Search for Neutral Higgs Bosons in CP Violating MSSM Scenarios at OPAL

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Workshop on CPV Higgs

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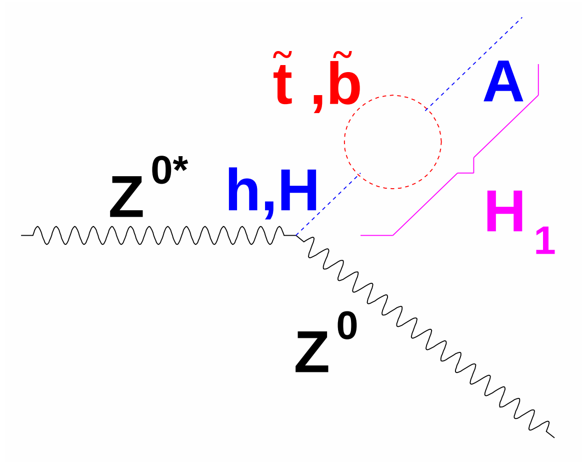
1. Introduction
2. The CPX benchmark set
3. The searches
4. The CPV MSSM exclusion

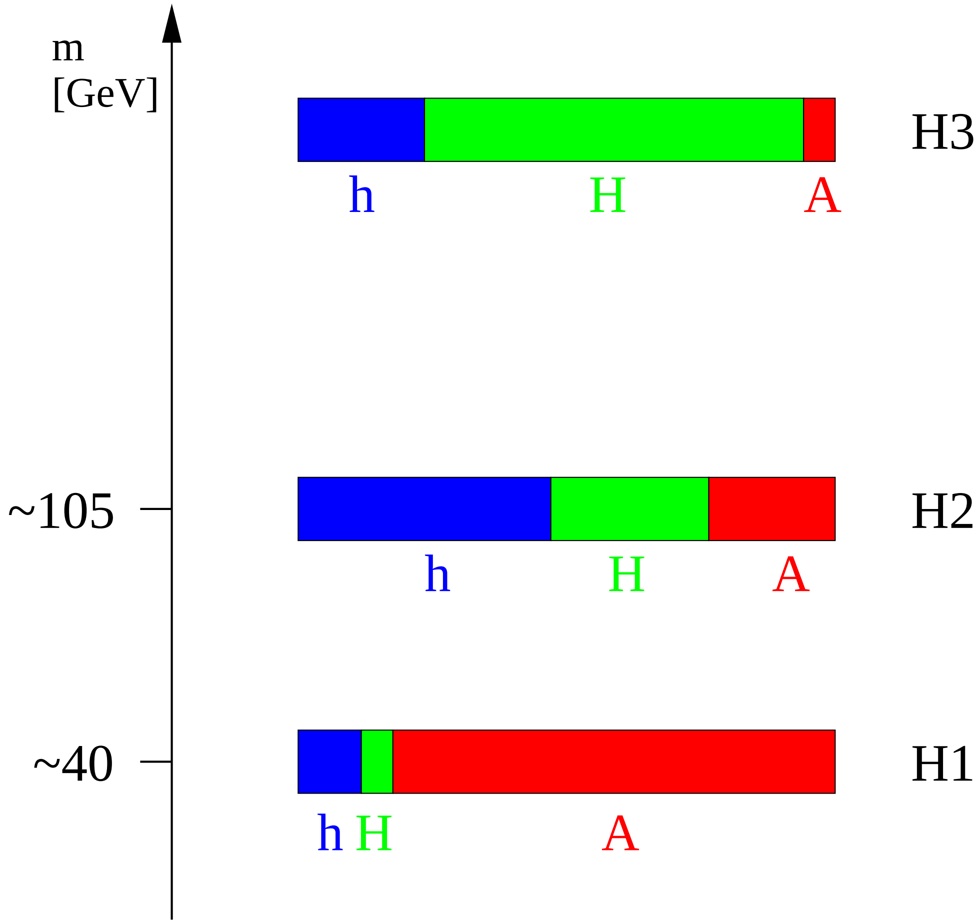
Mass eigenstates and CP-eigenstates

- Interesting features: Mixing and coupling suppression:



Only CP eigenstates h and H can couple to the Z^0, but the propagating particle is H_1

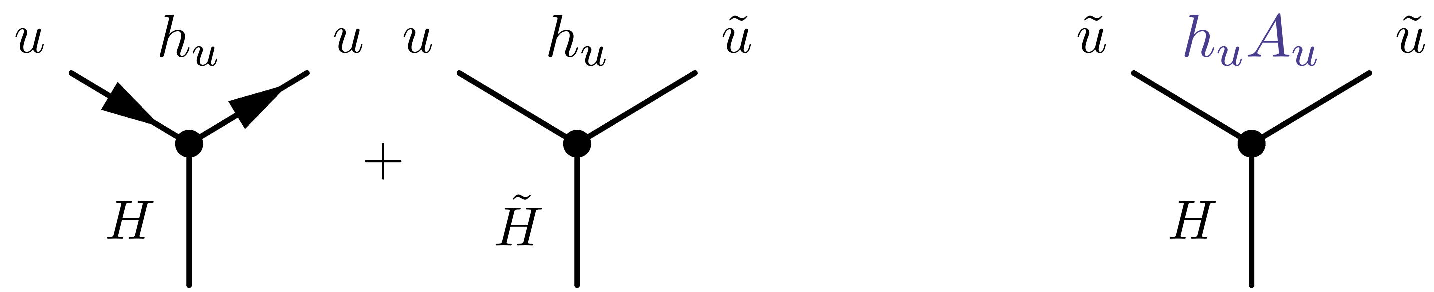
Lightest Higgs boson might have escaped detection at LEP2



