Constraints and prospects for charged Higgs bosons

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work done in collaboration with D. Eriksson and F. Mahmoudi
arXiv:0808.3551 [hep-ph]

The MSSM Higgs sector

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- MSSM Higgs sector special case of 2HDM (II) → No tree-level FCNC
  Two complex SU(2) doublets H_1, H_2

$$V(H_1, H_2) = \left(m_{H_1}^2 + |\mu|^2\right)|H_1|^2 + \left(m_{H_2}^2 + |\mu|^2\right)|H_2|^2 - B\mu\left(\epsilon_{ij} H_1^i H_2^j + \text{h.c.}\right) + \frac{1}{2}g^2\left|H_1^{i*} H_2^i\right|^2 + \frac{1}{8}\left(g^2 + g'^2\right)\left(|H_1|^2 - |H_2|^2\right)^2$$

- EWSB → Five physical Higgs states: h, H, A, H^+, H^-

- Potential fixed from SUSY in terms of Gauge couplings => Only two free parameters in the Higgs sector at tree-level, usually

$$\tan\beta = \frac{v_2}{v_1} \qquad m_A$$

- Tree-level mass relations for the other Higgs masses, for example

$$m_{H^+}^2 = m_A^2 + m_W^2$$

- Yukawa sector potentially richer than in the SM. This is where most constraints on MSSM Higgs sector come from. Charged Higgs H^+, H^- known to give strict constraints on MSSM parameters.

Constrained MSSM models

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- The full MSSM has 124 parameters → Can study only limited models
  Universality assumptions
  Minimal flavor violation (MFV)

- Constrained MSSM (CMSSM, “mSUGRA”) and models with Non-Universal Higgs Masses (NUHM) assume SUSY breaking mediated by gravity.

- CMSSM: unified boundary conditions at high “GUT” scale:

Universal scalar (incl. Higgs) masses:	m_0
Universal gaugino masses:	$m_{1/2}$
Universal trilinear couplings:	A_0
Sign of Higgsino mass parameter:	$\mathrm{sign}(\mu)$

- In the NUHM model the universality of scalar masses are relaxed for the Higgs doublets. → Two new mass parameters

- These GUT-scale parameters can be traded for the two parameters m_A and μ at the EW scale

Parameter Scan

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- To identify the allowed regions for the charged Higgs we scan over the NUHM parameter space.
- Theoretical constraints, such as radiative breaking of the EW symmetry, restricts the useful ranges for the input parameters
- Physical mass spectrum at EW scale through RGE running (SOFTSUSY)
  → All masses and couplings determined by the six input parameters

Parameter	min	max
m_0	50	2000
$m_{1/2}$	50	2000
A_0	-2000	2000
μ	-2000	2000
m_A	5	600
$\tan\beta$	1	60

Constraints

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- With R-parity conservation, all effects of SUSY on low-energy observables occur through loops

- Several types of observables constraining the parameters for charged Higgs bosons can be identified:

  Direct search limits

  Flavor data constraints

  Anomalous magnetic moment of muon
  Restricts $\mu > 0$

  Cosmological constraints on dark matter
  No exclusion power specifically for H^+

SuperIso

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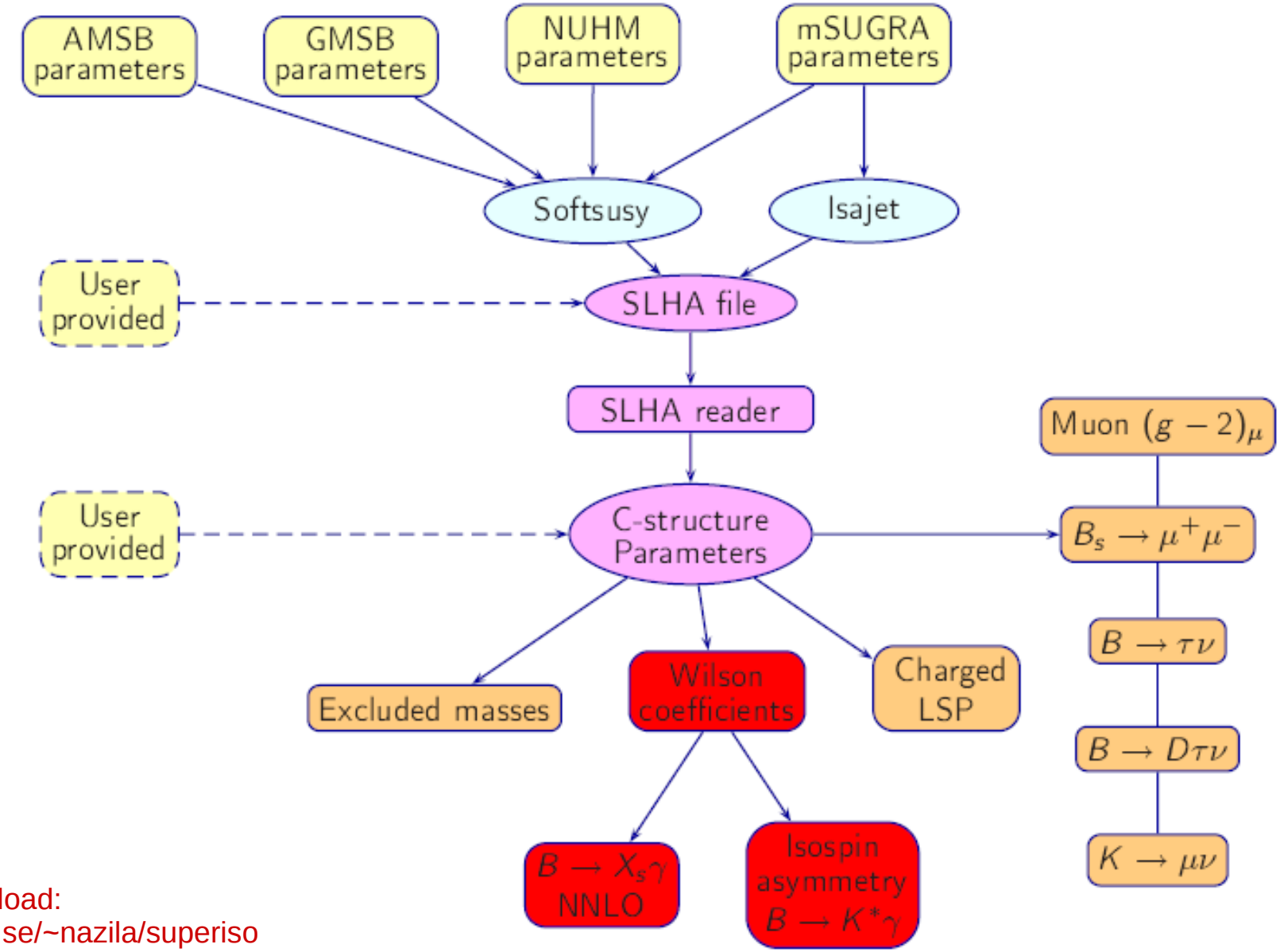

