Review of MSSM Higgs boson searches at LEP

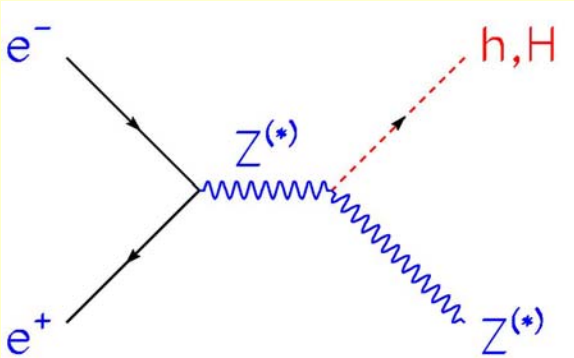
Vanina Ruhlmann-Kleider
CEA/DAPNIA/SPP

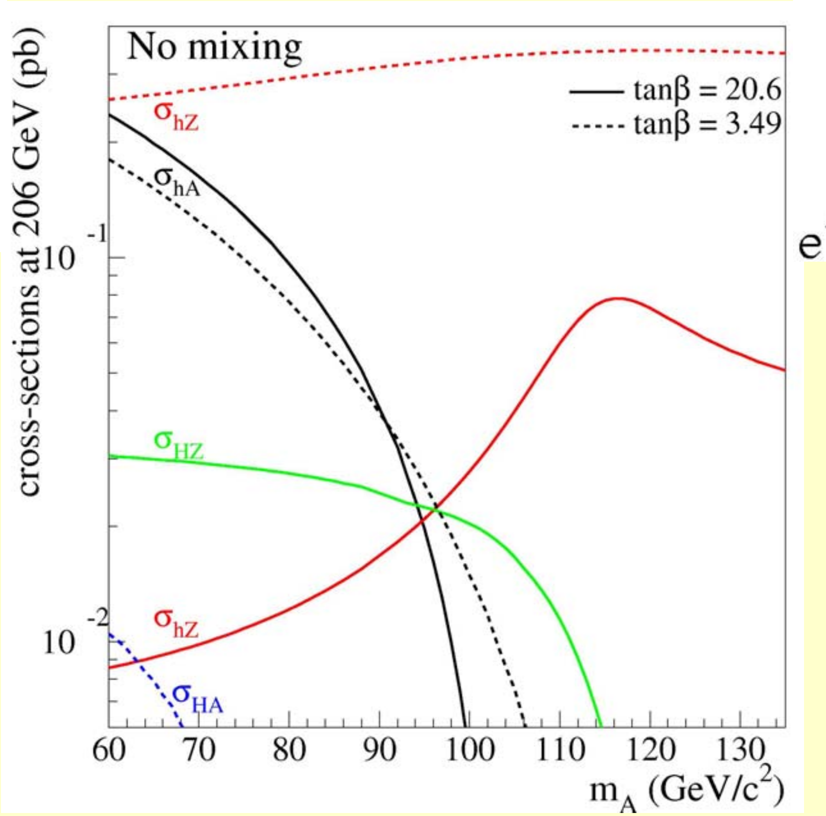
1) MSSM with CP conservation
2) MSSM with CP violation
3) Conclusions

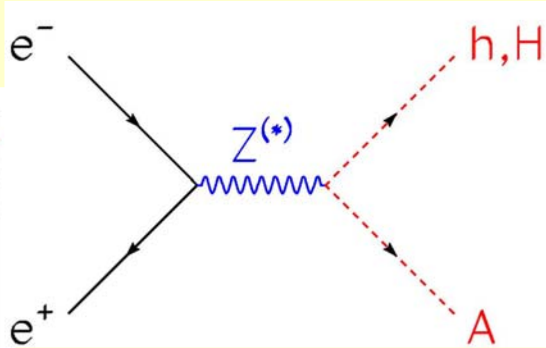
CP-conserving MSSM scenarios

3 neutral Higgs bosons: h, H, A CP-eigenstates

at tree level, 2 parameters : $\tan\beta$, m_A







hZ: low $\tan\beta$
large $\tan\beta$ & m_A

HZ: large $\tan\beta$ &
low m_A

hA: interm./large
$\tan\beta$ & low m_A

Higgs decays: invisible, $\gamma\gamma$, ee, $\mu\mu$, $\pi\pi$, KK, cc, $\tau\tau$, bb, AA, hadrons

The MSSM underlying parameters at higher order

m_{top} and the SUSY breaking parameters, assumed to be unified at some scale :

SU(2), U(1) gaugino mass terms unified at M_{GUT} → M_2 at M_{EW}

sfermion mass terms : unified at M_{EW} → M_{susy} at M_{EW}

squark trilinear couplings : unified at M_{EW} → A at M_{EW}

⇒ mixing parameter in the stop sector : → $X = A - \mu \cot\beta$

gluino mass and Higgs mixing parameter → $M_{\breve{g}}$ and μ

Total: 8 parameters

m_{top} is measured ; M_2, M_{susy}, $M_{\breve{g}}$, μ et X are chosen to define a "scenario"; $\tan\beta$ and m_A are free to vary ($\tan\beta \in [0.4, 50]$ and $m_A \in [0.02, 1000]$ GeV).

NB: radiative corrections in the Feynman-diagrammatic approach (the most complete at two-loop order)

The scenarios : 3 LEP / 5 LHC scenarios

- m_h^{max}: sparticules at high mass (M_2, M_{susy}, $M_{\tilde{g}}$ large), μ et X such that m_h range is maximal (m_{top}=174.3 GeV: m_h < 132.9 GeV).

  LHC variants: 1) $\mu \to -\mu$, 2) $\mu \to -\mu$ & $X \to -X$

- **No mixing:** counterpart of m_h^{max} with X=0; m_h range reduced (m_{top}=174.3 GeV: m_h < 115.5 GeV).

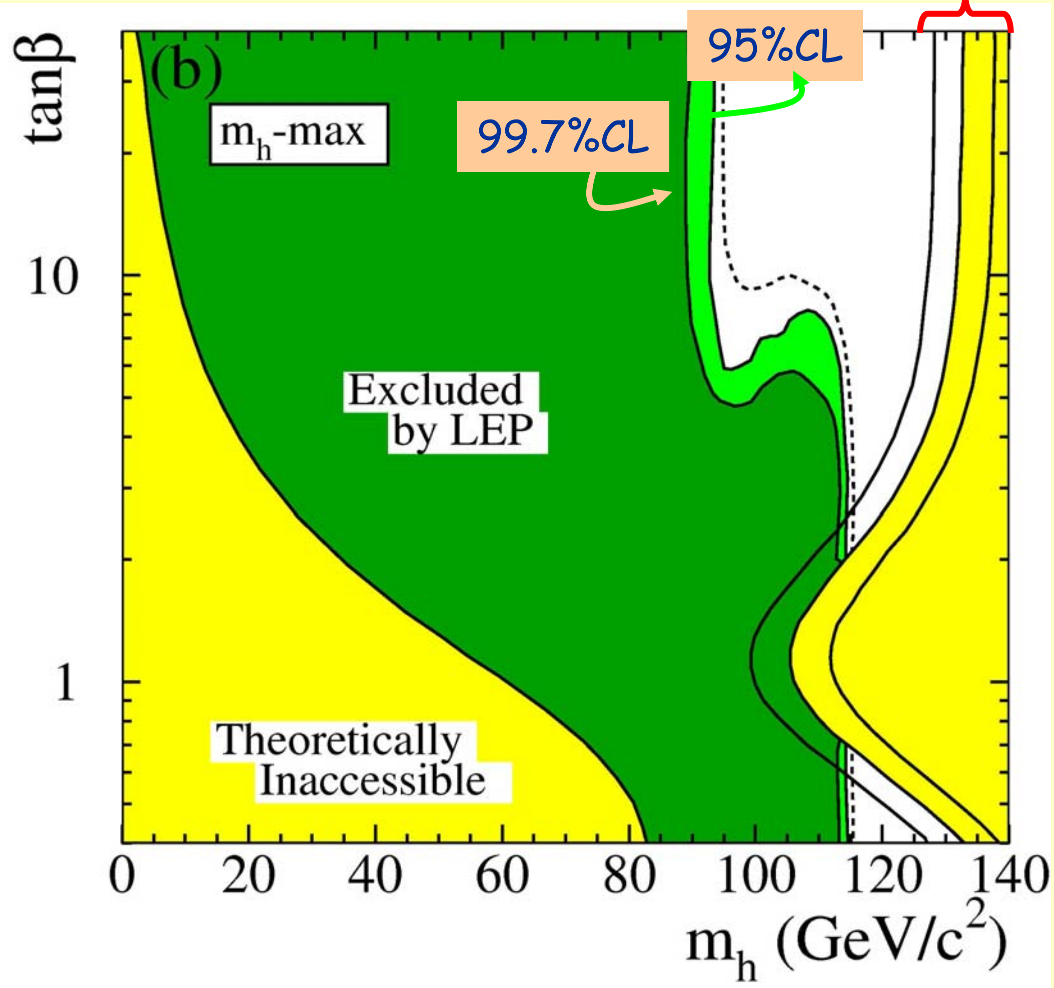
  LHC variant: 1) $\mu \to -\mu$, $M_{susy} \to 2\ M_{susy}$

- **Large μ:** at least one Higgs (h, A or H) kinematically accessible (m_{top}=174.3 GeV: m_h < 108.0 GeV) but Br(bb, $\tau\tau$) vanish at large tanβ.

