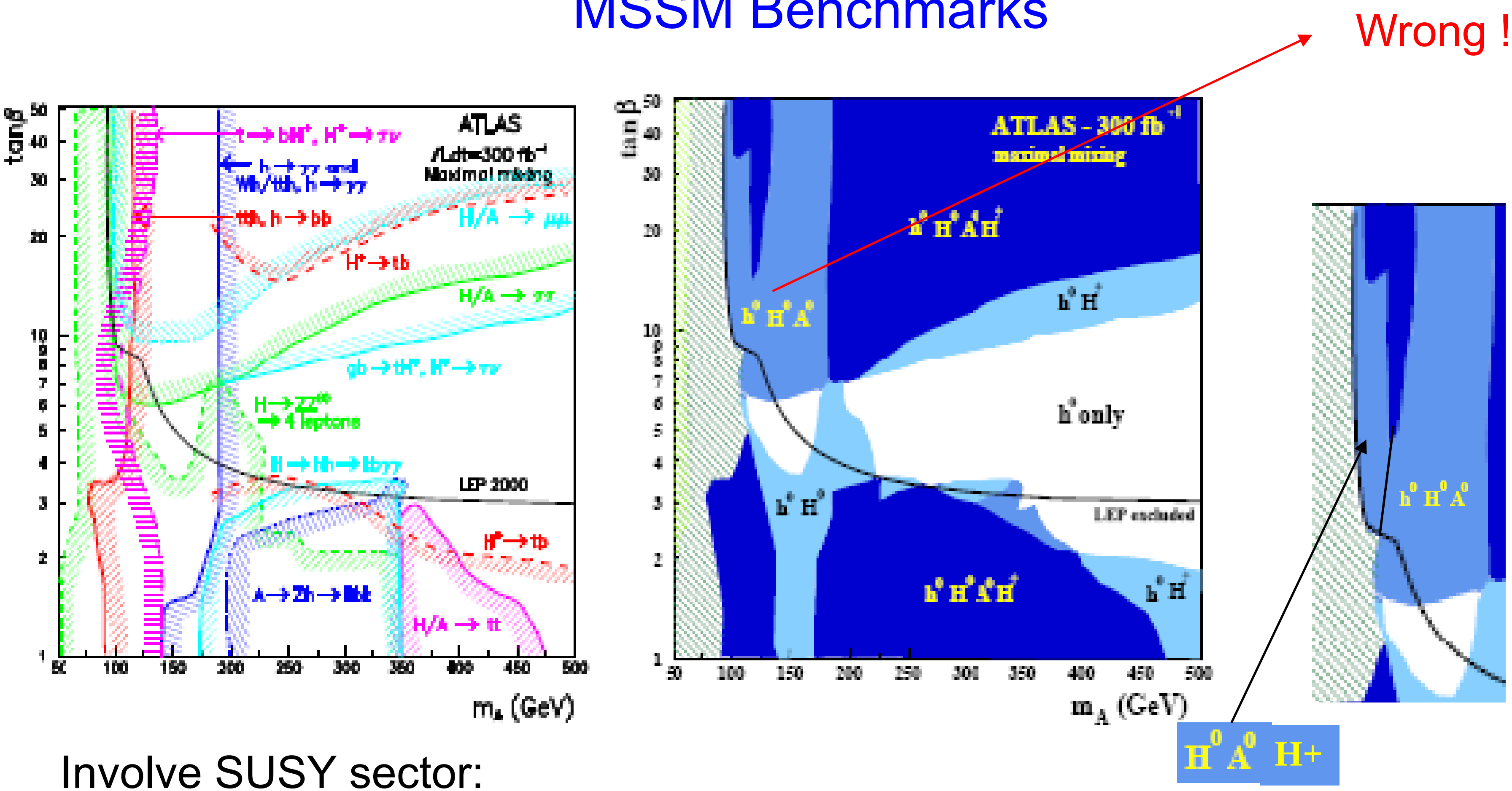
‘Charged 2008’, Uppsala, 17 Sep 2008

Benchmarks for Charged Higgses

Stefano Moretti (NExT Institute)

MSSM Benchmarks

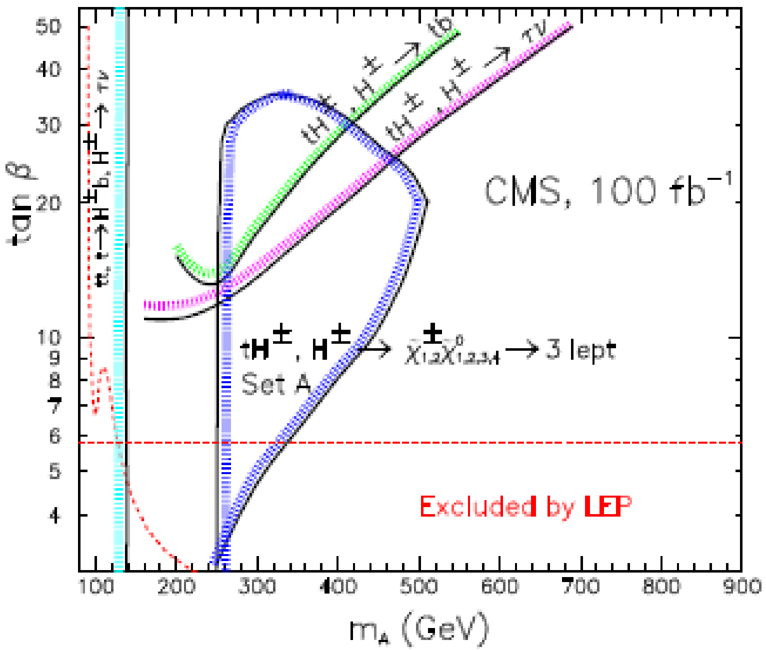


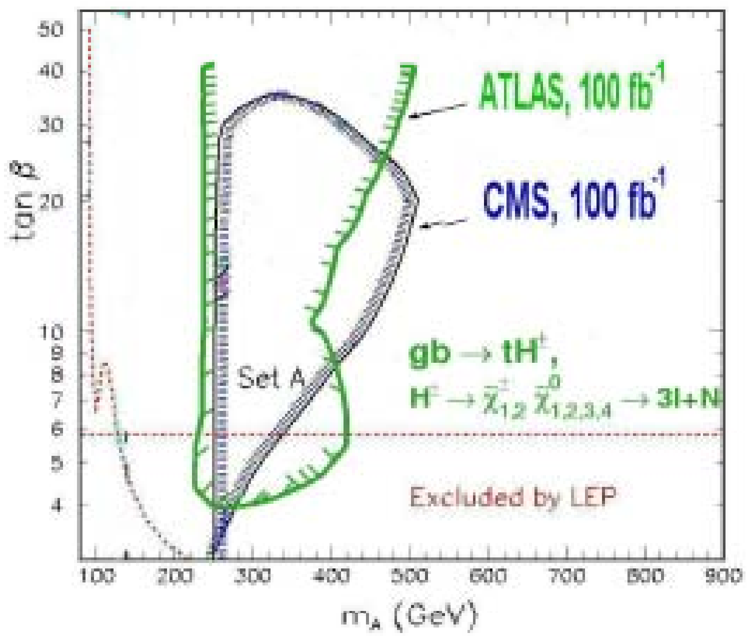
Involve SUSY sector:

1. Can be loop effects entering SM-like channels: LHS (see Belyaev's contribution below) & Sven's talk today
2. Can be real effects generating new channels H+/- -> SUSY or SUSY -> H+/- or SUSY & H+/-

H+ → SUSY

$M_2 = 210\,\mathrm{GeV},\ \mu = 135\,\mathrm{GeV},\ m_{\tilde{\ell}_R} = 110\,\mathrm{GeV},\ m_{\tilde{g}} = 800\,\mathrm{GeV},\ m_{\tilde{q}} = 1\,\mathrm{TeV}.$

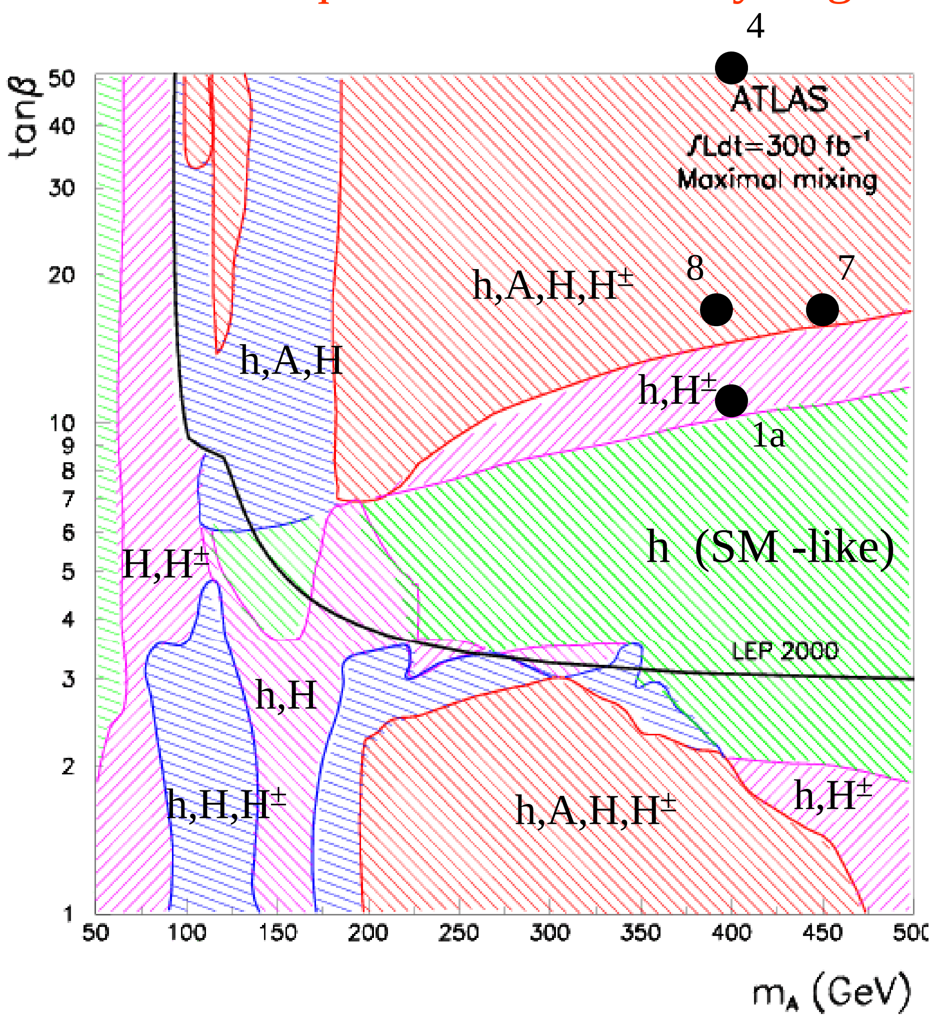




* Philosophy so far: scan parameter space to optimise leptonic signals (easiest)
* Discovery areas for different channels correspond to different SUSY configurations
* Problem: discovery plots cannot be superimposed (what's true LHC potential ?)
* Alternatively: adopt SUSY Higgs benchmark points (a la SPS, LHC points, etc.)

