LHCHWG Workshop
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2HDM Scans

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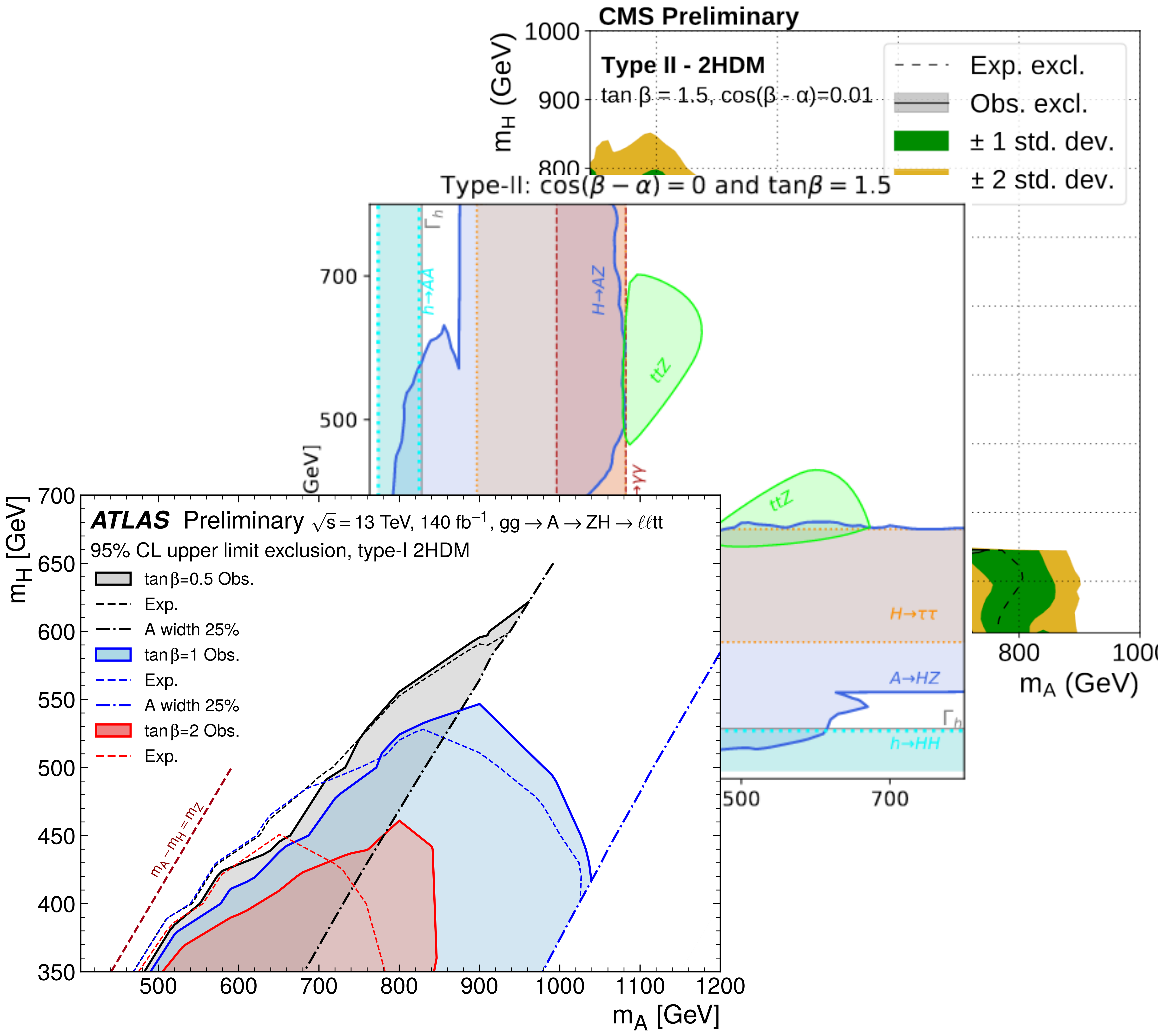
2HDM interpretations

A large plethora of analyses targeting BSM physics is performed at the LHC and several of them aim at setting constraints on 2HDM parameters

The analyses are often performed in a "model-independent" way and the results are consequently interpreted in the context of 2HDM (or any other BSM physics model)

⇒ It is fundamental to enforce a consensus on the theoretical inputs and calculations used for these interpretations, so to ensure cross-compatibility and consistency of the results/exclusion contours



Centrally provided inputs

Computations for 2HDM parameters available in the LHCHXSWG TWiki, but:

Introduction

This is a description on how to access cross sections and BRs for 2HDM benchmark points.

A generic CP-conserving 2HDM with a softly broken Z_2 symmetry ($\Phi_1 \to \Phi_1, \Phi_2 \to -\Phi_2$) has 7 free parameters:

- Higgs bosons: 2 CP-even with masses `mH` and `mh`; 1 CP-odd with mass `mA`; two charged scalars with mass `mCh`
- a mixing angle among the neutral Higgses, α
- the ratio of the vevs of the two Higgs doublets $\tan\beta = u1/u2$
- the m_{12} parameter of the potential, which is the softly breaking term of the Z_2 symmetry of the potential.

To define benchmarks we usually set `mh` = 125 GeV. The rest of the parameters can be assigned in principle arbitrary values. Nevertheless, the mass splitting among the rest of the Higgs bosons cannot be very large (e.g. >200 GeV) due to theoretical considerations. The m_{12} has also to be finely tuned in order to get a valid model.

In the limit $\sin(\beta - \alpha) \to 1$ then the choice $m_{12}^2 = m_A^2 \tan\beta/(1 + \tan^2\beta)$ gives always a valid model. This is the SM-like limit of the 2HDM (which is different from the decoupling limit).

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Row	m12_2	mH	mA
8	45000	300	540
9	45000	300	540
14	101250	450	520
15	101250	450	520
20	20000	200	230
21	20000	200	230
30	20000	200	300
31	20000	200	300
32	140450	530	750
33	140450	530	750
54	16200	180	680
55	16200	180	680
66	45000	300	350
67	45000	300	350
76	88200	420	540
77	88200	420	540

The value of m12 in the `root` file is inconsistent with what written in the TWiki

At tanb=1 we have $m_{12}^2 \propto m_H^2$

Why do we care about m_{12}?

m_{12} is one of the free parameters in the physical basis of the 2HDM :

Table 3: Parameter values used in the cross section prediction in the 2HDM.

Parameter	Value
m_{h}	125 GeV
$m_{\mathrm{H}^\pm}$	$\max(m_{\mathrm{A}}, m_{\mathrm{H}})$
m_{12}^2	$\min(m_{\mathrm{A}}, m_{\mathrm{H}})^2 \sin(\beta)\cos(\beta)$
$\cos(\beta-\alpha)$	0.01
$\lambda_{6/7}$	0

Being a free parameter, one can ideally choose any value, but the two most common ones are:

$$m_{12}^2 \propto \textbf{max}(m_A, m_H)^2 \textbf{ or } m_{12}^2 \propto \textbf{min}(m_A, m_H)^2$$

