Closing the window on light H+ in NMSSM

Thomas Rössler

based on arXiv:hep-ph/1206.1470 with J. Rathsman

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Motivation

- MSSM provides two doublets
  $h, H, A, H^{\pm}$ with $m^2_{H^{\pm}} = m^2_A + m^2_W$ at tree level
  - Higgs sector 2 param., e.g. $m_{H^{\pm}}, \tan\beta$
  - $H^{\pm} \to AW$ typically closed
- NMSSM adds additional singlet
  - singlet-doublet-mixing → $h^{\pm} \to a_1 W$ can be dominant
  - not searched for in standard searches
- considering collider constraints on NMSSM, put special focus on light a_1 closely above $b\bar{b}$ threshold
- fragmentation to single $b\bar{b}$ jet

NMSSM Higgs sector

$$\mu \hat{H}_u \cdot \hat{H}_d = 0$$

$$W_{\rm NMSSM} = W_{\rm MSSM} + \lambda \hat{S} \hat{H}_u \cdot \hat{H}_d + \kappa \hat{S}^3$$

$$V_{\rm soft}^{\rm NMSSM} = V_{\rm soft}^{\rm MSSM} + m_S^2 |S|^2 + \left(\lambda A_\lambda S H_u \cdot H_d + \frac{1}{3} \kappa A_\kappa S^3 + h.c. \right)$$

$$\mathcal{M}_P^2 = \begin{pmatrix} \frac{2\mu}{\sin 2\beta} \left(A_\lambda + \frac{\kappa}{\lambda} \mu \right) & \lambda v \left(A_\lambda - 2 \frac{\kappa}{\lambda} \mu \right) \\ \lambda v \left(A_\lambda - 2 \frac{\kappa}{\lambda} \mu \right) & \frac{\lambda^2 v^2 \sin 2\beta}{2\mu} \left(A_\lambda + 4 \frac{\kappa}{\lambda} \mu \right) - 3 \frac{\kappa}{\lambda} A_\kappa \mu \end{pmatrix}$$

$$m_{h^\pm}^2 = \frac{2\mu}{\sin 2\beta} \left(A_\lambda + \frac{\kappa}{\lambda} \mu \right) + m_W^2 - \lambda^2 v^2$$

$$A_\lambda, A_\kappa \rightarrow m_{h^+}, m_{a_1}$$

using 1-loop iterative procedure

$$\mu = \lambda v_s = \lambda < S >$$

solves μ-problem

Scenario specification

$\tan\beta = v_u/v_d \in [1, 60]$ $\mu \in [125, 1000]$ GeV
$\lambda \in [0, 0.7]$ $m_{h^\pm} \in [80, 170]$ GeV
$\kappa \in [-0.7, 0.7]$ $m_{a_1} \in [4, 150]$ GeV

- common sfermion mass $M_{\rm SUSY} = 1$ TeV & MFV
- gaugino masses by $M_1 = 100$ GeV, $M_2 = 200$ GeV, $M_3 = 800$ GeV (cf CMSSM, grav.med.)
- squark/slepton trilinears unified, but variable (stop mixing) $A_t = A_b = A_\tau \in$[-5000,5000] GeV

Experimental constraints I

- Collider
  - direct searches for Higgs bosons
  - direct searches for sparticles
- Low energy flavour
  - $B_u \to \tau^+ \nu_\tau$
  - $B_s \to \mu^+ \mu^-$

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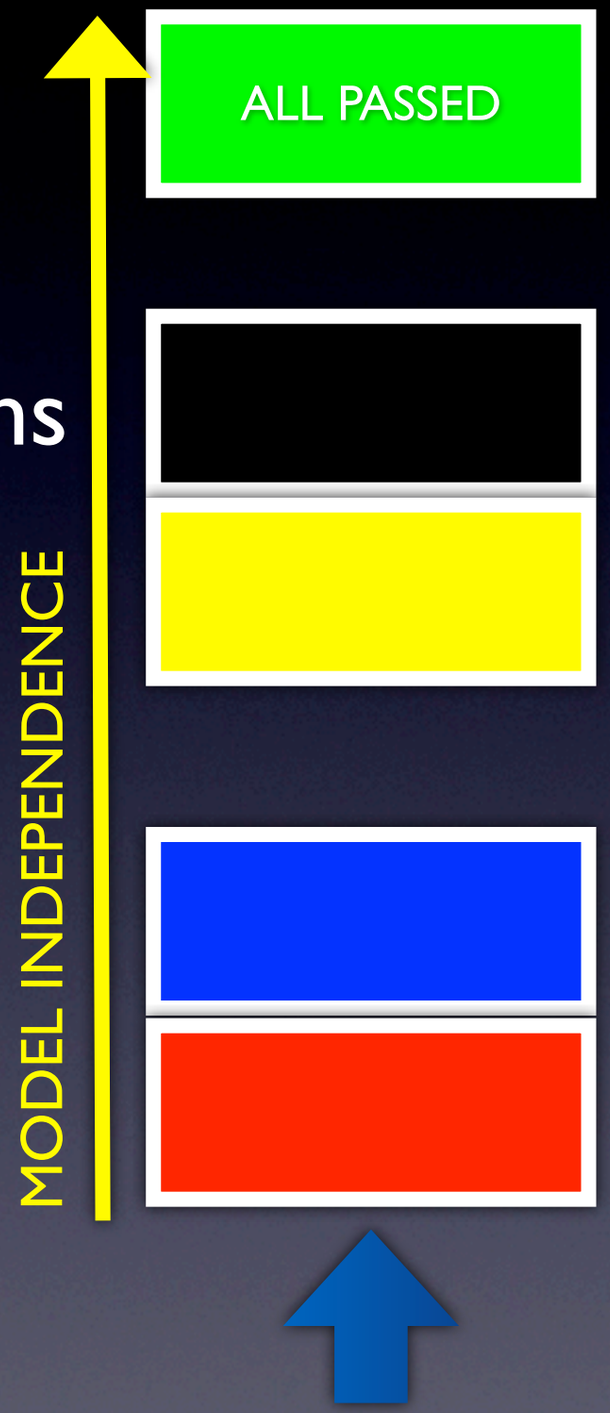

