MSSM neutral Higgs bosons search with the ATLAS detector at LHC

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on behalf of ATLAS Collaboration

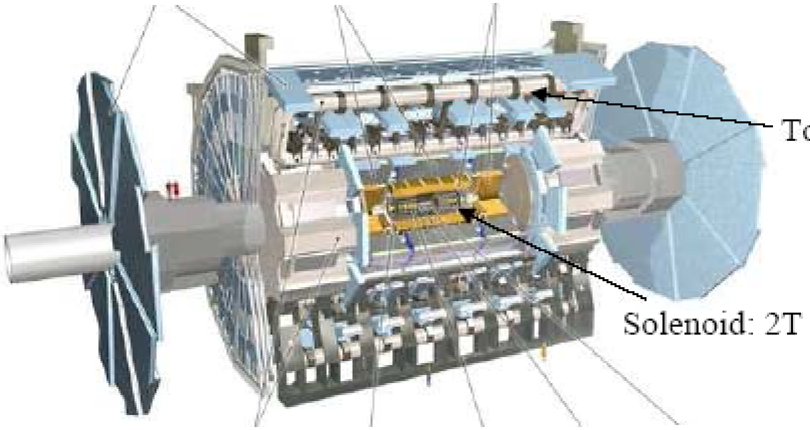
Outline

- Motivation
- Supersymmetric (SUSY) Higgs
- Signal production and properties
- Among all channels studied from ATLAS focus on :
  - $h/A/H \rightarrow \mu\mu$
  - $h/A/H \rightarrow \tau\tau$
  - $A/H \rightarrow \chi^0_{2,3,4}\chi^0_{2,3,4}$ and $A/H \rightarrow \chi^+_2 \chi^-_{1,2}$
- Conclusions

New

New results from recent detailed simulation

ATLAS detector



- 46 m length, 24 m diameter
- 7000 t weight
- 3000 km cables

Trigger:
10^9 Hz ⇨ 75 kHz ⇨ 100 MB / s storage

Detector component	Resolution	η coverage
Tracking	$\sigma / p_T = 0.05\ \%\ p_T$ [GeV] $\oplus$ 1 %	$\lvert\eta\rvert < 2.5$
EM calorimetry	$\sigma / E = 10\ \% / \sqrt{E}$ [GeV] $\oplus$ 0.7 %	$\lvert\eta\rvert < 2.5$
Hadronic calo: Barrel	$\sigma / E = 50\ \% / \sqrt{E}$ [GeV] $\oplus$ 3 %	$1.5 < \lvert\eta\rvert < 3.2$
Forward	$\sigma / E = 100\ \% / \sqrt{E}$ [GeV] $\oplus$ 10 %	$3.1 < \lvert\eta\rvert < 4.9$
Muon spectrometer	$\sigma / p_T = 2.3\ \%\ (p_T = 50$ GeV)	$\lvert\eta\rvert < 2.7$

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

Phenomenology decribed at Born level by tan β ,m_A

- 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

➢couplings: gMSSM = ξ · gSM
no coupling of A to W/Z
large tanβ: 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 angle between CP even Higgs bosons (calculable from tanβ and M_A)

Masses

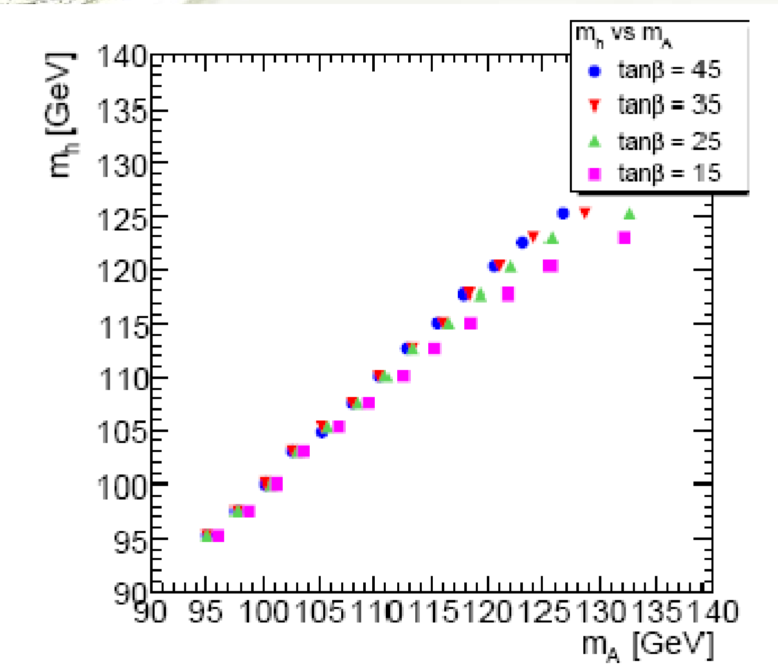
- For $M_A < 135$ GeV (M_h^{max} scenario)
- The ligth MSSM Higgs is SM-like

$$M_A \approx M_h$$

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

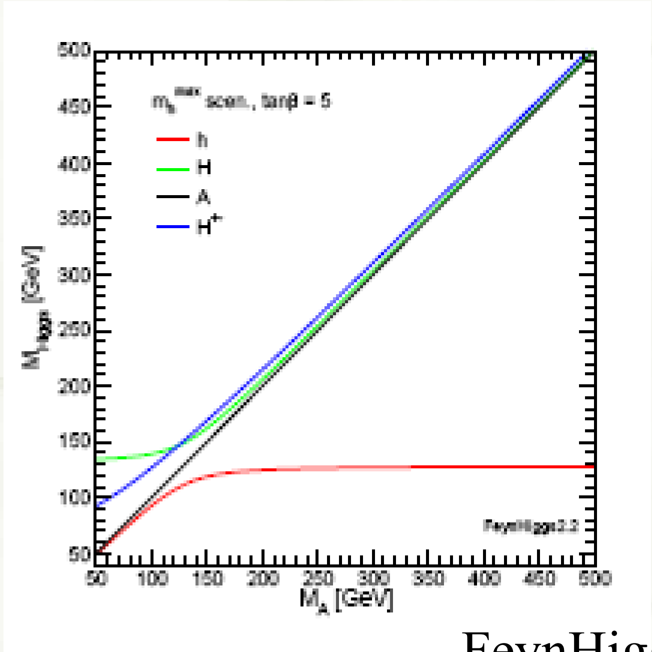
The heavy MSSM Higgs:

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



Pythia 6.226

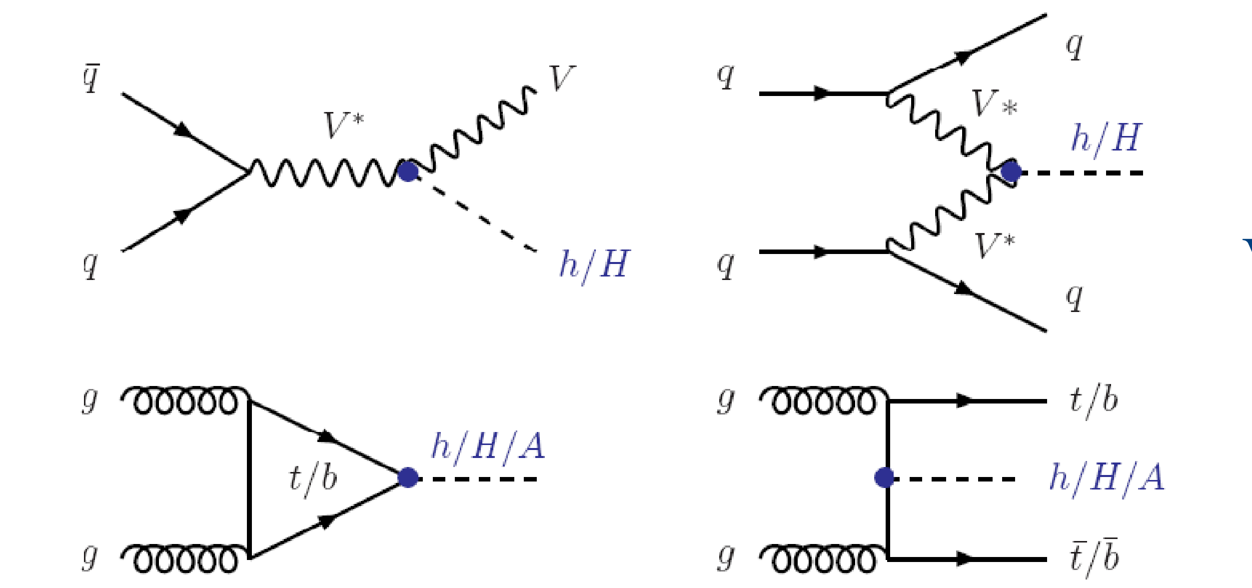
S.G, H.Bilokon,V.Chiarella,G.Nicoletti
ATL-PHYS-PUB-2007-001



FeynHiggs2.2

Sven Heinemeyer
Atlas meeting 29.01.2008

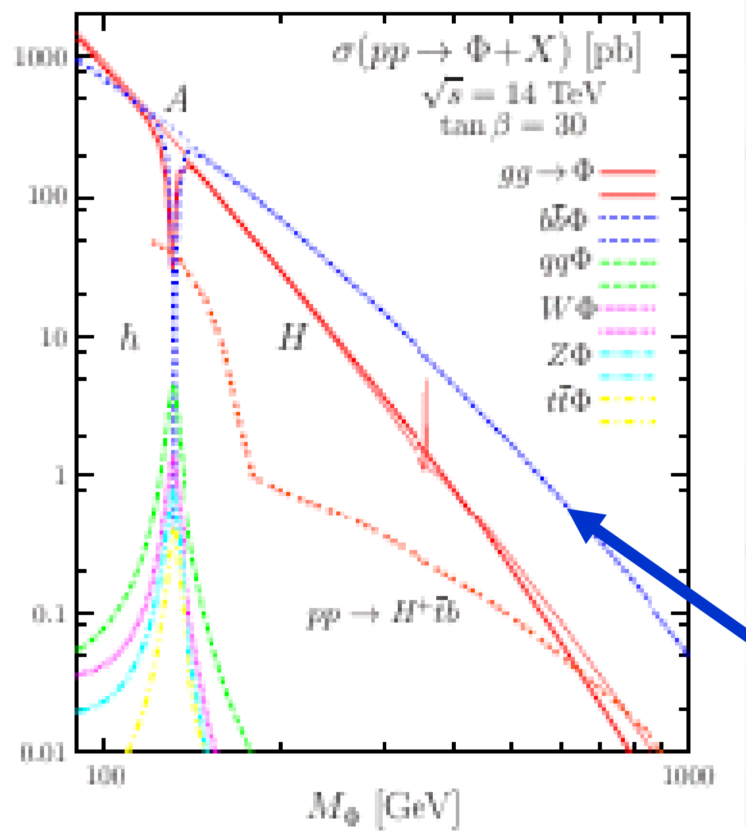
MSSM Higgs Production



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

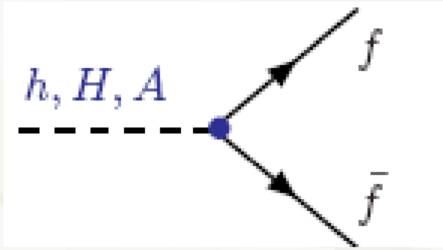
  important at $m_h \sim m_{hmax}$
- Higgsstrahlung neglegible
- At **high tanβ associated b quarks production dominates**