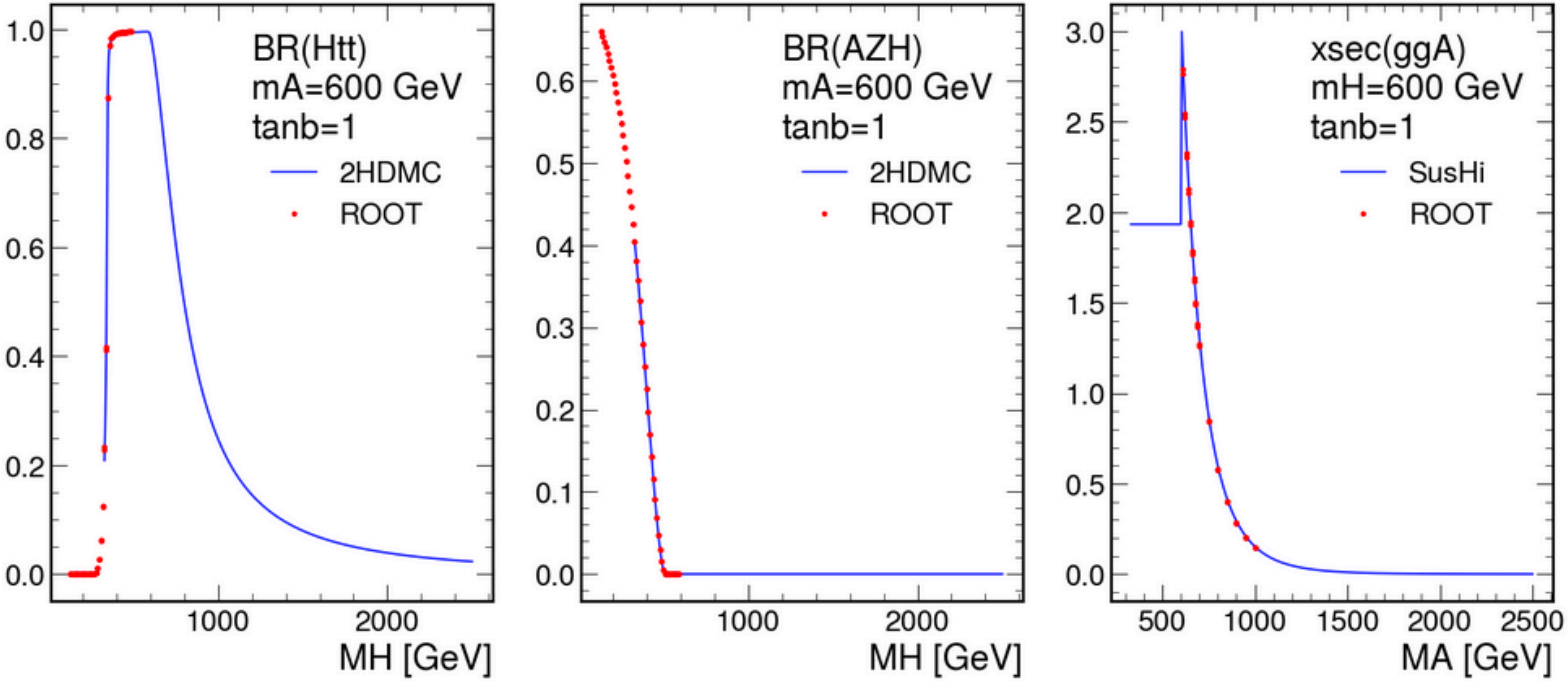
Which have different implications on the 2HDM theory values and vacuum stability

Note: Using $m_{12}^2 \propto m_A^2$ was apparently agreed upon in 2012 in the LHCHWG, but what is m_A here?

Intermezzo: validation of our results

One of the limits of the root files provided by the LHCHWG is the coarse granularity of the theory values available. Note: This affects all the analyses, which end up re-computing these numbers in most of the cases.

In order to have a fine granular coverage of the 2HDM phase space, we have re-calculated the theory values for what presented in the following. However, we have made sure that our calculations replicate the LHCHWG values when the same input parameters are used.

