First Look at the Interpretation of ATLAS Higgs Searches in the CPX Scenario of the Complex MSSM

Markus Schumacher , Bonn University

May 13th 2004, CERN

- Phenomenology of CPX Scenario
- Technicalities
- Discovery Potential
- Problematic Regions ?

Disclaimer: this are first very preliminary results from a study in progress and NOT official ATLAS results. Please do note quote plots as ATLAS results!

The CPX scenario

- ★ **MSSM Higgs Sector CP conserving at Born level**
- ★ **CP effects via complex couplings in loops: ComplexMSSM**

relevant for Higgs sector are:

complex trilinear couplings A_t, A_b and

complex gluino mass paramer M_{gluino}

Maximal effect in Higgs sector → CPX scenario

(suggested by Carena, Ellis, Pilaftsis, Wagner et al.)

★ **Parameter choice for this first scan:**

M_{SUSY} = 500 GeV, A_t=A_b=M_{gluino}=1 TeV, μ=2TeV,
M_2=200GeV, arg(A_t)=arg(A_b)=arg(M_{gluino})=90 degree

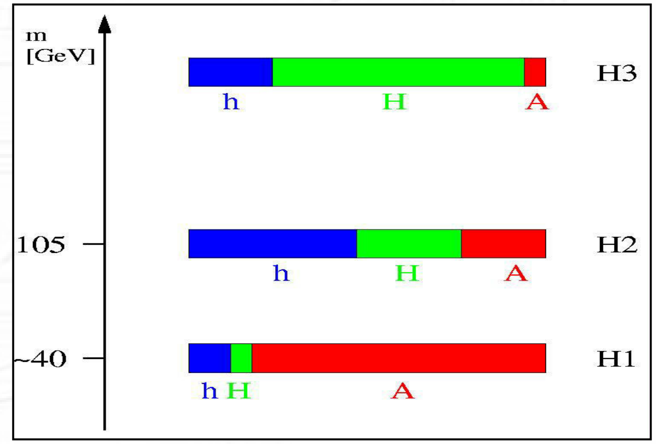
+ scan of Born level parameter: $\tan\beta$ and M_{H+-}

Phenomenology in the CPX scenario

★ **Mass eigenstates H_1, H_2, H_3 not equal CP eigenstates h,A,H**

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} = \begin{pmatrix} u_{11} & u_{12} & u_{13} \\ u_{21} & u_{22} & u_{23} \\ u_{31} & u_{32} & u_{33} \end{pmatrix} \cdot \begin{pmatrix} H \\ h \\ A \end{pmatrix}$$

→ **mixing between CP even and CP odd states**



★ **All neutral bosons can couple to pair of W and Z bosons**

among themselves H_i,H_j,H_k

★ **Compare to CP Conserving real MSSM:**

no born level coupling of A to WW,ZZ, A to hh (HH)

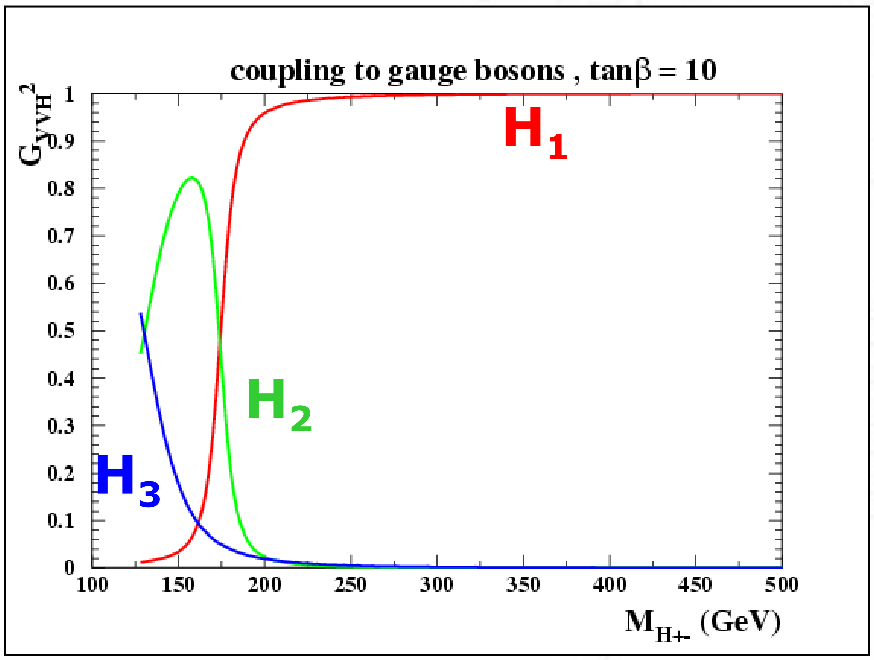
h(H) to Zh(H), A to AZ

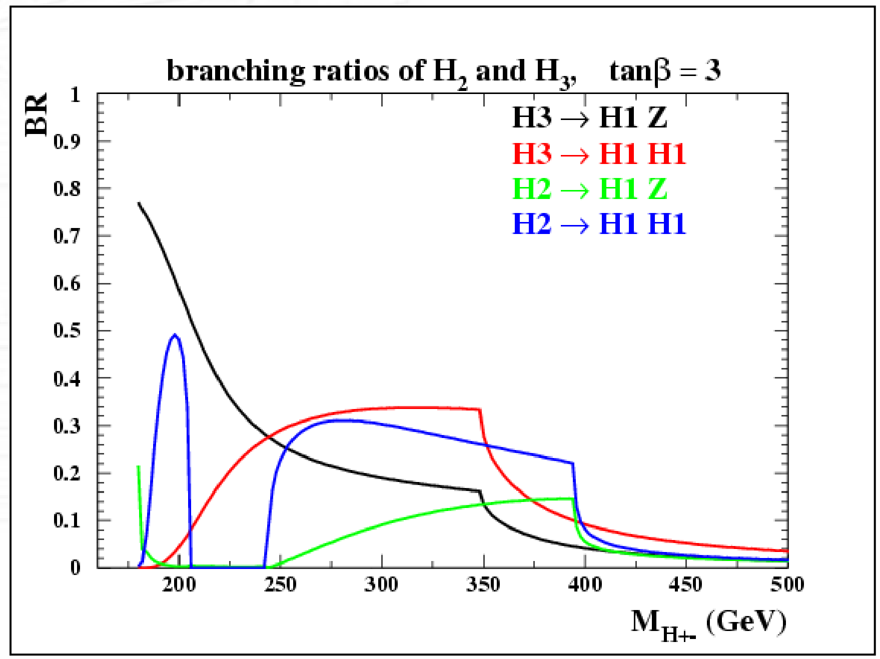
Phenomenology in the CPX scenario

★ H_1, H_2 and H_3 may
be produced in VBF, WH and ZH processes
decay to pair of W/Zs, pair of Higgs bosons, H+Z bosons

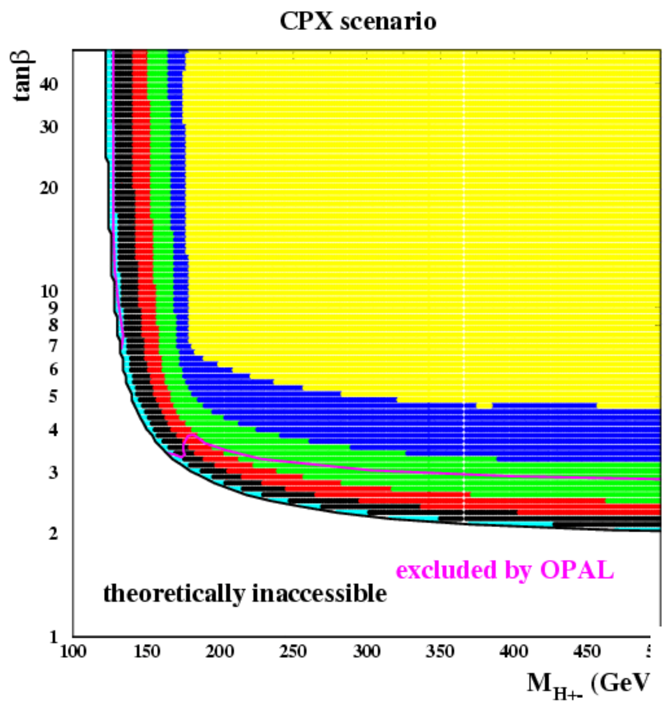
Sum rule for couplings:
$\sum_i^3 g_i^2 (ZZH_i) = g_{SM}^2 (ZZH_{SM})$