Code download:
www.isv.uu.se/~nazila/superiso

Old manual: Comput. Phys. Commun. 178 (2008) 745
New manual: arXiv:0808.3144

Constraints from direct searches

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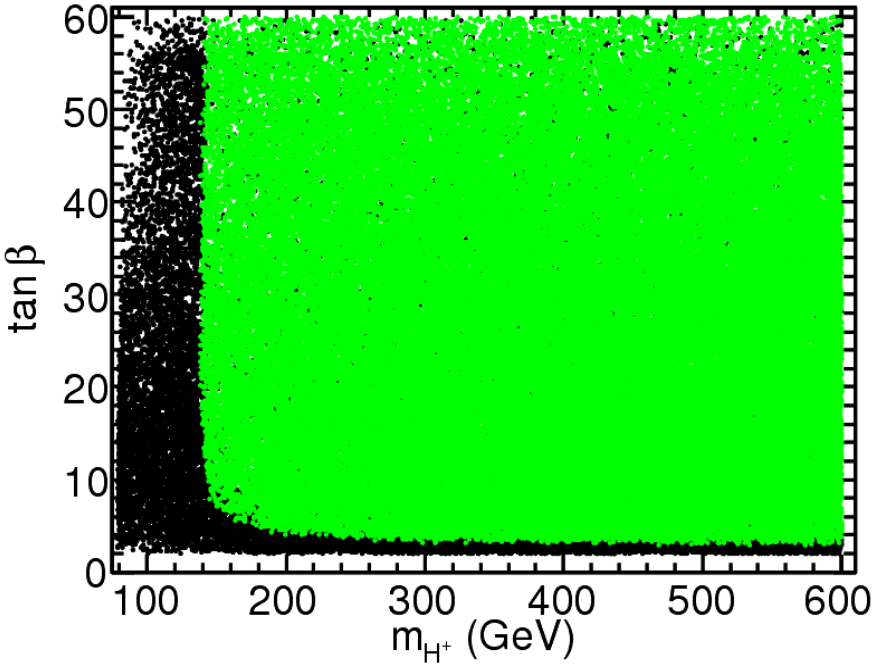
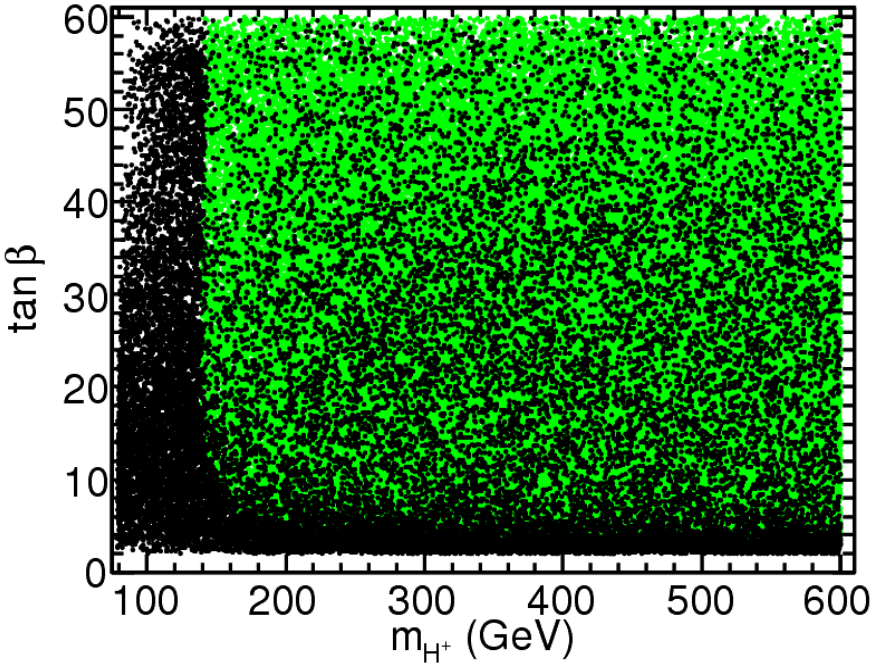
- Constraints at 95% C.L. from LEP searches for Higgs bosons and sparticles

Particle	H^+	h	χ_1^0	χ_1^+	$\tilde{e}_R$	$\tilde{\mu}_R$	$\tilde{\tau}_1$	$\tilde{\nu}$	$\tilde{b}_1$	$\tilde{t}_1$	$\tilde{g}$
Mass limit (GeV)	79.3	111	46	94	73	94	81.9	94	89	95.7	308

[PDG2008]

- Lightest Higgs mass limit gives sharp edge
  ~ $m_{H+} > 135$ GeV for $m_h > 111$ GeV SM-like light Higgs
  ~ $m_{H+} > 123$ GeV for $m_h > 93$ GeV m_h-max





$b \to s\gamma$

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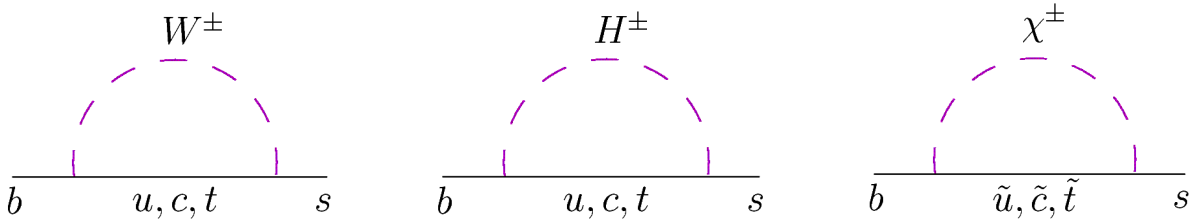
- Rare transition mediated by W loop in SM

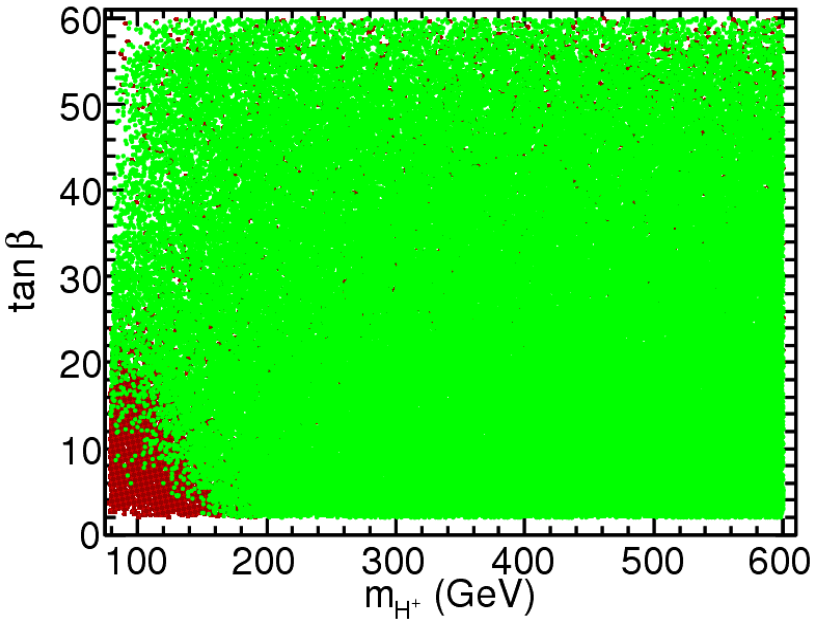


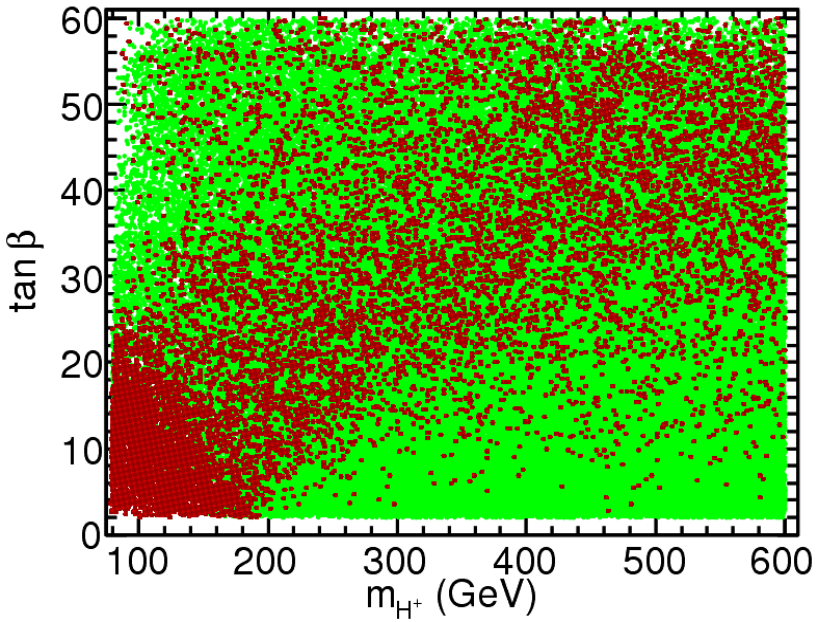
- MSSM contributions mainly from H^+ (constructive) and χ^+ (const. or dest.)

$$\mathrm{BR}(\bar{\mathrm{B}} \to \mathrm{X_s}\gamma)_{\mathrm{exp}} = (3.52 \pm 0.23 \pm 0.09) \times 10^{-4}$$ [HFAG]

$$\mathrm{BR}(\bar{\mathrm{B}} \to \mathrm{X_s}\gamma)^{\mathrm{NNLO}}_{\mathrm{SM}} = (3.15 \pm 0.23) \times 10^{-4}$$ [Misiak & Steihauser 07]

$$2.15 \times 10^{-4} \leq \mathrm{BR}(\bar{\mathrm{B}} \to \mathrm{X_s}\gamma) \leq 4.89 \times 10^{-4}$$ 95% CL





$B \to \tau \nu_\tau$

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- Tree-level decay, helicity suppressed in SM. Also H^+ at tree-level.
- SUSY effects enter through tan β-enhanced SUSY-QCD corrections ε_0.

