Determination of the Discovery Potential for Higgs Bosons in MSSM

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On behalf of the CMS and ATLAS collaborations

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Outline

- The MSSM Higgs Sector
- Discovery Potential
  - CP-Conserving scenarios
  - CP-Violating scenarios
- Summary

Standard Model and Supersymmetry

- The Standard Model does a great job in description of physics at the weak scale (100 GeV)
  - But: hierarchy problem in the Higgs sector
- SUSY at the TeV scale provides elegant solution to the hierarchy problem
  - ➢ Introduces superpartners of SM particles and cancels problematic loop corrections out
  - ➢ Allows light Higgs in the context of GUT without fine tuning

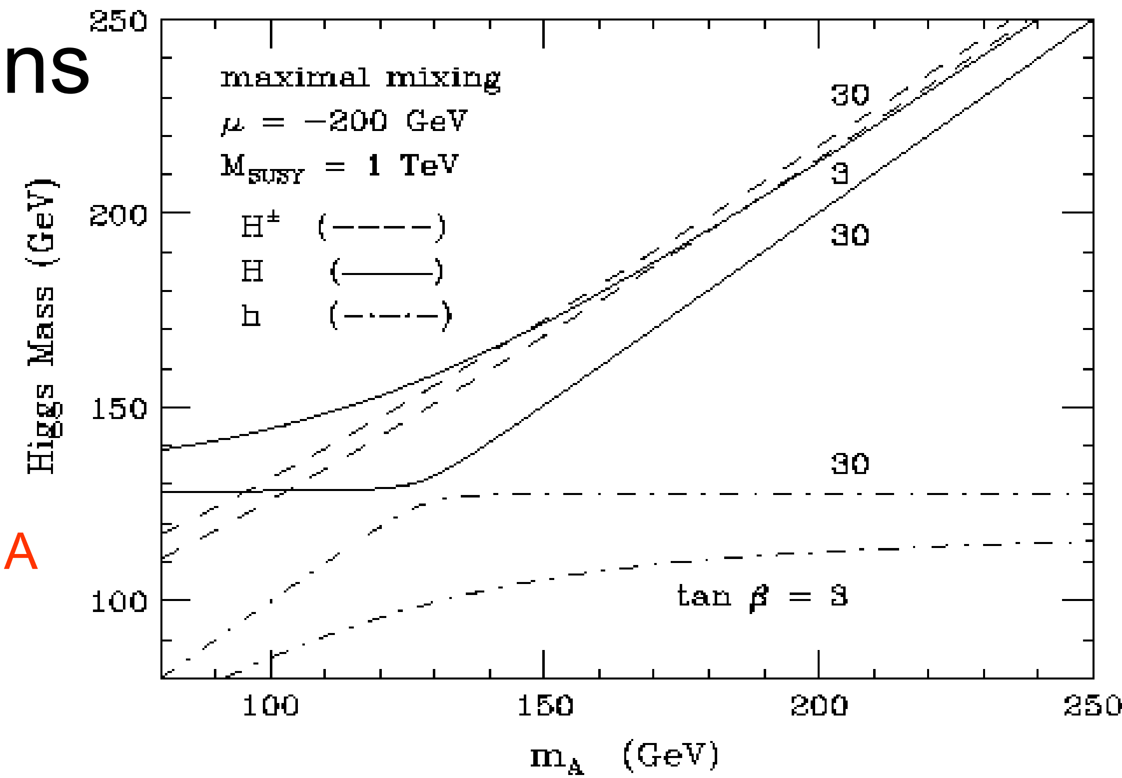
Minimal SyperSymmetric Model

- Thorough intro: Abdelhak Djouadi, SUSY07
  - http://indico.cern.ch/materialDisplay.py?contribId=78&sessionId=143&materialId=slides&confId=6210
- 2HDM - two isospin Higgs doublets
  - Φ_1 couples to down-, Φ_2 to up-type fermions
- Higgs sector described by 4 masses and 2 mixing angles
  - 3 of 8 degres of freedom absorbed by Z, $W^{\pm}$ after EW symmetry breaking, 5 physical higgses
  - h, H (scalar, CP-even),
  - A (pseudoscalar, CP-odd),
  - $H^{\pm}$ (charged)
  - β (VEVs), α (mixing of neutral CP-even)
    - $\tan\beta = v_2/v_1$, $v_1^2+v_2^2=1$

Minimal SyperSymmetric Model

- Assuming CP conservation, at tree level
  - Only 2 independent params.: choose M_A and tan β
  - Mass hierarchies: $M_h < M_Z$, $M_A < M_H$ & $M_{W\pm} < M_{H\pm}$

- Radiative corrections increase upper bound on M_h~135 GeV
  - Upper bound reached at large M_A => SM-like h



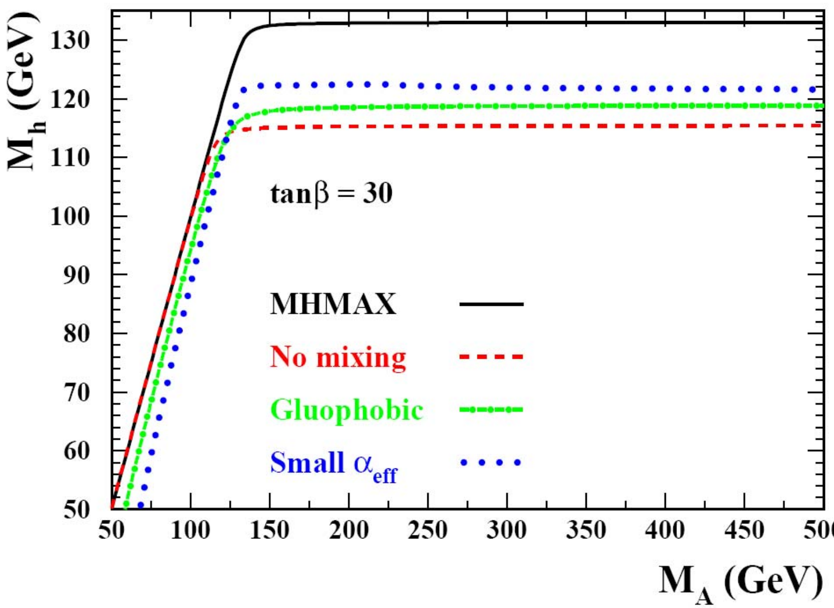
CP-Conserving Benchmark Scenarios

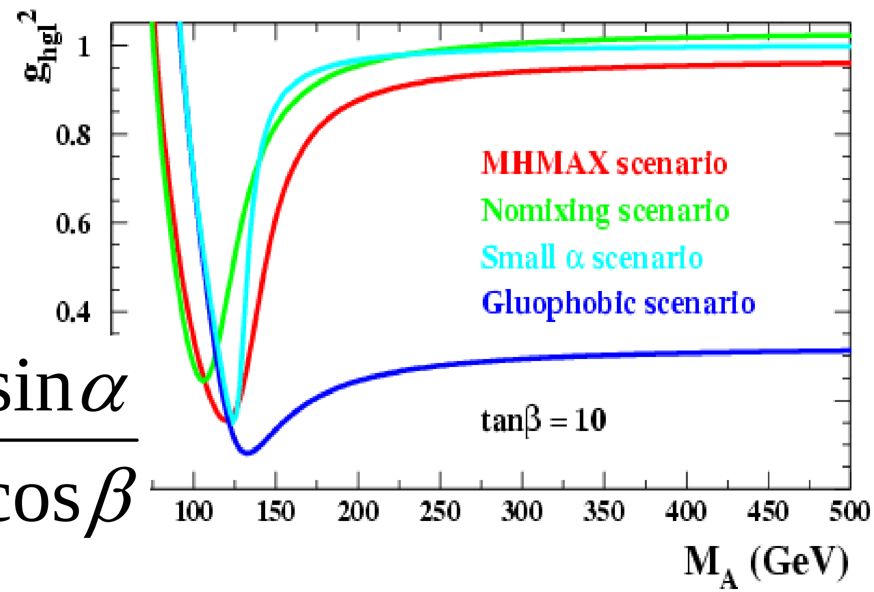
Unconstrained MSSM has large number of free parameters. Choose specific parameter points: **benchmark scenarios**

- M_h^{max} scenario
  - maximal M_h<133GeV
  - Conservative exlusion bounds on tan β and M_A
  - Used at LEP, M_{SUSY}=1TeV
- No-mixing scenario
  - Small M_h<116GeV
  - No stop mixing, X_t=0, M_{SUSY}=2TeV
- Gluophobic scenario
  - small $g_{h,gluon}$
    - main production channel gg→h strongly supressed
  - M_h<119 GeV, M_{SUSY}=350GeV
- Small-α scenario
  - small g_{hbb} and $g_{h\tau\tau}$
  - M_h<123 GeV,M_{SUSY}=800GeV

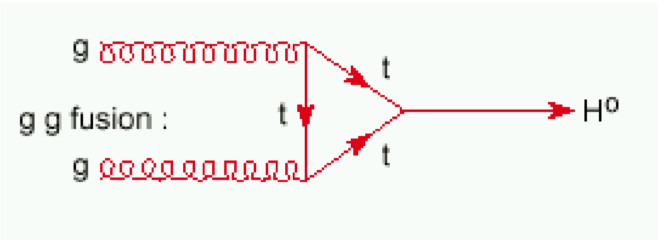
$$g_{hbb} = g_{Hbb}^{SM} \frac{\sin\alpha}{\cos\beta}$$

Carena et al. , Eur.Phys.J.C26,601(2003)





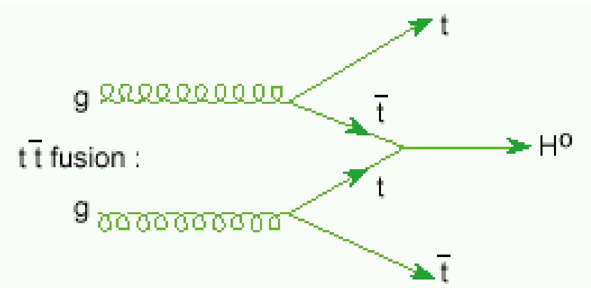
Neutral Higgs Production Mechanisms

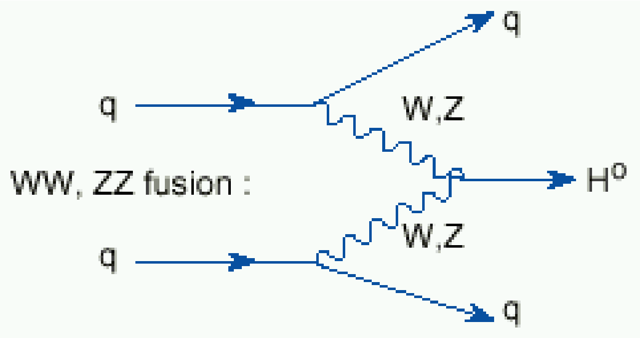


gg fusion: dominant at small & moderate tan β;