- **Gluophobic scenario:** $gg \to h$ (strongly) suppressed $\forall$ tanβ, m_A

- **Small α_{eff} :** Br_h(bb, $\tau\tau$) suppressed at large tanβ, moderate m_A

The m_h^{max} scenario(s)



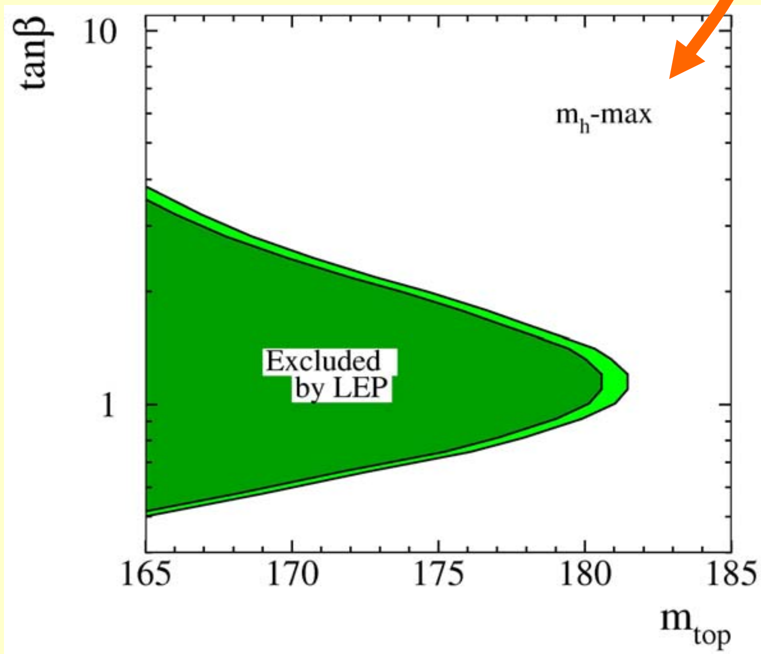
<u>m_{top}=174.3 GeV, 95% CL limits:</u>

m_h > 92.8 GeV, m_A > 93.4 GeV

insensitive to m_{top}

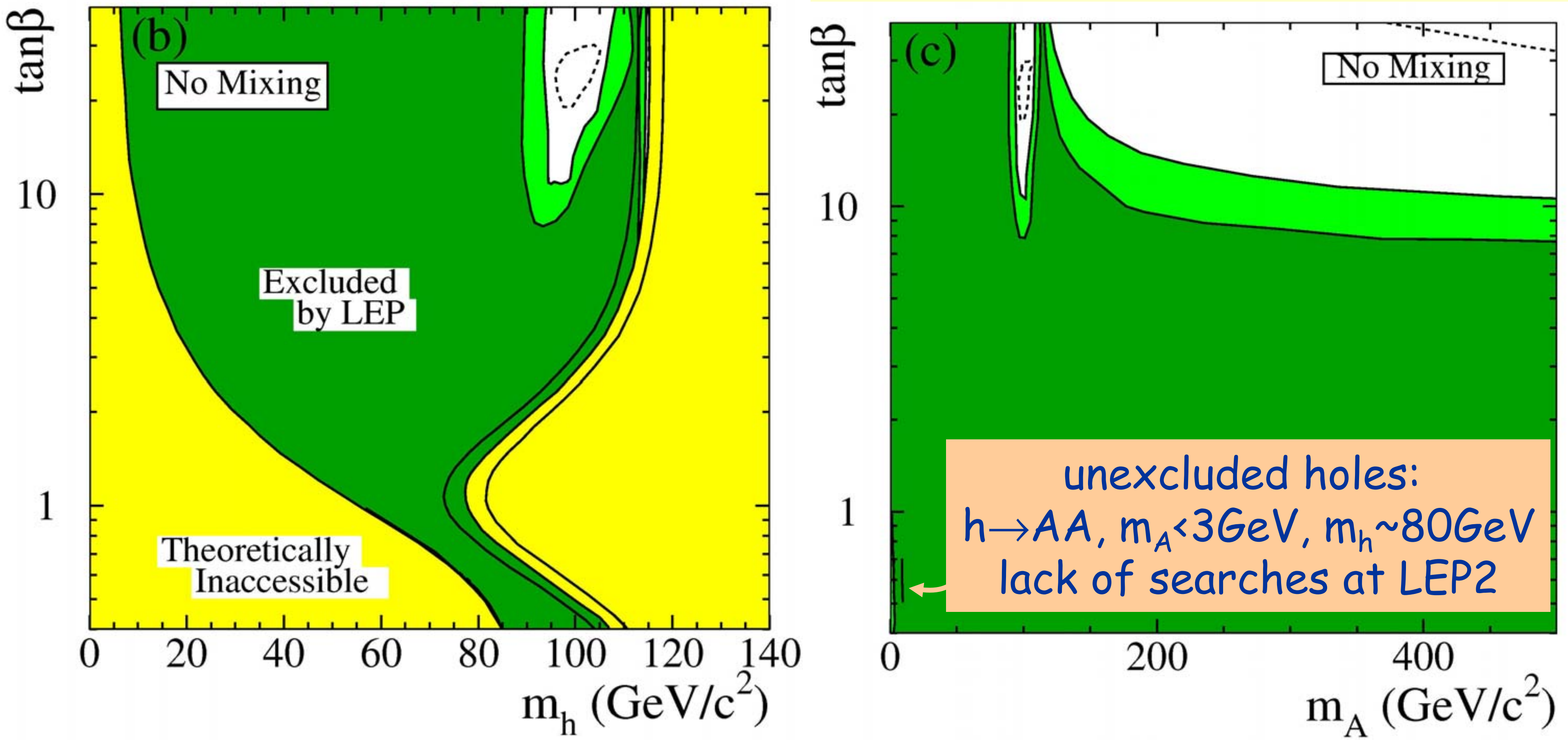
tanβ exclusion : 0.7 – 2.0

sensitive to m_{top}



LHC variants: ~identical mass limits, looser tanβ constraints

The no mixing scenario(s)



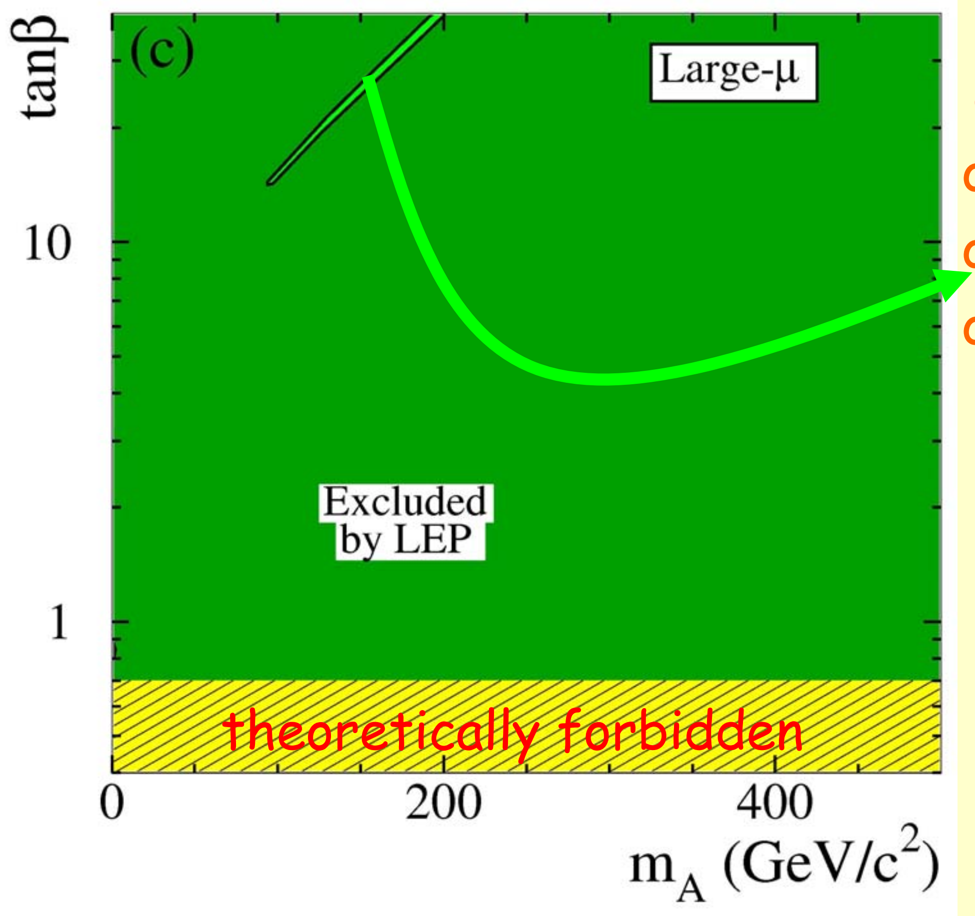
m_{top}=174.3 GeV, 95% CL limits:

m_h, m_A > 93.6 GeV (tanβ>0.7)   tanβ exclusion : 0.4 – 10.2 (mA>3GeV)

very sensitive to m_{top}: scenario fully excluded at m_{top}=169.3 GeV (H within reach)

LHC variant: tighter mass and tanβ limits

The large μ scenario



excluded at 95% CL, not at 99.7% CL:

- hZ only remaining process
- BR($h \to bb$) suppressed
- m_h~108GeV close to the sensitivity of the flavour-blind searches

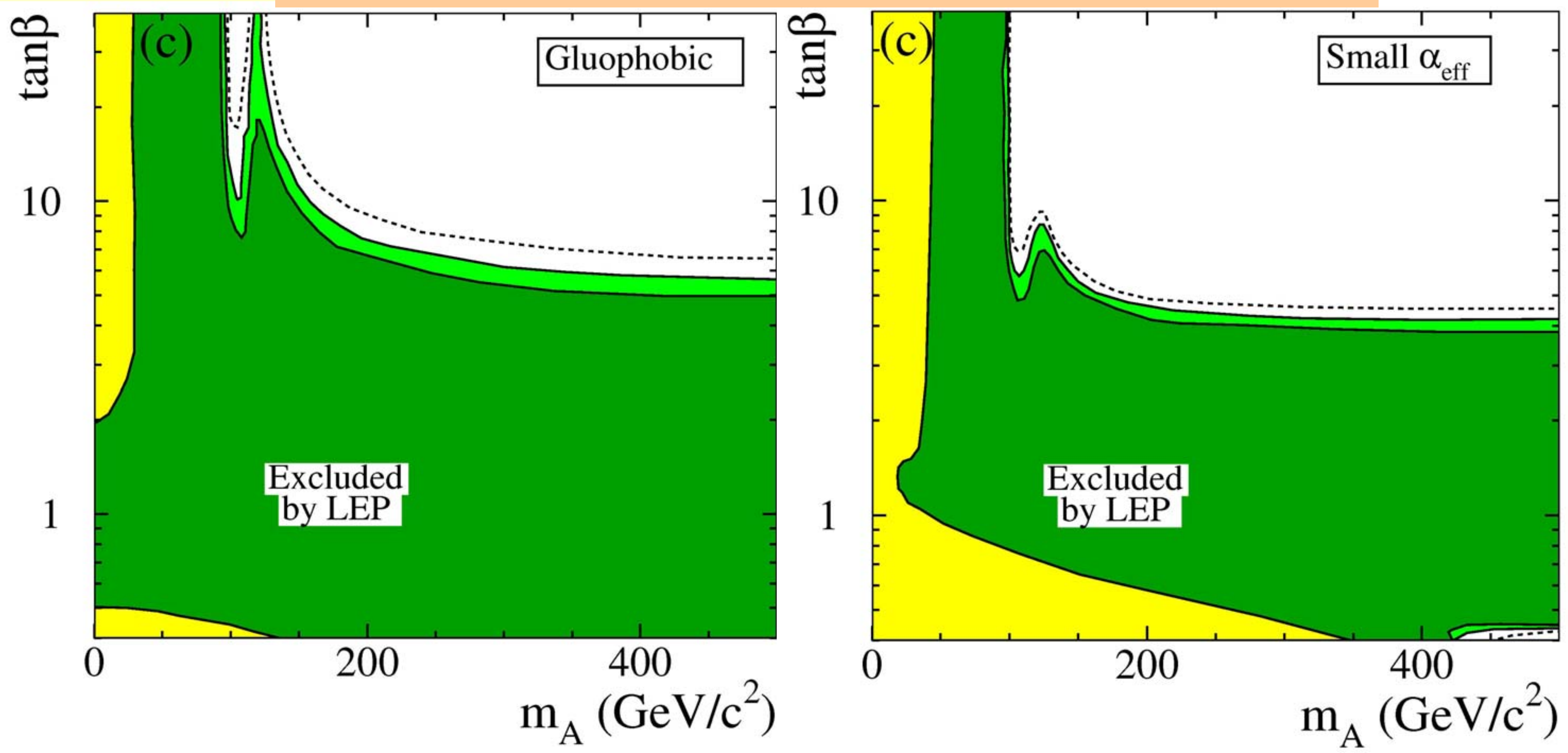
This strip grows with increasing m_{top}

