Benchmark group: H+ in the NMSSM

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NMSSM

- Adds one **scalar singlet** to the two scalar doublets of the MSSM [neutral, complex]
  - Two additional Higgs states, 1 CP-even, 1 CP-odd
  - Physical: h_1, h_2, h_3, a_1, a_2, $h^{\pm}$ [when CP-conserving]
    h_i, a_i: singlet component [size depends on mixing angle]

- Theoretically appealing:
  - Solves the **problem**: naturally at the electroweak scale [needed for electroweak symmetry breaking]
  - MSSM fine-tuning (little hierarchy) problem can be ameliorated

- Experimentally appealing: [unlike the MSSM, there is...]
  - **No mass degeneracy** between heavy Higgs bosons
  - **Singlet component** (couples only to the Higgs doublet)

NMSSM vs MSSM

- NMSSM: Non-degenerate Higgs masses allow
  - **Higgs pair production** [propagators do not cancel] and
    [MSSM: H^+ production almost exclusively in tbH^+]
  - **Higgs-to-Higgs decays**
    - e.g. $pp \rightarrow a_1 h^+$ and $h^+ \rightarrow a_1 W$
    - Distinct detector signal: e.g. $a_1 a_1 W \rightarrow 4b + \ell$

- NMSSM allows to **evade** some of the direct and indirect **constraints** (e.g. $m_{h^+} > \approx 120$ GeV; flavor constraints)

Our starting point

- Stefano's slide from cHarged08:

Some interesting NMSSM scenarios for the Charged Higgs sector
(to be discussed in Benchmark Break-out Session)

Must be different from MSSM:

1) H+ -> W+A1 (a la Godbole/Roy) but also WH1 & WH2
2a) H3/A2 -> W-H+
2b) H3 -> H+H- (by CPC, A cannot decay to 2 charged Higgses!)
3) m+ ≠ mA (mH+ just above mH2 and mA1, H3, A2 heavy and singlet)
4) m+ << mt-mb (a la Godbole/Roy)
5) m+ > mt-mb, all other Higgses < mt

	no constraints			SUSY, Higgs + theory			all constraints		
	# points	$\tan(\beta)$	m_{H^+}	# points	$\tan(\beta)$	m_{H^+}	# points	$\tan(\beta)$	m_{H^+}
BMP1	100k	1	90	30k	1.4	170	15k	15	250
BMP2a	380k	1	70	170k	1.4	160	80k	15	210
BMP2b	90k	1	70	24k	1.6	170	7k	16	210
BMP3	44k	1	70	6k	3	160	2k	18	215
BMP4	13k	1	70	3	18	150	-	-	-
BMP5	3	10	180	-	-	-	-	-	-

NMSSM (weak scale). Soft masses for sleptons at 1 TeV, 2.5 TeV for trilinears and 150 GeV, 300 GeV, 1TeV for M1, M2, M3 risp. I then randomly scanned on lambda, kappa, Alambda, Akappa, mu and tan(beta), taking 10^9 points. Positive mass squared for all scalars, all exp. constraints (LEP/Tevatron limits, b->sγ, g–2, etc.)

1,2 suppressed in MSSM, could be experimentally accessible

4 can have large cross section; very light h+ possible

Tasks

1. Identify interesting points in general NMSSM, and NMSSM versions of mSUGRA / NUHM for **pp->a1 h+** in connection with **h+ -> W+a1**