Mediated by t/b loops (also stop/sbottom loops M < 400 GeV/c^2)

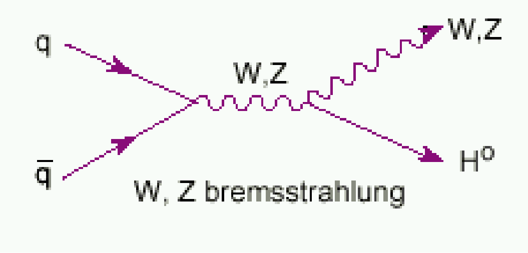
Associated production: ttΦ only important for h; bbΦ dominant process for large tan β





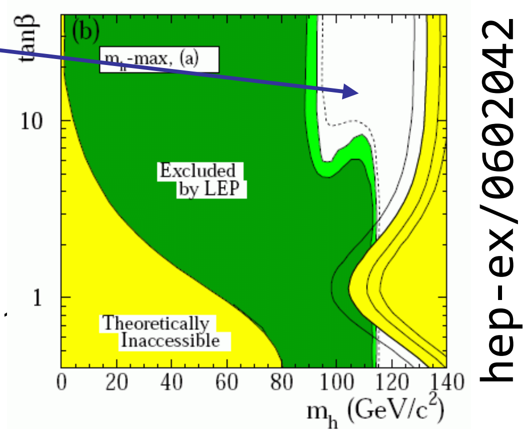
VBF: important when h at upper mass limit “SM-like” and H at lower mass bound. (No VBF for A at tree level)

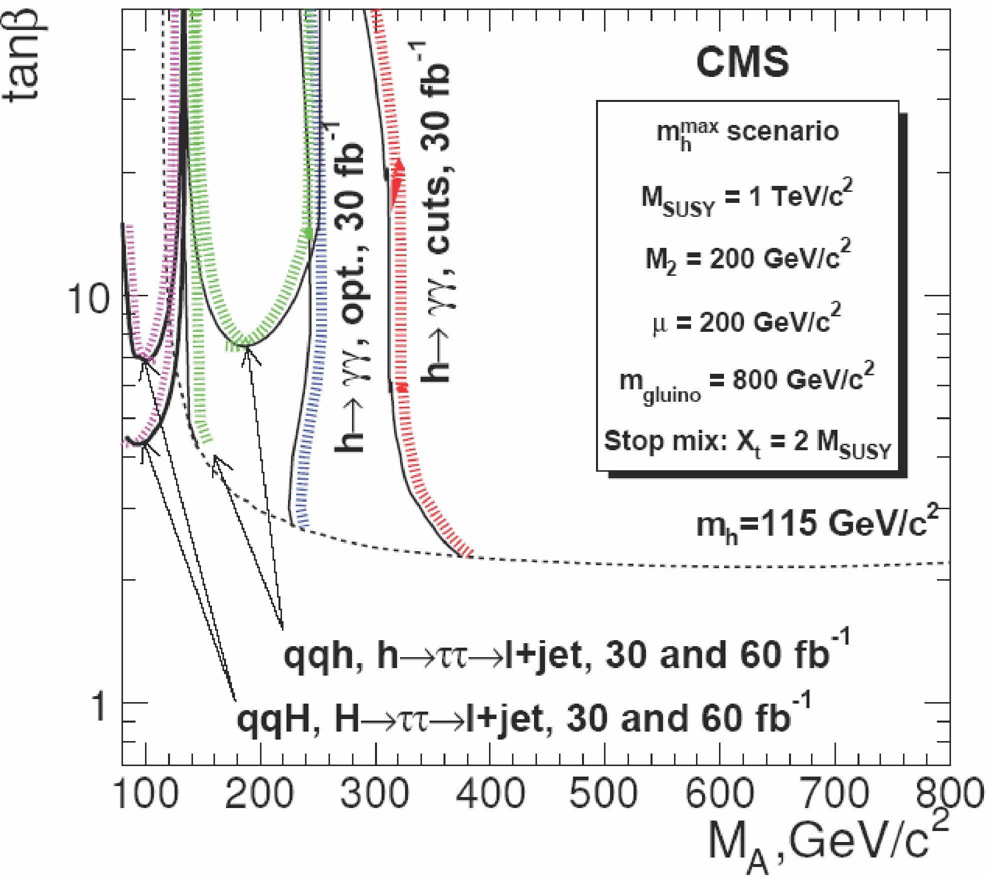
Not important for MSSM neutral Higgs production

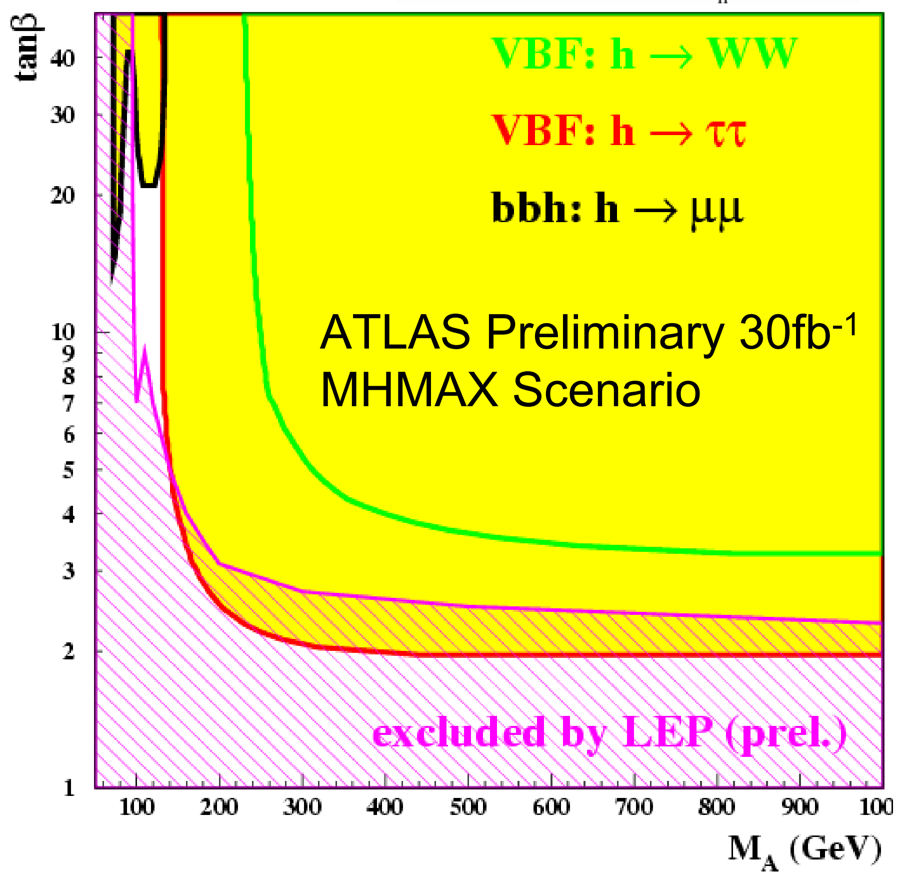


Light Neutral Higgs - Low Luminosity

- Light neutral scalar Higgs constrained to be "SM-like"
- Use SM Higgs search results to determine SUSY discovery potential
- M_h^{max} scenario, low luminosity
  - ➢ Production: VBF, decay: $\gamma\gamma$, WW, $\tau\tau$, $\mu\mu$
  - ➢ CMS: 30/60fb^{-1} (heavier H included in plot), ATLAS: 30fb^{-1}
- 5σ discovery regions

