ATLAS Discovery Potential for Higgs Bosons beyond the Standard Model

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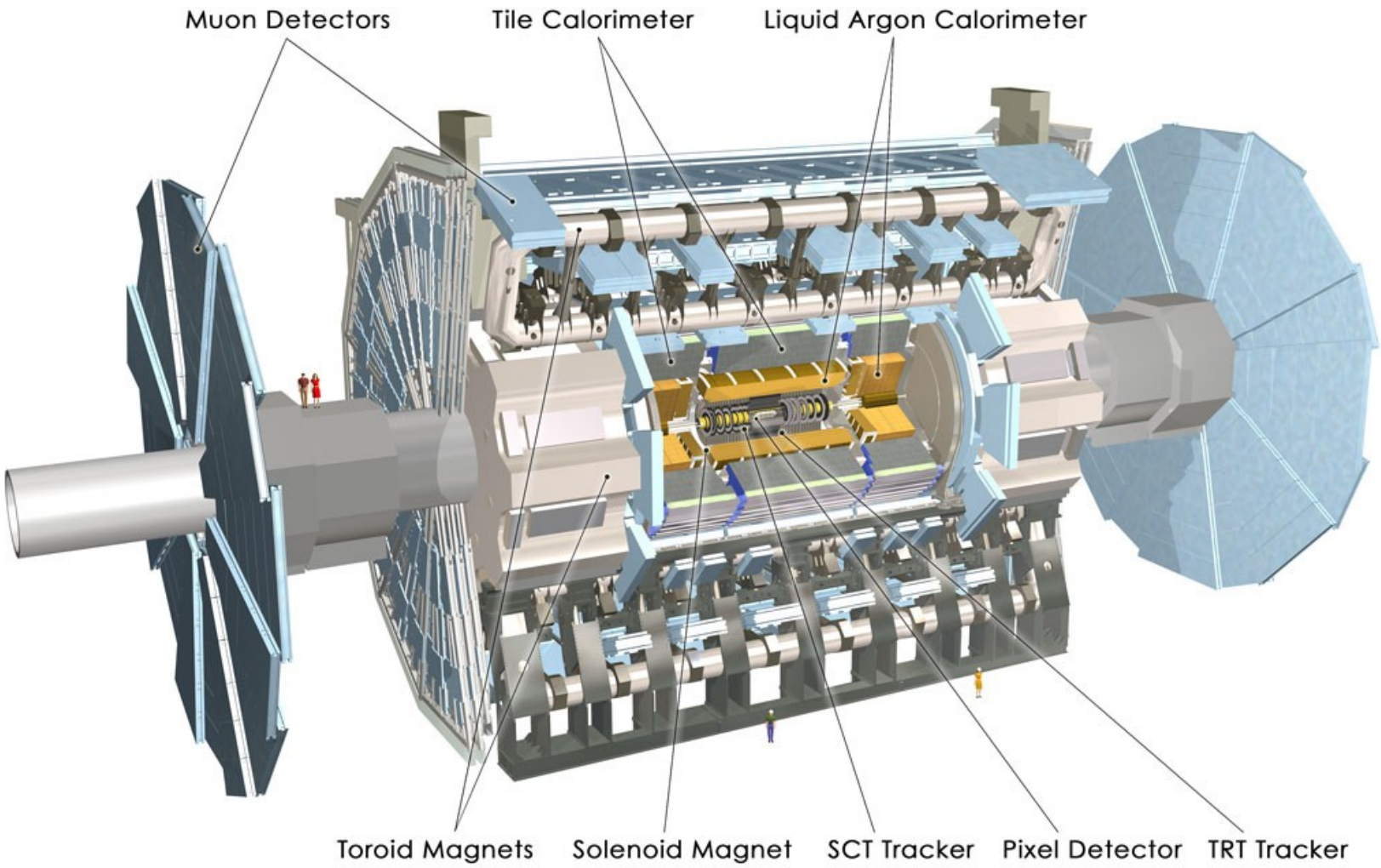
BMBF-Forschungsschwerpunkt
ATLAS Experiment
Physics on the TeV-scale at the Large Hadron Collider
FSP 101 ATLAS

2007 Europhysics Conference on High Energy Physics, Manchester

- **MSSM Higgs:**
  - **CP conserving benchmark scenarios**
  - **charged Higgs**
  - **CPX scenario**
- **Invisible Higgs**

The ATLAS Detector



- **multi-purpose detector**
- **installation progressing**
- **ready for LHC start-up in 2008**

MSSM Higgs Sector (CP conserved)

- 2 Higgs doublets → 5 Higgs: h, H (CP=+1), A (CP=-1), $H^{\pm}$
- tree level described by $\tan\beta = v_2/v_1$ and M_A

- couplings wrt. SM: $g_{MSSM} = \xi\, g_{SM}$
  - A doesn't couple to W/Z
  - small α: small BR(h→ττ,bb)
  - large $\tan\beta$: large BR(h/H/A→ττ,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	$\cot\beta$	$\tan\beta$	-----

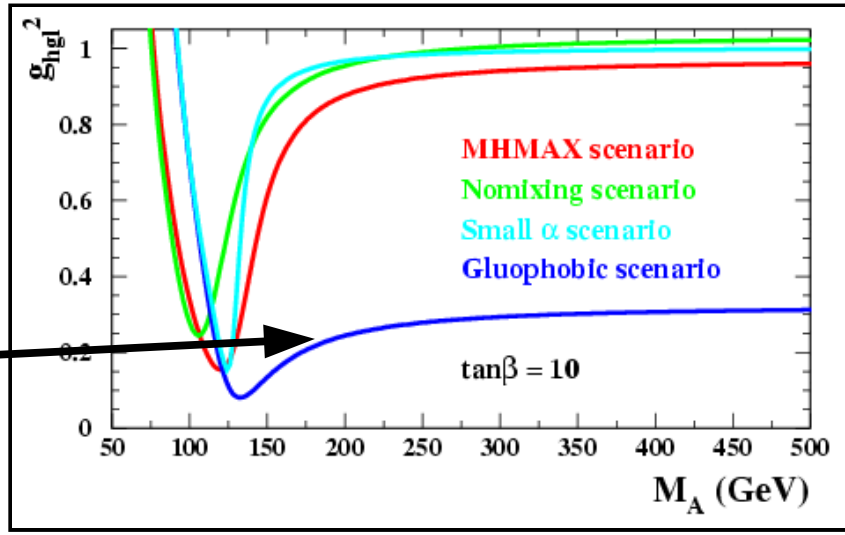
α = mixing btw. h,H

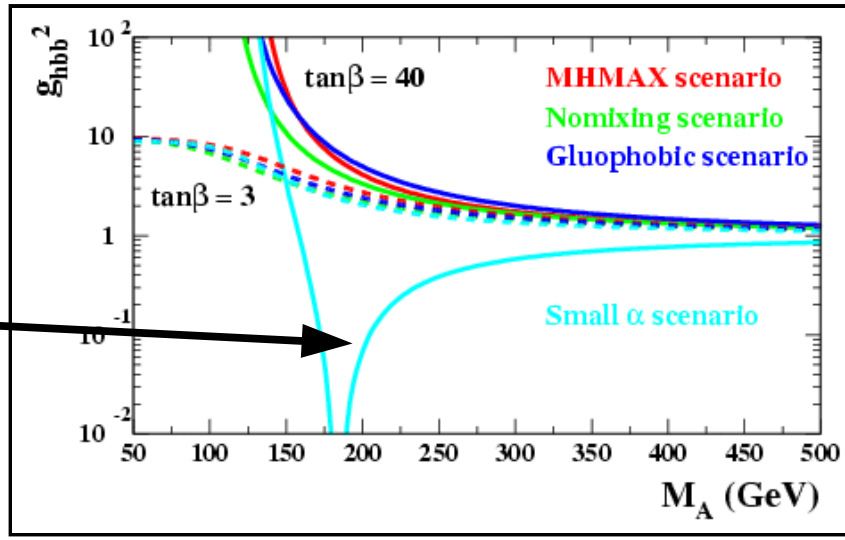
- Large loop corrections !
- Additional parameters: X_t, M_0, M_2, M_{gluino}, μ
- benchmark scenarios: fix all parameters except $\tan\beta$ and M_A

Benchmark scenarios

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

- **MHMAX:** maximal M_h<133 GeV
- **Nomixing:** small M_h<116 GeV
- **Gluophobic:** M_h<119 GeV
  - reduced $g_{h,gluon}$
  - harm discovery via gg→ h, h→γγ and h→ZZ→4 l
- **small α:** M_h<123 GeV
  - reduced g_{hbb}, $g_{h\tau\tau}$
  - harm discovery via VBF, h→ττ and tth, h→bb



