HIGGS ANOMALIES AND THE CP-CONSERVING FLAVOR-ALIGNED TWO-HIGGS-DOUBLET MODEL

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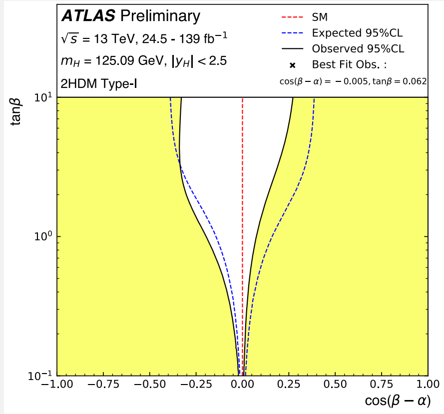
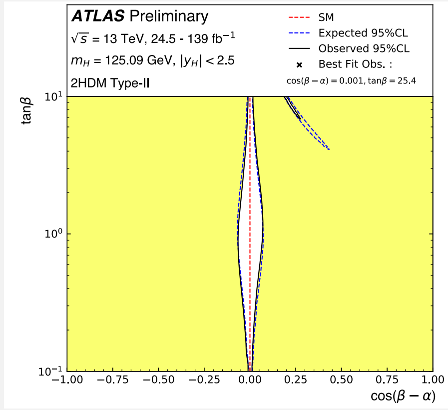
LET EXPERIMENT DETERMINE THE NATURE OF YUKAWA COUPLINGS

arXiv:1909.02845

- We want to know:
  - Are there more Higgs bosons?
  - If yes, what are their masses and how do they couple to the SM fermions?
- The four common $\mathbb{Z}_2$-symmetric models' Yukawa couplings are restricted.
- Why not generalize to the A2HDM and let experiment determine the nature of the Yukawa couplings?
- 2HDM Types I, II, X, and Y may still be allowed, but experiments can tell us that, and more, from the A2HDM perspective.





FLAVOR-ALIGNED TWO-HIGGS-DOUBLET MODEL (A2HDM)

- The four common $\mathbb{Z}_2$-symmetric 2HDM's have highly restricted Yukawa couplings.
- The A2HDM allows for more Yukawa coupling freedom in phenomenological BSM Higgs searches.

$$\begin{aligned}-\mathcal{L}_Y =& \overline{U}_L(\kappa^U H_1^{0\dagger} + \rho^U H_2^{0\dagger})U_R - \overline{D}_L K^\dagger(\kappa^U H_1^- + \rho^U H_2^-)U_R \\ &+ \overline{U}_L K(\kappa^{D\dagger} H_1^+ + \rho^{D\dagger} H_2^+)D_R + \overline{D}_L(\kappa^{D\dagger} H_1^0 + \rho^{D\dagger} H_2^0)D_R \\ &+ \overline{N}_L(\kappa^{E\dagger} H_1^+ + \rho^{E\dagger} H_2^+)E_R + \overline{E}_L(\kappa^{E\dagger} H_1^0 + \rho^{E\dagger} H_2^0)E_R + \text{h.c.}\end{aligned}$$

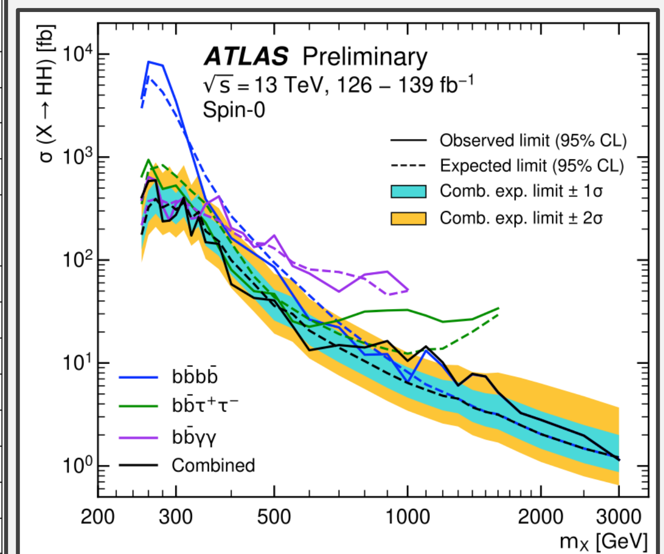
- In the A2HDM, the Yukawa matrices ρ^F are postulated to be proportional to the mass matrices κ^F.
  - Flavor diagonal (which avoids tree-level FCNC's)
  - ρ^F related to κ^F by coupling parameters $a^{U,D,E}$:

$$\rho^F = \epsilon_6 a^F \kappa^F$$

HIGGS ANOMALIES

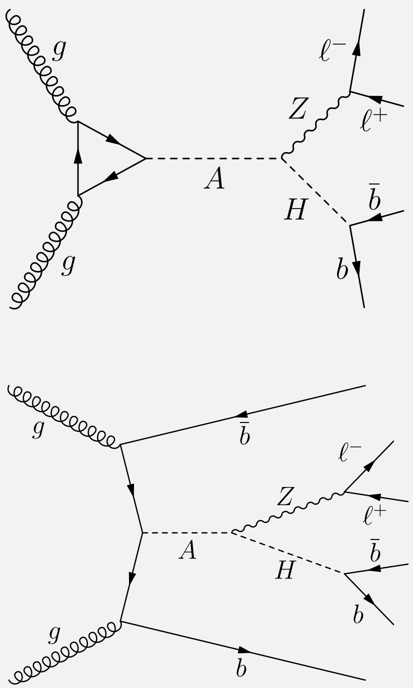
- We looked for "excesses" in ATLAS and CMS BSM Higgs exclusion plots.
- For example, at $m_H = 280$ GeV we found:

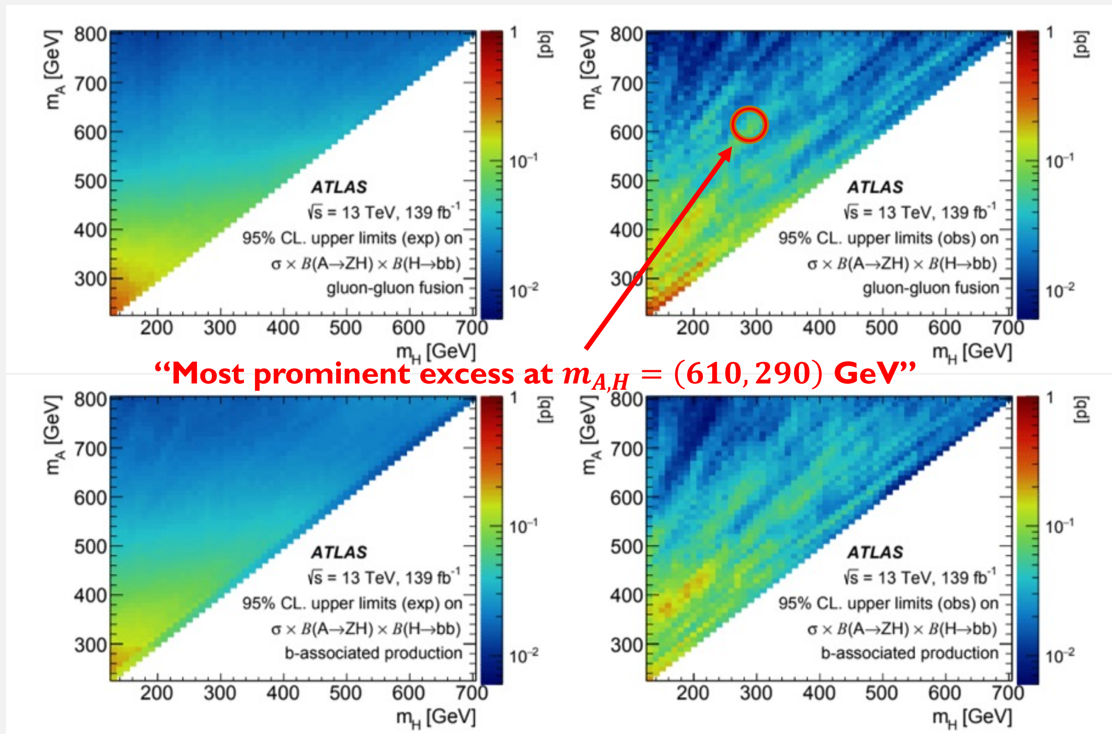
Possible Evidences of a Heavy Higgs Scalar H of Mass $m_H = 280$ GeV				
Source	Channel	Observed [pb]	Expected [pb]	Comments
ATLAS arXiv 1804.06174v1	bbbb	5	2	$\sim 2.5\sigma$
ATLAS JHEP07(2020)108	bbbb	1.2	1.1	126 fb-1 σ_{VBF}(pp-Xjj-HHjj)
ATLAS PhysLetB 800 (2020) 135103 BR's divided out	bbbb	14	5	largest excess
	$bb\tau\tau$	3	3	Deficit at $m < 280$
	$bb\gamma\gamma$	0.7	0.8	Data zigzags expected curve 1σ excess at 300
	Combined	0.83	0.74	Small excess closer to 300
CMS JHEP08(2018)152	bbbb	0.97	0.7	1σ
CMS PAS HIG-17-030	combined	1.7	0.8	2σ
CMS PAS HIG-17-032	bbZZ ($ll\nu\nu$)	0.3	0.5	1σ deficit
CMS (assumes SM BR) BR's divided out	$bbl\nu l\nu$	15	11	
	$bb\tau\tau$	7	5	Large peak at 270
	bbbb	2.7	2.1	sharp valley near peak
	$bb\gamma\gamma$	1.30	0.83	
	Combined	1.5	0.8	
CMS PhysRevLet 122.121803	Combined	1.7	0.8	2σ



HIGGS ANOMALIES

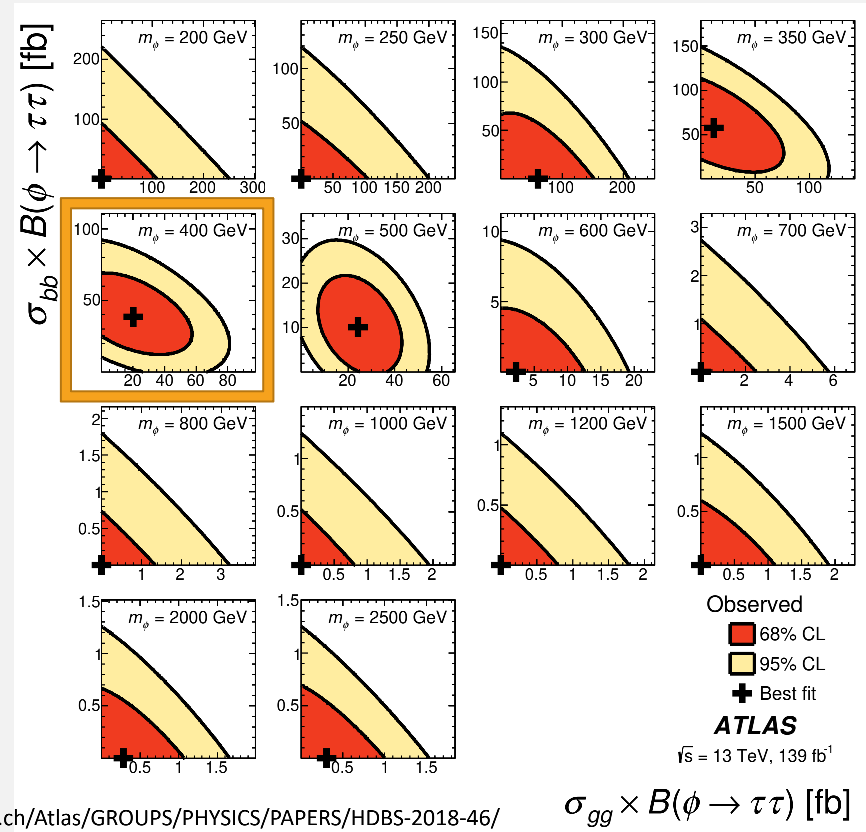
- Here are a few of the most prominent ATLAS and CMS Higgs anomalies that we decided are worth investigating. [arXiv:2011.05639]