- Can search for both H_1 and H_2 in Higgsstrahlung

CP-violation in the MSSM

- Trilinear Couplings A_u break SUSY and $\arg A_u$ introduces CP violation:



SUSY conserving, CP conserving — SUSY breaking, CP breaking

- Theoretically: $\arg A_u \neq 0$ is the most general case
- $\arg A_u \neq 0$ can be motivated by baryogenesis
- Size of CP violating effects proportional to

$$\mathcal{M}^2_{SP} \propto \frac{m_t^4}{v^2} \frac{\mathrm{Im}(\mu A_t)}{32\pi^2 m^2_{\mathrm{SUSY}}}$$

- $\Rightarrow$ Benchmark: large $\arg A_t$, large μ, relatively small m_{SUSY}

The CPX Scenario

$\tan\beta$	=	1 – 40	ratio of Higgs v.e.v.
m_{H^+}	=	0 – 1 TeV	charged Higgs mass
μ	=	2 TeV	Higgs doublet mixing
m_{SUSY}	=	500 GeV	SUSY breaking scale $= m_{\tilde{q}}$
m_2	=	200 GeV	SU(2) gaugino mass matrix parameter
$\lvert A_q \rvert$	=	1 TeV	strength of trilinear coupling
$\arg(A_q)$	=	90°	$\Rightarrow$ CP-violation
$\lvert m_{\tilde{\mathrm{g}}} \rvert$	=	1 TeV	gluino mass
$\arg(m_{\tilde{\mathrm{g}}})$	=	90°	$\Rightarrow$ CP-violation

Parameters roughly fulfill electron and neutron EDM constraints

proposed in Carena et al. hep-ph/0009212

CPH and FeynHiggs2.0

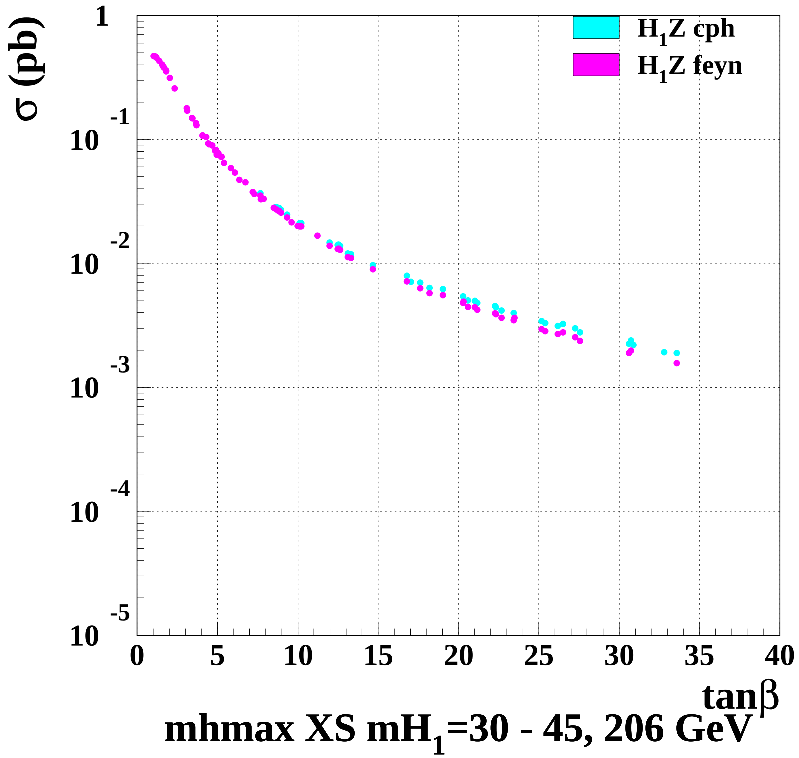
Two Scan Programs with complex phases available:

- CPH: (Carena,Pilaftsis,Wagner) Based on One-Loop Renormalization Group (RG) techniques
- FeynHiggs2.0: (Weiglein,Heinemeyer) Based on Two-Loop Feynman-Diagramatic approach

