THE WEAK SCALE AS A TRIGGER

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TODAY'S TALK

The Weak Scale As a Trigger

[Arkani-Hamed, **RTD**, Kim] '20

Sliding Naturalness

[**RTD**, Teresi] In Preparation

1. Hierarchy Problem 101
2. SM and BSM Triggers
3. Use your trigger: Linking the Higgs Mass and the Cosmological Constant

THE HIERARCHY PROBLEM

FINE-TUNING 101

A physical observable can be computed as the sum of multiple unrelated contributions

$$\mathcal{O} = O_1 + O_2 + ...$$

At least two of them are much larger than its observed value

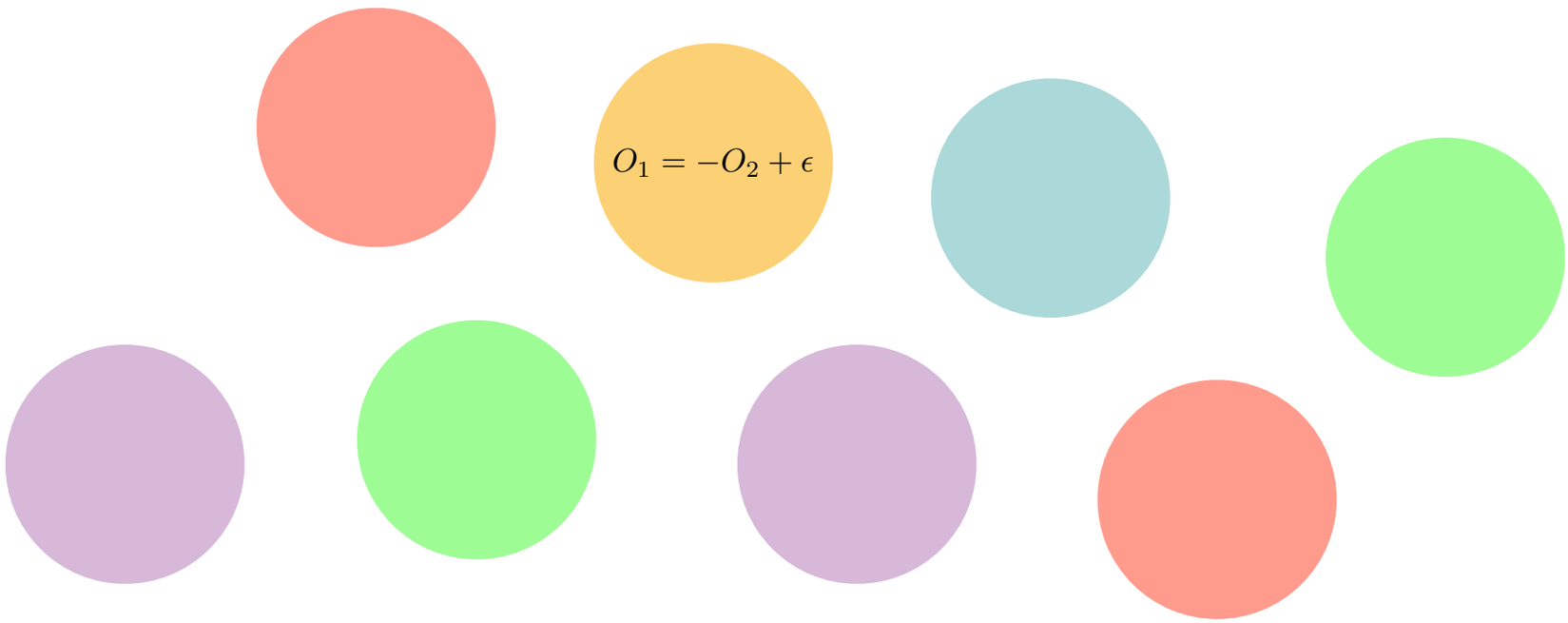
$$\mathcal{O}_{\rm obs} \ll |O_{1,2}|$$

FINE-TUNING 101

Is there a symmetry?

$$O_1 = -O_2 + \epsilon$$

Is there a landscape?



FINE-TUNING 101

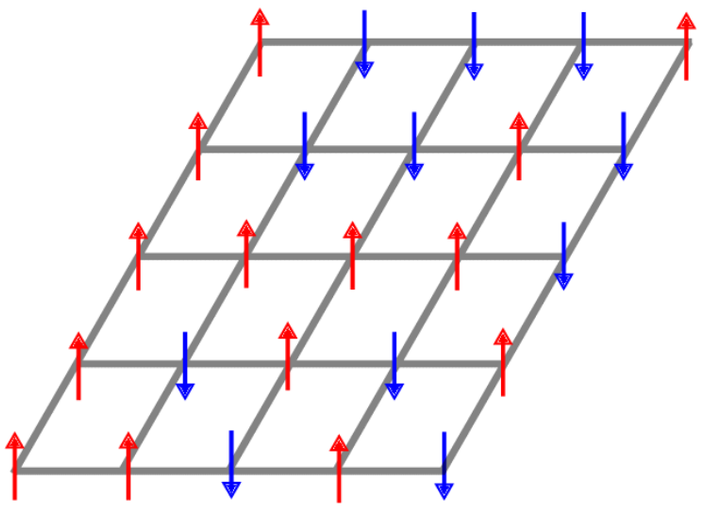
Is there a symmetry?

$$O_1 = -O_2 + \epsilon$$

Is there a landscape?

Example:

Prepare Ising Model



Scan Temperature

$$T - T_c \simeq 10^{-30}$$

The scalar is
much lighter
than the lattice spacing

Λ^4

Cosmological Constant

$$\Lambda^4$$

SIZE OF THE UNIVERSE

Higgs Mass Squared

$$m_h^2 |H|^2$$

WEAK FORCE, STRUCTURE OF NUCLEI, COMPLEX CHEMISTRY, …

Cosmological Constant

$$\Lambda^4$$

Theory ~ 10^{120} Experiment

Higgs Mass Squared

$$m_h^2 |H|^2$$

Theory~10^{30} Experiment

Cosmological Constant

Higgs Mass Squared

Is there a symmetry?

Theory ~ 10^{120} Experiment

Theory~10^{30} Experiment

Cosmological Constant

Higgs Mass

$$\Lambda \simeq 10^{-12} m_h$$

Extremely different scales

Traditional Approach: Factorize the problems

$$\left(\Lambda^4\right) \times \left(m_h^2 |H|^2\right)$$

Traditional Approach:

Factorize the problems

$$\left(m_h^2 |H|^2\right)$$

We have been looking for answers here

Higgs Boson

and we have not found them

We **have been looking** for these simple and elegant solutions for **more than 40 years**

It is a good time to **consider seriously more creative alternatives**

Λ^4

Cosmological Constant

Higgs Mass Squared

Is there a landscape?

Theory ~ 10^{120} Experiment

Theory~10^{60} Experiment

Change of perspective:

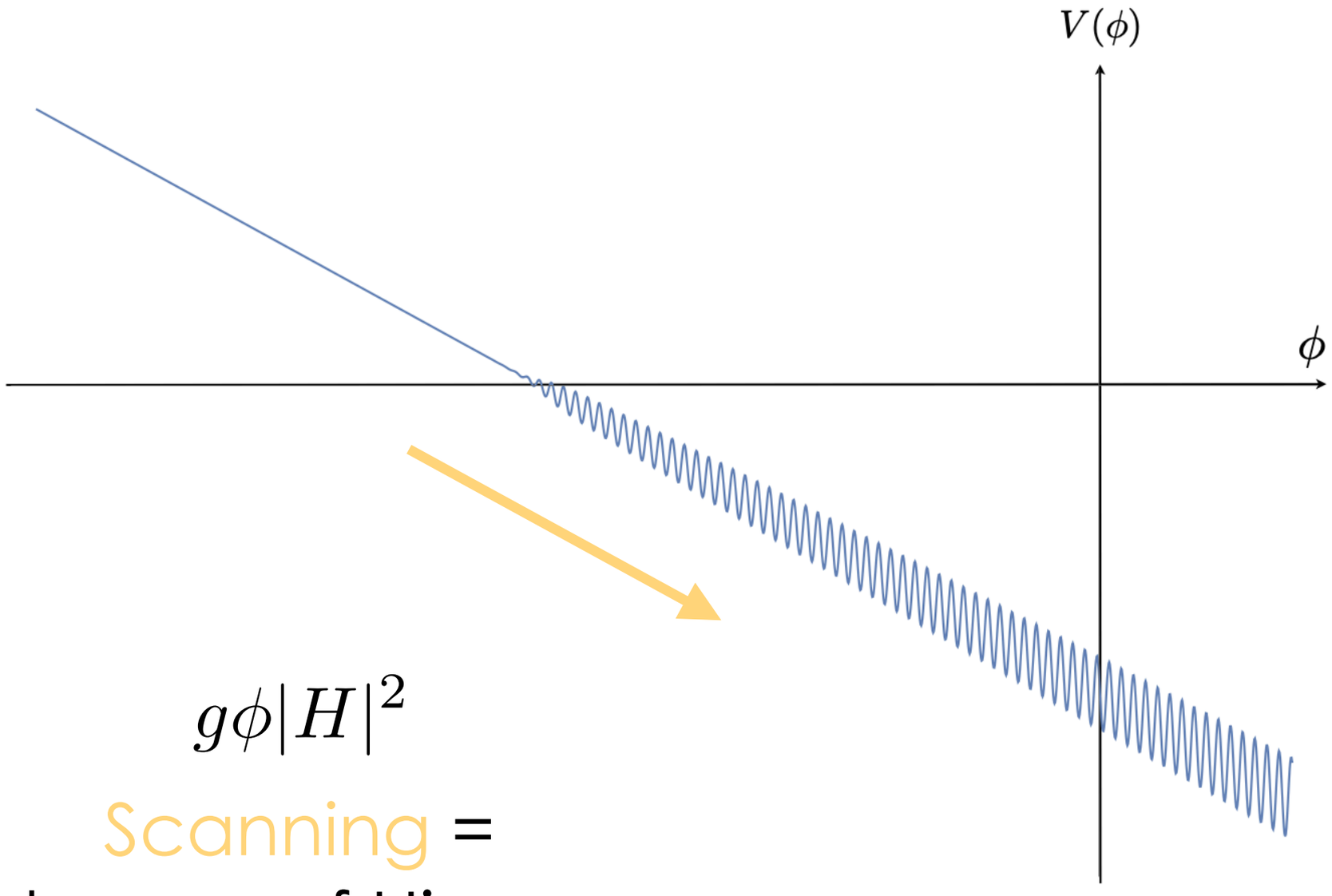
Can we find the origin of the weak scale early in the history of the Universe?

1. **SCANNING:** The Higgs mass takes many different values either in our Universe or in the Multiverse

2. **SELECTION:** Something is "triggered" in the evolution of the Universe when the Higgs mass crosses the weak scale

3. **OBSERVATION:** Today we measure an unnaturally small value of the weak scale as a consequence of an early Universe event that we can not (yet) observe

EXAMPLE: RELAXION

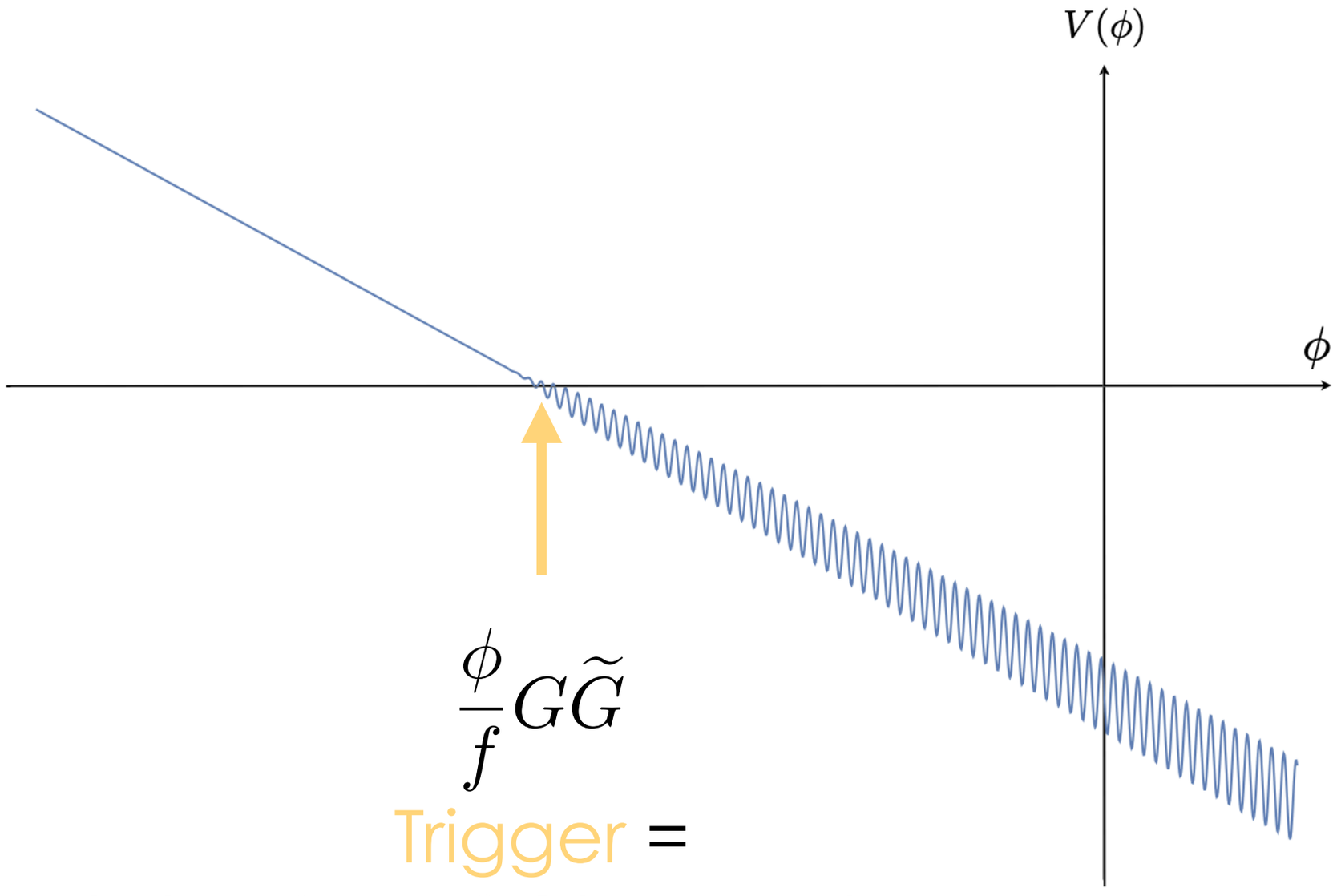


$$g\phi|H|^2$$

Scanning =

Landscape of Higgs vevs

EXAMPLE: RELAXION



$$\frac{\phi}{f} G\tilde{G}$$

Trigger =

Selection of Observed vev

2. **SELECTION:** Something is "triggered" in the evolution of the Universe when the Higgs mass crosses the weak scale

WEAK SCALE TRIGGERS

General QFT question relevant beyond cosmological naturalness:

Does anything change (in the SM) as we vary $\langle h \rangle$?

WEAK SCALE TRIGGERS

Most relevant phenomenologically:

Physics coupled to the Higgs with

$$m \lesssim v$$

One trigger = **Many solutions** to the hierarchy problem

SM TRIGGERS

HIERARCHY 102

Does anything change in the SM as we vary $\langle h \rangle$?

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$$\bar{e}_{\dot{\alpha}}(x) W(x-y) e_{\alpha}(y)$$

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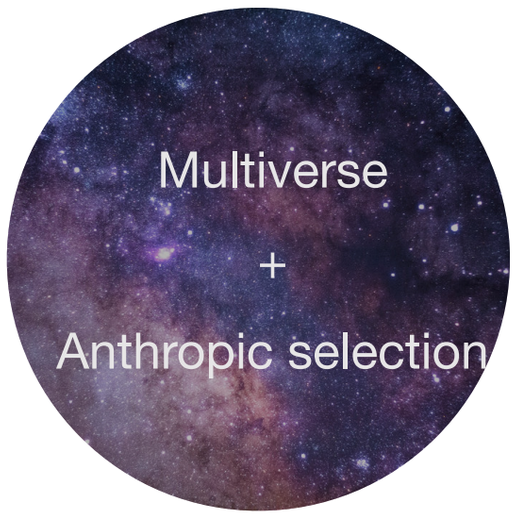


HIERARCHY 102

Does anything change in the SM as we vary $\langle h \rangle$?

1. Obviously the spectrum:

$$\bar{e}_{\dot{\alpha}}(x) W(x-y) e_{\alpha}(y)$$

2. If we look at local operators we discover the hierarchy problem:

$$\langle h^\dagger h \rangle \sim \Lambda_H^2$$

HIERARCHY 102

Does anything change in the SM as we vary $\langle h \rangle$?

$$\xi \phi \mathrm{Tr}\left[G\widetilde{G}\right]$$

$$\xi \phi \theta_{\mathrm{QCD}} m_\pi^2 f_\pi^2$$

$$\langle G\widetilde{G} \rangle \simeq \theta_{\mathrm{QCD}} m_\pi^2 f_\pi^2 \simeq \theta_{\mathrm{QCD}} (y_u + y_d) v \Lambda_{\mathrm{QCD}}^3$$

HIERARCHY 102

Does anything change in the SM as we vary $\langle h \rangle$?

$$\xi \phi \mathrm{Tr}\left[G\widetilde{G}\right]$$

Dvali, Vilenkin ‘01
Graham, Kaplan, Rajendran ‘15
Geller, Hochberg, Kuflik ’18
…

HIERARCHY 102

Does anything change in the SM as we vary $\langle h \rangle$?

$$\xi \phi \mathrm{Tr}\left[G\widetilde{G}\right]$$

Important Pheno Message:

Axion-Like phenomenology can be related to the hierarchy problem

HIERARCHY 102

$\mathrm{Tr}\left[G\widetilde{G}\right]$ → Why does it work?

$\mathrm{Tr}\left[G\widetilde{G}\right] = \partial_\mu K^\mu$ Shift symmetry

K^μ Not gauge invariant

POTENTIAL SM TRIGGERS

In the SM we can try other options

$$\mathrm{Tr}\left[W\widetilde{W}\right]$$

Needs extra B+L breaking
Beyond the SM

$$\frac{(Qu^c)(Qd^c)}{M^2}$$

Works only in 2HDM
In the SM at 3 loops it's sensitive to flavor breaking by Yukawas

WEAK SCALE TRIGGERS

Find Triggers = Find **physics related to naturalness that you weren't expecting** from symmetry solutions

A BSM TRIGGER

A SIMPLE BSM TRIGGER

$$H_1 H_2$$

Protected by the **Z2 symmetry**

$$H_1 H_2 \to -H_1 H_2$$

In the **absence of odd terms** in the Lagrangian the **vev** is **UV insensitive and calculable**

H1H2 **without Z4** first considered as 'paleo'-trigger in: [Espinosa, Grojean,Panico, Pomarol, Pujolas '15], [Dvali, Vilenkin '01]. Today these models require **two coincidences of scales to be alive at the LHC**.