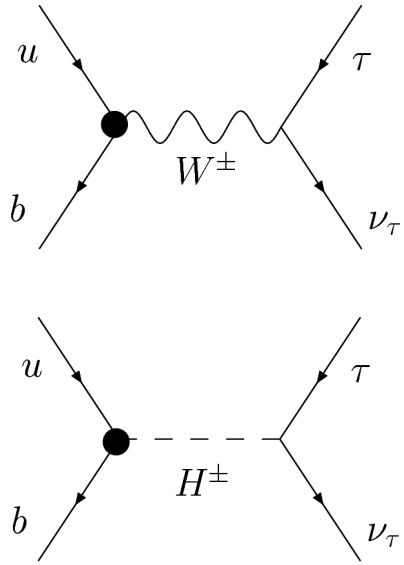
$$\mathrm{BR}_{\mathrm{MSSM}} = \frac{G_F^2 f_B^2 |V_{ub}|^2}{8\pi\Gamma_B} m_B m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 \left[1 - \left(\frac{m_B^2}{m_{H^+}^2}\right) \frac{\tan^2\beta}{1 + \epsilon_0 \tan\beta}\right]^2$$

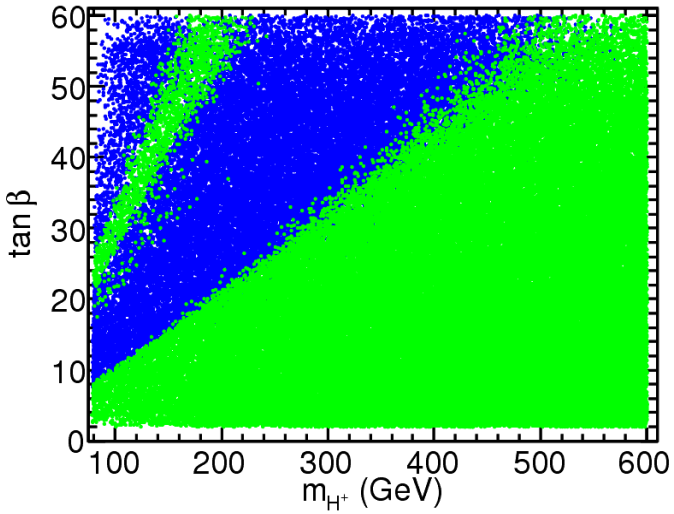
- Large parametric uncertainties from V_{ub}

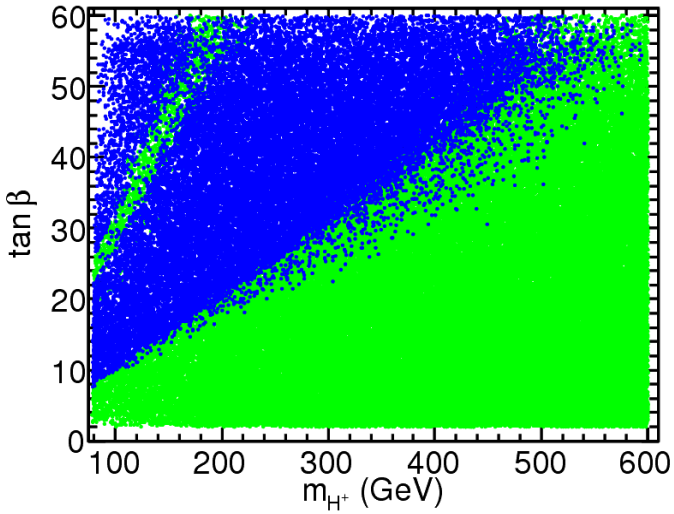
$$R_{\tau\nu_\tau}^{\mathrm{exp}} \equiv \frac{\mathrm{BR}(B_u \to \tau\nu_\tau)_{\mathrm{exp}}}{\mathrm{BR}(B_u \to \tau\nu_\tau)_{\mathrm{SM}}} = 1.28 \pm 0.38 \quad \text{[HFAG]}$$

$$0.53 < R_{\tau\nu_\tau}^{\mathrm{MSSM}} < 2.03$$

- Similar constraints, but weaker, from $\mathbf{B} \to \mathbf{D}\,\tau\,\nu_\tau$, $\mathbf{K} \to \mu\,\nu_\mu$







- Strong exclusion, but shifted if changing V_{ub}

$$|V_{ub}^{\mathrm{comb}}| = (3.95 \pm 0.35) \times 10^{-3}$$

[PDG2008]

Combined constraints in NUHM models

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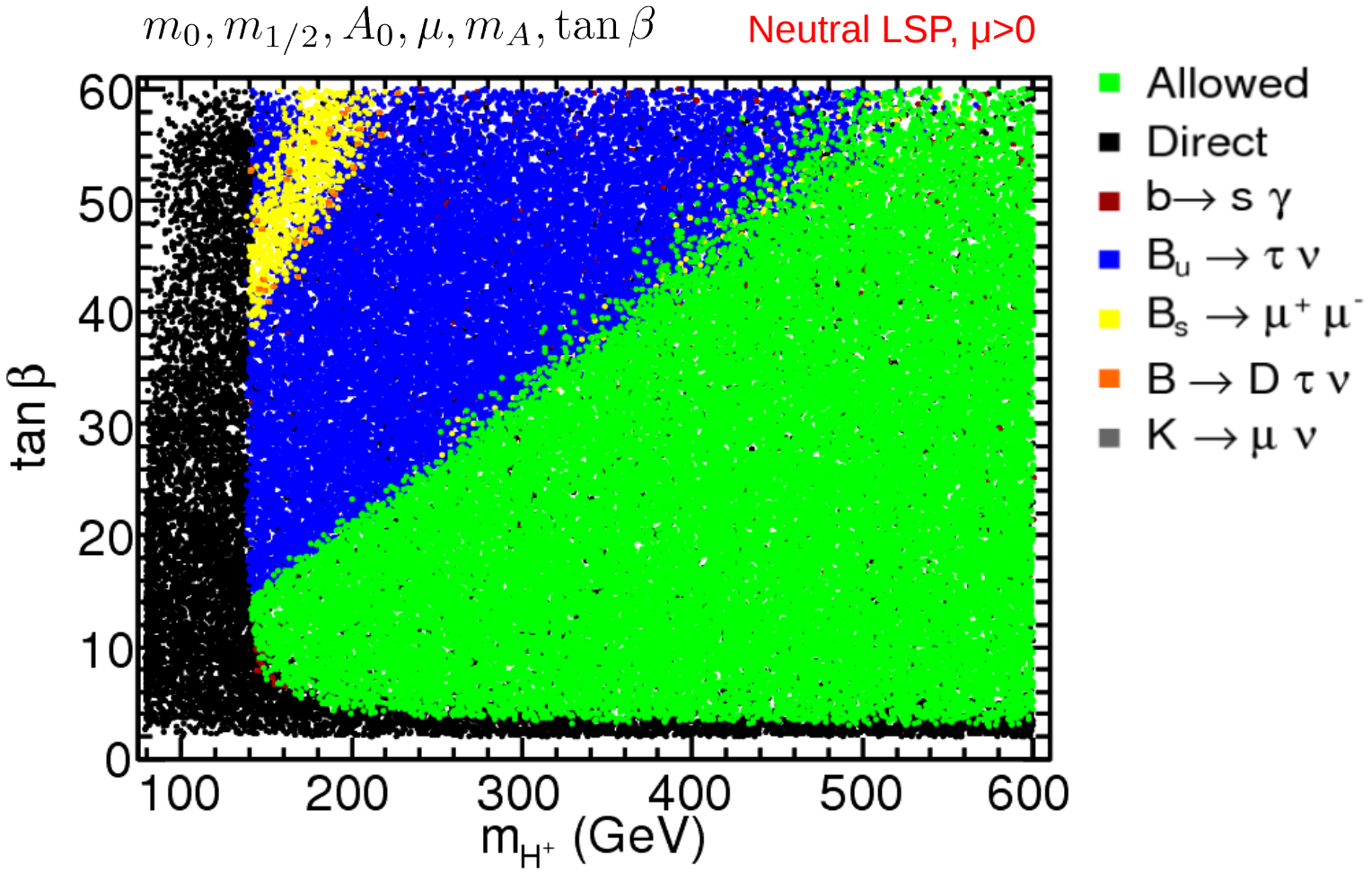
- Large exclusion by flavor constraints.
  Low charged Higgs mass allowed only for intermediate tan β.

