VRIJE UNIVERSITEIT BRUSSEL

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

SB, Goertz, PRL 123 no.22, arXiv:1903.06146

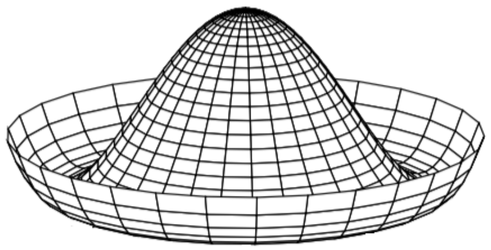
SB, Csaki, Goertz, arXiv:2004.06120

SIMONE BLASI

LITTLE HIERARCHY AND COMPOSITENESS

EOS be.h Winter Solstice Meeting, 16th December 2020

THE HIERARCHY PROBLEM



New heavy thresholds introduce quadratic corrections to the BEH mass: $\delta m_h^2 \sim \Lambda^2$

In the absence of an underlying mechanism the electroweak scale is unnatural.

two possible approaches to BSM:

- Leave the HP aside and focus on more concrete issues of the SM.
- The HP may not be a problem at all, or solved in a way that can't be captured by EFT.

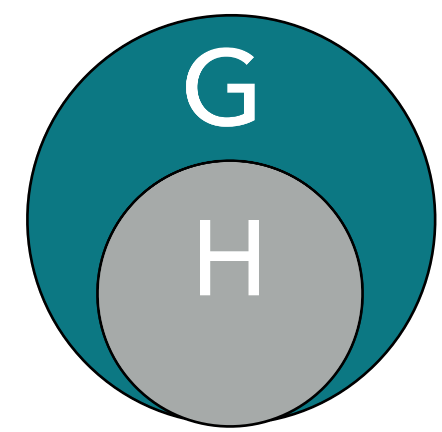
- Search for a structural solution to the HP based on QFT arguments.
- Uncovering the mechanism underlying EWSB will provide new insights for the other open questions.

A COMPOSITE BEH BOSON? Kaplan, Georgi, Dimopoulos…

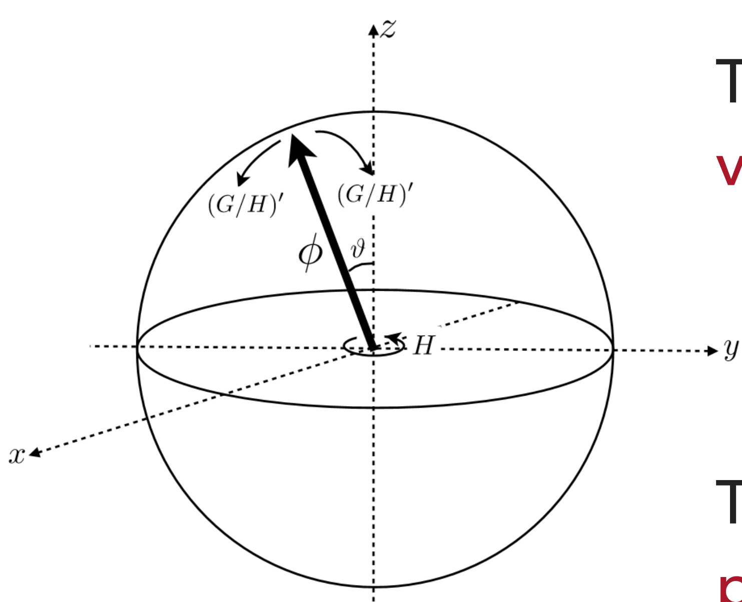
The BEH boson is no longer an elementary scalar but rather a bound state of a new strong dynamics which condenses not too far from the electroweak scale.

The HP is solved because the finite size of the BEH boson itself represents a cutoff for the corrections to the scalar potential.

Strong dynamics features a global symmetry G broken to H at the condensation scale: h boson as a pseudo Nambu-Goldstone boson.