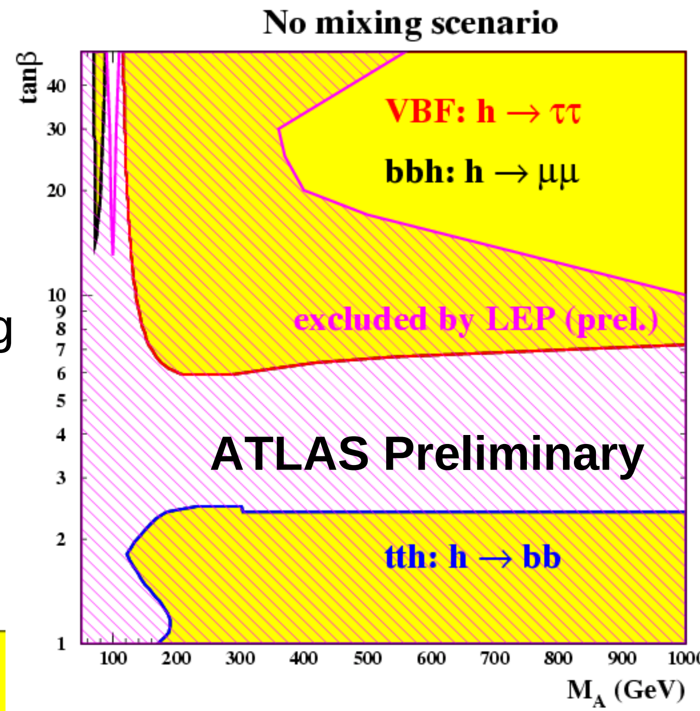


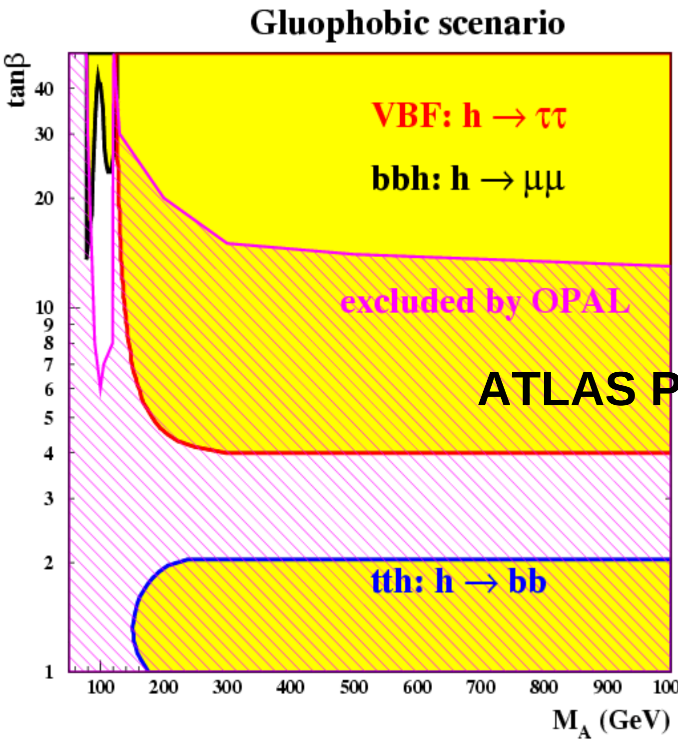


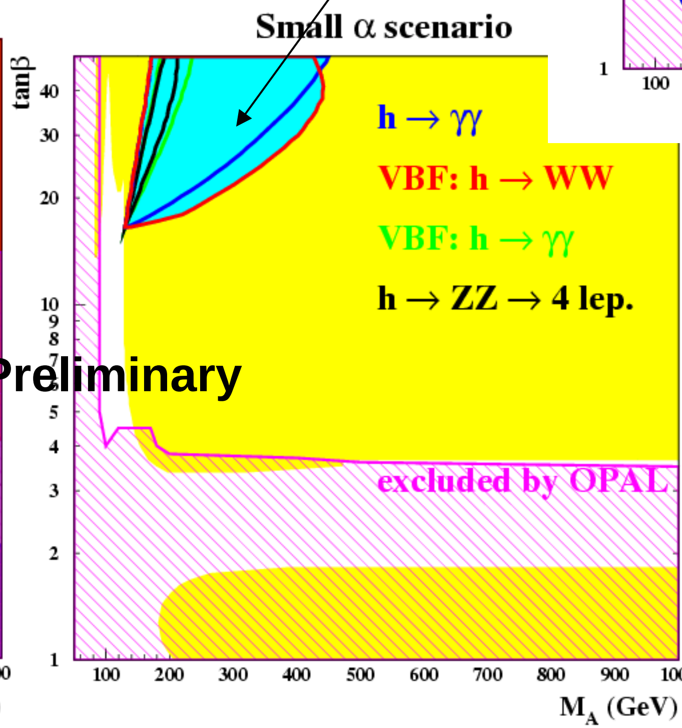


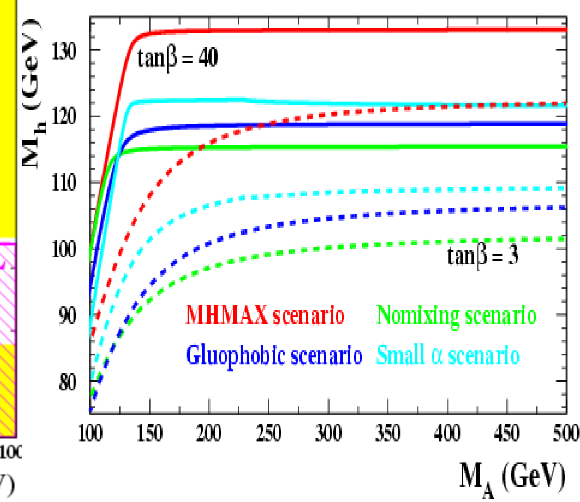
Light Neutral Higgs - Other Scenarios

- difference mainly due to different m_h in same ($\tan\beta$,M_A) (up to 17 GeV difference)
- $H\rightarrow\tau\tau$ main discovery channel. Assoc. production important at moderate $\tan\beta$ and small M_A
- „Hole“ in small-α scenario due to $H\rightarrow\tau\tau$ branching ratio closed by enhanced BR to gauge bosons
- Complementarity of search channels (almost) guarantees observation of h

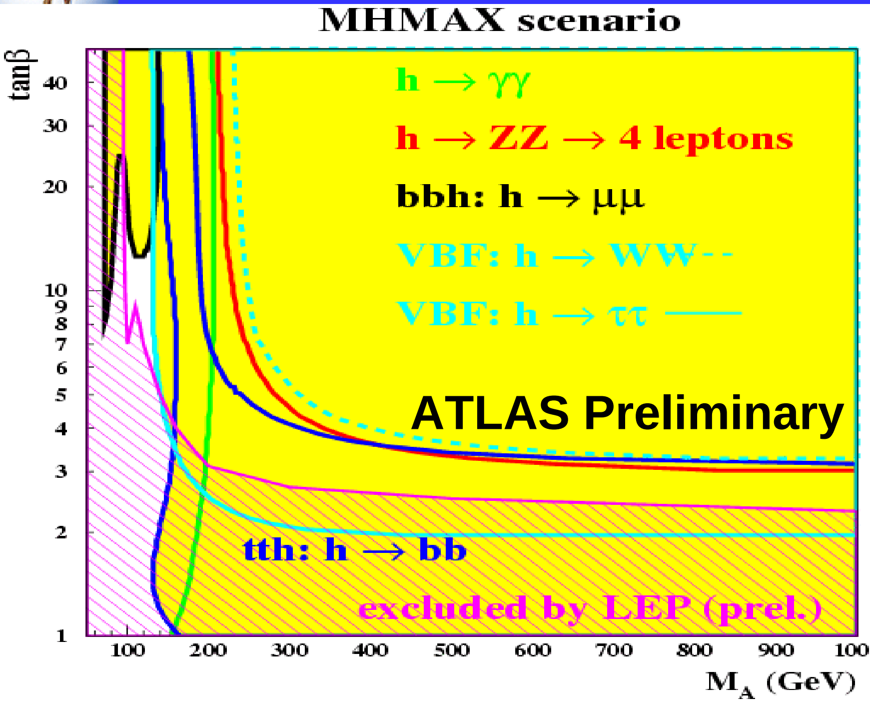




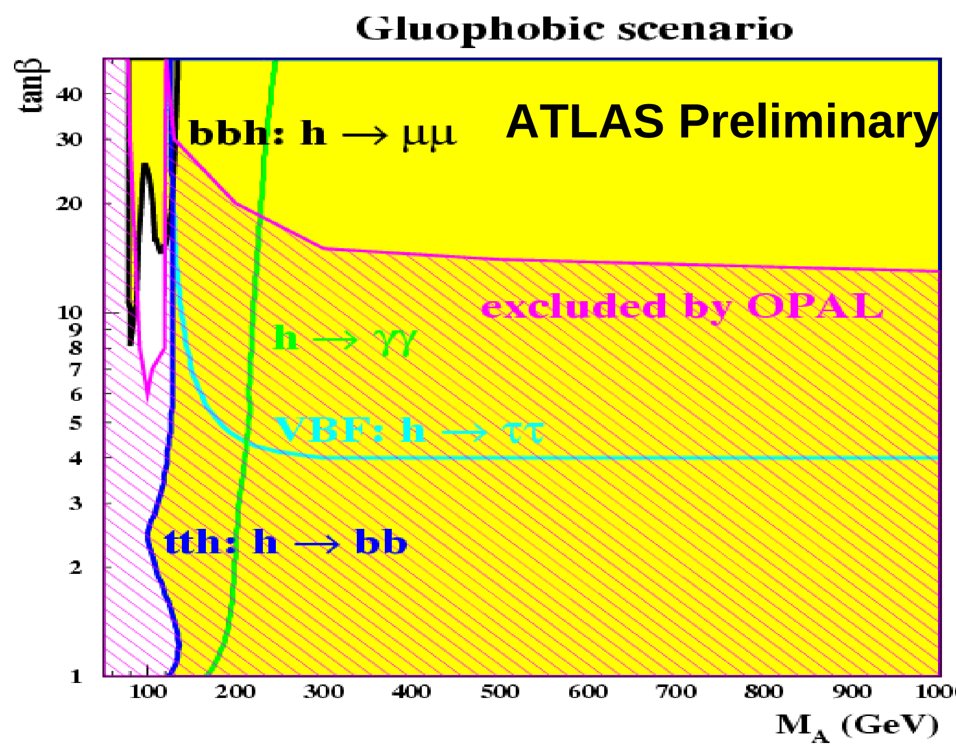




Light Neutral Higgs – High Luminosity



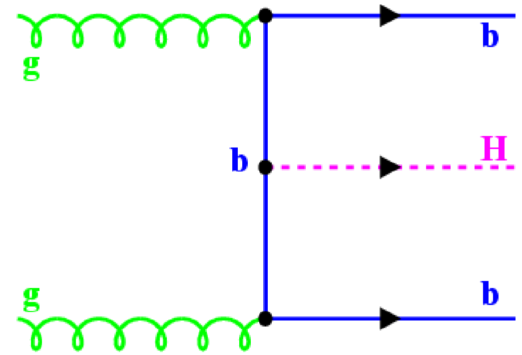
- $L=300fb^{-1}$ (only VBF at $30fb^{-1}$)
  - includes $h\to\gamma\gamma$, $h\to Z\to 4$ l, $tth\to bb$
- Small area uncovered m_h = 90÷100 GeV
- $h\to\gamma\gamma$ sensitive in gluophobic scenario due to Wh, tth production

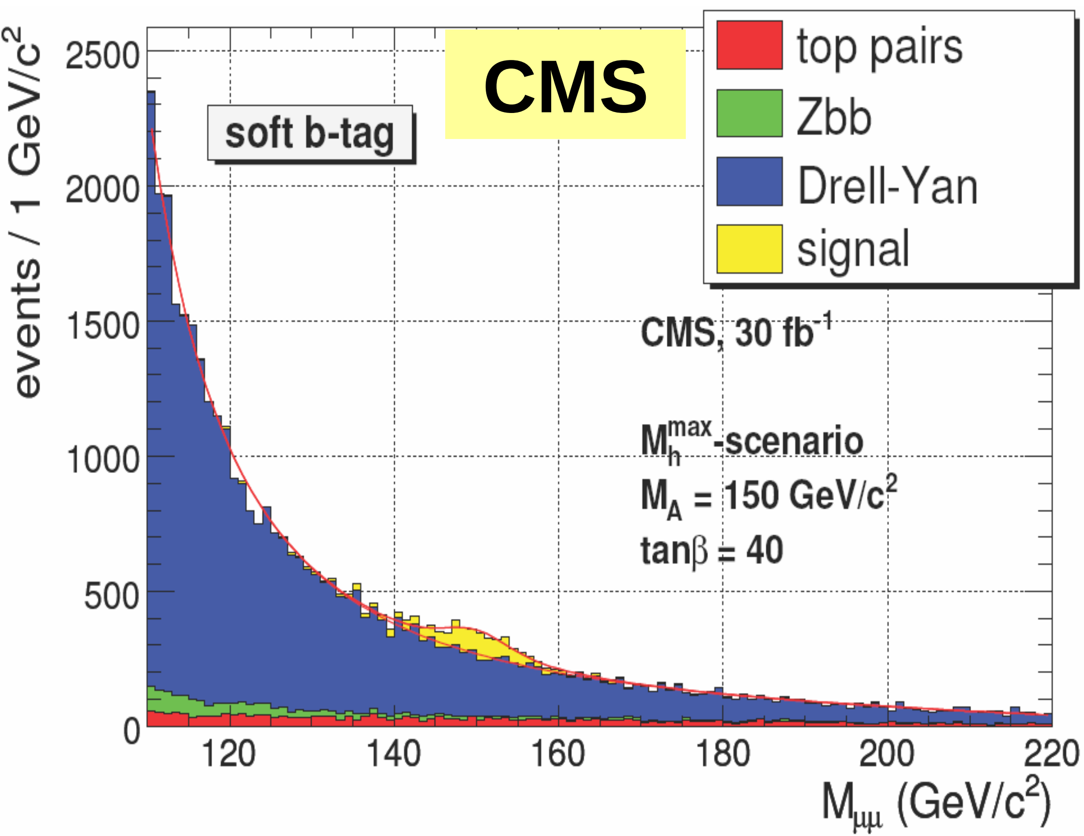


- large area covered by several channels
- sure discovery and parameter determination possible

