Status of Higgs searches

Higgs Physics at Future Colliders workshop
2004/2005

A.F.Żarnecki
27 X 2004

Precision (pseudo-)observables

Z lineshape (5) $M_Z \quad \Gamma_Z \quad \sigma_h^0 \quad \Gamma_{had}/\Gamma_l \quad A_{FB}^l$

tau polarisation - A_e(1)

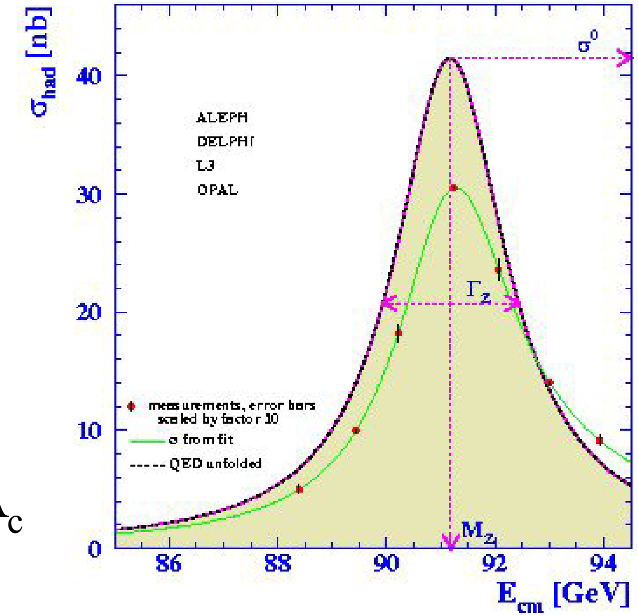
left-right asymm -A_e (1)

Z (b,c) properties (6) $R_b^0 \quad R_c^0 \quad A_{FB}^b \quad A_{FB}^c \quad A_b \quad A_c$

$\sin^2\vartheta_{eff}^{lept}$ (Q_{FB}^{had}) (1)

W properties (2) $M_W \quad \Gamma_W$

top quark mass (1)

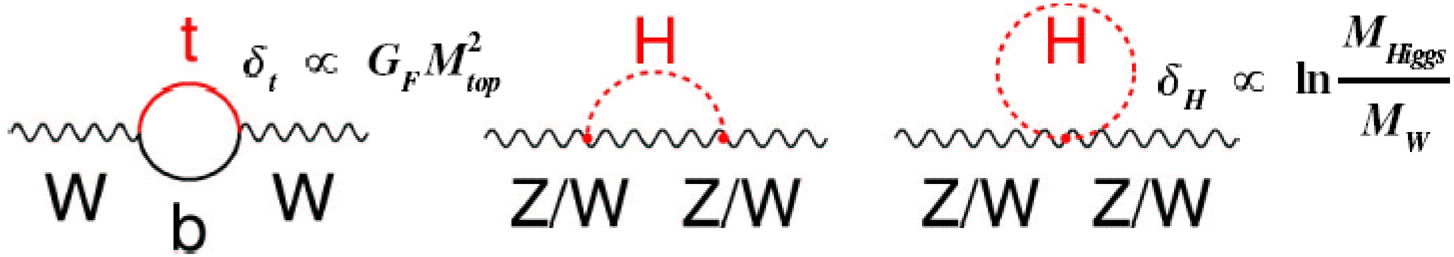


Total of 17 at high Q^2

(assuming lepton universality)

from > 1000 measurements with (correlated) uncertainties

Electroweak Corrections

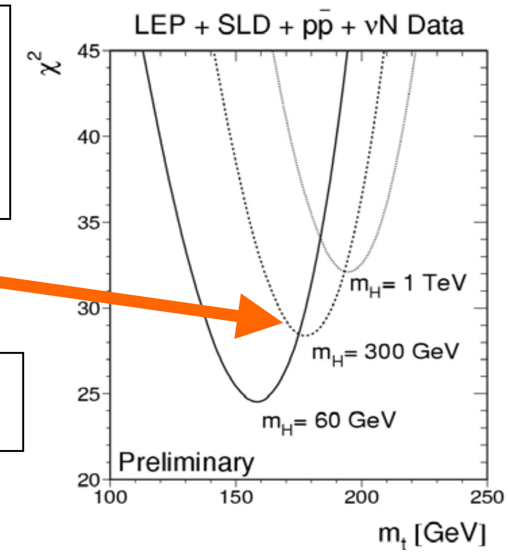


Standard Model parameters: $M_Z, G_F, \alpha(M_Z), \alpha_S(M_Z)$ & M_t

plus 'unknown' M_H

top-quark mass 'predicted' by electroweak corrections prior to direct discovery

eg LP 1995 Beijing



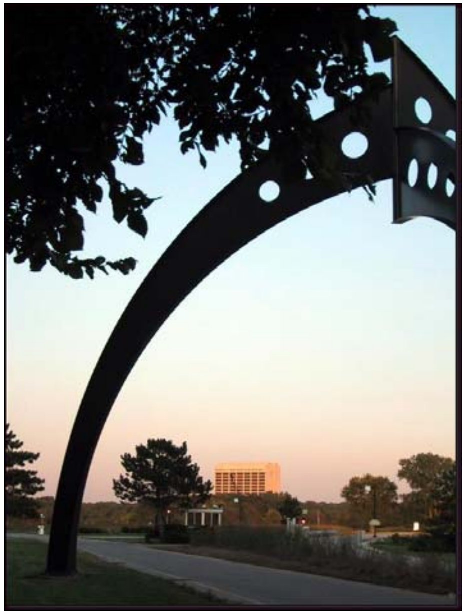
40th anniversary of Peter Higgs' papers

does this work for the Higgs ?

SM: TOPAZ0 and ZFITTER 6.40 new

$\sin^2\theta_{eff}$ fermion 2-loop: M_W full 2 (& leading 3)-loop

Tevatron $\bar{p}p$ Collider

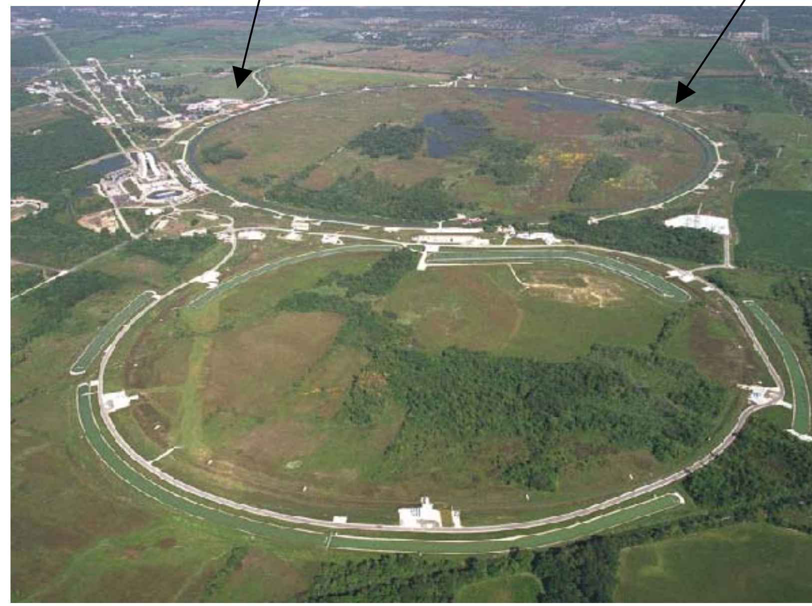


$\sqrt{s} = 1.96$ TeV

19th year!

CDF

D0



measurement of M_W, Γ_W and M_t (plus other electroweak quantities)

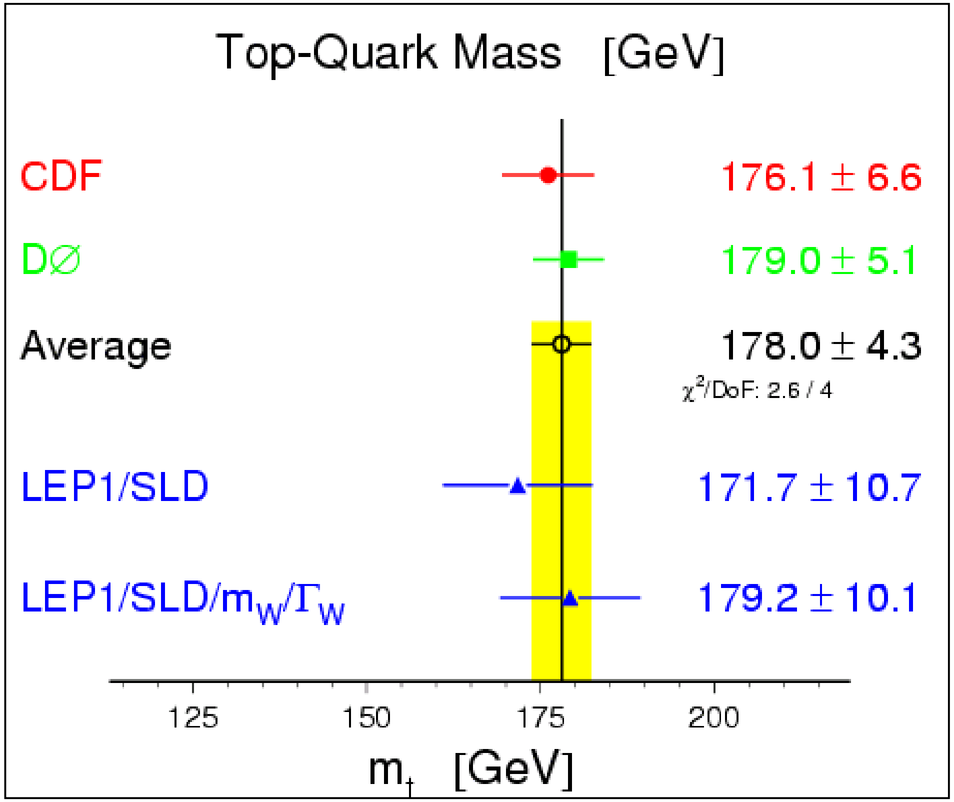
new Run 1 improved M_t measurement from D0 ~100 pb-1

new Run 2 prelim M_t measurements from CDF & D0 from ~160 pb^{-1}

combinations (Run 1 only) by Tevatron Electroweak Working Group

top quark mass: Run 1

new D0: improved Run 1 value



$\delta M_t / M_t \;\cong\; 2.4\ \%$

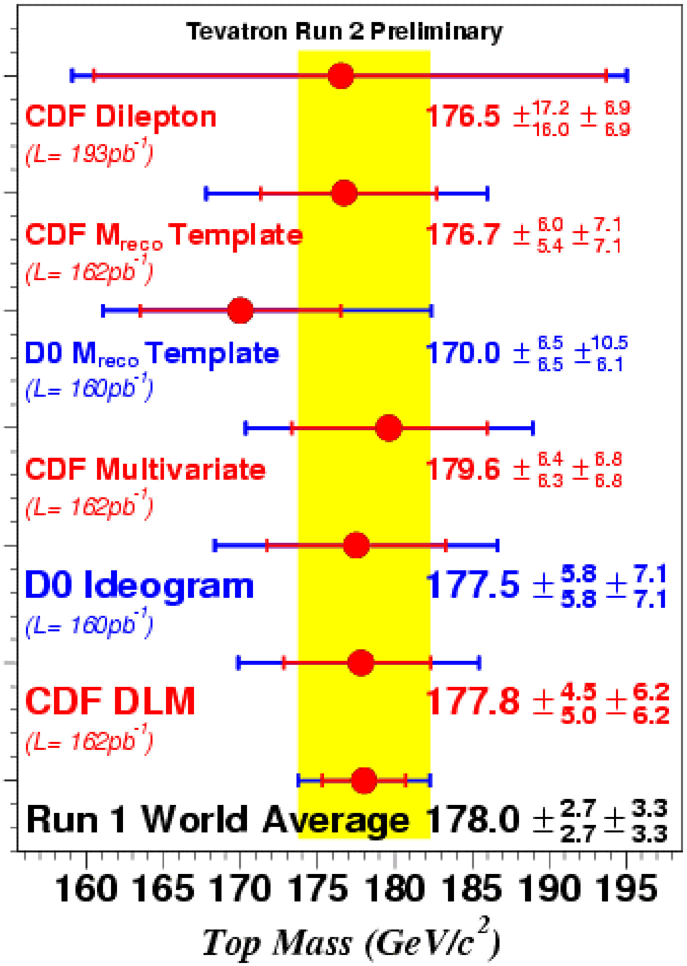
New world average (Run 1 only):

$m_t \;=\; 178.0 \;\pm\; 2.7(\text{stat}) \;\pm\; 3.3(\text{syst})\ \text{GeV}$

$\;=\; 178.0 \;\pm\; 4.3\ \text{GeV}$

(previous $m_t = 174.3 \pm 5.1\ \text{GeV}$)

top quark mass – Run 2 (prelim)



7

6

5

4

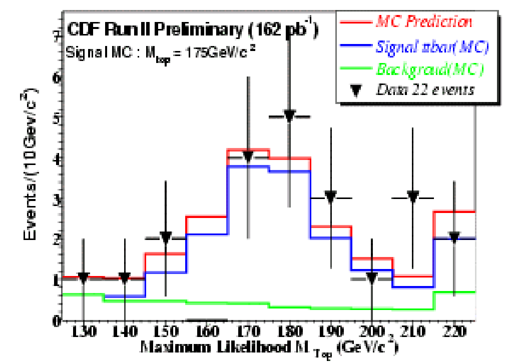
3

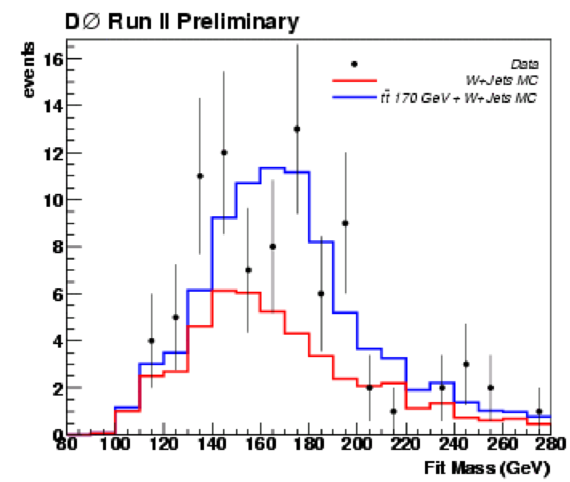
2

1

new CDF

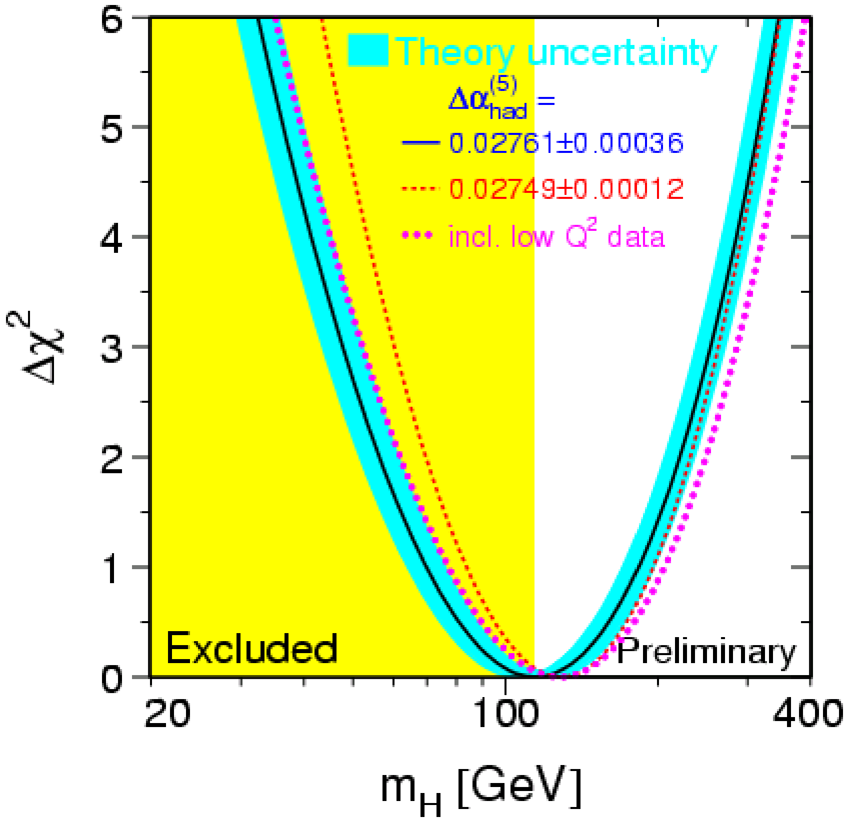
new D0





not yet included in world average

THE BLUE BAND PLOT



Global electroweak fit – high Q^2 data

$$m_t = 178.2 \pm 3.9 \text{ GeV}$$

$$\alpha_S(M_Z) = 0.1186 \pm 0.0027$$

$$m_H = 114 ^{+69}_{-45} \text{ GeV}$$

$$\chi^2 = 15.8/13 \text{ df} \quad (\text{prob} = 26\ \%)$$

$$m_H < 260 \text{ GeV} \quad (95\%\ \text{cl})$$

for $\Delta\alpha^{(5)}_{had}(M_Z) = 0.02749 \pm 0.00012$ $m_H \Rightarrow 129$ GeV

new 'blueband' from uncertainties of 2 (& leading 3) loops for M_W & $\sin^2\vartheta_{eff}$ (main effect for m_H)

Awramik,Czakon,Freitas,Weiglein hep-ph/0311148,0407317 &refs therein

Faisst,Kuhn,Seidensticker,Veretin N Phys B665,649(2003) + many more!

