BSM TARGETS FOR DI-HIGGS SEARCHES

Daniel Egana-Ugrinovic
Perimeter Institute

THE UBIQUITOUS HIGGS BOSON

EWSB

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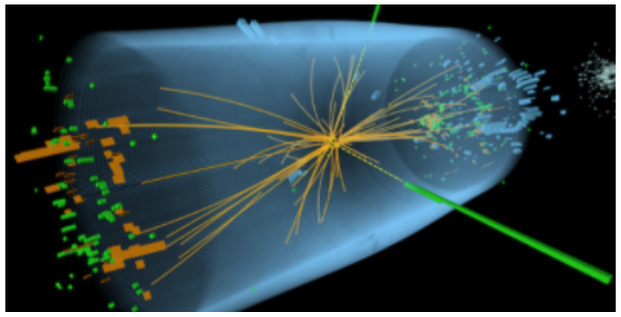
The Higgs boson



home.cern/science/physics/higgs-boson

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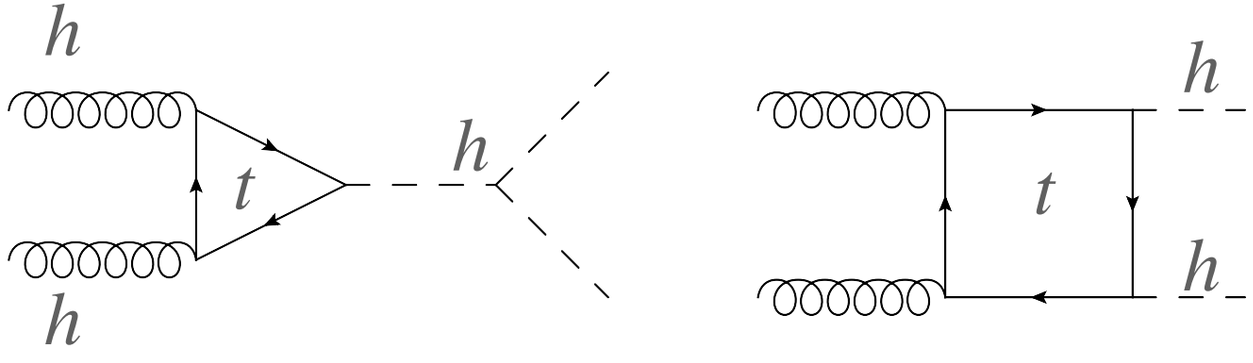
Flavored interactions

Di-Higgs production at colliders is intimately related with <u>both</u> the problems of EWSB and the flavor puzzle



$$\sigma_{hh}^{SM} = 31\ \text{fb}$$

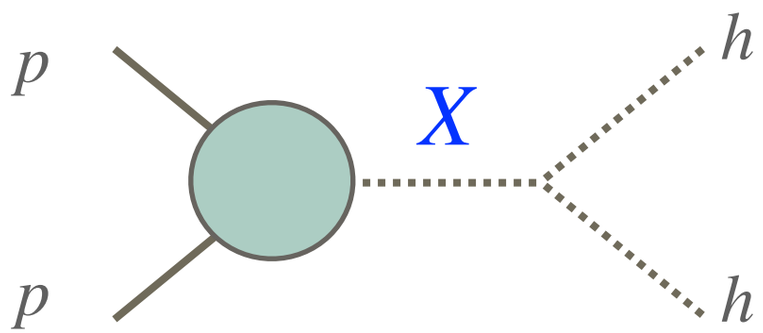
(Thousands of pairs already created, but hiding in backgrounds)

$$-1 < \lambda/\lambda_{\text{SM}} < 6.6$$

ATLAS-CONF 2021-052
CMS-HIG-19-018

$(-0.18 < \lambda/\lambda_{\text{SM}} < 3.6 \ @ \ \text{HL} - \text{LHC})$
1910.00012

Resonant di-Higgs production at the LHC

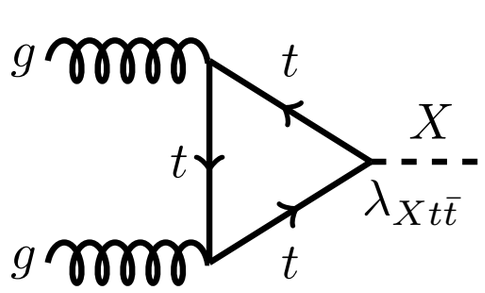


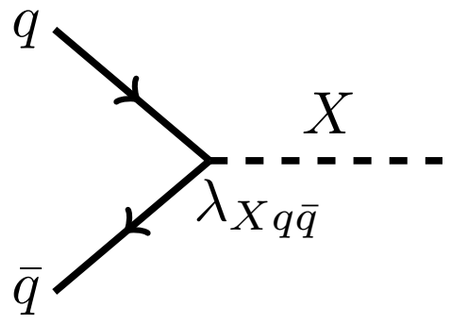
For concreteness, we'll
concentrate on scalar resonances

(for spin 2 targets and articles in loop see 1910.00012, their implications for EWBG see ***DEU*** *1707.02306).*

A TEST OF FLAVOR "TIMES" EWSB

On the production side we test flavor physics…





(q = *light quark*)

Minimal Flavor Violation (MFV), D'Alessandro et.Al. 0207036
Types I-IV Glashow, Weinberg PRD 15 (1977) 1958
MSSM Dimopoulos, Georgi NPB 193, 1981, 150

Spontaneous Flavor Violation (SFV).
***DEU**, Homiller, Meade 1811.00017, 1908.11376*
Horizontal symmetries, others? Leurer, Nir, Seiberg 9212278

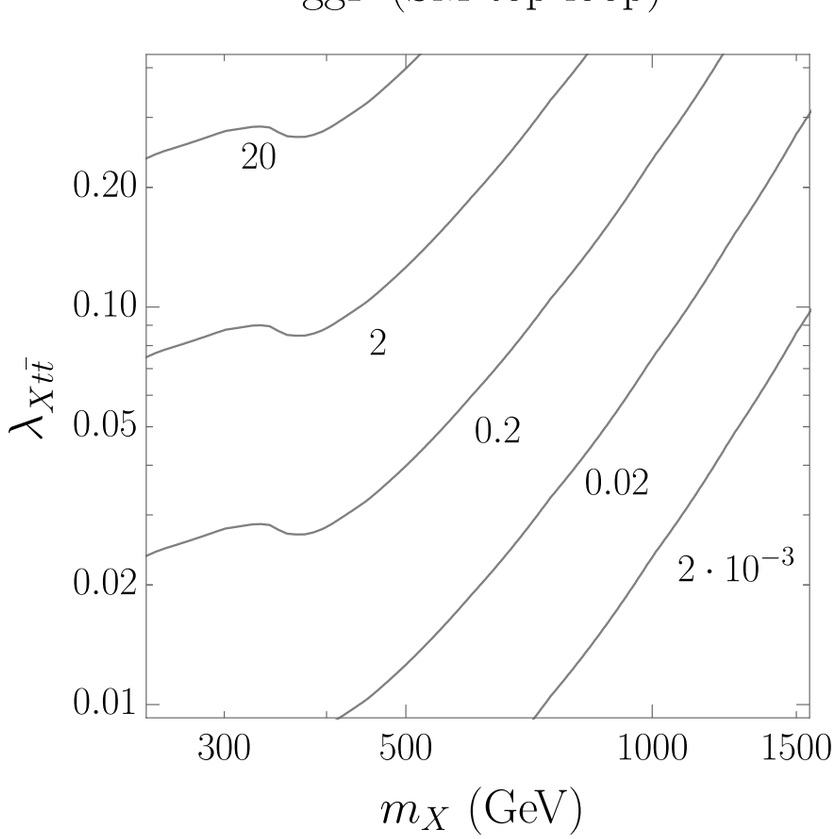
Different possibilities must account for the lack of FCNC's, and have