SUSY benchmark points in m_A tan β plane

⇒Require dedicated study to give suitable set of benchmark points



Snowmass points and slopes: SPS
hep-ph/0202233

Chosen with SUSY space rather than Higgs space in mind.

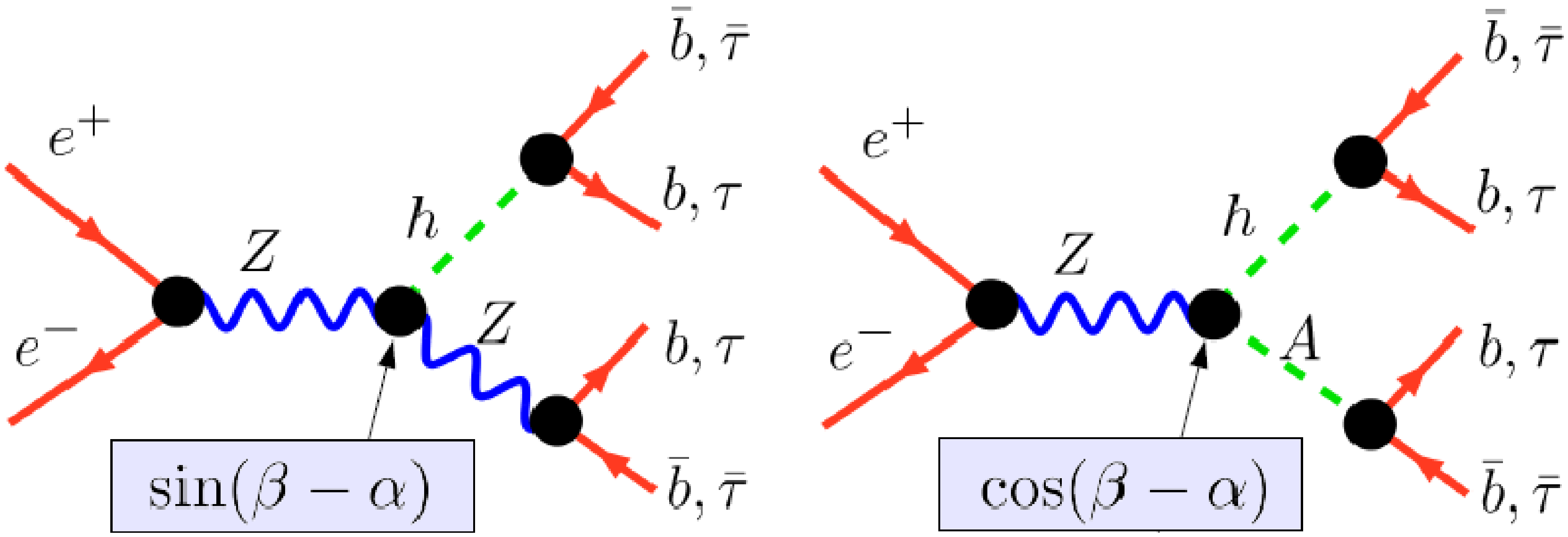
9 points: 5+1 mSugra, 2 GSMB,
1 AMSB

Only 4 points feature in usual Higgs plane. 1a, 4 (mSUGRA) 7,8 GMSB.

Benchmarks from Heinemeyer et al may be useful in this respect ?
(For virtual SUSY effects.)

Sven's slides here.

Virtual effects of SUSY (departing from max mix ?)

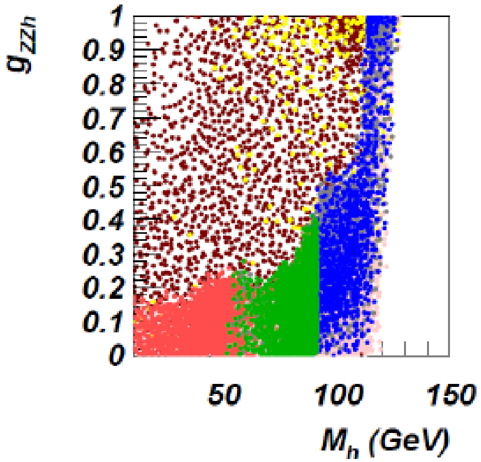


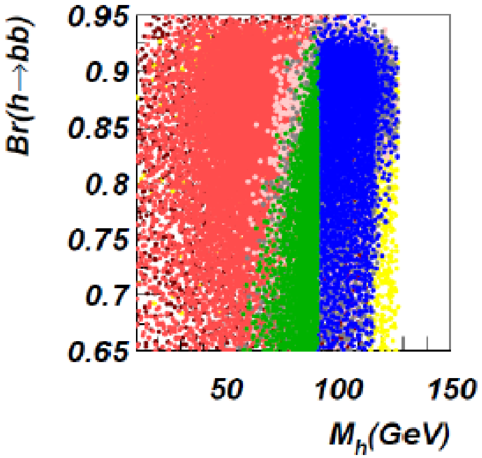
$$g^2_{ZZh} + g^2_{ZAh} = 1$$

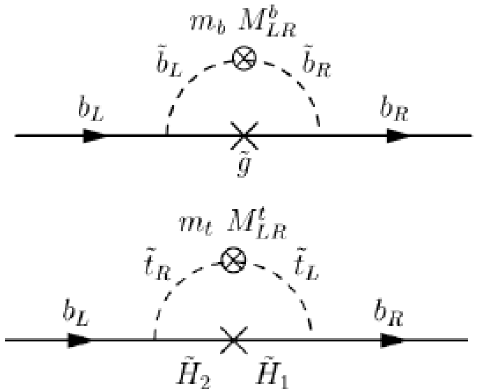
Zh and Ah channels are highly complementary!

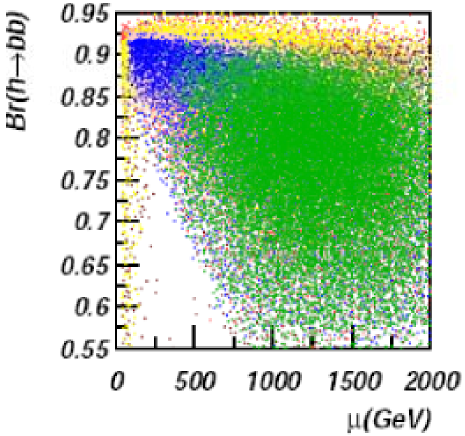
Key-point: SUSY corrections suppressing τ H and bbH couplings in non-universal way!

(Carena,Mrenna,Wagner;Borzumati,Farrar,Polonsky; Guasch,Hollik,Penaranda)









$$m_b + \delta m_b = \frac{m_b}{1 + \Delta m_b}$$

$$(\Delta m_b)_{\mathrm{SUSY-QCD}} \propto + \frac{2\alpha_S(M_{\mathrm{S}})}{3\pi}\, m_{\tilde{g}}\, \mu \tan\beta$$