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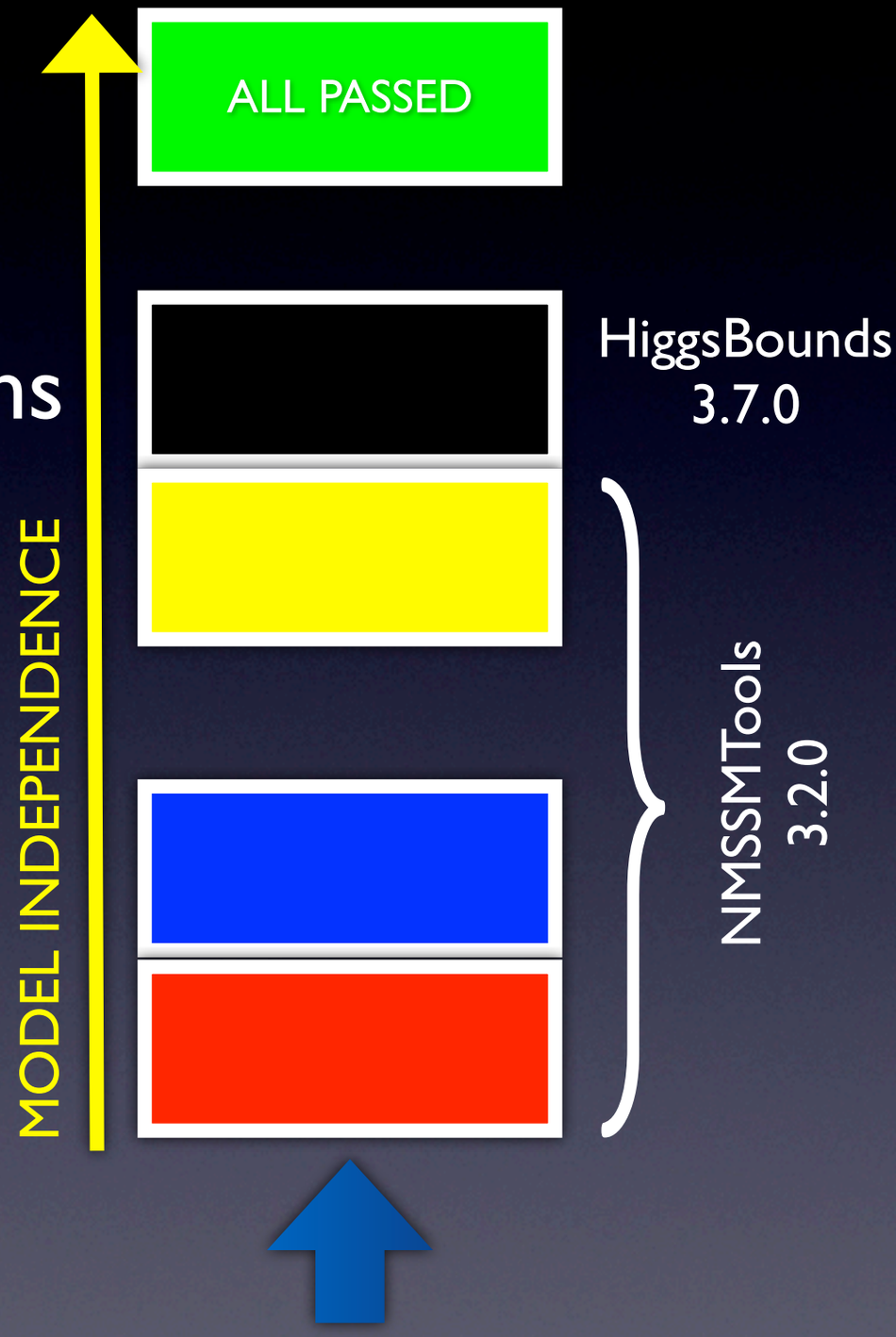
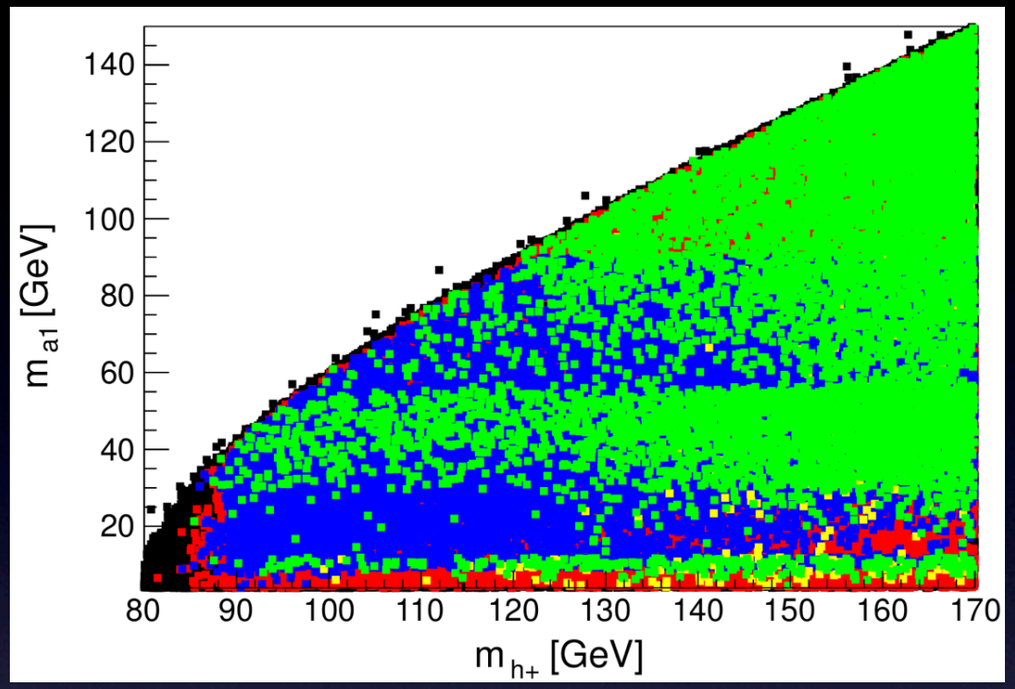
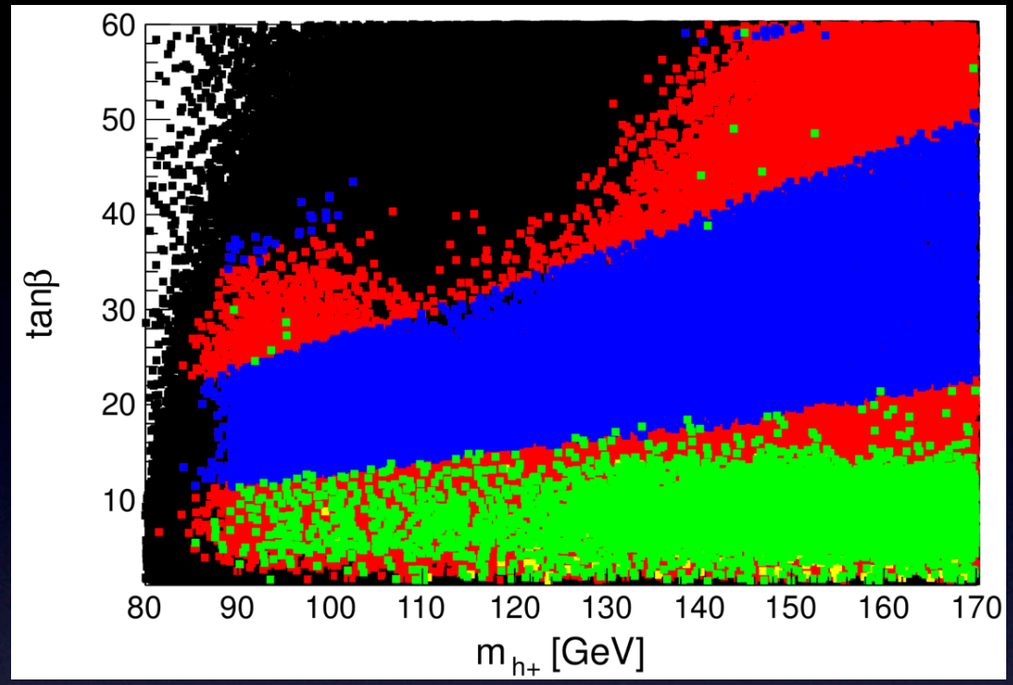
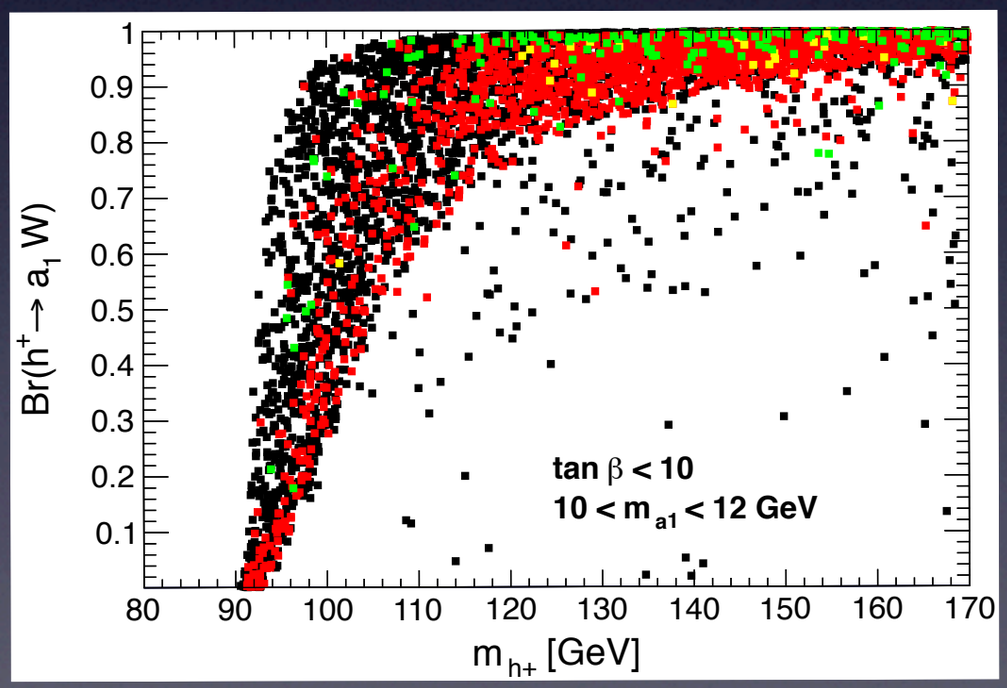


