MSSM Higgs Bosons decaying in SUSY cascade with ATLAS

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Outline

- Motivation
- MSSM Higgs in SUSY cascade search limits at LHC
- Bench mark points
- Detection MSSM Higgs in ATLAS
- Analysis: first results on neutral & charged Higgs discovery potential
- Conclusions
- The results presented are 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:

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

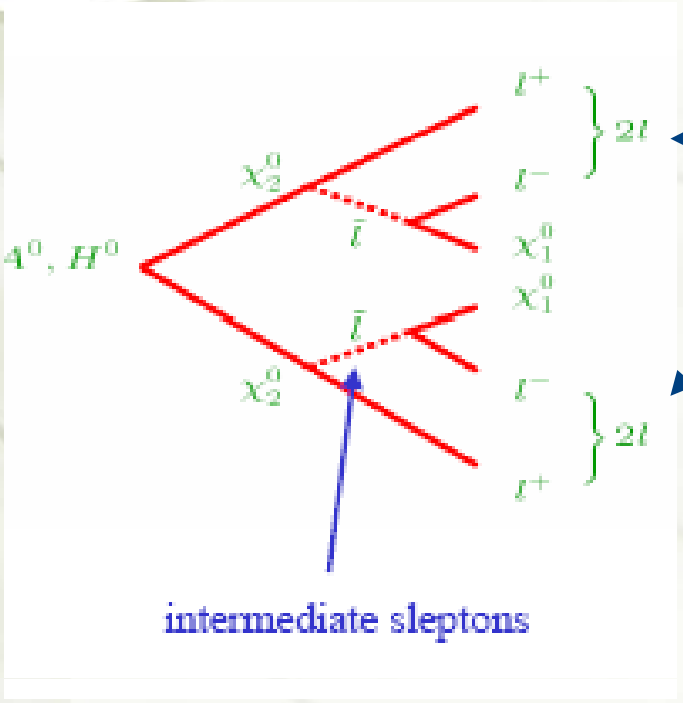
$$H^{\pm} \rightarrow \chi^0_2\chi^{\pm}_1 \rightarrow 3\,\ell^{\pm}\,X$$

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

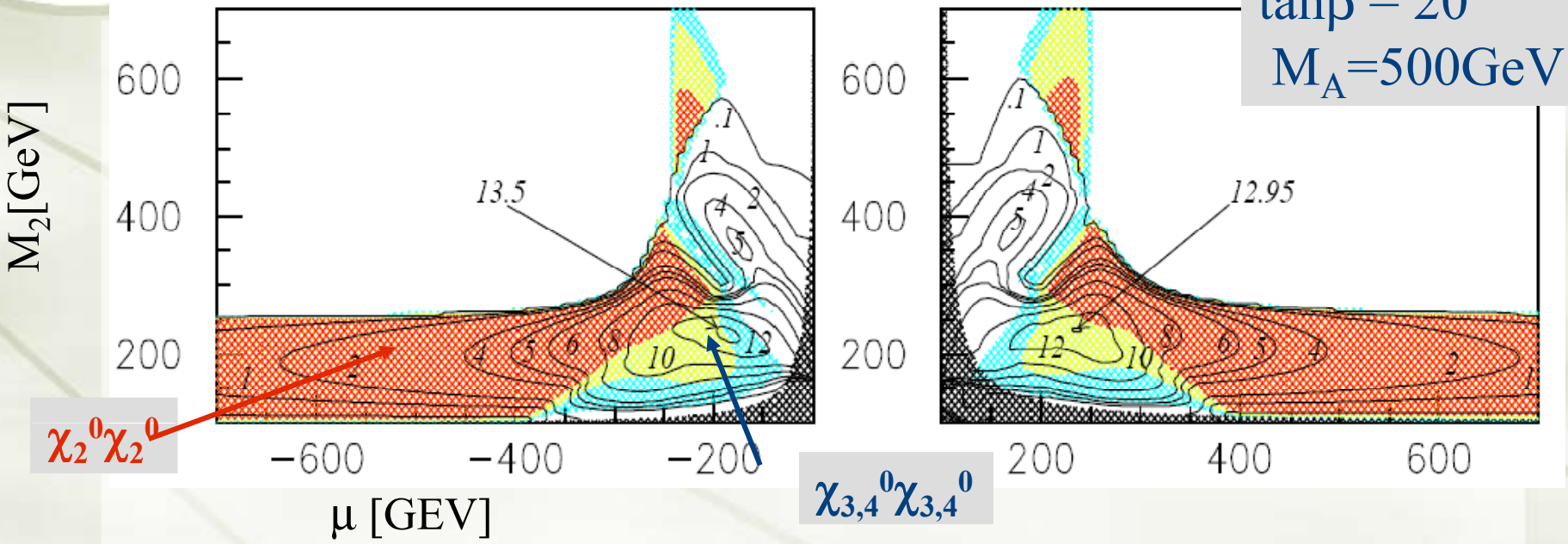
$$A,H \rightarrow \chi^0_{2,3,4}\,\chi^0_{2,3,4} \rightarrow 4\,\ell^{\pm} + E^{miss}_T$$

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

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

$\tan\beta = 20$

$M_A = 500\,GeV$



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

Search in a LHC detector

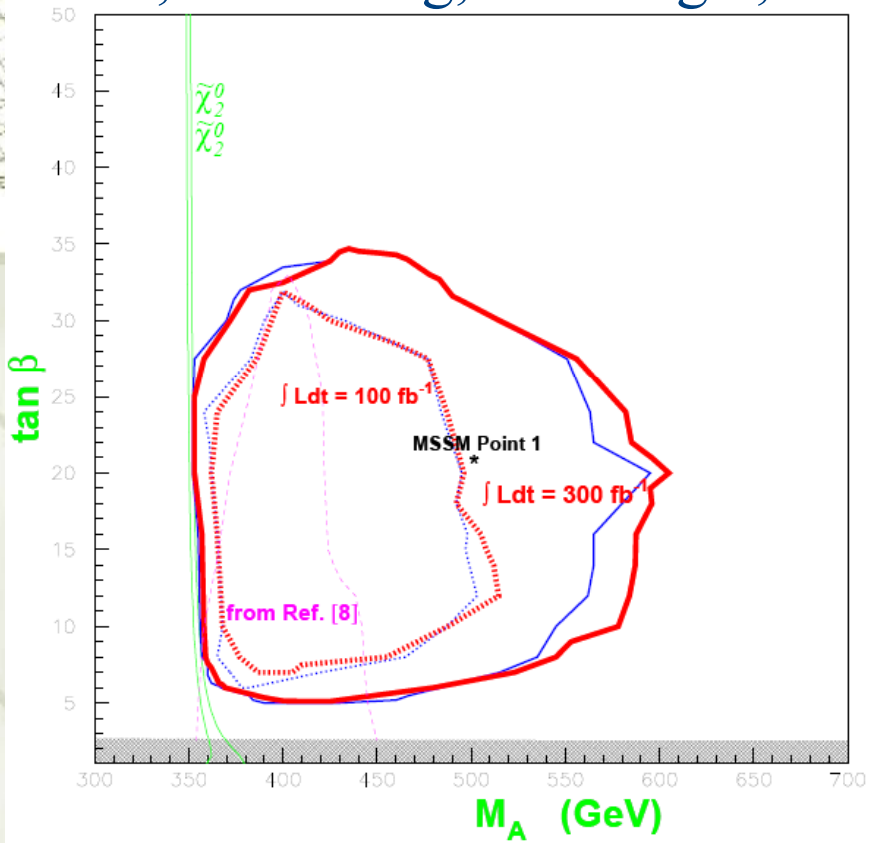
- Representive points studied:
  - **MSSM** representative Points
  - **MSugra** representative Points

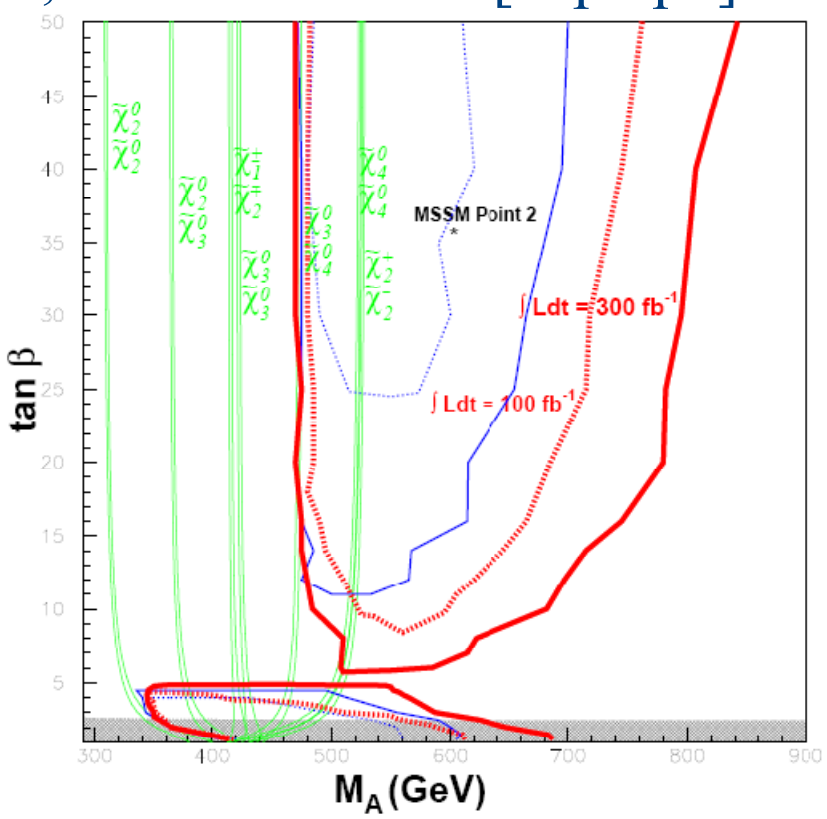
  Point A M_0=125 GeV tanβ=20
  Point B M_0=400 GeV tanβ=20
  $M_{1/2}$=165GeV sign(μ)=+1 A_0=0