excluded by: ■ *LEP2 Zh search* ■ *LEP2 Ah search* ■ *LEP2/TEV SUSY search*

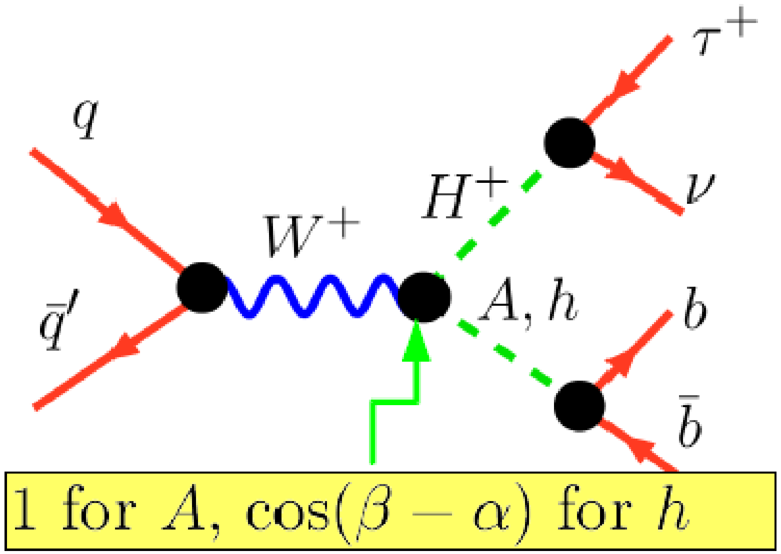
■ *the color breaking constraint*

allowed: ■ $M_h<M_Z$ ■ $M_h>M_Z$

Associated production of Charged – Neutral Higgses would a perfect test of LHS

- *case of large WH^+h coupling –*

  H^+h (H^+A) associate production very special –
  complementary to LEPII



- $g_{AH^+W^-} = 1$ ***: does not depend on SUSY parameters at tree-level***

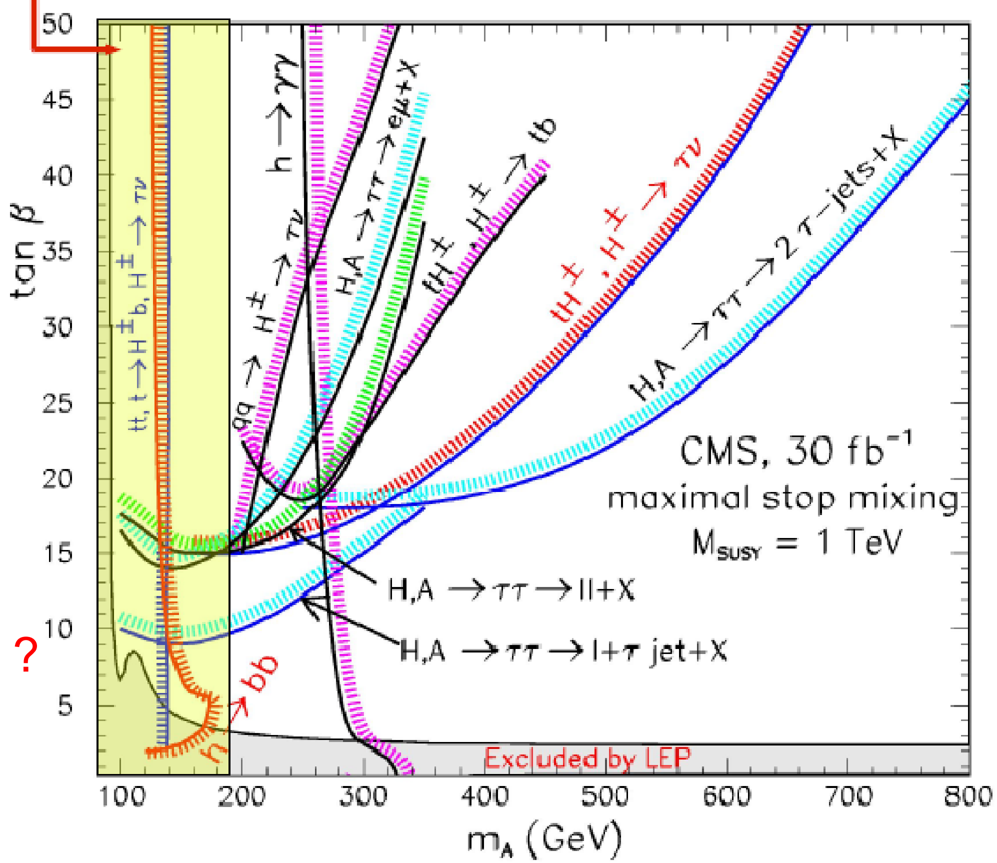
$$pp \rightarrow H^{+} h(A) \rightarrow \tau^{+}\nu \, b\bar{b} \rightarrow \pi^{+} \bar{\nu} \, \nu b\bar{b}$$

Projecting on to tanβ – M_A plane

H+ h, H^+A

Not max mix

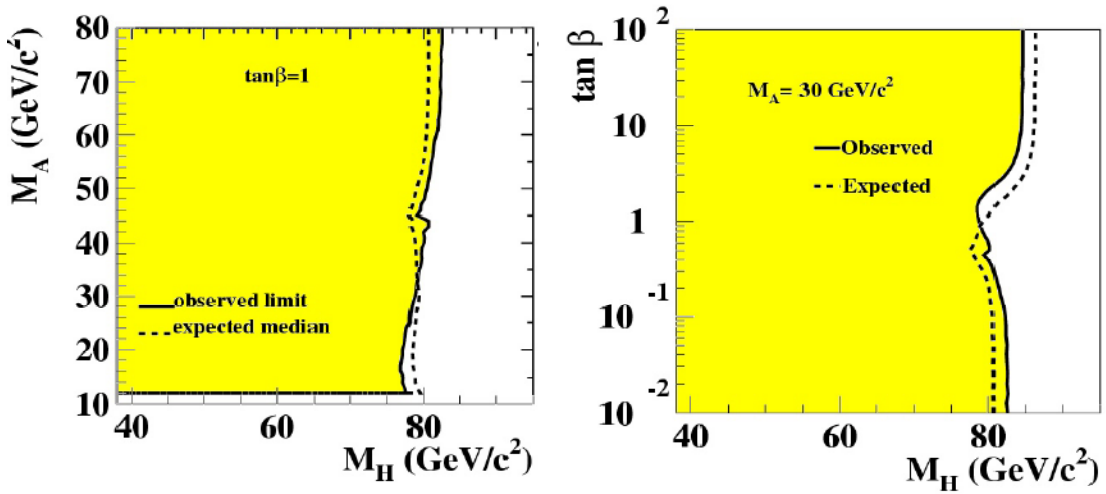
Need to adopt a new mixing scenario after the demise of min max ?



Also signature of Kanemura et al Type X model

Besides …

DELPHI Limits from $H^+ \rightarrow WA$



- Type-1 limit at 95% CL: $mH^+ > 76.7$ (77.1) GeV for any tanβ and mA > 12 GeV.

Light CP-odd Higgs and Small $\tan\beta$ Scenario in the MSSM and Beyond

Radovan Dermíšek[1,*]

[1] *School of Natural Sciences, Institute for Advanced Study, Princeton, NJ 08540*

(Dated: June 5, 2008)

We study the Higgs sector of supersymmetric models containing two Higgs doublets with a light MSSM-like CP odd Higgs, $m_A \lesssim 10$ GeV, and $\tan\beta \lesssim 2.5$. In this scenario all of the Higgses resulting from two Higgs doublets: light and heavy CP even Higgses, h and H, the CP odd Higgs, A, and the charged Higgs, $H^\pm$, could have been produced at LEP or the Tevatron, but would have escaped detection because they decay in modes that have not been searched for or the experiments are not sensitive to. Especially $H \to ZA$ and $H^\pm \to W^{\pm\star}A$ with $A \to c\bar{c}, \tau^+\tau^-$ present an opportunity to discover some of the Higgses at LEP, the Tevatron and also at B factories. Typical τ- and c-rich decay products of all Higgses require modified strategies for their discovery at the LHC.

LHS Benchmark

One of the points from the scan
within the LHS scenario (Mh=78 GeV)
satisfying all experimental constraints including B-physics ones

EW scale Model Parameters (M2=2M1)