Experimental constraints II







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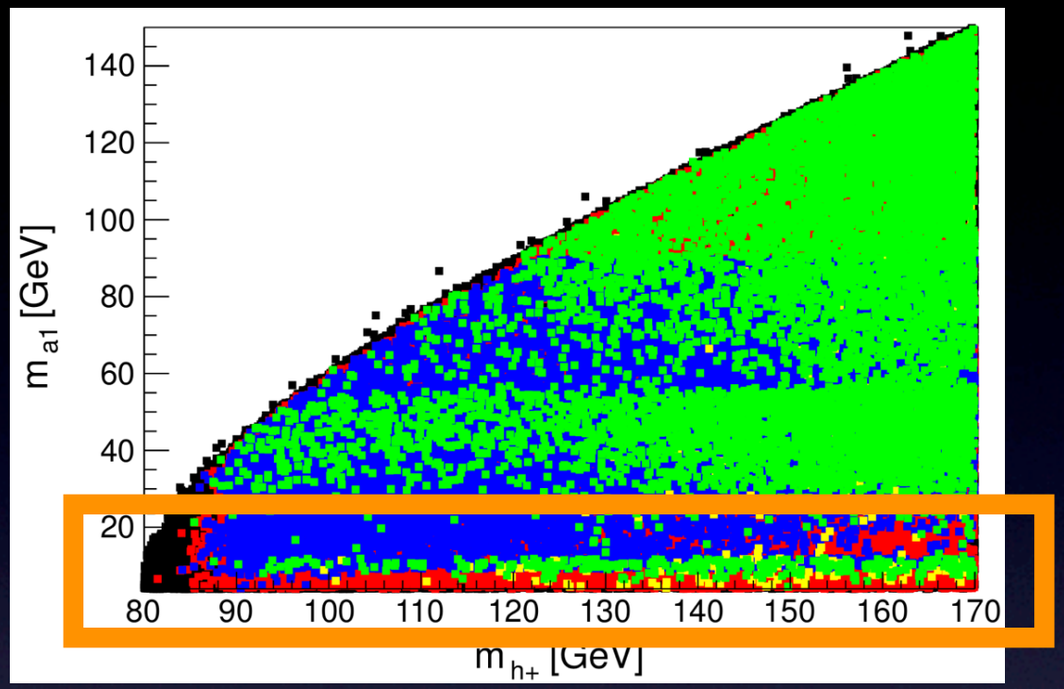
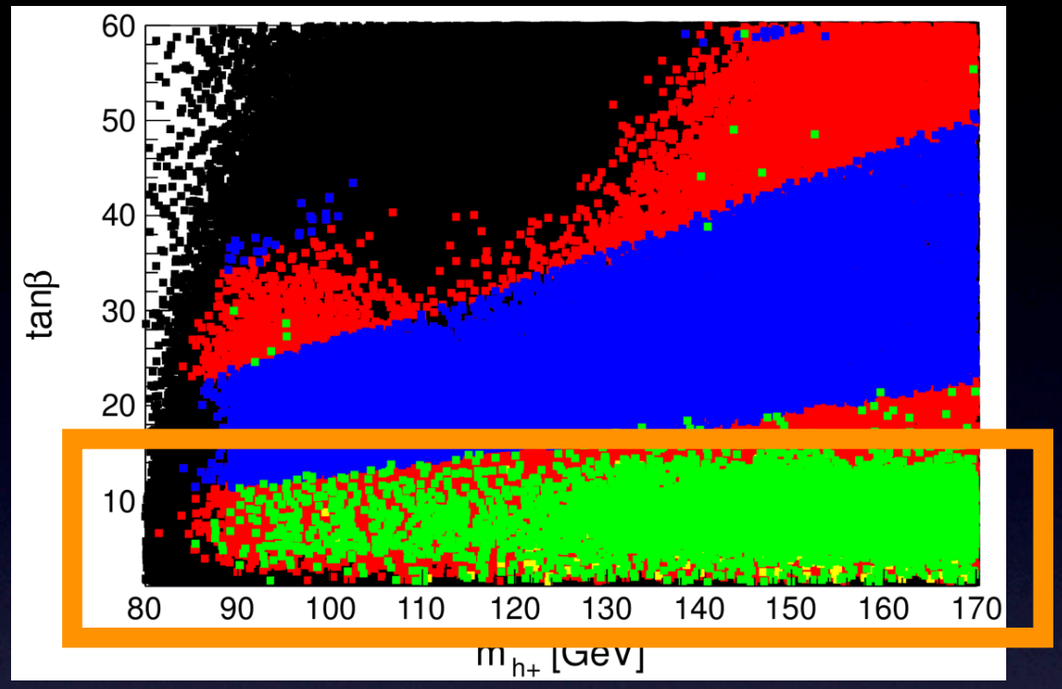
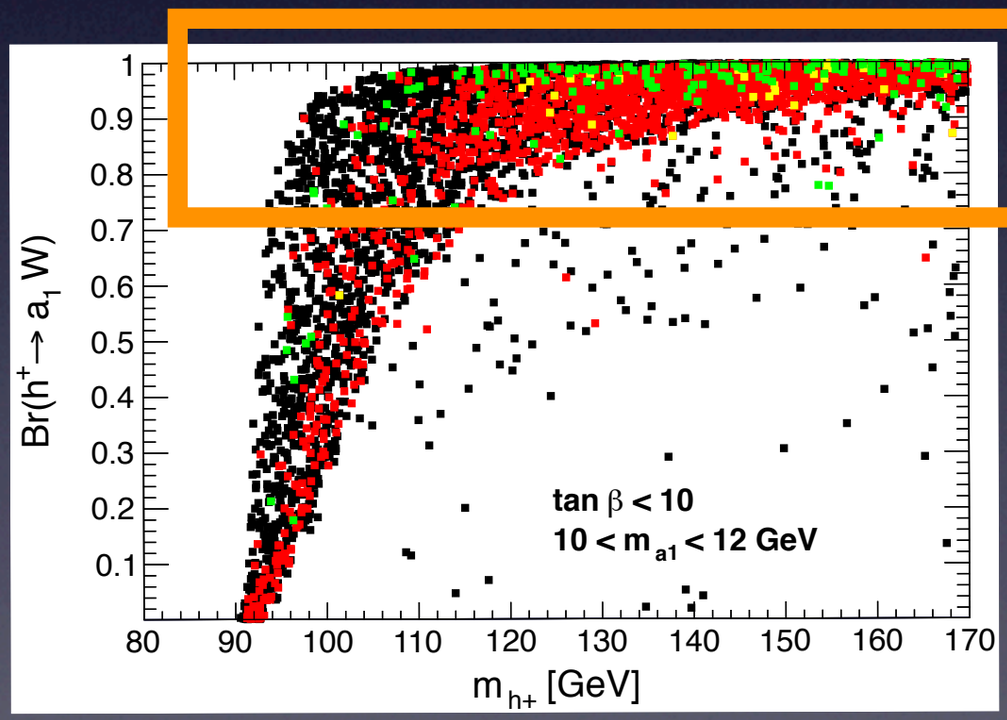






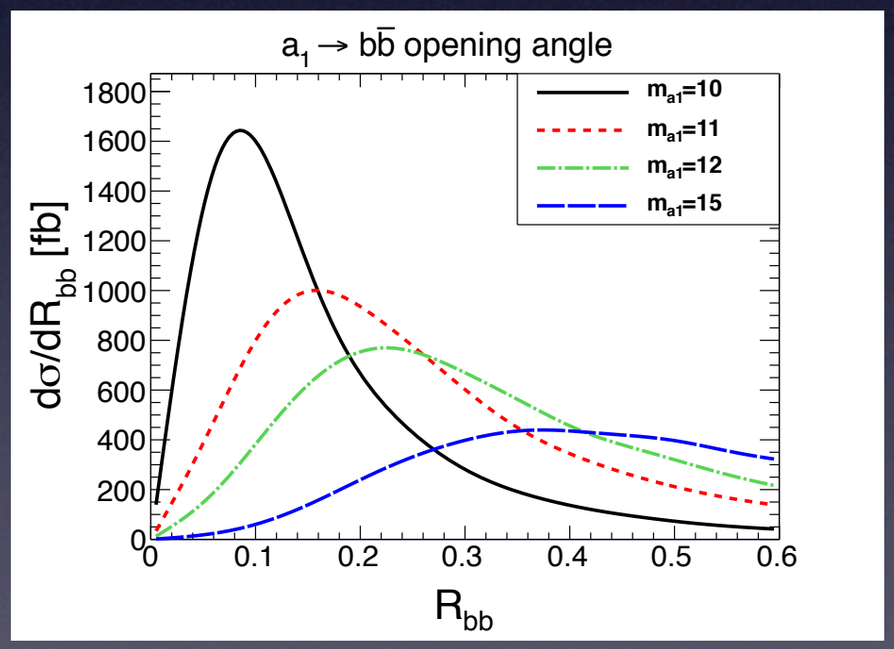
allowed for essentially all charged Higgs masses