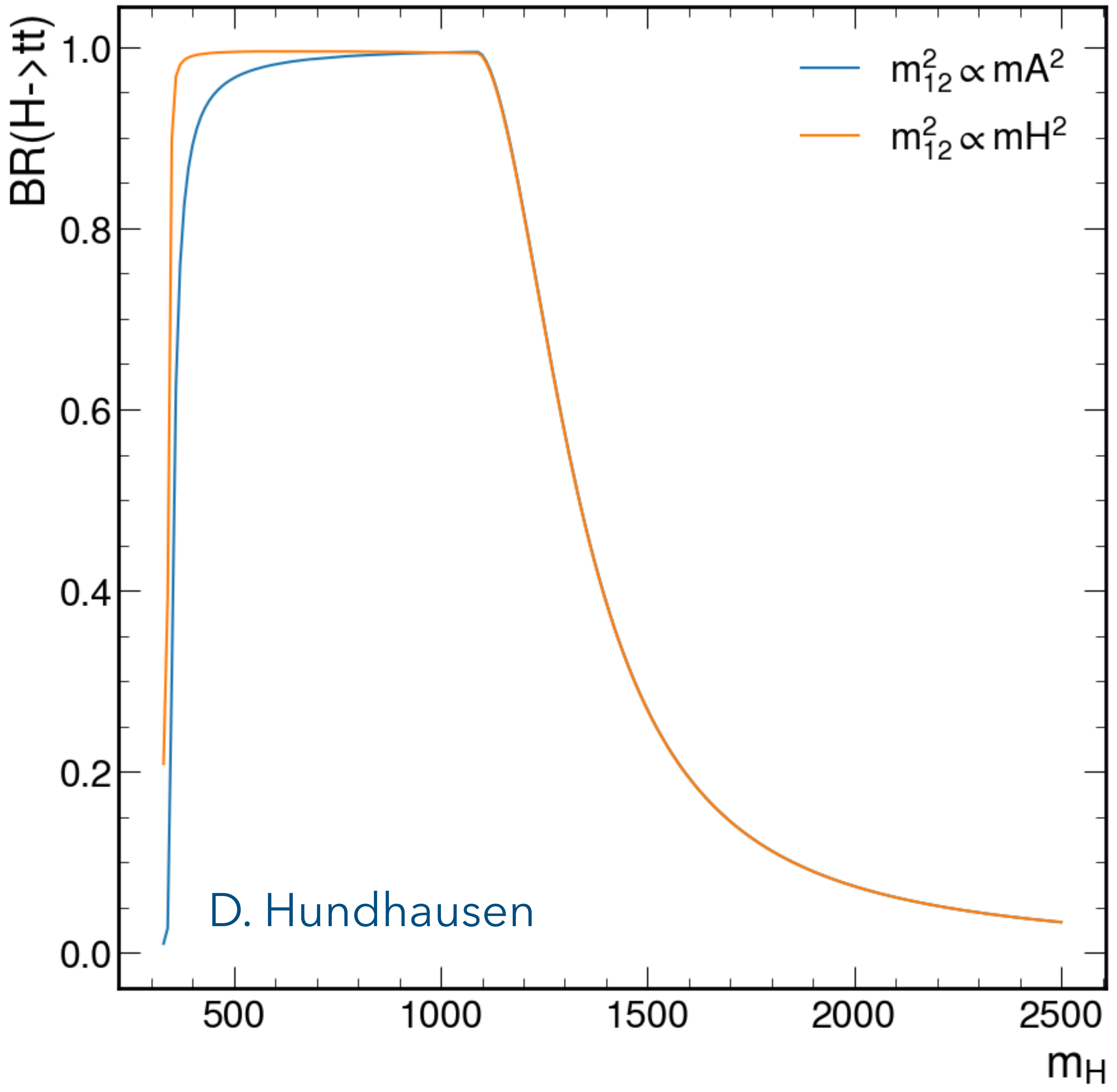


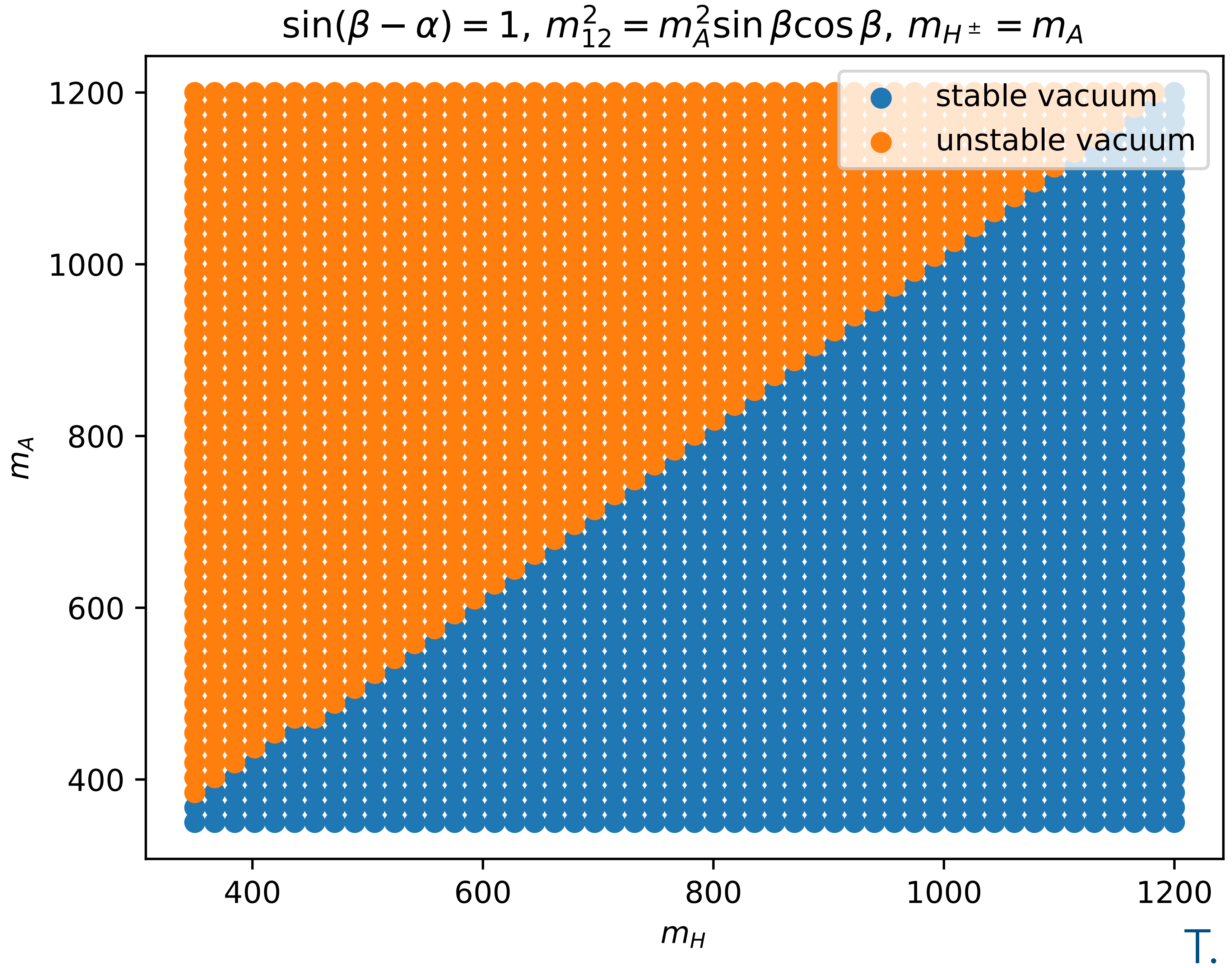
The impact of m_{12} on 2HDM

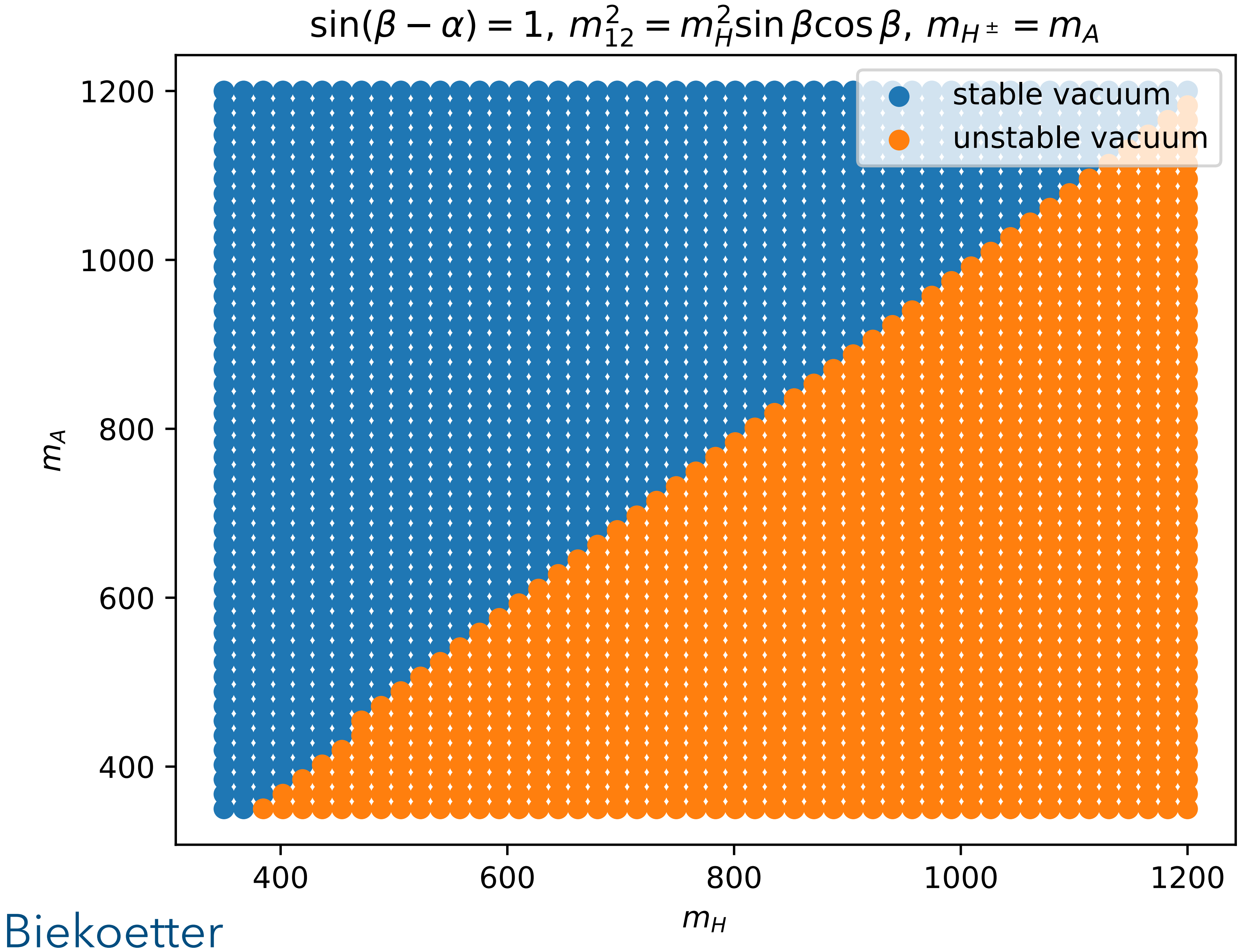
We have studied the impact of different m_{12} choices on the 2HDM parameters and concluded:

- **The only parameter affected in terms of xsec or BR is BR(H->tt), for more than 20% discrepancy at low m_H**

- **Different choices of m_{12} have also an impact on the vacuum stability** (private communication T. Biekoetter (KIT))
  $\Rightarrow$ **impact on our interpretations**