- 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

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





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

Choice of Bench mark points

To choose representative points in the search

$A/H \rightarrow \chi_i^0 \chi_i^0 \rightarrow 4\ \ell$

The following characteristics

- "High" branching ratio in

  $\chi^0_2\chi^0_2$

  $\chi^0_{2,3,4}\chi^0_{3,4}$

  $\chi_1^+\chi_2^-$

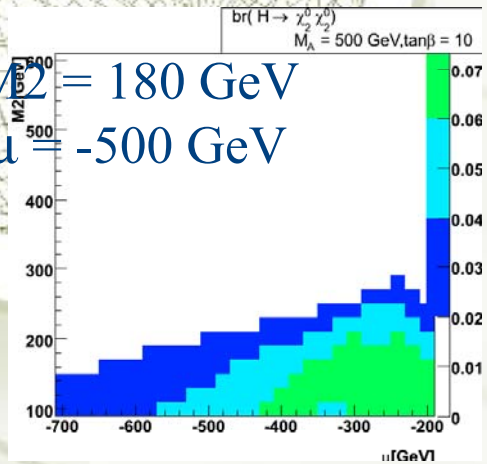
- "High" branching ratio in

  $\chi^0_2 \rightarrow \chi^0_1 \ell^+ \ell^-$

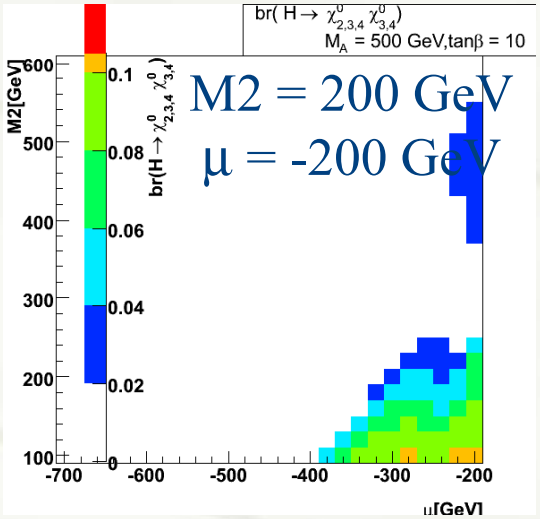
- m_{top}= 175 GeV
- m_b= 4.25 GeV
- tan β= 10
- m_A= 500 GeV
- M_{squark}= 1 TeV
- A_{tau}= 0
- A_ℓ= 0
- m_ℓ=$m_{\tau soft}$= 250 GeV

Branching ratio

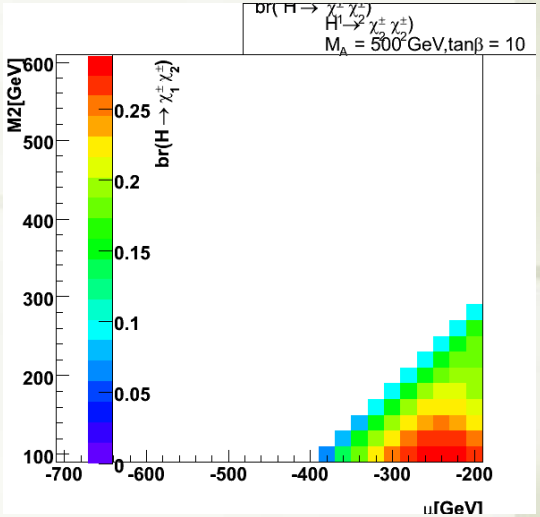
$\chi^0_2\chi^0_2$ $\chi^0_{3,4}\chi^0_{2,3,4}$, $\chi^+_1\chi^-_2, \chi^+_2\chi^-_2$

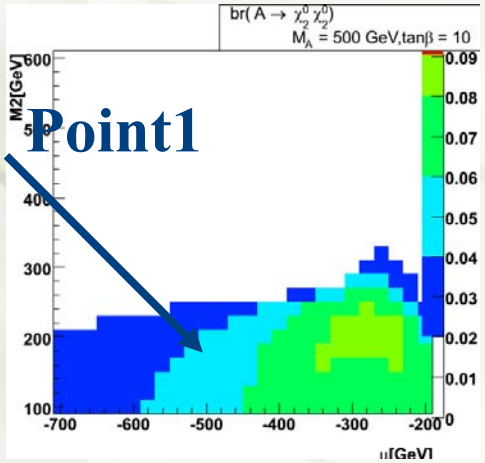


M2 = 180 GeV
μ = -500 GeV

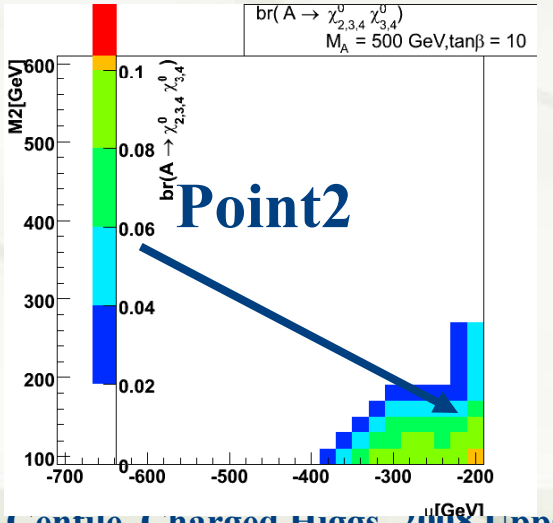


M2 = 200 GeV
μ = -200 GeV

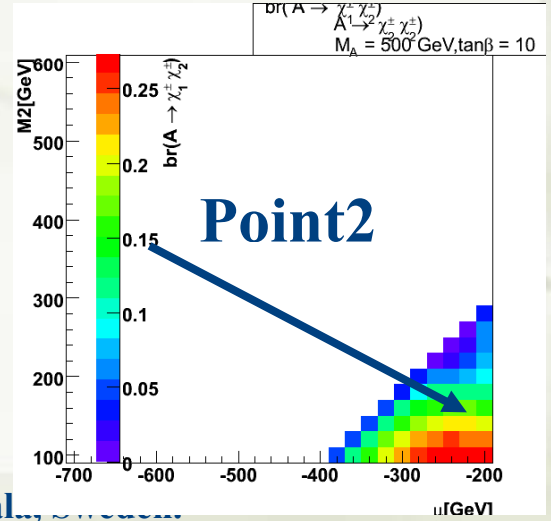




Point1



Point2

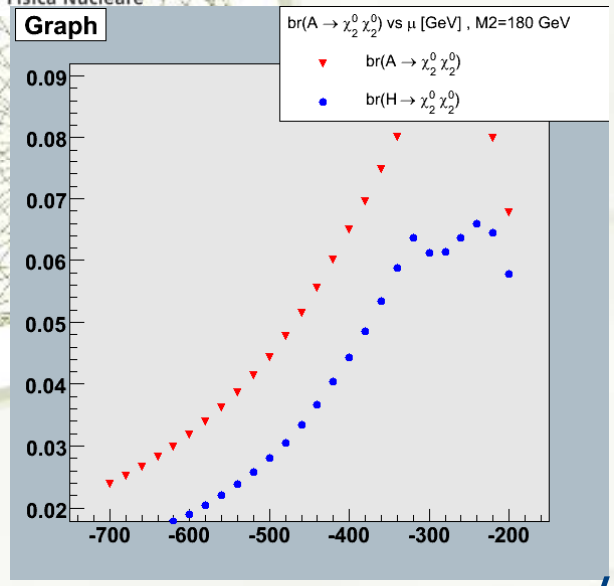


Point2

$\mu < 0$

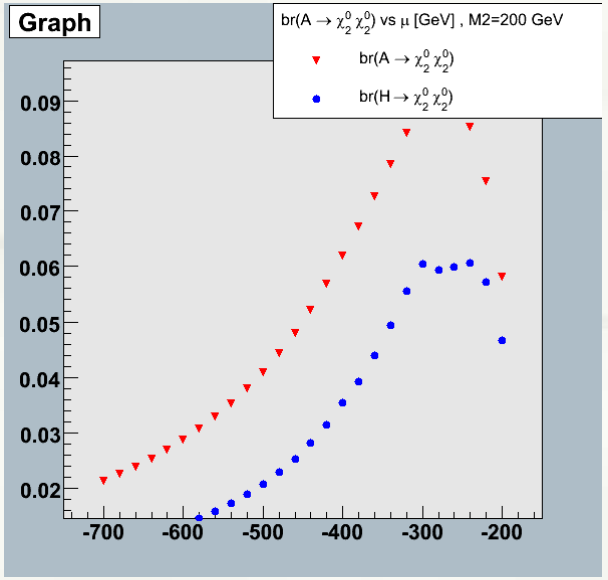
$A/H \rightarrow \chi_2^0 \chi_2^0 \rightarrow \chi_1^0 \chi_1^0\, 4\ell$ negative μ