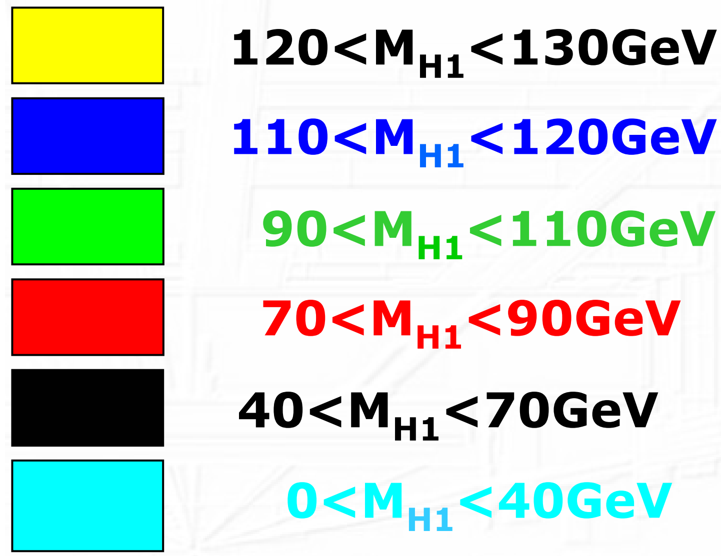
H_2 and H_3 decay into H_1H_1 and H_1Z

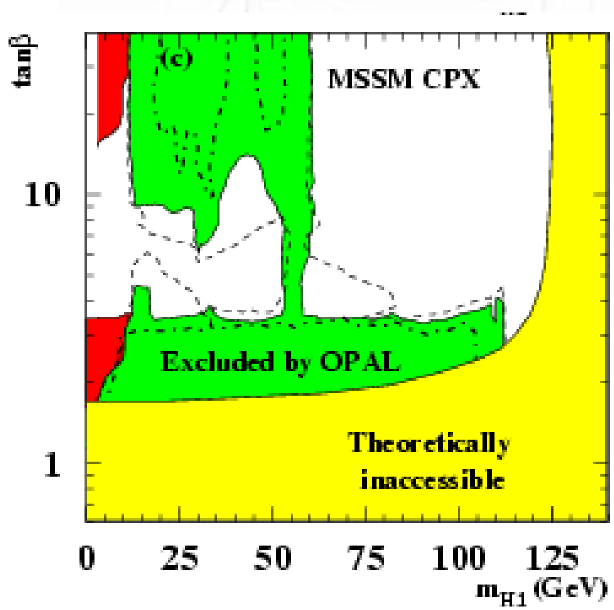


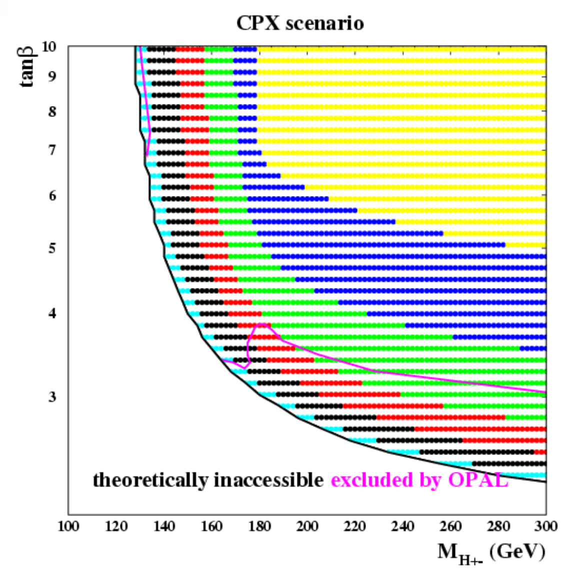


Mass of the Lightest Higgs Boson H1









- ★ even masses between 0 and 40 GeV not excluded by LEP
- → problematic for LHC

Some Technicalities

- **masses, couplings and branching ratios calculated so far with FEYNHIGGS 2.1(** Heinemeyer, Weiglein et al. **)**
- **needs/will be cross checked by CPSUPERH (** A.Pilaftsis, J.S.Lee et al**.)**
- **SM like cross sections calculated in leading order with M. Spira's programs + CTEQ5L parton density functions**
- **charged Higgs cross sections obtained from T. Plehn's program**

- **MSSM cross sections obtained by appropiate correction factors**

  Gluon fusion: $\sigma(MSSM) = \Gamma(H_i \rightarrow gg) / \Gamma(H_{SM} \rightarrow gg) \times \sigma(SM)$

  VBF,ZH,WH: $\sigma(MSSM) = g^2_{HiVV} \times \sigma(SM)$

  ttH/bbH: $\sigma(MSSM) = s^2_{ffHi} \times \sigma(ffH) + p^2_{ffHi} \times \sigma(ffA)$

- **running bottom quark mass usedd for bbH, gb→tH+-**

- **discovery = 5 sigma excess using Poissonian statistics combination of channels with likehood ratio method**

Experimental Inputs

- ★ efficiencies and background predictions taken from documented ATLAS analysis (see below)
- ★ corrections due to larger total decay width taken into account
- ★ for VBF channels: assume same efficiencies for contribution of CP even and CP odd states (needs to be checked)
- ★ for ttH: efficiencies for CP even and odd bosons are the same

VBF channels: SN-ATLAS-2003-024

ttH, H→bb: ATL-PHYS-2003-003

Charged Higgs: ATL-PHYS-2003-58 (low mass), SN-ATLAS-2002-017, (high mass)

bbH/A→$\mu\mu$: ATL-PHYS-2002-021 (low mass),ATL-PHYS-2000-005 (high masses)

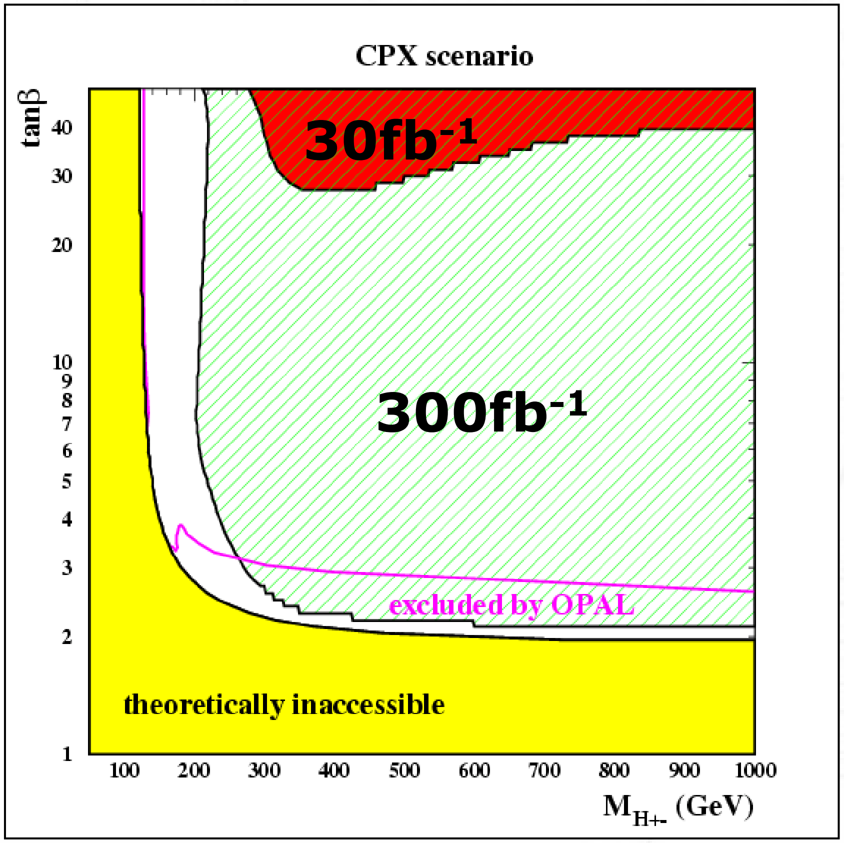
bbH/A→$\tau\tau$: $\tau\tau$→lep. had :ATL-PHYS-2000-001 (low m.), ATL-PHYS-2003-008 (high m.)