  pp → bb →h/H/A+ bb

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

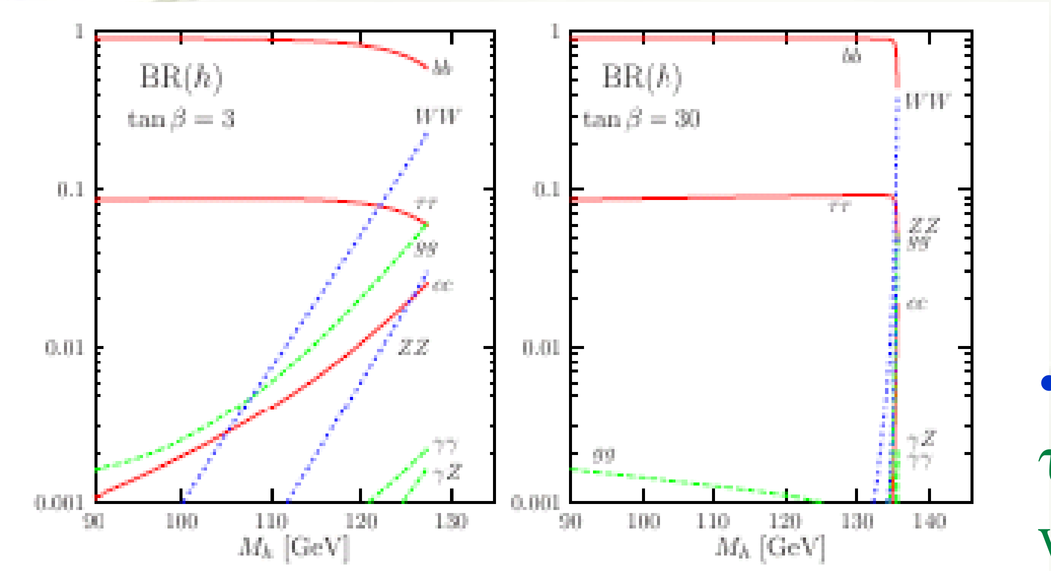
Branching ratio

- Decoupling region
  $M_A \geq 150$ GeV tanb ≈30
  or $M_A \geq 400$-500 GeV tanβ=3



Production rate

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

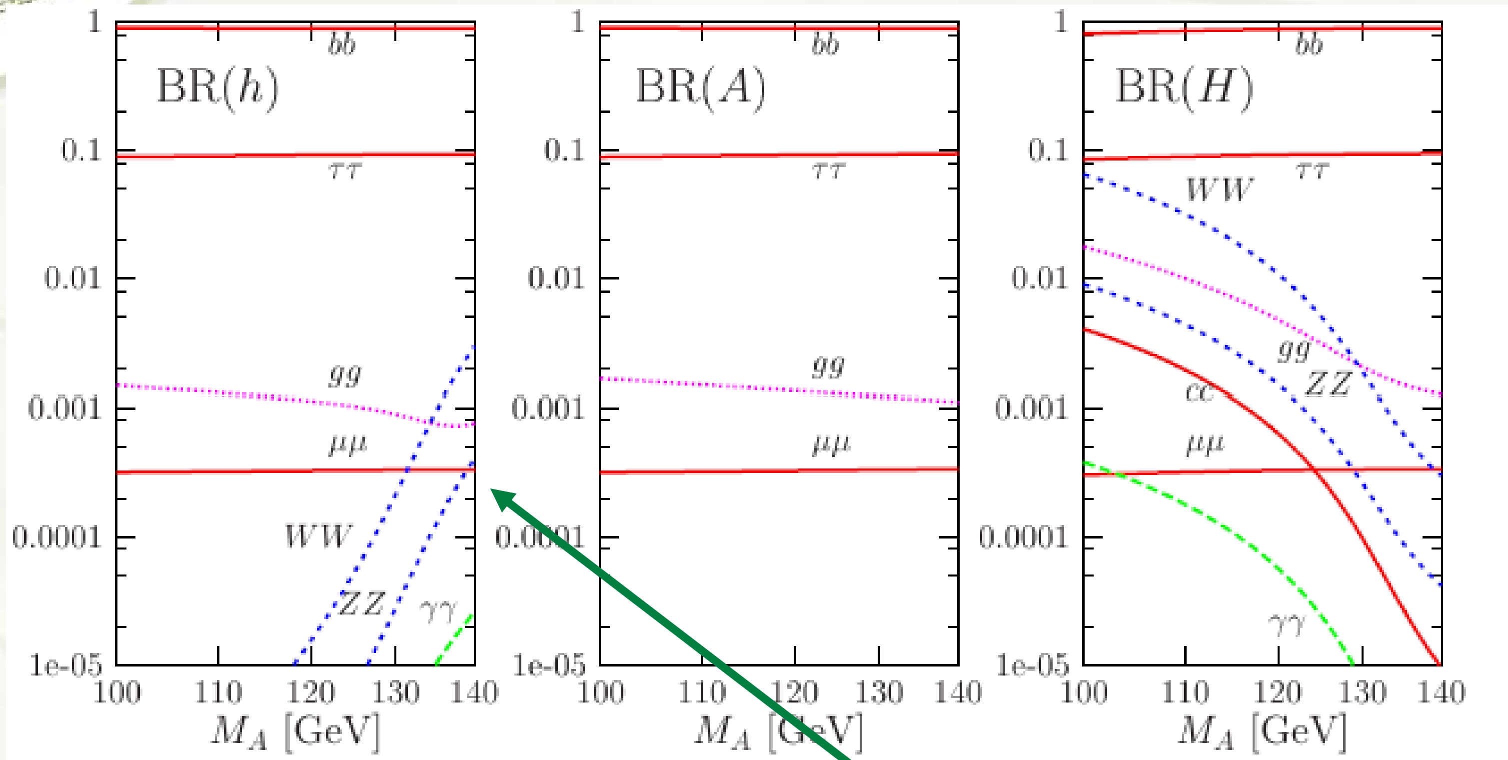


- Decay bb dominates,
  ττ lower background
  weaker sensitivy on
  SUSY parameters

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 ($X_t = 0$)

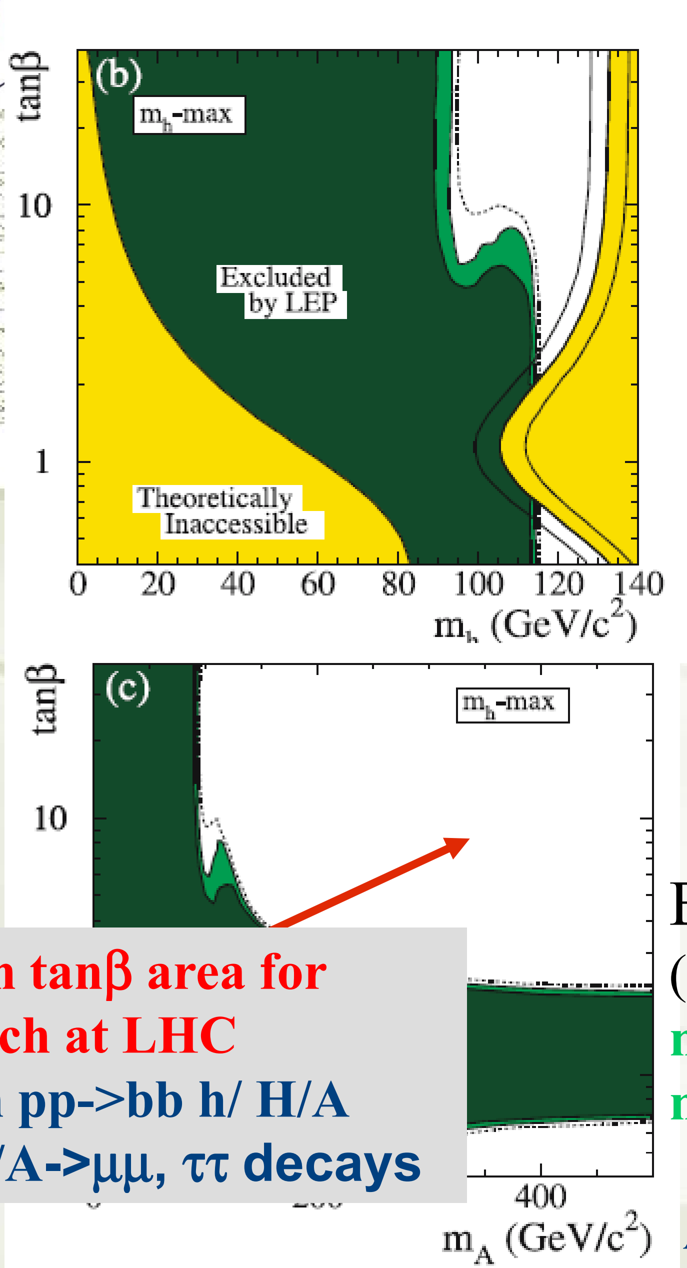
- small α_{eff} scenario

Hb coupling~ sin α_{eff}/ cos β can be zero: $\alpha_{eff} \rightarrow 0$:
Main decay mode vanishes, important search channel vanishes

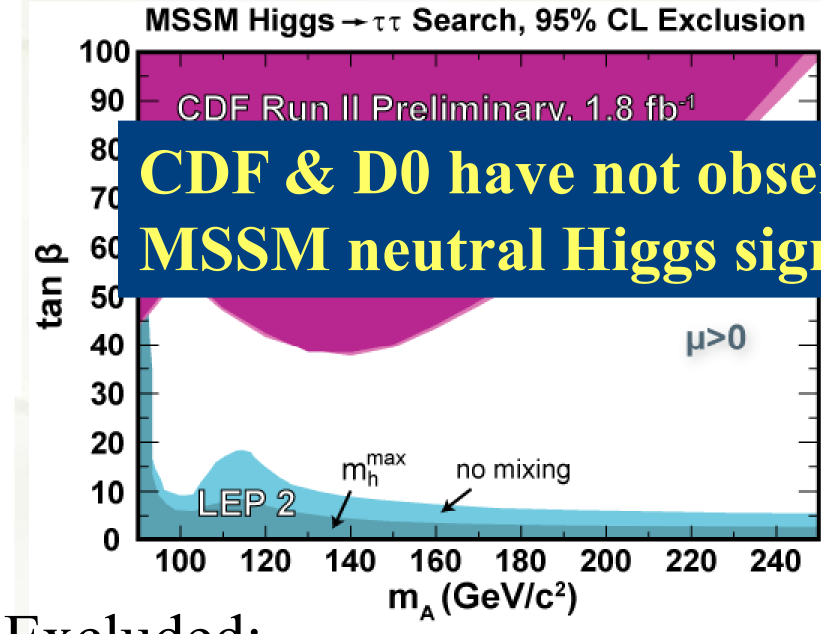
- gluophobic Higgs scenario

hgg coupling is small: main LHC production mode vanishes.