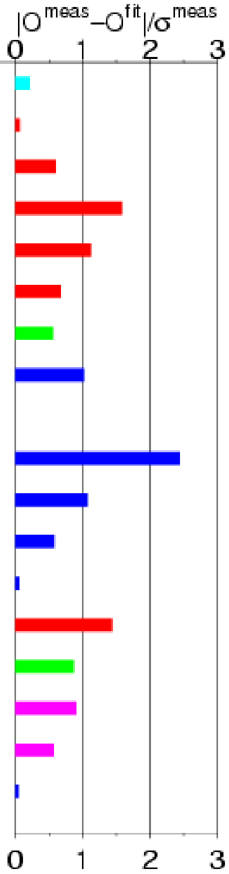
Since Aachen EPS Summer 2003

new top mass increases m_H by ~20 GeV

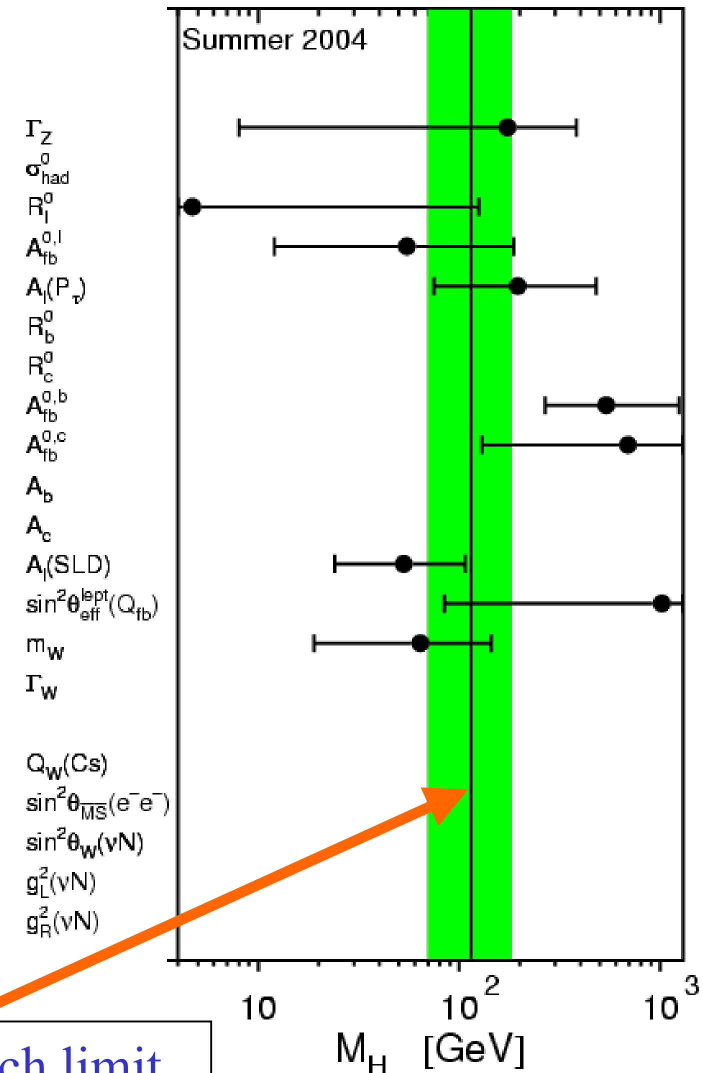
new 2-loop terms etc increase m_H by ~6 GeV

pulls

	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02761 ± 0.00036	0.02769
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4966
σ_{had}^0 [nb]	41.540 ± 0.037	41.481
R_l	20.767 ± 0.025	20.739
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01650
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1483
R_b	0.21630 ± 0.00066	0.21562
R_c	0.1723 ± 0.0031	0.1723
$A_{fb}^{0,b}$	0.0998 ± 0.0017	0.1040
$A_{fb}^{0,c}$	0.0706 ± 0.0035	0.0744
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.026	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1483
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.425 ± 0.034	80.394
Γ_W [GeV]	2.133 ± 0.069	2.093
m_t [GeV]	178.0 ± 4.3	178.2

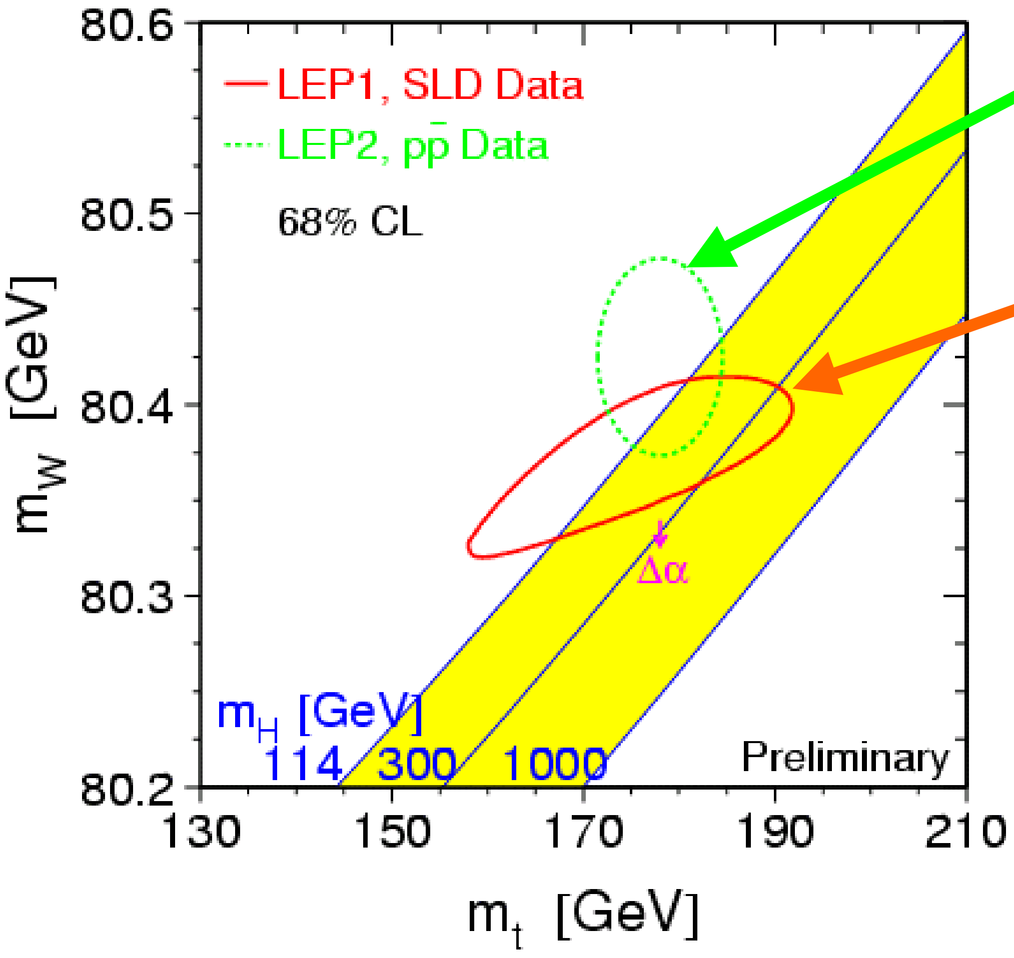


Higgs mass from individual measurements



direct search limit

m_t , m_w direct vs indirect

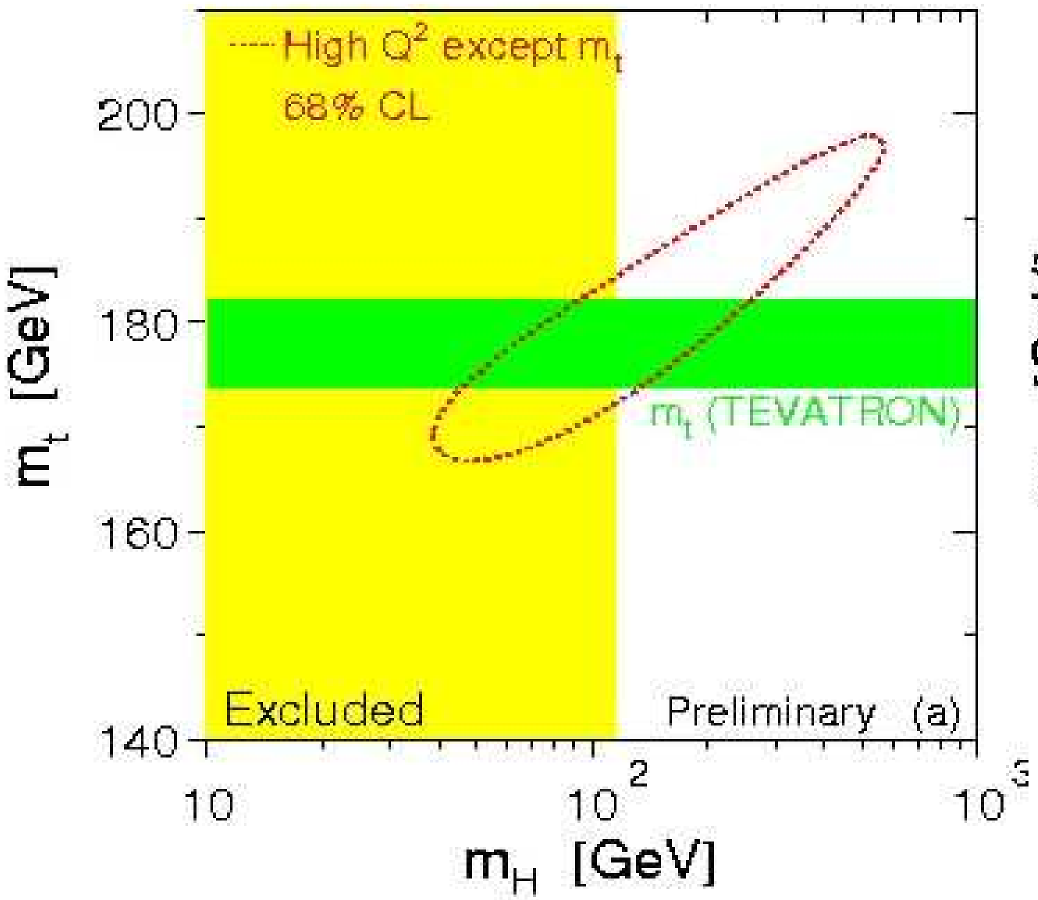


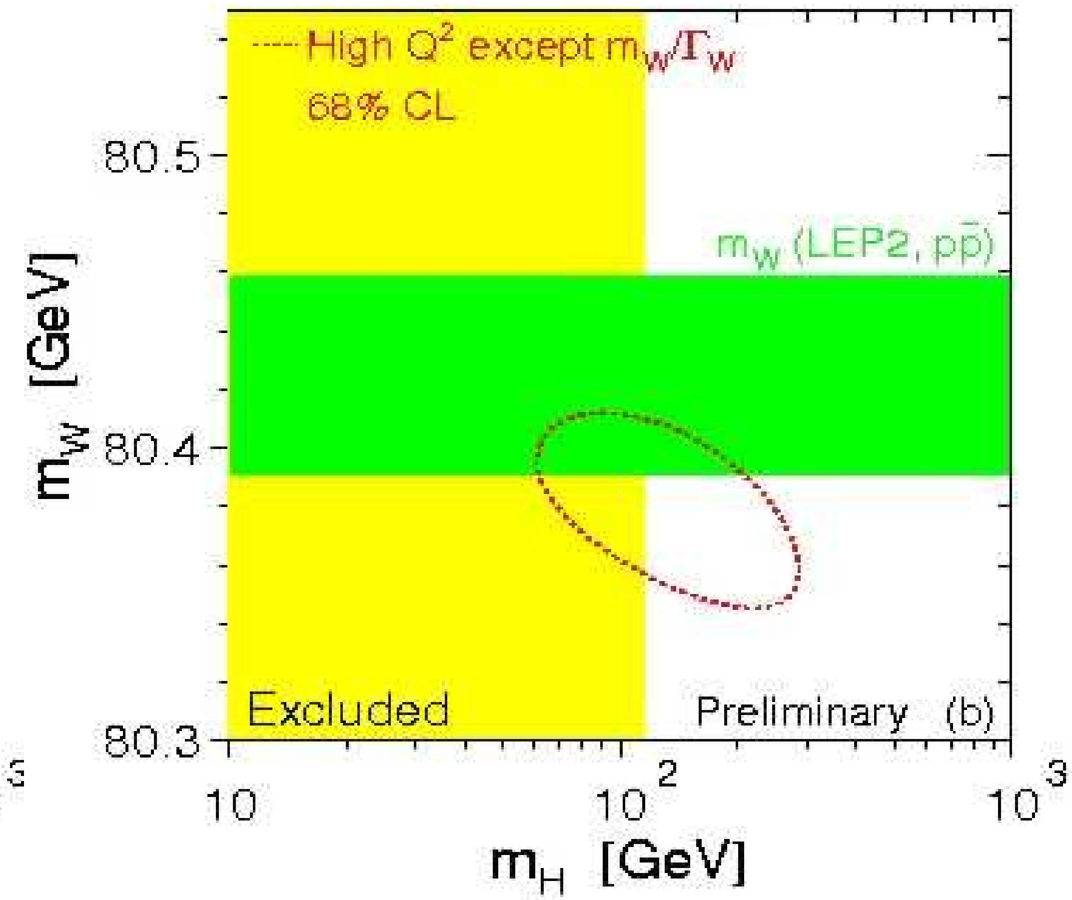
direct m_t and m_w

indirect m_t and m_w

- reasonable degree of overlap
- powerful test of SM

Consistency with the SM





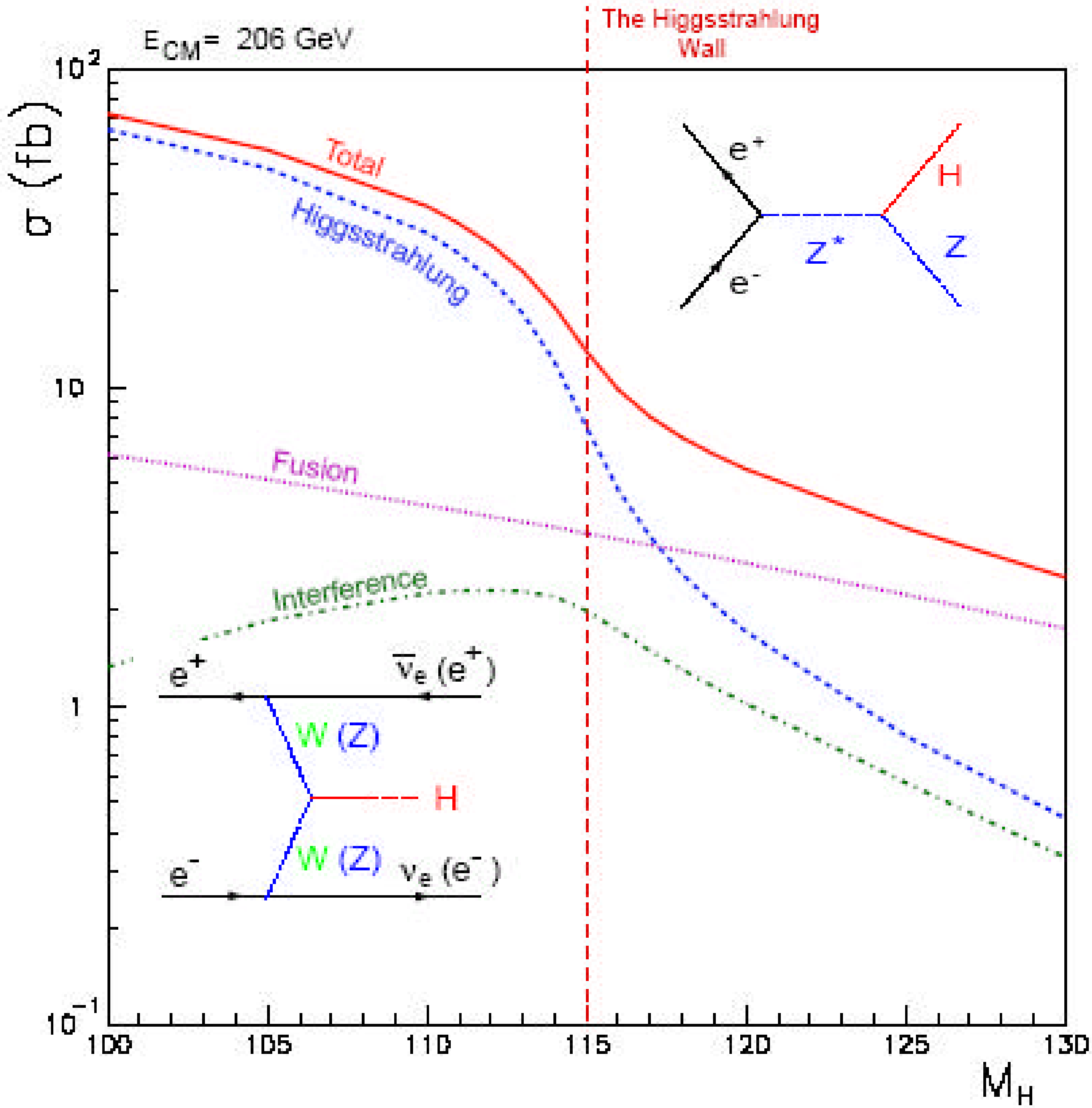
m_{top} (fit) = 179 ± 10 GeV
(χ^2/dof = 15.8/12)

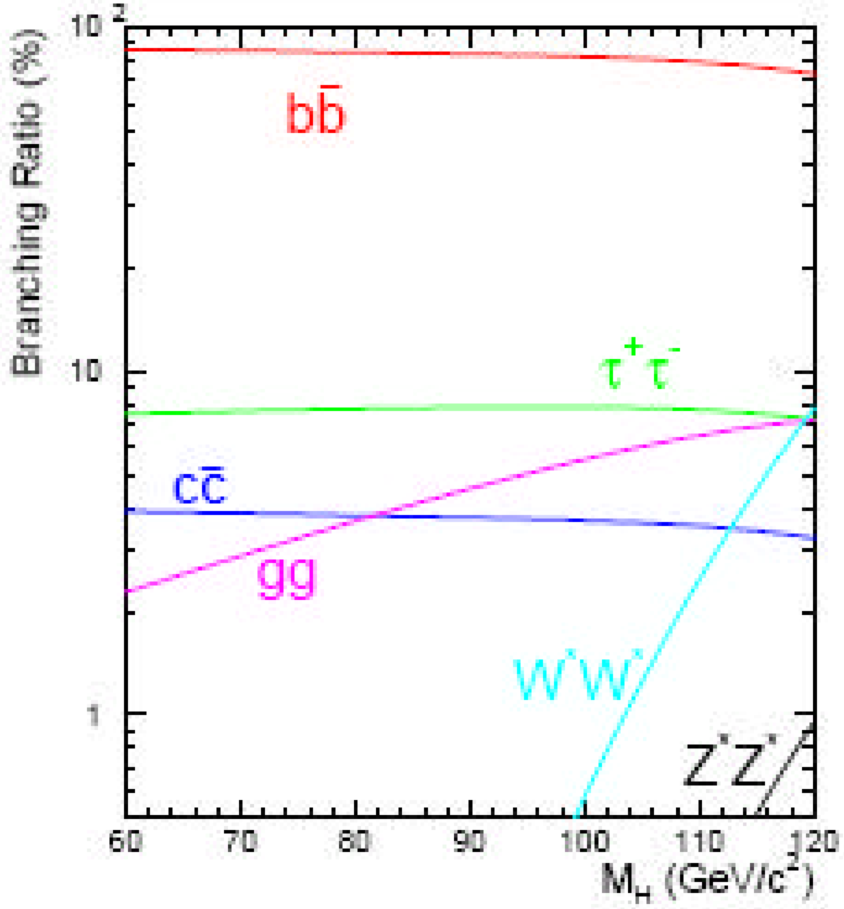
m_{top} (exp) = 178.0 ± 4.3 GeV

m_W (fit) = 80.379 ± 0.023 GeV
(χ^2/dof = 14.1/11)

