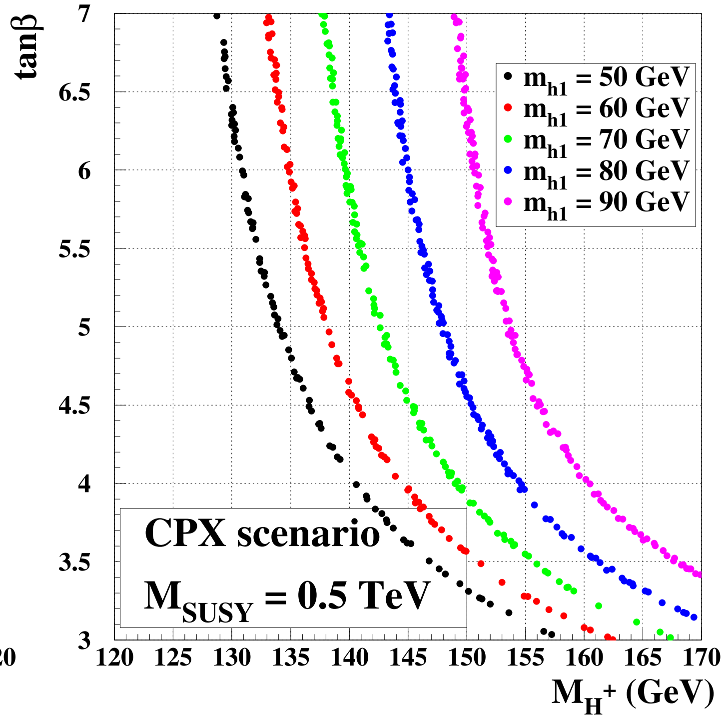
Possible scenario:

m_{H_1} **= 60, 97 GeV**

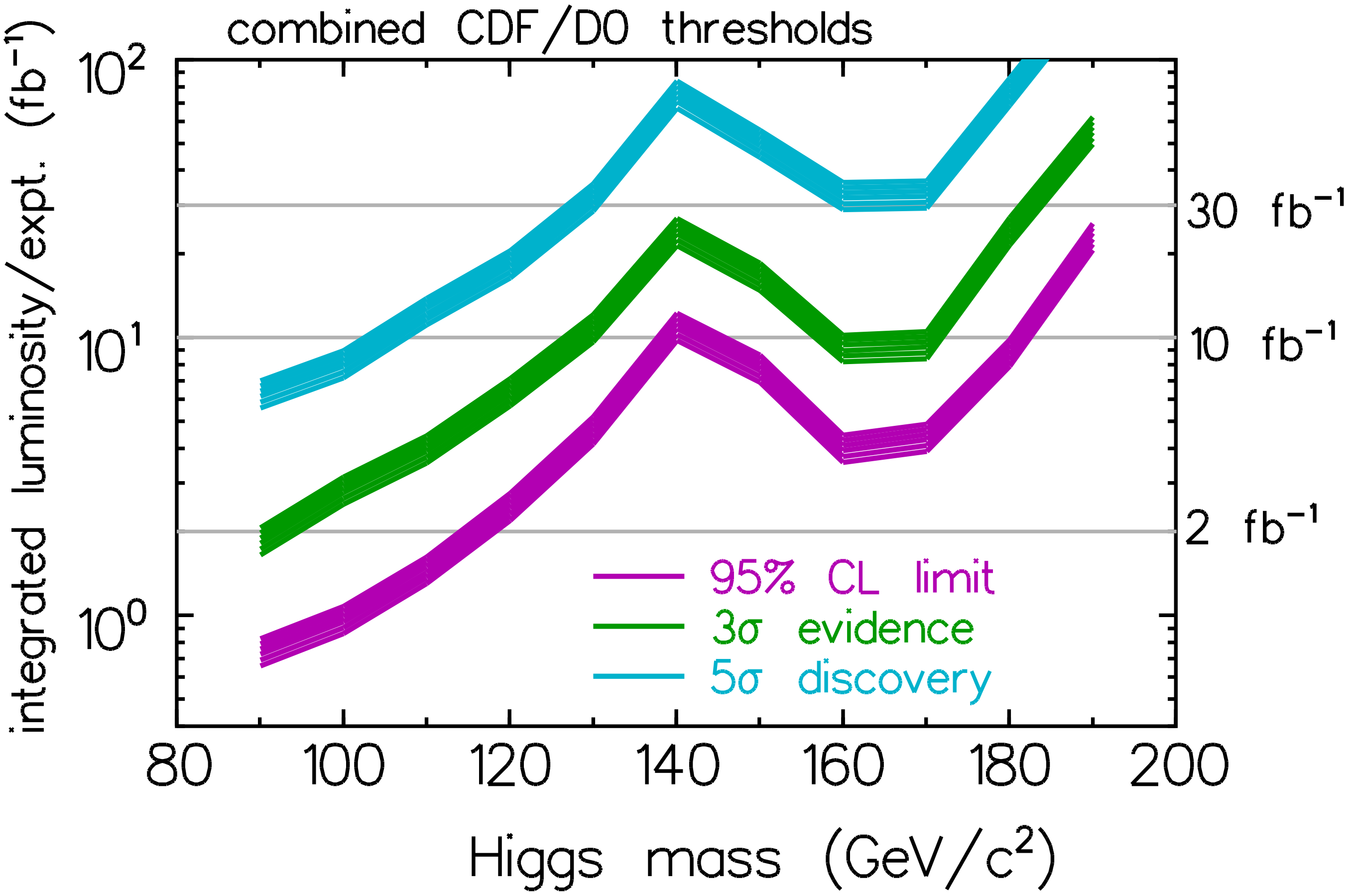
m_{H_2} **= 115 GeV**

... work in progress ...