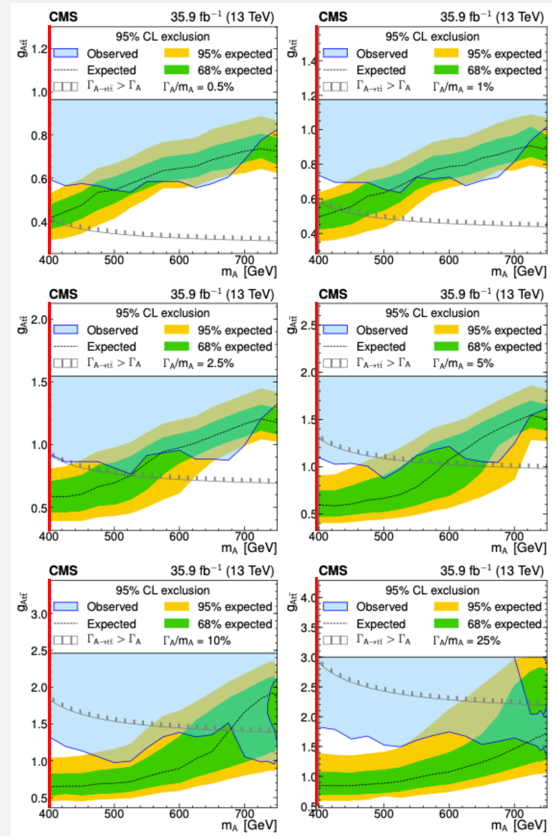


HIGGS ANOMALIES

[arXiv:1908.01115]



atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HDBS-2018-46/

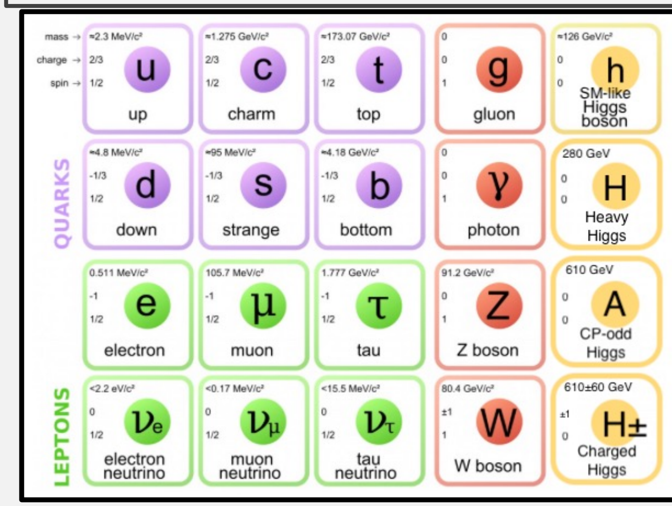


HIGGS ANOMALIES

- A single anomalous signal is likely to be a statistical fluctuation upwards.
- Scenarios with two or more Higgs anomalies are more likely to be real signals.
- We devised two scenarios with two anomalies each, compatible with the A2HDM.

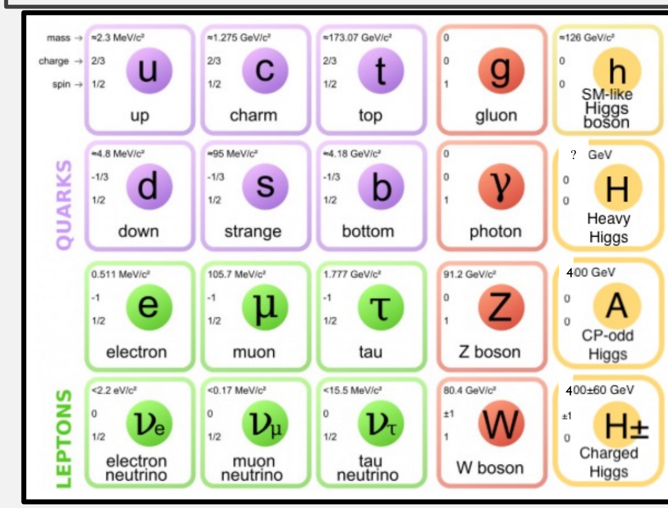
Scenario 1:

$m_A = 610$ GeV, $m_H = 280$ GeV

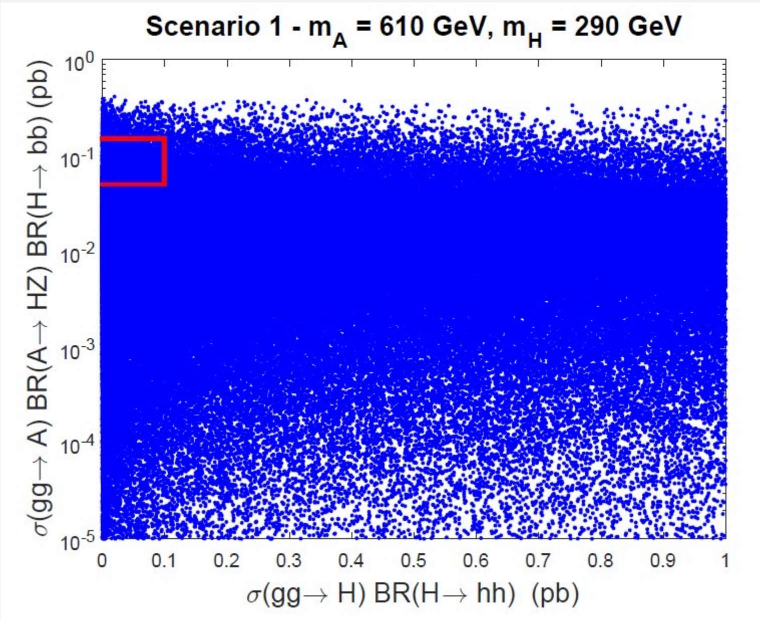


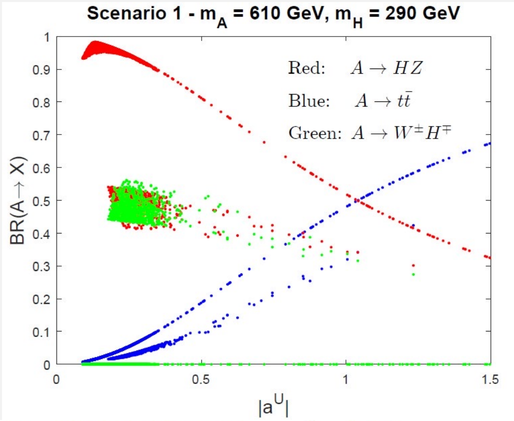
Scenario 2:

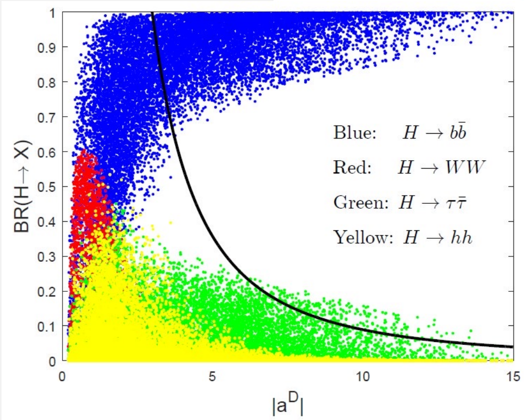
$m_A = 400$ GeV

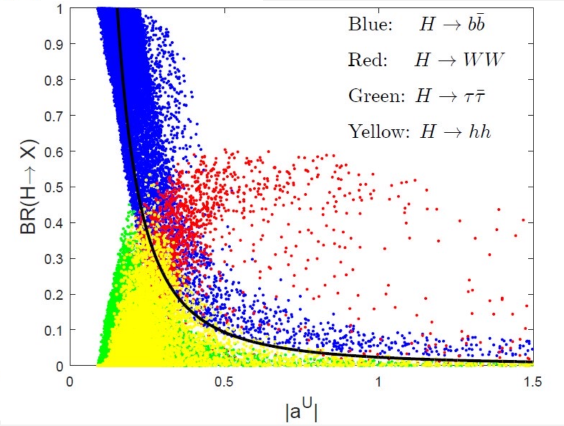


SCENARIO 1 RESULTS









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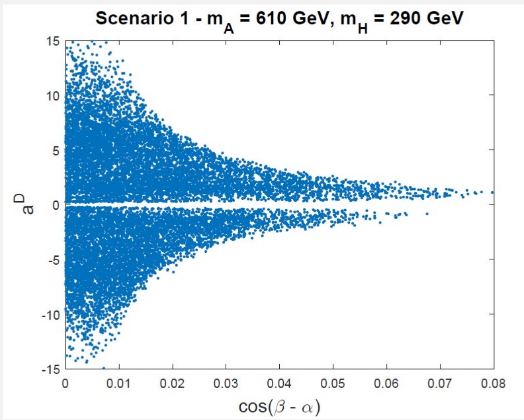