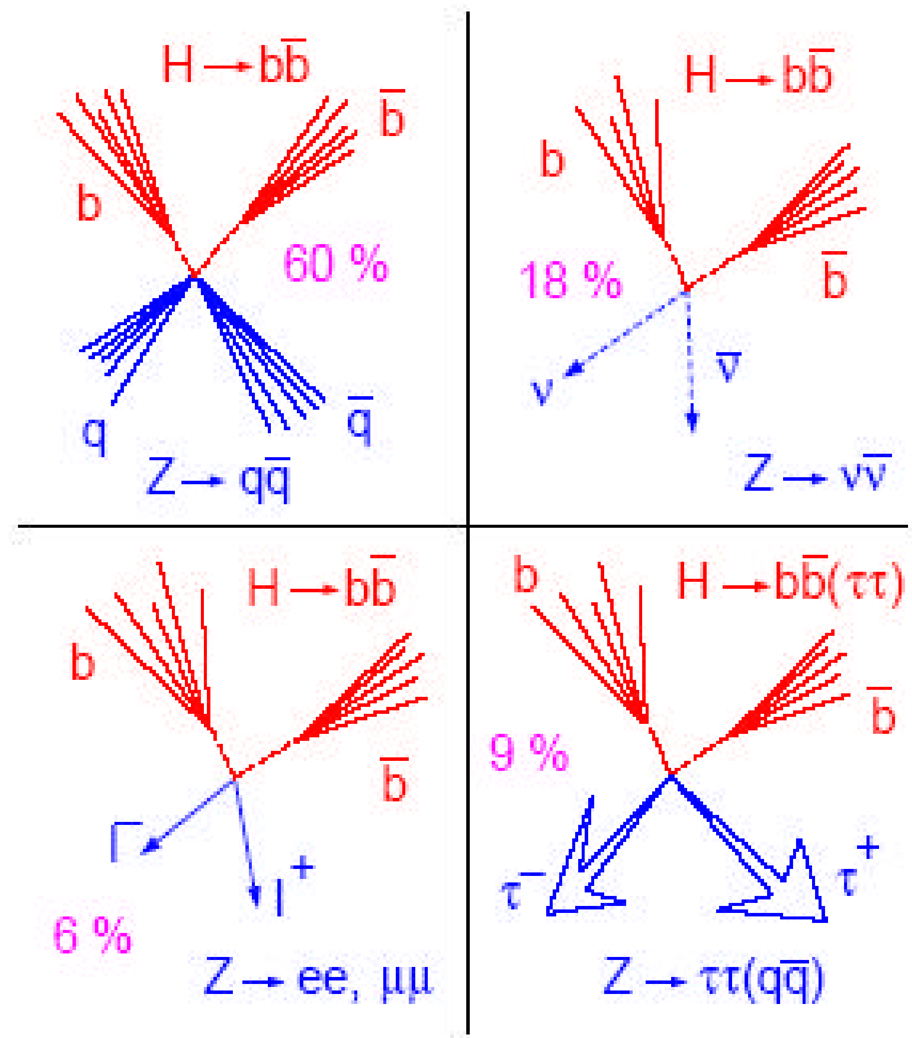
m_W (exp) = 80.425 ± 0.034 GeV

SM Higgs Production at LEP



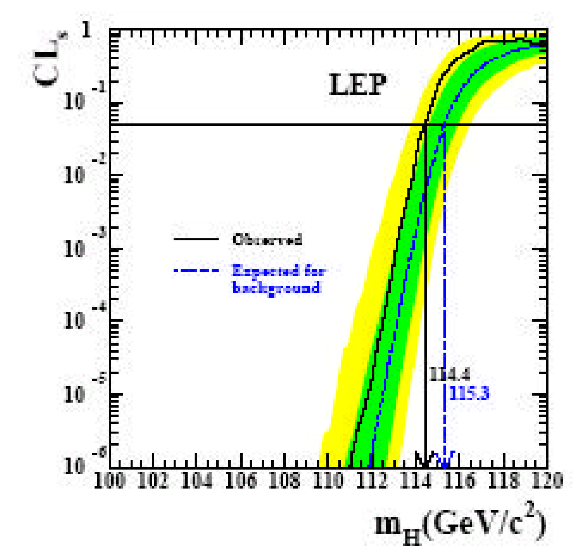


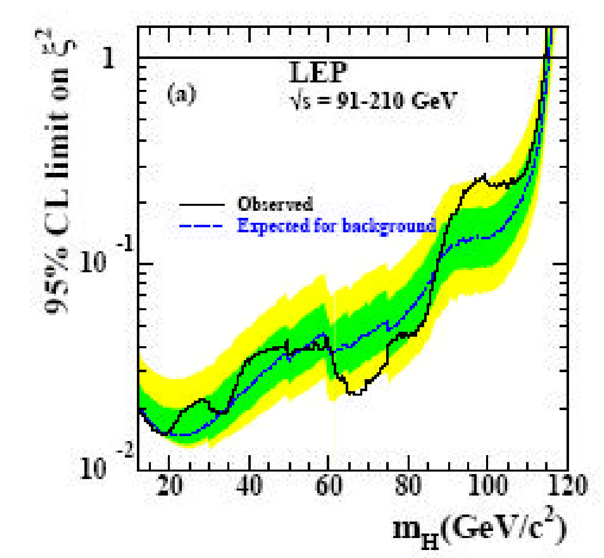
SM final state topologies



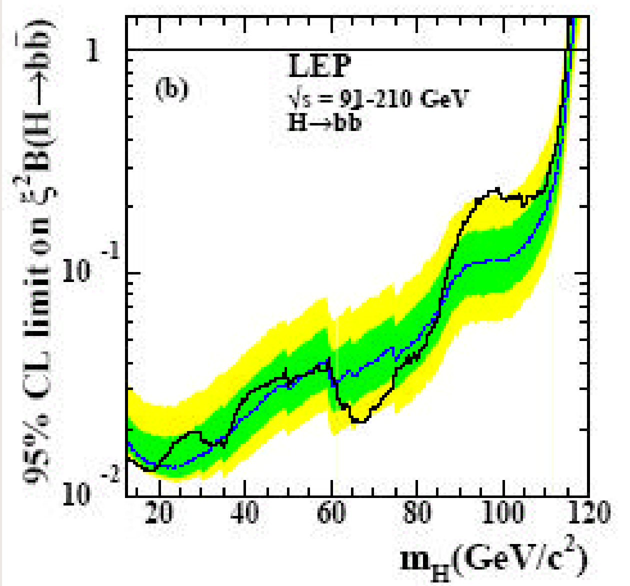
SM Higgs Decays at LEP

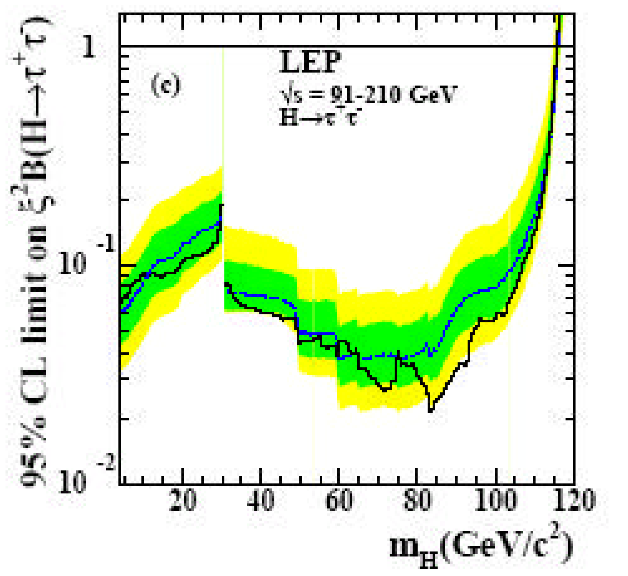
LEP Combination: Bounds for the Higgs boson mass (114.4 GeV) and couplings ($\xi^2 = (g_{HZZ}/g_{HZZ}^{SM})^2$)





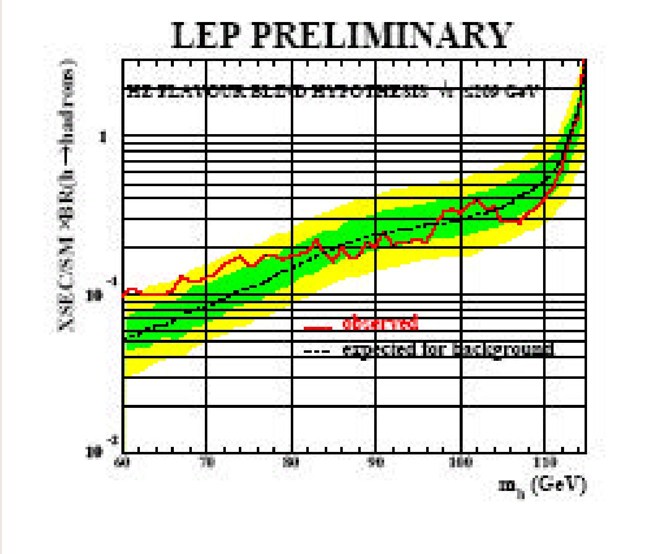
a) SM BR's
b) Limits on ξ^2 BR($H \to b\bar{b}$)
c) Limits on ξ^2 BR($H \to \tau^+\tau^-$)

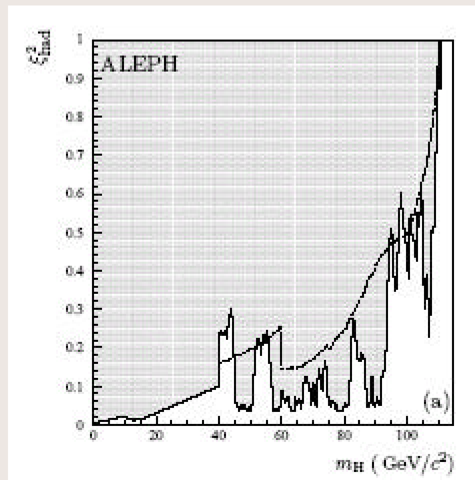


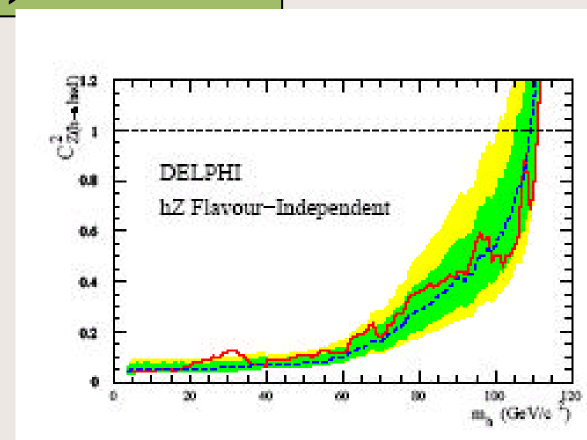


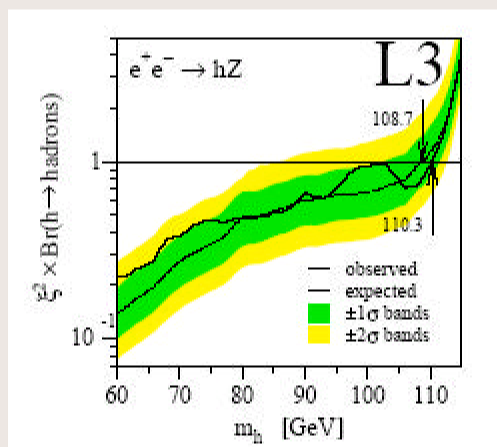
The HZZ coupling limits
95 % CL limit on $\xi^2 = (g_{HZZ} / g^{SM}_{HZZ})^2$

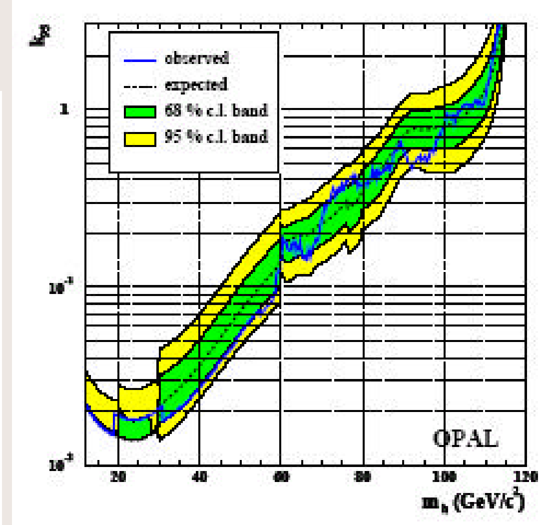
Flavour blind searches: Higgs boson decays to down type fermions are suppressed; BR(H->hadrons) = 100 %











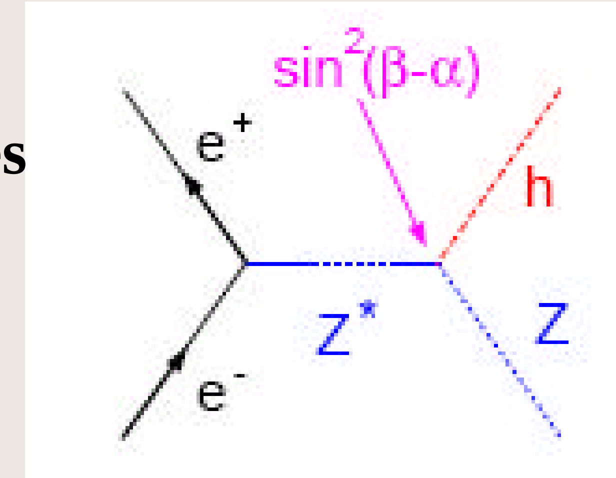
A 110.6 GeV
D 110.6 GeV
L 110.3 GeV
O 104.0 GeV
LEP 112.9 GeV

Two Higgs Doublet Models (2HDM)

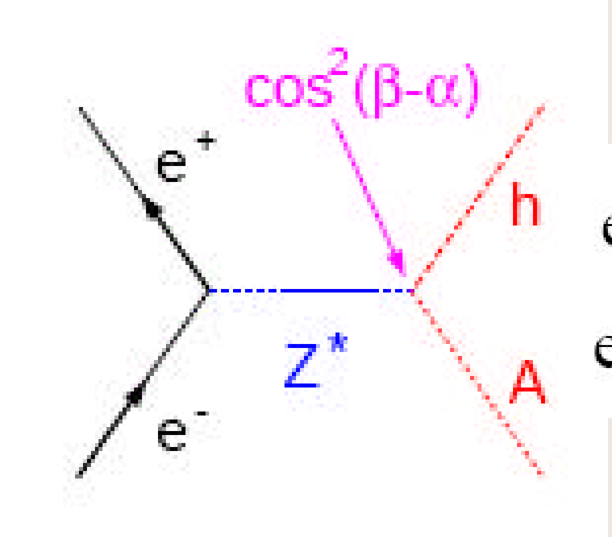
Simplest extension of SM with 2 complex scalar field doublets, in total 5 physical scalar Higgses:

- **CP even scalars: h, H**
- **CP odd scalar: A**
- **Two charged scalars: $H^{\pm}$**

6 Free parameters: 2 angles, 4 masses



Two production processes:



$$e^+e^- \to h^0 Z^0 : \quad \sigma_{hZ} = \sin^2(\beta-\alpha)\, \sigma_{HZ}^{SM}$$

$$e^+e^- \to h^0 A^0 : \quad \sigma_{hA} = \cos^2(\beta-\alpha)\, \bar{\lambda}\, \sigma_{HZ}^{SM}$$

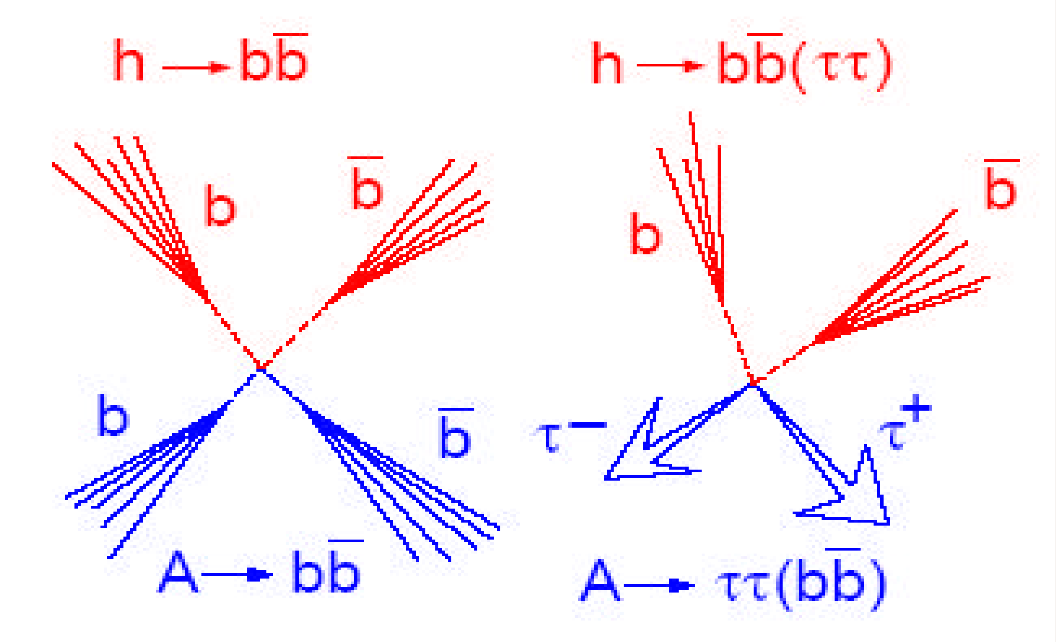
$\bar{\lambda}$ **: kinematic factor**

The type of 2HDM is determined by the couplings of the Higgs doublets to fermions:

- **Type I: quarks and leptons only couple to the 2nd Higgs doublet**
- **Type II: 1st Higgs doublet couples only to down-type fermions, 2nd Higgs doublet couples only to up-type fermions**

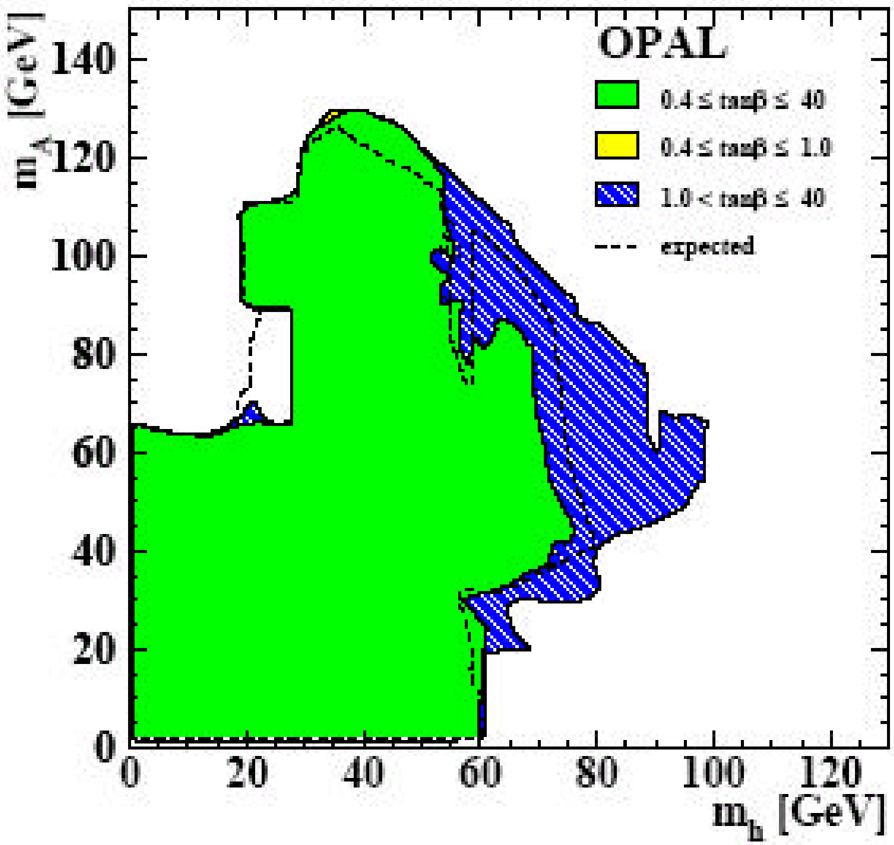
$h^0 c\bar{c} \sim \frac{\cos\alpha}{\sin\beta}$ $h^0 b\bar{b} \sim \frac{\sin\alpha}{\cos\beta}$ $A^0 c\bar{c} \sim \cot\beta$ $A^0 b\bar{b} \sim \tan\beta$

