Discovery Potential for MSSM Higgs Bosons with ATLAS

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on behalf of the ATLAS collaboration

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MSSM Higgs Sector

- MSSM: 2 Higgs doublets → 5 physical bosons: h, H, A, H^+, H^-
- phenomenology at **Born level** described by $\tan\beta$, m_A
- mass prediction: $M_h < M_Z$
- couplings: $g_{MSSM} = \xi \cdot g_{SM}$
  - no coupling of A to W/Z
  - large $\tan\beta$: large BR(h,H,A → $\tau\tau$,bb)

ξ	t	b/τ	W/Z
h	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\sin(\alpha-\beta)$
H	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos(\alpha-\beta)$
A	$\cot\beta$	$\tan\beta$	-----

α: mixing angle between CP even Higgs bosons (calculable from $\tan\beta$ and M_A)

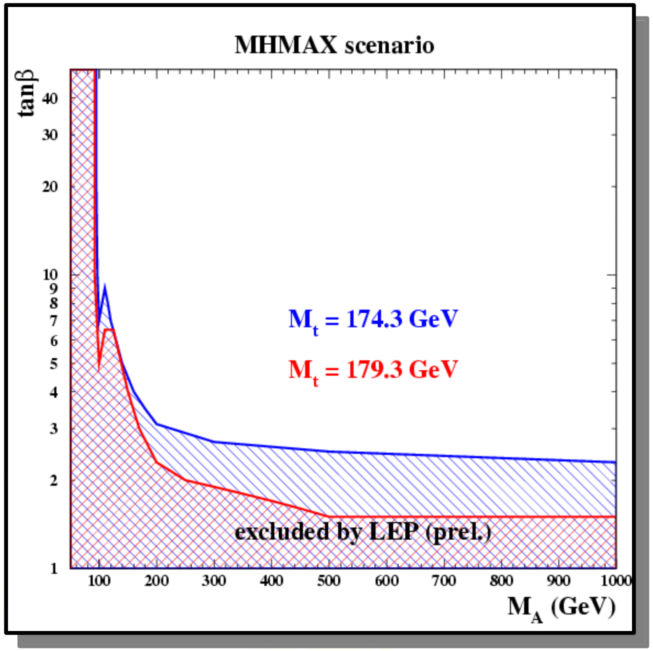
- large loop corrections to masses and couplings
- mainly dependent on $t/\tilde{t}$ sector
- parameters: M_{top} and X_t, M_{SUSY}, M_2, μ, M_{gluino}
- mass prediction $M_h < 133$ GeV (for $M_t = 175$GeV)

for exclusion bounds and discovery potential: fix the 5 parameters in benchmark scenarios and scan ($\tan\beta$, M_A)- plane

The (tanβ, M_A)-Plane

current exclusion in (tanβ,M_A)-plane:

- LEP searches for light Higgs
- excludes low tanβ and low M_A
- note: no exclusion for M_t >~183 GeV



main questions for LHC/ ATLAS:

- **Can at least 1 Higgs be discovered in the allowed parameter space?**
- **How many Higgs bosons can be observed ?**
- **Can we discriminate the SM from beyond the SM (like MSSM) ?**

Benchmark Scenarios

- **4 CP conserving scenarios considered**
- **to examplify the discovery potential**
- **mainly influence on phenomenology of h**

Name	M_{SUSY} (GeV)	μ (GeV)	M_2 (GeV)	X_t (GeV)	M_{gluino} (GeV)
m_h-max	1000	200	200	2000	800
no mixing	2000	200	200	0	800
gluophobic	350	300	300	-750	500
small α	800	2000	500	-1100	500

suggested by Carena et al., EPJ C26, 601(2003)

already at LEP

Newly designed for hadron colliders

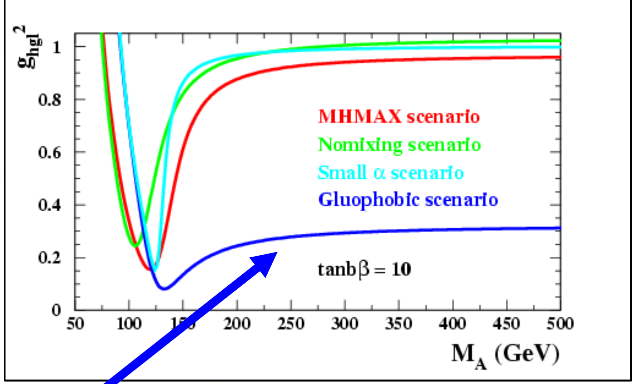
1) MHMAX scenario maximal M_h < 133 GeV

2) Nomixing scenario small M_h < 116 GeV

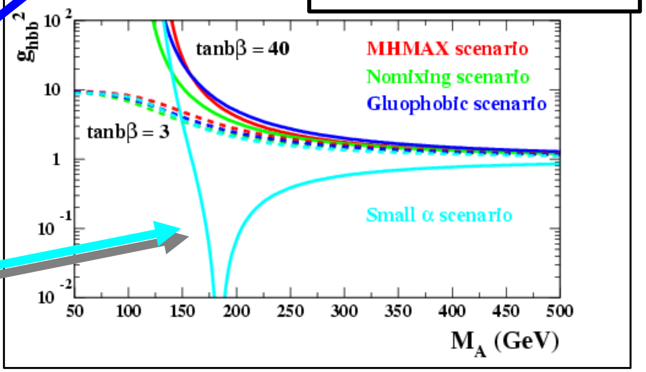
3) Gluophobic scenario M_h < 119 GeV
- coupling of h to gluons suppressed
- designed to affect discovery via gg→ h, h→γγ and h→ZZ →4l

4) Small α scenario M_h < 123 GeV
- coupling of h to b (τ) suppressed (for large tanβ and M_A 150→500GeV)
- designed to affect discovery via VBF, h→ττ and tth, h→bb

eff. hg - coupling

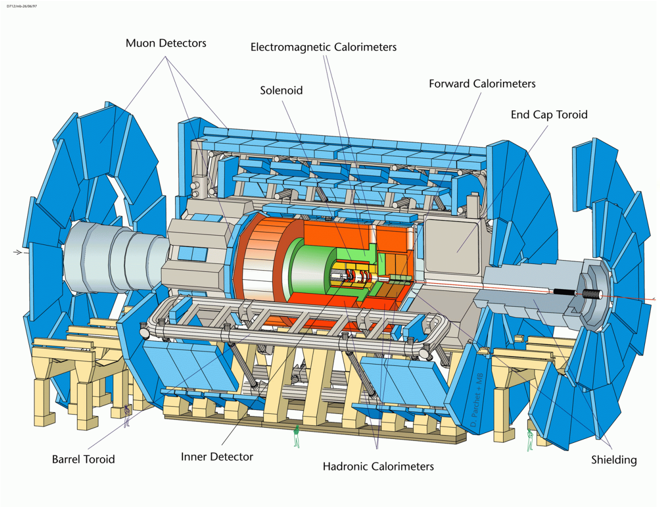


hbb - coupling



masses, coupling and BRs calculated with FeynHiggs (Heinemeyer et al.)

Technical Issues



- **combination of latest results from (MSSM corrected) studies for SM Higgs boson and dedicated MSSM Higgs analysis (heavy higgs states)**
- **key performance numbers obtained from full simulation: (e.g. trigger efficiencies, b-tagging, τ-identification, mass resolutions...)**
- **signal efficiencies and background expectations from fast simulations**

developments/ improvements:

2) new and updated search channels:

- new: VBF with Higgs decay to $\tau\tau$, WW, $\gamma\gamma$.
- new: tt→bW+bH→bqq+b$\tau\nu$
- updated: ttH, H→bb (better simulation of bgr.)
- updated/ new: bbH→H→$\mu\mu$ ($\tau\tau$), now also had. τ decay

3) improved theoretical calculations:

- FeynHiggs: full one-loop corrections and dominant two-loop corrections included (increase of M_h by several GeV)

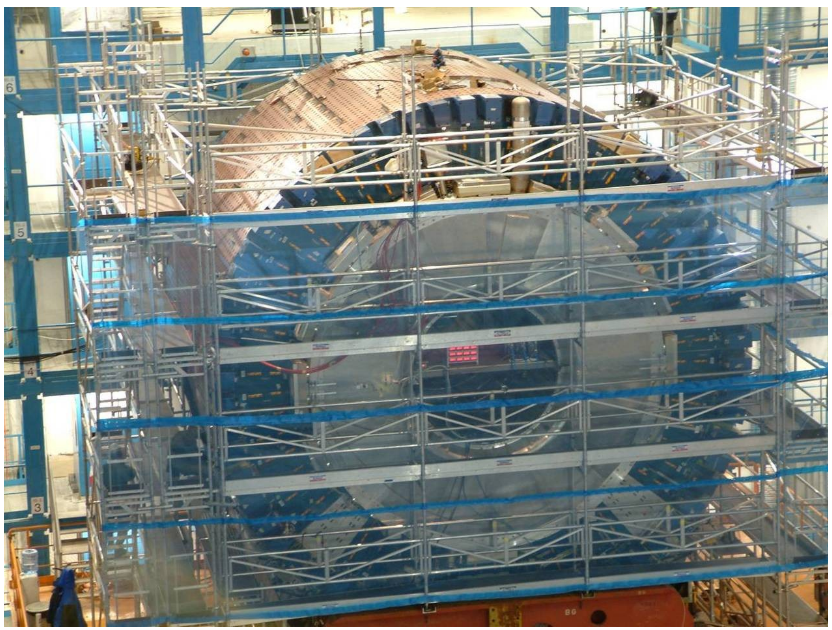
→ considered to give most accurate calculations at present

