
WG2: Plans for the Remainder of the Workshop

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Goals of the LHC2FC Workshop

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Exciting physics at the LHC could open up a window of opportunity to get a new major facility on the way

Goals of the LHC2FC Workshop

The idea of this workshop is to discuss possible scenarios of physics at the LHC — as long as they are still hypothetical — and to assess their potential impact on the future direction of the field

Options for accelerator-based facilities at the TeV scale beyond the first phase of the LHC:

SLHC, ILC, CLIC, LHeC, DLHC, muon collider, ...

Charge of working groups:

- Investigate various possible scenarios of early LHC data, their interpretations and implications
“Early LHC data”: $\approx 10 \text{ fb}^{-1}$
- Produce ≈ 10 page report

WG2: "No Higgs signal"

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⇒ No Higgs candidate in the first $\approx 10 \text{ fb}^{-1}$ at the LHC

<http://sites.google.com/site/lhc2fcnohiggs/>

Conveners: Georges Azuelos, Christophe Grojean, Mark Lancaster and Georg Weiglein

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We are asked to address the following questions:

- How well do the observed signatures in the early LHC data constrain the possible physics scenario?
- What could be the impact of early LHC results on the choice of the next facility and its (ultimate) energy reach and luminosity?
- What would be the possible implications for the machine and the detector design?

WG2: questions, continued

- How would additional LHC luminosity further constrain / support the scenario and the choice of the future facility?
- What are the prospects for an interplay with results from the LHC, low-energy experiments and cosmological data?

Need to discuss:

- signatures vs. their interpretation in different models
- experimental and theoretical uncertainties
- detector and machine specifications needed to reach the physics goals

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- There is a Higgs boson (or more than one), but it has non-standard properties that make it difficult to detect:
 - Suppressed couplings to gauge bosons and / or fermions
 - Higgs decays into jets, invisible Higgs decays, ...

Examples: MSSM with complex parameters, NMSSM, Higgs–radion mixing, ...

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- There is really no Higgs boson:
 - Technicolour-like models, BESS models, ...
 - Higgsless models in extra dimensions

Impact on longitudinal vector boson scattering, gauge boson self-couplings: anom. couplings, resonances, ...

Example: MSSM with complex parameters

‘Simplest’ extension of the minimal Higgs sector:

Minimal Supersymmetric Standard Model (MSSM)

- Two doublets to give masses to up-type and down-type fermions (extra symmetry forbids to use same doublet for both)
- Supersymmetry imposes relations between the parameters

⇒ Two parameters at lowest order instead of one:

$$\tan \beta \equiv \frac{v_u}{v_d}, \quad M_A \text{ (or } M_{H^\pm})$$

Higgs couplings, lowest order

Couplings to gauge bosons

$$g_{hVV} = \sin(\beta - \alpha) g_{HVV}^{\text{SM}}, \quad g_{HVV} = \cos(\beta - \alpha) g_{HVV}^{\text{SM}}, \quad V = W^\pm, Z$$

$$g_{hAZ} = \cos(\beta - \alpha) \frac{g'}{2 \cos \theta_W}, \quad g_{HAZ} = \sin(\beta - \alpha) \frac{-g'}{2 \cos \theta_W}$$

$$\Rightarrow g_{hVV} \leq g_{HVV}^{\text{SM}}$$

large suppression possible

$g_{hVV}, g_{HVV}, g_{hAZ}, g_{HAZ}$ cannot all be small

Couplings to fermions: large enhancement / suppression possible

Higgs decays into SUSY particles, SUSY particle decays into Higgs

Higher-order corrections in the MSSM Higgs sector

- Quartic couplings in the Higgs sector are given by the gauge couplings, g_1, g_2 (SM: free parameter)
⇒ Upper bound on the lightest Higgs mass
 - Large higher-order corrections from Yukawa sector:
⇒ Leading corr.: $\Delta m_h^2 \sim G_\mu m_t^4$
Can be of $\mathcal{O}(100\%)$
- ⇒ Higher-order corrections are phenomenologically very important (constraints on parameter space from search limits / possible future measurements)
- Can induce \mathcal{CP} -violating effects

\mathcal{CP} violation in the Higgs sector

MSSM Higgs sector is \mathcal{CP} -conserving at tree level, but complex parameters enter via loop corrections