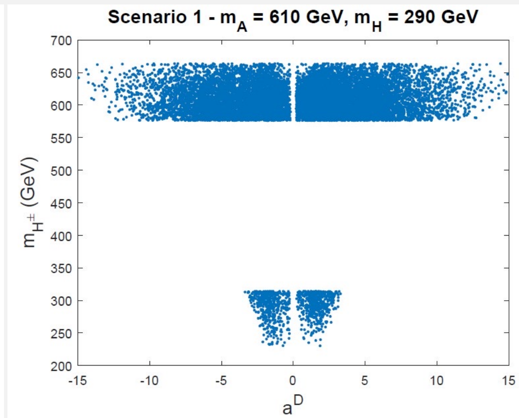

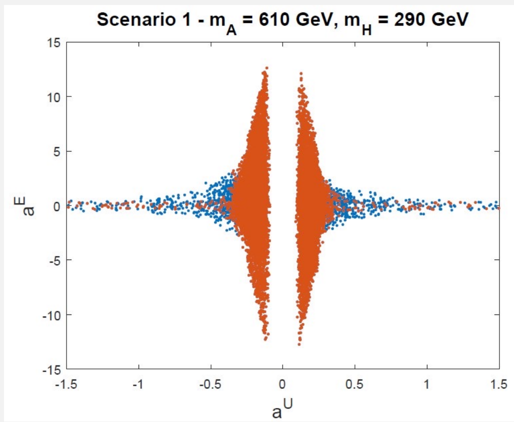

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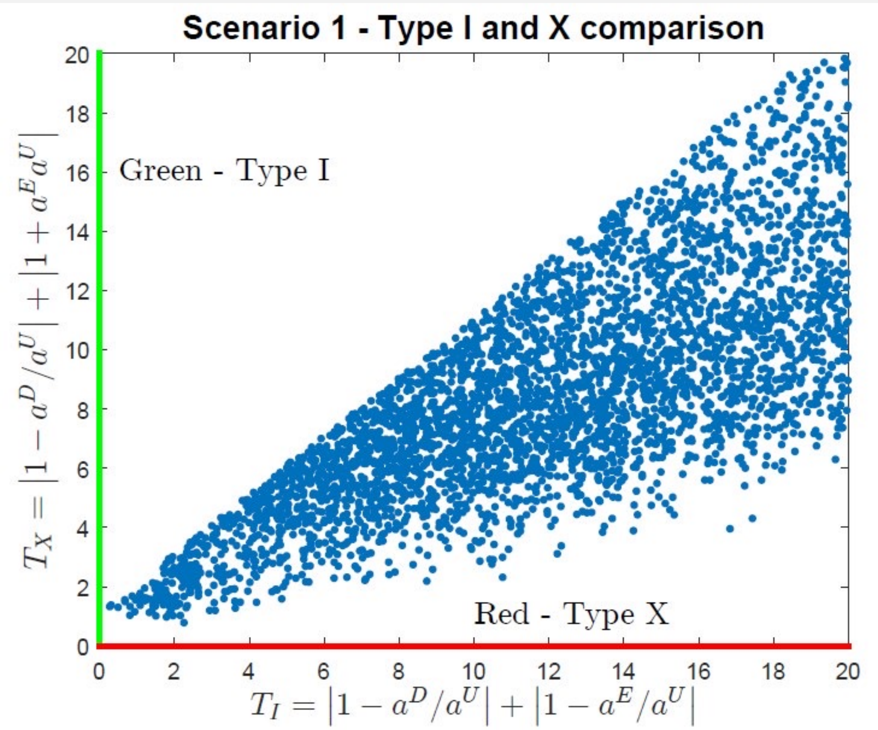
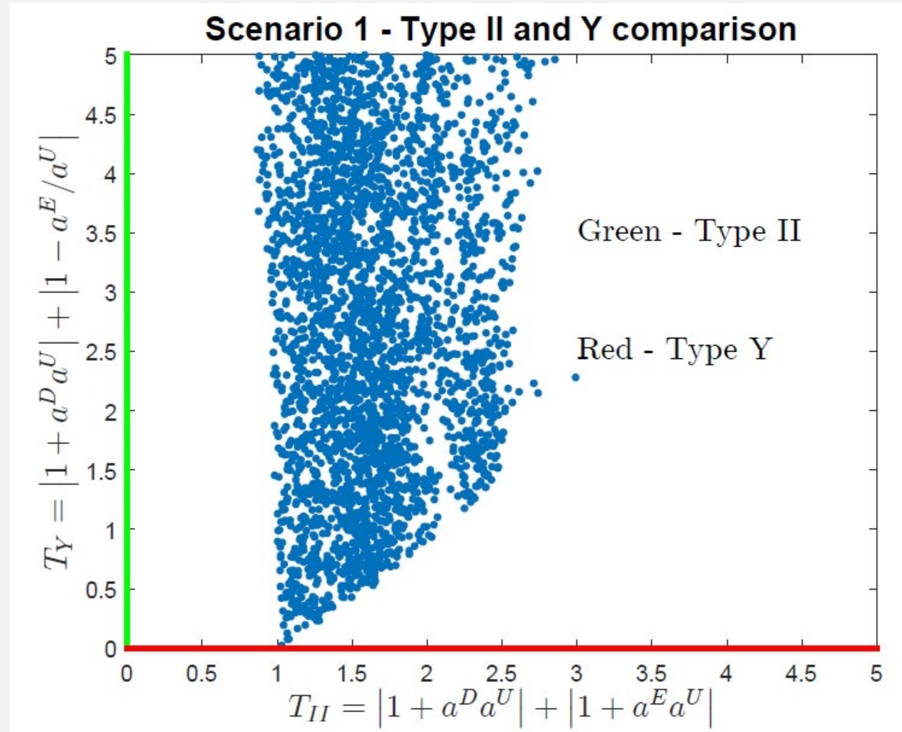
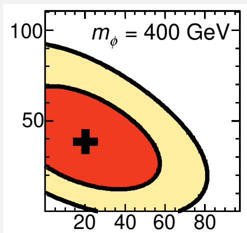
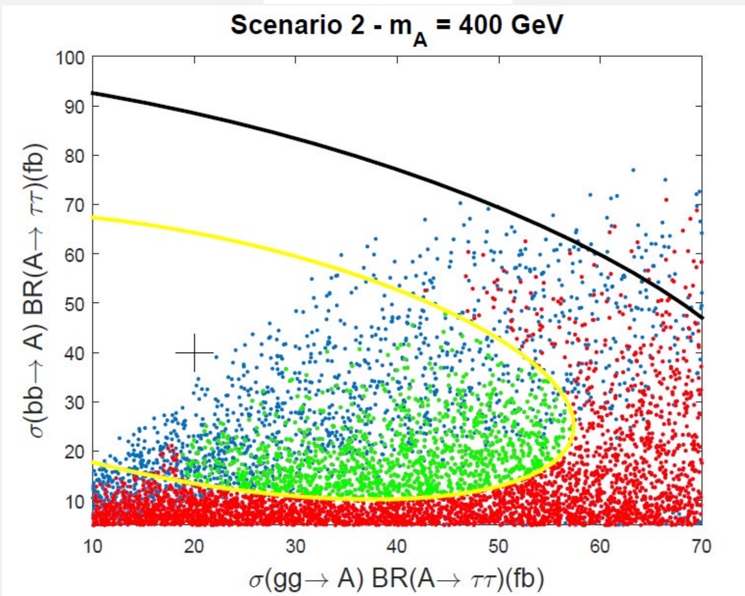
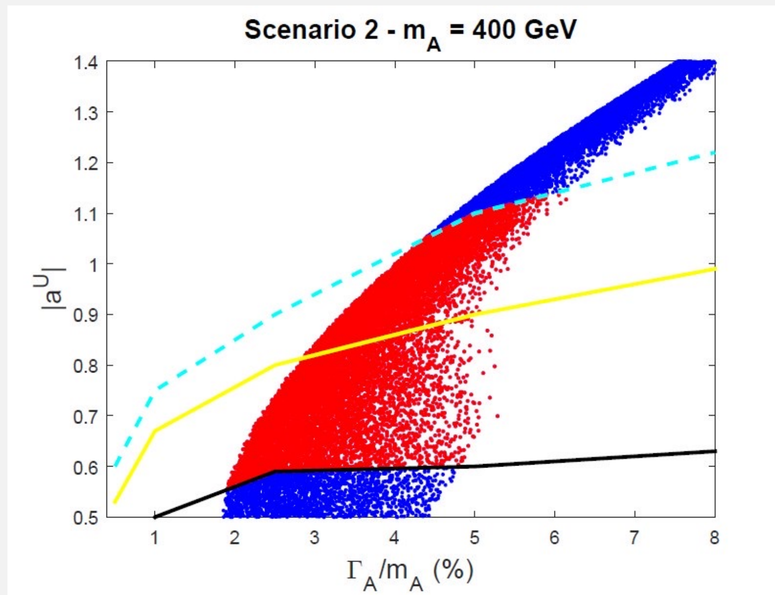




