STATUS OF SUSY TWIN HIGGS

new signals for naturalness at the LHC

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25/05/2017

based on arXiv:1611.08615 with A. Katz, A. Mariotti, S. Pokorski R. Ziegler

and work in progress

Why TWIN SUSY?

The Twin Higgs is the last resort of the SYMMETRY paradigm for Naturalness (cit.)

1) It gives a CONCRETE answer to the question:

Have we built all the possible “natural” theories?

2) It gives a NEW EFT FRAMEWORK at the TeV scale to test against experiments

Why SUSY TWIN?

It puts the Twin proposal (almost) on the same footing of standard SUSY scenarios:

1) Calculability of the Higgs sector and fine-tuning (see Andrey and Marcin talks in this conference)

Focus of this talk

2) Sharp phenomenological predictions

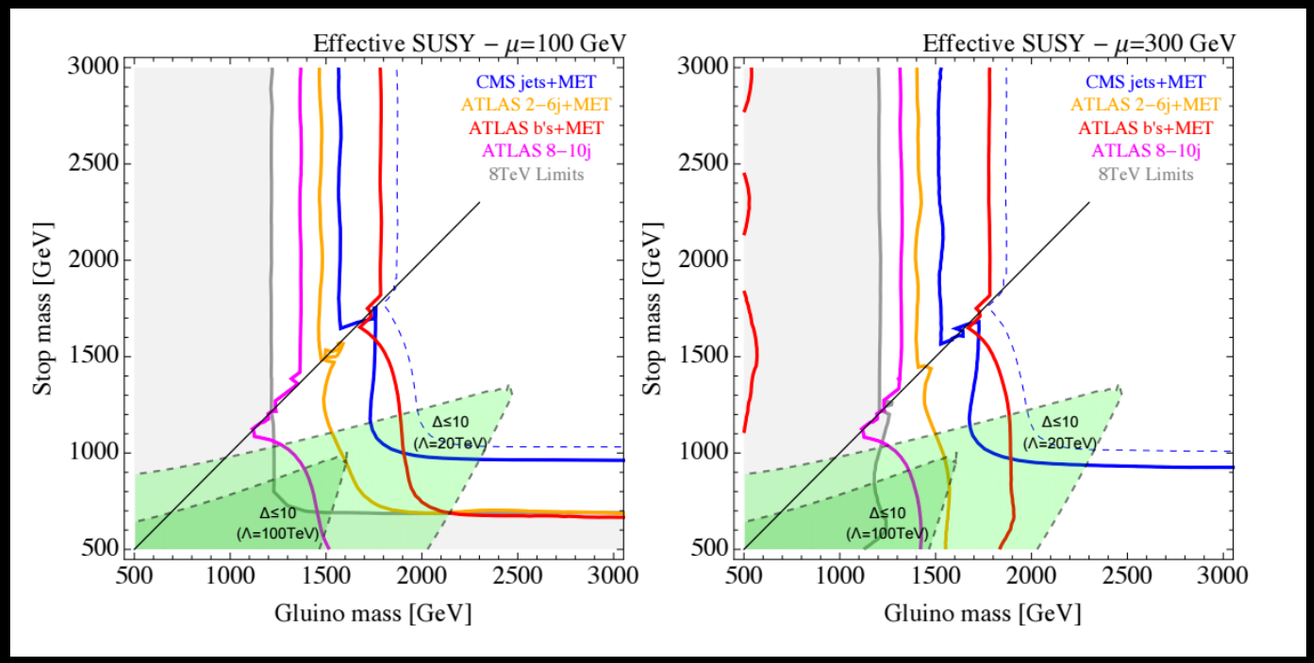
SUSY paradigm

$$m_{\rm soft}^2 \lesssim \frac{2\pi^2}{3y_t^2} \frac{\Delta\ m_h^2}{\log \frac{m_*}{m_{\rm soft}}}$$