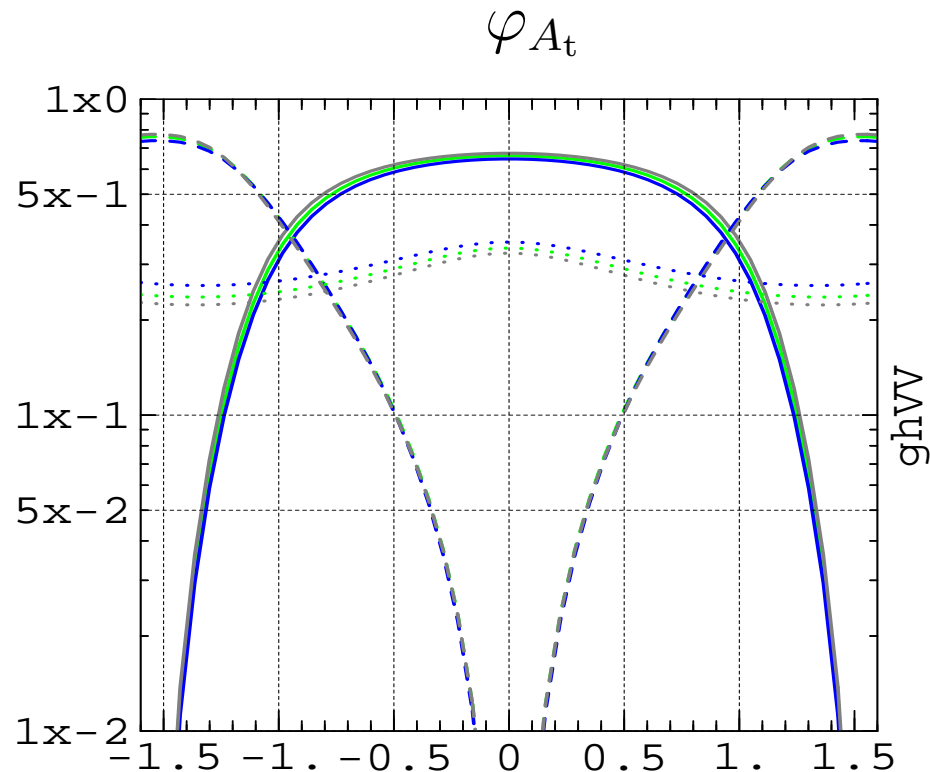
⇒ can induce \mathcal{CP} -violating effects

⇒ Mixing between neutral Higgs bosons h_1, h_2, h_3

⇒ Complex phases can have large effects on Higgs couplings

\mathcal{CP} violation in the Higgs sector

Example: g_{hVV}^2 for h_1, h_2, h_3 : [M. Frank, S. Heinemeyer, W. Hollik, G. W. '03]



full: h_1 , dashed: h_2 , dotted: h_3

Parameters:

$$M_{\text{SUSY}} = 500 \text{ GeV},$$

$$M_2 = 500 \text{ GeV},$$

$$\mu = 2000 \text{ GeV},$$

$$|A_t| = 1000 \text{ GeV},$$

$$M_{H^\pm} = 150 \text{ GeV}, \tan \beta = 5$$

⇒ Complex phases can have large effects on Higgs couplings

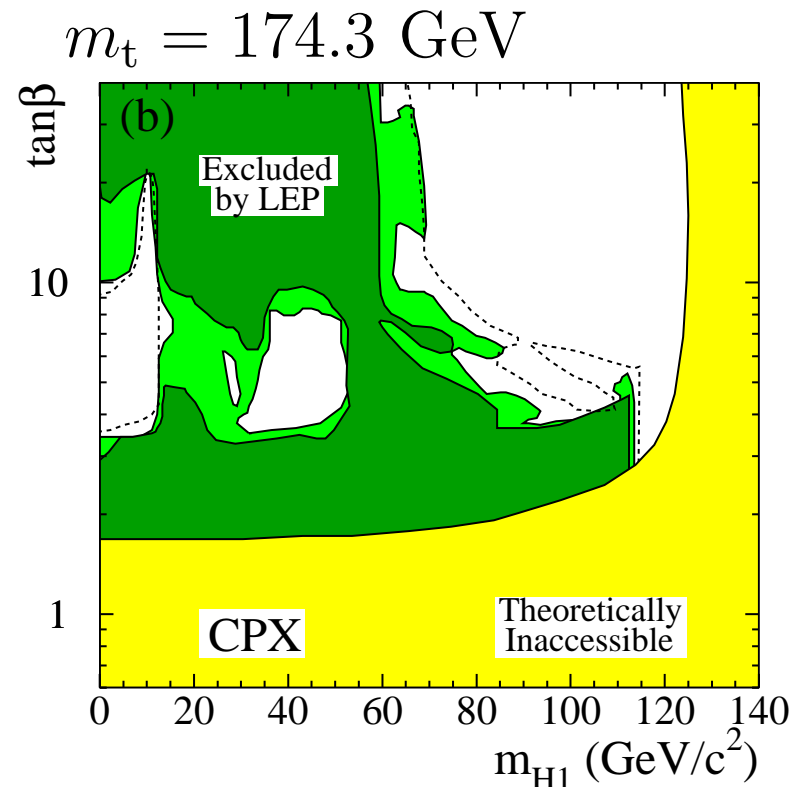
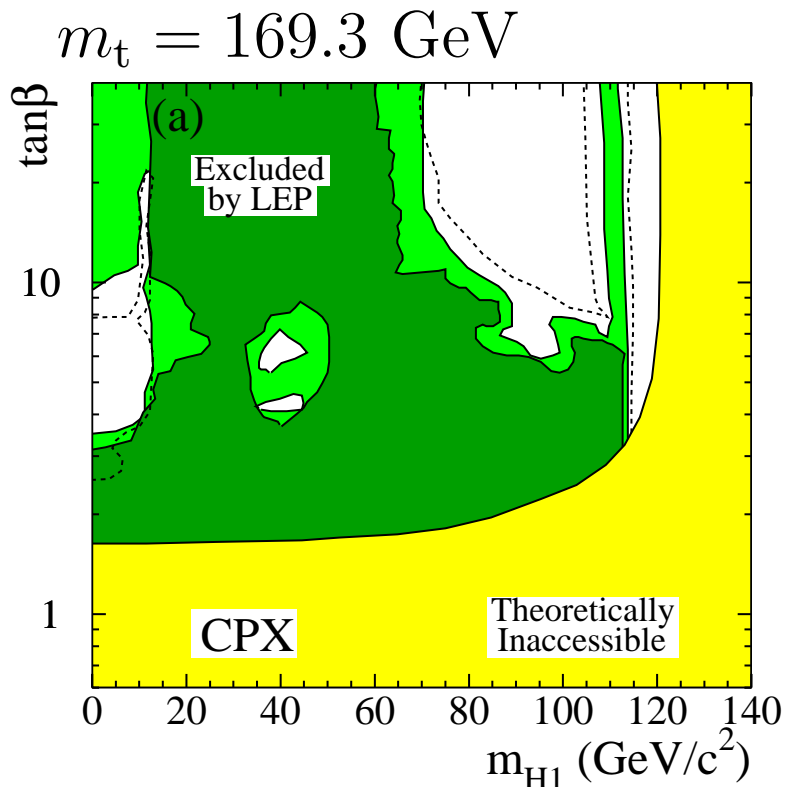
CP -violating case (CPX scenario):

LEP exclusion bounds

Light Higgs, h_1 : strongly suppressed $h_1 VV$ couplings

Second-lightest Higgs, h_2 , possibly within LEP reach (with reduced $VV h_2$ coupling), h_3 beyond LEP reach

Large $BR(h_2 \rightarrow h_1 h_1) \Rightarrow$ difficult final state [LEP Higgs WG '06]



\Rightarrow no lower limit on M_{h_1} : light SUSY Higgs not ruled out!

Recent reanalysis with latest theoretical predictions; program *HiggsBounds*, $m_t = 170.9$ GeV