$\tau\tau$→had. Had: ATL-PHYS-2003-008 (masses > 450 GeV)

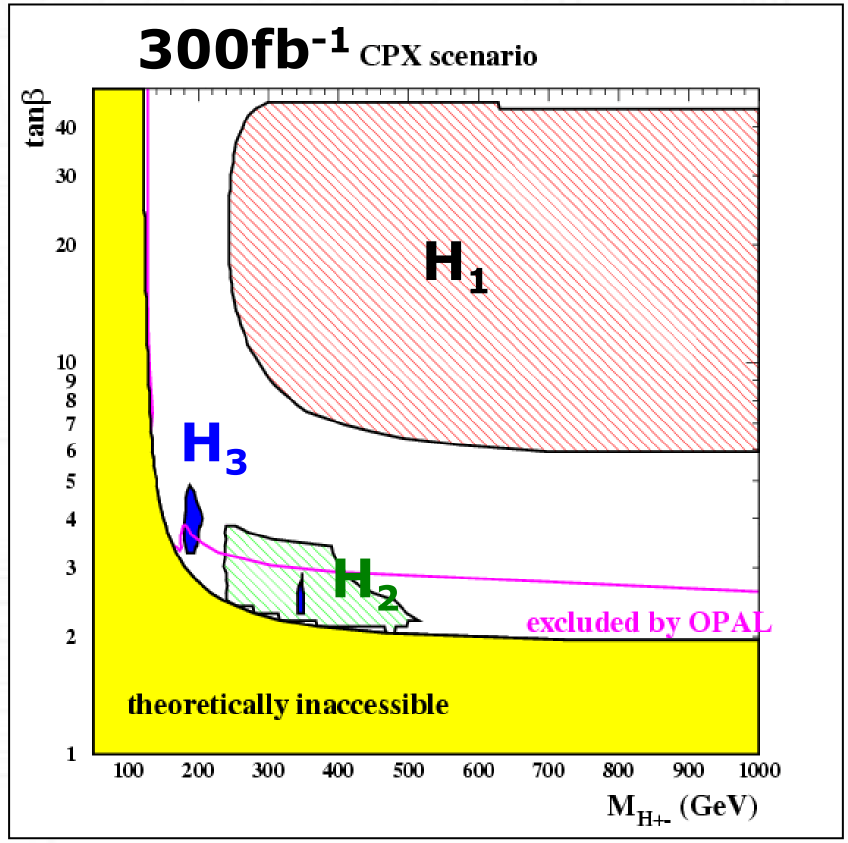
Remaining analysis from ATLAS Detector and Physics Performance TDR

$H \to \gamma\gamma$ and $H \to ZZ \to 4$ leptons

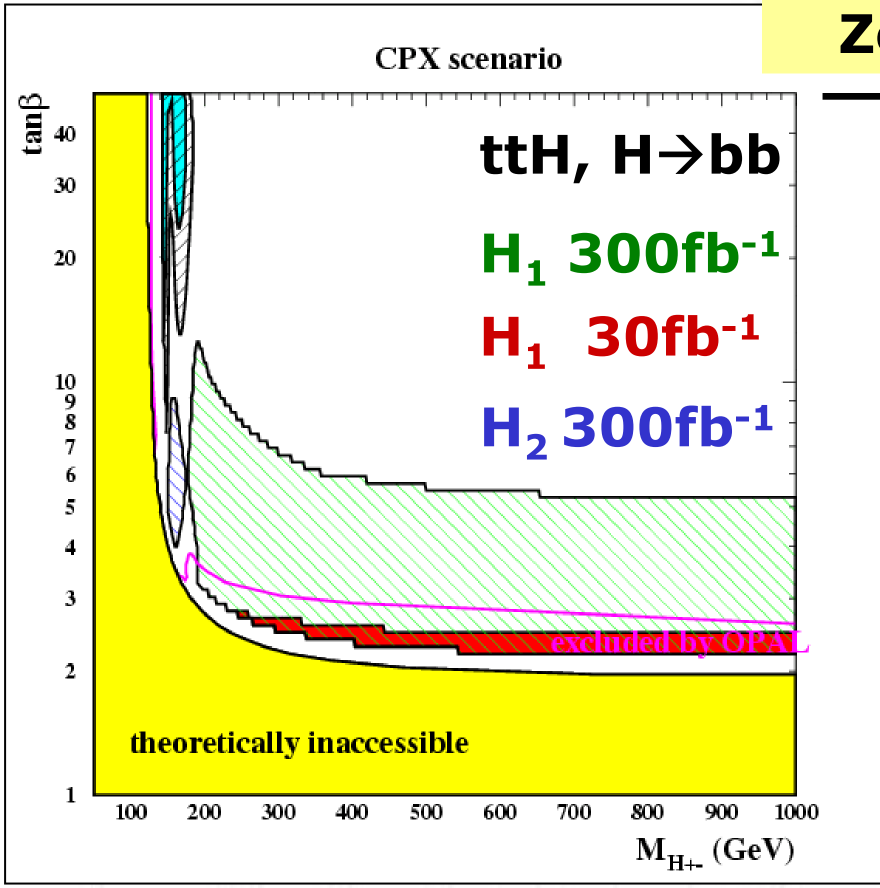
$H_1 \to \gamma\gamma$, GGF+ass. prod.



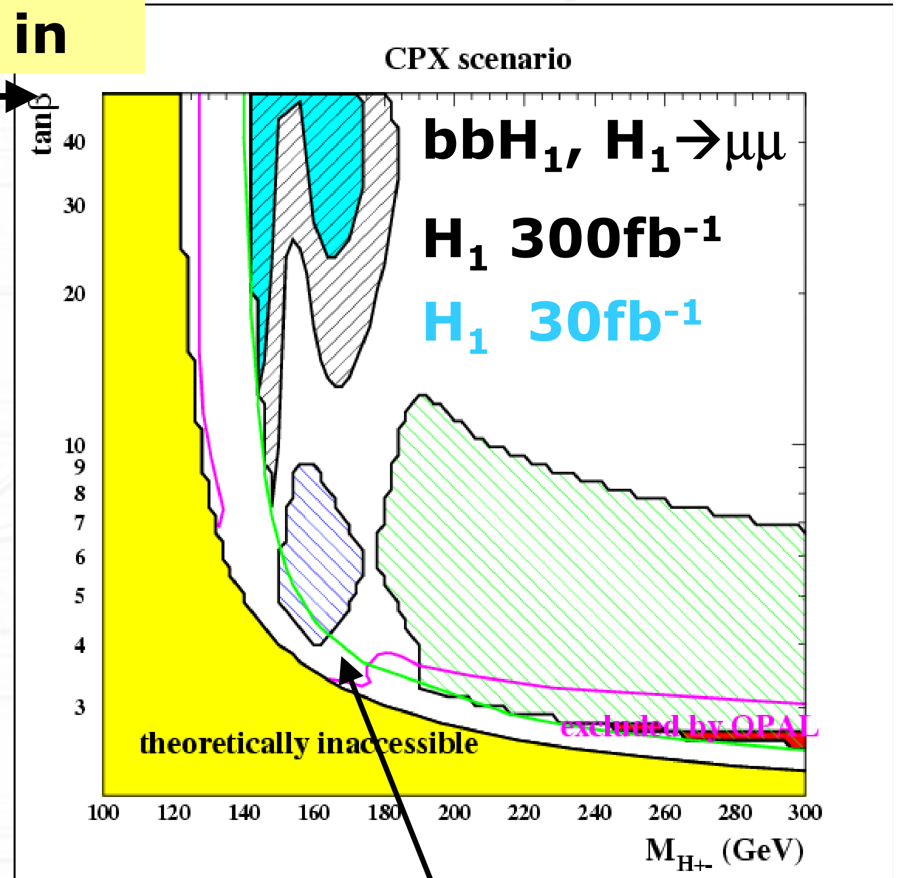
$H_i \to ZZ \to 4l$



ttH with H→bb and bbH with H→μμ



Zoom in

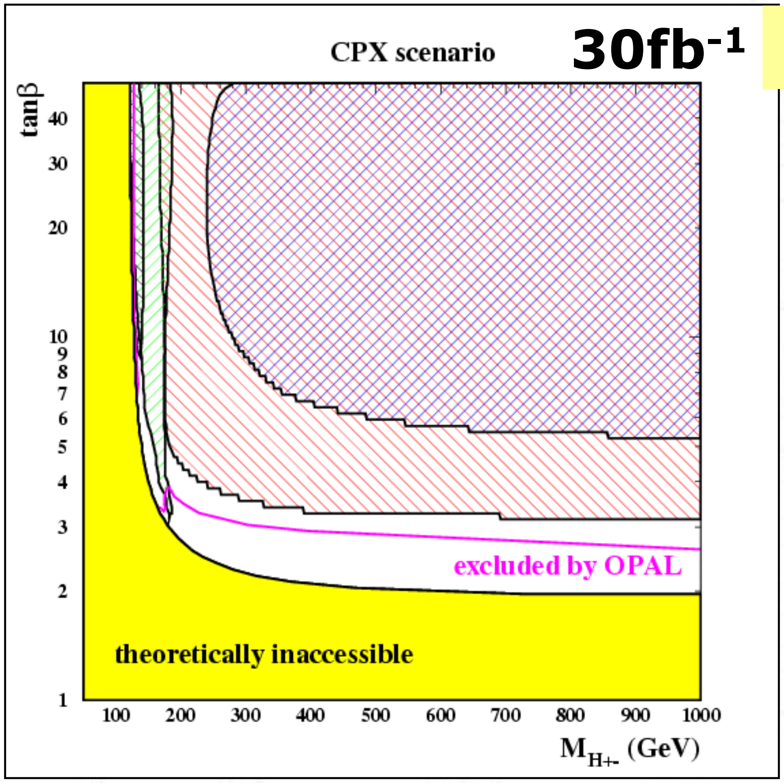


discovery region partially limited by avaibility of inputs only down to M_H = 70 GeV (ttH at low tanβ, bbH at low M^{+-})