$Br(A/H \rightarrow \chi_2^0 \chi_2^0)$



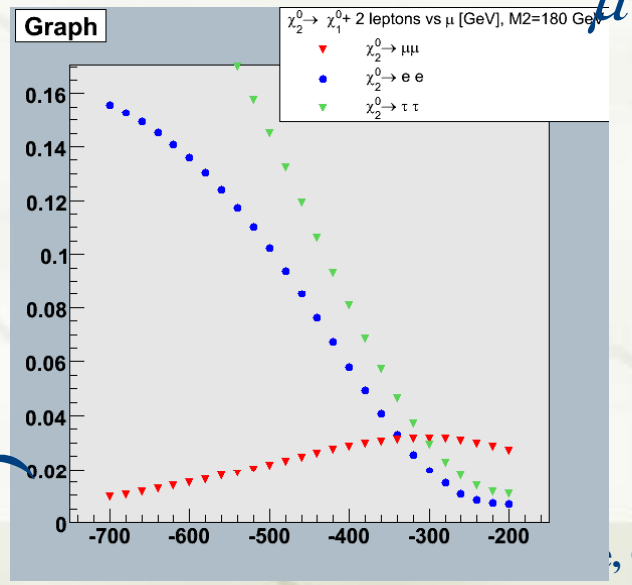
μ

$Br(A/H \rightarrow \chi_2^0 \chi_2^0)$



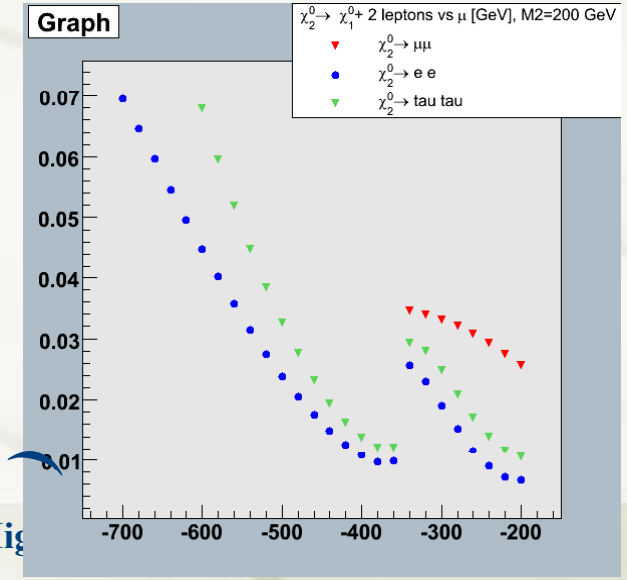
μ

$Br(\chi_2^0 \rightarrow \chi_1^0 2\ell)$



μ

$Br(\chi_2^0 \rightarrow \chi_1^0 2\,\ell)$



μ

Sample of events

➢ **Signal**

$H \rightarrow 4\ell$

$A \rightarrow 4\ell$

➢ **Standard Model Background**

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

➢ **MSSM Background**

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

$\rightarrow 4\ell$

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

MSSM particle masses

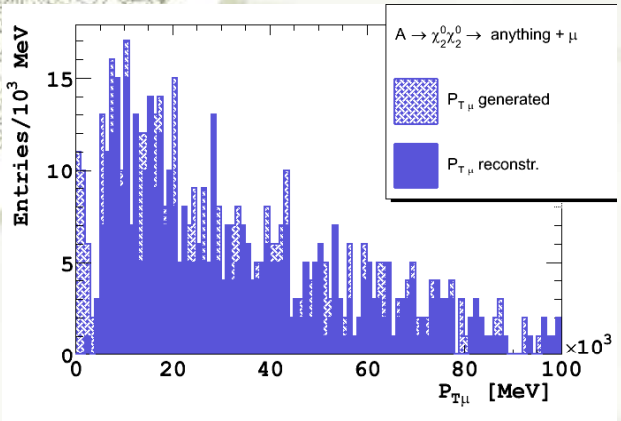
	Point 1 [GeV]	Point 2 [GeV]	Point A [GeV]	Point B [GeV]
M_A	500.0	600.0	257.4	439.5
M_H	503.4	603.9	259.1	442.5
$\tilde{\chi}_1^0$	89.7	93.9	61.1	62.3
$\tilde{\chi}_2^0$	176.3	155.5	109.4	111.9
$\tilde{\chi}_3^0$	507.0	211.9	235.9	241.9
$\tilde{\chi}_4^0$	511.0	262.6	259.8	265.4
$\tilde{\chi}_1^\pm$	176.3	153.1	108.7	111.6
$\tilde{\chi}_2^\pm$	514.0	263.6	260.2	265.9

Simulation & reconstruction in ATLAS detector

- **ATLAS detector response has been full simulated** taking into account the effetcts of energy loss, multiple scattering and showering in the detector through ATHENA interface.
- SM background cross section , as signal are considered at **LO approximation**
- **Study at L_{int} =300 fb^{-1} scenario ·(→ L_{int} =100 fb^{-1})**
- **The statistics used corrisponds to AT LEAST this luminosity. In some delicate points the statistics is increased up a factor 2, with exception tt background.**

Muons

preliminary



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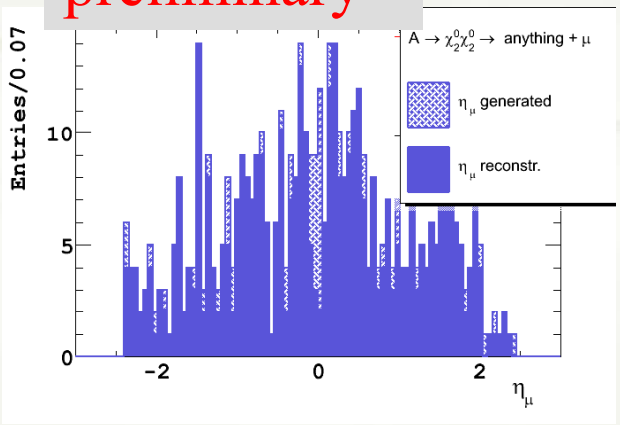
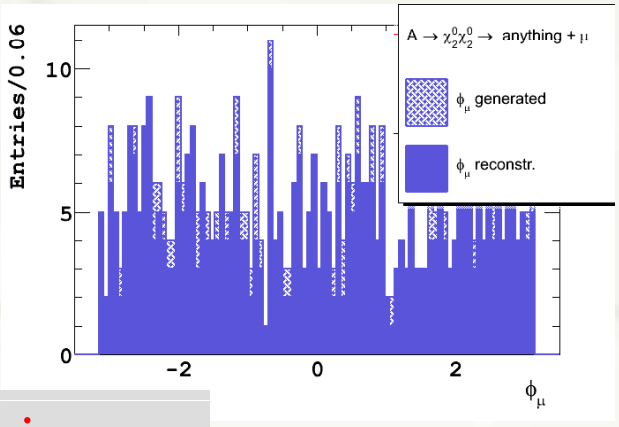


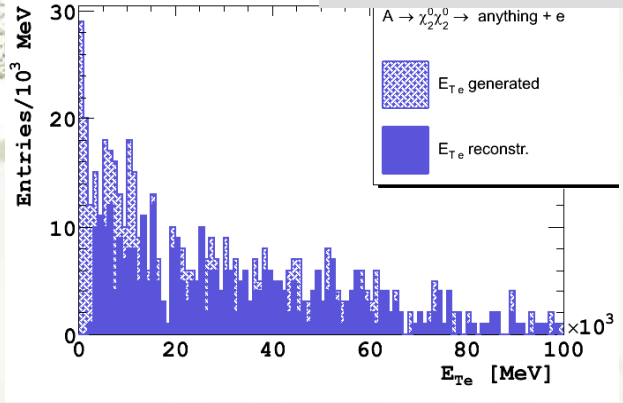


preliminary

- For A Sample μ in events $A/H \rightarrow \chi_2^0\chi_2^0 \rightarrow \mu$ .....

Electrons & E_T^{miss}

- For A Sample in events $A/H \rightarrow \chi_2^0 \chi_2^0 \rightarrow$ e ..... preliminary



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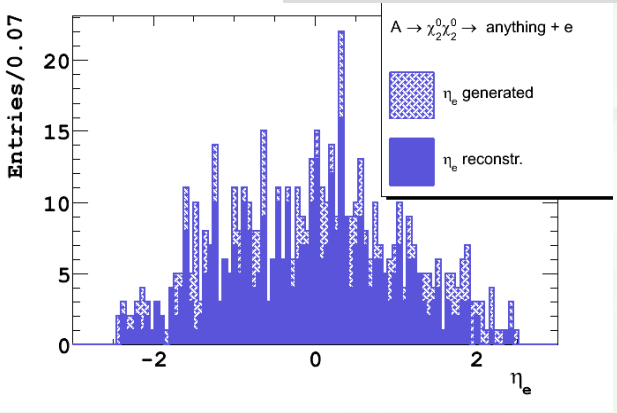

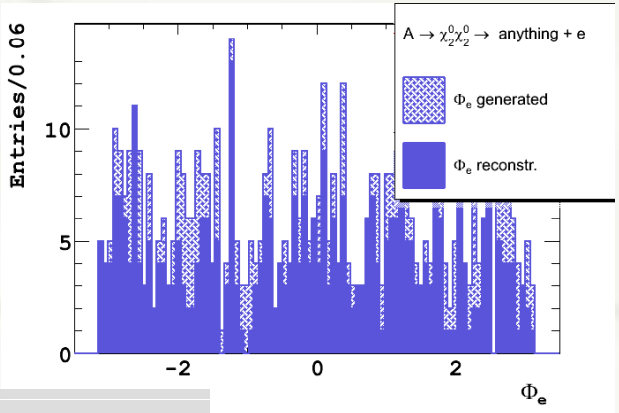

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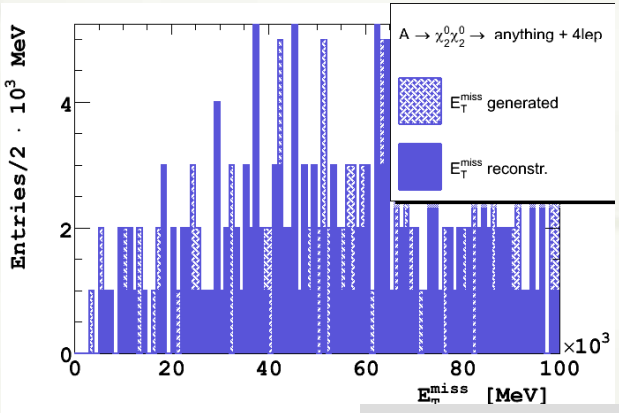

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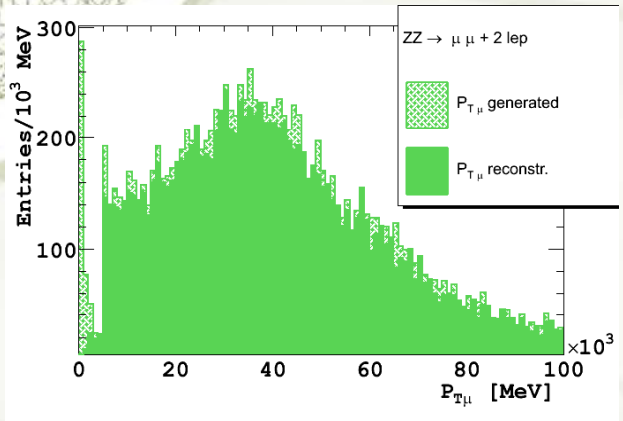
ZZ and tt sample

preliminary



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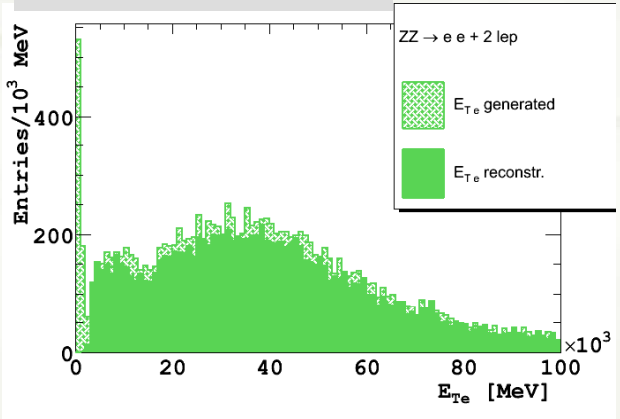
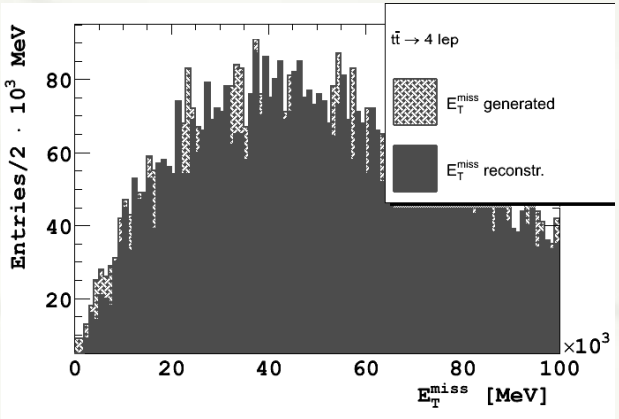




preliminary

Selection 1 part

➢**Generation Event Filter: 4 $\ell \rightarrow$ and $|\eta| < 2.7$, $p_T^{\ell} > 5$GeV**

