Detect MSSM neutral Higgs bosons at LHC

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Outline

- ✦Motivation
- ✦ Supersymmetric (SUSY) Higgs
- ✦Experimental status
- ✦ Search at LHC,what can be done: few examples
- ✦Conclusions

Minimal Super Symmetric Model

The MSSM is the most investigated extension of SM provides:

- The unification of coupling constants
- SUSY provides a ColdDarkMatter candidate
- **Three neutral Higgs bosons: A, CP-odd, and CP-even H, h the lightest. Two charged H^+, and H^-.**
- **Large loop corrections depend on SUSY parameters**

Unconstrained MSSM has huge number (105) of parameters in addition SM ones, making any phenomenogical analysis very complicated

- A simplified version at some GUT scale: CMSSM/mSUGRA

Most of phenomenogical analysis models are based on that.

MSSM parameters constrains

- M_{susy}, sfermion mass at EW scale
- M_2, $SU(2)_L$ gaugino mass at EW scale
- μ, supersymmetric Higgs boson mass parameter.
- **tan β**, the ratio of the two Higgs fields doublets
- A_0, a universal trilinear higgs-squarks coupling at EW scale. It is assumed to be the same for up-type squarks and for down types quarks.
- m_A, mass of CP-odd Higgs boson.
- M_{gluino}, it affects loop corrections for stop and bottom

Phenomenology decribed at Born level by tan β, m_A

- couplings: gMSSM = ξ · gSM
  no coupling of A to W/Z
  large tanβ: large $BR(h,H,A \to \tau\tau, bb)$

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 tanβ and M_A)

Masses

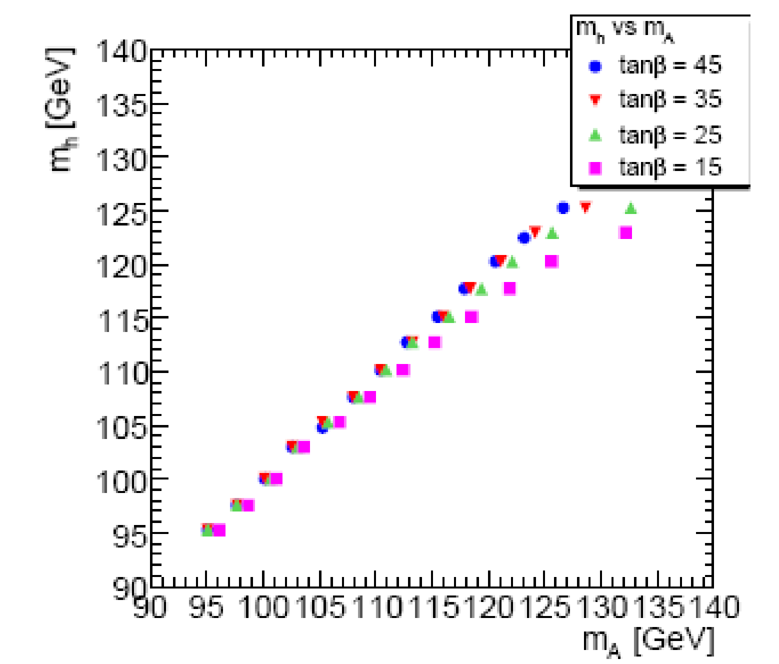
- For $M_A < 135$ GeV (M_h^{max} scenario)
- The ligth MSSM Higgs is SM-like

$$M_A \approx M_h$$

- For $M_A > 150$ GeV (decoupling limit)

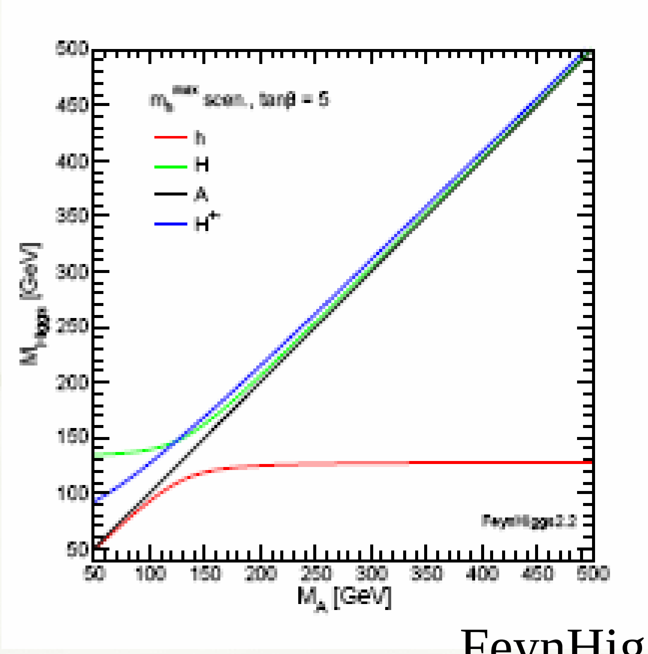
The heavy MSSM Higgsess:

$$M_A \approx M_H \approx M_{H^\pm}$$



Pythia 6.226

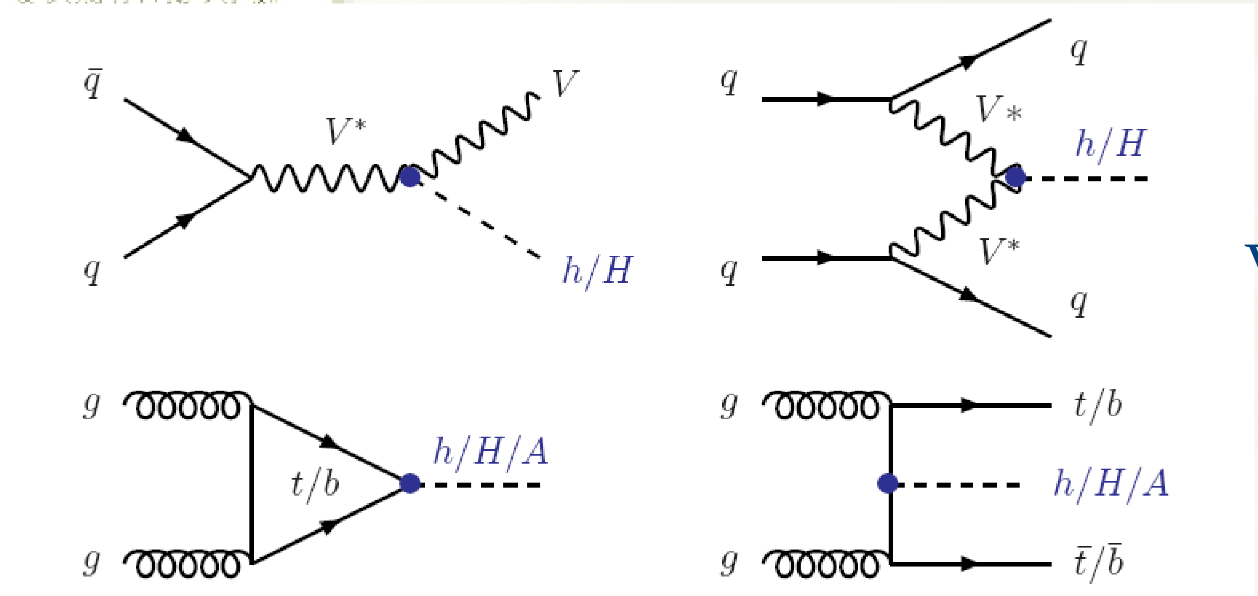
S.G, H.Bilokon,V.Chiarella,G.Nicoletti
ATL-PHYS-PUB-2007-001



FeynHiggs2.2

Sven Heinemeyer
Atlas meeting 29.01.2008

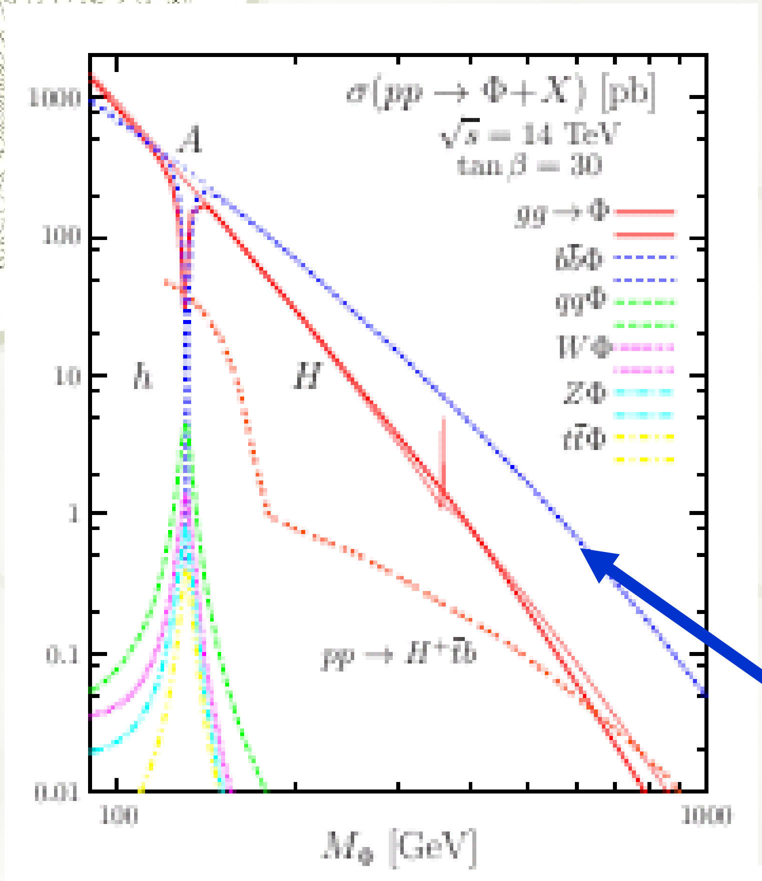
MSSM Higgs Production



V*=W/Z

- Main production mechanism ~SM
- For high and moderate tanβ the production with b quarks is enhanced
- For $m_A >> m_Z$ A/H behave very similar →decoupling region
- A, H, $H^{\pm}$ cross section ~$\tan\beta^2$

Production cross section



Φ=h,H,A

- At small tanβ gg→h,H,A dominant
- Vector boson fusion process
- pp→qq→qq+WW/ZZ→qq+h/H important at $m_h \sim m_{hmax}$
- Higgsstrahlung neglegible
- At **high tanβ associated b quarks production dominates**

  pp → bb →h/H/A+ bb

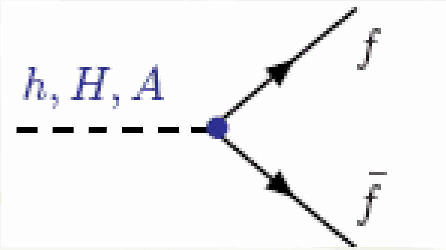
Abdelhak Djouadi arXiv:hep-ph/0503173v2 (2005)