M_{H1}= 70GeV

Weak Vector Boson Fusion

30fb^{-1}



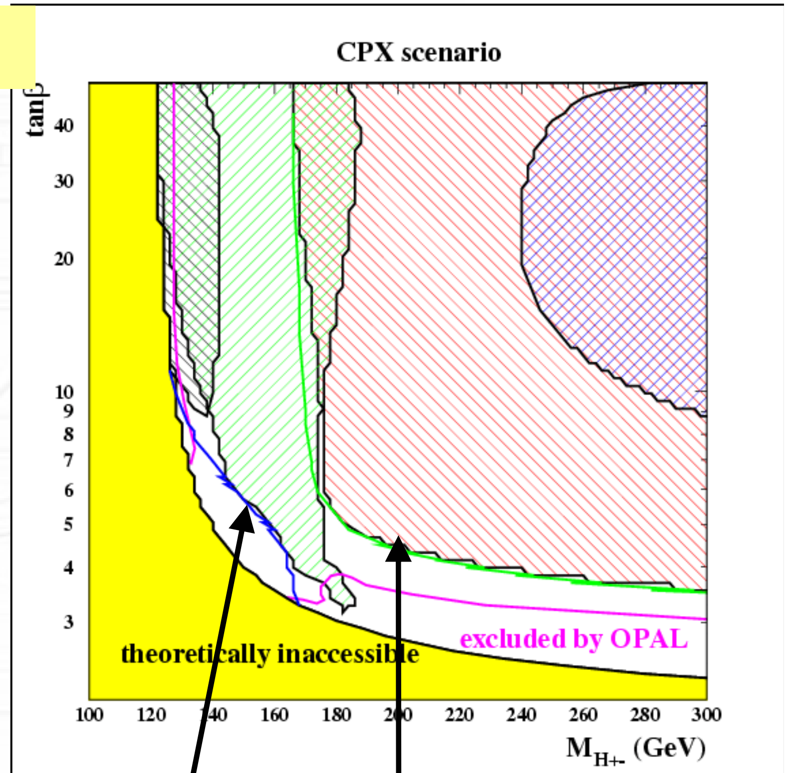
Zoom in

$H_1 \rightarrow \tau\tau$

$H_1 \rightarrow WW$

$H_2 \rightarrow \tau\tau$

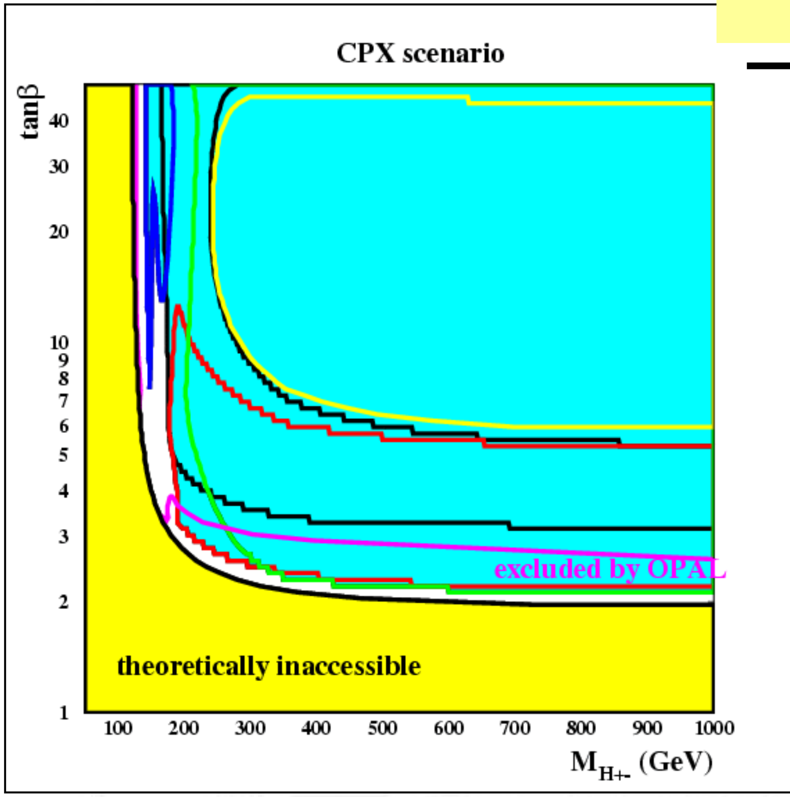
$H_3 \rightarrow \tau\tau$



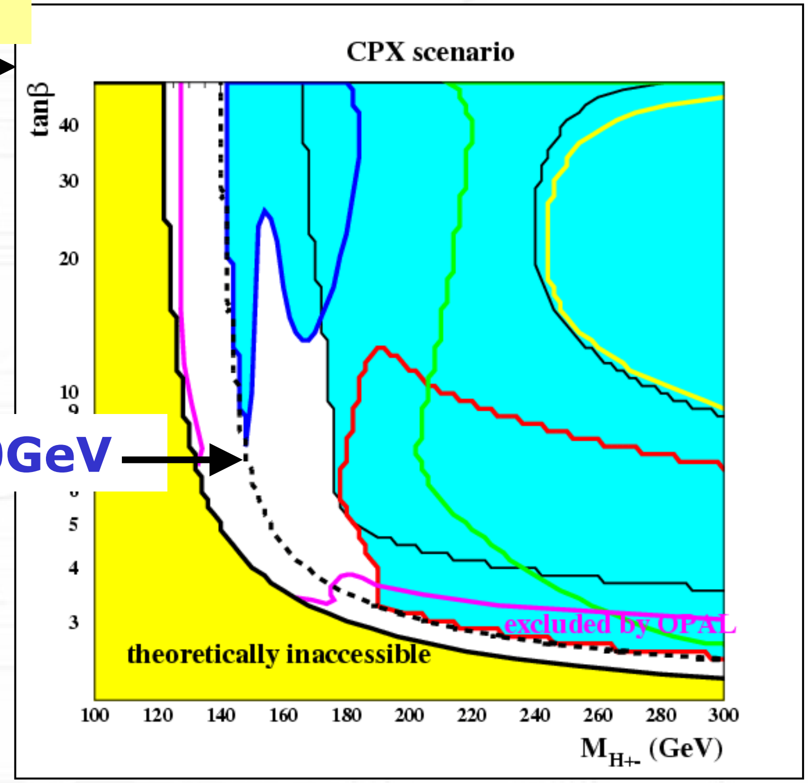
M_{H2}= 110GeV M_{H1}= 110GeV

- ★ only studied for low luminosity running so far (forward jet tagging, central jet veto in presence of pile up)
- ★ discovery region for low tanβ limited by avaibility of inputs only down to 110 GeV