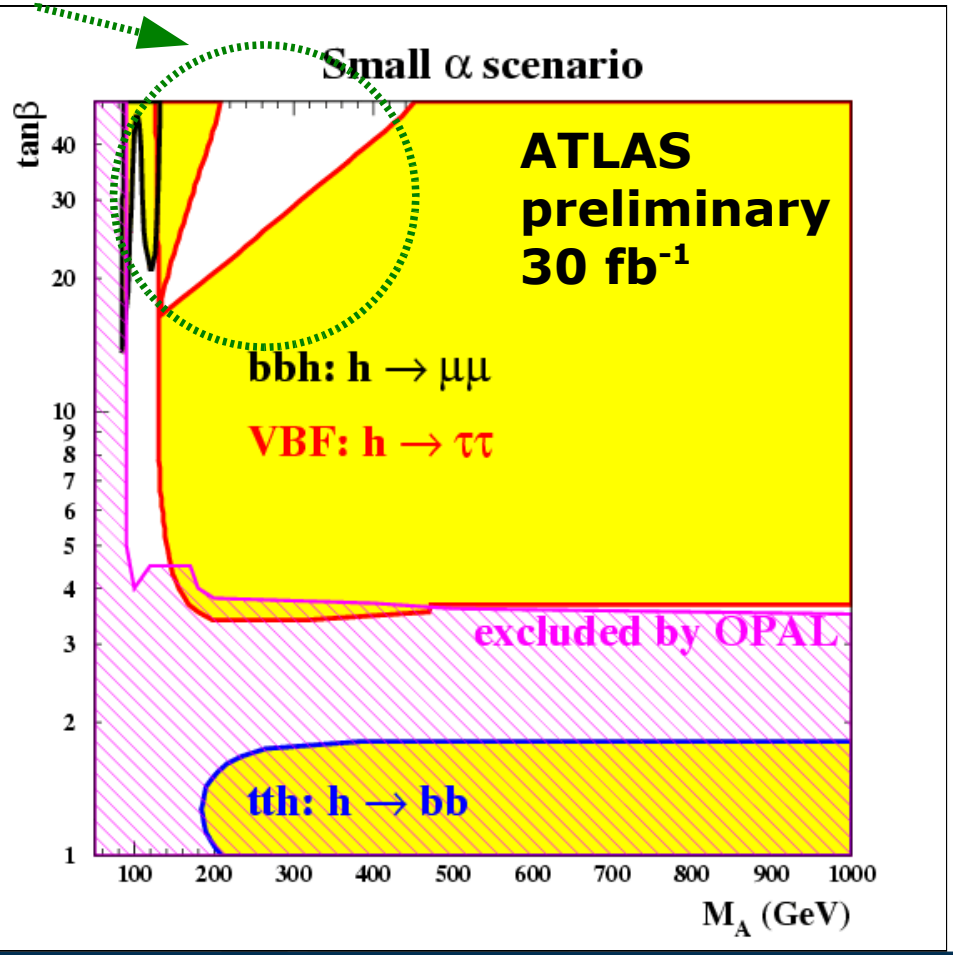


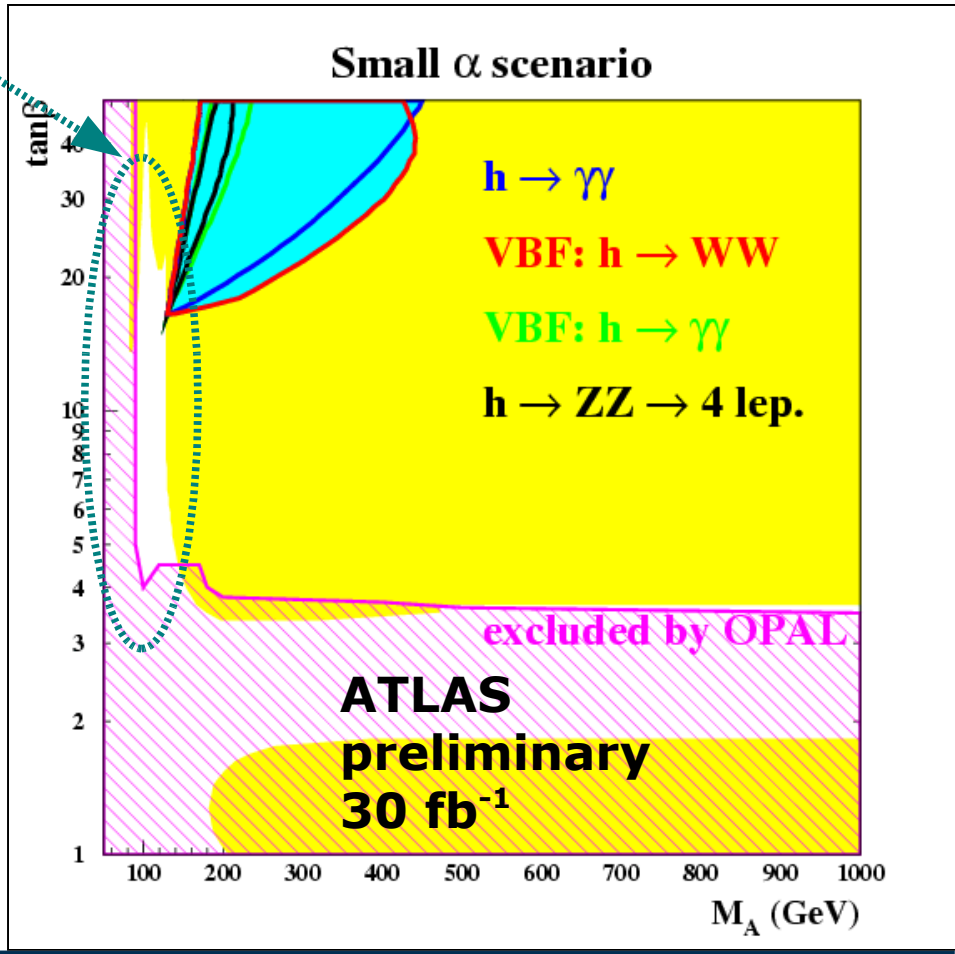
Analysis

hep-ph/0410112,
ATL-COM-PHYS-2004-070

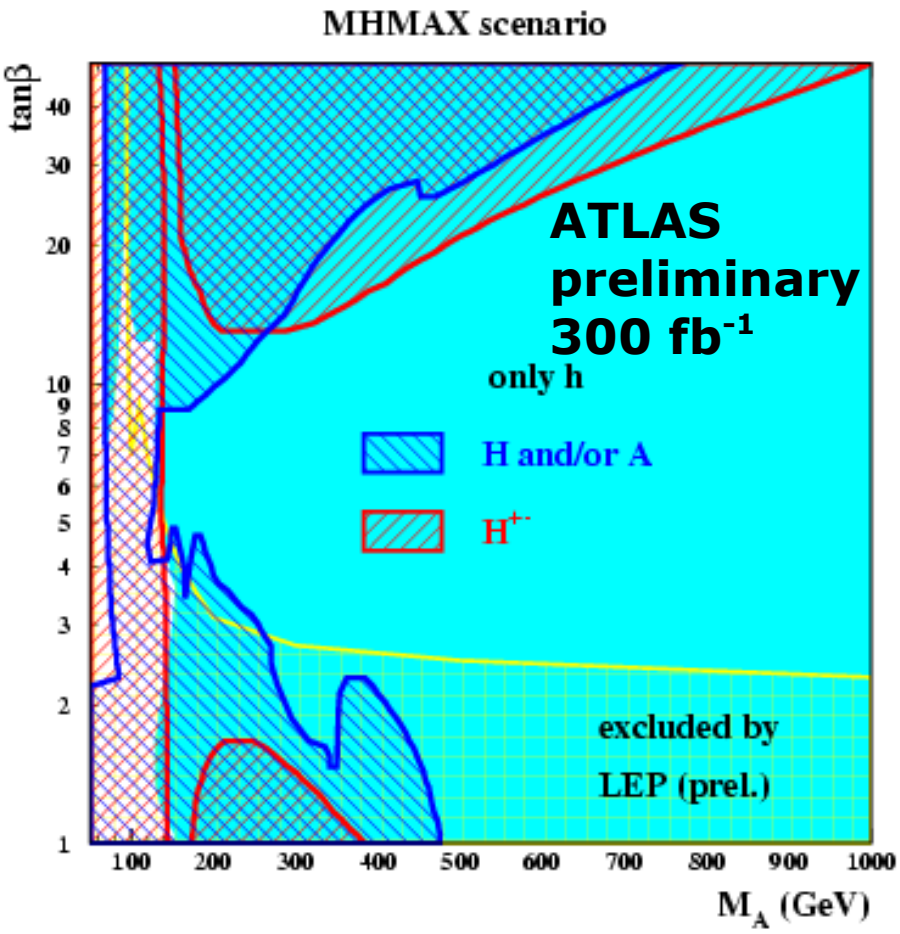
example: small α scenario, discovery potential for h:

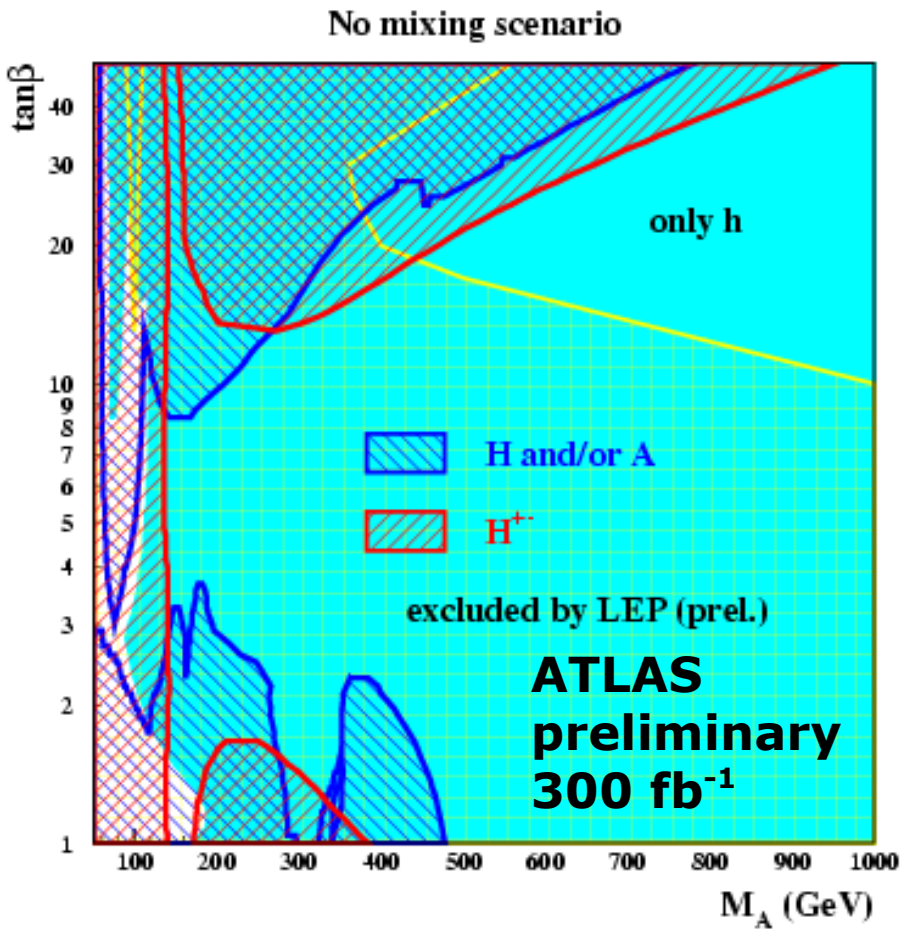
- **reduced discovery potential in h→ττ**
- **covered by bosonic decays (enlarged BR to gauge bosons)**
- **search channels complementary**
- **region where h not observable covered by H/A signals**





Overall discovery potential



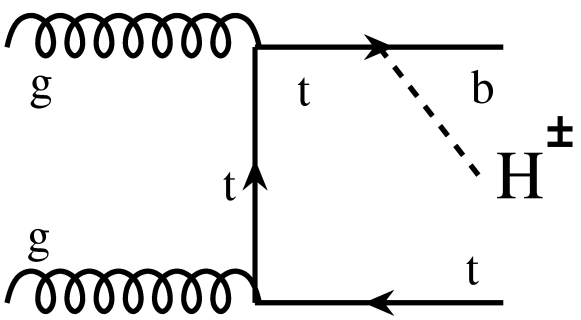


- at least one Higgs boson observable for all parameters (in all four CP-conserving benchmark scenarios)
- significant region where only h can be discovered
- decays into supersymmetric particles ?

New: $H^{\pm}$ in transition region

low mass ($M_{H\pm} < M_t$):

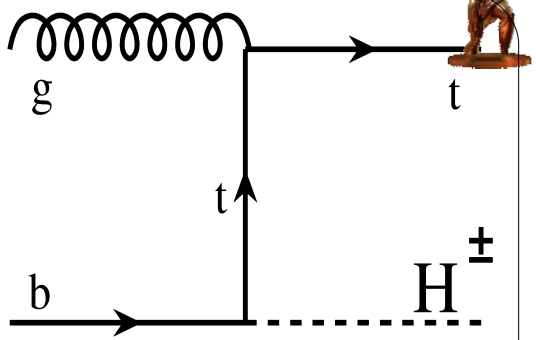
- gg→tt
- one t decays to $H^{\pm}b$, $H^{\pm}\rightarrow\tau\nu$



- discovery with 30 fb^{-1}

new analysis covers also transition region

high mass ($M_{H\pm} > M_t$):



- $gb\rightarrow H^{\pm}t$
- $H^{\pm}\rightarrow tb$: higher BR
- $H^{\pm}\rightarrow\tau\nu$: clearer signature:
  - hard cut on p_t of τ-jet (>100GeV)
  - cut on azimuthal angle between τ -jet and direction of p_t^{miss}