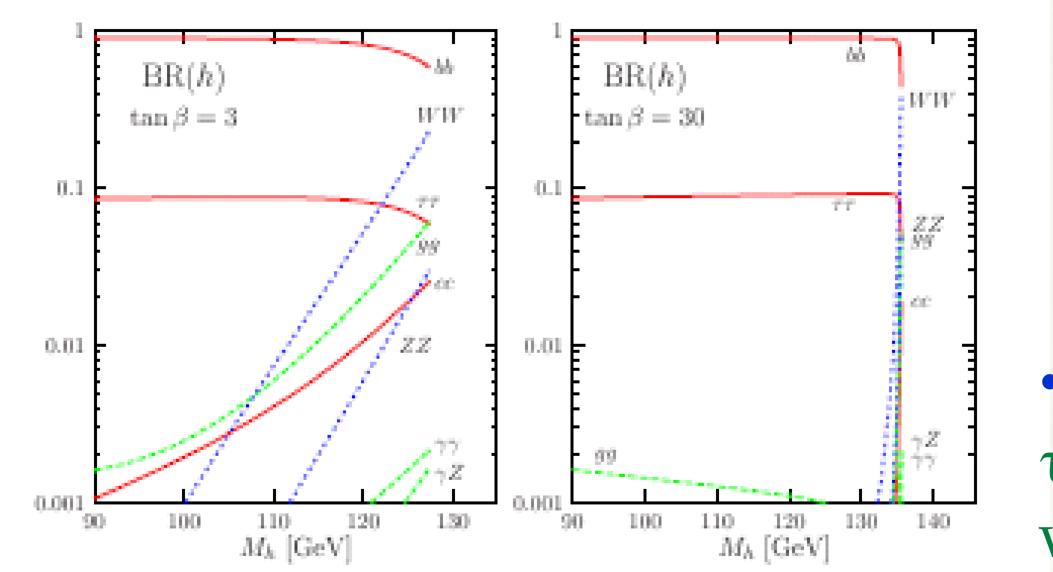
Branching ratio

•Decoupling region

$M_A \geq 150$ GeV tanb ≈30

or $M_A \geq 400$-500 GeV tanβ=3





Production rate

$$\Gamma(h, H, A) \propto m_f^2$$

•Decay bb dominates,

ττ lower background

weaker sensitivy on

SUSY parameters

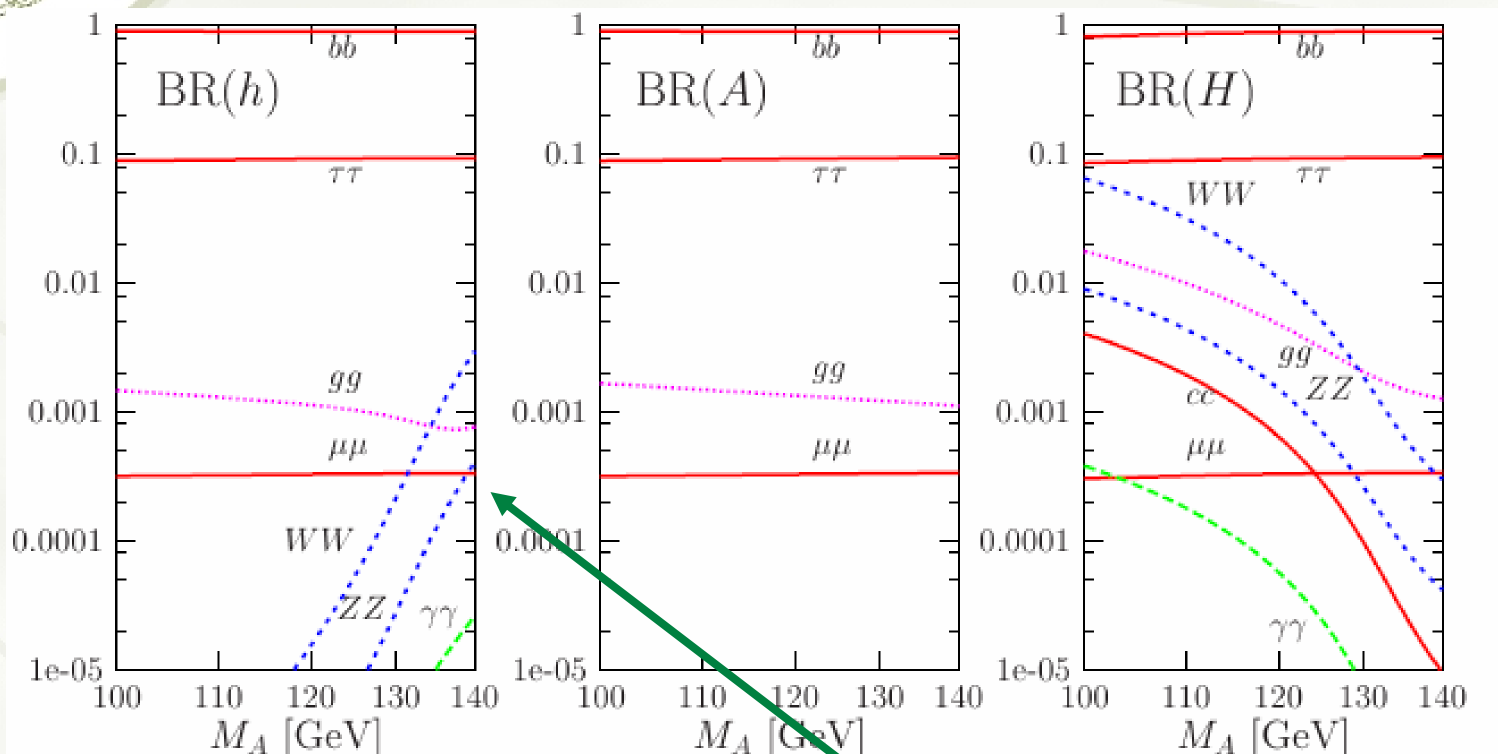
Abdelhak Djouadi arXiv:hep-ph/0503173v2 (2005)

Branching ratio

•Intense coupling region tanb ≈30 M_A~ 120-140 GeV

Coupling to W,Z up quarks suppressed

Coupling down quark (b) and τ enhanced



Abdelhak Djouadi arXiv:hep-ph/0503173v2 (2005)

•Decay bb, ττ dominates

•Decay μμ possible

Benchmark scenarios

- **m_h ^{max} scenario**

It allows the maximum value for $m_h(X_t = 2M_{SUSY})$.

It can be obtained conservative tanβ exclusion bounds

- **no-mixing scenario**

No mixing in scalar top sector ($X_t = 0$)

- small α_{eff} scenario

Hb coupling~ sin α_{eff}/ cos β can be zero: $\alpha_{eff} \rightarrow 0$:

Main decay mode vanishes, important search channel vanishes

- gluophobic Higgs scenario

hgg coupling is small: main LHC production mode vanishes.

MSSM

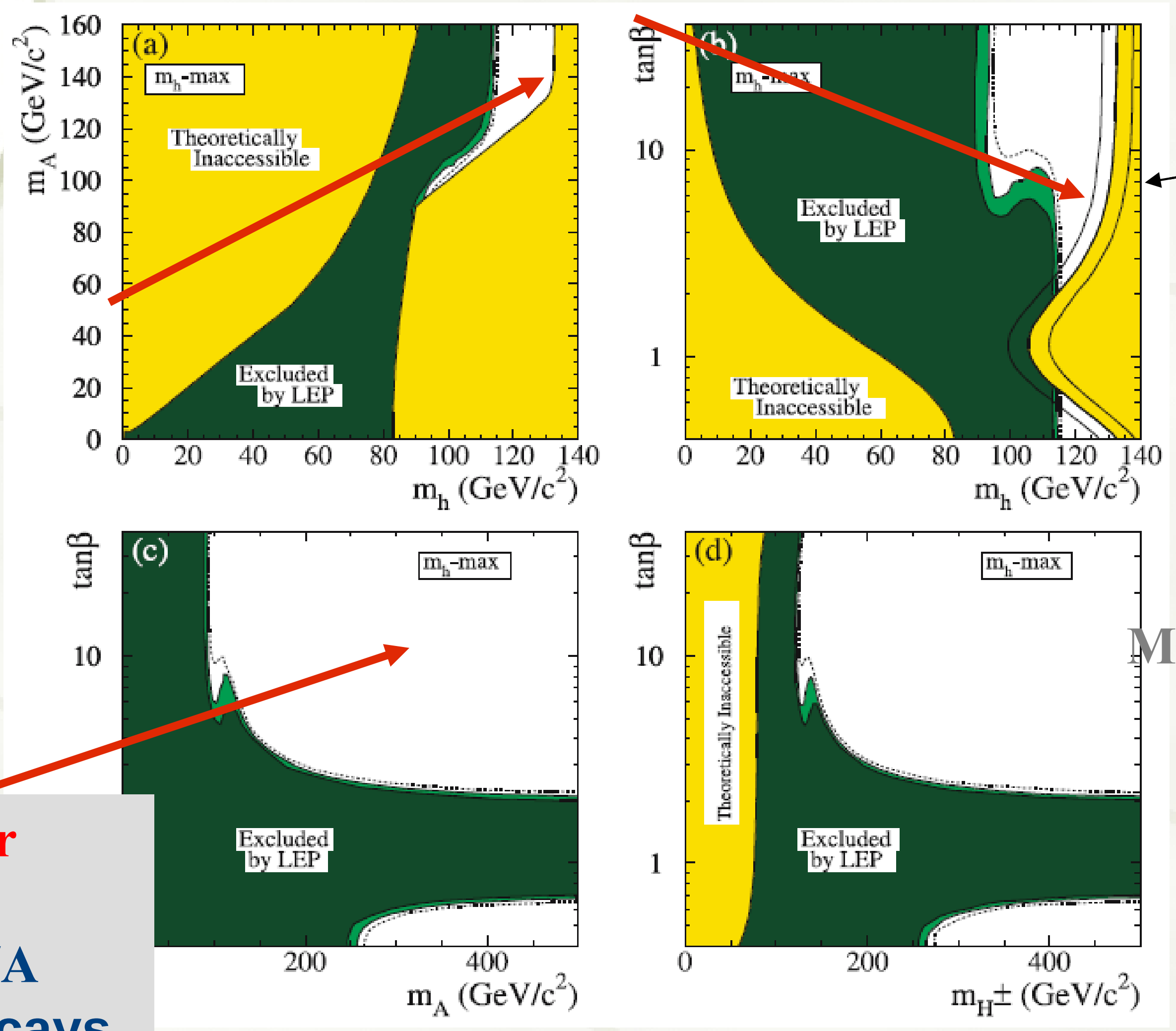
Constrained:

- Two Higgs doublets $\rightarrow h_0$, H, A, H^+, H^-
- Three neutral Higgs bosons: H, A, CP-odd, and h the lightest CP-even.
- Large loop corrections depend on SUSY parameters (expecially stop): M_{susy}, M_2, μ, **tan β**, A, $\mathbf{m_A}$, m_{gluino}
- $X_t \sim A = 6^{1/2} M_{susy}$, $|\mu| << M_{susy}$ for maximal top mixing
- X_t=0 no mixing scenario
- Measurement of Higgs masses, coupling and Br → test of theory

Varying m_A tanβ, keeping all other SUSY parameters fixed.

LEP legacy

Low tanβ is not completely excluded: search for LHC with pp->A; A->Zh, γγ, tt



M_t [GeV]=
169.3
174.3
179.3
183.0

tanβ 0.7 2.0
Excluded

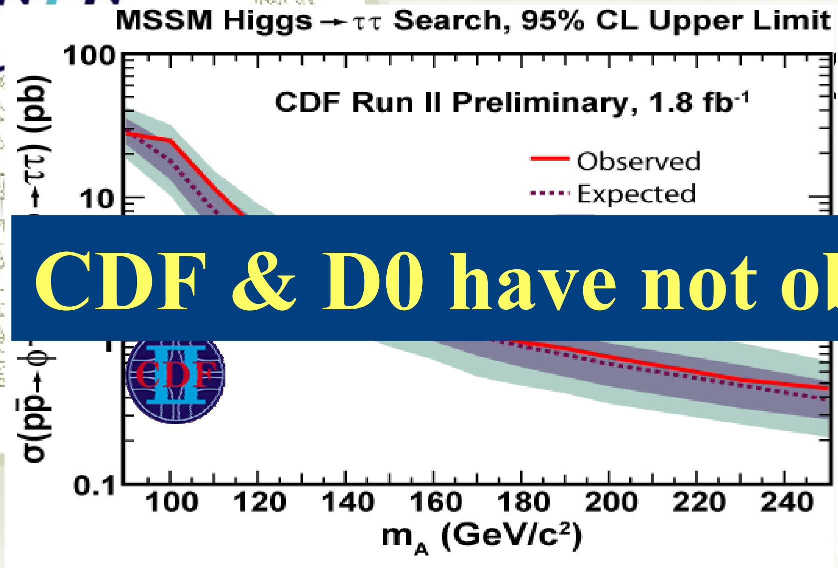
$M_{H\pm}$>78.6 GeV

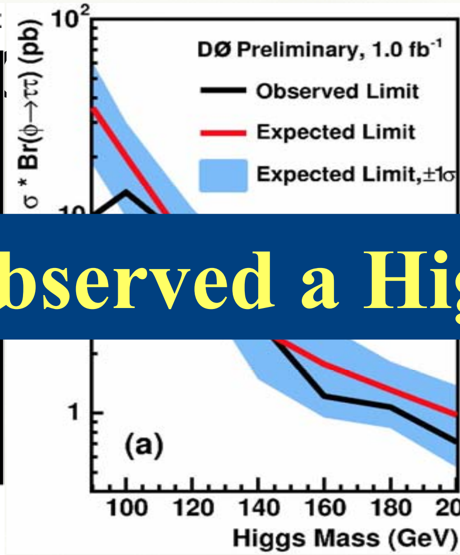
Excluded:
(m_h^{max}scenario)
m_h>92.8 GeV
m_A>93.4 GeV