Heavy Neutral Higgs Production

- Measure large tanβ, unexplored at LEP
- Associated production: gg/qq→bbΦ
- Decays: gg/qq→bbΦ, Φ→bb, ττ, μμ
  - Leptonic decays smaller branching ratio but much cleaner signature





Width measurement possible

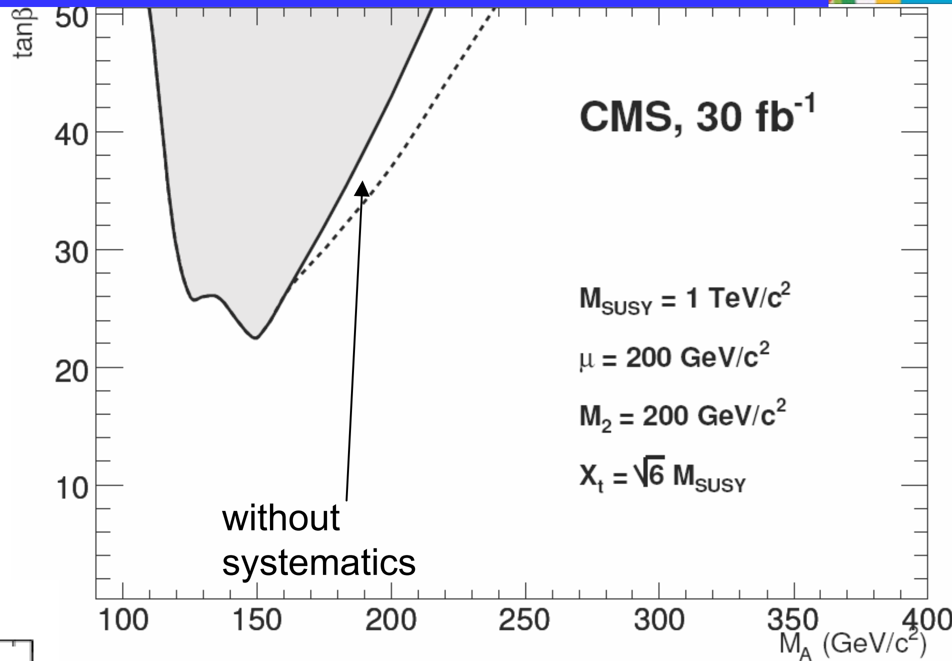
- large tan β => Φ width comparable to / dominates experimental mass resolution
- μμ decay gives best mass and width measurement for

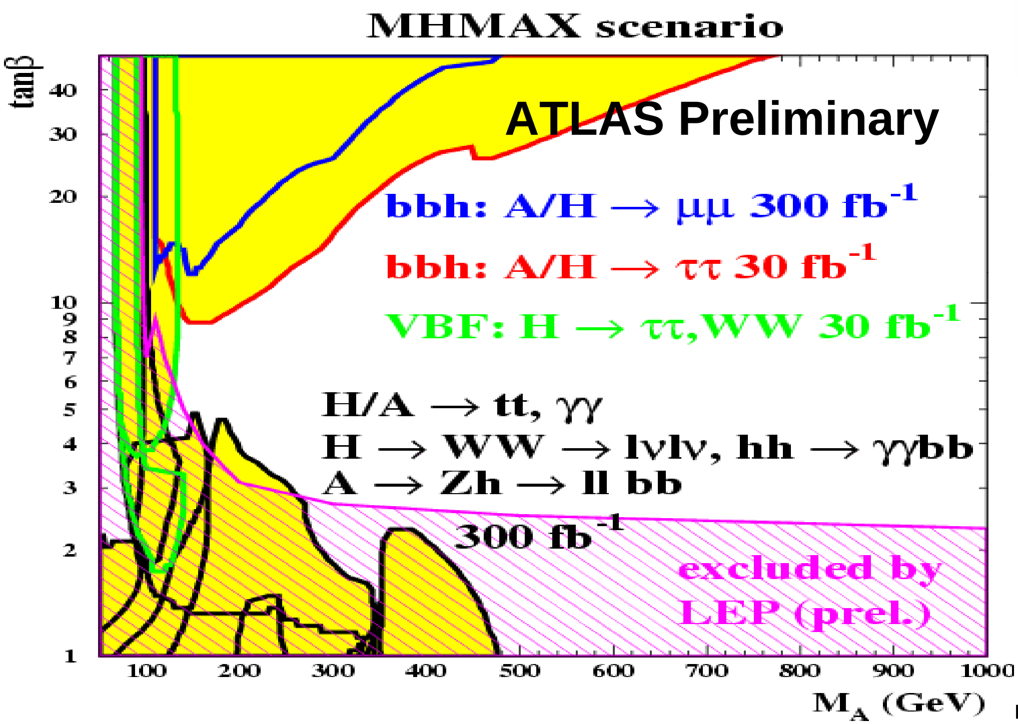
  Φ = H/A

Heavy Neutral Higgs production

3 different regimes

- Low M_A: $M_A < M_{hMAX}$
  - $M_A \sim M_h$
- Intensive coupling:
  - $M_A \sim M_h \sim M_H$
- Decoupling:
  - $M_A >> M_h$, $M_A \sim M_H \sim M_{H+}$, $M_h \sim M_{hMAX}$





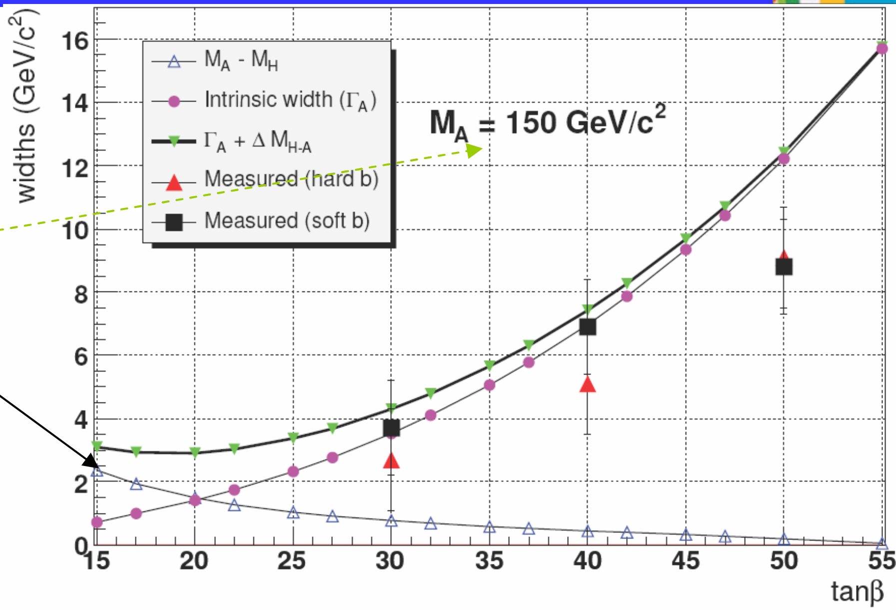
- Coverage in the M_h^{max} scenario.
- Coverage in other scenarios similar

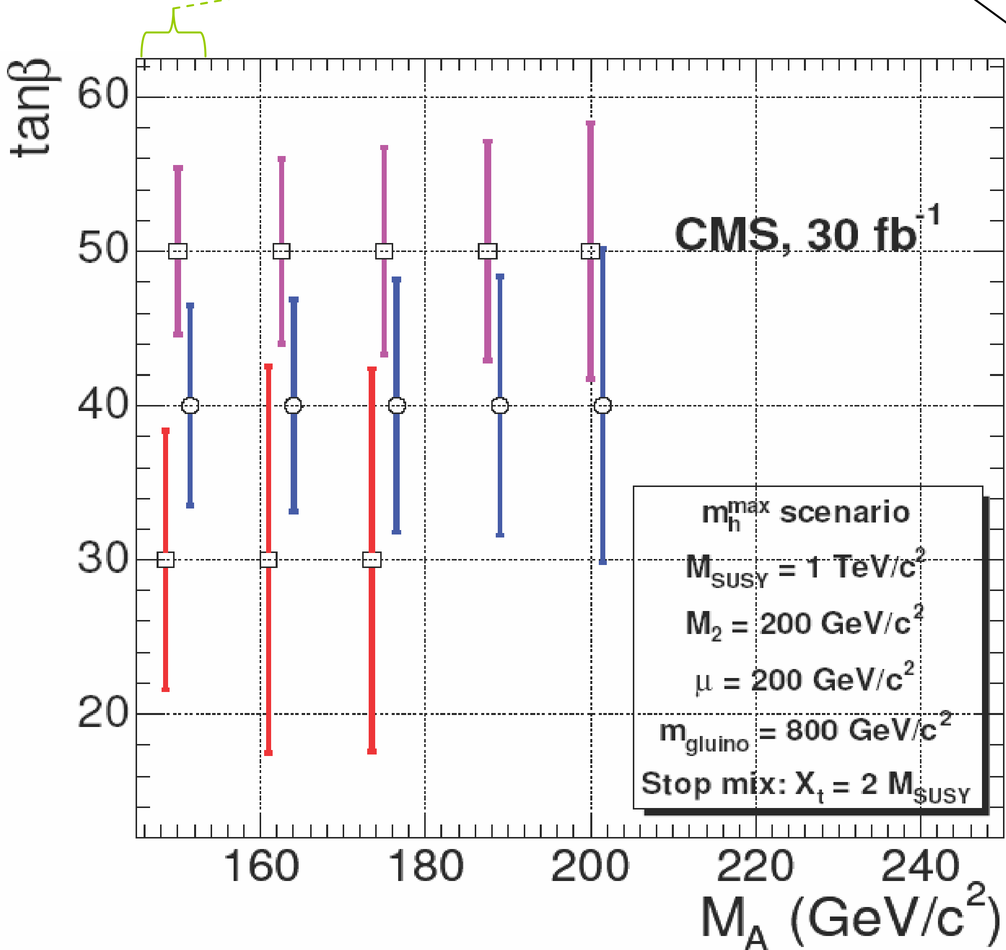
Neutral Higgs production: Constrain tanβ