➢**Preselection cuts:**

- Trigger one:1 electron isolated E > 22 GeV or a μ isolated > 20 GeV (1μ20i or 1e22i)
- $p_T^{\ell} > 5$GeV
- Isolation $\Sigma\, p_T < 6$ GeV in cone $\Delta R = 0.2$
- Medium electron definition considered

reconstruction

➢**Selection**

- **Lepton pair charge and flavour constrains $\ell_1^- \ell_1^+ \ell_2\, \ell_2^+$**

Selection 2 part

Selection cuts:

- Impact significance parameter for μ > 4 and e > 6
- $p_T^{\ell 1} > 8$ GeV

tt

- **35 GeV< E_T^{miss} < 130 GeV**
- **Z veto : $|M_{inv}(\ell^+ \ell^-) - M_z| > 6$ GeV**

Zbb, ZZ

$\tilde{q}, \tilde{g}$

- 1st high energy lepton $p_T^{\ell 1}$, 2nd high energy lepton $p_T^{\ell 2}$

25 GeV < $p_T^{\ell 1}$ < 110 GeV

- $p_T^{\ell 1}$ < 100 GeV and $p_T^{\ell 2}$ > 60 GeV
- $p_T^{\ell 2}$ > 60 GeV (only Set2 & SetA)

$\tilde{\ell}, \tilde{\nu}$

$\tilde{\chi}\tilde{\chi}, \tilde{q} / \tilde{g}\tilde{\chi}$

- **$P_T^{Min} > 20$ GeV**
- **$N_{jet} \leq 5$ $P_T^{jet} > 20$ GeV (with 1 track)**

$\tilde{q}, \tilde{g}$

$\tilde{\chi}\tilde{\chi}, \tilde{q} / \tilde{g}\tilde{\chi}$

- **Minv ($\ell^+ \ell^- \ell^+ \ell^-$) < 125 GeV (SetA)**

veden.

$\tilde{\ell}, \tilde{\nu}$

$\tilde{\chi}\tilde{\chi}, \tilde{q} / \tilde{g}\tilde{\chi}$

Reference Point 1 Sample

	Particle	σ_e [pb]	BR_{4lep}	Nev (300 fb^{-1})	Sample Used ($\chi^0\chi^0$)	N Sel (300 fb^{-1})
SIGNAL	A	1.18	0.0051	1800	2250 *(226)*	30
	H	1.16	0.0049	1700	2500 *(164)*	14
Back SM	Zbb	60.5	0.00942	171000	44500	2
	tt	500	0.00728	1092000	570555	82
	ZZ	0.21	0.219*	13500	115700	10
MSSM	$\tilde{q},\tilde{g}$	1.49	0.034	15000	17000	1
	$\tilde{\ell},\tilde{\nu}$	0.15	0.15	1100	1500	44
	$\tilde{\chi}\tilde{\chi},\tilde{q}/\tilde{g}\tilde{\chi}$	2.97	0.019	1700	2500	7
	$tH^- + c.c.$	0.136	0.0078	315	500	0

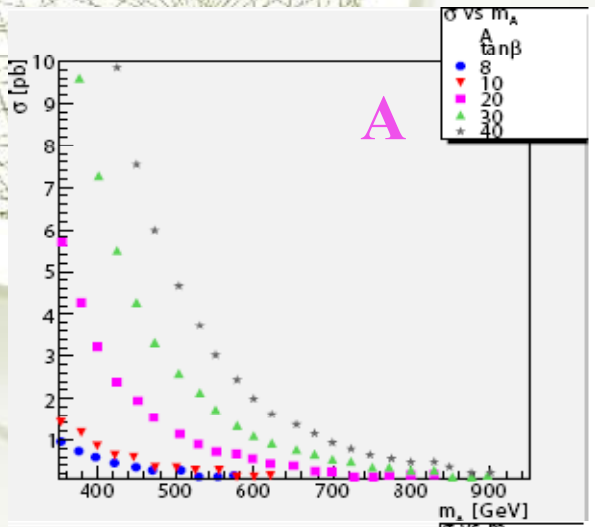
***σ x br** without box diagram 34.8 fb (weight 1.49)

Set1:Cross Section & Br A,H

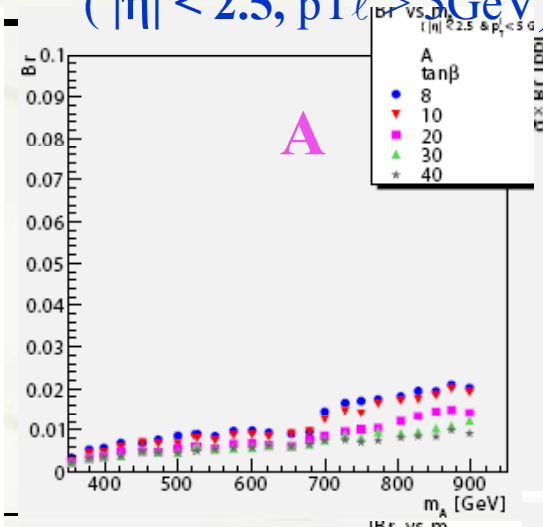
σ

$Br_{4\ell}$ ($|\eta| < 2.5$, $pT\ell > 5GeV$)

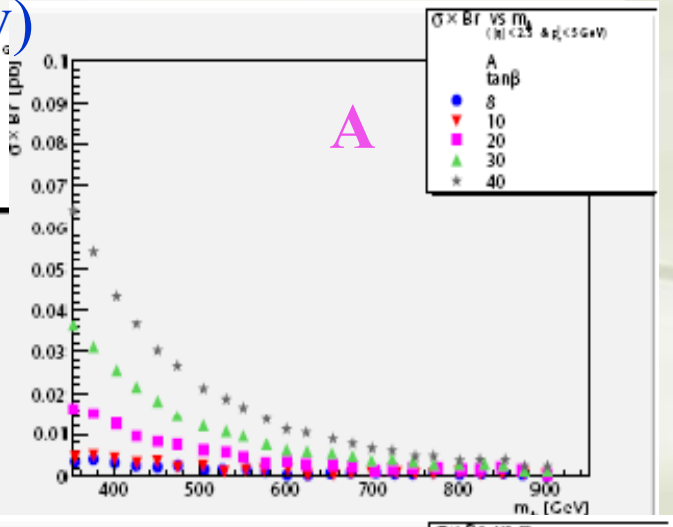
$\sigma \times Br_{4\ell}$



A



A



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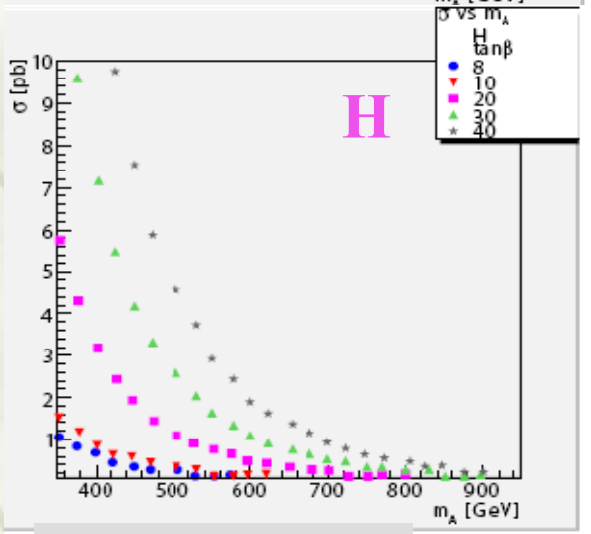
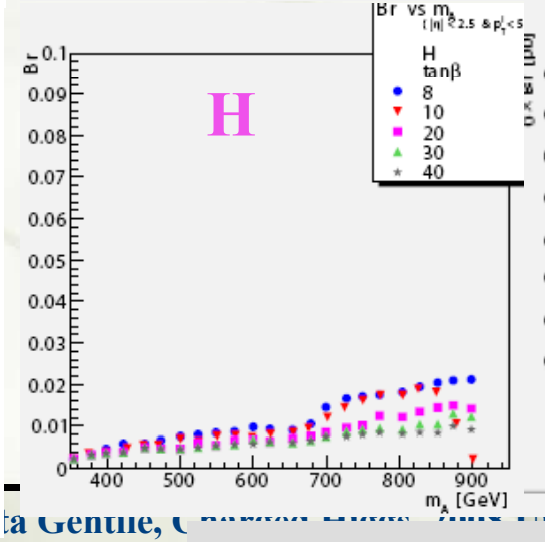
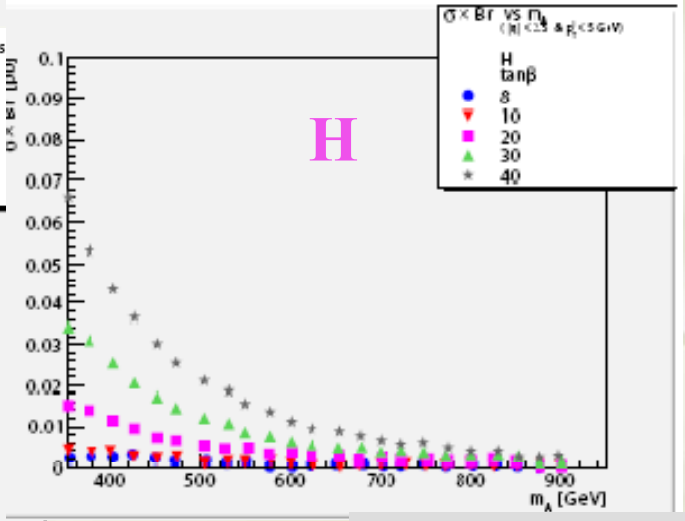