$h^{\pm} \to a_1 W$ dominant in this region

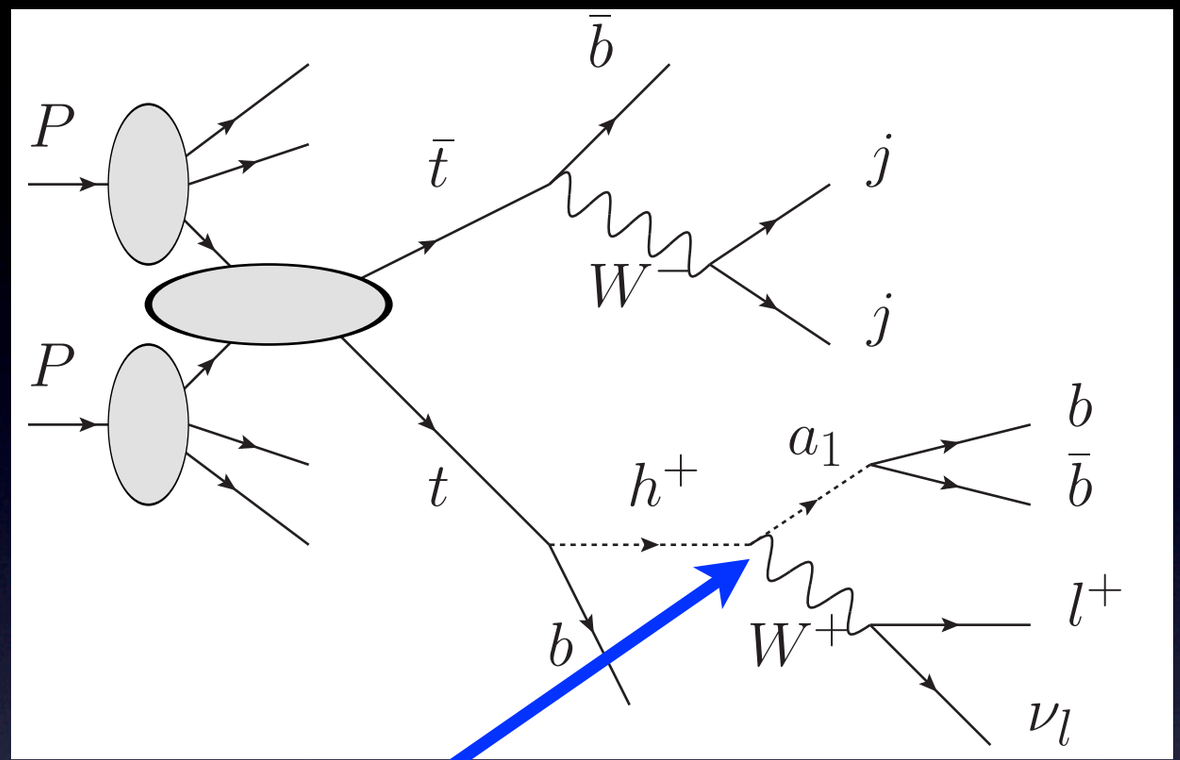
S/B analysis

- LHC @ 8 TeV
- m_{a_1} set to 11 GeV
- m_{h^+} =100/130/150 GeV

  repr. kinematic cases



⇒ to be clustered as 1 jet



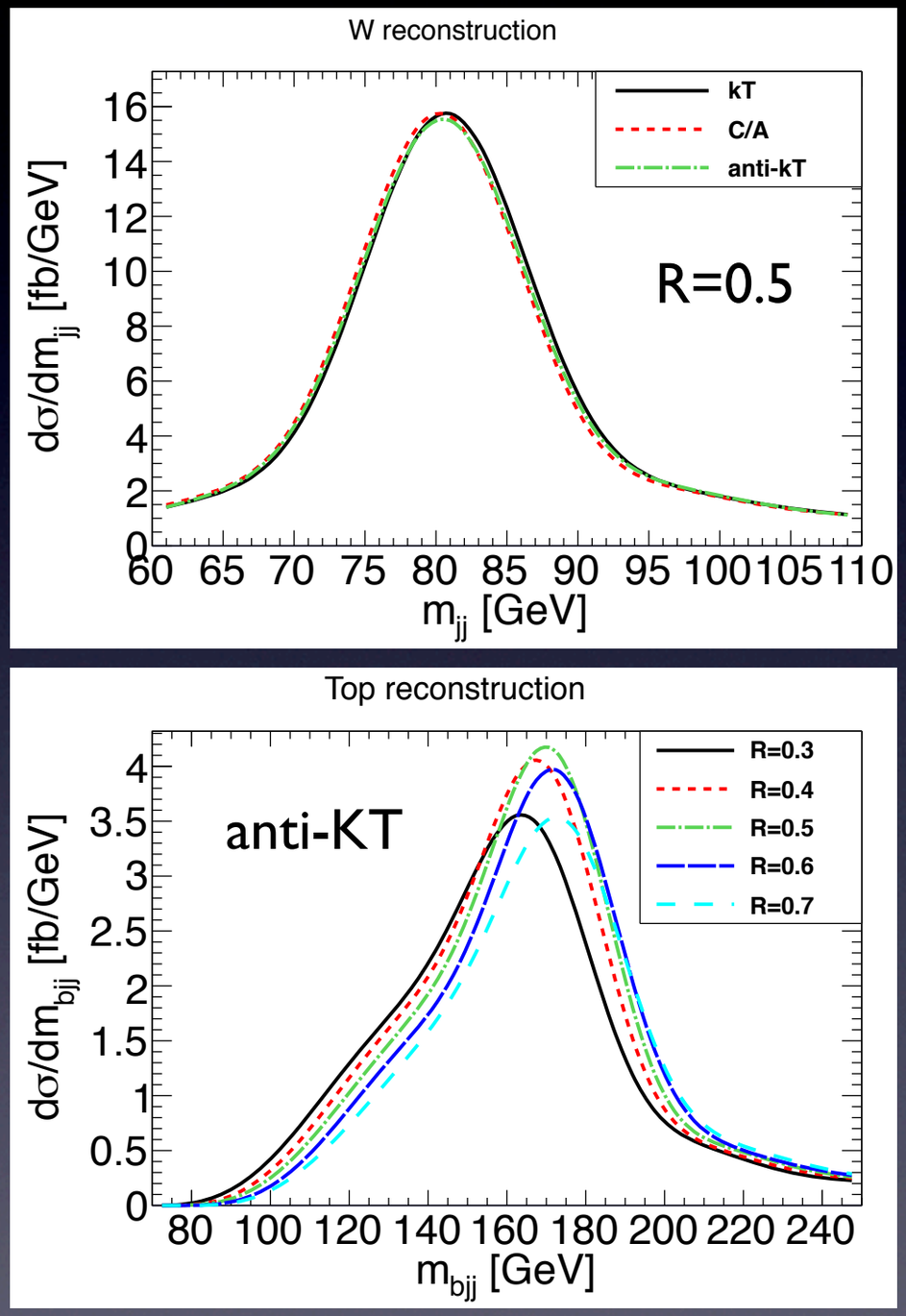
- $\cos^2\theta_A$ dependence
- W+/- lept./hadr. selected
- BG: $t\bar{t}b\bar{b}$ and $t\bar{t}$ + mistag

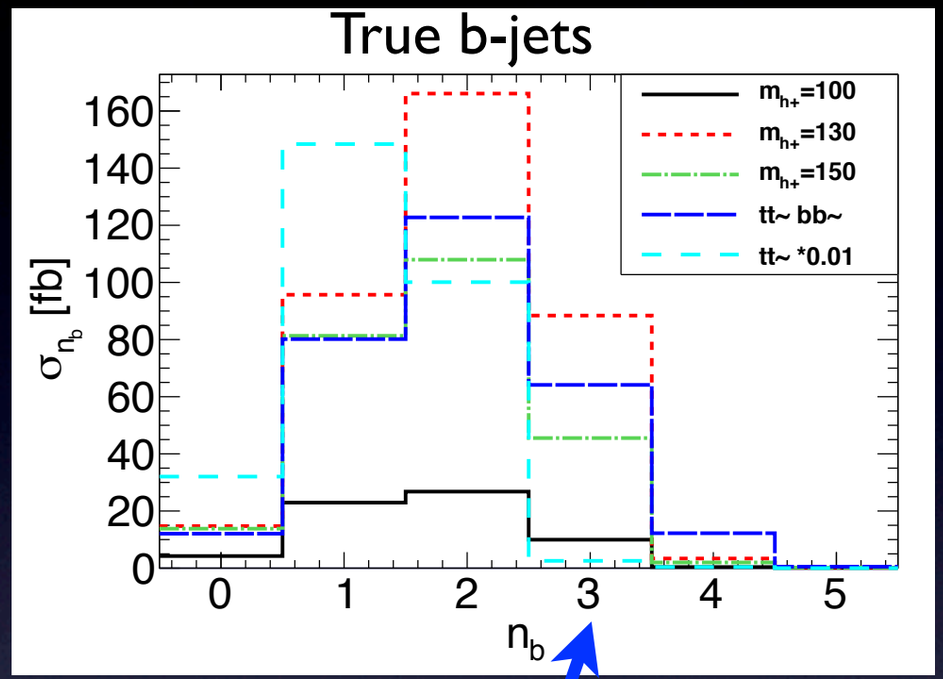
Packages, reconstruction, tagging

- ME from 2HDMC / MadEvent 5 1.3.16
- Full hadron-level simulation using PYTHIA 8.1.5.3
- Jet recon. using FastJet libraries (anti-kT, R=0.5)
- Simplified b-tagging sim.: cone R=0.4 around true parton-level b-quark if $|\eta|$ < 2.5, assumed efficiency 0.6
- reducible BG: $t\bar{t}$ + mistag (0.01 mistag probability for jets inside tagger region)

Reconstruction

- std kinematical cuts (iso. lepton, lepton $p_\perp$, η, MET, ...)