SCENARIO 2 RESULTS







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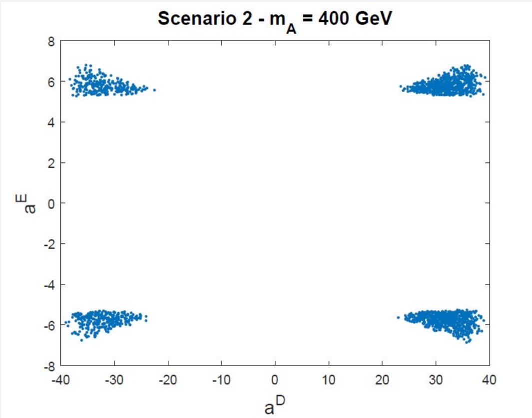
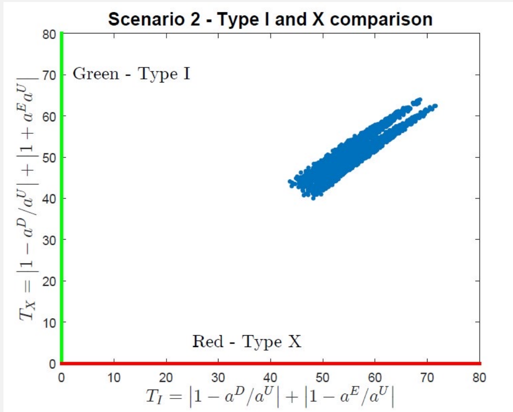
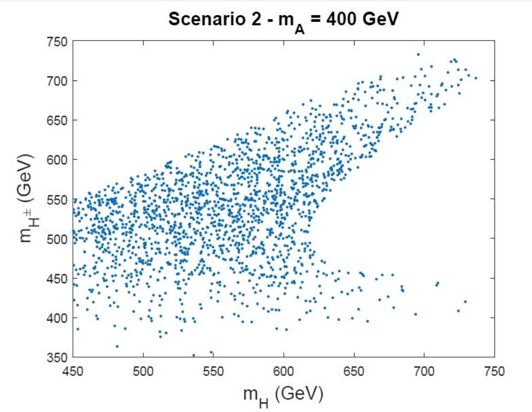
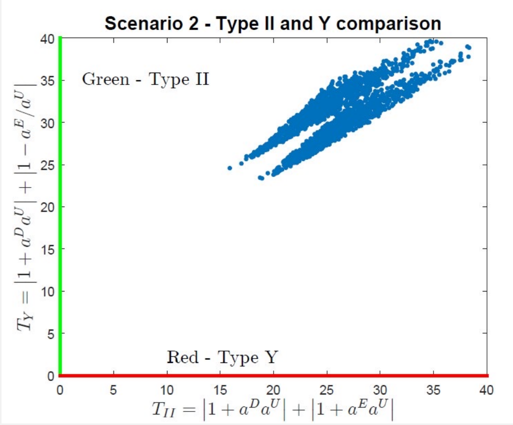