TYPE-0 2HDM

Z2 symmetric 2HDM

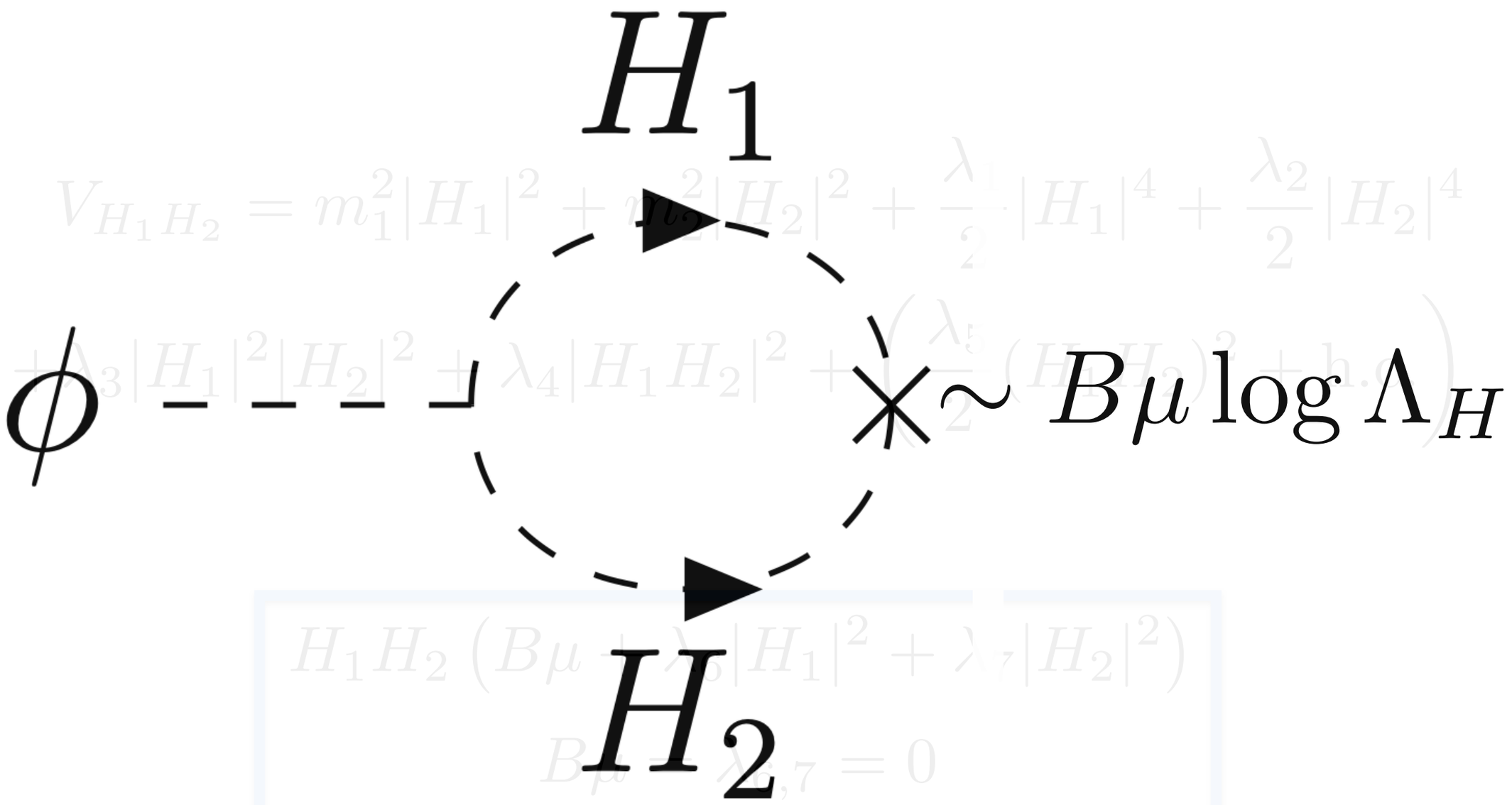
$$V_{H_1 H_2} = m_1^2|H_1|^2 + m_2^2|H_2|^2 + \frac{\lambda_1}{2}|H_1|^4 + \frac{\lambda_2}{2}|H_2|^4$$

$$+\lambda_3|H_1|^2|H_2|^2 + \lambda_4|H_1 H_2|^2 + \left(\frac{\lambda_5}{2}(H_1 H_2)^2 + \text{h.c.}\right)$$

$$H_1 H_2\left(B\mu + \lambda_6|H_1|^2 + \lambda_7|H_2|^2\right)$$

$$B\mu = \lambda_{6,7} = 0$$

TYPE-0 2HDM



A SIMPLE BSM TRIGGER

$$H_1 H_2$$

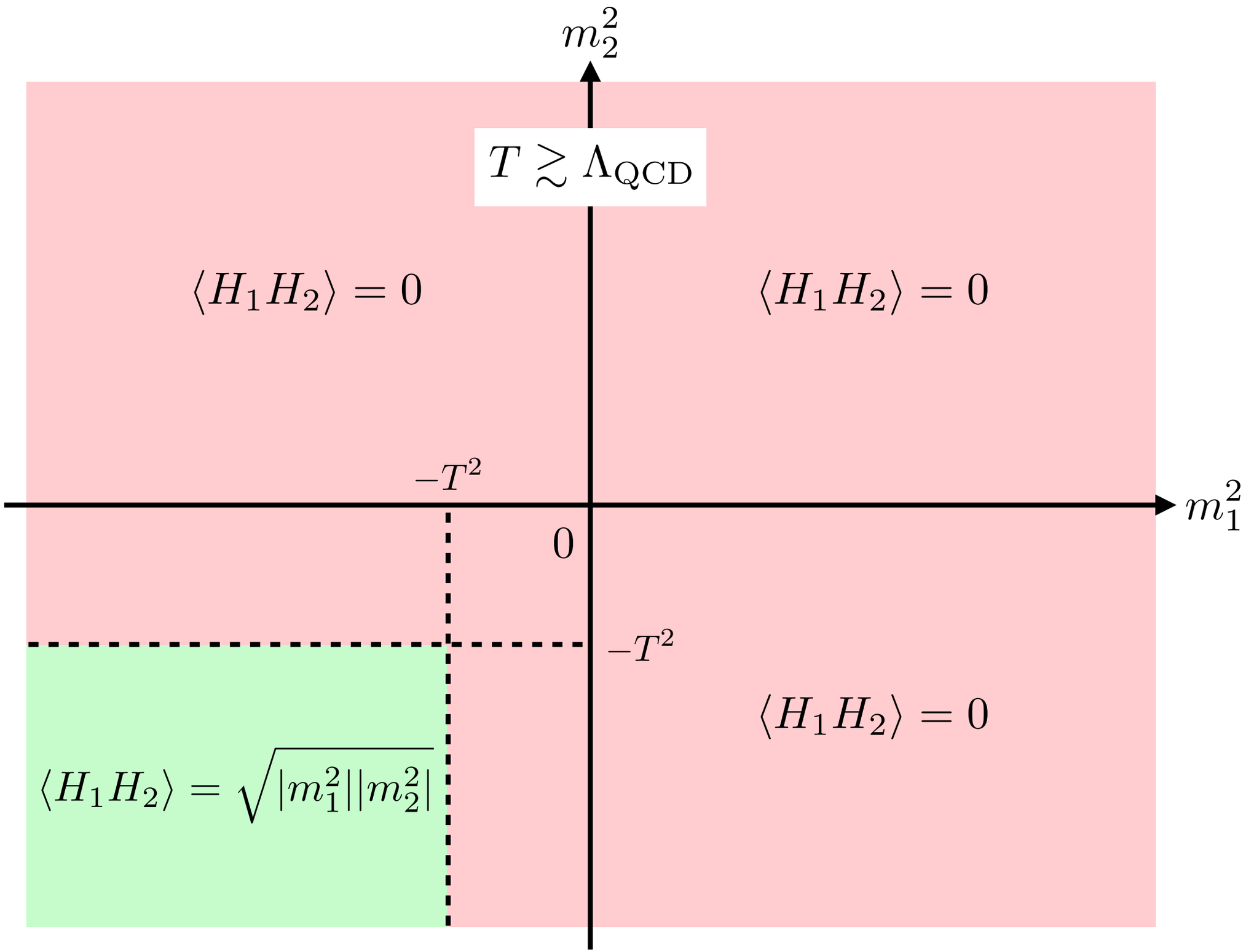
For quarks and leptons we choose the
phenomenologically safest Z2 charge assignments

$$H_2 \to -H_2, \quad (qu^c) \to -(qu^c), \quad (qd^c) \to -(qd^c), \quad (le^c) \to -(le^c)$$

This gives

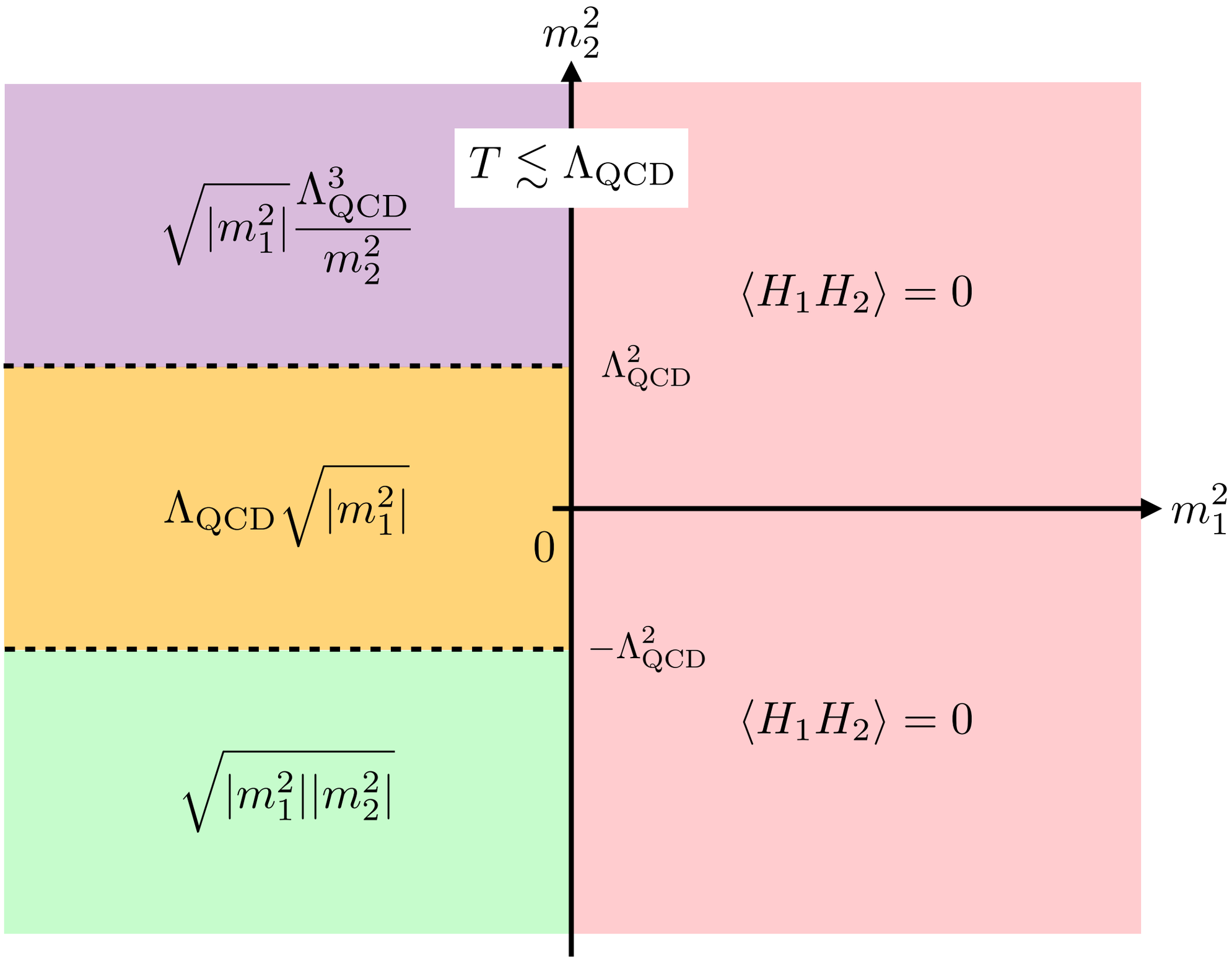
$$V_Y = Y_u q H_2 u^c + Y_d q H_2^\dagger d^c + Y_e l H_2^\dagger e^c$$

A SIMPLE BSM TRIGGER



N.B. in reality need tiny breaking of H1->-H1 to avoid domain walls, so “0” really means << v

A SIMPLE BSM TRIGGER



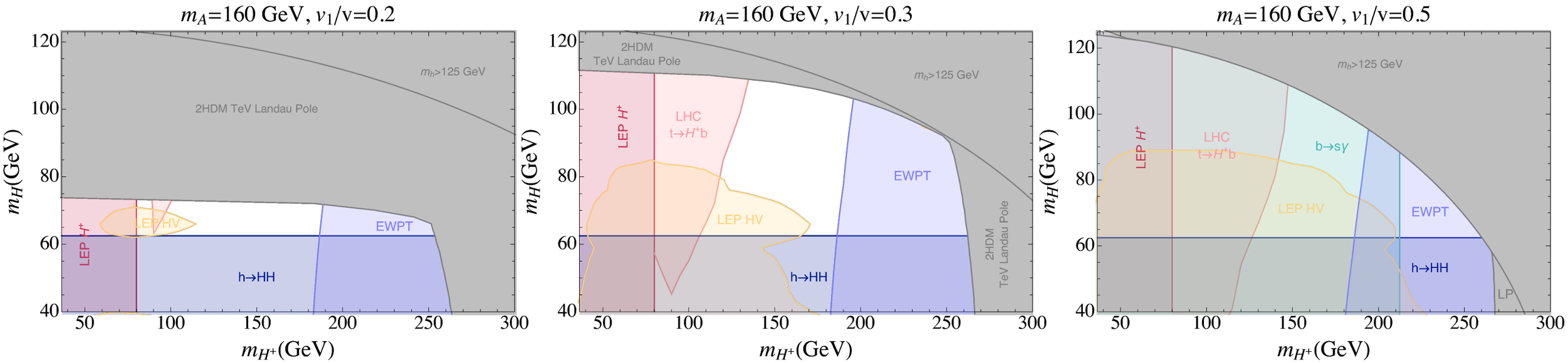
N.B. in reality need tiny breaking of H1->-H1 to avoid domain walls, so “0” really means << v

TYPE-0 2HDM PHENOMENOLOGY

$$m^2_{A,H^\pm} \sim \lambda v^2, \quad \lambda \lesssim 2$$

$$m^2_H \sim \lambda_1 v_1^2 \leq m^2_h = (125\ \mathrm{GeV})^2$$

TYPE-0 2HDM PHENOMENOLOGY



Sharp target for HL-LHC which **can't be decoupled**!
(See also the next slide)

EXERCISES FOR THE READER

1. Are there other SM triggers?
2. Are there other (simple) BSM triggers?
3. Can we use the 2HDM trigger to explain the value of the weak scale?

General expectation:

Light physics related to “trigger operators” (we have only 2 so far, 3 counting BSM confining groups)

USE YOUR TRIGGER PART I: GENERIC EXPECTATIONS

TRIGGER BASICS

Sliding Naturalness

[**RTD**, Teresi] In Preparation

New Scalar ϕ

Coupled to the Higgs

TRIGGER BASICS

Sliding Naturalness

[**RTD**, Teresi] In Preparation

$$V_\phi \sim m_\phi^2 M_*^2$$

M_* Cutoff

$\frac{m_\phi}{M_*} \ll 1$ Shift Symmetry

TRIGGER BASICS

Sliding Naturalness

[**RTD**, Teresi] In Preparation

$$V_\phi \sim m_\phi^2 M_*^2$$

$$V_{\phi H} \sim \kappa m_\phi \phi H_1 H_2$$

TRIGGER BASICS

Sliding Naturalness

[**RTD**, Teresi] In Preparation

$$V_\phi \sim m_\phi^2 M_*^2$$

$$V_\phi / V_{\phi H} \sim 1$$

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TRIGGER BASICS

Sliding Naturalness

[**RTD**, Teresi] In Preparation

$$V_\phi \sim m_\phi^2 M_*^2$$

$$\boxed{m_\phi \simeq \frac{\kappa v^2}{M_*}}$$

$$V_{\phi H} \sim \kappa m_\phi \phi H_1 H_2$$

TRIGGER BASICS

Sliding Naturalness

[**RTD**, Teresi] In Preparation

The **Higgs vev affects at O(1) the ϕ potential** near its minimum **in our universe**

$$m_\phi \simeq \frac{\kappa v^2}{M_*}$$

This reasoning is quite general and **is true for several ideas involving cosmological selection** (relaxion, crunching dilaton, …)