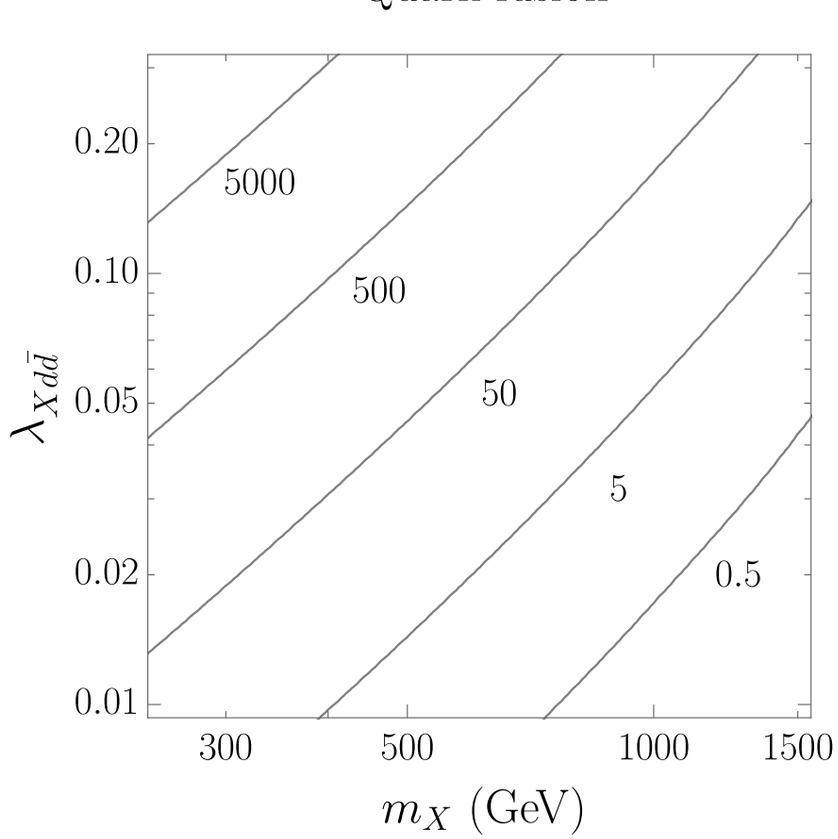
-very- deep implications for flavor in the UV

See also C. Murgui's talk

HEAVY SCALAR PRODUCTION

Scalar production xsecs at 13 TeV LHC

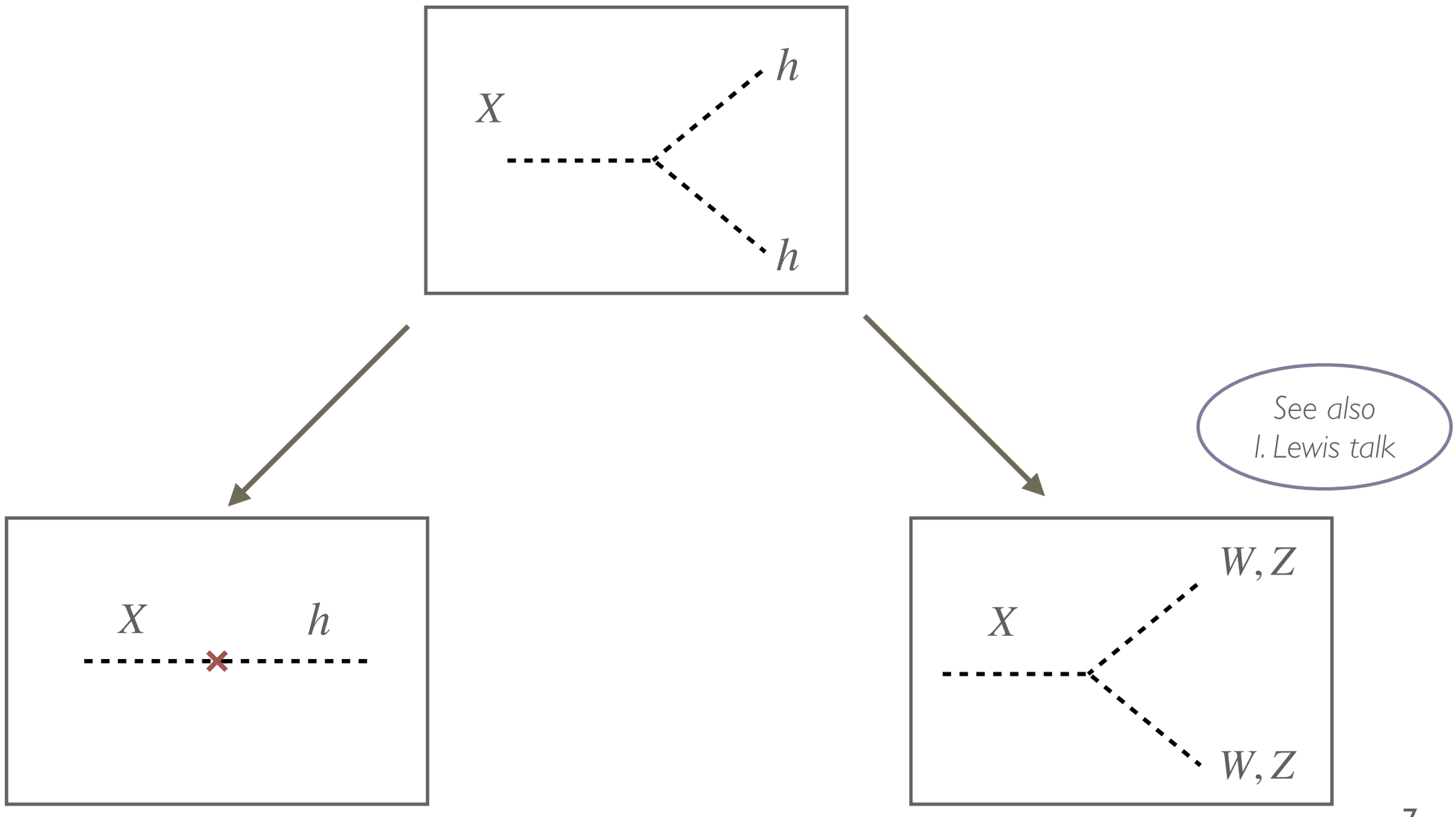




x-sec normalized to LO SM di-Higgs xsec (15fb)
***DEU**, Homiller, Meade, 2101.04119*

