Constraints on charged Higgs bosons in the CMSSM and NUHM models

Oscar Stål
Uppsala universitet

Prospects for charged Higgs discovery at colliders
Uppsala, 2008-09-17

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

CMSSM and NUHM models

UPPSALA UNIVERSITET

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

- Both constrained MSSM (CMSSM) and models with Non-Universal Higgs Masses (NUHM) assume SUSY breaking mediated by gravity.

- CMSSM 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 μ parameter:	sign(μ)

- 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

UPPSALA UNIVERSITET

- To identify the allowed regions for the charged Higgs we scan over the parameter spaces in CMSSM and NUHM
- Theoretical constraints, such as radiative breaking of the EW symmetry, restricts the useful ranges for the input parameters
- Physical mass spectrum at the EW scale calculated with SOFTSUSY

Parameter	min	max	note
m_0	50	2000	
$m_{1/2}$	50	2000	
A_0	-2000	2000	
μ	-2000	2000	CMSSM: only sign $\pm$
m_A	5	600	NUHM only
$\tan\beta$	1	60	

Constraints

UPPSALA UNIVERSITET

- 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 for H^+

- Flavor data constraints calculated using SuperIso 2.3 [F. Mahmoudi, arXiv:0808.3144]
  → Talk by Nazila Mahmoudi

- Constraints calculated from 95% CL allowed range, adding theoretical and experimental error in quadrature*

Constraints from direct searches

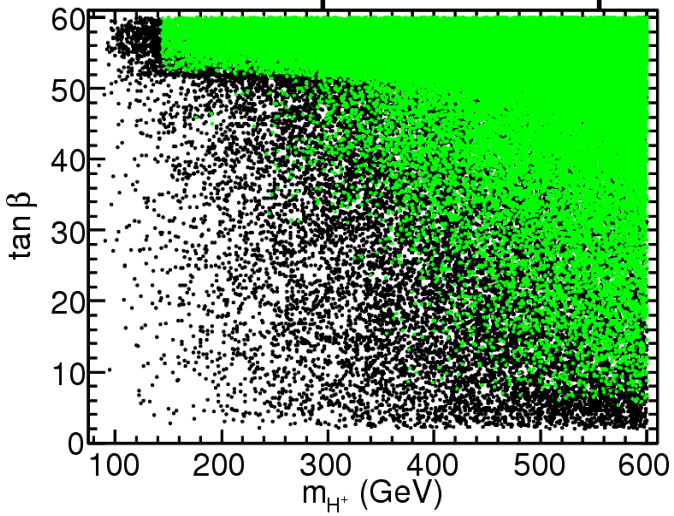
UPPSALA UNIVERSITET

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

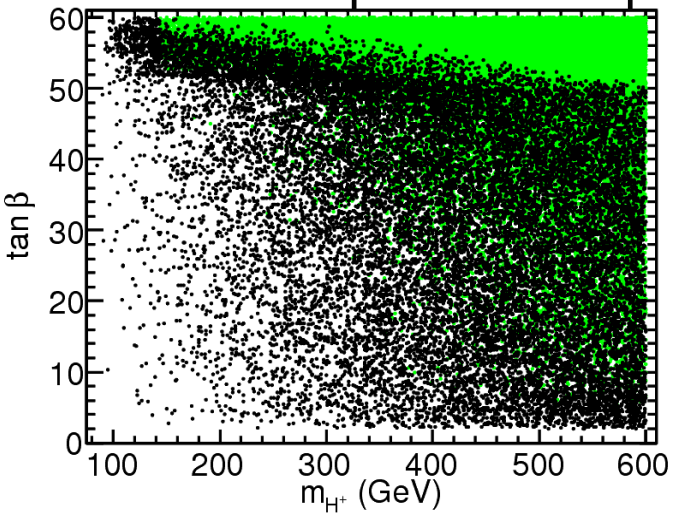
Particle	H^+	A	h	χ_1^0	χ_1^+	$\tilde{e}_R$	$\tilde{\mu}_R$	$\tilde{\tau}_1$	$\tilde{\nu}$	$\tilde{b}_1$	$\tilde{t}_1$	$\tilde{g}$
Mass limit (GeV)	79.3	93.4	111	46	94	73	94	81.9	94	89	95.7	308

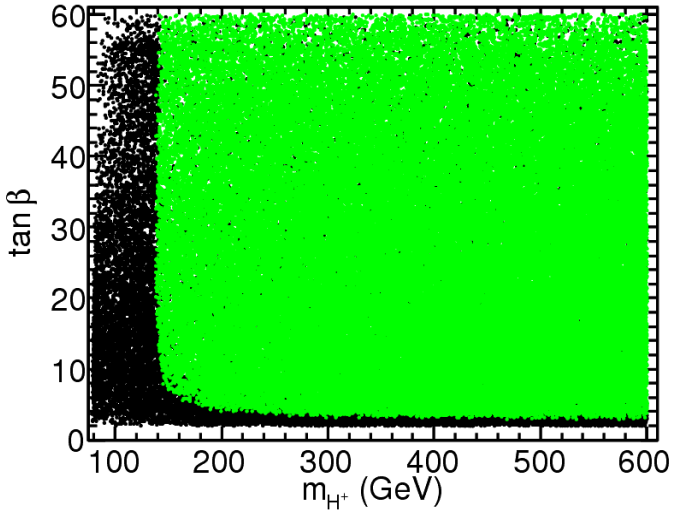
[PDG2008]