Notable exception: Dvali, Vilenkin '01

General expectation:

$$m_\phi \sim \kappa v \frac{v^n}{M_*^n}$$

Extremely light new scalars (or pseudo-scalars) triggered by the Higgs

A ULTRALIGHT WIMP MIRACLE

$$V_\phi / V_{\phi H} \sim 1$$

$$T \simeq v \rightarrow \quad \Delta\phi_i = \mathcal{O}(M_*)$$

A ULTRALIGHT WIMP MIRACLE

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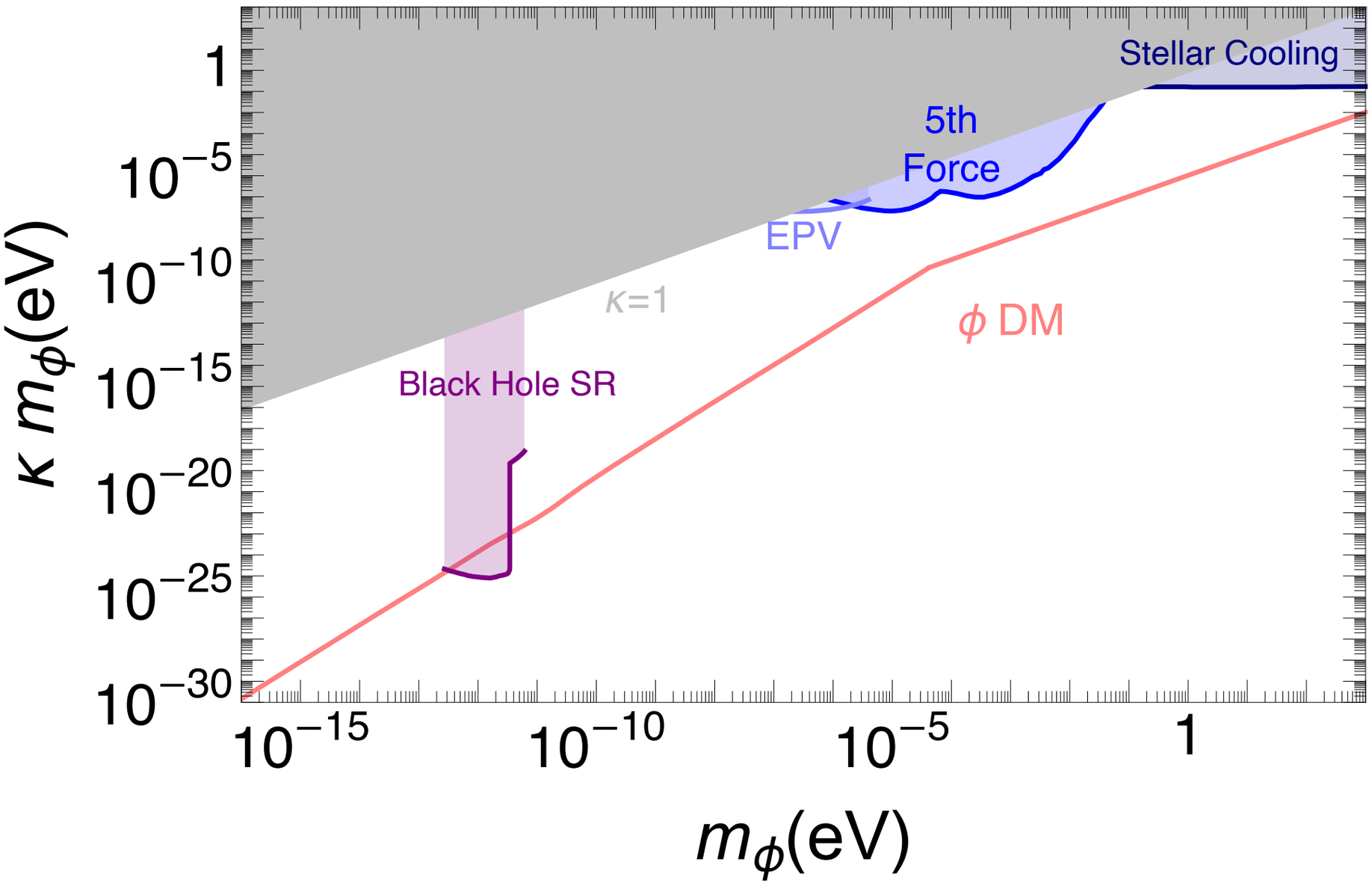
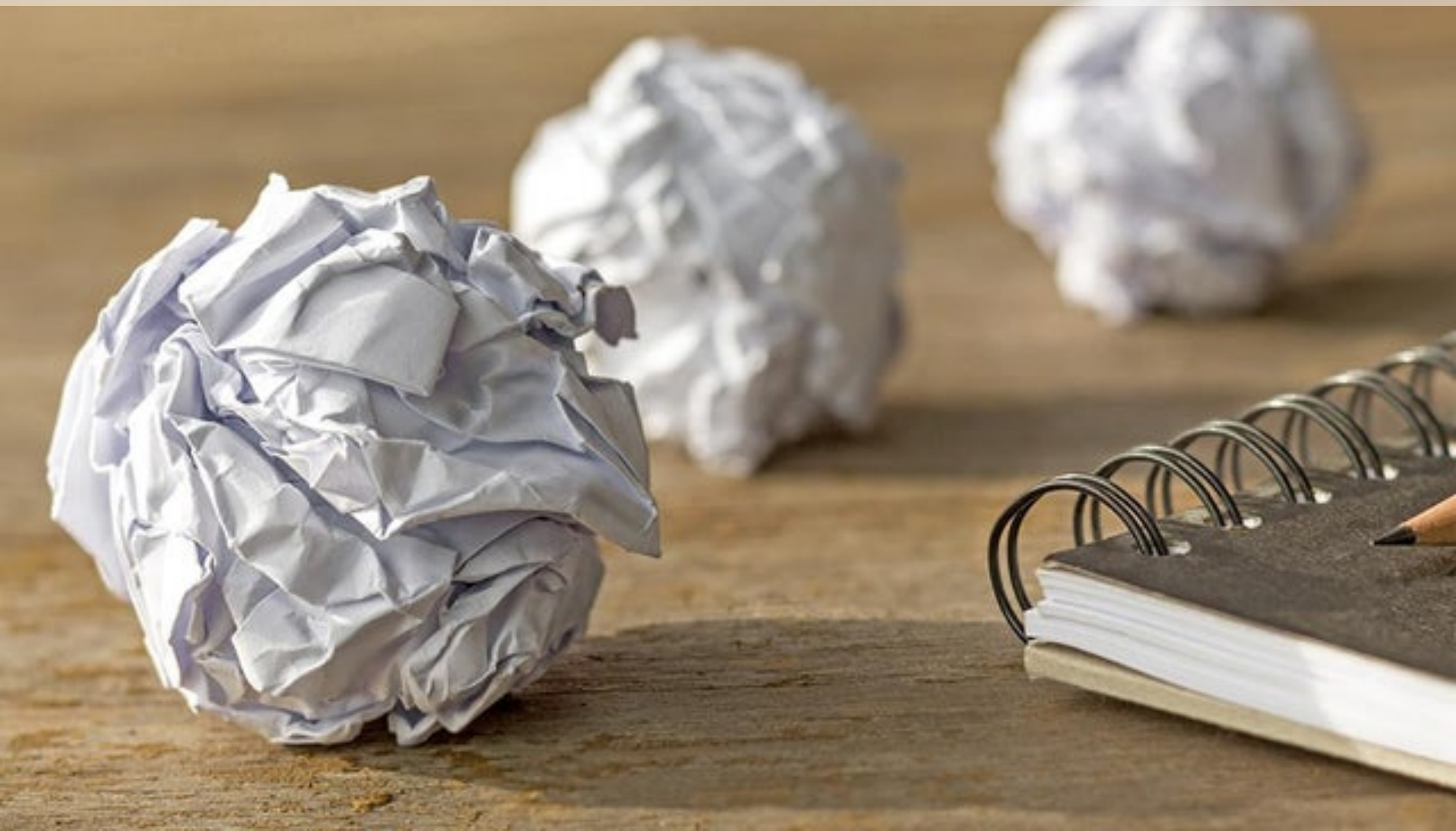


[Arkani-Hamed, **RTD**, Kim] '20 = [**RTD**, Teresi] In Preparation

USE YOUR TRIGGER PART II: CRUNCHING



PERTURBATIVE CRUNCH

Sliding Naturalness

[**RTD**, Teresi] In Preparation

BSM Ingredients:

$$\phi_{\pm}$$

Predictions:

- Minimally: Two ultralight scalars that can mediate long-range forces and be dark matter (target for 5th force searches!)
- Possibly also: New Higgs below 125 GeV

BASIC PICTURE

Landscape of Higgs Masses populated by inflation

$$-M_*^2 \leq m_H^2 \leq M_*^2$$

$\langle H^0 \rangle \simeq v$

$\langle H^0 \rangle \simeq v$

$\langle H^0 \rangle \simeq v$

$\langle H^0 \rangle \simeq v$

BASIC PICTURE

After reheating and a time

$$t_c \sim 1/m_\phi \gtrsim 10^{-11}\ \mathrm{s}$$

All patches where the Higgs vev

$$\langle H^0 \rangle \equiv h$$

$\langle H^0 \rangle \simeq v$

Is outside of a certain range

$$h_{\rm min} \lesssim h \leq h_{\rm crit}$$

$\langle H^0 \rangle \simeq v$

crunch

$\langle H^0 \rangle \simeq v$

$\langle H^0 \rangle \simeq v$

BASIC PICTURE

Only universes with the observed value of the weak scale can live longer than EW time.

Today the multiverse looks like:

$\langle H^0 \rangle \simeq v$

$\langle H^0 \rangle \simeq v$

$\langle H^0 \rangle \simeq v$

$\langle H^0 \rangle \simeq v$

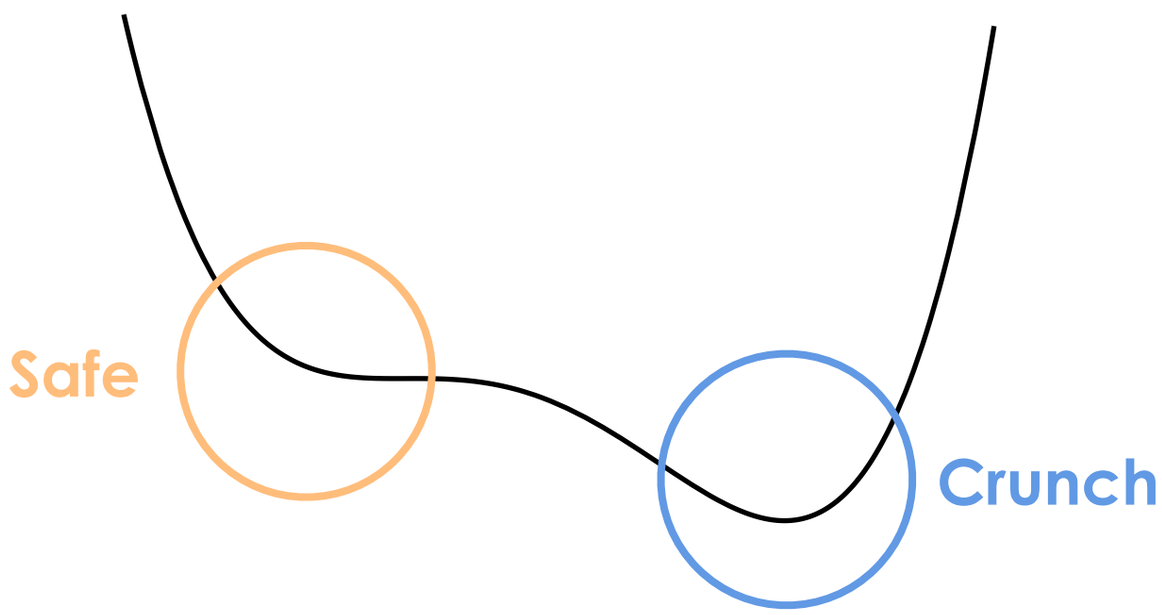
PERTURBATIVE CRUNCH

Sliding Naturalness

[**RTD**, Teresi] In Preparation

$$V_{\phi_-} = V(\phi_-) + (\kappa m_\phi \phi_- H_1 H_2 + \text{h.c.})$$

$$\langle H_1 H_2 \rangle = 0$$



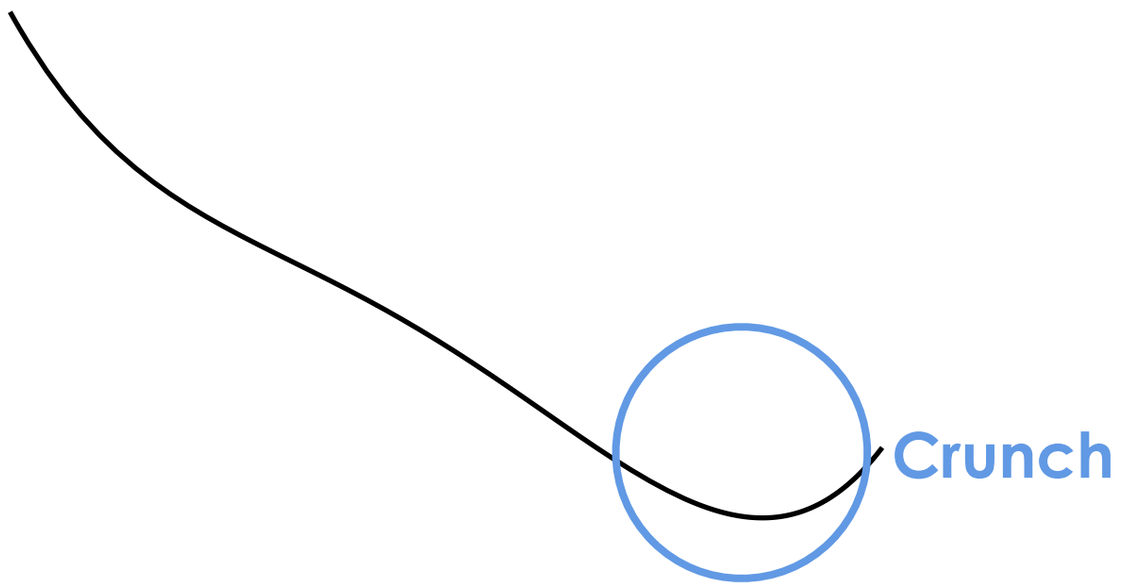
PERTURBATIVE CRUNCH

Sliding Naturalness

[**RTD**, Teresi] In Preparation

$$V_{\phi_-} = V(\phi_-) + (\kappa m_\phi \phi_- H_1 H_2 + \text{h.c.})$$

$$\langle H_1 H_2 \rangle \gg v^2$$



PERTURBATIVE CRUNCH

Sliding Naturalness

[**RTD**, Teresi] In Preparation

$$V_{\phi_+} = V(\phi_+) + (\kappa m_\phi \phi_+ H_1 H_2 + \text{h.c.})$$

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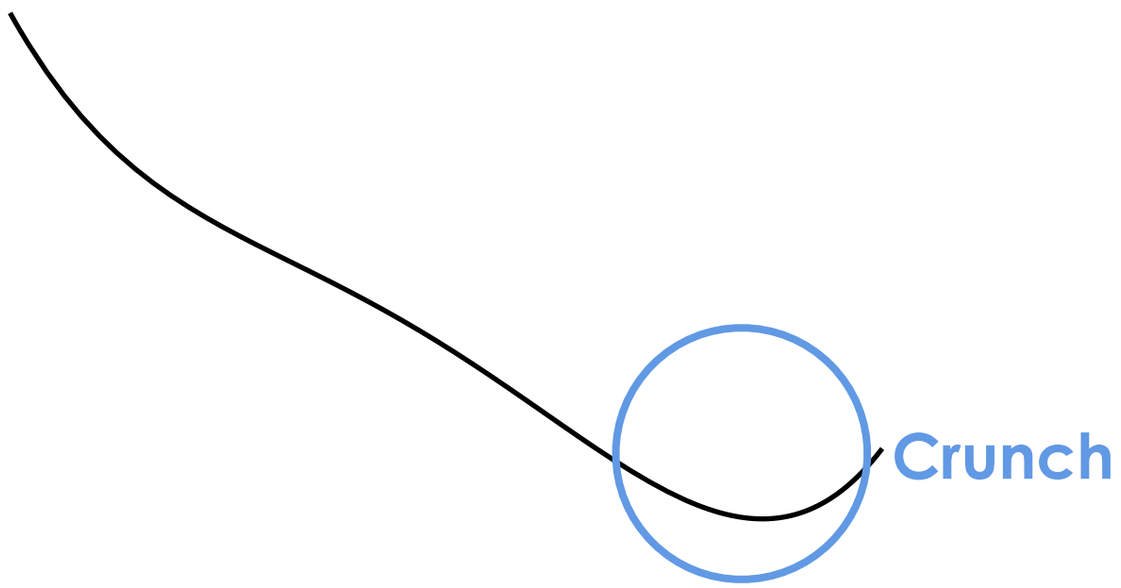

PERTURBATIVE CRUNCH

Sliding Naturalness

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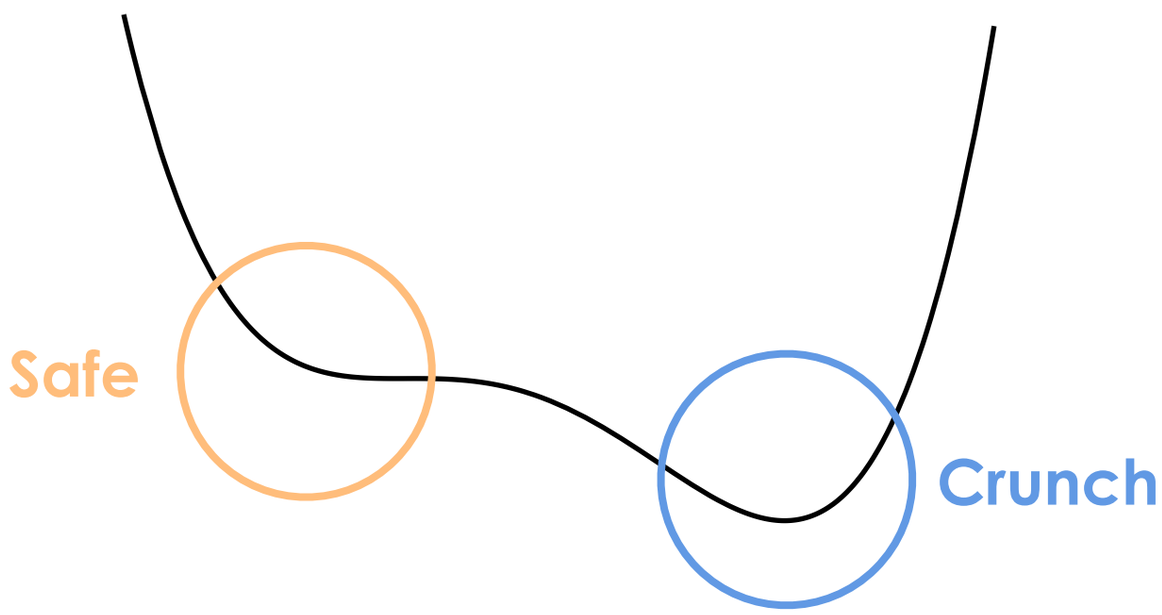


General expectation:

$G\tilde{G}$

$H_1 H_2$

Light physics related to “trigger operators”

General expectation:

$$m_\phi \sim \kappa v \frac{v^n}{M_*^n}$$

Extremely light new scalars (or pseudo-scalars) triggered by the Higgs

CONCLUSION

- A **systematic way** of thinking about **cosmological solutions to the hierarchy problem** in terms of **weak scale triggers**
- **New BSM trigger** from a 2HDM that will be either **discovered or excluded at HL-LHC**
- **A new way** of using this trigger **to explain the value of the weak scale**
- **New DM paradigm: ultralight miracle**
- General Program: understand and test common predictions of cosmological solutions to the HP

BACKUP

USE YOUR TRIGGER: CC AND WEAK SCALE

Ingredients:

UV Landscape: Heavy fields (masses just below the cutoff) that scan the CC and the Higgs mass squared

$$N_{\rm UV} \ll \frac{M_*^4}{\rm meV^4}$$

IR Landscape: Light fields with degenerate minima and a coupling to the Higgs

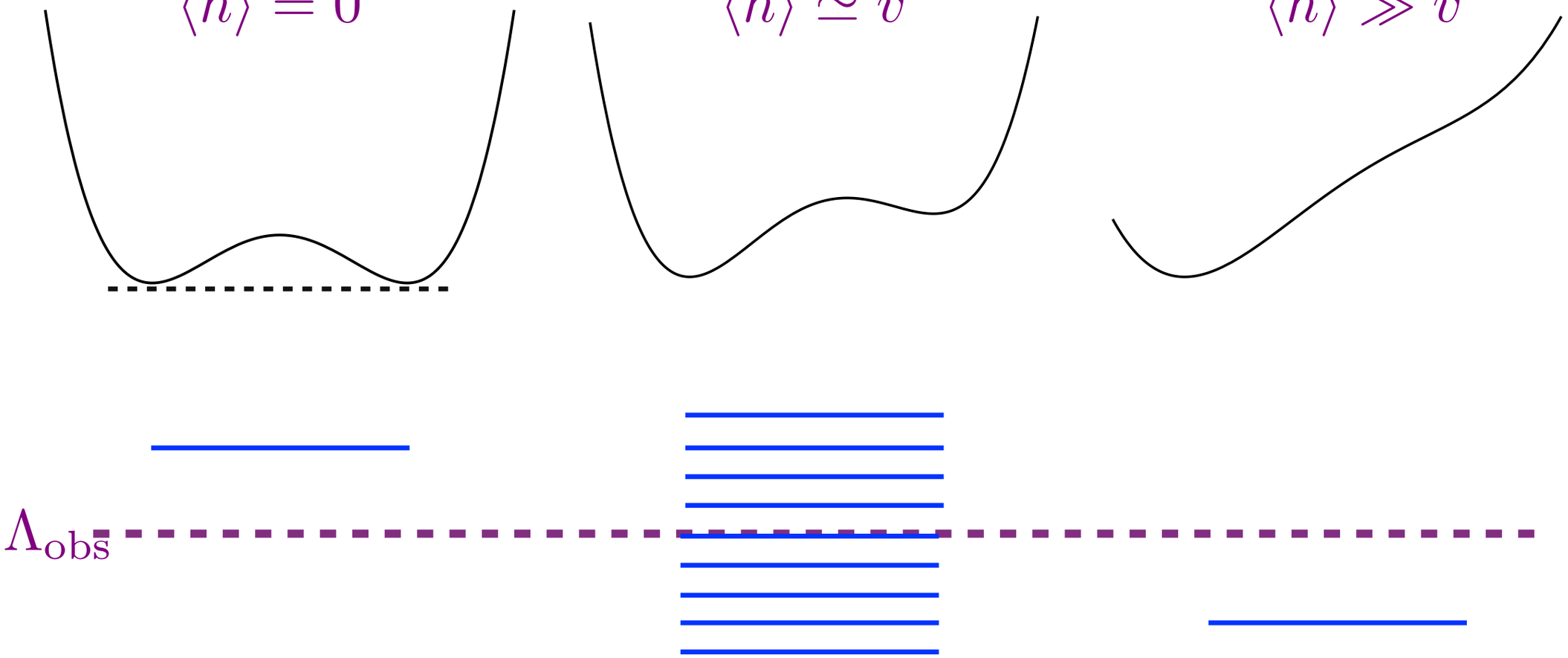
$$N_{\rm UV} + n_\phi \gg \frac{M_*^4}{\rm meV^4}$$

USE YOUR TRIGGER: CC AND WEAK SCALE

Low Energy Landscape

$$m_\phi \sim v^2/M_* \quad \langle\phi\rangle \sim M_*$$

$\langle h\rangle = 0$ $\quad$ $\langle h\rangle \simeq v$ $\quad$ $\langle h\rangle \gg v$



$$V_\phi = \sum_{i=1}^{n_\phi} \frac{\epsilon_i^2}{4}\left(\phi_i^2 - M_{*,i}^2\right)^2 + \left(\sum_{i=1}^{n_\phi} \frac{\kappa_i \epsilon_i M_{*,i}^{3-\Delta_T}}{\sqrt{n_\phi}} \phi_i \mathcal{O}_T + \text{h.c.}\right)$$

USE YOUR TRIGGER: CC AND WEAK SCALE

Example:

$$V^{(I)} = \sum_{i=1}^{n_\phi} \left[\frac{\epsilon^2}{4} \left(\phi_i^2 - M_*^2 \right)^2 + \frac{\epsilon\kappa}{\sqrt{n_\phi}} M_* \phi_i H_1 H_2 \right] + V_H^{(I)}$$

Degenerate IR landscape Minima

CC scanning

Higgs and CC Scanning

$$\mu_S^2 \lesssim \langle H_1 H_2 \rangle \lesssim \mu_B^2$$

Not enough scanning

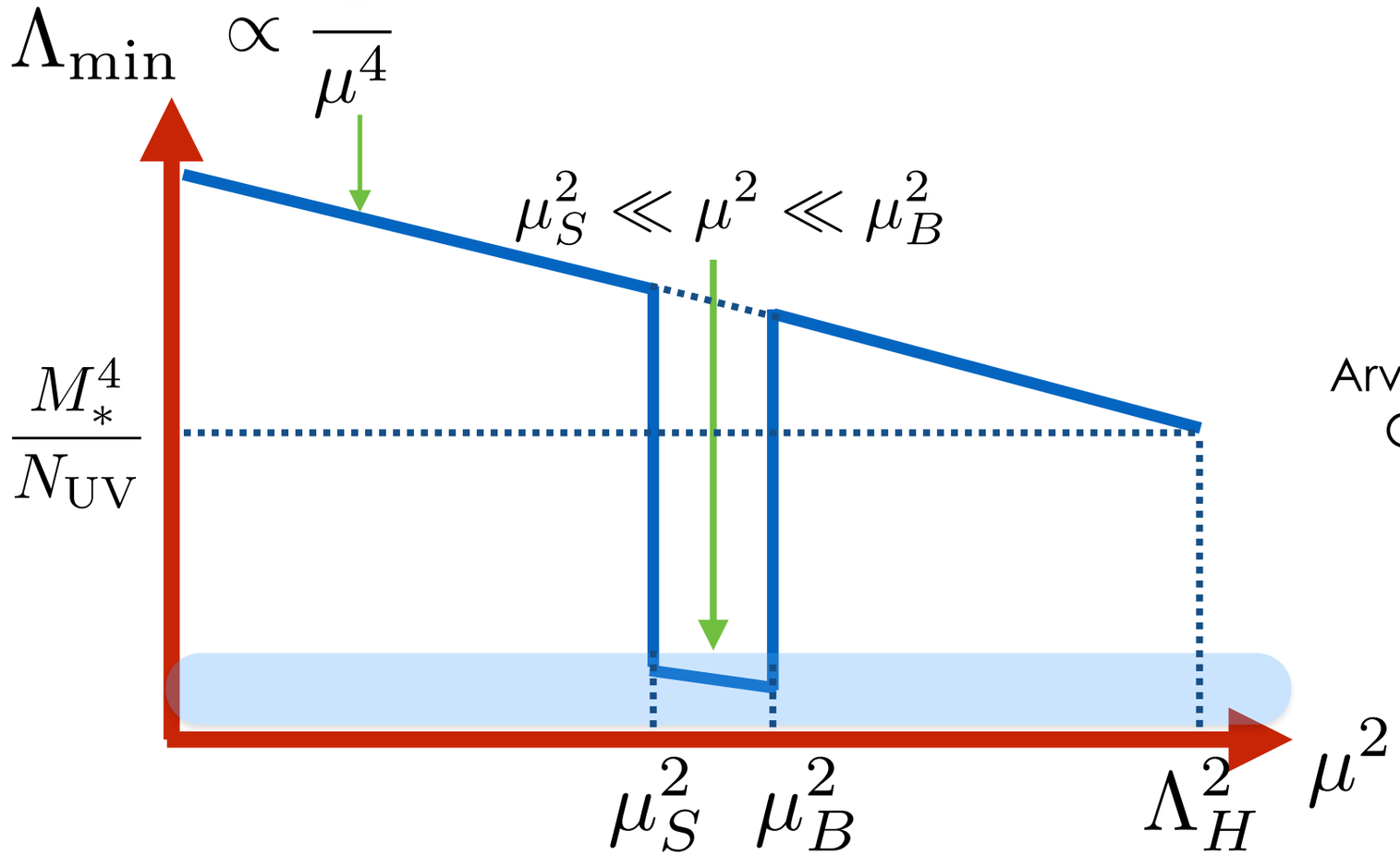
Not enough Minima

USE YOUR TRIGGER: CC AND WEAK SCALE

Example:

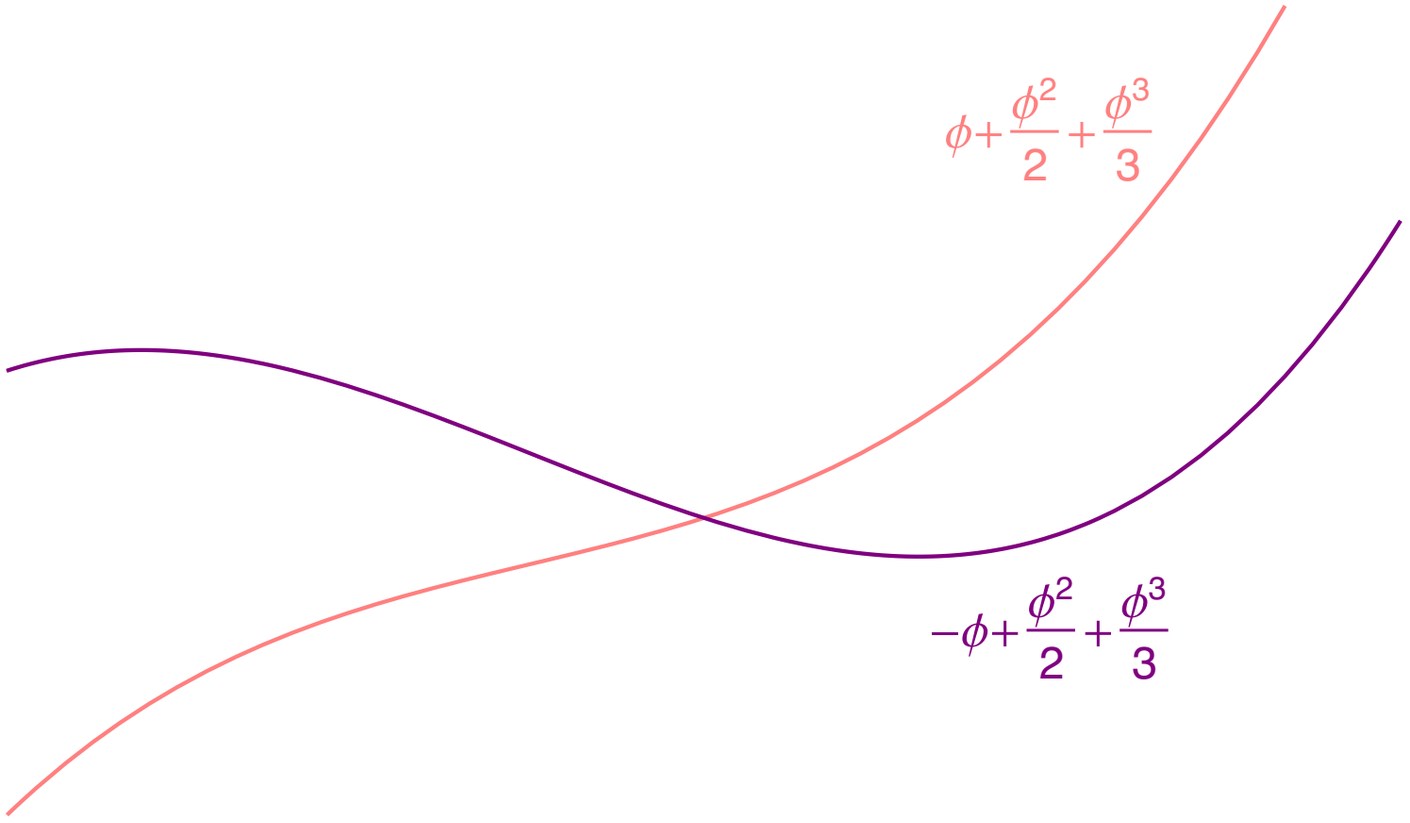
$$V^{(I)} = \sum_{i=1}^{n_\phi} \left[\frac{\epsilon^2}{4} \left(\phi_i^2 - M_*^2 \right)^2 + \frac{\epsilon\kappa}{\sqrt{n_\phi}} M_* \phi_i H_1 H_2 \right] + V_H^{(I)}$$

$$\Lambda_{\rm min} \propto \frac{1}{\mu^4}$$

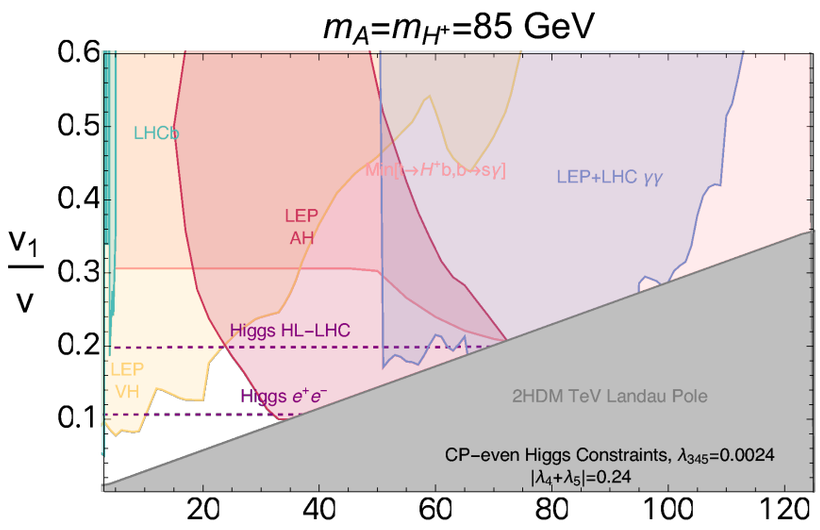


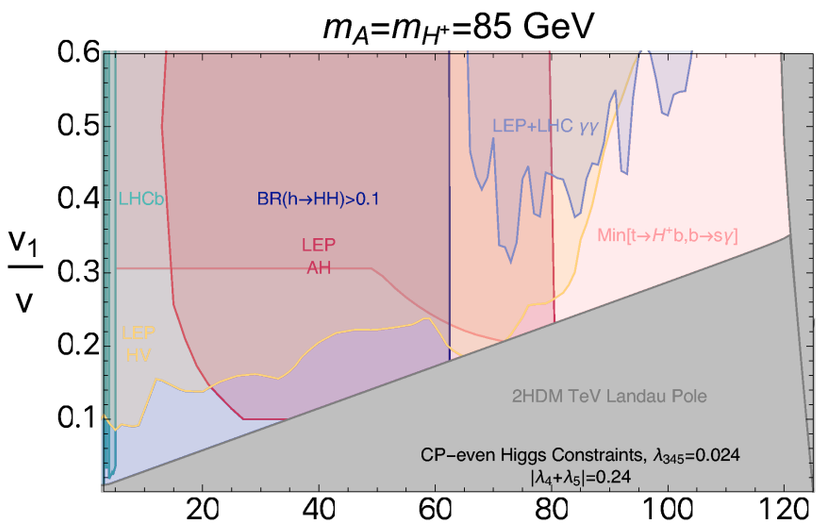
Similar goal to:
Arvanitaki, Dimopoulos, Gorbenko, Huang, Van Tilburg ‘16

