Contents

Higgs bosons in supersymmetric models

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The content of this talk is the result of the work of many people in CMS and ATLAS, many thanks to all involved

MSSM Higgs Bosons

- In MSSM/2HDM five Higgs particles are predicted, three neutral and two charged
- if CP is conserved

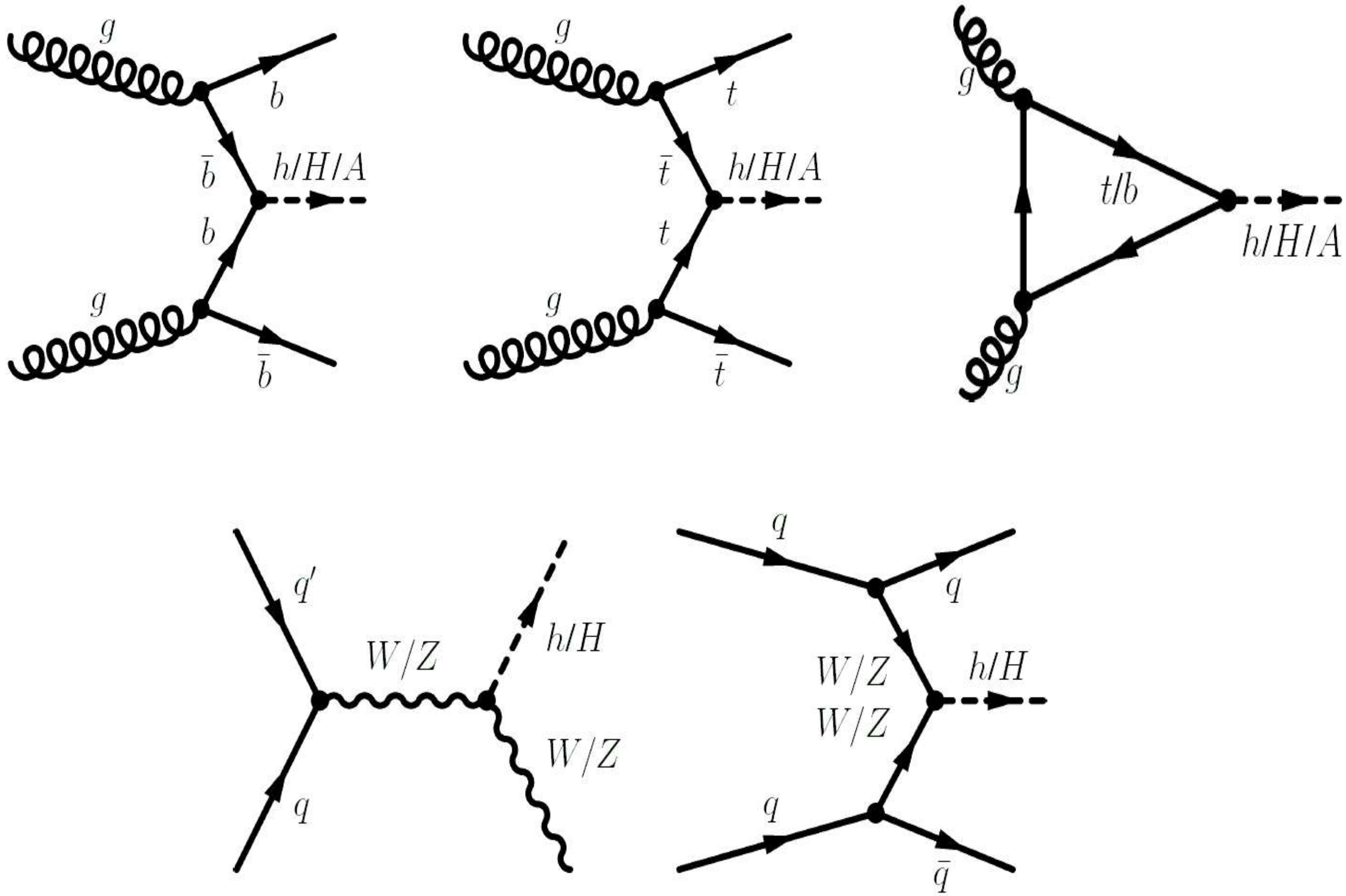
	h		H	A	$H^{\pm}$
Mass	m_h	<	m_H	m_A	$m_{H\pm}$
CP	even		even	odd	/

- Properties to tree level given in terms of two parameters, usually the mass of the CP-odd neutral Higgs A and tanβ, at born level : $m_h < m_Z$
- large loop corrections from SUSY breaking parameters X_t, M_0, M_2, M_{gluino}, μ
- e.g. m_h<~133 GeV, for m_{top}=175 Gev, M_{SUSY}= 1 TeV
- definition of five benchmark scenarios, in terms of these paramters
- couplings: $g_{MSSM}=\xi\ g_{SM}$ (α = mixing between the CP even, neutral Higgs bosons)

ξ	t	b/τ	W/Z
h	cosα/sinβ	-sinα/cosβ	sin(α-β)
h	cosα/cosβ	sinα/sinβ	cos(α-β)
A	cotβ	tanβ	---

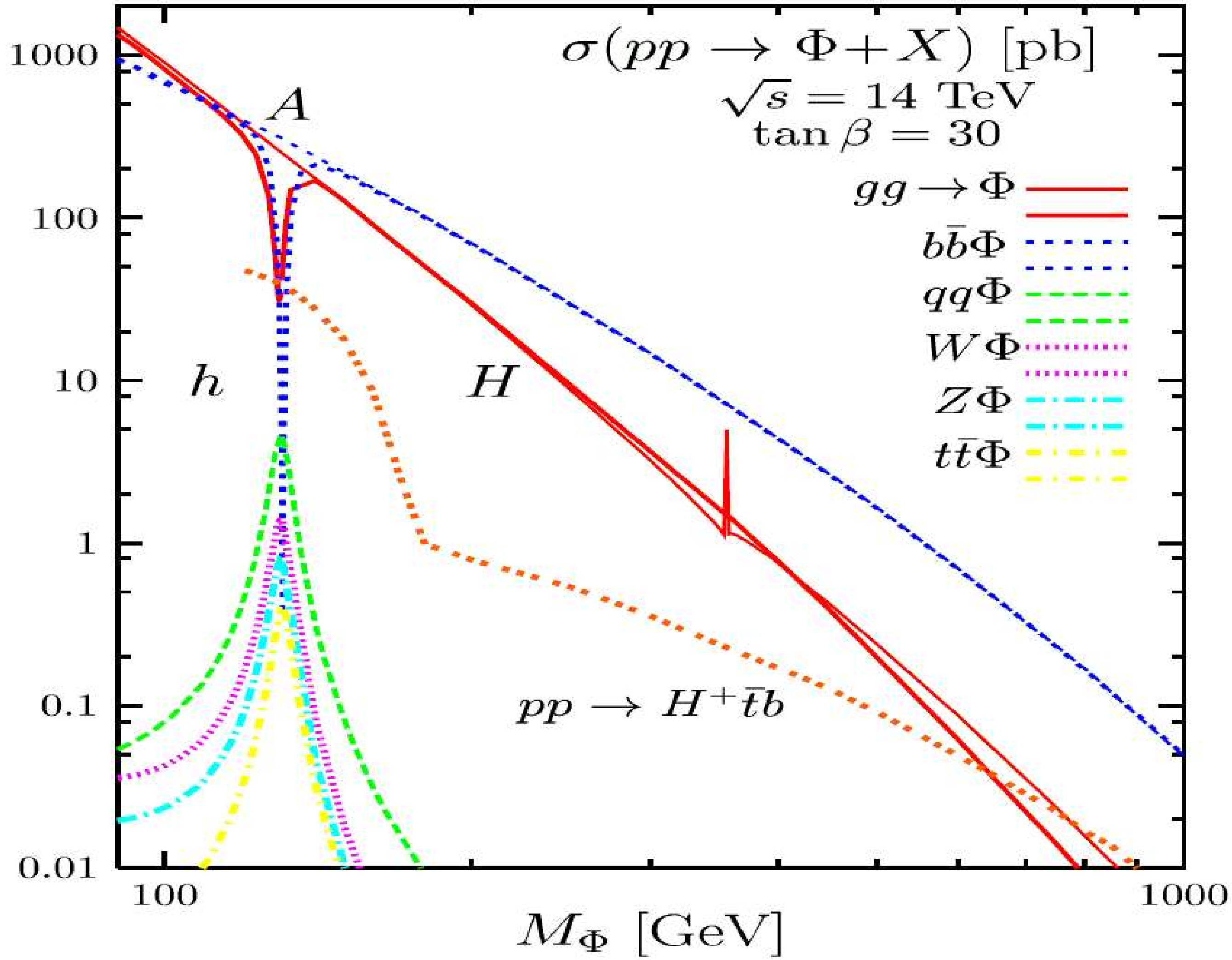
- no coupling of A to W/Z
- small α → small coupling h→ττ, h→bb
- large β → large coupling h, H, A → ττ, bb