Azimuthal Opening Angle

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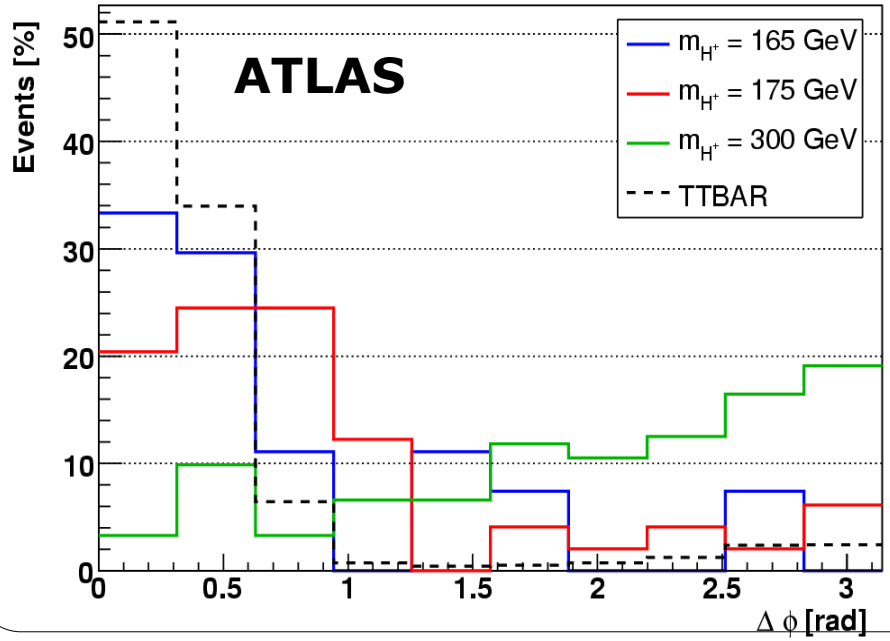

Analysis of transition region

- use MATCHIG generator (hep-ph/0503124)
- main backgrounds:
  - ttbar
  - W+jets
  - QCD
- reconstruct W and top
- hard cuts on p_t of τ-jet
- azimuthal opening angle

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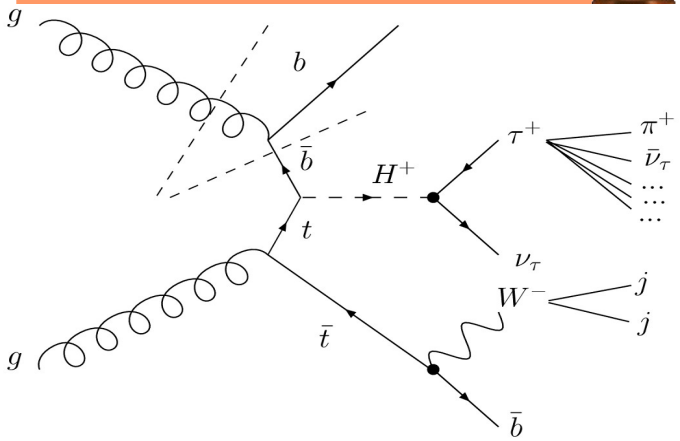
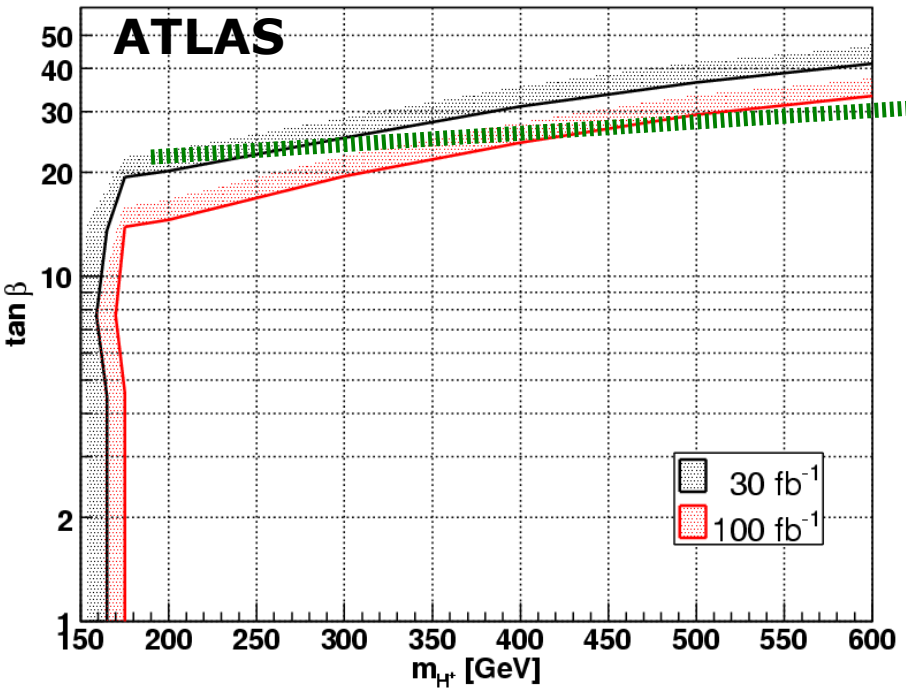
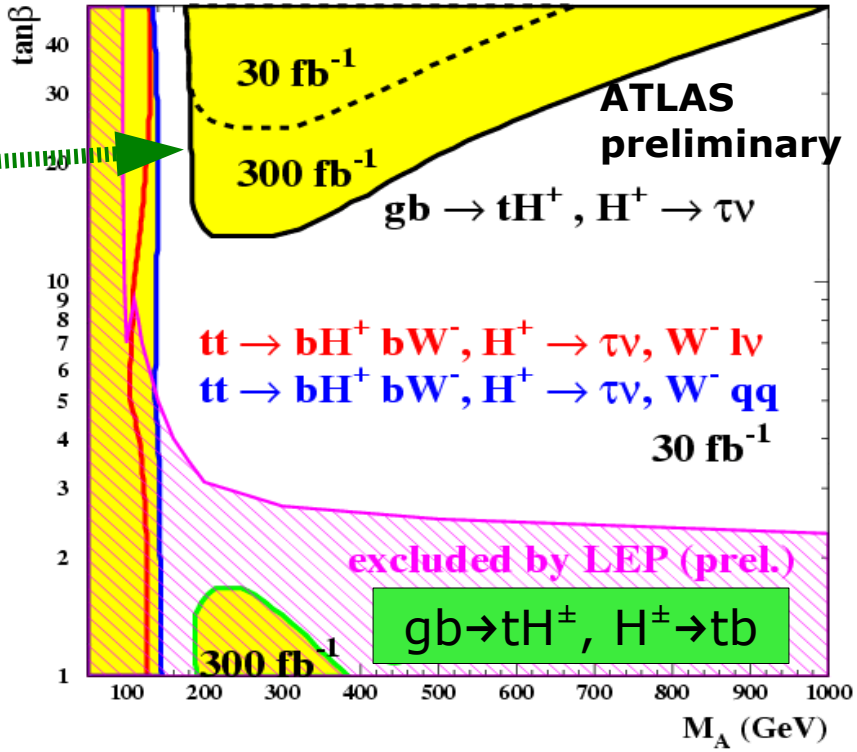


Discovery Contour



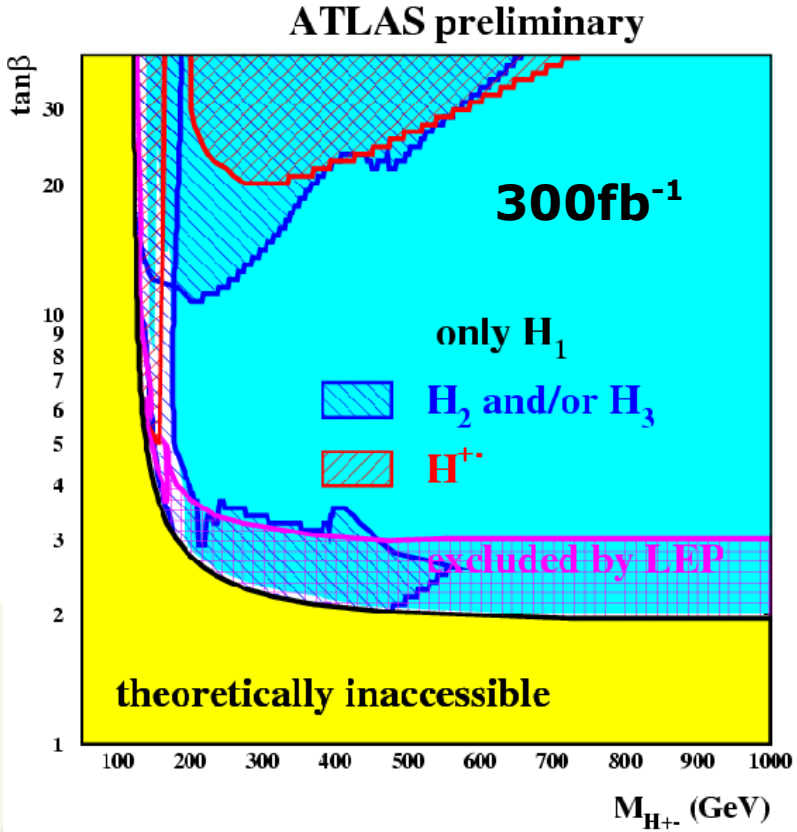
MHMAX scenario

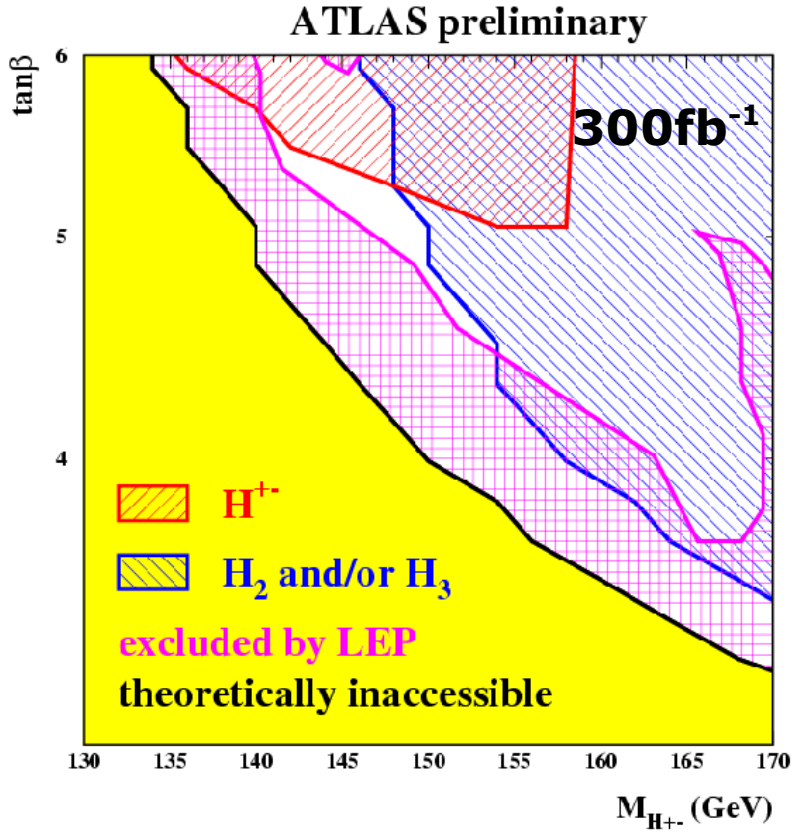


CPX scenario

Carena et al., Phys.Lett B495 155(2000)

- CP violation via loop corrections maximized (complex parameters)
- Mixing: h, H, A → H_1, H_2, H_3 **no lower bound on M_{H1} from LEP !**