Φ width sensitive to tanβ

$\Gamma_\Phi \sim \tan^2\beta$

imperfect A-H degeneracy gives contribution to width





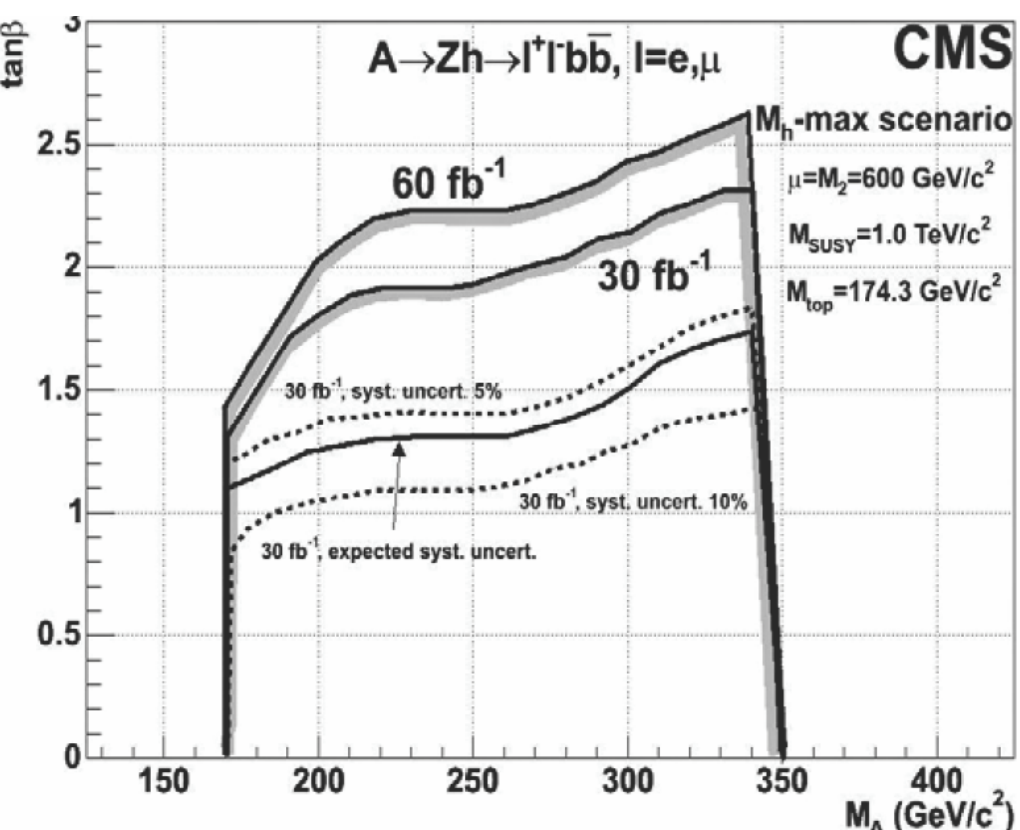
- Uncertainty on tanβ measurement using the width-angle relation
- 15% theoretical uncertainty included
- Further constraints can be applied using the relation

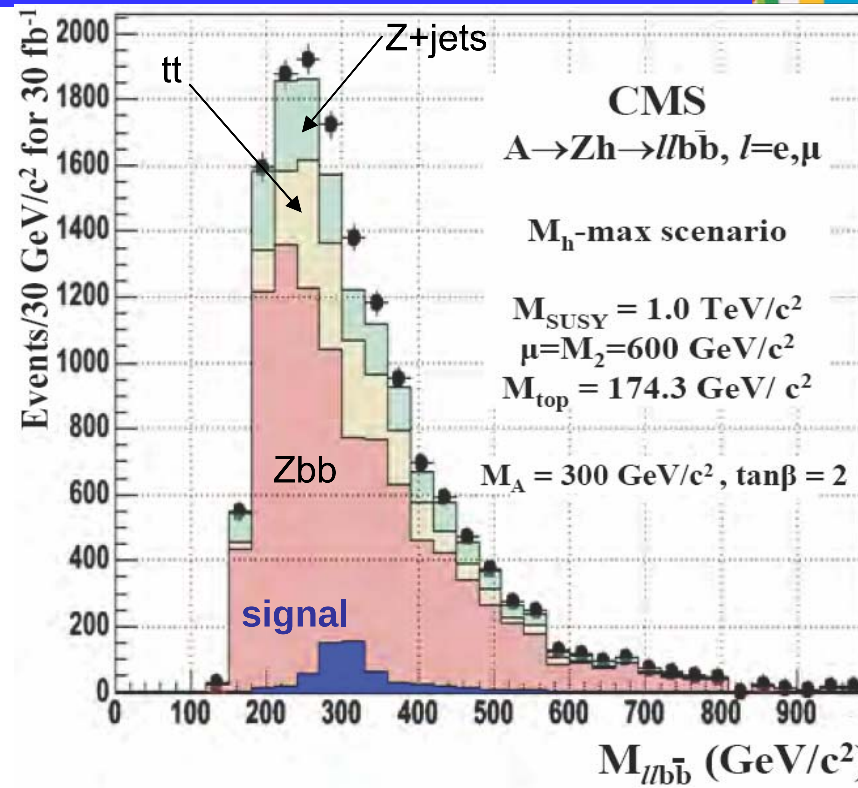
  $\sigma \times Br \sim \tan^2\beta_{eff}$

Neutral Higgs production: Access to low tanβ

Search for **gg(qq)→A→Zh**

- decays: $Z \to l^+l^-$, $h \to bb$
- detect A and h simultaneously
- Largest Br(A→Zh) for low tanβ and $M_Z+M_h<M_A<2M_{top}$





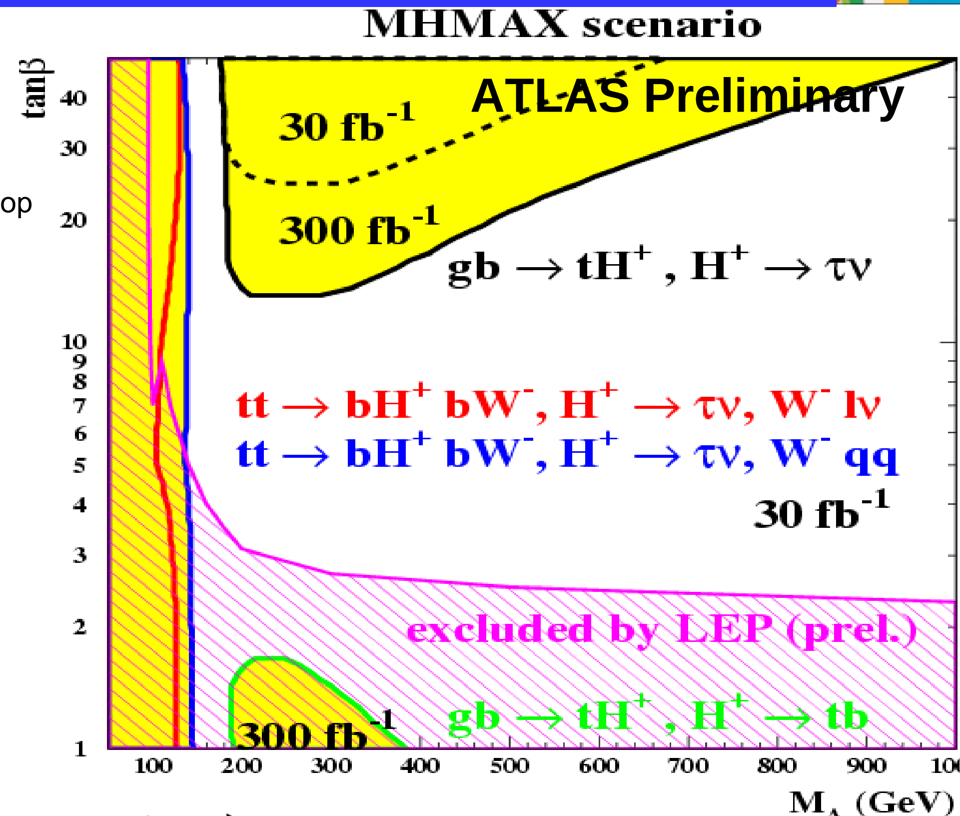
- Measure low tanβ region not completely excluded by LEP
- 5σ discovery contours for 30 and 60 fb^{-1}
  - ➢ For 30 fb^{-1}, tested systematic uncertainty

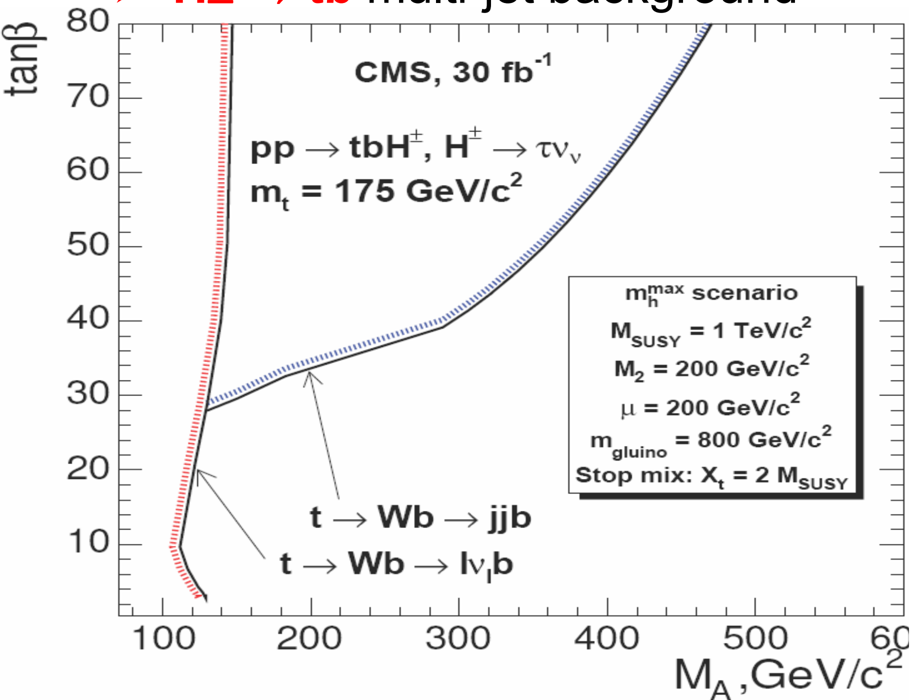
Charged Higgs Production

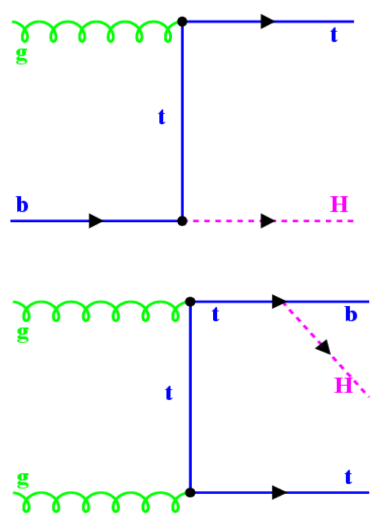
- No charged Higgs in SM
  - tree level: $M_{H+}^2 = M_A^2 + M_W^2$
  - Radiat. corr. can push mass below the m_{top}