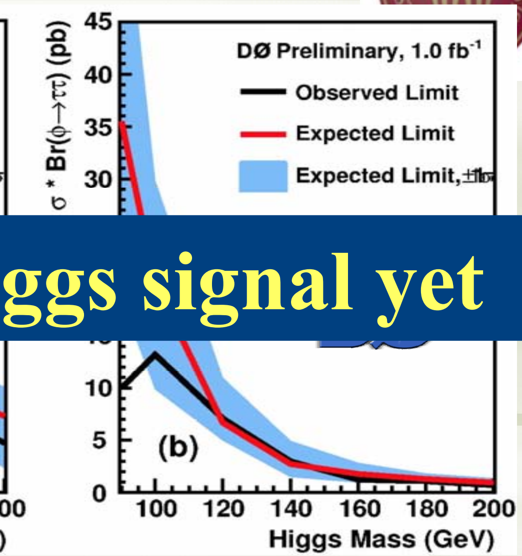
High tanβ area for search at LHC with pp->bb h/ H/A h/H/A->μμ, ττ decays

Eur.Phys. J C 47, 547

Tevatron results

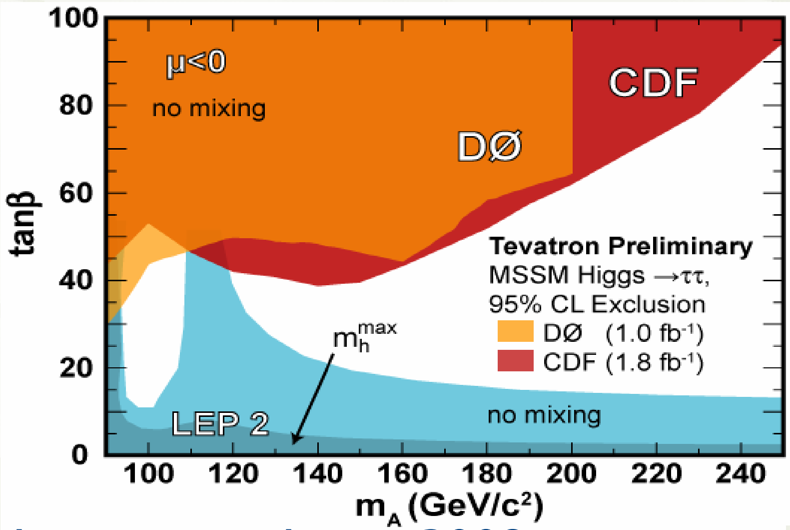


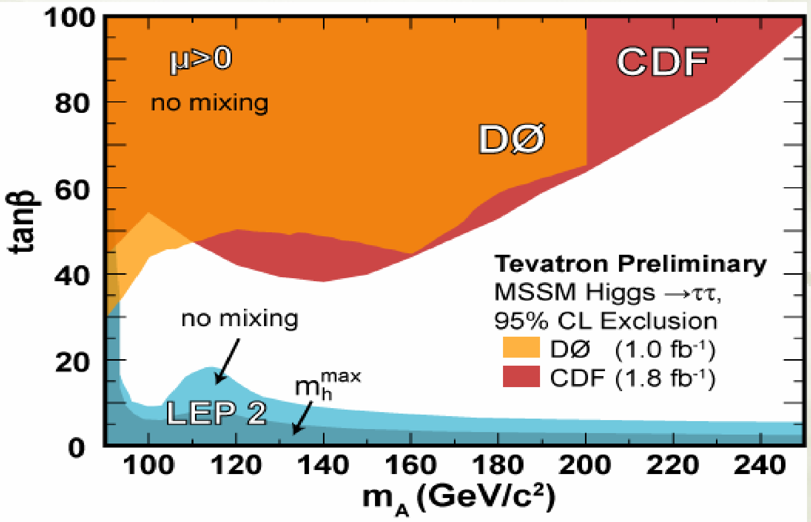




CDF & D0 have not observed a Higgs signal yet

Interpretation of the limits





Anton Anastassov Aspen 2008

Quest & strategy

Look for MSSM bosons in the entire parameter space.

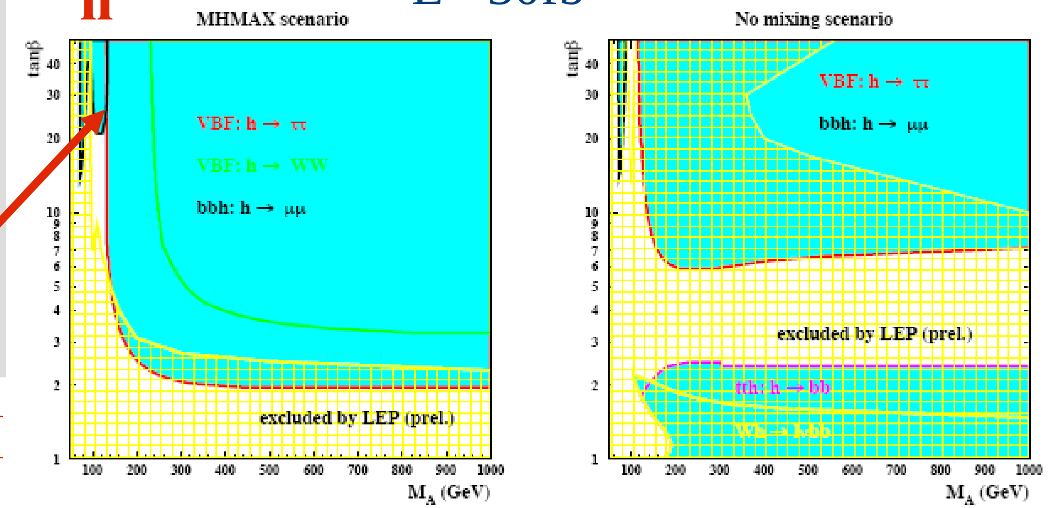
- Using the same analysis strategy for SM ,MSSM
- Among all channels studied from ATLAS and CMS focus on:
  - **$pp \to bb$ h/ H/ A– moderate and high $\tan\beta$**
    - **h/ H/ A ->$\mu\mu$**
    - **h/ H/ A ->$\tau\tau$**
  - **$pp \to A$ at low $\tan\beta$**
    - **$A \to Zh$**
      - **$Z \to \ell\ell$ (ℓ =e, μ)**
      - **$h \to bb$**
  - **$pp \to A/H \to \tilde{\chi}^0_{2,3,4} \tilde{\chi}^0_{2,3,4}$**

Light higgs boson

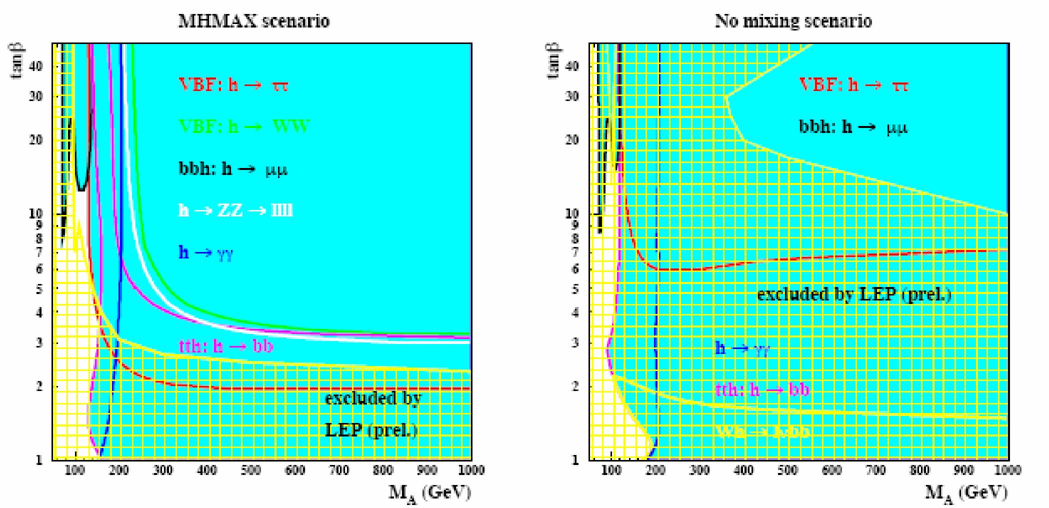
- VBF dominates at low luminosity
- Large space covered by several channel
- **Region around $m_h \sim$ 95GeV difficult**
- **$h \to \mu\mu$ channel at low masses**

h

L =30fb^{-1}



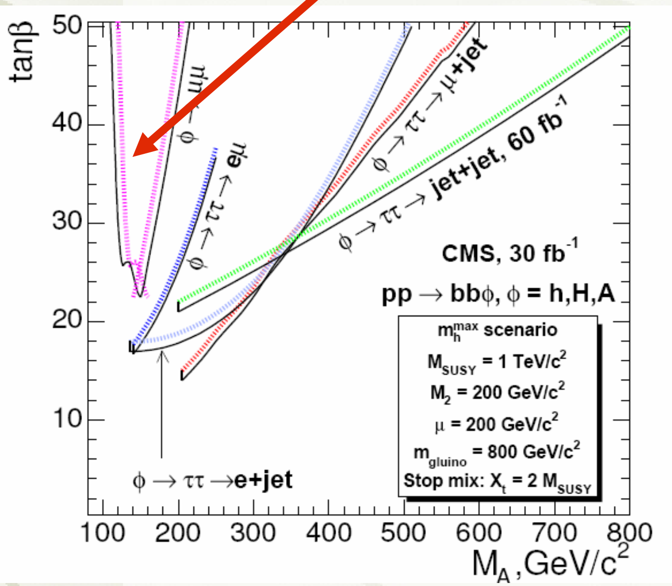
L =300fb^{-1} **NOT UPDATED**



ATLAS

h/A/H

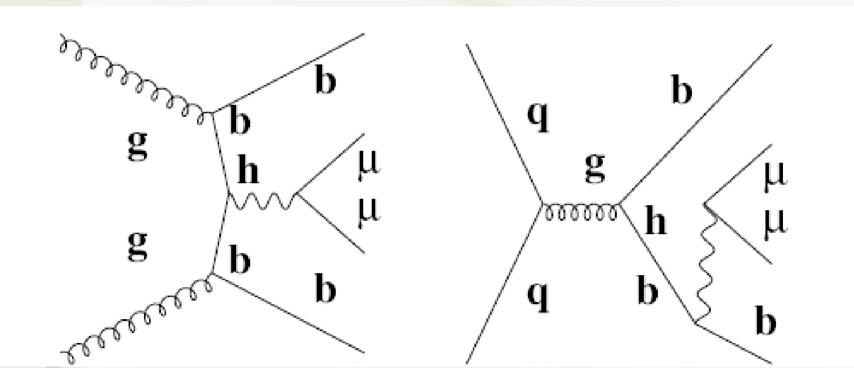
CMS TDR



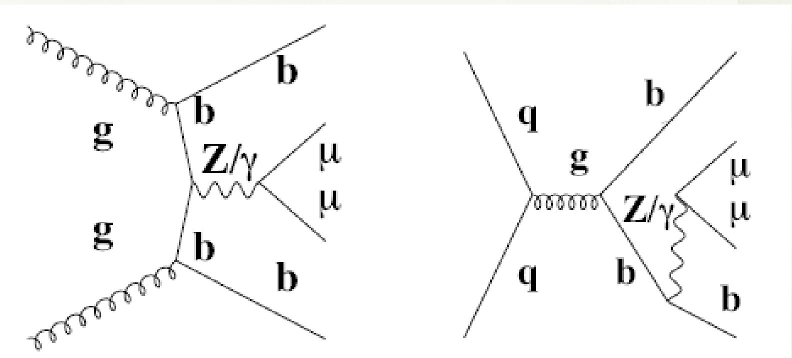
$bb\ h/A \rightarrow bb\mu\mu$

- **Associated h/A/H production with b-jets → large σ**
- The adavange of ττ channel due to the mass is counterbalanced by difficulty of identify τ decays
(smaller detector acceptance, ν in final state)
- Excellent μ resolution of detectors