$G \to H \supset SU(2) \times U(1)$



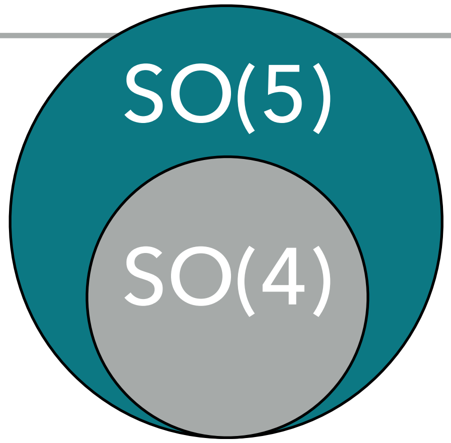
Graphics from Azatov et al.'12

The electroweak symmetry is broken via vacuum misalignment:

$$\xi \equiv \frac{v^2}{f^2} = \sin^2(\langle h \rangle / f)$$

The presence of a light SM-like h boson helps with electroweak precision tests (as opposed to *technicolor).*

THE MINIMAL COMPOSITE HIGGS MODEL



Agashe, Contino, Pomarol 2005

- G = SO(5) and H = SO(4): G/H contains 4 dofs + custodial protection, best realization by means of holography.
  - Slice of AdS delimited by UV brane and IR brane.
  - SO(5) gauge symmetry in the bulk reduced to SU(2) x U(1) on the UV brane, SO(4) on the IR brane via dedicated boundary conditions + brane-localized terms.
  - Gauge-Higgs unification: h doublet as scalar component of SO(5)/SO(4) broken gauge fields.
  - SM fermions embedded in 5D fields, flavor puzzle addressed by partial compositeness + explicit breaking.

*One also needs an extra U(1) factor to reproduce fermion hypercharges.

PARTIAL COMPOSITENESS

DIRICHLET TYPE $[+] : \psi = 0$ $[-] : \chi = 0$

SO(5) x U(1)

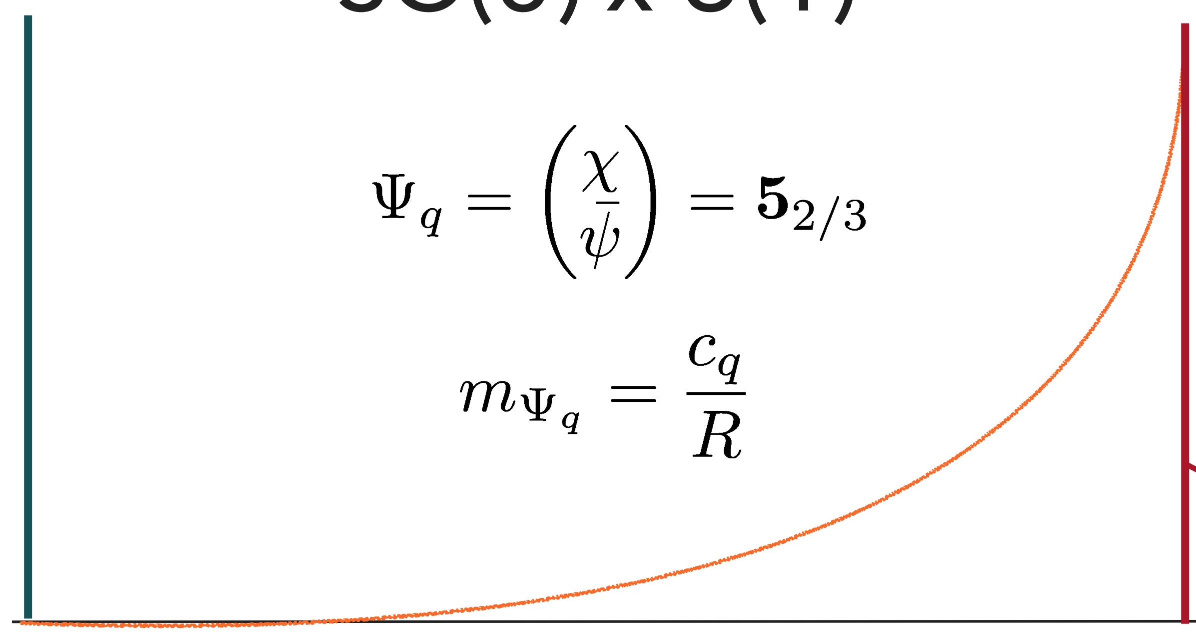
SU(2) x U(1)

$$\begin{pmatrix} [-] & [+] \\ [-] & [+] \end{pmatrix} \oplus [-]$$

UV

$$\Psi_q = \begin{pmatrix} \chi \\ \bar{\psi} \end{pmatrix} = \mathbf{5}_{2/3}$$

$$m_{\Psi_q} = \frac{c_q}{R}$$



SO(4) x U(1)