A TEST OF FLAVOR "TIMES" EWSB

…while on the decay side we test the vacuum potential

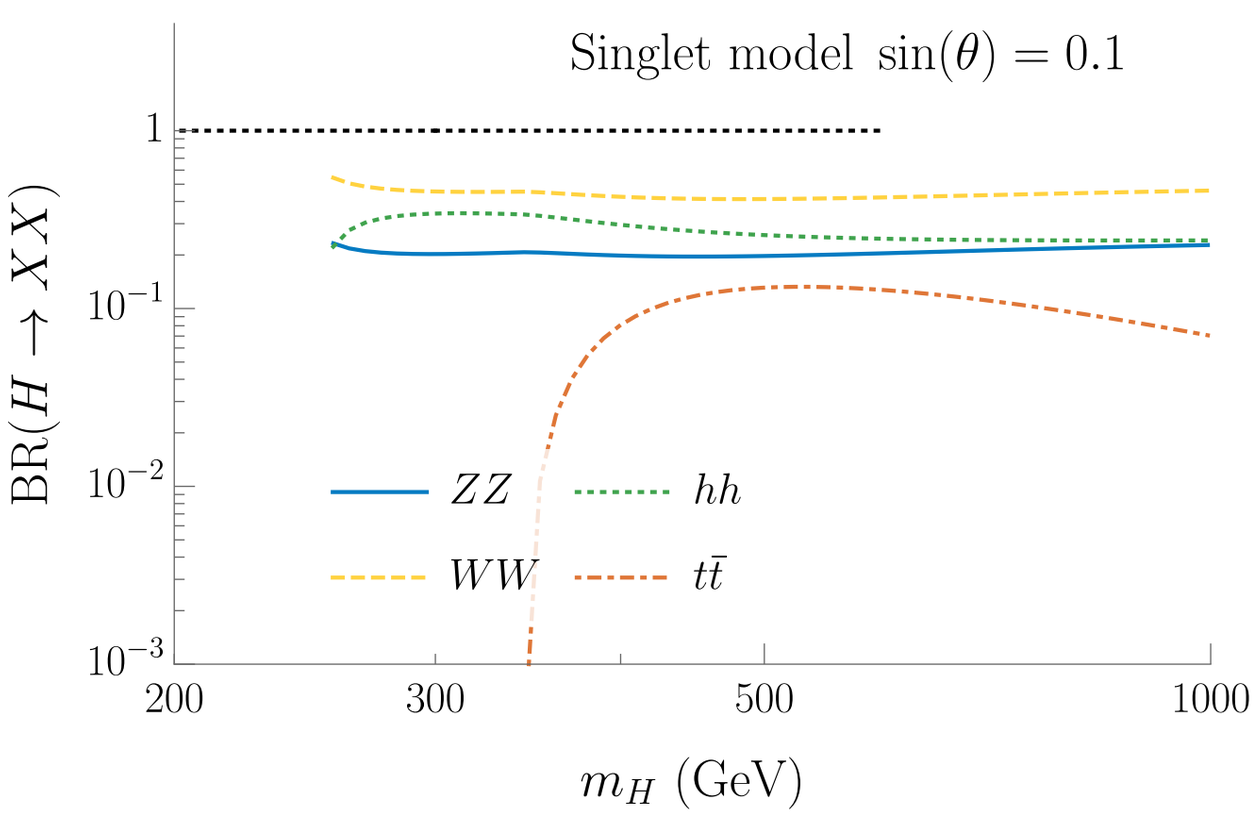


SINGLET SCALAR BRANCHING FRACTIONS

- Br's are very model dependent. I'll give you 2 examples

1. *Scalar singlet model*

$$\sin\theta = 0.1$$



$$\Gamma_{WW} = 2\Gamma_{ZZ} = 2\Gamma_{hh}$$

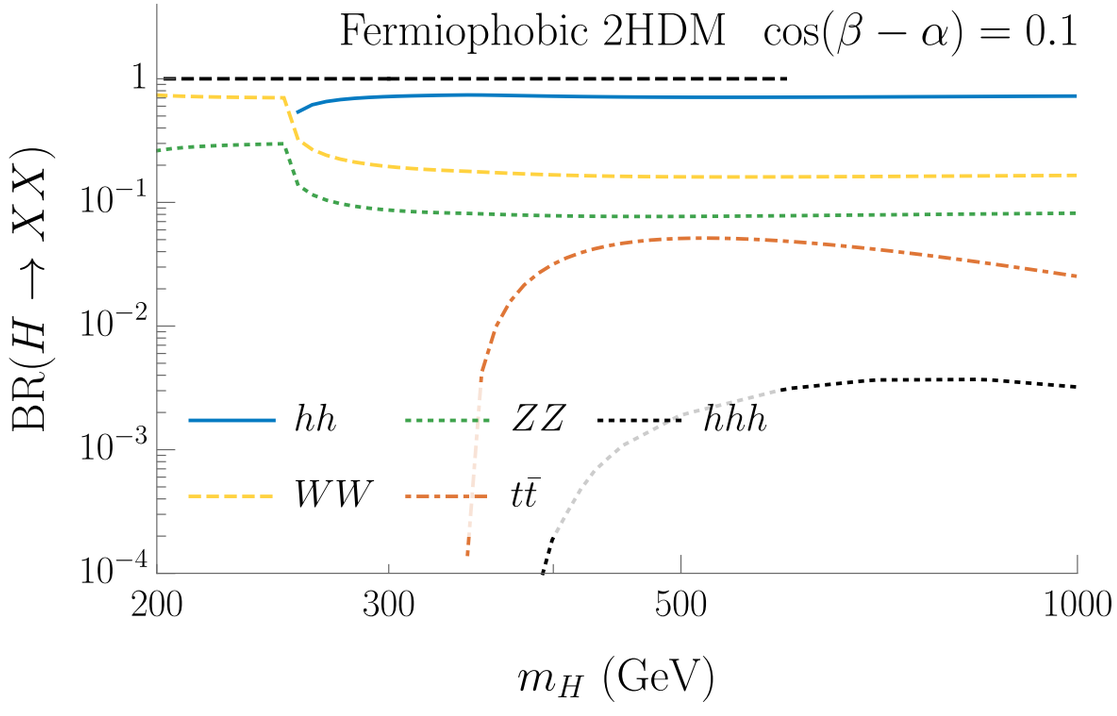
(at high energies)

Singlets in the context of 2h production:
see e.g., Chen, Dawson, Lewis 1410.5488,
Robens, Stefaniak 1601.07880
See especially ***Lewis, Sullivan 1701.08774***