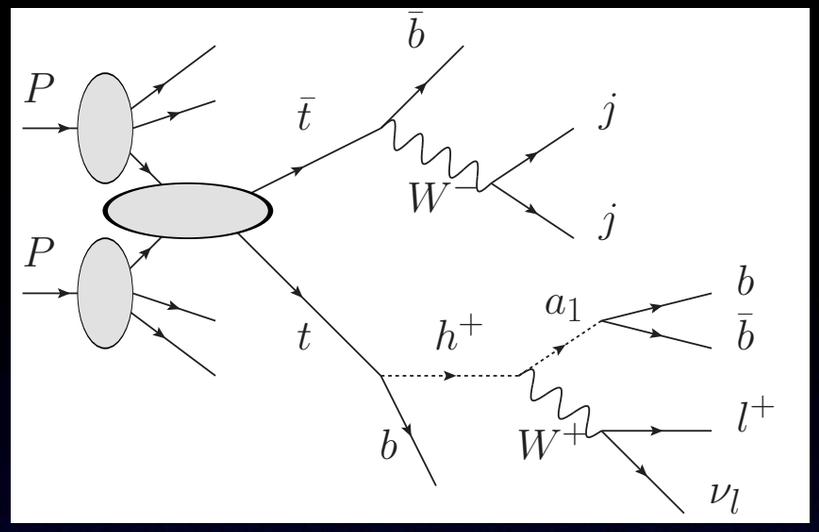
no double-counting
$\Rightarrow$ remove $t\bar{t}b\bar{b}$ part of the $t\bar{t}$