$$\approx (500\ {\rm GeV})^2 \times \frac{\Delta}{10} \times \frac{4}{\log}$$

SUSY is an EXACT symmetry of the high energy theory

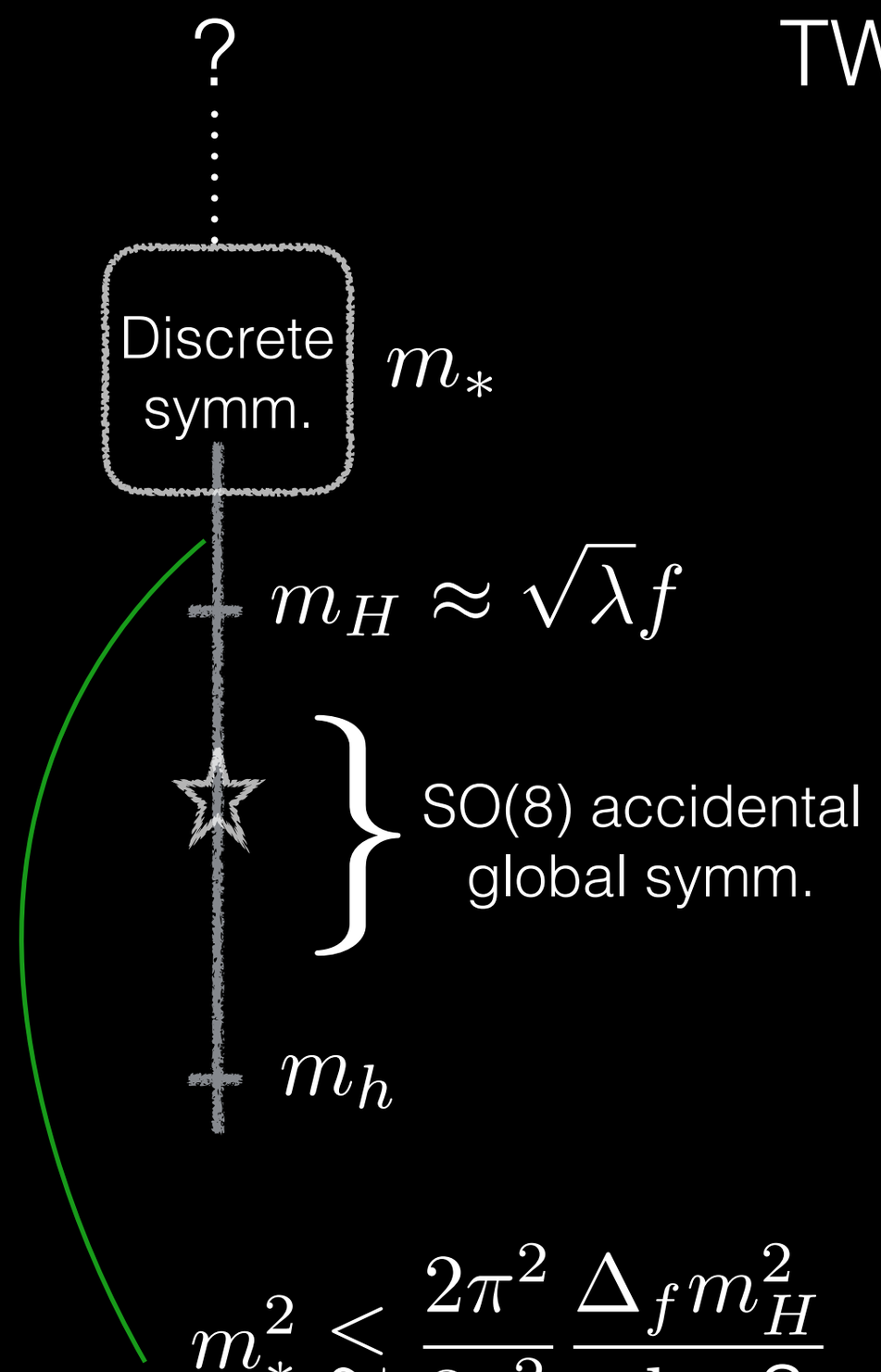
The top super-partners are colored



LHC vs Δ

D. Shih et al. 1610.08059

TWIN paradigm



$$m_*^2 \lesssim \frac{2\pi^2}{3y_t^2} \frac{\Delta_f m_H^2}{\log ?}$$

$$\approx (3.5\ \mathrm{TeV})^2 \times \frac{\Delta_f}{10} \times \frac{\lambda}{1} \times \frac{2}{\log}$$

The SM Higgs is the PGB of an accidental global symmetry enforced by a discrete symmetry

If $Z_2 \ : \ SU(3) \leftrightarrow SU(3)'$

the top-partners at the scale $\sim y_t f$

ARE color neutral

G. Burdman, H.S. Goh and R. Harnik
0506256

?

Discrete symm.

m_*

$m_H \approx \sqrt{\lambda} f$

SO(8) accidental global symm.

$m_h \approx \sqrt{\kappa} f$

$$m_*^2 \lesssim \frac{2\pi^2}{3y_t^2} \frac{\Delta\, m_h^2}{\log ?}$$

$$\approx (10\ \text{TeV})^2 \times \frac{\Delta_f}{10} \times \frac{\lambda}{1} \times \frac{2}{\log} \times \frac{m_H^2}{0.5^2\ \text{TeV}^2}$$

colored top-partners live at $\sim m_*$

ENRICHED HIGGS SECTOR

$$m_h \ll m_H \quad \leftrightarrow \quad k \ll \lambda$$

$$Z_2 : \ SU(2)_A \leftrightarrow SU(2)_B$$
$$H_A \leftrightarrow H_B$$

if Z_2 is unbroken: $\langle H_A \rangle = \langle H_B \rangle$

the SM Higgs is maximally mixed with a SM singlet

?