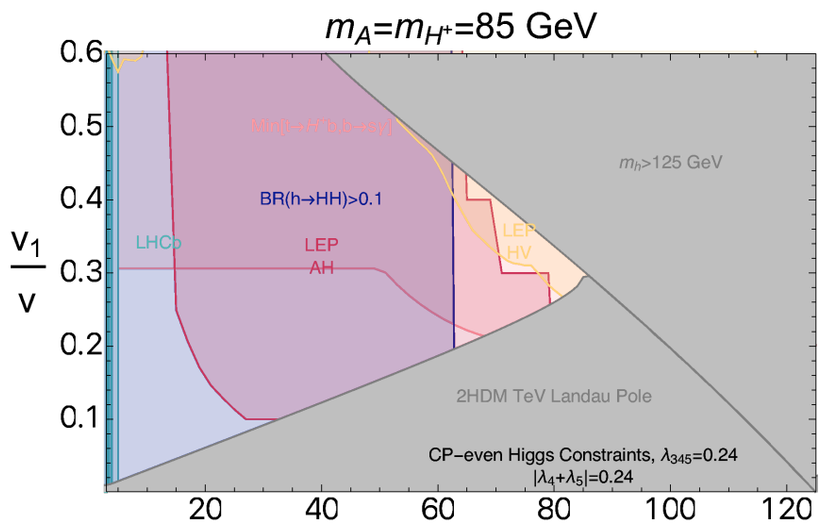
CRUNCHING TADPOLES

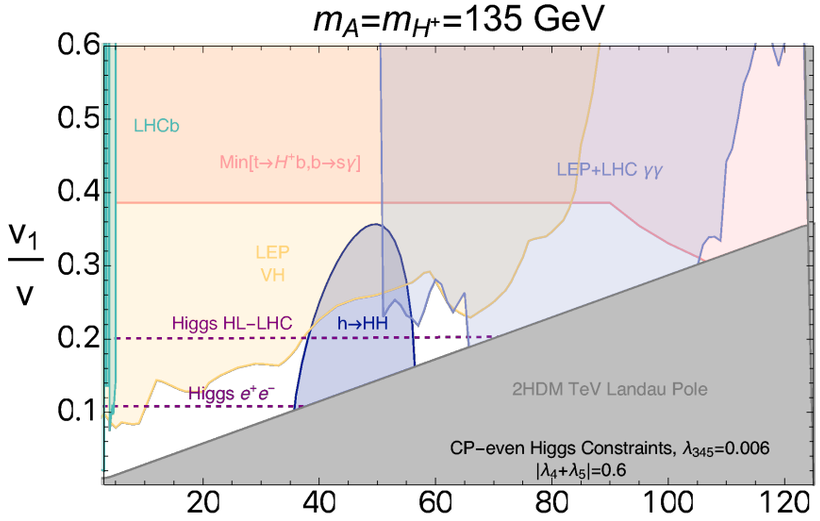


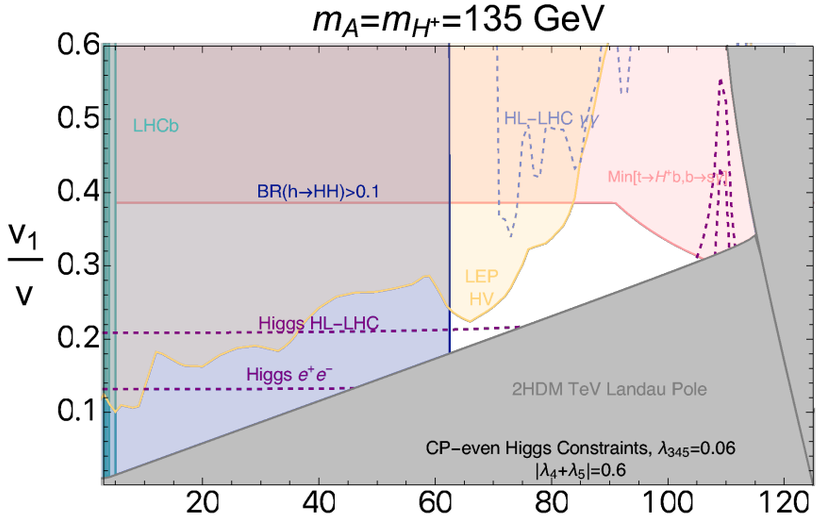
TYPE-0 2HDM PHENOMENOLOGY

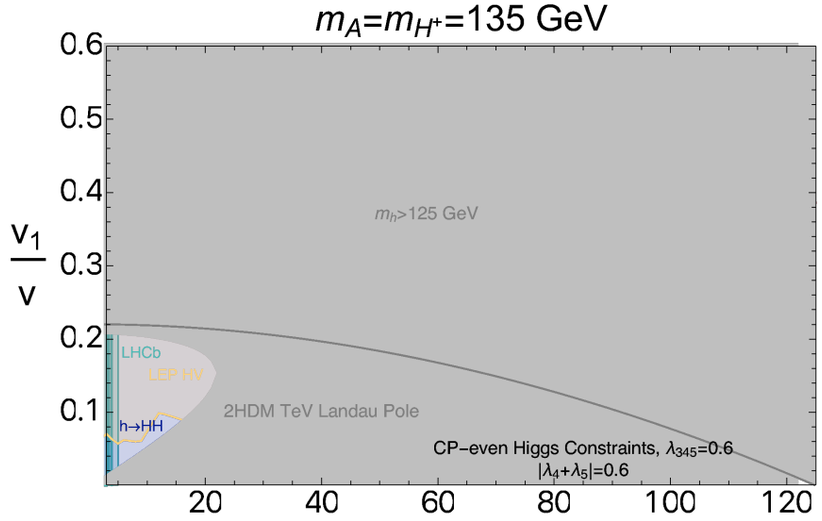




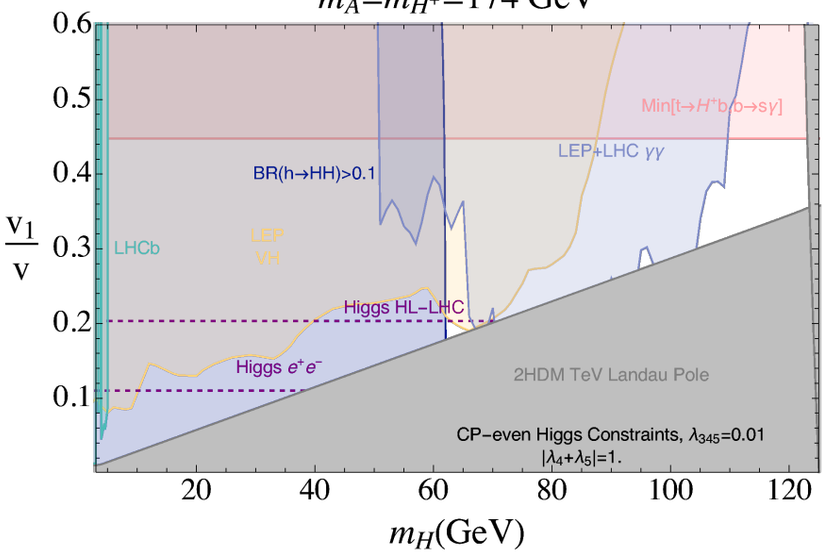


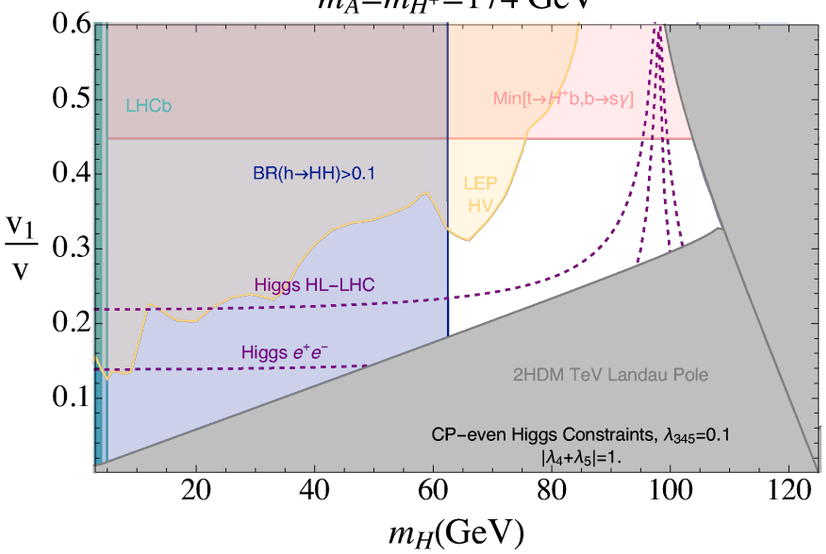


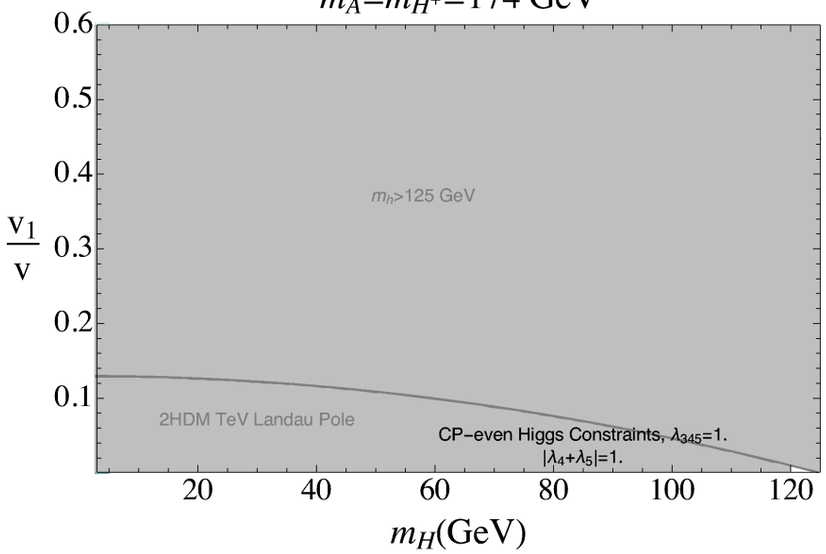




m_A=m_{H^+}=174 GeV



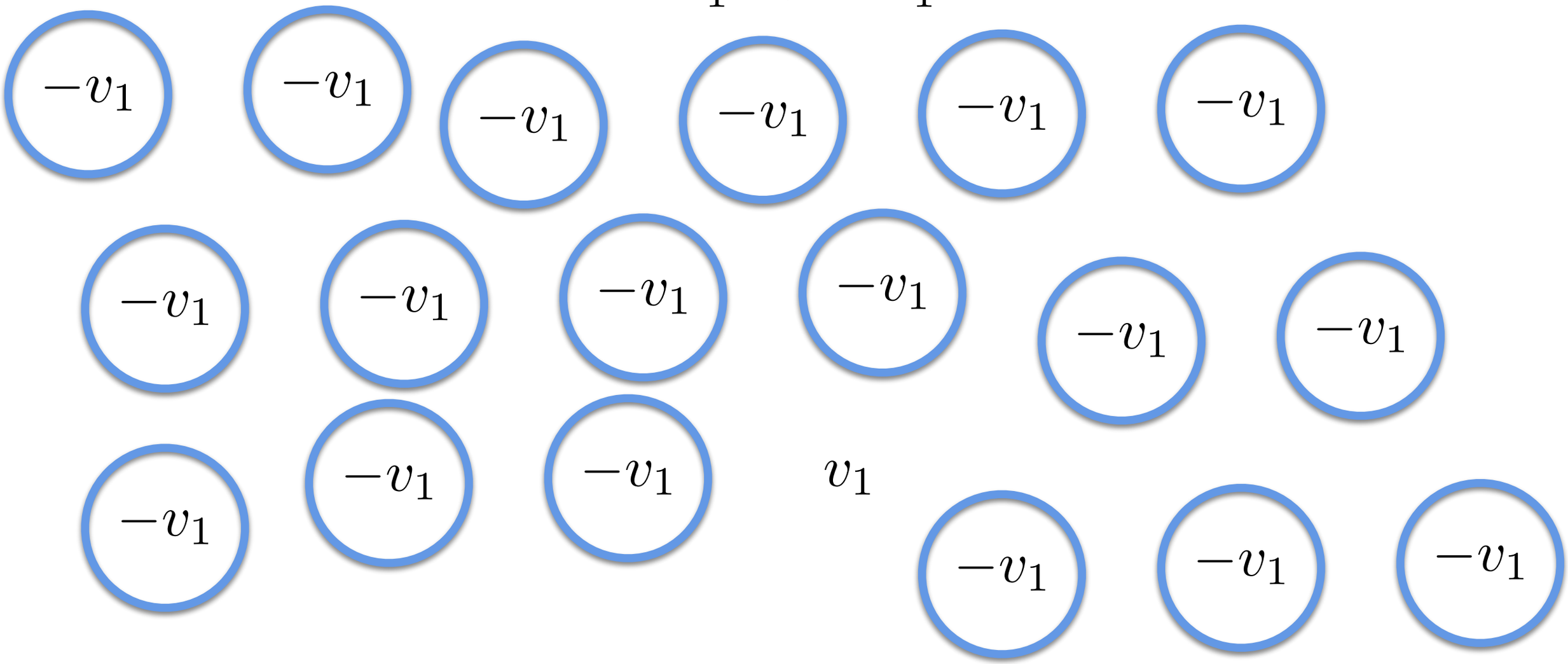




DOMAIN WALLS

Even after EW symmetry breaking a Z_2 subgroup of the Z_4 is spontaneously broken

$$H_1 \to -H_1$$



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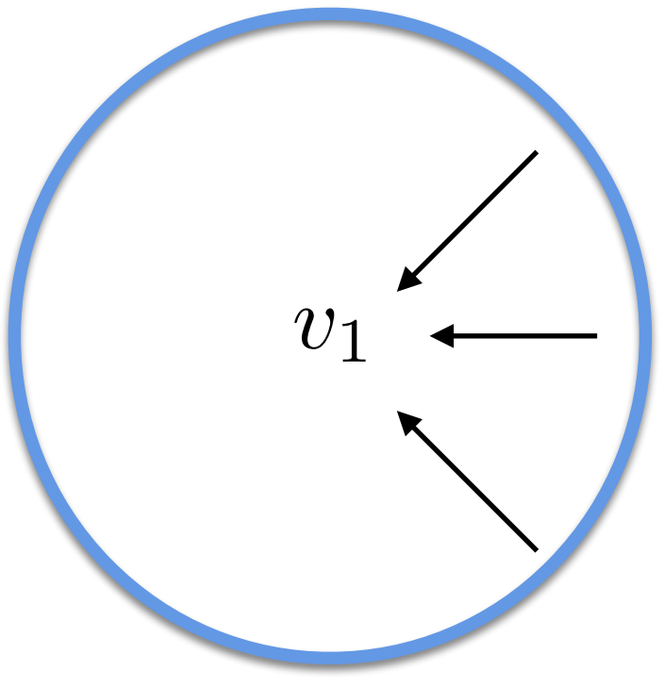