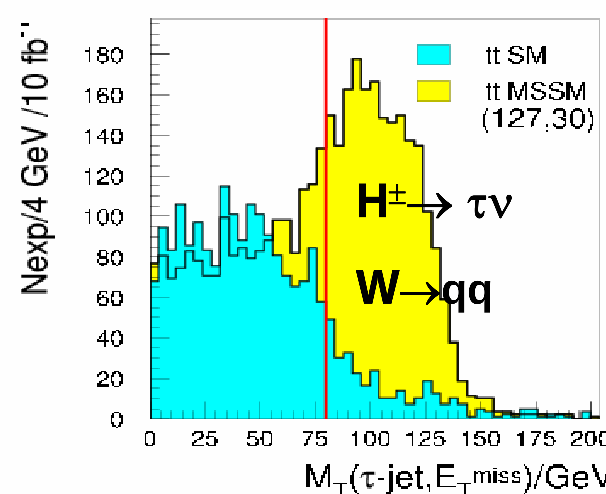
<u>Production mechanisms:</u>

- High mass, $M_{H\pm} > M_{top}$: $gb \rightarrow tH^\pm$
- Low mass, $M_{H\pm} < M_{top}$: $gg \rightarrow tbH^\pm$
- Two main decay channels:
  - **$H^\pm \rightarrow \tau\nu$** clean, good reach
  - **$H^\pm \rightarrow tb$** multi-jet background

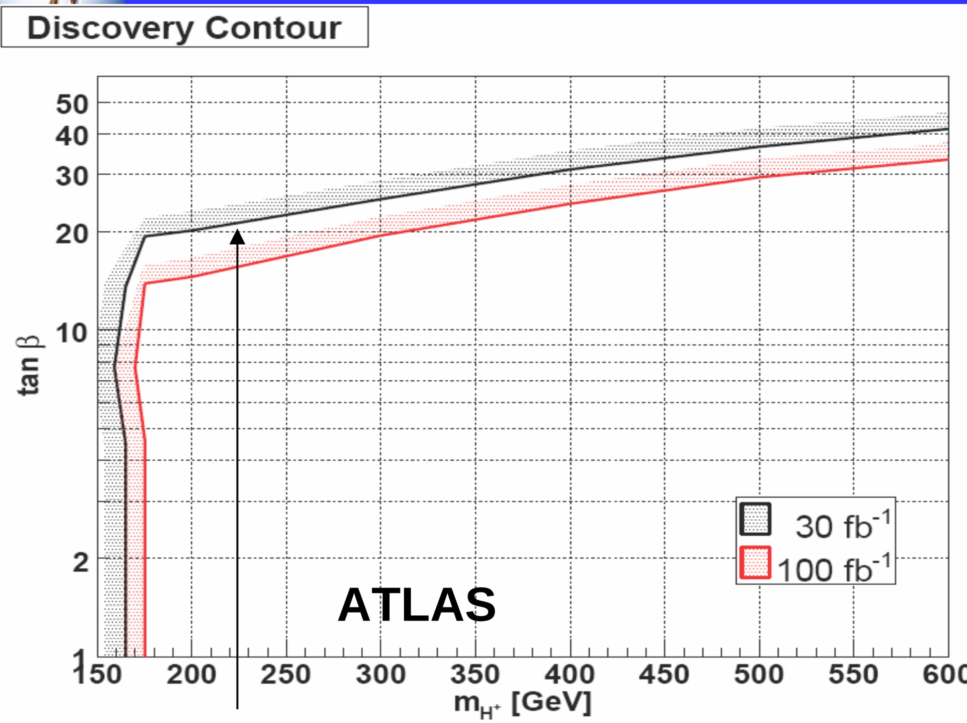






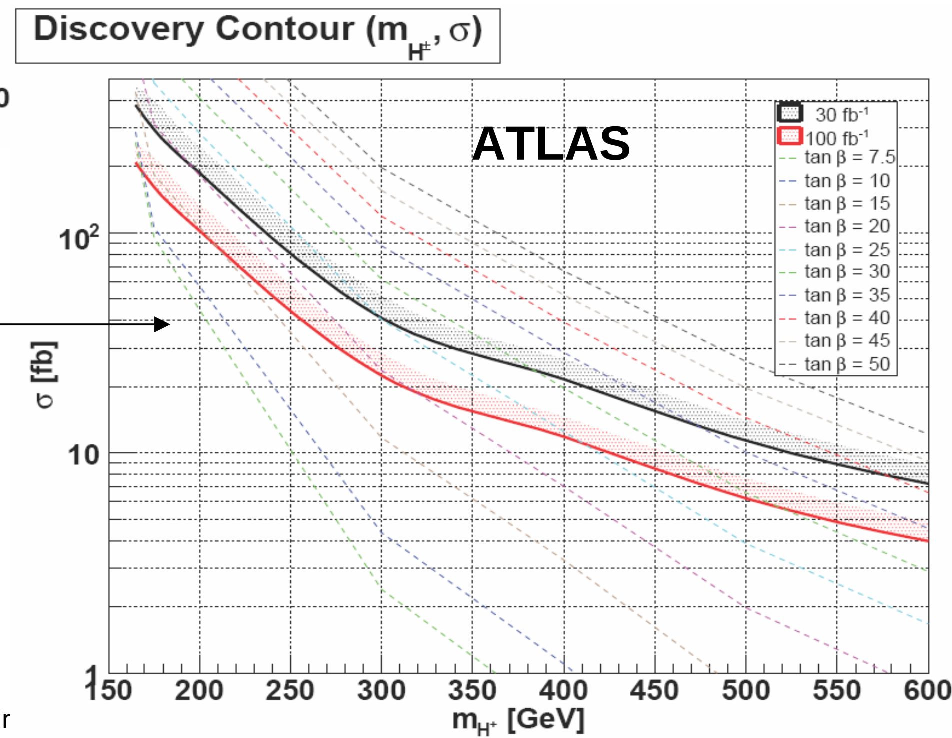


Charged Higgs Production



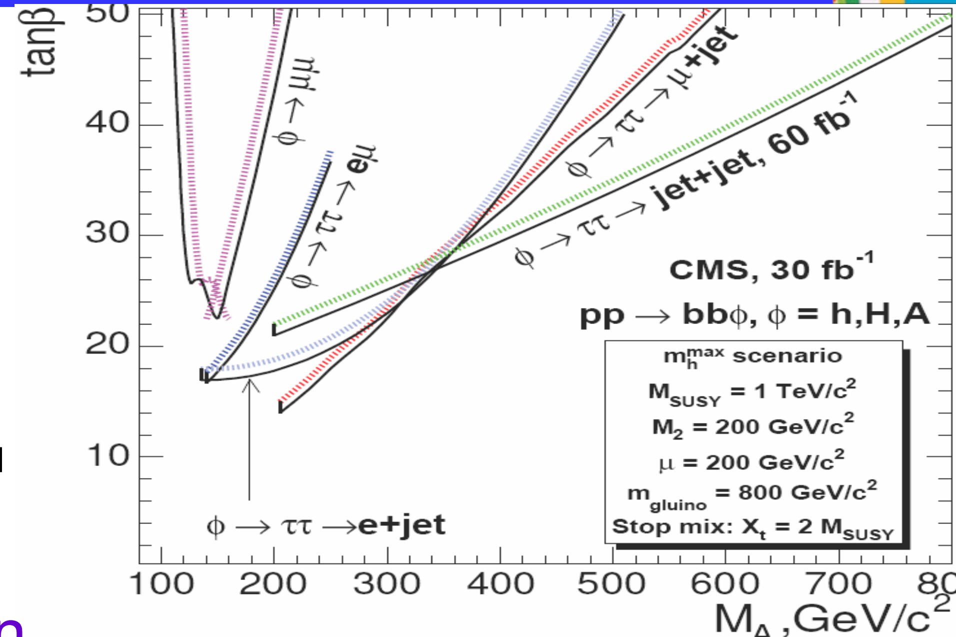
- NLO includes tt prod. for $M_{top} > M_{H\pm}$
  - Careful handling of predictions in transition region
  - Avoid double counting of different processes
- Decay channels $H^{\pm} \rightarrow \tau\nu_{\tau}$, $t \rightarrow bjj$ studied with matched production $gg \rightarrow tbH$, $gb \rightarrow tH$
- MATCHIG (J. Alwall hep-ph/0503124)

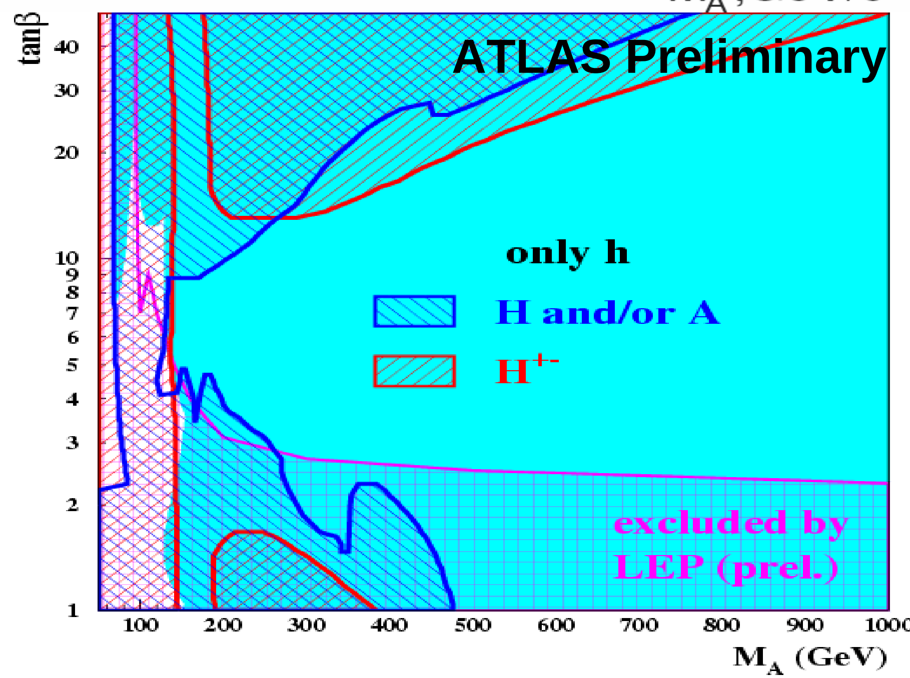
- @ 30fb^{-1}: discover H$^{\pm}$<160GeV for all tanβ, all mass region for tanβ>40
- Decrease of cross section vs. $M_{H\pm}$ explains shape of discovery contour in ($M_{H\pm}$,σ)
- First results using properly-handled theory to look at full mass range



Overall Discovery Potential CP-Conserving MSSM

- Discovery potential
  - ➢ CMS: 30/60fb^{-1}, only associated neutral higgs here, others in previous slides
  - ➢ ATLAS: 300 fb^{-1} M_h^{max}, VBF channels , H/A→tt only with 30fb^{-1}
- At least one Higgs boson observable for all parameters in all four scenarios
- Only h for significant part of phase space
- can this MSSM h be discriminated from the SM Higgs?