New phenomena, in addition to hZ SM-like



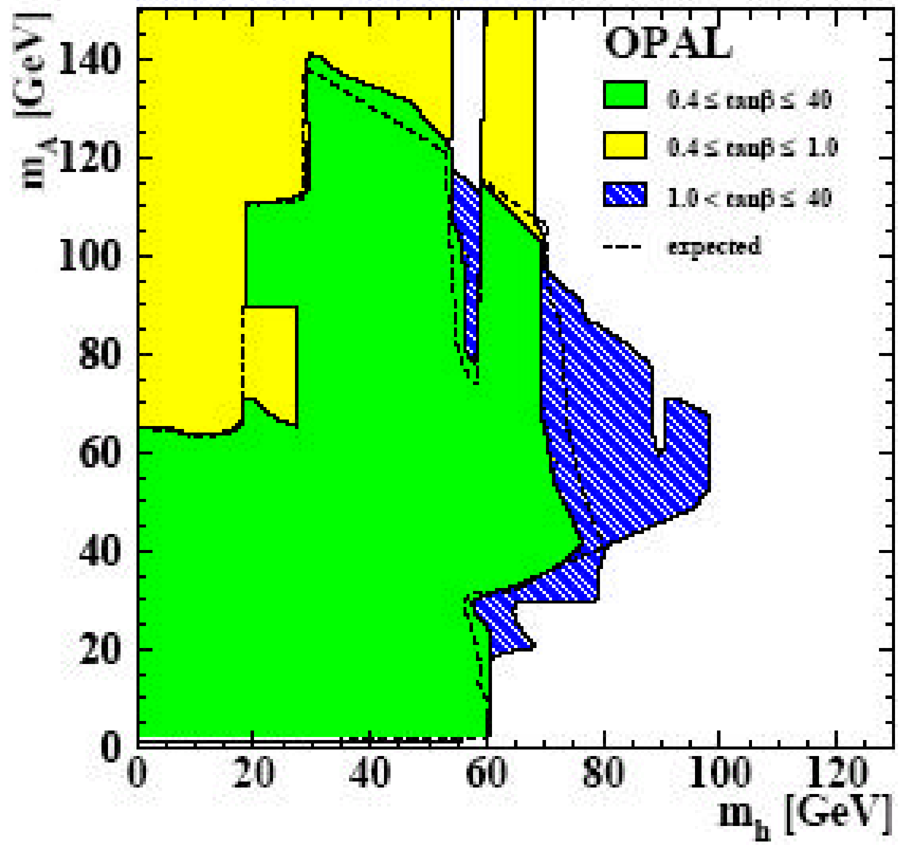
General 2HDM(II)

$$-\pi/2 \leq \alpha \leq \pi/2$$

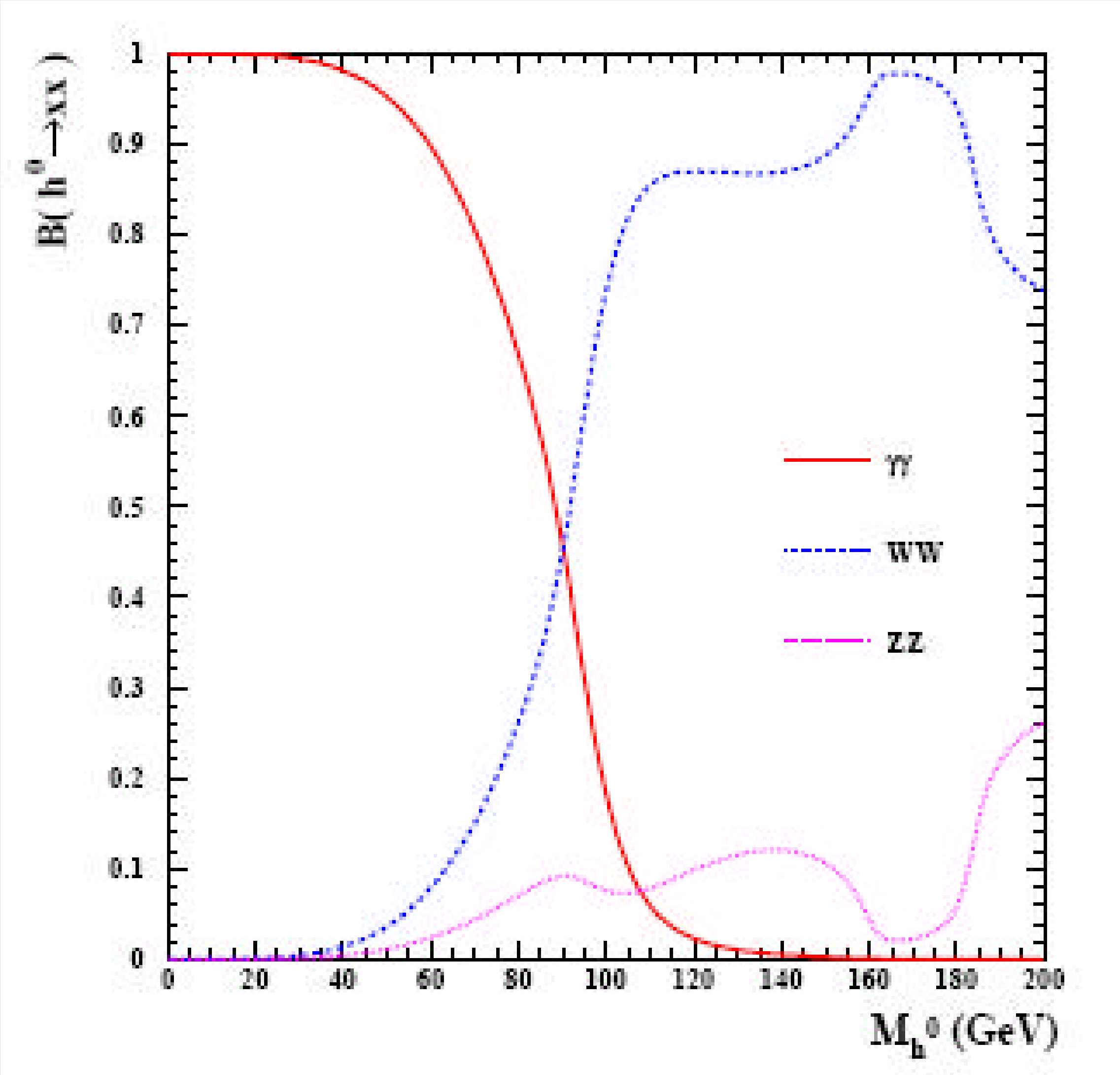


MSSM-like

$$-\pi/2 \leq \alpha \leq 0$$

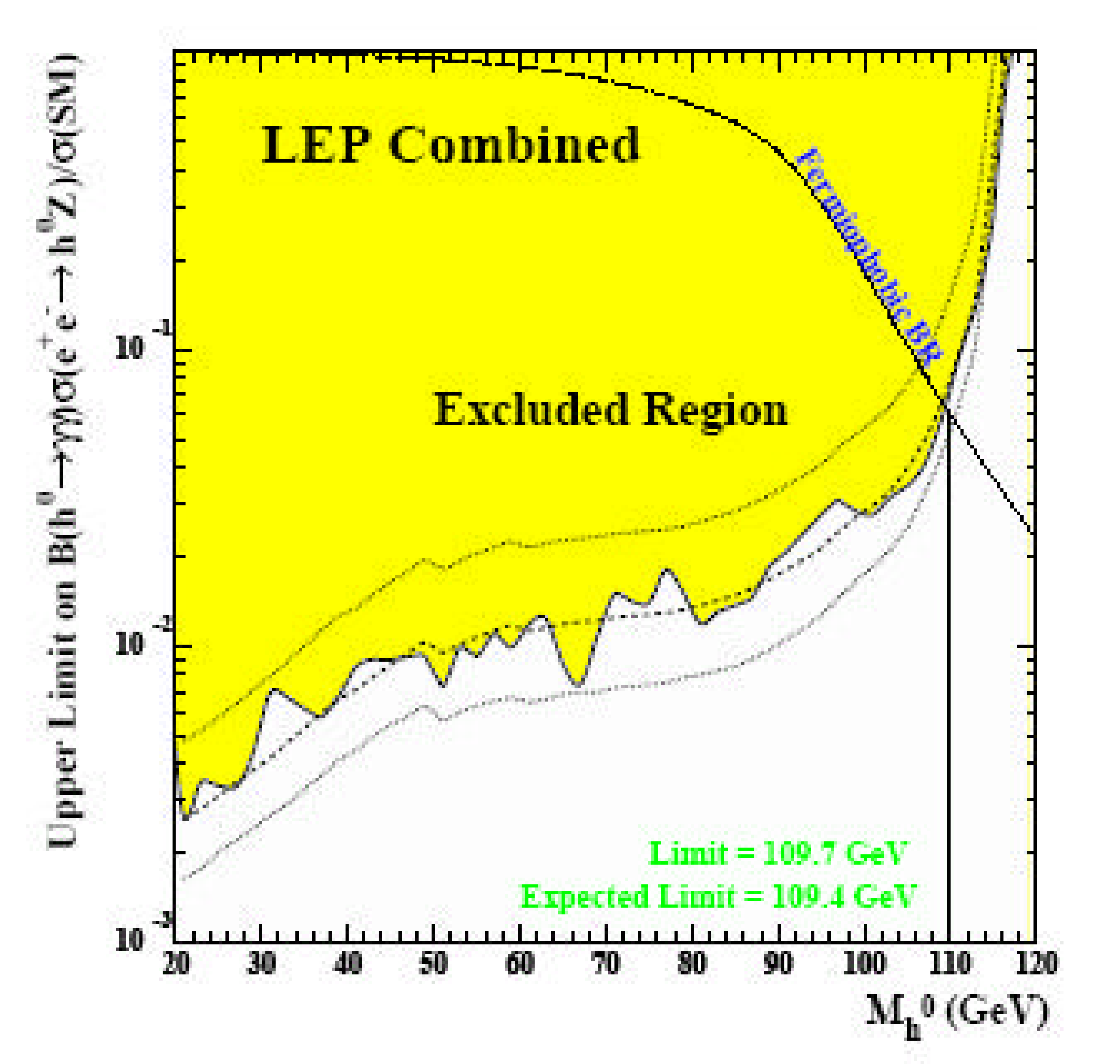


Fermiophobic Higgs searches:

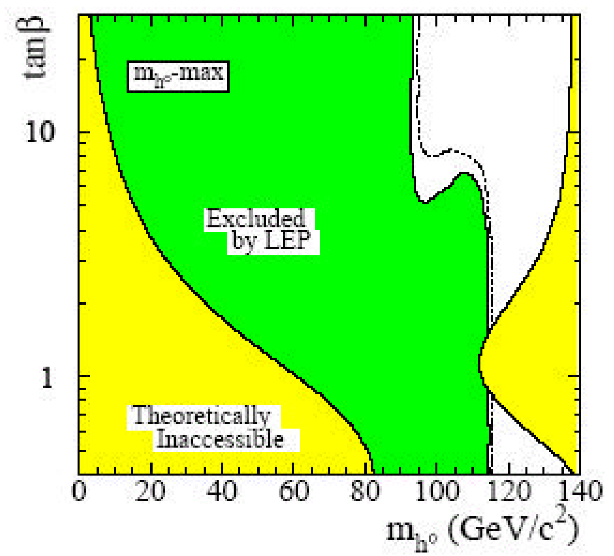


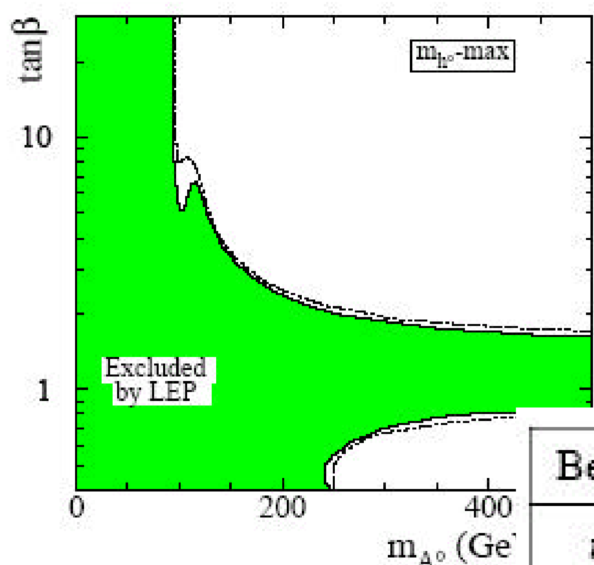
Benchmark: HZ-SM production cross-section with all direct decays into fermions removed

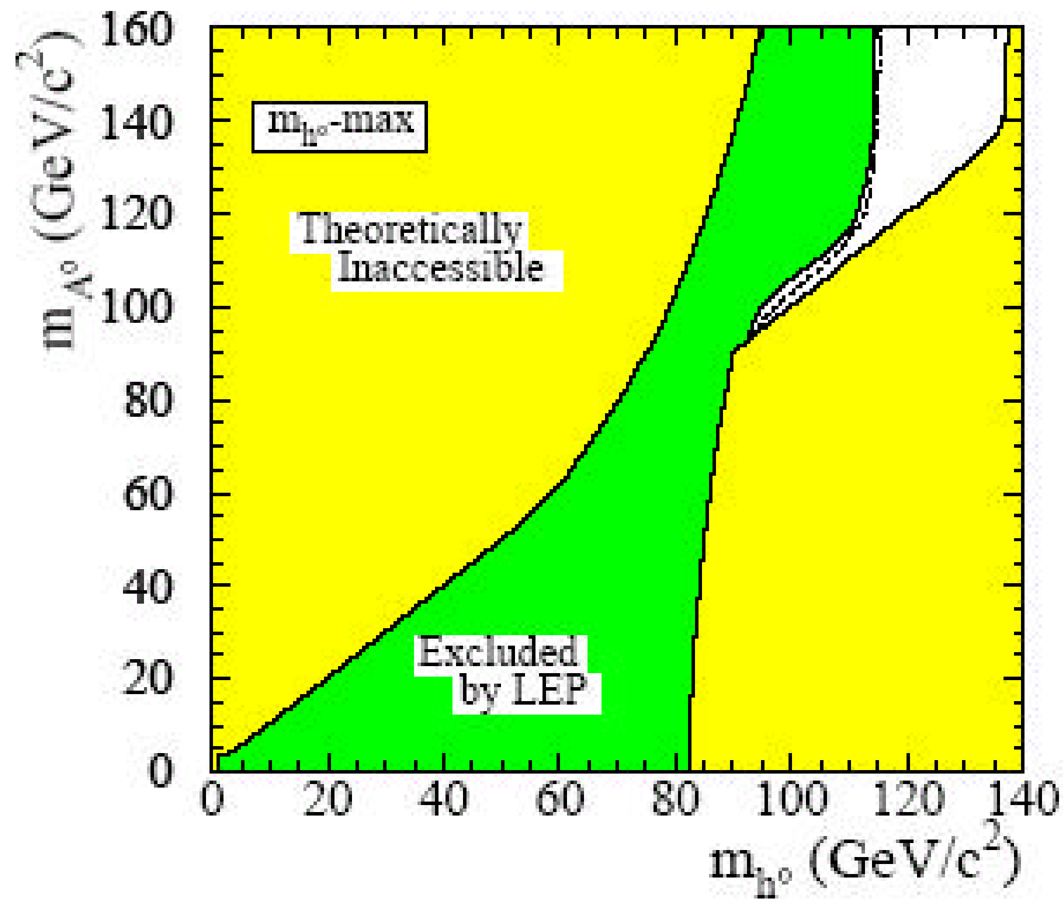
LEP fermiophobic limit: 109.7 (109.4) GeV



LEP MSSM Exclusions at 95 % CL for the m_h –max benchmark scenario (m_t = 179.3 GeV)