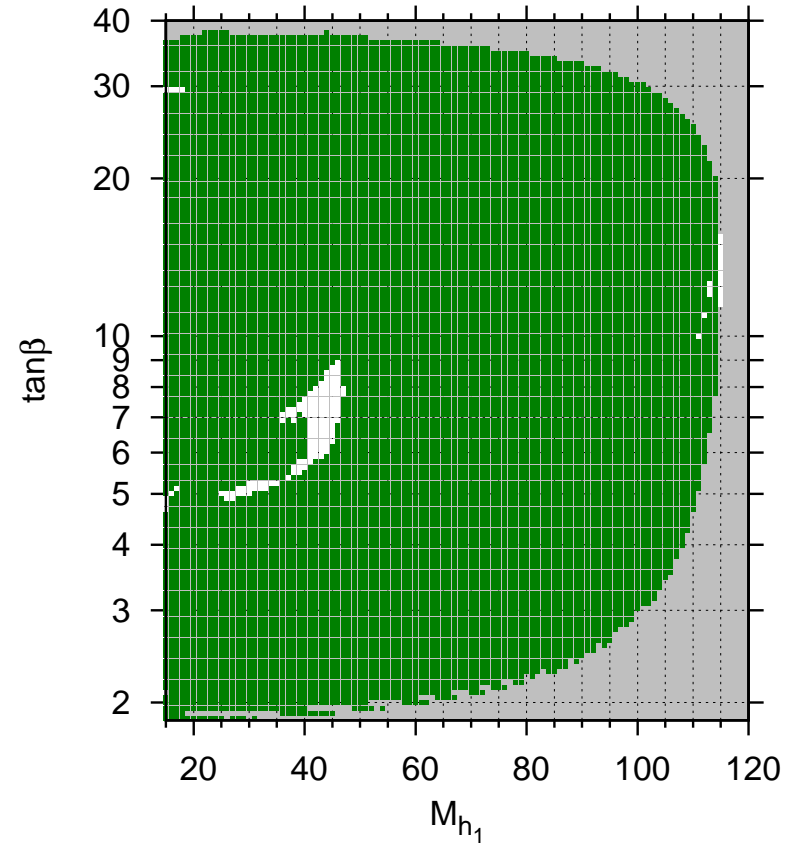
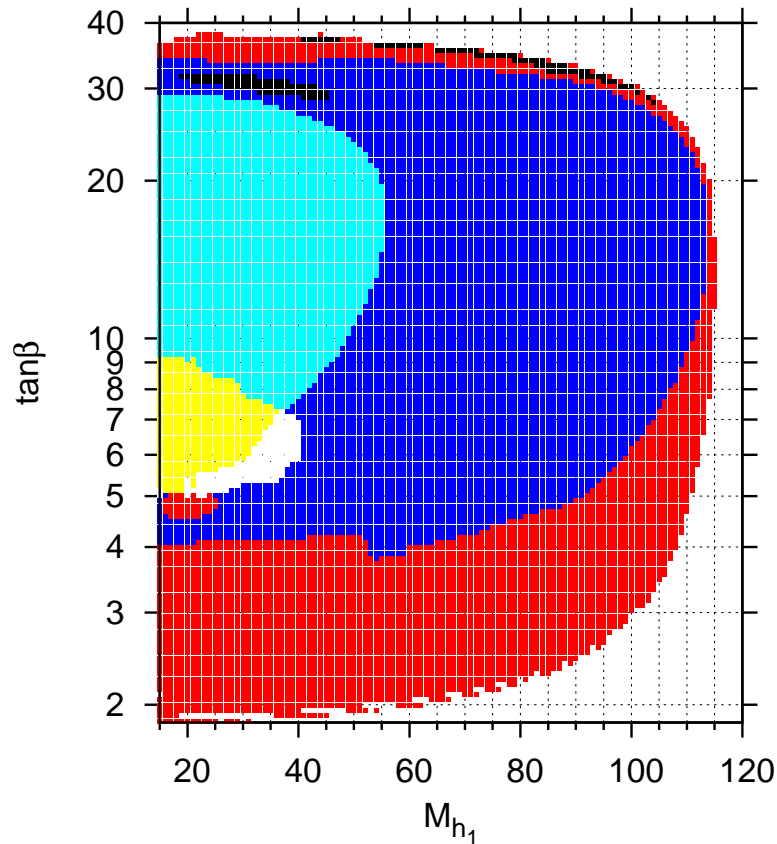
Channels (*HiggsBounds*)

(□) : $(h_2 Z) \rightarrow (h_1 h_1 Z) \rightarrow (b\bar{b}b\bar{b}Z)$

Excluded region from LEP,

95% C.L.