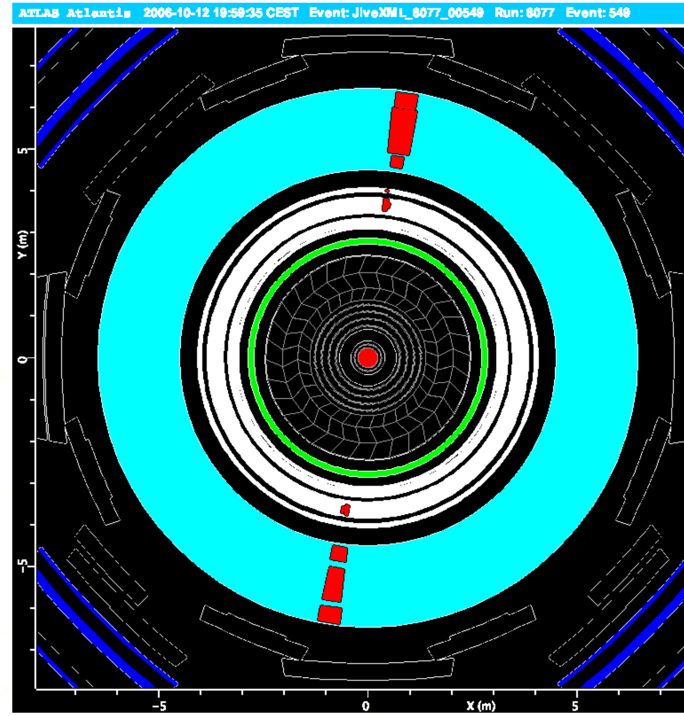
- **two expected data sets: 30 fb^{-1} and 300 fb^{-1}**
- **discovery = 5 σ excess using Poisson statistics**
- **no systematics included**

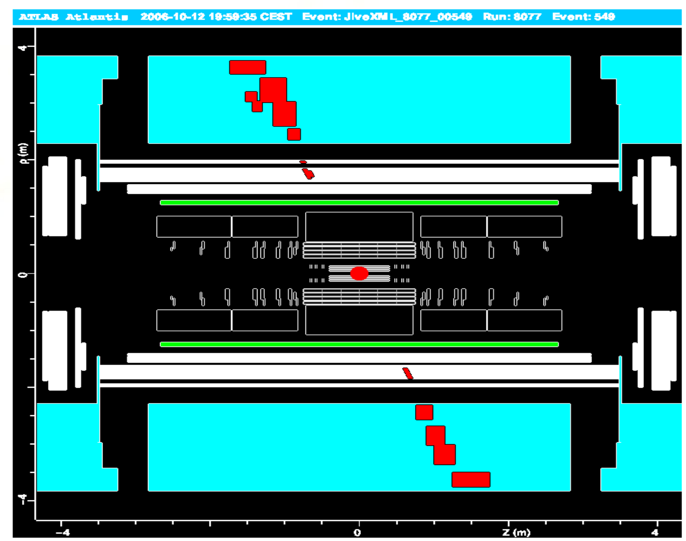
Becoming a Reality

First Cosmic rays observed by the combined ATLAS Tile+LAr calorimeters in the underground cavern this Fall!

Huge effort from ATLAS physicists to understand the detector (calibration, alignment, etc)

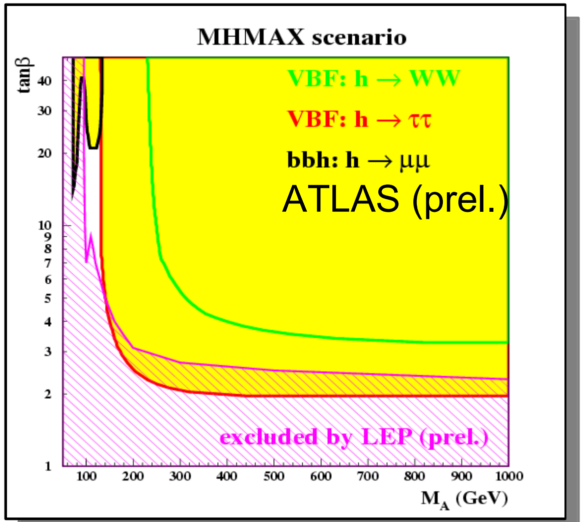


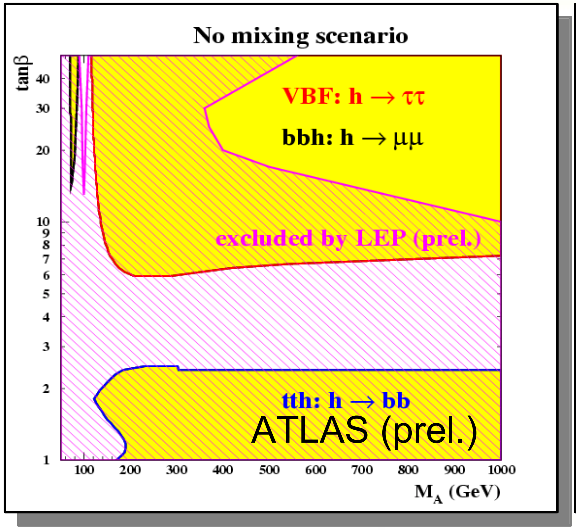


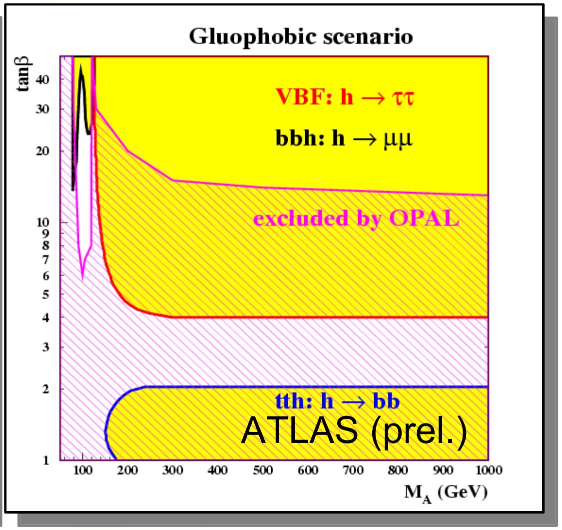


Light Higgs Boson (30 fb^{-1})

h observable in entire parameter space and for all benchmark scenarios?

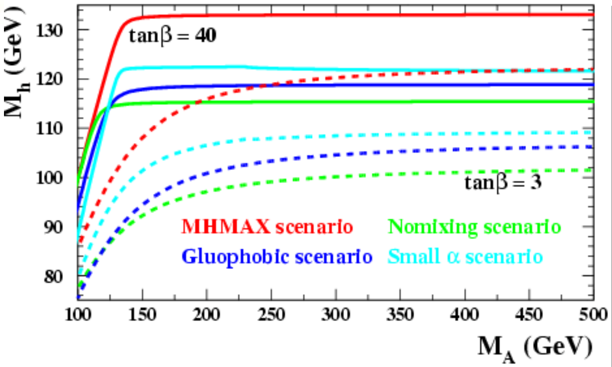




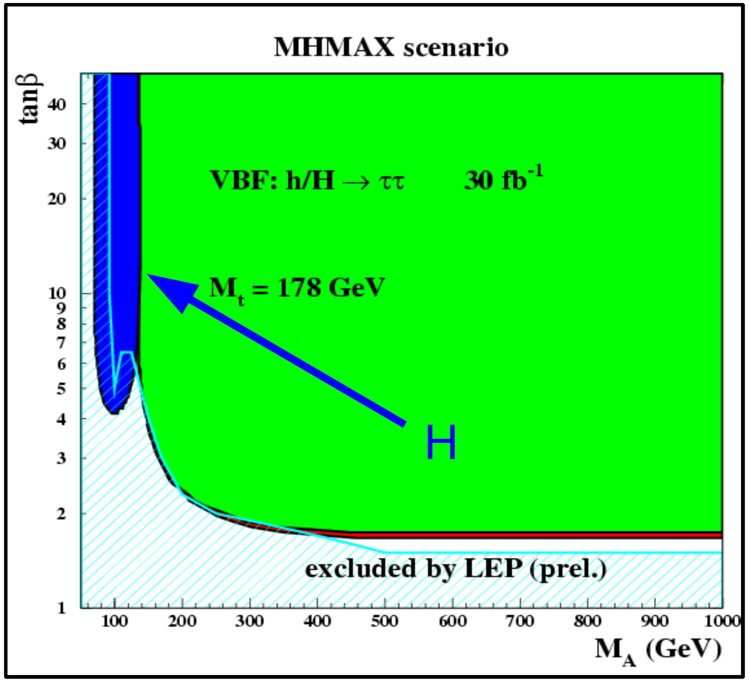


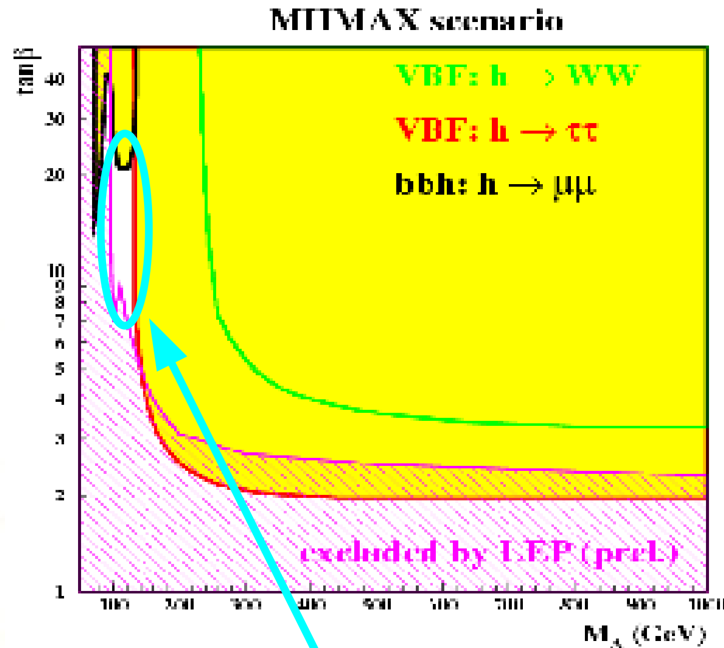
- most important channels: VBF
- differences mainly due to M_h