Discovery Potential Light Higgs Boson H1



Zoom in

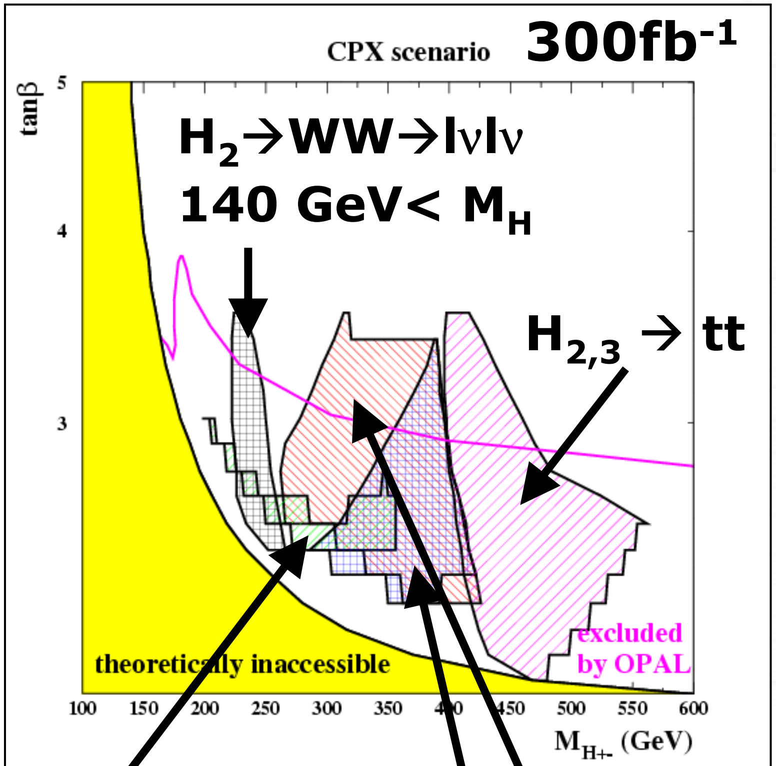


- bbH_1, $H_1 \rightarrow \mu\mu$ (blue)
- ttH_1, $H_1 \rightarrow bb$ (red)
- $H_1 \rightarrow \gamma\gamma$ (green)
- $H_1 \rightarrow ZZ \rightarrow 4l$ (yellow)
- VBF: $H_1 \rightarrow \tau\tau$ (black)

★ low Higgs masses below 70 GeV not studied yet in ATLAS

★ for M_{H+-} >190GeV discovery in at least two channels

Discovery Potential H2 and H3

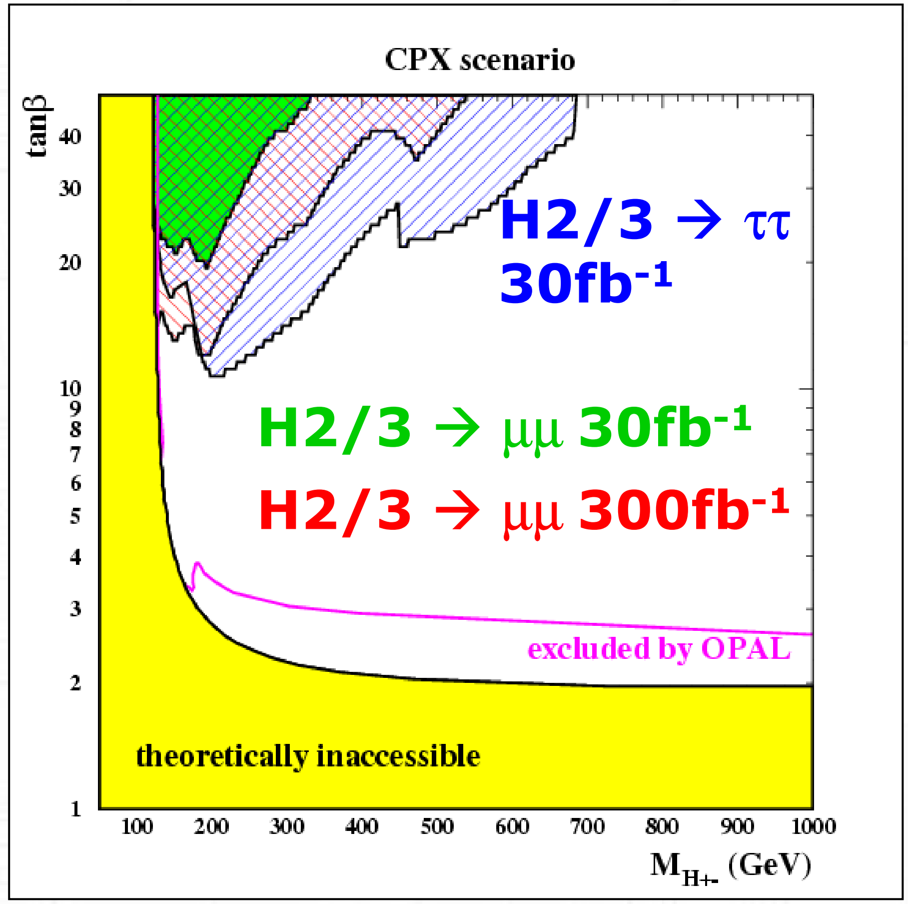


$H_2 \rightarrow H_1 H_1 \rightarrow bb\ \gamma\gamma$

$H_3 \rightarrow H_1\ Z \rightarrow bb\ ll$

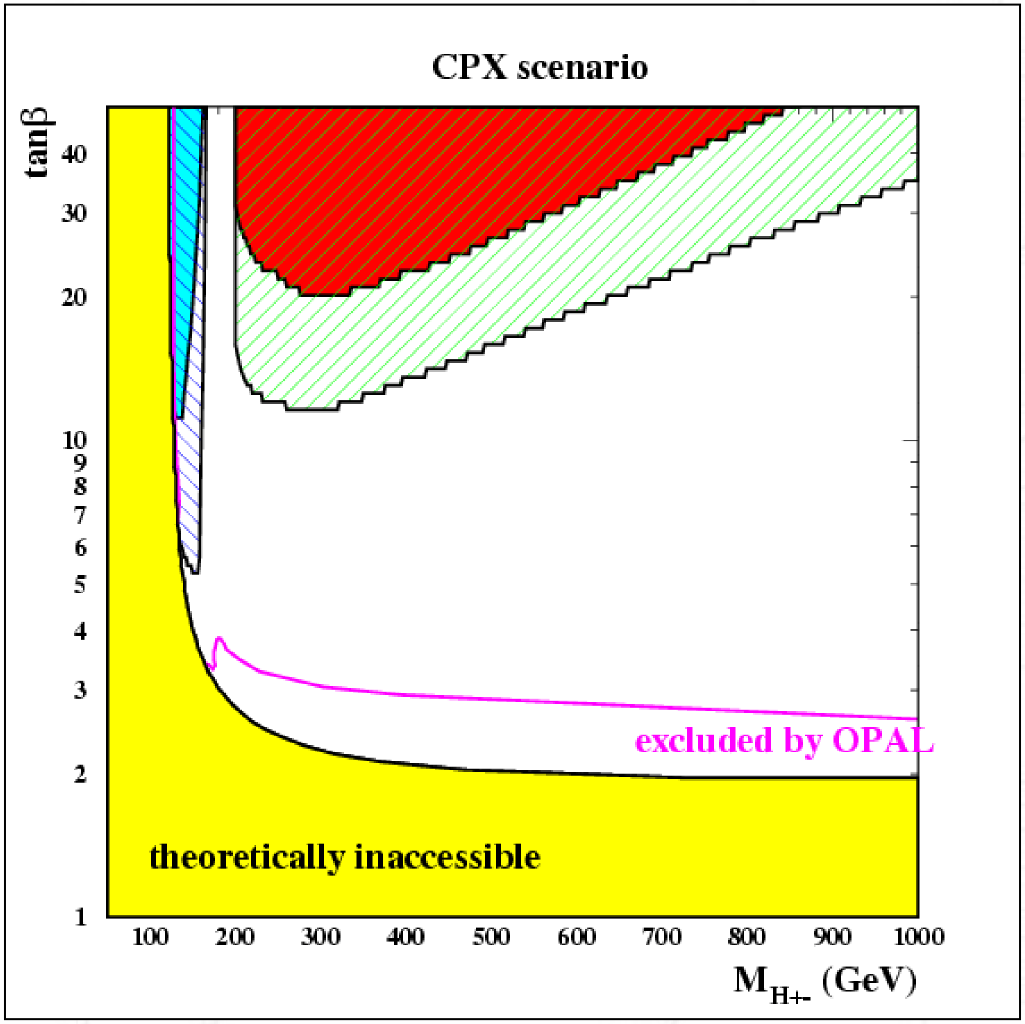
$H_2 \rightarrow H_1\ Z \rightarrow bb\ ll$