$$m_{H^+} \gtrsim 135 \ \text{GeV}$$



LHC discovery prospects

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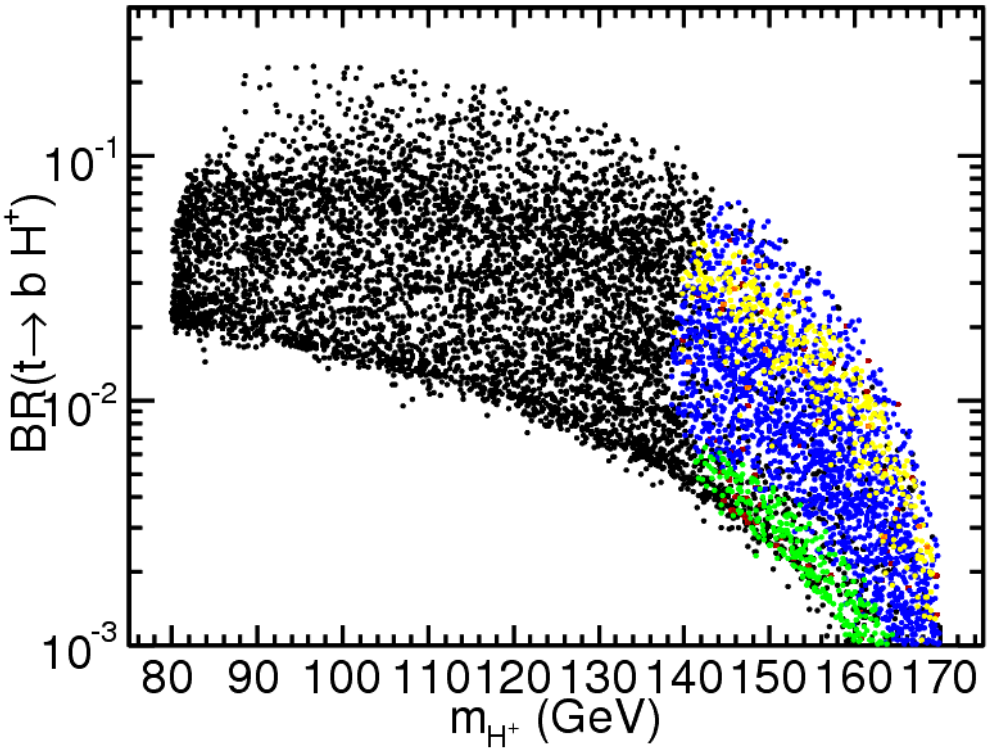
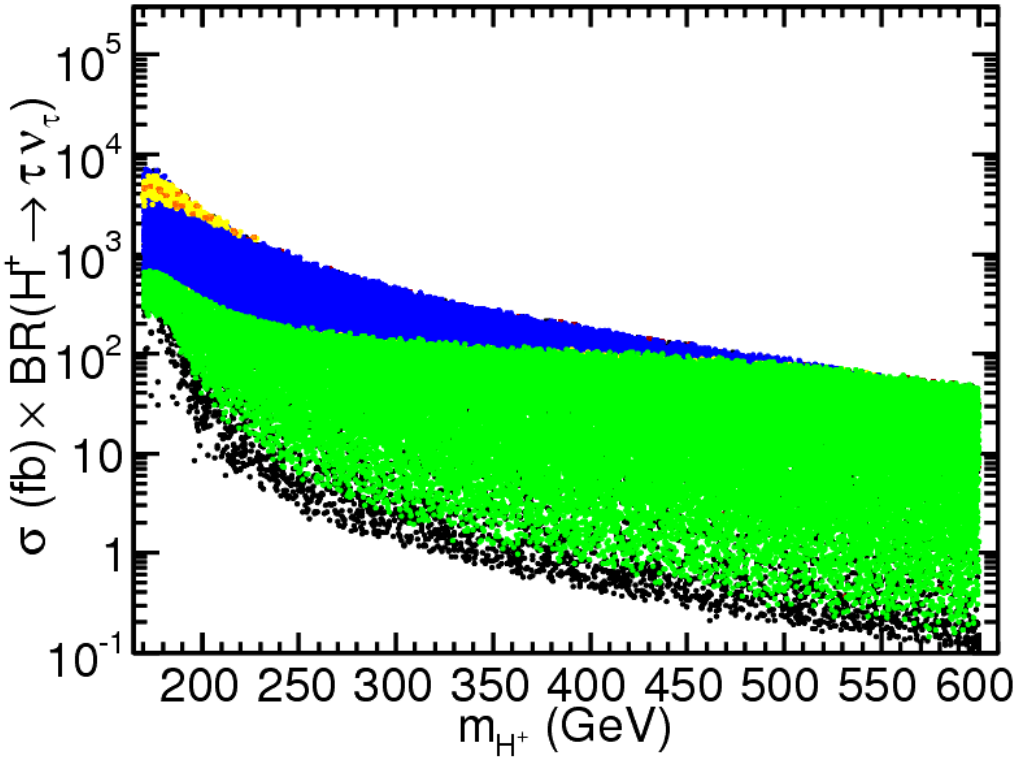
- Main discovery channel is $H^+ \rightarrow \tau^+ \nu_\tau$, both for light and heavy H⁺
- Determine cross section (BR) for each point in NUHM scan
  Parametrization of NLO cross section + HDECAY (FeynHiggs)
  tan β-enhanced corrections to m_b included consistently
- Points which have highest cross-section (BR) are also those for which the indirect constraints are most efficient

Neutral LSP, μ>0

- Allowed
- Direct
- b→ s γ
- $B_u \rightarrow \tau \nu$
- $B_s \rightarrow \mu^+ \mu^-$
- $B \rightarrow D \tau \nu$
- $K \rightarrow \mu \nu$





Comparison to experimental reach

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- Tevatron results with 1 fb^{-1} from this summer starting to probe interesting NUHM region

DØ Note 5715-CONF

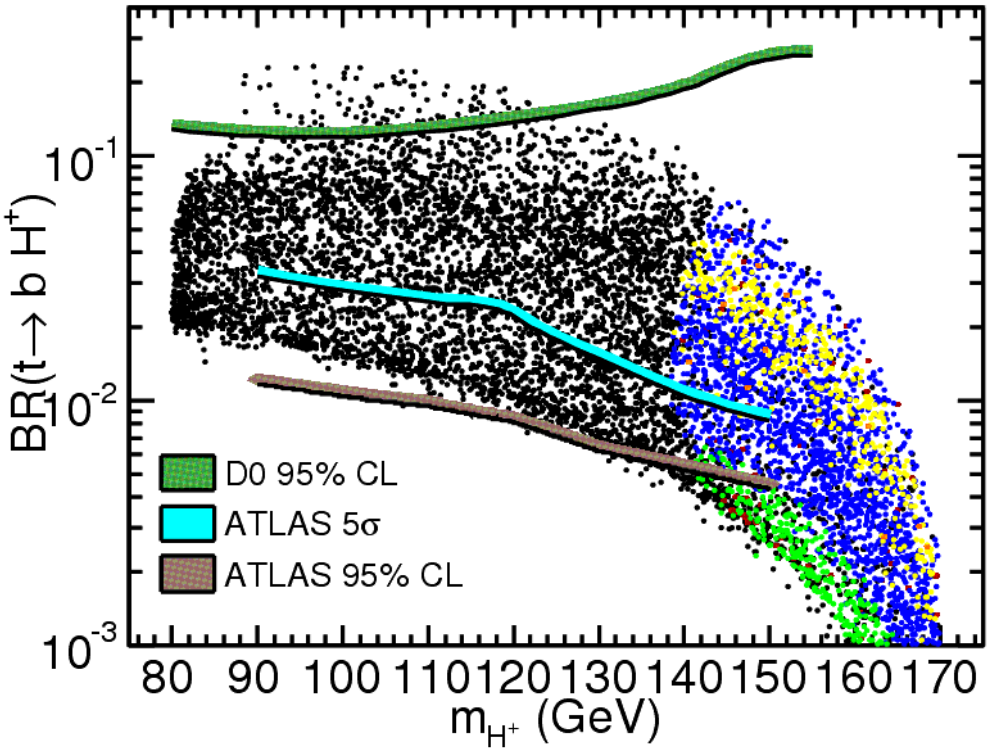
- Reach for CMS and ATLAS with 30 fb^{-1}