T. Biekoetter

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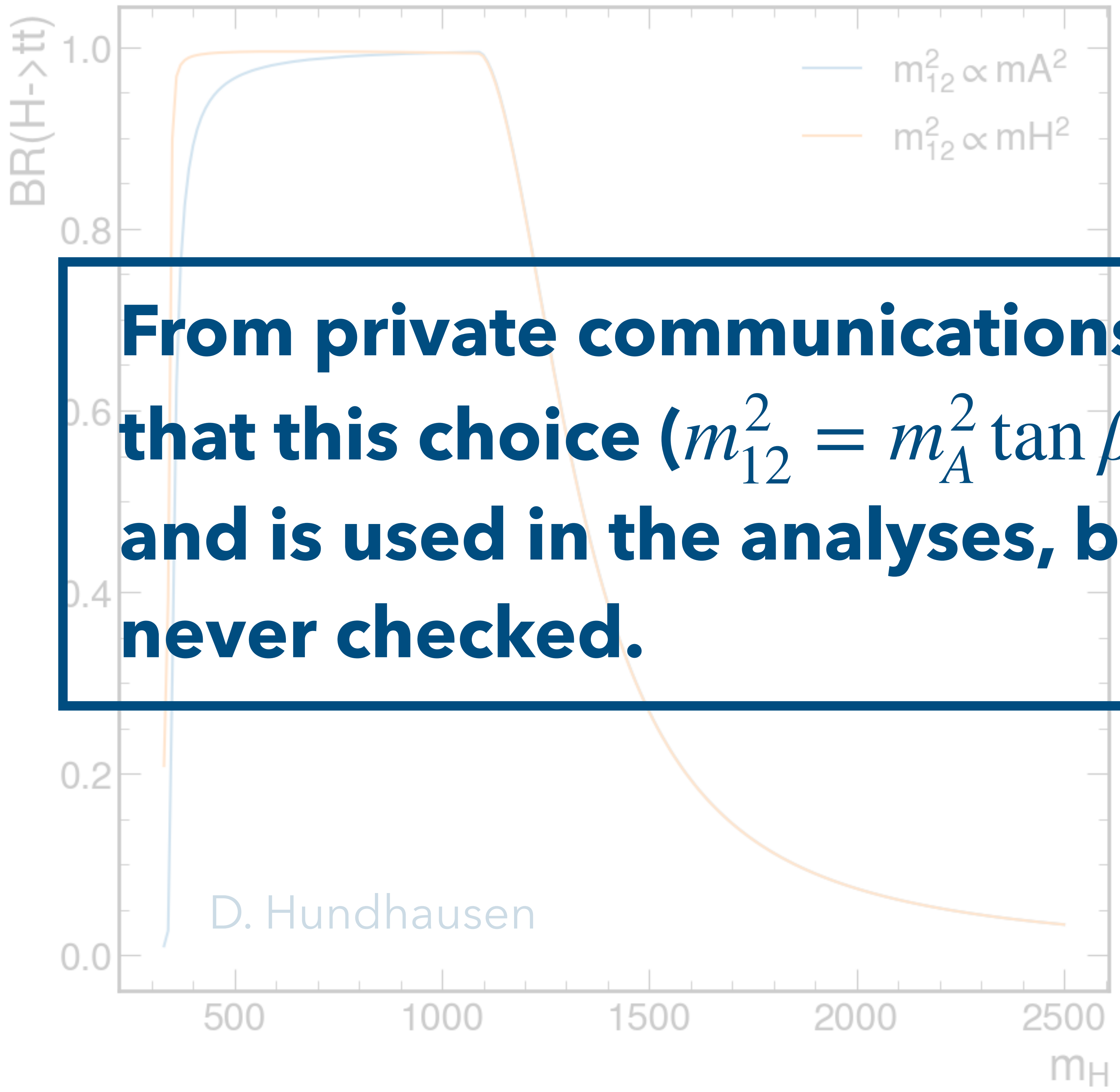