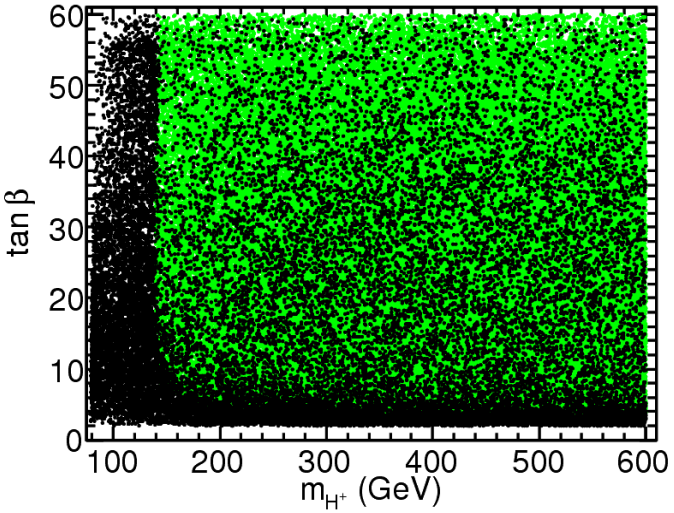
Allowed points on top



Excluded points on top







CMSSM

- Light Higgs mostly for high tan β from RGE running

NUHM

- Lightest Higgs mass limit gives sharp edge

$b \to s\gamma$

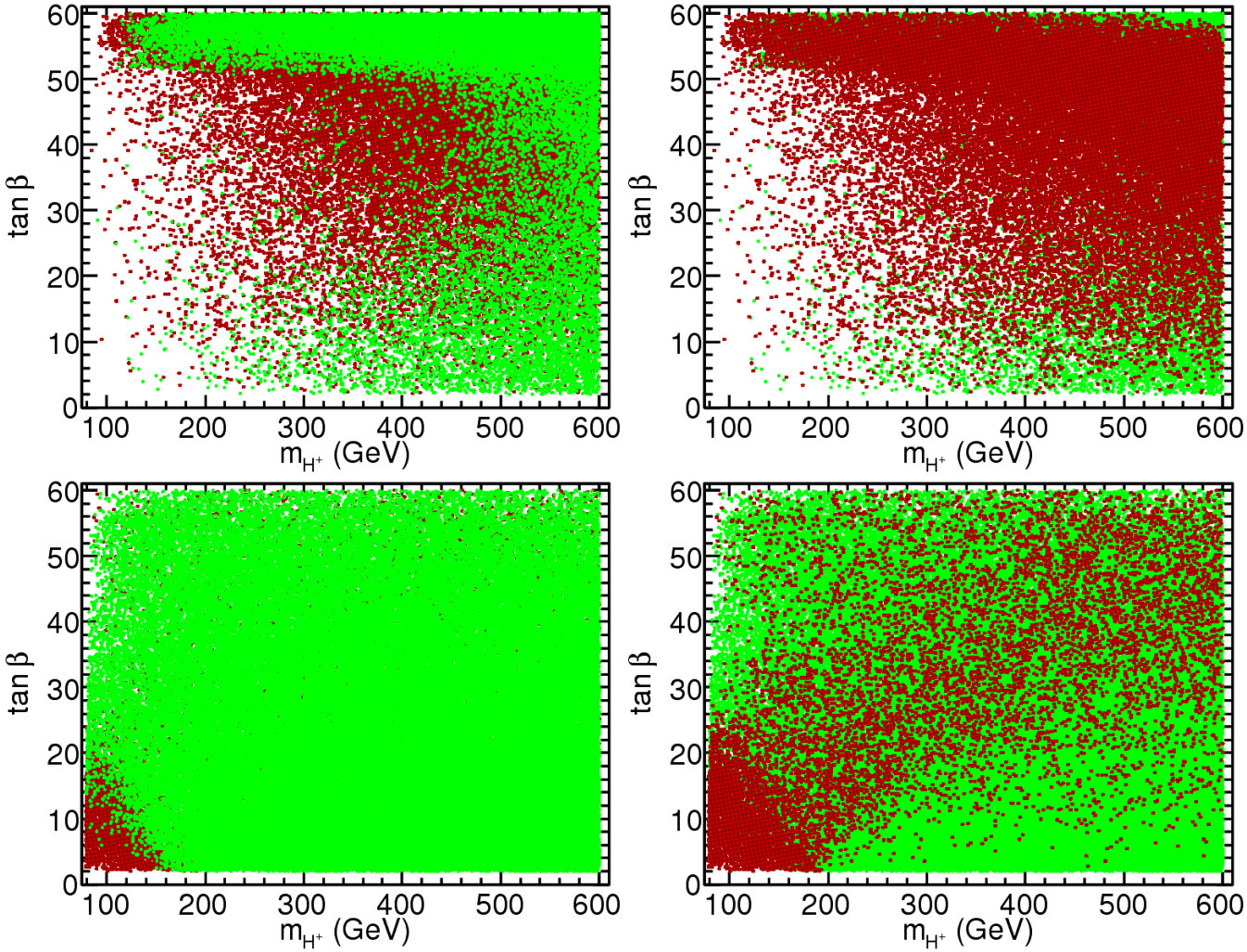
UPPSALA UNIVERSITET

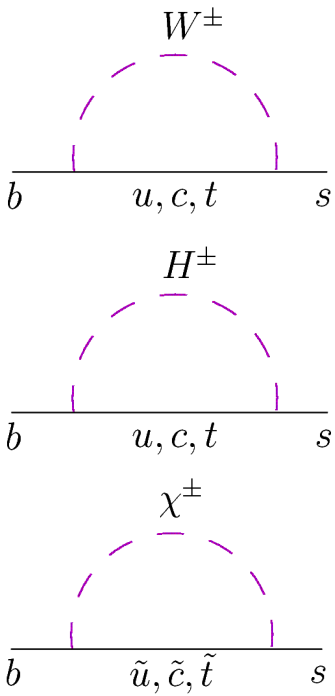
- Rare transition mediated by W loop in SM: BR and isospin asymmetry
- MSSM contributions from H^+ and χ^+

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

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

$$-1.7 \times 10^{-2} < \Delta_0 < 8.9 \times 10^{-2}$$



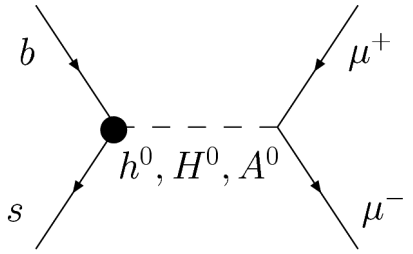


$\mathbf{B_s \to \mu^+ \mu^-}$

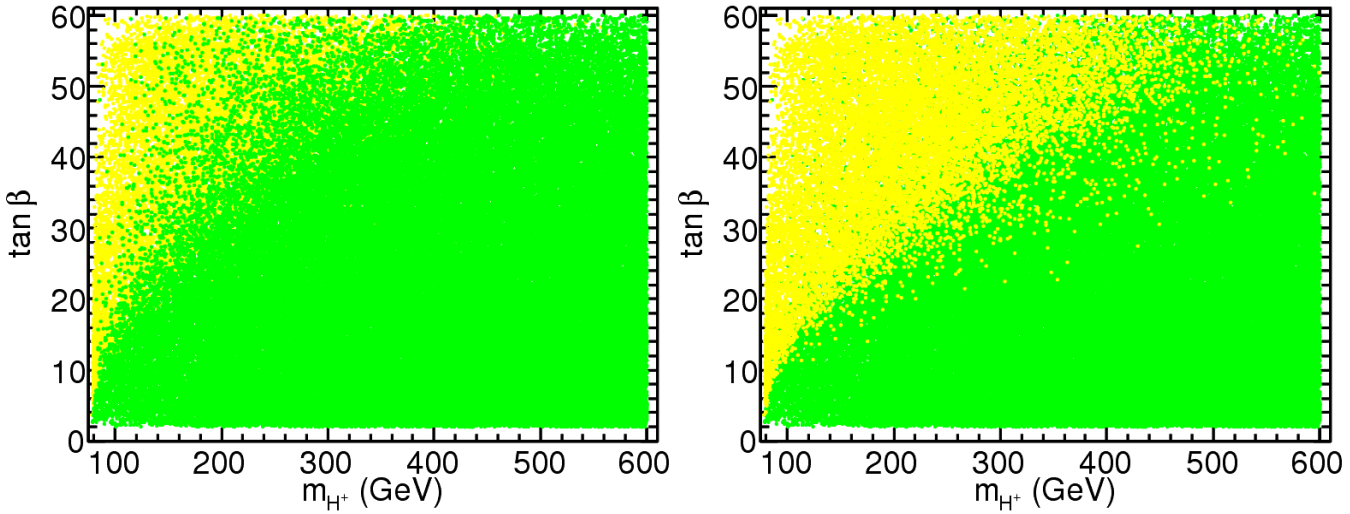
UPPSALA UNIVERSITET

- Rare FCNC mediated by neutral Higgs bosons
- Decay not observed. 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 $m_{H^+}^2 \simeq m_A^2 + m_W^2$