Production rate
h→μμ and h →ττ $\propto \left(\frac{m_\tau^2}{m_\mu^2} \right)$



signal



background

S.G., H.Bilokon, V.Chiarella,G.Nicoletti, Eur.Phys. J. C. 52, 229-245 (2007)

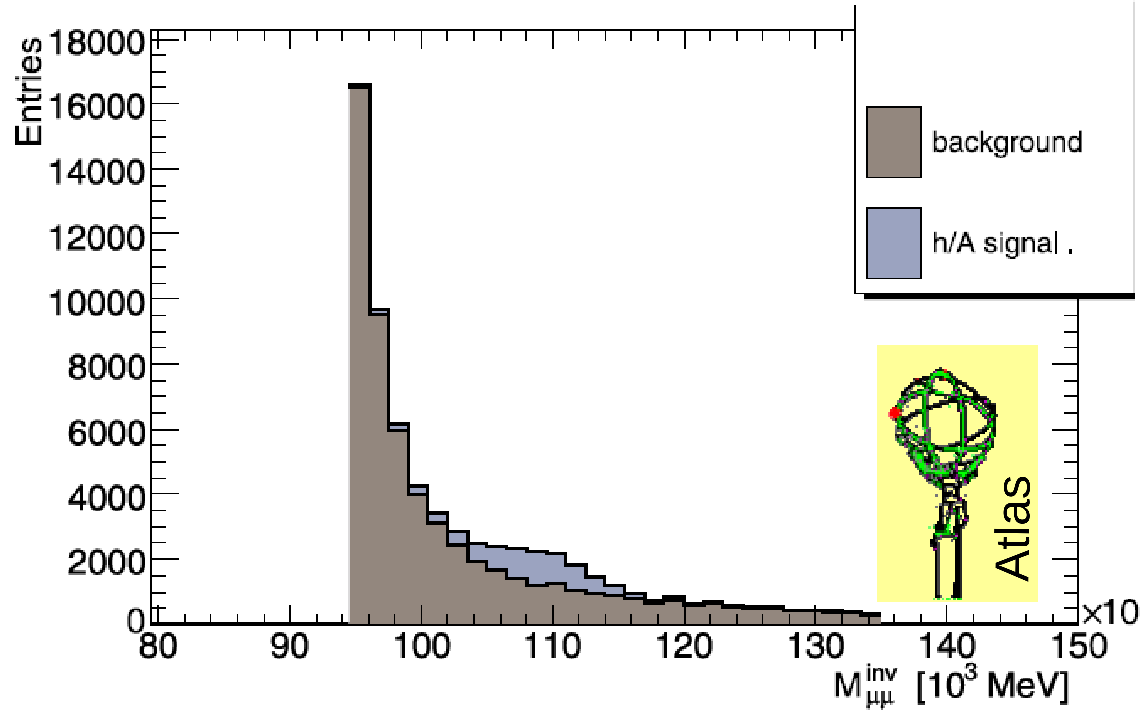
SN-ATLAS-2007-063
17 May 2007

ATL-PHYS-PUB-2007-001
11 January 2007

ATL-PHYS-PUB-2006-019
03 July 2006

$bb \rightarrow h/A\mu\mu$

M_A=110.31 GeV, M_h= 110 GeV, tanβ=45



Atlas : tanβ 15-50
m_A 95-130 GeV

- 2 μ p_T>20GeV
- 2 jets p_T>10GeV
- 1 b-jet (p_T>15GeV)
- $M_{\mu\mu}$
- μ-isolation,no hadronic activity

•Background bbZ→bbμμ
tt →bbμμ
ZZ→bbμμ

Full detector simulation
Corresponding to L=300fb^{-1}

Background evaluation

- **bbZ→bbμμ** large cross section ($\sigma \approx 22.8$ pb) large theoretical uncertainties (≈ 25%)

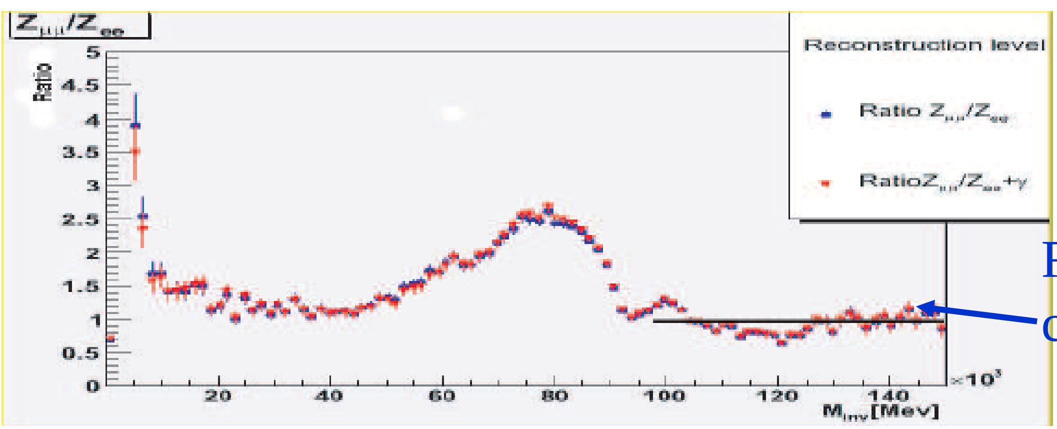
Proposed **data driven method** based on bbZ→bbee

- Rate of signal suppresed by $\left(\frac{m_\mu}{m_e}\right)^2$

Background same rate:

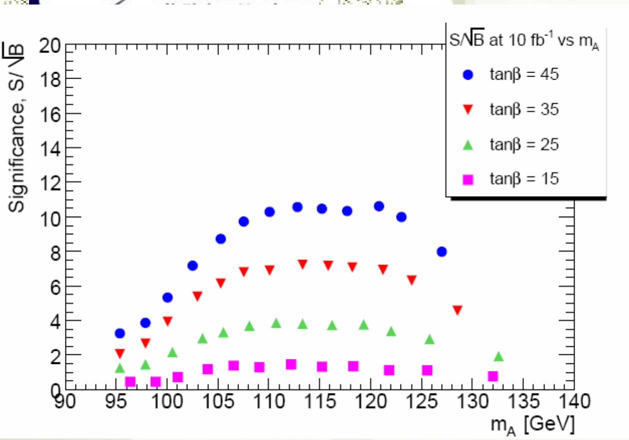
same production diagram, and lepton universality

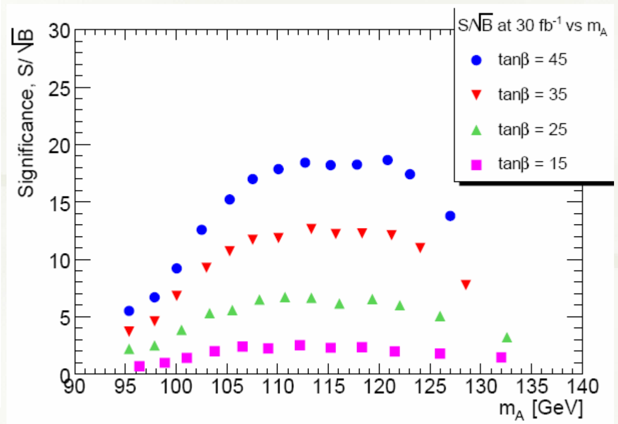
different inner bremsstrahlung and detector reconstruction