GENERIC 2HDM BRANCHING FRACTIONS

2. *"Generic" 2HDM*

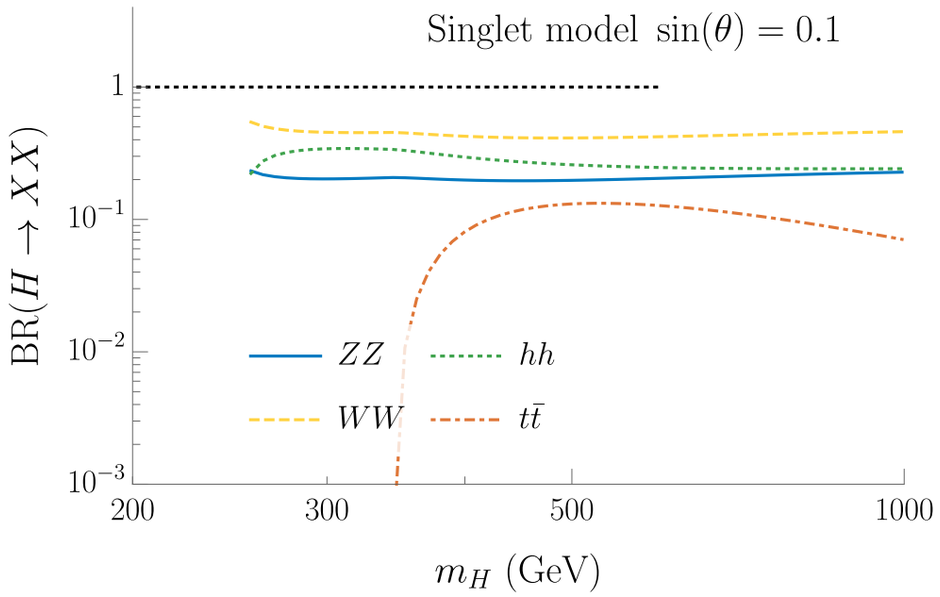
$\cos(\beta - \alpha) = 0.1$



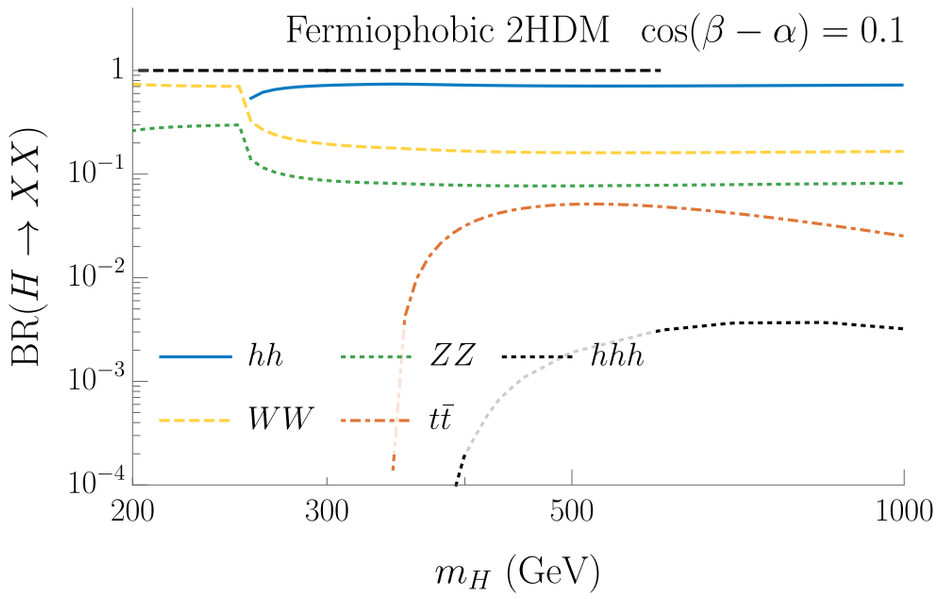
$$\Gamma_{hh} = 9/2\,\Gamma_{WW} = 9\Gamma_{ZZ}$$

(at high energies)

***DEU**, Homiller, Meade, 2101.04119*

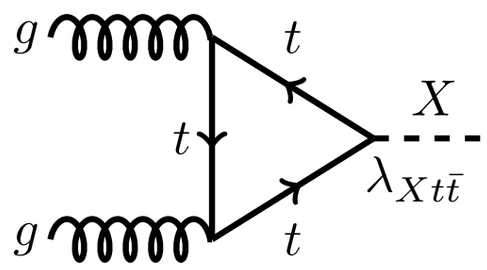


Scalar singlet model,
$\sin\theta = 0.1$

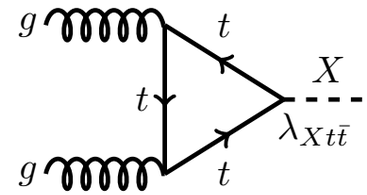


"Generic" 2HDM
$\cos(\beta - \alpha) = 0.1$

1. Production via gluon fusion



SCALAR SINGLET MODEL



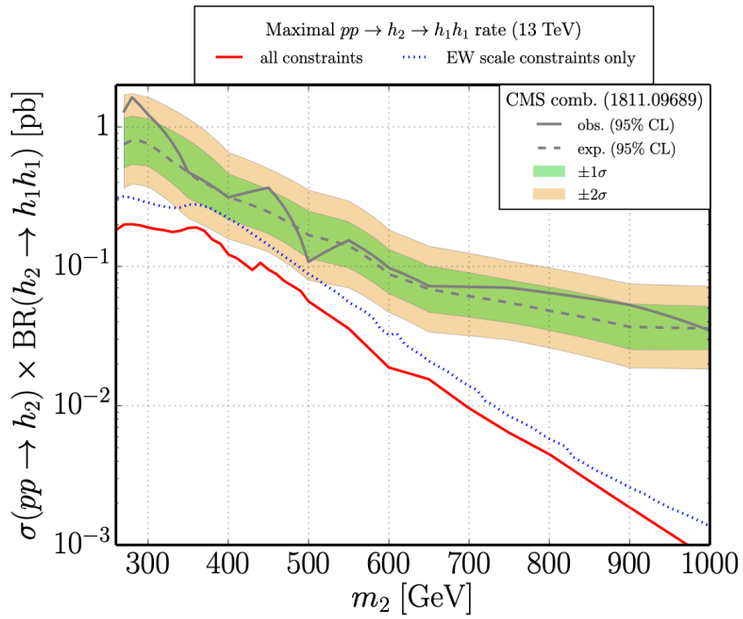
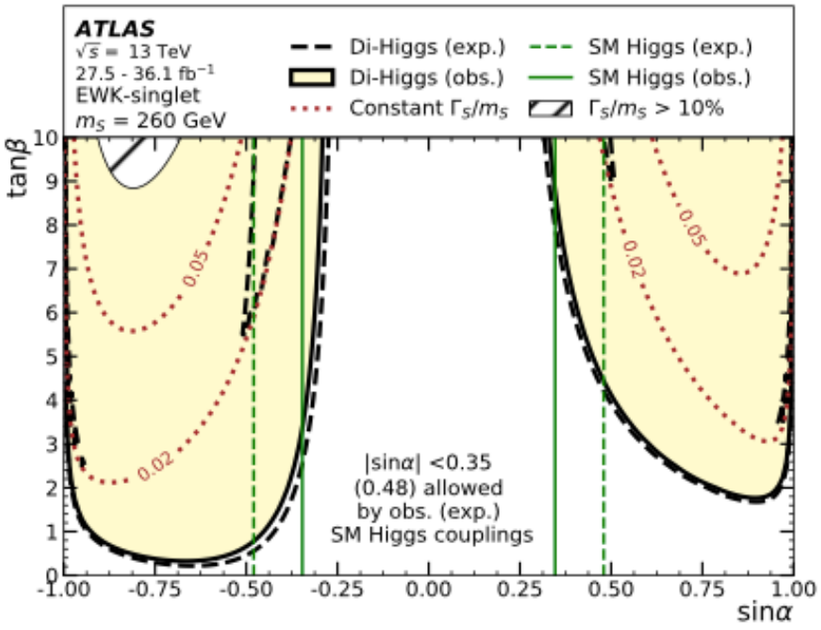


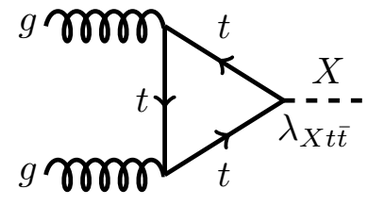
Figure 3.1: Maximal allowed $pp \to h_2 \to h_1 h_1$ signal rate at the 13 TeV LHC in the softly-broken Z_2-symmetric case. Shown are values after applying (red solid) all constraints and (blue dotted) only constraints at the EW scale. The corresponding $\mathrm{BR}_{\mathrm{max}}^{h_2 \to h_1 h_1}$ values are given in Table 3.1. For comparison we include the current strongest cross section limit (at 95% CL), obtained from the combination of various CMS $h_2 \to h_1 h_1$ searches at 13 TeV with up to 36 fb^{-1} of data [63].