60 GeV< M_{H1},
200<$M_{H2/3}$ < 360 GeV



★ **ττ only studied for low luminosity running so far**

Charged Higgs Bosons



high mass: $m_{H+-} > m_{top}$

$gb \rightarrow H^{+-}t$

$H^{+-} \rightarrow \tau\nu$, $t \rightarrow bqq$

$30fb^{-1}$ $300fb^{-1}$

low mass: $m_{H+-} < m_{top}$

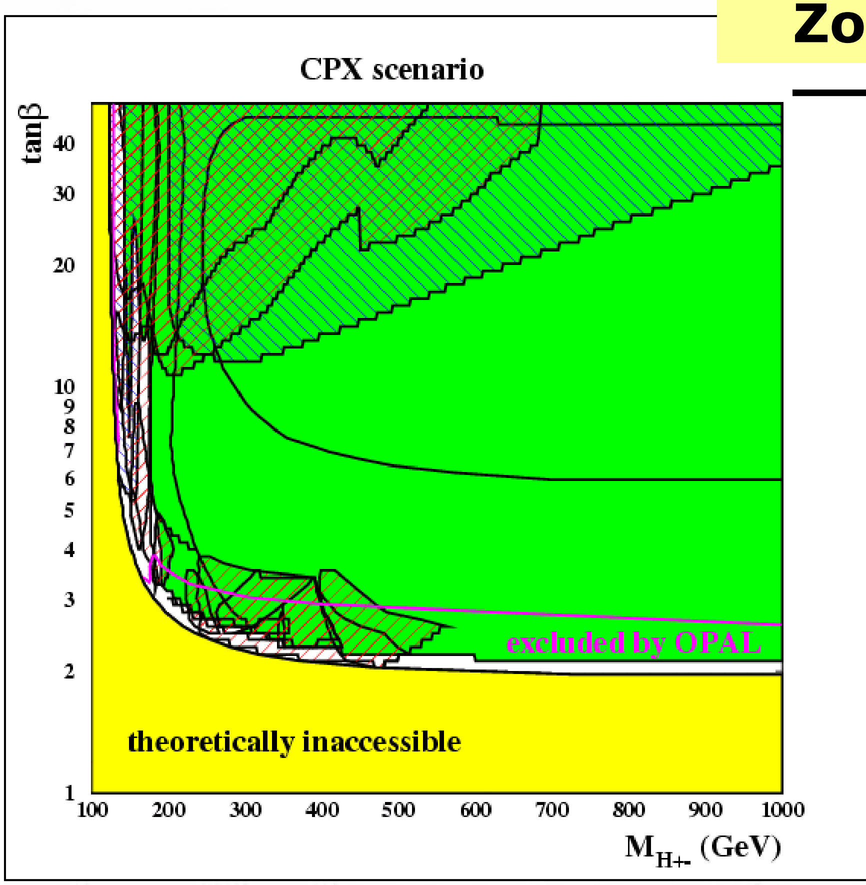
$tt \rightarrow H^{+-}$ b Wb

$W \rightarrow l\nu$ $H^{+-} \rightarrow \tau\nu$ $30fb^{-1}$

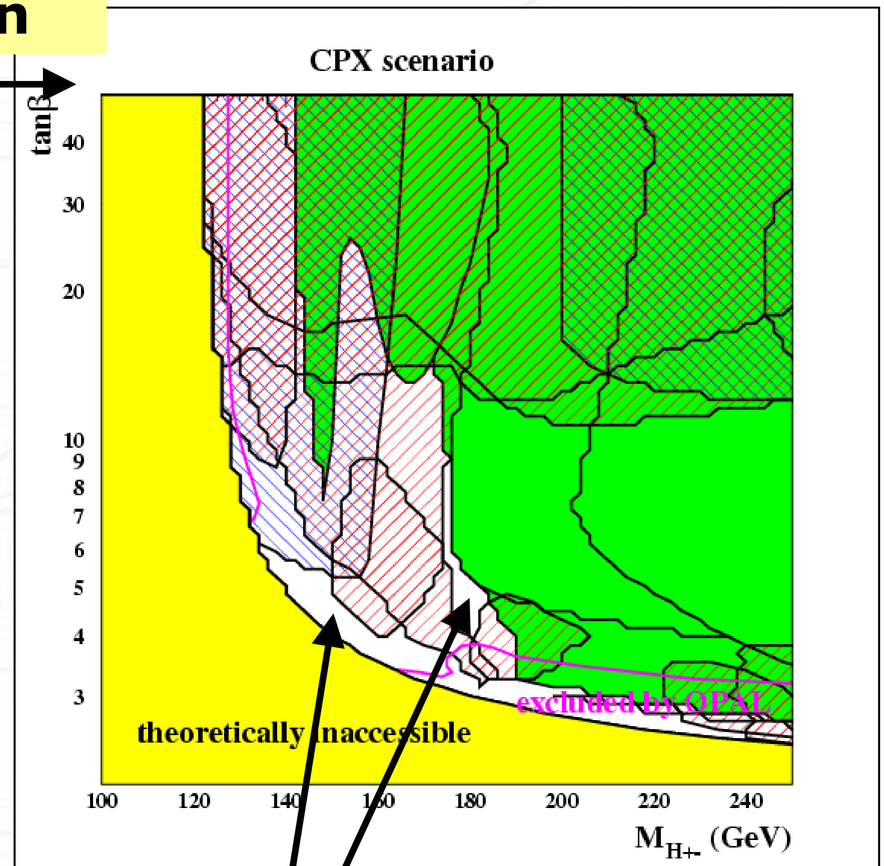
$W \rightarrow qq$ $H^{+-} \rightarrow \tau\nu$ $30fb^{-1}$

- ★ **only studied for low luminosity running so far (tau tagging for soft taus in presence of pile up)**

Overview of Discovery Potential



Zoom in



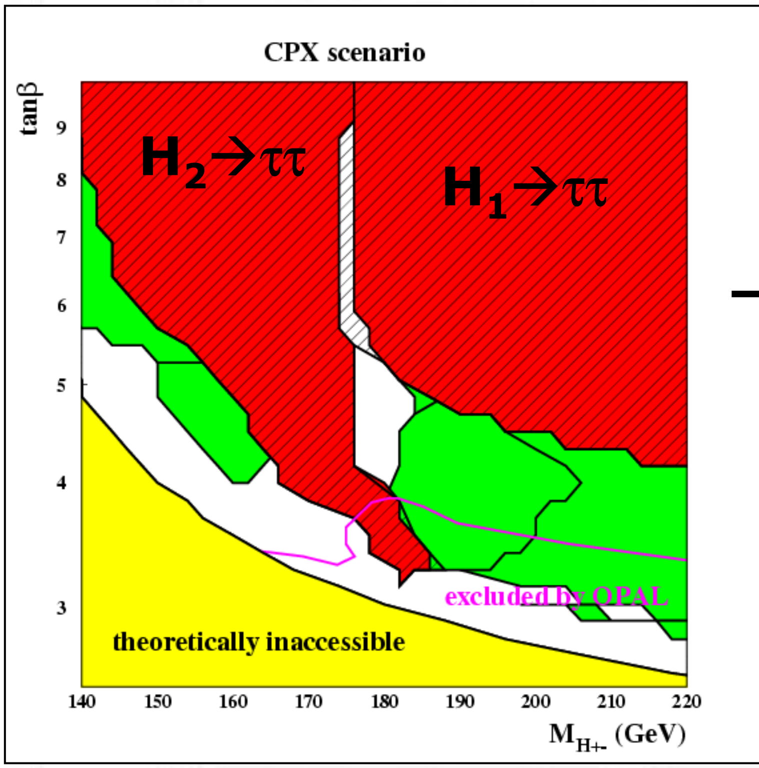
- **Discovery of H_1**
- **Discovery of H_2 and/or H_3**
- **Discovery of H^{+-}**

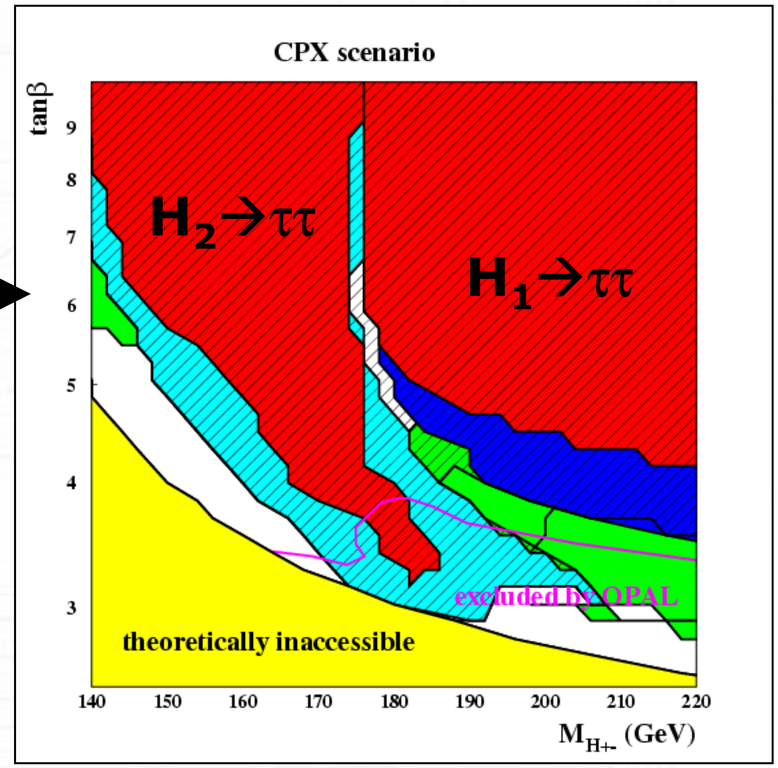
Two „problematic" regions

Problematic Region I

VBF, H→ττ
So far:M>110GeV,
int. lumi= 30fb^{-1}

see what happens if:
increased lumi. = 60fb^{-1}
extrapolate inputs to M_H=100 GeV