NUHM

$B \to \tau \nu_\tau$

UPPSALA UNIVERSITET

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

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

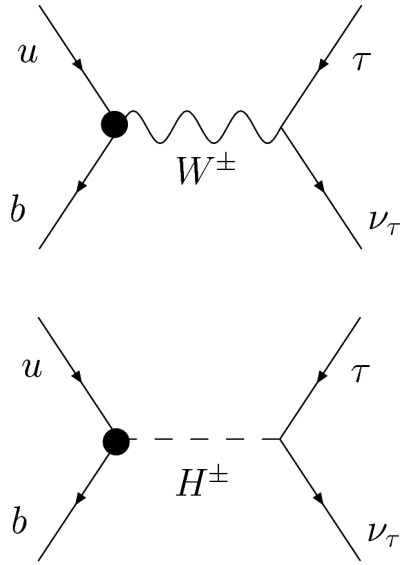
- Large parametric uncertainties from V_{ub}

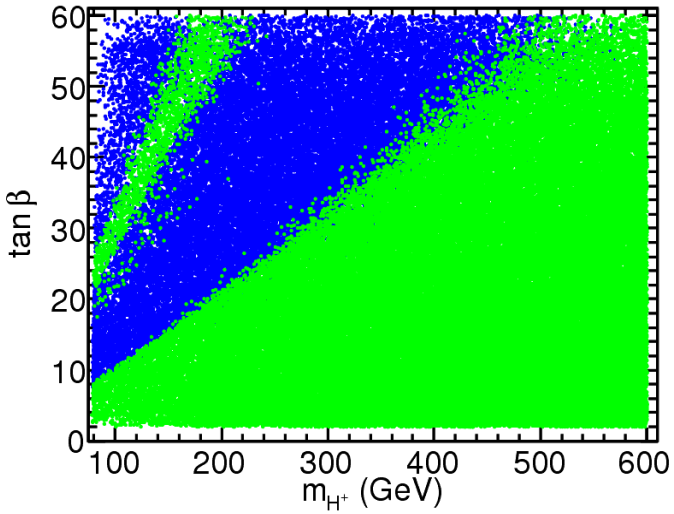
$$R_{\tau\nu_\tau}^{\mathrm{exp}} \equiv \frac{\mathrm{BR}(B_u \to \tau\nu_\tau)_{\mathrm{exp}}}{\mathrm{BR}(B_u \to \tau\nu_\tau)_{\mathrm{SM}}} = 1.28 \pm 0.38$$

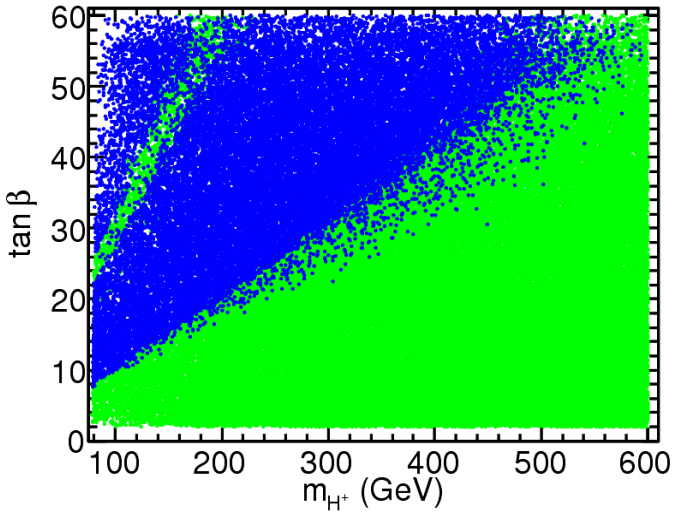
[HFAG combination]

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

→ Talk by Steven Robertson







NUHM

- Strong exclusion, but can be shifted by change in V_{ub}

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

[PDG2008]

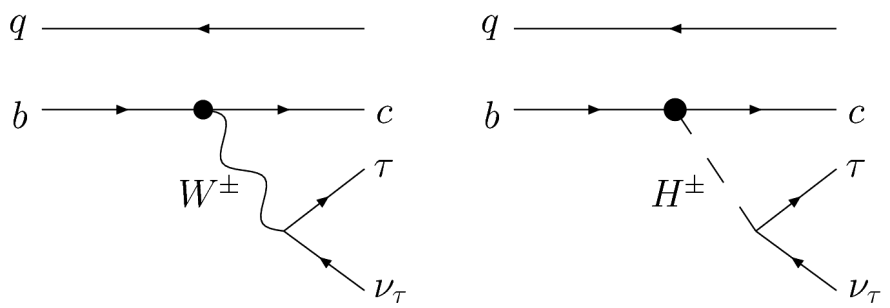
$B \to D \tau \nu_\tau$

UPPSALA UNIVERSITET

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

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

$$w = v_B \cdot v_D$$

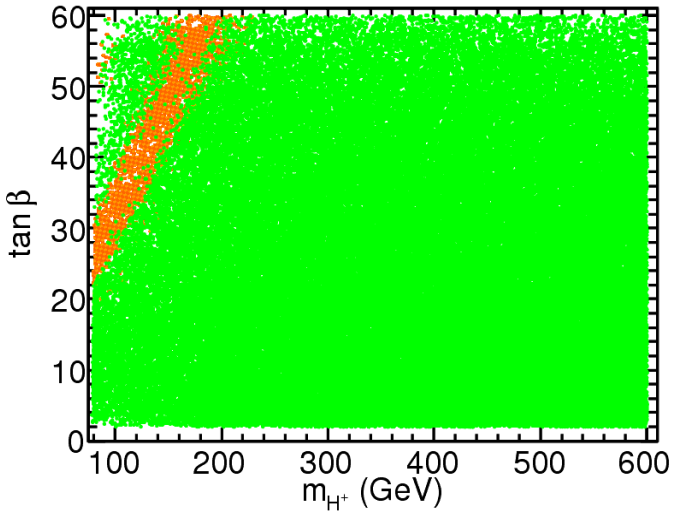


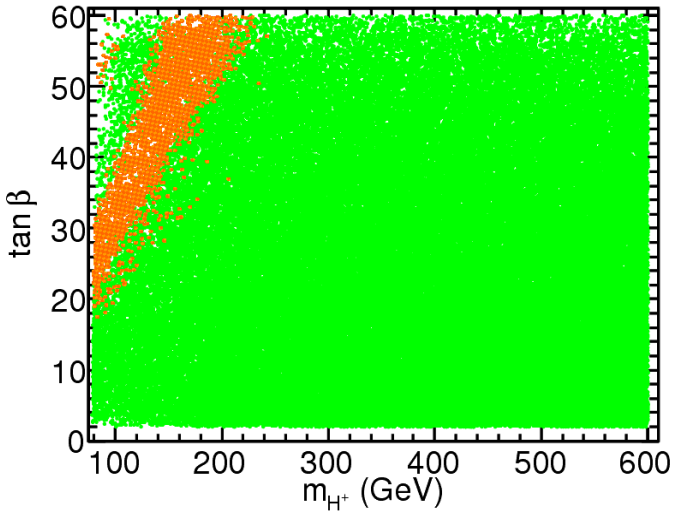
- Uncertainties from form-factors ρ_V and ρ_S.