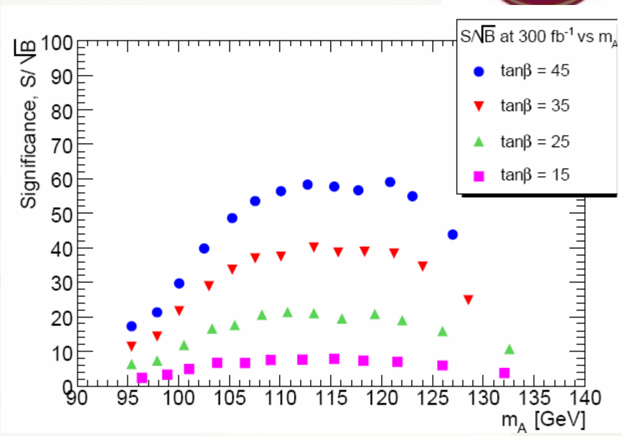


Ratio stable & without large corrections factor

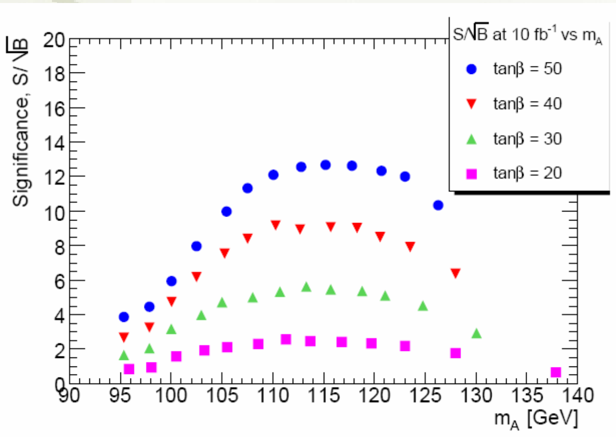
h/A/H significance reach

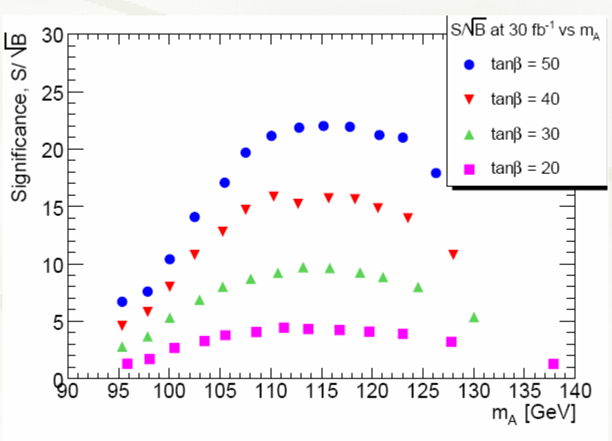


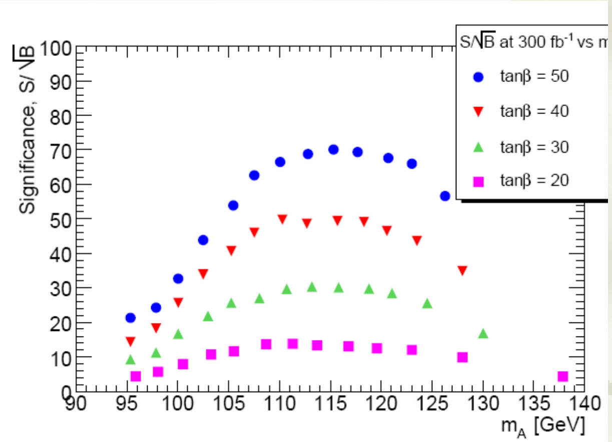




L=10 fb^{-1} **L=30 fb^{-1}** **L=300 fb^{-1}**





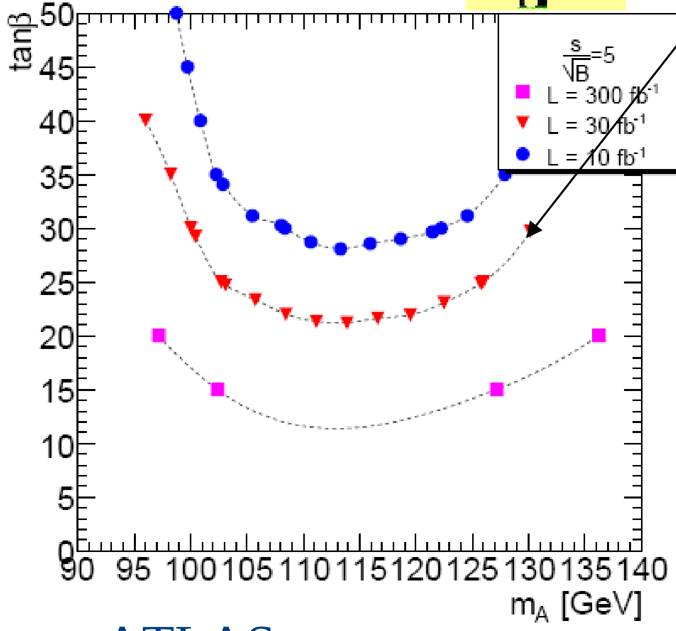


M_h^{max} scenario

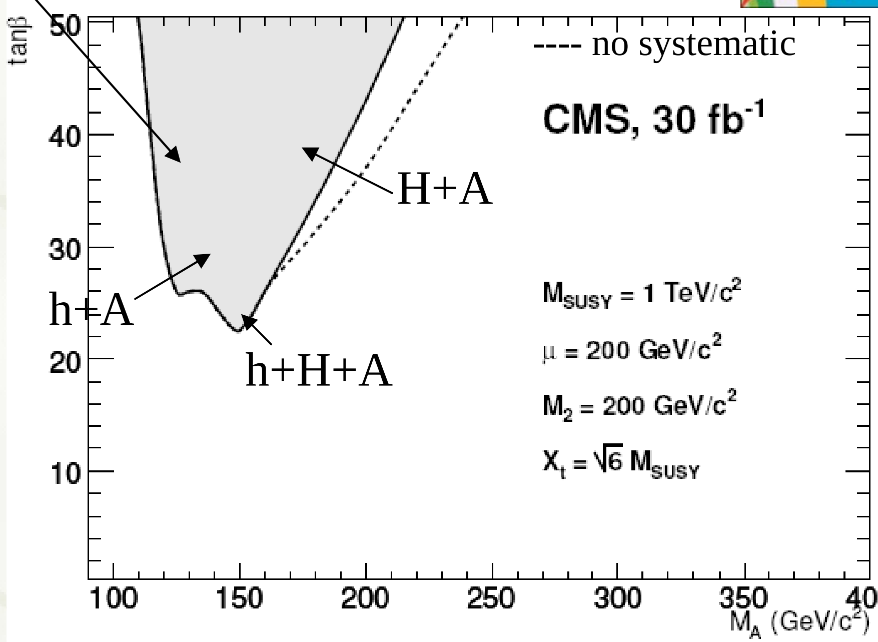
Atlas

Discovery contours

5 σ at L =30 fb^{-1}



ATLAS

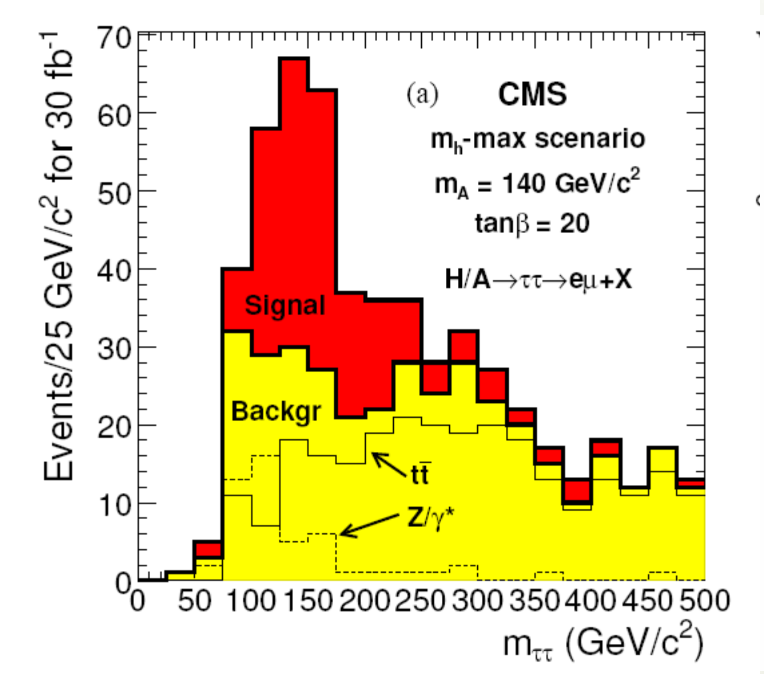


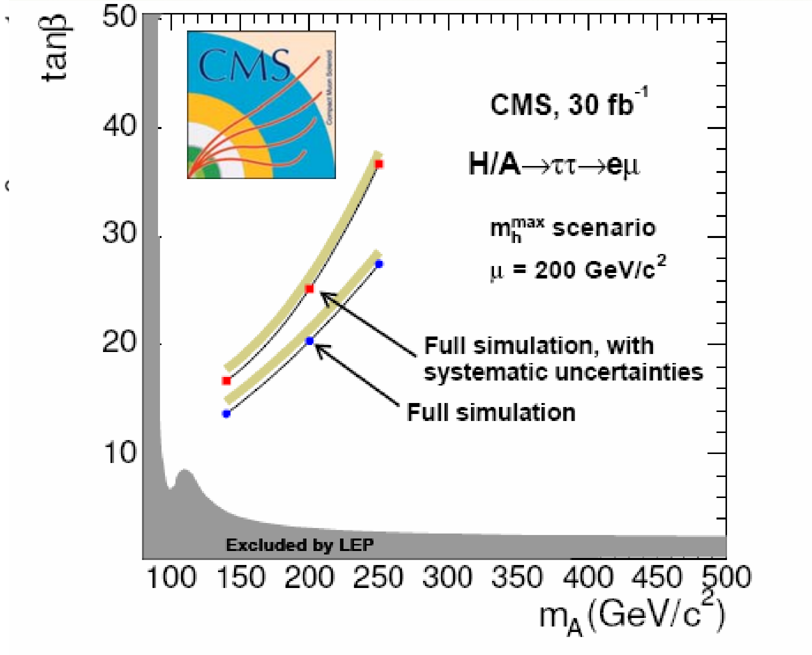
CMS TDR

Others channel: τ decays

✦ Full leptonic: $bbH \rightarrow bb\tau\tau \rightarrow e\mu + E_T^{miss}$

- Lower rate than full hadronic or hadronic/lepton $Br(\tau \rightarrow \ell\nu\nu) \sim 0.17$
- Clean signal and easy trigger
- Higgs mass reconstruction using collinear approxomation
- Approssimation method requires **excellent missing $E_T$resolution**
- Main background:Z+jet,ttbar,Zbb





Higgs Search in A→ Zh channel

- **Low tanβ region**
- Final state Z→ ℓℓ (ℓ = e,m) h →bb
- Low tanβ $M_z+m_h \leq MA \leq 2m_{top}$ (highest Br)
- Depends strongly on MSSM parameters
- Main backgrounds: Zbb,ttbar and Z+jet
- Systematic can be important