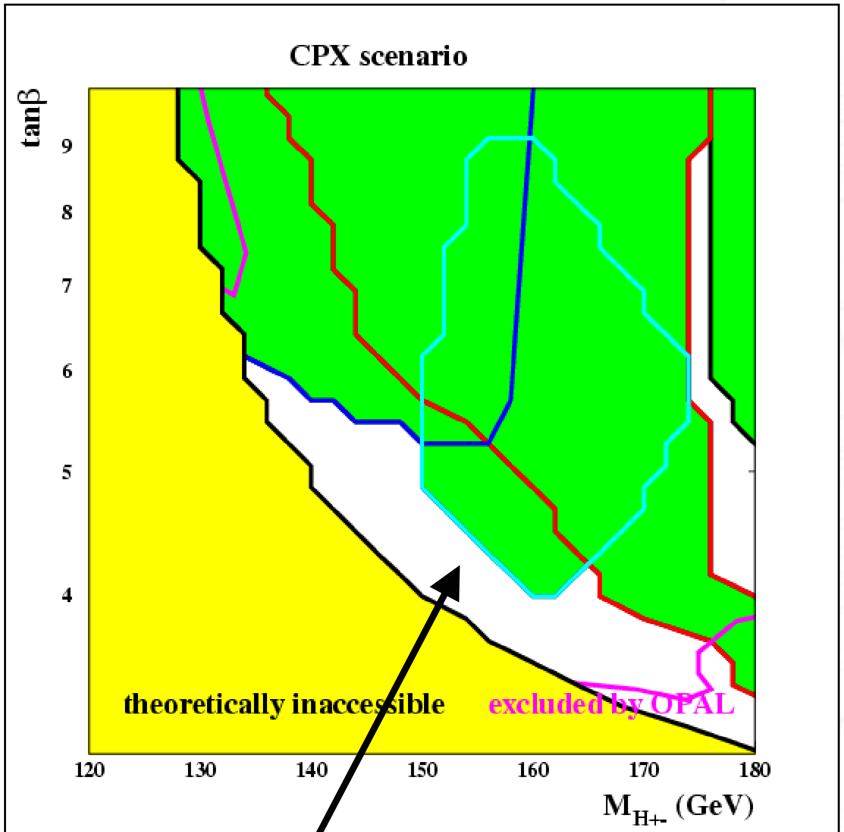




poor man's combination of :
H_1→ττ and H_2→ττ
partially covers hole

increased coverage +
combination covers hole

Problematic Region II



M_{H1}<50GeV

100<M_{H2}<110 GeV

130<M_{H3}<180 GeV

Analysis surrounding hole:

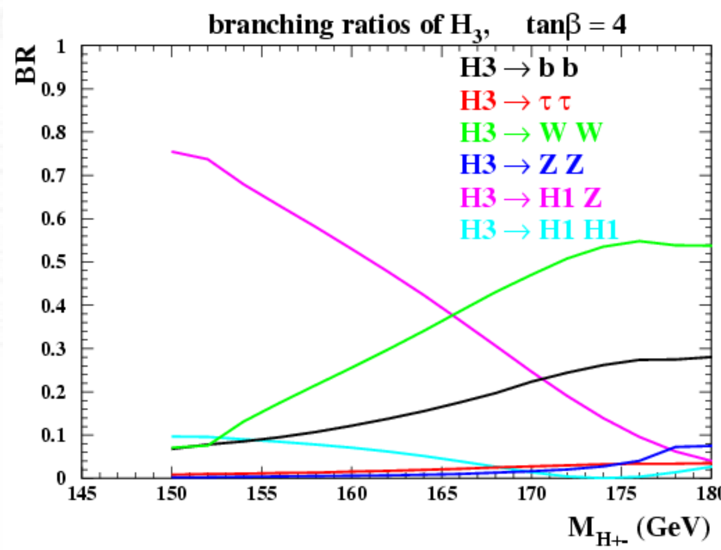
Charged Higgs tt→H^{+-} b Wb

W→qq H^{+-} →τν 30fb^{-1}

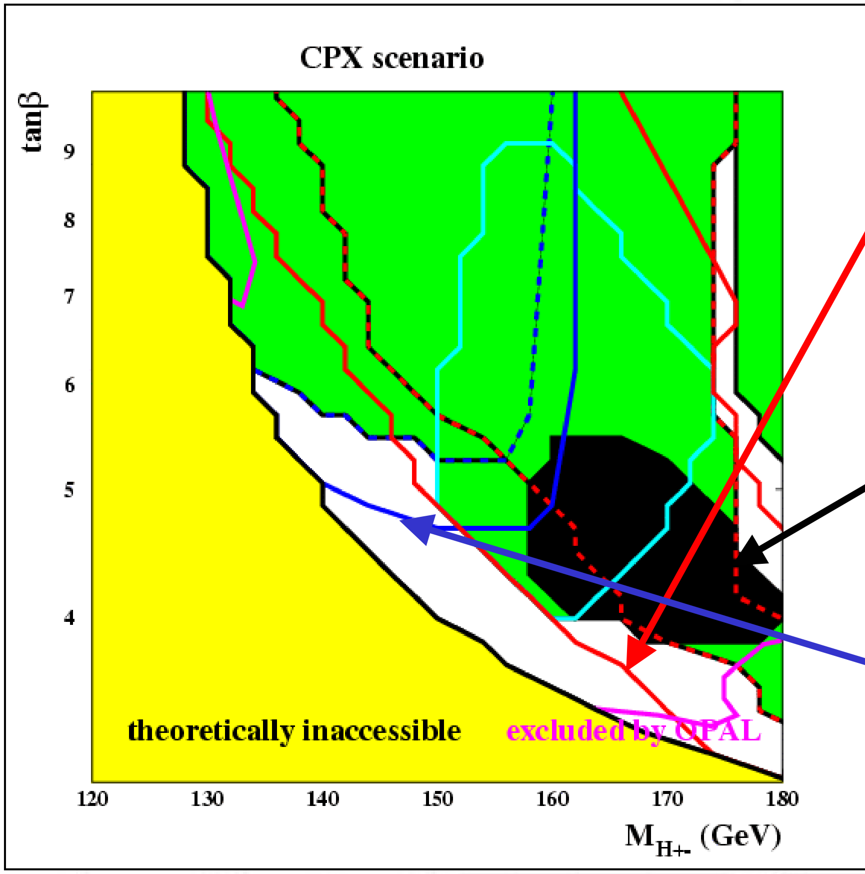
ttH_2, H_2→bb

VBF: H_2→ττ, 30fb^{-1}, 110GeV<M_H

try look for H_3→WW→lνlν



Problematic Region II



VBF: $H_2 \rightarrow \tau\tau$

$30fb^{-1}$ → $60fb^{-1}$

$110GeV < M_H$ → $100GeV < M_H$

$H_3 \rightarrow WW \rightarrow l\nu l\nu$
$3\,\sigma$ observation with $300fb^{-1}$

Charged Higgs
$30fb^{-1}$ → $100fb^{-1}$

other ideas for improved coverage:

investigate high luminosity running for VBF,

lower masses for $H_3 \rightarrow ZH_1 \rightarrow llbb$, try $gg \rightarrow H+1$ hard jet, $H \rightarrow \tau\tau,\mu\mu$

$H^{+-} \rightarrow WH_1$, Higgs pair production + other new or rare decay modes ??