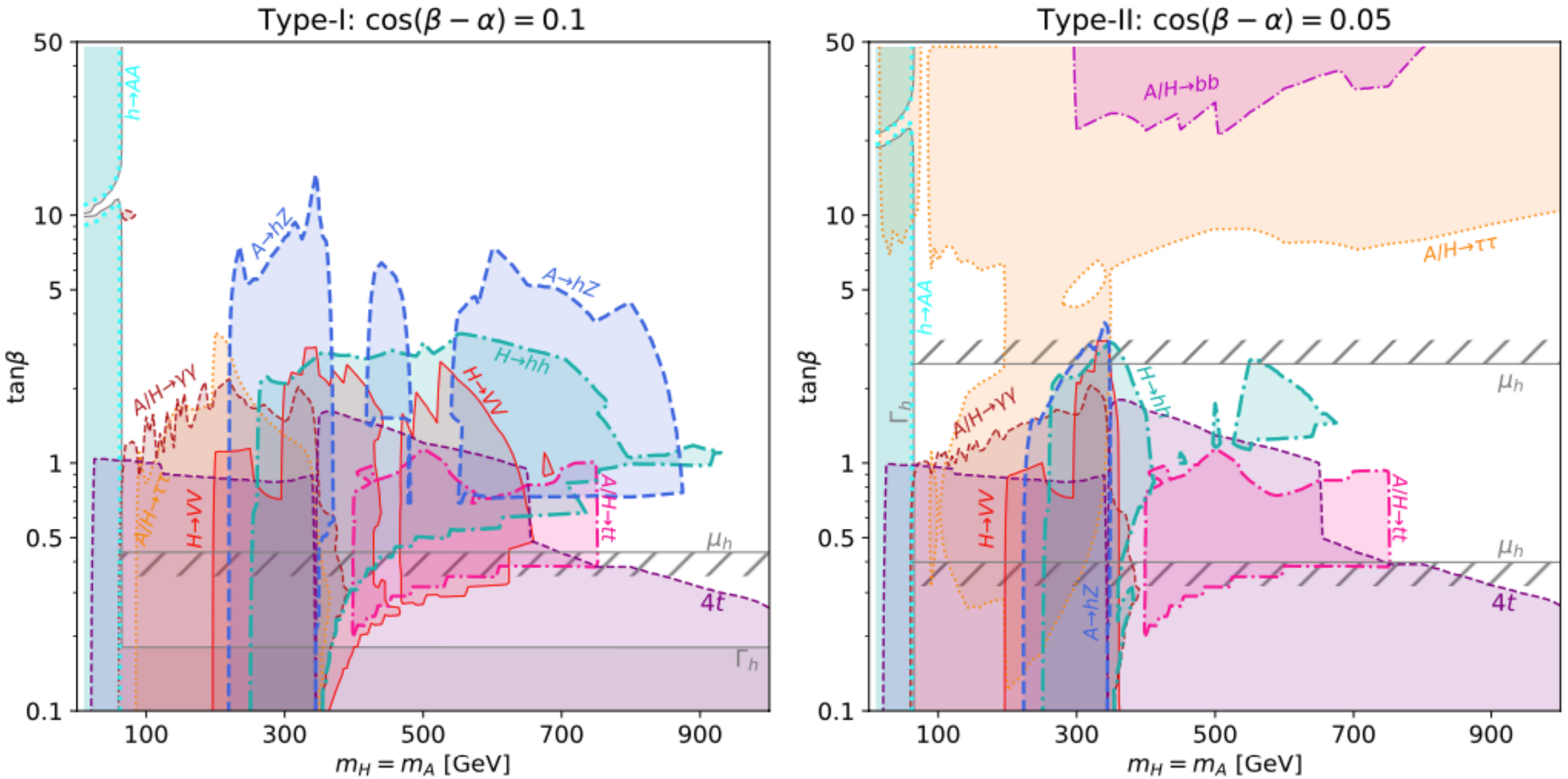
Chen, Dawson, Lewis 1410.5488
Robens, Stefaniak 1601.07880
Di Micco et.al. 1910.00012



ATLAS coll., 1906.02025

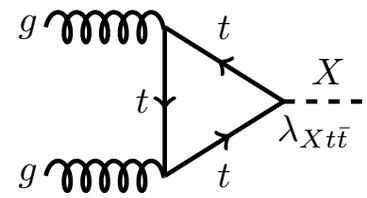
TYPES I/II 2HDM

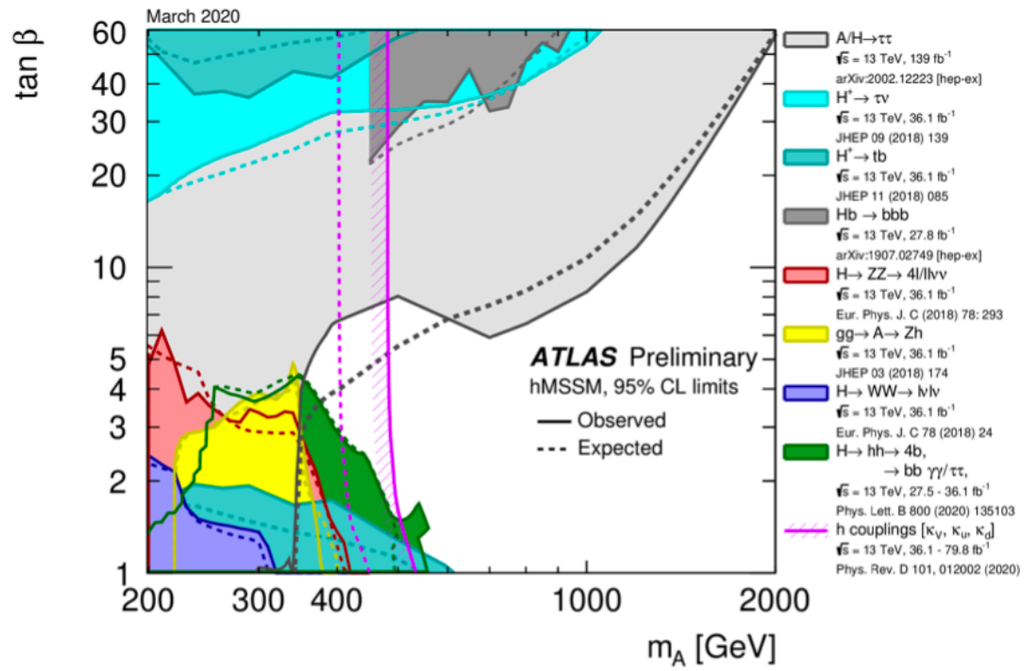


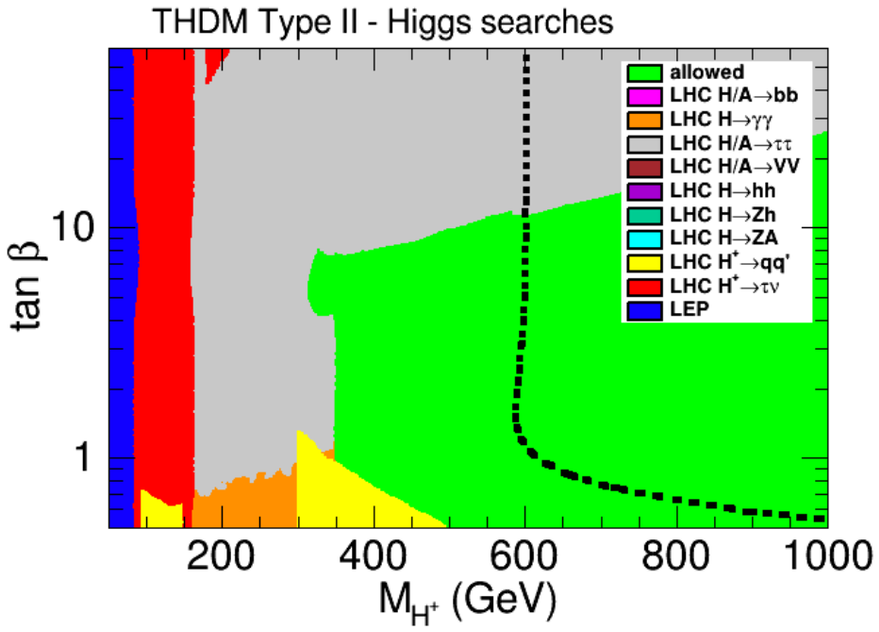


Kling, Su & Su 2004.04172
For implications to 1st order PT see Su et.al. 2011.04540

TYPE II 2HDM (MSSM)