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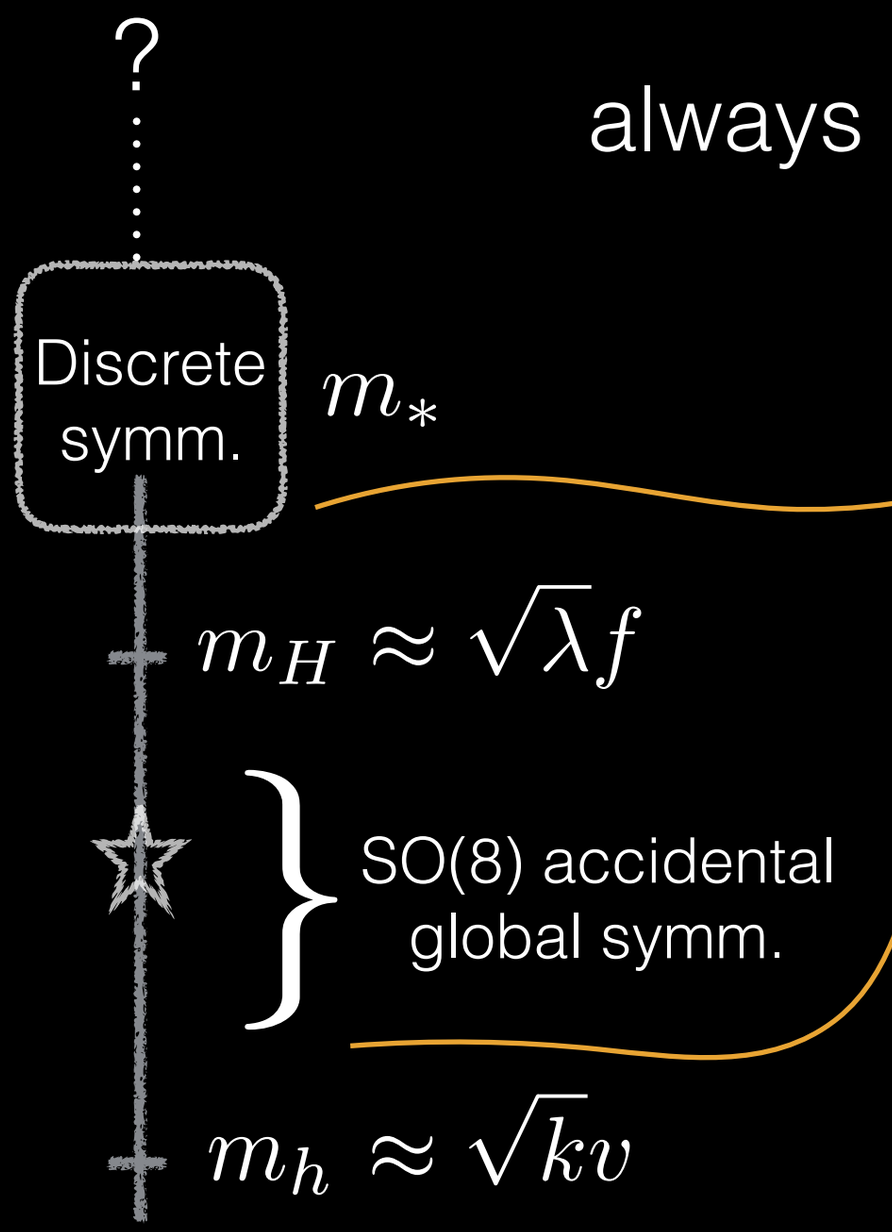
the … maximally mixed … SM singlet

Z_2- breaking is needed!

Breaking Z_2
always implies extra tuning!

$$\Delta = \Delta_f \times \Delta_{f/v}$$



SOFT: $\Delta_{f/v} \approx f^2/2v^2$

Z_2 is broken by a mass term

$$m_*^2 \lesssim \frac{4\pi^2}{3y_t^2} \frac{\Delta\, m_h^2}{\log} \frac{\lambda}{\lambda_{\rm SM}} \approx (3\ {\rm TeV})^2 \times \frac{\Delta}{10} \times \frac{\lambda}{1} \times \frac{2}{\log}$$

HARD: $\Delta_{f/v} \approx f^2/2v^2 \times \dfrac{8\kappa v^2}{m_h^2}$

Z_2 is broken by a mass quartic

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better FT if $\kappa \ll \lambda_{SM}$

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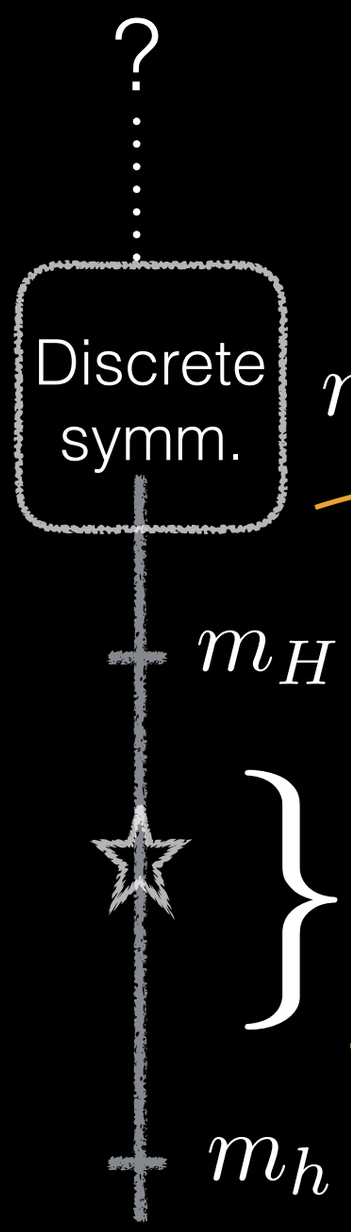

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Z_2 is broken by a mass quartic

(AFTER f & v are fixed)
the final scale of
colored states depends
on one (or two) NEW quartic!

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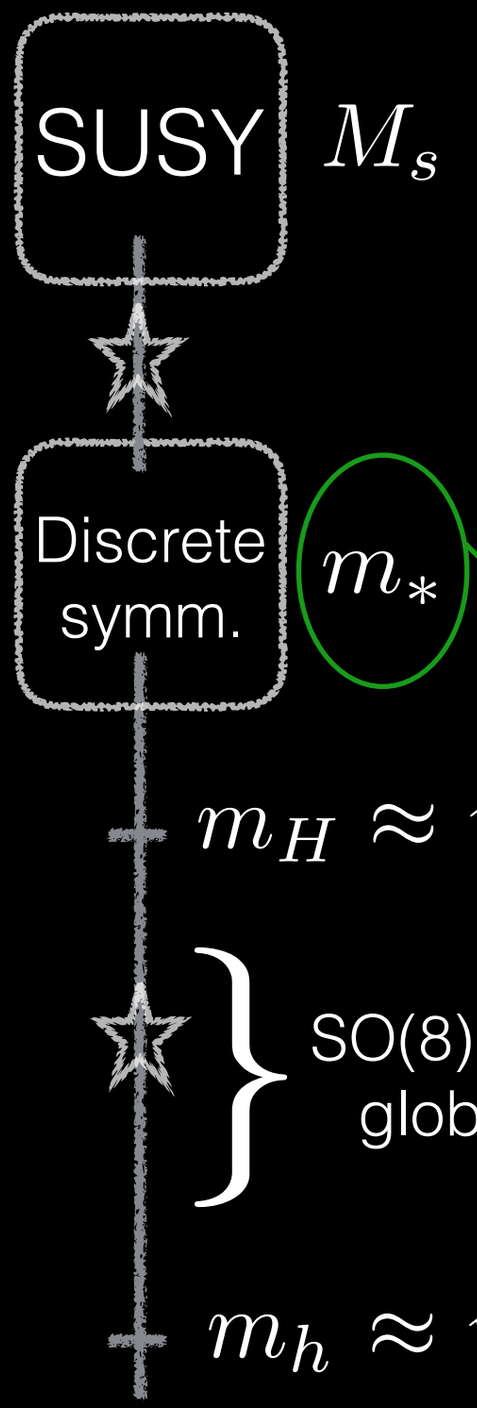
better FT if