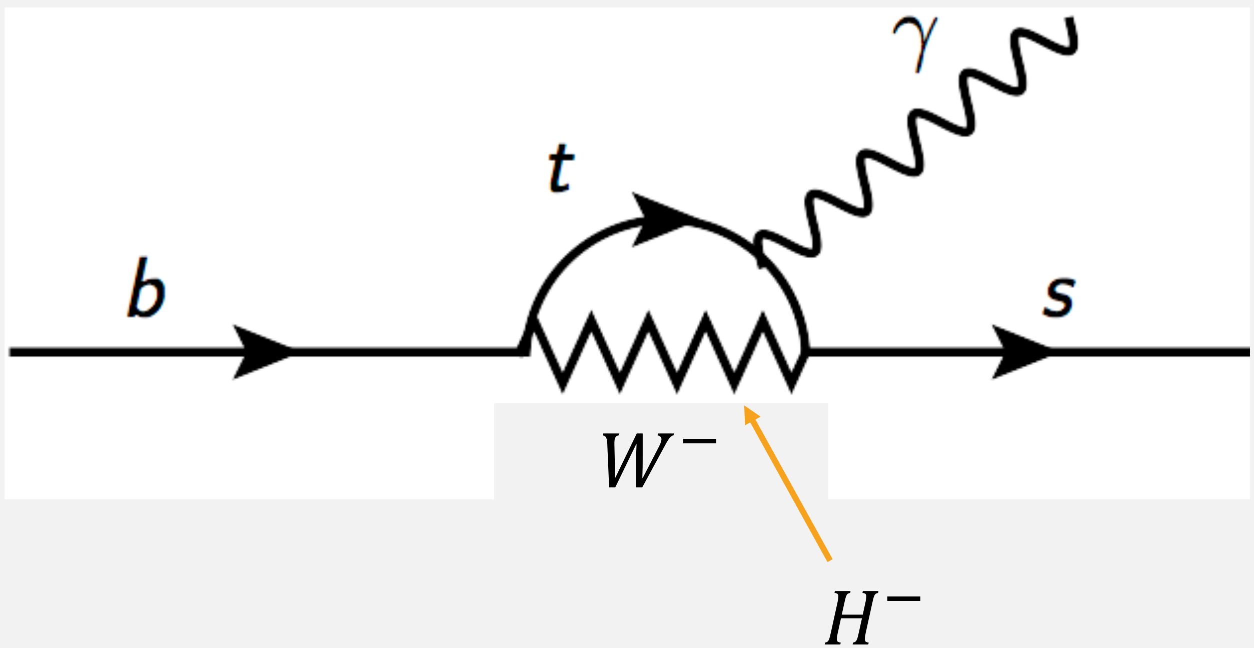






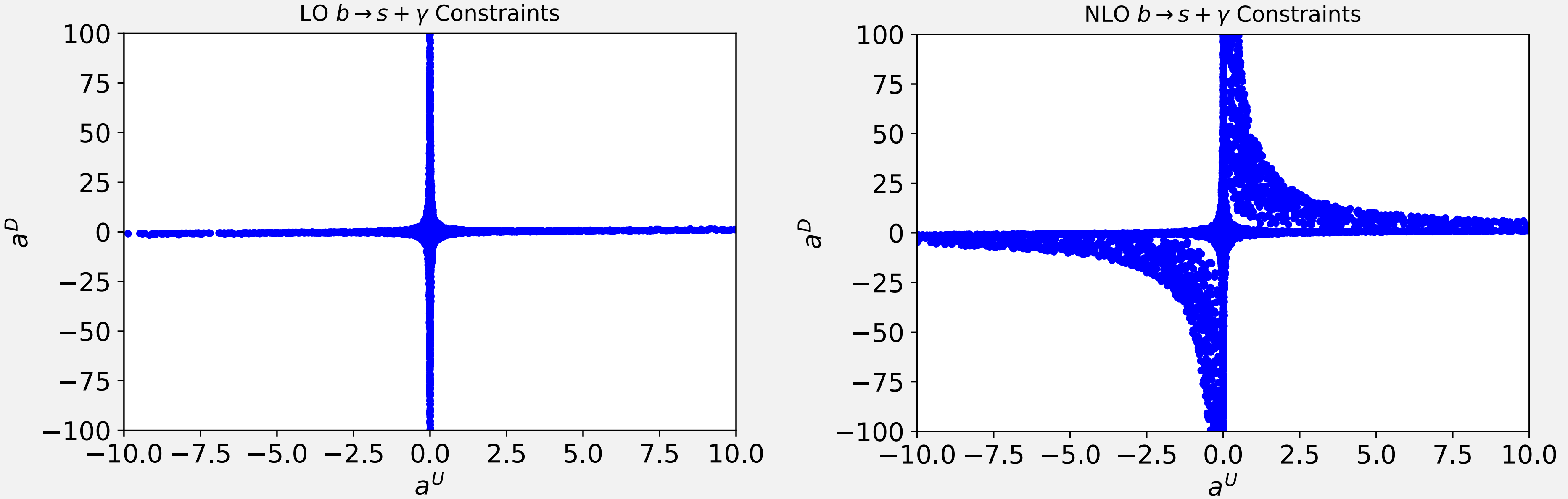
$b \to s + \gamma$ CONSTRAINTS

- $b \to s + \gamma$ constraints place the most stringent experimental cuts on our models.



$b \to s + \gamma$ CONSTRAINTS

- $b \to s + \gamma$ constraints place the most stringent experimental cuts on our models.
- We showed that the LO calculation of this constraint is insufficient, one must go to NLO.