m_{top}=174.3 GeV or smaller:

scenario fully excluded at 95%CL

thanks to: H searches and flavour-blind analyses

The gluophobic and small α scenarios



m_{top}=174.3 GeV , 95% CL limits:

m_h > 90.5 GeV, m_A > 96.3 GeV — m_h > 87.3 GeV, m_A > 98.8 GeV

tanβ exclusion : 0.4 – 5.4 — tanβ exclusion : 0.4 – 4.2

moderately sensitive to m_{top}

NB: h, A not degenerate in mass at large tanβ

CP-conserving MSSM scenarios, conclusions:

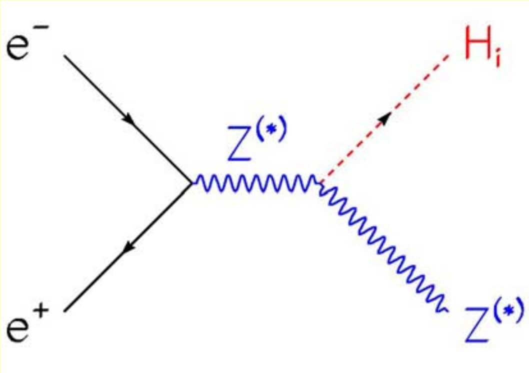
- 8 representative scenarios scanned with ADLO results on neutral Higgs boson searches at LEP1 & LEP2 ;
- improved sensitivitity thanks to H searches and flavour-blind analyses (esp. for low m_{top})
- mass limits are set at large tanβ and ~ O(90) GeV in m_h,m_A
- tanβ limits are set by the LEP m_h^{max} scenario :

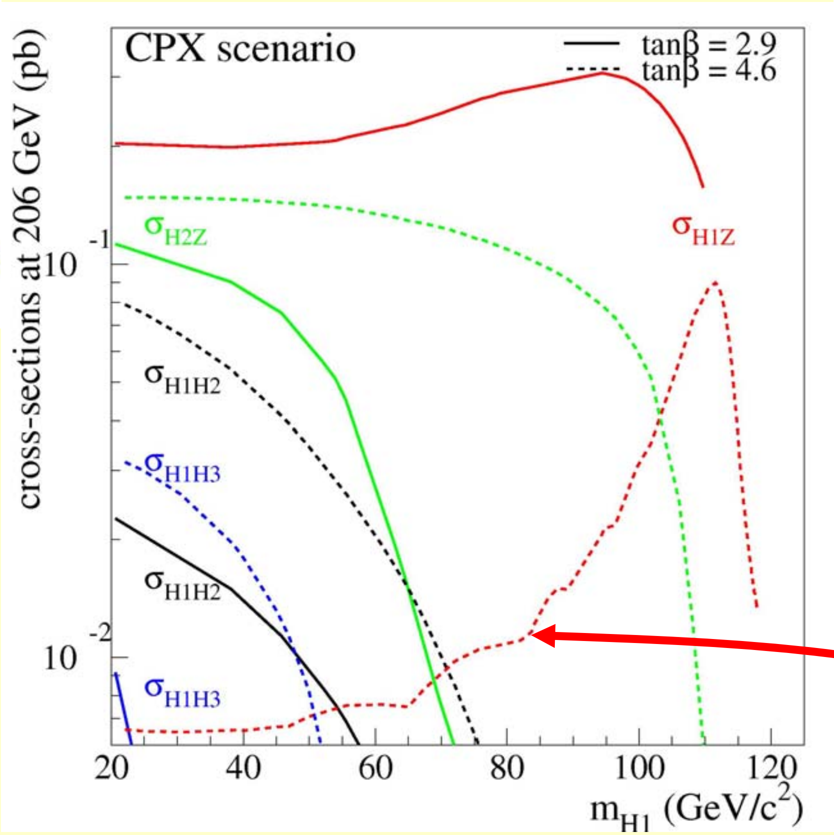
tanβ exclusion (95%CL) : 0.7 – 2.0 for m_{top}=174.3 GeV

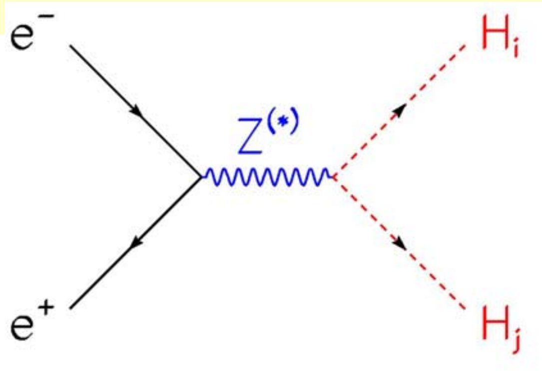
CP-violating MSSM scenarios

3 neutral Higgs bosons: H_1,H_2,H_3 mixtures of CP-eigenstates

at tree level, 2 parameters : $\tan\beta$, $m_{H^\pm}$







H_1Z: low $\tan\beta$, large $\tan\beta$ & m_{H1}

H_2Z: low/interm. $\tan\beta$ & low m_{H1}

H_1H_2: interm./large $\tan\beta$ & low m_{H1}

wrt CPC case:

more processes a priori, but some ZZH_i couplings can be suppressed

similar decays, but $H_j \rightarrow H_iH_i$ is enhanced

The MSSM underlying parameters

- The usual eight MSSM underlying parameters :
  - at tree level : $\tan\beta$, $m_{H\pm}$
  - through radiative corrections : m_{top} and the SUSY breaking parameters: M_2, M_{susy}, $M_{\breve{g}}$, μ and $A_{t,b}$
- Additional CPV parameters :
  - two CPV phases : $\arg(A_{t,b})$ and $\arg(M_{\breve{g}})$

- Dominant CPV effects scale as: $m_{top}{}^4\, \mathrm{Im}(\mu A_{t,b})/(v_1{}^2+v_2{}^2)32\pi^2 M_{susy}{}^2$

  $\Rightarrow$ low M_{susy}, large μ and $\arg(A_{t,b})\sim 90^o$

  $\Rightarrow$ the CPX scenario:

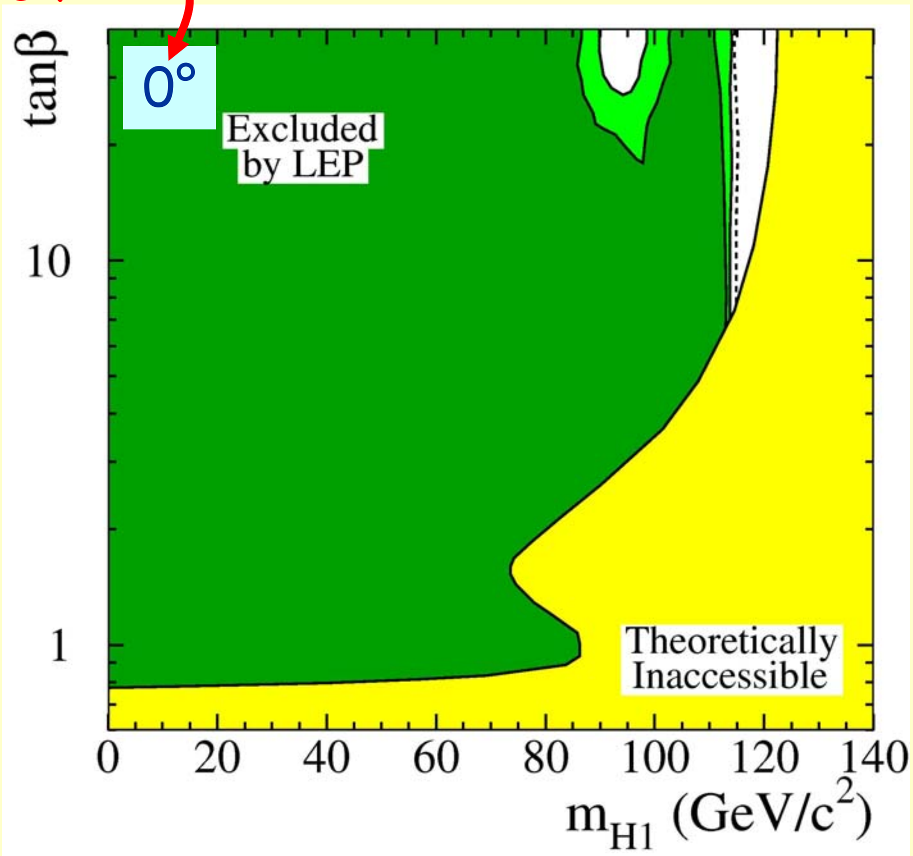
M_{susy}=500GeV, $\mu=4M_{susy}$=2TeV, $|A_{t,b}|=M_{\breve{g}}=2M_{susy}$=1TeV, M_2=200GeV
and $\arg(A_{t,b})=\arg(M_{\breve{g}})=90^o$