H



H



H

preliminary

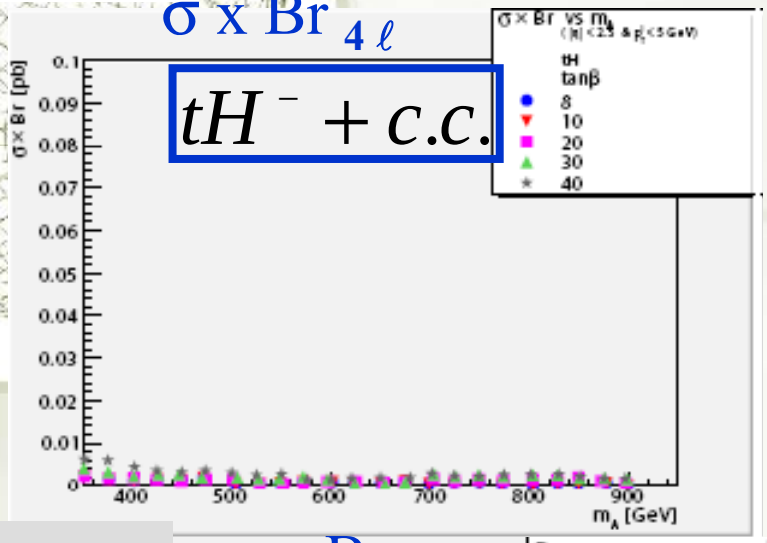
preliminary

preliminary

Background effective cross section

$\sigma \times Br_{4\ell}$

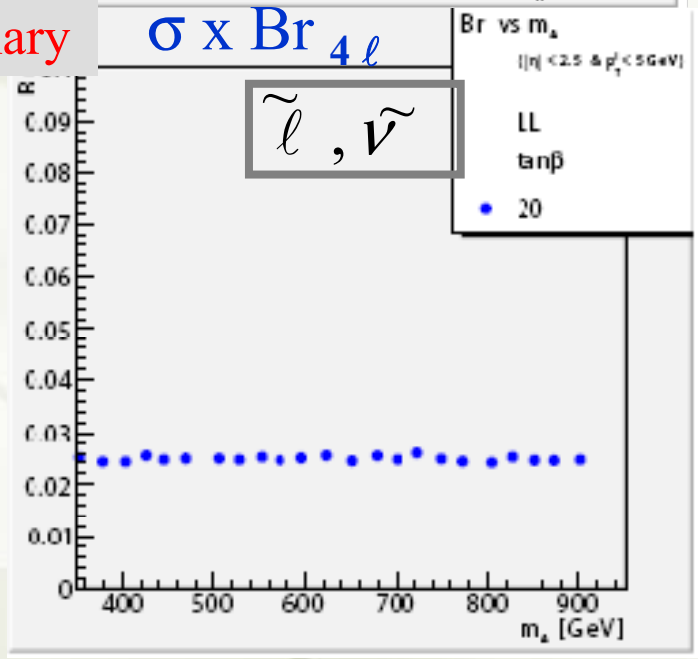
$tH^- + c.c.$



preliminary

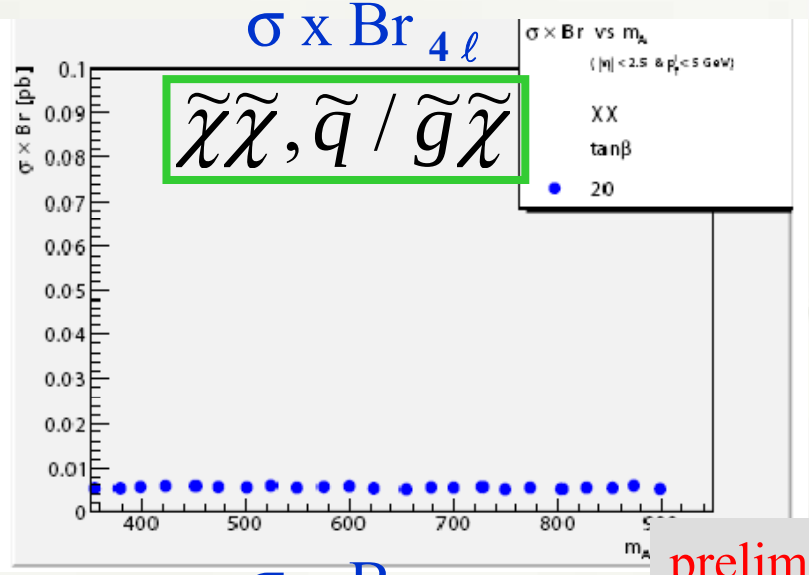
$\sigma \times Br_{4\ell}$

$\tilde{\ell}, \tilde{\nu}$



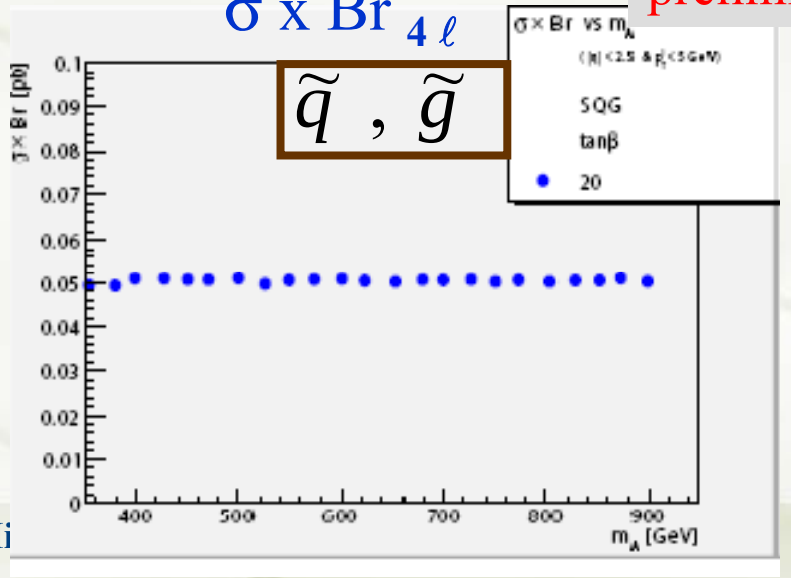
$\sigma \times Br_{4\ell}$

$\tilde{\chi}\tilde{\chi}, \tilde{q}/\tilde{g}\tilde{\chi}$



$\sigma \times Br_{4\ell}$

$\tilde{q}, \tilde{g}$



preliminary

Set 1-MSSM Background

$\tilde{q}, \tilde{g}$

$\tilde{\ell}, \tilde{\nu}$

$\tilde{\chi}\tilde{\chi}, \tilde{q} / \tilde{g}\tilde{\chi}$

$tH^- + c.c.$

- **σ x Br $_{4\ell}$ not depending from M_A,** as expected. The events processed at each tanβ at M_A= 500 GeV are used.

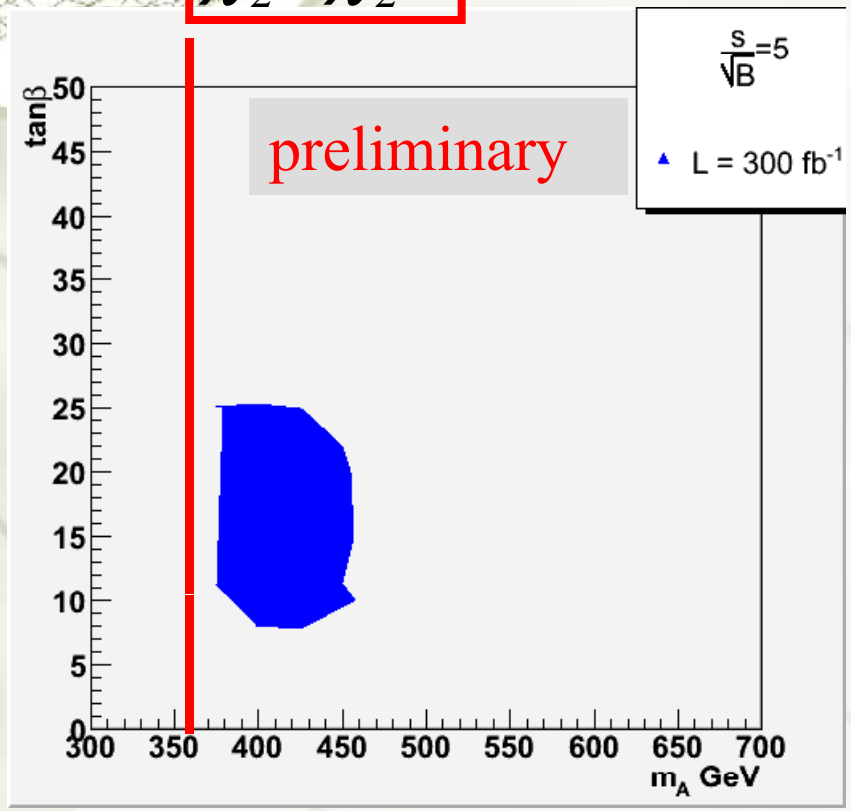
- tH events studied at each point (tanβ,M_A)

Explored region:

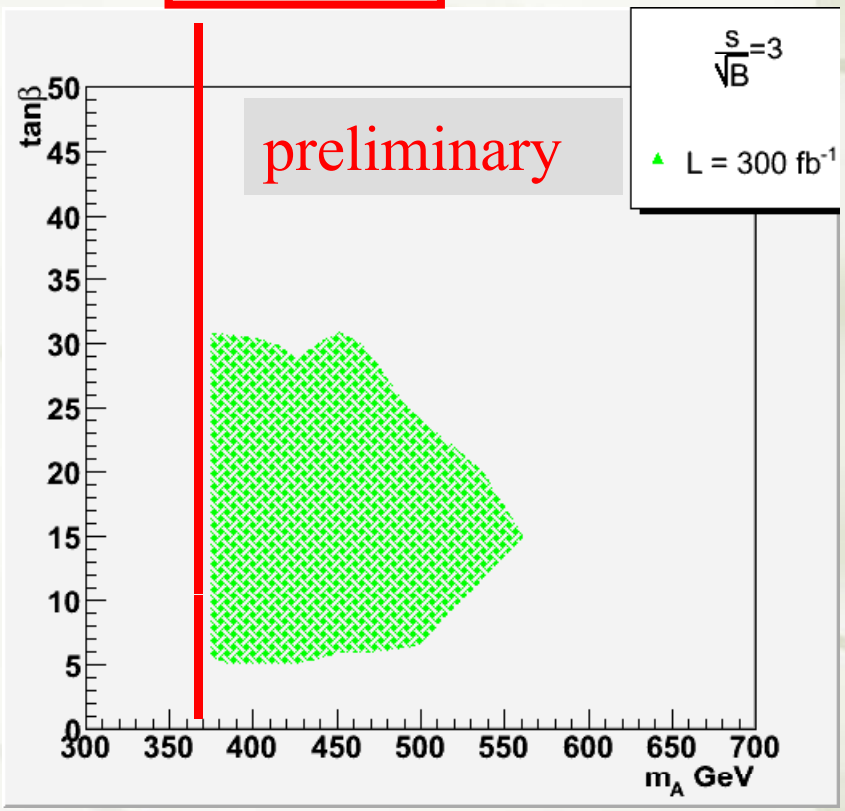
•tanβ 5,8 and
10-40 step 5
•M_A 375-900 GeV
step 25 GeV