almost entire (tanβ, M_A)-plane covered



The Hole at Low mA



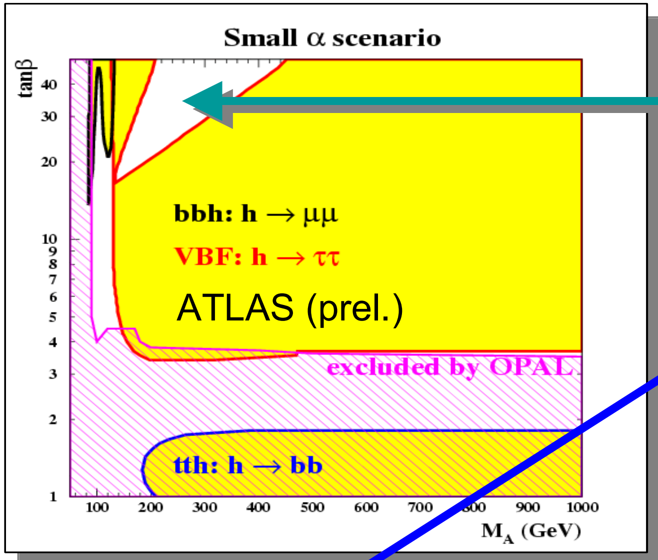


- VBF (hVV) decouples for high tanβ and low m_A --> must use bbh, however…
- The h→ττ has DY background and no mass reconstruction possible.
- h→μμ is cleaner but with a very small BR.
- Therefore for small m_A the bbh with h→μμ leaves a hole towards lower tanβ

➢At low mA from 90-100 GeV, the h becomes unobservable in most models

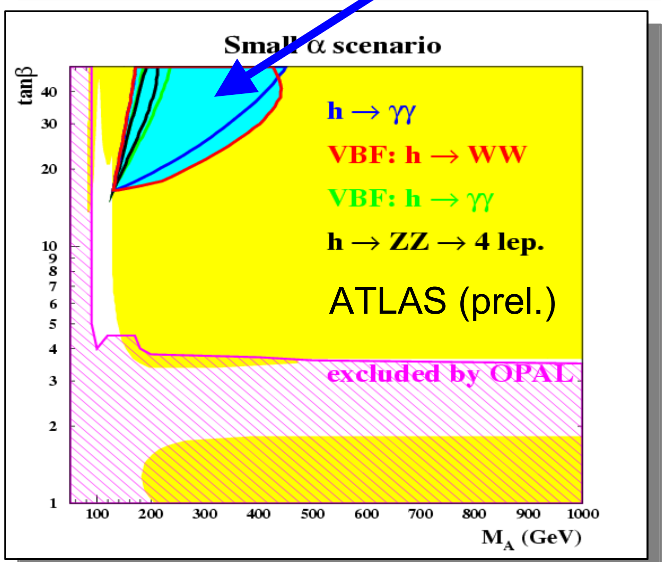
➢However, the H is always observable in this region, from H→ττ

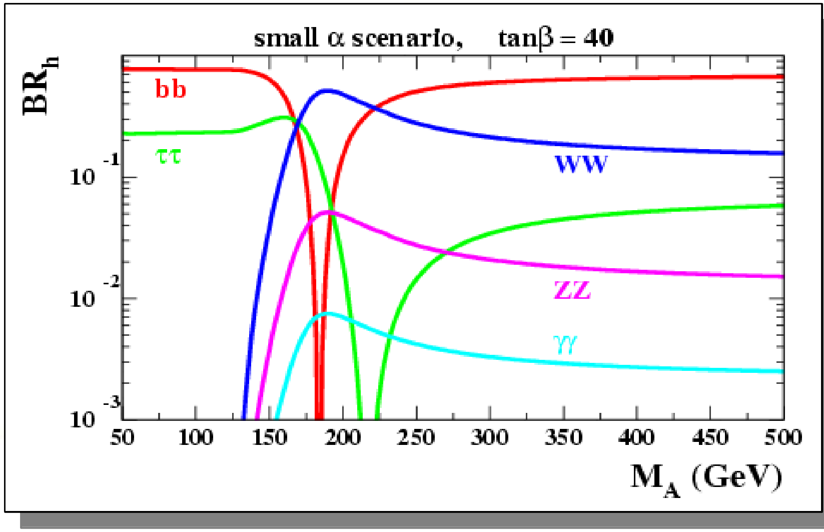
Light Higgs in Small α Scenario (30 fb^{-1})



hole due to reduced BR for h→ ττ

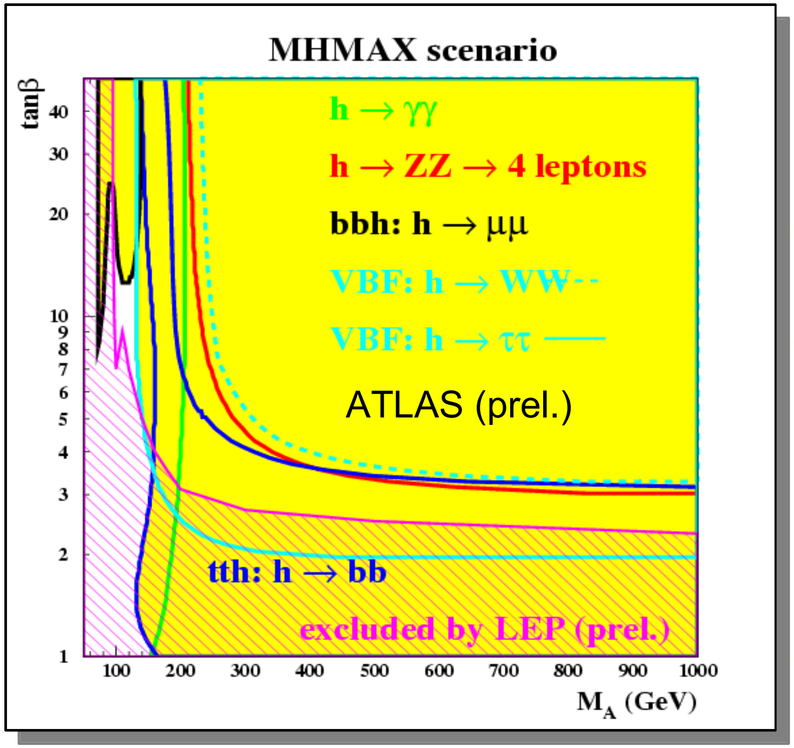
covered by enhanced BR to gauge bosons

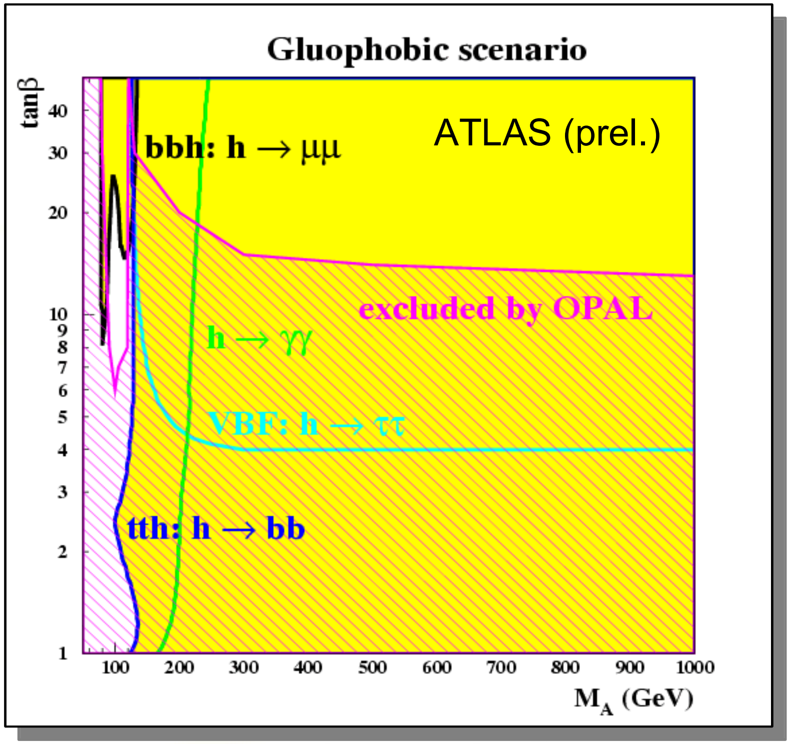




Complementarity of search channels almost guarantees the discovery of h

Light Higgs Boson (300 fb^{-1})