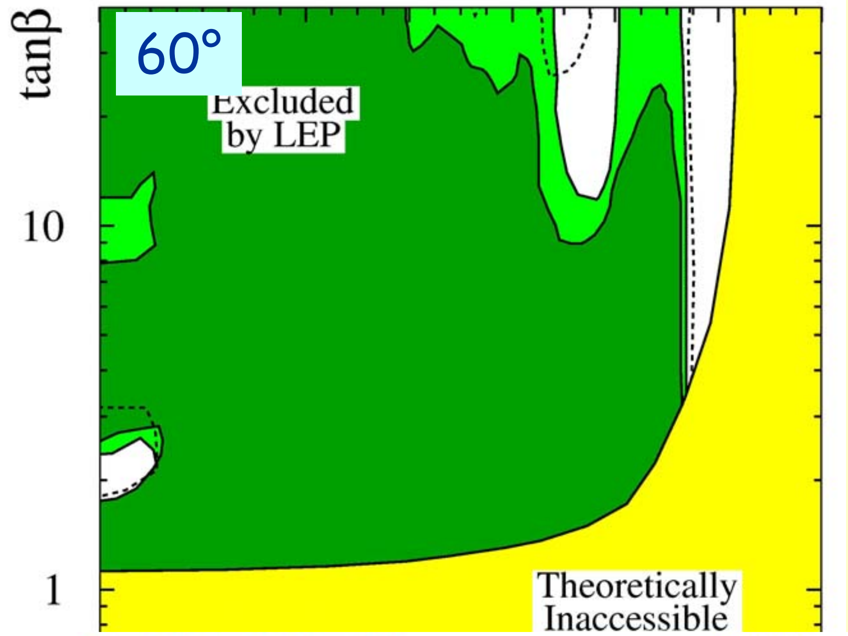
+ 10 variants to study the dependence with $\arg(A_{t,b})$, μ and M_{susy}.

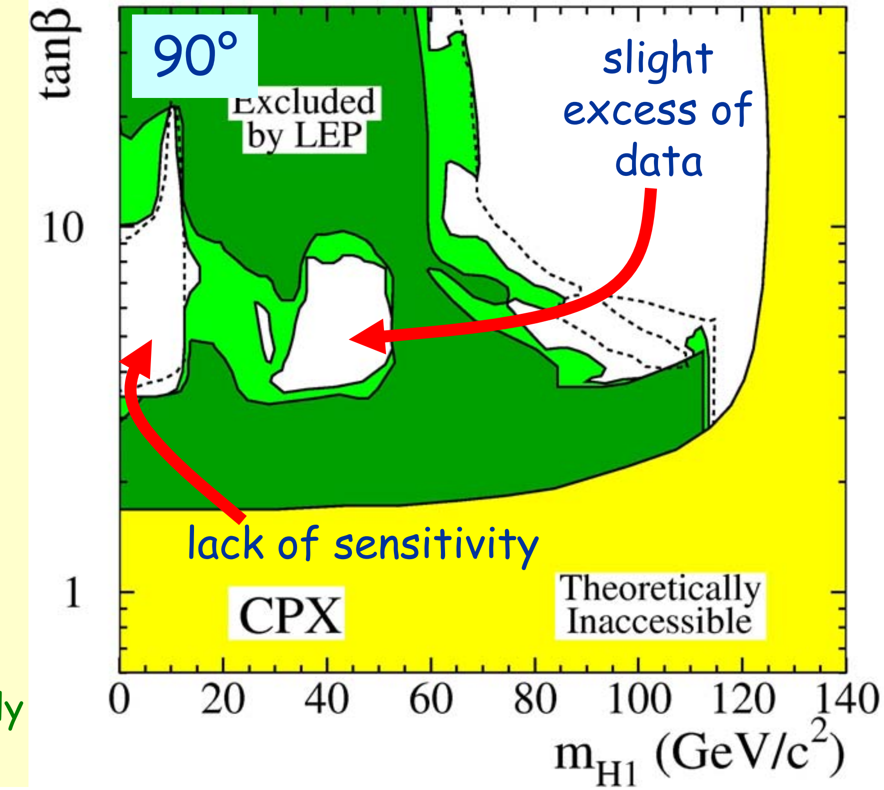
NB: radiative corrections in the renormalization group and Feynman-diagrammatic approaches (presently at the same stage of developpement)

Dependence with the CP-violating phases

CPC !