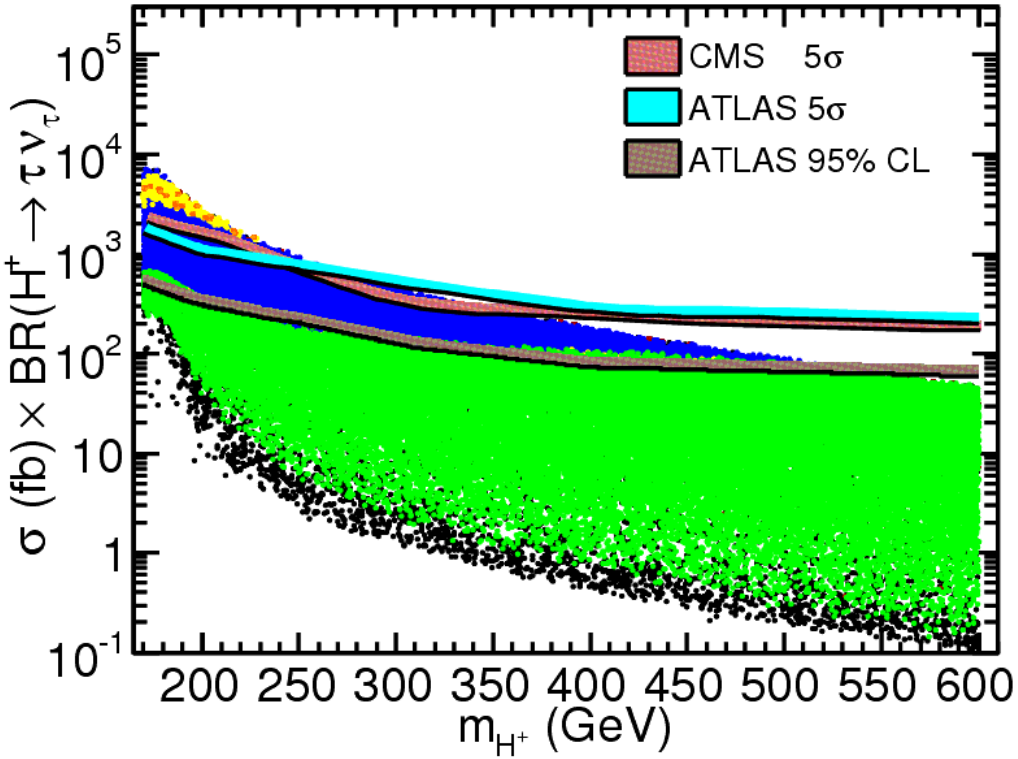
CMS-NOTE-2006-100, 2006-056
CERN-OPEN-2008-020

- LHC experiments will probe most of the NUHM parameter space for low m_{H^+}.

Neutral LSP, μ>0

- Allowed
- Direct
- $b \to s\,\gamma$
- $B_u \to \tau\,\nu$
- $B_s \to \mu^+\,\mu^-$
- $B \to D\,\tau\,\nu$
- $K \to \mu\,\nu$





Model-dependent comparison

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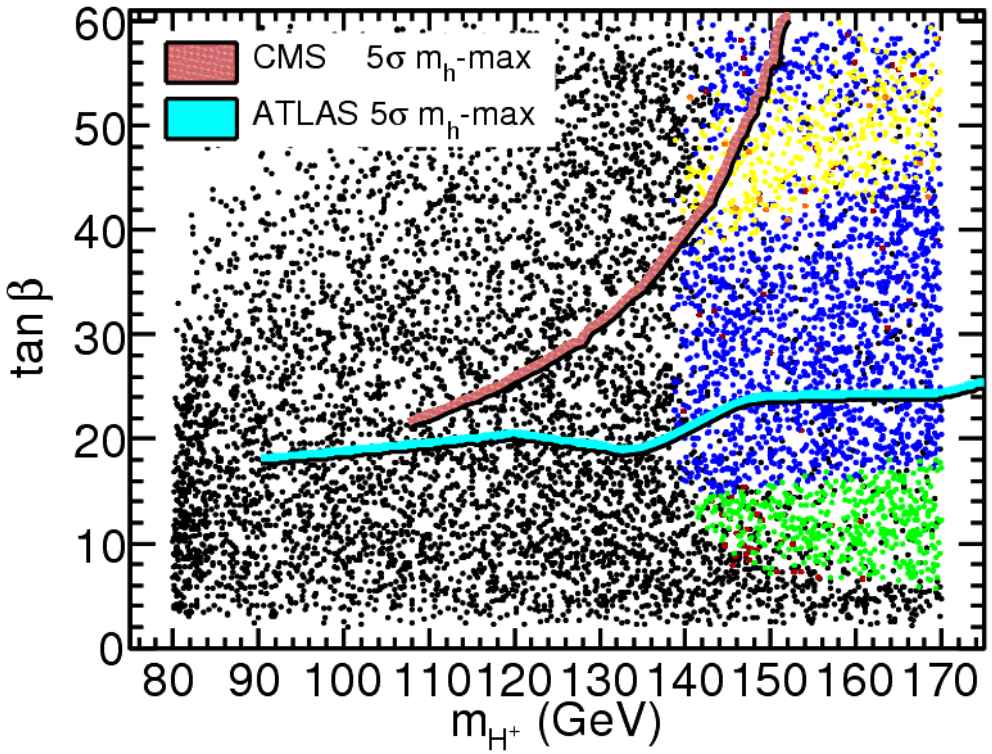
- Experimental results interpreted in m_h-max scenario
- NUHM model points with constraints superimposed

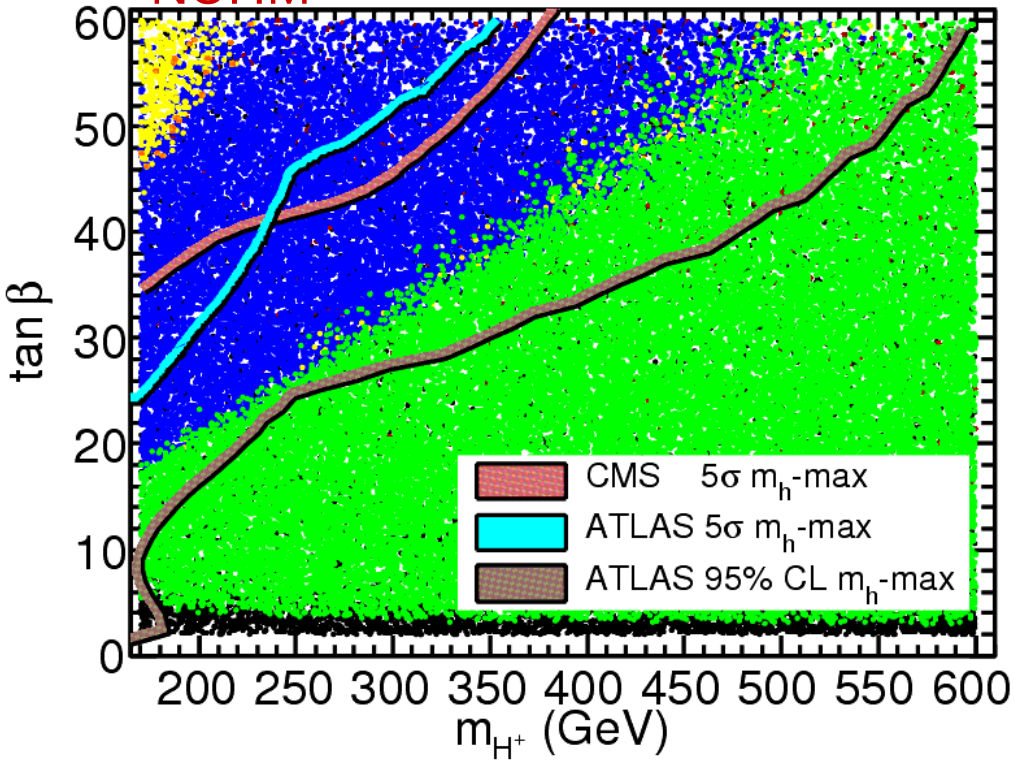
Neutral LSP, μ>0

- Allowed
- Direct
- $b \rightarrow s\,\gamma$
- $B_u \rightarrow \tau\,\nu$
- $B_s \rightarrow \mu^+\mu^-$
- $B \rightarrow D\,\tau\,\nu$
- $K \rightarrow \mu\,\nu$

NUHM



NUHM



Summary and Conclusions

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- We have studied constraints on charged Higgs bosons in MSSM models with non-universal Higgs masses using the SuperIso tool.
- B-physics observables yield powerful constraints, but uncertainties both from theory and experiment are still quite large.
- The region where indirect searches obtain the highest exclusion power is where the largest cross sections are expected for H^+ production at the LHC.
- Finding a charged Higgs early at the LHC points to non-minimal models.