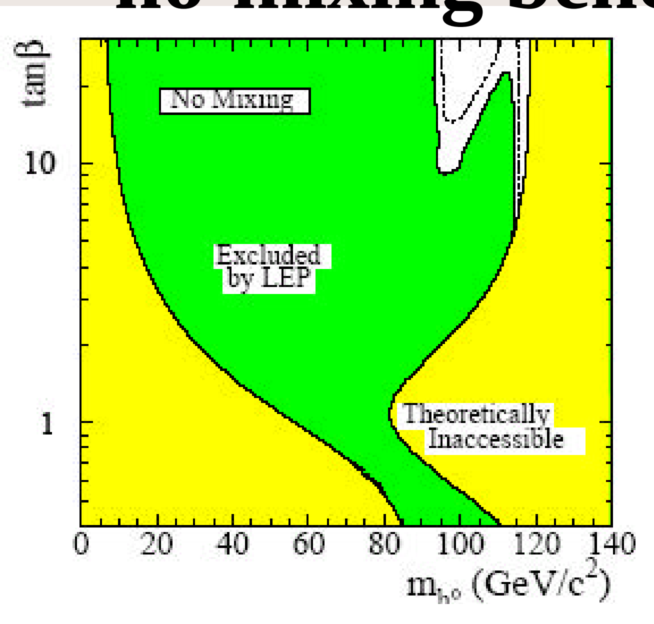


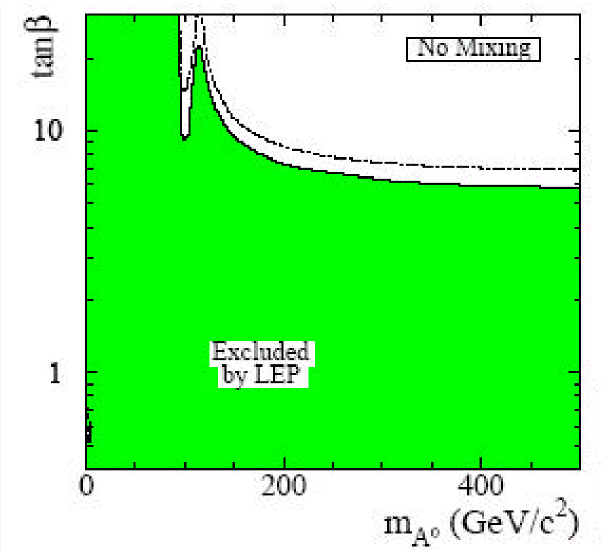


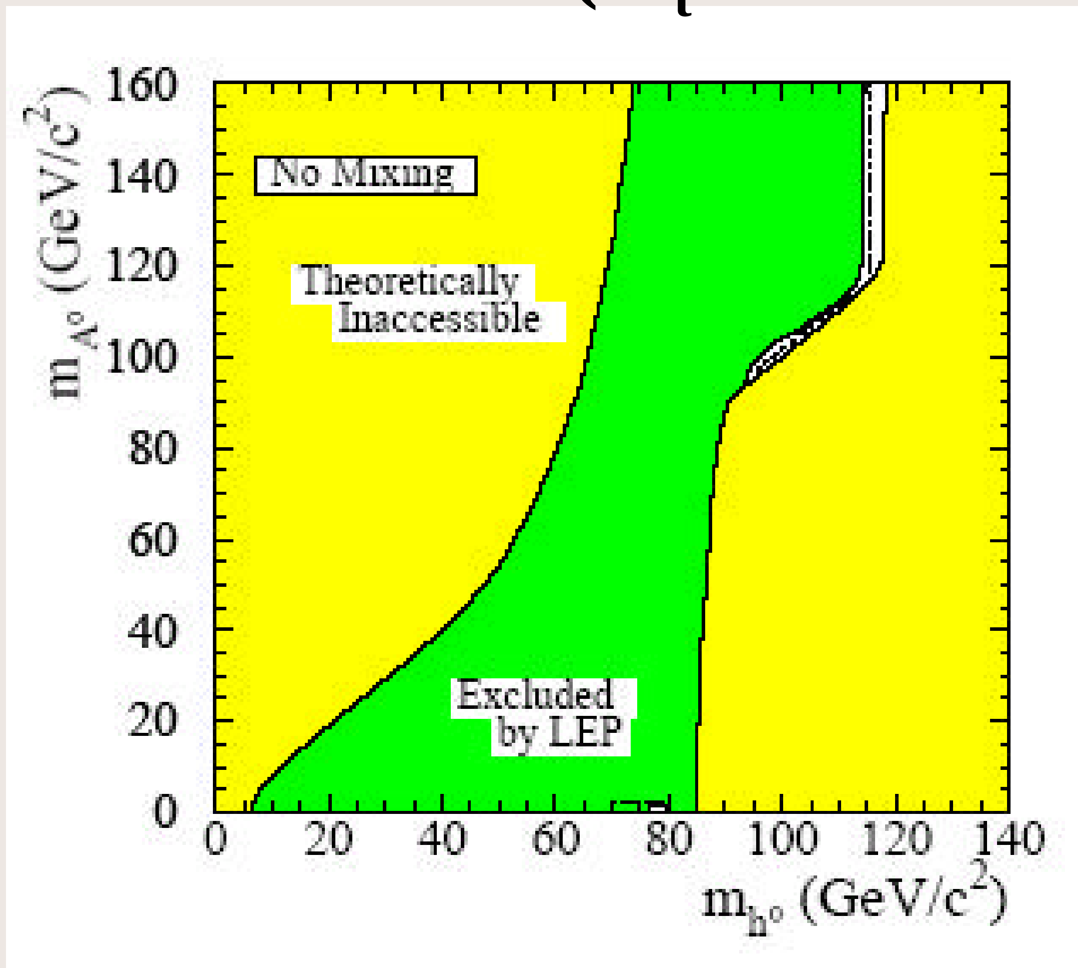


Benchmark	m_h limit (GeV)	m_A limit (GeV)	Excluded tan β range
m_h-*max*	92.9	93.4	$0.9 < \tan\beta < 1.5$

LEP MSSM Exclusions at 95 % CL for the no-mixing benchmark scenario (m_t = 179.3 GeV)

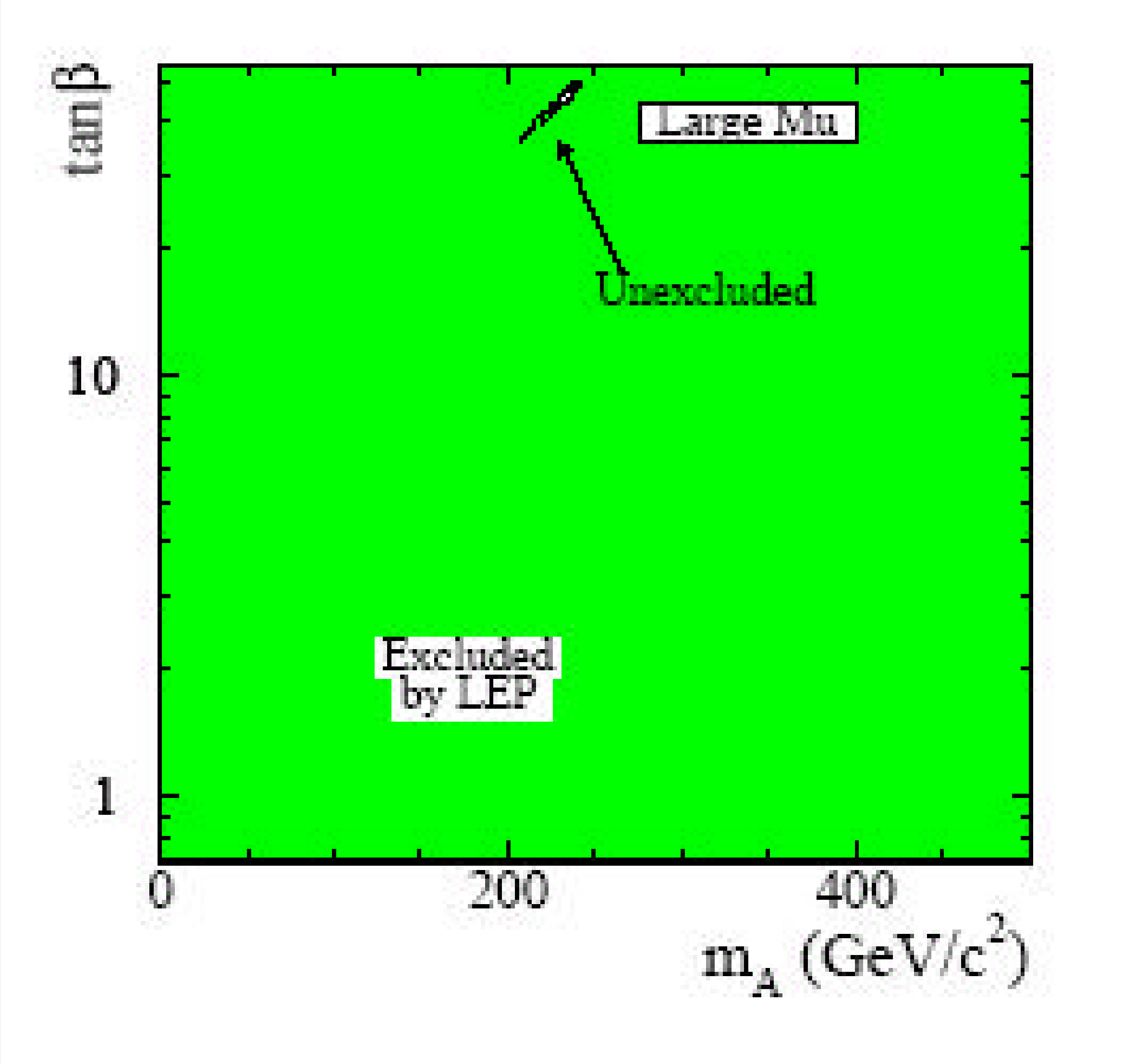




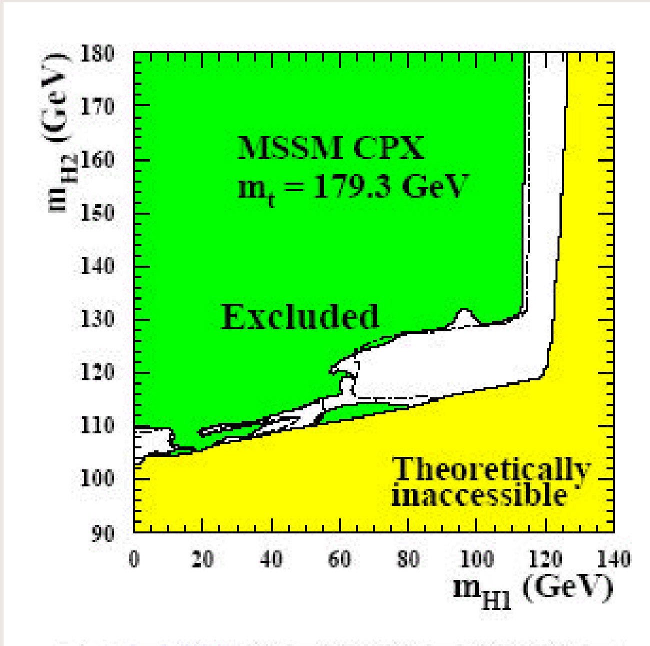


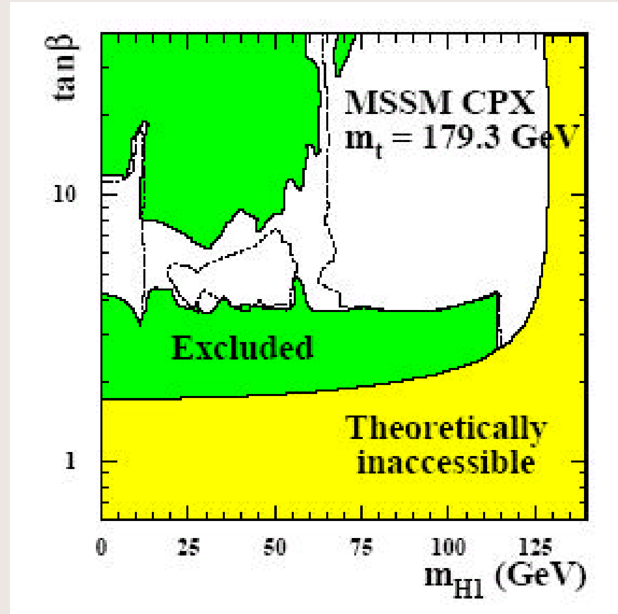
Benchmark	m_h limit (GeV)	m_A limit (GeV)	Excluded $\tan\beta$ range
no-mixing	93.3	93.3	$0.4 < \tan\beta < 5.6$

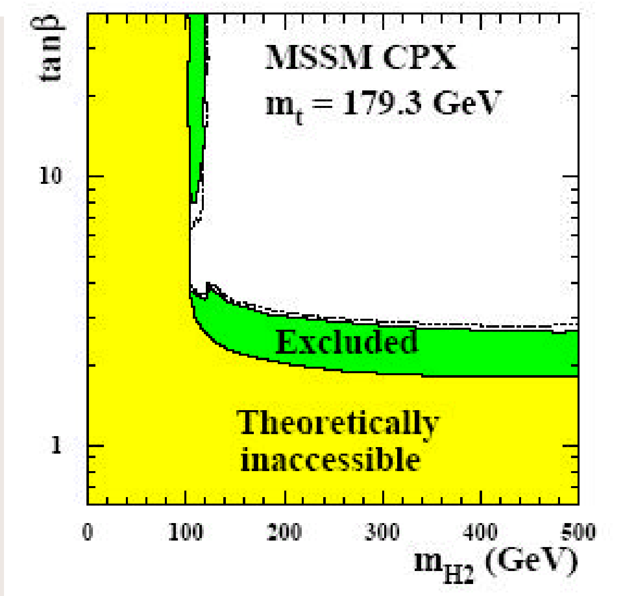
LEP MSSM Exclusions at 95 % CL for the *large-μ* benchmark scenario (m_t = 179.3 GeV)

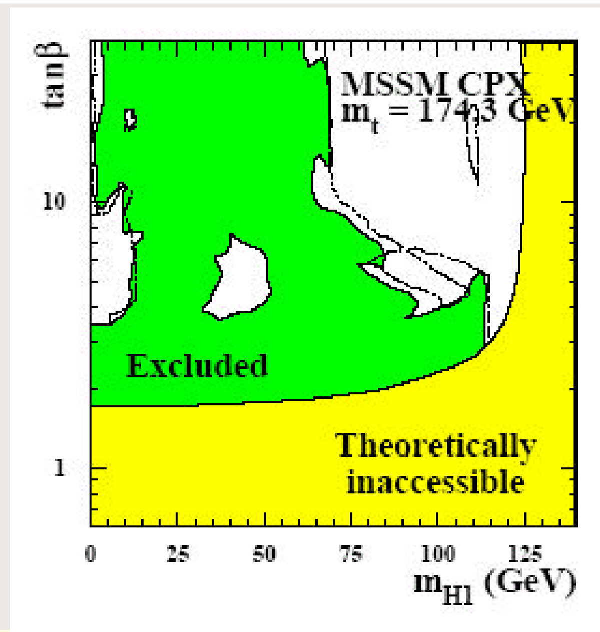


LEP Exclusions at 95 % CL for the CPX scenario









SM Higgs Production at the Tevatron

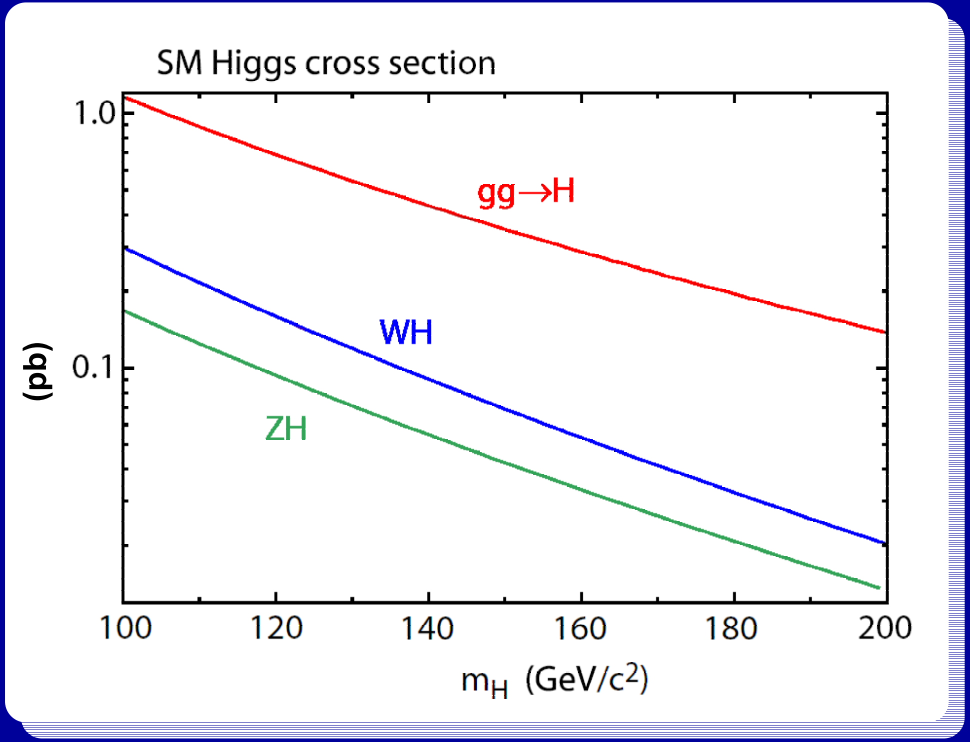
- Though Higgs production could be quite copious, not all channels are accessible

gg→H

- Useful for M_H>140 GeV
- H→WW→llνν
- Background: WW

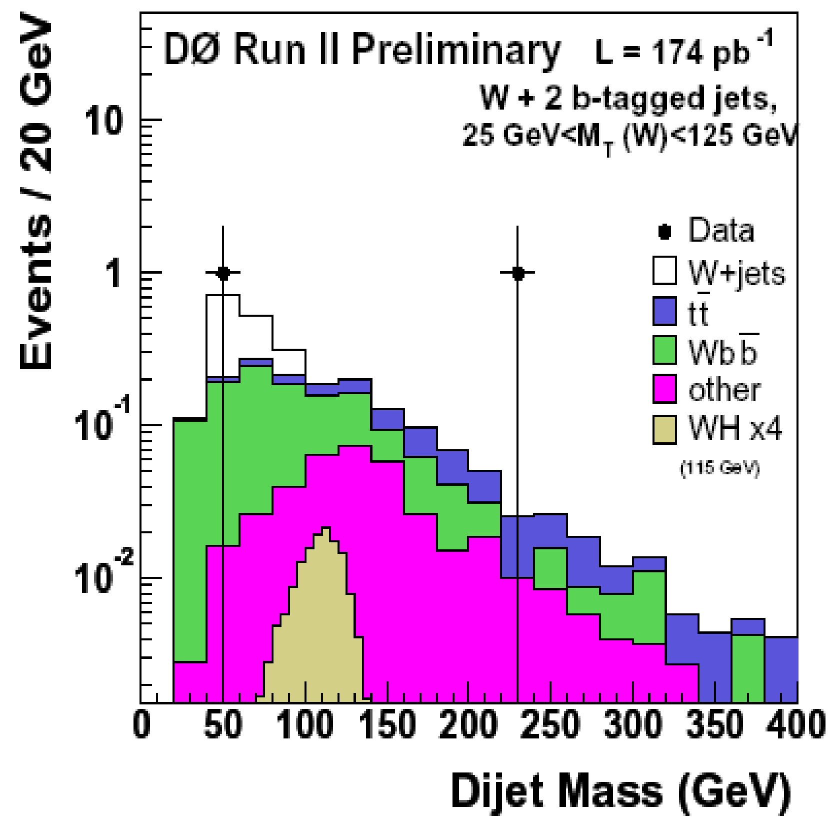
W/Z+H

- M_H<140 GeV
- WH→lνb$\bar{b}$
- ZH→llb$\bar{b}$, ννb$\bar{b}$
- Background: W+b$\bar{b}$, Z+b$\bar{b}$, top



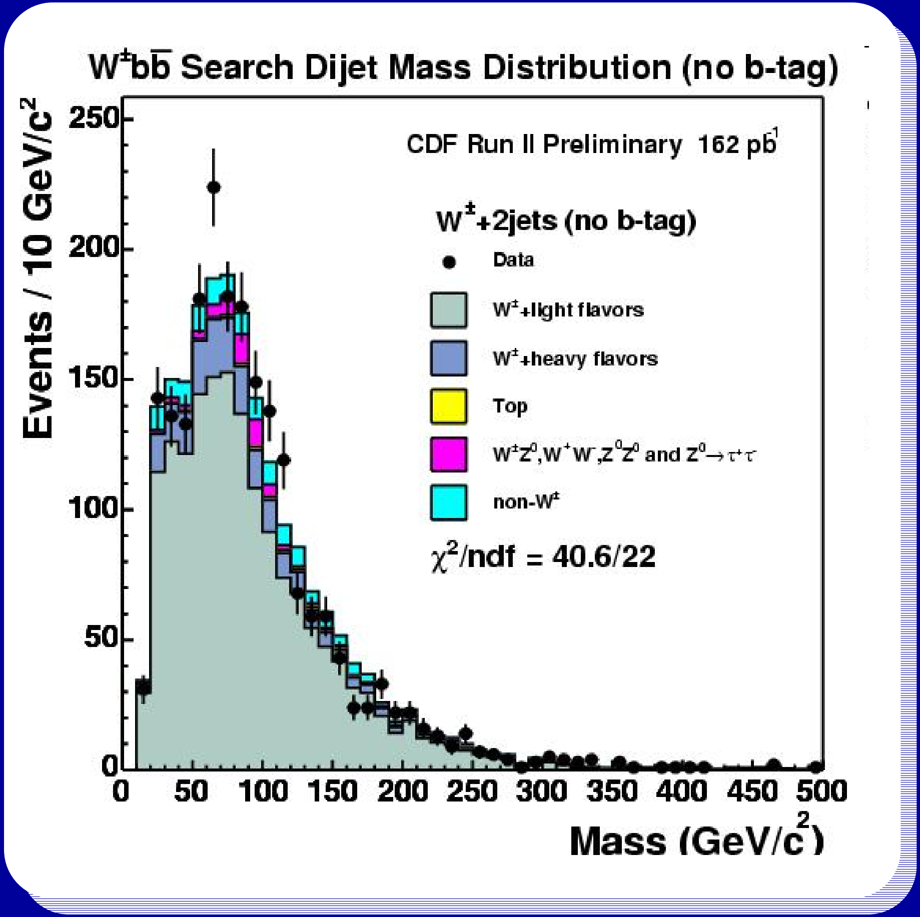
WH Cross Section Limit (DØ)

For M_H=115 GeV Higgs
$\sigma(WH)\times BR(H\rightarrow b\bar{b})<12.4$ pb
(95% C.L.)