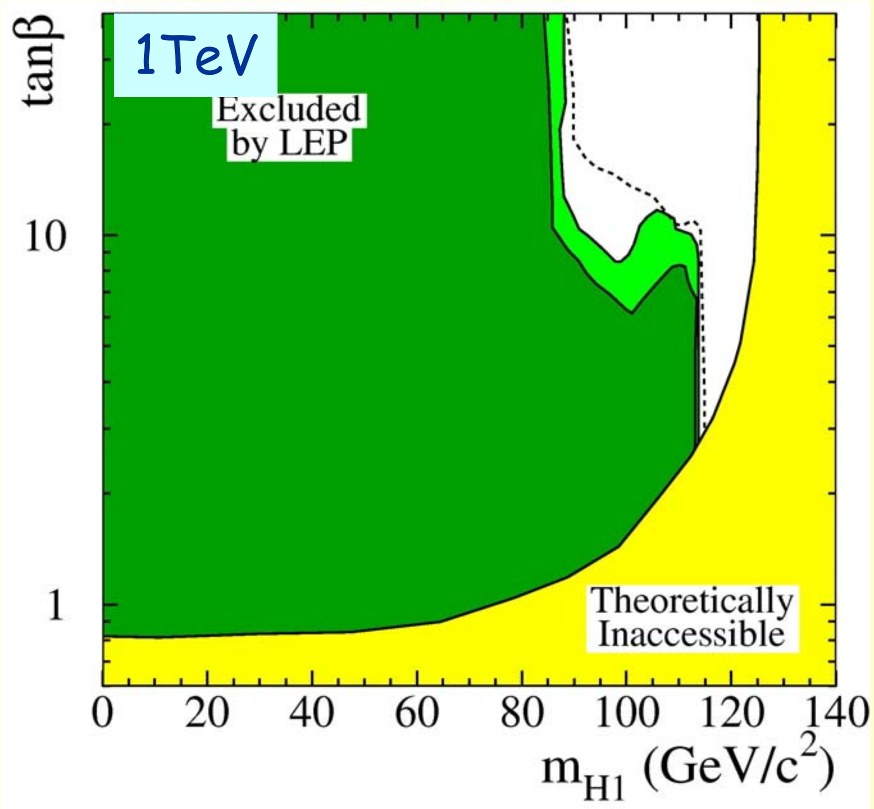


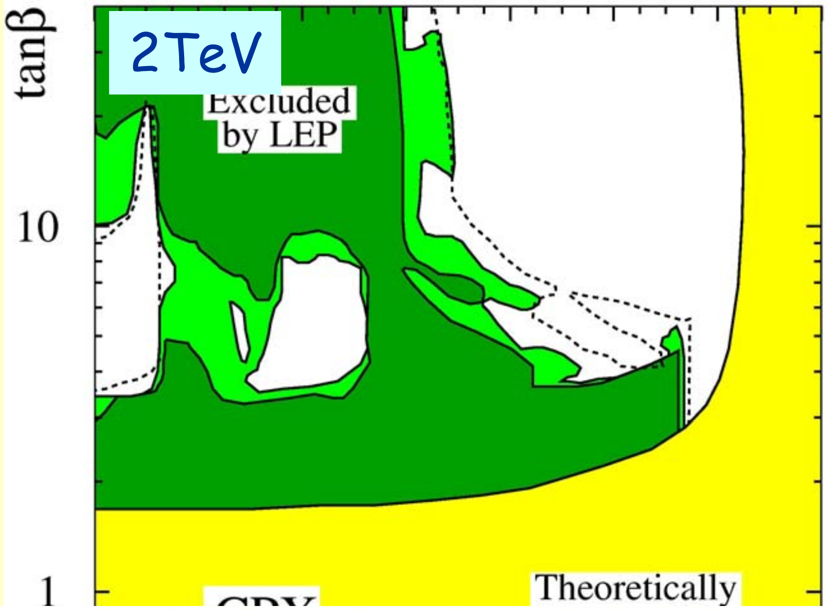
<u>Phases ~90°:</u> H_1Z suppressed

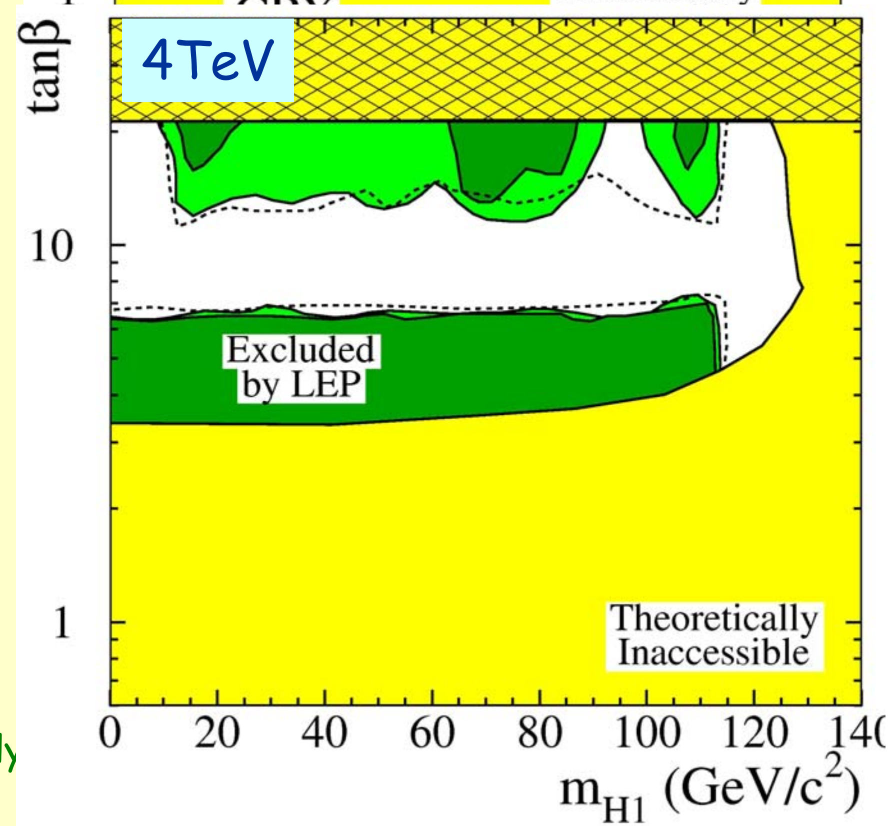
large tanβ: H_1H_2

interm.tanβ: H_2Z, esp. $H_2 \rightarrow H_1H_1$

Dependence with μ



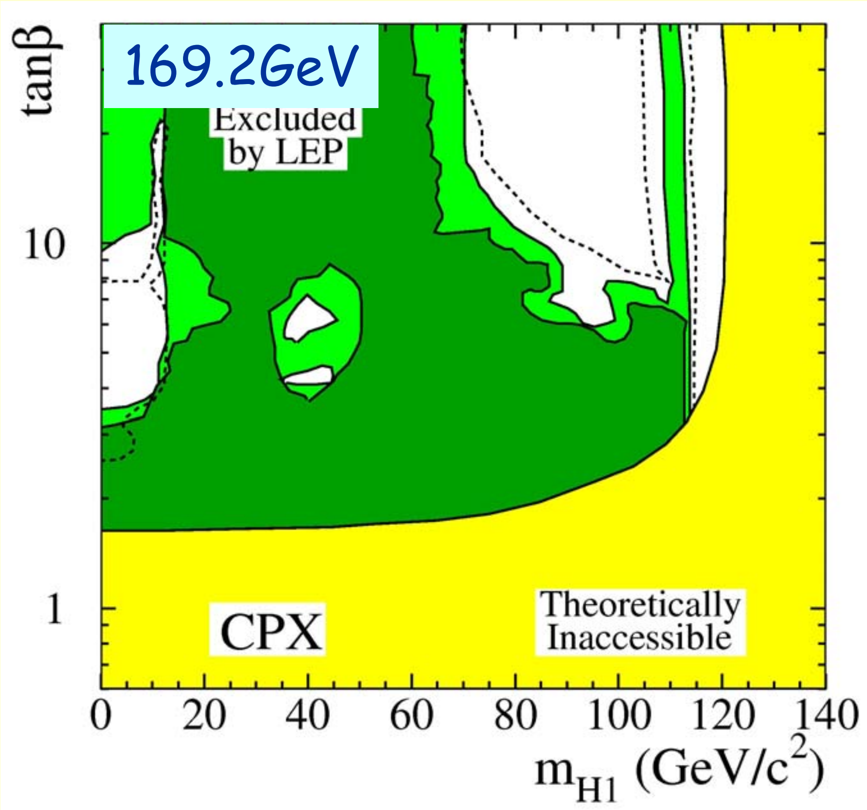


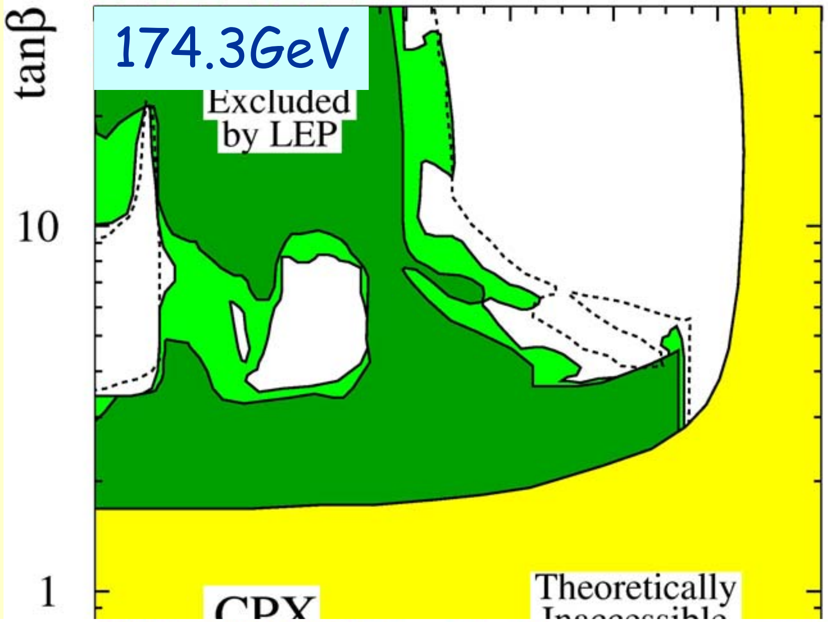


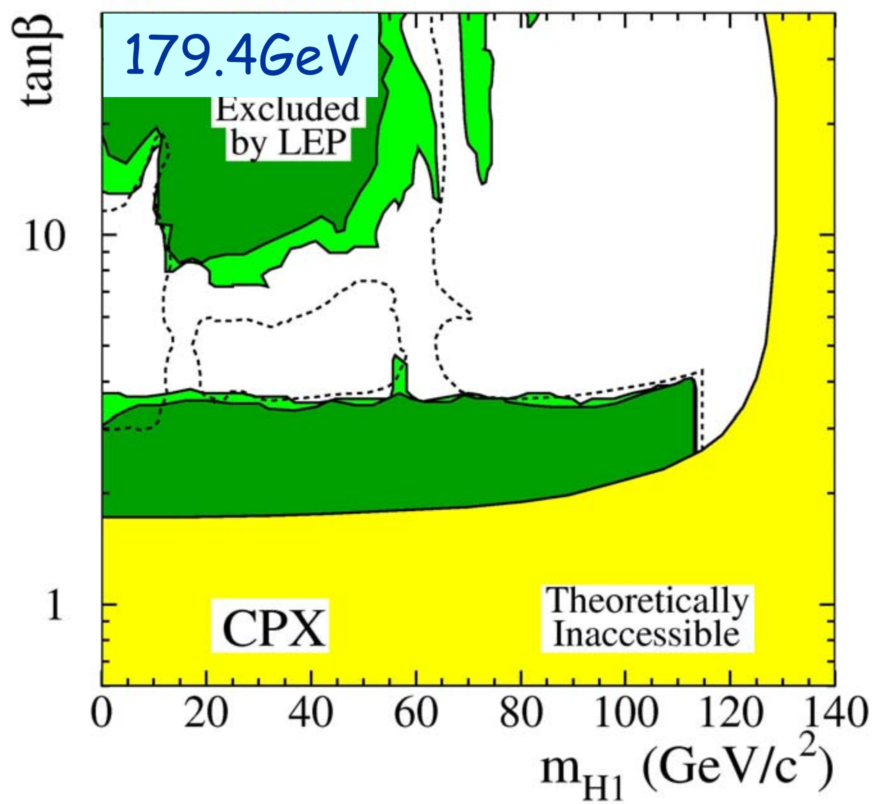
At intermediate tanβ:

- μ=1TeV: two processes left
- μ=2TeV: one process left
- μ=4TeV: no process left

Dependence with m_{top}







At intermediate tanβ:

H_1Z, H_2Z and H_1H_2 suppression gets stronger with increasing m_{top}

CP-violating MSSM scenarios, conclusions:

- 11 representative scenarios scanned with ADLO results on neutral Higgs boson searches at LEP1 & LEP2 ;
- Significant effects require $\arg(A_{t,b})=90°,135°$, $m_{top}\geq 174GeV$, and $\mu|A_{t,b}|/M_{susy}^2 \geq 8$;
- CPV = redundancy lost ⇒ reduced sensitivity of LEP at intermediate $\tan\beta$ down to the lowest masses ⇒ No absolute mass limits !
- $\tan\beta$ limits are set by the CPX scenario :

$$\tan\beta > 2.9 \text{ (95\% CL) for } m_{top}=174.3 \text{ GeV}$$

- Results are qualitatively the same in the renormalization group and Feynman-diagrammatic approaches.

Conclusions

From the neutral Higgs boson searches at LEP applied to a set of representative MSSM scenarios :

- If CP is conserved in the Higgs sector:
  - absolute mass limits around 90 GeV in m_h, m_A ;
  - low tanβ region not favoured (0.7 – 2.0 excluded in the LEP m_h^{max} scenario for m_{top}=174.3 GeV).

- If CP is not conserved in the Higgs sector:
  - No absolute mass limits (at intermediate tanβ) !
  - low tanβ region still not favoured (tanβ<2.9 excluded in the CPX scenario for m_{top}=174.3 GeV);
  - Calculations of radiative corrections not yet as complete as in the CP-conserving case.

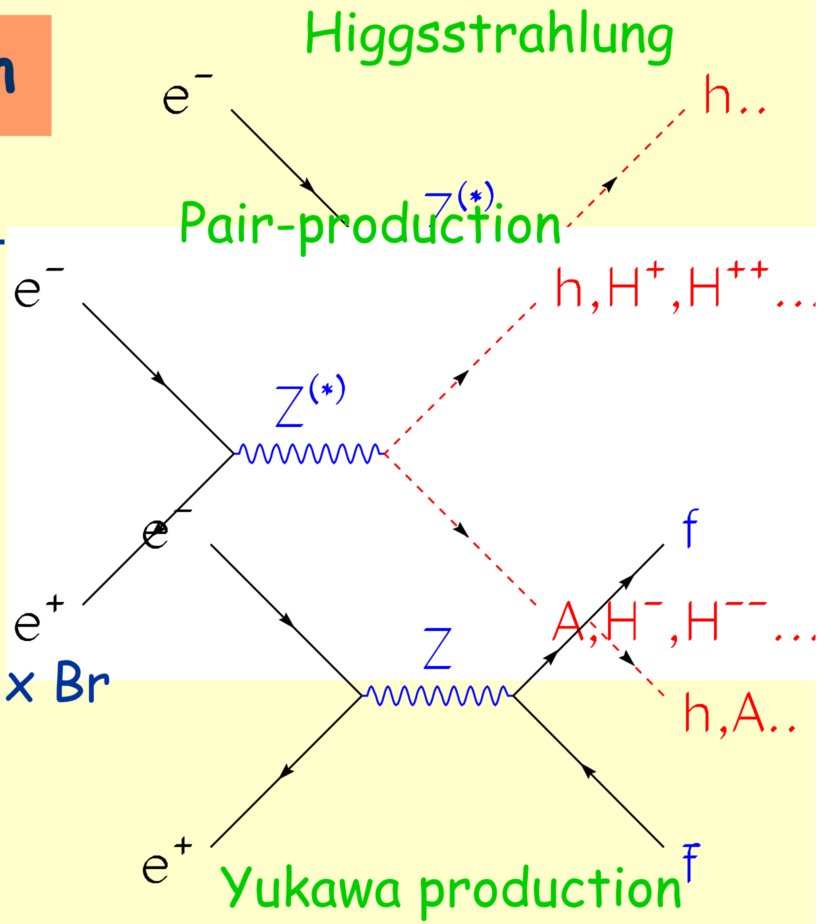
Introduction

Higgs boson searches at LEP:

- Direct searches :
  - Only 3 production processes
  - Almost all decays can be exploited