MSSM Higgs Bosons



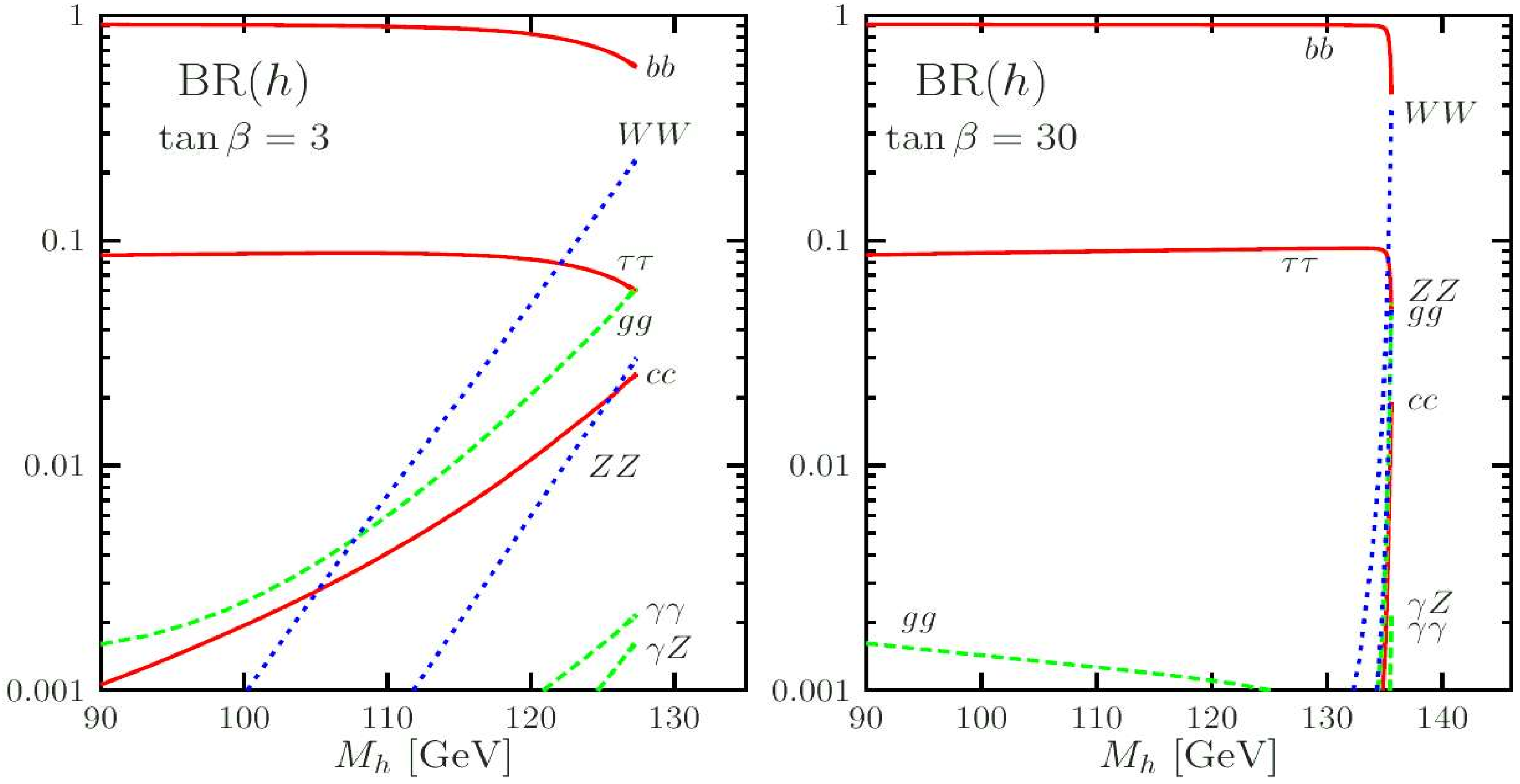
- main production mechanism ~ SM
- for high tanβ the production in association with b quarks is enhanced
- A,H,$H^{\pm}$ cross section ~ $\tan^2\beta$

Production cross sections



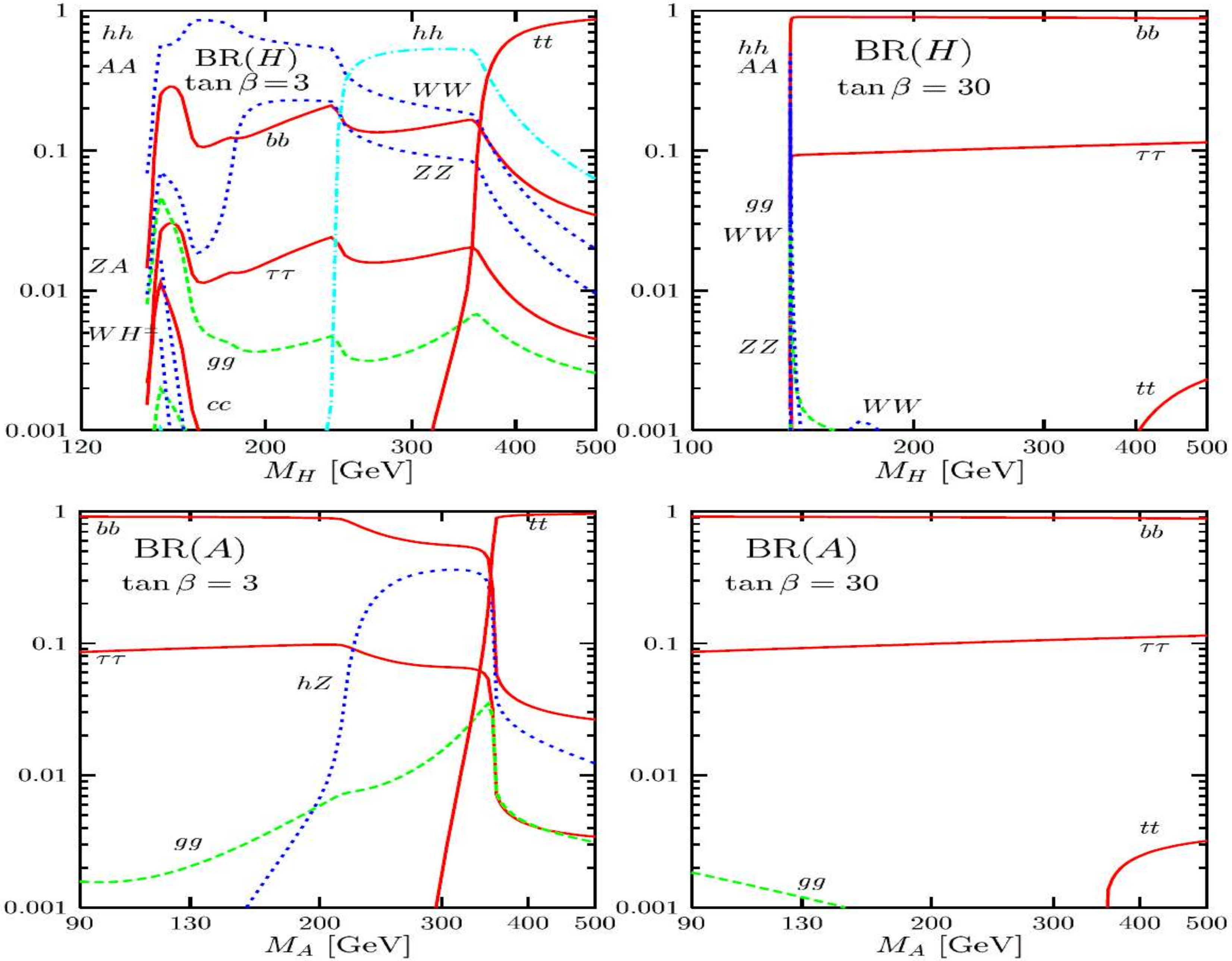
- for high tanb, b associated production dominates
- for $m_A >> m_Z$ A/H behave very similar → decoupling region

Branching ratios (h)



- decay to bb dominates, followed by ττ
- gg also present for m_h>120 GeV, BR~10^{-3}

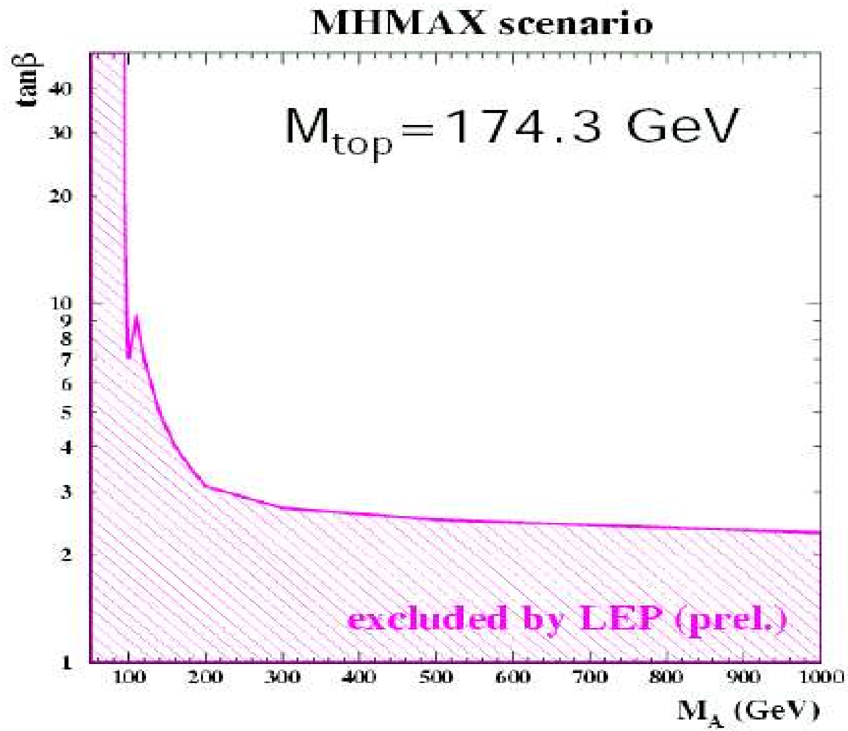
Branching ratios (A,H)