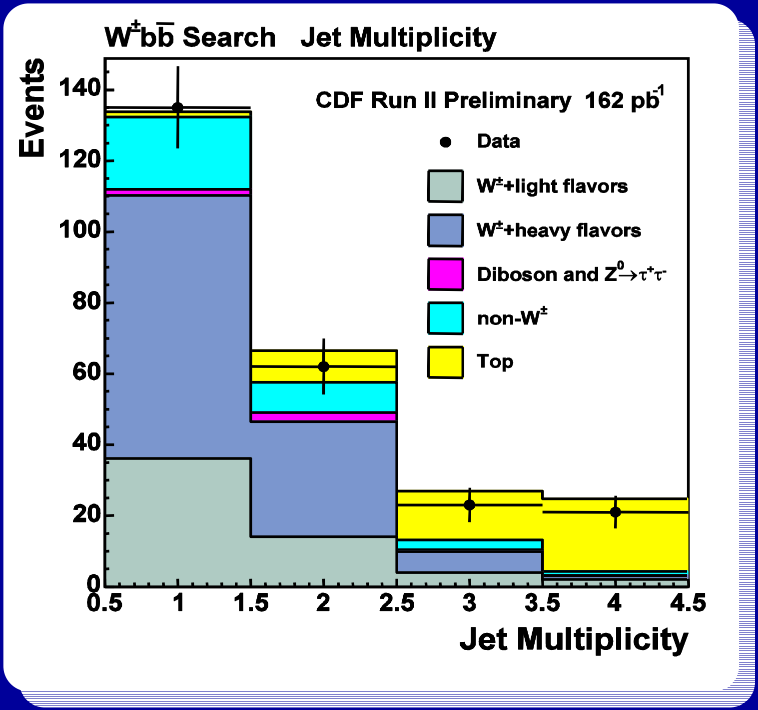
WH Searches (CDF)

- Using 162pb^{-1} of data in muon and electron channels
- Event selection
  - lepton: p_T>20 GeV, central region
  - Missing E_T: $\not{E}_T$>20 GeV
  - 2 Jets: p_T>15 GeV, $|\eta|$<2.5
- Veto on
  - Additional high p_T track
  - 3rd and 4th jet

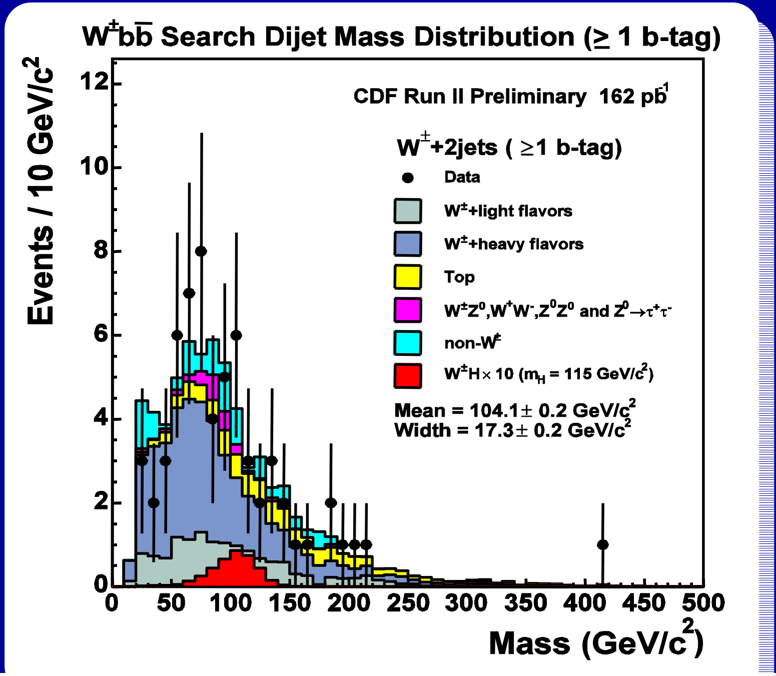


WH Searches (CDF)

- Single b-tag analysis
  - Secondary vertex tagging



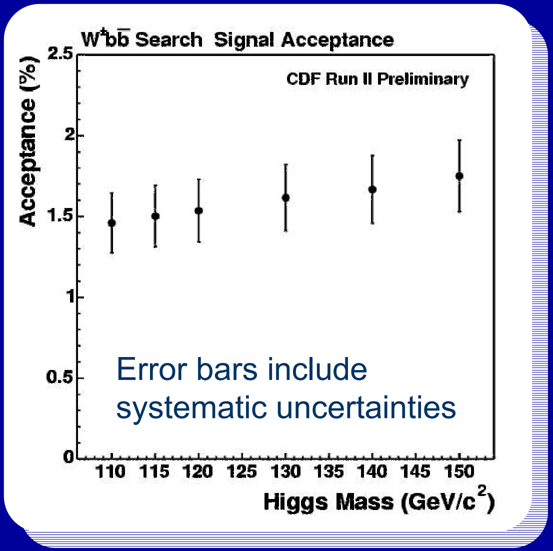
- Exclusive W + 2 jets
  - 62 events (67±9 expected)

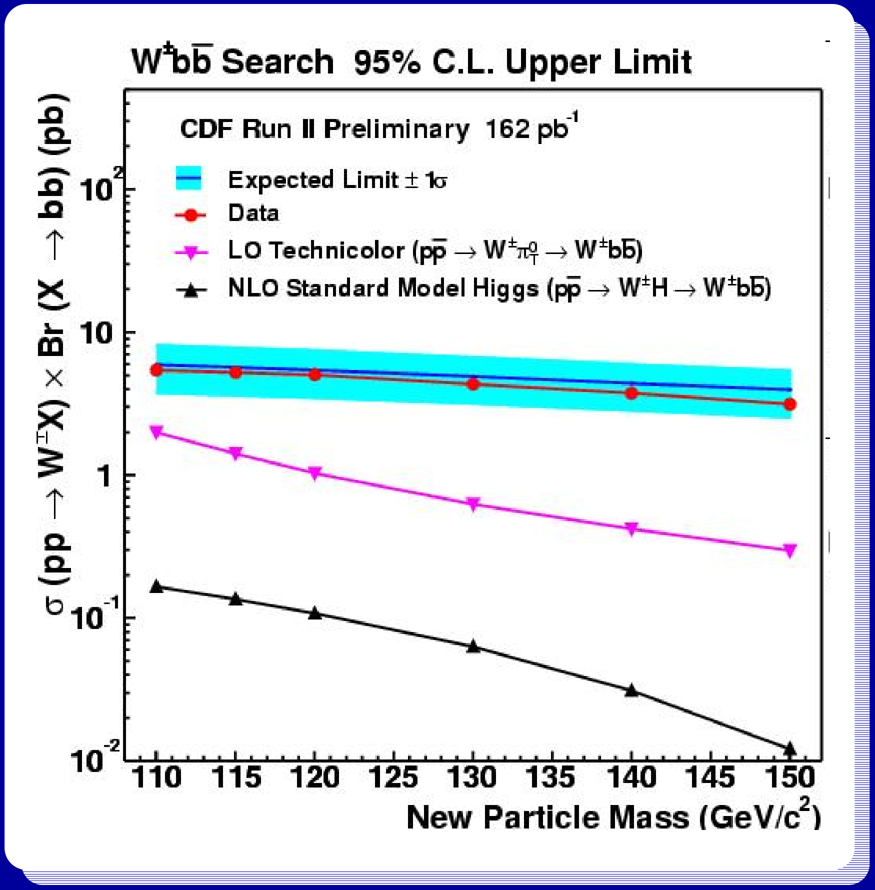


Mistag	QCD	Wbb	Wcc+Wc	top	Diboson / Z
14.1	8.5	19.1	13.3	8.9	2.5

WH Cross Section Limit (CDF)

- Signal acceptance

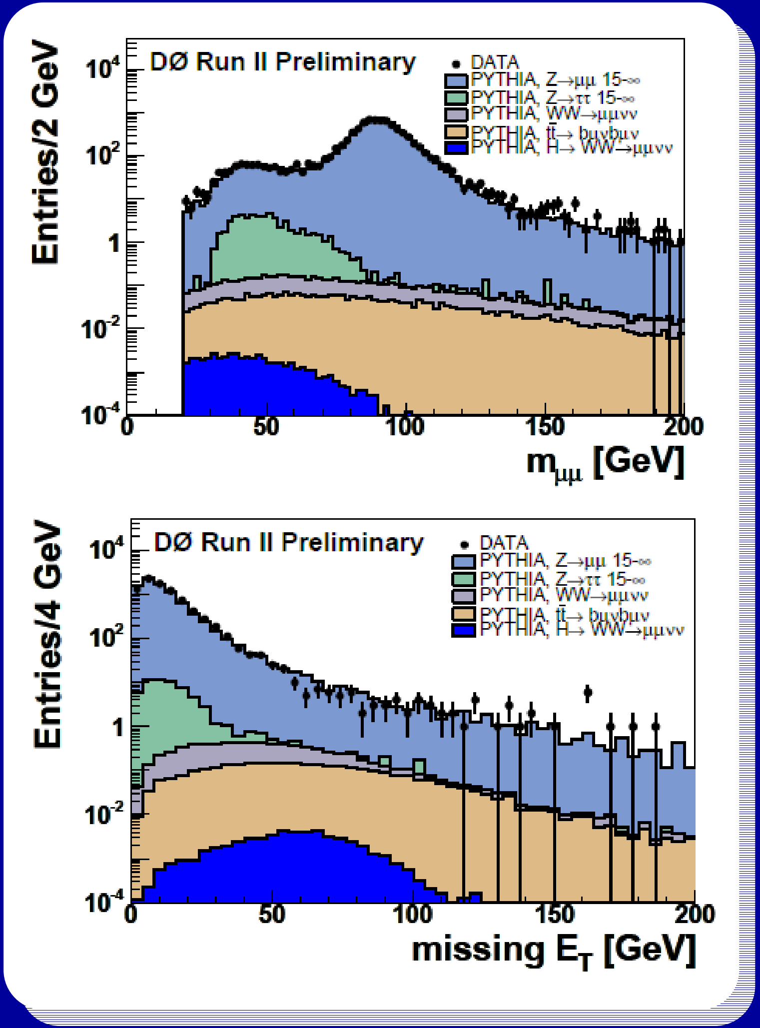




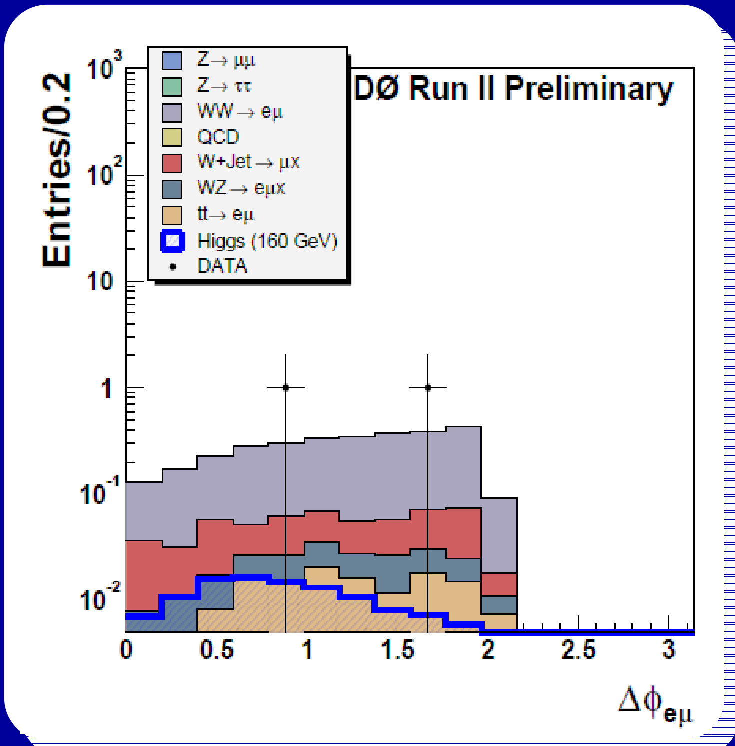
$\sigma(WH)*Br(H\rightarrow b\bar{b}) < 5\text{-}6$ pb @ 95% C.L.

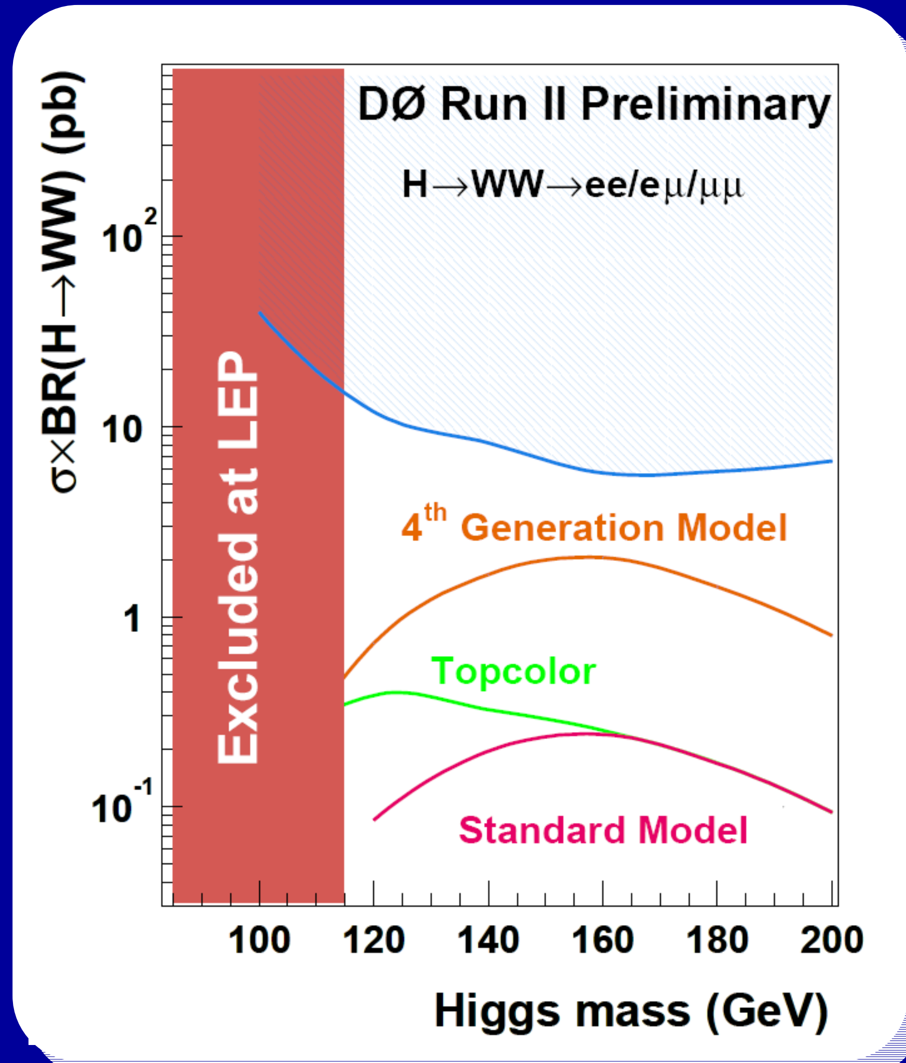
$H \rightarrow WW$ (DØ)

- Search in 3 channels
  - ee, eμ, μμ
  - 147~177 pb^{-1} of data
- Selection
  - 2 oppositely charged leptons
  - Large MET
  - Di-lepton mass or min($M_T(e)$, $M_T(\mu)$)
  - Scalar sum of lepton p_T and MET
  - Jet veto
  - $\Delta\Phi_{ll}$
  - ☞ reduce Z, W+jets, tt-bar
- Cuts optimized for each mass point



H→WW (D0)