Exclusion Limit from LEP And Tevatron



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



CDF & D0 have not observed a MSSM neutral Higgs signal yet

Excluded:

(m_h^{max}scenario)

m_h>92.8 GeV

m_A>93.4 GeV

tanβ 0.7 2.0
Excluded

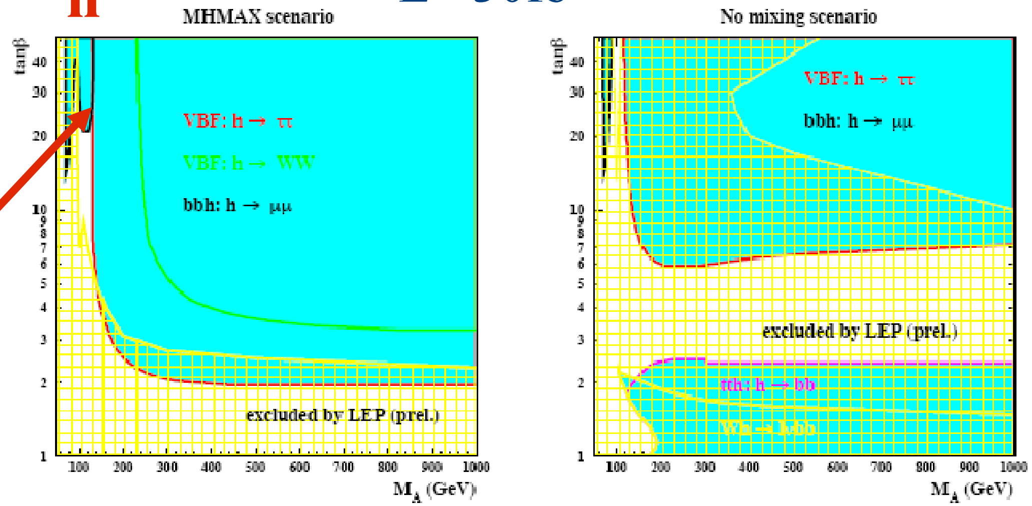
S. Lowette ICHEP 2008

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

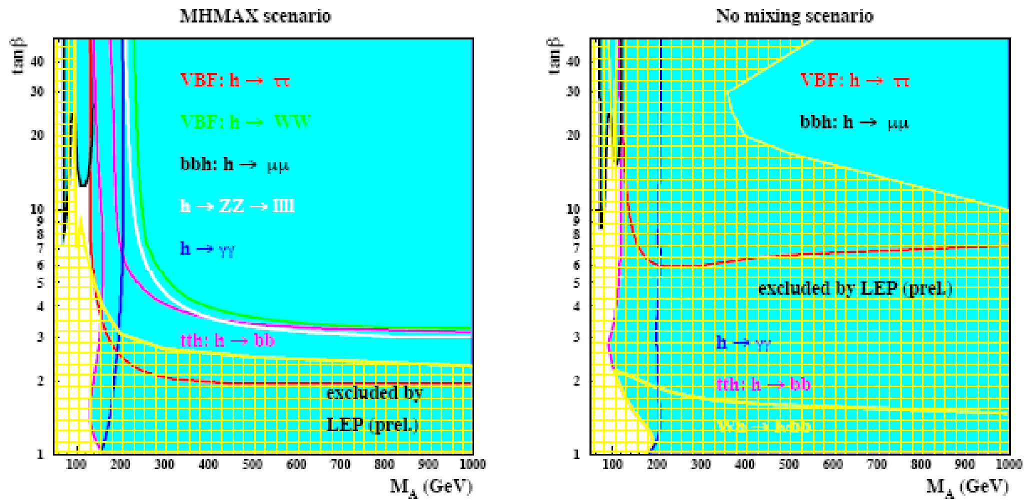
L =30fb^{-1}



h/A/H

L =300fb^{-1}

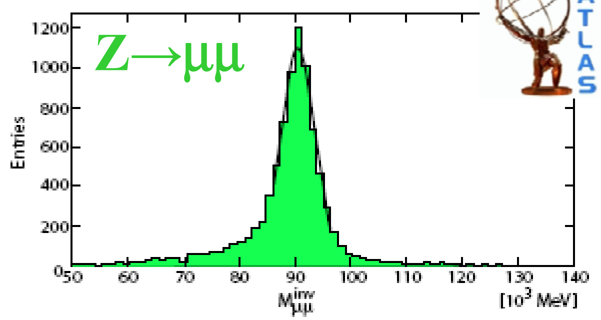
NOT UPDATED



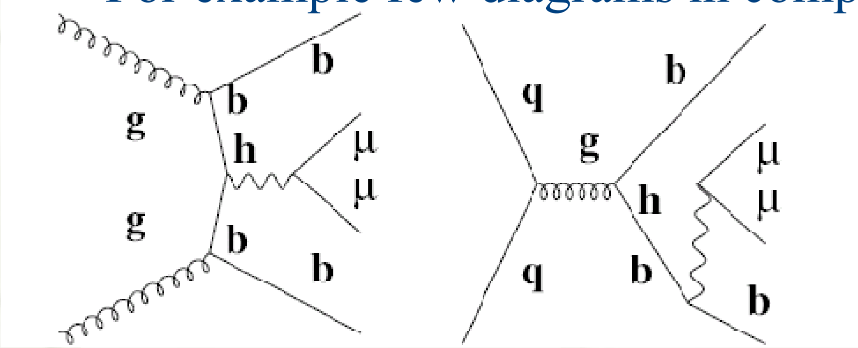
bb h/A→bbμμ

- **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

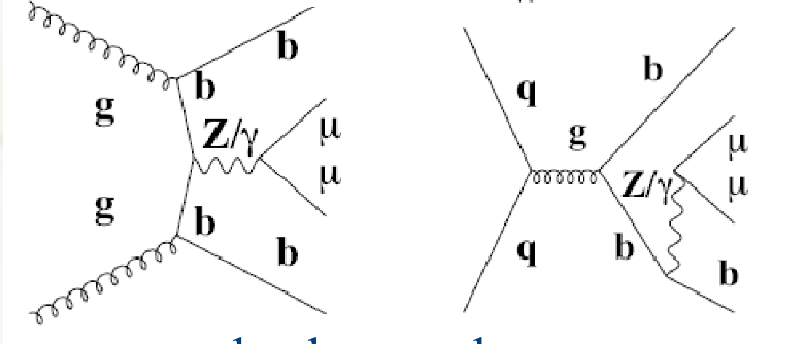
Productio
h→μμ an
→ττ



For example few diagrams in comparison:



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

pioniering work

See also: ATL-PHYS-PUB-2006-030, ATL-PHYS-PUB-2002-021, ATL-PHYS-PUB-2002-013 ATL-PHYS-PUB-2000-001

Background evaluation

- **$bbZ \rightarrow bb\mu\mu$** large cross section ($\sigma \approx$ 22.8 pb) large theoretical uncertainties ($\approx$ 25%)

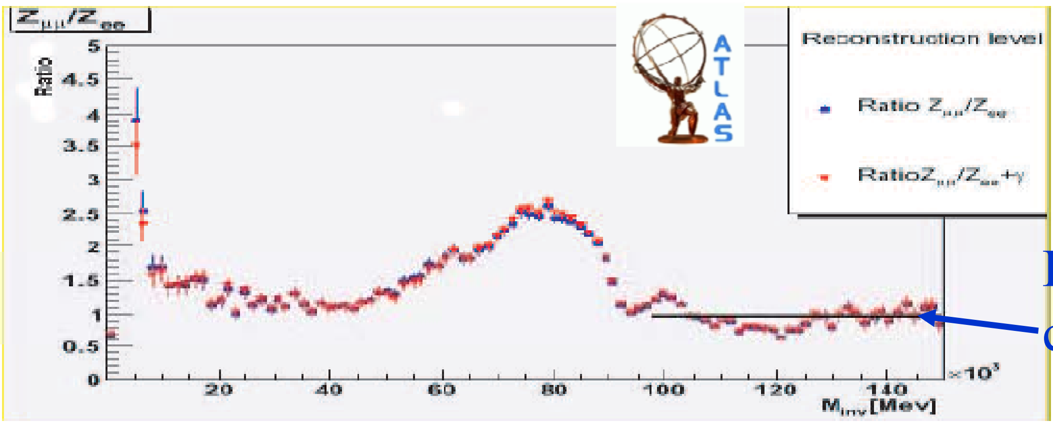
Proposed **data driven method** based on $bbZ \rightarrow bbee$

- 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

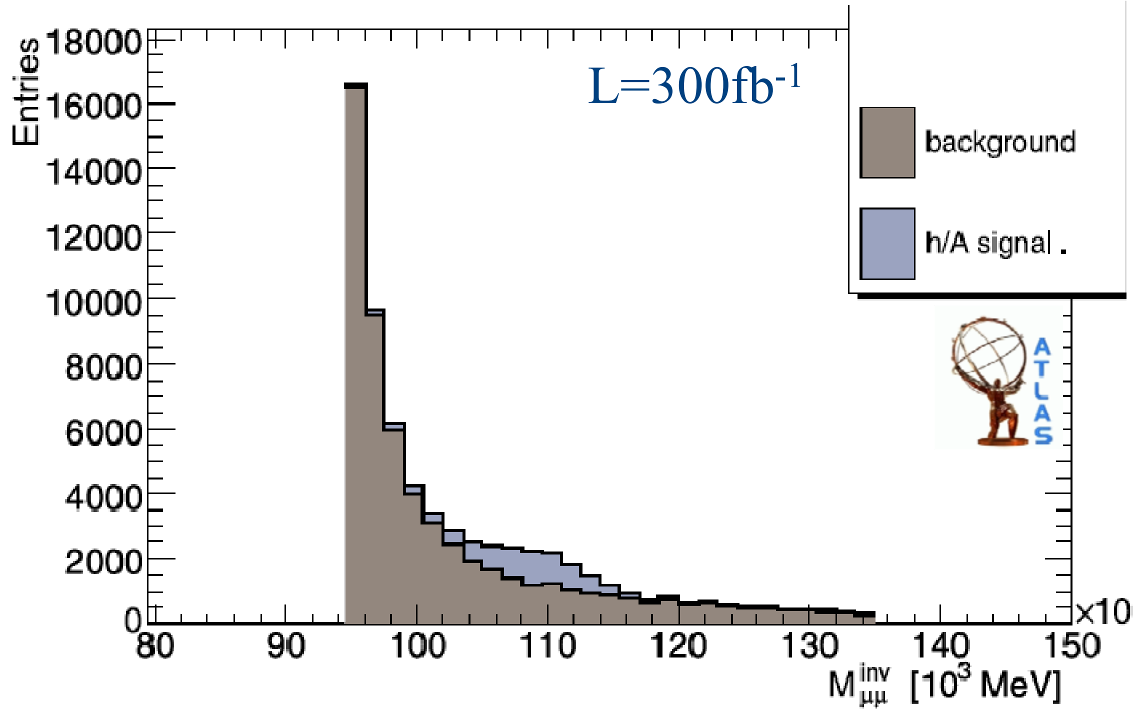


Ratio stable & without large corrections factor

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

$b\bar{b} \to b\bar{b}h/A\mu\mu$ low mass region

M_A=110.31 GeV, M_h= 110 GeV, tanβ=45



LO order cross section

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

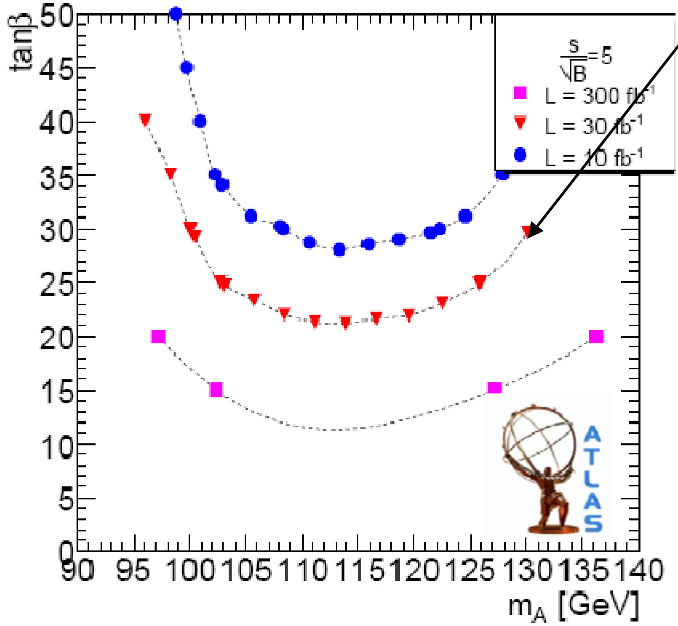
Full detector simulation
Corresponding to L=300fb^{-1}