- generally decay to bb dominates, followed by ττ
- for low tanβ many available decay channels

LEP and Tevatron

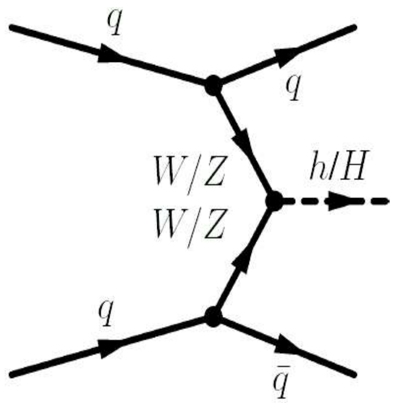
- general strategy : use the analysis set up for SM in the MSSM case
- questions to be answered for the LHC
  - Is at least 1 Higgs boson observable in the entire parameter space ?
  - How many Higgs bosons can be observed ?
  - Can we discriminate the SM from the MSSM ?
- Input from LEP
  - no exclusion of tanβ for m_t > 183 GeV



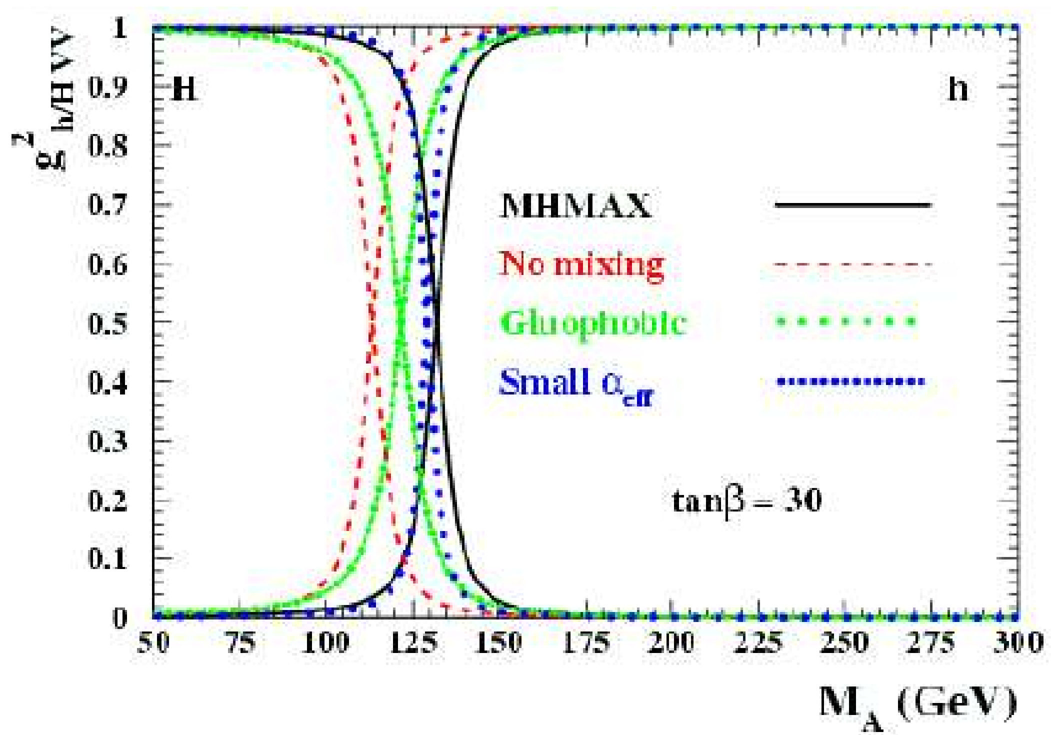
- from Tevatron
  - tanβ > 50, m_A < 200 GeV
- four benchmark scenarios considered

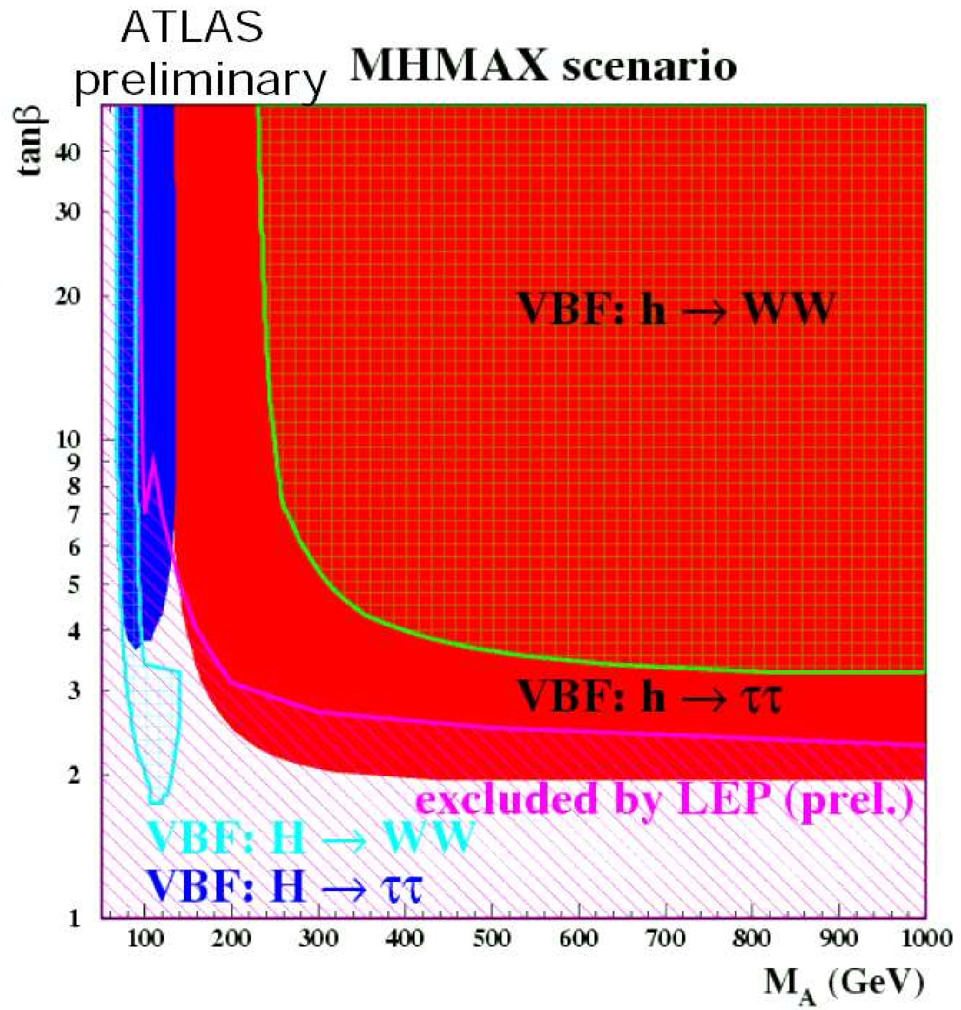
	Benchmark parameters			
	(1) $m_h - max$	(2) *no-mixing*	(3) *gluophobic*	(4) *small-*α_{eff}
M_{SUSY} (GeV)	1000	1000	350	800
M_2 (GeV)	200	200	300	500
μ (GeV)	−200	−200	300	2000
$m_{\tilde{g}}$ (GeV/c²)	800	800	500	500
X_t (GeV)	2 M_{SUSY}	0	−750	−1100
A (GeV)	$X_t+\mu \cot\beta$	$X_t+\mu \cot\beta$	$X_t+\mu \cot\beta$	$X_t+\mu \cot\beta$
arg(A)=arg($m_{\tilde{g}}$)	-	-	-	-