MH+	At	mu	Mq3	tb	M1	M3
132.1	1093.	1369.	462.2	16.64	324.	849.6

Mass spectrum and observables

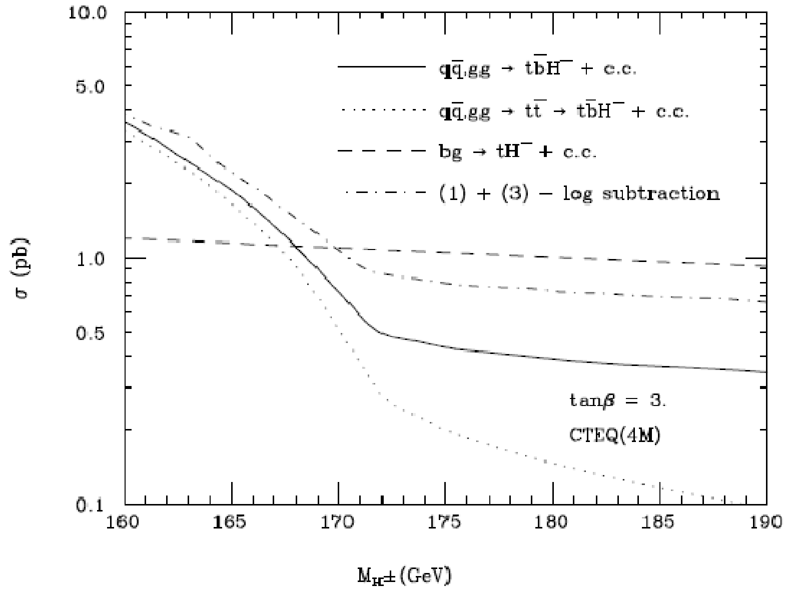
mh	ma	mH
78.17	113.2	122.4

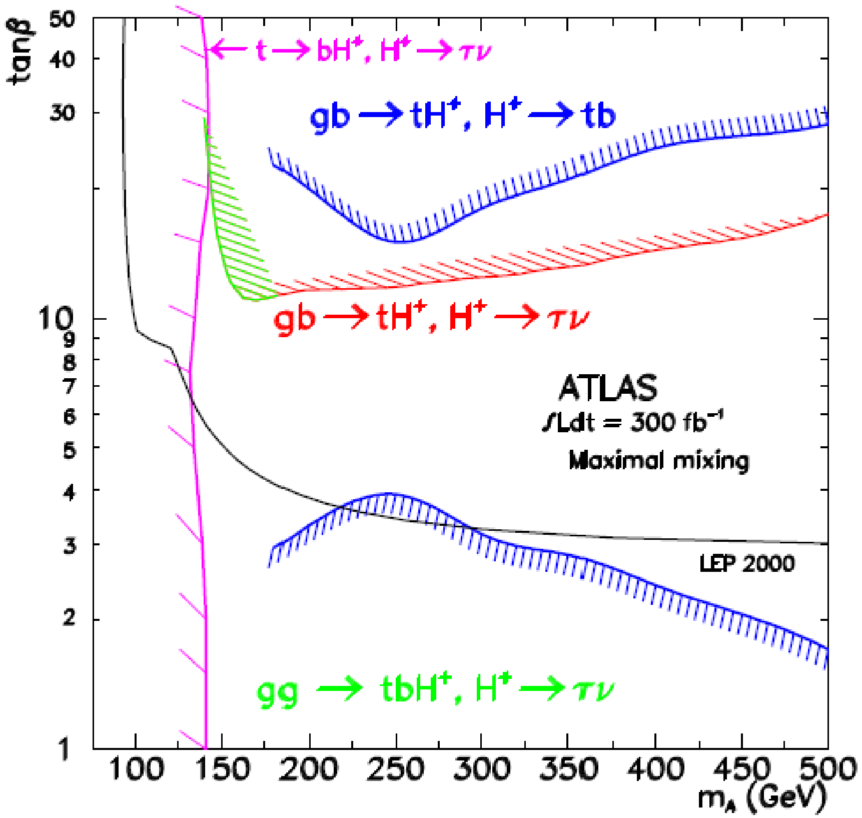
mch	Mstop	Msbottom
644.4	277.2	423.9

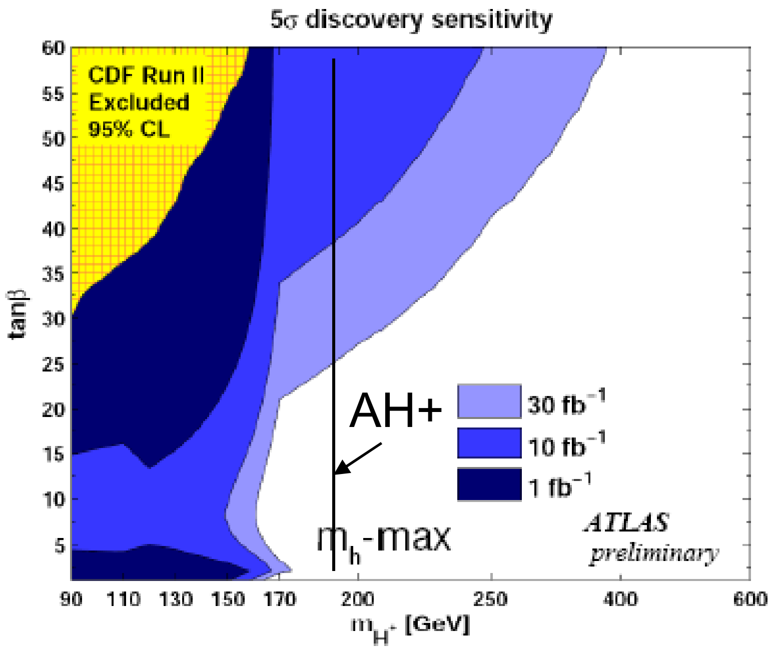
Br(b ->sgamma)	Br(Bs->mu+mu-)
4.1 x 10^-4	5.5 x 10^-8

Based on CPC CPSuperH !
Agrees with Hdecay, Also
FeynHiggs finds LHS but for
slightly different A's & μ …

The wedge/threshold region through H+ signals







From previous slide: AH+ could help too !

NMSSM Benchmarks for H+ searches

1. If ($M_{H^+} \sim 120$ GeV) one has a dominantly singlet H_1 with ($M_{H_1} \sim 50$ GeV). Thus this H_1 will evade LEP searches and will be difficult to produce at LHC as well. There is a light (50 GeV) pseudoscalar A_0 with significant doublet component. Such $H^\pm$ can be searched through $H^+ \to \tau^+\nu$.

2. ($M_{H^\pm} > 130$ GeV), (in this $\tan\beta$ range), decays dominantly via the $H^+ \to W^+ A_1^0$. This is a good channel for the $H^\pm$ as well as A_1^0 search.

$\tan\beta$	M_{H^+} (GeV)	M_{A_1} (GeV)	B_{A_1} (%)	λ, κ	$x = v_s/\sqrt{2}, A_\lambda, A_\kappa$ (GeV)
2	147	38	94	.45,-.69	224,-8,2
3	159	65	83	.33,-.70	305,40,38
4	145	48	89	.28,-.70	563,170,85
5	150	10	91	.26,-.54	503,109,38

Interesting new phenomenology for a light charged Higgs boson at the LHC

Benchmark scenarios for the NMSSM

A. Djouadi[1,2,3], M. Drees[3], U. Ellwanger[1], R.Godbole[4], C. Hugonie[5], S.F. King[2], S. Lehti[6], S. Moretti[1,2], A. Nikitenko[7], I. Rottländer[3], M. Schumacher[8], A. M. Teixeira[1]

P5 cannot be a benchmark for
BR(H+ -> W+A1)~1x10^3 &
BR(H+ -> W+H1)~1x10^2

NMSSMTools from Ellwanger et all include constrained/universal NMSSM version with RGE evolution, in addition to test all exp. bounds and generating all EW level spectra of couplings and masses as well as all decay rates

Output can be fed into a public NMSSM CalcHEP/Pythia event generator via SLHA2

Proper simulations could be done right now !

Point	P1	P2	P3	P4	P5
GUT/input parameters					
sign($\mu_{\rm eff}$)	+	+	+	−	+
$\tan\beta$	10	10	10	2.6	6
m_0 (GeV)	174	174	174	775	1500
$M_{1/2}$ (GeV)	500	500	500	760	175
A_0	-1500	-1500	-1500	-2300	-2468
A_λ	-1500	-1500	-1500	-2300	-800
A_κ	-33.9	-33.4	-628.56	-1170	60
NUHM: M_{H_d} (GeV)	-	-	-	880	-311
NUHM: M_{H_u} (GeV)	-	-	-	2195	1910
Parameters at the SUSY scale					
λ (input parameter)	0.1	0.1	0.4	0.53	0.016
κ	0.11	0.11	0.31	0.12	-0.0029
A_λ (GeV)	-982	-982	-629	-510	45.8
A_κ (GeV)	-1.63	-1.14	-11.4	220	60.2
M_2 (GeV)	392	392	393	603	140
$\mu_{\rm eff}$ (GeV)	968	968	936	-193	303
CP even Higgs bosons					
$m_{h_1^0}$ (GeV)	120.2	120.2	89.9	32.3	90.7
R_1	1.00	1.00	0.998	0.034	-0.314
t_1	1.00	1.00	0.999	0.082	-0.305
b_1	1.018	1.018	0.975	-0.291	-0.644
BR($h_1^0 \to b\bar{b}$)	0.072	0.056	7×10^{-4}	0.918	0.895
BR($h_1^0 \to \tau^+\tau^-$)	0.008	0.006	7×10^{-5}	0.073	0.088
BR($h_1^0 \to a_1^0 a_1^0$)	0.897	0.921	0.999	0.0	0.0
$m_{h_2^0}$ (GeV)	998	998	964	123	118
R_2	-0.0018	-0.0018	0.005	0.999	0.927
t_2	-0.102	-0.102	-0.095	0.994	0.894
b_2	10.00	10.00	9.99	1.038	2.111
BR($h_2^0 \to b\bar{b}$)	0.31	0.31	0.14	0.081	0.87
BR($h_2^0 \to t\bar{t}$)	0.11	0.11	0.046	0.0	0.0
BR($h_2^0 \to a_1^0 Z^0$)	0.23	0.23	0.72	0.0	0.0
$m_{h_3^0}$ (GeV)	2142	2142	1434	547	174
CP odd Higgs bosons					
$m_{a_1^0}$ (GeV)	40.5	9.1	9.1	185	99.6
t'_1	0.0053	0.0053	0.0142	0.0513	-0.00438
b'_1	0.529	0.528	1.425	0.347	-0.158
BR($a_1^0 \to b\bar{b}$)	0.91	0.	0.	0.62	0.91
BR($a_1^0 \to \tau^+\tau^-$)	0.085	0.88	0.88	0.070	0.090
$m_{a_2^0}$ (GeV)	1003	1003	996	546	170
Charged Higgs boson					
$m_{h^\pm}$ (GeV)	1005	1005	987	541	188

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)