•Background bbZ→bbμμ
tt →bbμμ
ZZ→bbμμ

•good muon momentum resolution makes Higgs mass peak stand out on a falling background

Discovery contours

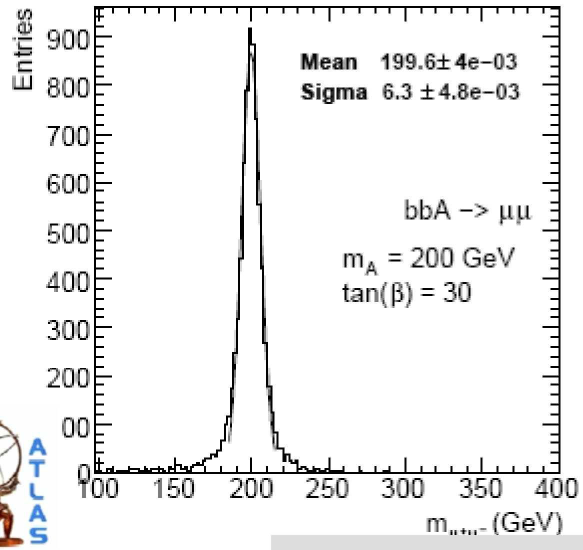
5 σ at L =30 fb^{-1}



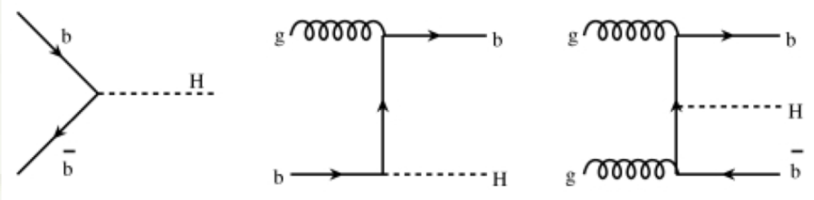
ATLAS

- In the region **M_A< 135GeV** neutral MSSM Higgs production is dominated by h/A
- In the region **M_A> 135GeV** the production is dominated by H/A

/H higher mass range



preliminary



- using NLO σ
- Z+udcs background

tanβ= 30

	A boson mass (GeV)					
(GeV)	110	130	150	200	300	400
Natural width	2.16	2.48	2.80	3.60	5.61	8.46
Reconstructed σ	2.59 ± 0.02	3.83 ± 0.03	4.11 ± 0.04	6.29 ± 0.05	10.2 ± 0.2	15.0 ± 0.3
Reconstructed mass	109.818 ± 0.006	129.738 ± 0.005	149.796 ± 0.006	199.589 ± 0.005	298.82 ± 0.04	399.37 ± 0.04

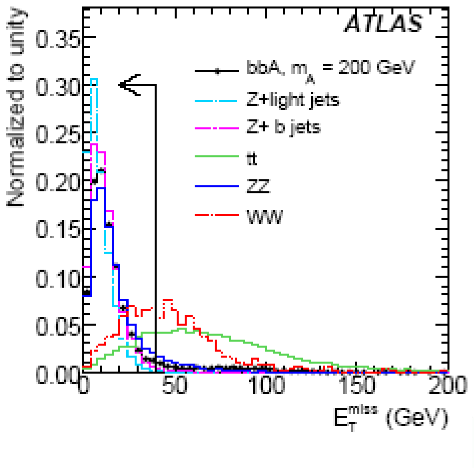
preliminary

Generators:
- h/A/H SHERPA
- tt MC@NLO
- ZZ PYTHIA
- bbZ AcerMC/PYTHIA

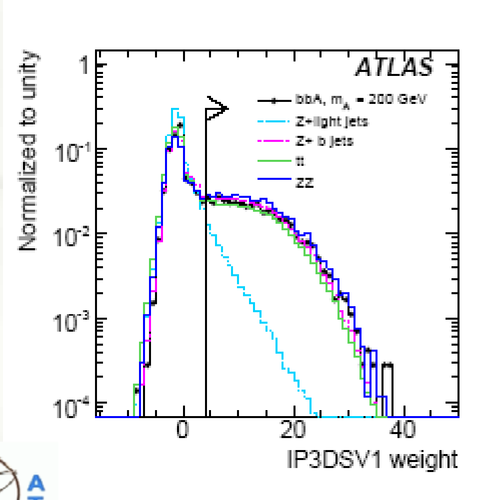
ATLAS Collaboration,
Expected Performance of the ATLAS Experiment,
Detector, Trigger and Physics,
CERN-OPEN-2008-020, Geneva, 2008, to appear.

Signature

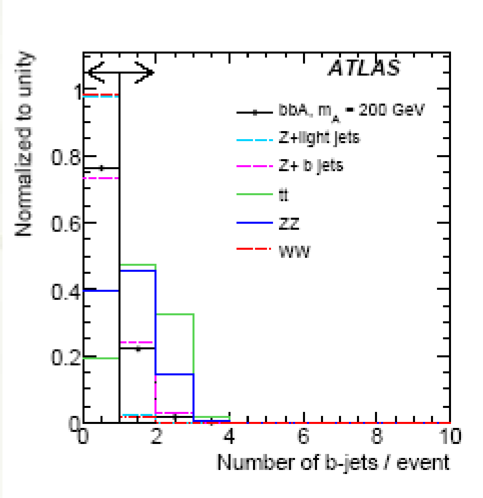
- Preselection :Trigger One μ with p_T >20 GeV and 2, p_T^{μ}> 20 GeV



E^T_{miss} < 40 GeV



b-tag weight >4



a) O-b-jet b)≥ 1 b-jet

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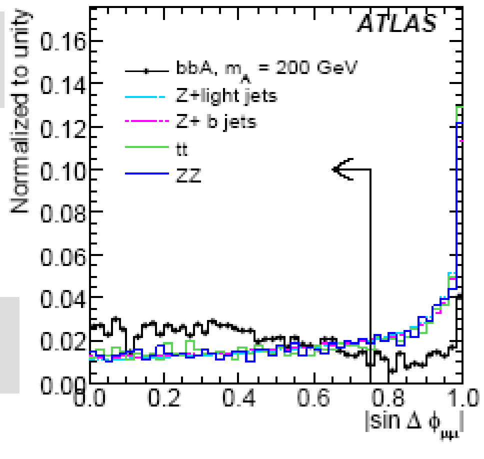
b)≥ 1 b-jet



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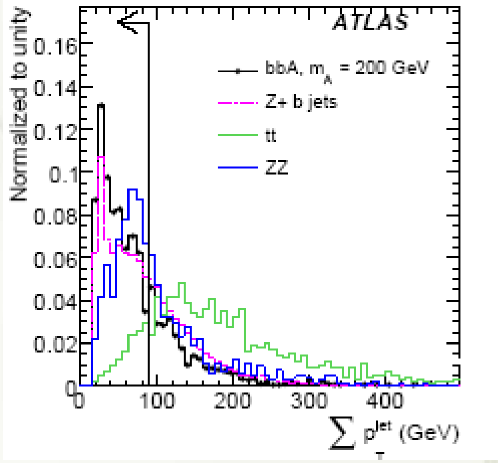
|sin Δϕ μμ <0.75|



ΣP_T^{jet} < 90GeV

High mass analysis

- Analysis divided in two independent branches:
- A) events with **0 reconstructed b-jets in final state**
- B) events with **at least one reconstructed b-jet in the final state**.
- **Final discovery A)+B)**
- Signal events considered in $\Delta m = m_A \pm 2\sigma_{\mu\mu}$
- Background sideband estimation from data

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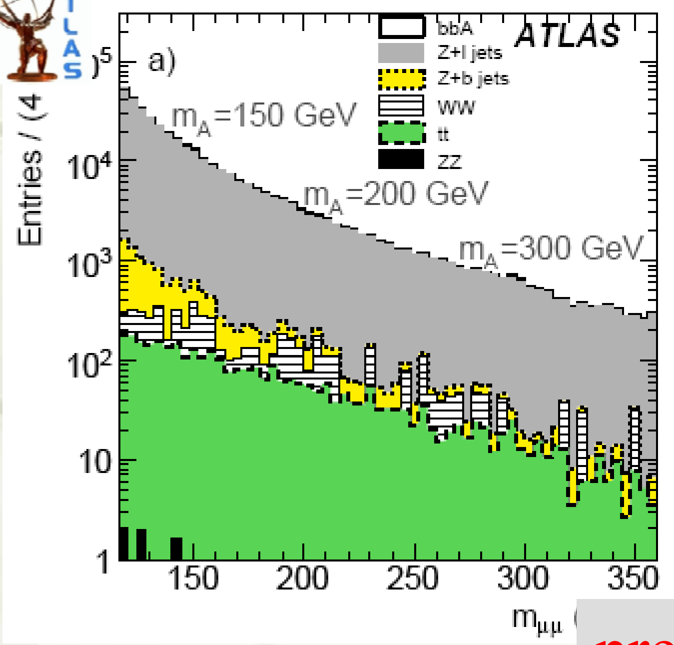
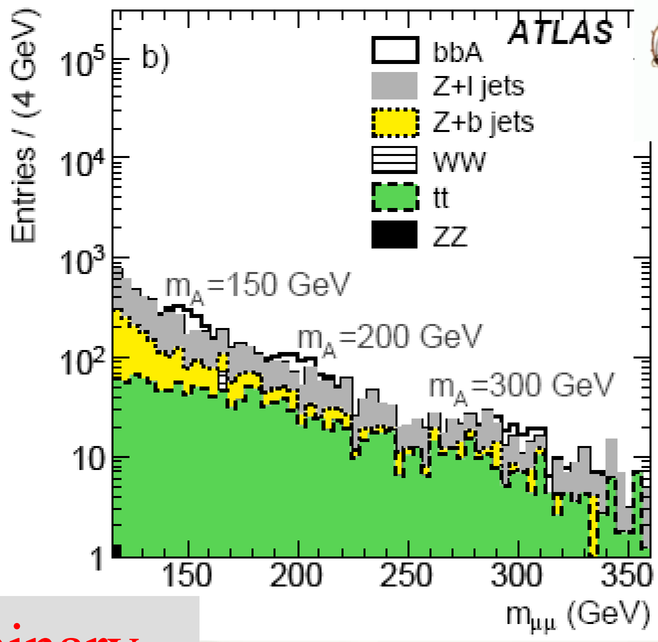
0-bjets