$\kappa \ll \lambda_{SM}$

What if the cut-off of the Twin Higgs is stabilised by SUSY?



$M_s = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$ MSSM stops

$Z_2 : \; SU(2)_A \leftrightarrow SU(2)_B$

$\{h_u^A \; , \; h_d^A\} \leftrightarrow \{h_u^B \; , \; h_d^B\}$ 4HDM

$t_\beta^A \approx t_\beta^B$

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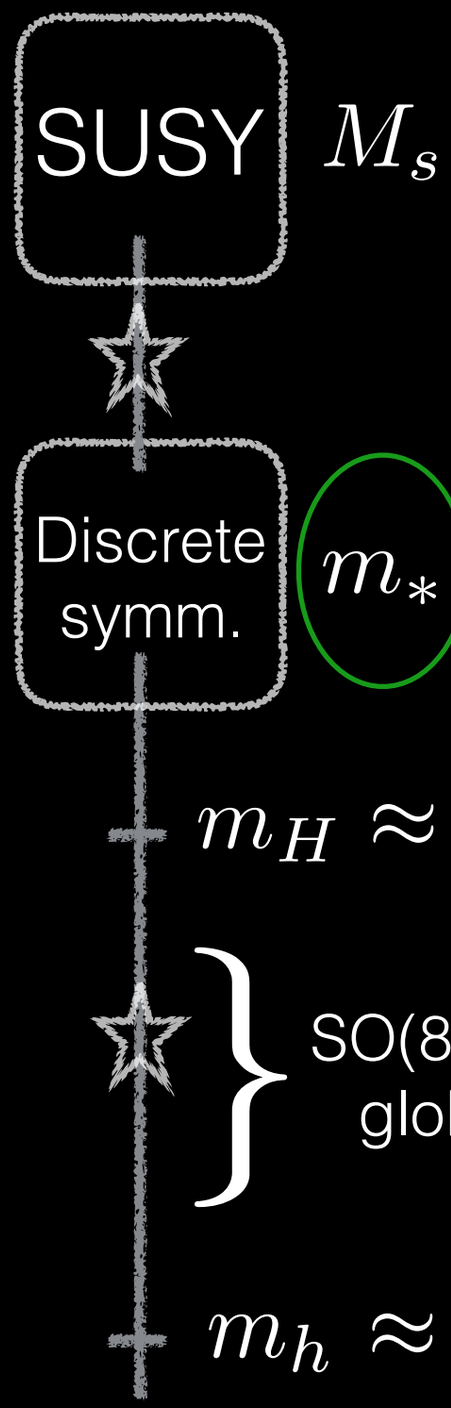

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Non-decoupling effect or extra light Higgses

- F-term — Falkowski et al. 0604066, Craig et al. 1312.1341, Katz et al. 1611.08615
- D-term — Badziak et al. 1703.02122
- else?

$\lambda \approx \lambda_S^2 \times f(\beta)$

- $\sin 2\beta^2$
- $\cos 2\beta^2$
- $\ldots$

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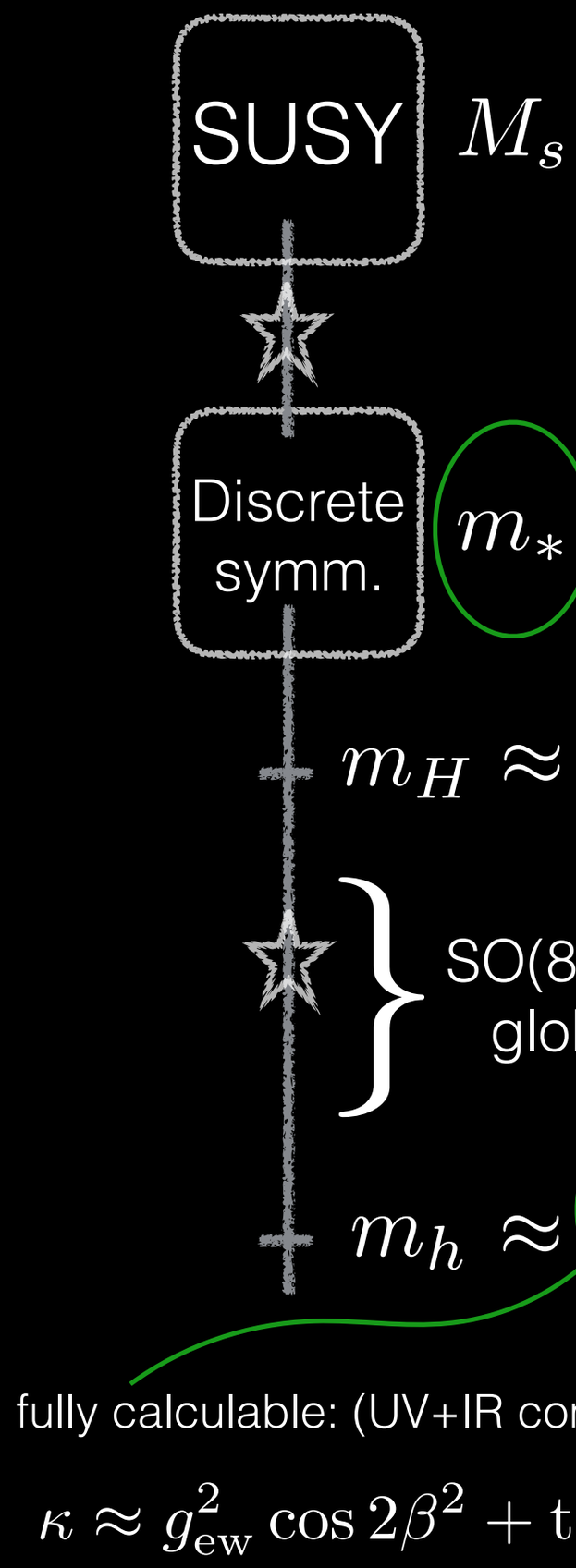