$$\begin{pmatrix} [+] & [+] \\ [+] & [+] \end{pmatrix} \oplus [+]$$

IR

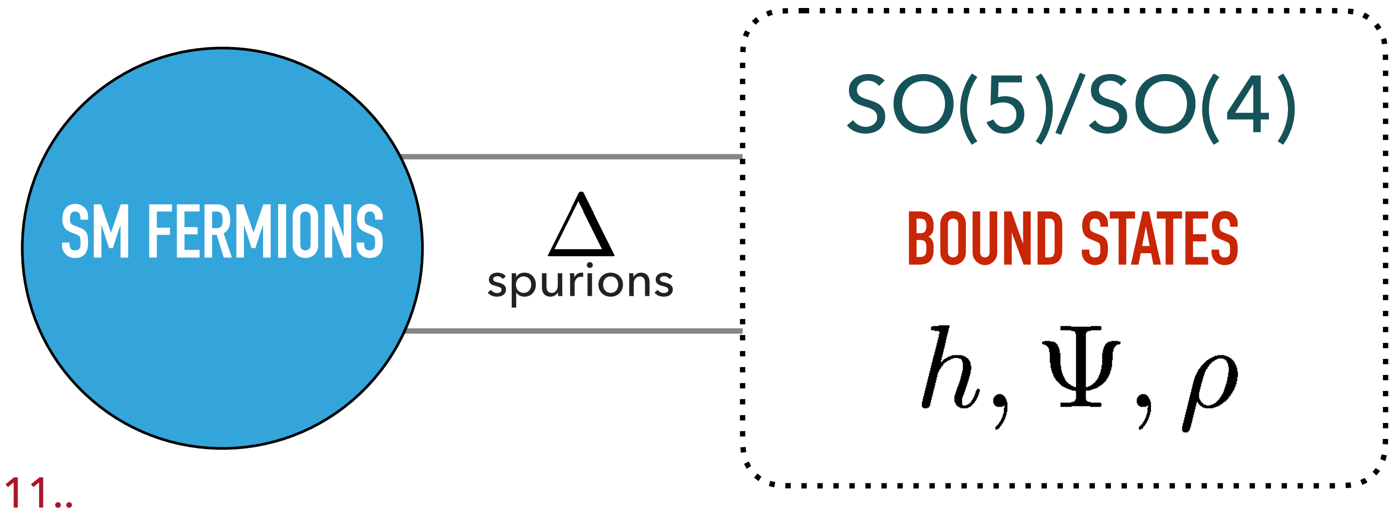
$z = R$ [+,+] : LH zero mode $z = R'$

brane localized terms to give mass to SM fermions

- SM fermions as zero-modes.
- Specific boundary conditions break SO(5).
- 5D bulk masses impact localization of the zero-modes and hence their masses after EWSB.

$$R \sim M_{\rm Pl}^{-1}$$
$$R' \sim {\rm TeV}^{-1}$$

PARTIAL COMPOSITENESS



DeCurtis et al.'11, Panico et al.11..

- 4D effective theory below the condensation scale describes a mixing between SM fermions and composite resonances:

$$\mathcal{L}_{\text{mixing}} = \lambda_L \bar{q}_L \Delta_L U \Psi_R + \lambda_R \bar{t}_R \Delta_R U \Psi_L + \text{h.c.}, \quad U = \exp\left(-i\frac{\sqrt{2}}{f}T^{\hat{a}}h_a\right)$$

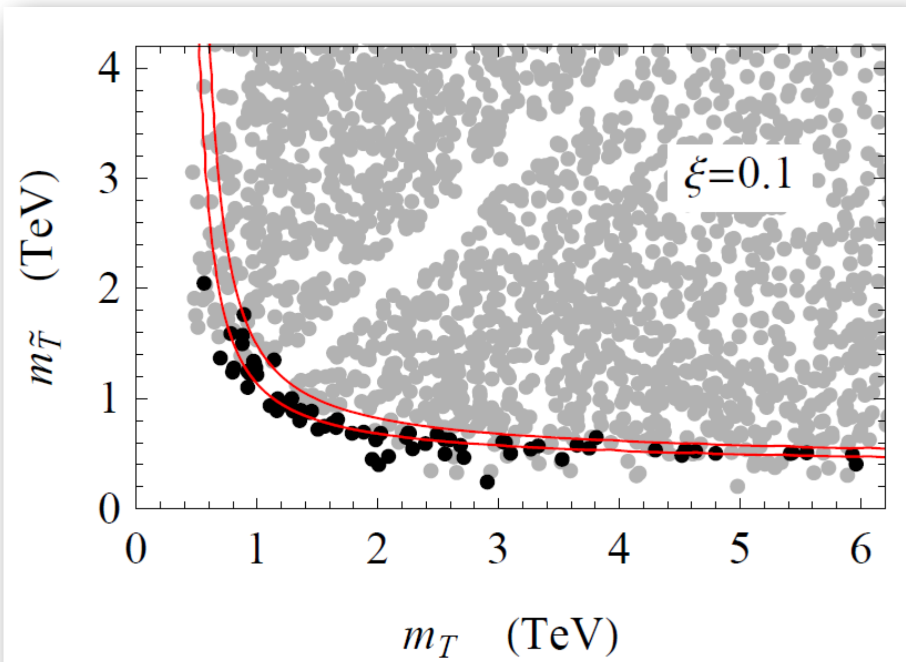
- Spurions signal explicit breaking due to SM fermions being incomplete SO(5) irreps (specific boundary conditions in 5D): largest contribution from the top quark.