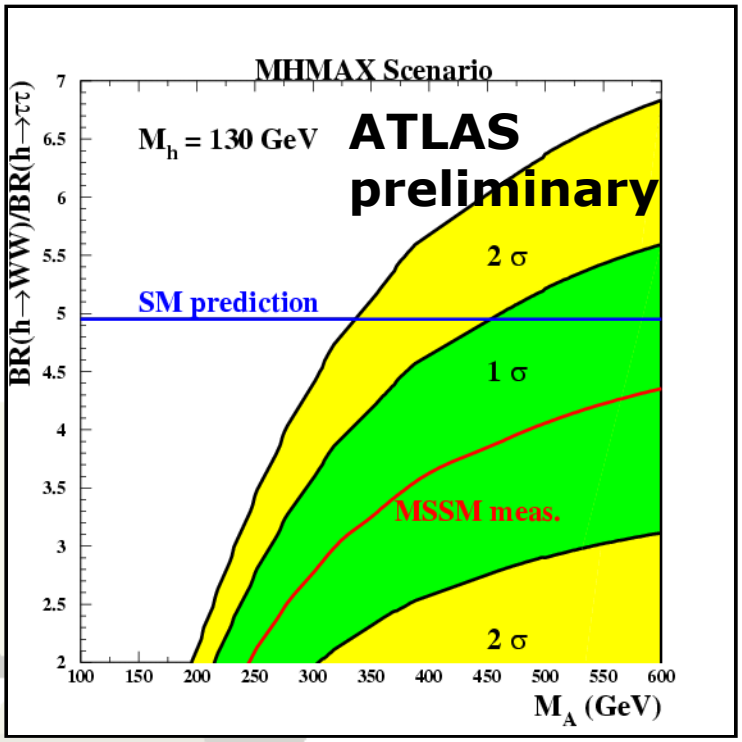
CERN-2006-009

- at least one Higgs boson visible in almost all parameter space
- small hole remaining: M_{H1}<50 GeV
- exact position depends on used calculation
- might be closed by tt, one $t \to bH^{\pm} \to bWH_1 \to bqqbb$

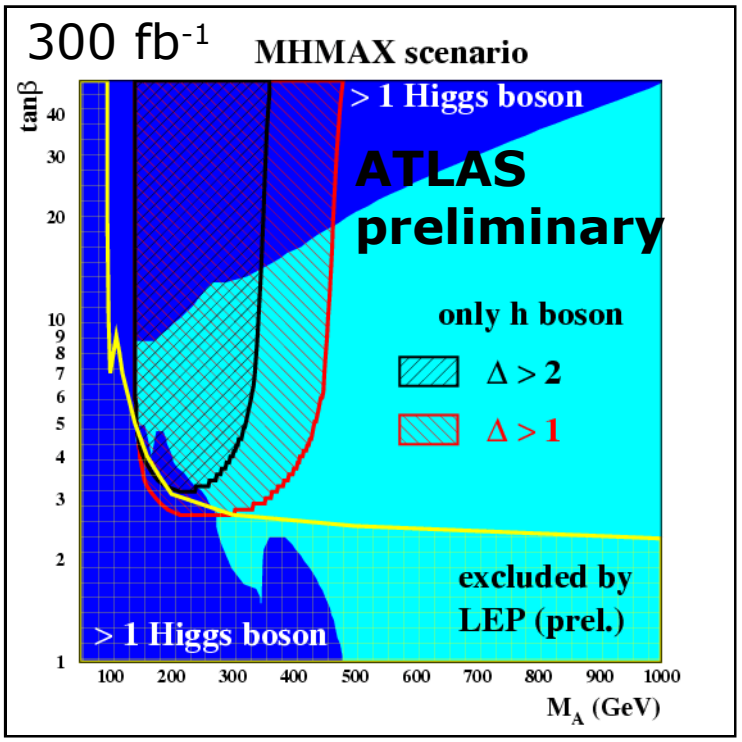
SM or MSSM when only h seen ?

- compare ratio of production rates in VBF channels ($30fb^{-1}$) to predictions from MSSM and 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

Invisible Higgs

Standard Model: BR(H→ZZ→νννν) ~ 1-1.5% above 180 GeV

- **MSSM: decays to Neutralinos, Gravitinos**
- **Massive 4th generation neutrinos**

  (K.Belotsky et al., hep-ph/0210153)
- **Extra dimension models:**
  - **Mixing with Kaluza-Klein scalars**
- **Extra gauge singlets**
  - **e.g.„Stealthy Higgs"**

(J.v.d.Bij, ZPC75 (1997) 17, hep-ph/0608245)

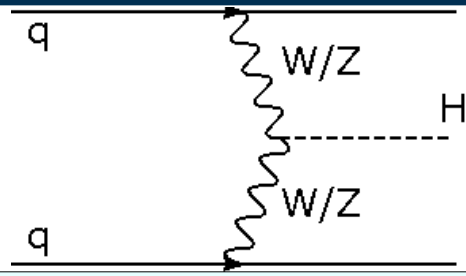
invisible decays might be dominant !

sensitivity expressed in parameter $\xi^2 = BR(H\rightarrow inv)\cdot\sigma_{BSM} / \sigma_{SM}$

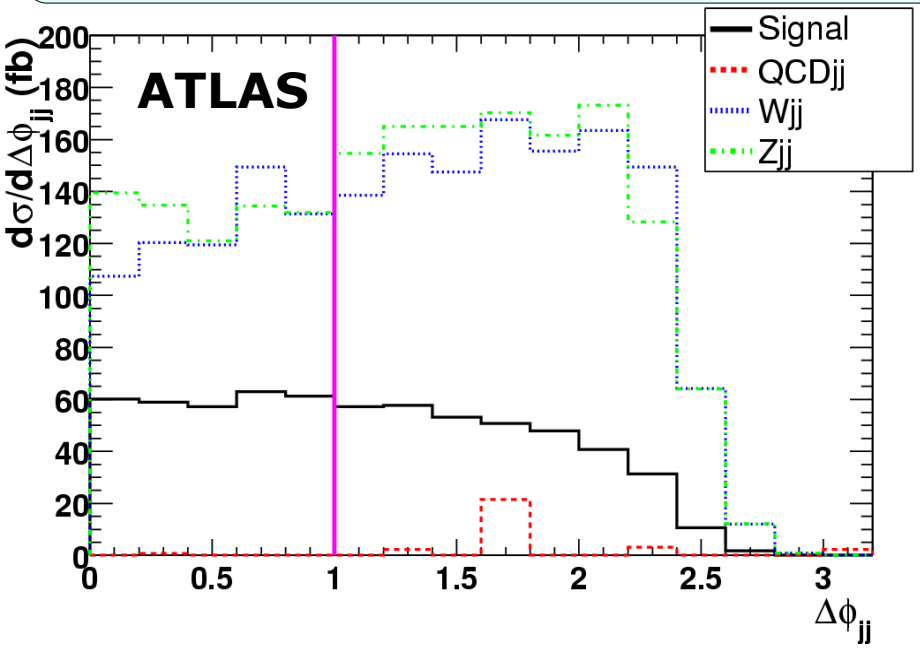
- **$\xi^2 > 1$: exclusion/discovery with SM production impossible**
- **$\xi^2 < 1$: sensitivity for BR(h→inv) = ξ^2 with SM production**

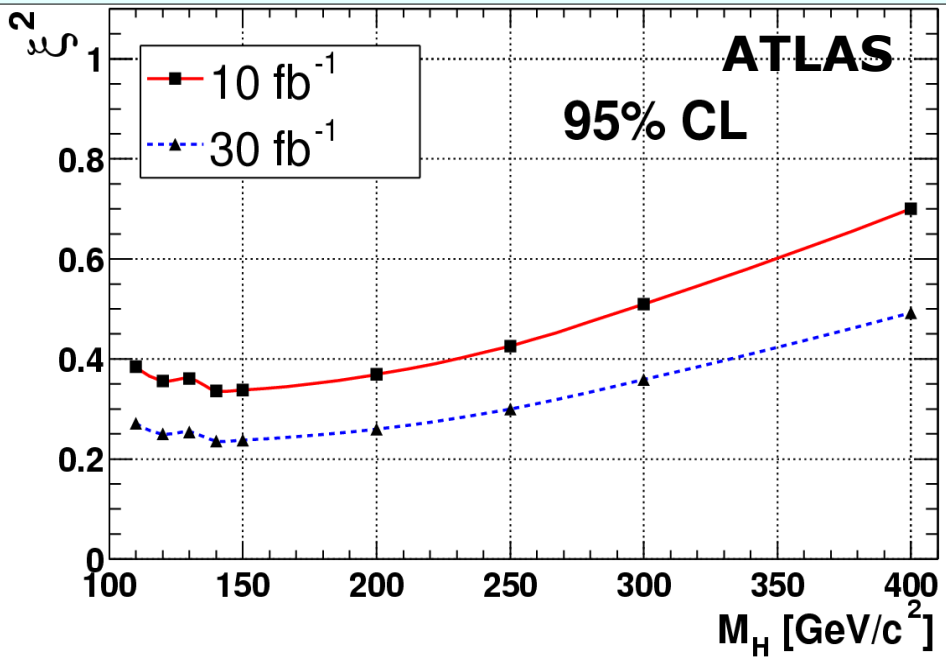
VBF, H→invisible

- 2 forward-jets in opposite hemispheres
- no major jet-activity in between
- large p_t^{miss}



- no mass peak: important to get background from data !
- major backgrounds:
  - Zjj, Z→νν (irreducible): estimate from Z→ee,μμ
  - Wjj, W→ℓν (missed lepton): est. from W→ℓν with id. lepton





Needs specific LVL1 "2 Jets +E_t^{miss}"-trigger !

Sensitivity to invisible Higgs

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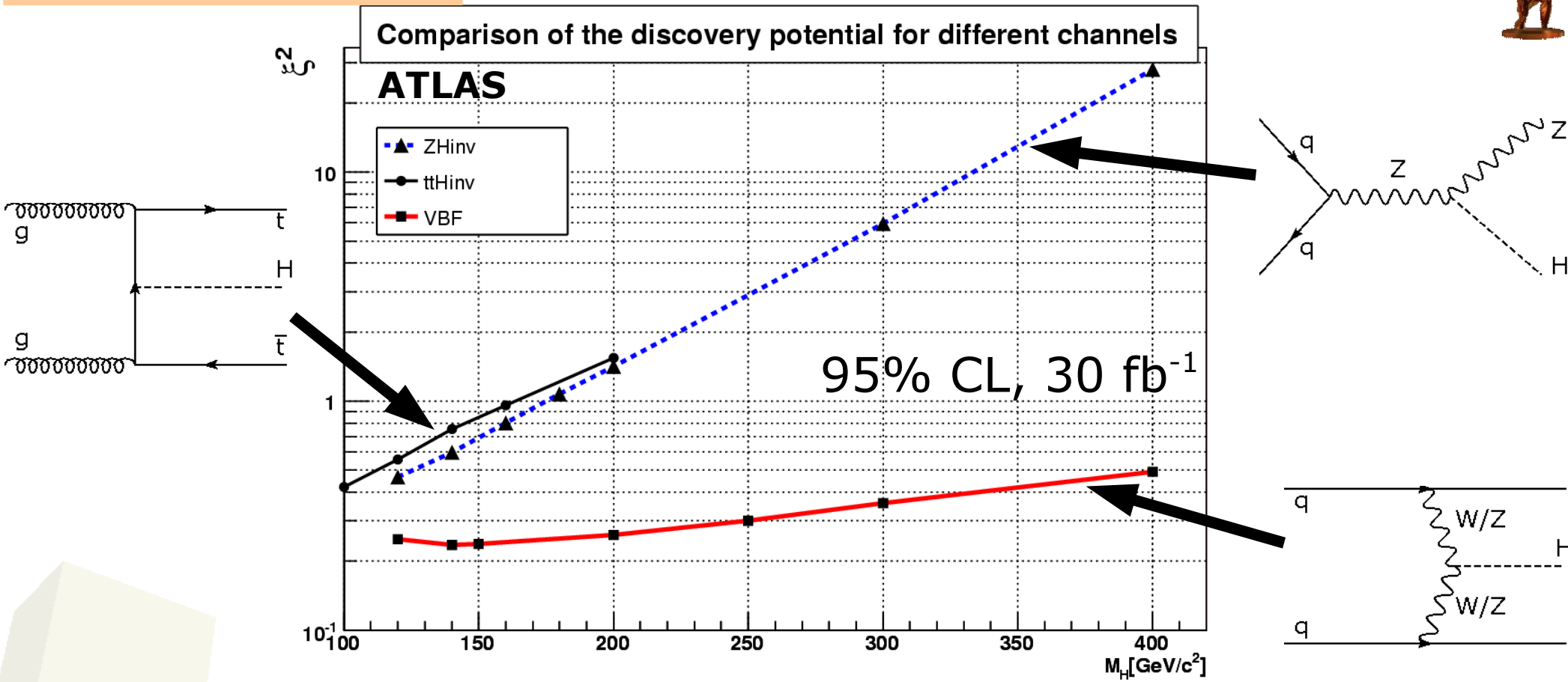
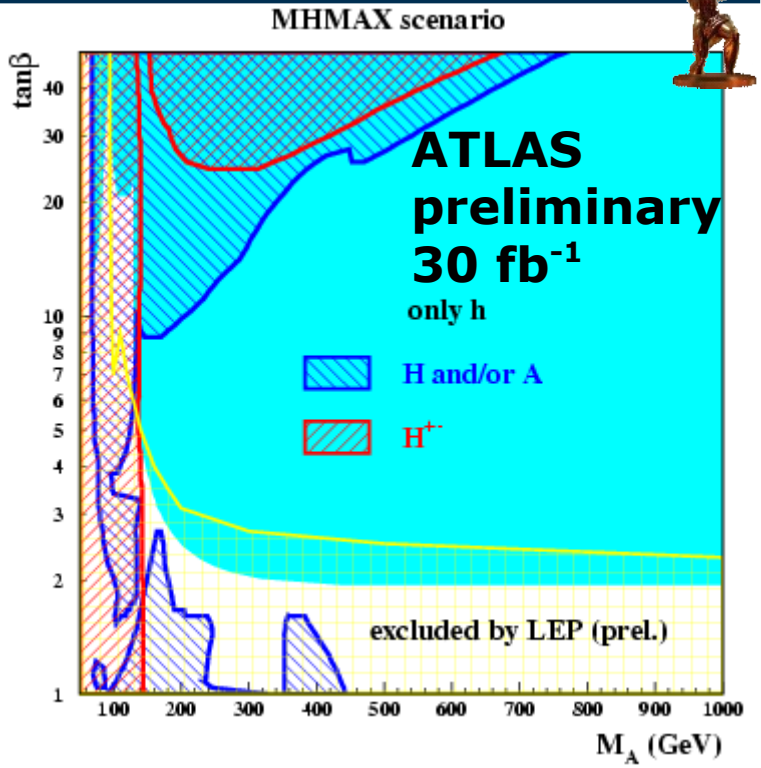