A+H

≥ 1b-jet





$\tan\beta=30$ $L=30fb^{-1}$

Z+jets dominating

preliminary

ttbar Z+jets dominating

Discovery Potential

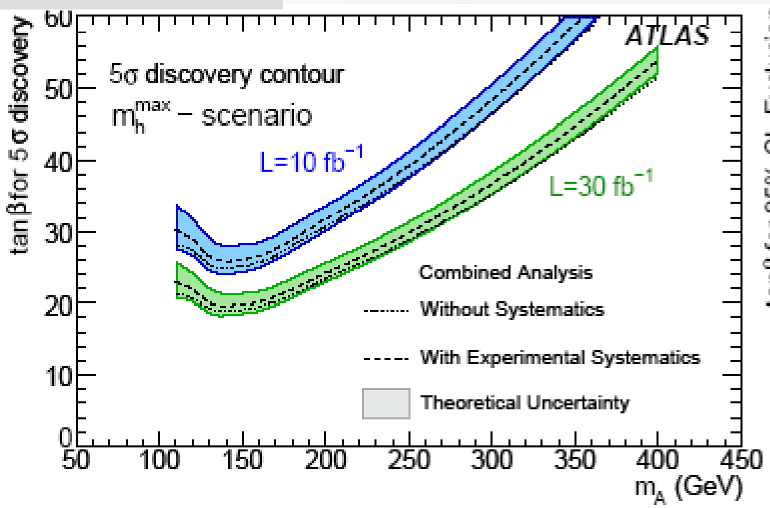
- Signal cross section uncertainties 17%
- Systematic experimental uncertainties based on detector expected performances:

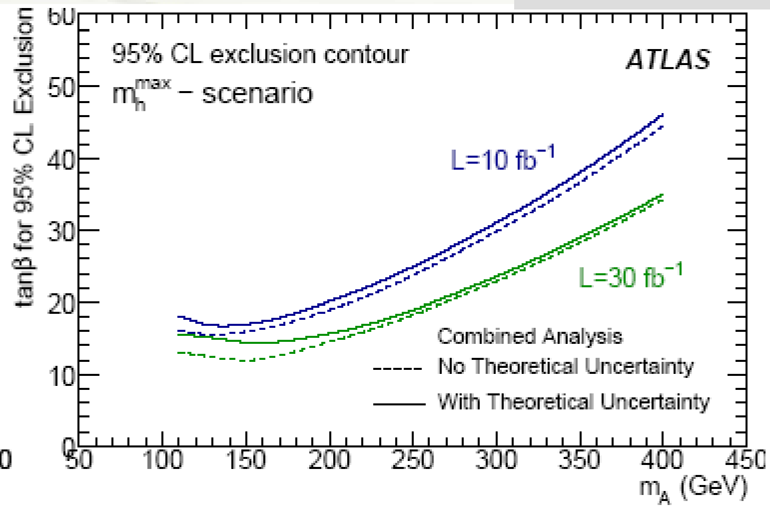
e.g. muon efficiency, muon PT scale, muon resolution, Jet energy scale, Jet energy resolution, btag efficiency, b-tagging fake rate.

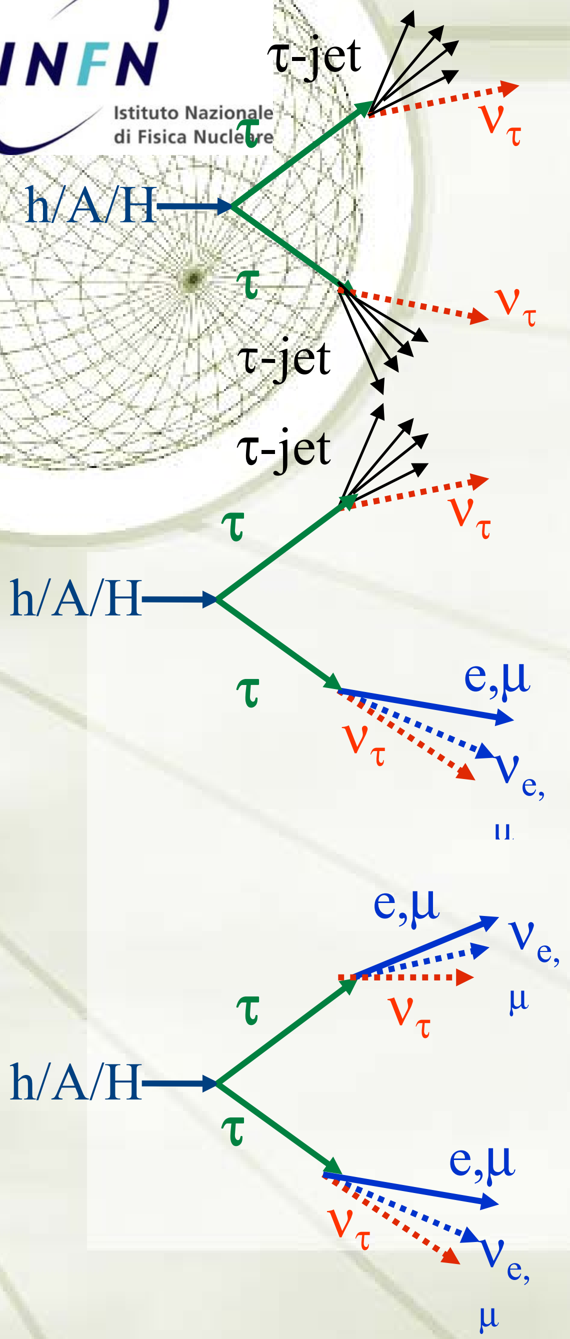
Based on detector expected performance 10-20%

Large systematic uncertainties demand for data-driven method background estimation

preliminary Combined 0-b-jet and ≥1 b-jet analysis preliminary







bb H/A → bb ττ

➢High rate but difficult from background

➢ bb H/A →bb ττ covers large tanβ region

➢Hadron/leptonic: bbH→bbττ→e/μ+jet +E_T^{miss}

Higher rate of full leptonic channel

(lepton Br($\tau \rightarrow \ell\, \nu_\tau \nu_\ell$) ~0.17)

- easier detection of full hadronic channel
- <u>good coverage</u> of MSSM parameter space.

➢Full leptonic: bbH→bbττ→eμ+E_T^{miss}

Lower rate than full hadronic or hadronic/lepton Br($\tau \rightarrow \ell\, \nu_\tau \nu_\ell$) ~0.17

clean signal and easy to trigger

•Discussion on full leptonic channel **New**

See also ATL-PHYS-2003-009

bb H/A →bb ττ → ℓ ℓ

- Higgs mass reconstruction using **collinear approximation**
- Approximation method requires **excellent missing E_T resolution**
- Main background:Z+jet,ttbar,Zbb

✦ Analysis:

- Trigger Single or dilepton
- At least one b-tagged jet
- Njet <3 cut tt background
- Dilepton-mass and missing energy cut to veto $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$
- E_T^{Miss}
- $\Delta\Phi_{\ell\ell}$
- **$Z \rightarrow \tau\tau$ estimated from data**
- Asymmetric mass window cut

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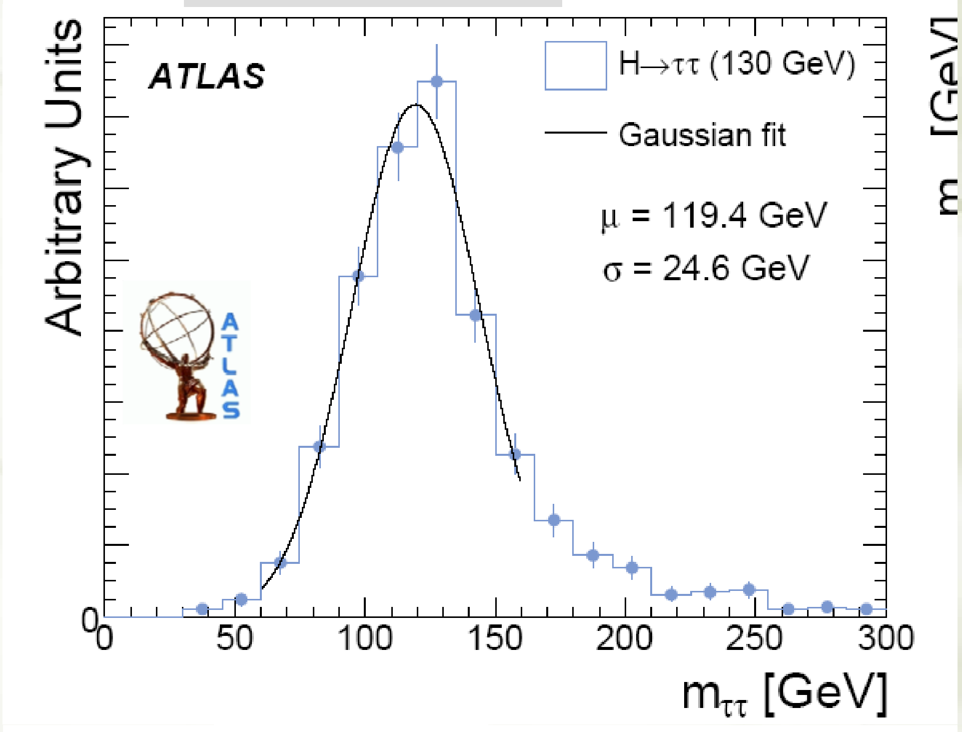

$x = p_{T,\ell} / p_{T,\tau}$

$0 < x < 1$

$$m_{\tau\tau} = \frac{m_{\ell\ell}}{\sqrt{x_1 \cdot x_2}}$$

ATLAS Collaboration,
Expected Performance of the ATLAS Experiment,
Detector, Trigger and Physics,
CERN-OPEN-2008-020, Geneva, 2008, to appear.

bb H/A →bb ττ → ℓ ℓ

- **RESULTS**
- Low M_A Range : $Z \rightarrow \tau\tau$ dominant background
- High M_A range: tt background dominant
- **Dominat Systematic Uncertainties**
- Jet Energy scale/resolution
- b-tag efficiencies

L= 30 fb^{-1}

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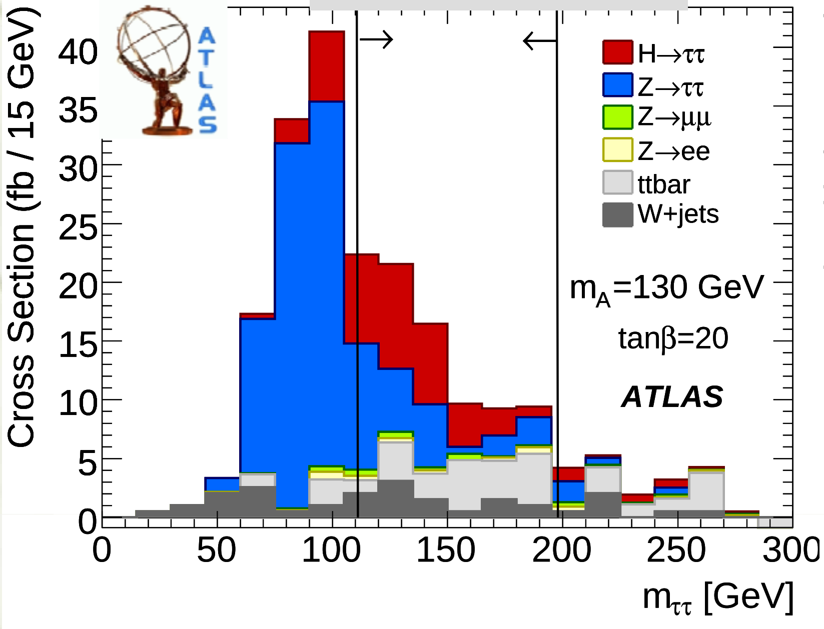