At Large value of M_2 and μ can dominate A→χχ

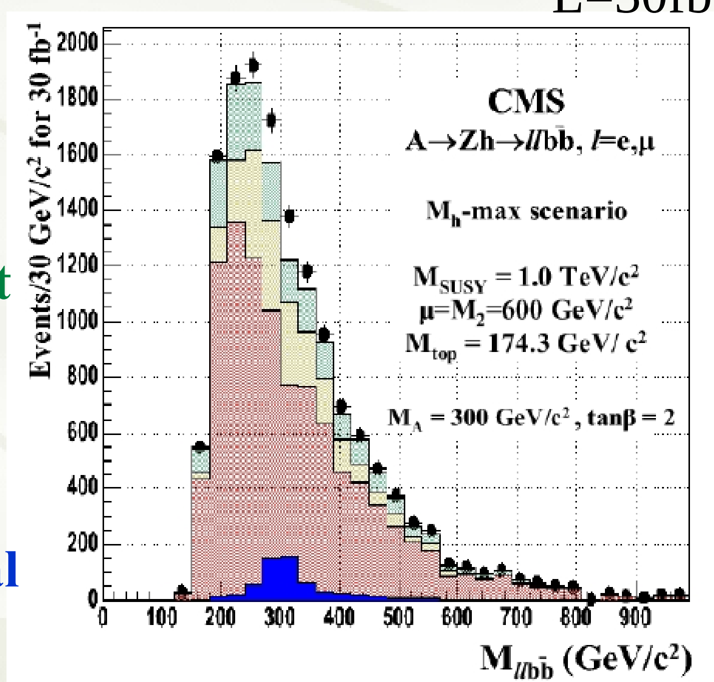
L=30fb^{-1}

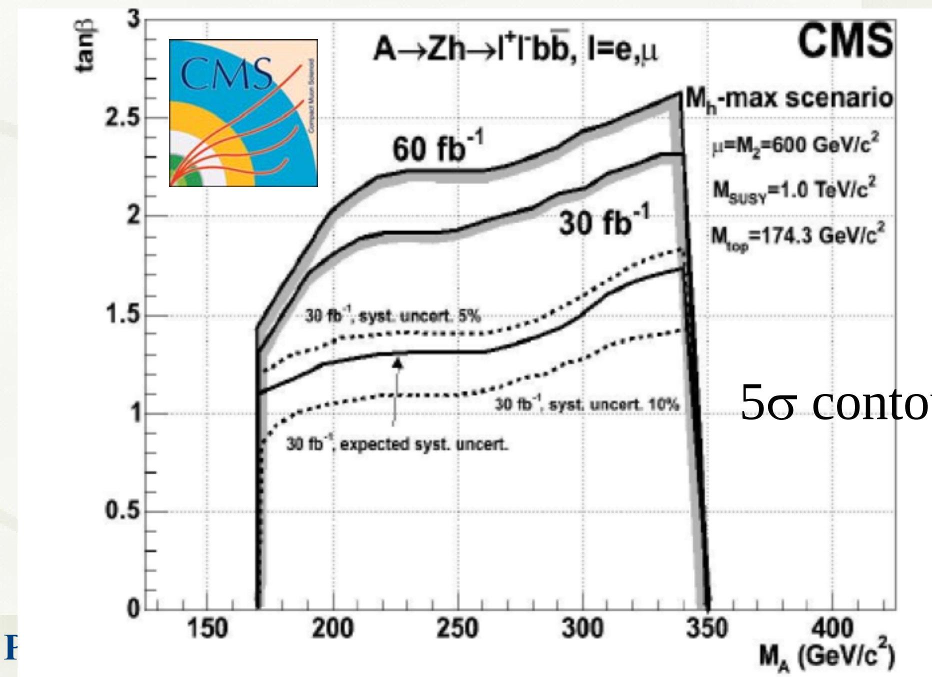
Z+jet

tt

Zbb

signal

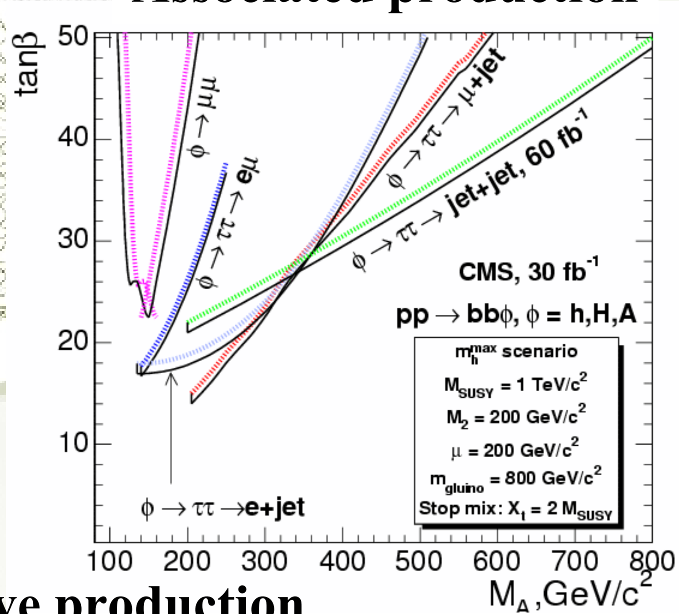


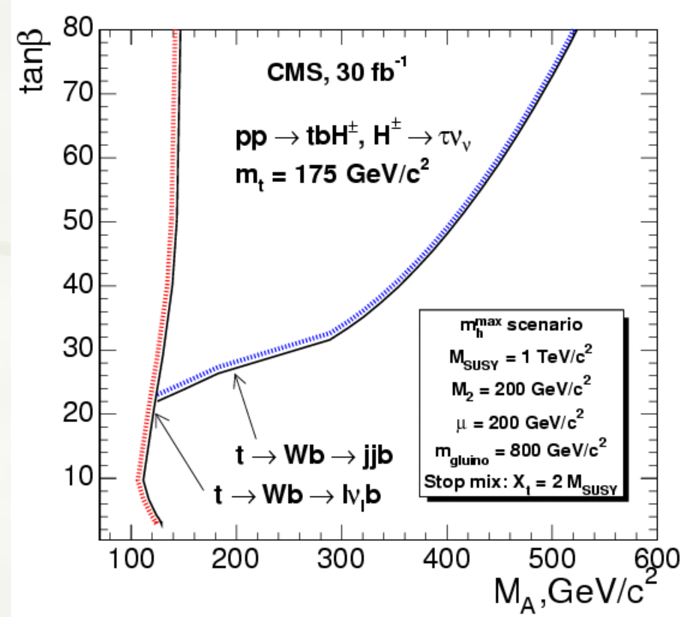


5σ contour

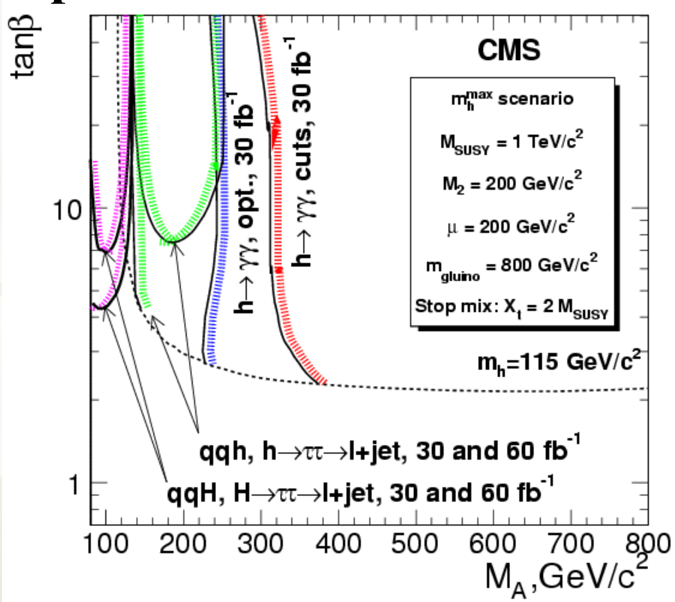
Summary of CMS reach in M_A-$\tan\beta$

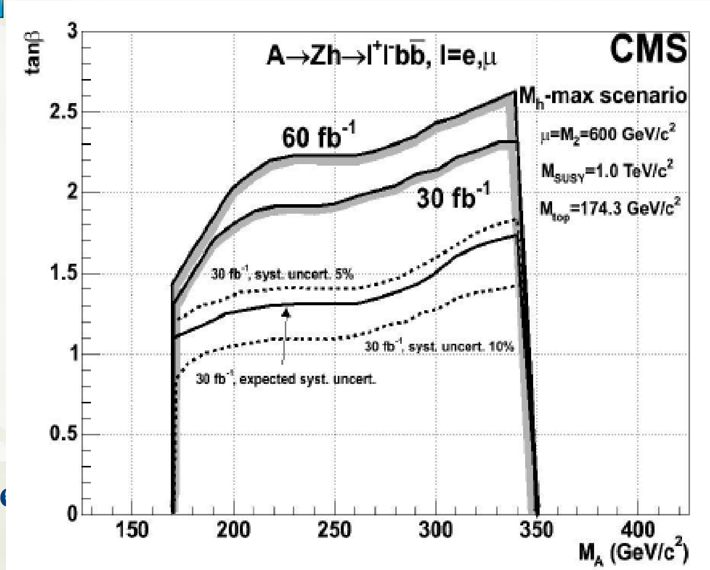
Associated production



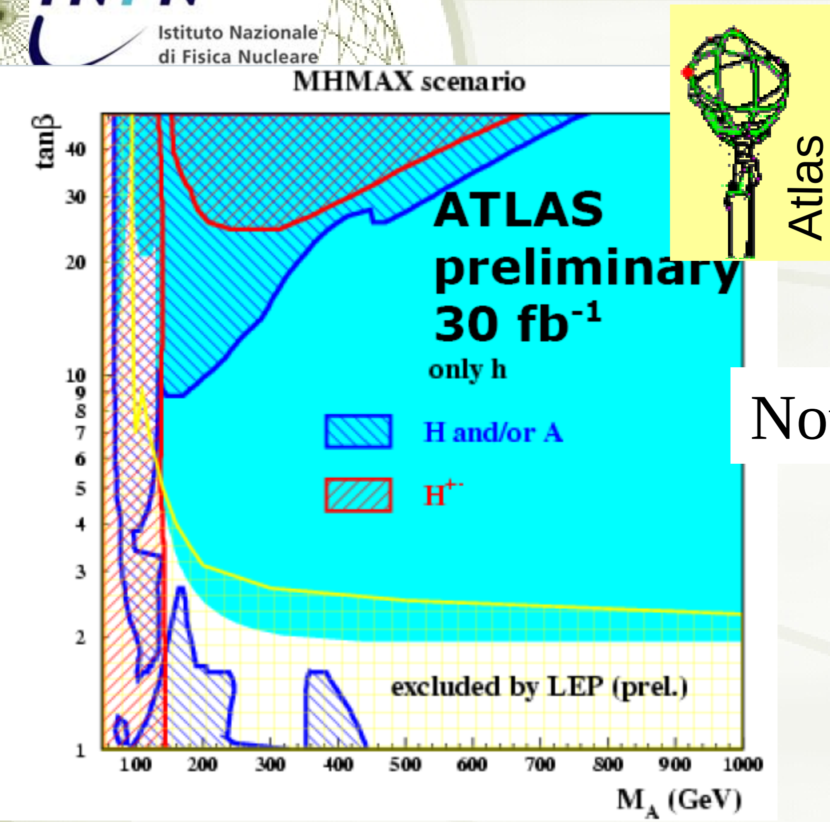


Inclusive production

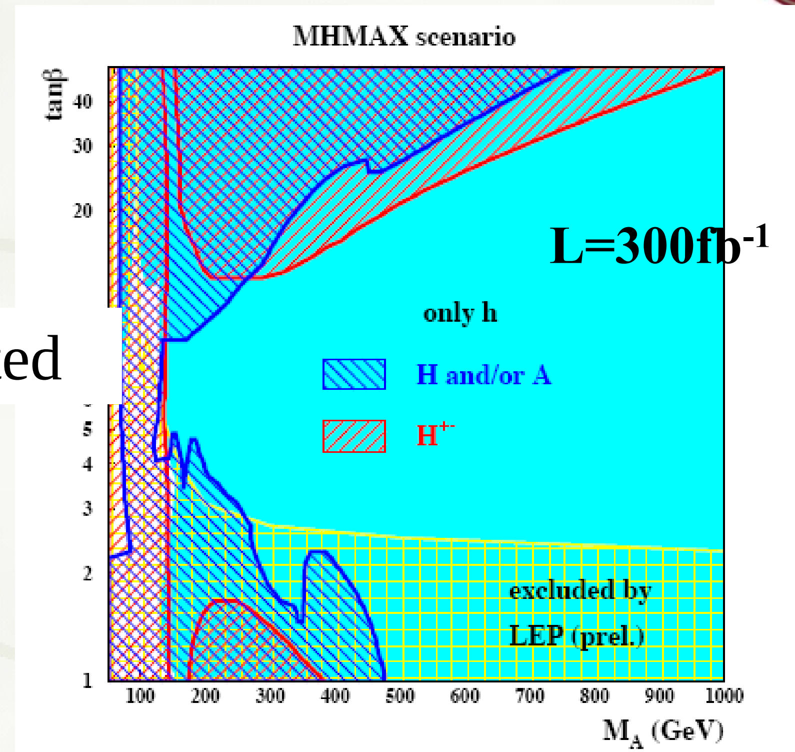




ATLAS reach for MSSM Higgs bosons



Not updated



- At least one Higgs boson observable
- significant area where only h is observable
- Difficult to distinguish from SM

- whole plane covered in CP conserving benchmark scenarios
- significant area where only h is observable

LHC searches for MSSM higgses

Other discovery channels possible .. :

- $h \rightarrow \gamma\gamma$ inclusive production and production in association tth final states
- h,A,H → $\mu\mu$ inclusive and bb associated
- H →bb in association with bb
- h,A,H →$\tau\tau$ with 2 ℓ, ℓ + τ-jet and 2 τ-jet final states.
- .....
- gb → t $H^{\pm}$, $H^{\pm} \rightarrow \tau\nu$
- gg →tt → $H^{\pm}$ bWb

Note:

•**They only include SM-particles to Higgs interactions**

•**This assumes no interaction between Higgs & sparticle sectors: i.e., SUSY mass scales are heavy**

SUSY & Higgs interplay

If SUSY kinematically accessible, then real production of sparticles.

- **Higgs can decay directly to or come from decay of SUSY particles**
- Associated production modes: e.g, squark-squark-Higgs
- SUSY particles suppress or enhance loop induced production or decays Higgs into sparticle decay modes can compete with SM modes:

$$\mathbf{H/A} \rightarrow \chi^0_2\chi^0_2 \rightarrow 4\ \ell^\pm\ \mathbf{X}$$

$$\mathbf{H^\pm} \rightarrow \chi^0_2\chi^\pm_1 \rightarrow 3\ \ell^\pm\ \mathbf{X}$$

Pioneering papers:

[1] F. Moortgat, S. Abdullin, D. Denegri". hep-ph/0112046
[2] M.Bisset, F. Moortgat and S. Moretti "**Eur.Phys.J.C30:419-434,2003.**
[3] C. Hansen, N. Gollub, K. Assamagan, T. Ekelof **Eur.Phys.J.C44S2:1-9,2005.**