- **Only VBF channel sensitive to $\xi^2 < 1$ for all masses**
- **low masses: sensitivity in more than one channel**

Summary

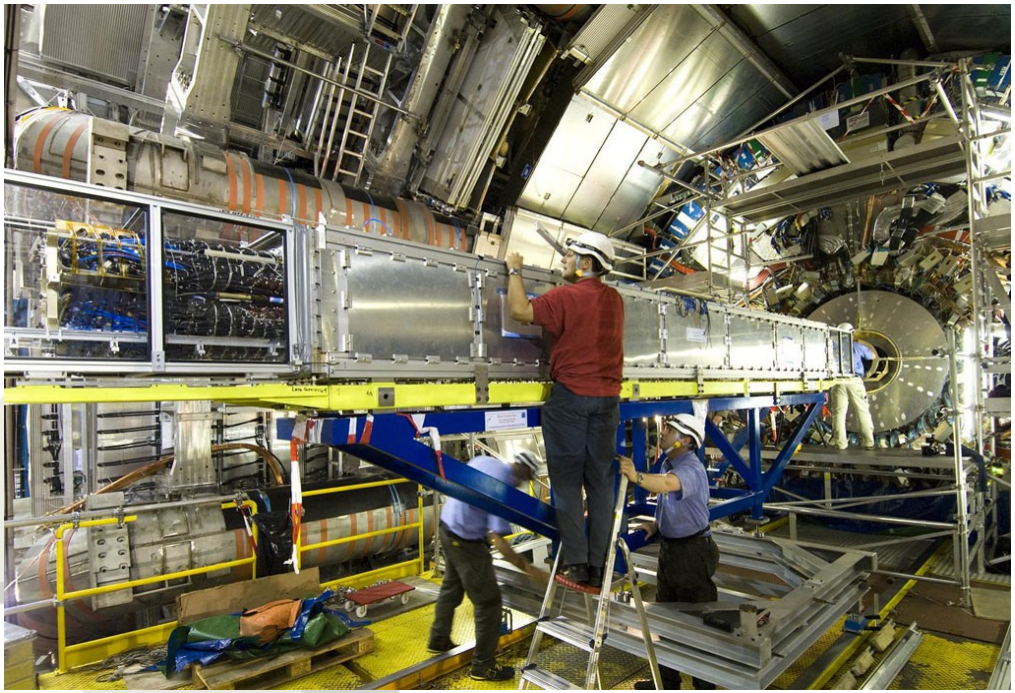
- **MSSM:**
  - CPC benchmark scenarios:
    - at least one Higgs boson observable for all parameters ($30fb^{-1}$ of good data)
    - large region where only h observable
    - difficult to distinguish from SM
  - new analysis for transition region in search for $H^{\pm}$
  - CPX-scenario:
    - small uncovered region (M_{H1}<50 GeV)



- **invisible Higgs:**
  - best sensitivity in vector boson fusion

Eagerly awaiting real data, ATLAS is getting ready !