$$\Delta_R = (0,0,0,0,1) \quad \Leftrightarrow \quad \begin{pmatrix} [-,+] & [-,+] \\ [-,+] & [-,+] \end{pmatrix} \oplus [-,-]$$

LIGHT TOP PARTNERS

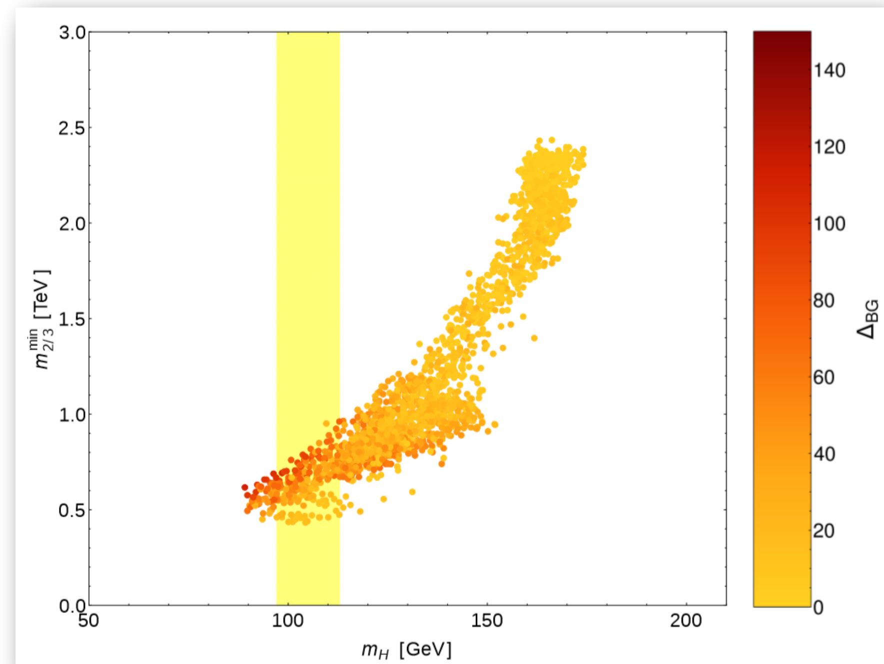
$$m_h \sim \frac{m_T}{f} m_t$$

4D effective theory



Matsedonskyi, Panico, Wulzer 2012

5D holographic



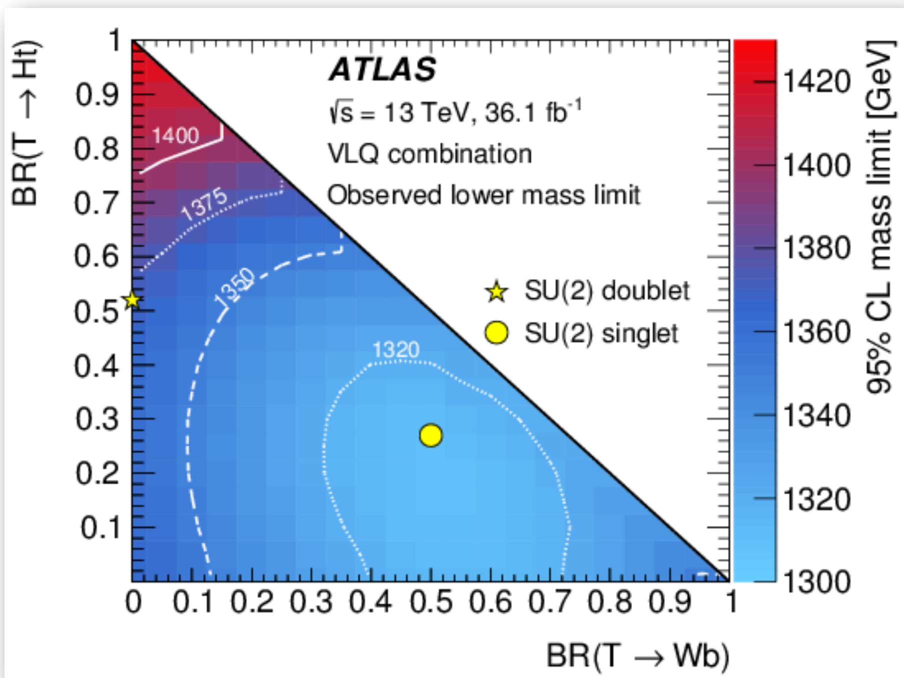
Carmona, Goertz 2015

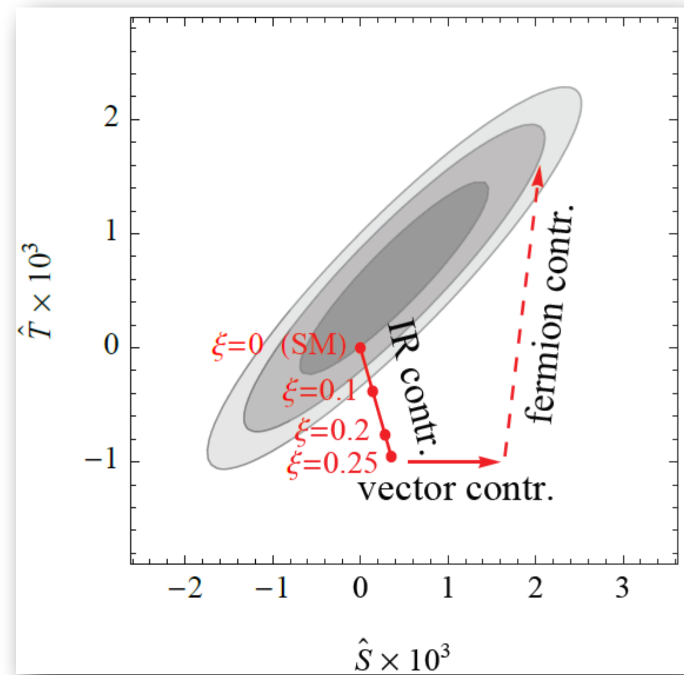
- Minimal realizations such as the MCHM5 and MCHM10 predict light top partners in order to be compatible with a light h boson (anomalously light KK in 5D).
- Strong correlation between top yukawa and explicit breaking requires light states to cure it.

EXPERIMENTAL CONSTRAINTS

$$m_h \sim \frac{m_T}{f} m_t$$

Grojean et al. 2013





- Direct searches can constrain top partners as heavy as 1.4 TeV.
- The only way minimal models can comply with this is by making the h boson more elementary, namely increasing the condensation scale.

THE TUNING INCREASES AND SURPASSES THE 10% IMPLIED BY LEP

$$\Delta \propto \frac{1}{\xi} = \frac{f^2}{v^2}$$

POSSIBLE SOLUTIONS

- **Raise** the scale ***f*** as much as necessary to comply with current constraints
- Move to **non-minimal** models
- Keep the MCHM but change representations (**14**) Panico et al.'12
- Inclusion of a realistic **lepton** sector Carmona, Goertz'15
- Enhance the (**maximal**) symmetry Csaki et al.'17
- New physics as a **continuum** rather than particle excitation Georgi'05, Csaki et al.'18
- Make partners **uncolored** (twin-Higgs) Chacko et al.'05, Barbieri et al.'05..
- …