A/H susy decays

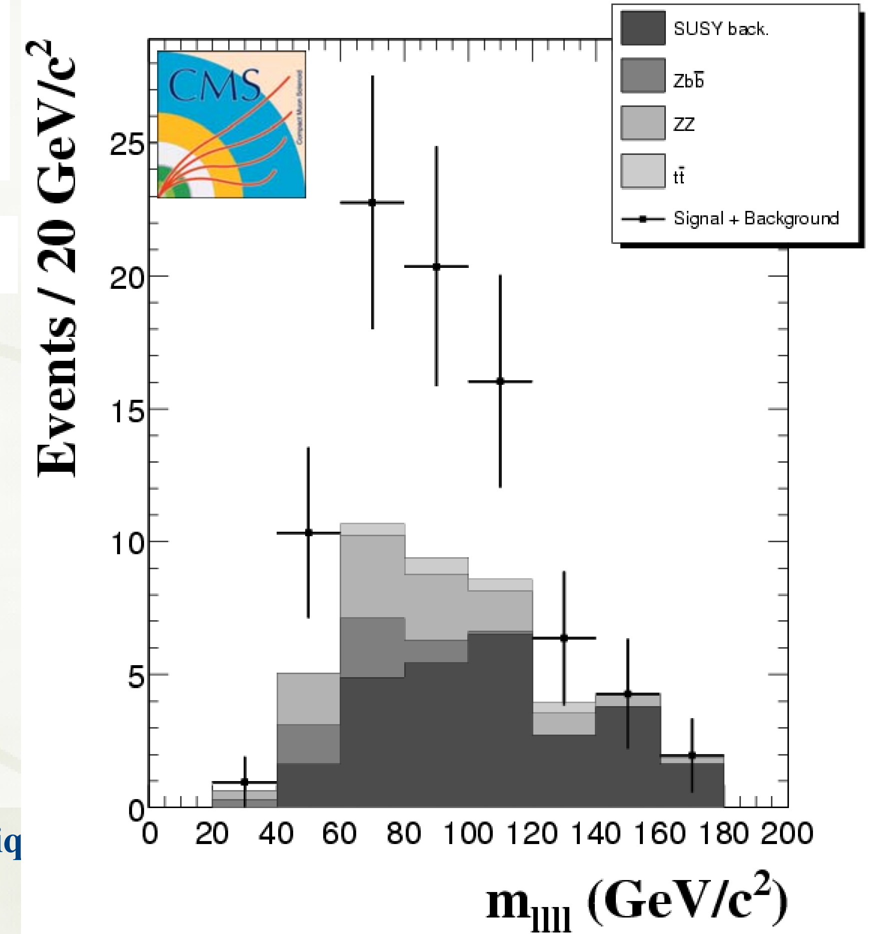
CMS

Access to low tanβ with $A/H \to \chi_2^0 \chi_2^0 \to 4\ \ell + E_T^{miss}$

Chosen points in mSUGRA

Point	m_0 (GeV)	$m_{1/2}$ (GeV)	A_0 (GeV)	tanβ	$sign(\mu)$
A	60	175	0	10	+
B	80	200	0	5	+
C	50	150	0	5	+

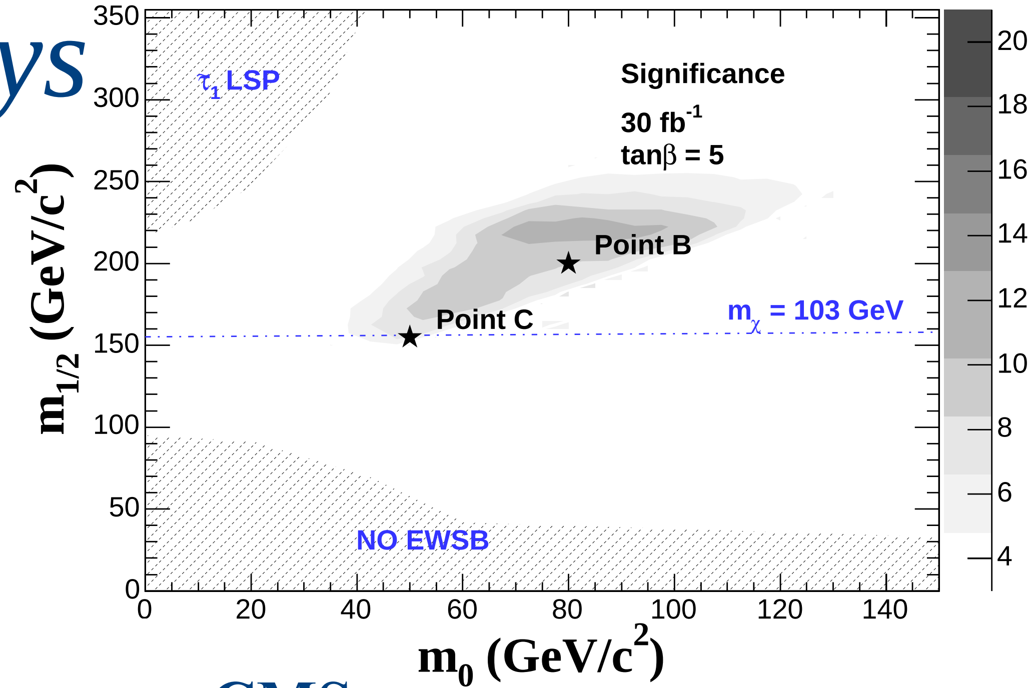
Point C after selections

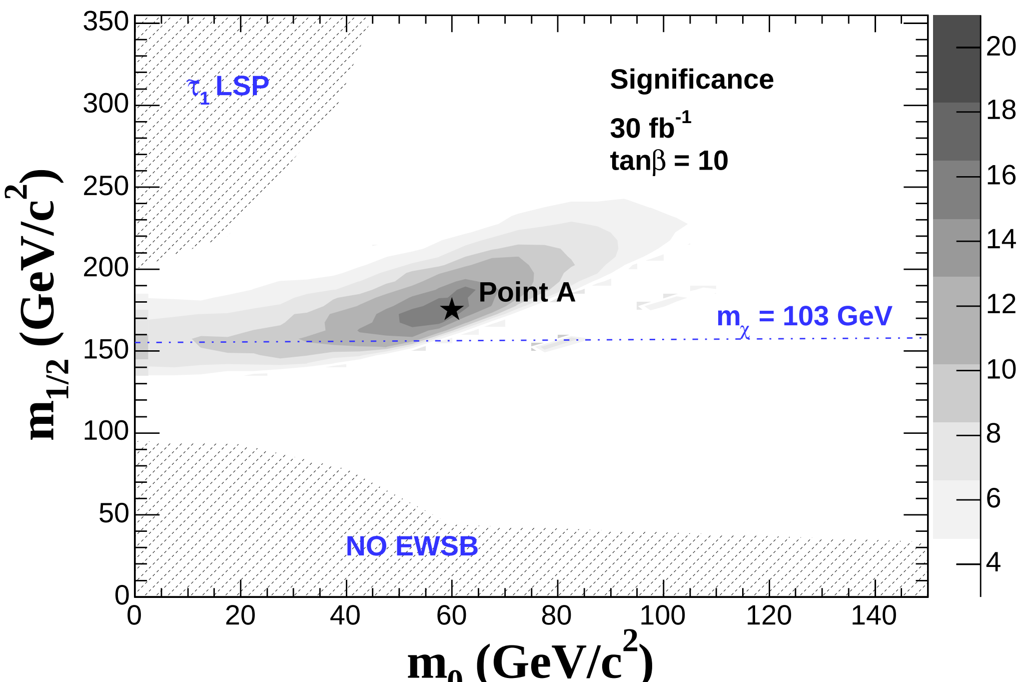


- **Background**
  - **SUSY, SM: tt, ZZ, Zbb**
- **Selections:**
  - **Lepton isolation**
  - **Jet veto**
  - **E_T^{miss}, p_T^{4l} < 80 GeV**
  - **Z veto**

A/H susy decays

Access to low $\tan\beta$ with $A/H \to \chi_2^0 \chi_2^0 \to 4\ell$





CMS

$\tan\beta = 5$ $150 < m_{1/2} < 250$
$30 < m_0 < 120$

$\tan\beta = 10$ $150 < m_{1/2} < 250$
$m_0 < 120$

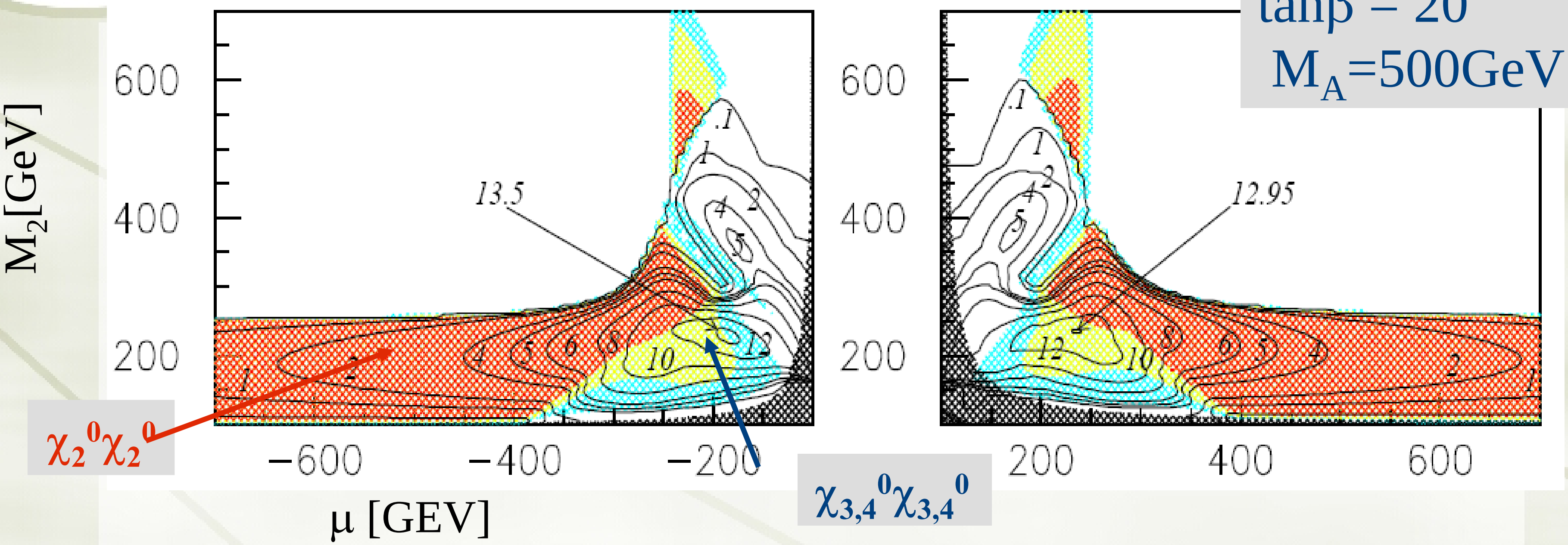
A/H susy decays

$$A,H \rightarrow \chi^0_{2,3,4}\,\chi^0_{2,3,4} \rightarrow 4\,\ell^{\pm} + E^{miss}_T$$

$\ell = e\mu$

$$A,H \rightarrow \chi^+_2\,\chi^-_{1,2} \rightarrow 4\,\ell^{\pm} + E^{miss}_T$$

$\sigma(pp \rightarrow H/A)\ Br(A,H \rightarrow 4\,\ell^{\pm} + N)$



M.Bisset,N.Kersting,F.Moortgat,S.Moretti,arXi:0709.10029[hep –ph]

Search in a LHC detector

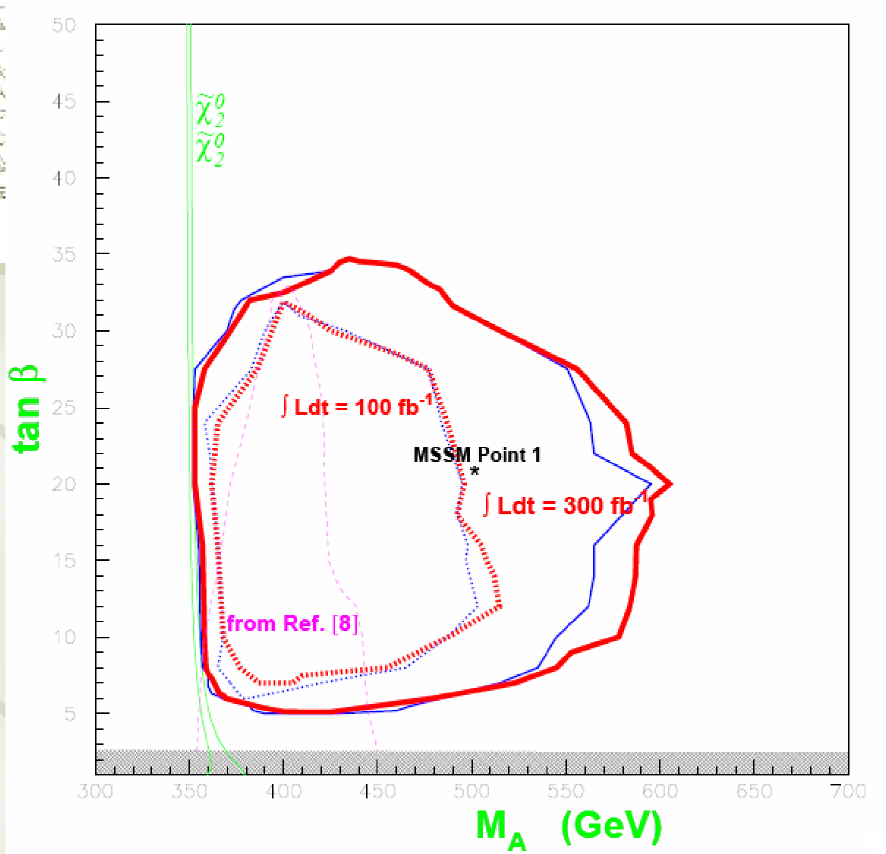
- Representive points studied:
  - **MSSM** representative Points
  - **MSugra** representative Points