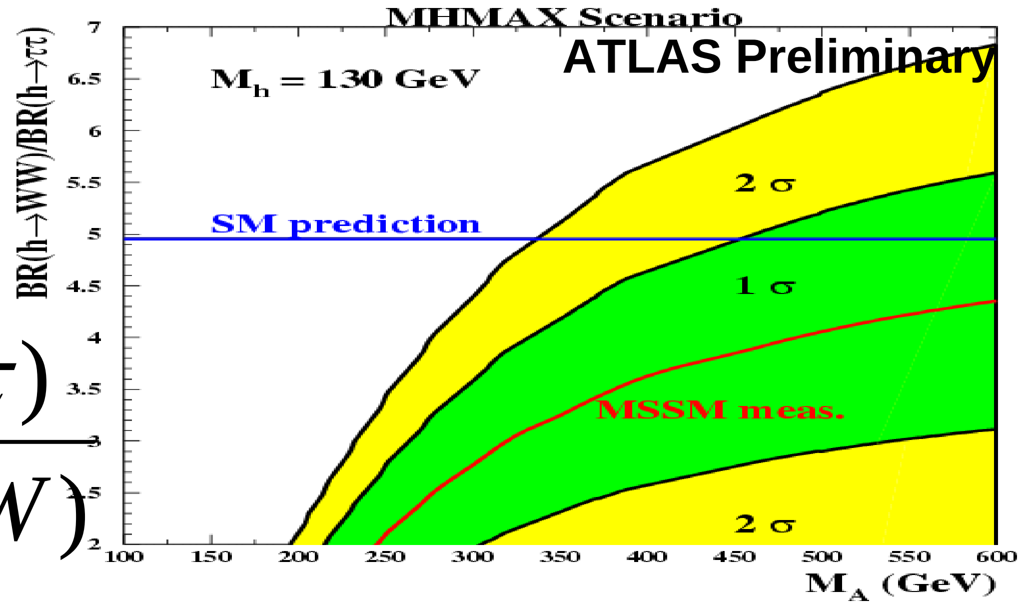




SM or Extended Higgs Sector ?

- estimate sensitivity from rate measurements in VBF (30fb^{-1})
  - Only stat errors, assume M_h exactly known

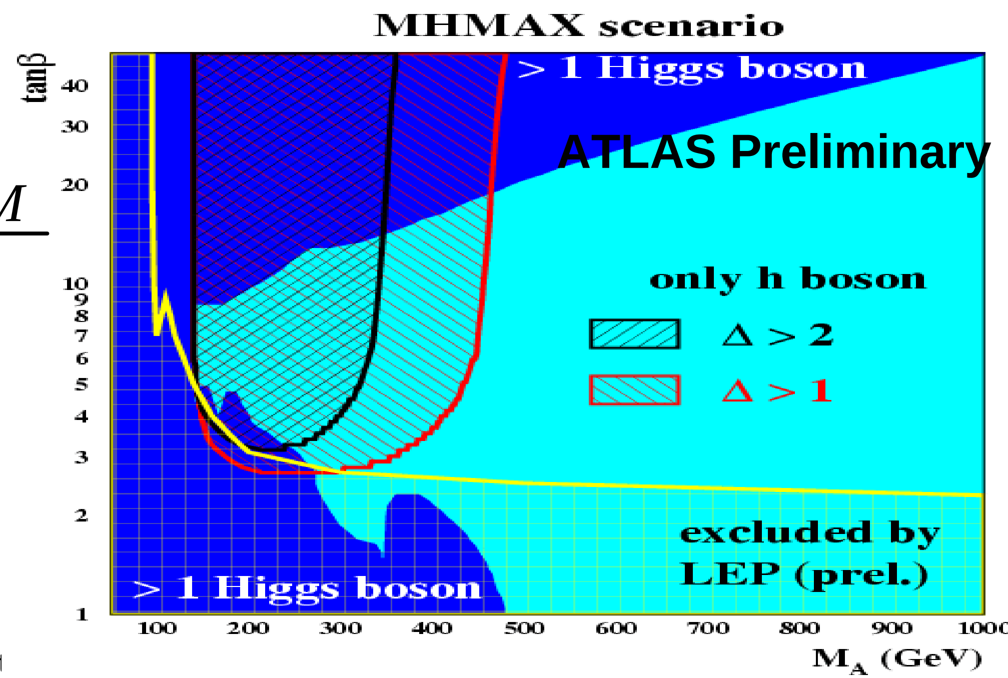
$$R = \frac{BR(h \to \tau\tau)}{BR(h \to WW)}$$



- Compare MSSM (expected) measurement with SM prediction

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

- Potential for discrimination
  - Seems promising, further studies will include syst. errors



Distinguish Between MSSM & SM Couplings

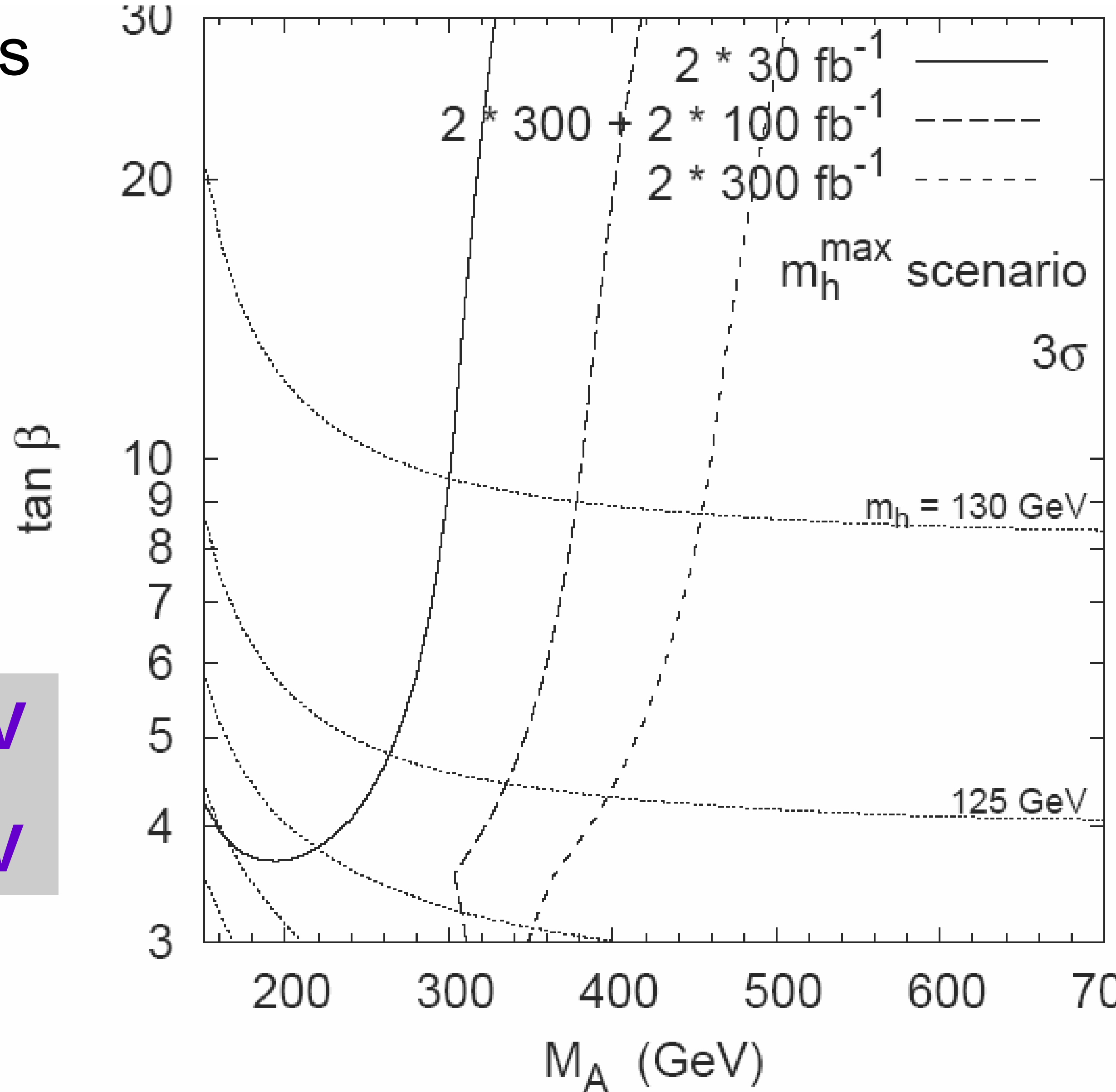
M. Duhrssen et al. hep-ph/0406323

- Perform χ^2 analysis of couplings. Exlusion of SM
- Plot at 3σ discrepancy from standard model

For 2*300 fb^{-1}:

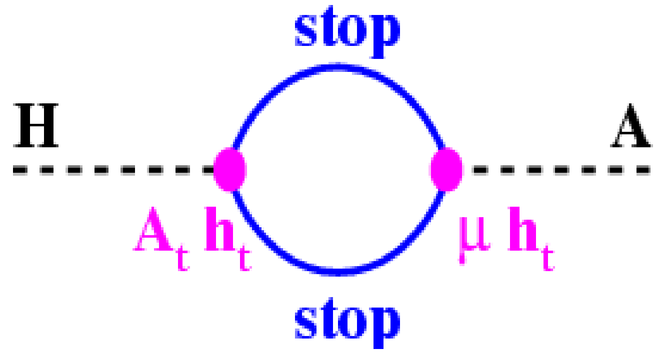
$3\sigma \rightarrow M_A < 450$GeV

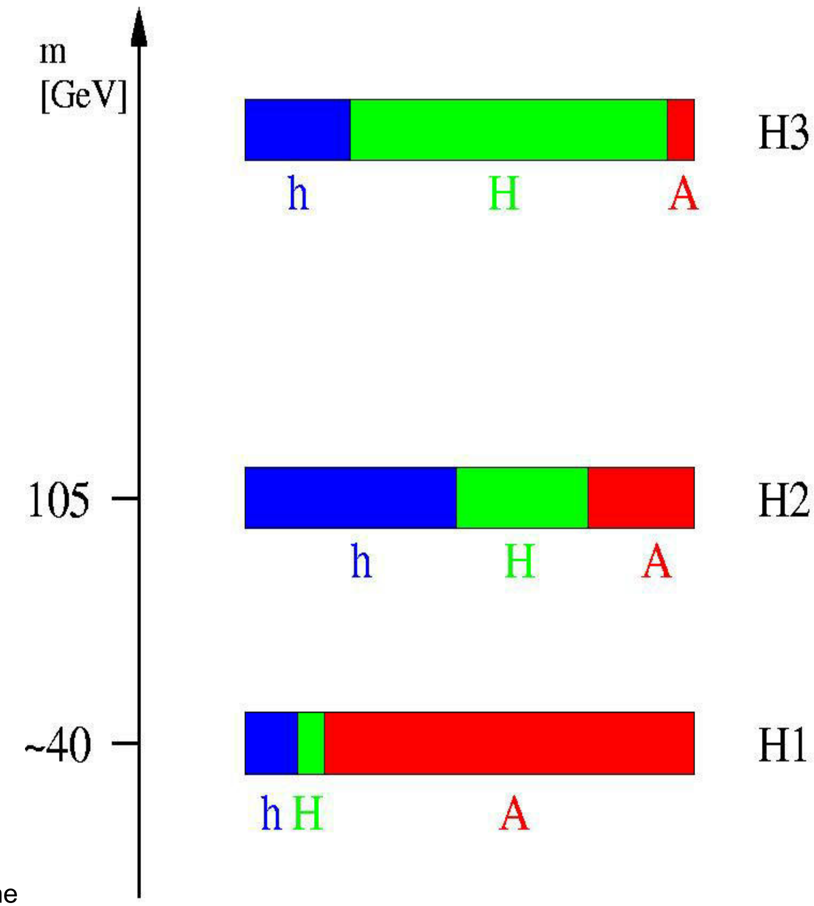
$5\sigma \rightarrow M_A < 350$GeV



The CP violating CPX scenario

- CP conserving at Born level but CP violation via complex trilinear couplings $A_{t,b}$
- CP eigenstates h, A, H mix to mass eigenstates H1, H2, H3
  - $M_{H1}<M_{H2}<M_{H3}$
- No more well defined M_A , the only remaining well defined mass parameter is M_{H+}
- CPX scenario: maximize effect $\arg(A_{t,b})=\arg(M_{gluino})=90^o$
- Carena et al.
  - hep-ph/0202167
  - hep-ph/0009212

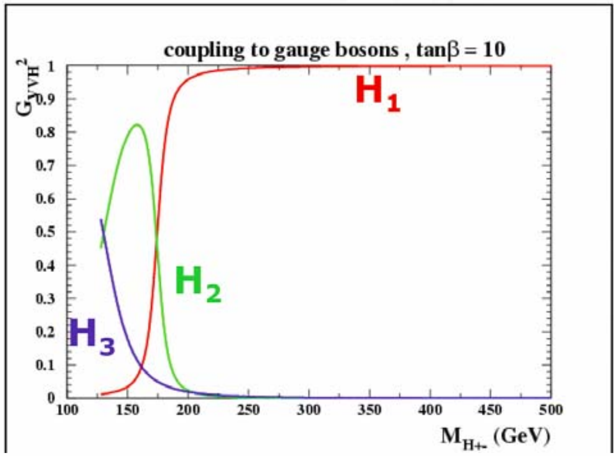


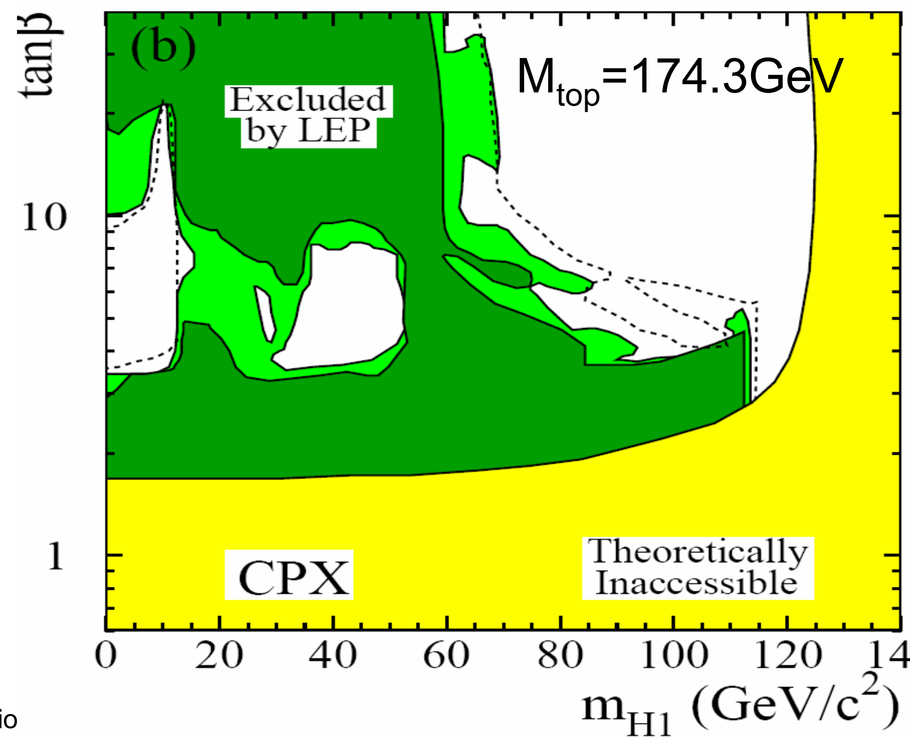


The CPX Scenario

- H_1,H_2, H_3 couple to W,Z
  - No g_{AVV} coupling in CPC
  - H_1 decouples from boson foe m_{H+}<150GeV
- No absolute limit on H_1 from LEP
  - Loss of sensivity for tanβ=3÷10 due to complexity of final states
  - Insensitivity to low Higgs mass
  - Exclusion region strongly depends on M_{top}
- LHC: H_1 relevant channels
  - VBF: H_1→WW, H_1→ττ
  - bbh: H_1→μμ
  - tth: H_1→bb

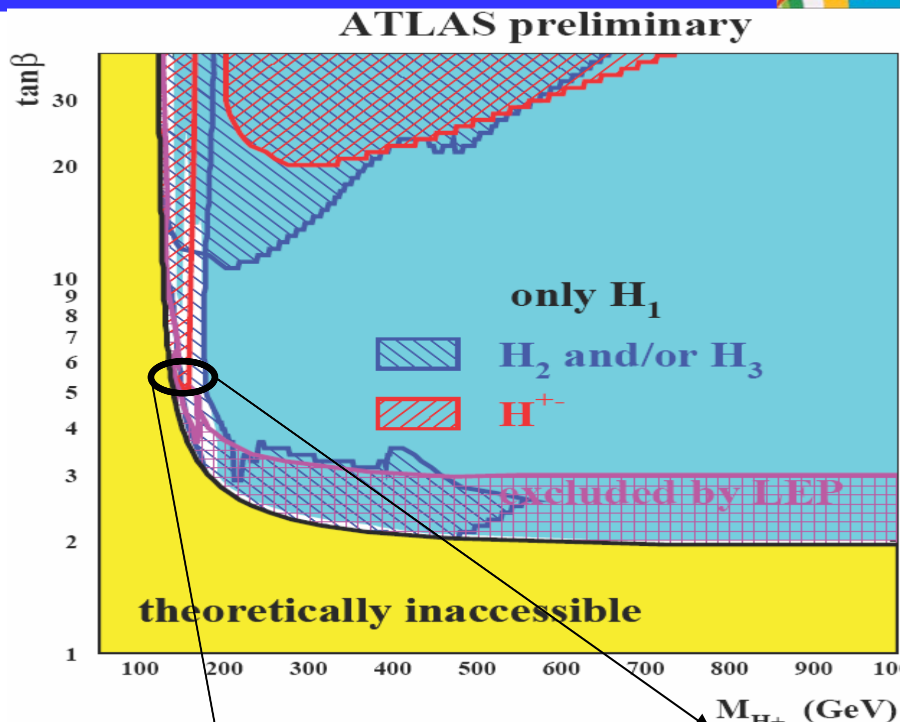
$$\Sigma_i^3 g_i^2 (ZZH_i) = g_{SM}^2 (ZZH_{SM})$$

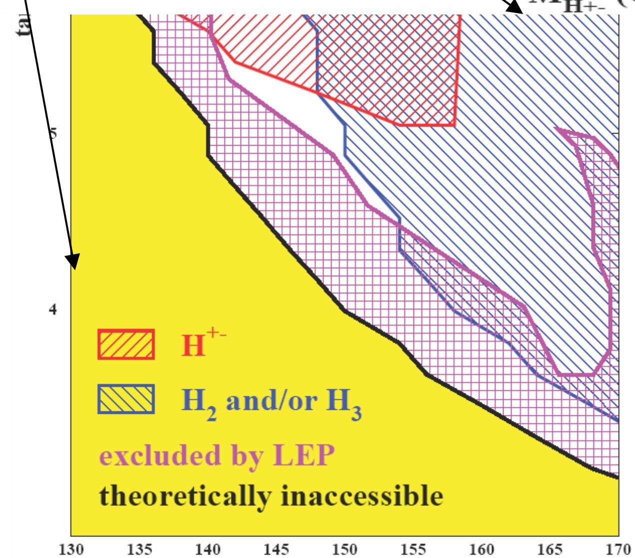




CPX Overall Sensitivity

- Discovery potential with 300fb^{-1}
- Almost whole parameter space covered by observation of at least one Higgs boson
- Only H1 observable in intermediate tanβ
- Small uncovered region not yet excluded by LEP
  - ➢ Calculations for uncovered region strongly depend on the top quark mass
    - FeynHiggs2.1, M_{top}=175 GeV, gives: M_{H1}<50, 105<M_{H2}<115,140< M_{H3}<180, 130<$M_{H\pm}$<170GeV
  - ➢ Studying possibility to cover this area with top pair production using the decay chain
    - $t \rightarrow bH+ \rightarrow bWH_1 \rightarrow bqqbb$
    - $t \rightarrow bW$





Summary

- For the CP-Conserving MSSM Higgs all of the parameter space is potentially covered (30 fb^{-1}) by discovery of at least one Higgs boson
- Coverage seen on all 4 benchmark scenarios reflects probably most of MSSM phase space
- In large regions of the phase space only the SM-like MSSM Higgs boson might be observed. Working on strategies to distinguish between SM and MSSM origin in this case

- For the CP-Violating MSSM, almost all parameter space covered by observation of at least one Higgs in the CPX scenario.
- Studies ongoing on small uncovered space (M_{H1}<50GeV) not excluded by LEP searches