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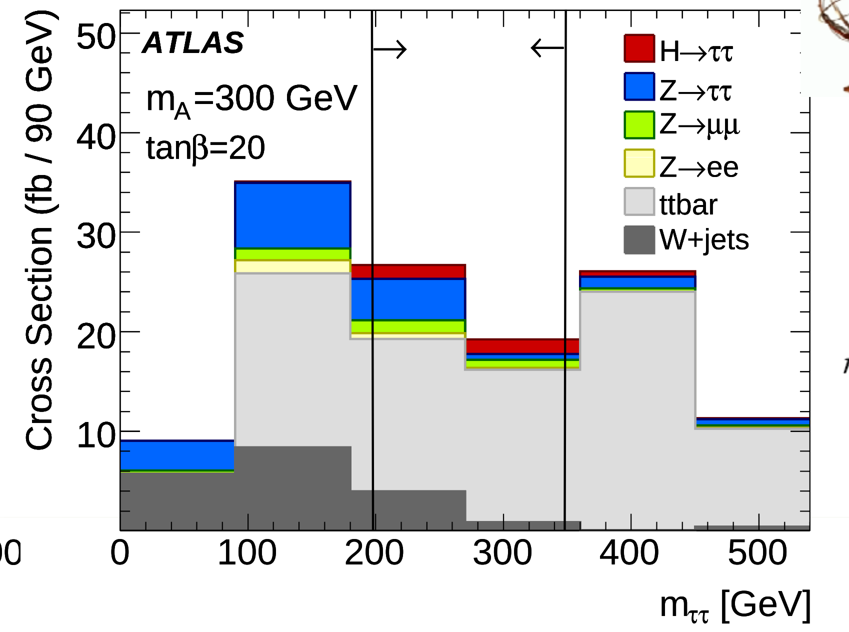


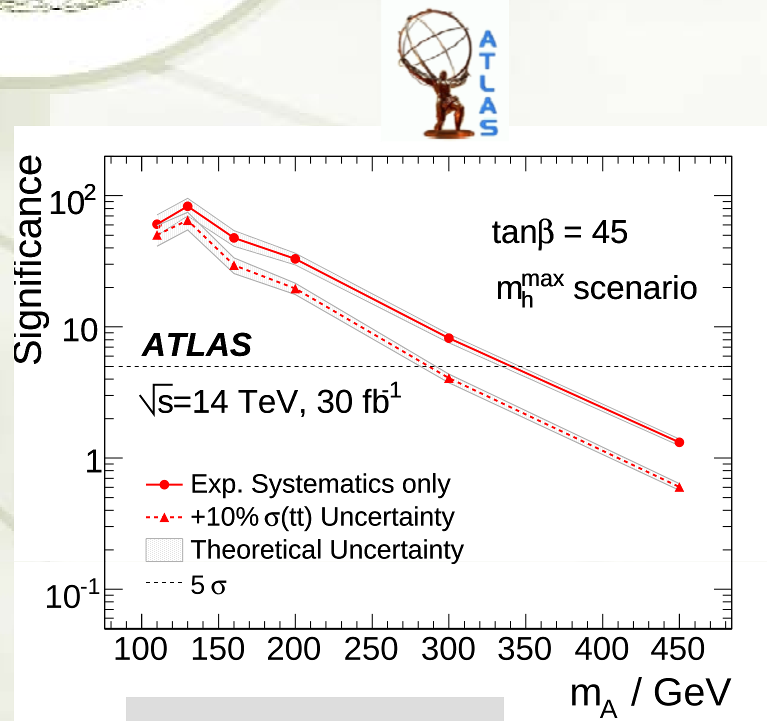
$x = p_{T,\ell} / p_{T,\tau}$

$0 < x < 1$

$$m_{\tau\tau} = \frac{m_{\ell\ell}}{\sqrt{x_1 \cdot x_2}}$$

bb H/A →bb ττ → ℓ ℓ

- **Discovery of Higgs boson in the m_h^{max} scenario is possible** for m_A= 150 GeV and tanβ > 20 , for m_A=275 GeV tanβ >35 and m_A > 300 GeV for tanβ > 45 with integrated L= 30fb^{-1}.



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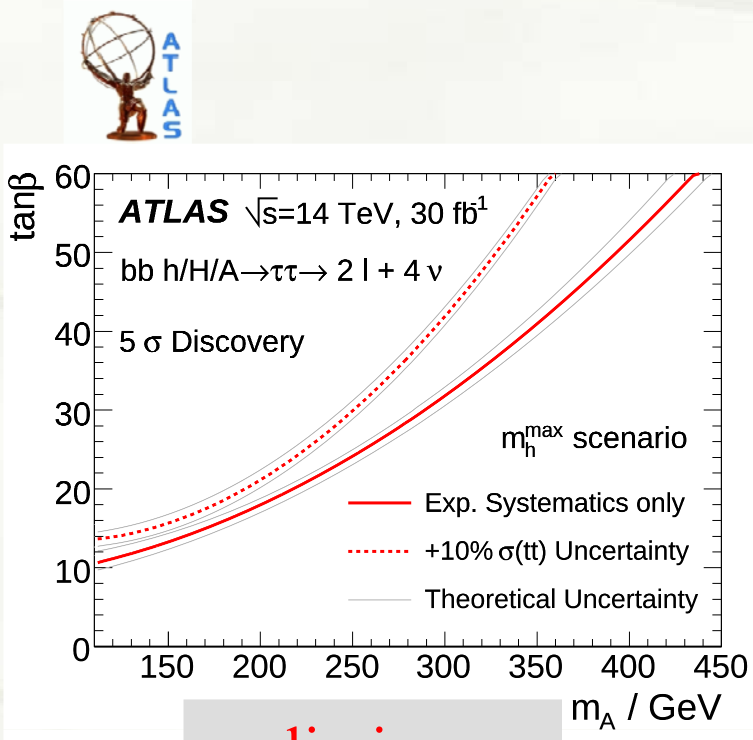


preliminary

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:

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

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

Pioneering papers:

[1] ATLAS Coll., ATLAS detector and Physics Perfomance, Vol.2 p766

[2] F. Moortgat, S. Abdullin, D. Denegri". hep-ph/0112046

[3] M.Bisset, F. Moortgat and S. Moretti "**Eur.Phys.J.C30:419-434,2003.**

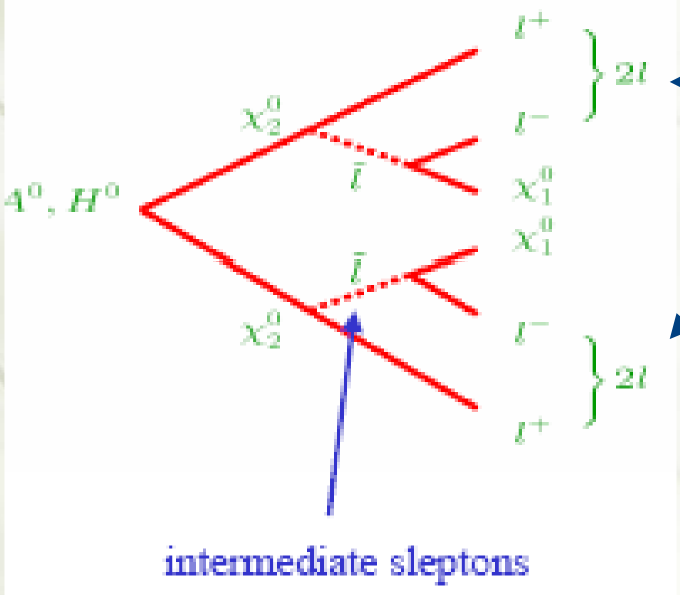
[4] C. Hansen, N. Gollub, K. Assamagan, T. Ekelof **Eur.Phys.J.C44S2:1-9,2005.**

[5] CMS Coll., CMS detector and Physics Perfomance, Vol.1

Signature

- Assume a classical production Mechanism

- Decays



4 isolated leptons (e,μ)+ E_T^{miss}

powerful signature against the SM + SUSY backgrounds at LHC

A/H susy decays

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

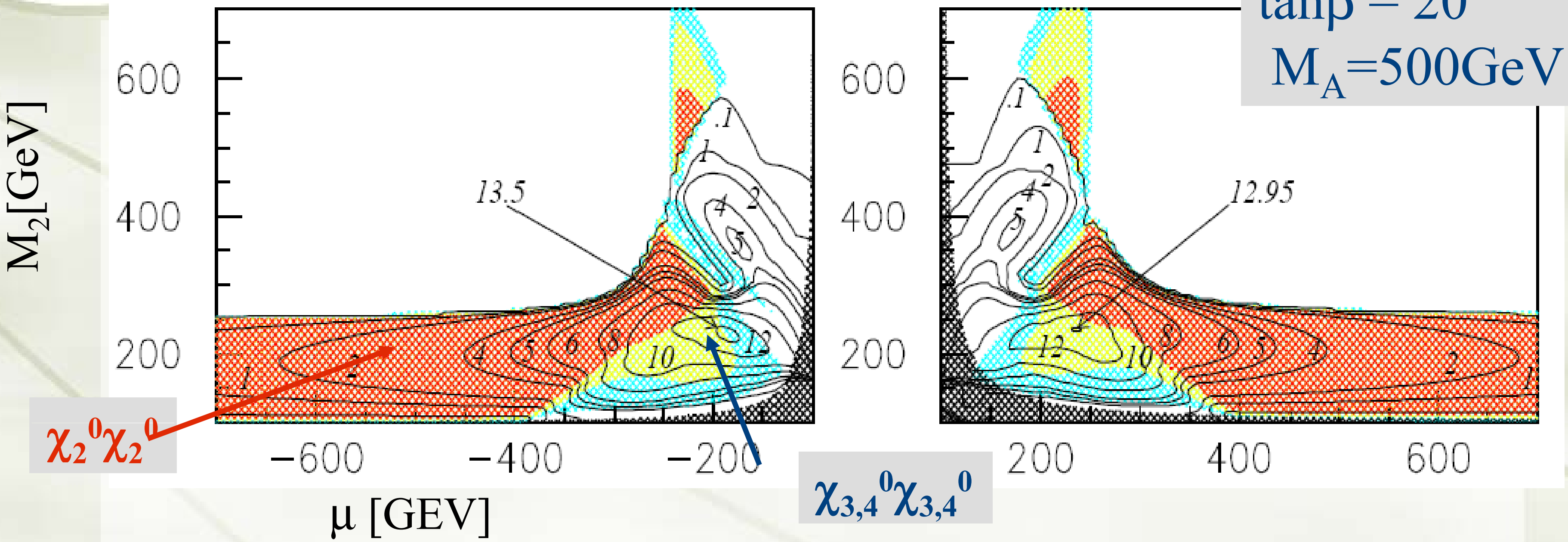
$A,H \rightarrow \chi^+_2\,\chi^-_{1,2} \rightarrow 4\,\ell^{\pm} + E^{miss}_T$

ℓ=eμ

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

tanβ = 20

M_A=500GeV



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

Choice of Bench mark points

To choose representative points in the search

$A/H \to \chi_i^0 \chi_i^0 \to 4\,\ell$

The following characteristics

- "High" branching ratio in
  $\chi^0_2\chi^0_2$
  $\chi^0_{2,3,4}\chi^0_{3,4}$
  $\chi_1^+\chi_2^-$
- "High" branching ratio in
  $\chi^0_2 \to \chi^0_1\,\ell^+\,\ell^-$

- m_{top}= 175 GeV
- m_b= 4.25 GeV
- tan β= 10
- m_A= 500 GeV
- M_{squark}= 1 TeV
- A_{tau}= 0
- A_ℓ= 0

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

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=150GeV M_τ= 250GeV m_g=800GeV
M_q=1000GeV

Sample of events

➢ Signal

$H \rightarrow 4\,\ell$

$A \rightarrow 4\,\ell$

➢ Standard Mode Background

- **bbZ $\rightarrow 4\,\ell$**
- **tt $\rightarrow 4\,\ell$**
- **ZZ $\rightarrow 4\,\ell$**