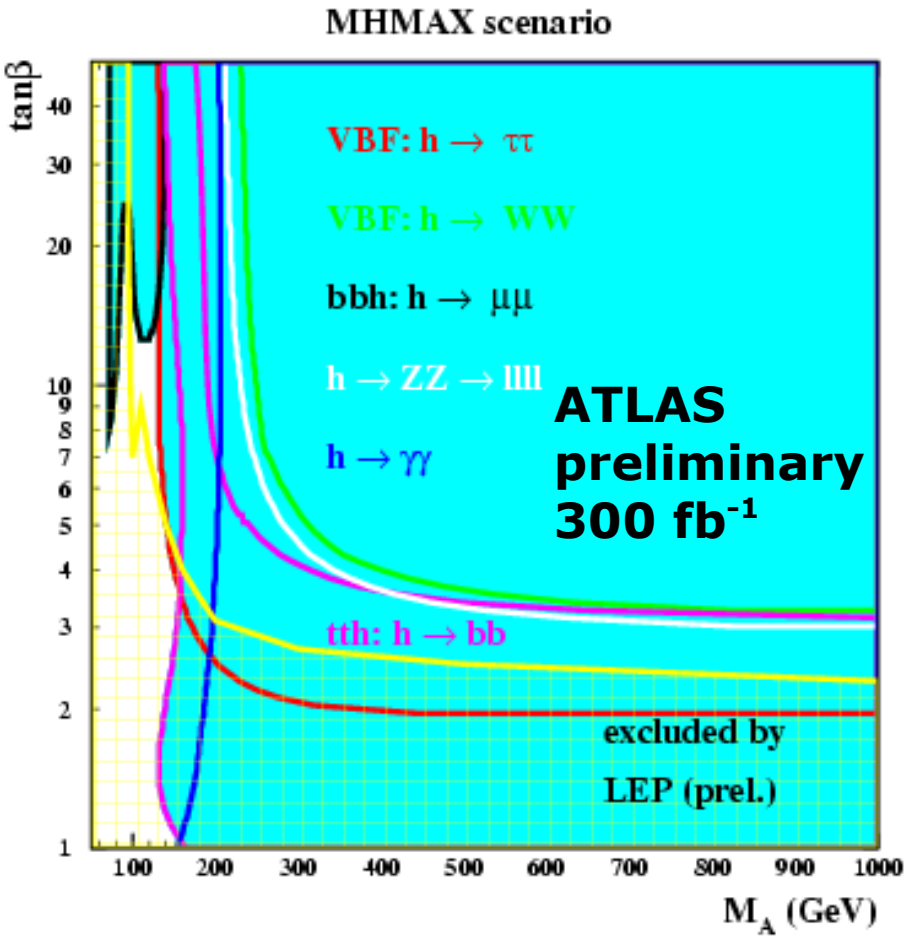
Insertion of pixel detector

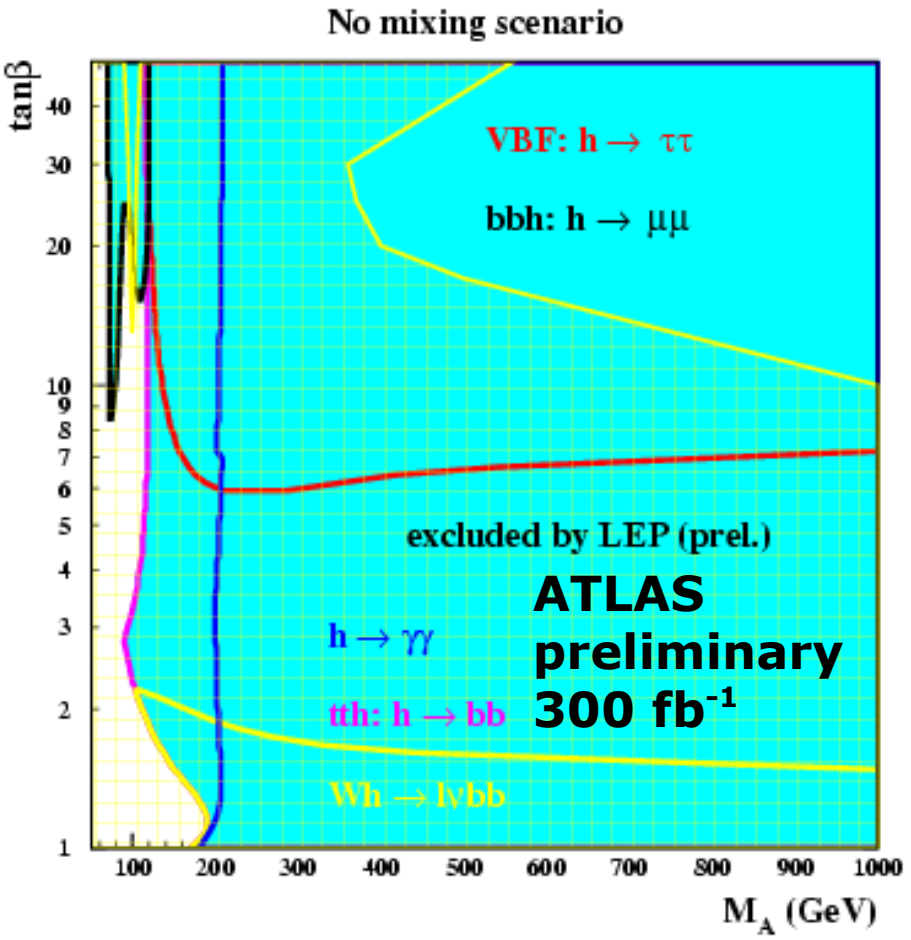


Lowering of endcap toroid

Backup slides

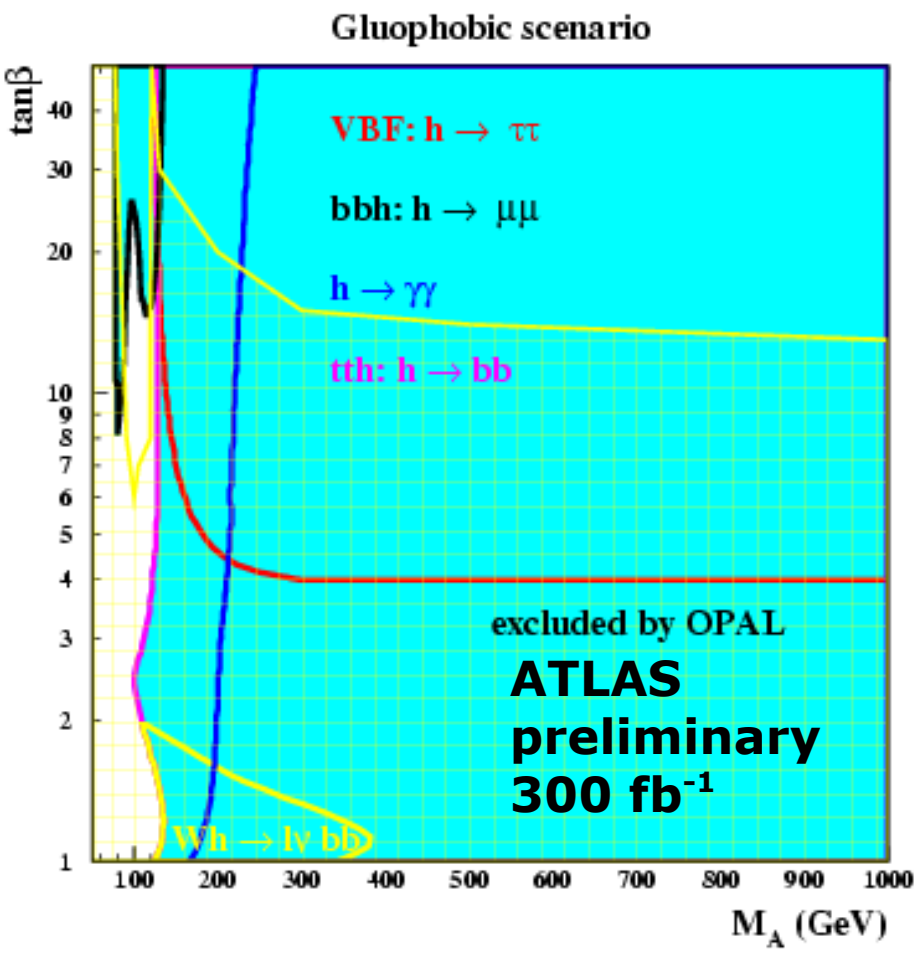
Discovery potential for h

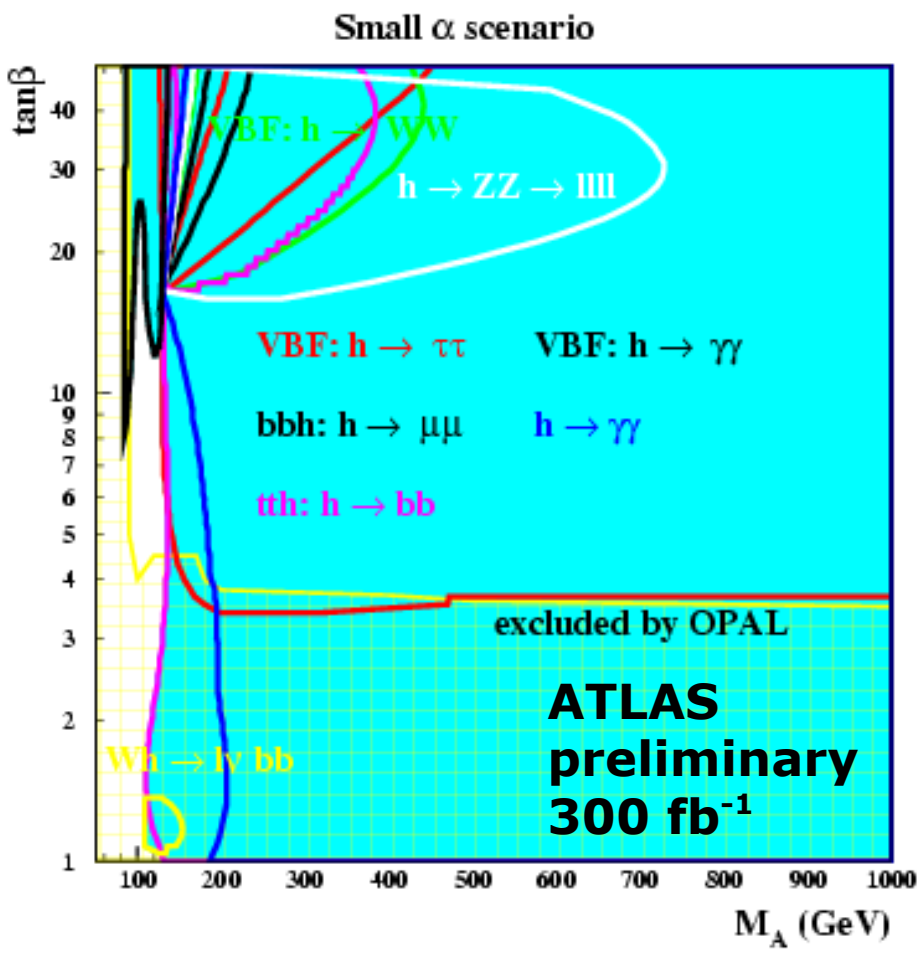




- almost same for other scenarios (differences mainly due to different M_h at same tanβ, M_A)
- large area covered by more than one channel !
- small uncovered region for small m_h
- here H/A will be visible !

Discovery potential for h



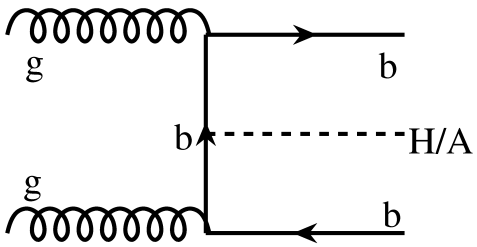


h→γγ contributes in gluophobic scenario via associated production (Wh, tth)

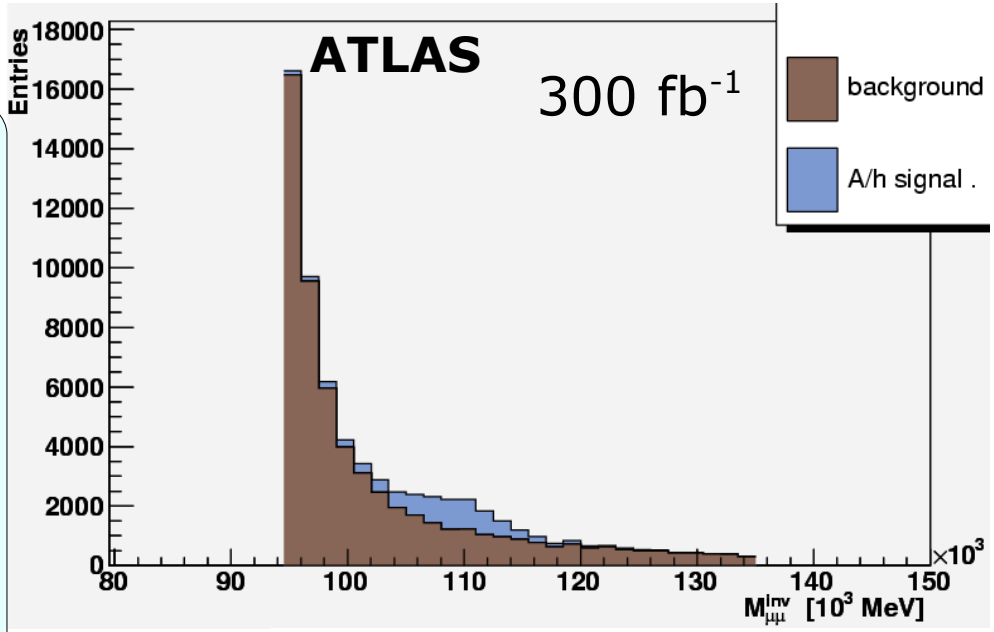
bbh/A→μμ

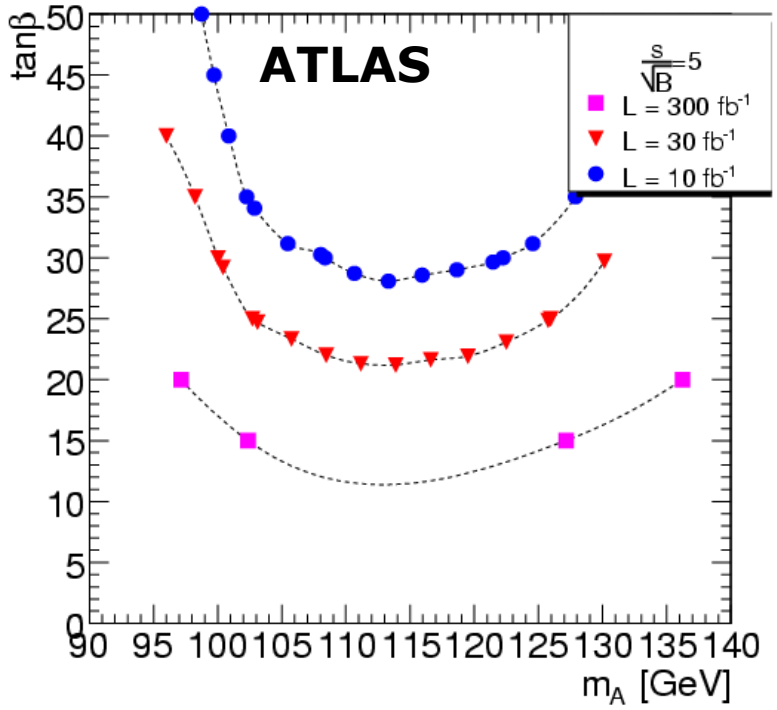
SN-ATLAS-2007-063

- New analysis based on full detector simulation
- b-associated production enhanced for high tanβ