2. Investigate possibility of a ***very* light h+**

3. Investigate **h3/a2 -> W-h+, h3 -> h+h-**

4. **WH+** production in the NMSSM

everything shown is for $\sqrt{s}$=14 TeV

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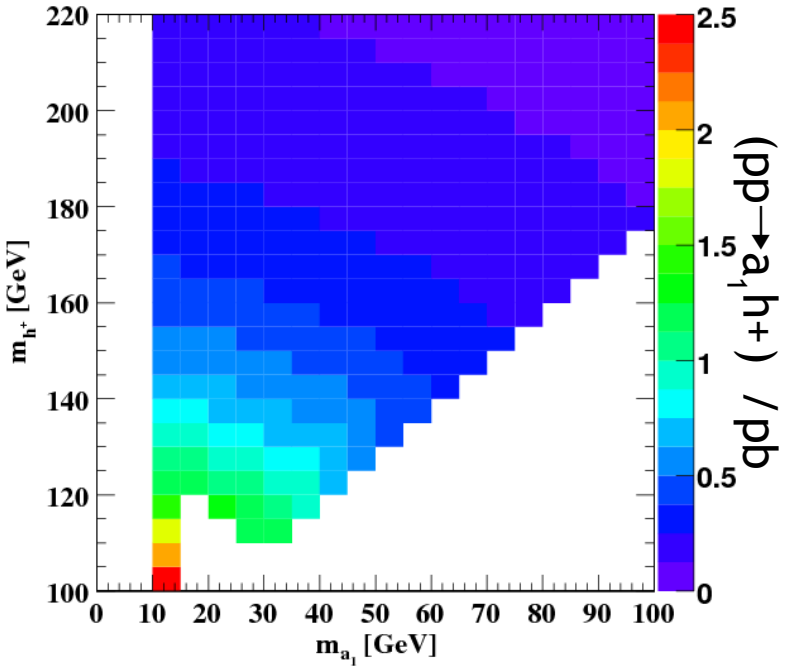
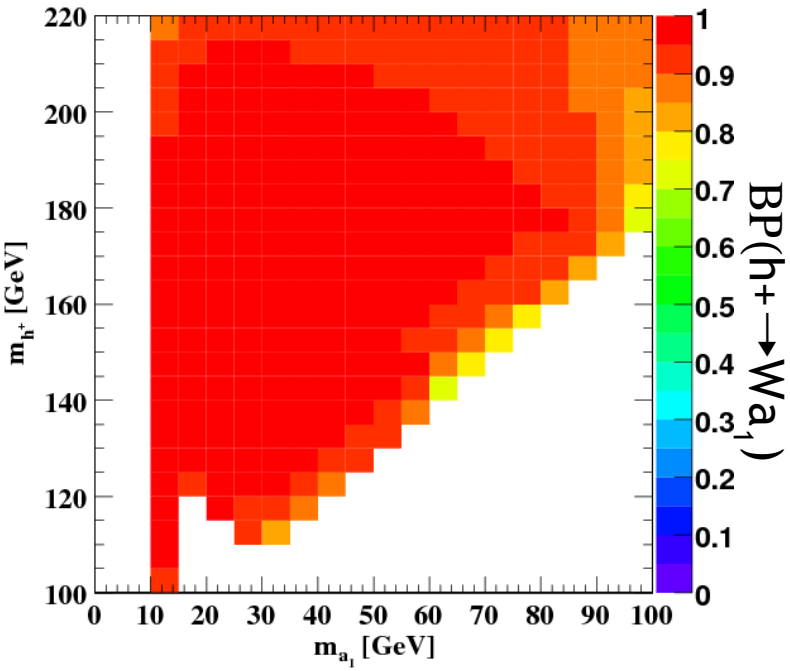
1. pp->a1 h+ , h+ -> W+a1

Production and decay: a1h+

- **maximum (a1h+) and BR(h+->Wa1)** values as a function of mh+ and ma1
  - Including all NMSSMtools constraints (theoretical consistency, direct collider, B Physics, etc)