➢ MSSM Background

- $\tilde{q}, \tilde{g}$; $\tilde{\ell}, \tilde{\nu}$; $\tilde{\chi}\tilde{\chi}, \tilde{q} / \tilde{g}\tilde{\chi}$; $tH^{-} + c.c.$ $\rightarrow 4\,\ell$

Main selections:

- ℓ **Isolation**
- **charge and flavour constrains** $\ell_1^{-}\ell_1^{+}\ell_2^{+}\ell_2^{+}$
- Impact significance
- **35 GeV< E_T^{miss} < 130 GeV**
- **Z veto : |Minv (ℓ+ ℓ-) –Mz|**
- 1st high energy lepton $p_T^{\ell 1}$, 2nd high energy lepton $p_T^{\ell 2}$
- **P_T^{JetMin} > 20 GeV**
  $N_{jet} \leq 5$ P_T^{jet} >20 GeV (with 1 track)

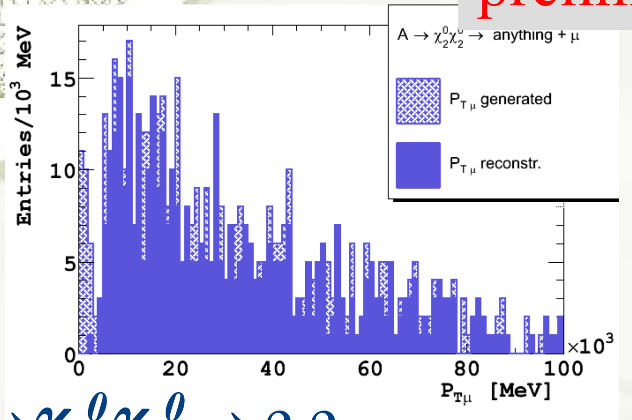
Reference points: (same BKMM)

1) **MSSM Point 1** M_A=500 GeV tanβ=20
2) **MSSM Point 2** M_A=600 GeV tanβ=35
3) **MSUGRA Point A** tanβ=20
4) **MSUGRA Point B** tanβ=20

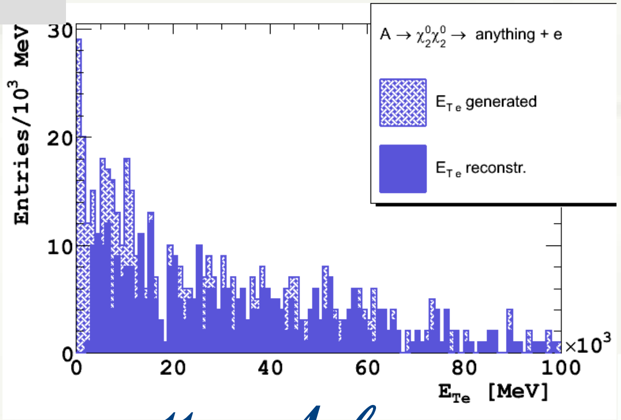
Detector Performances

preliminary

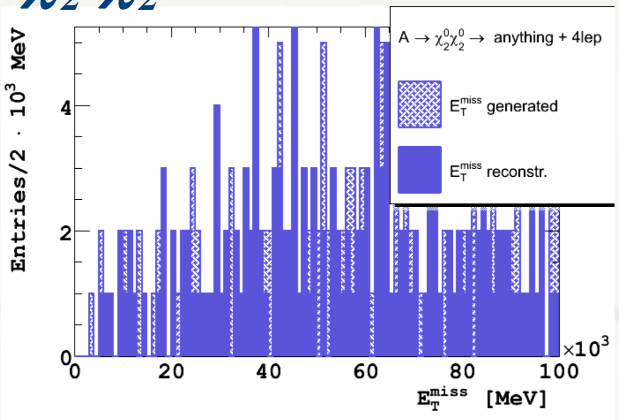
$A \rightarrow \chi_2^0 \chi_2^0 \rightarrow \mu\ \mu$



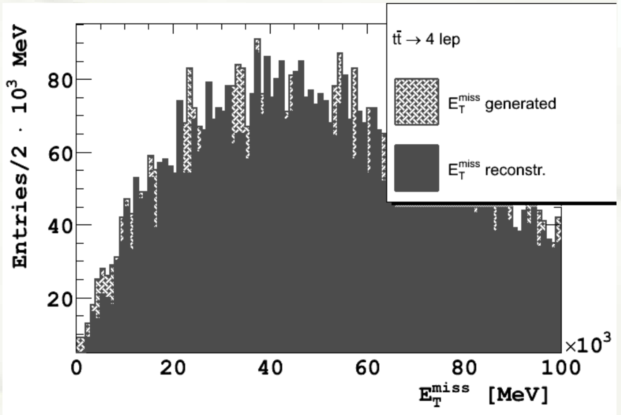
$A \rightarrow \chi_2^0 \chi_2^0 \rightarrow e\ e$



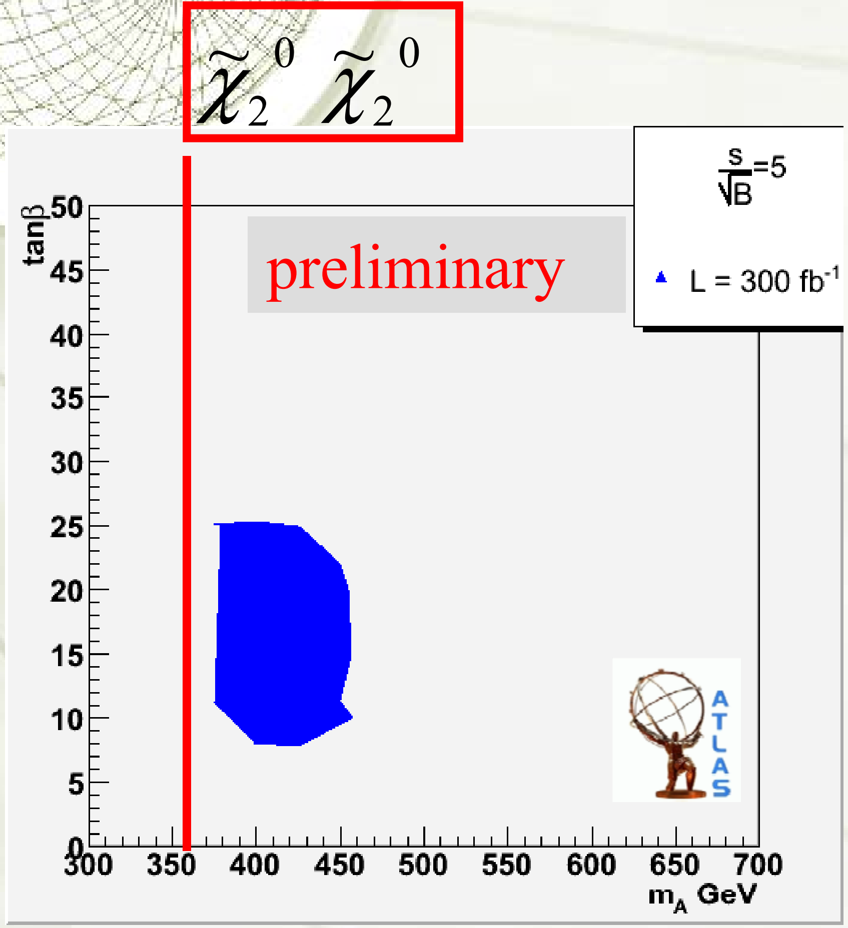
$A \rightarrow \chi_2^0 \chi_2^0 \rightarrow e\ e$