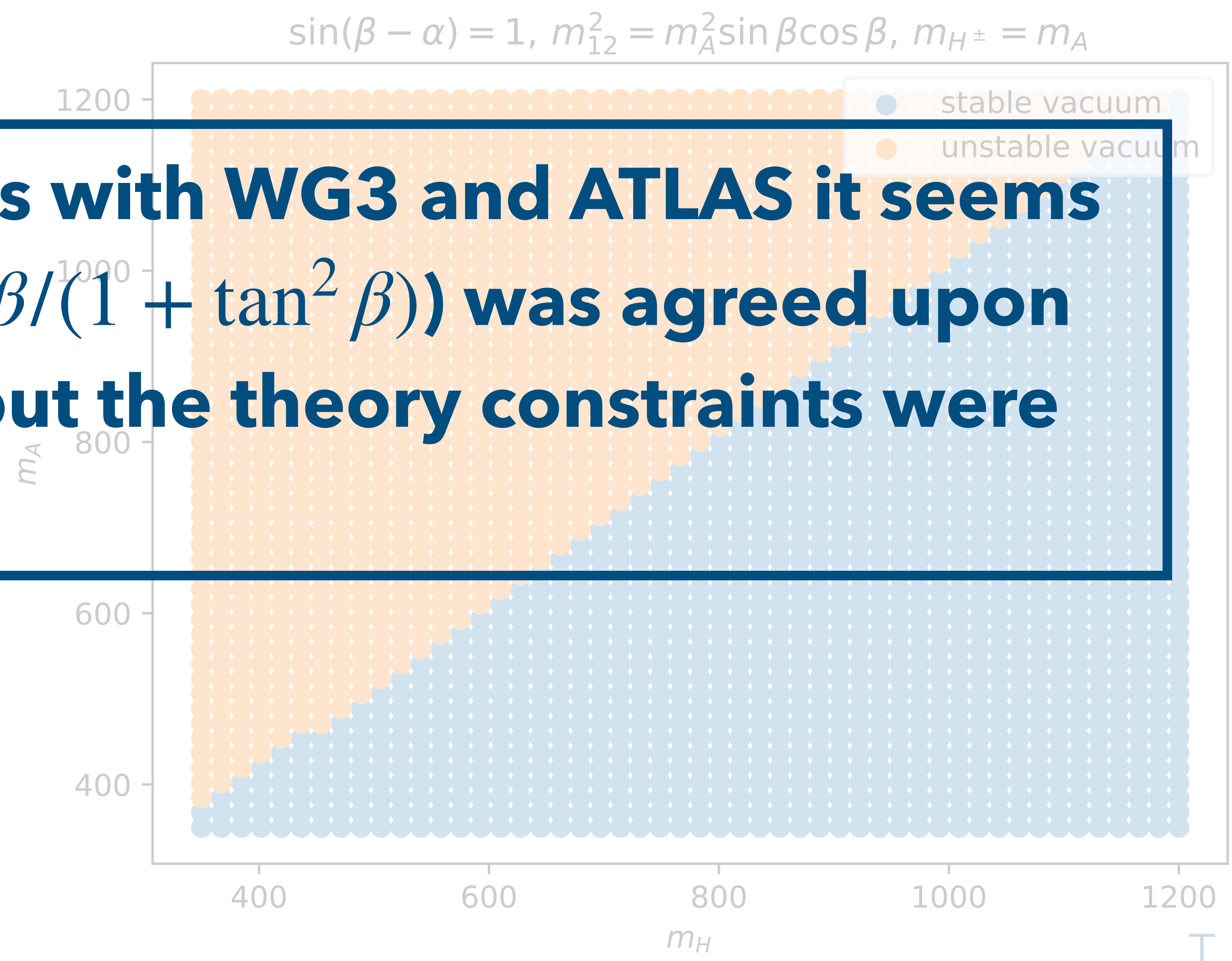

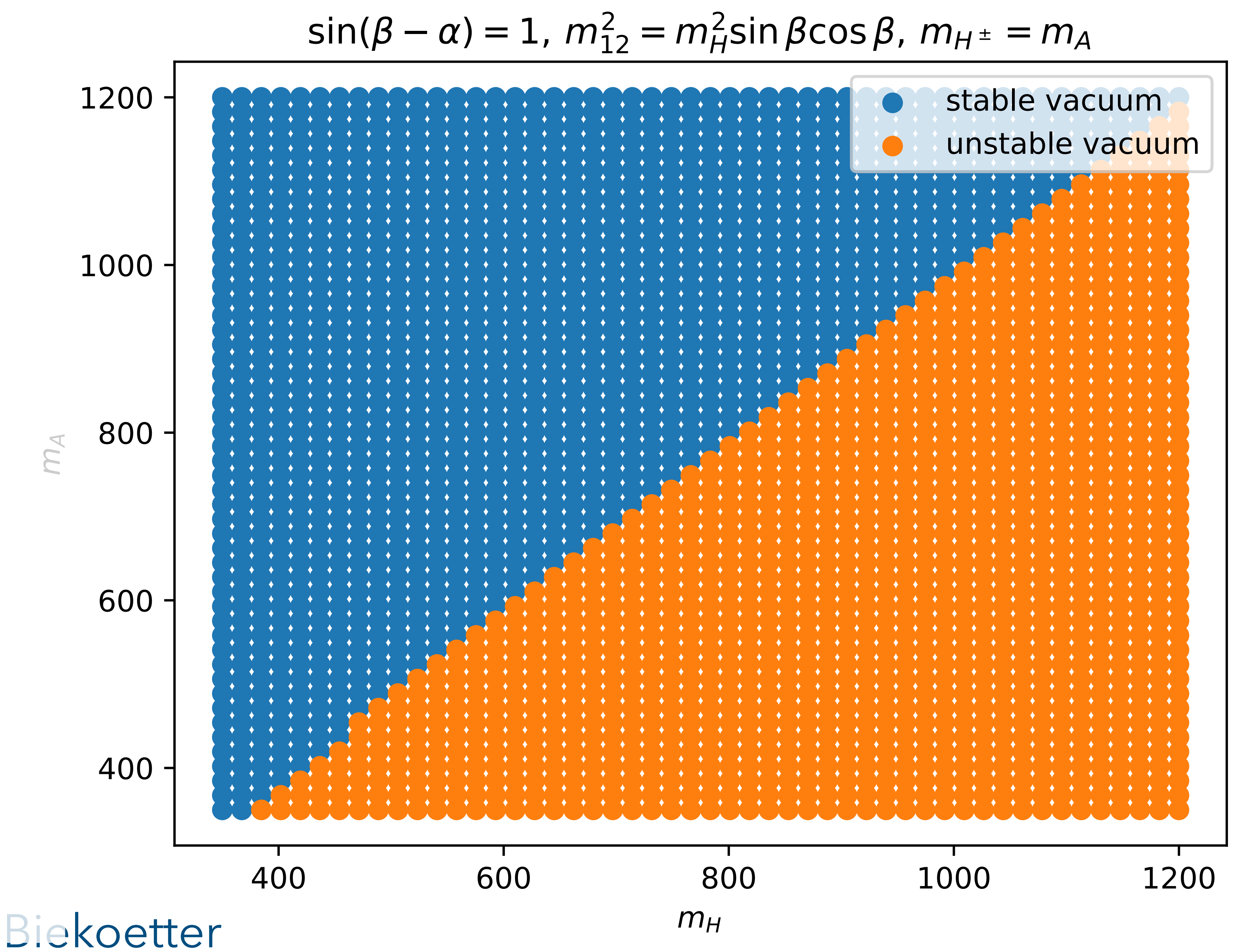

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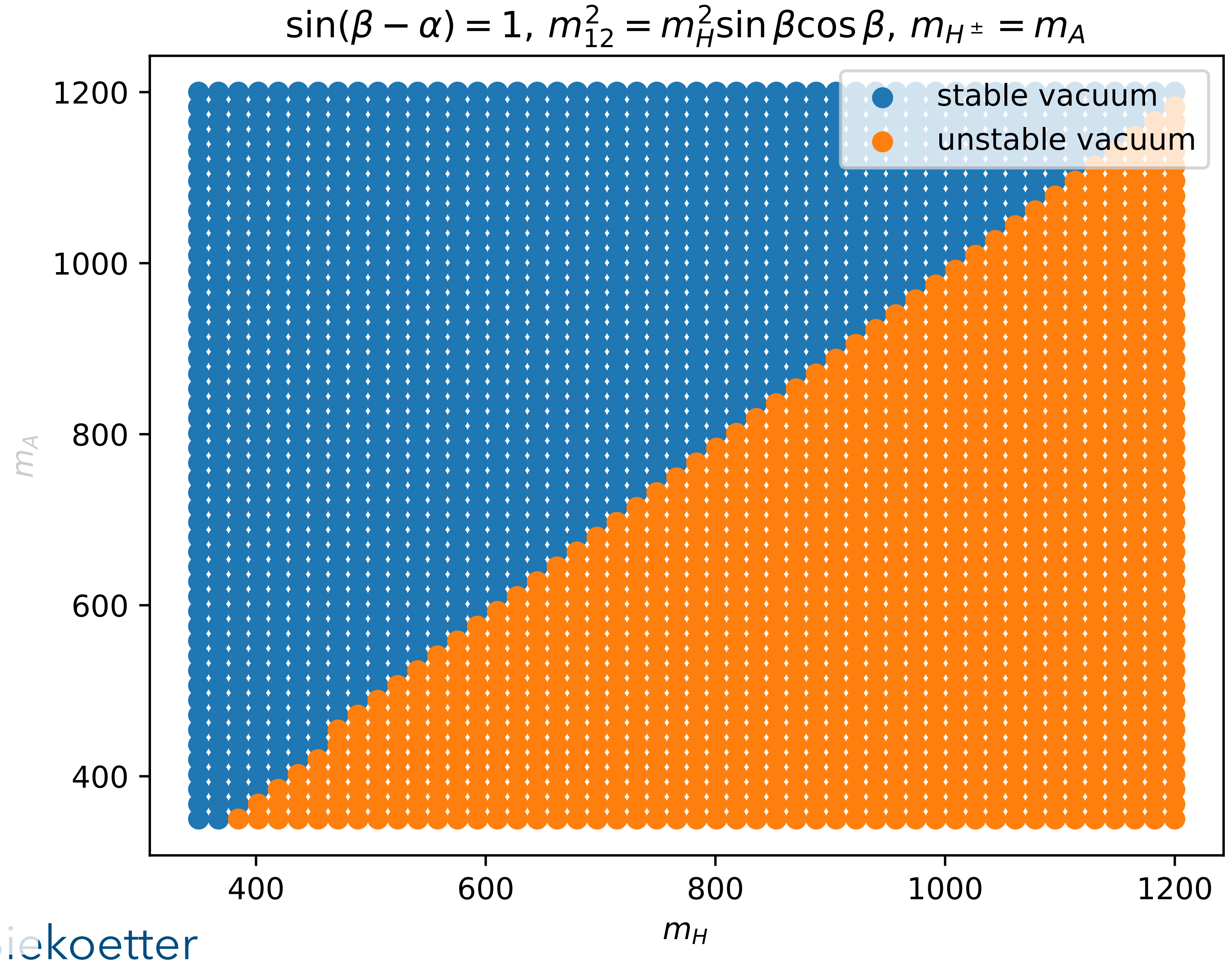
Note: what really matters is the hierarchy between m_H and m_A
(and we usually assume $m_A > m_H$)