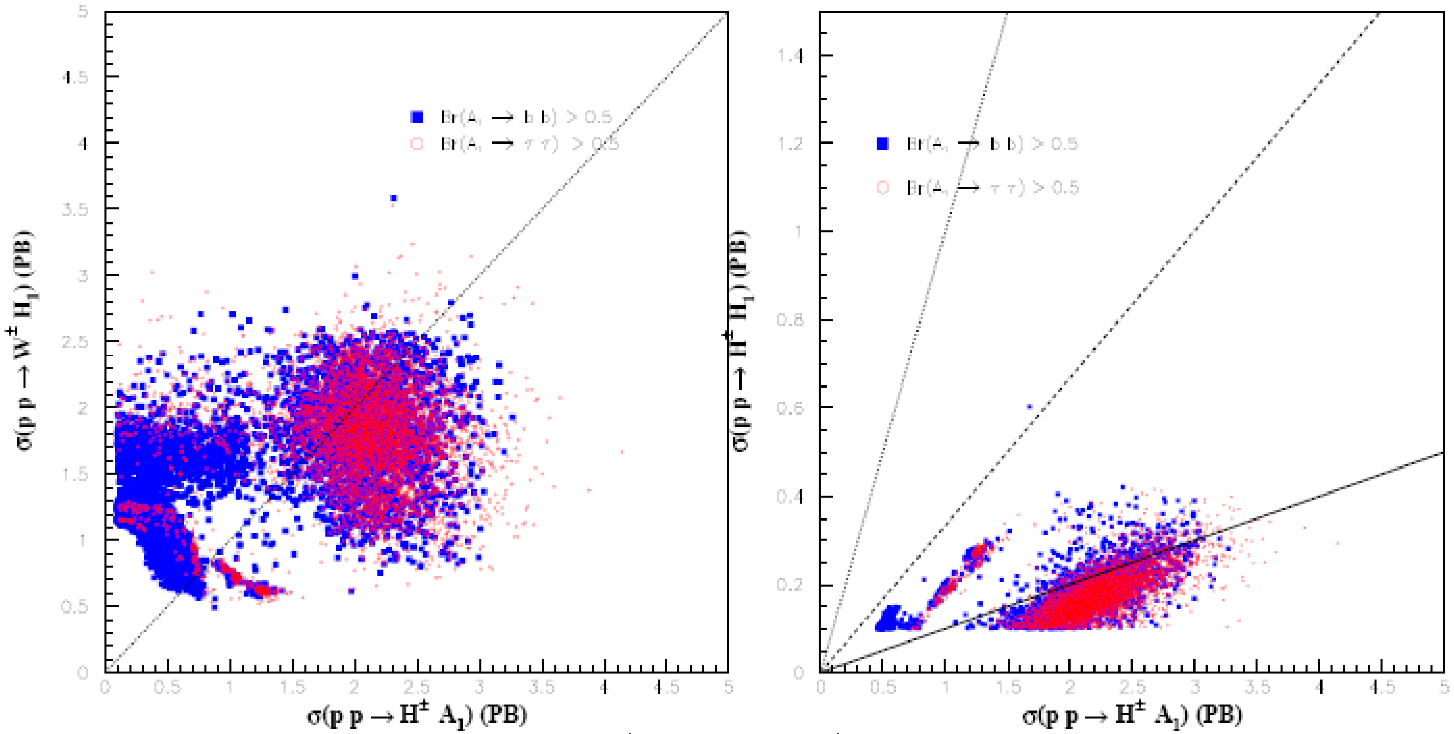
5) m+ > mt-mb, all other Higgses < mt

	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	160	-	-	-
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.)

Establish a benchmark from Abdesslam's scans ?

$\mathrm{Br}(H^\pm \to W^\pm A_1)$ and $\mathrm{Br}(h_1 \to A_1 A_1) \gtrsim 50\%$



It is possible to have $pp \to H^\pm A_1 \to W^\pm A_1 A_1 \to \{W4b, W4\tau\}$ and $pp \to W^\pm h_1 \to W^\pm A_1 A_1 \to \{W4b, W4\tau\}$ with sizeable cross sections.

MSSM+1CHT Higgs Sector

- For the MSSM we have at tree/level

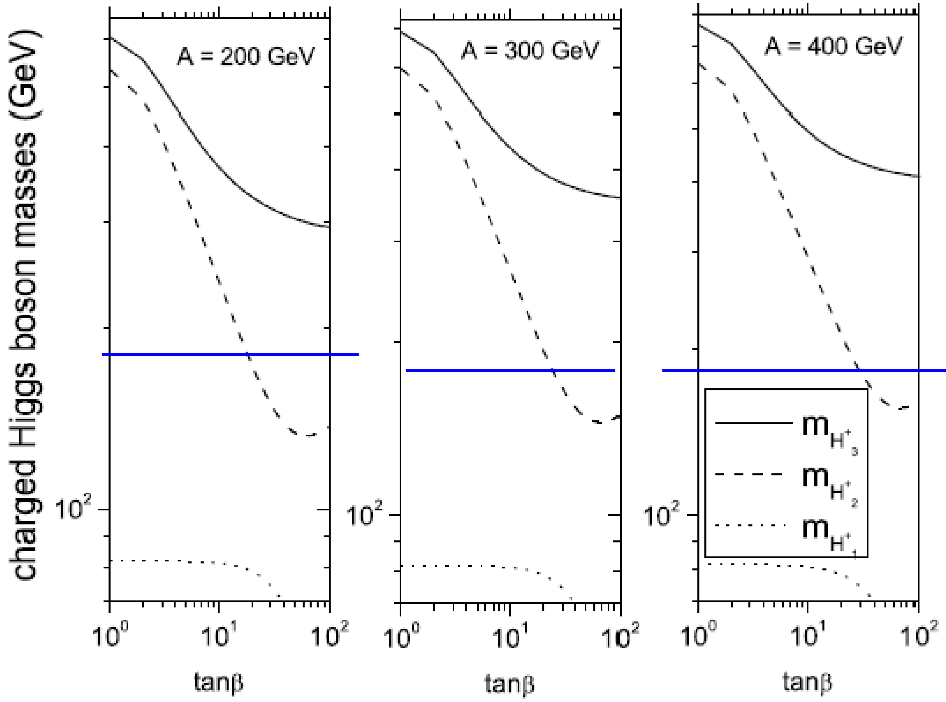
(4) $$m_{H^\pm}^2 = m_W^2 + m_W^2$$

- While in this model we have

(5) $$Trm_{H_i^\pm}^2 > m_W^2 + Trm_{A_k}^2$$

- Thus, we could have one charged Higgs lighter than the W boson.

Higgs content:
- 3 CP-even neutral Higgs states
- 2 CP-odd neutral Higgs states
- 6 C.C. charged Higgs states (3 masses)



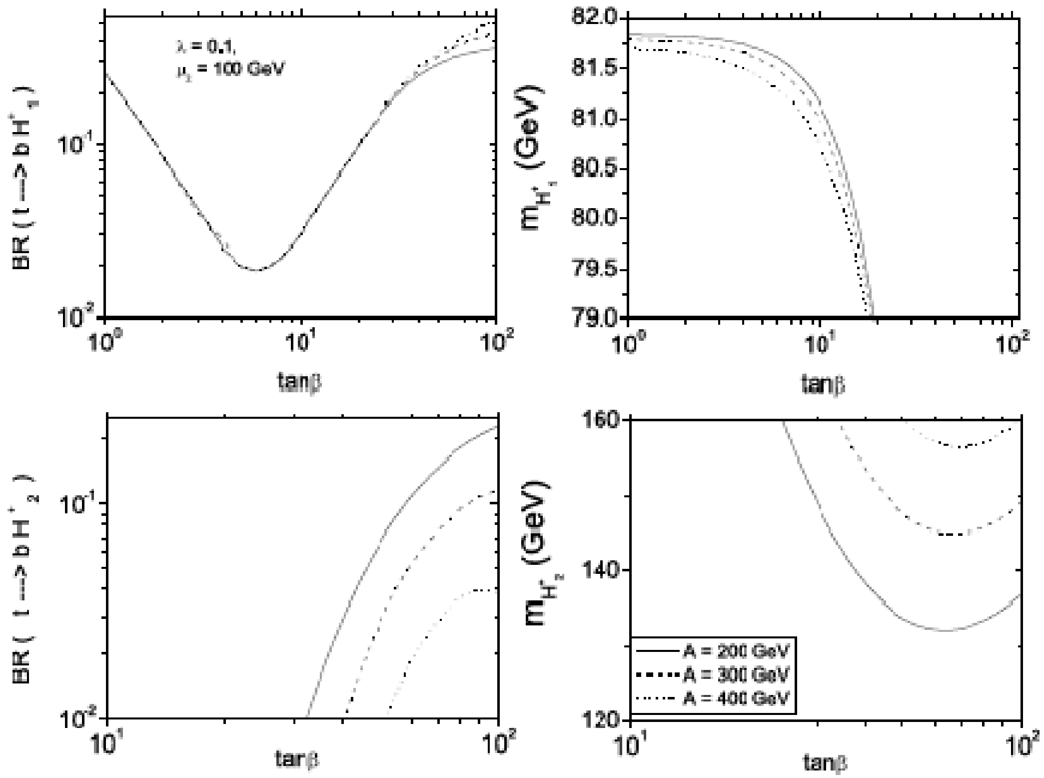
Diaz/Hernandez/Moretti/Rosado, 2007

Scenario A, λ=0.1

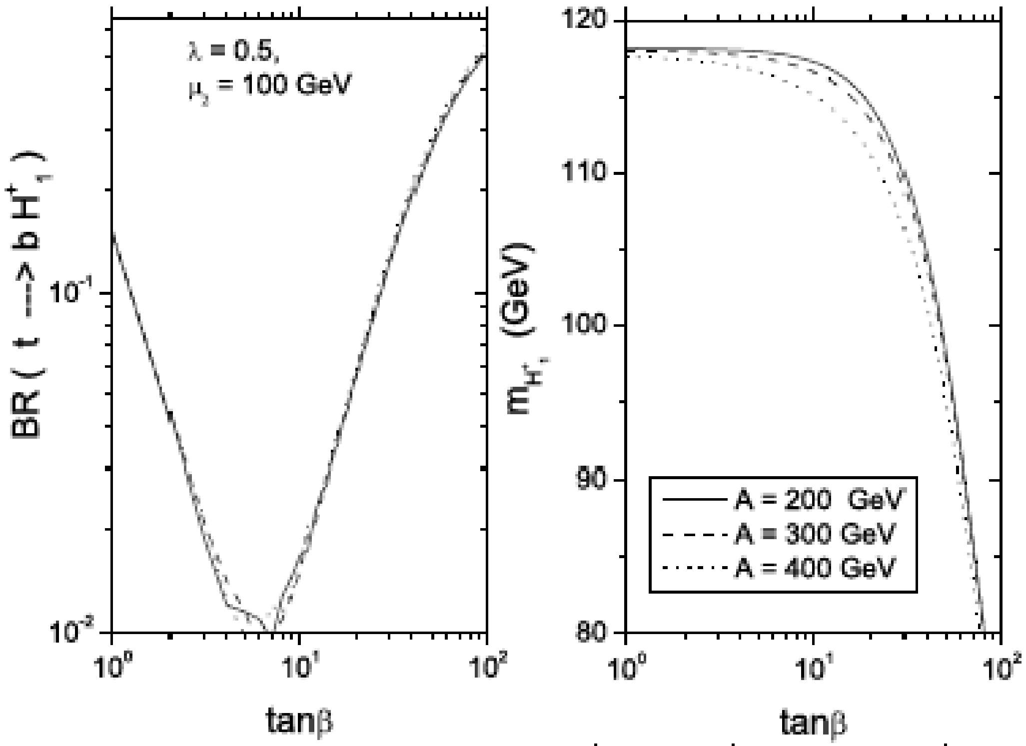
Two Higgs states below top mass

Possible benchmarks (Diaz-Cruz/Hernandez-Sachez/Moretti/Rosado, 2007)

B1. The point mu2=100 GeV, lambda=0.1, A=200 GeV for say tan(beta)=30 or 50 as represented in Fig. 1 (left panel). This is an interesting situation, in which one has both MH+/-(1) and both MH+/-(2) below mt, so that one could have two charged Higgs decays of a top quark that may be accessible (see Fig. below) at Tevatron and/or LHC.