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- $\cos 2\beta^2$
- $\dots$

The final gain in FT depends A LOT on how

$$m_h = 125\ \mathrm{GeV}$$

foliates the parameter space

ex: in minimal Twin Higgs model M_s t_β are correlated by the Higgs

AT FIXED stop masses t_β is predicted!

BIG WARNING

To compare the FT gain of TWIN SUSY
with standard SUSY schemes better
accuracy in the Higgs computation is needed!

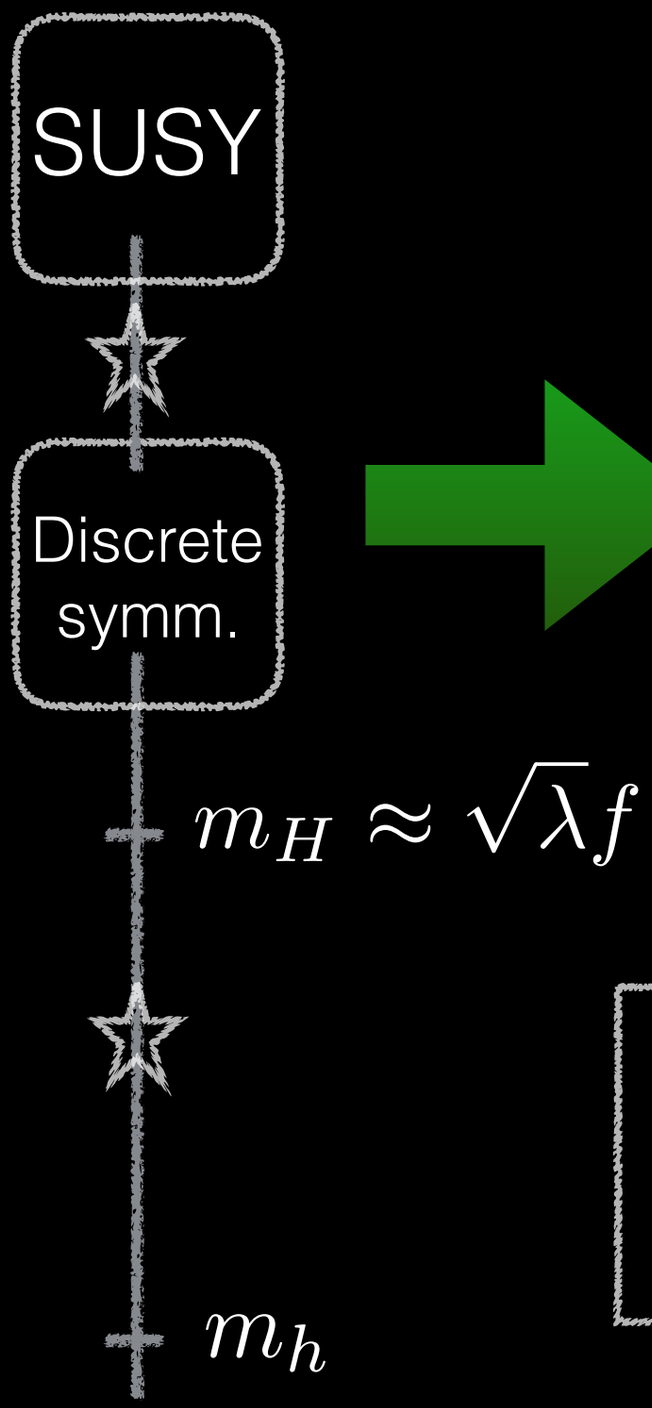
SARAH package is the natural tool to apply to this problem! (in progress with Florian & co…)

This is quite different than in composite Higgs models
where the contributions to the Higgs potential
are IR dominated

see Rattazzi et al. 1702.00797

see Greco et al. 1609.05922 for the RG improved NNLL potential from top loops

Can we say something general about the PHENO of TWIN SUSY models?



4HDM is a robust prediction

$$Z_2 : \; SU(2)_A \leftrightarrow SU(2)_B$$

$$\{h_u^A \; , \; h_d^A\} \leftrightarrow \{h_u^B \; , \; h_d^B\}$$

an exception would be if we do not Twin SU(2)
see Thaler et al. 0808.1290

If the colored states are out of reach can we hunt for the extra Higgses at the LHC?