$\Rightarrow t\bar{t}$ contributes only with mistagged jets

Require $\geq$3 b-jets

for signal and irreducible BG

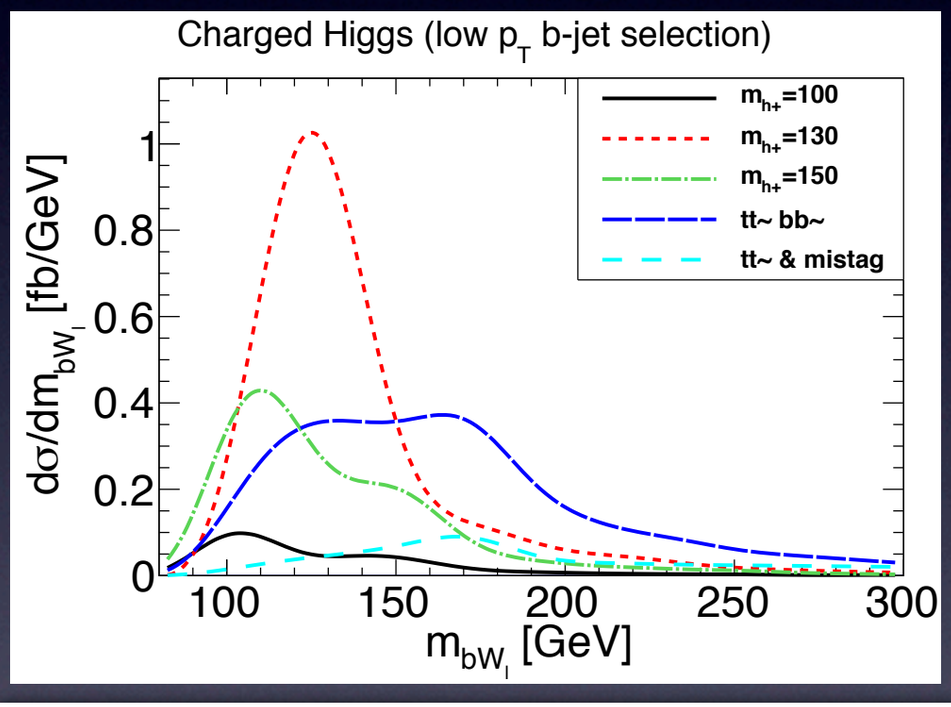
h+ reconstruction

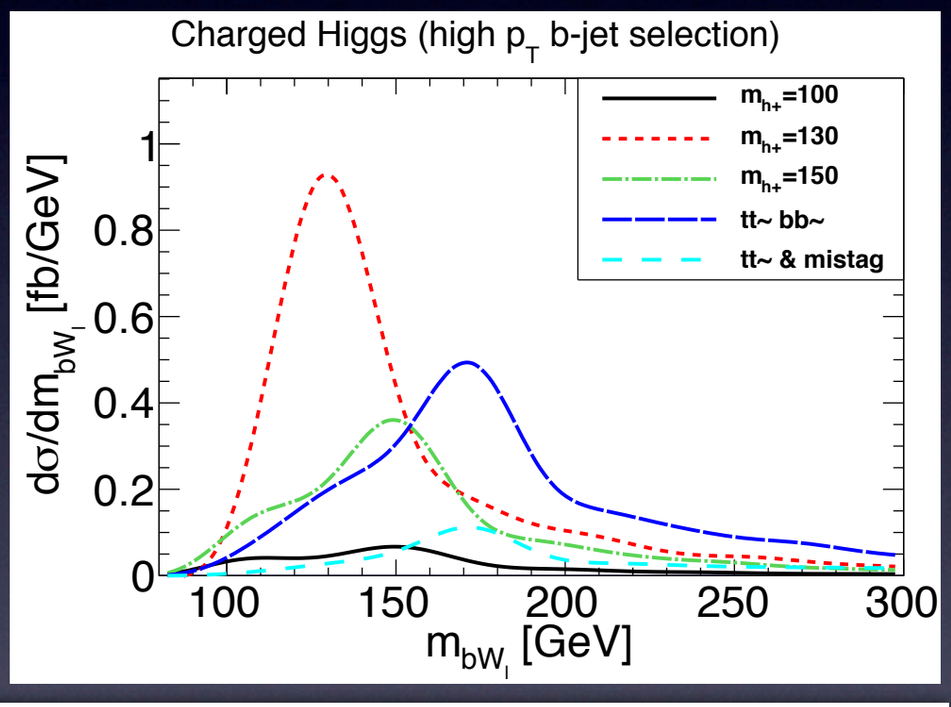


ambiguity in identifying

$a_1 \to b\bar{b} \to b-\text{jet}$

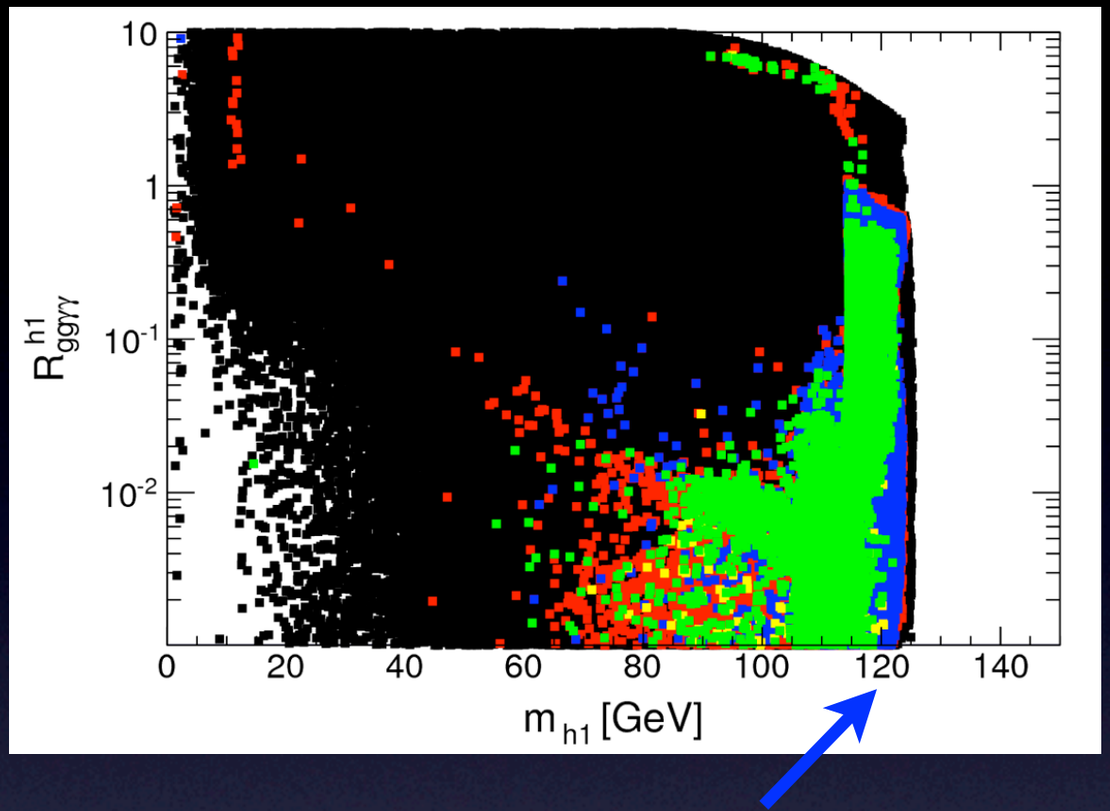
$W_{lept} \to b-\text{jet}$



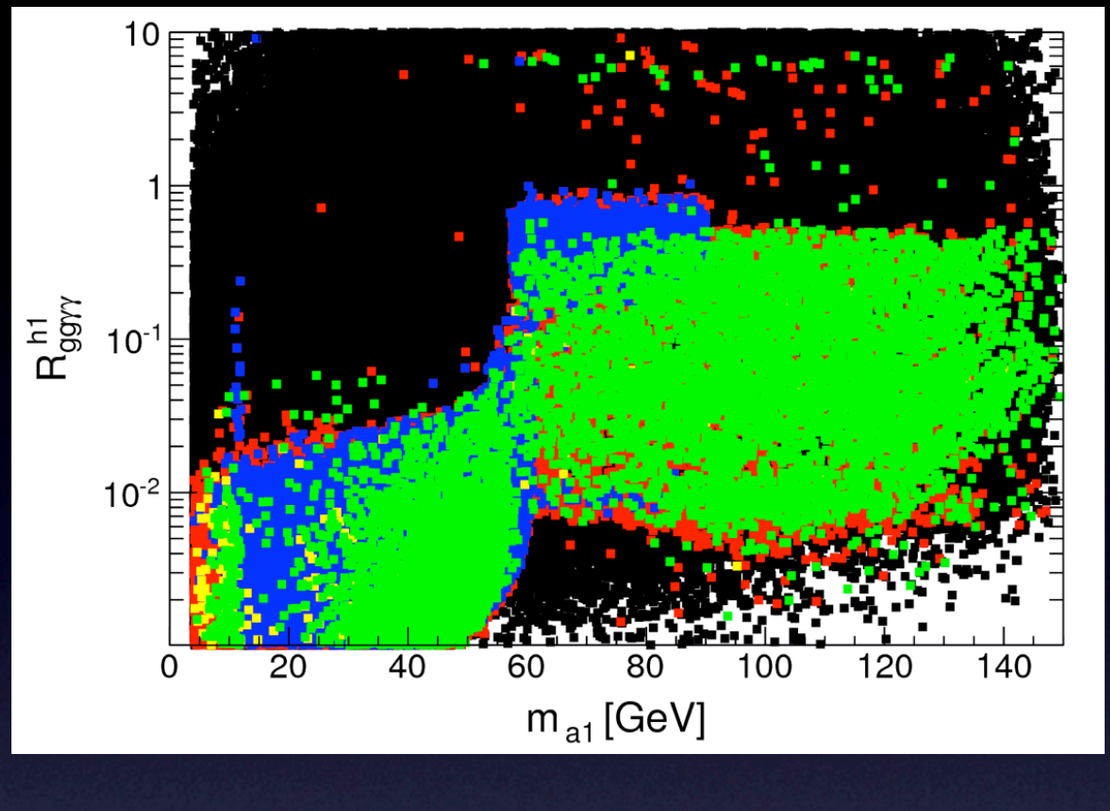


$m_{h^\pm}$	100 GeV		130 GeV		150 GeV	
b-jet selection	high $p_\perp$	low $p_\perp$	high $p_\perp$	low $p_\perp$	high $p_\perp$	low $p_\perp$
$\text{BR}_{crit}(t \to bh^+ \to ba_1W \to bb\bar{b}W)$	0.014	0.014	0.0060	0.0065	0.0085	0.0085

Compatibility with „Higgs“ signal I



theoret. uncertainty?
other scenario?

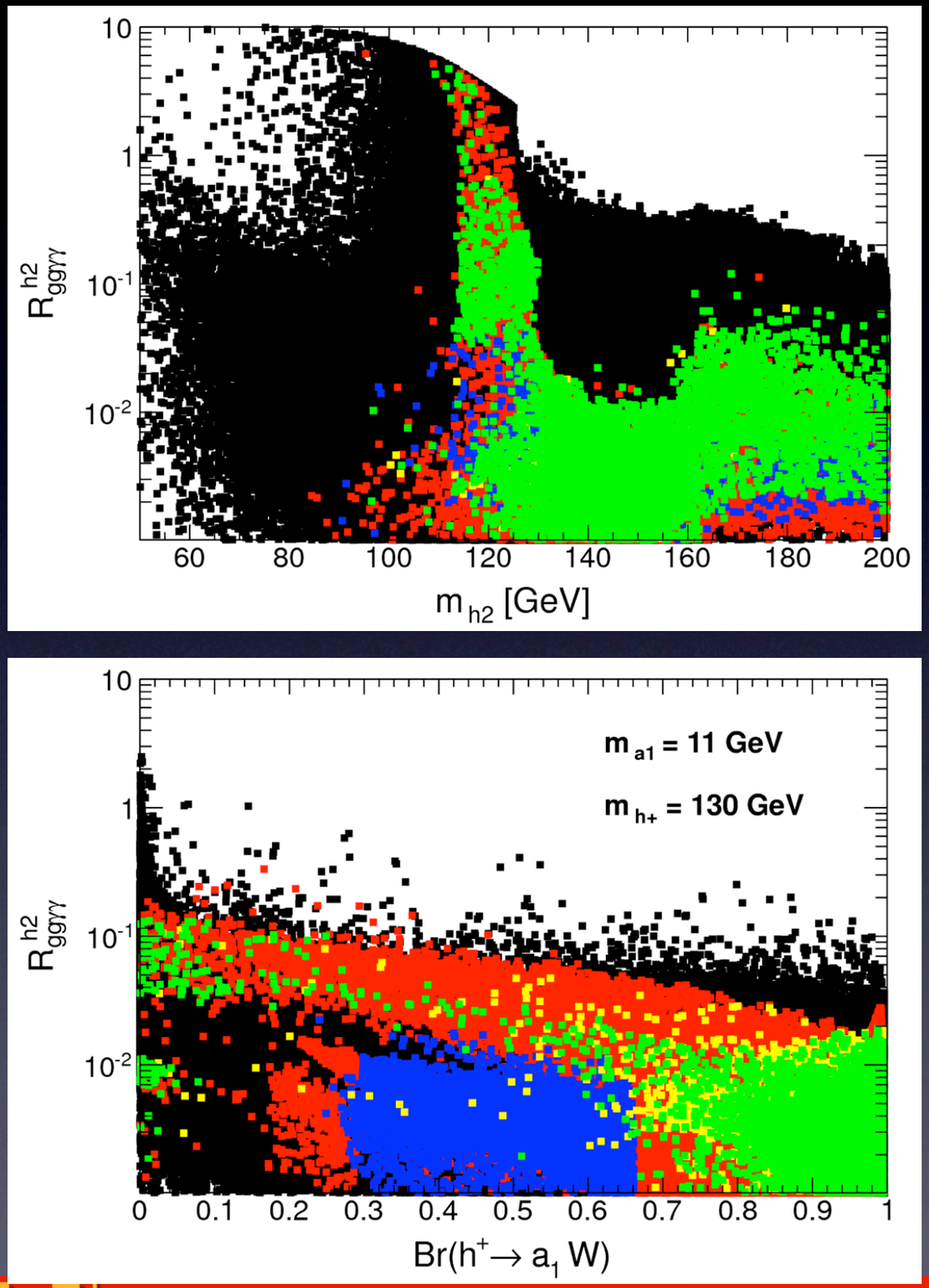


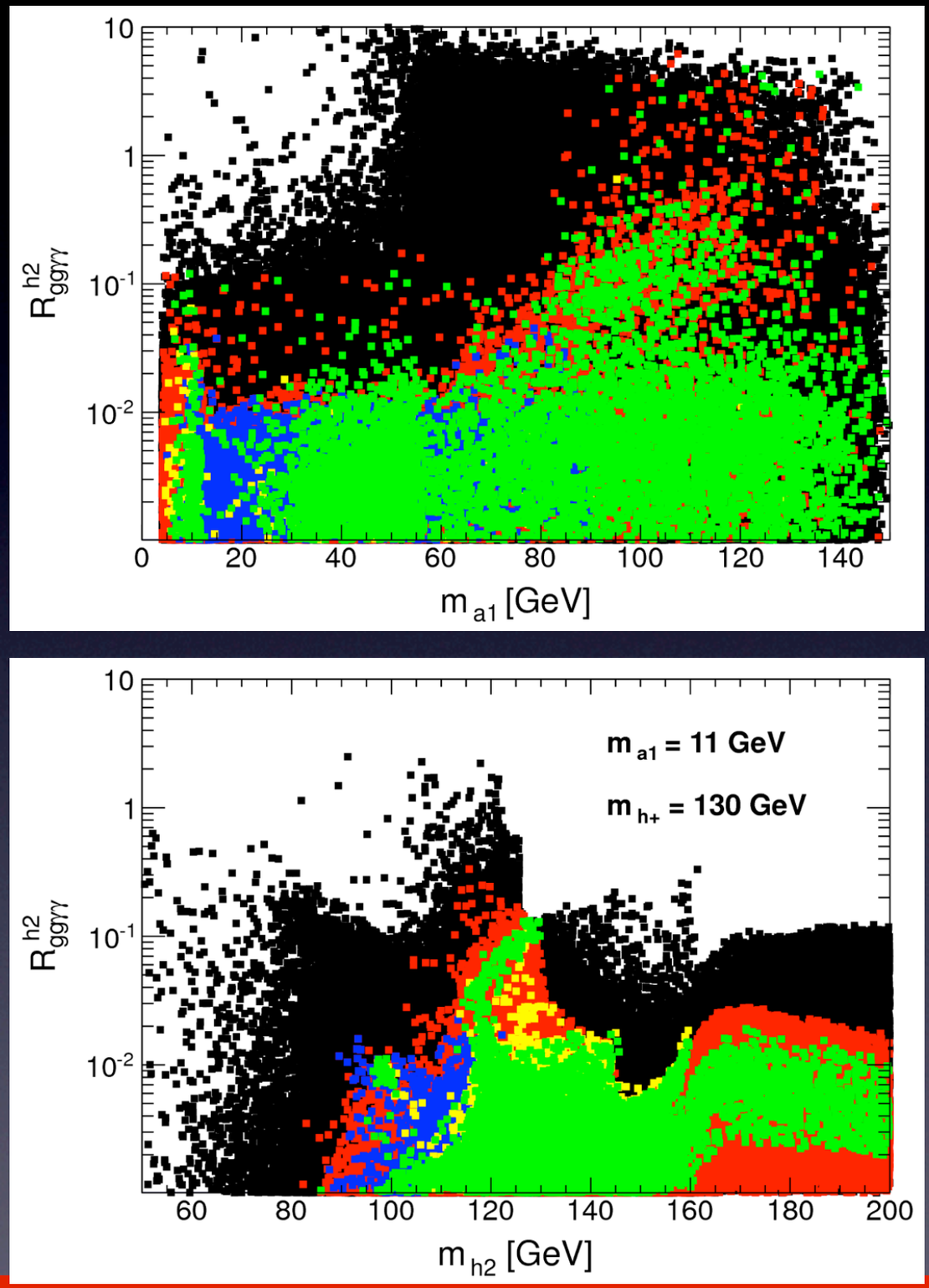
h_1 lightest CP-even Higgs

$$R^{h_i}_{gg\gamma\gamma} = \frac{\sigma(gg \to h_i)_{\rm NMSSM}}{\sigma(gg \to \phi)_{\rm SM}} \frac{Br(h_i \to \gamma\gamma)_{\rm NMSSM}}{Br(\phi \to \gamma\gamma)_{\rm SM}}$$