⇓

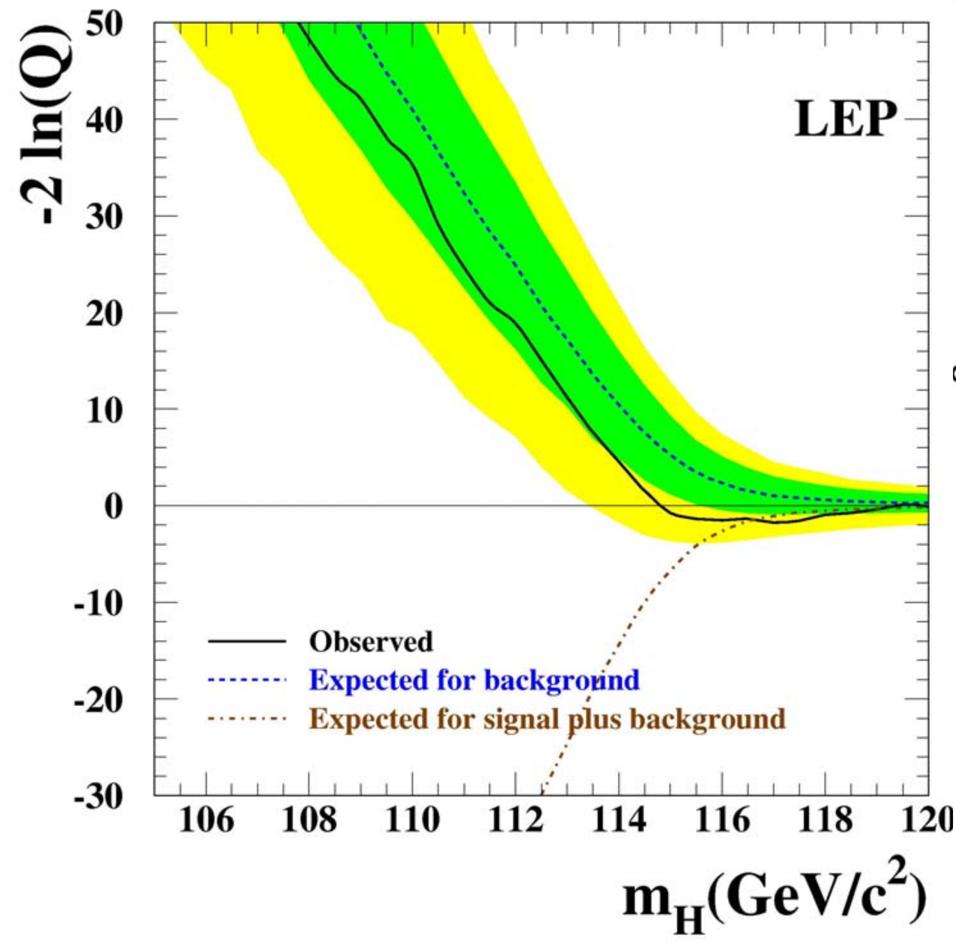
  - model-independent constraints on σ x Br
  - model scans : SM, MSSM, 2HDM

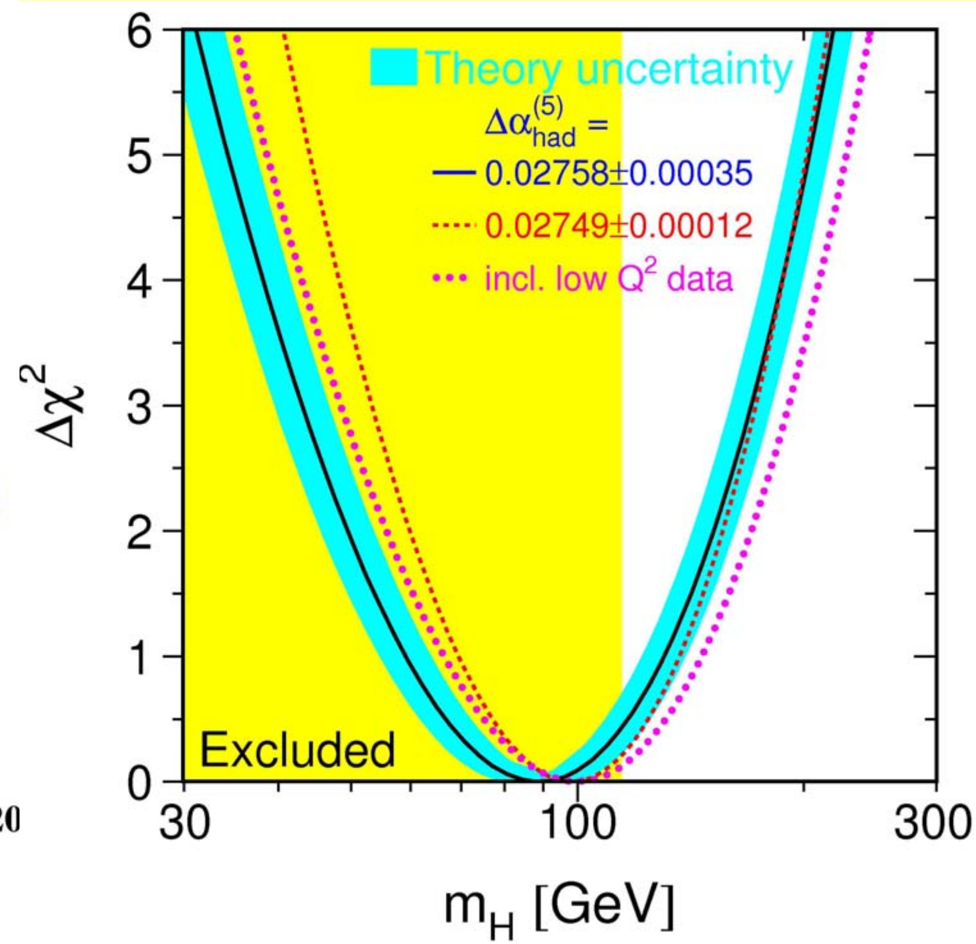


- Indirect constraints through EW precision measurements

In this talk: SM + MSSM neutral Higgs boson direct searches
published in April 2006

Current summary about the SM Higgs boson:





Direct searches :

$M_H \geq 114.4$ GeV (95% CL)

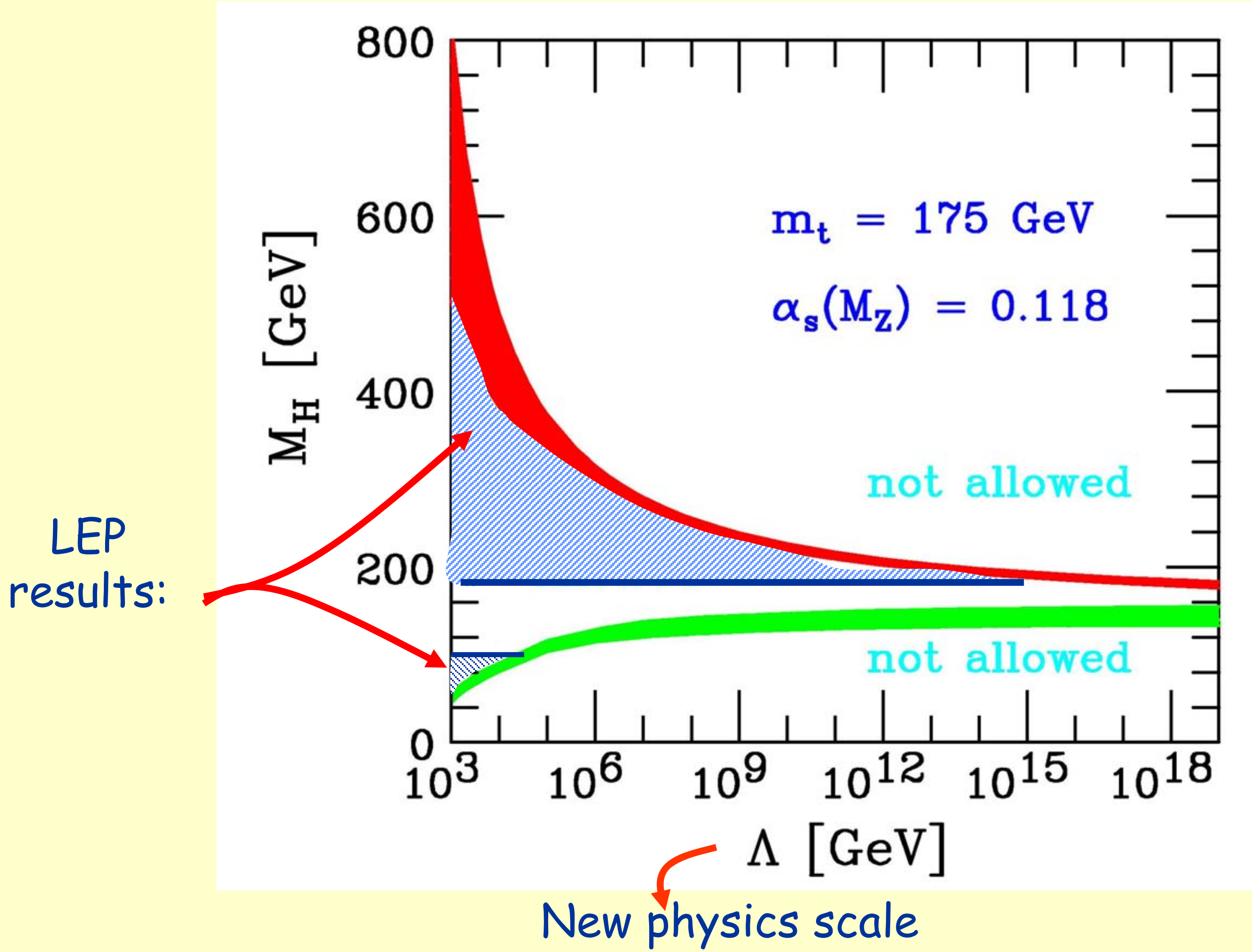
$M_H \subset [115,118]$ GeV ?