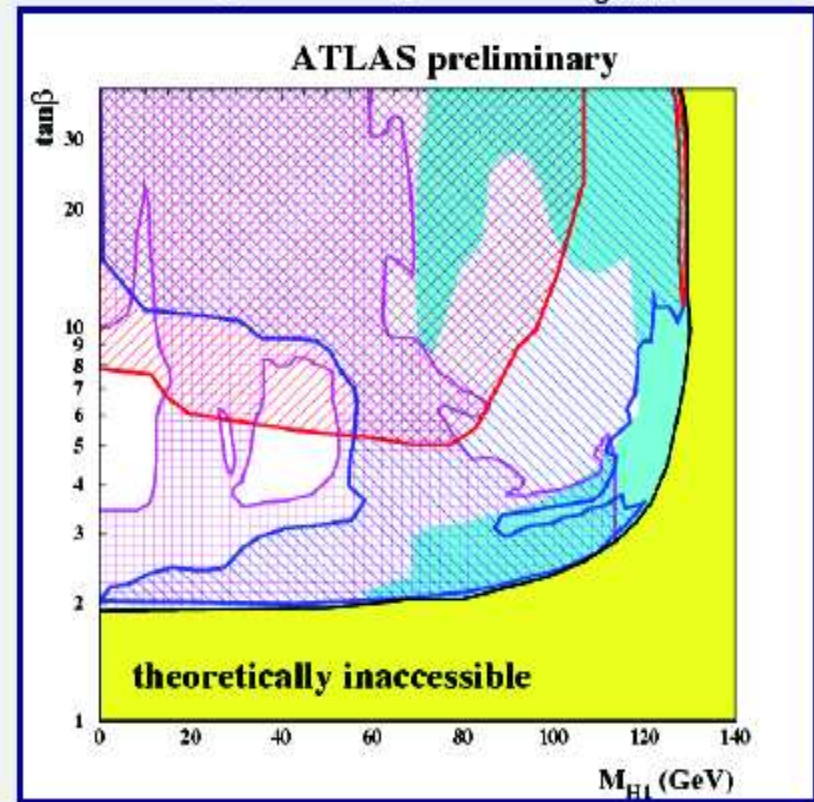
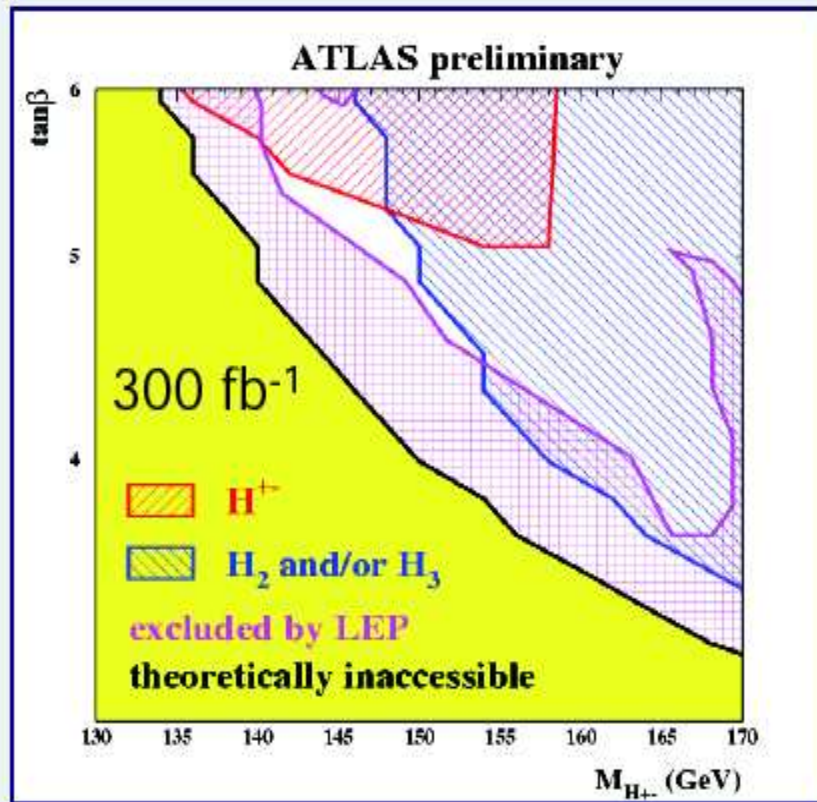
[K. Williams, G. W. '07]



⇒ “Hole” in the LEP coverage confirmed

CPX holes are difficult to cover at the LHC

[M. Schumacher, ATLAS '07]



M_{H_1} : < 50 GeV, M_{H_2} : 105 to 115 GeV, M_{H_3} : 140 to 180 GeV, $M_{H^{+-}}$: 130 to 170 GeV

Markus Schumacher

Prospect for Higgs Boson Physics at LHC

Euro-GDR SUSY07, Brussels

⇒ “CPX holes” cannot be covered in conventional channels

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⇒ Strong motivation for a 500 GeV e^+e^- Linear Collider?

WG2 programme: talks in the first week

- "Kick-off talk" by C. Grojean
- "Gauge boson self-couplings" by T. Han
- "EW precision tests in Higgsless and triplet Higgs models" by S. Dawson
- "WW scattering at ATLAS/CMS" by E. Ozcan and P. Govoni

WG2: talks planned for week 2

- "BESS and deconstructed Higgsless models"
by S. de Curtis, Wed. 18th 3:30pm

- "Effective approaches to Higgsless models"
by G. Isidori, Wed. 18th 4:30pm

WG2: talks planned for week 3

- "Invisible Higgs — experimental perspective"
by M. Schram, Mon. 23th 5:30pm
- "Technicolor" by F. Sannino, Wed. 25th 10am
- "Non-standard Higgs decays"
by J. Gunion, Wed. 25th 11am
- "Collider signatures of technicolor like models"
by A. Martin, Wed. 25th 5:30pm
- Working group summaries: Fr. 27th 2pm

⇒ WG2 Report

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Your input is needed!