$\Rightarrow$ Masses and Rotation Matrix ROT

$$H_i^{\text{mass}} = \text{ROT}_{ij} \times H_j^{\text{CP}}$$

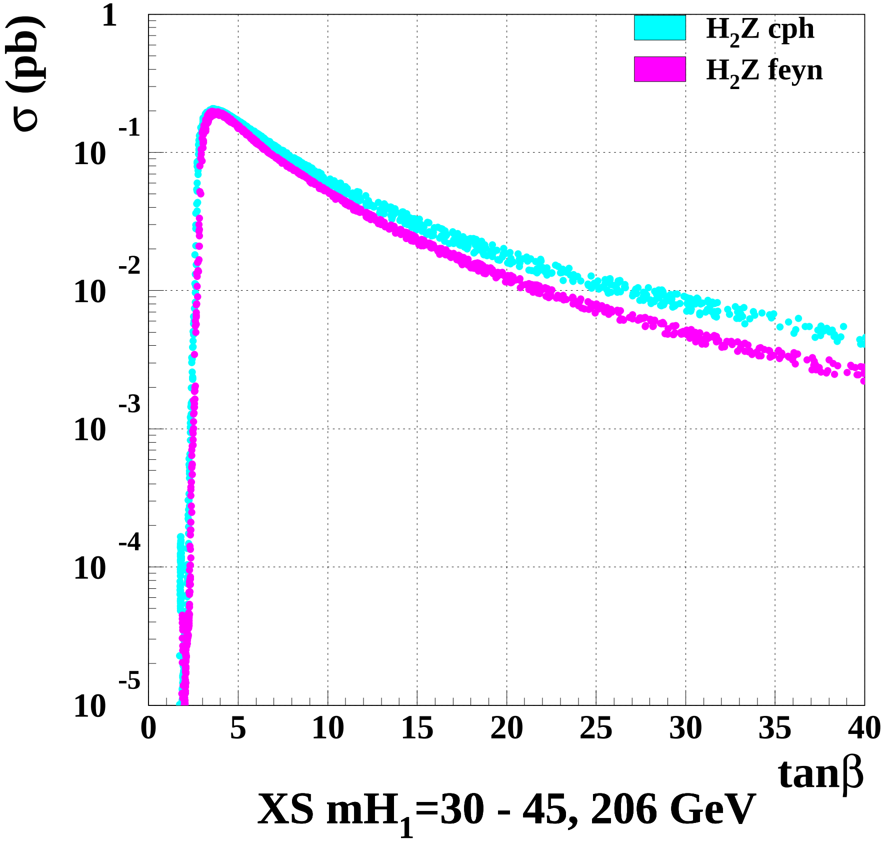
can potentially be different

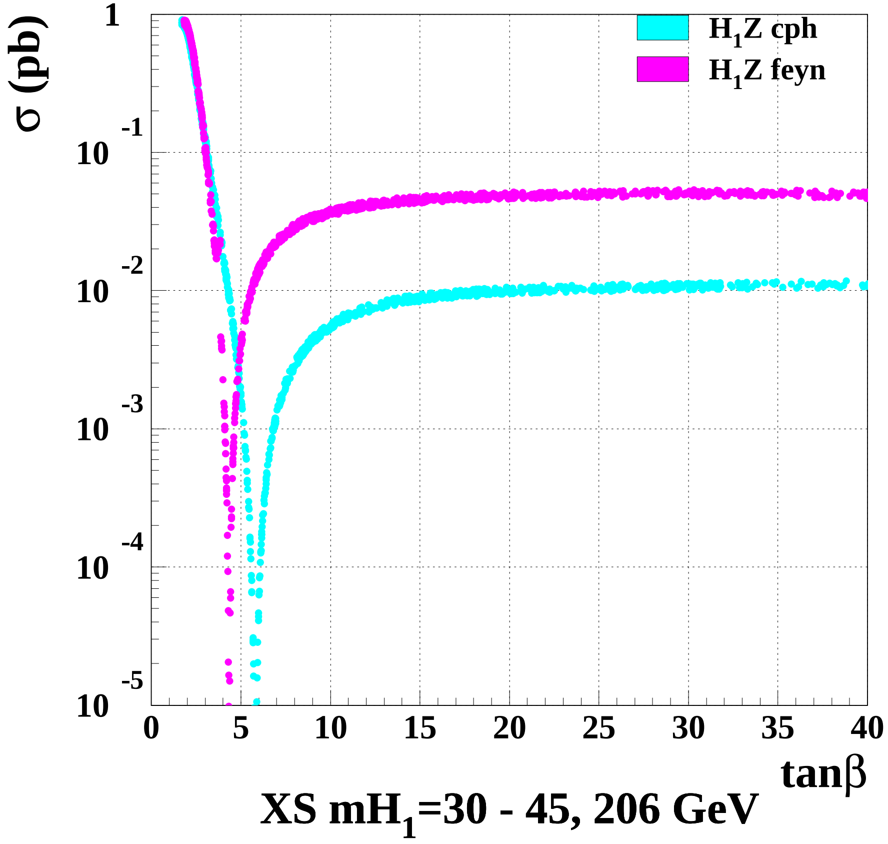


Good agreement in the m_h-max case

Differences between FH and CPH

- $\arg A = 90°$:

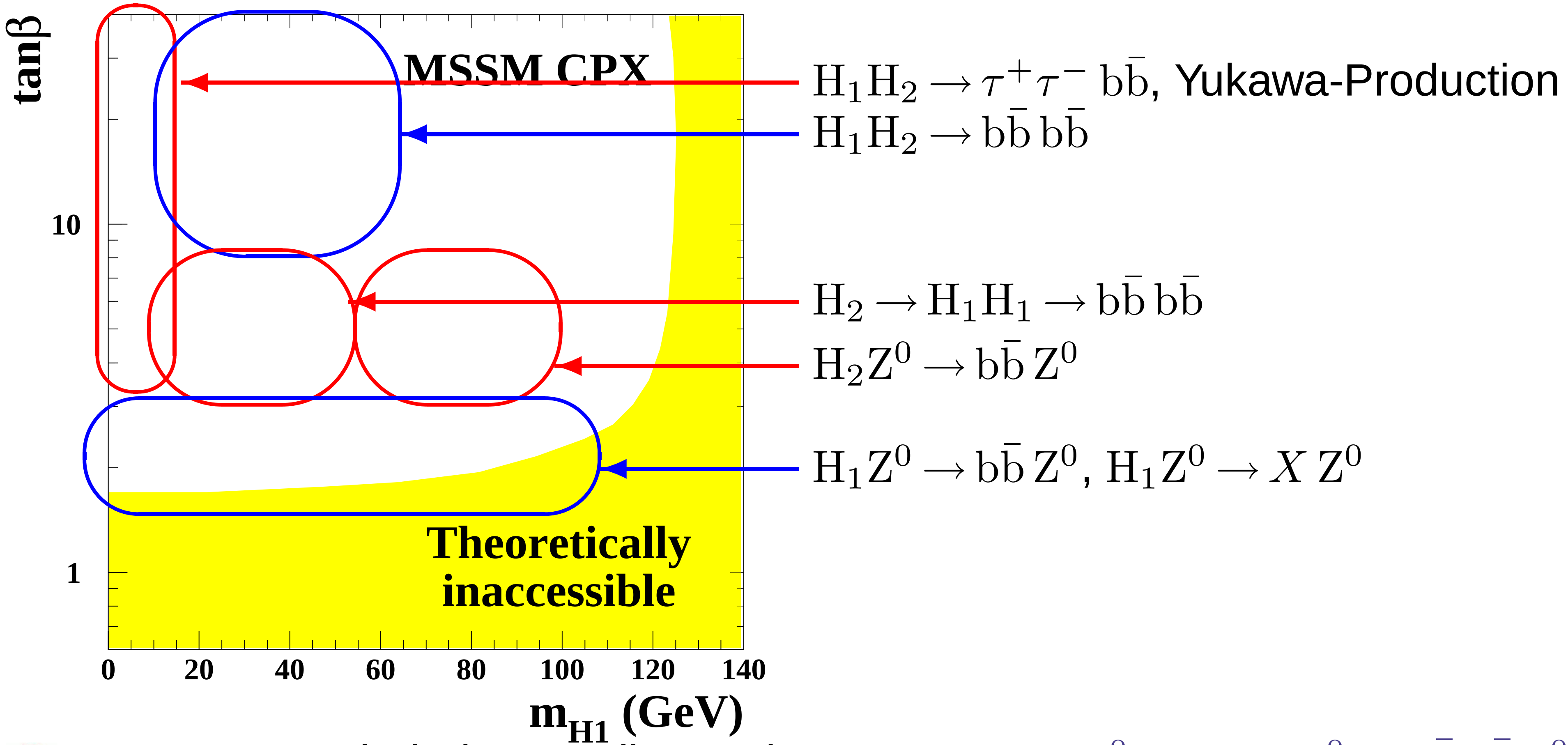




$\sigma_{\mathrm{H_2Z^0}}, m_{\mathrm{H_1}} = 40$ GeV
CPX

$\sigma_{\mathrm{H_1Z^0}}, m_{\mathrm{H_1}} = 40$ GeV
CPX

Useful Searches for the CPV case

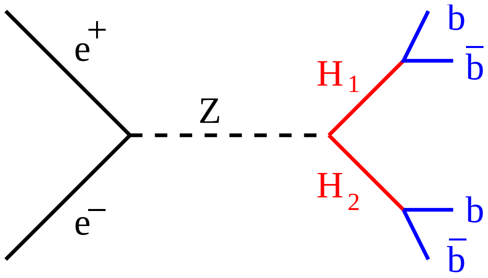


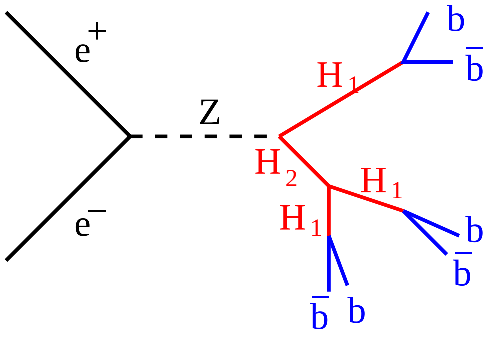
- Areas not excluded at small m_{H_1} due to strong $H_2Z^0 \to H_1H_1Z^0 \to b\bar{b}\, b\bar{b}\, Z^0$ decays with $m_{H_2} \approx 100 - 110$ GeV.

Dedicated $H_2 \rightarrow H_1H_1$ Searches

- Pair production

  $e^+e^- \rightarrow H_1H_2 \rightarrow H_1H_1H_1 \rightarrow b\bar{b}b\bar{b}(b\bar{b})$

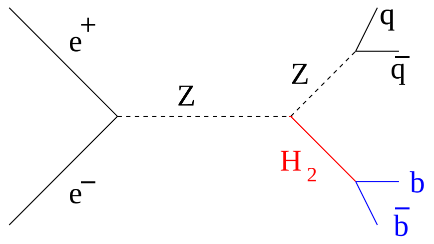


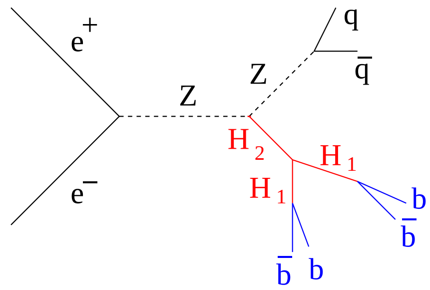


- $H_2 \rightarrow H_1H_1$ useful at $\tan\beta \approx 10$
- One selection for both $b\bar{b}b\bar{b}$ and $b\bar{b}b\bar{b}b\bar{b}$ signal

- Higgsstrahlung

  $e^+e^- \rightarrow H_2Z^0 \rightarrow H_1H_1Z^0 \rightarrow b\bar{b}(b\bar{b})q\bar{q}$