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

$\tilde{\chi}_2^0 \; \tilde{\chi}_2^0$

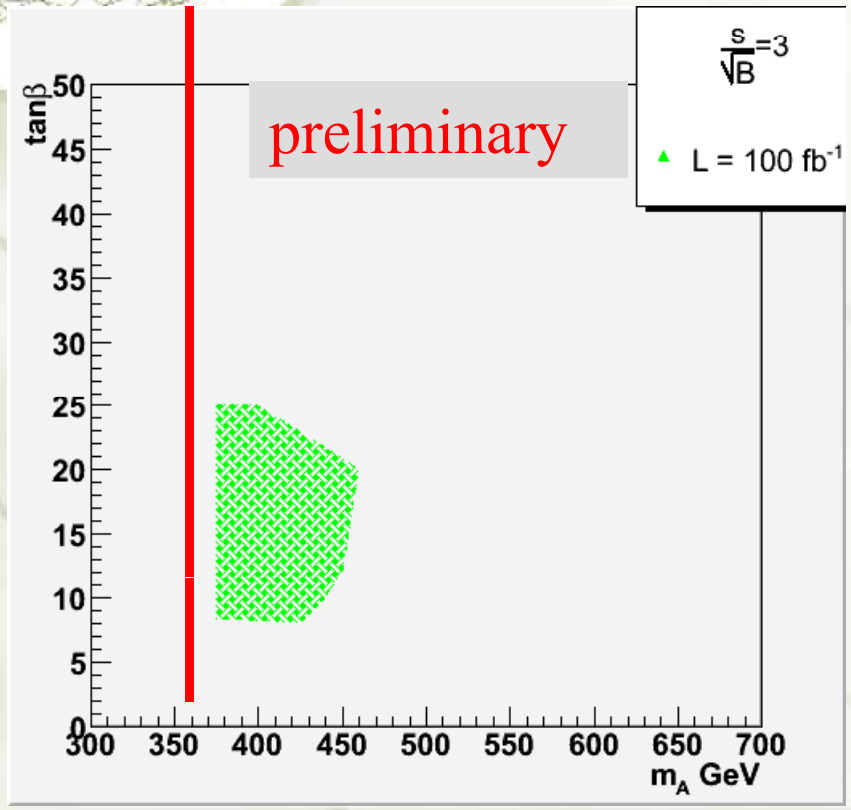


$\tilde{\chi}_2^0 \; \tilde{\chi}_2^0$



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

$\tilde{\chi}_2^0 \; \tilde{\chi}_2^0$



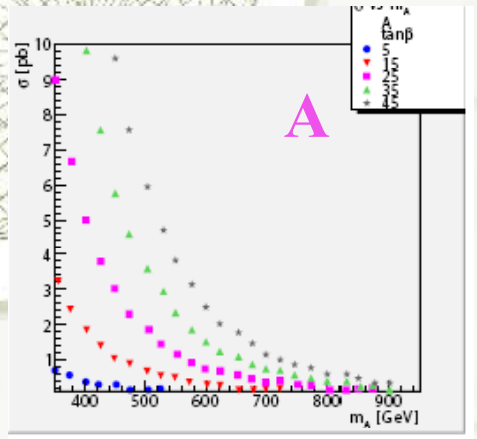
- The discovery region for **A/H→$\chi_2^0\chi_2^0$→4 ℓ+ E_T^{miss}** can be accessible only after L=300fb^{-1}.
- No clear discovery possibilty at lower luminosity
- The background are mainly **ZZ and slepton pair** and **tt pair.**

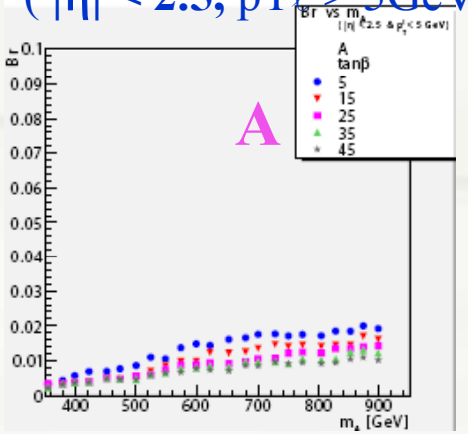
Set 2 :Cross Section & Br A,H

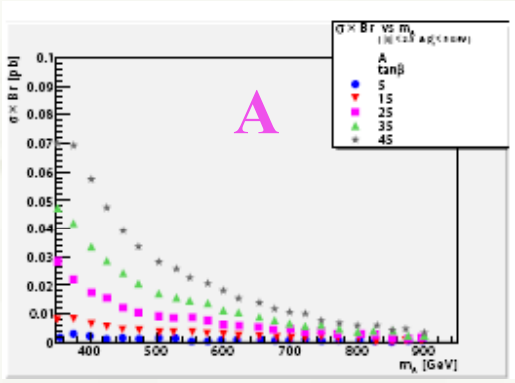
σ

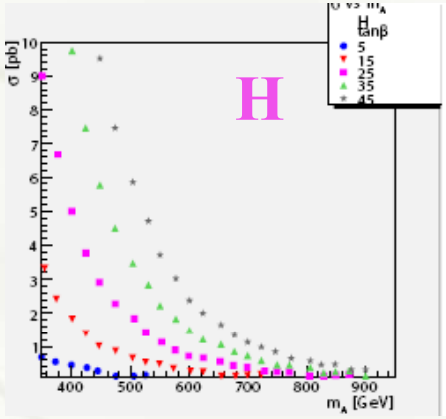
$Br_{4\ell}$ ($|\eta| < 2.5$, $pT\ell > 5GeV$)