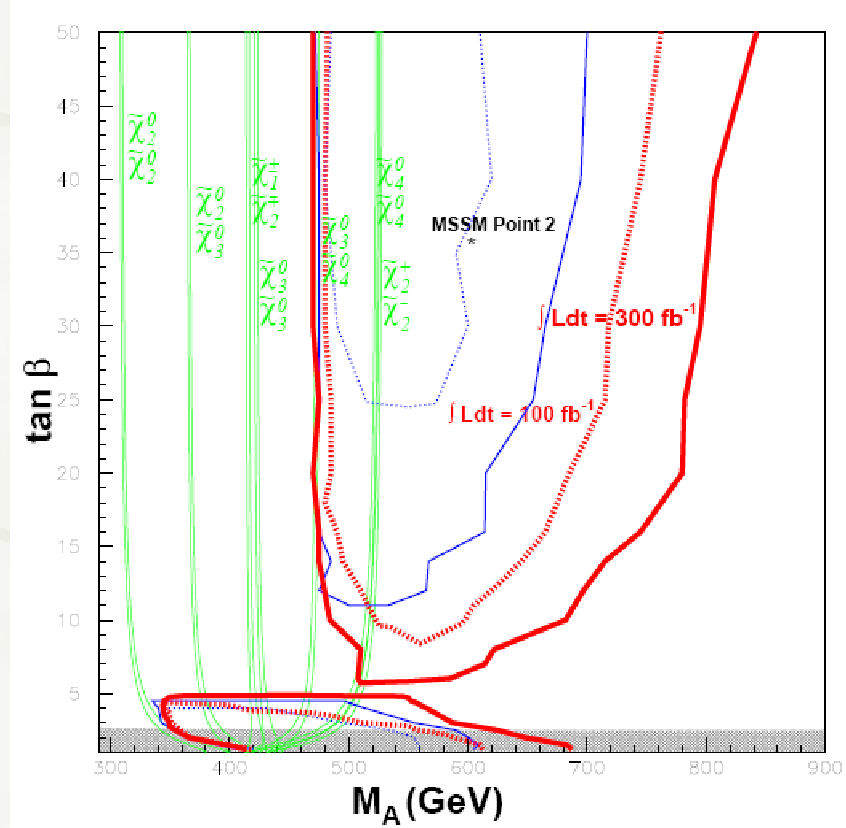
Point A M_0=125 GeV tanβ=20
Point B M_0=400 GeV tanβ=20
$M_{½}$=165GeV sign(μ)=+1 A_0=0

- Discovery potential in a typical LCH detector investigated with this selections:

- 4 leptons $|\eta^{\ell}| < 2.4$, $E_T^{\ell} > 7.4$ GeV
- lepton Isolation
- 2pairs of opposite sign
- $|M_Z \pm 10$ GeV$|$ veto
- 20 GeV $< E_T^{\ell} <$ 80 GeV
- $E_T^{jet} <$ 50 GeV

Reach for MSSM Higgs bosons in $\chi^0_{2,3,4}\chi^0_{2,3,4}$ or $\chi_{1,2}^+\chi_2^-$ pairs

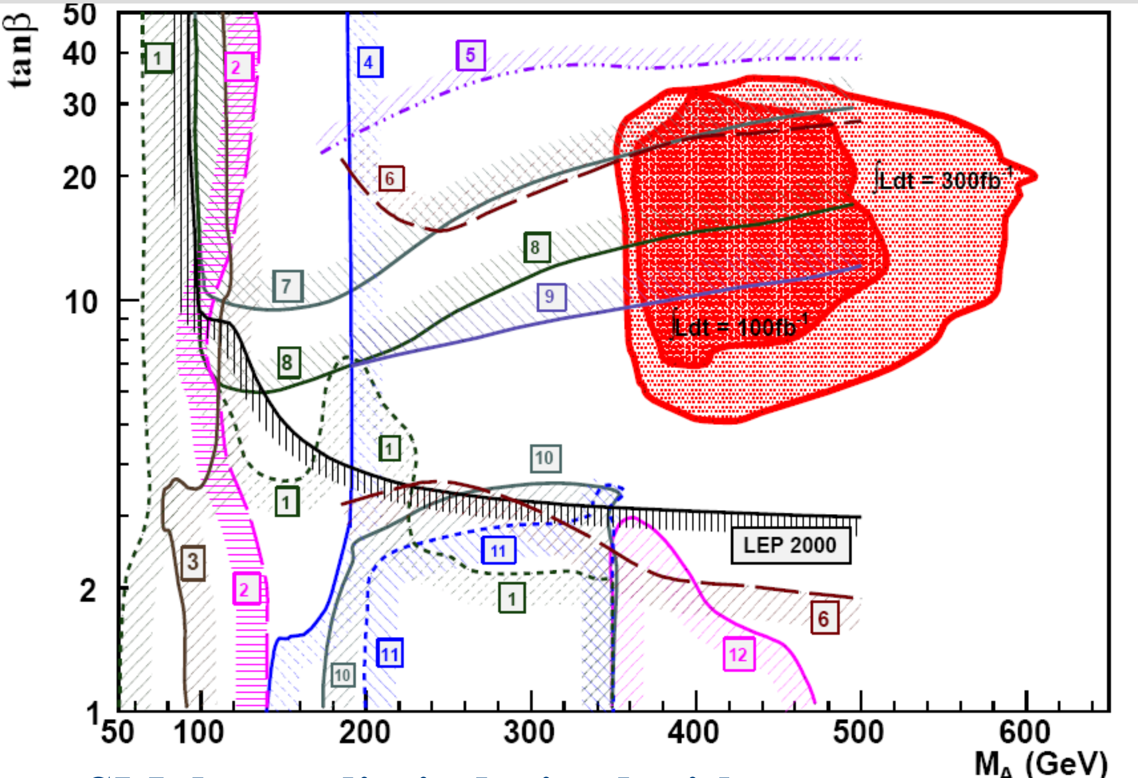




Point 1 M_A=500 GeV tanβ=20
M_1=90GeV M_2=180 GeV μ=-500GeV
M_ℓ=M_τ= 250GeV m_g=M_q=1000GeV

Point 2 M_A=600 GeV tanβ=35
M_1=100GeV M_2=200 GeV μ=-200GeV
M_ℓ=150GeVM_τ= 250Gev m_g=800GeV
M_q=1000GeV

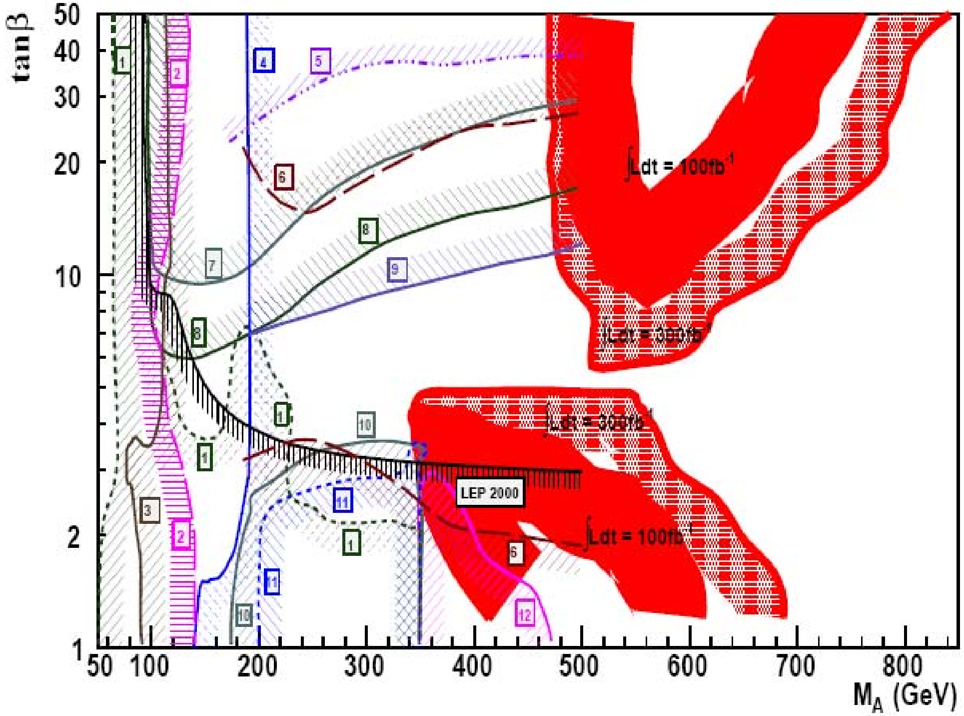
*Discovery region for **H/A** $\rightarrow \chi^0_{2,3,4}\chi^0_{2,3,4}$ $\chi_{1,2}^{+}\chi_2^{-}$ **Set 1** superimposed to Atlas discovery reach with SM particles*



1. $H \rightarrow ZZ^* \rightarrow 4\ \ell$
2. $tH \rightarrow bH^+, H^+ \rightarrow \tau\nu$ +cc
3. $tth, h \rightarrow bb$
4. $h \rightarrow \gamma\gamma$
5. $bbH/A, H/A \rightarrow bb$
6. $H^+ \rightarrow tb$ +c.c.
7. $H/A \rightarrow \mu^+\mu^-$
8. $H/A \rightarrow \tau^+\tau^-$
9. $gb \rightarrow tH^+, H^+ \rightarrow \tau+\nu$
10. $H \rightarrow hh \rightarrow bb\gamma\gamma$
11. $A \rightarrow Zh \rightarrow \ell\ell\, bb$
12. $H/A \rightarrow tt$

SM decays limit derived with hypotesis that H/A can't decay in SUSY particles.
DIFFERENT parameter!!

*Discovery region for **H/A** $\rightarrow\chi^0_{2,3,4}\chi^0_{2,3,4}$ $\chi_{1,2}^+\chi_2^-$ **Set 2** superimposed to Atlas discovery reach with SM particles*



1. $H \rightarrow ZZ^* \rightarrow 4\ell$
2. $tH \rightarrow bH^+, H^+ \rightarrow \tau\nu$ +cc
3. tth , $h \rightarrow bb$
4. $h \rightarrow \gamma\gamma$
5. bbH/A, $H/A \rightarrow bb$
6. $H^+ \rightarrow tb$ +c.c.
7. $H/A \rightarrow \mu^+\mu^-$
8. $H/A \rightarrow \tau^+\tau^-$
9. $gb \rightarrow tH^+$, $H^+ \rightarrow \tau+\nu$
10. $H \rightarrow hh \rightarrow bb\gamma\gamma$
11. $A \rightarrow Zh \rightarrow \ell\ell bb$
12. $H/A \rightarrow tt$

SM decays limit derived with hypotesis that H/A can't decay in SUSY particles.

DIFFERENT parameter!!

Conclusions

- Atlas & CMS are preparing for first collision data
- Discovery potential of MSSM Higgs boson has been estimated by ATLAS and CMS.
- A early discovery of a neutral MSSM boson in some channels (e.g.bb h/A$\rightarrow\mu\mu$) looks possible with integrated luminosity =10 fb^{-1} , i.e. after only one year of data taking.
- First data has the possibilty to exclude/or confirm the entire MSSM
- Others decay channel (as $\chi_2^0\ \chi_2^0$) can be explored later for unexplored region of parameter plane.