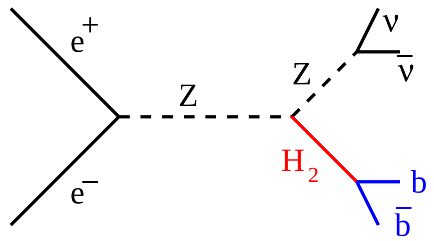


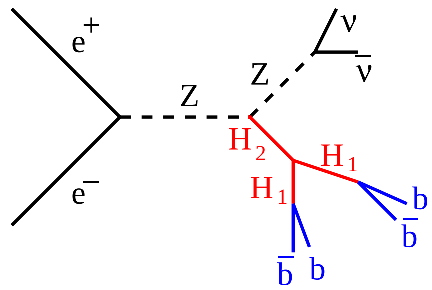


- One selection for both

- Higgsstrahlung

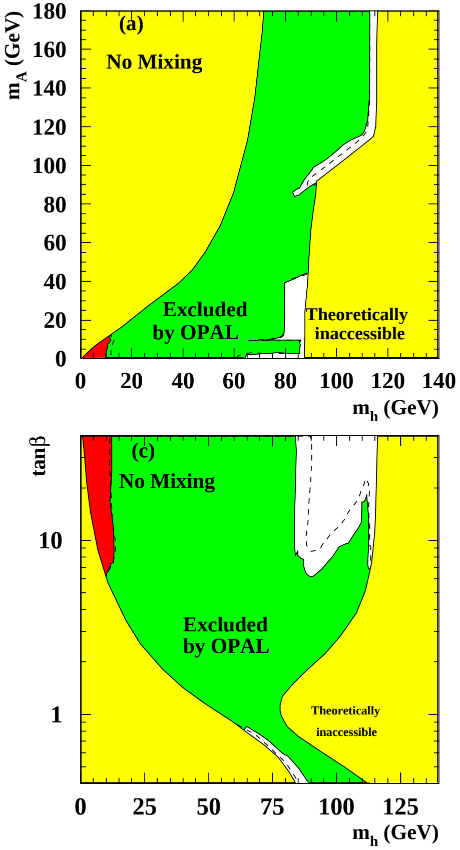
  $e^+e^- \rightarrow H_2Z^0 \rightarrow H_1H_1Z^0 \rightarrow b\bar{b}(b\bar{b})\nu\bar{\nu}$