VBF: only 30 fb^{-1}

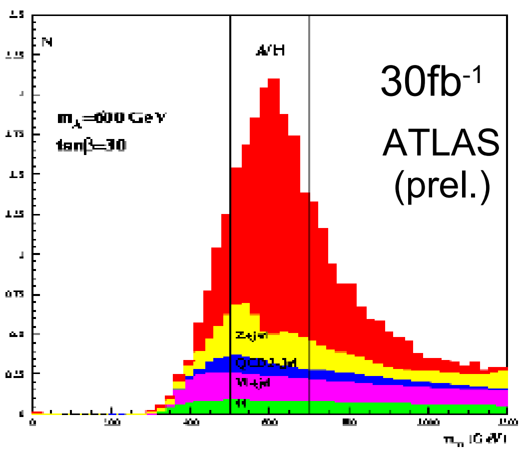
- also $h \to \gamma\gamma$, $h \to ZZ \to 4$ leptons, $tth \to bb$ contribute
- large area covered by several channels
  → stable discovery and parameter determination possible
- small area (M_h = 90 to 100 GeV) covered only by H

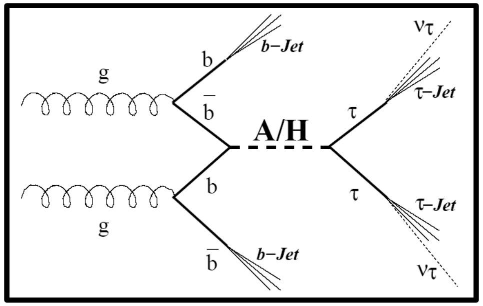
Neutral Heavy Higgs Bosons (H/A)

example: bbH/A, H/A → ττ

- σ_{prod} ~ $(\tan\beta)^2$; important at large tanβ
- new analysis: ττ→ had. had.
- BR(H/A→ττ) ~ 10 % , rest is bb

rec. mass for ττ→had.had.

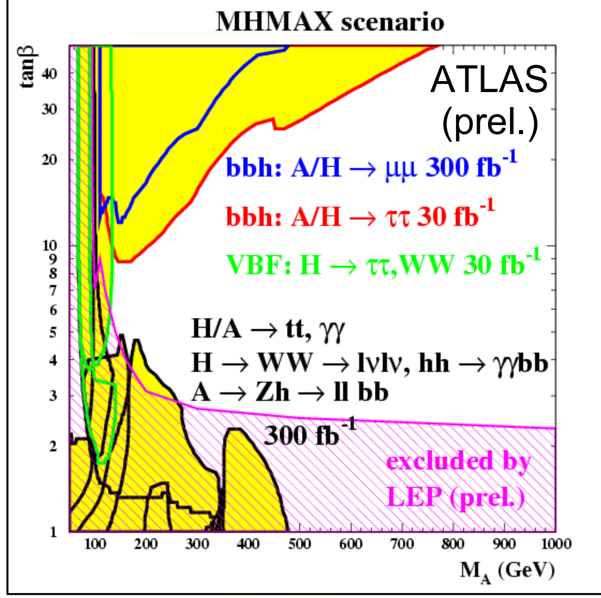




New: take running b-quark mass for σ_{prod}

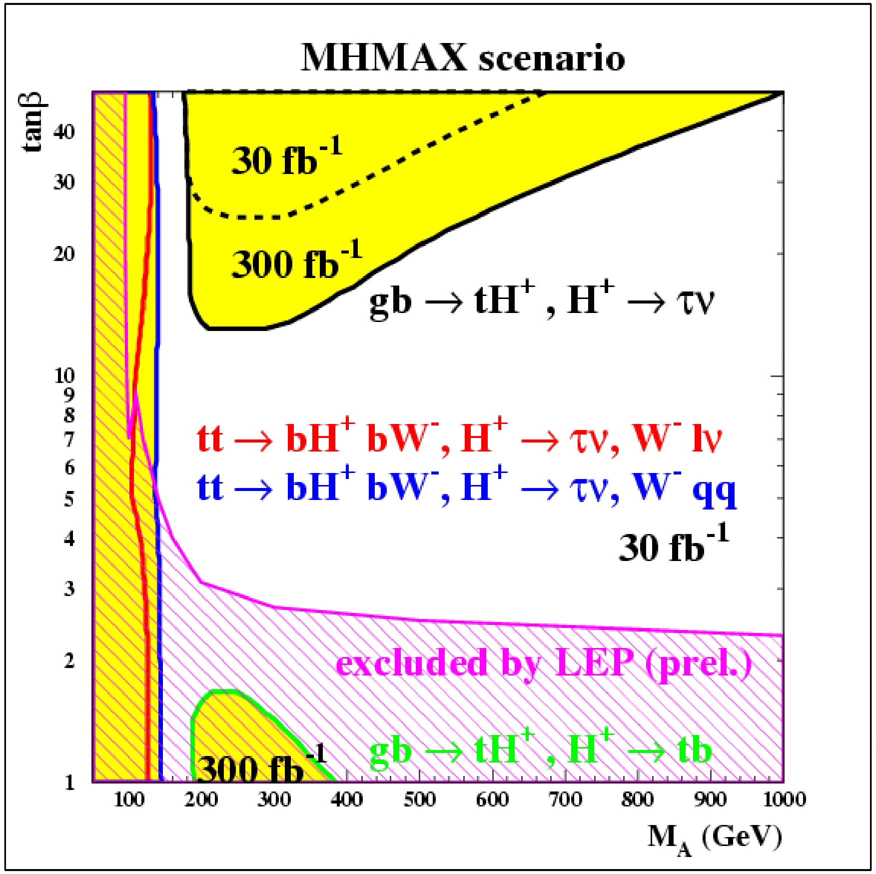
- only very few events remain after cuts (acceptance ~10^{-3})
- LVL1 trigger performance crucial
- detailed study: >90% LVL1 efficiency for M_A>450GeV via "jet+$E_{T,miss}$" and "τ+ $E_{T,miss}$" triggers with a rate of ~1.4 kHz (within rate limit)

discovery reach for H/A:

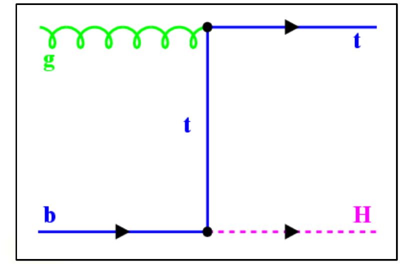


- bb H/A →bb ττ covers large tanβ region
- other scenarios similar
- intermediate tanβ region not covered

Charged Higgs Bosons



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

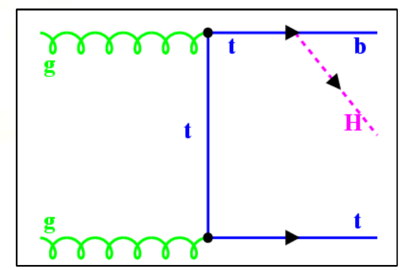


low mass: $m_{H+-} < m_{top}$

gg→tt

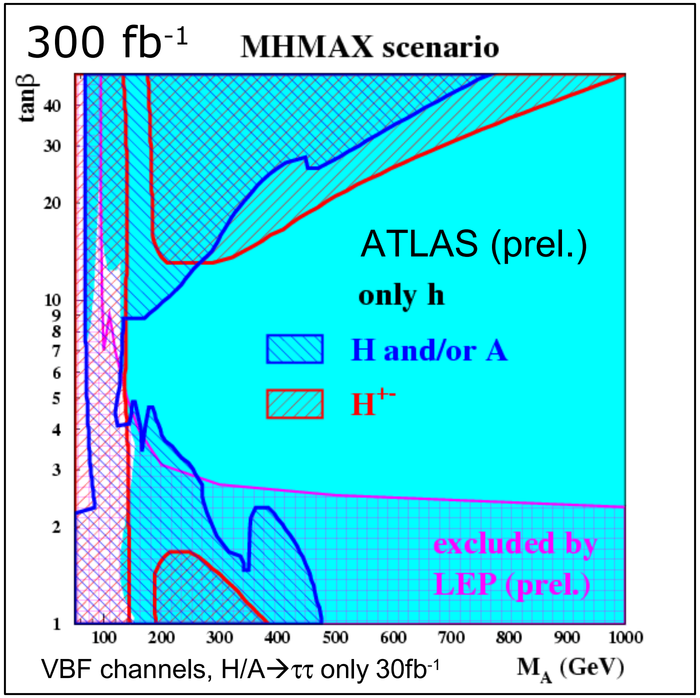
tt→H^{+-}bW

only low lumi.



- A consistent study of the gap region ($\sim m_{top}$) is almost complete.