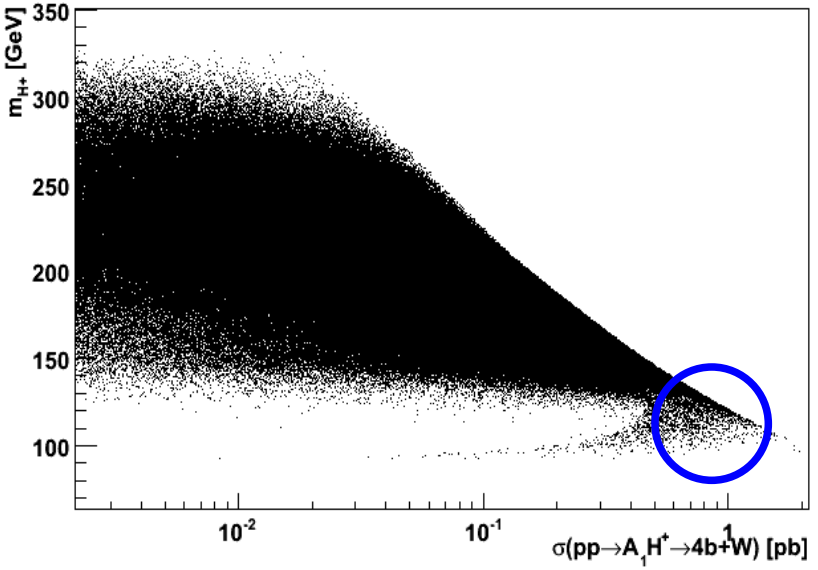


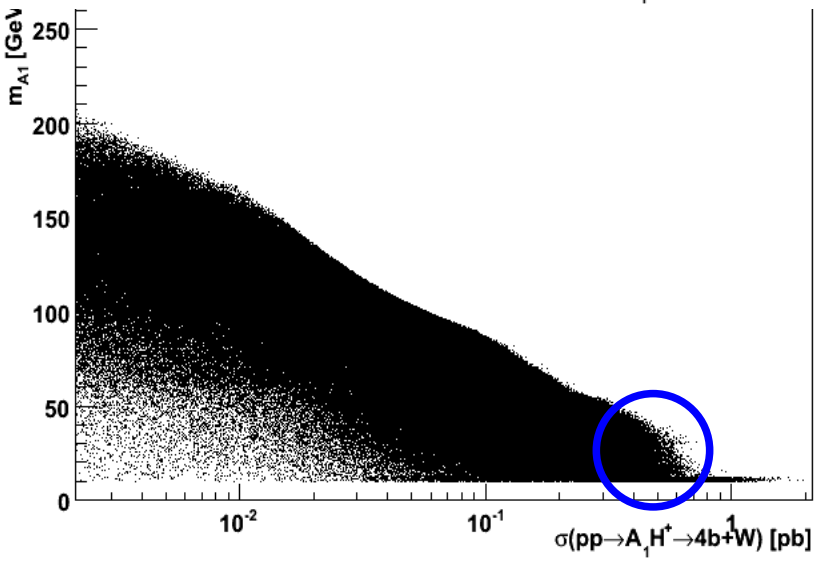


- of O(pb) possible; BR can always be ≈1

pp→a1 h+ , h+→W+a1, a1→bb

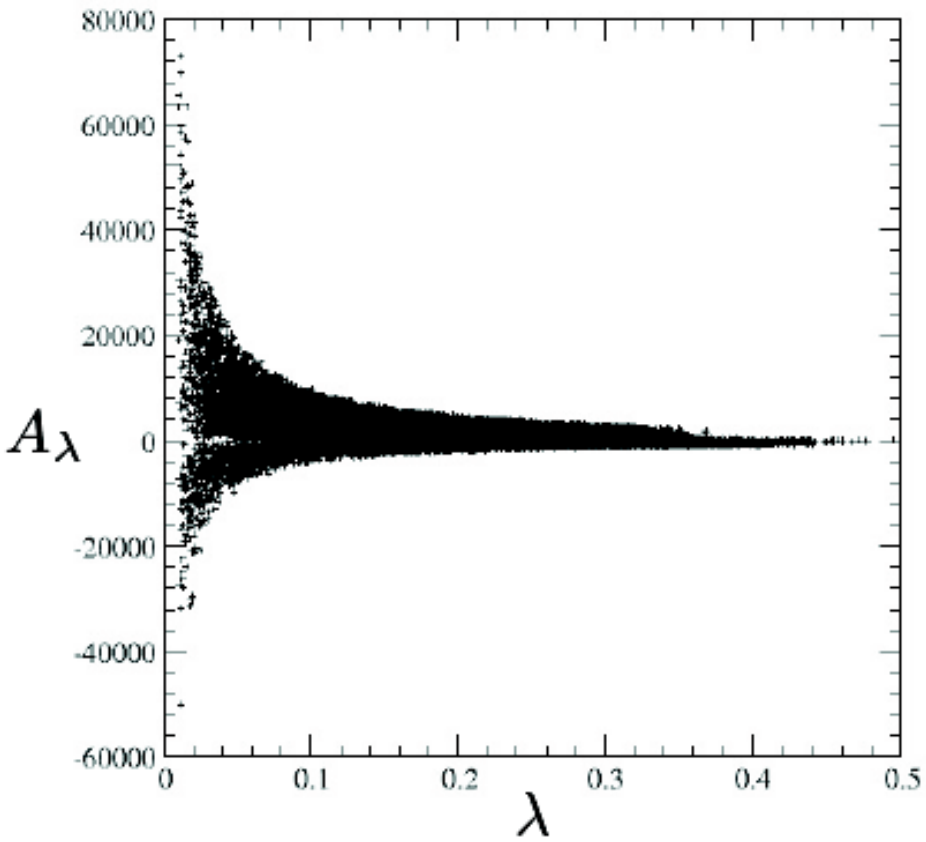
- Can
  - pp→a1 h+
  - h+→W+a1
  - a1→bb
- be **large at the same time**?
- Can reach cross section of **≈1 pb for 4b+W** final state
  - very light a1 (<<50 GeV)
  - mh+ = 100-150 GeV
- To do: look for points in mSUGRA / NUHM models