D. Hundhausen



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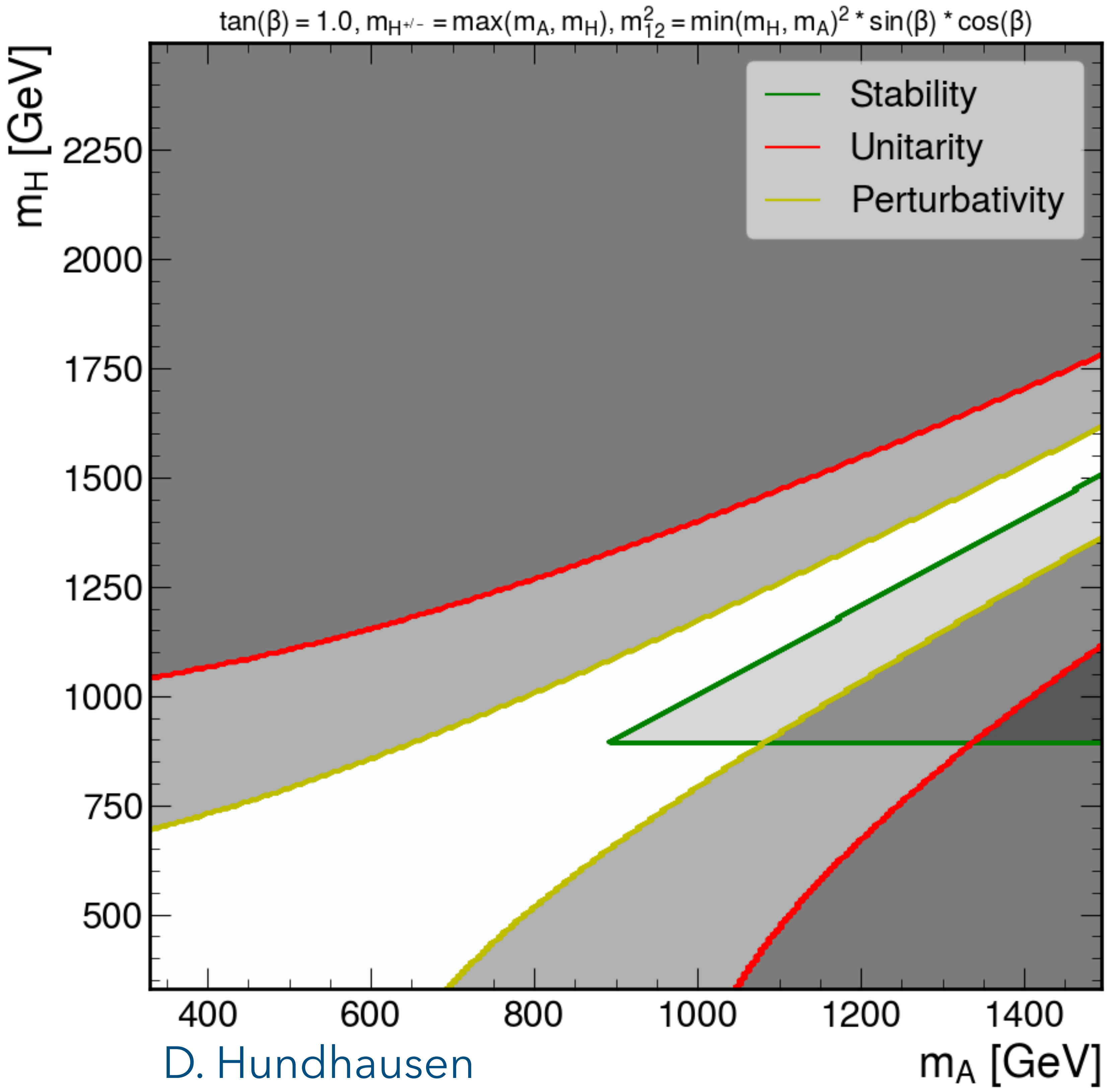
Let’s check the theory constraints

Using 2HDMC and SusHi we have checked the validity of all the different theory constraints as a function of the free parameters of the 2HDM, always setting $m_{12}^2 \propto m_H^2$ to ensure vacuum stability.

$\Rightarrow$ when a convention is agreed upon, we have the machinery in place to provide xsec and BR numbers for all the 2HDM models and for a full coverage of the (m_A, m_H) mass plane