Overall Discovery Potential (300 fb^{-1})



- **at least one Higgs boson is observable for all parameter points (in all four benchmark scenarios)**
- **in some parts: >1 Higgs bosons observable**

  → distinguish between SM and extended Higgs sector
- **but: significant area where only h or H is observable.**
- **basic conclusions independent of m_{top}**

ongoing:

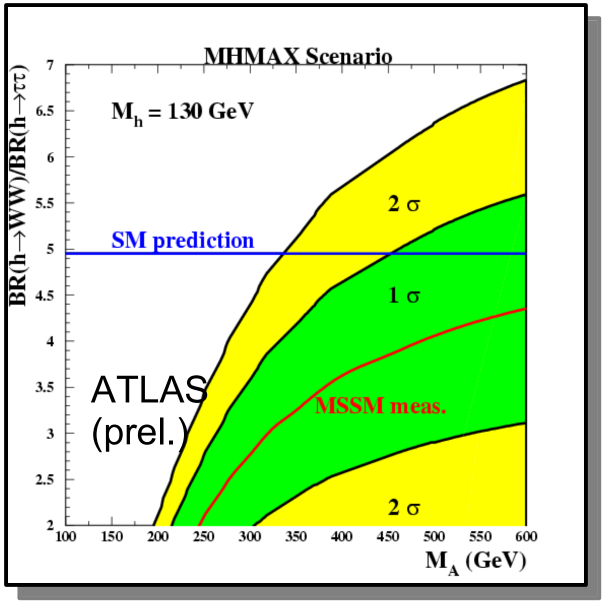
- **including SUSY decay modes to increase areas for heavy Higgs bosons , e.g. $H^{\pm} \rightarrow \chi^{\pm}_{1,2}\chi^{0}_{1,2,3,4} \rightarrow 3l + E_{T,miss}$**
- **can SM be discriminated from extended Higgs sector by parameter determination e.g. via rate measurements?**

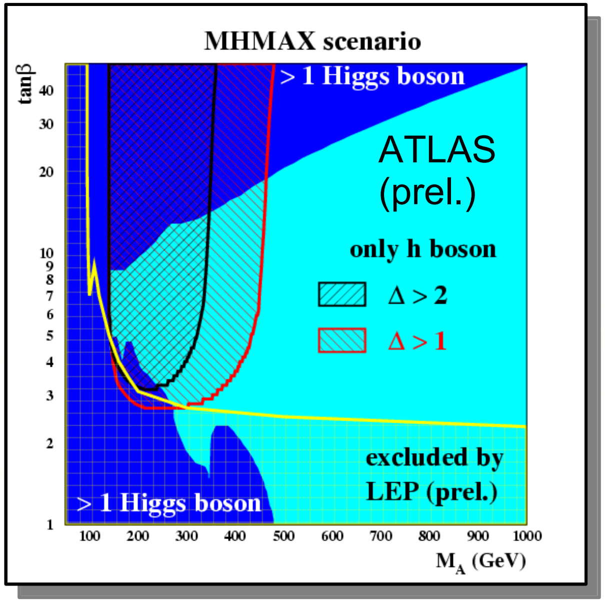
SM or Extended Higgs Sector ?

- estimate of sensitivity from rate measurements in VBF channels (30 fb^{-1})
- compare expected measurement of R in MSSM with prediction from SM

$$R = \frac{BR(h \rightarrow WW)}{BR(h \rightarrow \tau\tau)}$$

$$\Delta = |R_{MSSM} - R_{SM}| / \sigma_{exp}$$





- only statistical errors
- assume M_h exactly known

potential for discrimination

- seems promising
- needs further study incl. sys. errors

CP-Conserving Summary

- A consistent investigation of the ATLAS discovery potential in the MSSM Higgs sector with new MC studies and new theoretical calculations has been performed.

- In all 4 CP conserving MSSM benchmark scenarios at least one Higgs boson can be discovered.

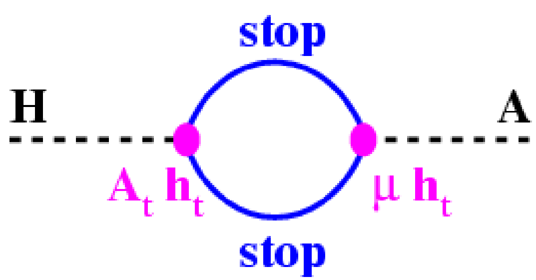
Evaluation of discovery potenital
with sys. err. in progress...

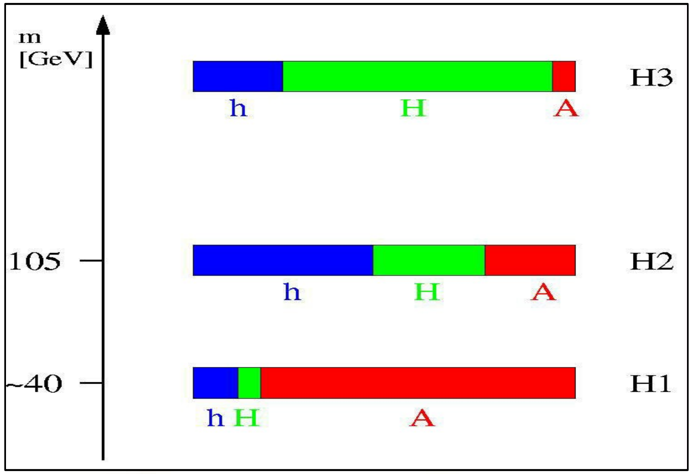
- In some areas of the parameter space more than one Higgs bosons can be discovered.

Need work on discrimination between
SM and extended Higgs sector in this case...

The CP-Violating CPX scenario

- CP conserving at Born level, but CP violation via complex $\mathbf{A_t}$, $\mathbf{A_b}$ $\mathbf{M_{gl}}$





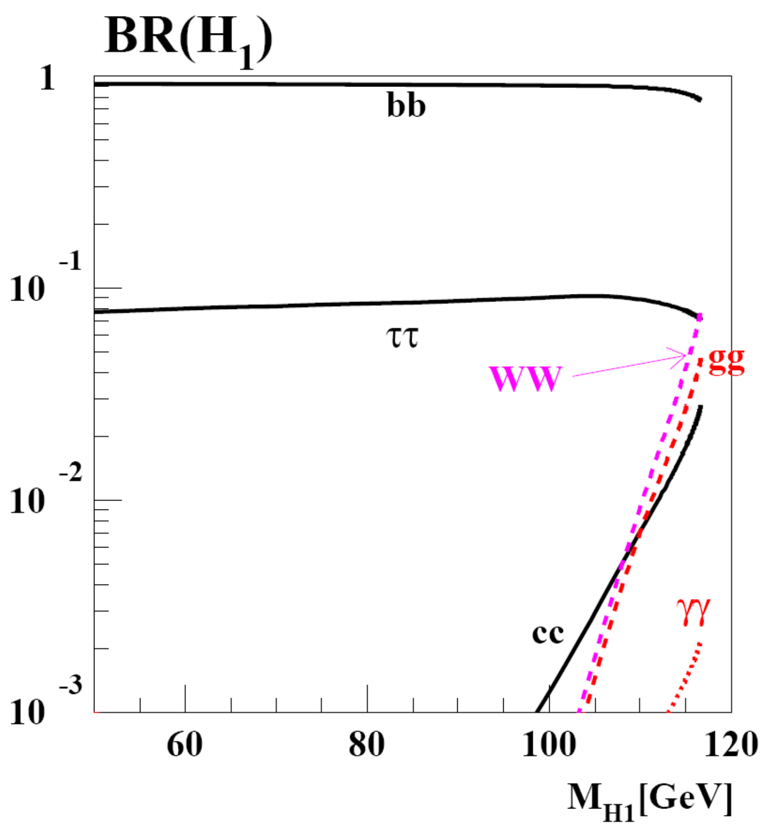
- CP eigenstates h, A, H mix to mass eigenstates H_1, H_2, H_3

- maximise effect → CPX scenario (Carena et al., Phys.Lett B495 155(2000))
  $\arg(A_t)=\arg(A_b)=\arg(M_{gluino})=90$ degrees

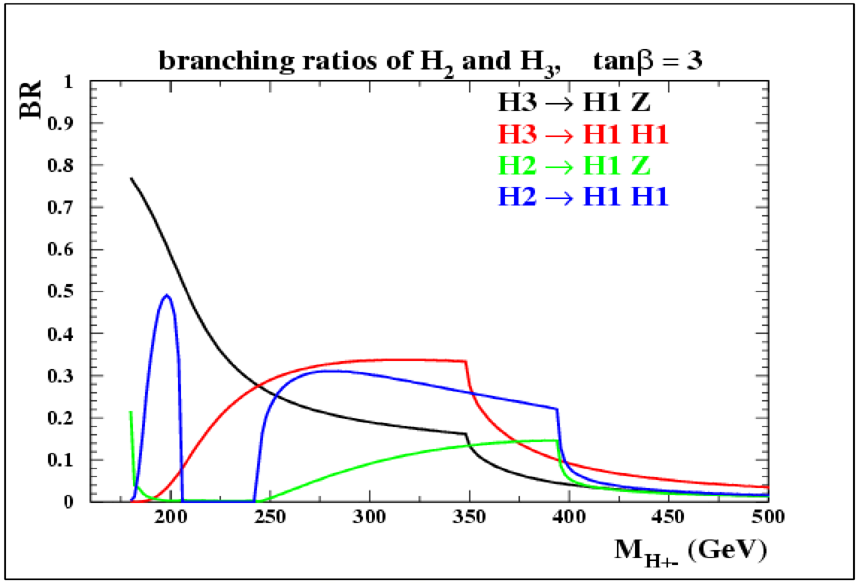
- scan of Born level parameters: tanβ and M_{H+-}