A caveat: small λ

As in the MSSM $m_A = \dfrac{2\mu B}{\sin 2\beta}$ except that $B = A_\lambda + \dfrac{\kappa}{\lambda}\mu$



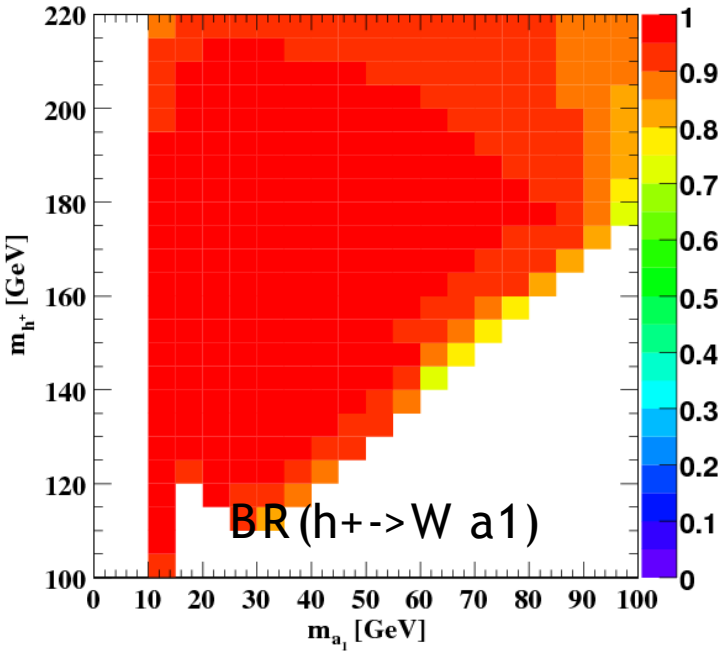
When m_A and μ are fixed:
small λ ⇒ large A_λ

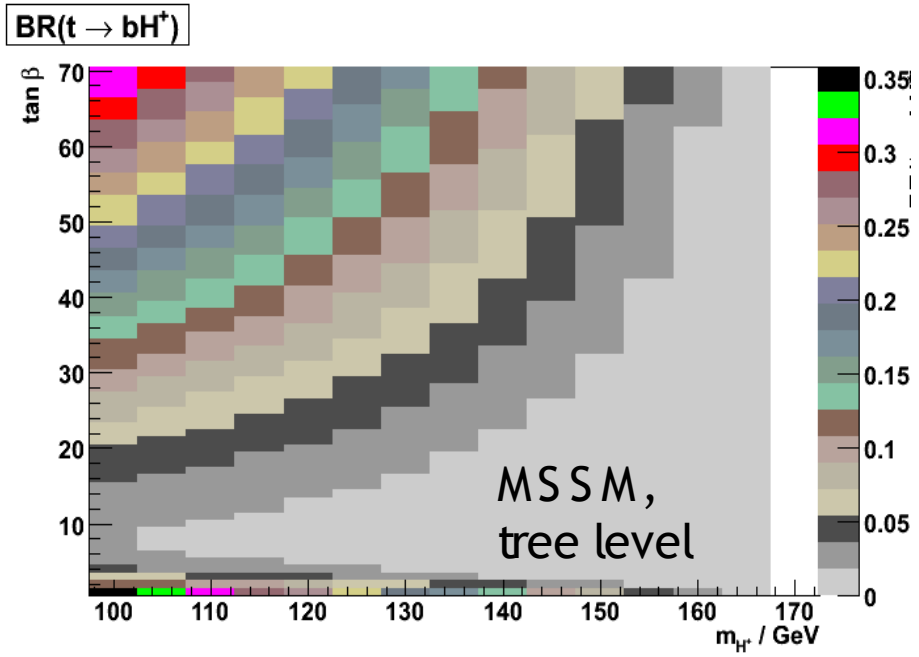
Same when A_λ is fixed:
small λ ⇒ large m_A