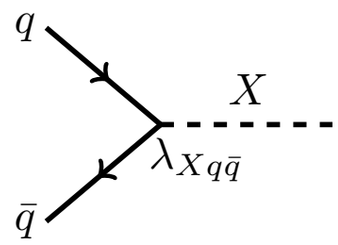




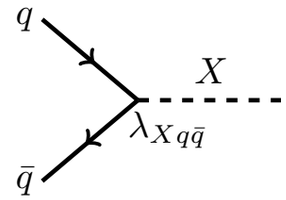
References in
PoS LHCP2020 (2021) 011

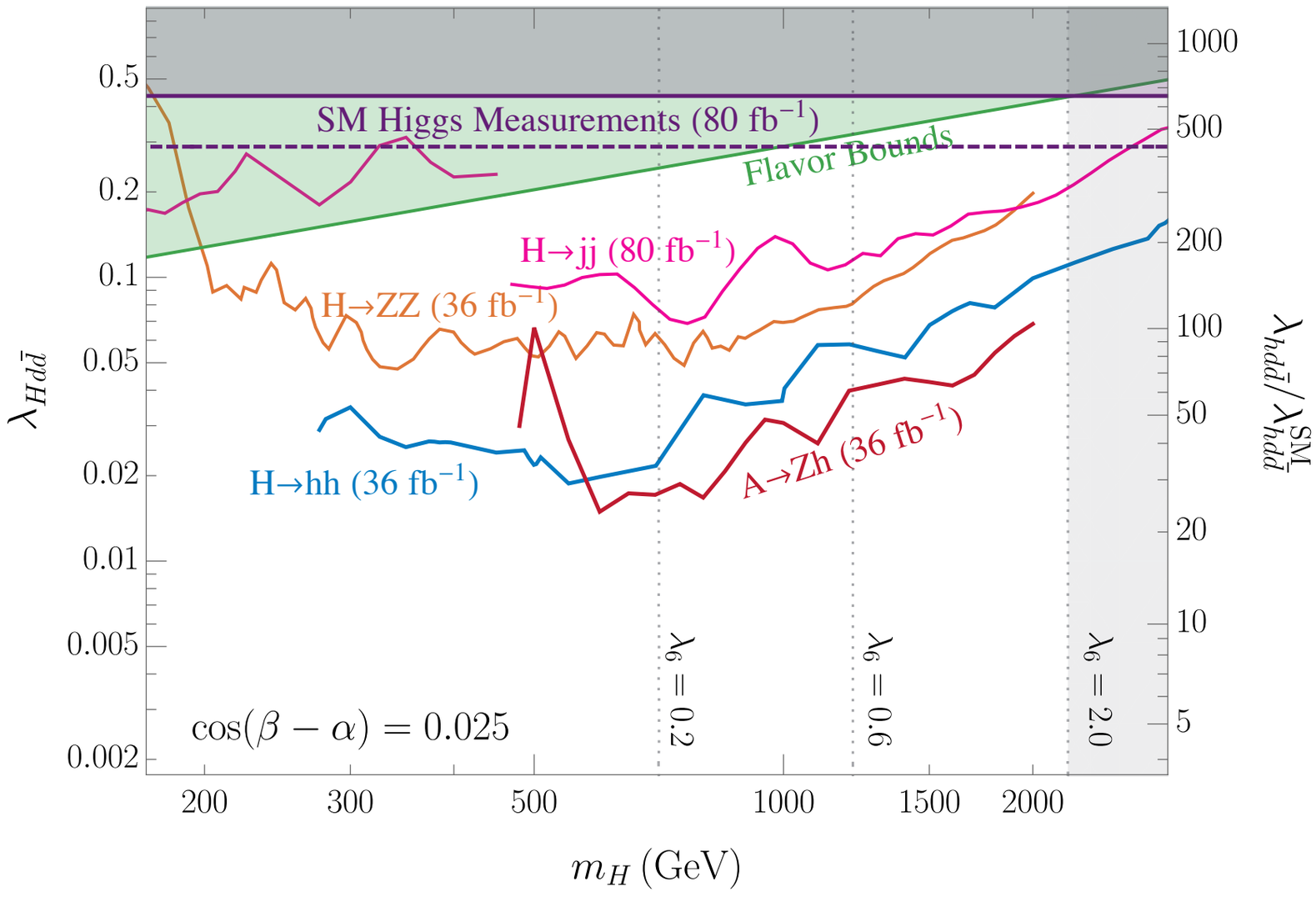
Strong constraints from radiative b decays
Arbey et.al.,
1706.07414,
see however
SIMBA coll. 2007.04320

2. Production via quark fusion



HIGGSES COUPLING TO LIGHT QUARKS





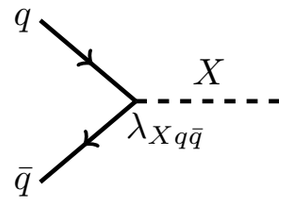
SFV 2HDMS

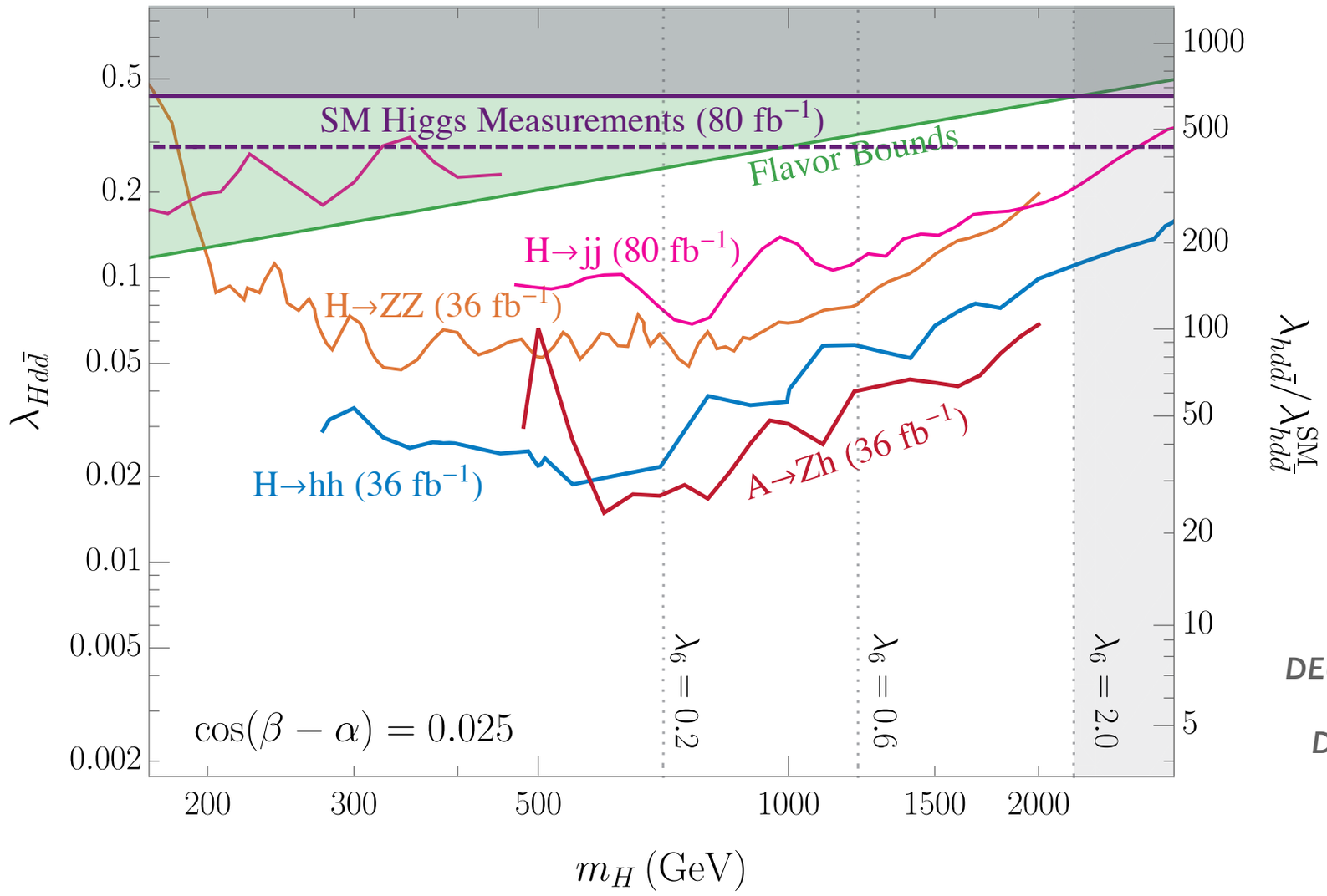
DEU, *Homiller, Meade, 1908.11376 and 1811.00017*