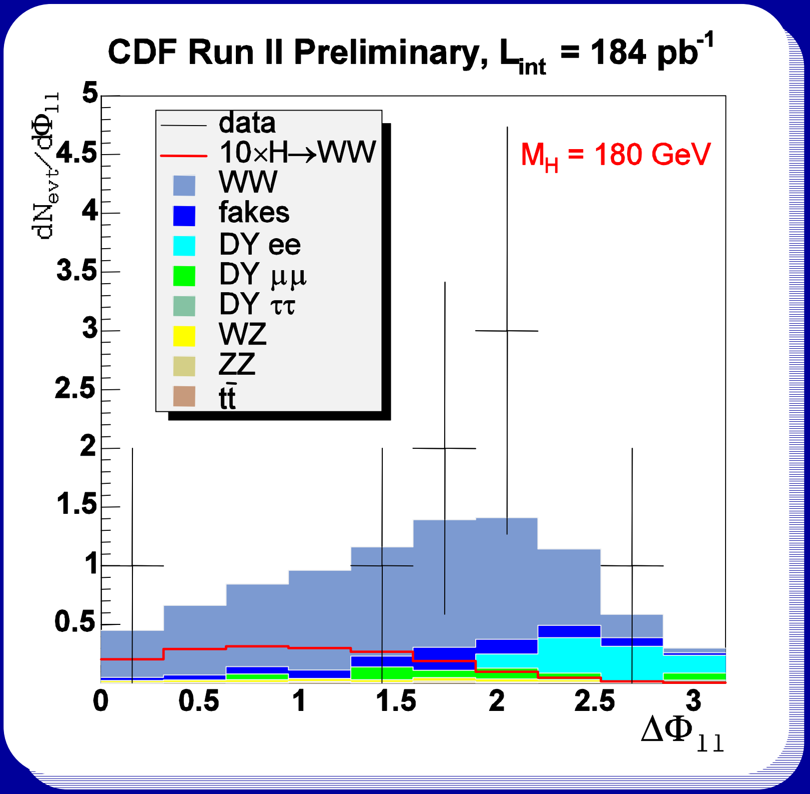


- Limit set in each channel by counting
- Combine the likelihoods

σ*BR(H→WW) < 5.7pb
For M_H=160 GeV

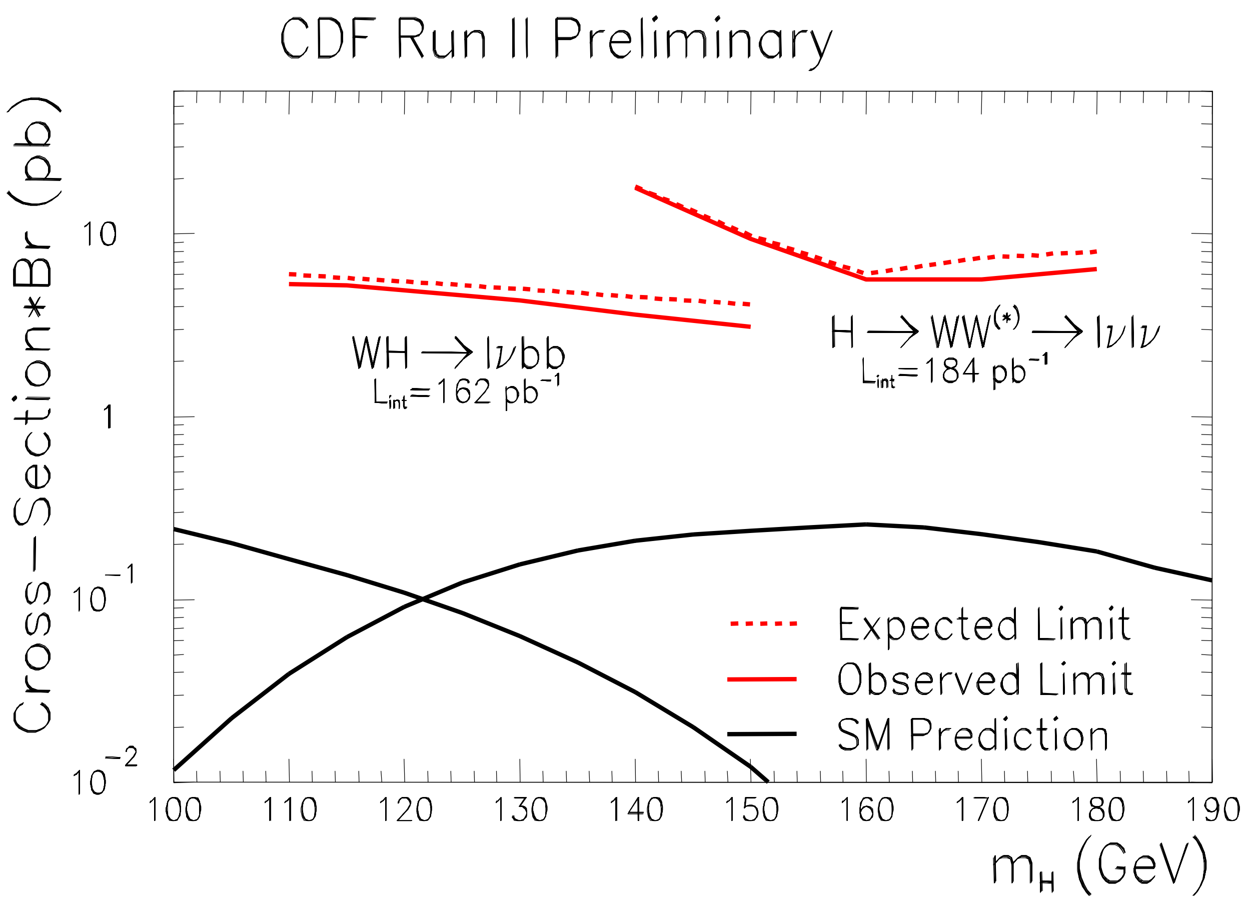
H→WW (CDF)

- Seach in 3 channels
  - ee, eμ and μμ
- Selection
  - 2 isol. leptons p_T>20 GeV
  - Oppositely charged
  - MET > 25 GeV
  - Veto on jets E_T>15, |η|<2.5
  - $M_{ll} < M_H/2$
- 8 events observed
  - 8.9±1.0 expected
- Limits are extracted by performing likelihood fit to the $\Delta\Phi_{ll}$ distribution



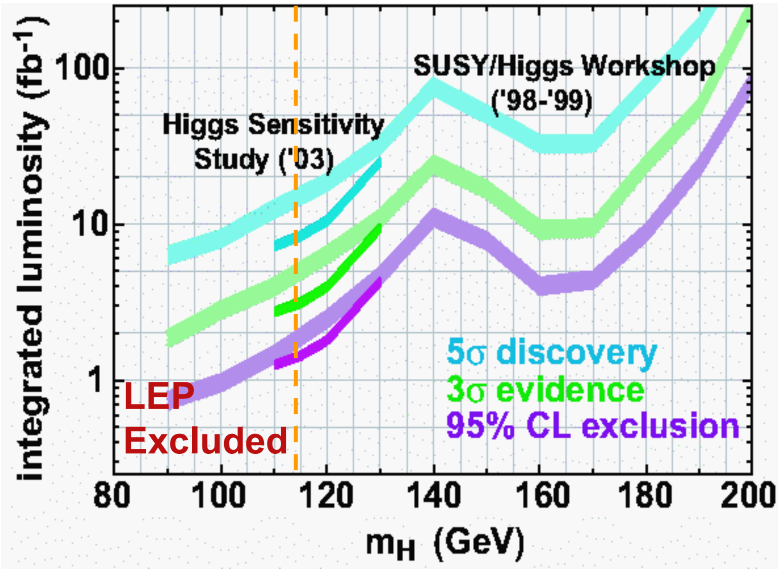
WW	Drell-Yan	Fakes
6.5 ± 0.8	1.3 ± 0.5	0.81 ± 0.25

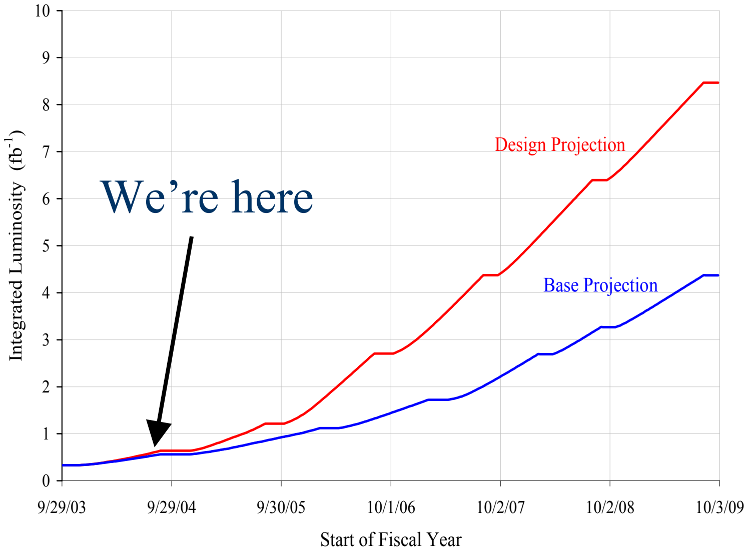
H→WW (CDF)



σ*BR(H→WW) < 5.6pb @ 95% CL For M_H=160 GeV

Outlook





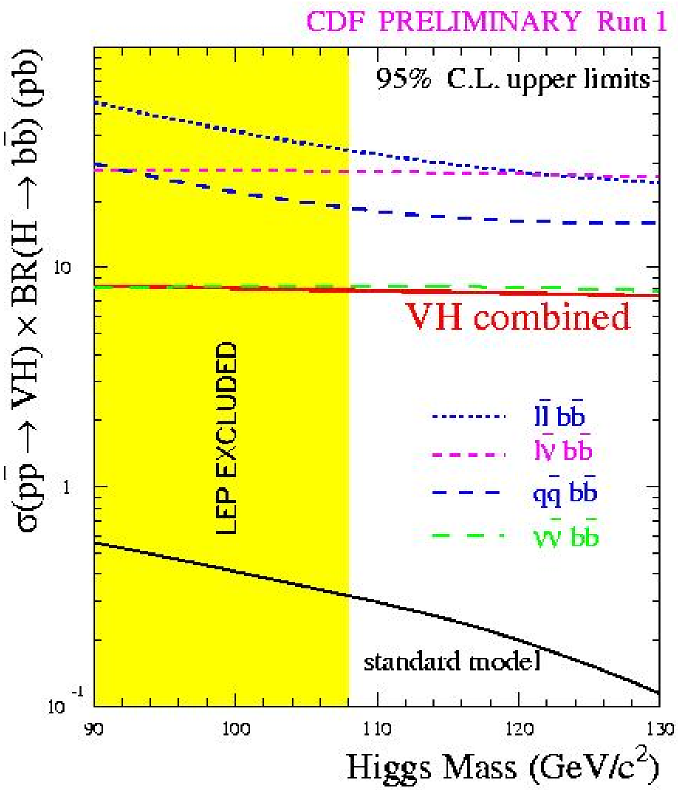
- Need >2 fb^{-1} per experiment to exclude M_H
- Working on further optimization
- Benchmark: $WZ \rightarrow l\nu bb$

- Excellent performance of the Tevatron
  - Met the design projection for this year
- Need to understand high luminosity environment

Higgs Search at Tevatron (Run1)

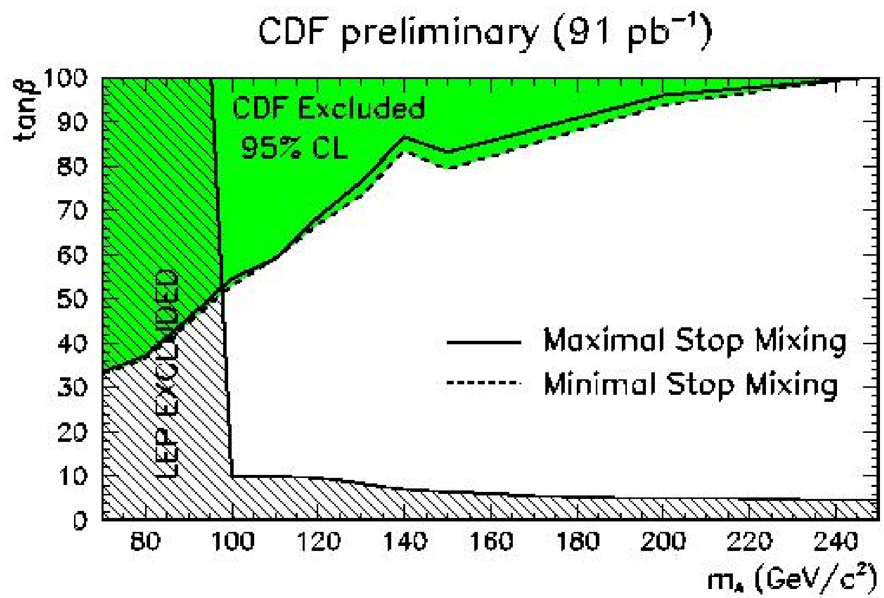
SM Higgs Search

- $Wh \to (l\nu, q\bar{q}')b\bar{b}$
- $Zh \to (l^+l^-, \nu\bar{\nu})b\bar{b}$
- set $\sigma_{Vh} \cdot B < 8$ pb at 95% CL



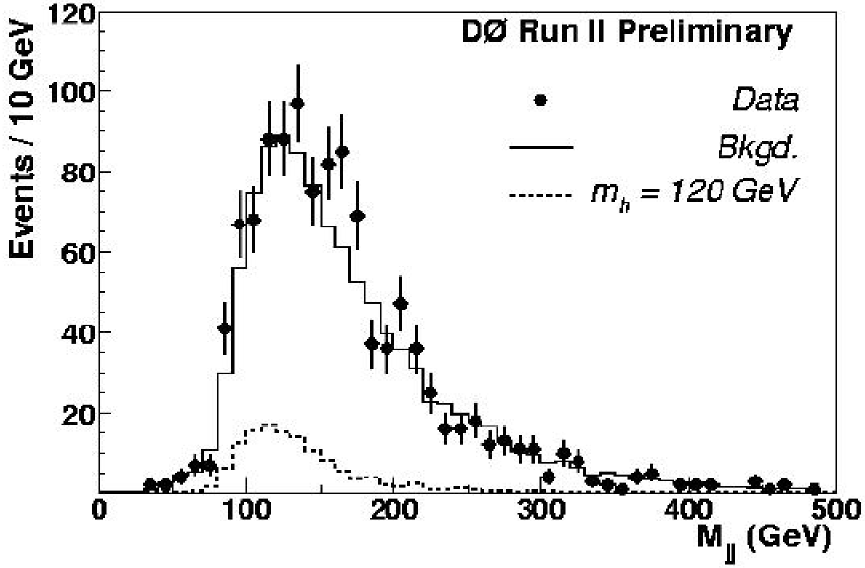
MSSM Higgs Search

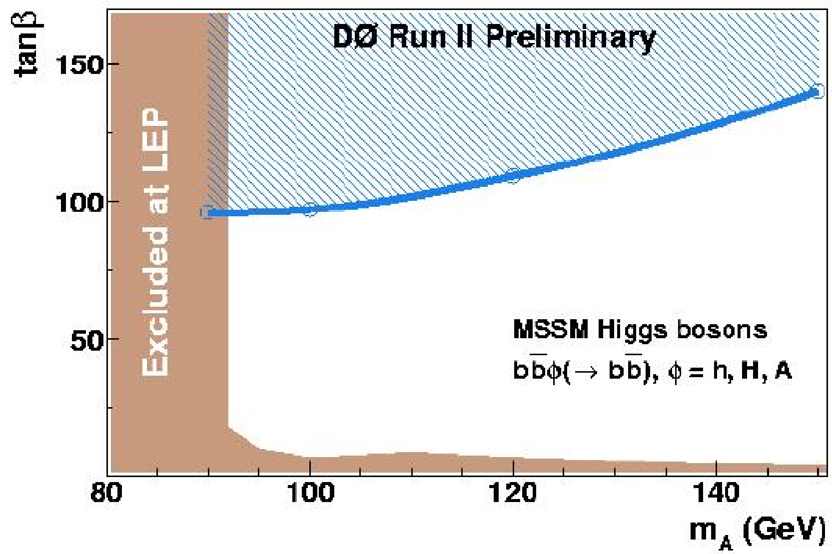
- Due to enhancement of $b\bar{b}h/H/A \to b\bar{b}b\bar{b}$ xsec at large $tan\beta$
- Selecting 3 b-jets from multi-jet sample
- set $tan\beta > 50$ at 95% CL for $m_A = 100$ GeV



No real sensitivity yet ...

Search for MSSM Higgs: $Ab\bar{b} \to b\bar{b}b\bar{b}$ (D0)





- $b\bar{b}(h/H/A)$ enhanced at large $tan\beta$
- Selecting events on multijet trigger (131 pb^{-1})
- Requiring 4 jets with 3 b-tags
- Invariant mass of the two highest b-tag jets and set a limit on $tan\beta$ vs m_A

Search for charged Higgs: $H^{\pm}$

- **Standard Model Higgs not found (yet).**
- **Extensions to the Standard Model with more Higgs doublets predict Higgs bosons which can be lighter: in the MSSM, $m_{H^{\pm}} < m_W$ is barely possible.**
- **In particular, 2HDM (already introduced) predict two charged Higgs bosons: $H^{\pm}$.**
- **The production cross-section in e^+e^- is a function of $m_{H^{\pm}}$ and $\sqrt{s}$.**
- **The branching ratios are model dependent:**
  - **Type II:** $H^+H^- \to c\bar{s}\bar{c}s$, $c\bar{s}\tau^-\bar{\nu}_\tau$ **and** $\tau^+\nu_\tau\tau^-\bar{\nu}_\tau$.
  - **Type I: for light A, decay** $H^{\pm} \to W^*A$, **final states** $H^+H^- \to W^*AW^*A$ **and** $W^*A\tau\nu_\tau$.

Note: indirect limits from $\Gamma(Z \to H^+H^-)$ calculated in 2HDM and from Γ_Z^{fit} using LEP precision data: $m_{H^{\pm}} > 40$ GeV at 95% C.L.

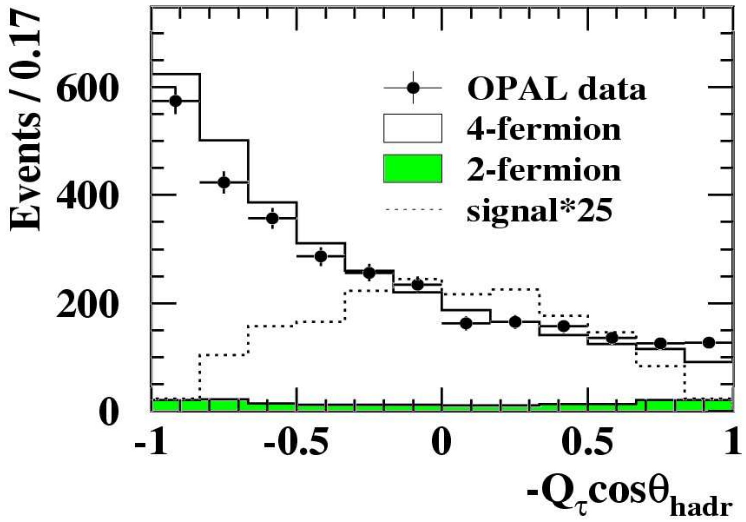
- **Charged Higgs bosons can be produced at LEP in $e^+e^- \longrightarrow H^+H^-$.**
  Production and decays of $H^\pm$ very similar to that of $W^\pm$ (main background).
  Different spin: the boson production angle plays a fundamental role.

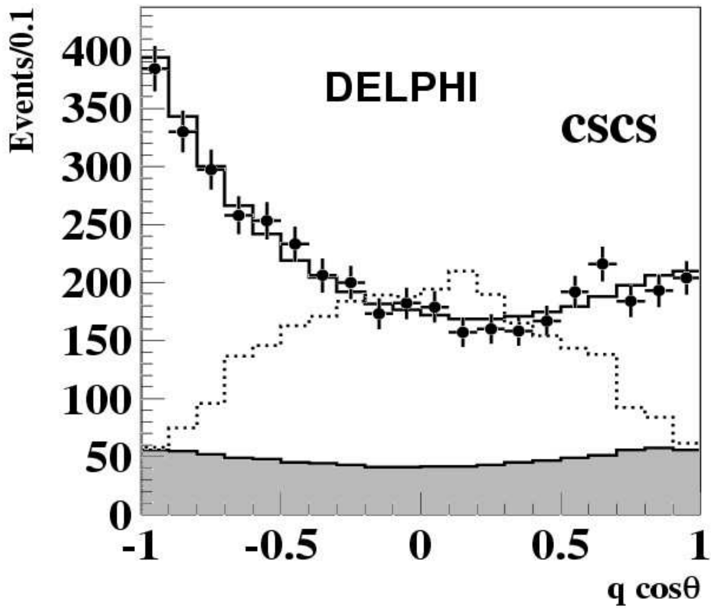
- **At $\sqrt{s} = 206$ GeV, $\sigma \sim 0.28 - 0.17$ pb for $m_{H^\pm} \sim 70 - 80$ GeV.**
  Luminosity per experiment $\sim 650\,\mathbf{pb}^{-1}$ above 189 GeV.
  Events expected: $\mathcal{O}(100)$ signal and $\mathcal{O}(1000)$ background.