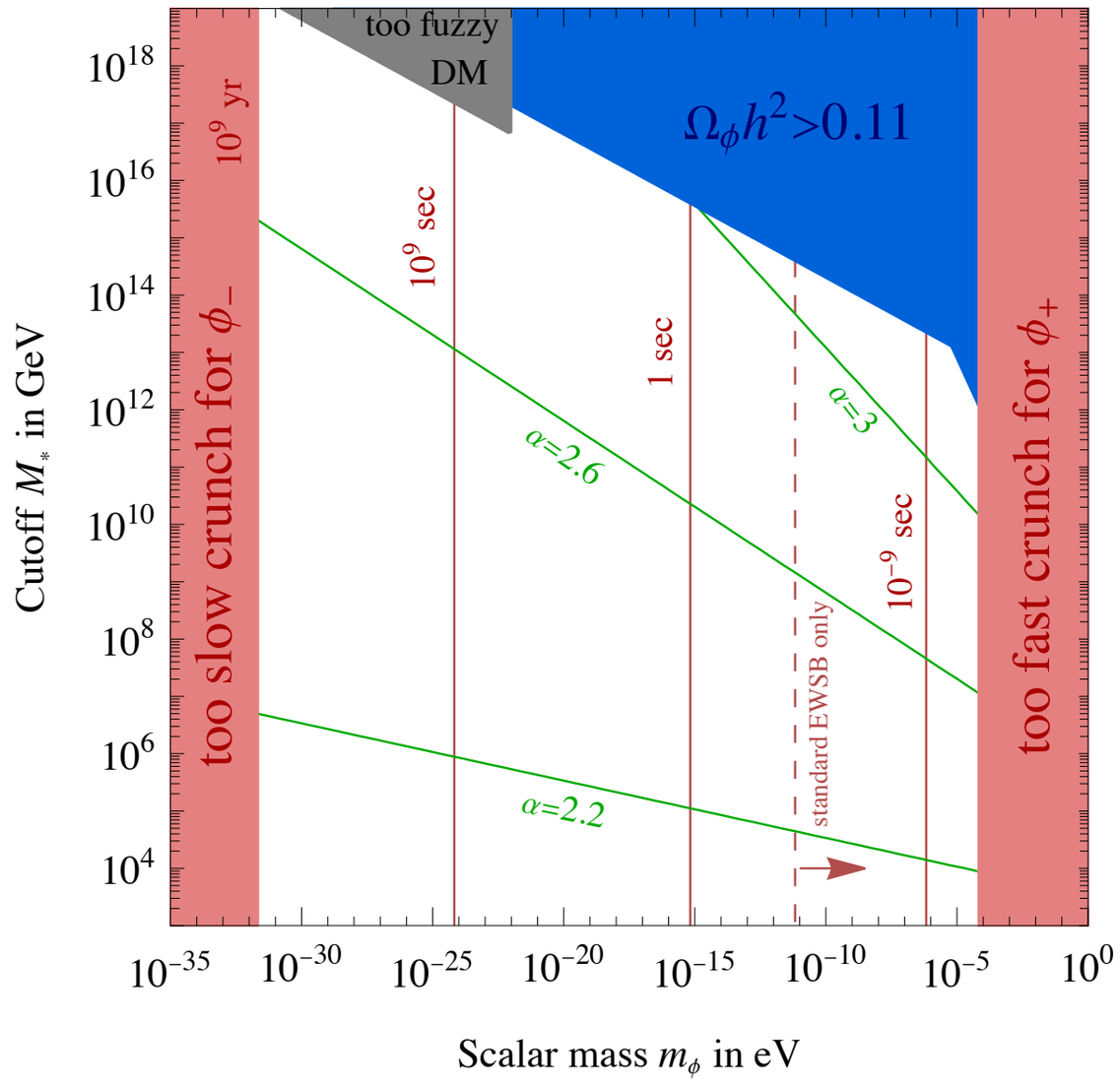
$$V \supset B\mu v_2 v_1$$

$$B\mu \gtrsim \frac{v^4}{M_{\rm Pl}^2}$$

PERTURBATIVE CRUNCH

Sliding Naturalness

[**RTD**, Teresi] In Preparation



COMPUTE VEVs

Add tiny coupling $\xi \phi \mathcal{O}$

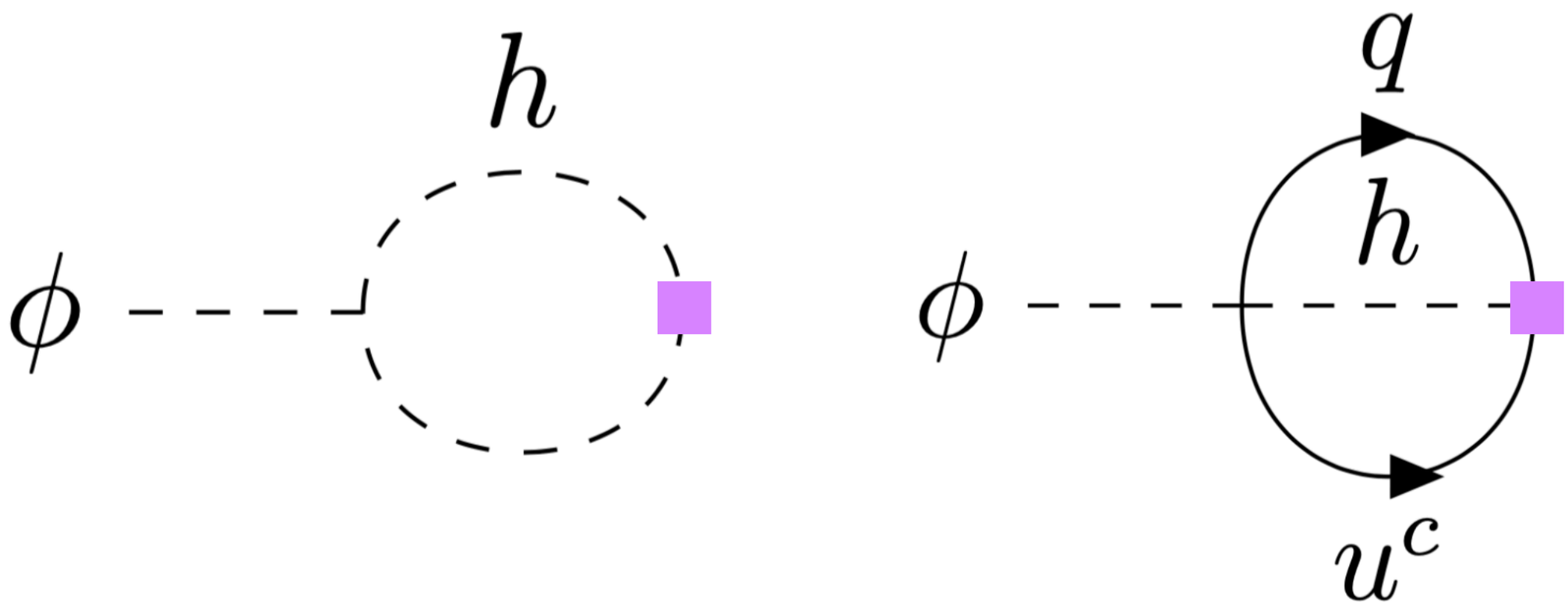
Integrate out $\mathcal{O}$

The low energy tadpole
gives the vev

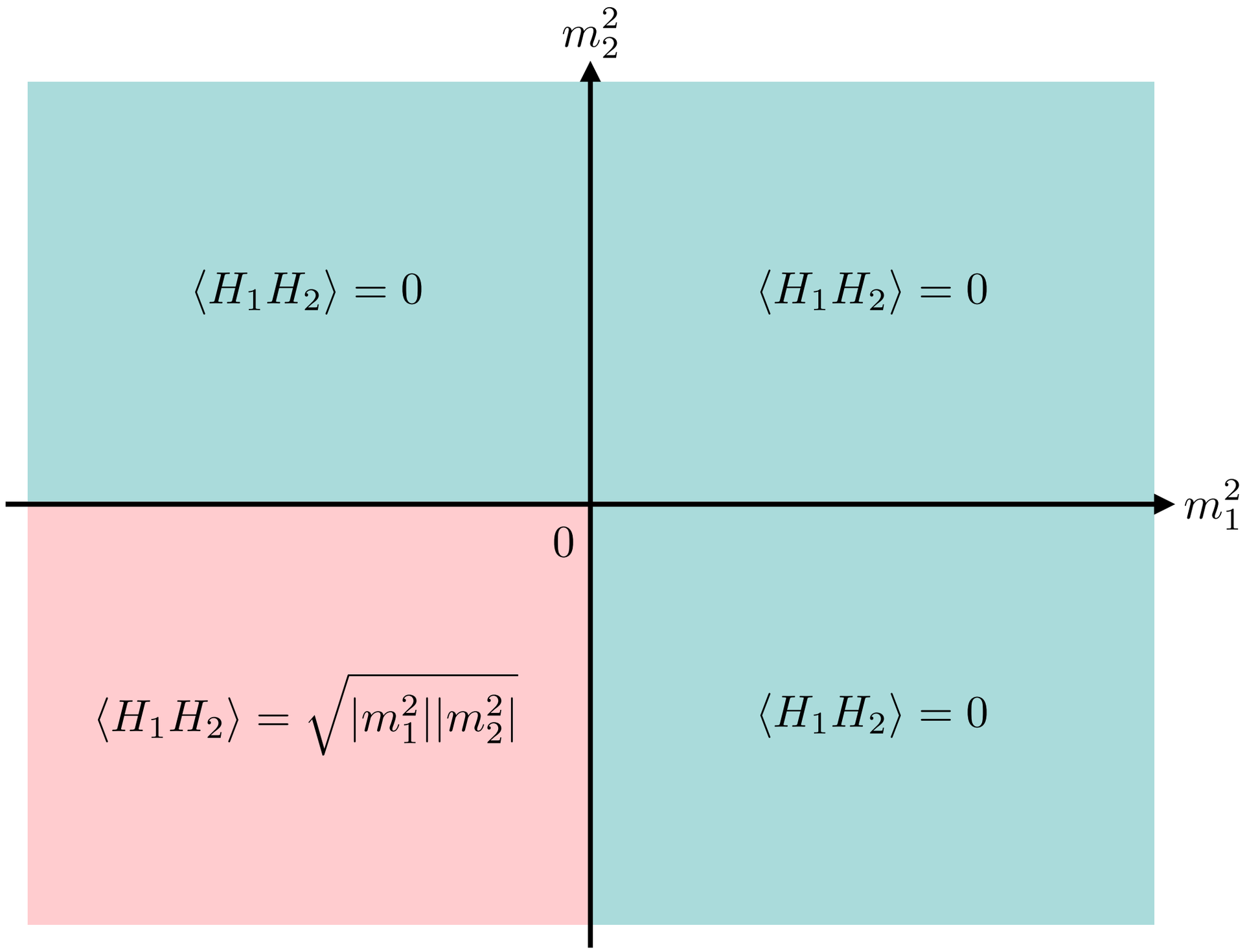
HIERARCHY 102

- If you consider gauge singlet operators in the SM Lagrangian you can always close the loop

$$\simeq \xi \phi \Lambda_H^n$$

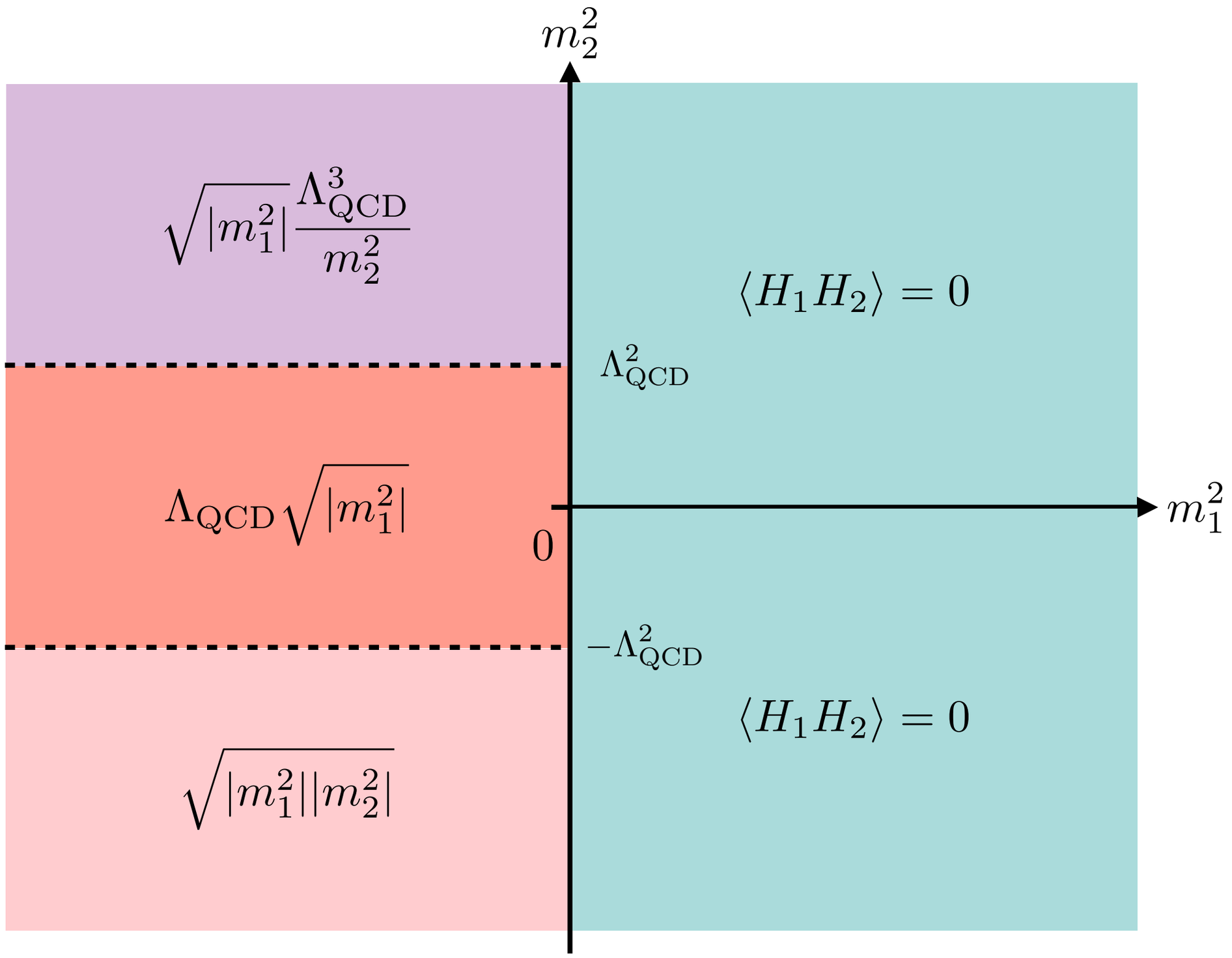


A SIMPLE BSM TRIGGER



Tree Level

A SIMPLE BSM TRIGGER

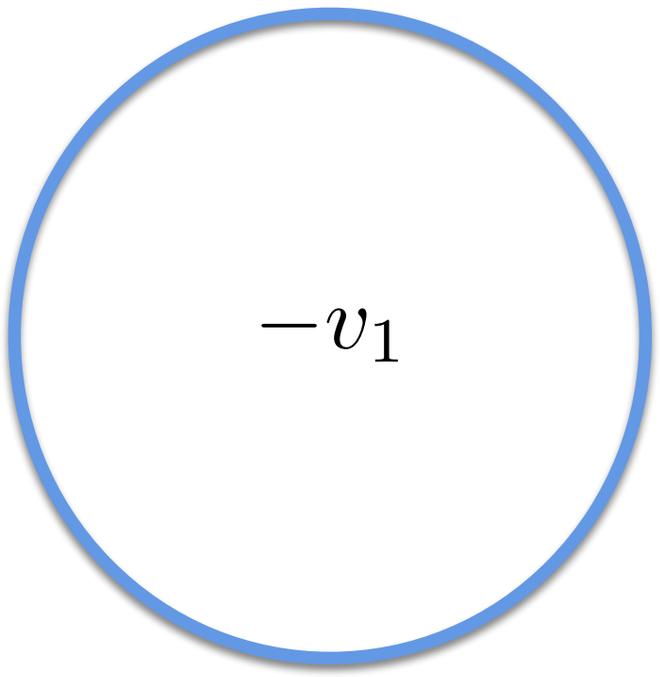


N.B. in reality need tiny breaking of H1->-H1 to avoid domain walls, so “0” really means << v

DOMAIN WALLS

Even after EW symmetry breaking a Z_2 subgroup of the Z_4 is spontaneously broken

$$H_1 \to -H_1$$

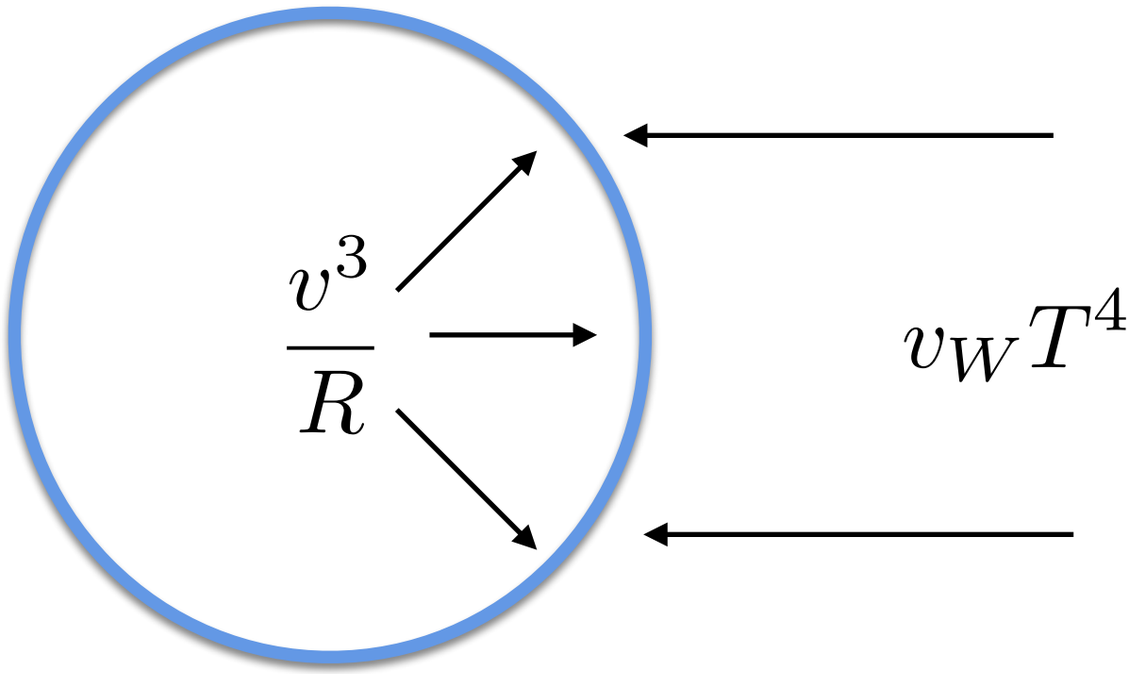


$$\rho_{\rm DW} \simeq \frac{v^3}{R}$$

DOMAIN WALLS

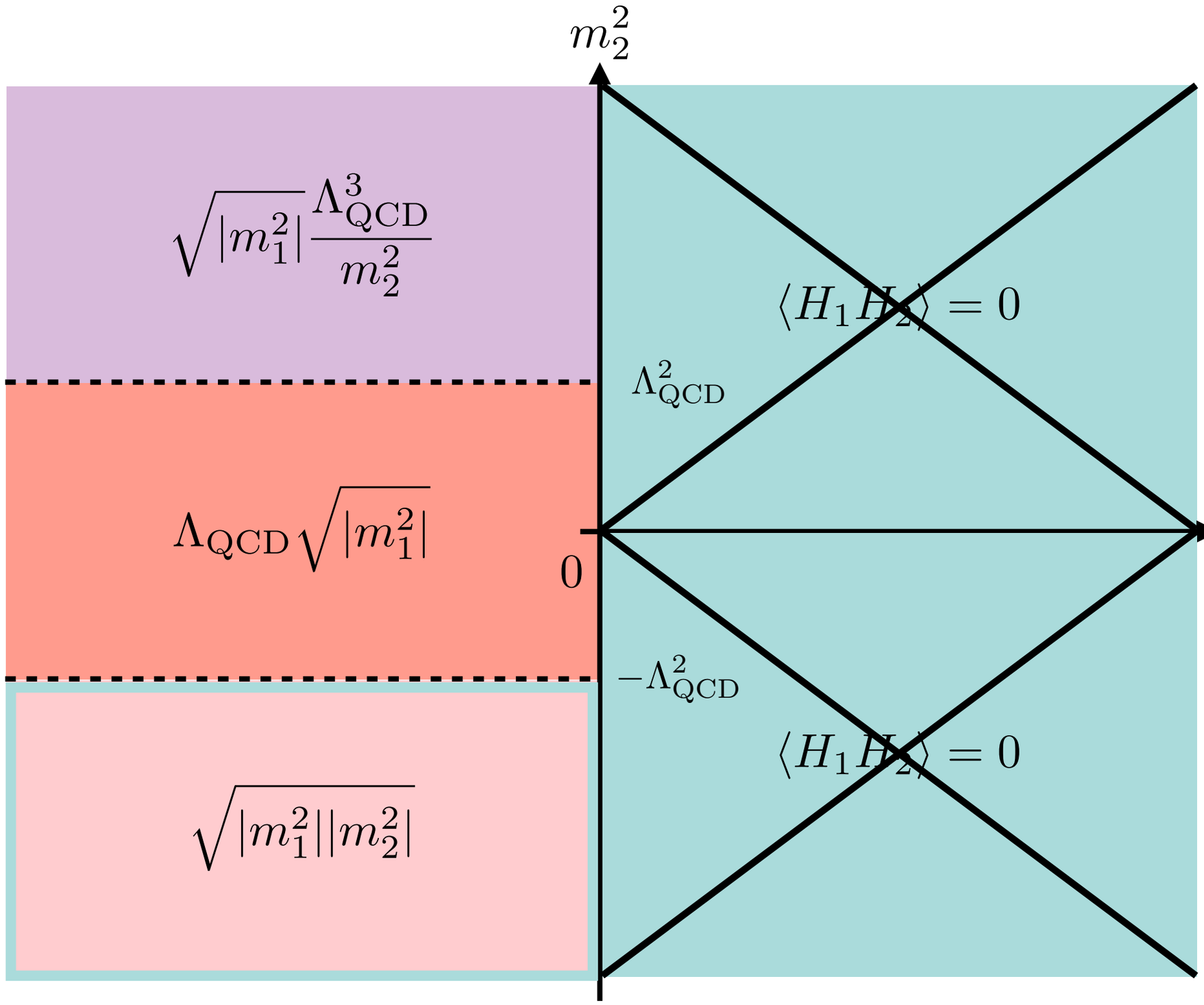
Even after EW symmetry breaking a Z_2 subgroup of the Z_4 is spontaneously broken

$$H_1 \to -H_1$$



$$\frac{\rho_{\rm DW}}{\rho_\gamma} \simeq \frac{v^3}{T^2 M_{\rm Pl}}$$

USE YOUR TRIGGER: CC AND WEAK SCALE



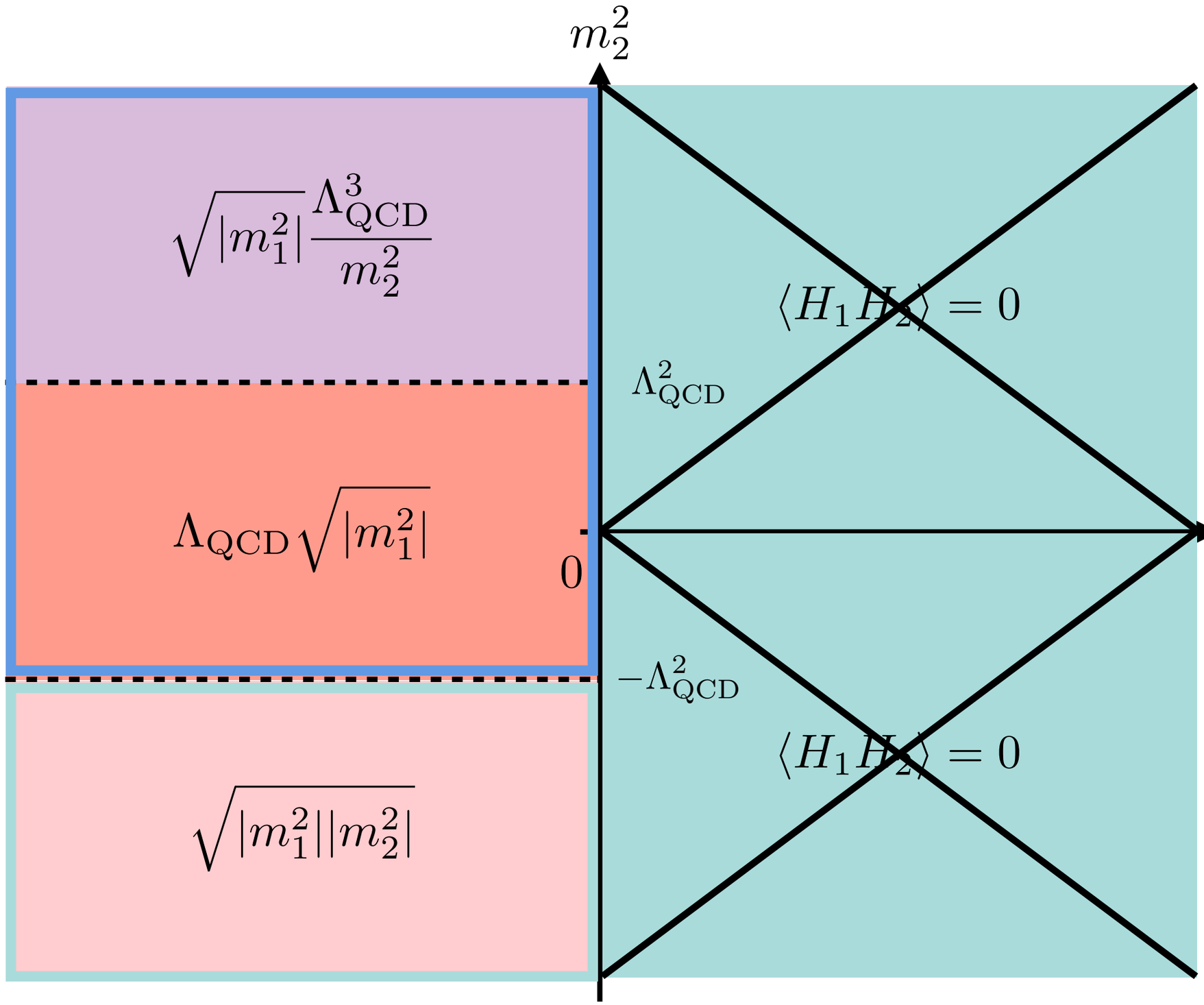
Huge CC

Looks like our Universe

Huge CC

USE YOUR TRIGGER: CC AND WEAK SCALE

What happens here?