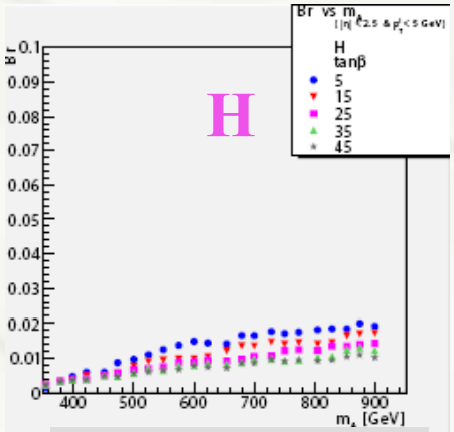
σ x $Br_{4\ell}$

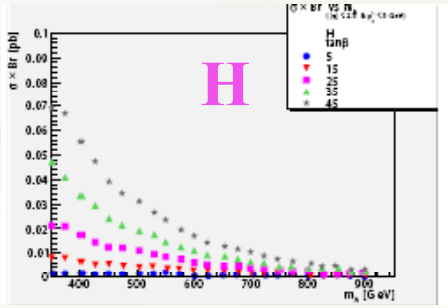










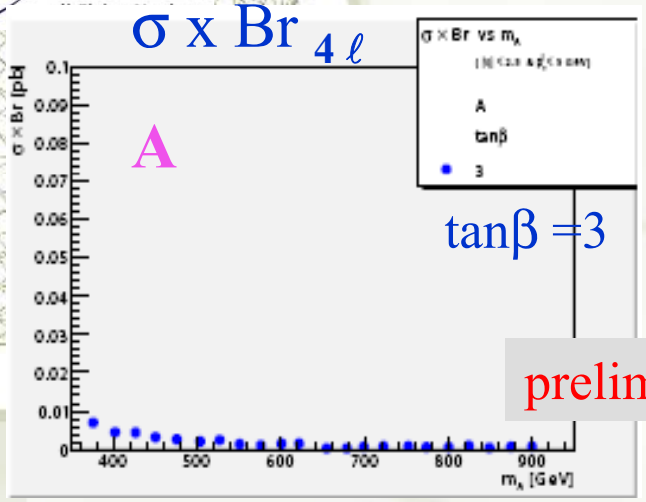


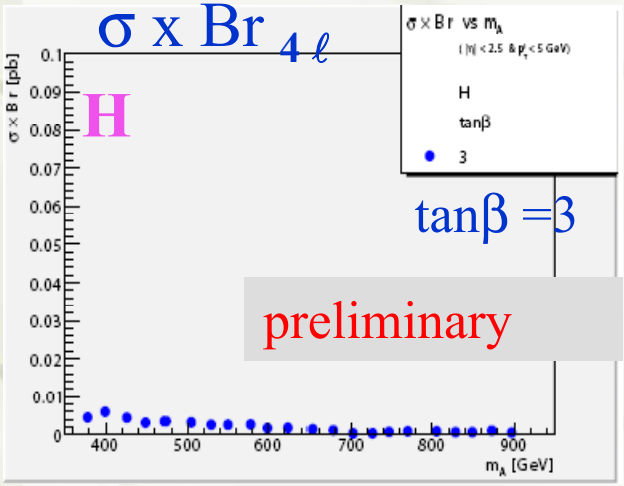
preliminary

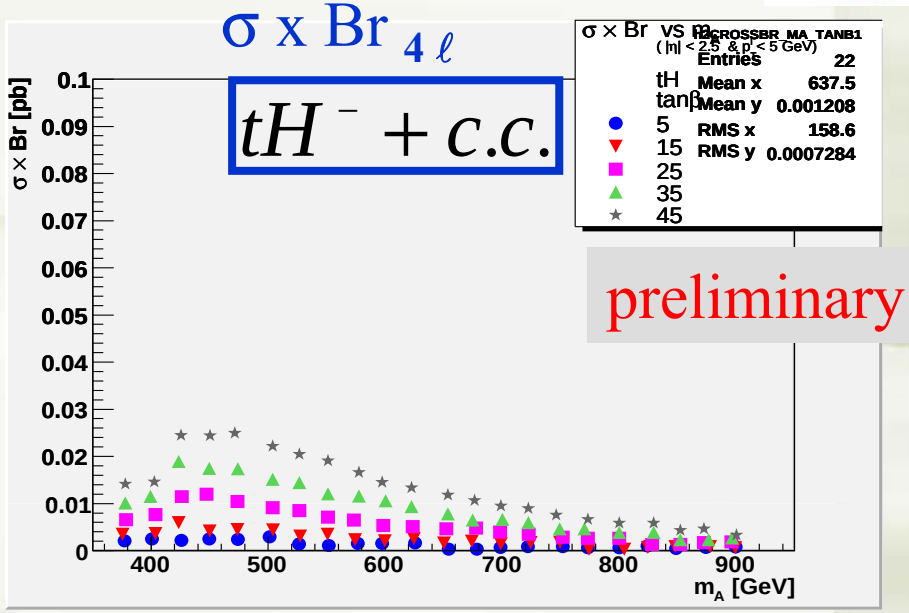
preliminary

preliminary

Background effective cross section







- low tan β region

Signal dominated

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

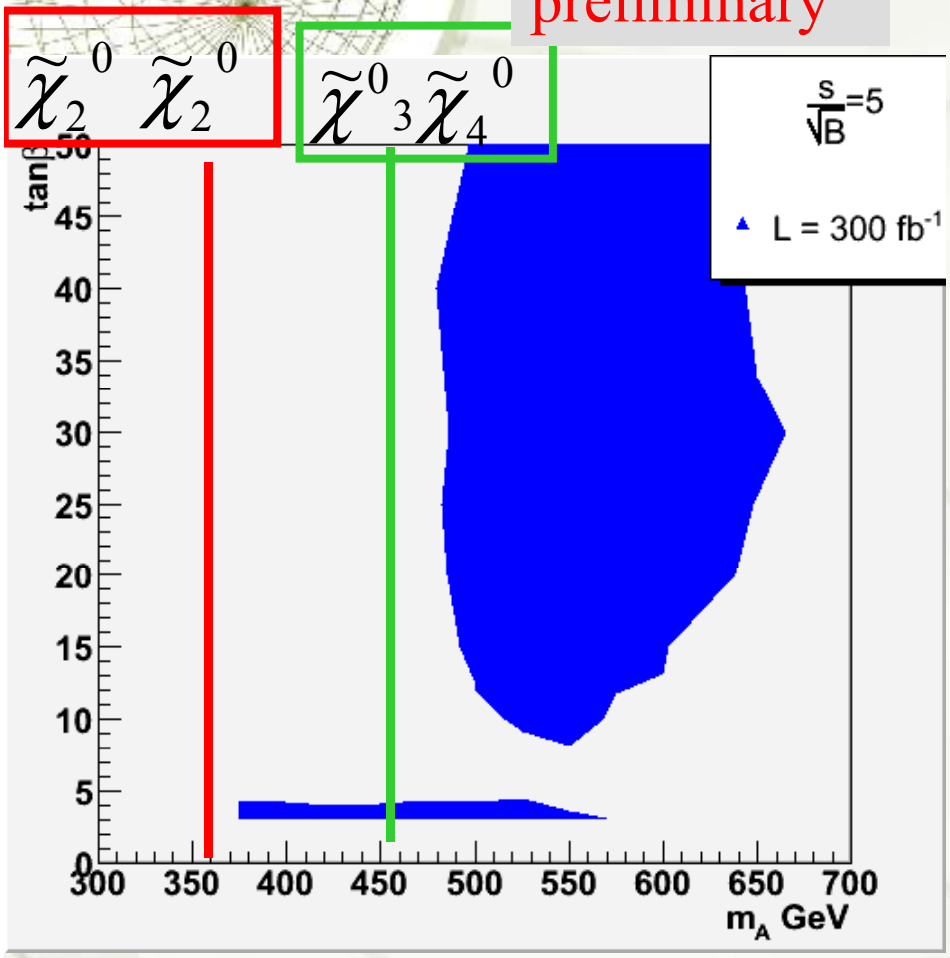
- tH background not anymore neglegible
- LL background neglegible

Explored region:

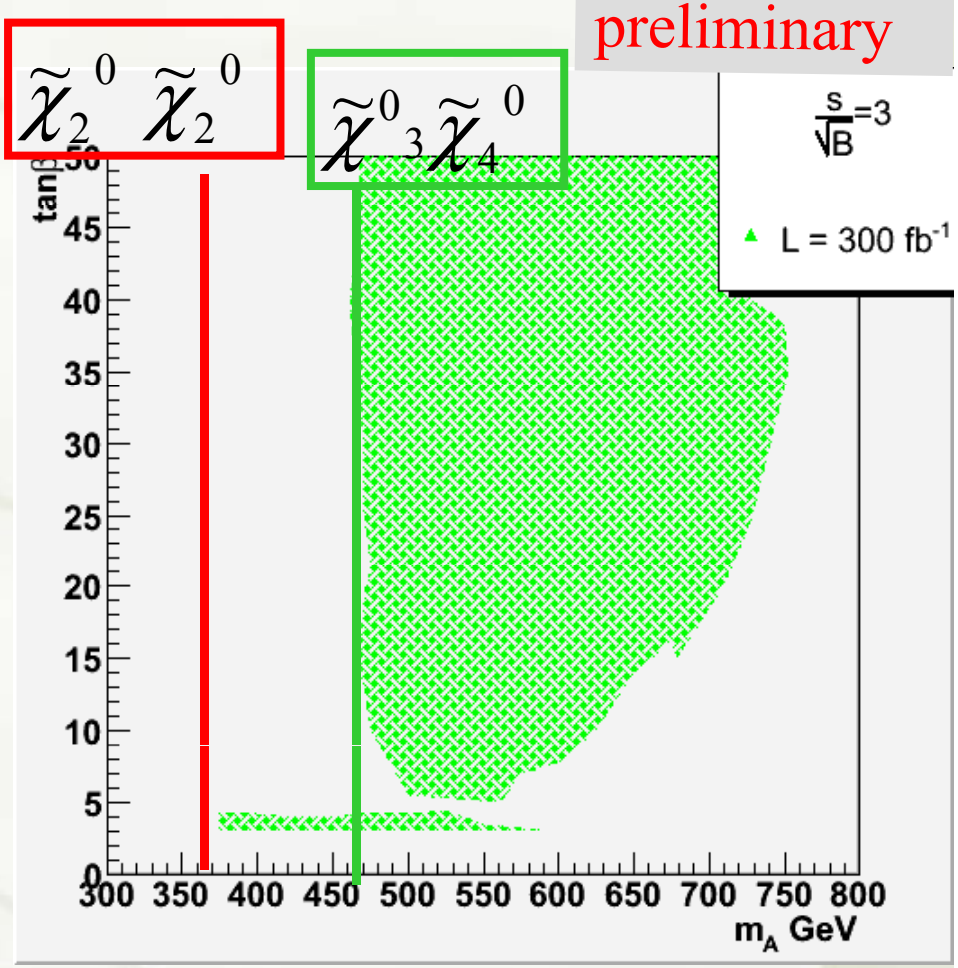
- Tanβ 3 and 5-50 step 5
- M_A 375-900 GeV step 25 GeV

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

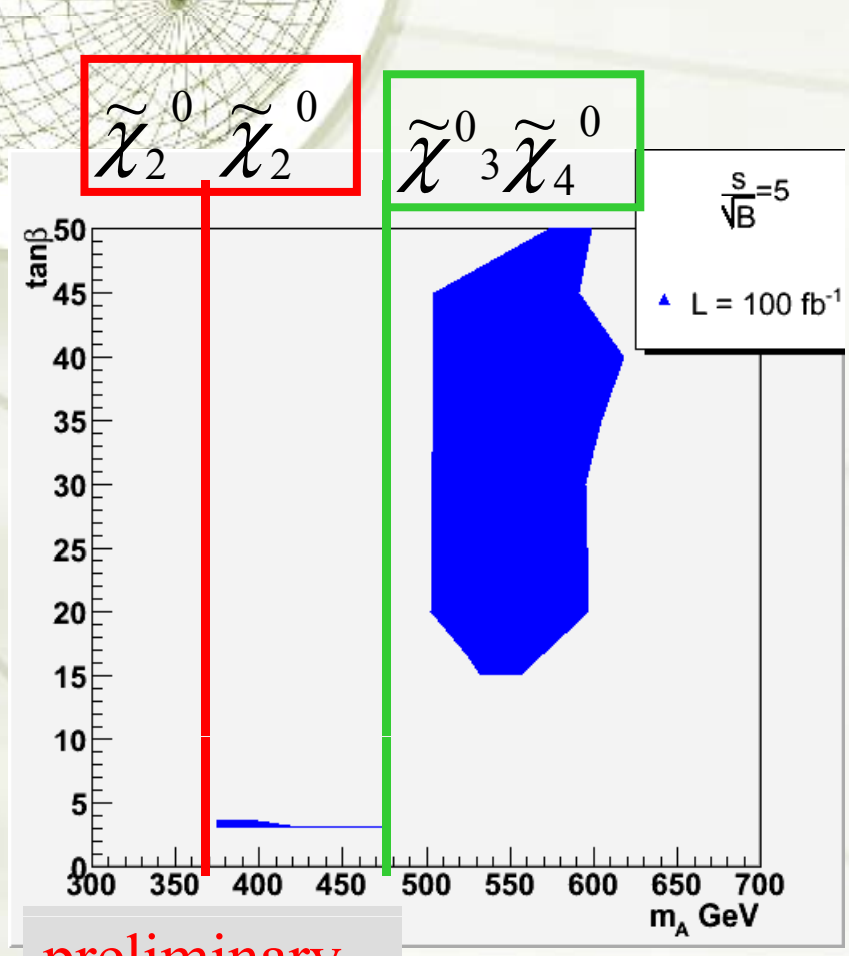
preliminary

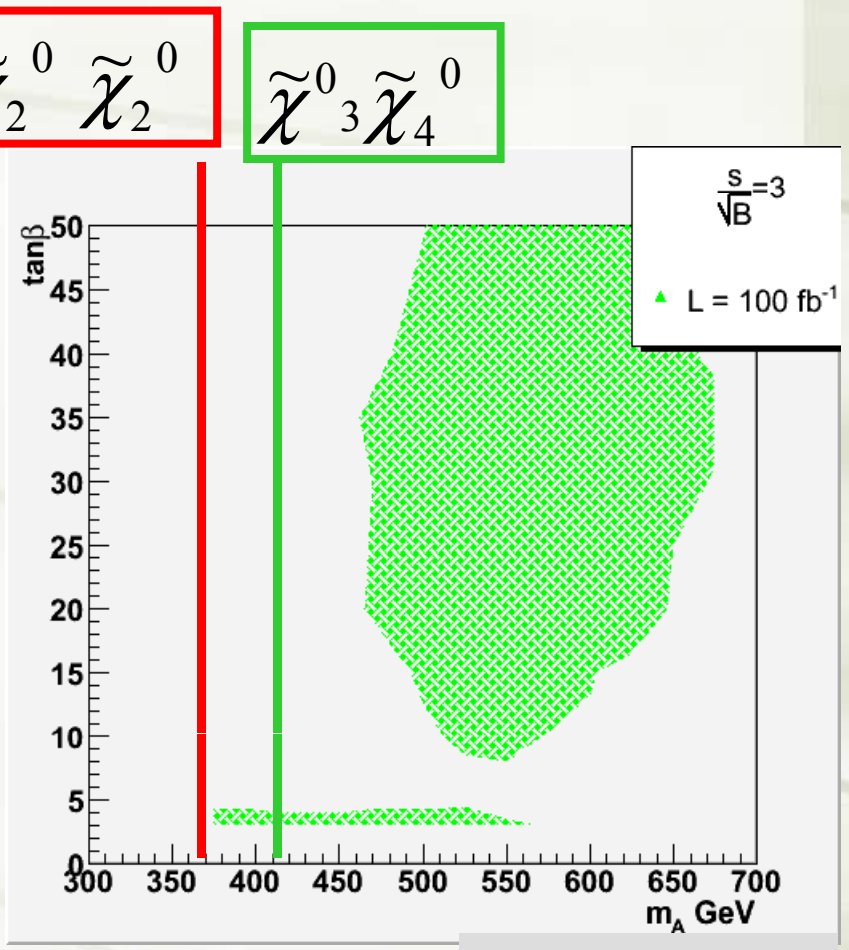


preliminary



Set2 Discovery plots at L = 100 fb^{-1}





Conclusion of Set2

- The detection region of

$A/H \rightarrow \chi^0_{2,3,4}\, \chi^0_{2,3,4} \rightarrow 4\,\ell + E_T^{miss}$