Phenomenology in the CPX scenario

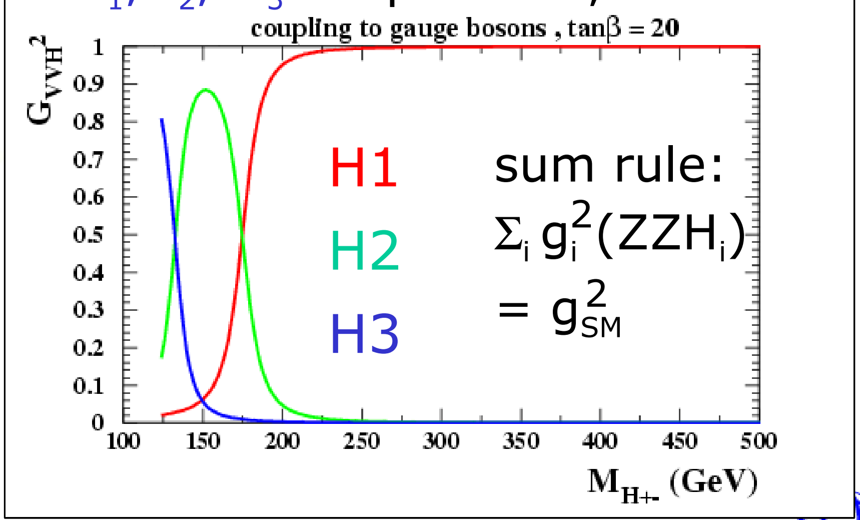
Production VBF ; pp→ttH$_i$, bbH$_i$; pp→H$_i$ & tt→H$^+$bWb, gb→H$^+$t



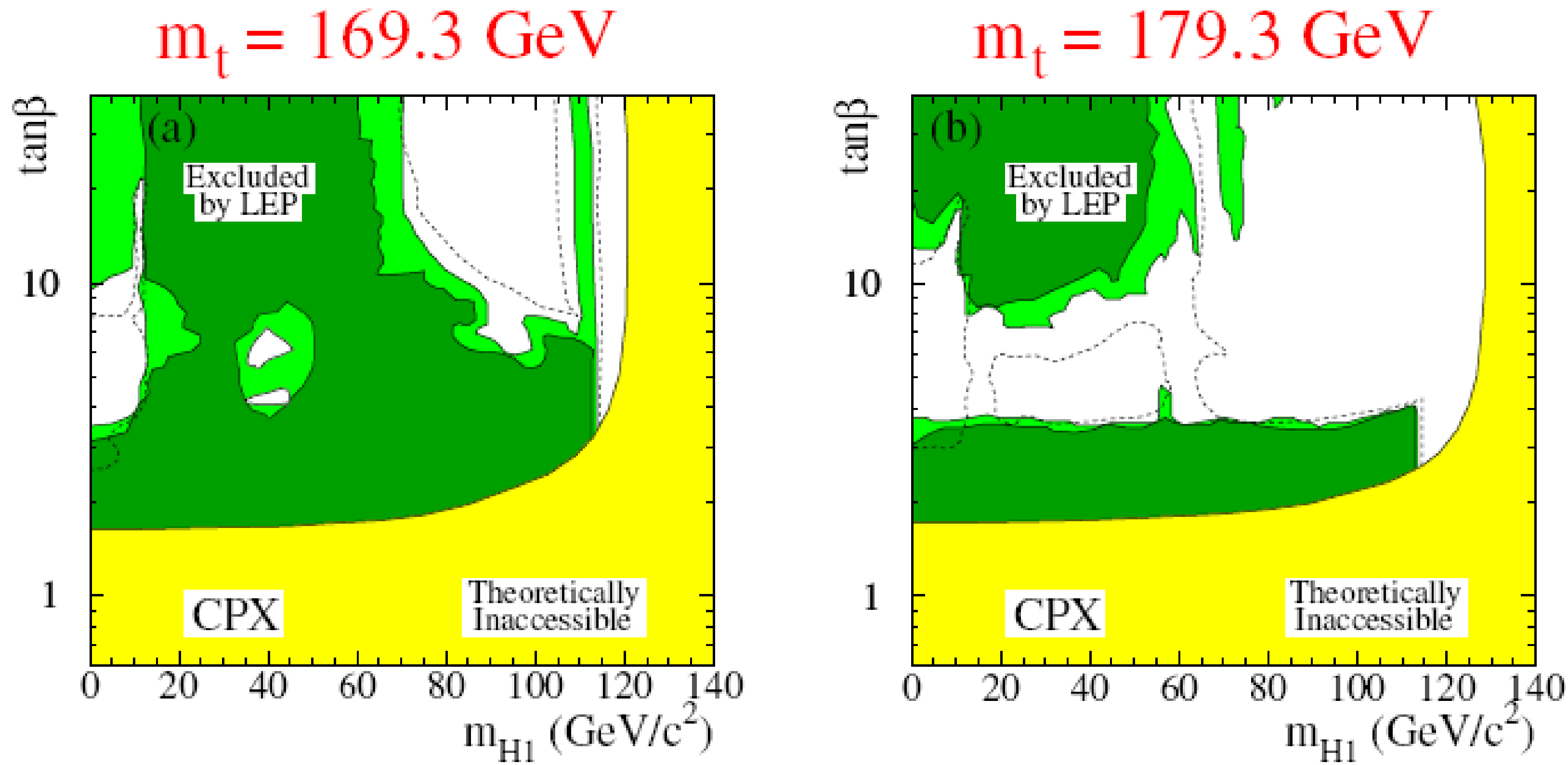
- H$_2$,H$_3$ → H$_1$H$_1$, ZH$_1$,WW, ZZ decays



- H$_1$,H$_2$, H$_3$ couple to W,Z

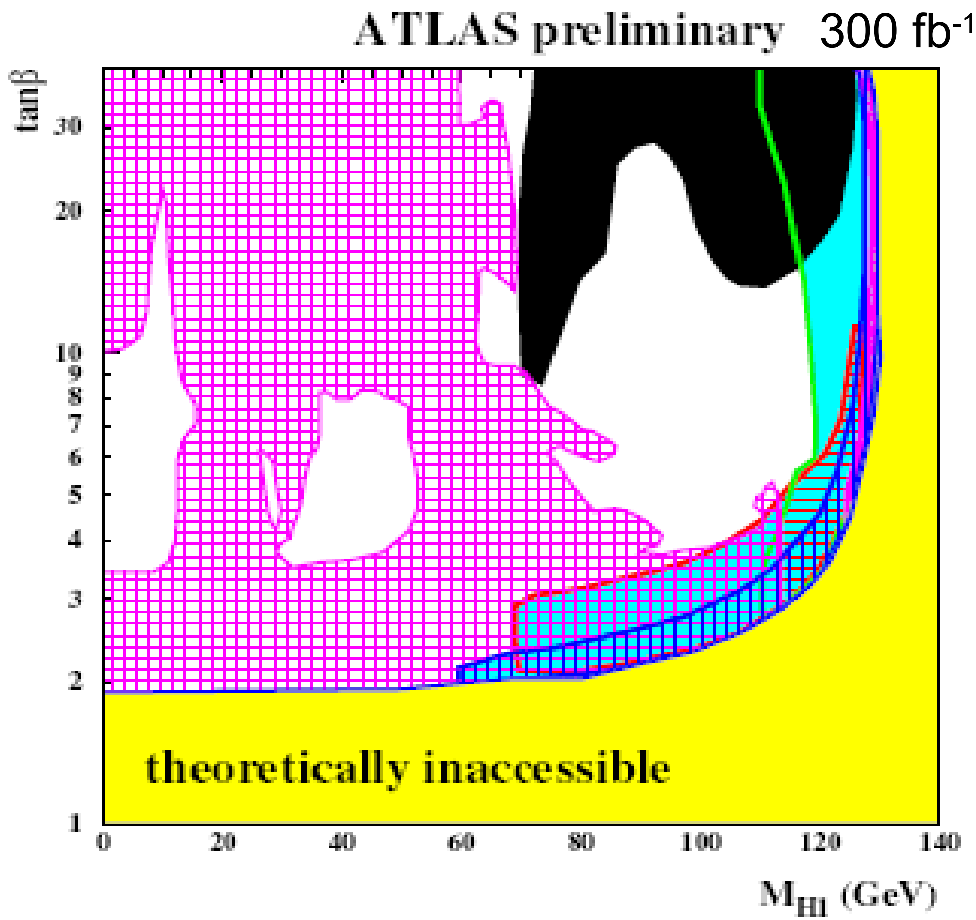


LEP Limits in the CPX scenario



- Loss of sensitivity around tanβ~3-10 due to complexity of final states: (ZH2->6 jets… H_1H_2->bbbb etc.) and insensitivity to very low H1 mass
- no absolute limit on mass of H_1 from LEP
- strong dependence of excluded region on m_{top} and on calculation (FeynHiggs vs CPH)

CPX Scenario: A Light Higgs Boson H_1



main difference from CPC scenarios, weaker exclusion from LEP:

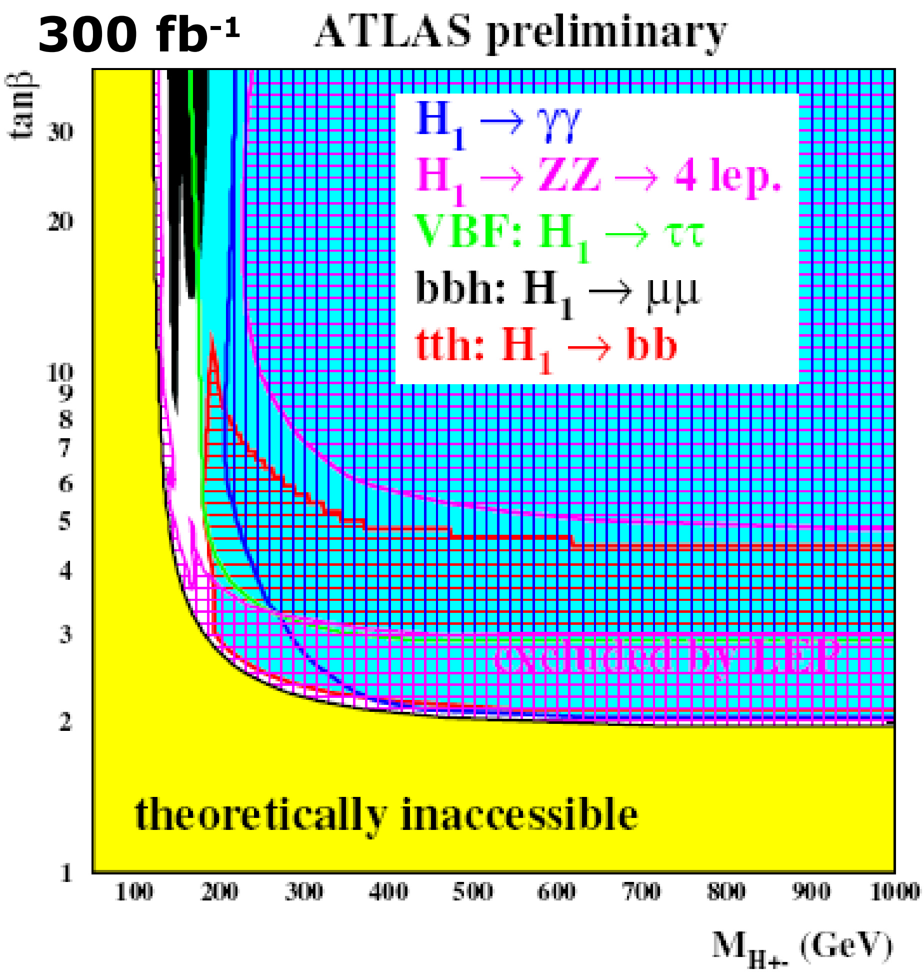
CPC scenarios:
$M_h < M_Z$ excluded

CPV: no limit on M_{H1}

Excellent summary in the CERN CPNSH Yellow Report:
hep-ph / 0608079

VBF: $H_1 \rightarrow WW$
VBF: $H_1 \rightarrow \tau\tau$
bbh: $H_1 \rightarrow \mu\mu$
tth: $H_1 \rightarrow bb$

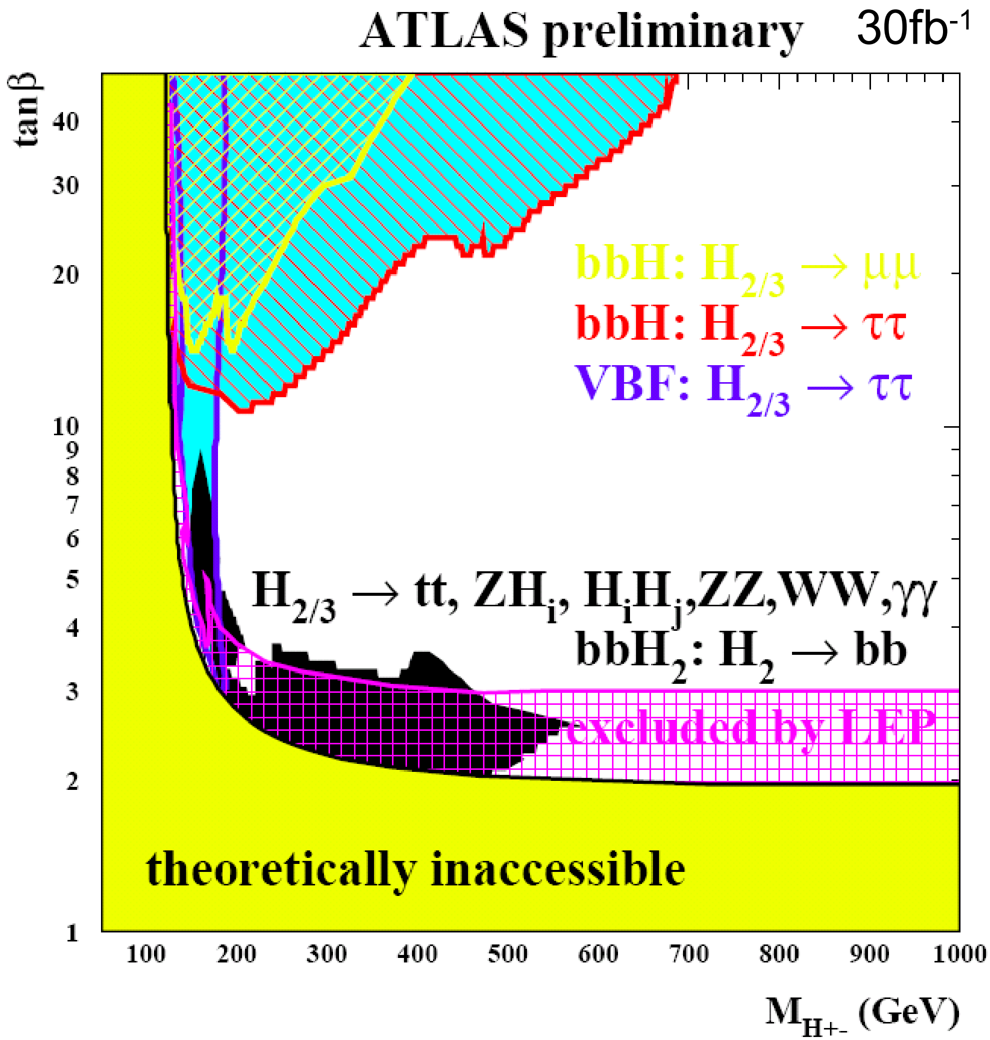
CPX Scenario: A Light Higgs Boson H_1



- border at low tanβ due to availability of MC studies (VBF: M_h >110 GeV, ttH and γγ :M_h > 70 GeV)
- border at low M_{H+-} due to decoupling of H_1 from W,Z and t

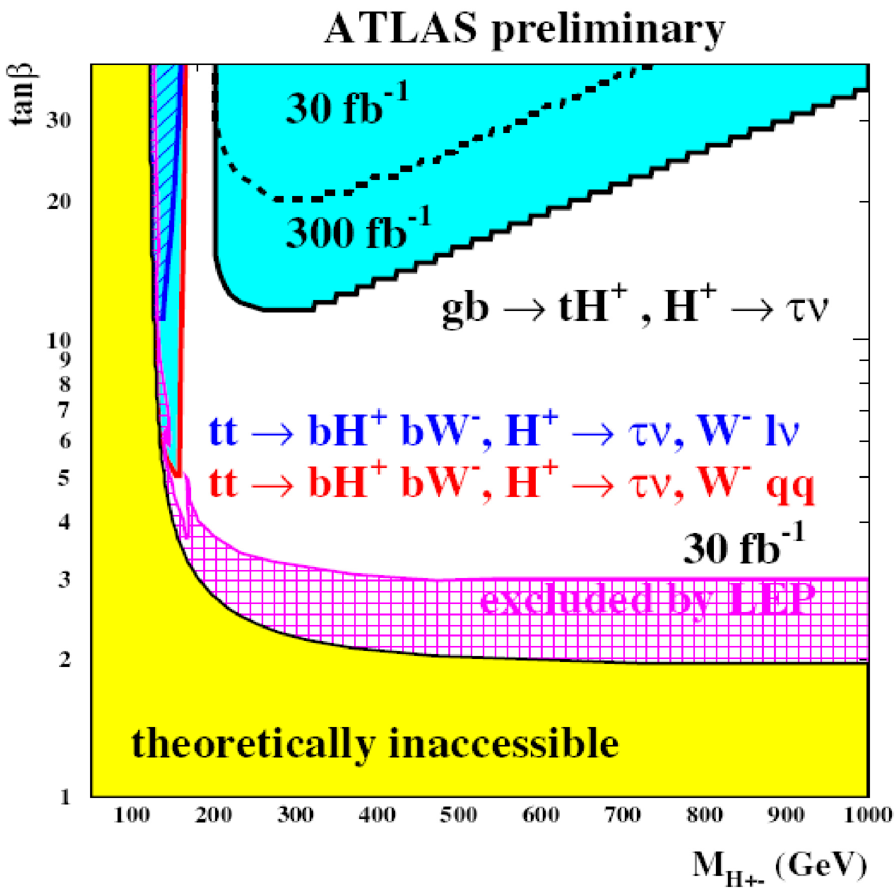
CPX Scenario: Heavier Higgs Bosons H_2 and H_3