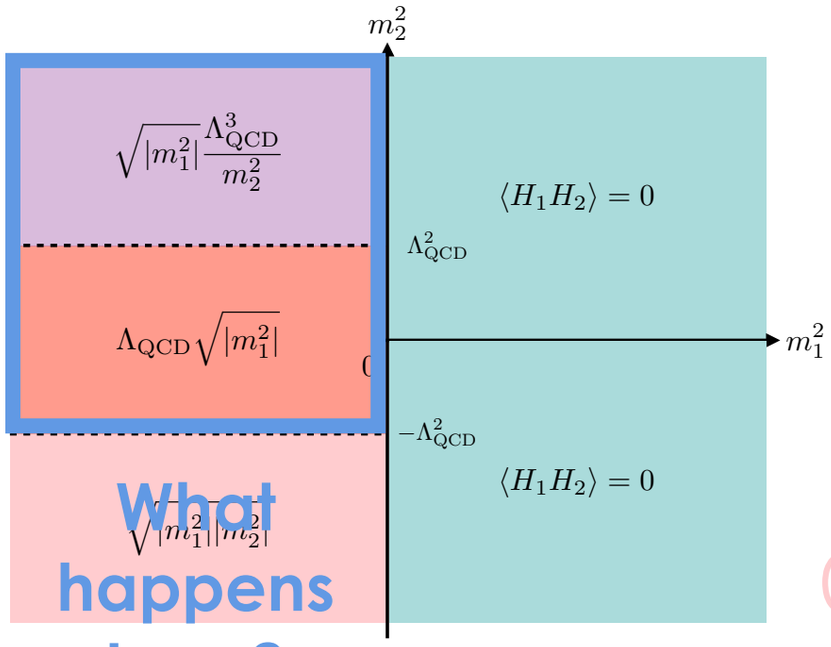


Huge CC

Looks like our Universe

Huge CC

USE YOUR TRIGGER: CC AND WEAK SCALE



What happens here?

$$\langle H_1 H_2\rangle \equiv \mu^2 \sim \sqrt{|m_1^2|}\Lambda_{\rm QCD}^3/m_2^2$$

CC cutoff

Higgs cutoff

$$\Delta\Lambda_{\rm UV}^{\rm min} \sim \frac{M_*^4}{N_{\rm UV}}\frac{\Lambda_H^2}{m_2^2} \sim \frac{M_*^4}{N_{\rm UV}}\frac{\mu^2\Lambda_H}{\Lambda_{\rm QCD}^3}$$

$$\kappa^2\mu^2\mu_B^2 \gg \Delta\Lambda_{\rm UV}^{\rm min}$$

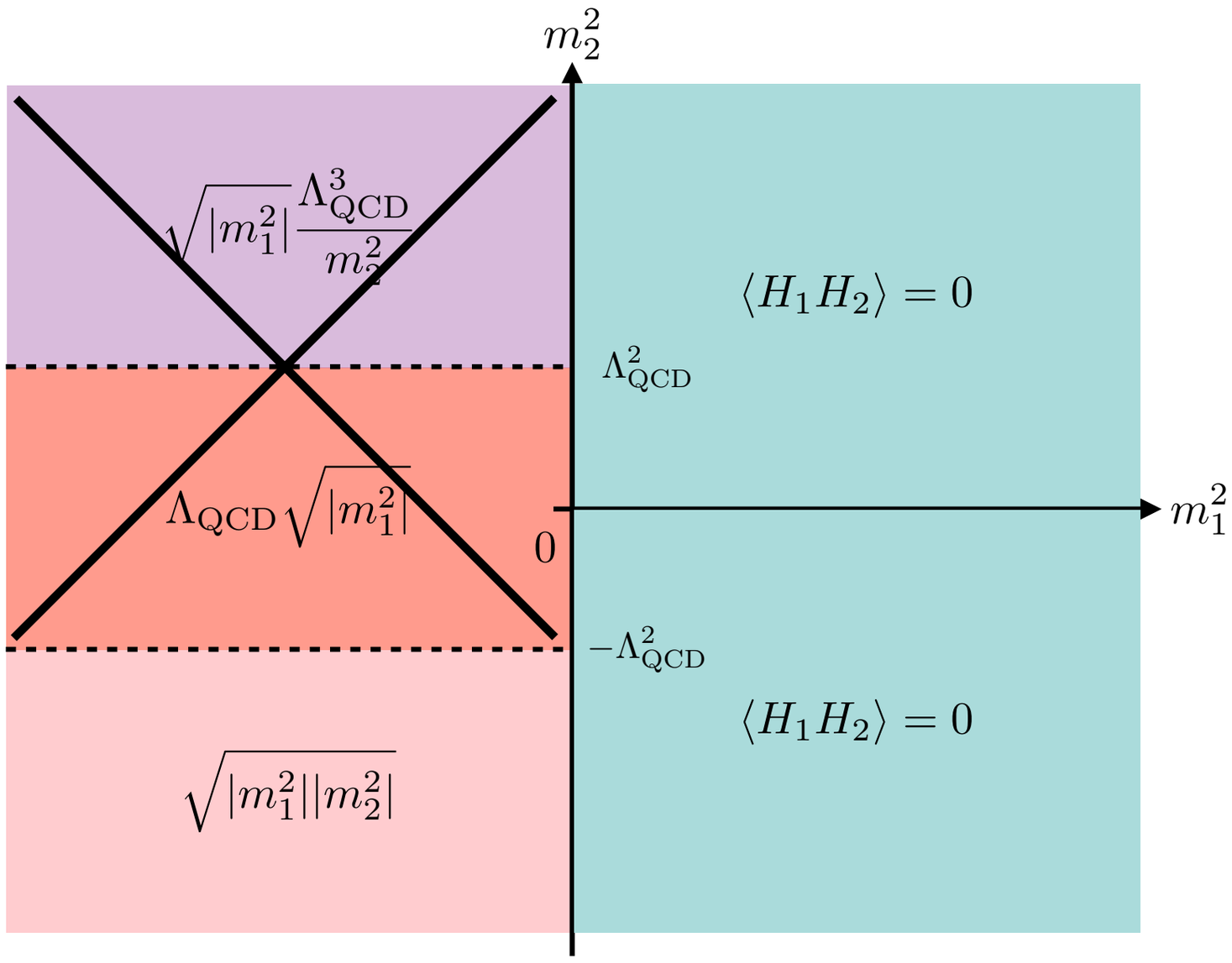
Splittings in the IR landscape

USE YOUR TRIGGER: CC AND WEAK SCALE

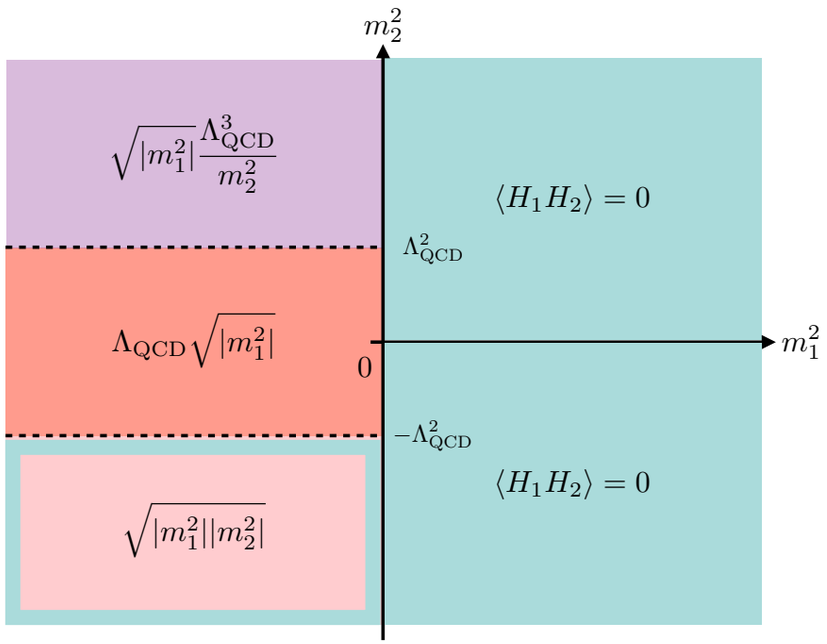
If $$\mu_B^2 \lesssim \frac{M_*^4}{N_{\rm UV}} \frac{\Lambda_H}{\kappa^2 \Lambda_{\rm QCD}^3}$$

Not enough scanning

Huge CC



USE YOUR TRIGGER: CC AND WEAK SCALE



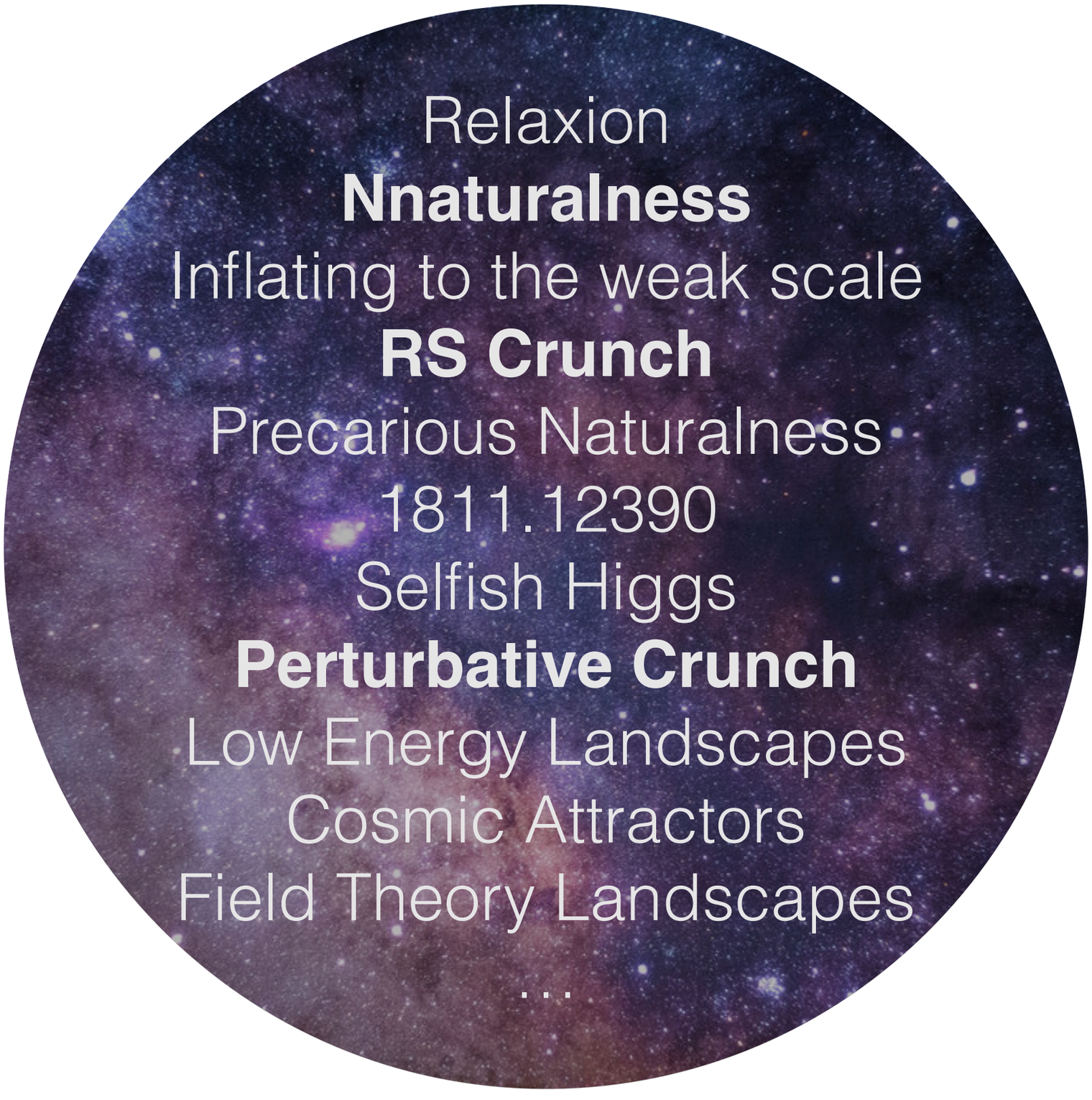
Looks like our Universe

In the general type-0 2HDM **we expect the two masses to be comparable (otherwise we need to tune)**

Furthermore, if the UV landscape is scanning the two masses squared, we have a logarithmic distribution

$$\int_{\mu_S^2<\mu^2<\mu_B^2} \frac{dm_1^2}{\Lambda_H^2}\frac{dm_2^2}{\Lambda_H^2} = \int_{m^2_{\rm min}}^{\Lambda_H^2} \frac{dm_1^2}{\Lambda_H^2}\int_{\mu_S^4/m_1^2}^{\mu_B^4/m_1^2}\frac{dm_2^2}{\Lambda_H^2} \simeq \frac{\mu_B^4}{\Lambda_H^4}\int_{m^2_{\rm min}}^{\Lambda_H^2}\frac{dm_1^2}{m_1^2}$$

Quite a few Ideas on the Market



But not all are created equal

BEFORE READING THE PAPERS

Do you need to make inflation cry?

Is your cutoff at most 10 TeV?

A SIMPLE BSM TRIGGER

$$H_1 H_2$$

Protected by the **Z4 symmetry**

$$H_1 \to i e^{i\alpha} H_1, \quad H_2 \to i e^{-i\alpha} H_2$$

$$H_1 H_2 \to -H_1 H_2$$

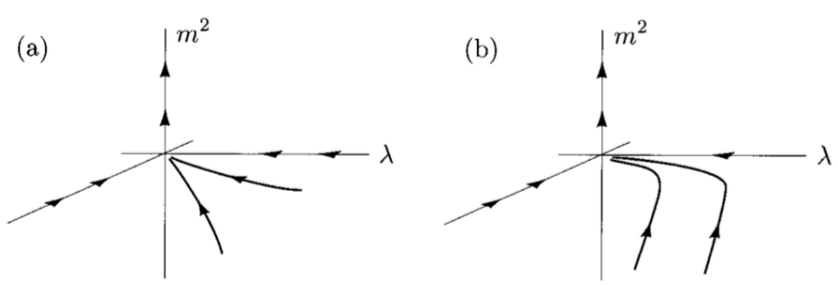
The Weak Scale As a Trigger

[Arkani-Hamed, **RTD**, Kim] '20

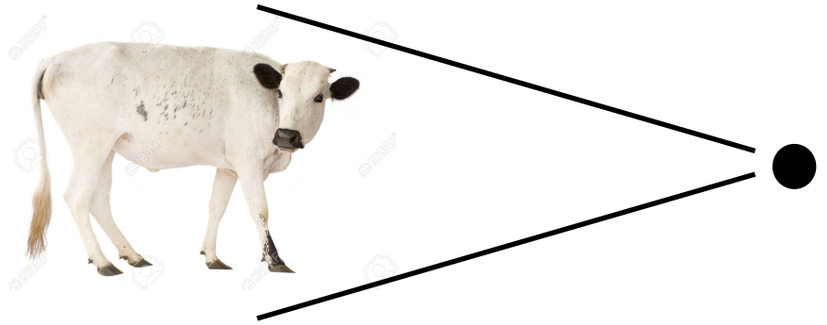
EFFECTIVE FIELD THEORY

In Quantum Field Theory: Systematic way of integrating out high energy degrees of freedom to obtain a simplified low energy theory