	CP-even Higgses			
States:	h	h_T	H	H_T
Masses:	m_h^2	$\lambda_S^2 s_{2\beta}^2 f^2$	$m_{A_T}^2 - \lambda_S^2 f^2$	$m_{A_T}^2 - \lambda_S^2 f^2 s_{2\beta}^2$

	CP-odd Higgses		Charged Higgses	
States:	A_T	A	$H^\pm$	$H_T^\pm$
Masses:	$m_{A_T}^2$	$m_{A_T}^2 - \lambda_S^2 f^2$	$m_{A_T}^2 - \lambda_S^2 f^2$	$m_{A_T}^2 - \lambda_S^2 f^2$

radial mode

MSSM Higges

MSSM Dark Higges

The Mass hierarchies are controlled by: f , $m_A = \sqrt{m_{A_T}^2 - \lambda_S^2 f^2}$

controls the quality of Z_2

The "minimal" pheno depends on: λ_S , t_β

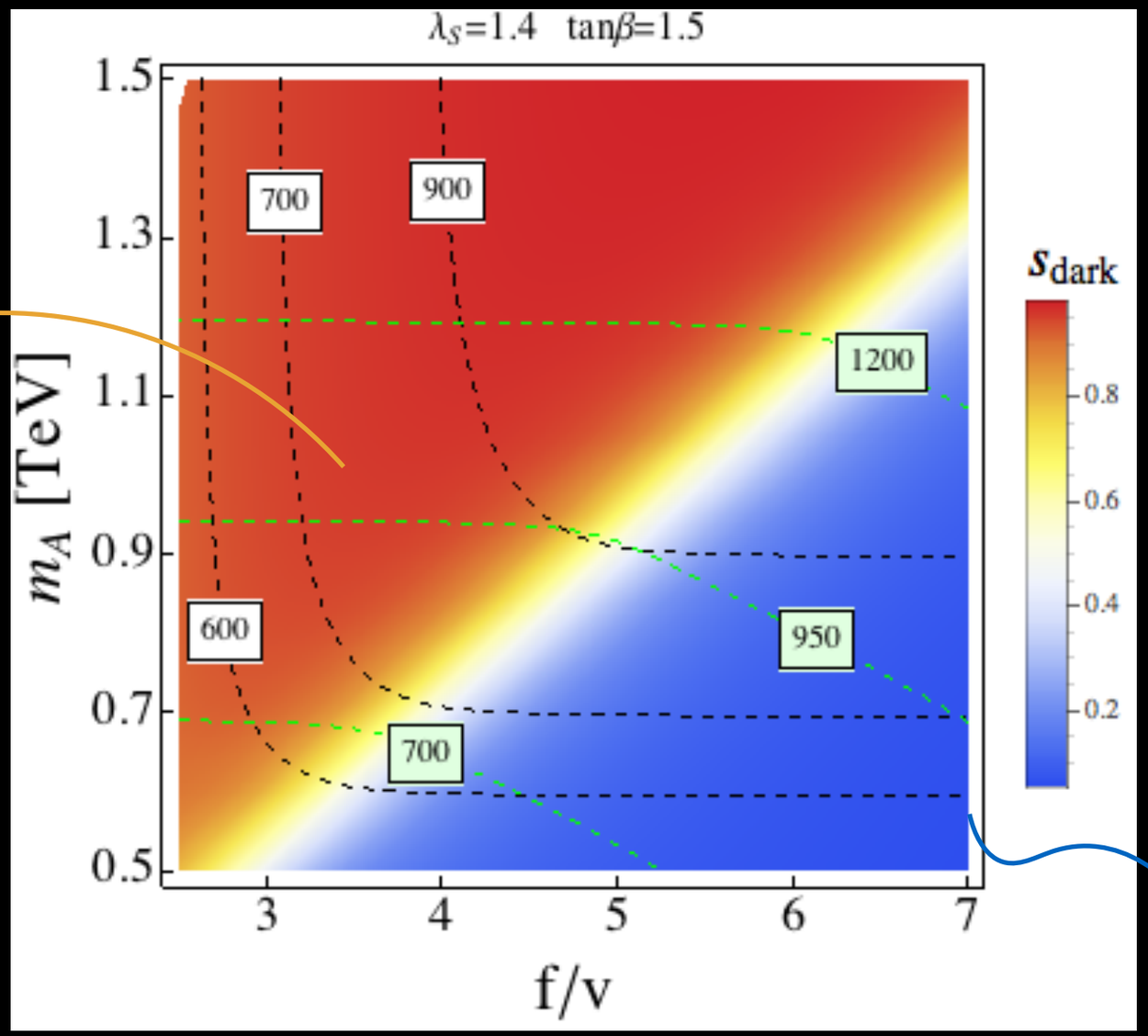
large for best FT

fixed to be small for stops and gluinos out of reach of the LHC

THE HIGGS SPECTRUM

low f region