Conclusions

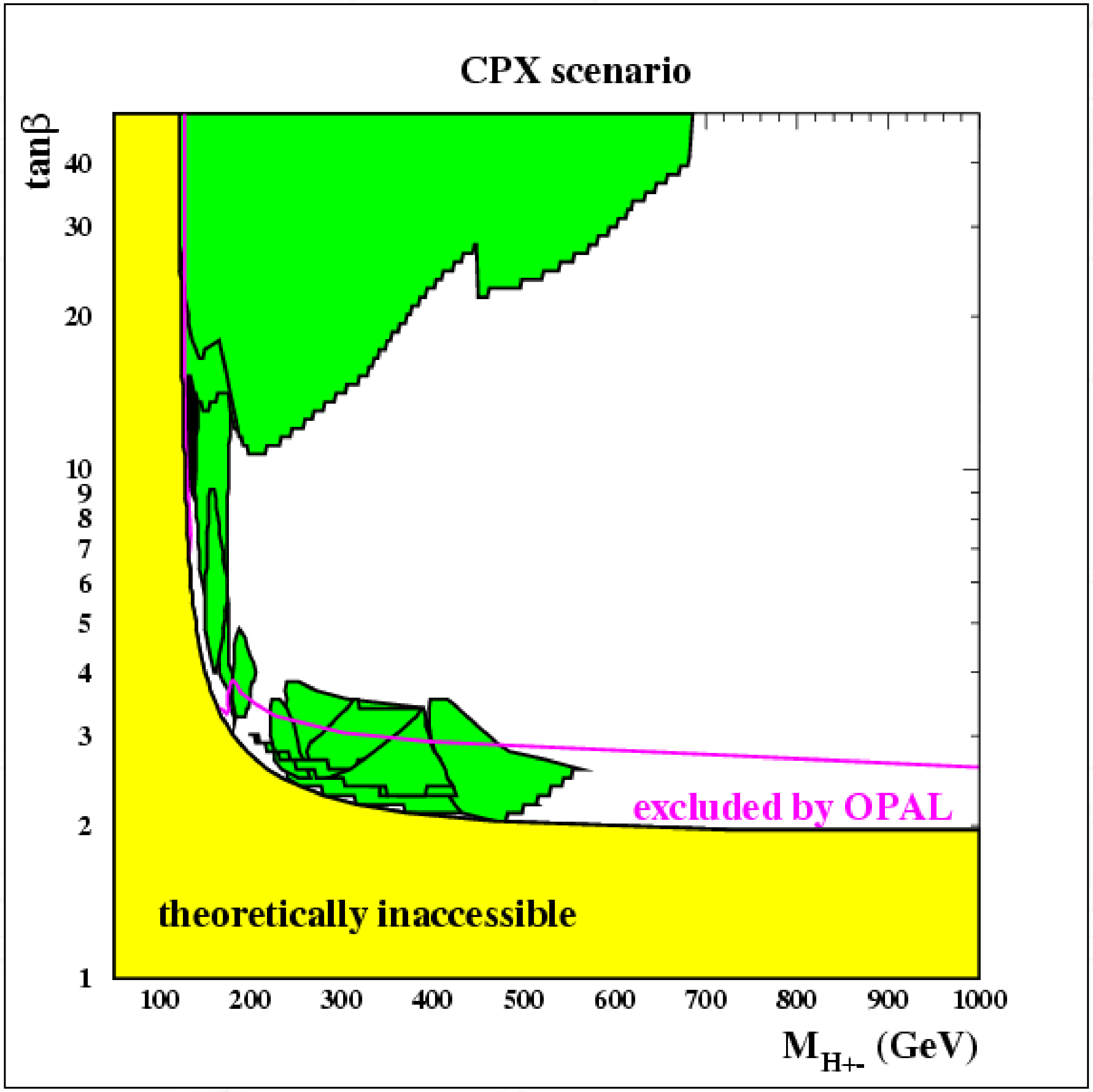
- ★ First preliminary interpretation of ATLAS Higgs searches in CPX scenario has been performed
- ★ Good coverage over most of $\tan\beta$ vs. M_{H+-} plane, two problematic regions have been identified and ideas for coverage are on the way
  → study smaller Higgs boson masses at LHC
- ★ Investigate „problematic" regions in more detail
  → maybe suggest new analysis/ search channels
- ★ Crosscheck results with CPSUPERH
- ★ Study different values for complex phases

Thanks for programs and discussions to:

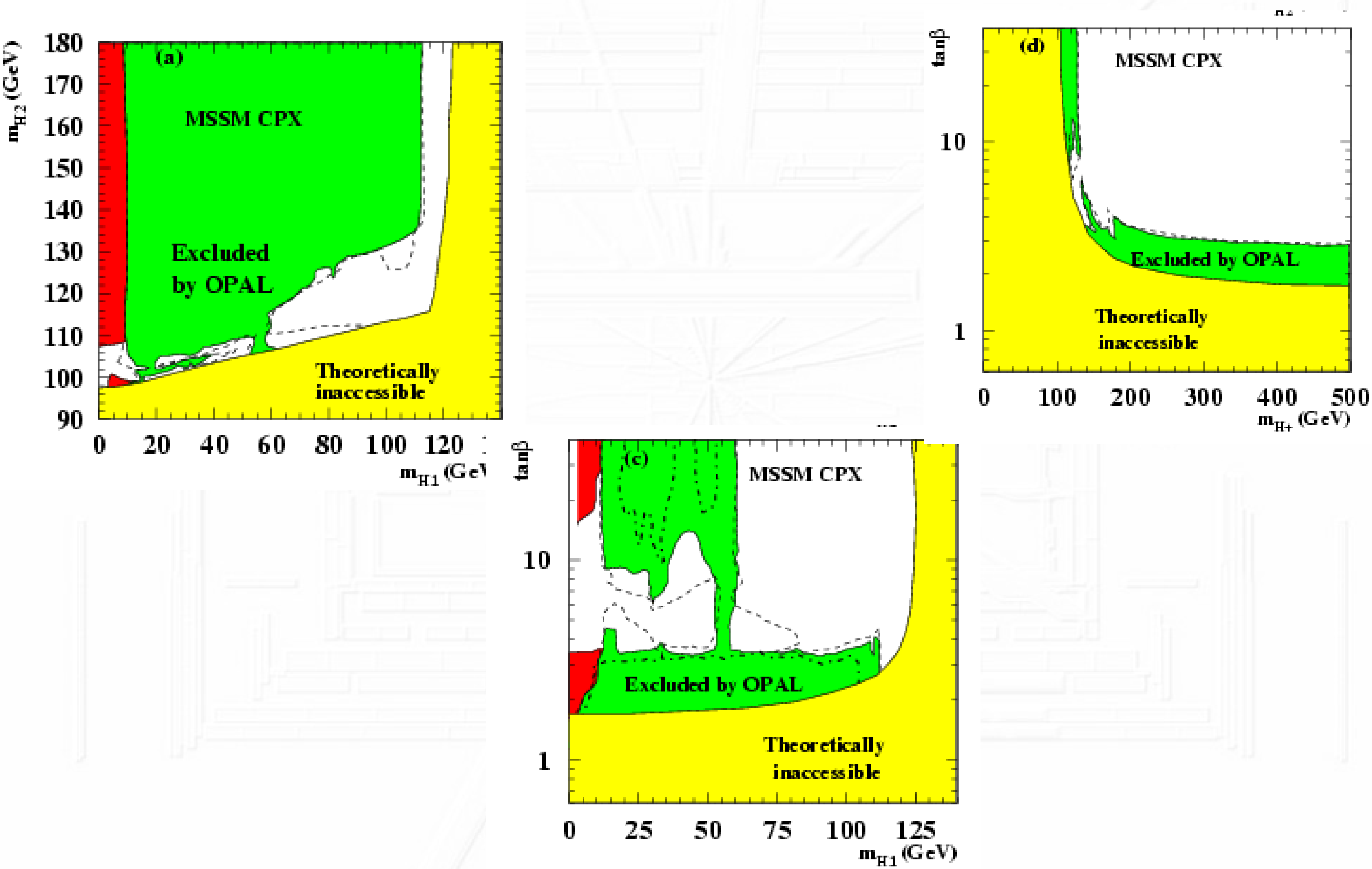
Philip Bechtle, Sven Heinemeyer, Tilman Plehn
David Rainwater, Michael Spira,...

Backup Slides

Discovery Potential for Heavy Neutrals



OPAL PLOTS



(a)
MSSM CPX
Excluded by OPAL
Theoretically inaccessible
m_{H2} (GeV)
m_{H1} (GeV)
(d)
MSSM CPX
Excluded by OPAL
Theoretically inaccessible
tanβ
m_{H+} (GeV)
(c)
MSSM CPX
Excluded by OPAL
Theoretically inaccessible
tanβ
m_{H1} (GeV)