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

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

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





NUHM

- Complementary to $B \to \tau \nu_\tau$

$K \to \mu \nu_\mu$

UPPSALA UNIVERSITET

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

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

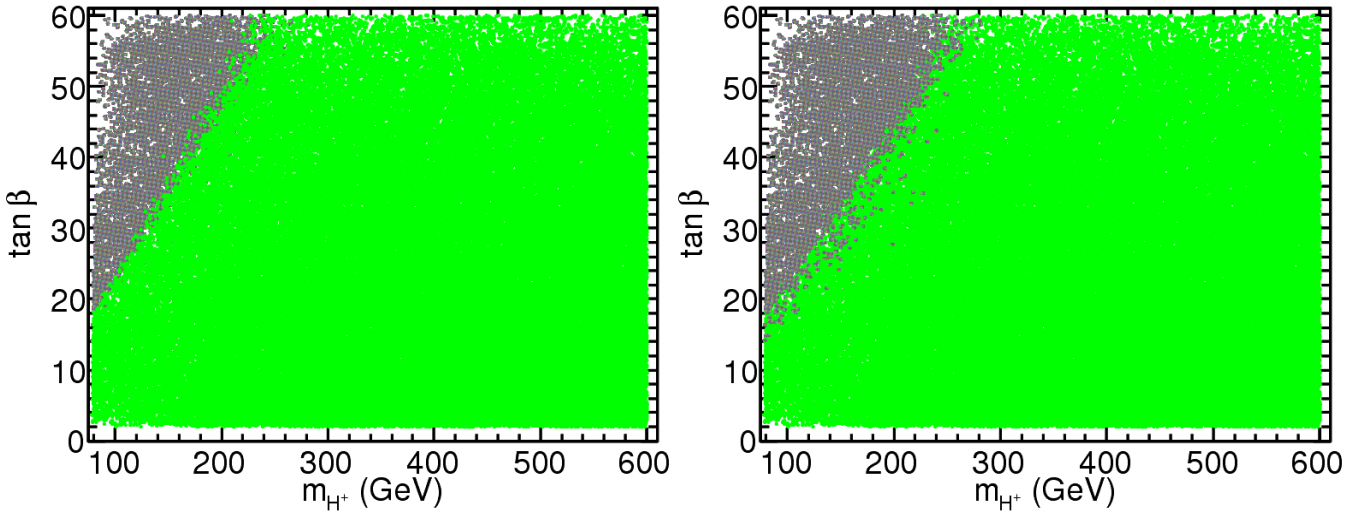
[FlaviaNet Kaon WG, arXiv:0801.1817]

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

- Large parametric uncertainty in this quantity from f_K/f_π obtained using lattice QCD

$$f_K / f_\pi = 1.189 \pm 0.007$$

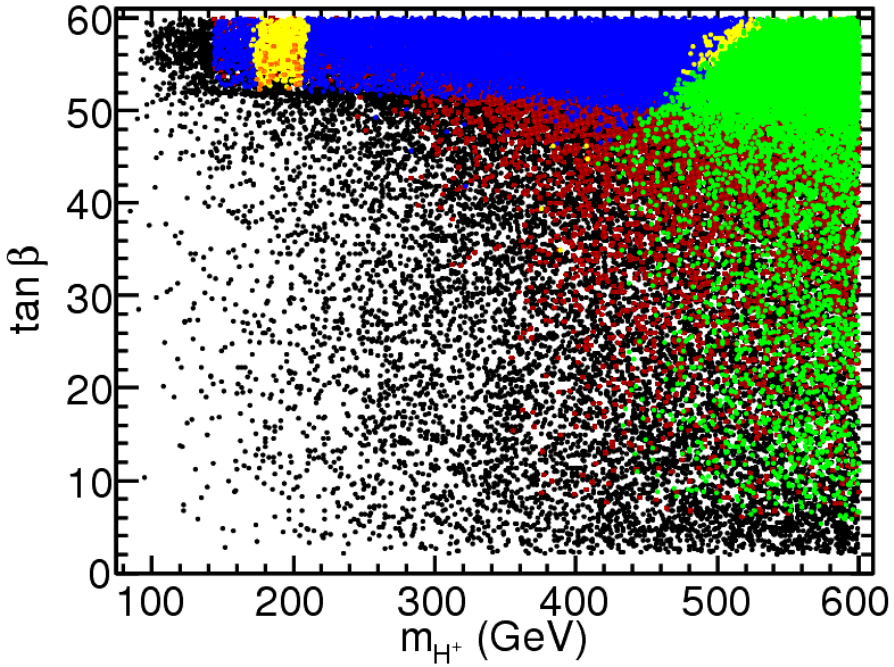
Using value with larger error removes constraint.