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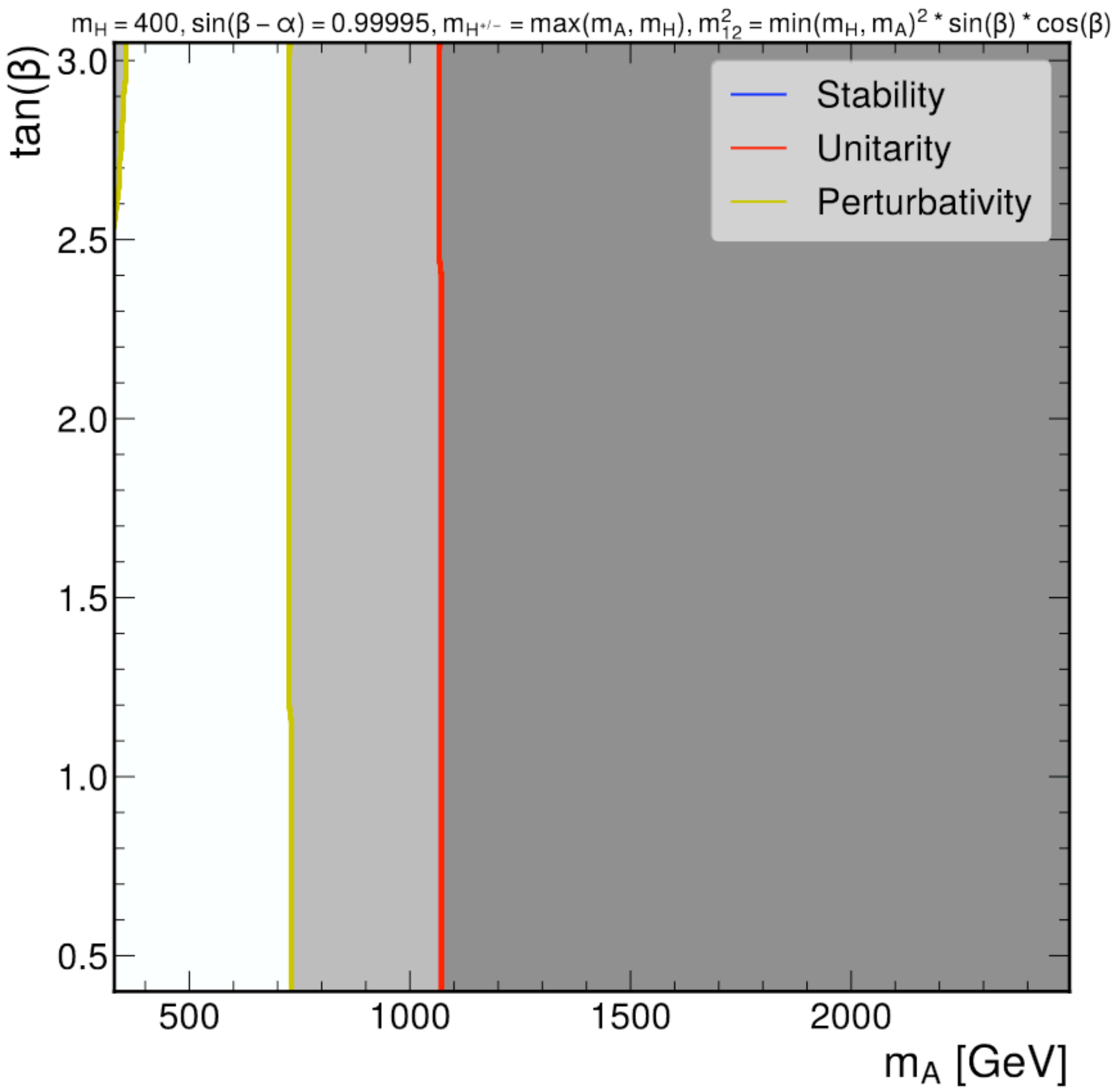
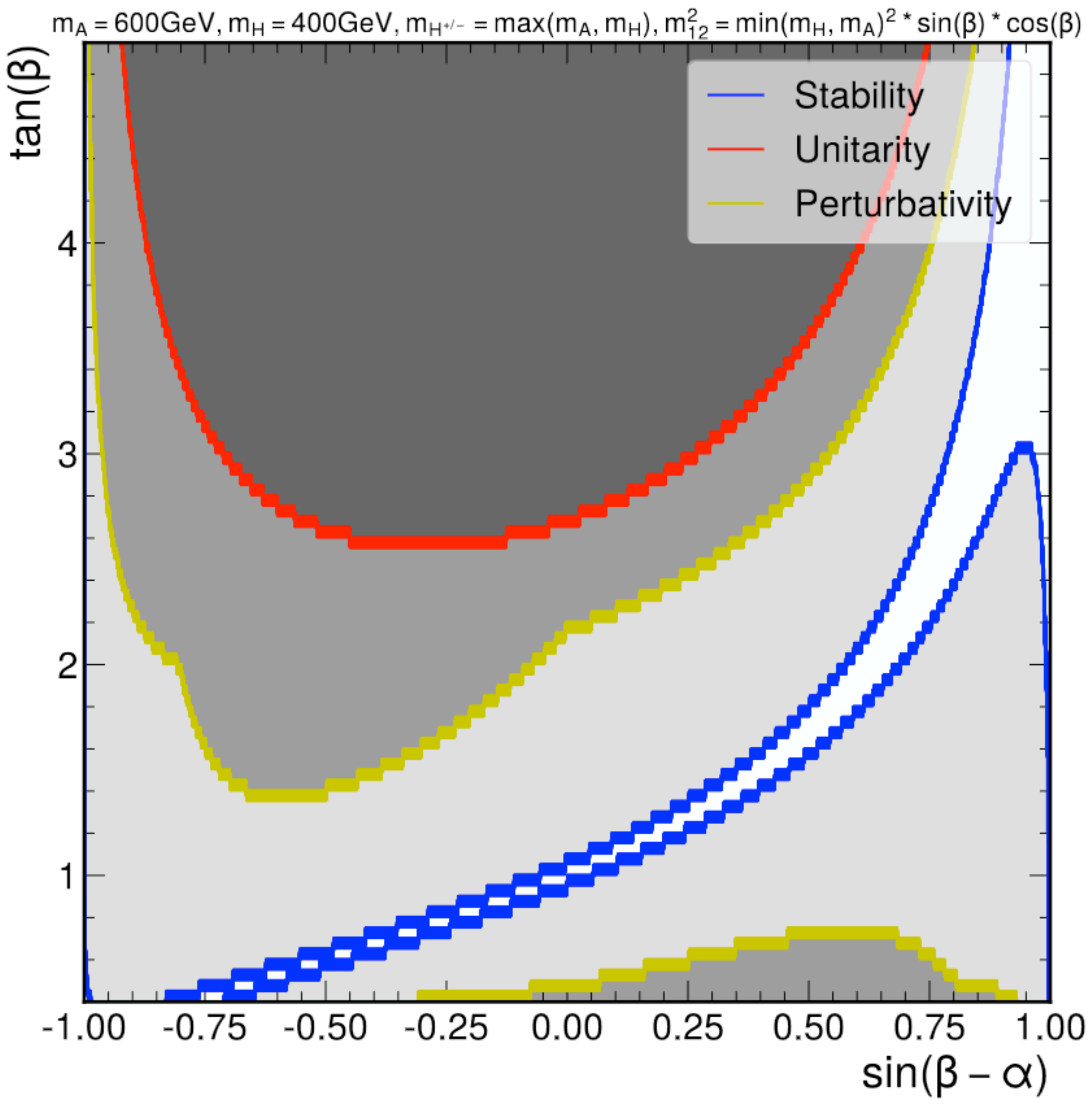
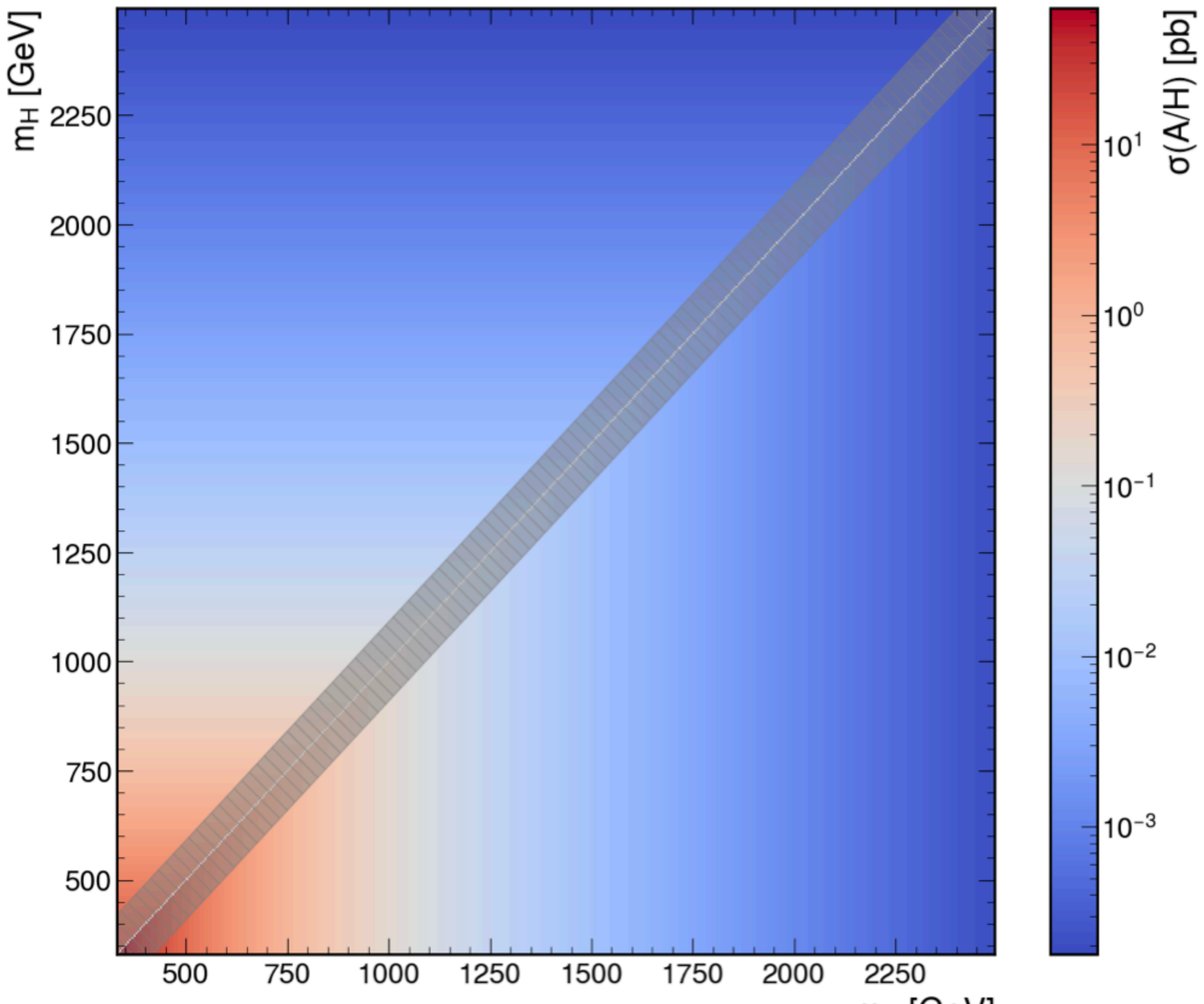