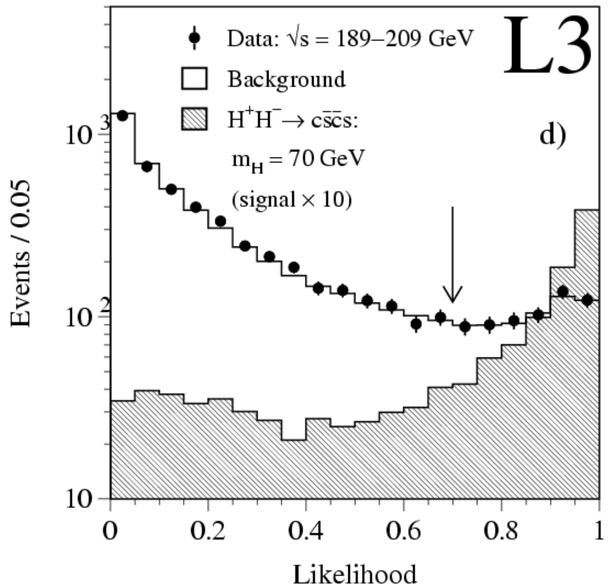
- **Final state topologies:**
  - **Type II: 4-jet events in $c\bar{s}\bar{c}s$**
    2 jets, τ-jet and $\not{E}$ in $c\bar{s}\tau^-\bar{\nu}_\tau$
    2 τ-jets and $\not{E}$ in $\tau^+\nu_\tau\tau^-\bar{\nu}_\tau$.
  - **Type I: W^*AW^*A and $W^*A\tau\nu_\tau$, jets, b-tag, τ-jets and $\not{E}$.**

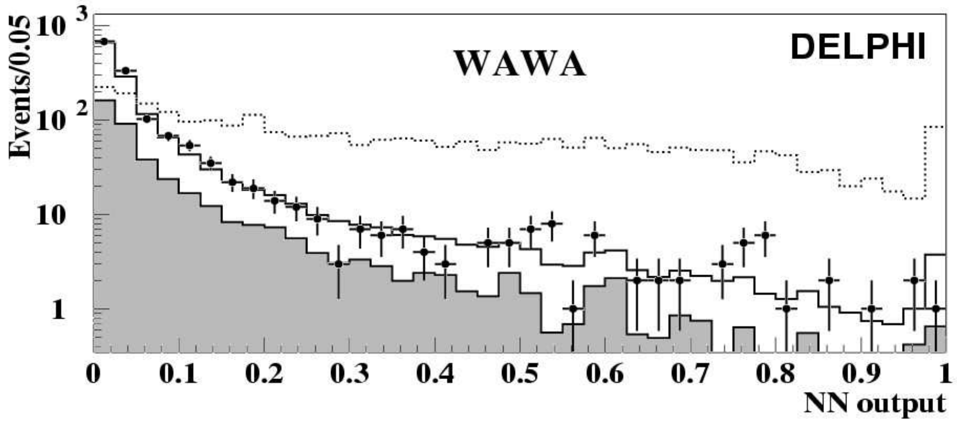
- **The analysis are mostly likelihood- and multidimensional-NN-based.**
  Typical efficiencies $\sim 30 - 60\%$, depending on the channel.

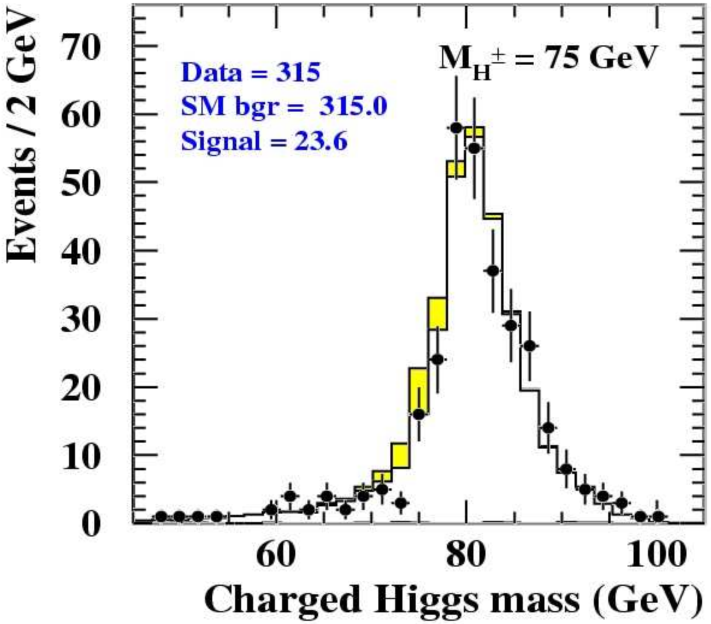
Distributions used for the analysis, different experiments and channels:

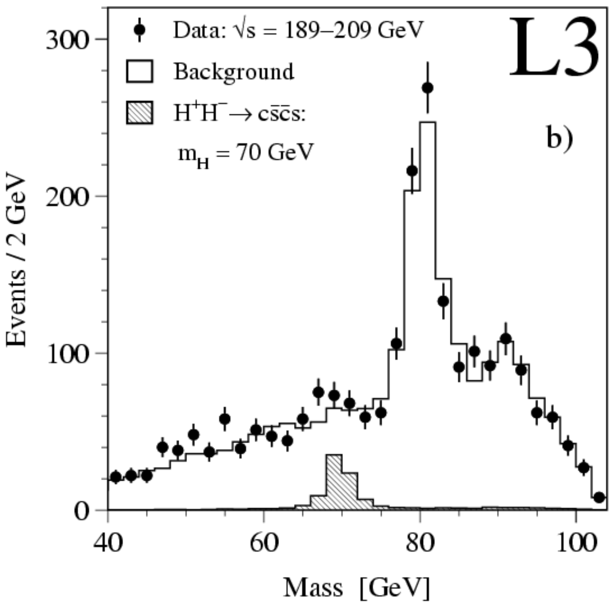






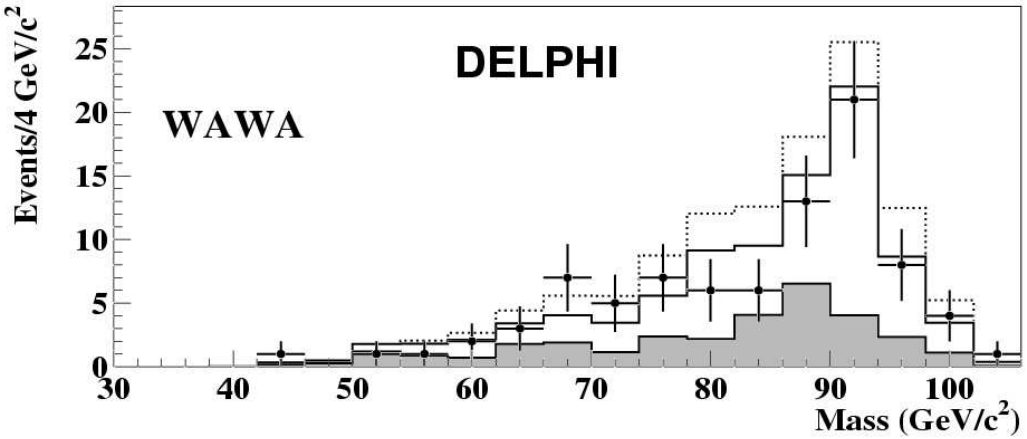






<u>Mass resolution</u>: **1.5 GeV $c\bar{s}\bar{c}s$, 2-4 GeV $c\bar{s}\tau^-\bar{\nu}_\tau$**

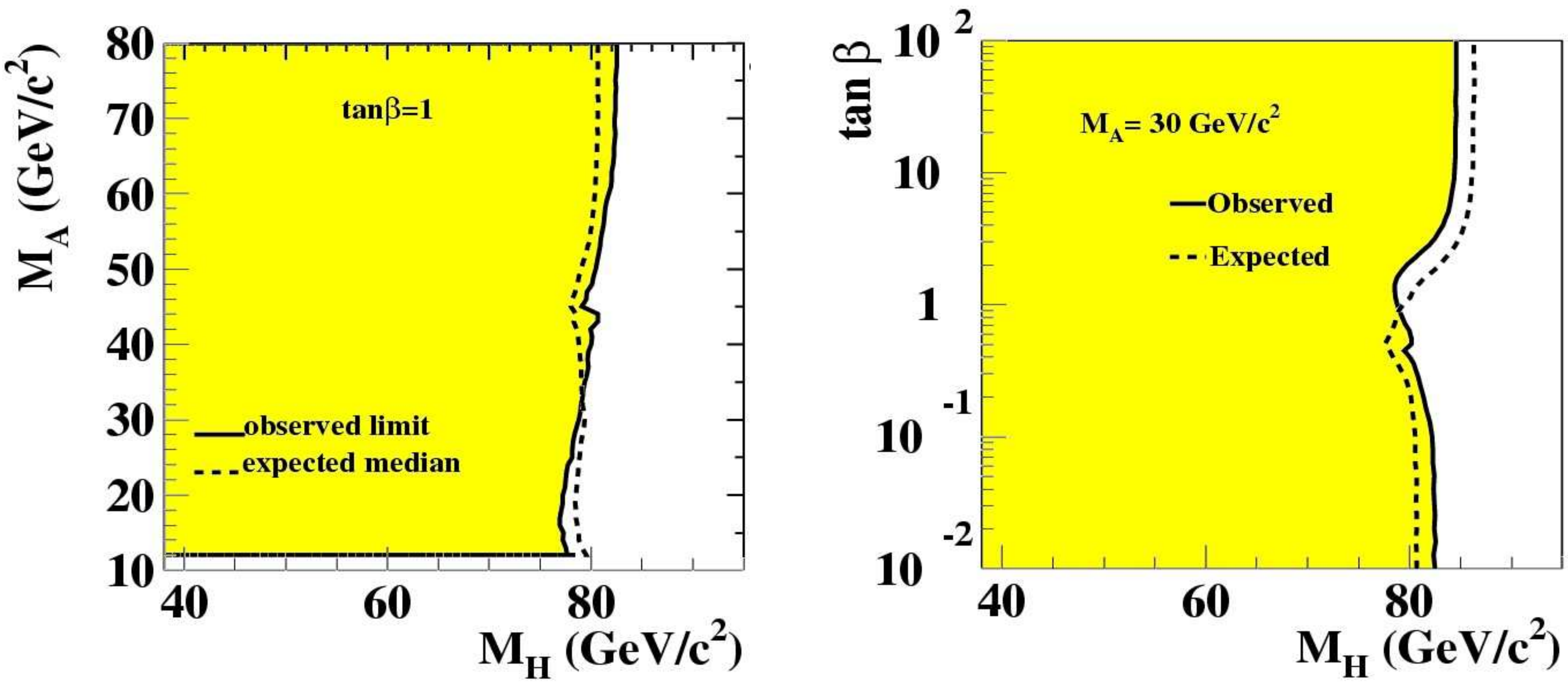
Good agreement data/expectations (w/o signal), both in the number of events and in the shape of the distributions.



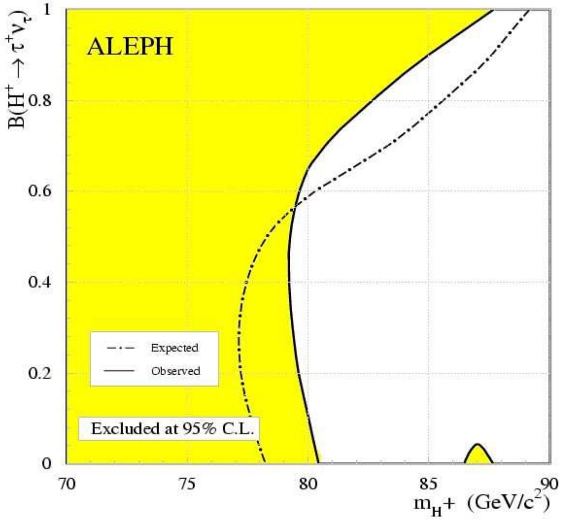
The L3 anomaly at 68 GeV persists only in the 4-jet channel and with reduced significance: statistical fluctuation of the background (2.5σ).

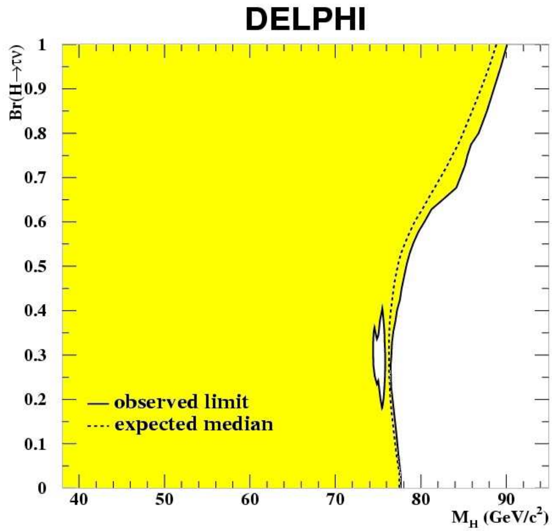
DELPHI limits on $m_{H^\pm}$ vs. m_A

Exclusion contours (95% C.L.) in the $m_{H^\pm} - m_A$ and $m_{H^\pm} - \tan\beta$ planes:



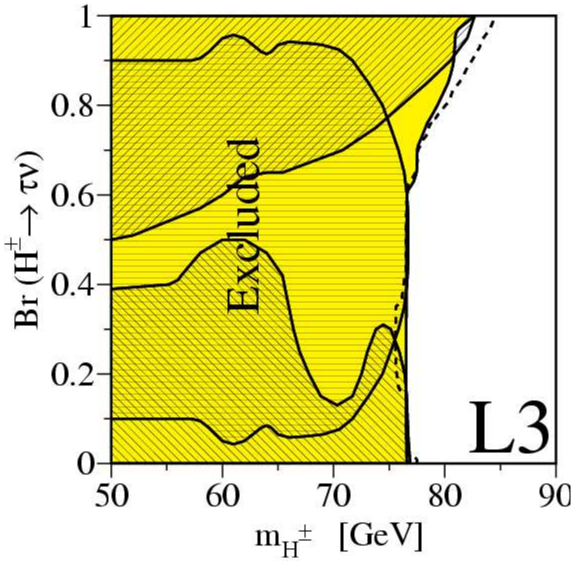
- **Limits for Type I:** $m_{H^\pm} > 76.7$ GeV (77.1) **for any** $\tan\beta$ **and** $m_A > 12$ GeV.
- **Log likelihood method used for the statistical analysis.**
- **Systematic errors included: detector, cuts, normalisation of background and signal.**

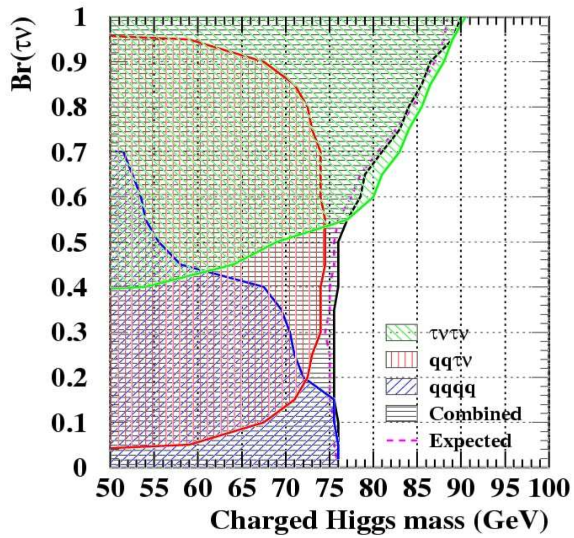




Lower limits at 95% CL (GeV):

	observed	expected
ALEPH	79.3	77.1
DELPHI	74.4	76.3
OPAL	75.5	74.5
L3	76.5	75.6

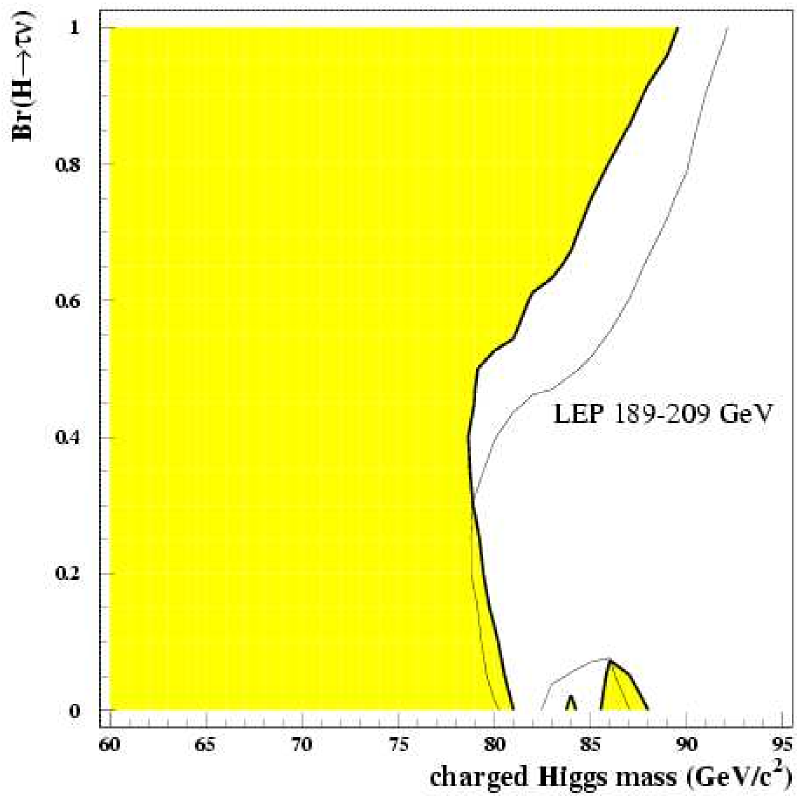




Systematic errors included: limits reduced by 200-600 MeV, depending on the channel.

LEP combined results

Exclusion contours (95% C.L.) in the $m_{H^\pm} - Br(H^\pm \to \tau\nu)$ plane (old from 2001):



- **No new combined results (manpower problems): L3 was 'late', OPAL not yet final.**
- **Results (95% CL limits) NOT expected to change significantly: $m_{H^\pm} > 78.6$ GeV (78.8)**
- **Significant improvement in CL_b, specially due to the L3 change.**