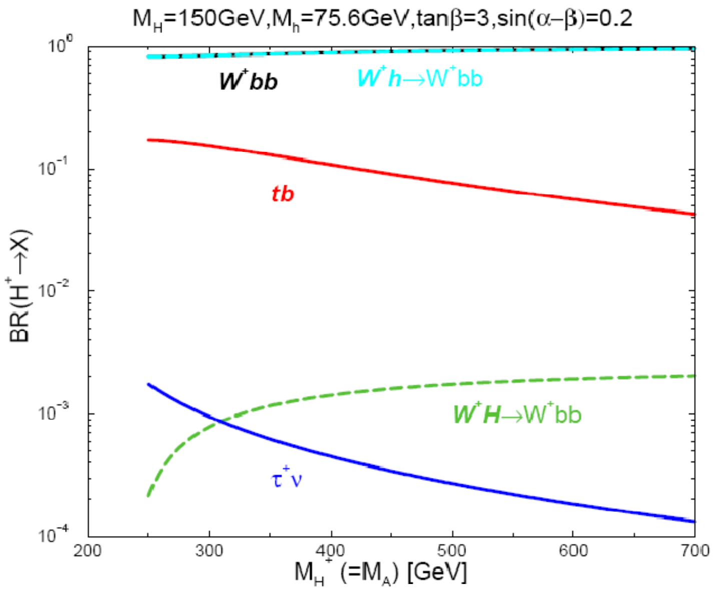
B2. The point mu2=100 GeV, lambda=0.5, A=200 GeV for say tan(beta)=50, see Fig. below. Here, there seems to be scope to access H+/-(1) in top decays as well as H+/-(2) in either tb or W+/-A0(1)/H0(1) or both, see row 3 of Tab. below, at least for the LHC.

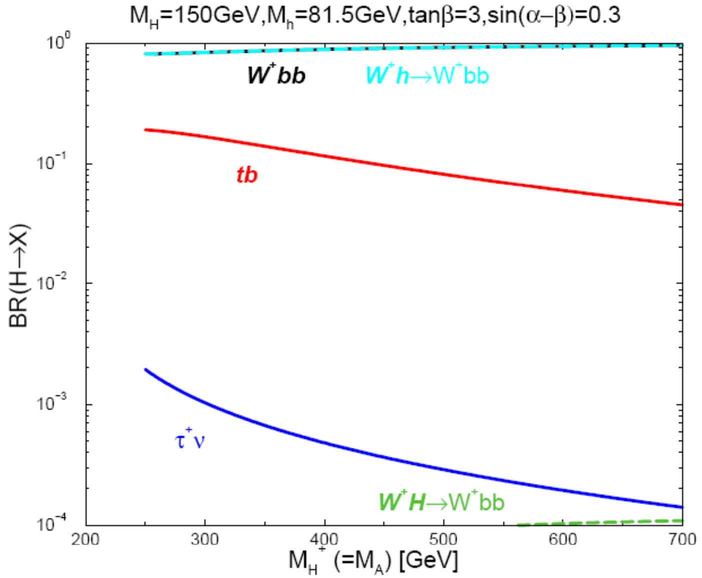


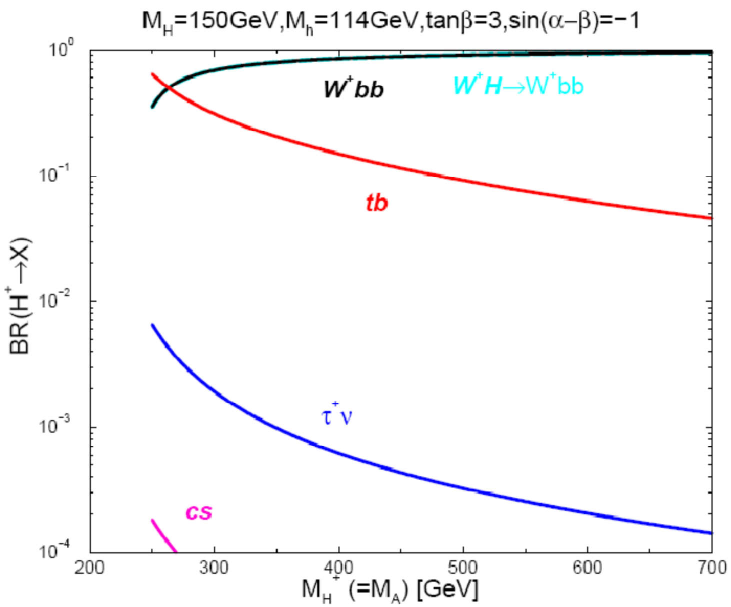
Assumes 100 inverse fb

λ	$(A, \tan\beta)$	$m_{H_i^+}$ in GeV	$\sigma(pp \to H_2^+ tb)$ in pb	Relevant BR's	Nr. Events
0.5	(200,50)	(98,290,370)	8.7×10^{-1}	$\mathrm{BR}(H_2^+ \to \tau^+\nu_\tau) \approx 8.2 \times 10^{-2}$	7134
				$\mathrm{BR}(H_2^+ \to tb) \approx 8.4 \times 10^{-1}$	73080
				$\mathrm{BR}(H_2^+ \to W^+A_1^0) \approx 2.4 \times 10^{-2}$	2088
				$\mathrm{BR}(H_2^+ \to W^+H_1^0) \approx 4.8 \times 10^{-2}$	4176

Possible 2HDM II Benchmarks for H+/- (I): H+ -> W+ bb







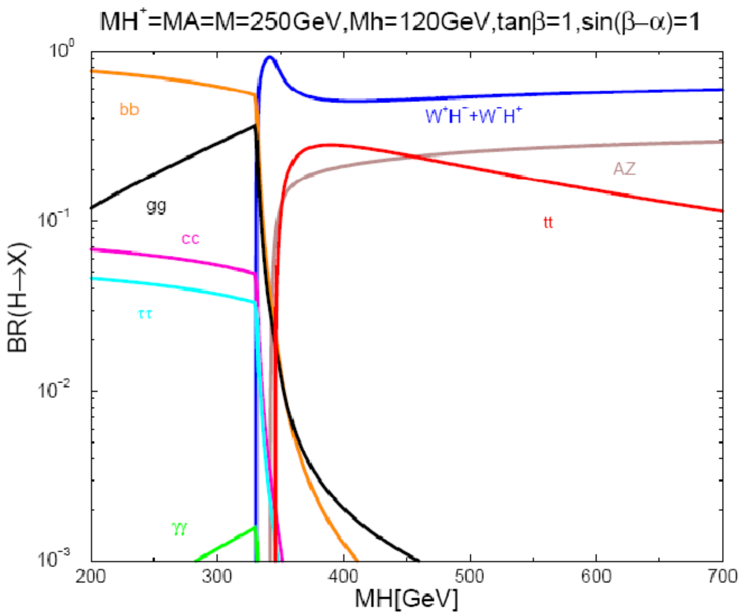
Branching of Wbb with A mediation is smaller than 10^-4 as mH+=mA is kept to avoid the ρ parameter constraints.

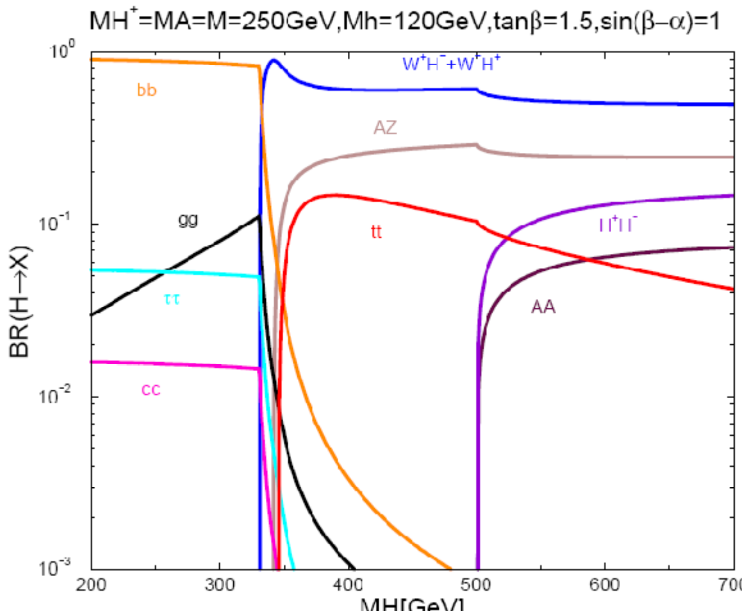
LEP search limits enforced, B-> sγ compliant & Unitarity respected.