NUHM

Combined constraints

UPPSALA UNIVERSITET

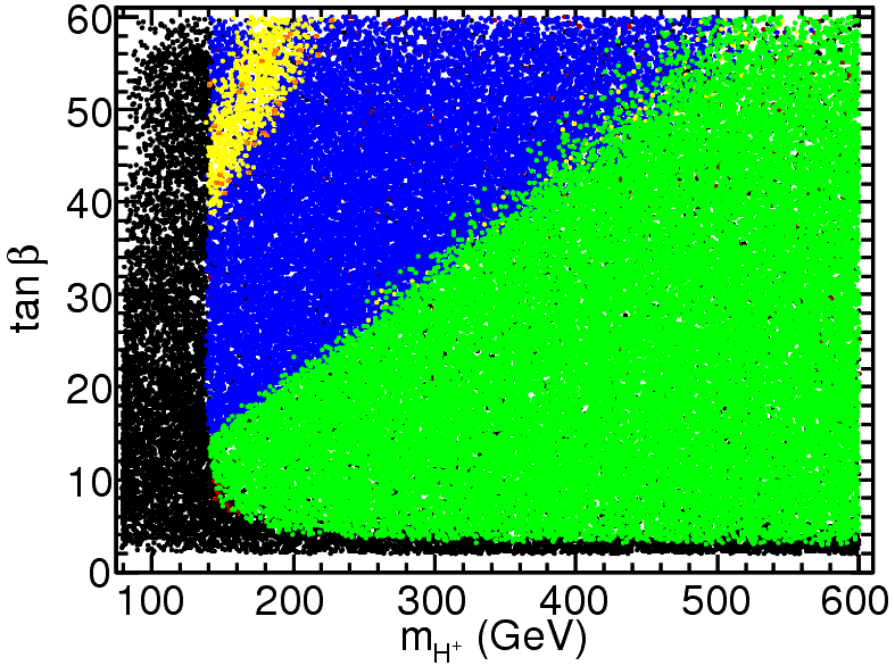


CMSSM

$m_0, m_{1/2}, A_0, \mathrm{sign}(\mu), \tan\beta$

- High tan β tail excluded by combined flavor constraints

$$m_{H^+} \gtrsim 400 \ \mathrm{GeV}$$



NUHM

$m_0, m_{1/2}, A_0, \mu, m_A, \tan\beta$

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

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

Neutral LSP, μ>0

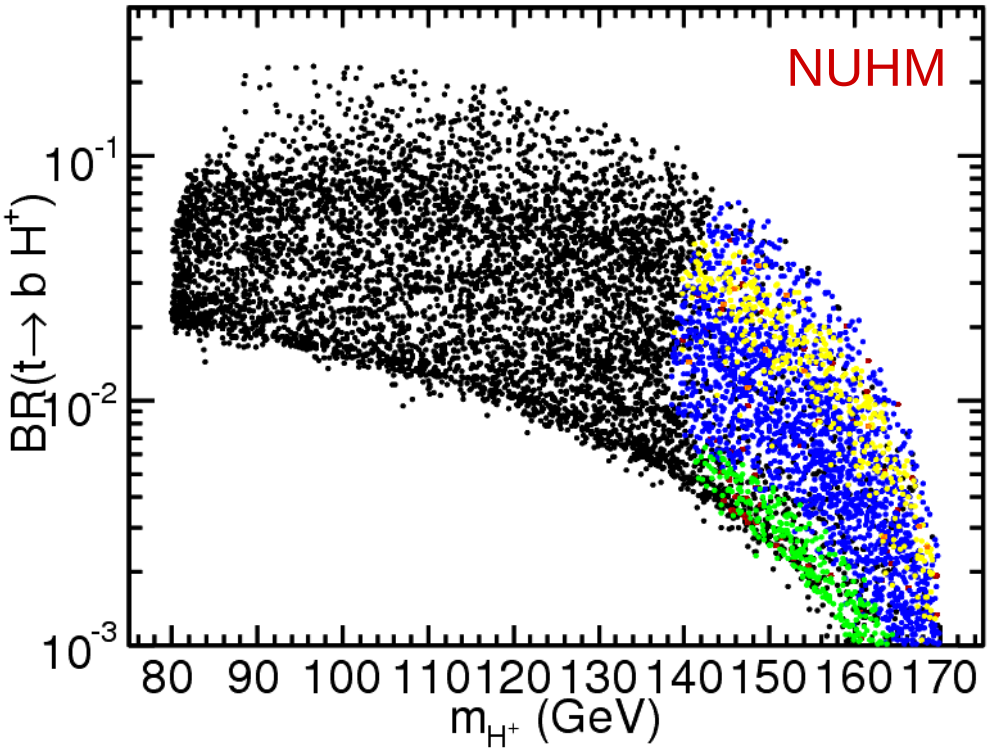
LHC discovery prospects

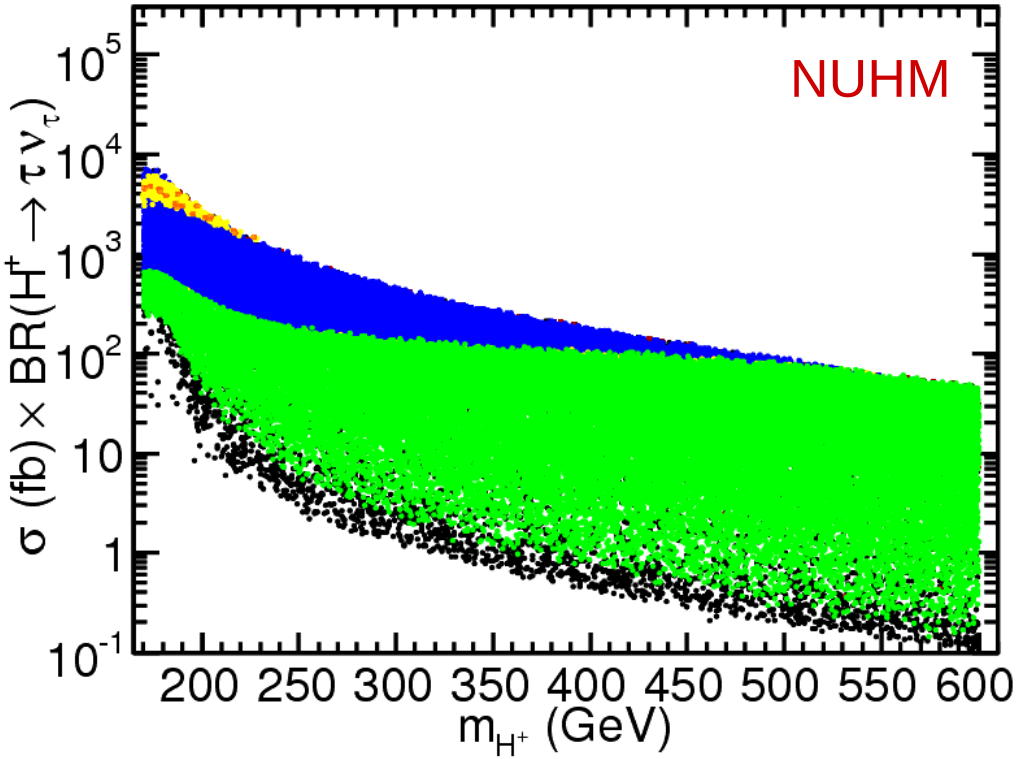
UPPSALA UNIVERSITET

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





Comparison to experimental reach

UPPSALA UNIVERSITET

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

DØ Note 5715-CONF

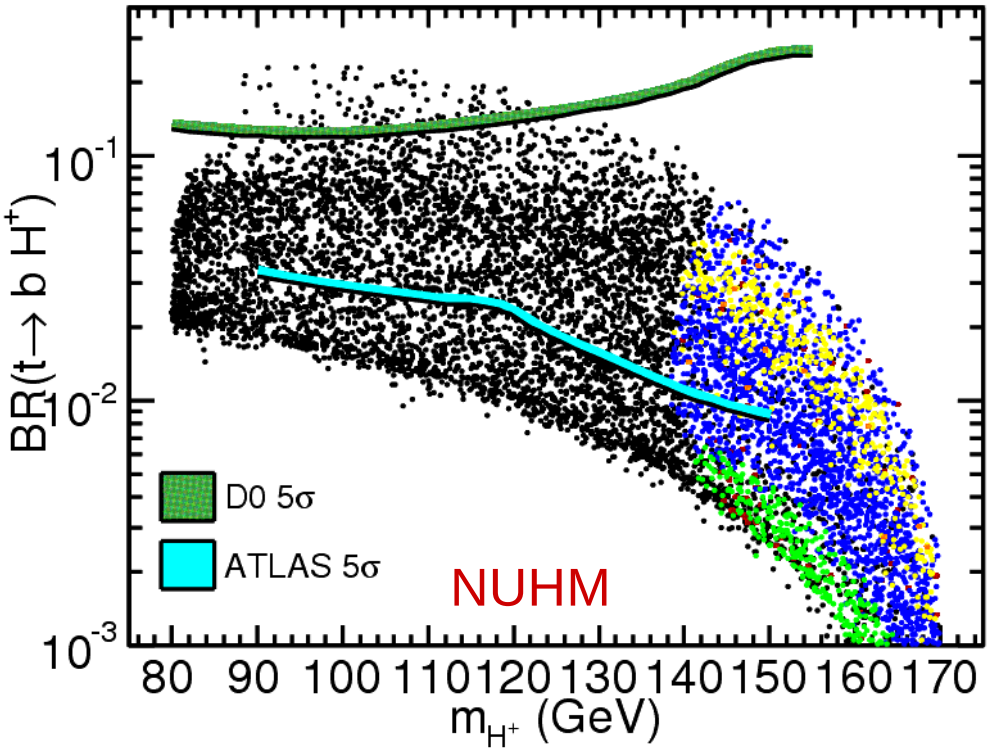
- Reach for CMS and ATLAS with 30 fb^{-1}
  → CMS and ATLAS talks at this meeting