Tevatron Discovery Potential



Collider / Detector upgrades ...Time profile

Run II ... start March 2001

March 2003 ... 2 fb^{-1} / experiment (CDF, D0)

Shutdown ... 6 months

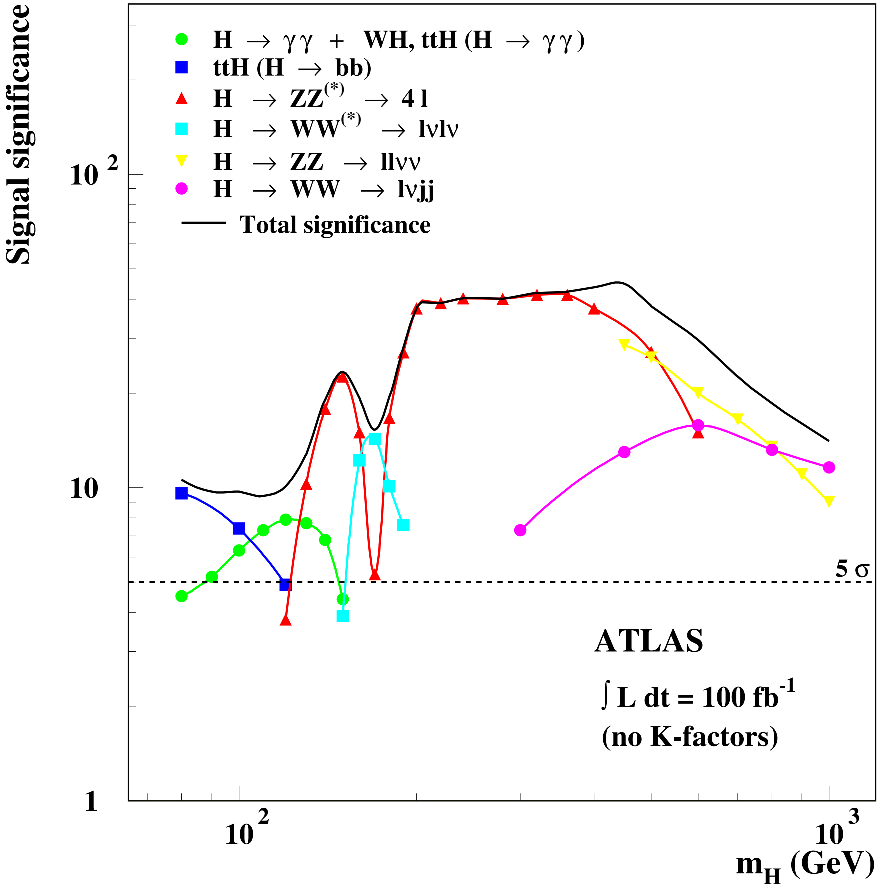
End 2004 ... 6.5 fb^{-1} / expt.

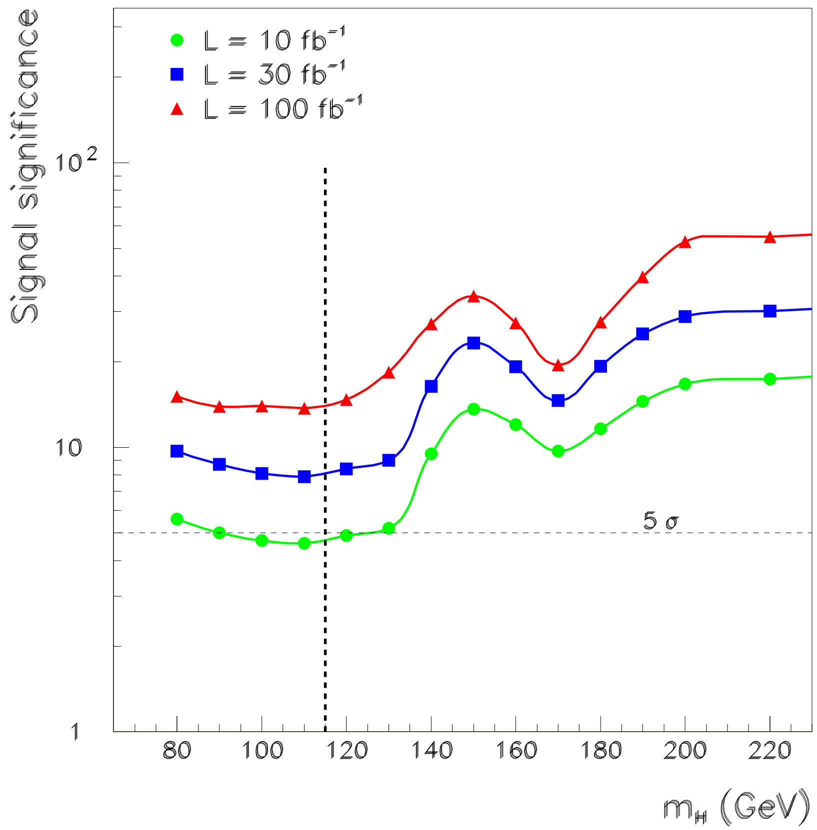
End 2006 ... ≈ 15 fb^{-1} / expt.

LHC Higgs Discovery Potential (SM)

Complex situation @ $m_H = 115$ GeV ... Several prod/decay processes contributing

- $H \rightarrow \gamma\gamma$ + WH, $t\bar{t}$H ($H \rightarrow \gamma\gamma$)
- $t\bar{t}$H ($H \rightarrow b\bar{b}$)





For 5σ discovery ... $10 fb^{-1}$ / expt. $\Rightarrow$ End of 2007

... be prepared for surprises ...