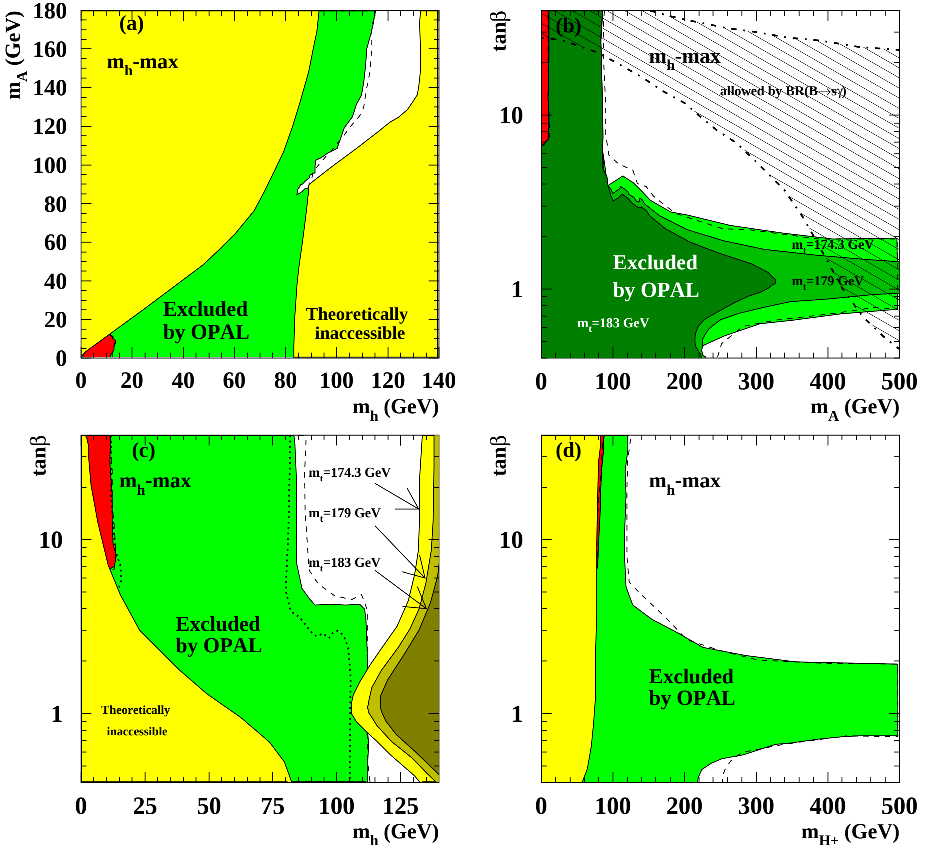


- 2 selections

CPC MSSM Limits



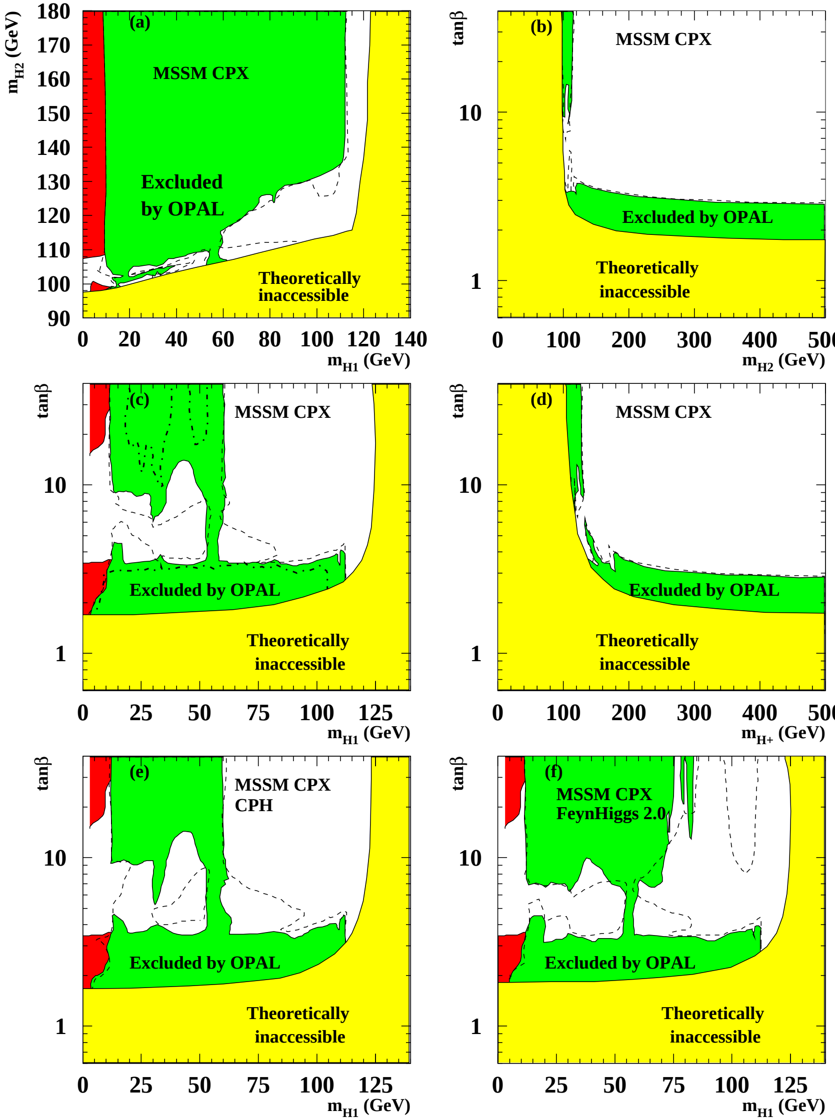
No Mixing



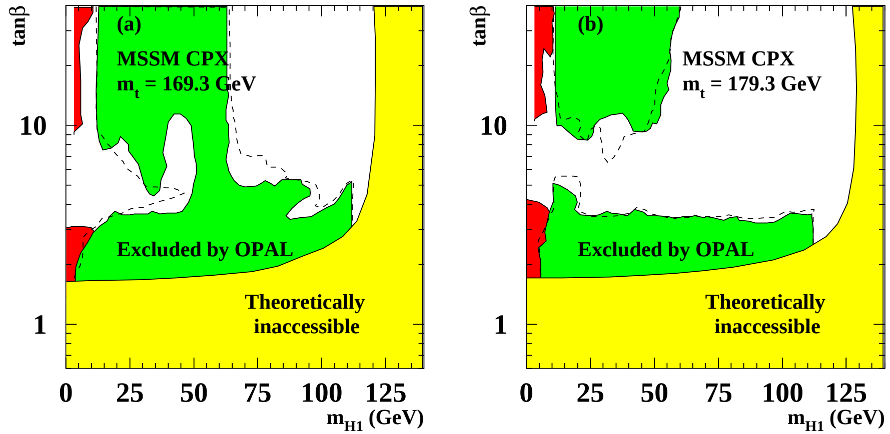
m_{h}-max

- For comparison: Exclusion in the CPC MSSM

CPV MSSM Limits: CPX

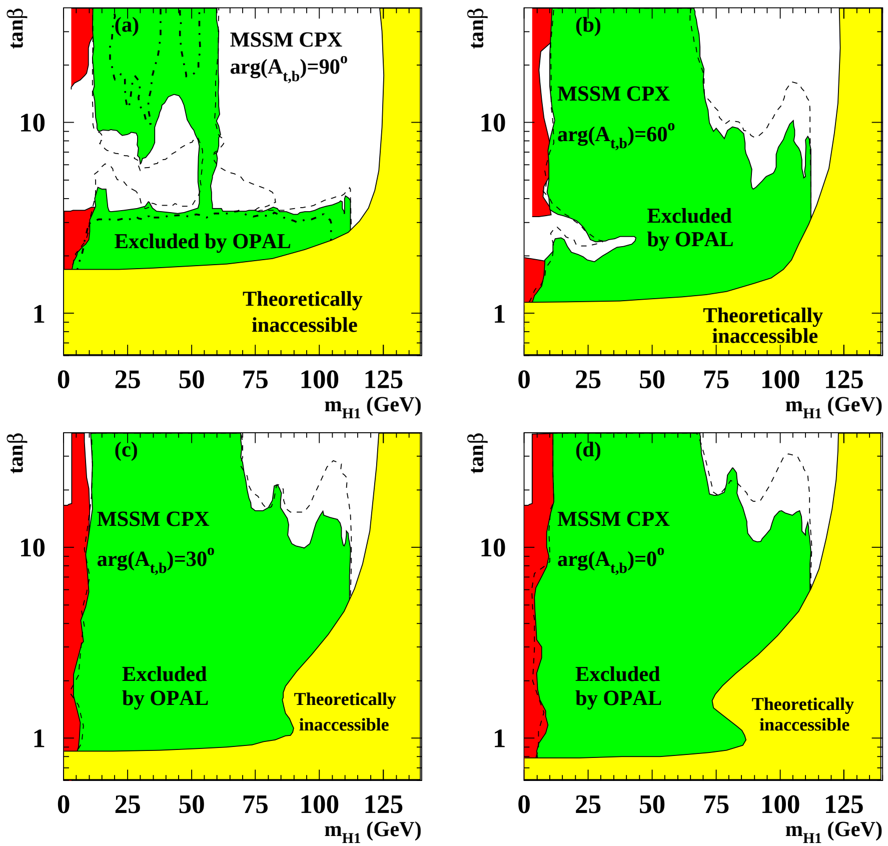


CPX

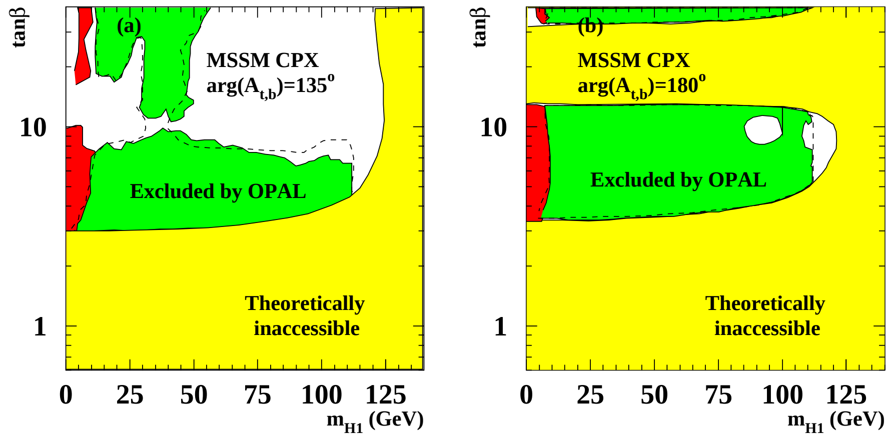


Variation of $m_{\rm top}$

CPV MSSM Limits: Different Phases

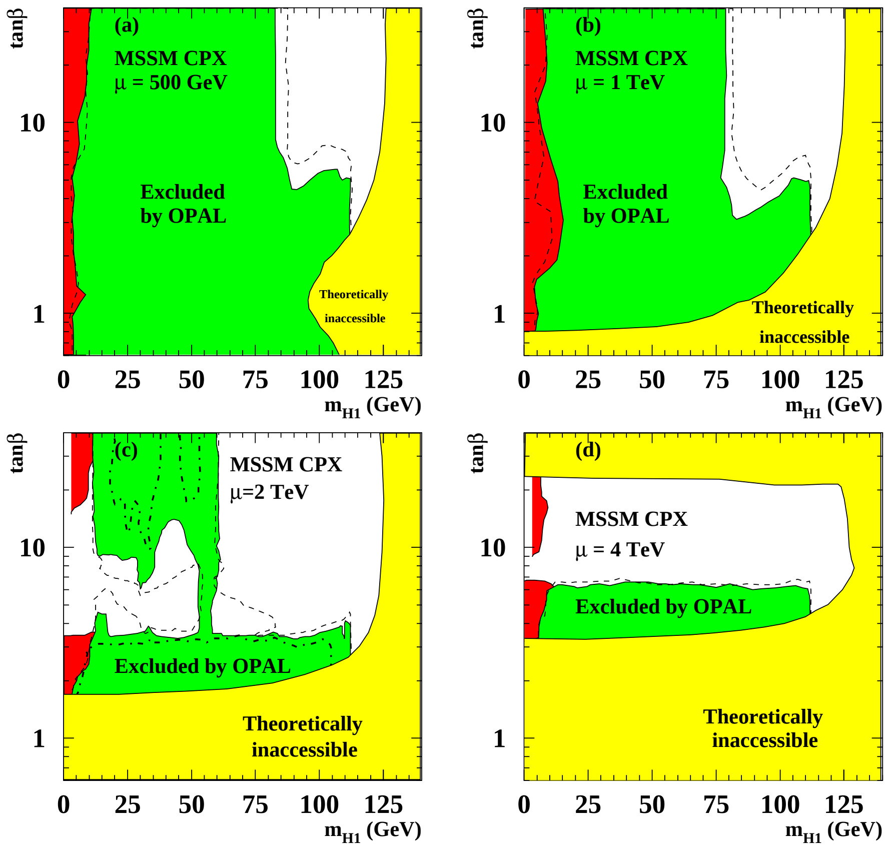


CPX with smaller phases

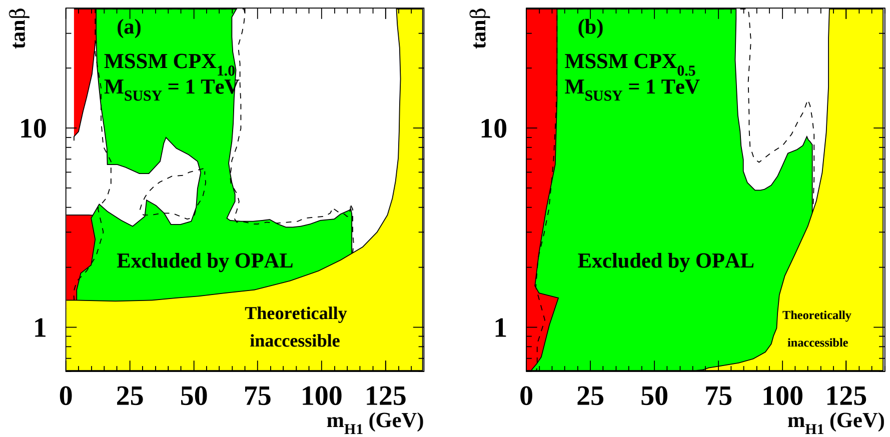