DEU, *Homiller, Meade, 2101.04119 (possible implications for baryogenesis, Davoudiasl et.al. 2103.12089)*

See also JM Cano's talk

HIGGSES COUPLING TO LIGHT QUARKS





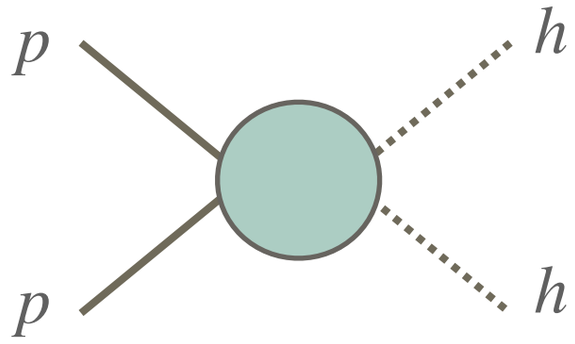
SFV 2HDMS

DEU, *Homiller, Meade, 1908.11376 and 1811.00017*

DEU, *Homiller, Meade, 2101.04119*

Dihiggs production is the most effective probe of the $\boldsymbol{h_{125}}$ *couplings to light quarks (in 2HDMs)*

Non-resonant di-Higgs production
When can it beat bump hunts?

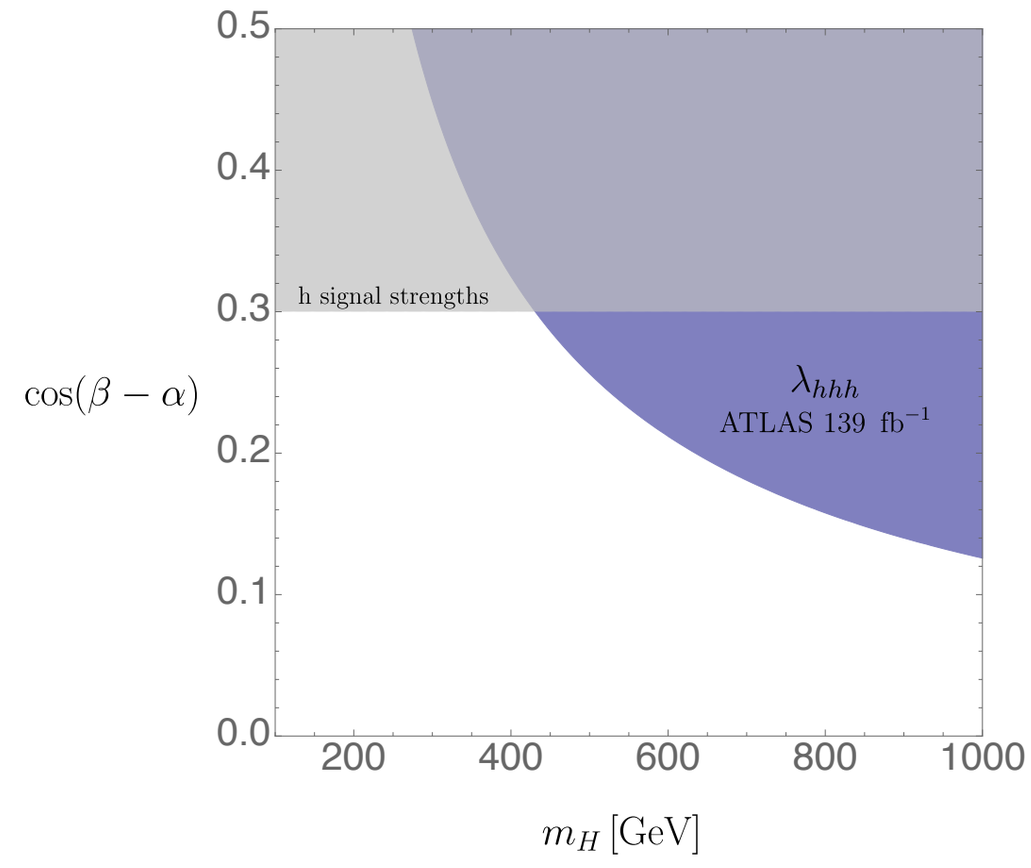


PRODUCTION BLIND SPOTS

- Even if new physics is light, non-resonant searches can cover regions of parameter space where production is suppressed

Example: ggF

$$\lambda_{Ht\bar{t}} \sim \kappa_t - y_t \cos(\beta - \alpha)$$



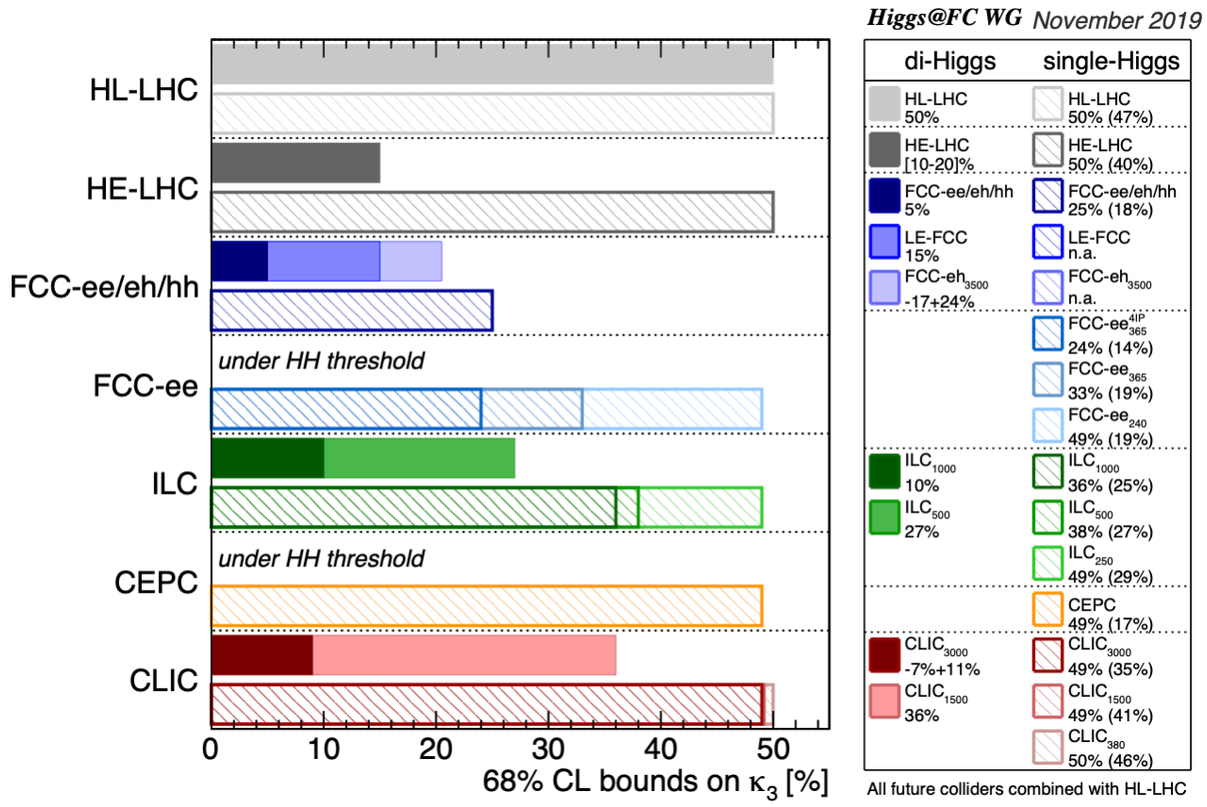
***DEU**, Homiller, Meade, 2101.04119 and upcoming arXiv:xxxx*

FUTURE COLLIDERS

- FCC-ee, ILC, CLIC, CEPC could reach O(10-50%) precision.