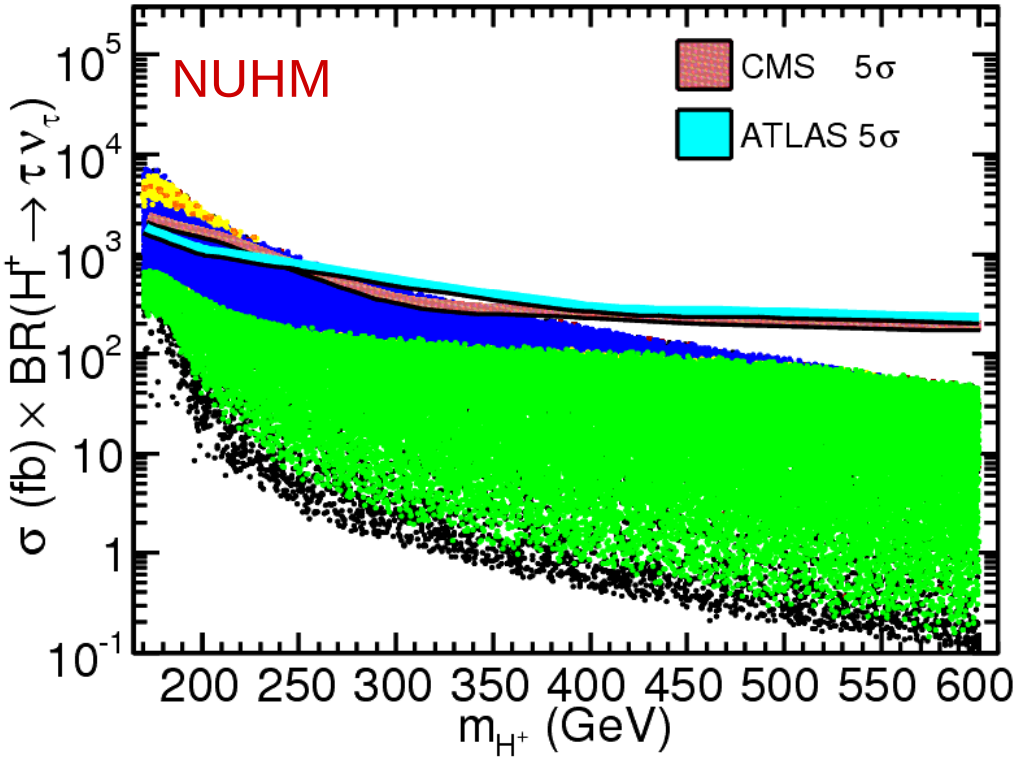
CMS-NOTE-2006-100, 2006-056
ATLAS CSC-talks

- 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

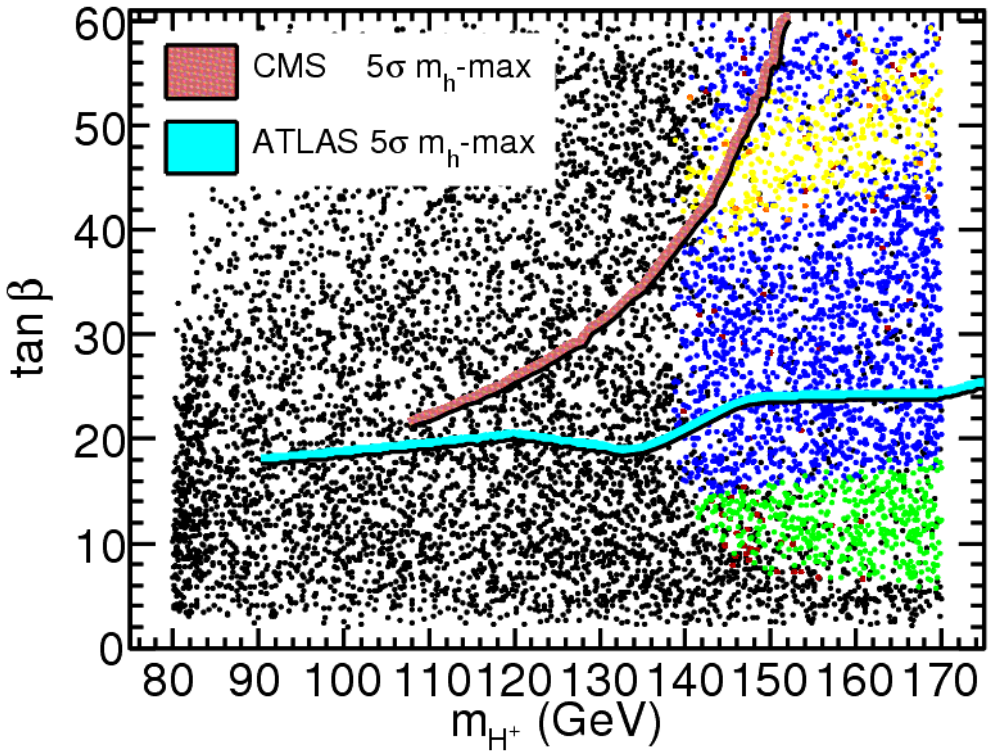
UPPSALA UNIVERSITET

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

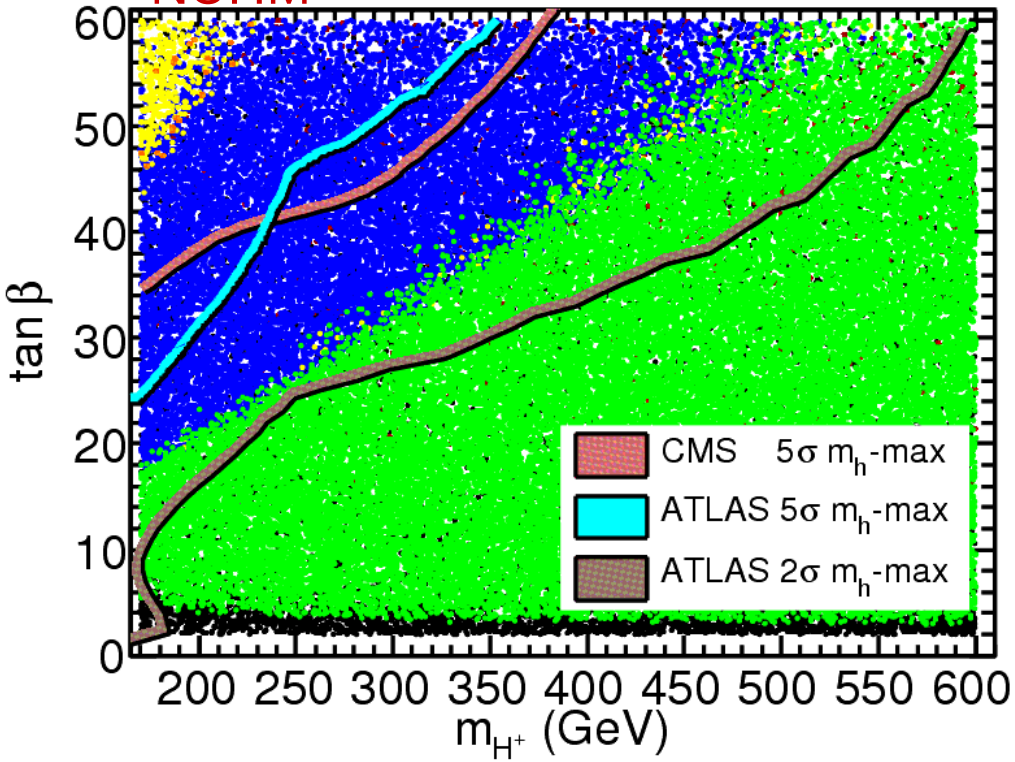
Neutral LSP, μ>0

- 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



Conclusions and outlook

UPPSALA UNIVERSITET

- Restrictive constraints already exist on charged Higgs bosons in the CMSSM and NUHM models.
- In particular B-physics observables yield powerful constraints, although the uncertainties from theory and experiment are still rather large.
- The region where indirect searches obtains the highest exclusion power is where the largest cross sections are obtained for H^+ production at the LHC.
- Finding a charged Higgs early at the LHC points to non-minimal models.