THIS TALK

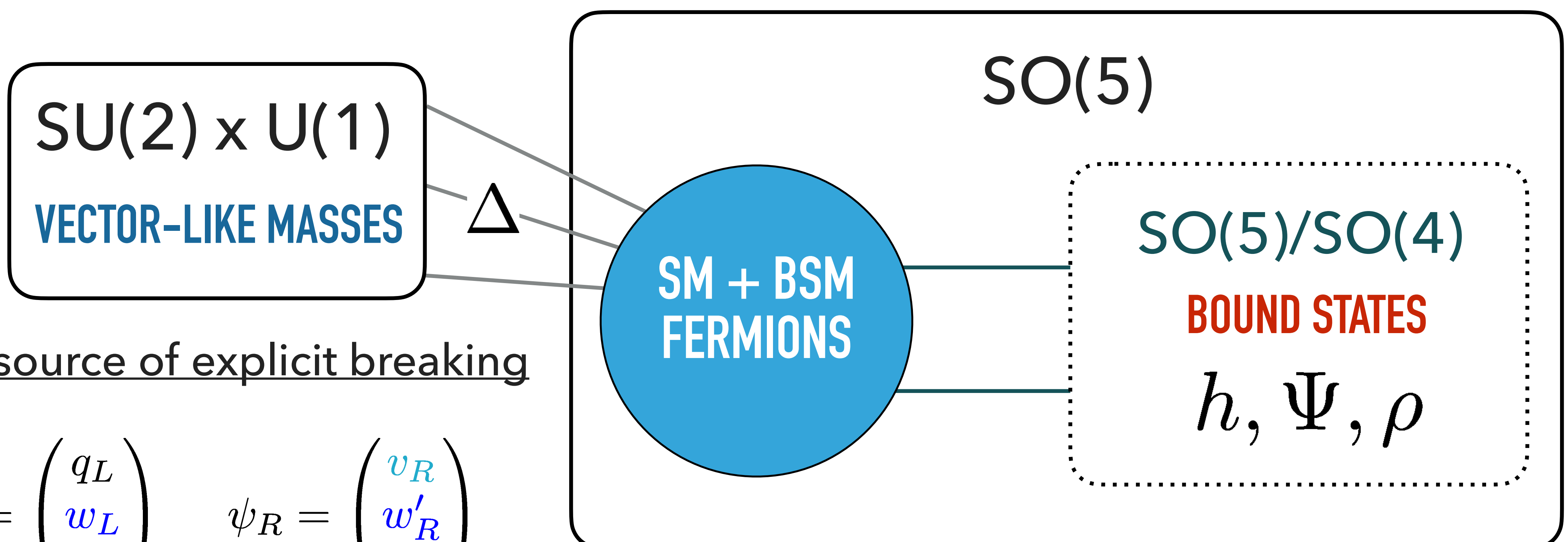
- **Soften** the explicit breaking & **maximal** symmetry SB, Goertz '19, SB, Goertz, Csaki '20

A SOFT COMPOSITE BEH

SB, Goertz 2019

We want to construct a model that:

- keeps **minimality** and the nice features of **partial compositeness**
- **gets rid** of the **correlation** between h boson mass and top partners



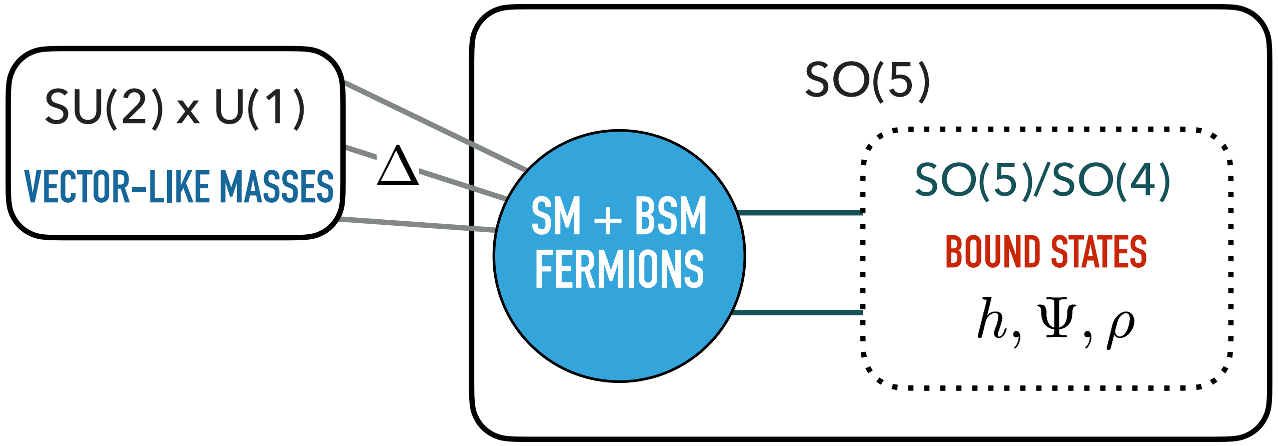
new source of explicit breaking

$$\psi_L = \begin{pmatrix} q_L \\ w_L \\ s_L \end{pmatrix} \qquad \psi_R = \begin{pmatrix} v_R \\ w'_R \\ t_R \end{pmatrix}$$