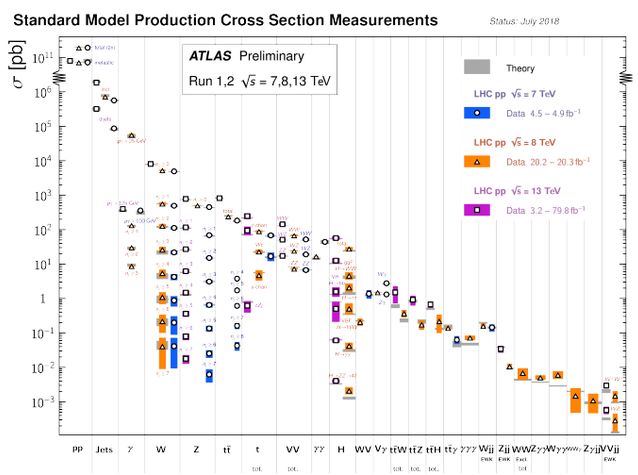
RENORMALIZATION



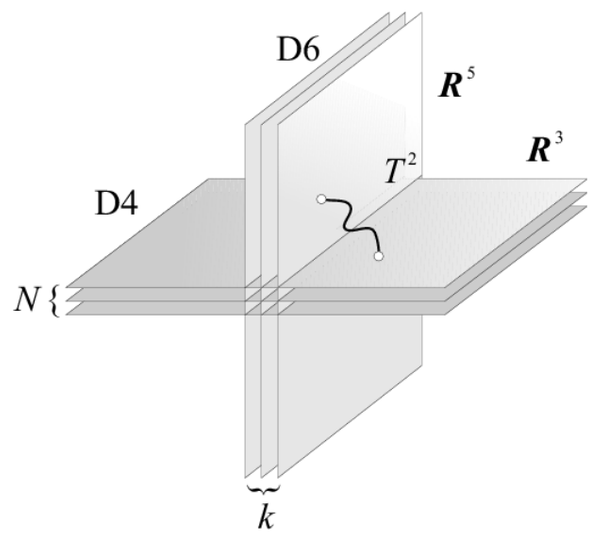
SYMMETRIES FROM COARSE GRAINING



PRECISION CALCULATIONS

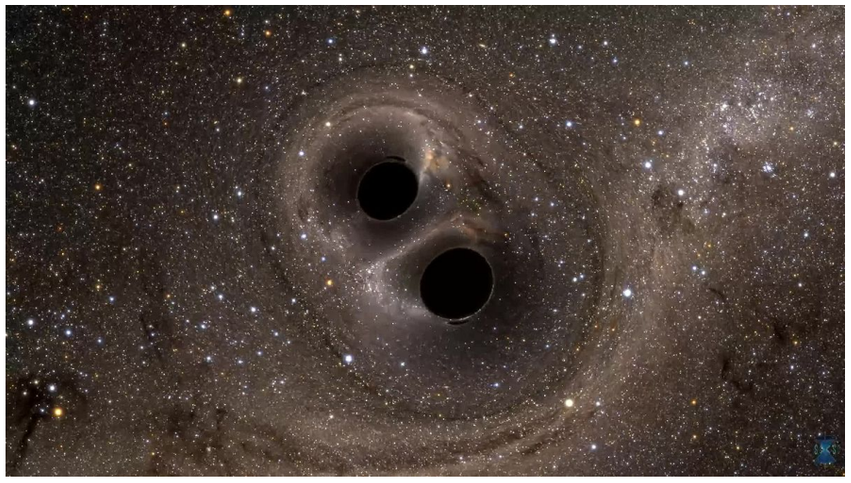


QFT INSIGHTS FROM STRING THEORY

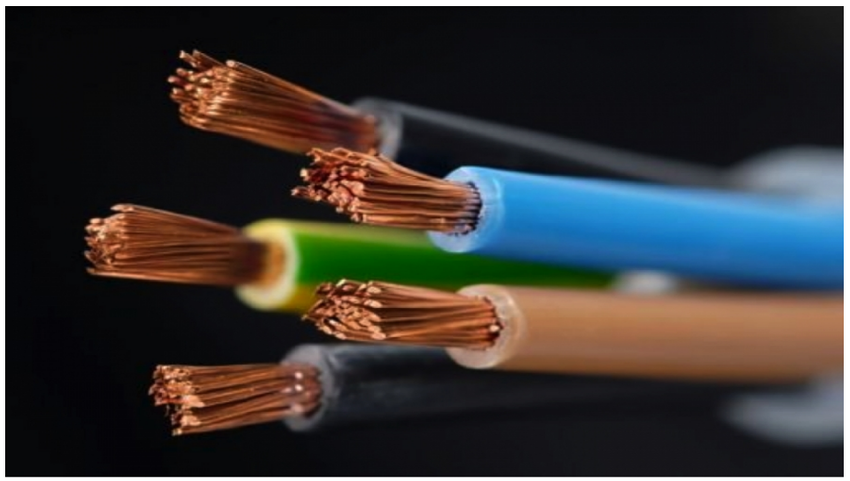


ONE TOOL FOR MULTIPLE APPLICATIONS

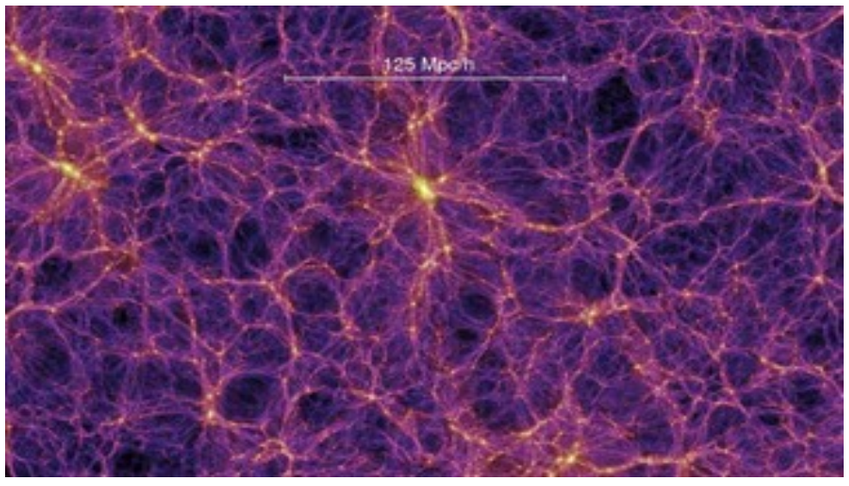
POST-NEWTONIAN EXPANSIONS



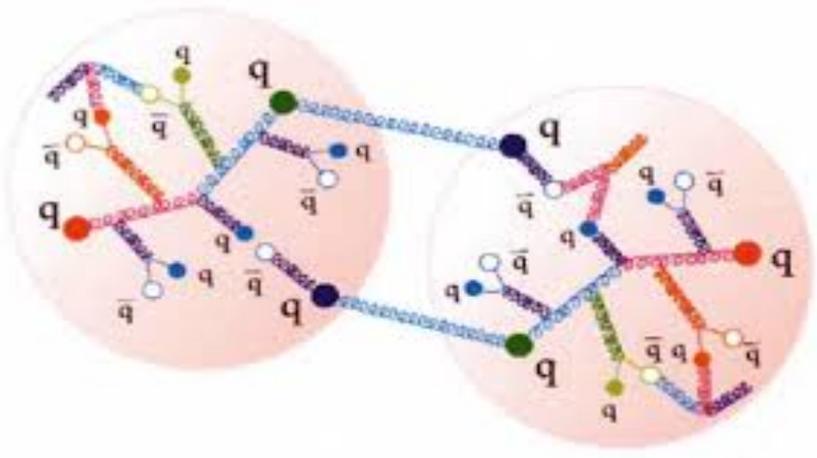
LANDAU THEORY OF FERMI LIQUIDS



LARGE SCALE STRUCTURE



CHIRAL PERTURBATION THEORY



THE HIERARCHY PROBLEMS

Take a heavy mass scale [Gravity] and apply this procedure of integrating out:

SIZE OF THE UNIVERSE ~ 10^{-60} observed

HIGGS BOSON MASS ~ 10^{16} observed

Assumption: in the UV mh and the CC are calculable

THE HIERARCHY PROBLEMS

Take a heavy mass scale [Gravity] and apply this procedure of integrating out:

These answers are based on something more fundamental than the procedure itself: Symmetry

$\sim 10^{-60}$ observed

$\sim 10^{16}$ observed

Assumption: in the UV mh and the CC are calculable

HIERARCHY 101

For scalars there is **nothing special** about

$$m_h^2 = 0$$

So **dimensional analysis** (i.e. the selection rules of dilatations) places their masses near the highest mass scale of the theory

$$m_h^2 \simeq \Lambda_H^2$$

Finding $m_h^2 \ll \Lambda_H^2$ is a **mystery**

HIERARCHY 101

After discovering the Higgs boson

$$m_h \simeq 125 \text{ GeV}$$

We expect **something new** to happen **at** (LEP) **the LHC**

$$\Lambda_H \simeq 100 - 1000 \text{ GeV}$$

HIERARCHY 102

In the absence of obvious new physics at

$$\Lambda_H \simeq 100 - 1000 \text{ GeV}$$

We can start **questioning our assumptions**: does anything change in the SM as we vary m_h^2 ?

Maybe $m_h^2 = 0$ is not special in a general QFT, but it is special in our very special QFT of the Universe

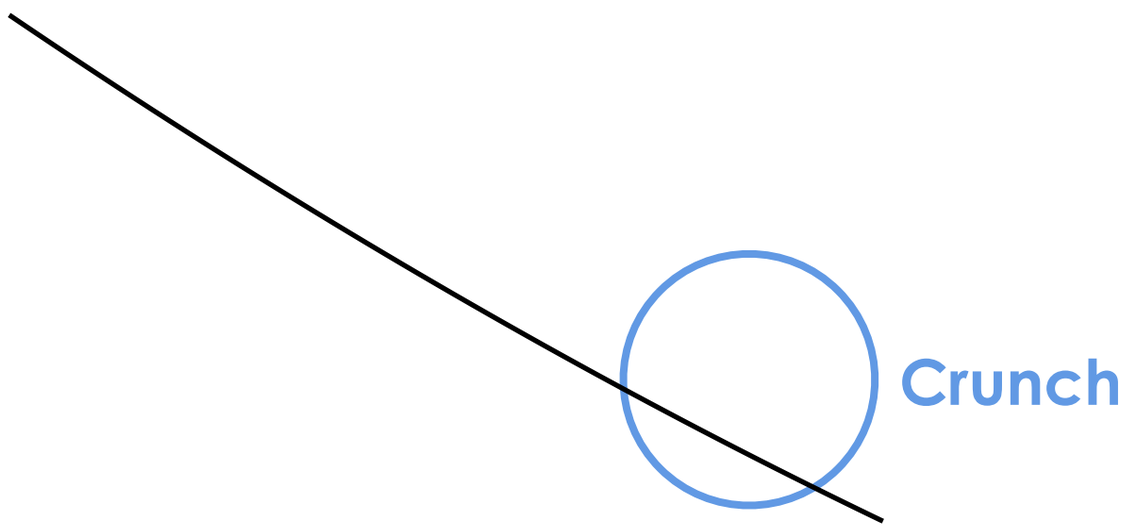
PERTURBATIVE CRUNCH

Sliding Naturalness

[**RTD**, Teresi] In Preparation

$$V(\phi_+) = \eta M_*^3 \phi_+ + \eta^2 M_*^2 \phi_+^2 + ... + (\lambda \phi_+^2 H_1 H_2 + \text{h.c.})$$

$$\langle H_1 H_2 \rangle = 0$$



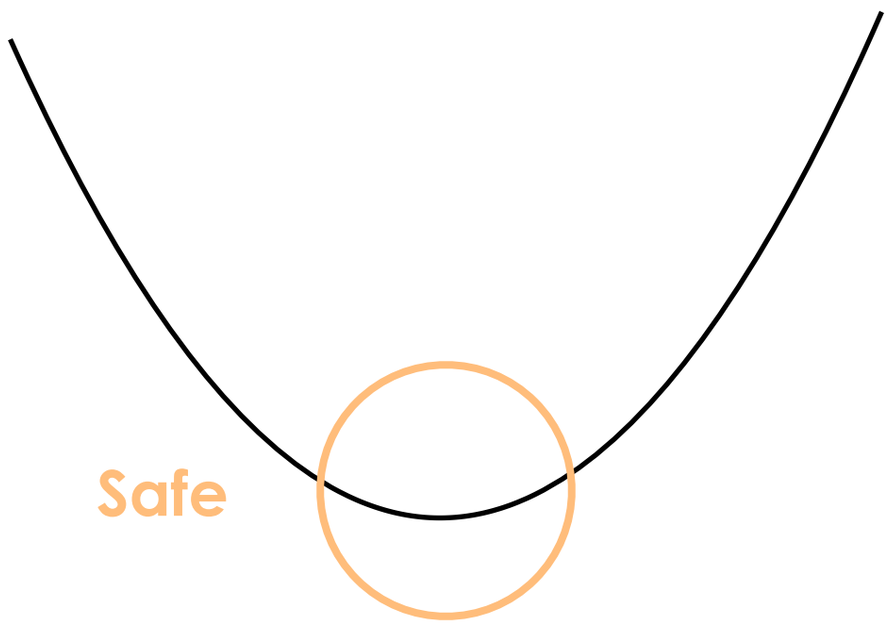
PERTURBATIVE CRUNCH

Sliding Naturalness

[**RTD**, Teresi] In Preparation

$$V(\phi_+) = \eta M_*^3 \phi_+ + \eta^2 M_*^2 \phi_+^2 + ... + (\lambda \phi_+^2 H_1 H_2 + \text{h.c.})$$

$$\langle H_1 H_2 \rangle \gtrsim v^2$$



TRIGGER BASICS

Example I: Relaxion

$$V_{\phi H} \simeq \frac{\phi^2}{f^2}\Lambda_{\rm QCD}^4 \simeq \frac{M_*^2}{f^2}\Lambda_{\rm QCD}^4$$

$$V_\phi \simeq m_\phi^2 M_*^2$$

$$V_\phi/V_{\phi H} \sim 1 \quad \rightarrow \quad m_\phi^2 \simeq \frac{\Lambda_{\rm QCD}^4}{f^2}$$

HIERARCHY 102

Does anything change in the SM as we vary m_h ?

We can even define a degree of tuning when $\langle h^\dagger h \rangle$ is calculable

$$r = \frac{\langle h^\dagger h \rangle}{m_h^2}$$

SUSY

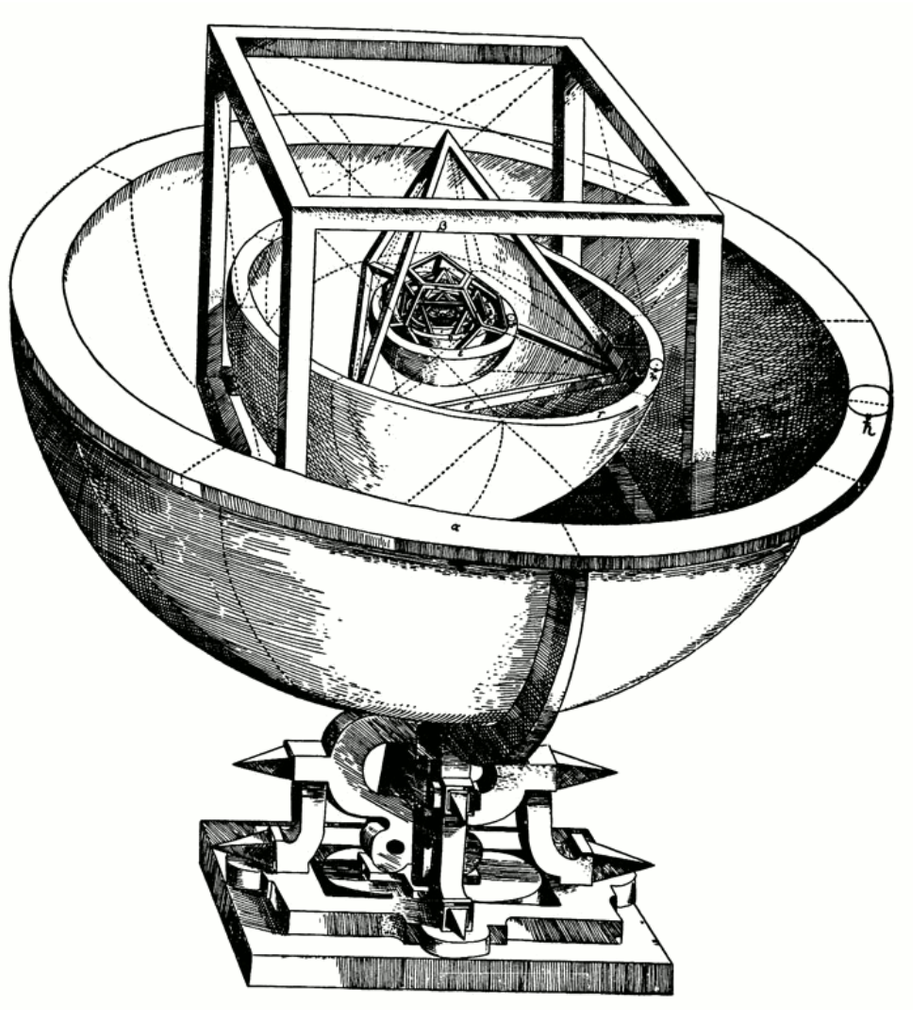
$$r \sim \frac{m_{\rm SUSY}^2}{m_h^2}$$

Compositness

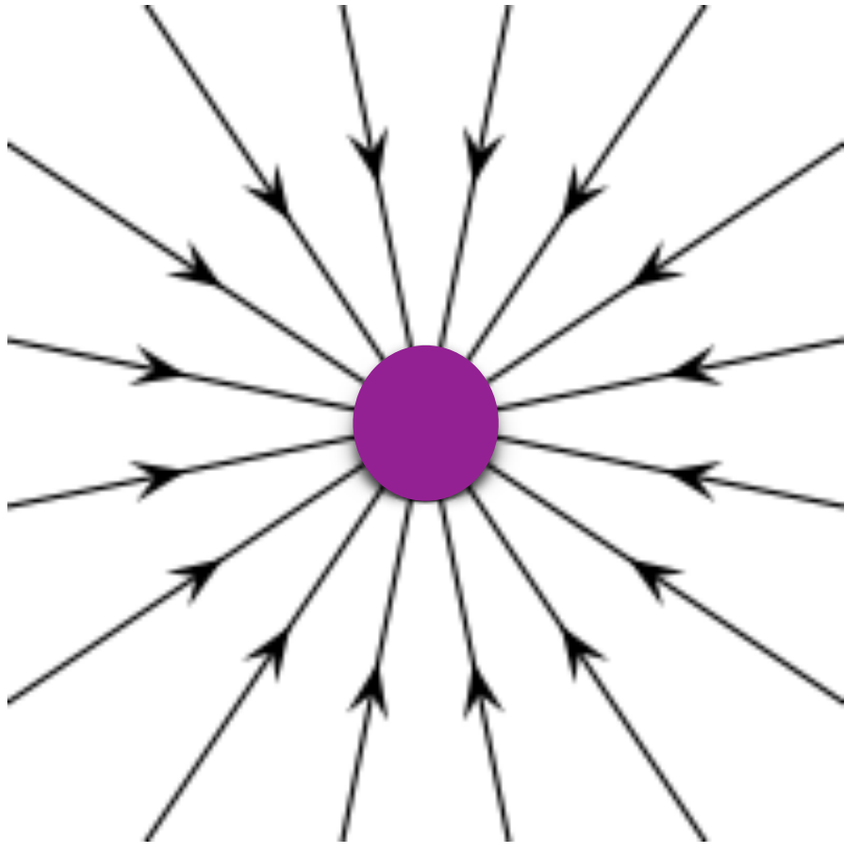
$$r \sim \frac{f_\pi^2}{m_h^2}$$

PAST FINE-TUNING PROBLEMS

Mysterium Cosmographicum



Electron Self-Energy



PAST FINE-TUNING PROBLEMS

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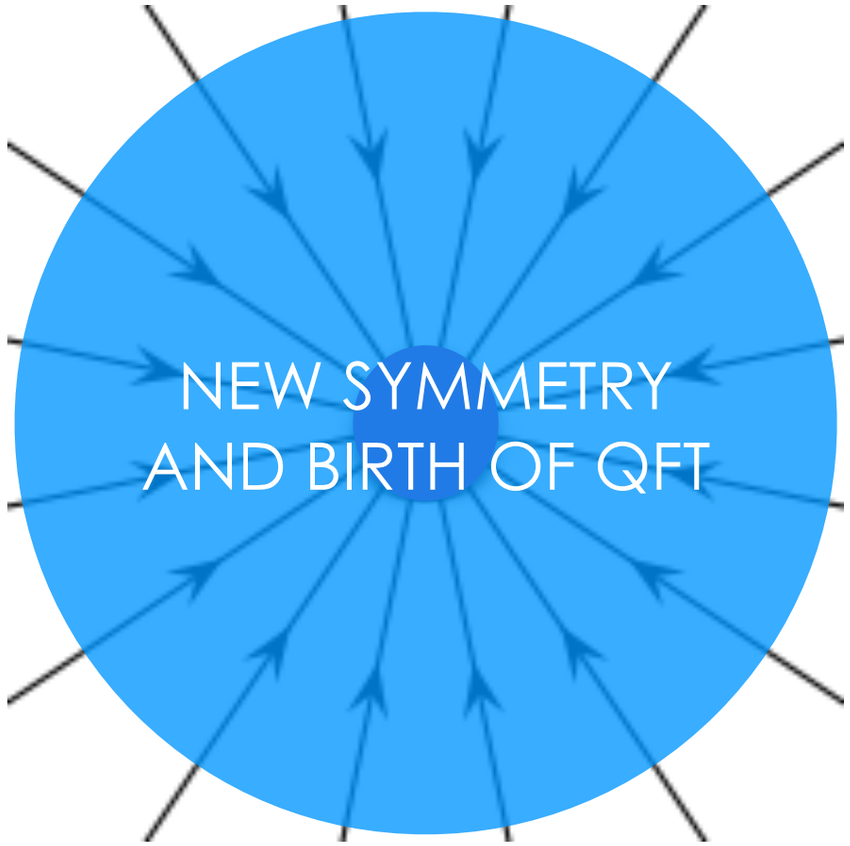

Both have paradigm-shifting resolutions