Extensions, improvements:

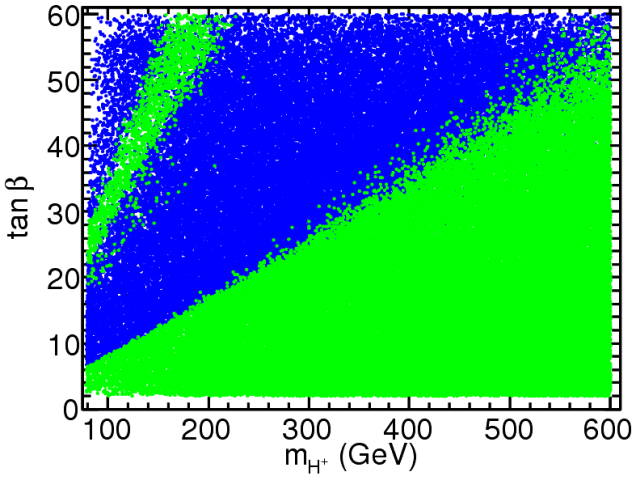
- Charged Higgs in other mediation scenarios: GMSB, AMSB, ...
- Constraints in non-minimal models, such as the NMSSM
- Alternative production of charged Higgs bosons in SUSY decay chains

Backup Slides

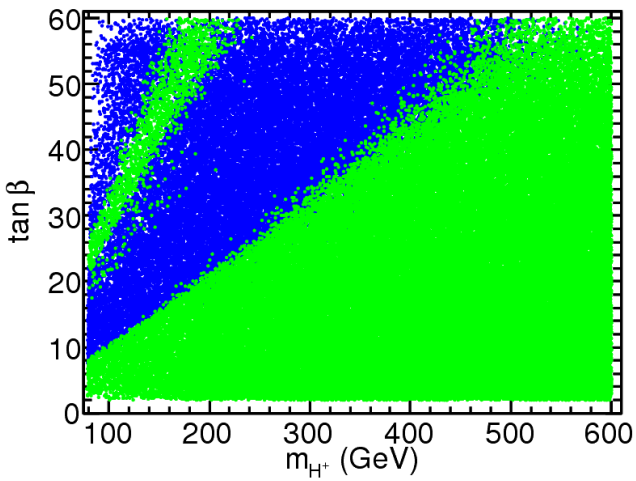
Uncertainties in $B \to \tau \nu_\tau$ from V_{ub}

UPPSALA UNIVERSITET

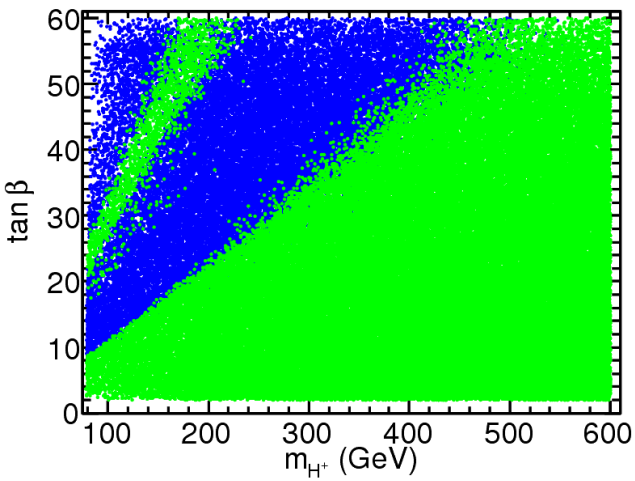
$|V_{ub}^{\mathrm{excl}}| = (3.5 \pm 0.6) \times 10^{-3}$