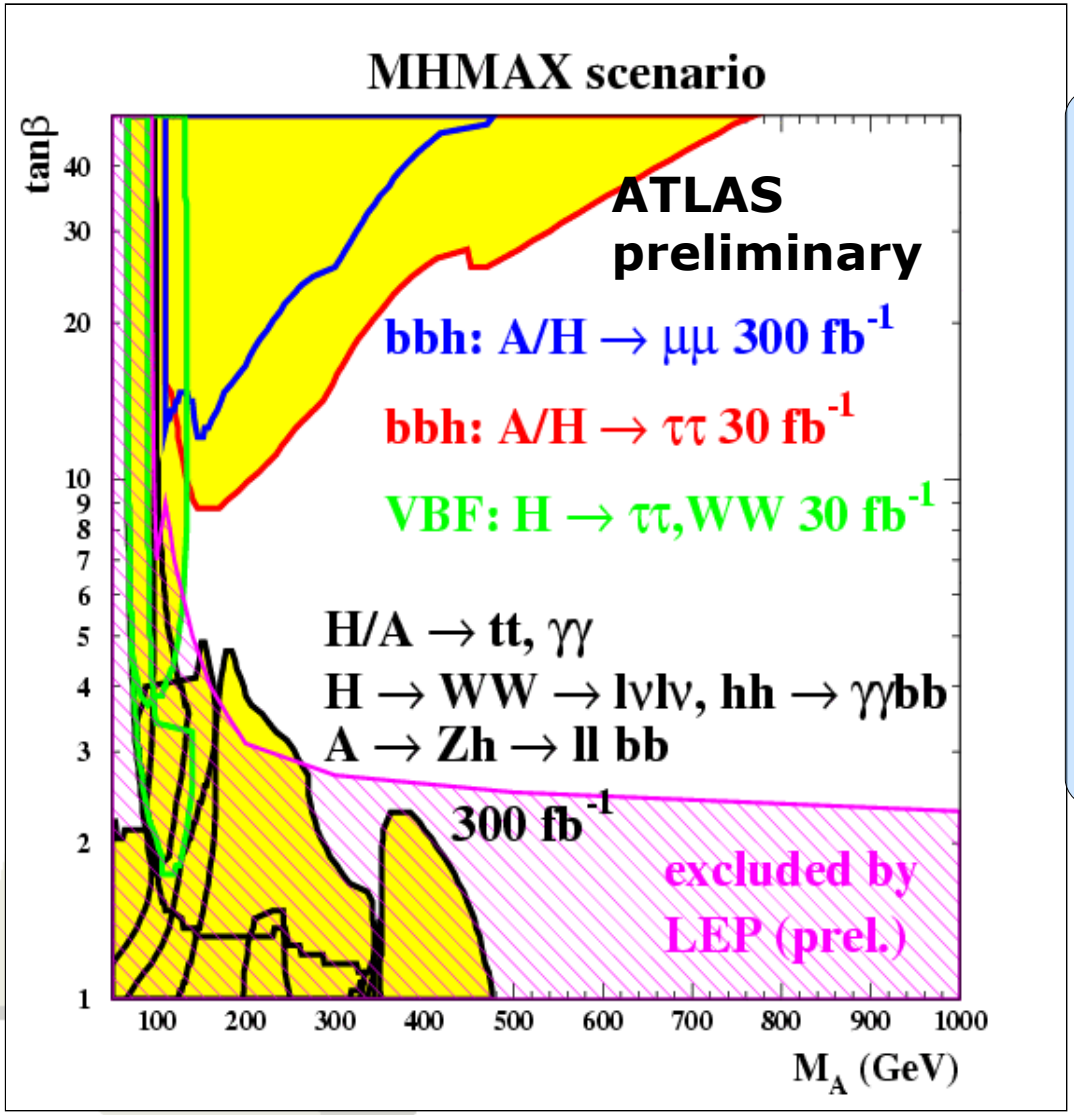


- main backgrounds:
  - Zbb
  - tt
- excellent mass resolution helps to compensate low BR

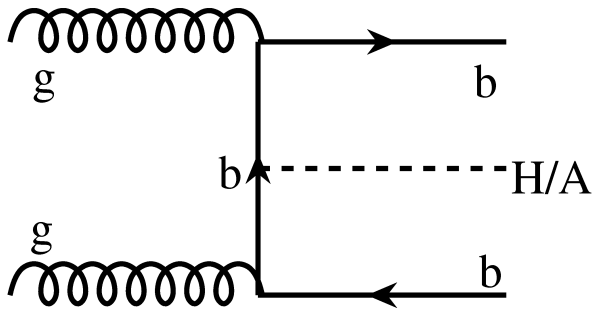




Heavy Neutral Higgs Bosons

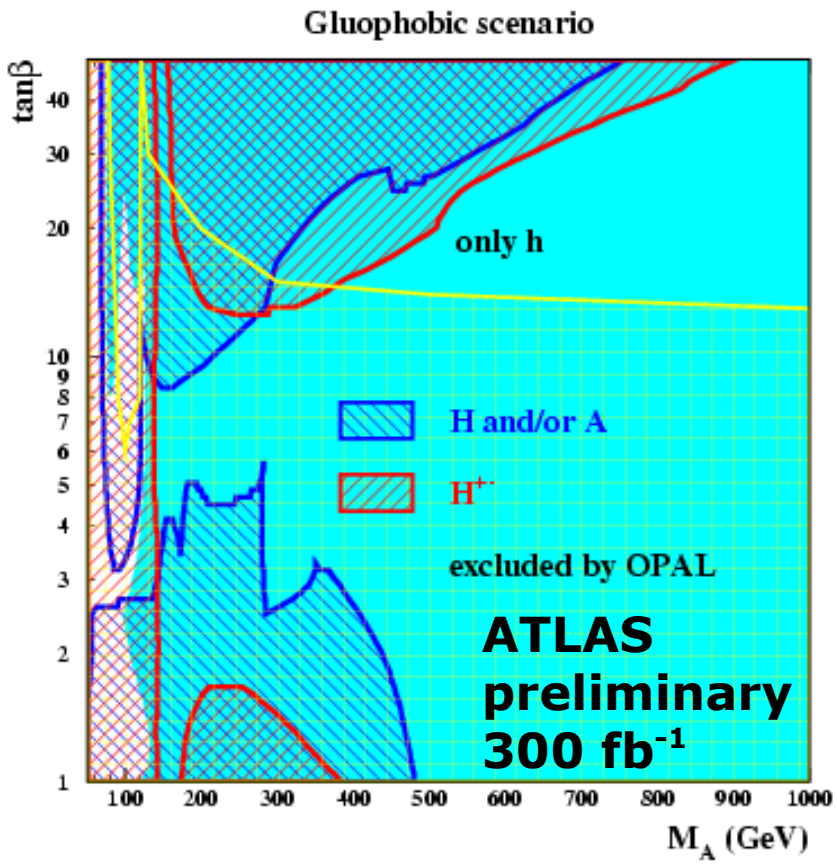


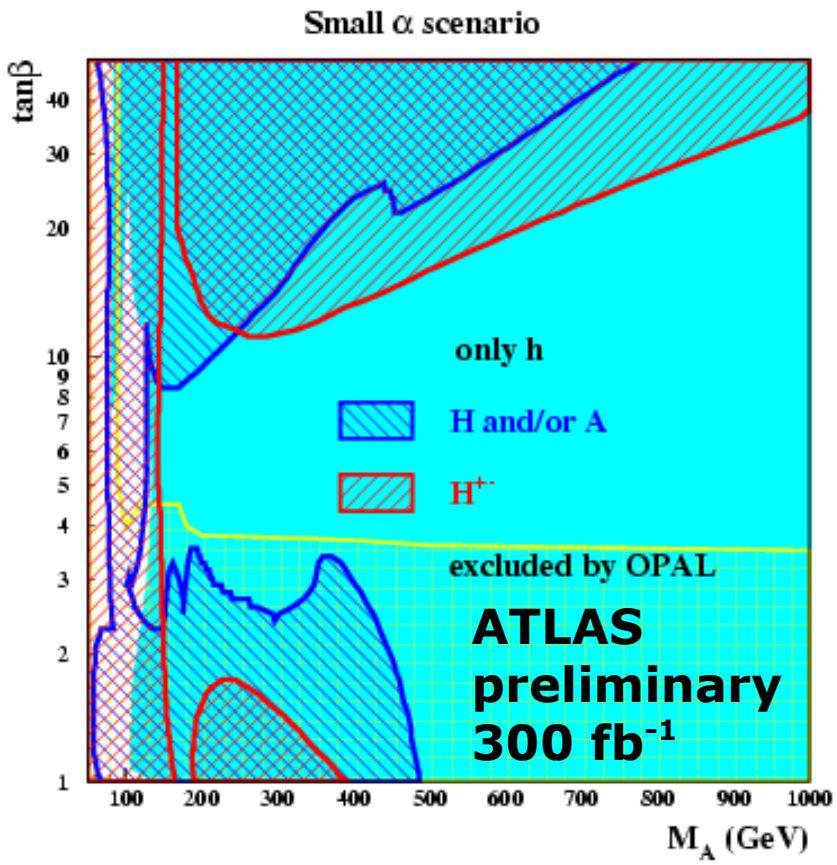
- low tanβ covered by multiple channels
- low masses covered by VBF
- closes hole in discovery reach for h
- high tanβ covered by b-associated production (enhanced coupling to b-quarks)



very similar in other 3 scenarios

backupOverall Discovery Potential II

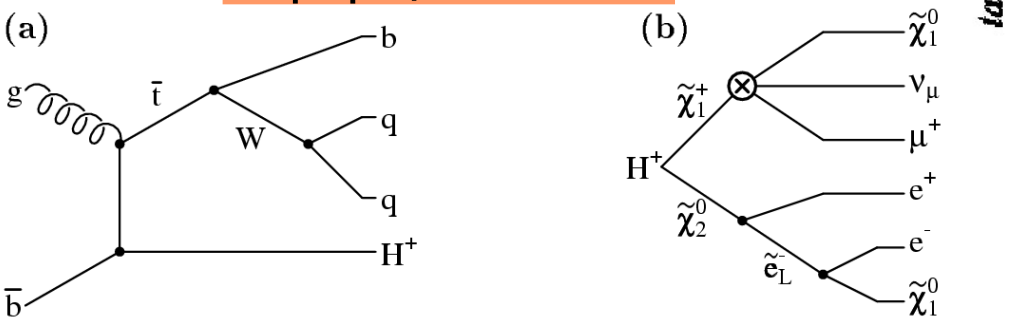




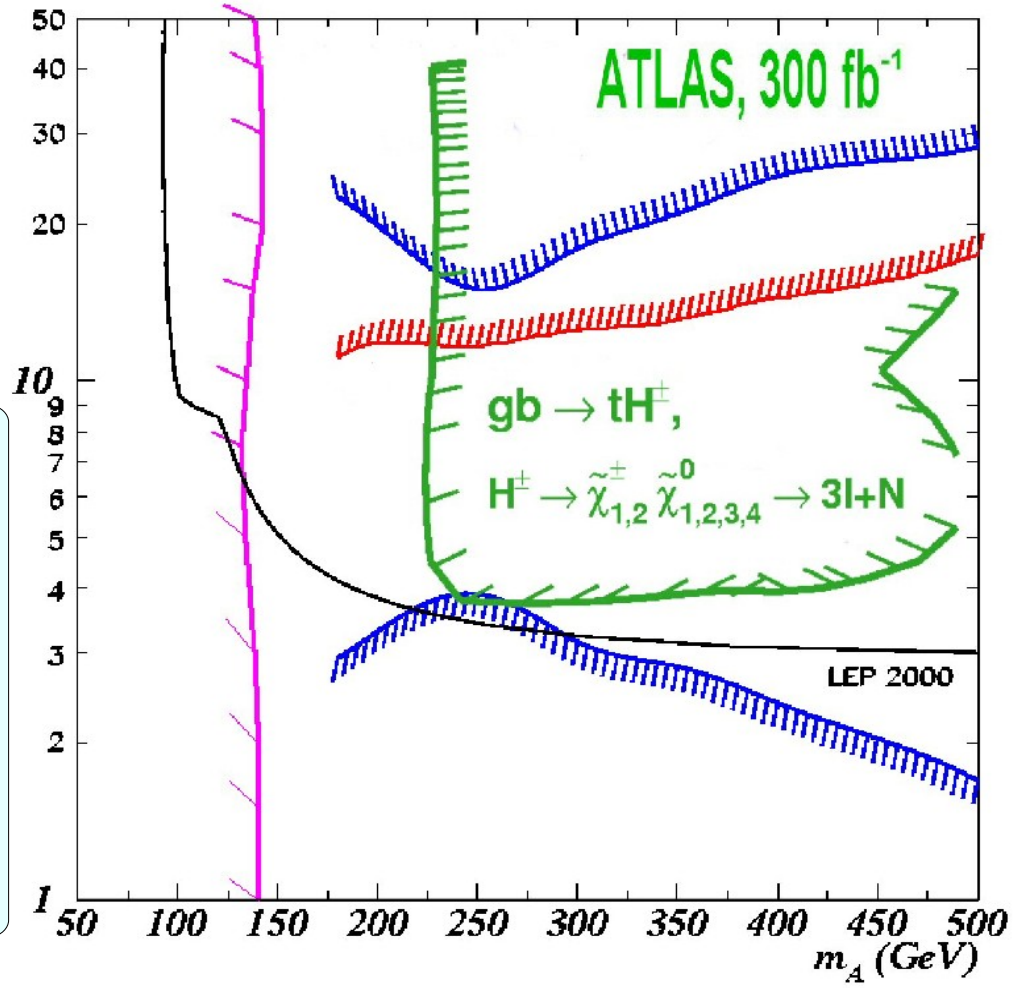
$H^{\pm} \rightarrow$ sparticles

No discovery potential for intermediate tanβ using only SM decays !