In the cNMSSM: $\dfrac{\kappa}{\lambda} \sim 1$

h+→Wa1 for light h+

- Can also be produced in **ttbar decays**
  - Much higher cross section possible!
    - (ttbar) ≈ 900 pb
  - BR(h+→Wa1) can be ≈1 for most mh+/tan β values





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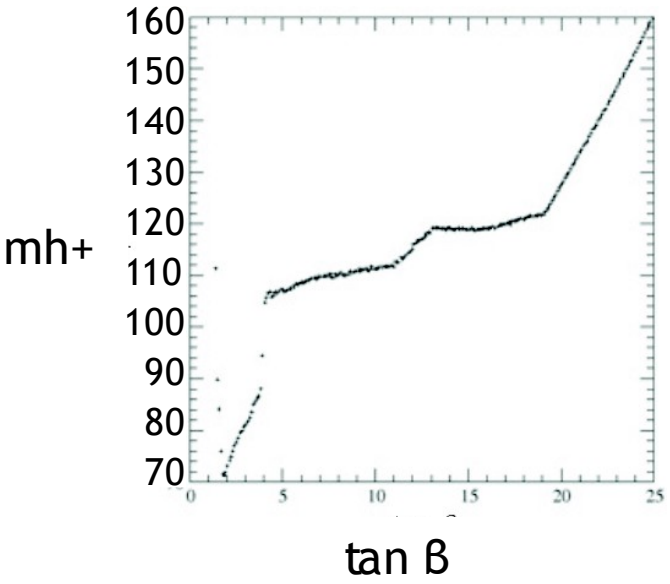
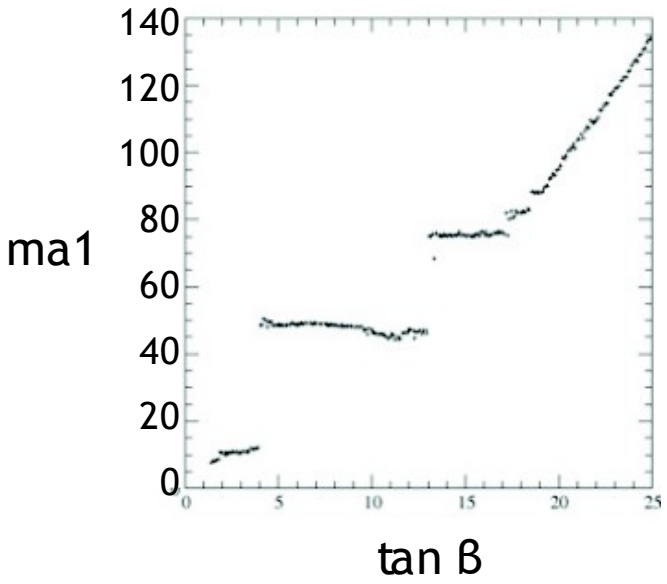
2. Light h+ in the NMSSM

Minimum h+ mass

- **mh+ (and ma1) minimum**, as a function of tan
  - General NMSSM scan, >0
- Applying all NMSSMTools constraints