Backup Slides

$\mathbf{B_s \to \mu^+ \mu^-}$

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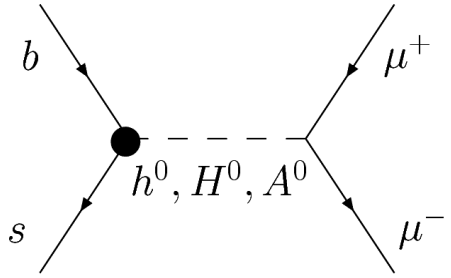
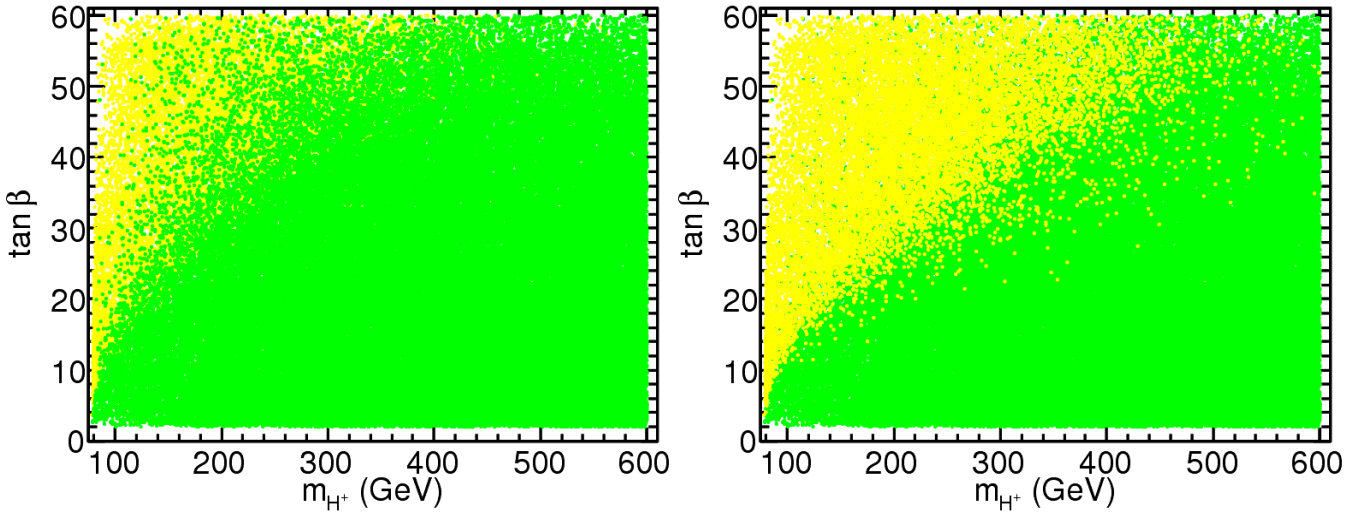
- Rare FCNC mediated by neutral Higgs bosons
- Decay not observed, only upper limit:

$$\mathrm{BR}(B_s \to \mu^+\mu^-) < 5.8 \times 10^{-8}$$ [CDF]



- SM prediction: $\mathrm{BR}(B_s \to \mu^+\mu^-)_{\mathrm{SM}} = (3.2 \pm 0.5) \times 10^{-9},$
- MSSM contribution at high tan β proportional to $\dfrac{m_\mu^2 m_B^2}{m_A^4} \tan^6 \beta$
- Charged Higgs constraints from $m_{H^+}^2 = m_A^2 + m_W^2$



$\mathbf{B \to D \tau \nu_\tau}$

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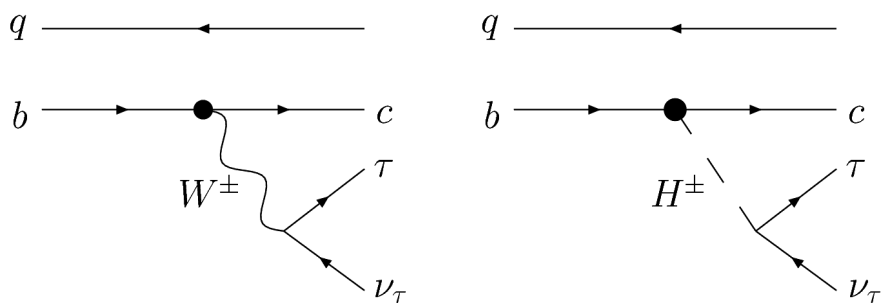
- Another tree-level process. Proportional to V_{cb} instead of V_{ub}.

$$\frac{d\Gamma(B \to D\ell\nu)}{dw} = \frac{G_F^2 |V_{cb}|^2 m_B^5}{192\pi^3} \rho_V(w) \times \left[1 - \frac{m_\ell^2}{m_B^2} \left| 1 - t(w) \frac{m_b}{(m_b - m_c) m_{H^+}^2} \frac{\tan^2\beta}{1 + \epsilon_0 \tan\beta} \right|^2 \rho_S(w) \right]$$

$$w = v_B \cdot v_D$$

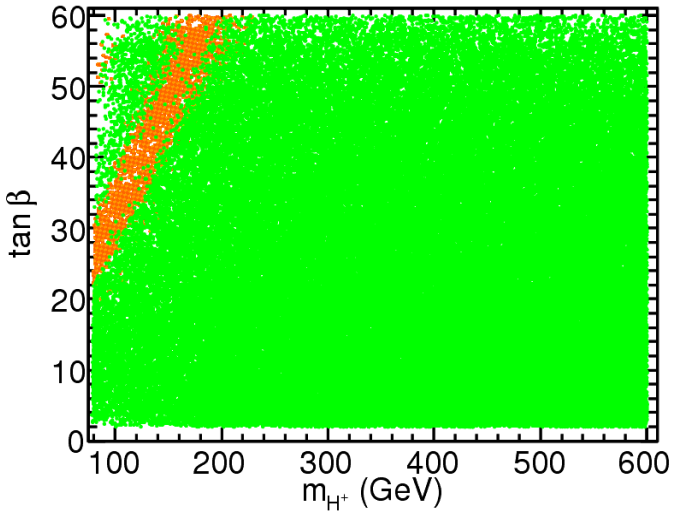


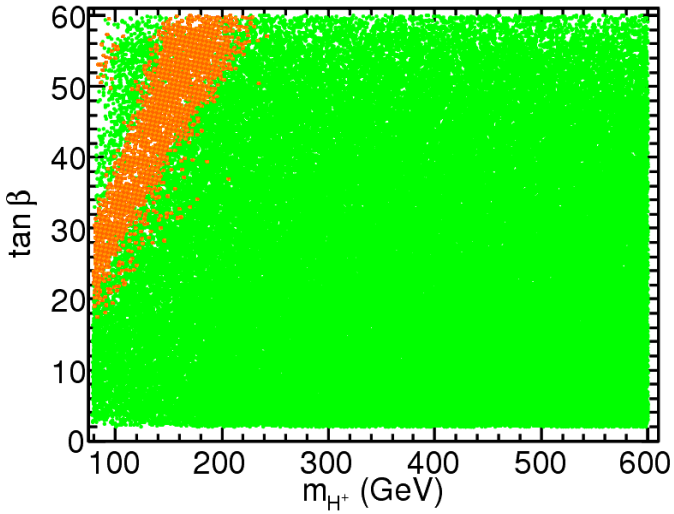
- Uncertainties from form factors ρ_V and ρ_S.