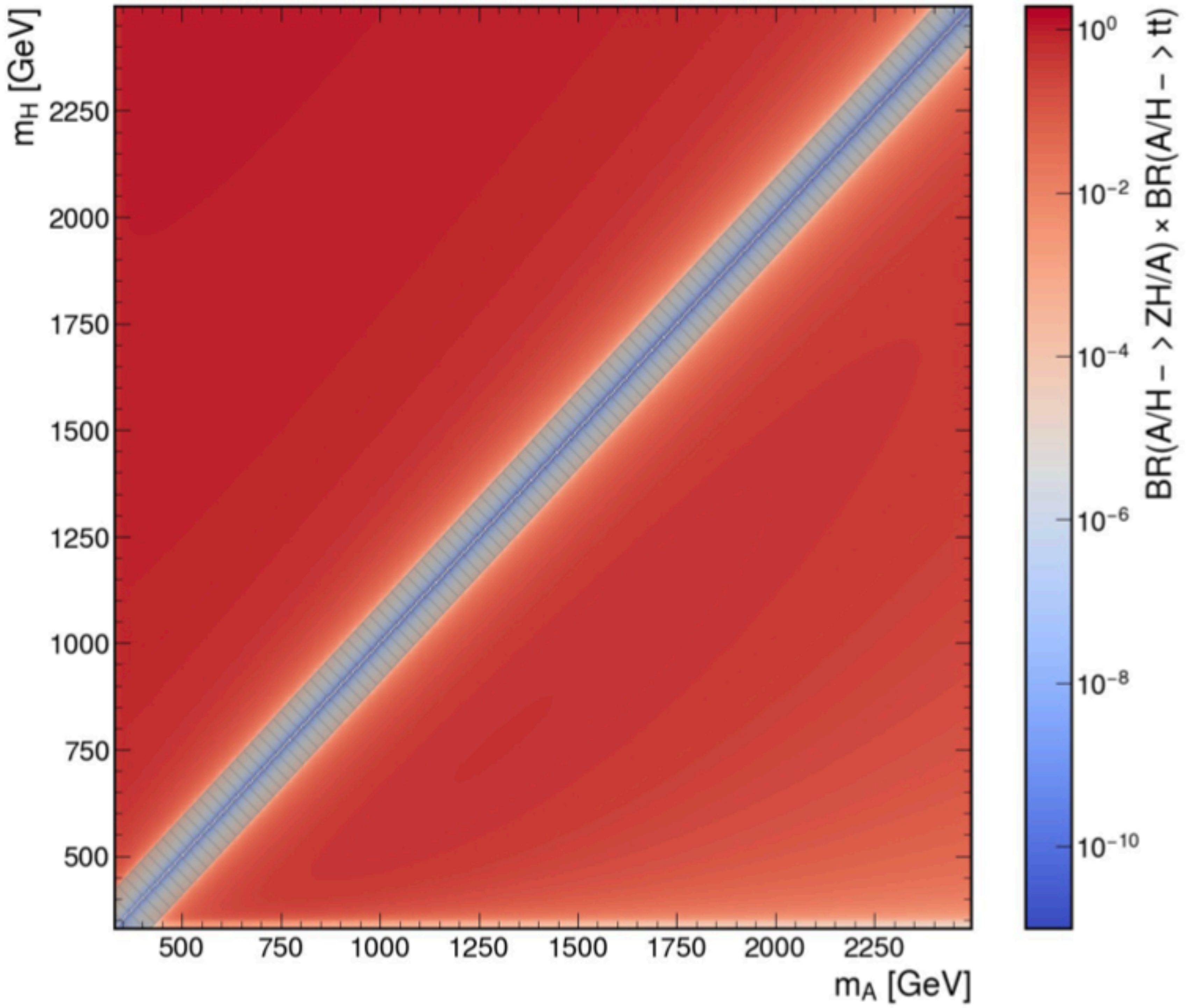


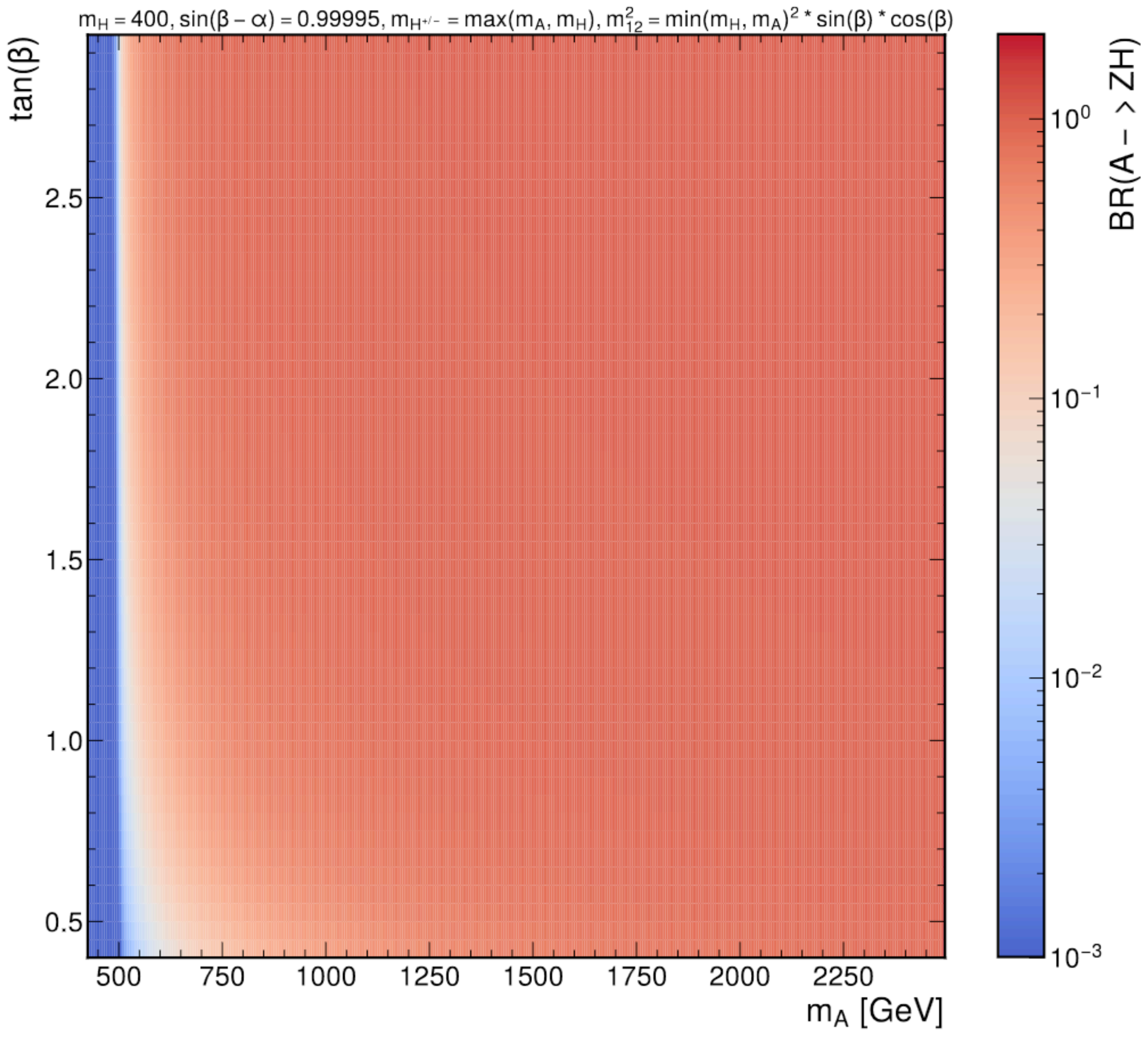
2HDMC & SusHi computations

With Run3 (and HL-LHC) coming up, it is fundamental to (re-)ensure stability across the theory inputs used by the different analyses for the interpretations. The ideal solution would be to revise the numbers centrally provided by LHCHWG and update/extend them if needed.

In CMS we have set up the full chain of xsec and BR calculations using 2HDMC and SusHi and we would be available to extend this to a wider scope and provide central numbers.







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Outlook

Theoretical inputs are crucial for BSM analyses when it comes to the interpretation of the results

- **LHCHWG centrally provides numbers for 2HDM, but with coarse granularity so analysers end up recomputing them**
- **It seems like the theoretical inputs currently available were not checked against theoretical constraints**

Can we agree on a convention to be propagated to all the analyses?

- What value of m_{12}^2 should be used for the computations? Do we care about the interplay between interpretations and vacuum stability?
- It would be good to harmonise the choice of input parameters across all the analyses, but to do so we have to agree on the inputs

Centrally providing new/updated numbers in the wider context of LHCHWG

- In CMS: 2HDMC and SusHi computations of σ, BR for a high granular coverage of the $(\mathrm{m_A}, \mathrm{m_H})$ plane
- Person-power from CMS to contribute to producing 2HDM updated numbers following central conventions/agreement
- Computations benchmarked against available theory numbers and could be provided for all 2HDM scenarios

BACKUP SLIDES