EW precise measurements:

$M_H \leq 175$ GeV (95% CL)

(status as of spring 2006)

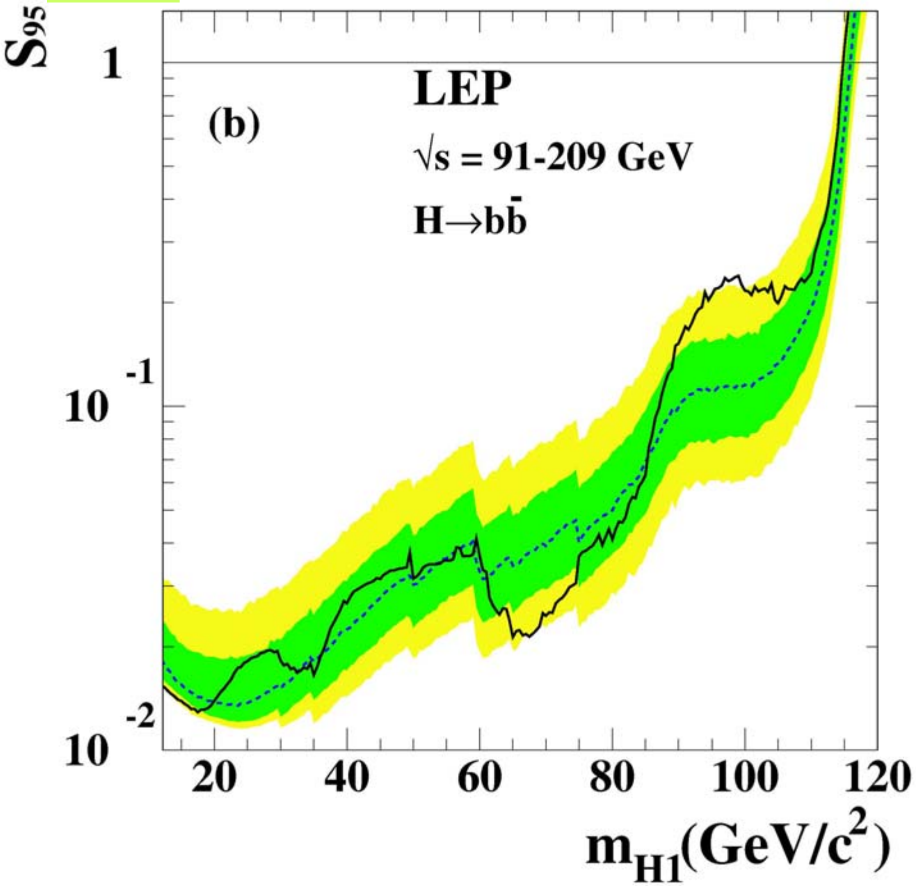
The Standard Model after LEP



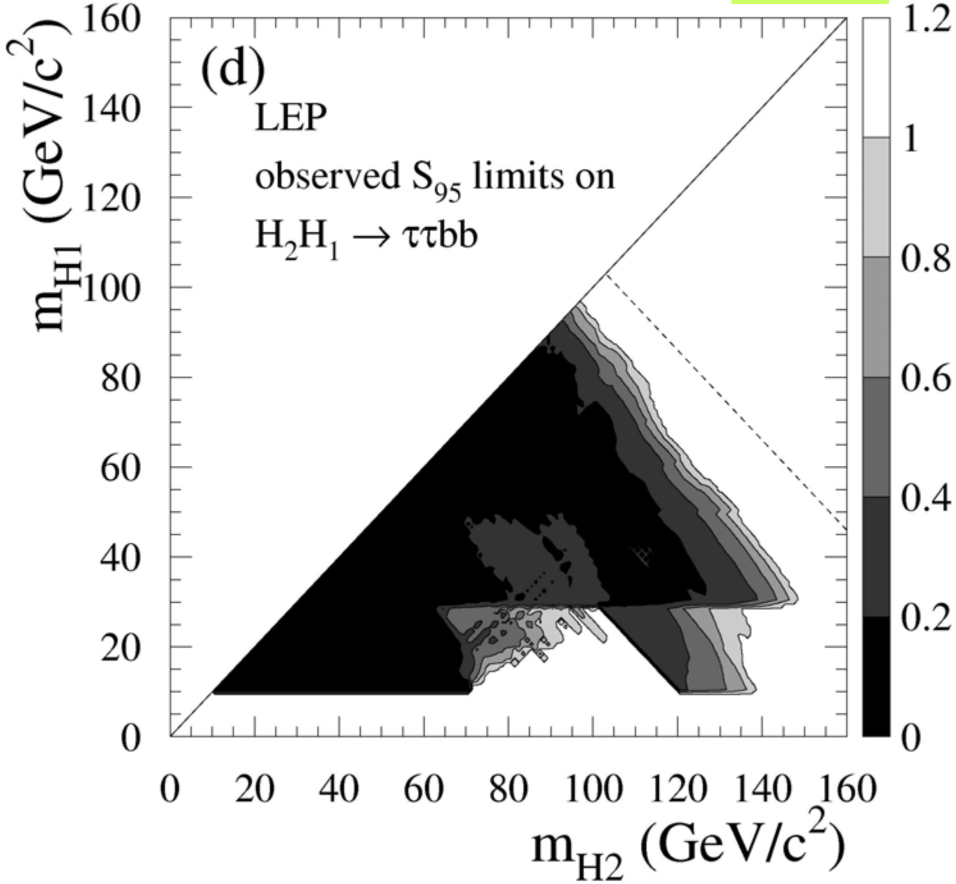
95% CL upper bounds on σ x Br

dominant decays : direct decays in bb or ττ

H_1Z



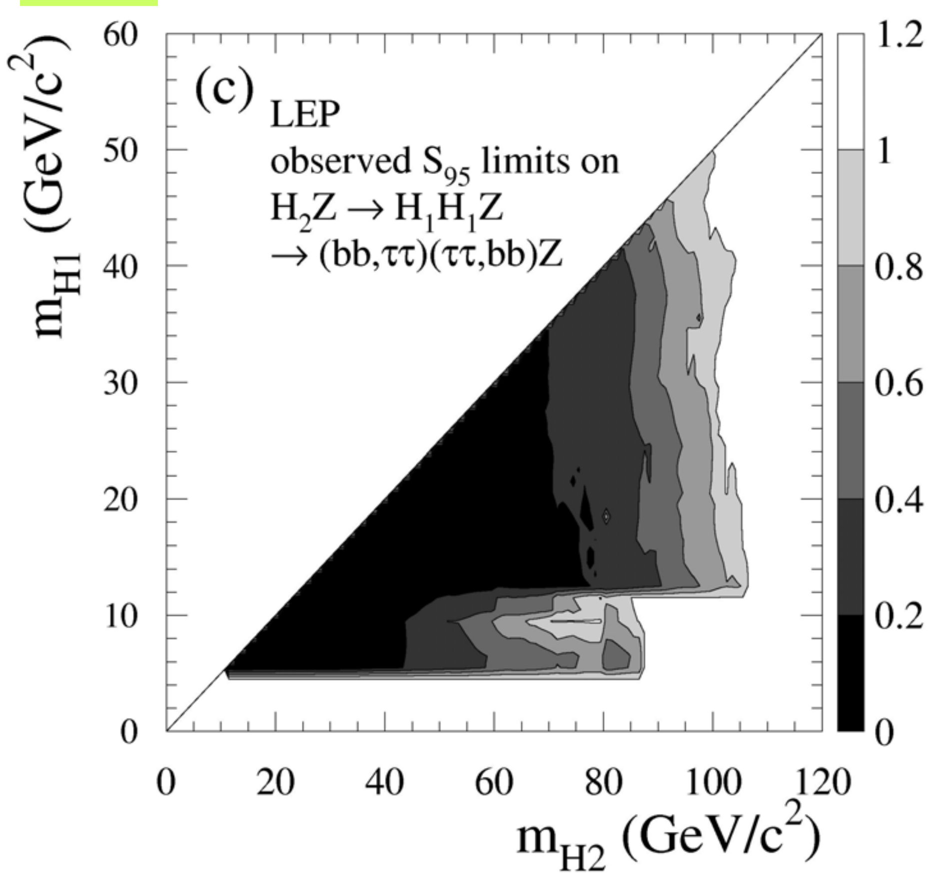
H_2H_1



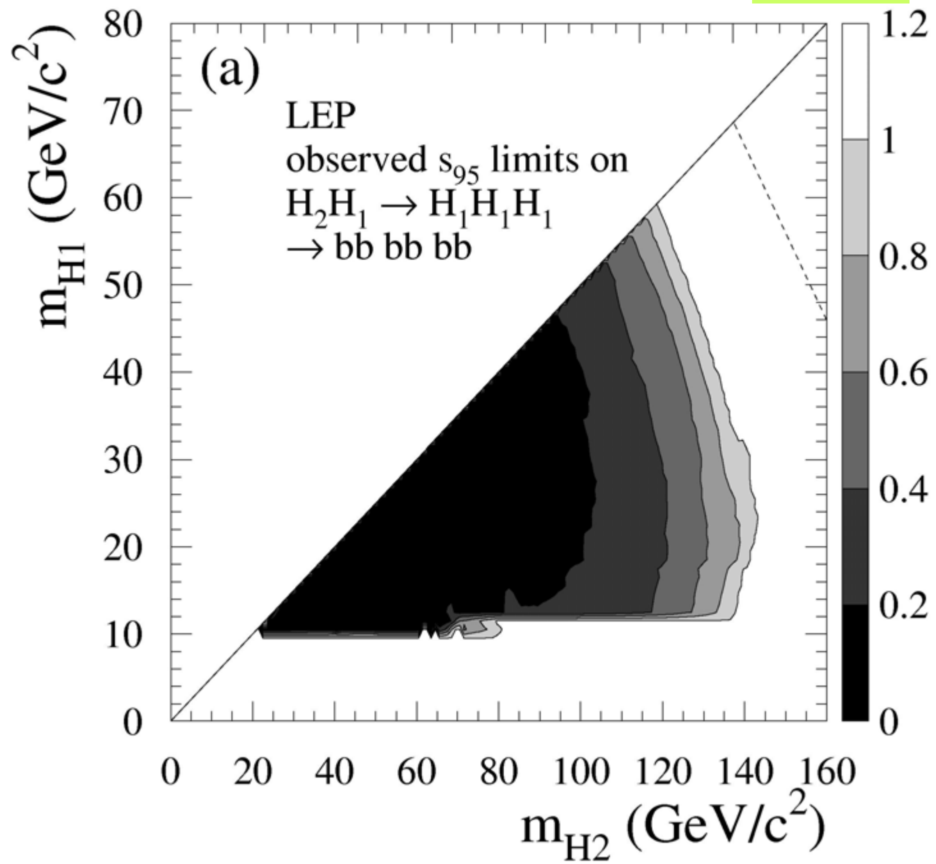
95% CL upper bounds on σ x Br

non dominant decays : the example of the $H_2 \rightarrow H_1H_1$ cascade