CPX with larger phases

CPV MSSM Limits: Different Phases

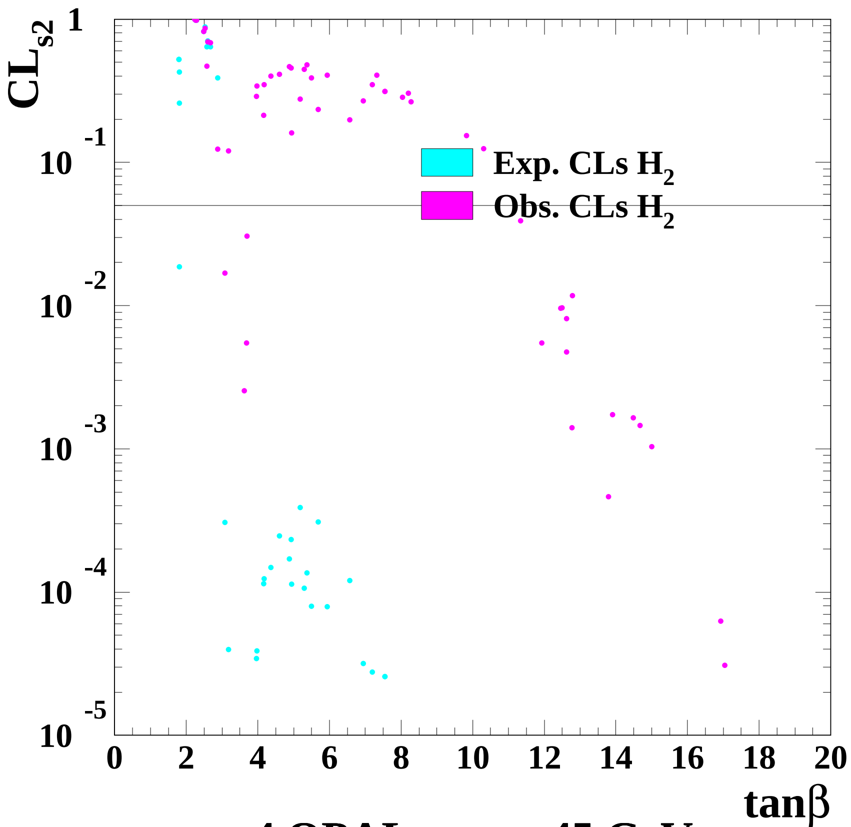


CPX with different μ

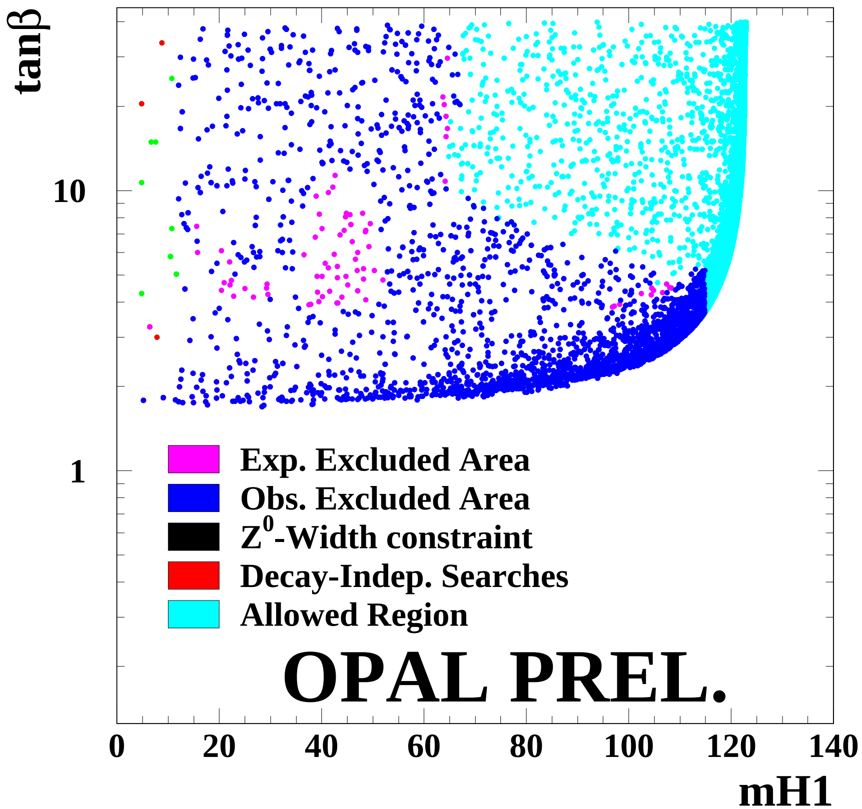


CPX with different M_{SUSY}

Expectations for a LEP combination



4 OPAL m_{H1} = 45 GeV



2 OPAL CPX

$4\times$ OPAL

Don't look at obs. CL_s

Exclusion region of $2\times$ OPAL

No hole in exp CL_s

- Still open region with $e^+e^- \to H_1H_2 \to X\, b\bar{b}$ production, $m_{H_1} < 10$ GeV, $m_{H_2} \geq 90$ GeV

Summary

- For the first time, all 8 CPC benchmark scenarios and 9 different CPV scenarios are studied.
- MSSM limits:
  - CPC: $m_{\mathrm{h}} \approx m_{\mathrm{A}} > 85$ GeV
  - CPC: m_{h}-max: $0.7 < \tan\beta < 1.9$ excluded for $m_t = 174.3$ GeV
  - CPC+CPV: strong dependence of $\tan\beta$ limit on m_t
  - CPX: no absolute limit on m_{H_1}
  - CPX: $\tan\beta > 2.8$
- LEP Combination is expected to cover the unexcluded region at intermediate $\tan\beta$.
- Results are presented in CERN-PH-EP/2004-020