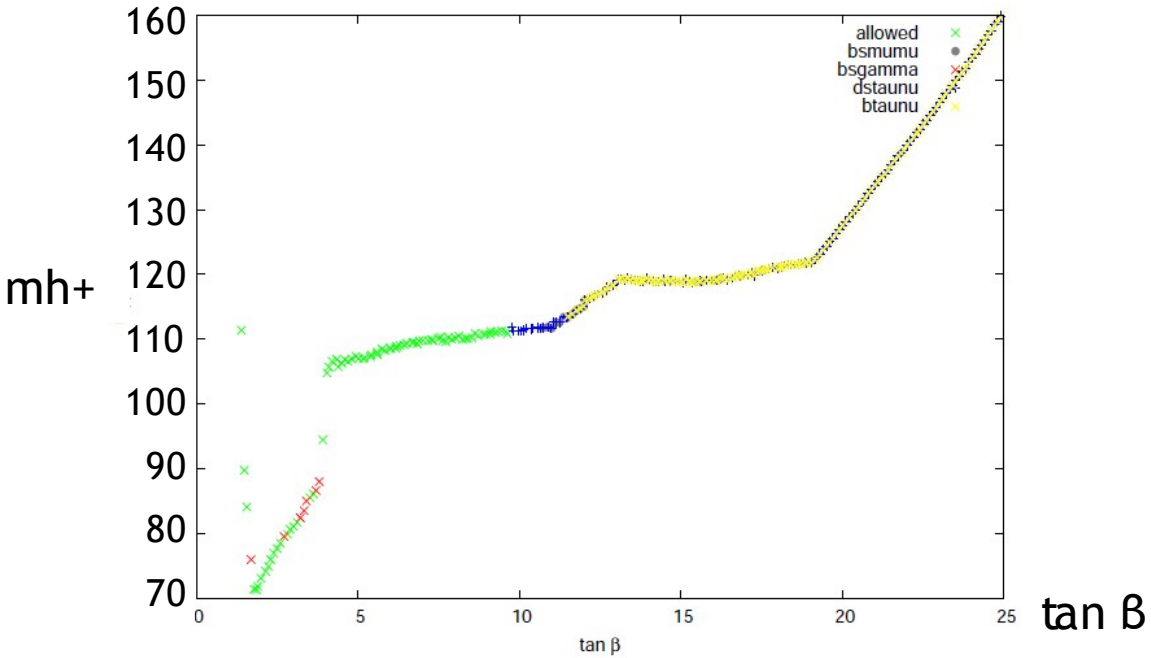




- **mh+ can even be below 80 GeV**

SuperISO constraints

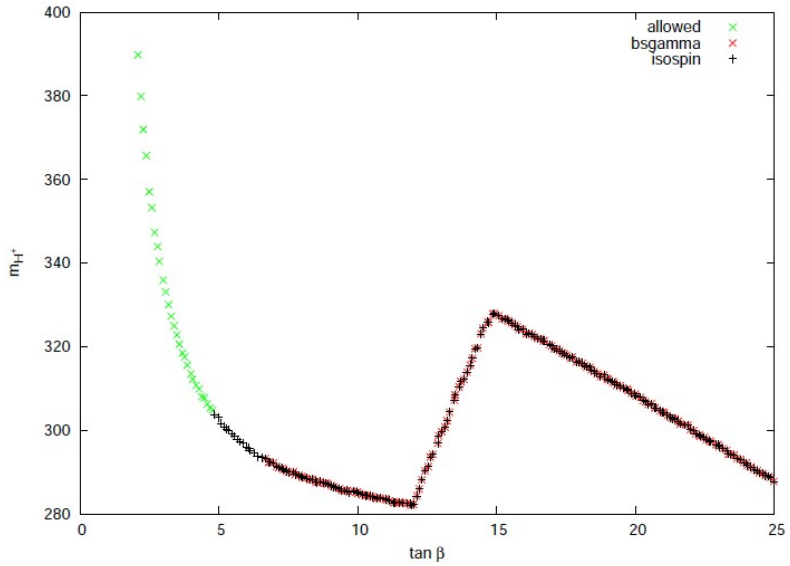
- Same as before – applying **SuperISO constraints**
  - *These* light h+ points not allowed for tan β>10 (D/B→τν)
  - b→s limits can be evaded with a bit of fine-tuning