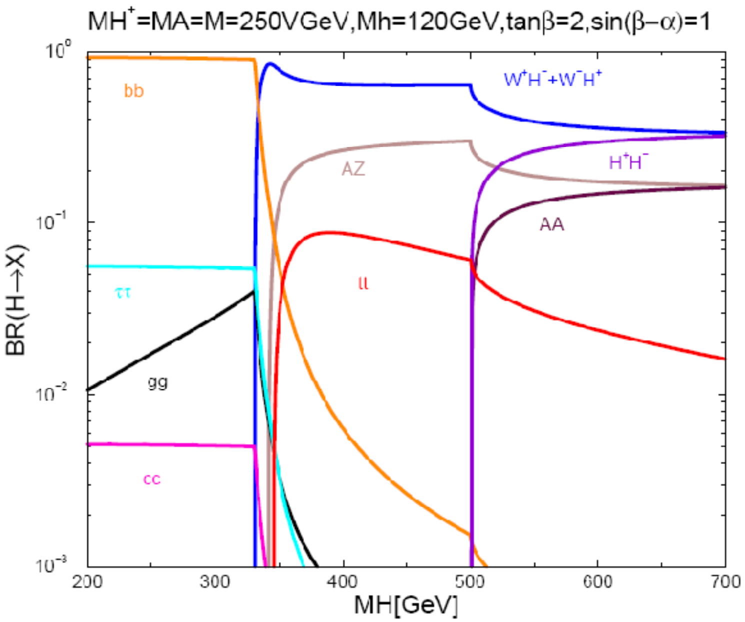
Kanemura/Moretti/Mukai/Santos/Yagyu, preliminary (also following figures).

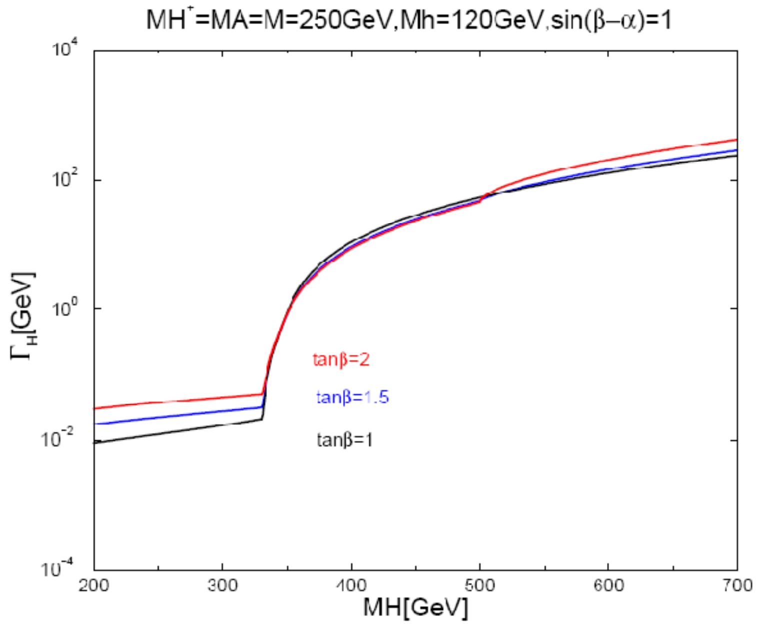
CPV in progress (with P. Osland)

Possible 2HDM II Benchmarks for H+/- (II): H -> H+H- & W+H-

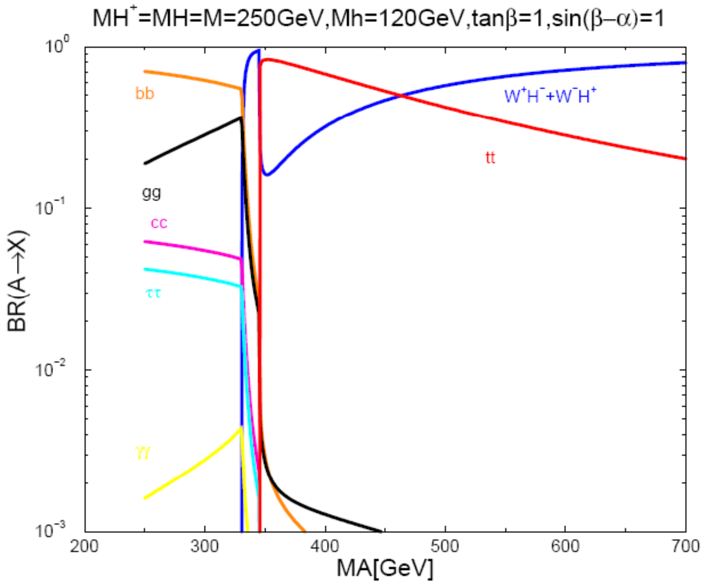


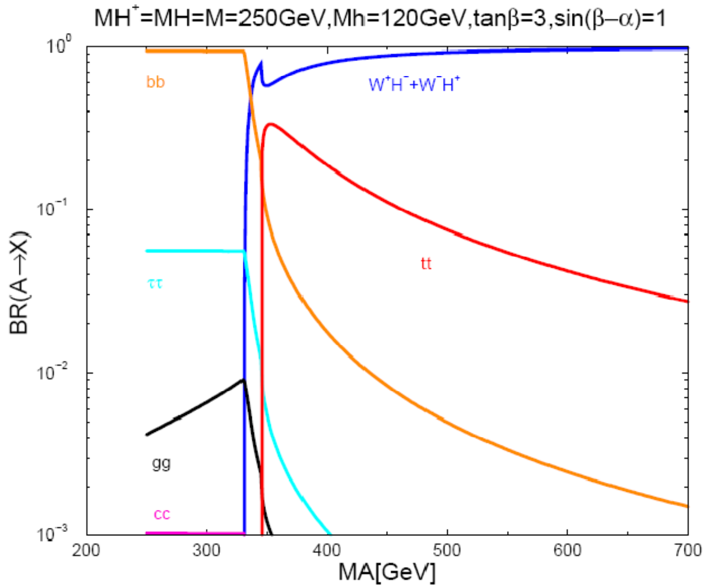


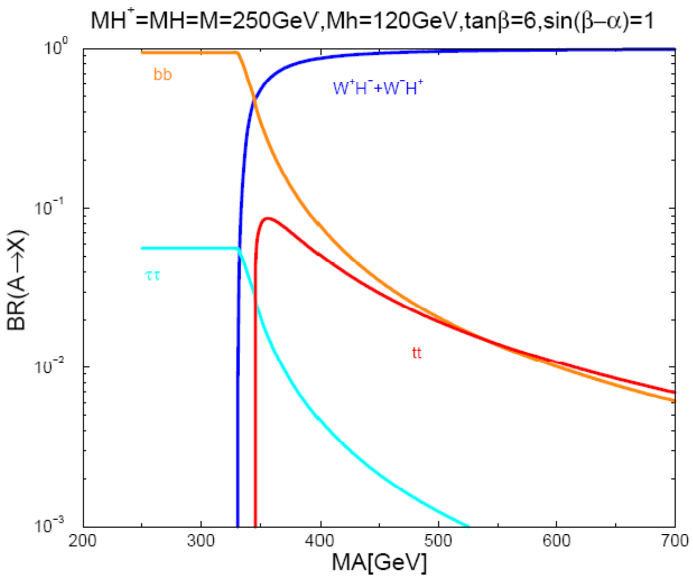


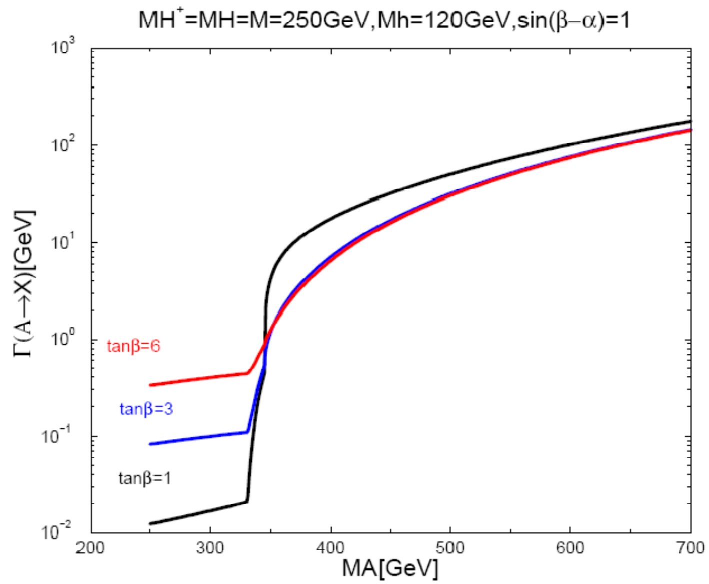


Possible 2HDM II Benchmarks for H+/- (III): A -> W+H-



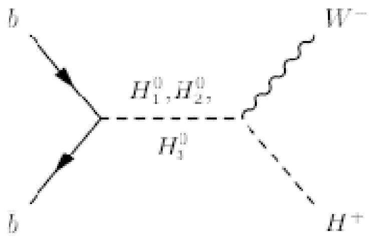


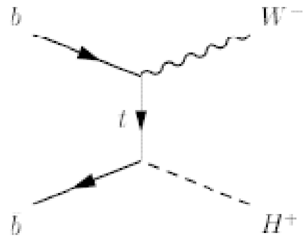


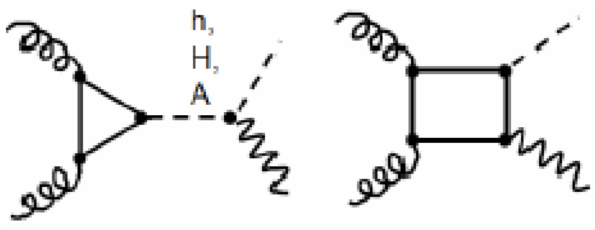


$H^{\pm}W^{\mp}$ production at LHC

- At hadron colliders: $b\bar{b} \to H^{\pm}W^{\mp}$ and $gg \to H^{\pm}W^{\mp}$
- Here: focus on $m_{H^{\pm}} \sim m_t$ and large tan β with large $BR(H^{\pm} \to \tau\nu)$
  $\to$ $b\bar{b} \to H^{\pm}W^{\mp}$ dominates:







- Neutral Higgs bosons in s-channel
  - CP-conserving MSSM (real parameter): $\{H_1^0, H_2^0, H_3^0\} = \{h, H, A\}$
  - CP-violating MSSM (complex parameters):
    mass eigenstates $\{H_1^0, H_2^0, H_3^0\}$ ≠ CP eigenstates

Poor scope in the MSSM !!! How about 2HDM type II ?