the radial mode lightest-non-SM Higgs



$$\equiv \sqrt{V_{23}^2 + V_{24}^2}$$

large f region
MSSM-Higgses lightest

$$H_I = \sum_i V_{Ii} h_i \qquad h_i = \{h_u^A, h_d^A, h_u^B, h_d^B\}$$

MAIN DECAY modes of the lightest extra Higgs

the radial mode

in the Goldstone limit

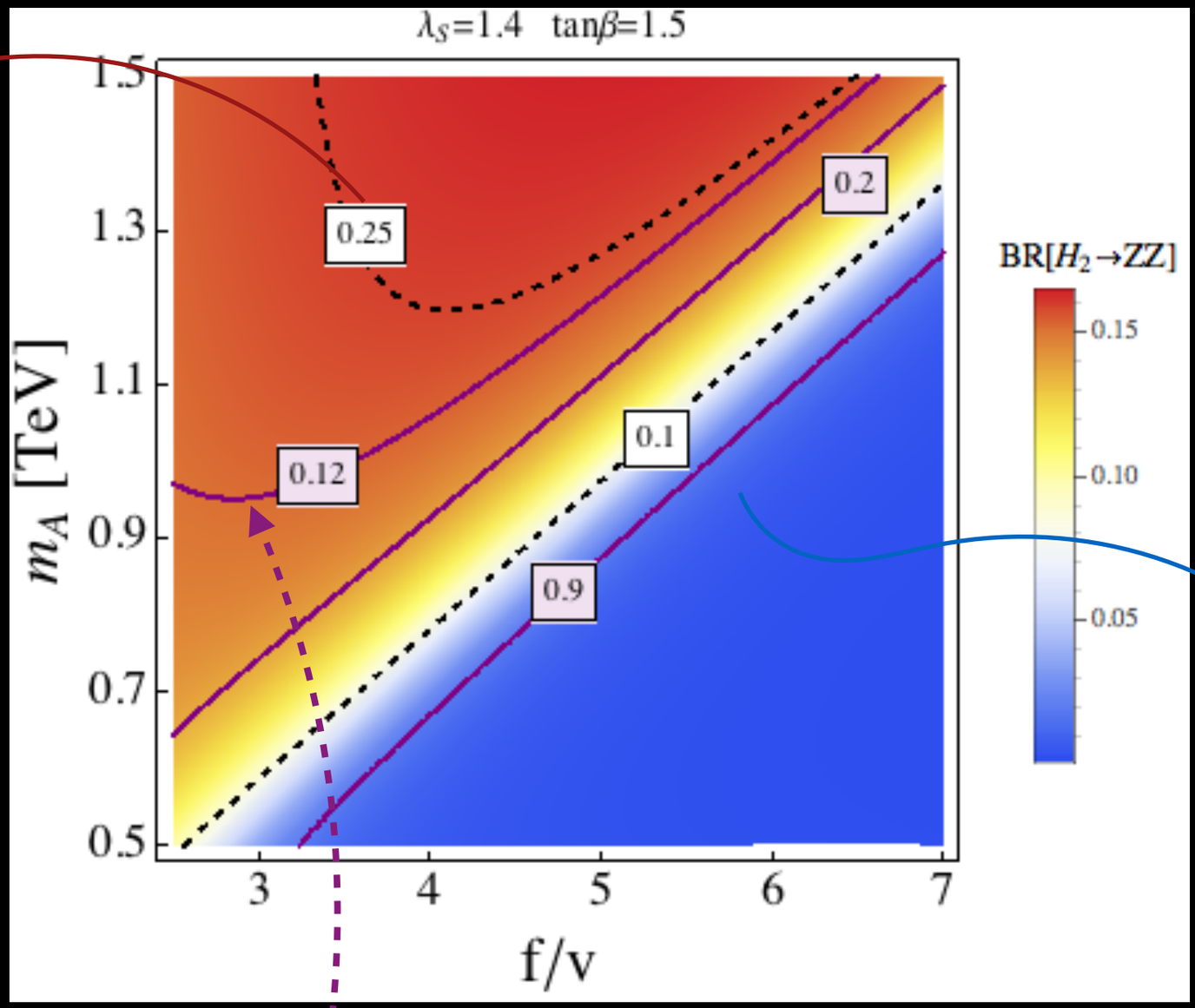
Buttazzo, Sala, Tesi
1505.05488

$\mathrm{BR}_{ZZ} \approx 1/7$

# of GB

$\mathrm{BR}_{\mathrm{inv}} \approx 3/7$

3 “dark” GB



the MSSM Higgs

$\mathrm{BR}_{t\bar{t}} \approx 90\%$

Craig & many others
1504.04630
1605.08744

World is not perfect:
- large BR into visible tops
- decay into dark GB can be kinematically closed!

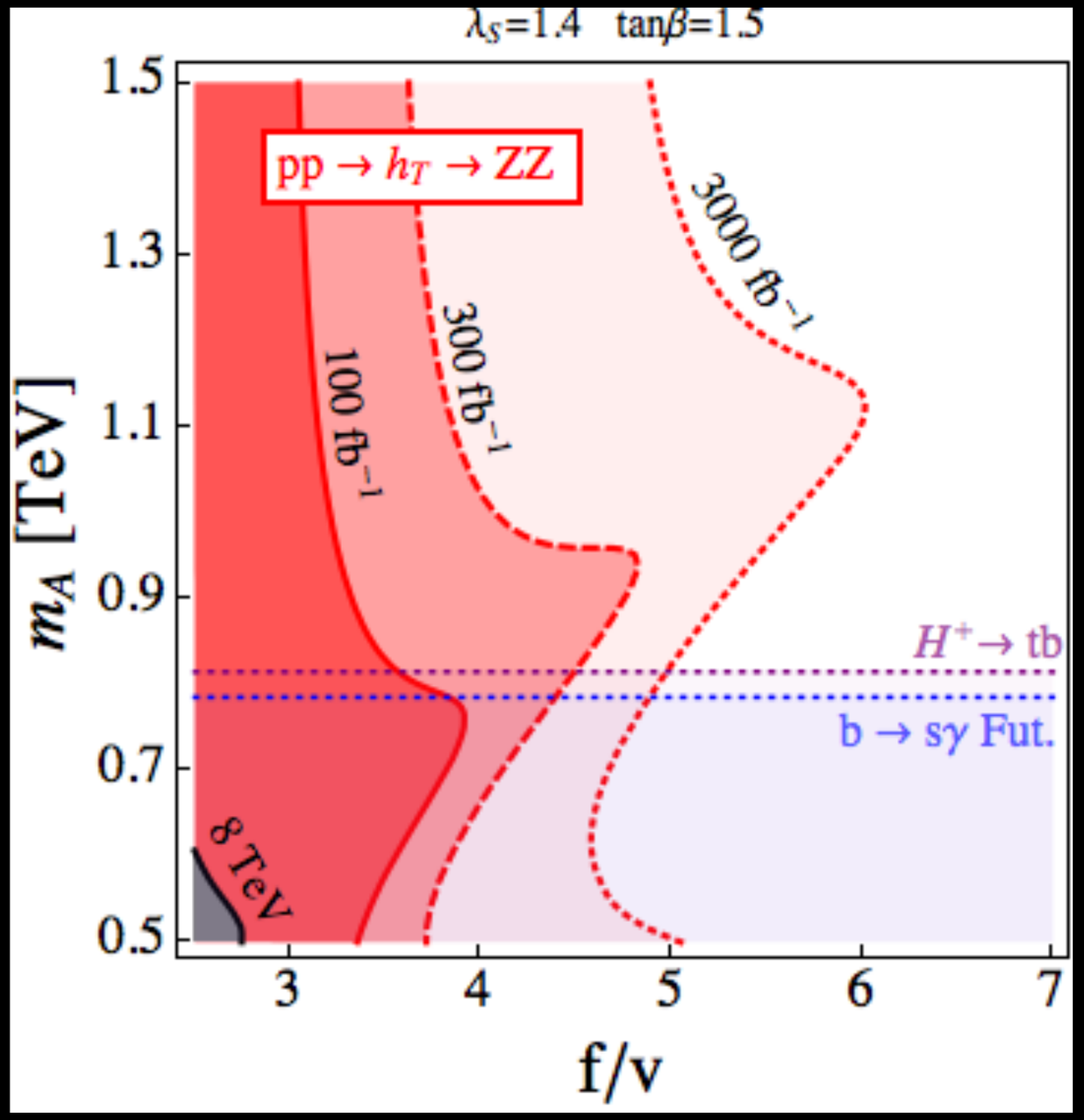
LHC vs *weakly* coupled Neutral Naturalness