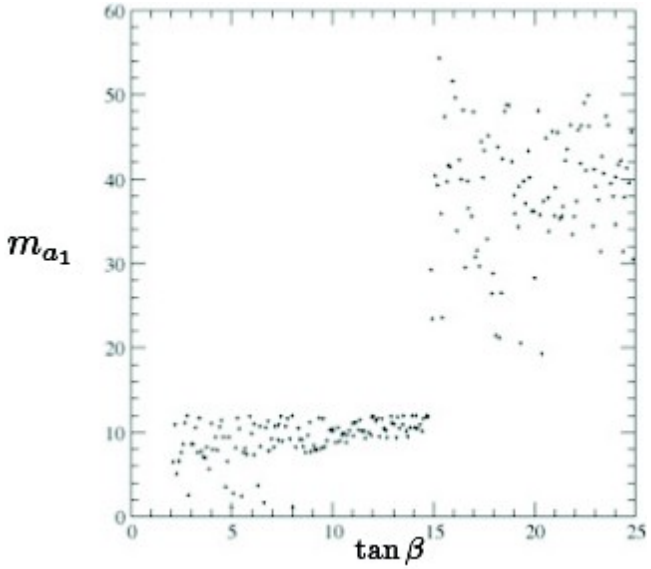


  - **Very light h+ still possible for tan <10**
  - News: **NMSSMTools now fully interfaced with SuperIso**

Constrained NMSSM

- Similar, for the **constrained NMSSM** (mSUGRA)
  - **No points with mh+ <280 GeV** found





- Same for NUHM would be of interest

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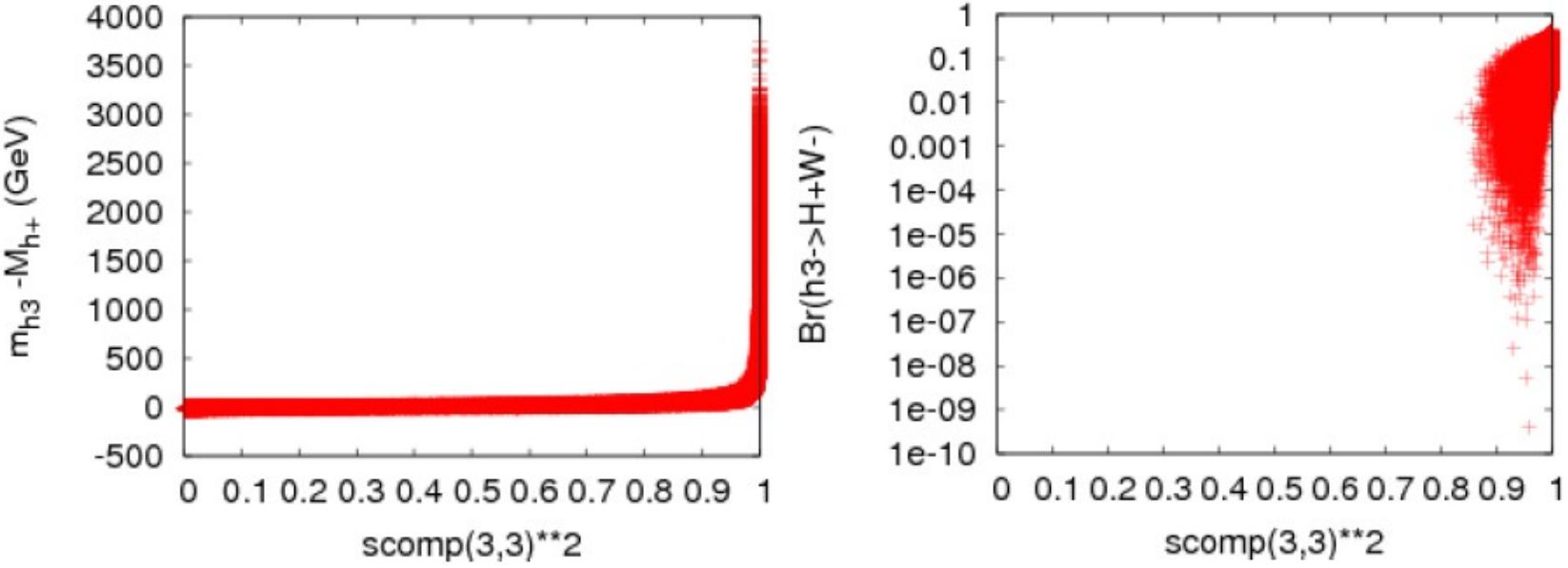
3. h3 -> Wh+

h3 -> Wh+

- h3→Wh+
  - Needs **large mass splitting h3, h+**
    - Possible **if h3 is singlet-dominated**
    - Large phase space gives high BR in spite of singlet suppression
  - But: **h3 production if singlet-dominated?**
    - Only option seems associated production with 2 charginos