$$\xi_{D\ell\nu} \equiv \frac{\mathrm{BR}(B \to D\tau\nu_\tau)}{\mathrm{BR}(B \to De\nu_e)}$$

$$\xi_{D\ell\nu}^{\mathrm{exp}} = (41.6 \pm 11.7 \pm 5.2) \times 10^{-2} \quad \text{[BaBar]}$$

$$15.1 \times 10^{-2} < \xi_{D\ell\nu} < 68.1 \times 10^{-2}$$





- Exclusion complementary to $\mathbf{B \to \tau \nu_\tau}$

Uncertainties in $B \to \tau \nu_\tau$ from V_{ub}

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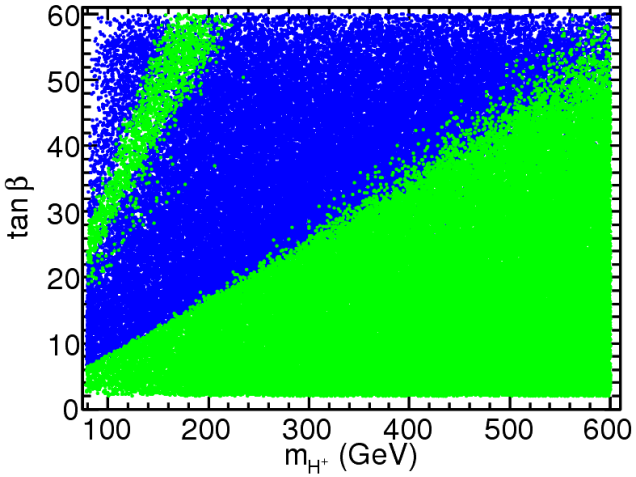
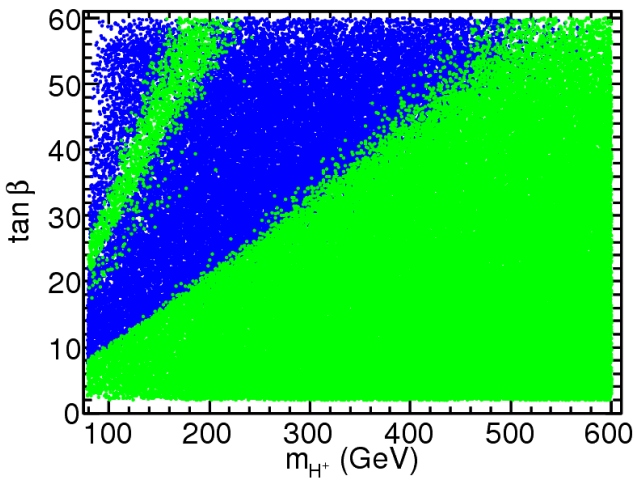
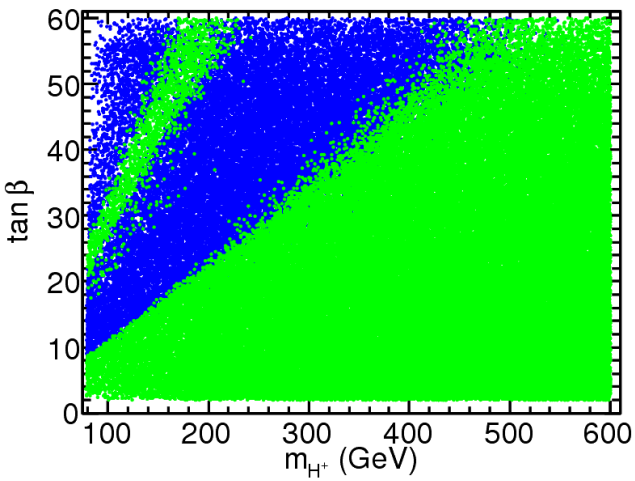
$|V_{ub}^{\mathrm{excl}}| = (3.5 \pm 0.6) \times 10^{-3}$



$|V_{ub}^{\mathrm{comb}}| = (3.95 \pm 0.35) \times 10^{-3}$



$|V_{ub}^{\mathrm{incl}}| = (4.12 \pm 0.43) \times 10^{-3}$



$K \to \mu \nu_\mu$

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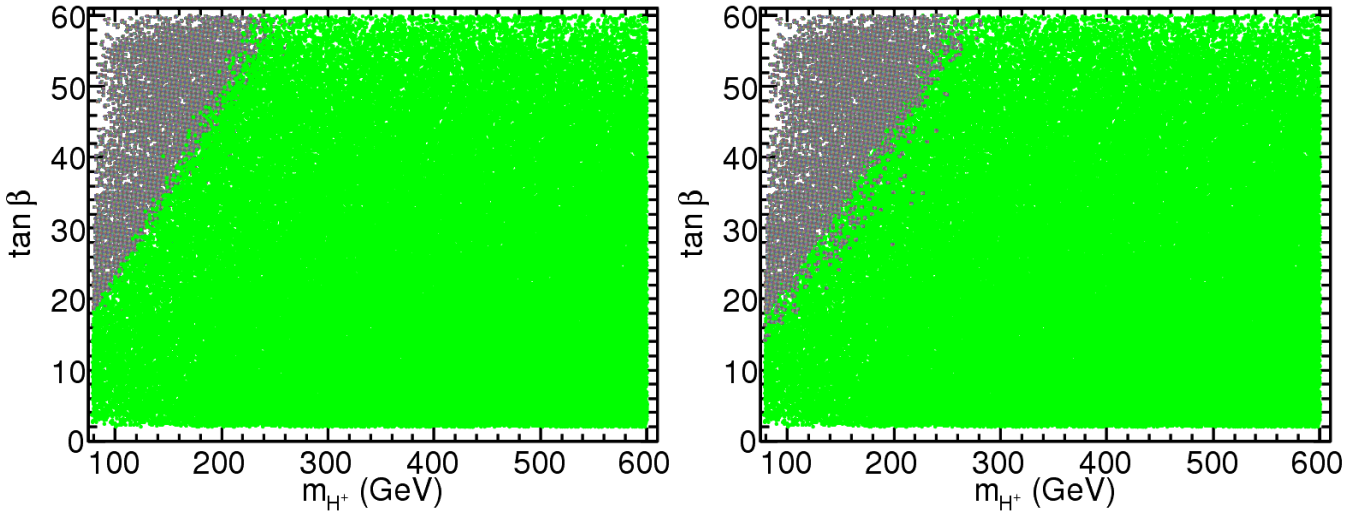
- Similar to $B \to \tau \nu_\tau$. Also mediated by H^+ at tree-level.

$$R_{\ell 23} \equiv \left| \frac{V_{us}(K_{\ell 2})}{V_{us}(K_{\ell 3})} \times \frac{V_{us}(0^+ \to 0^+)}{V_{ud}(\pi_{\ell 2})} \right| = \left| 1 - \frac{m_{K^+}^2}{M_{H^+}^2} \left(1 - \frac{m_d}{m_s} \right) \frac{\tan^2 \beta}{1 + \epsilon_0 \tan \beta} \right|$$

[FlaviaNet Kaon WG, arXiv:0801.1817]

$$R_{\ell 23} = 1.004 \pm 0.007$$

- Large parametric uncertainty in this quantity from f_K/f_π obtained using lattice QCD
  Using value with larger error removes constraint.