- The bbH cross section is decreasing with increasing H mass and decreasing tanβ
- There is a reduction in the ττ decay BR in favor of bb and $H_2 \rightarrow H_1H_1$ while light H_1 was not yet studied for LHC



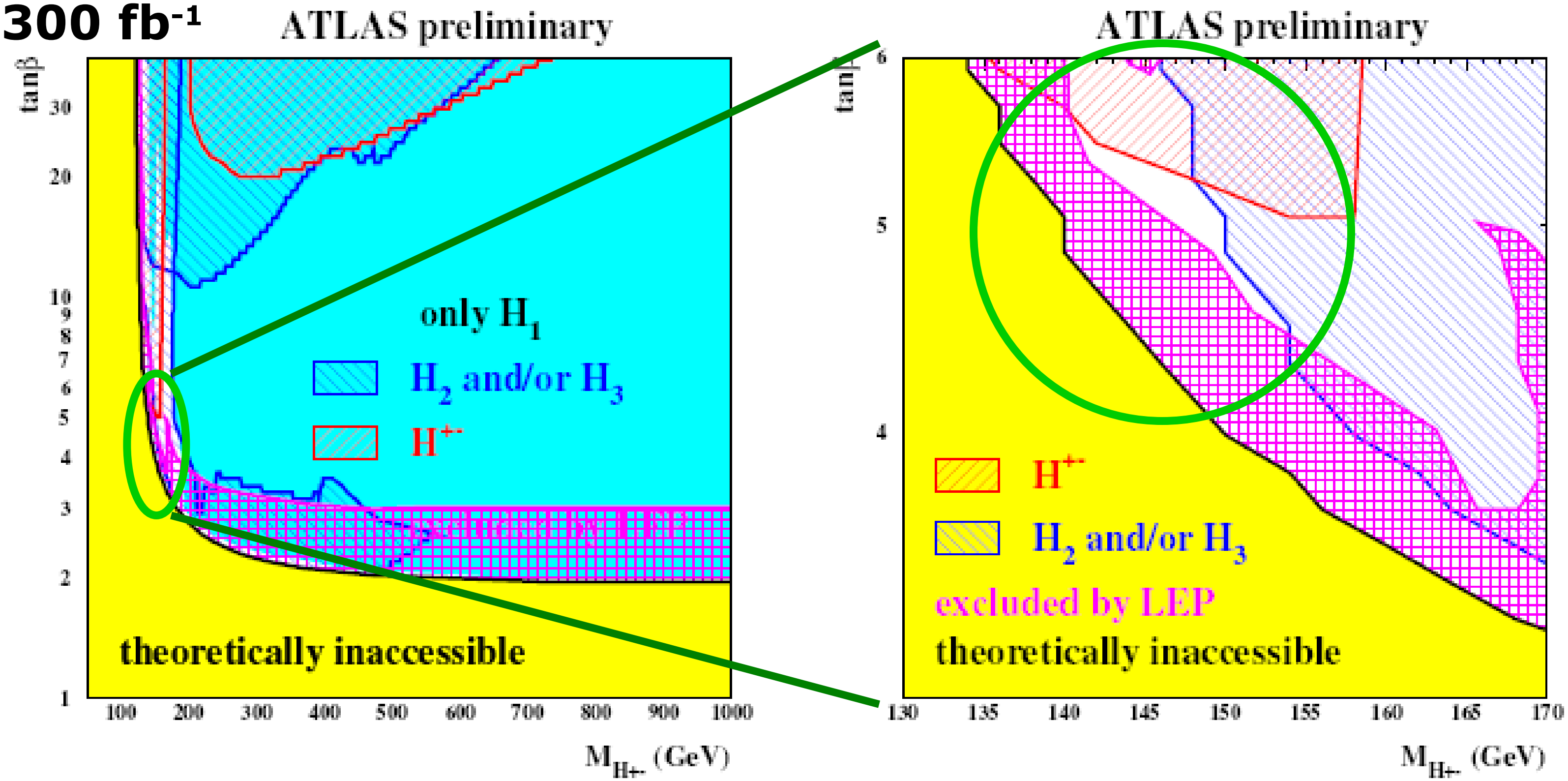
CPX Scenario: Charged Higgs

- The charged Higgs are still eigenstates
- Limits are very similar to CPC case...



Overall Discovery Potential in CPX Scenario

300 fb^{-1}



Small uncoverd region !

M_{H1}: < 70 GeV

M_{H2}: 105 to 120 GeV

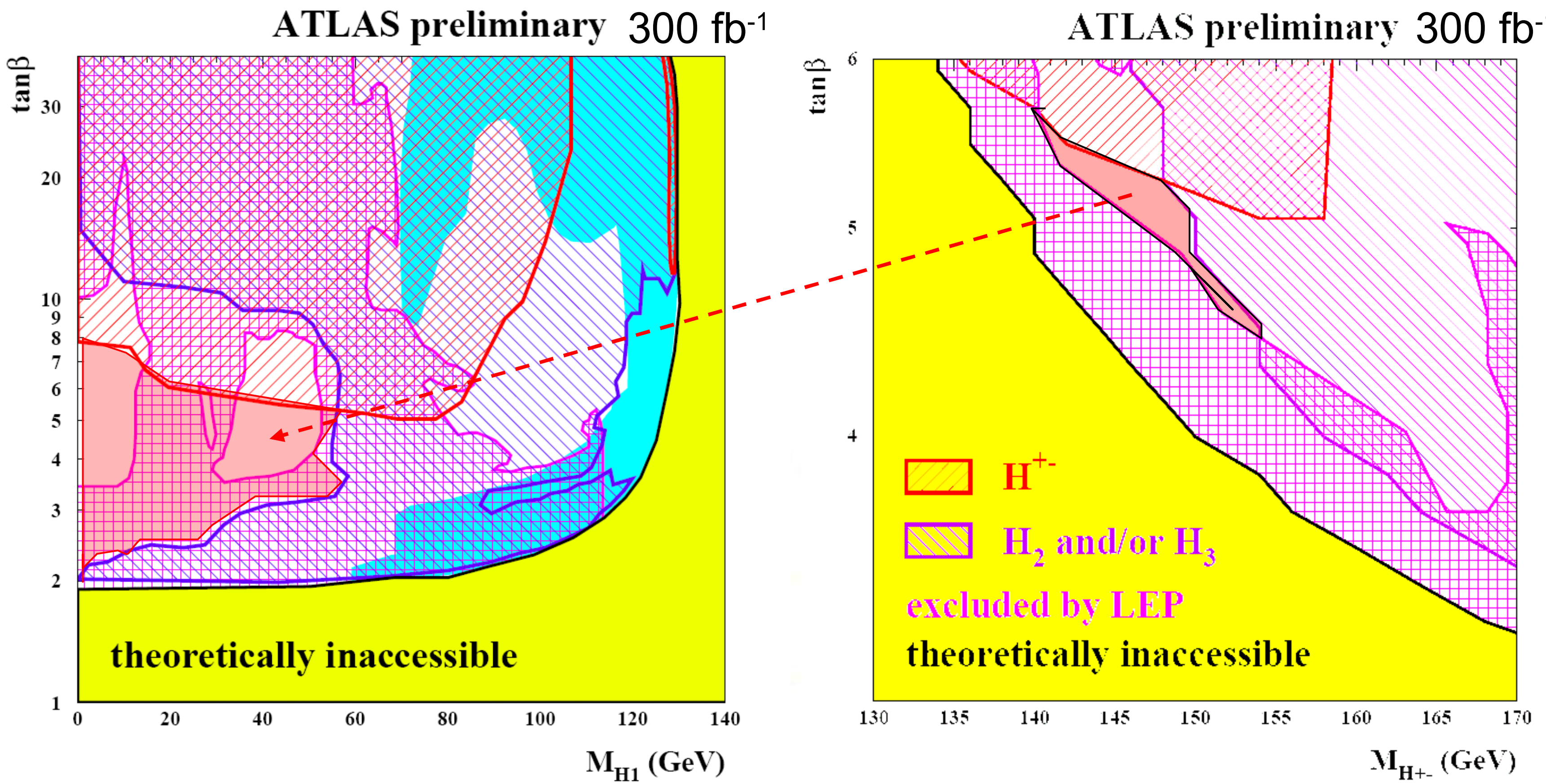
M_{H3}: 140 to 180 GeV

- The hole corresponds to light Higgs: $m_{H1}<70$, $m_{H^+}<m_{top}$

Size of 'hole' depends on

- assumed M_t due to LEP exclusion
- FH versus CPSUPER

Covering the 'hole' in the CPX Scenario



promising channel:

$tt \to bH^+bW^-$ $H^+ \to H_1\ W^+$ $H_1 \to bb$, same final state as ttH, $H \to bb$

Conclusions

CP-conserving MSSM:

- whole parameter space covered by at least one Higgs boson

  evaluation of discovery potenital with sys. err. in progress...

- very possible that only one Higgs boson will be observable

  ongoing studies for SUSY decay modes and

  discrimination between SM and non-SM in this case...

CP-violating MSSM:

- possibly a 'hole' as M_h below 70 GeV
  - may be covered by $tt \rightarrow Wb\ H^{+-}\ b, H^{+} \rightarrow WH_1 \rightarrow Wbb$
- otherwise at least one Higgs boson is observable

Thanks to: Markus Schumacher, Eilam Gross, Johannes Haller, and the ATLAS Higgs WG