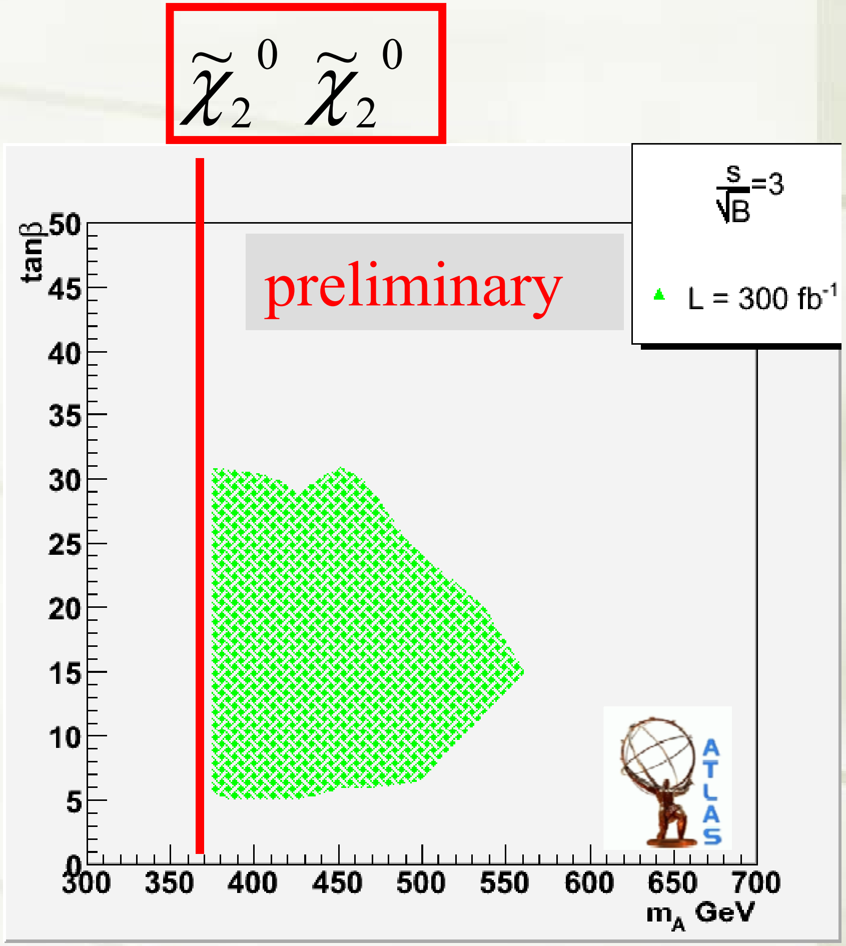


$tt \rightarrow 4\ \ell$

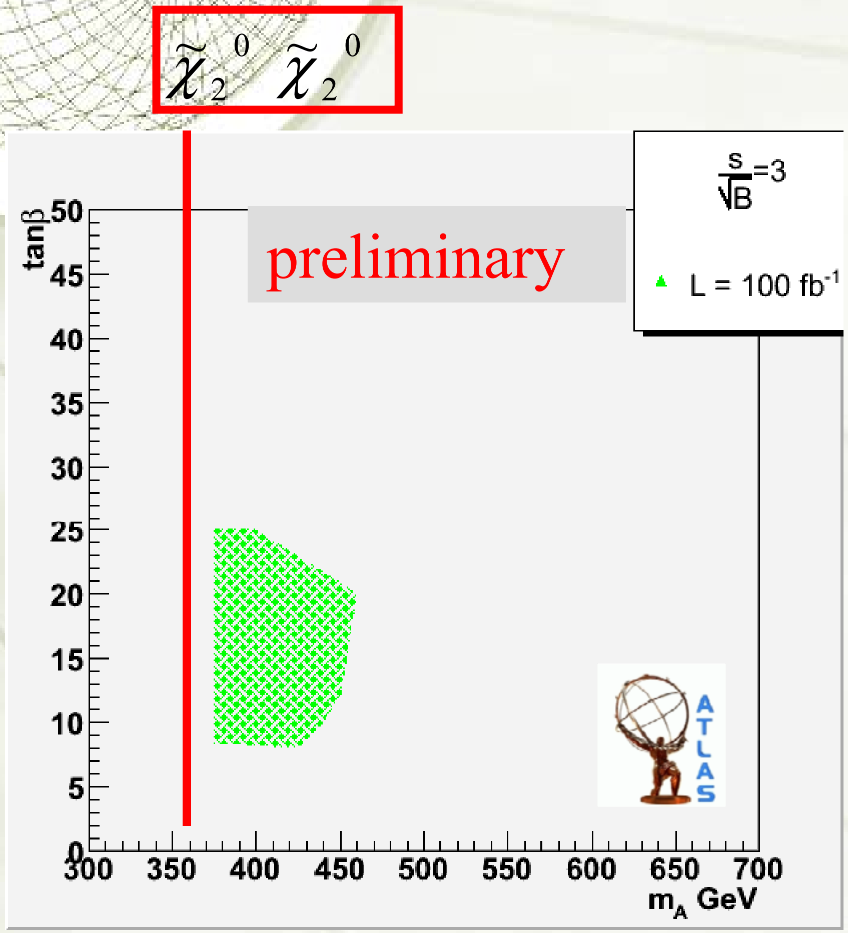


Set 1 Discovery plots at $L = 300\ fb^{-1}$



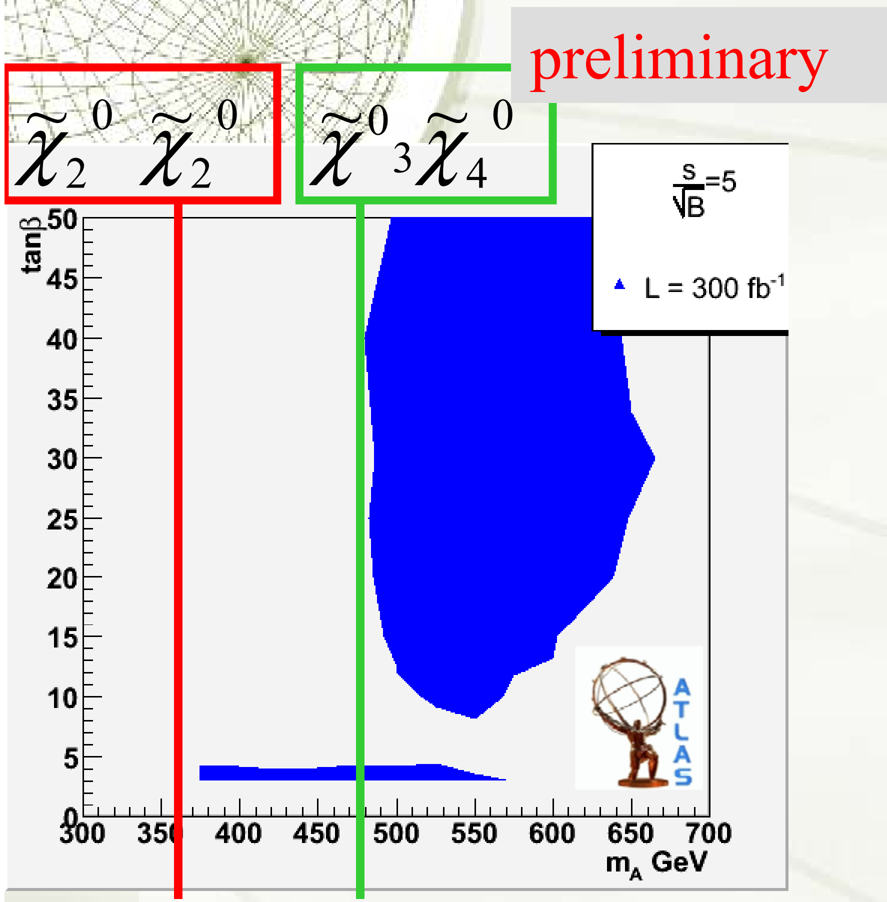


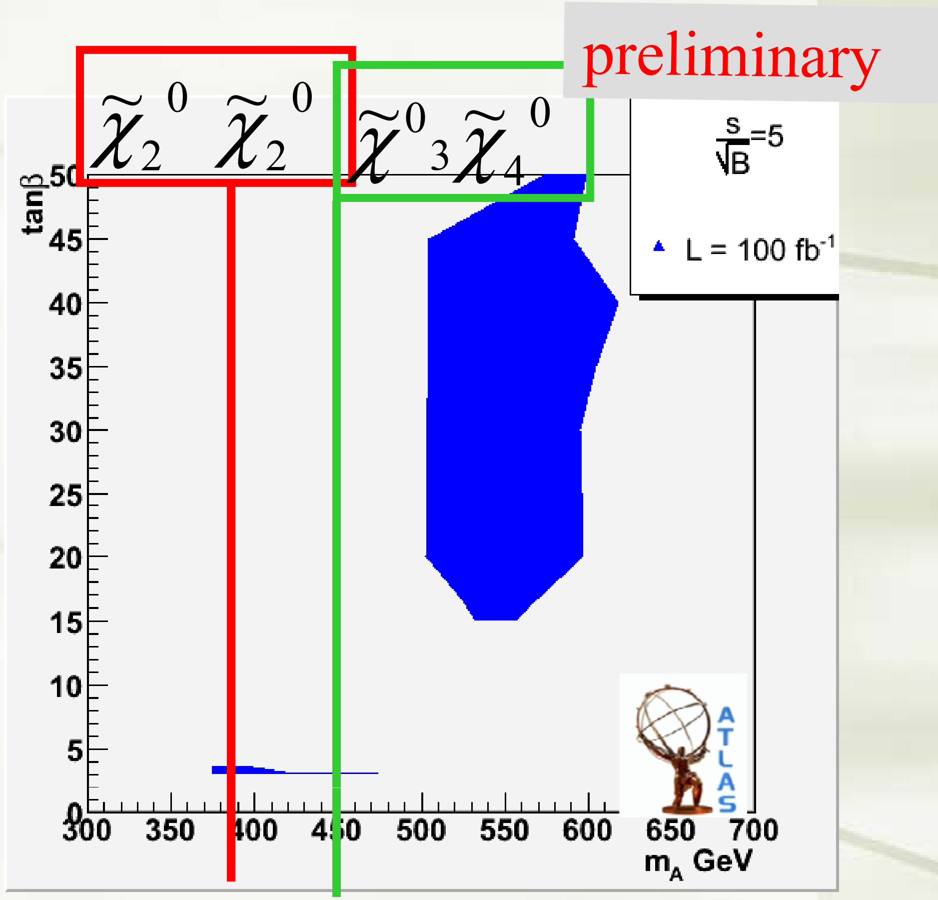
Set 1 Discovery plots at L = 100 fb^{-1}



- The discovery region for **$A/H \rightarrow \chi_2^0 \chi_2^0 \rightarrow 4\ \ell + E_T^{miss}$** can be accessible only after L=300fb^{-1}.
- No clear discovery possibilty at lower luminosity
- The background are mainly **ZZ and slepton pair** and **tt pair.**

Set2 Discovery plots at L = 300 fb^{-1}



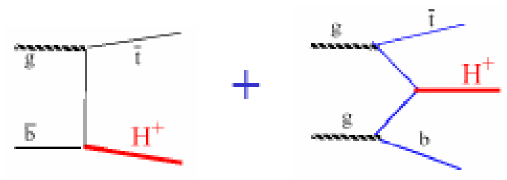


- **Discovery accessible also with L=100fb-1.**

The remaing background are mainly **ZZ** and **tt pair, direct χ χ, tH± production is not neglegible**

Charged Higgs involvement

Analogue production mechanism for $H^{\pm}$



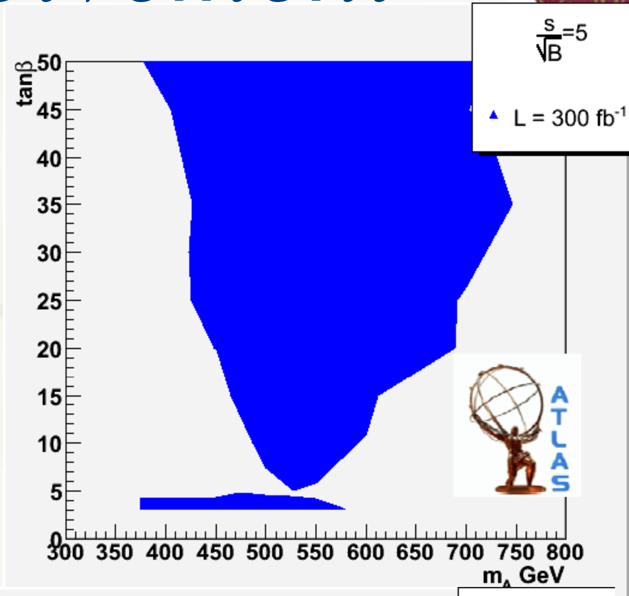
Analogue decay mode:

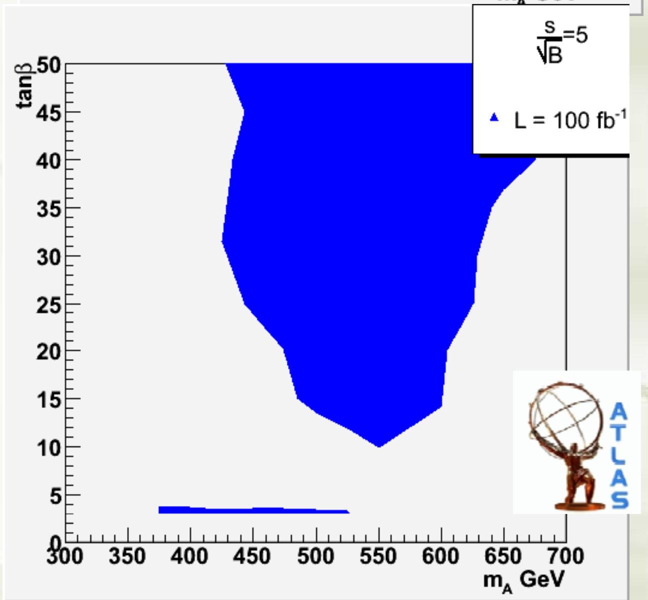
$H^{\pm} \rightarrow \chi_{2,3}^{0}\, \chi_{1,2}^{\pm} \rightarrow 3l + E_T^{miss}$

Final state: Only 3 lepton

+another lepton from a top decay

➢ The **range of discovery is enlarged**, extending the search to all MSSM Higgs(H/A/H±) respect to neutral H/A, a discovery can be reached also with L=100fb $^{-1}$





Conclusions

- Atlas is preparing for first collision data.
- The search for MSSM Higgs can full exploit the design of ATLAS experiment: excellent tracking , EM calorimeter , μ-spectrometer resolution,Missing energy reconstruction and b and τ tagging capabilities.
- Discovery potential of MSSM Higgs boson has been estimated by ATLAS .
- A early discovery of a neutral MSSM boson in some channels (e.g.bb h/A→μμ, ττ) looks possible with integrated luminosity =10 fb^{-1} , i.e. after only 1-2 year of data taking.
- First data has the possibilty to exclude/or confirm the entire MSSM
- Others decay channel (as $\chi_{2,3,4}^0 \chi_{2,3,4}^0$) can be explored later for unexplored region of parameter plane and first results can be achieved with L =100 fb^{-1}.