*SM gauge bosons still couple directly to strong sector

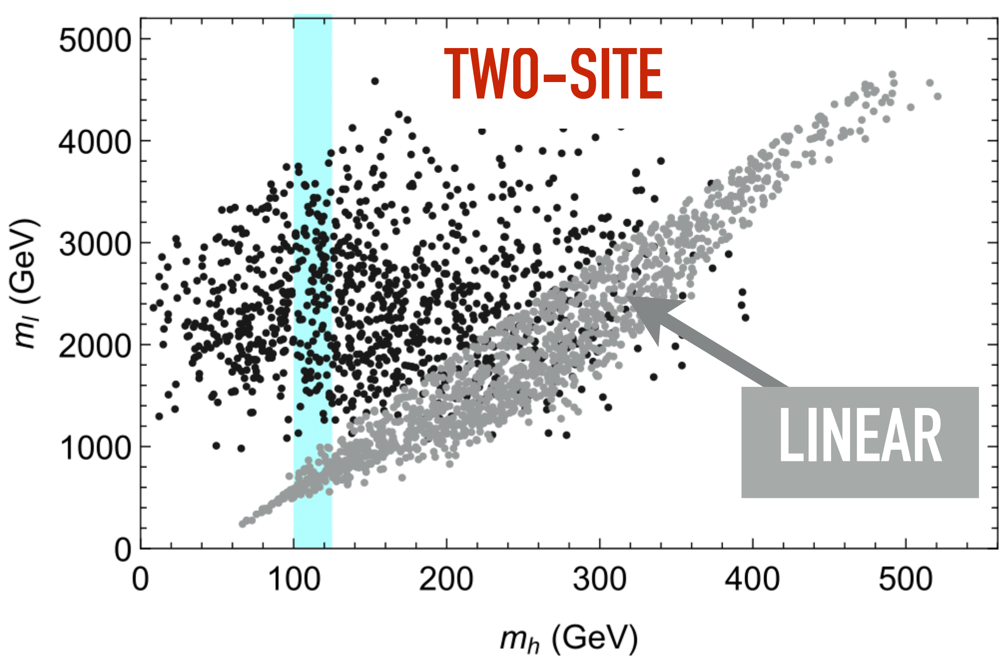
A SOFT COMPOSITE BEH

SB, Goertz 2019



TWO RELEVANT LIMITS:

- Vector-like masses >> compositeness scale: no effect (decoupling).
- Vector-like masses << compositeness scale: light top partners "by hand".



- h boson generically **lighter** wrt standard partial compositeness
- Heavy top partners are now compatible **without** raising ***f***

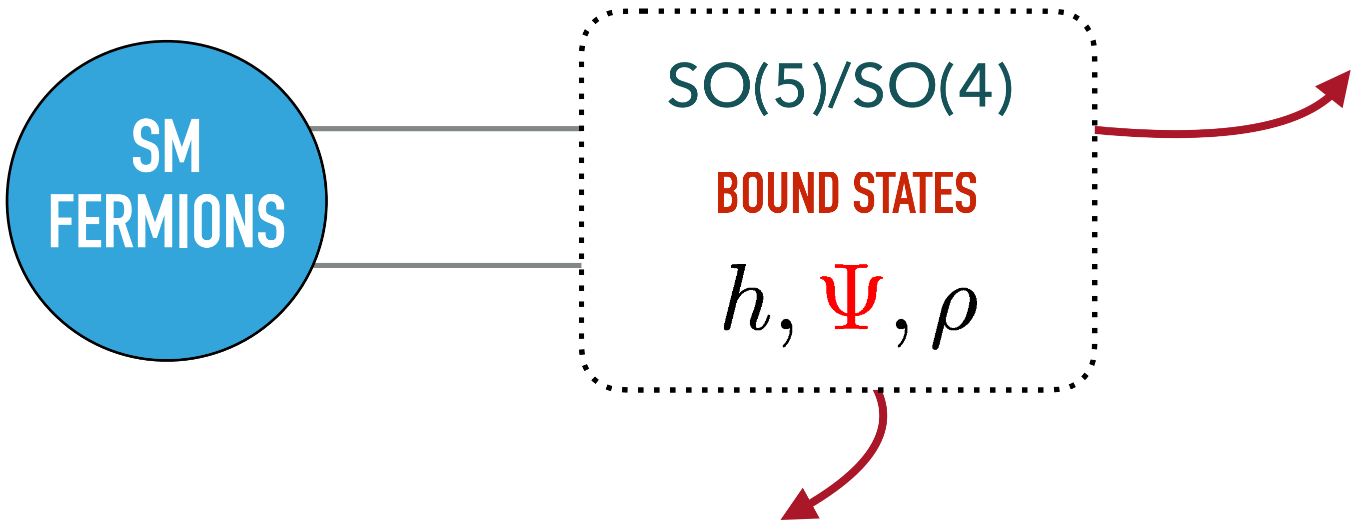
- Intermediate case: correlation between h mass and top partner masses is broken!