NUHM

Lattice uncertainties in $K \to \mu \nu_\mu$

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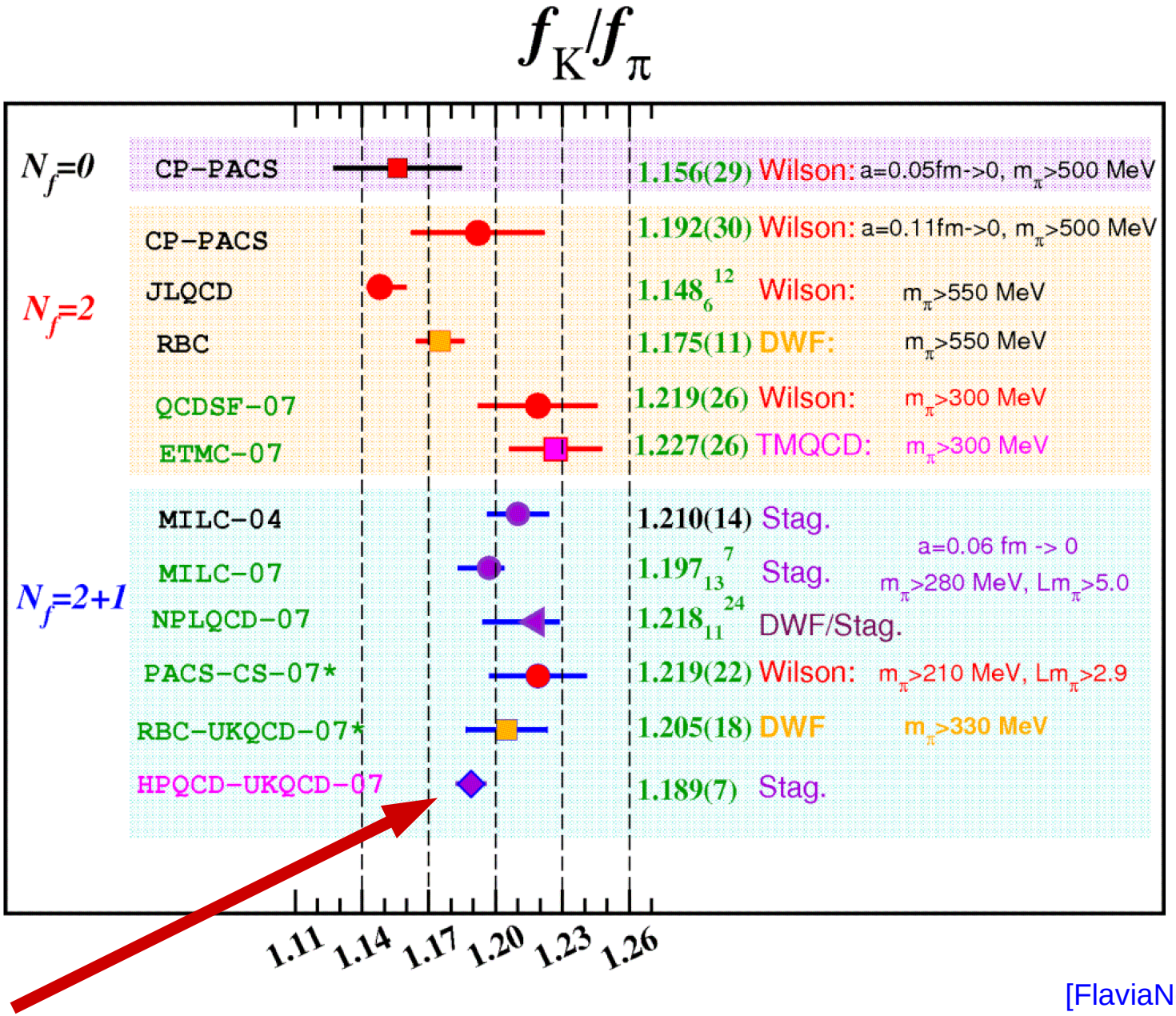

[FlaviaNet Kaon WG, arXiv:0801.1817]

Charged Higgs decays to sparticles

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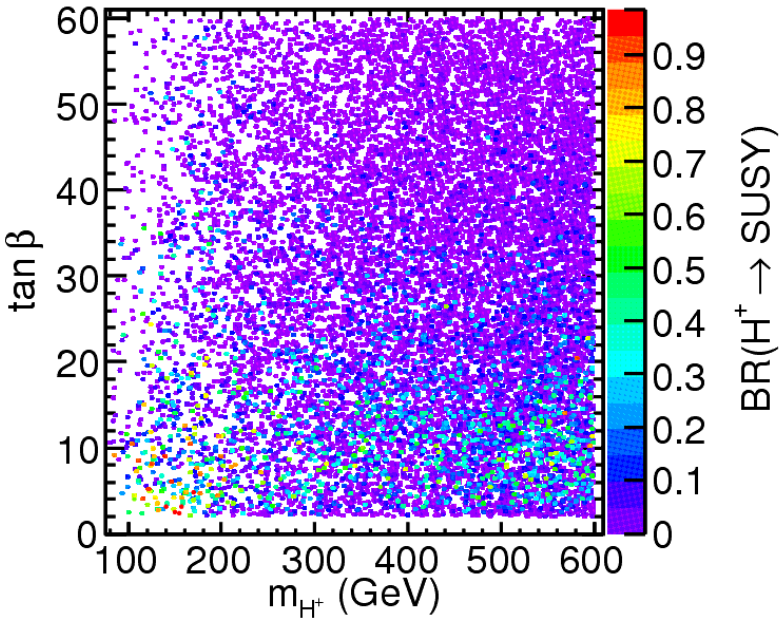

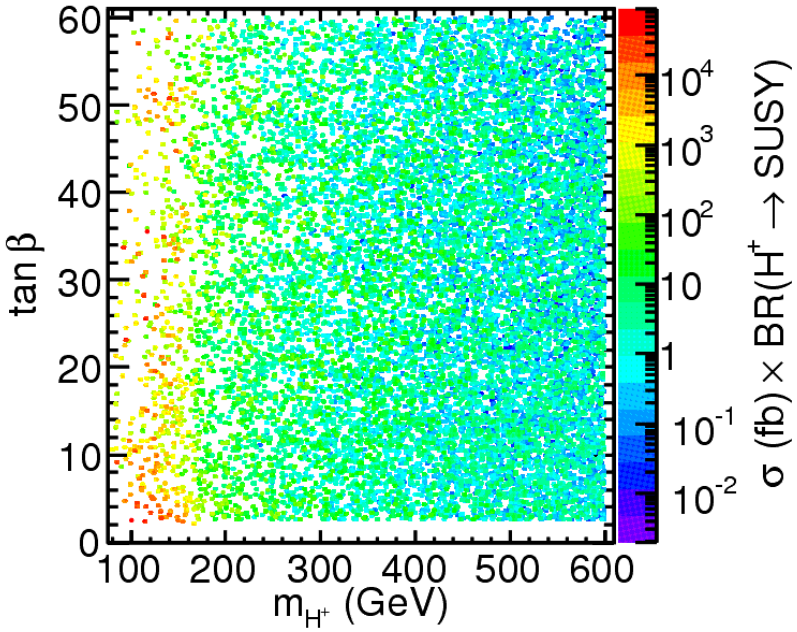

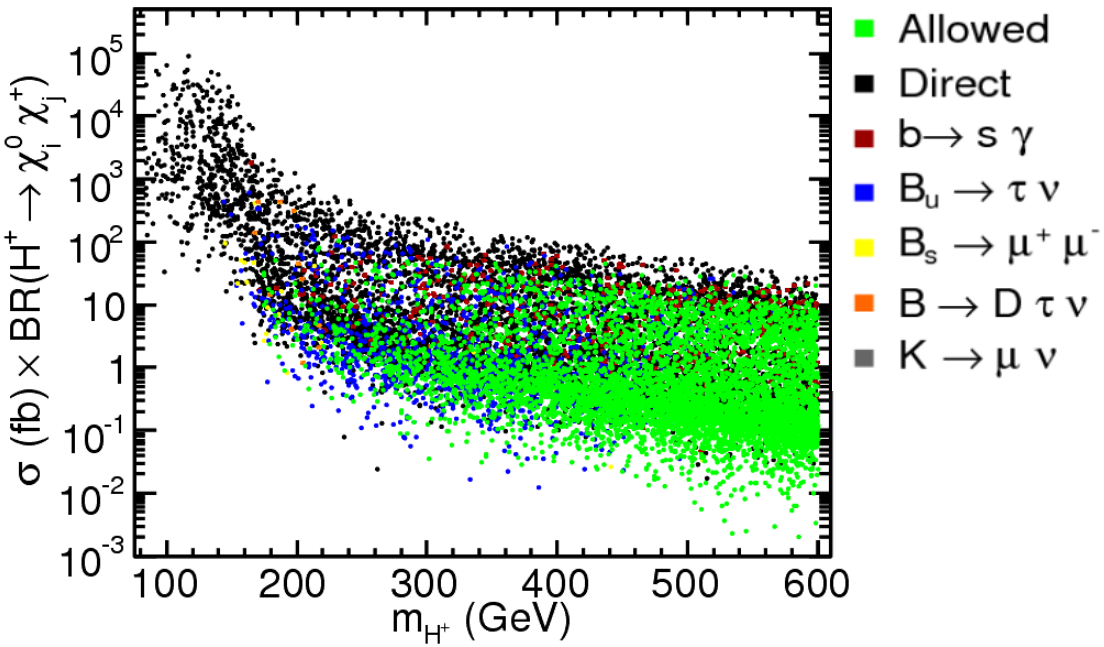

- Points with highest $\sigma \times \mathrm{BR}$ to SUSY already excluded by direct constraints

NUHM model dependence

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- Green: NUHM points which are “5σ detectable” by ATLAS
- Red: NUHM points which are **not** 5σ detectable due to ε_b corrections
- Blue: NUHM points which are 5σ detectable thanks to ε_b corrections