H_2Z

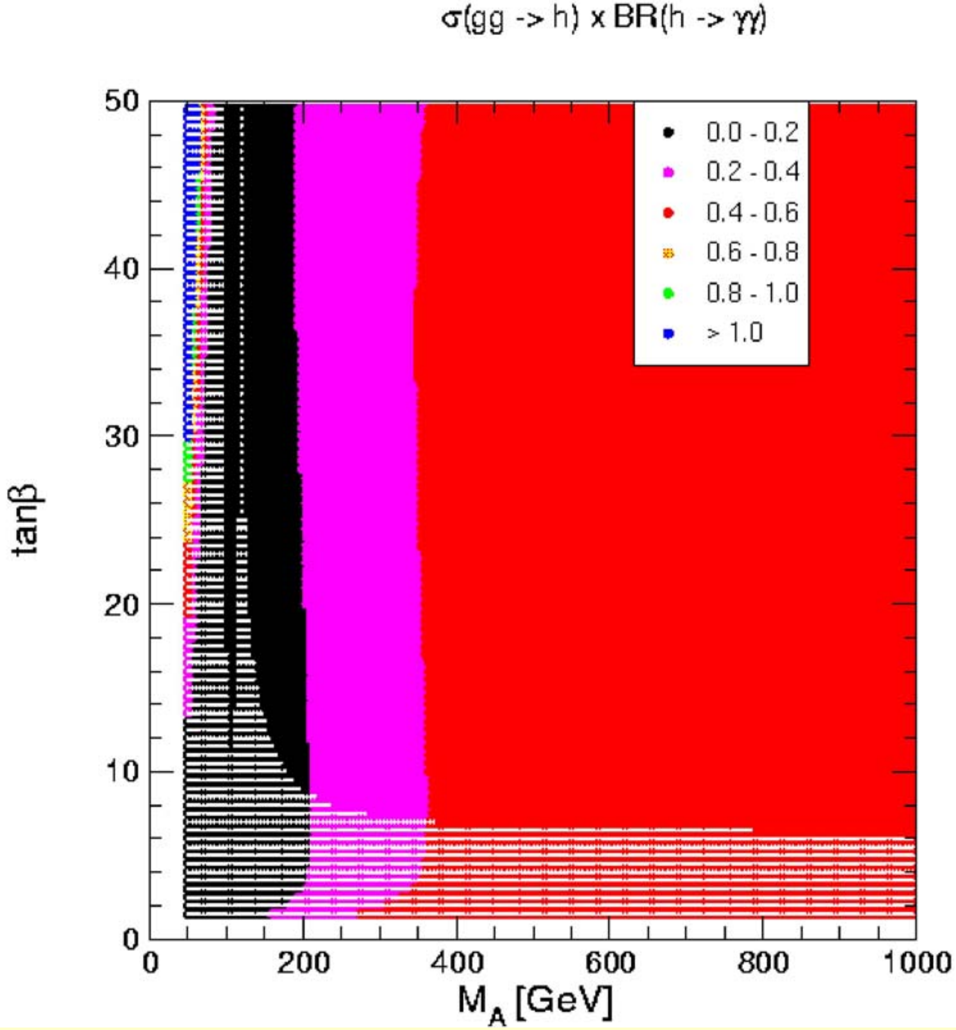


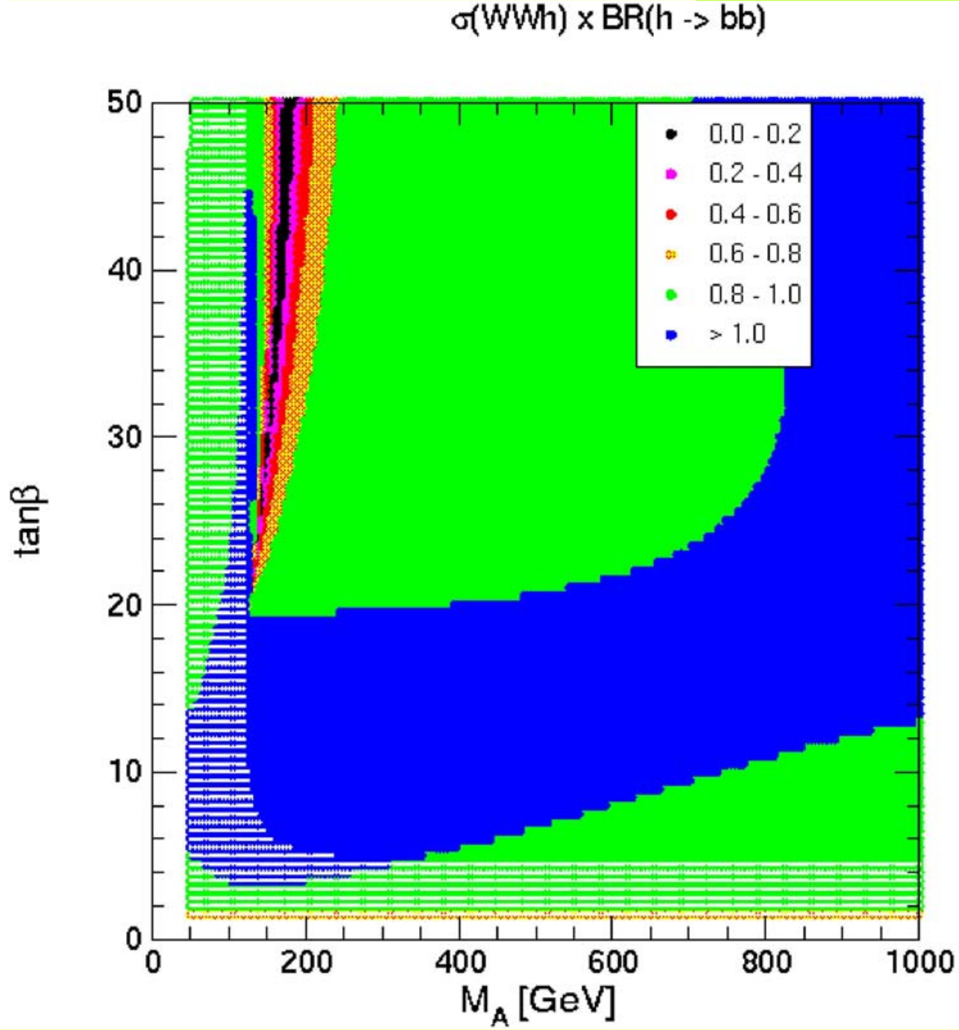
H_2H_1



The gluophobic and small α scenarios

gluo. scen. — σ Br(MSSM)/σ Br(SM) predictions — small α

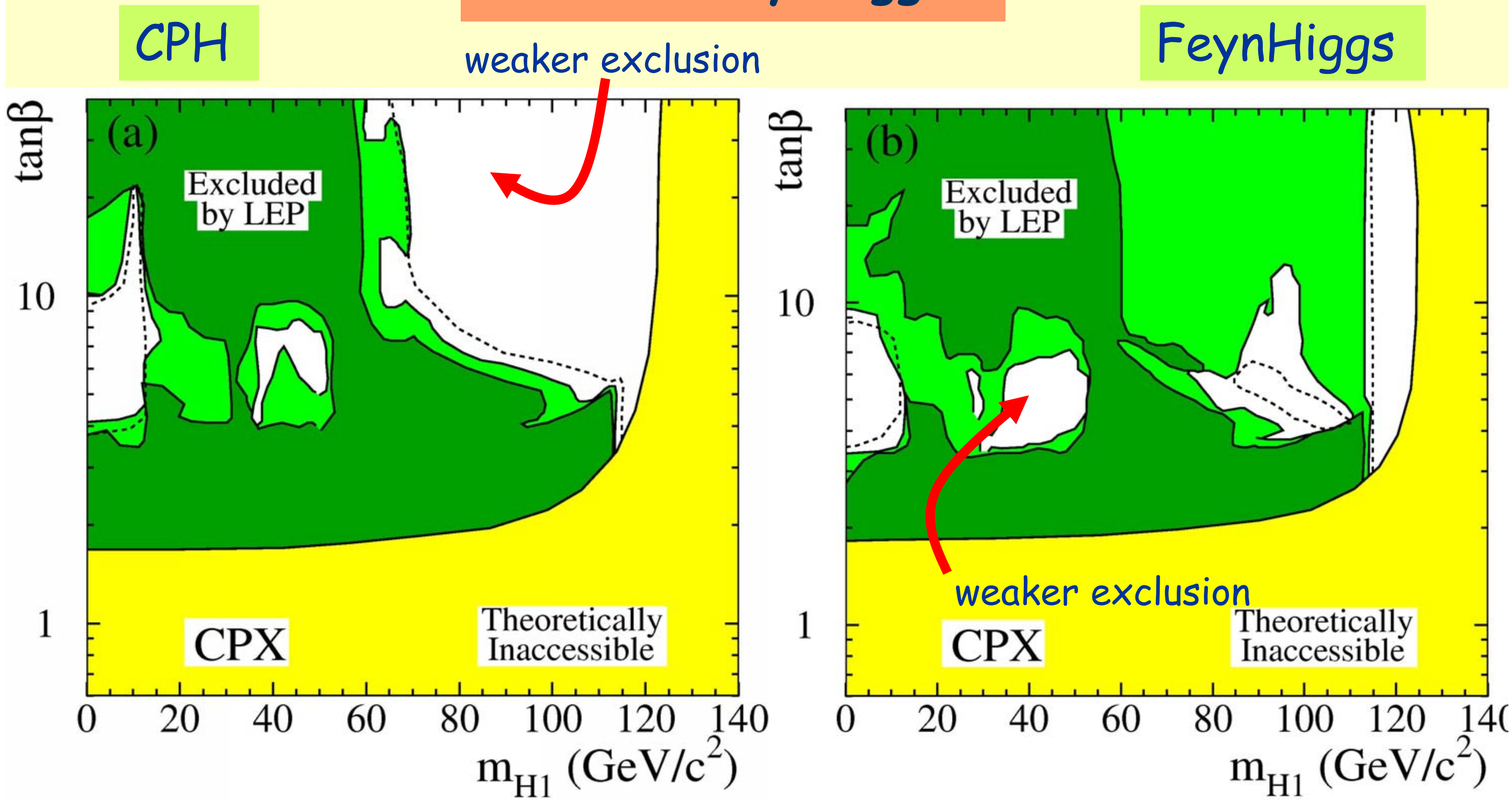




NB: tth→ttbb and WW fusion channels enhanced

NB: h→γγ channel unsuppressed

CPH vs FeynHiggs



more one-loop and two-loop order corrections in FeynHiggs
phase dependence more complete in CPH than in FeynHiggs