- FCC-hh, percent-level precision.

- Muon colliders could also reach ~5%-20% precision
(see Han et.Al. 2008.12204, and L. Giambastiani + S. Homiller's talks)



Blas et.Al.1905.03764
See also I. Ojalvo's talk

SUMMARY

- Di-Higgs production is a fantastic tool to test a variety of new physics theories.

- Current resonant di-Higgs searches already are a discovery channel for some BSM models, notably some types of 2HDMs.

- In extended higgs sectors, together other decay channels, hh production provides an exquisitely detailed picture of *very profound* questions regarding *BSM flavor.*

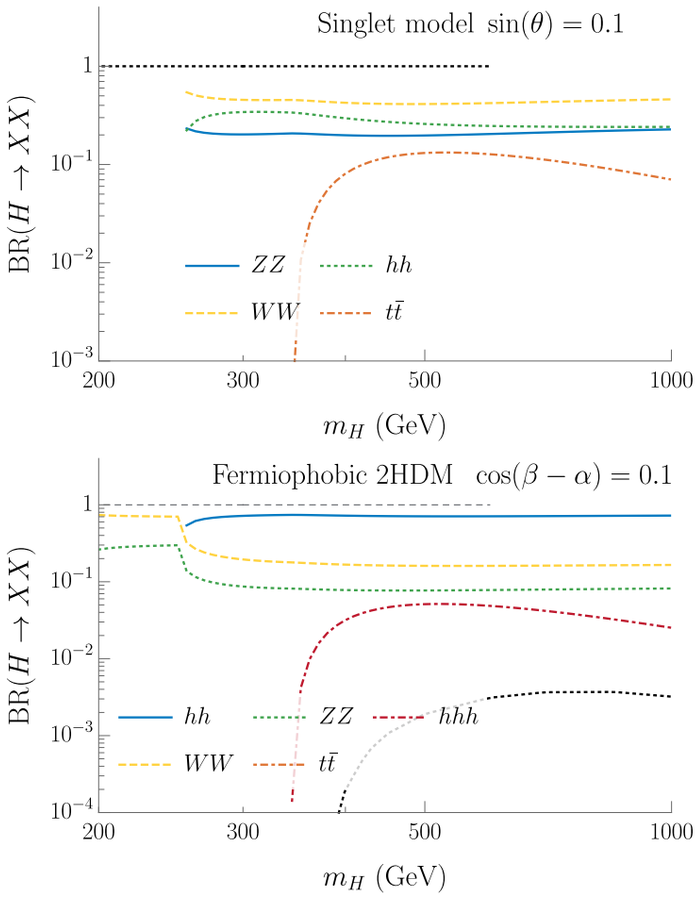
- BSM physics with large flavored couplings to light quarks are a prime target, and it is quite unexplored. Same story for couplings to light leptons!

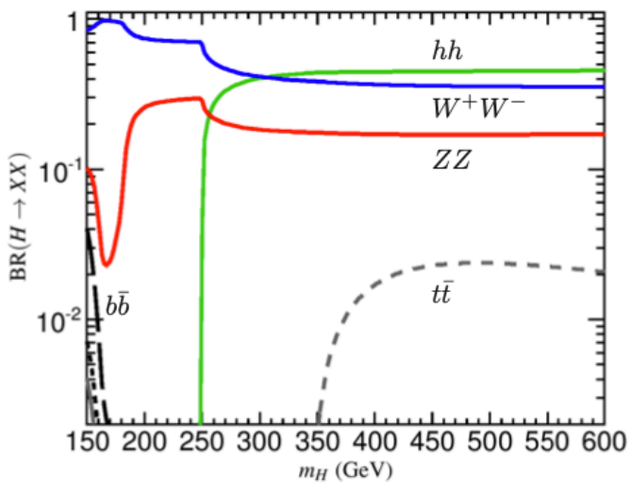
- Other signatures? 3h production! *Dutta, **DEU**, Homiller, Meade, Mina, Peña arXiv:XXXX.*

Thanks!

FLAVORED COUPLINGS: WINDOWS INTO THE FLAVOR PUZZLE

SM-like *(aligned to third-generation)*	*Flavor-aligned* *(couplings to all generations allowed)*
Minimal Flavor Violation (D'Alessandro et.Al. 0207036)	Spontaneous flavor violation (**DEU**, Homiller, Meade, 1811.00017)
Holomorphy (MSSM) (Dimopoulos NPB 193, 1981, 150)	Horizontal symmetries (Leurer, Nir, Seiberg 9212278)
Z2-PQ symmetries (types I-IV 2HDM) (Glashow, Weinberg, PRD 15 (1977) 1958)	Extra-dim. GIM? Others? (Cacciapaglia et.Al. 0709.1714 , Davidson et.Al. 0711.3376)





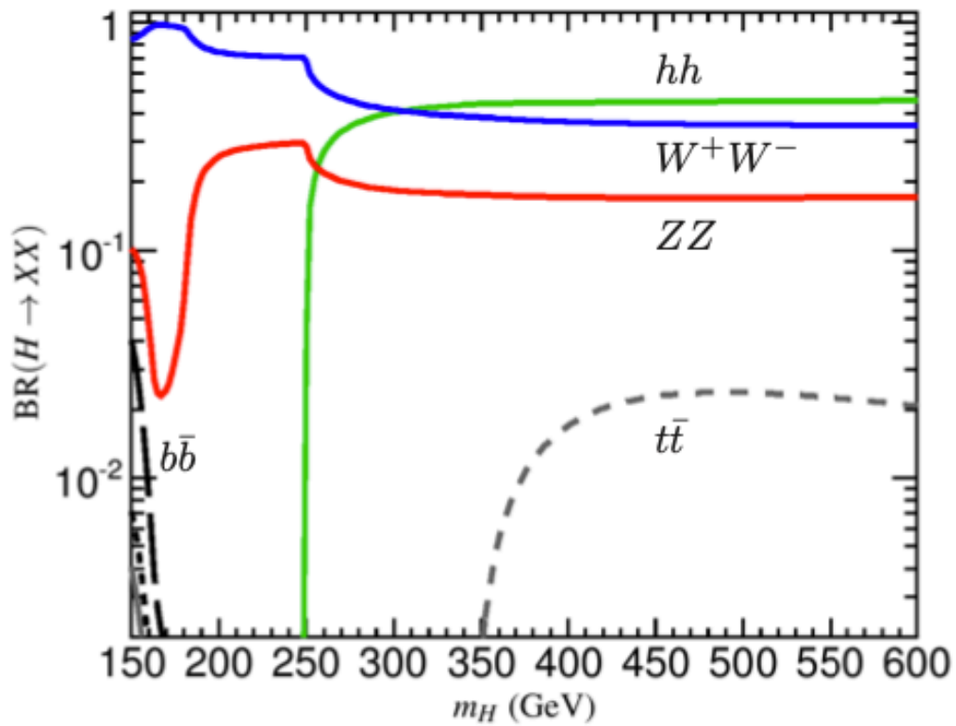
Scalar singlet model,
$\sin\theta = 0.1$

"Generic" 2HDM
$\cos(\beta - \alpha) = 0.1$

Type I 2HDM at large $\tan\beta$*,*
$\cos(\beta - \alpha) = 0.1$

TYPE I 2HDM BRANCHING FRACTIONS

3. *Type I 2HDM at large* $\tan\beta$, $\cos(\beta-\alpha)=0.1$



Haber, Stal 1507.04281.
See also Craig et. Al. 1504.04630