SUSY M_s

Discrete symm.

$m_H \approx \sqrt{\lambda} f$

m_h



searches for a resonance in ZZ
push the Twin scale UP!

CHALLENGE

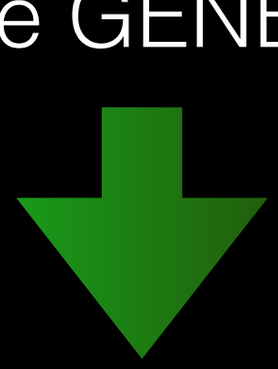
MSSM Higgses @ low t_β

TAKE HOME MESSAGE

TWIN SUSY is a calculable setup
for Neutral Naturalness

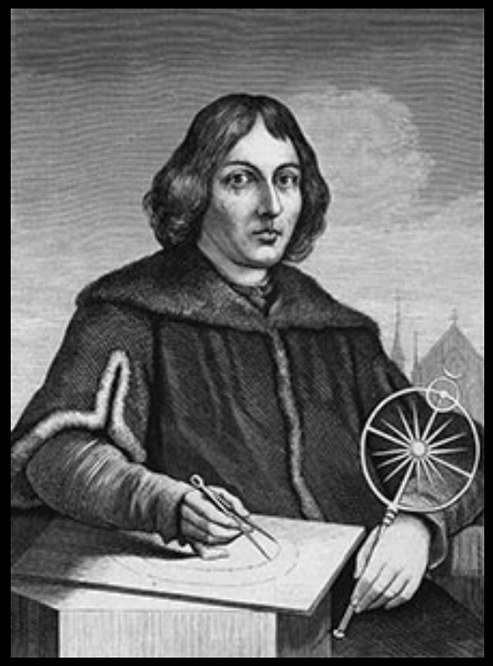
many things to compute/understand better!

New Higgses are GENERIC predictions



Standard Higgs searches can probe (weakly coupled) Neutral Naturalness!

major pheno difference with strongly coupled UV completions



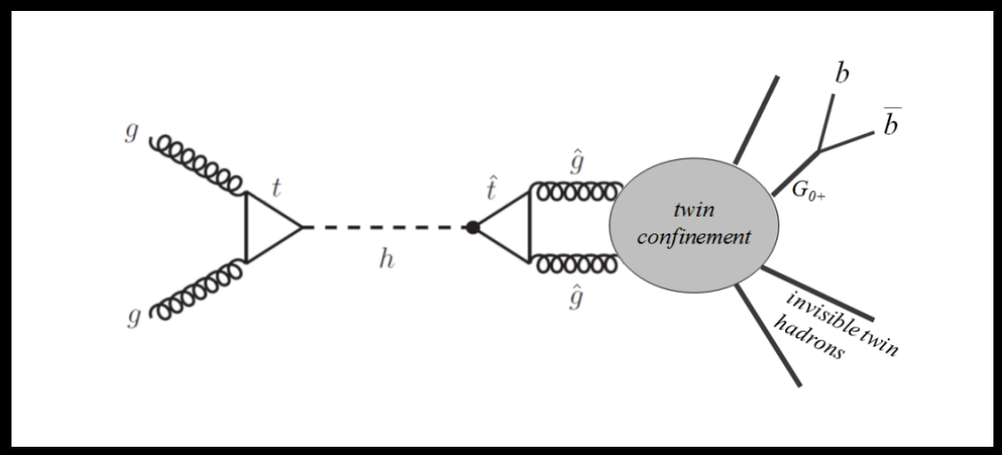
Looking forward…

WHAT IS THE NEXT STEP
FOR SEARCHES OF EXTRA HIGGES?

connection with Cosmology

In the fraternal Twin Higgs INVISIBLE decays of the extra Higgses might get back to us!

see Craig, Katz, Strassler, Sundrum 1501.05310 & many works afterwards



LOOKING for exotics decay of radial mode/ MSSM Higgses

(SMALL BR's but ZERO Background searches)