Vector Boson Fusion



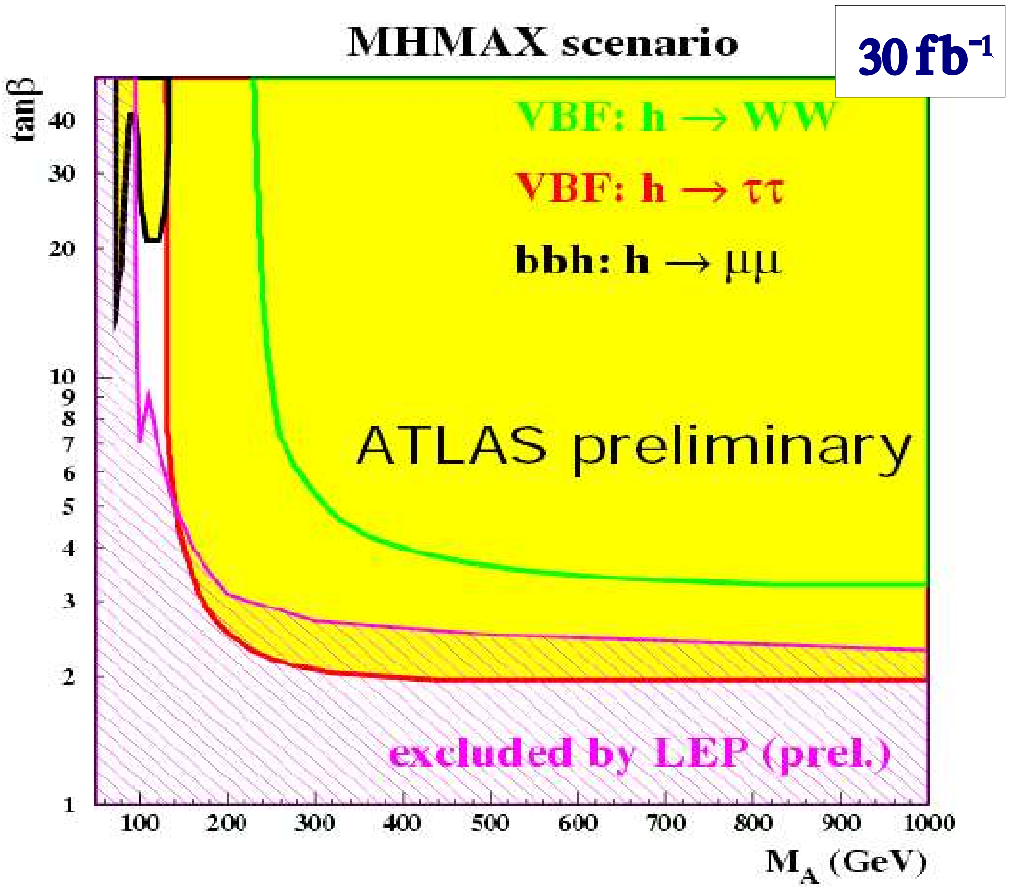
- Analysis same as in the SM case
- production of a light (h) or heavy (H) CP-even Higgs boson together with two separated forward "tagging" jets
- coupling is either high for light or heavy Higgs
- either light or heavy Higgs observable for $\int L dt = 30 fb^{-1}$

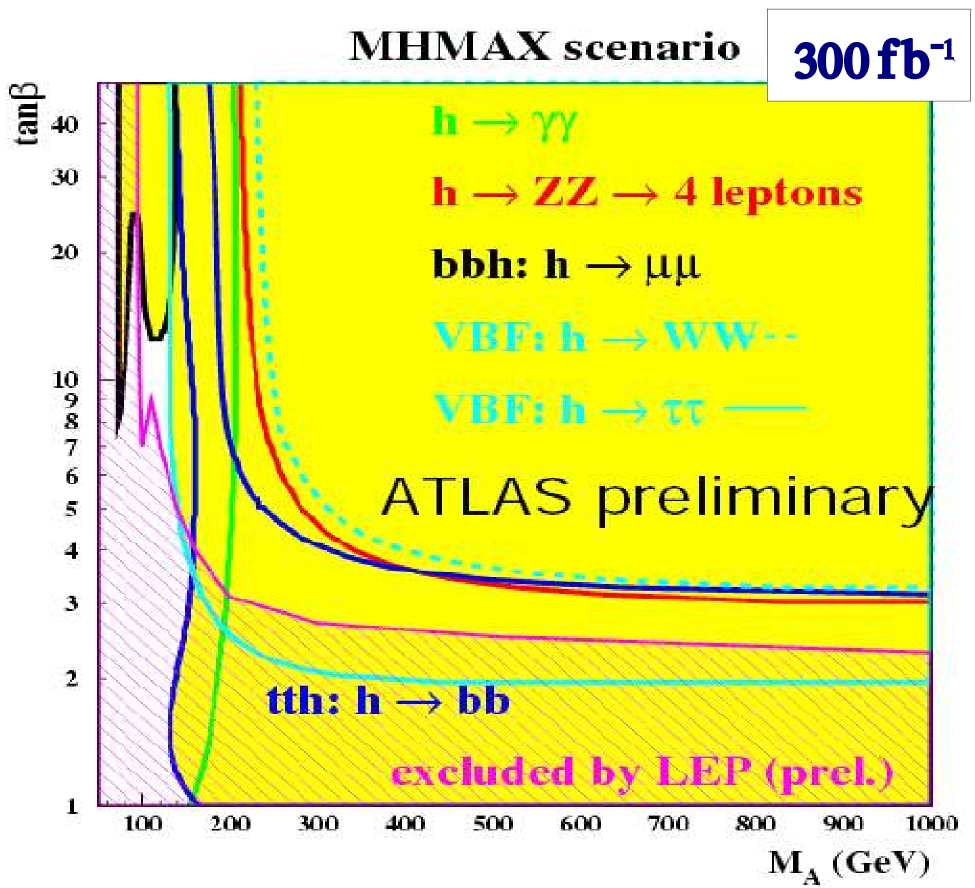




light Higgs boson

- VBF dominates for low luminosity
- small area from bbh→μμ
- large space covered by several channels
- determination of parameters possible
- small are m_h ~ 95 GeV uncovered