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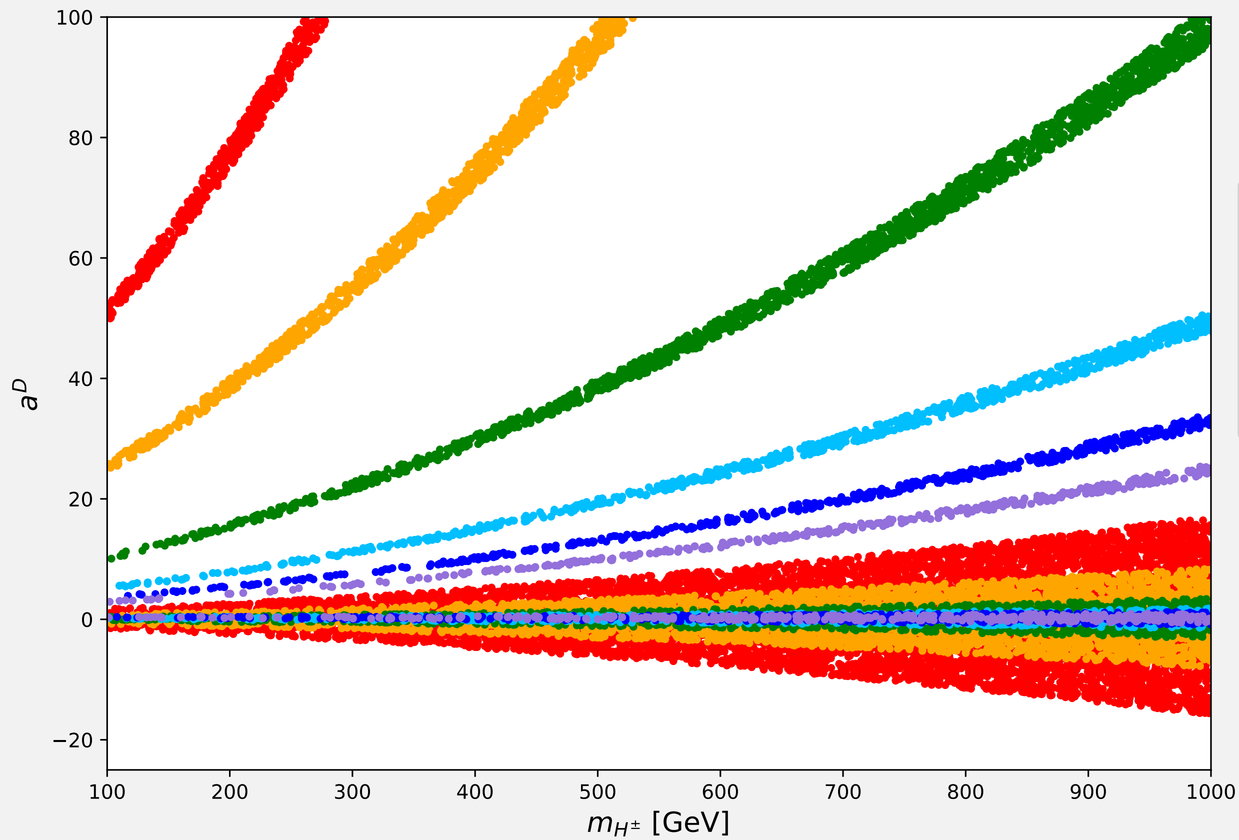
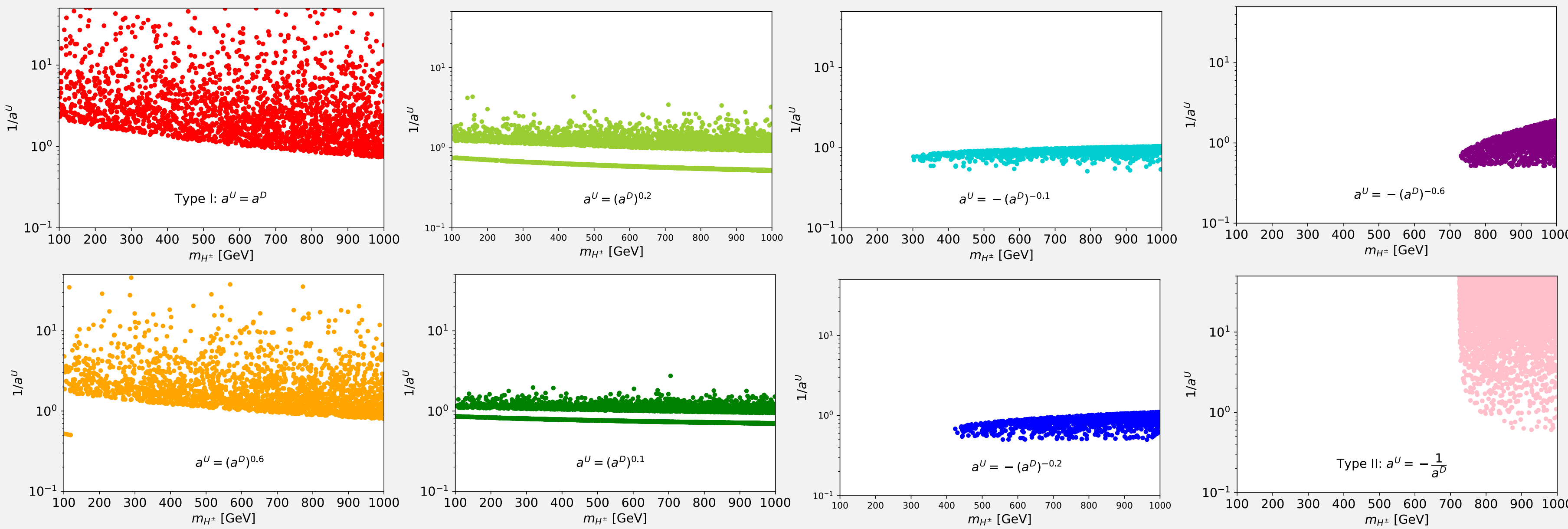


Regions of A2HDM parameter space that satisfy the $b \to s + \gamma$ constraint at various a^U.

$b \to s + \gamma$ CONSTRAINTS

We showed the 2HDM Types I and II limits and intermediate slices of parameter space via the relationship:

$$a^U = (a^D)^p \, \mathrm{sgn}(p) \, , \qquad -1 < p < 1$$



THANK YOU

- Big thank you to the institute here in Lisbon, Howie Haber, and Pedro Ferreira!

- Questions?