Conclusions

- Some interesting NMSSM parameter regions have been identified where benchmark points could be defined
- Main interest:
  - Large σ(pp → a1h+ → a1a1W → bb bb lv)
    - Further studies in cNMSSM/NUHM needed
  - Very light h+ (below 80-100 GeV)
- Further investigations
  - h3->h+W does not seem viable
  - Wh+ production not studied yet (NMSSM)
- Other progress
  - NMSSMTools is now fully interfaced with SuperISO

Backup slides

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NMSSM Tools constraints

chargino too light

excluded by Z -> neutralinos

charged Higgs too light

excluded by ee -> hZ

excluded by ee -> hZ, h -> bb

excluded by ee -> hZ, h -> tautau

excluded by ee -> hZ, h -> invisible

excluded by ee -> hZ, h -> 2jets

excluded by ee -> hZ, h -> 2photons

excluded by ee -> hZ, h -> AA -> 4bs

excluded by ee -> hZ, h -> AA -> 4taus

excluded by ee -> hZ, h -> AA -> 2bs 2taus

excluded by Z -> hA (Z width)

excluded by ee -> hA -> 4bs

excluded by ee -> hA -> 4taus

excluded by ee -> hA -> 2bs 2taus

excluded by ee -> hA -> AAA -> 6bs

excluded by ee -> hA -> AAA -> 6taus

excluded by ee -> Zh -> ZAA -> Z + light pairs

excluded by stop -> b l sneutrino

excluded by stop -> neutralino c

excluded by sbottom -> neutralino b

squark/gluino too light

selectron/smuon too light

stau too light

lightest neutralino is not LSP

Landau Pole in l, k, ht, hb below MGUT

unphysical global minimum

Higgs soft masses >> Msusy

excluded by WMAP (checked only if OMGFLAG=1)

eff. Higgs self-couplings in Micromegas > 1

b->s gamma more than 2 sigma away

Delta M_s more than 2 sigma away

Delta M_d more than 2 sigma away

B_s->mu+mu- more than 2 sigma away

B+-> tau+nu_tau more than 2 sigma away

(g-2)_muon more than 2 sigma away

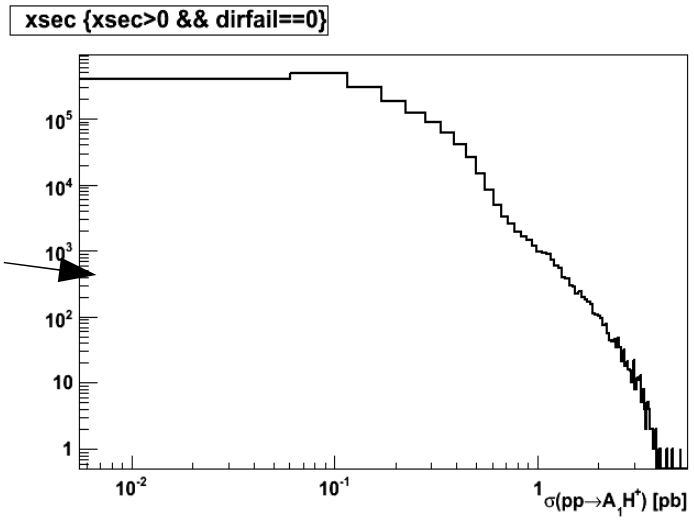
excluded by Upsilon(1S) -> A gamma

excluded by etab(1S) mass difference

Scan slide 8

- Random scan, 500M points in the general NMSSM
  - =0..0.7 =-0.65..0.65 m_{A1}=1..220 M_1=100...800 tan =1..20 μ_{eff}=-500..500 A =-300..300,
  - $M_2=2M_1$ $M_3=6M_1$ $A_{t,b,\tau}$=-2500$m_{\tilde{l}}$=300 $m_{\tilde{q}}$=1000

All points		500M
Theoretical Contraints I	(consistency)	49M
$m_{H+} > m_A+m_W$		10M
All Theoretical and Direct Contraints		1.8M
xsec*br_hp_a1w*br_a_bb*br_a_bb>100fb [= $(pp \to AH^+ \to 4b+\ell\nu)$]		0.5M
B physics etc Constraints		0.07M



$$M^2_{H^\pm} = \frac{2\mu_{eff}}{\sin 2\beta}(A_\lambda + \kappa s) + M^2_W - \lambda^2 v^2$$