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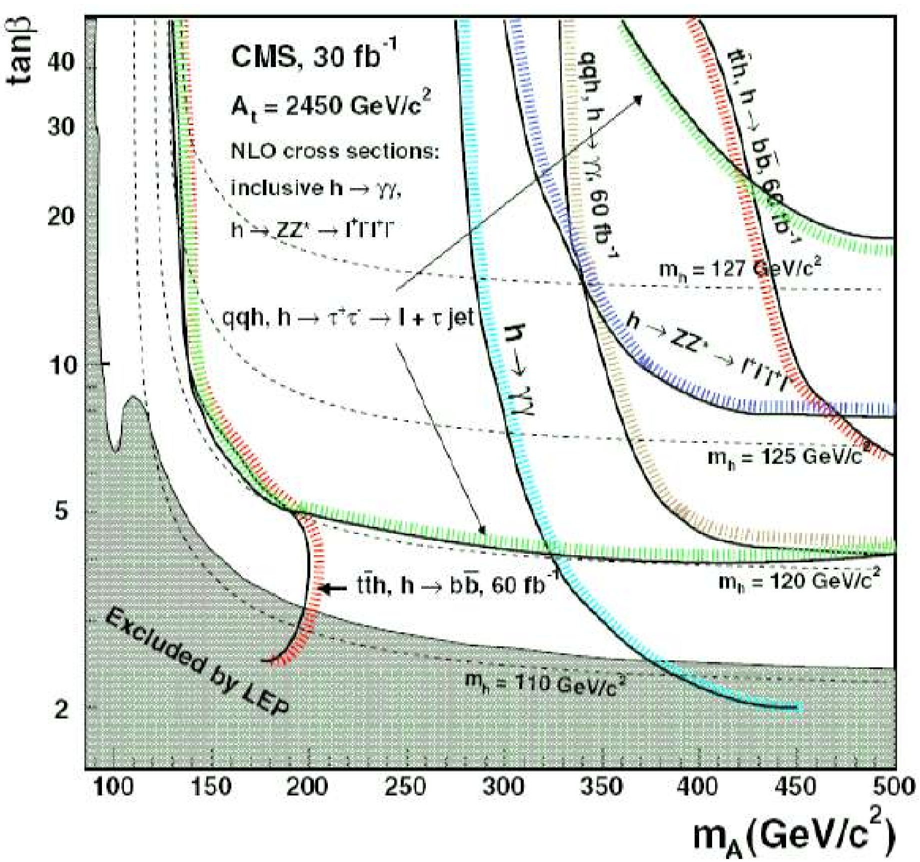
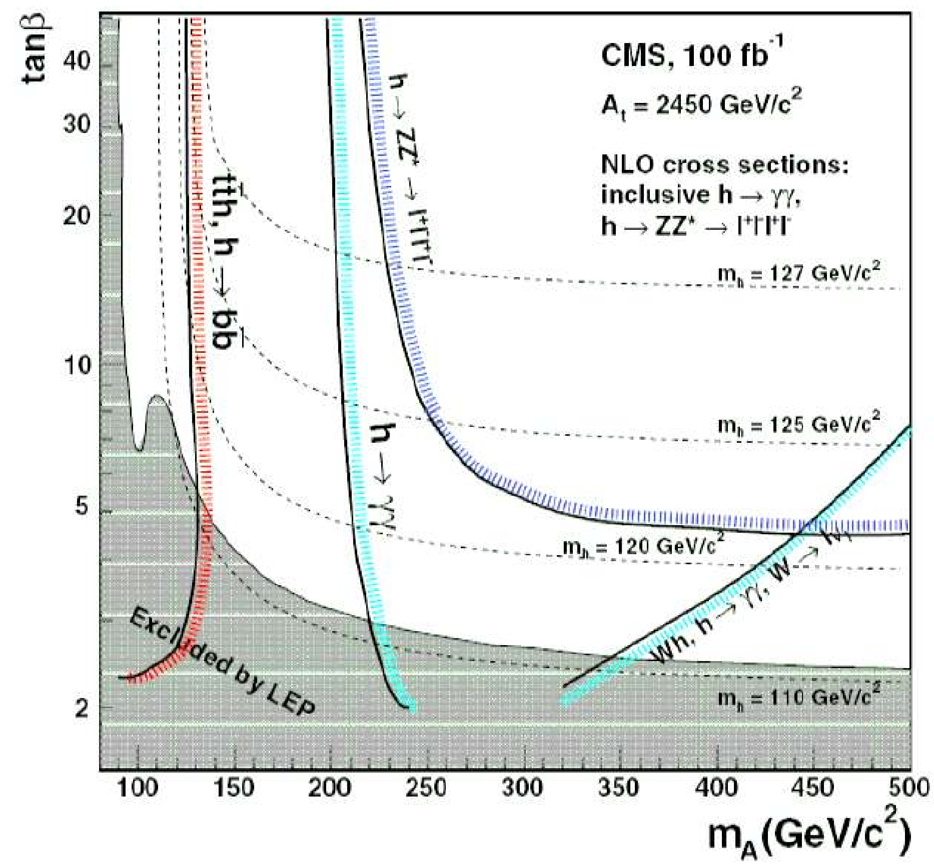
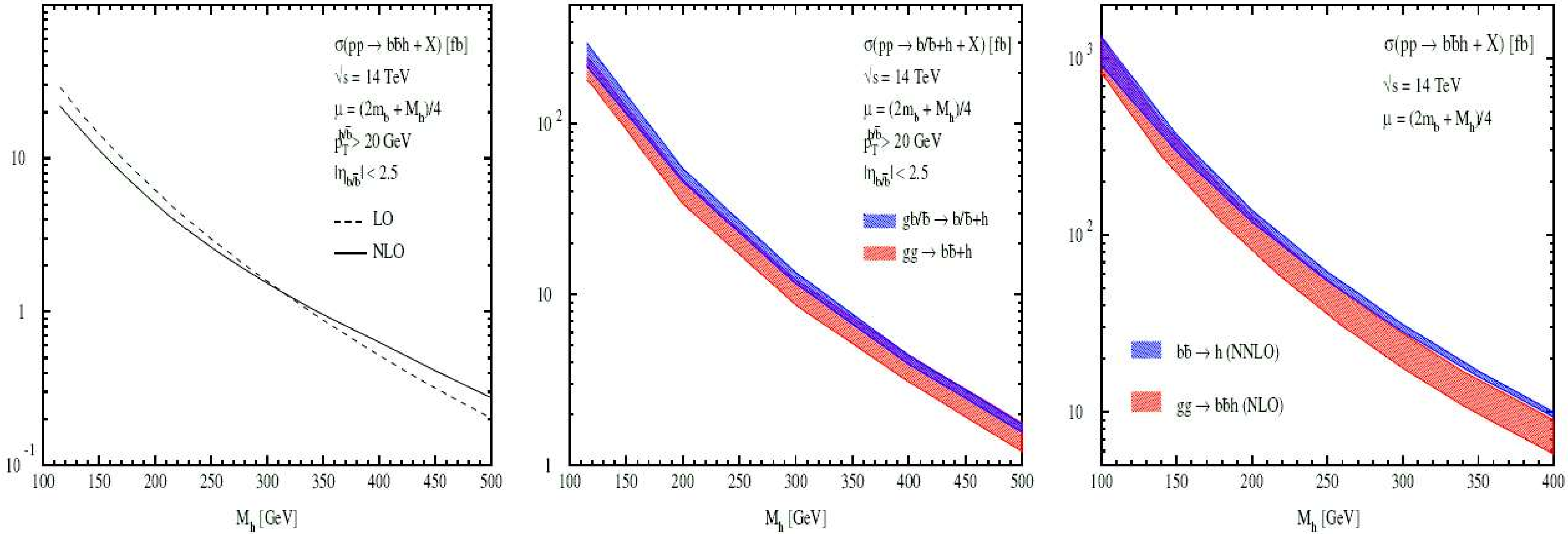


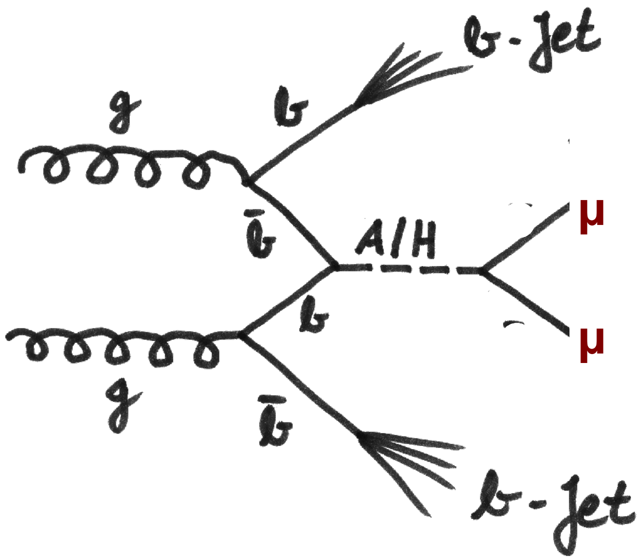


Neutral heavy Higgs bosons

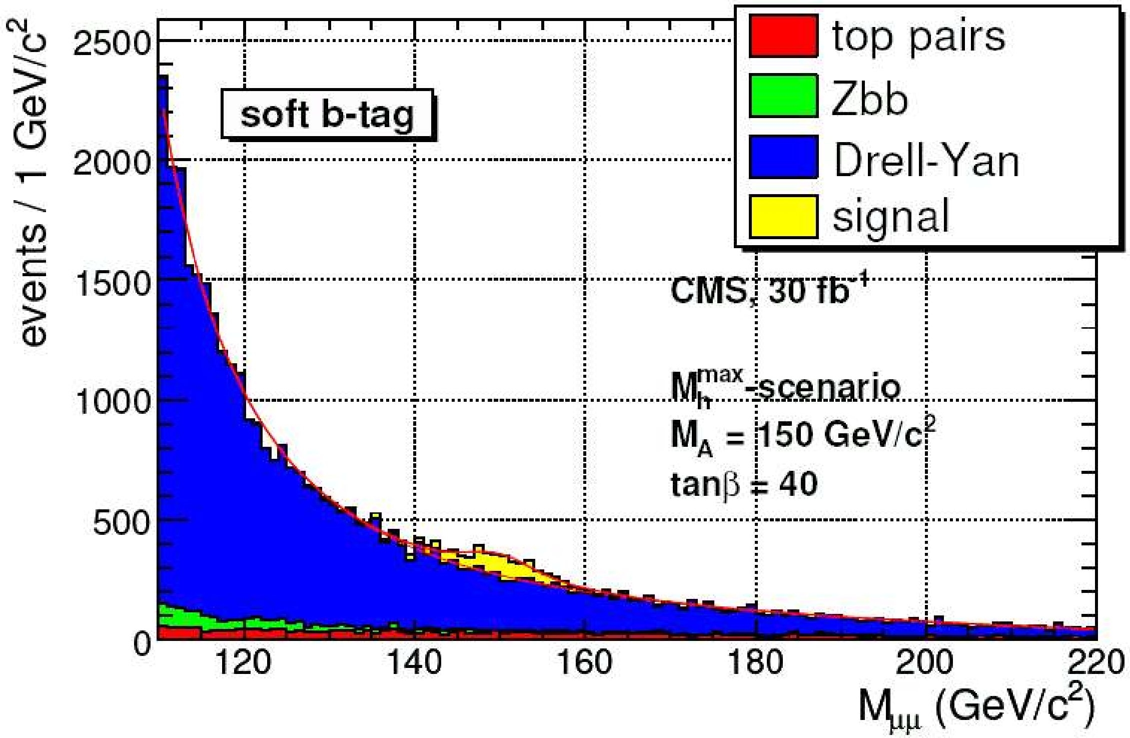


- open questions on the treatment of the production
- several possibilities bb→A/H, gb→bA/H, gg→bbA/H
- differences resolved if calculated to higher orders (partly up to NNLO)
- only born level Monte Carlos available
- use of SHERPA under inverstigation
- similar question for the important background Z + jet production