ATLAS 1.8 ± 0.5
CMS 1.6 ± 0.4

Compatibility with „Higgs“ signal II





Conclusion

- Constraints on parameter space (incl. LHC) for NMSSM from direct searches and indirect/flavour observables
- Light CP-odd Higgs signal search in $t\bar{t}$ production using $h^{\pm} \to a_1 W$:
  signal visible if combined BR $t \to b h^+ \to b a_1 W \to b b \bar{b} W$ is larger than ≈ 0.01
- ATLAS/CMS Higgs signal: different scenarios of compatibility: h_2 seems to be most promising

Thank you

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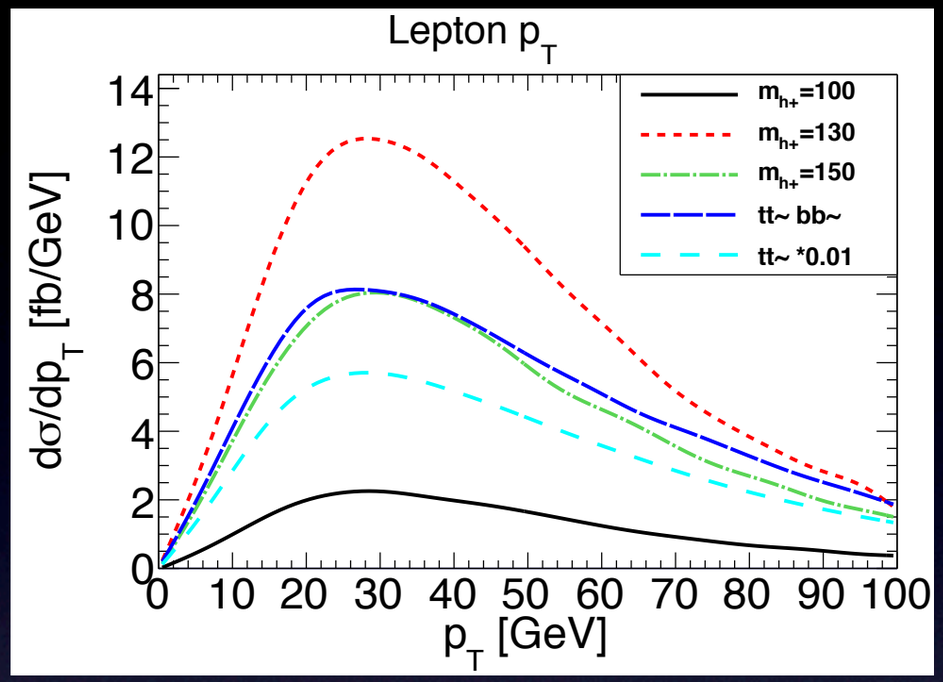
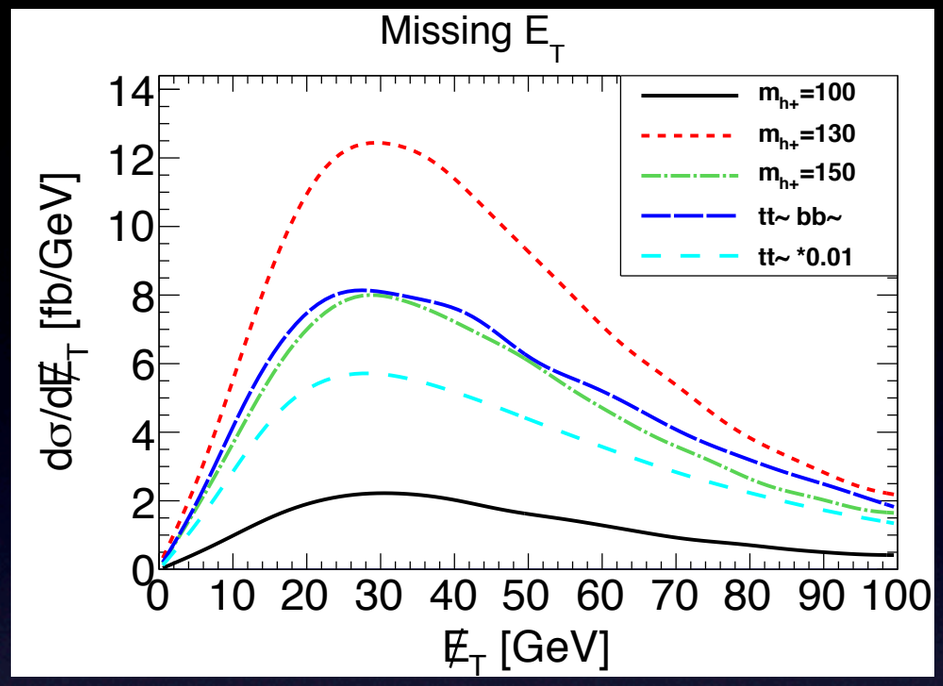
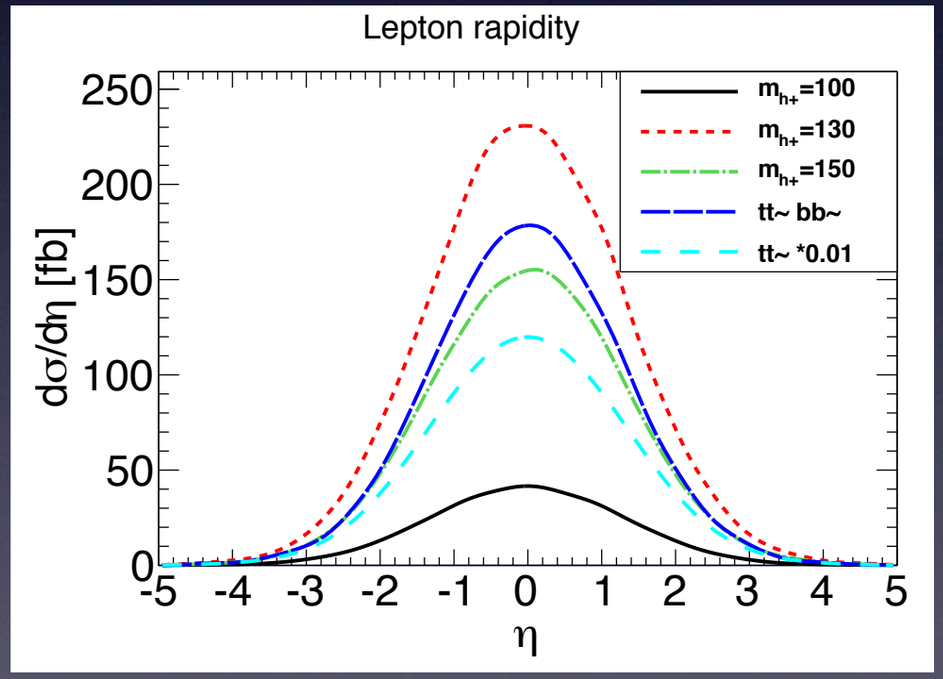
Backup