hep-ph/0504216



- $H^{\pm}$ → Neutralino Chargino
  → 3 leptons+Neutralinos
- highly tuned MSSM-point:
  - BR maximized
  - very low slepton-masses to maximize BR of Neutralino to leptons



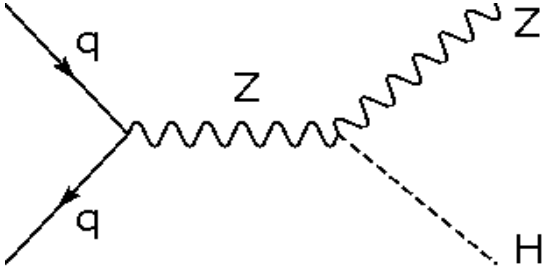
main backgrounds: tt, ttZ, ttH, SUSY

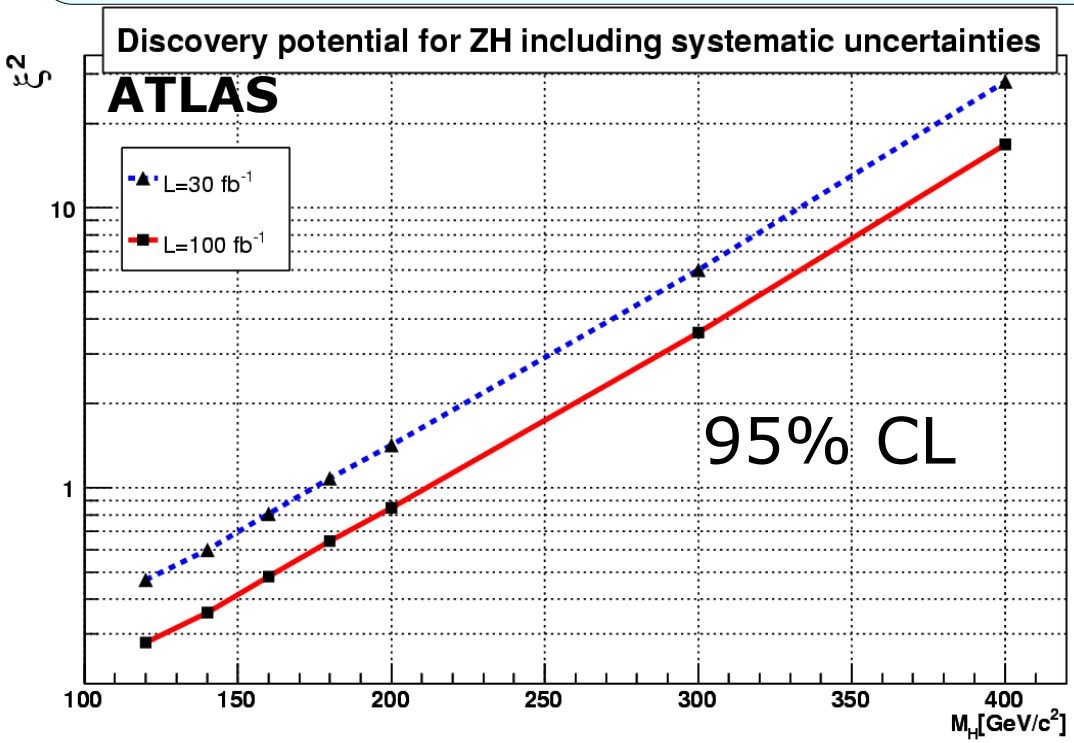
Other contours drawn for MHMAX scenario !

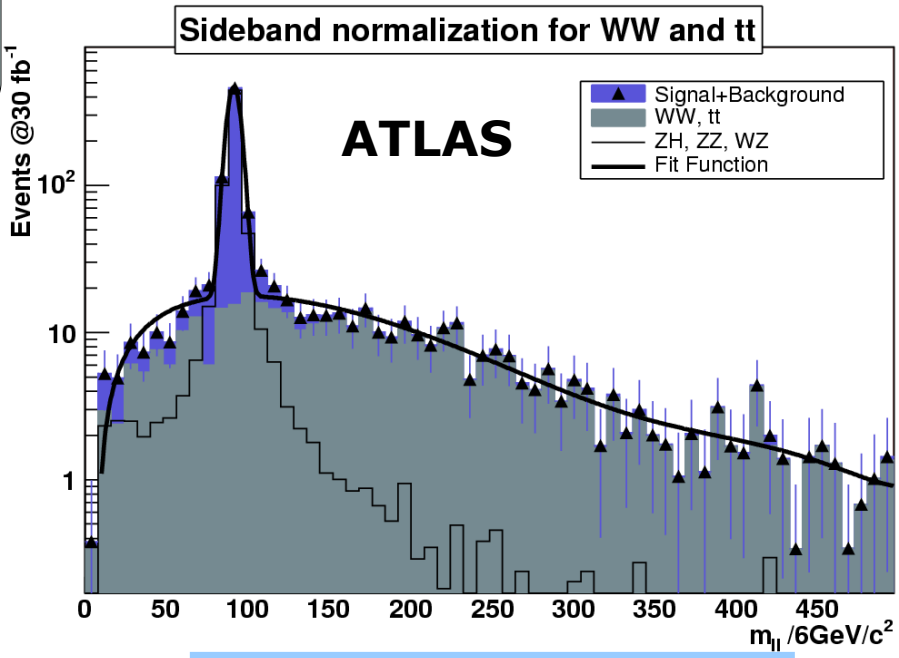
ZH, Z→ℓℓ, H→invisible

ATL-PHYS-PUB-2006-009
ATL-PHYS-PUB-2005-011

- **Main backgrounds:**
  - **ZZ→ℓℓνν (irreducible):**
    estimate from ZZ→4ℓ
  - **WZ→ℓℓℓν (missed lepton)**
    estimate from 3ℓ final states
  - **WW/tt:**
    estimate from sidebands



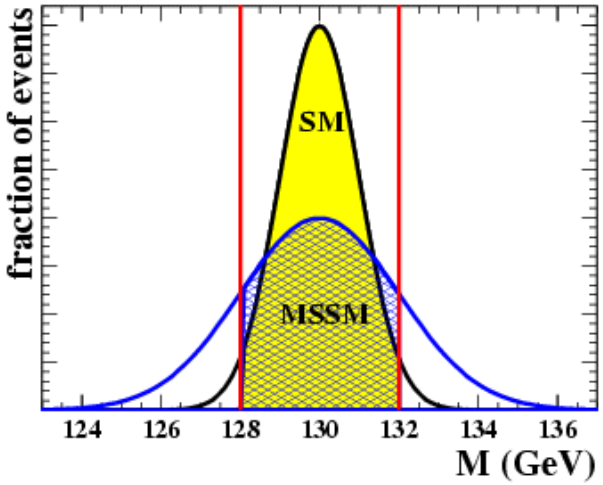




WH, H→inv. overwhelmed by bkg.

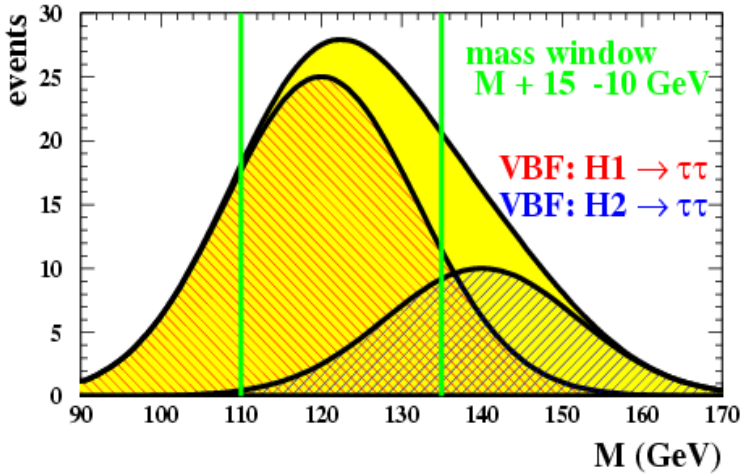
Technicalities

- masses, couplings, widths by Feynhiggs
- scaled SM-like cross sections with MSSM couplings, BRs
- efficiencies and background rates from published MC studies
- 5σ contours for 30 fb^{-1} and 300 fb^{-1} (some channels only 30 fb^{-1})
- corrections for degenerate Higgs masses and large Higgs widths
- only decays to SM-particles considered



$$K = \frac{\text{grid}}{\text{yellow}}$$

$$\varepsilon_{MSSM} = K\,\varepsilon_{SM}$$



Technicalities

$$
\begin{aligned}
\text{GGF}: \quad & \sigma_{MSSM} && = \frac{\Gamma(h(H,A) \to gg)_{MSSM}}{\Gamma(H_{SM} \to gg)_{SM}} \times \sigma_{SM} \\
\text{VBF}: \quad & \sigma_{MSSM}(h) && = \sin^2(\alpha-\beta) \times \sigma_{SM} \\
& \sigma_{MSSM}(H) && = \cos^2(\alpha-\beta) \times \sigma_{SM} \\
\text{W(Z)}\Phi: \quad & \sigma_{MSSM}(h) && = \sin^2(\alpha-\beta) \times \sigma_{SM} \\
& \sigma_{MSSM}(H) && = \cos^2(\alpha-\beta) \times \sigma_{SM} \\
\text{bb}\Phi: \quad & \sigma_{MSSM}(h) && = \sin^2(\alpha)/\cos^2(\beta) \times \sigma_{SM} \\
& \sigma_{MSSM}(H) && = \cos^2(\alpha)/\cos^2(\beta) \times \sigma_{SM} \\
& \sigma_{MSSM}(A) && = \tan^2(\beta) \times \sigma_{SM} \\
\text{tt}\Phi: \quad & \sigma_{MSSM}(h) && = \sin^2(\alpha)/\sin^2(\beta) \times \sigma_{SM} \\
& \sigma_{MSSM}(H) && = \cos^2(\alpha)/\sin^2(\beta) \times \sigma_{SM} \\
& \sigma_{MSSM}(A) && = \cot^2(\beta) \times \sigma_{SM} \\
\text{gb} \to \text{H}^{\pm}\text{t}: \quad & \sigma_{MSSM} && = [(M_b \tan\beta)^2 + (M_t \cot\beta)^2] \times \sigma_{SM}
\end{aligned}
$$

Contributing Analyses

channel	lumi	mass range	publication
VBF, H→ττ,WW,γγ	low	M>110 GeV	SN-ATLAS-2003-024
ttH, H→bb *	low+high	M>70GeV	ATL-PHYS-2003-003
bbH/A→μμ	low+high	70<M<135GeV M> 120 GeV	ATL-PHYS-2002-021 ATL-PHYS-2000-005
bbH/A→ττ: ττ→lep.had ττ→had. had.	low low	M >120 GeV M > 450 GeV	ATL-PHYS-2000-001 ATL-PHYS-2003-009 ATL-PHYS-2003-003
WW→lνlν	low+high	140<M <120GeV	ATL_PHYS-2000-015
H→γγ	low+high	M > 70 GeV	TDR
ZZ→4l	low+high	M > 100 GeV	TDR
A→Zh→llbb, H→hh→γγ bb	low+high	60 <ML<130 100<MH<360	TDR TDR
H/A→tt	low+high	M > 350 GeV	TDR
gb→tH+-, H→τν,tb	low+high	M >180 GeV	SN-ATLAS-2002-017
tt→bW bH+-, H+-→τν	low	M < 170 GeV	ATL-PHYS-2003-58/TDR