A/H→μμ

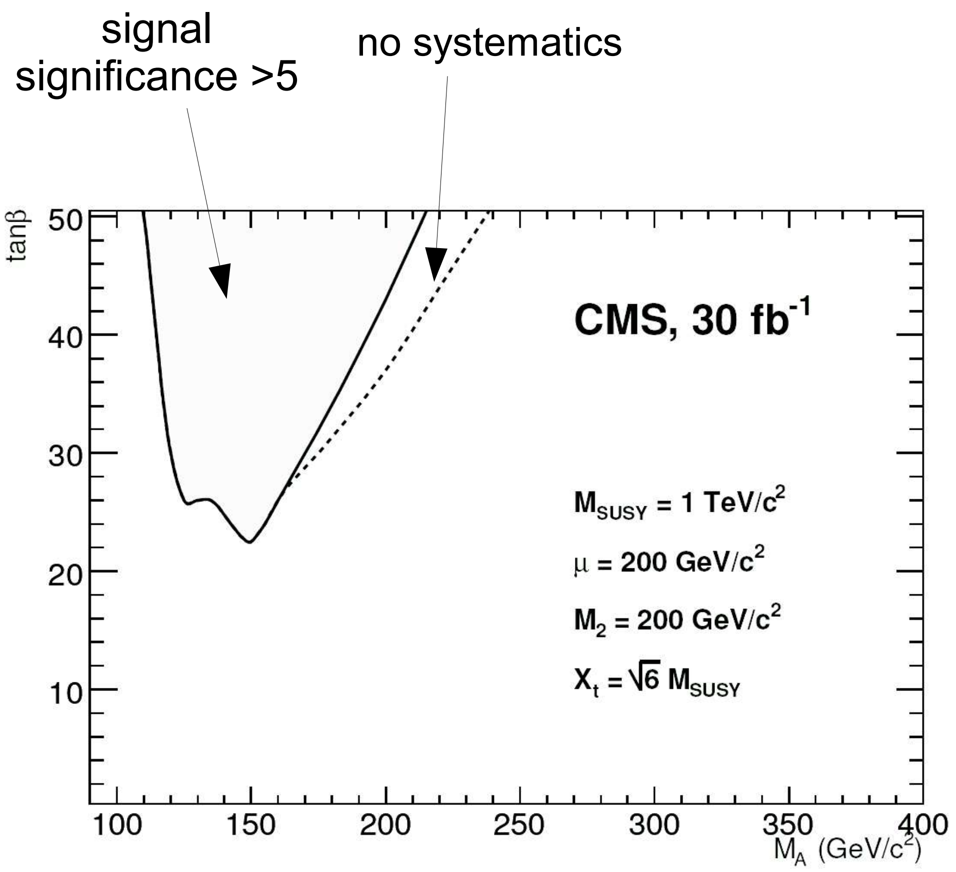


- two opposite sign muons
- two jets (≥1b)
- $M(\mu^+\mu^-)$ +/- ΔM
- ETMiss < cut



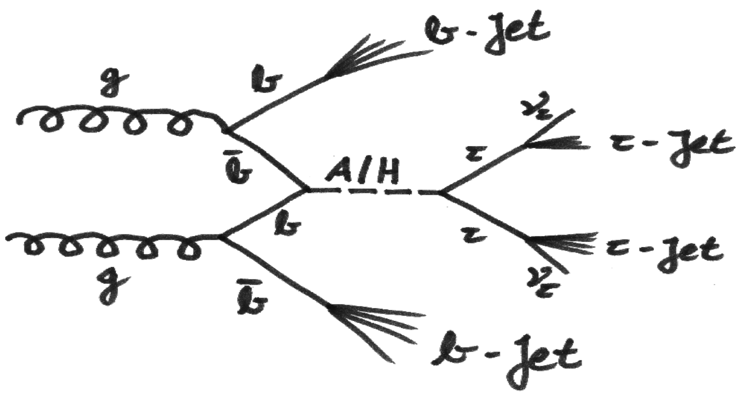
- b-tagging to suppress Drell-Yang background
- signal fitting crucial to reduce dependence on the Monte Carlo

A/H→μμ



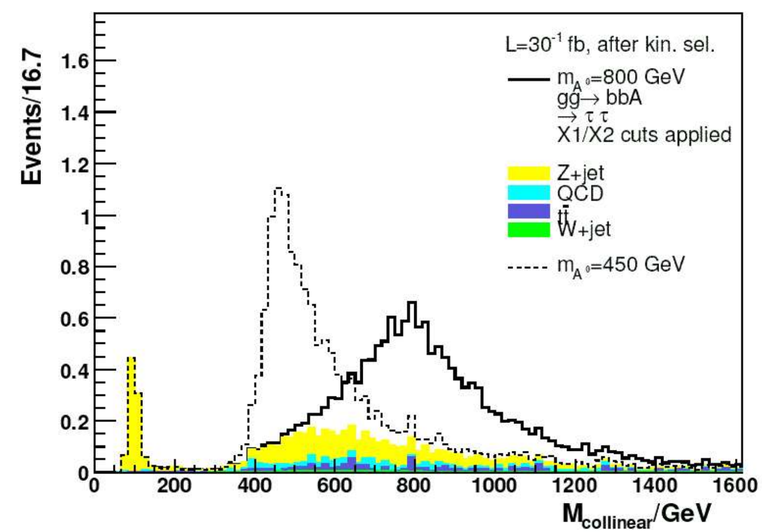
- di muon invariant mass provides good mass measurement
- can constrain tanβ at high values
- observation only possible for low masses and high tanβ

A/H→ττ



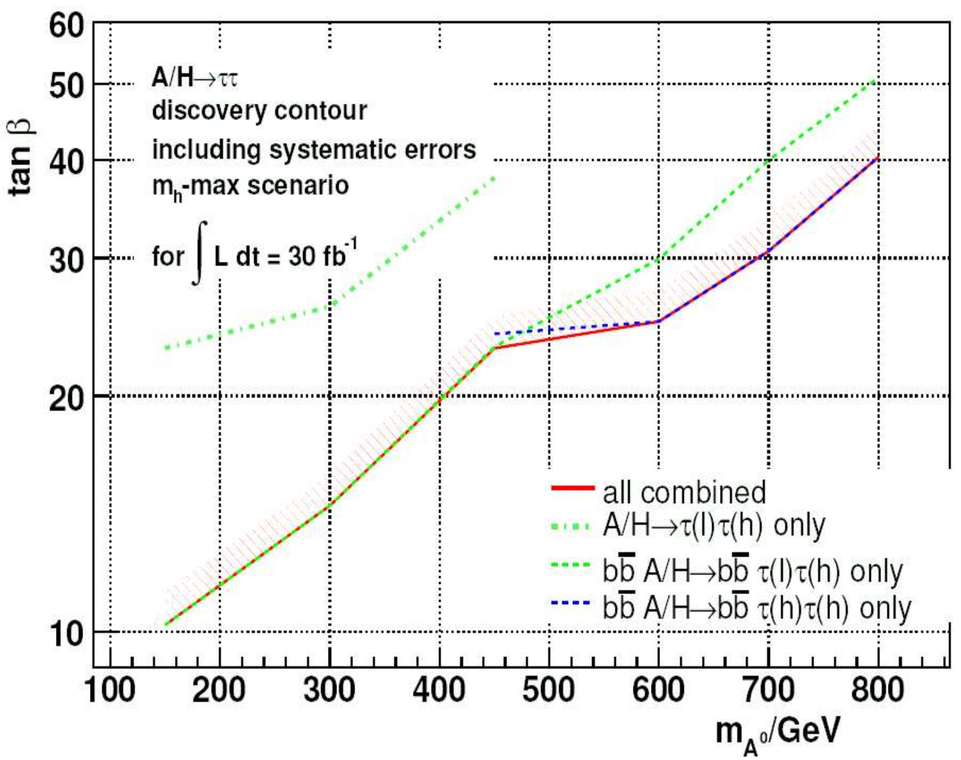
- bb $A^0/H^0 \rightarrow \tau$(had) τ(had)
  - two jets from the taus (τ-taggable)
  - two jets from the bs (b-taggable)
    - bs are very low $p_T \rightarrow$ most of the time only one b-jet seen
  - $E\!\!\!/_T$ from the ν_τ
  - no leptons (e, μ)
- A Higgs mass reconstruction is possible using the collinear approximation and $E\!\!\!/_T$ → neutrino is parallel to it's tau jet → $(\nu_{\tau 1} + \nu_{\tau 2})_T = E\!\!\!/_T$
- $E\!\!\!/_T$ resolution is crucial for the inv. mass

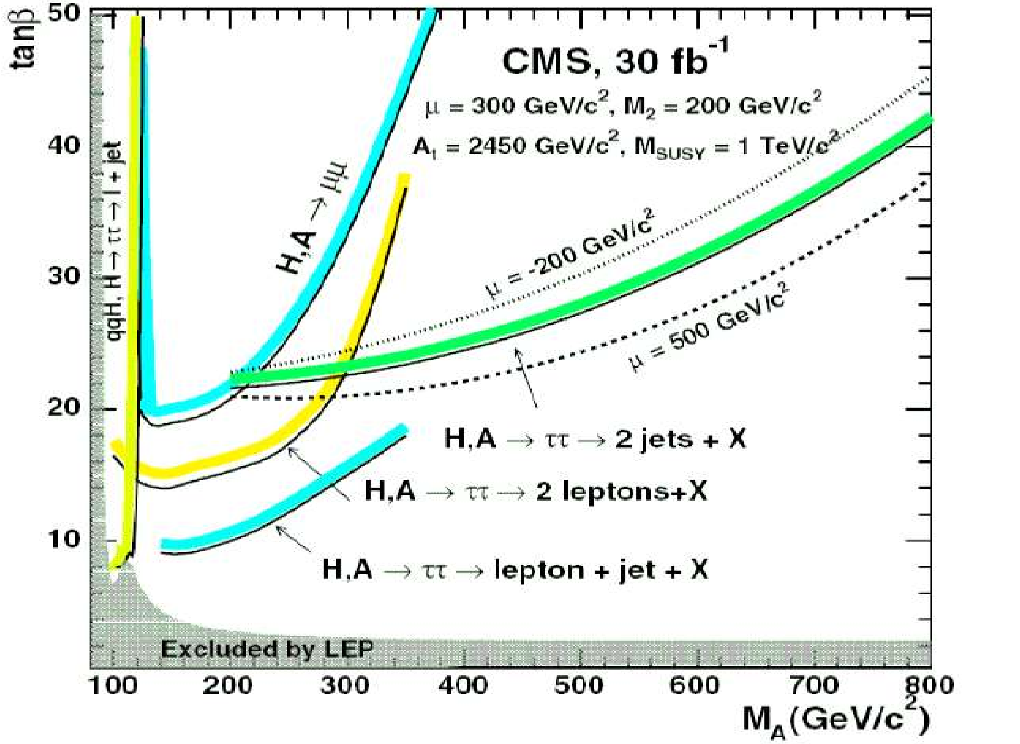
- **Cuts**
  - $E\!\!\!/_T$ > 65 GeV
  - no leptons with p_T > 10 GeV
  - not more than four jets with |eta|<3.2, p_T>20 GeV
  - two τ-jets p_T > 100 GeV
  - 1 tagged b-jets
  - transverse mass < 50 GeV
  - 145º < $\Delta\varphi(\tau 1, \tau 2)$ < 175º
  - successful invariant mass reconstruction
  - mass window +- 1.5 σ