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

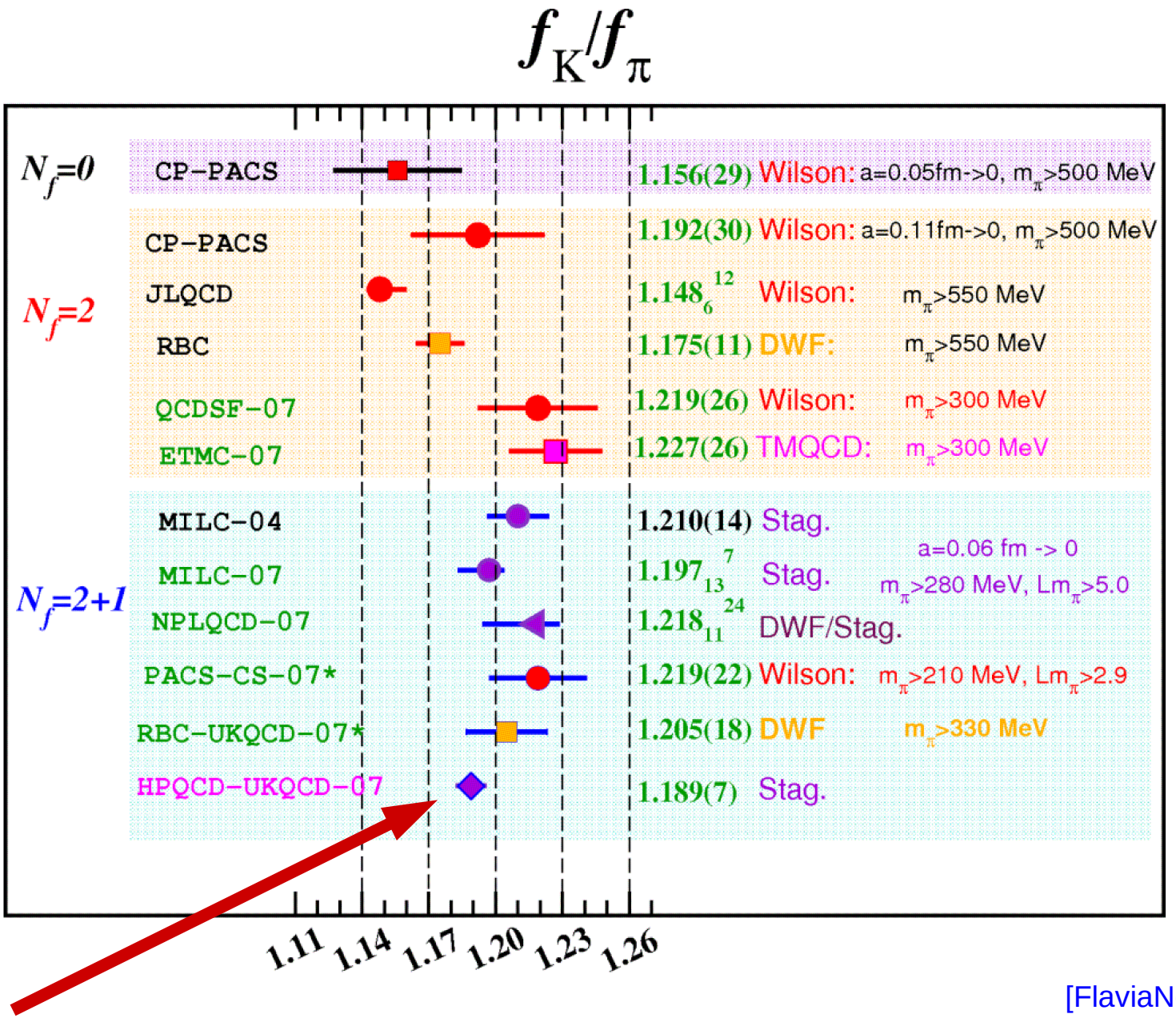


$|V_{ub}^{\mathrm{incl}}| = (4.12 \pm 0.43) \times 10^{-3}$



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

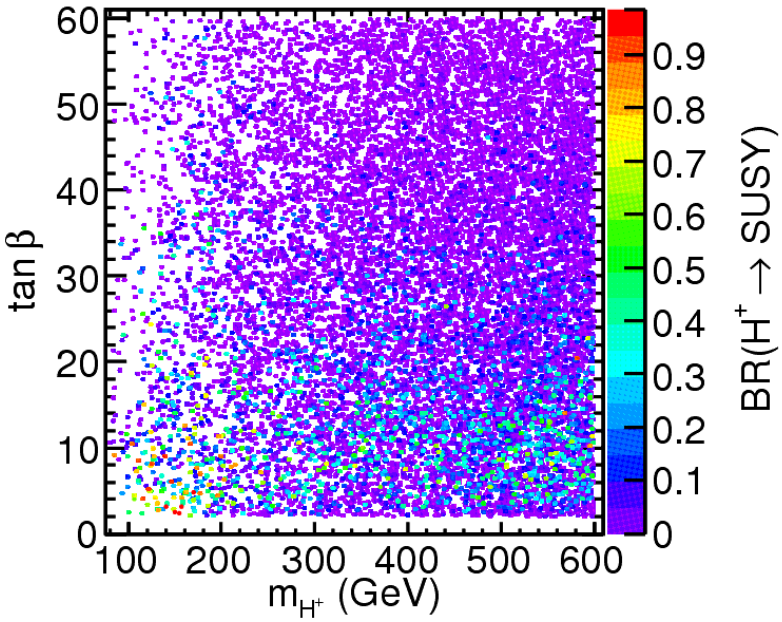
UPPSALA UNIVERSITET

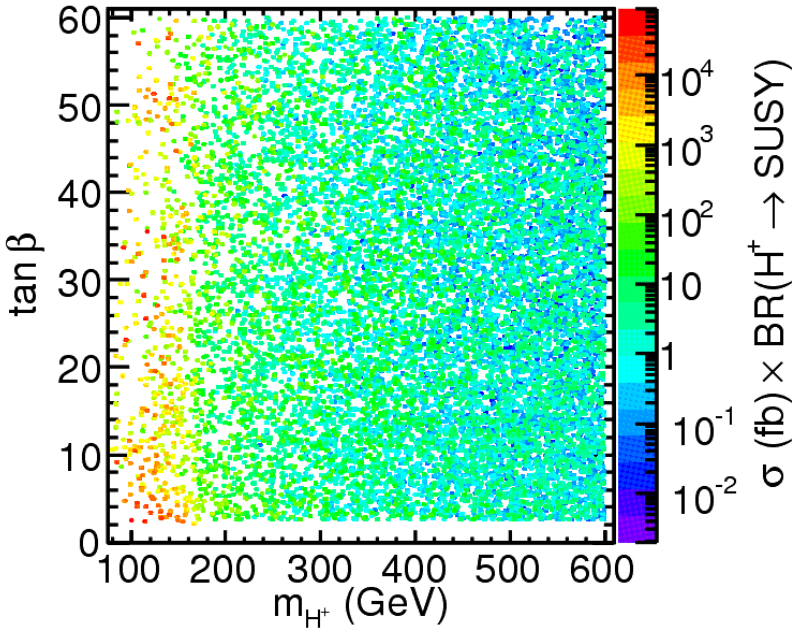


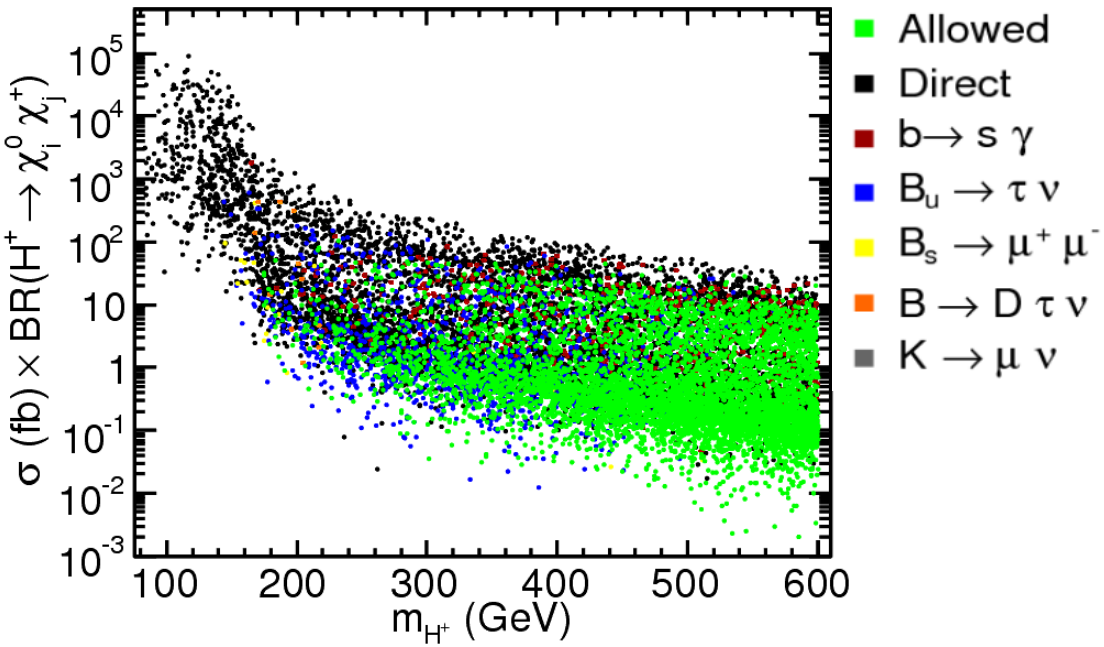
[FlaviaNet Kaon WG, arXiv:0801.1817]

Charged Higgs decays to sparticles

UPPSALA UNIVERSITET







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

NUHM model dependence

UPPSALA UNIVERSITET

- 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