1. Can enhance Higgs-Higgs-W coupling
2. Can choose Higgs masses in s-channel propagators suitably to remove MSSM cancellations

General question, how to distinguish/rule out different 2HDMs ?

Higgs Triplet Model

no ν_R

"Yukawa" int. with a complex Higgs triplet

H^{++} : doubly charged Higgs

$$h_{\alpha\beta}\left(-\overline{(l_{\alpha L})^C}, \overline{(\nu_{\alpha L})^C}\right)\underbrace{\begin{pmatrix} \Delta^-/\sqrt{2} & \Delta^{--} \\ \Delta^0 & -\Delta^-/\sqrt{2}\end{pmatrix}}\begin{pmatrix}\nu_{\beta L} \\ l_{\beta L}\end{pmatrix} + \text{h.c.}$$

$\Delta : SU(2)_L$ triplet, $Y=2$, $L=-2$

Higgs potential

$\Phi \equiv (\phi^+, \phi^0)^T : SU(2)_L$ doublet, $Y=1$, $L=0$

$M^2 > 0$ (no Majoron)

$$V = -m^2(\Phi^\dagger\Phi) + \lambda_1(\Phi^\dagger\Phi)^2 + M^2\mathrm{Tr}(\Delta^\dagger\Delta) + \lambda_2[\mathrm{Tr}(\Delta^\dagger\Delta)]^2 + \lambda_3\mathrm{Det}(\Delta^\dagger\Delta)$$
$$+ \lambda_4(\Phi^\dagger\Phi)\mathrm{Tr}(\Delta^\dagger\Delta) + \lambda_5(\Phi^\dagger\tau_i\Phi)\mathrm{Tr}(\Delta^\dagger\tau_i\Delta) + \left(\frac{1}{\sqrt{2}}\mu(\Phi^T i\tau_2\Delta^\dagger\Phi) + \text{h.c}\right)$$

$v \equiv \sqrt{2}\langle\phi^0\rangle$: spontaneous breaking of $SU(2)_L$

$v_\Delta \equiv \sqrt{2}\langle\Delta^0\rangle \simeq \frac{\mu v^2}{2M^2}$: explicit breaking of L

$1\,\text{eV}(\text{LFV decay}, m_\nu) \lesssim v_\Delta \lesssim 10\,\text{GeV}(\rho\text{-param.})$

Majorana ν_L mass

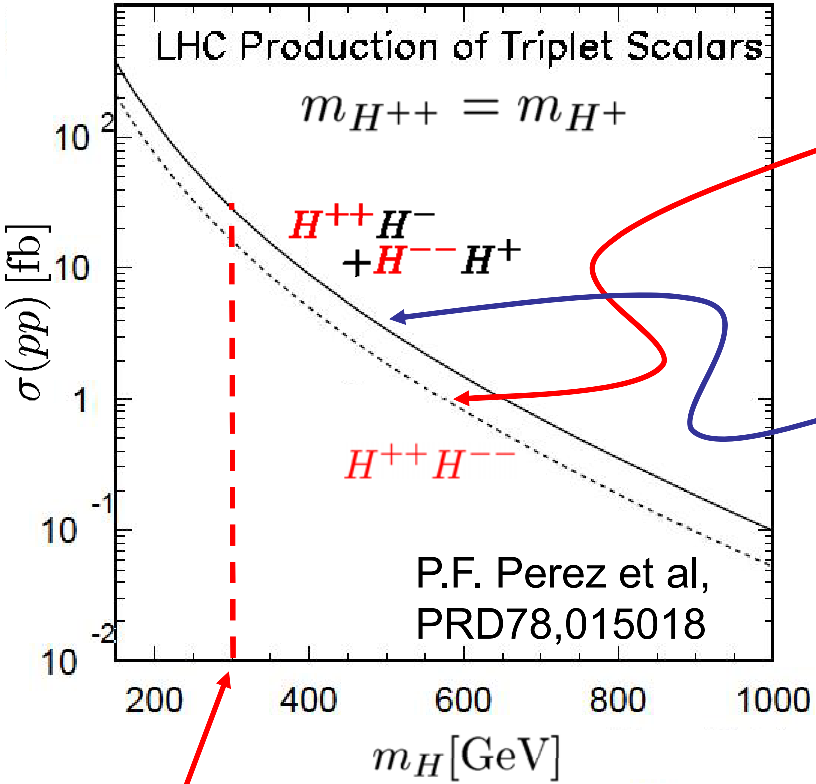
$$m^{(\nu)}_{\alpha\beta} = \sqrt{2}\, v_\Delta\, h_{\alpha\beta}$$

ν exp. $\leftrightarrow$ LFV decay

$H^{\pm\pm}$ Production

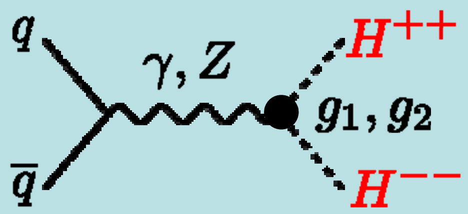
$$\underbrace{H^{\pm\pm} = \Delta^{\pm\pm},\quad H^{\pm} \simeq \Delta^{\pm},\quad H^0 \simeq \mathrm{Re}(\Delta^0),\quad A^0 \simeq \mathrm{Im}(\Delta^0),}_{\text{mass splittings} \lesssim 100\text{GeV } (\rho\text{-param.})}\quad h^0 \simeq \mathrm{Re}(\phi^0)$$

Production at hadron collider :

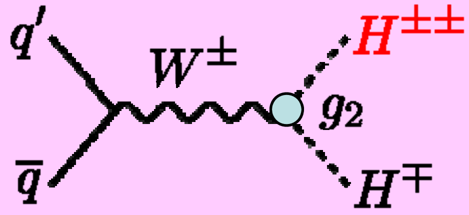


$m_{H^{\pm\pm}} = 300\text{GeV}$

$\Rightarrow \quad \sigma(pp) \simeq 20\text{ - }30\text{fb}$



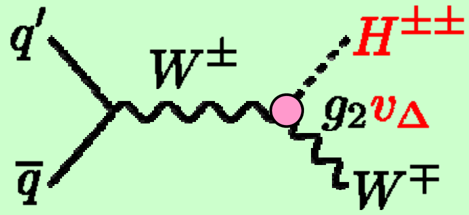
conventional mode



$SU(2)_L$-charged $H^{\pm\pm}$

(c.f. $SU(2)_L$ singlet with $Y = 4$)

stressed in A.G. Akeroyd, M. Aoki, PRD72,035011



suppressed by v_Δ

Benchmark Points

$$\begin{cases} m_{H^{\pm\pm}} = m_{H^{\pm}} = 300\,\mathrm{GeV}\ (600\,\mathrm{GeV}) \\ v_\Delta \simeq 1\mathrm{KeV} \end{cases}$$

$$\Rightarrow \begin{cases} \sigma(pp \to H^{++}H^{--}) \simeq 20\,\mathrm{fb}\ (1\,\mathrm{fb}) \\ \sigma(pp \to H^{++}H^{-}) + \sigma(pp \to H^{--}H^{+}) \simeq 30\,\mathrm{fb}\ (2\,\mathrm{fb}) \\ \mathrm{BR}(H^{\pm\pm} \to l^{\pm}l^{\pm}) = 100\% \end{cases}$$

CPV

$$\sin^2 2\theta_{23} = 1,\ \sin^2 2\theta_{13} = 0,\ \varphi_1 = \frac{\pi}{2},\ \varphi_2 = 0$$

ν mass spectrum	$\mathrm{BR}(H^{\pm\pm} \to l^{\pm}_{\alpha} l^{\pm}_{\beta})$ (ee, $\mu\mu$, $\tau\tau$, $e\mu$, $e\tau$, $\mu\tau$)
$m_3 \gg m_2 > m_1 = 0$	(0.3%, 25%, 25%, 0.7%, 0.7%, 49%)
$m_2 > m_1 > m_3 = 0$	(28%, 7%, 7%, 22%, 22%, 14%)
$m_2 \simeq m_1 \simeq m_3$	(19%, 19%, 19%, 14%, 14%, 16%)

"large" mass ($\simeq$ 0.1eV)

largest, next to largest

Rationale for the benchmarks (from A Akeroyd)

Main aim is to show that all six leptonic decays of H++ should be given equal importance, since there are scenarios in the model where each of the six can be the dominant one, and even scenarios where all six are roughly equal in magnitude.

BRs are mainly determined by three unknown parameters (two Majorana phases and one neutrino mass).

We do not have any real theoretical motivation when choosing specific values of these parameters, although choosing non-zero Majorana phases has motivation from maybe leptogenesis. However, I think that this simple model has to be extended in order to accommodate realistic leptogenesis.

Full detector simulations have not been carried out for pp to W to H++H-. (Even for pair production, pp to H++H--, only a few full detector simulations have been carried out). The simulations in Han arXiv:0805.3536 and Del Aguila 0808.2468 or pp to H++H- (which are currently the only ones for this mechanism) are not full detector simulations.

As for event generators, the Del Aguila paper on page 13 talks about the new event generator "triada" which contains all these production processes and H++ to ll decay. As for us, our plans were to do a CALCHEP triplet model file which can be used as input for PYTHIA.This project will take some time and I don`t think we will have anything complete in the near future. Del Aguila et al seem to be at a much more advanced stage concerning the implementation of the Higgs Triplet model in generators.