A/H→ττ

- for high masses and high tanβ a discovery is given in the channel (bb) A/H → ττ
- channels is challenging from the experimental point of view since tau and b-tagging and missing transverse energy resolution are all crucial to the channel
- ττ → had had, ττ → had lep and ττ → lep lep are combined to reach lowest possible tanβ values





Charged Higgs

The $H^{\pm}$, a charged scalar, would show physics beyond the SM

- three overlapping production mechanisms

$gb \rightarrow t H^{\pm}$ $gg \rightarrow tbH^{\pm}$

- from top decays

$gg \rightarrow t\, t \rightarrow H^{\pm}b\, Wb$

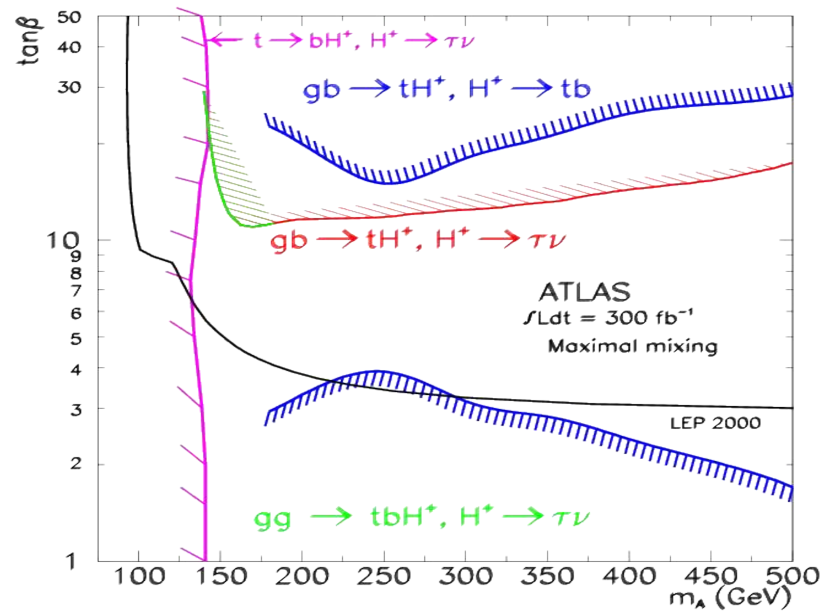
and mainly four decay modes have been exploited

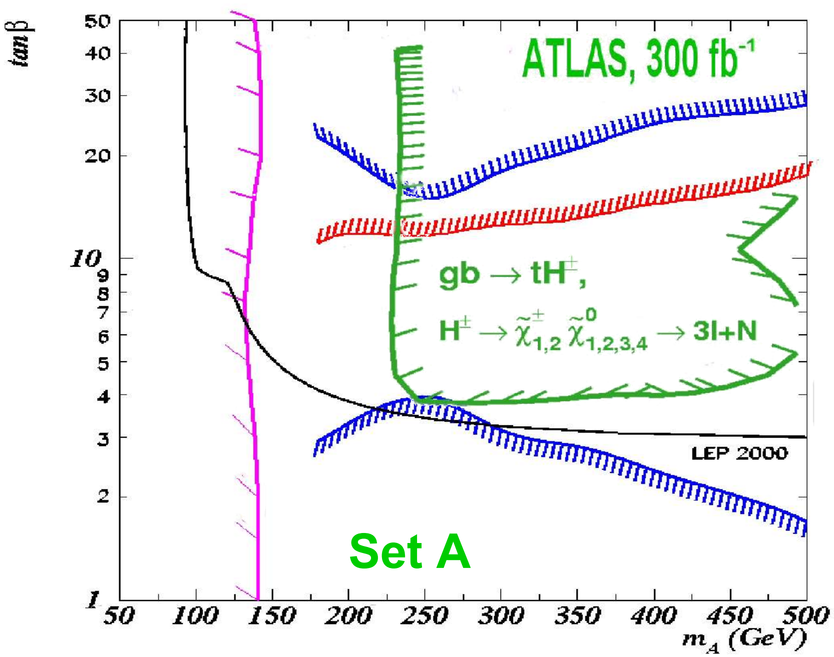
$\rightarrow tb$ $\rightarrow \tau\nu$ $\rightarrow$ SUSY $\rightarrow H^0 W$

- low $\tan\beta$ covered by tb

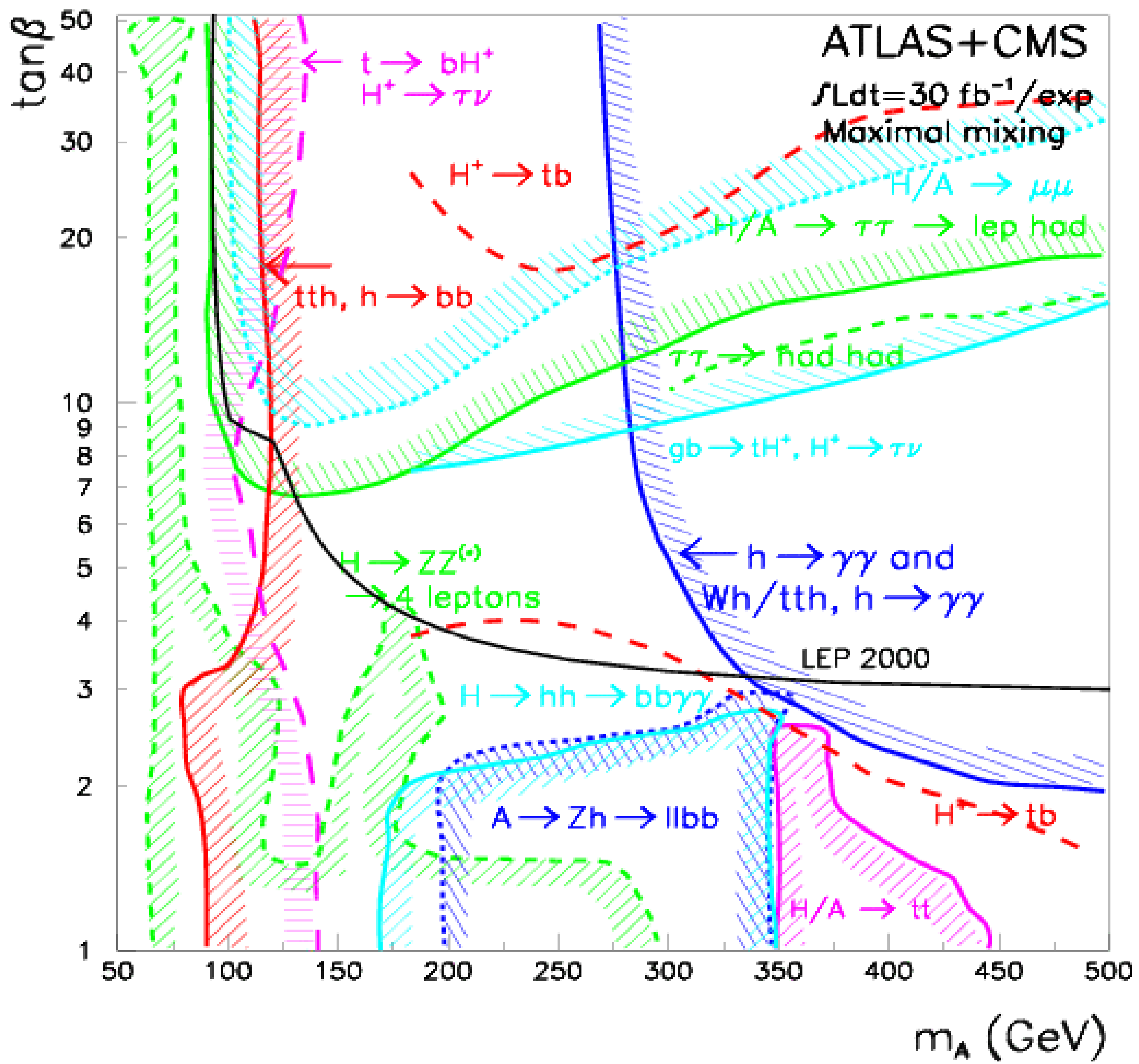
- $\tau\nu$ covers high $\tan\beta$

- intermediate $\tan\beta$ difficult, maybe covered by SUSY





MSSM Higgs Boson (OVERVIEW)