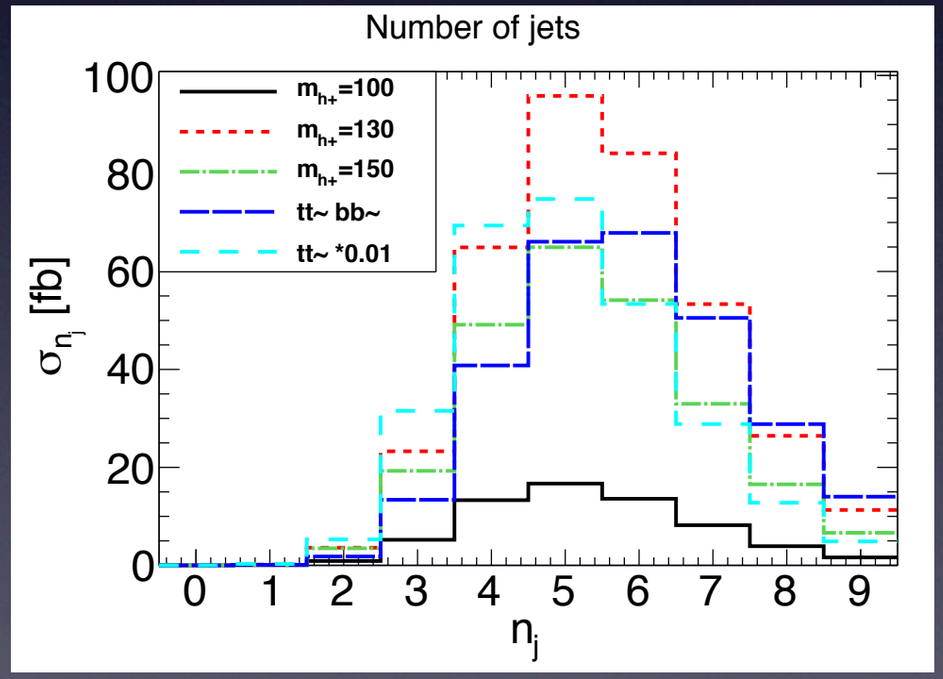
Vertex	NMSSM	MSSM	SM
h_1tt	$\frac{\mathbf{S}_{11}}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	1
h_1bb	$\frac{\mathbf{S}_{12}}{\cos\beta}$	$\frac{\sin\alpha}{\cos\beta}$	1
h_2tt	$\frac{\mathbf{S}_{21}}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	n.a.
h_2bb	$\frac{\mathbf{S}_{22}}{\cos\beta}$	$\frac{\cos\alpha}{\cos\beta}$	n.a.
a_1tt	$\cot\beta\ \cos\theta_A$	$\cot\beta$	n.a.
a_1bb	$\tan\beta\ \cos\theta_A$	$\tan\beta$	n.a.
h_1VV	$\sin\beta\,\mathbf{S}_{11}+\cos\beta\,\mathbf{S}_{12}$	$\sin(\beta-\alpha)$	1
h_2VV	$\sin\beta\,\mathbf{S}_{21}+\cos\beta\,\mathbf{S}_{22}$	$\cos(\beta-\alpha)$	n.a.
a_1h_1Z	$(\cos\beta\,\mathbf{S}_{11}-\sin\beta\,\mathbf{S}_{12})\cos\theta_A$	$\cos(\beta-\alpha)$	n.a.
a_1h_2Z	$(\cos\beta\,\mathbf{S}_{21}-\sin\beta\,\mathbf{S}_{22})\cos\theta_A$	$\sin(\beta-\alpha)$	n.a.
$h_1h^+W^-$	$\cos\beta\,\mathbf{S}_{11}-\sin\beta\,\mathbf{S}_{12}$	$\cos(\beta-\alpha)$	n.a.
$a_1h^+W^-$	$\cos\theta_A$	1	n.a.

Kinematical distributions

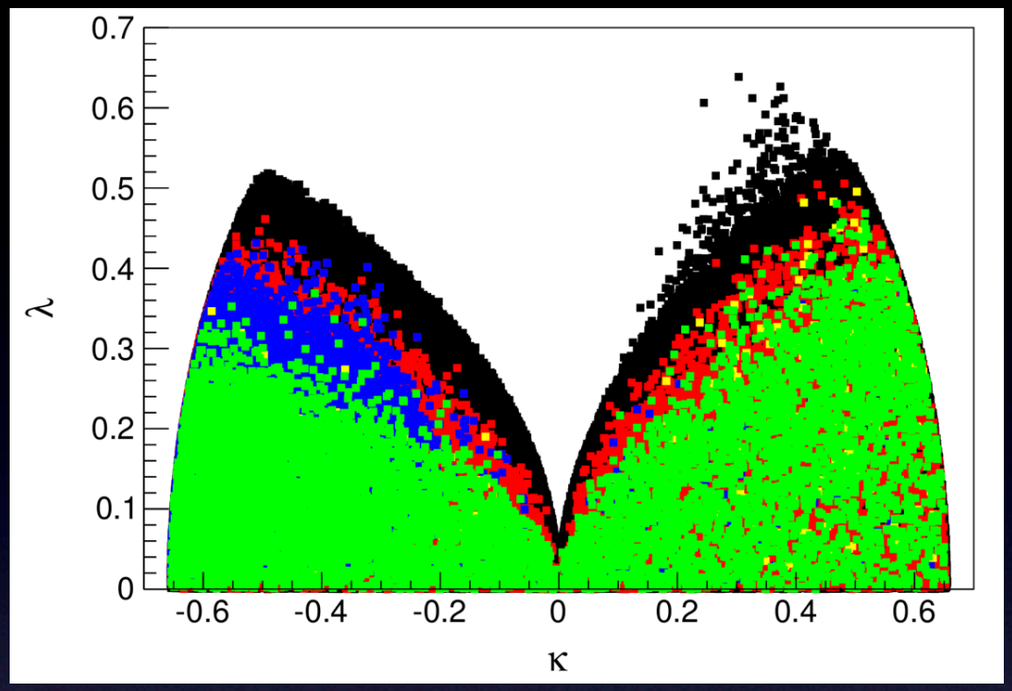


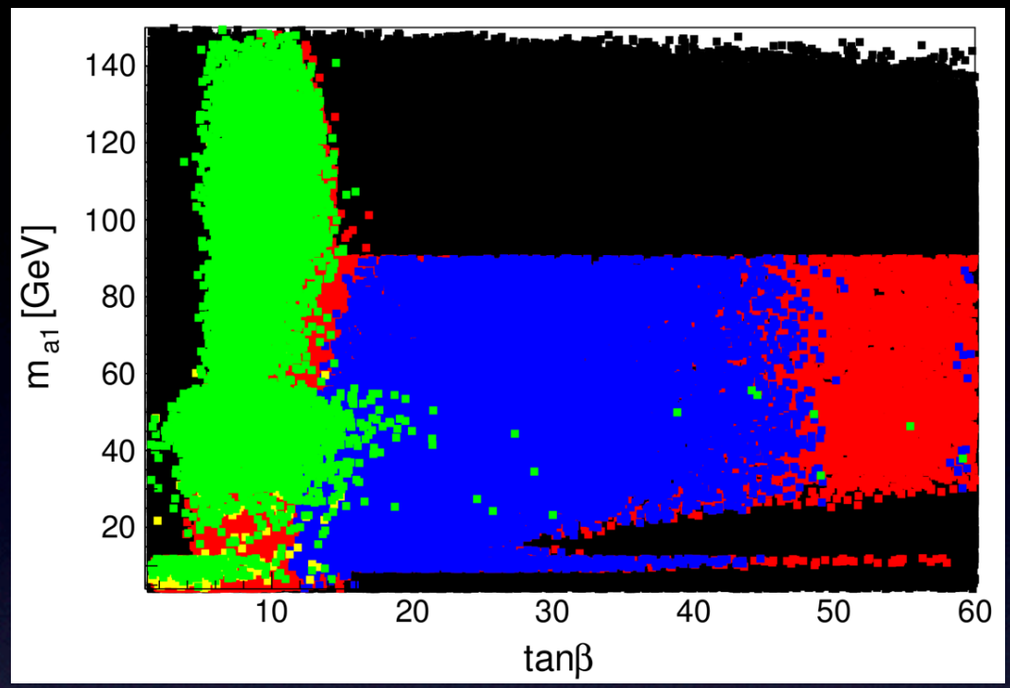


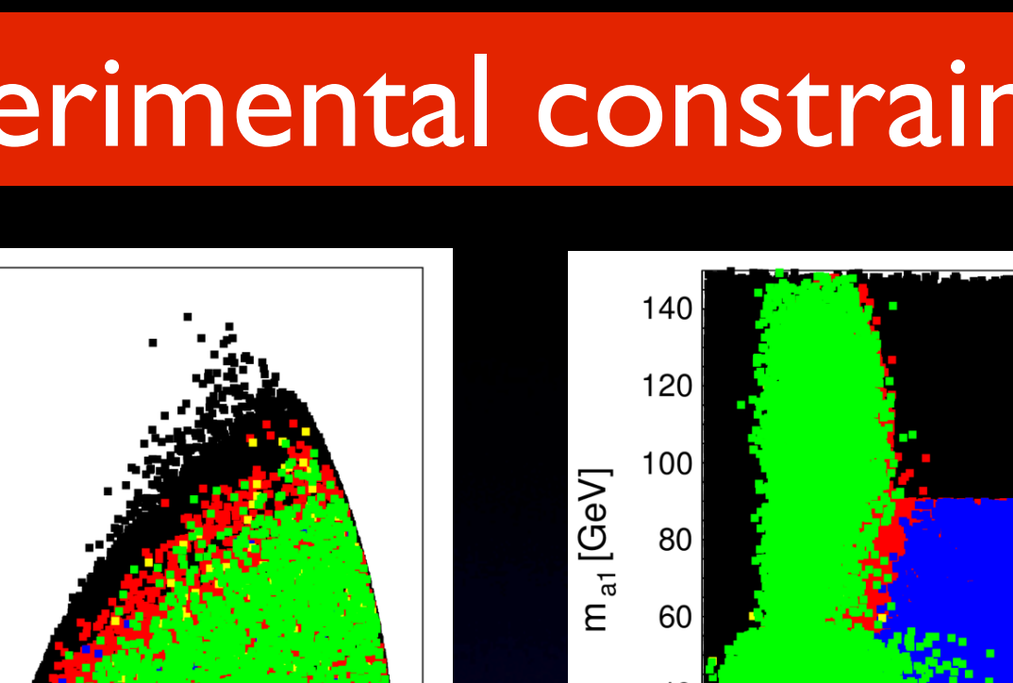




Experimental constraints II







Experimental constraints III