and

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

is **accessible also with L=100fb^{-1}.**

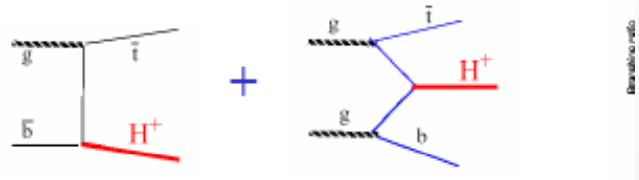
- The remaing background are mainly **ZZ** and **tt pair, direct $\chi\,\chi$, $tH^{\pm}$ production is not neglegible.**

- Preliminary study also on MSUGRA has been performed, SetA, In this scenario the copious background is tt pair $\tilde{\ell}, \tilde{\nu}, \tilde{\chi}\tilde{\chi}, \tilde{q} / \tilde{g}\tilde{\chi}$
- The point at M_A= 257 GeV and tan β= 20

has been studied . The significance achieved is after L =300fb^{-1} is $\geq 5\,\sigma$.

Charged Higgs involvement

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



Analogue decay mode:

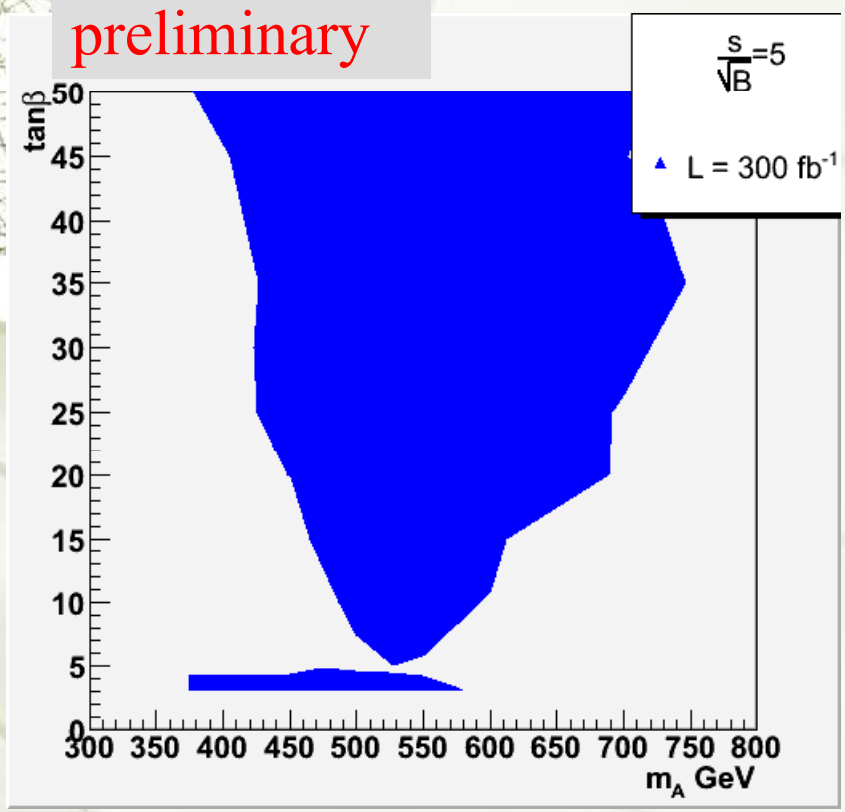
$$H^{\pm} \rightarrow \chi_{2,3}^{0}\, \chi_{1,2}^{\pm} \rightarrow 3l + E_T^{miss}$$

Final state: Only 3 lepton +another lepton from a top decay

Is not the best final state for a dedicated H^- search…..

Charged Higgs role

preliminary

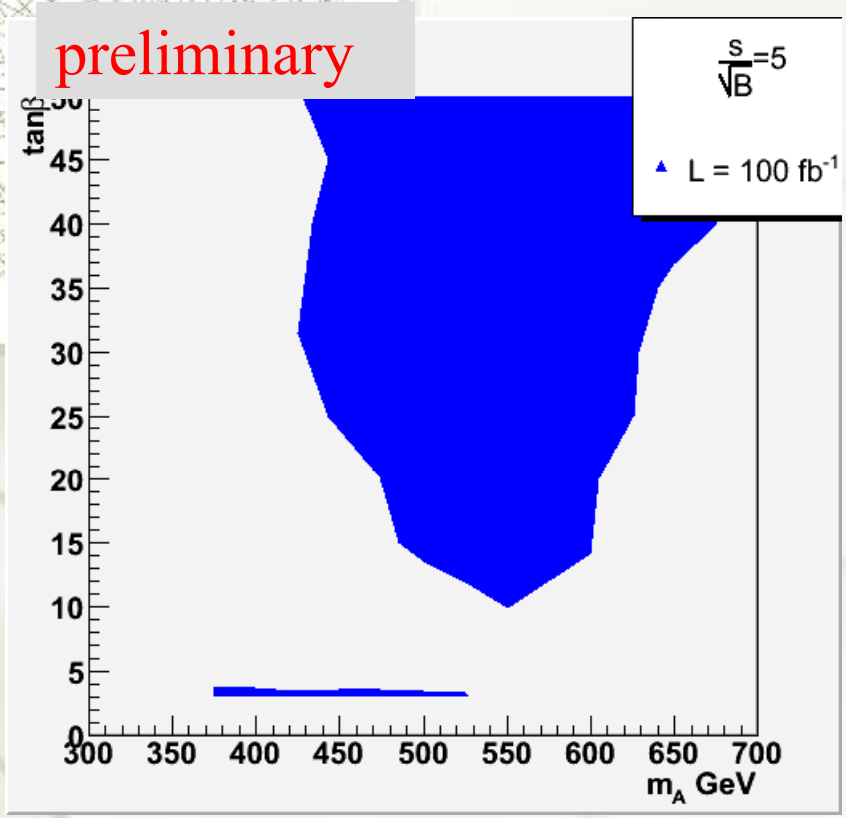


- The **range of discovery is enlarged**,

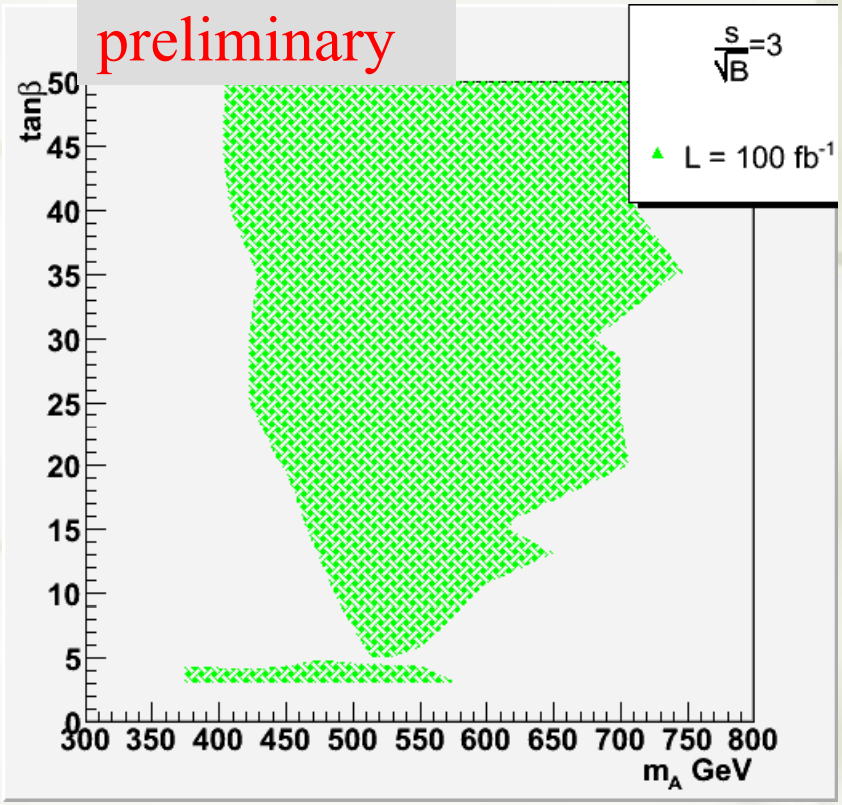
extending the search to all MSSM Higgs($H/A/H^{\pm}$) respect to neutral H/A..

Charged Higgs role

preliminary



preliminary



➢ The **range of discovery is enlarged**, extending the search to all MSSM Higgs(H/A/H$^{\pm}$) respect to neutral H/A..

Conclusion

- Discover potential study in MSSM neutral Higgs boson, **A/H→ 4 ℓ + E_T^{miss}** in ATLAS has provided the first results.
- A scan in (M_A,tanβ) plane with the the points dominated by $\chi_2^0\chi_2^0$ decays (Set1) and $\chi_{2,3}^0\chi_{2,3,4}^0$ **decays** (Set2) has been performed using full simulation of ATLAS detector
- With Set1 parameters the possibilty of discovery of neutral MSSM Higgs are after L=300 fb^{-1},
- With Set 2 the perspective are more encouraging even with L=100fb^{-1}
- The inclusion of charged Higgs decay extends the possibility of discovery a MSSM Higgs even with L=100fb^{-1}.

➢ I would like to thank Stefano Moretti and Filip Mortgart for discussions and informations.

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