not updated

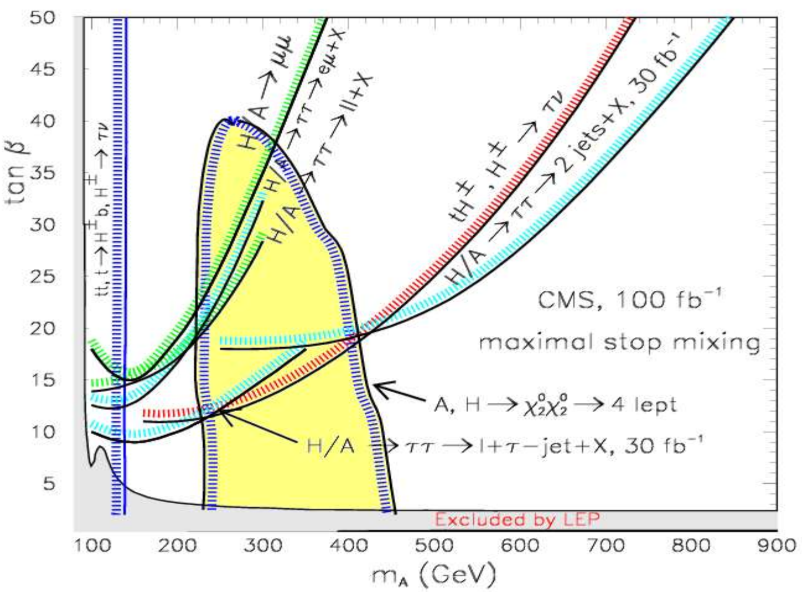
but nice overview

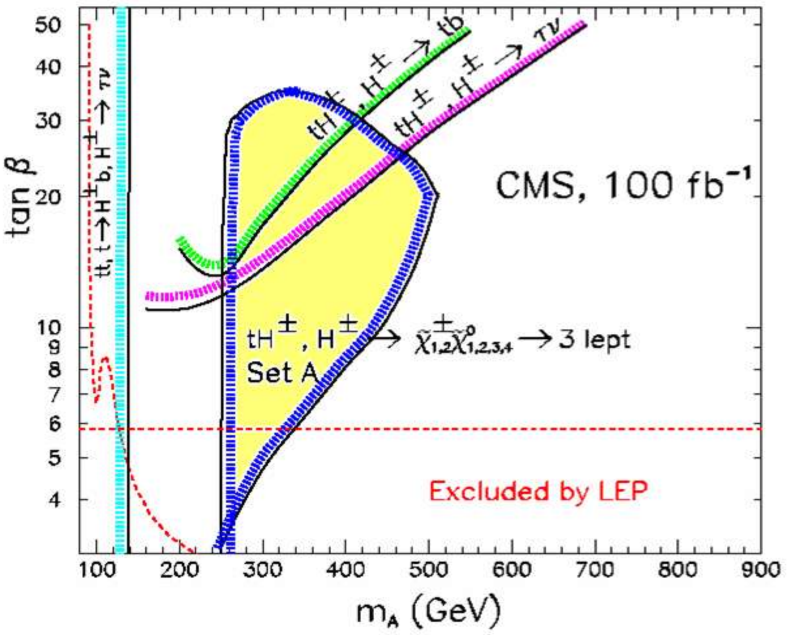
Higgs decay via SUSY particles

If SUSY exists : search for

$H/A \rightarrow \chi^0{}_2\chi^0{}_2 \rightarrow \ell\ell\chi^0{}_1\ \ell\ell\chi^0{}_1$

$gb \rightarrow tH^+,\ H^\pm \rightarrow \chi_{2,3}{}^0\ \chi_{1,2}{}^\pm \rightarrow 3l+E_T{}^{miss}$





CMS: special choice in MSSM (no scan)

M_1 = 60 GeV

M_2 = 110 GeV

μ = -500 GeV

Exclusions depend on MSSM parameters (slepton masses, μ)

Conclusions

- In MSSM/2HDM five Higgs particles are predicted, three neutral and two charged
- Lightest neutral Higgs boson observable in (almost) full parameterspace
- Heavy Higgs bosons (neutral and charged) not observable in an intermediate tanβ "wedge"-region
- This might be covered by HIGGS → SUSY or SUSY → HIGGS ?
- Many analysis require a good understanding of the detector (especially ETMISS and jet tagging) which might not be fully available at the beginning of data taking

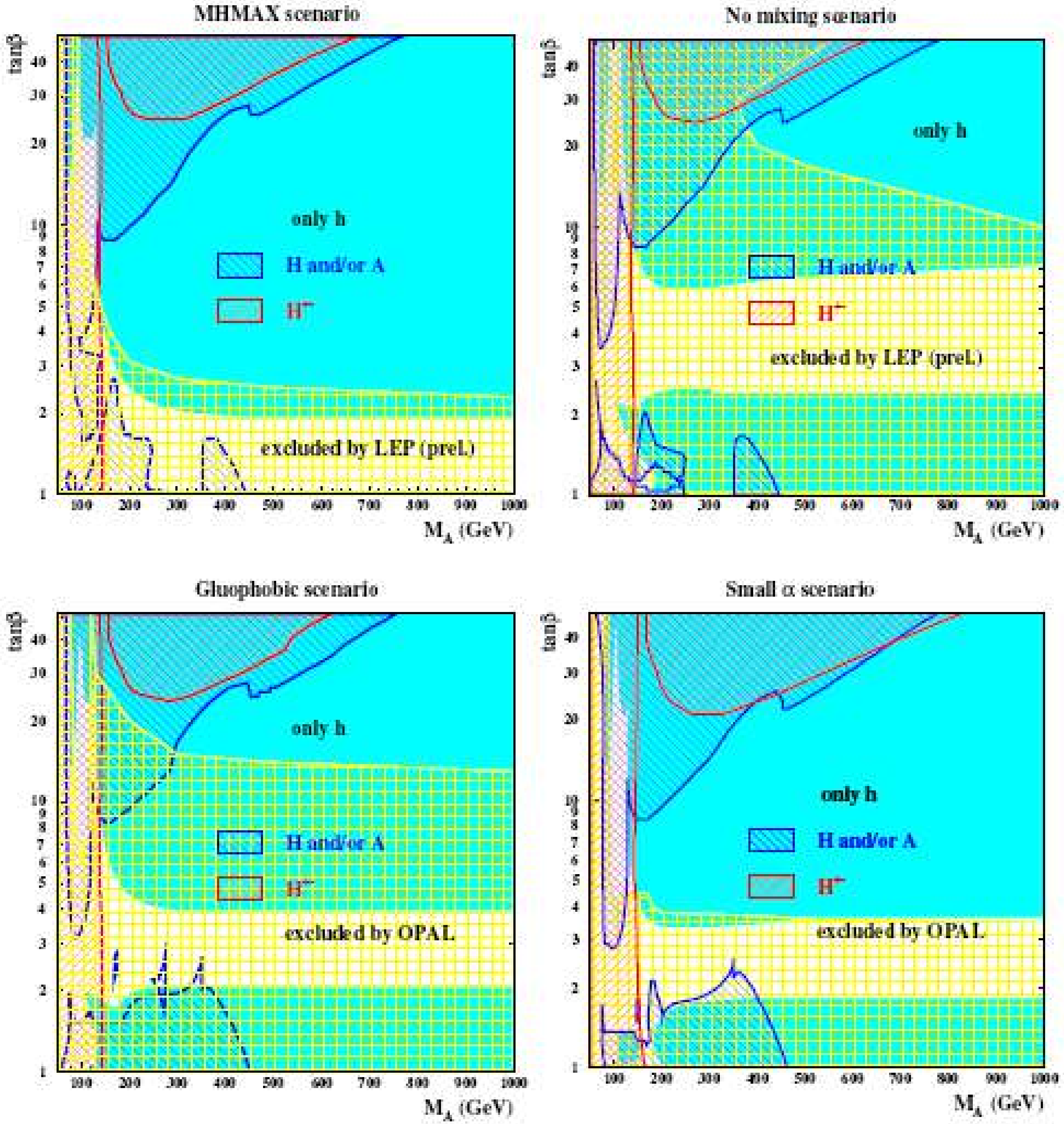
- Description of the associated production may need improvement on the Monte Carlo side
- More realistic MC studies needed with e.g. misaligned and miscalibrated detectors
- Deeper understanding of background estimation from data especially for the jet-tagging

- Additional studies necessary e.g. for SUSY↔HIGGS
- Omitted here: CP violating scenarios with studies in progress

Backup

BACKUP
SLIDES

MSSM discovery potential for various benchmark scenarios



- Full parameter range can be covered with modest luminosity, 30 fb^{-1}, for all benchmark scenarios !
- Only one Higgs boson, h, in some regions
  (moderate tanβ – large m_A wedge)