MAXIMAL SYMMETRY

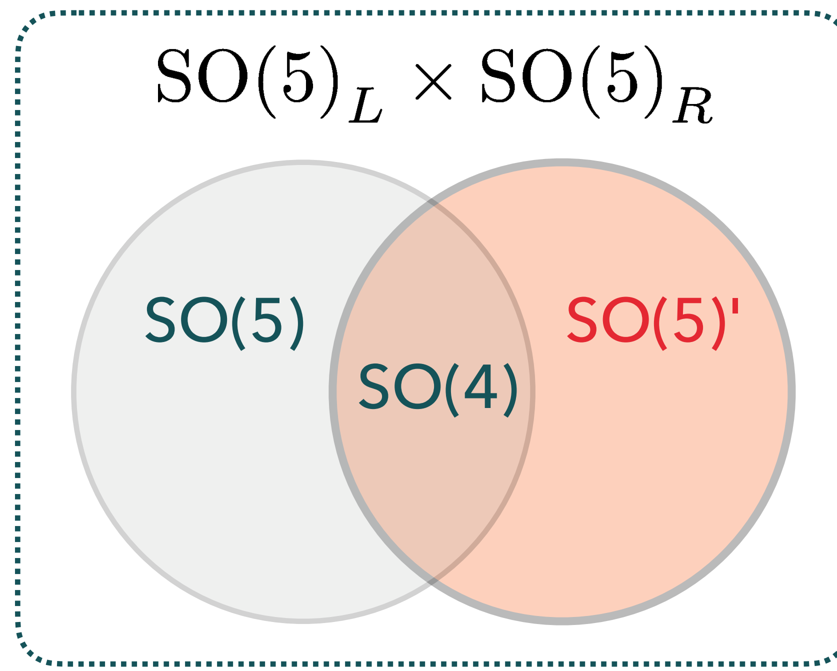
Csaki et al.'17,'18

$$V^\dagger T^a V = T^a, \quad V^\dagger T^{\hat a} V = -T^{\hat a}$$

It is a symmetry of the strong sector that can emerge under certain assumptions.



- Symmetric coset: existence of a **Higgs parity V**.



- Composite fermions as **full SO(5) irreps**:

$$\Psi = \begin{pmatrix} Q \\ \tilde{T} \end{pmatrix}$$

- **Largest** symmetry **group** with non-zero masses for composite fermions still generating a potential for h:

$$\mathcal{L}_{\rm mass} = \bar{\Psi}_L \left[\cancel{(m_Q + \tilde{m}_T)} + (m_Q - \tilde{m}_T)V\right] \Psi_R + \text{h.c.}$$

MAXIMAL SYMMETRY

Csaki et al.'17,'18

$$V^\dagger T^a V = T^a, \quad V^\dagger T^{\hat{a}} V = -T^{\hat{a}}$$

Imposing maximal symmetry further constrains the structure of the generated h potential ensuring structural cancellations.

In particular, there is unbroken **Higgs parity** as long as fermions are concerned:

$$\sin^2(h/f) \leftrightarrow -\cos^2(h/f) \Rightarrow \xi \equiv \frac{v^2}{f^2} = 0.5$$

Gauge contribution can however be important as well, and helps misalign the vacuum in the right way.

$$\Delta_{\text{max sym}} \simeq \frac{f^2}{v^2} = 9 \left(\frac{m_T}{1\,\text{TeV}}\right)^2 \qquad \Delta_5 \simeq \frac{f^2}{v^2}\left(\frac{g_*}{\lambda}\right)^2 \sim 90 \left(\frac{m_T}{1\,\text{TeV}}\right)^2$$

DOUBLE TUNING IS REMOVED!

(Standard MCHM5 Panico, Redi,Tesi 2012)

SMALL SUMMARY

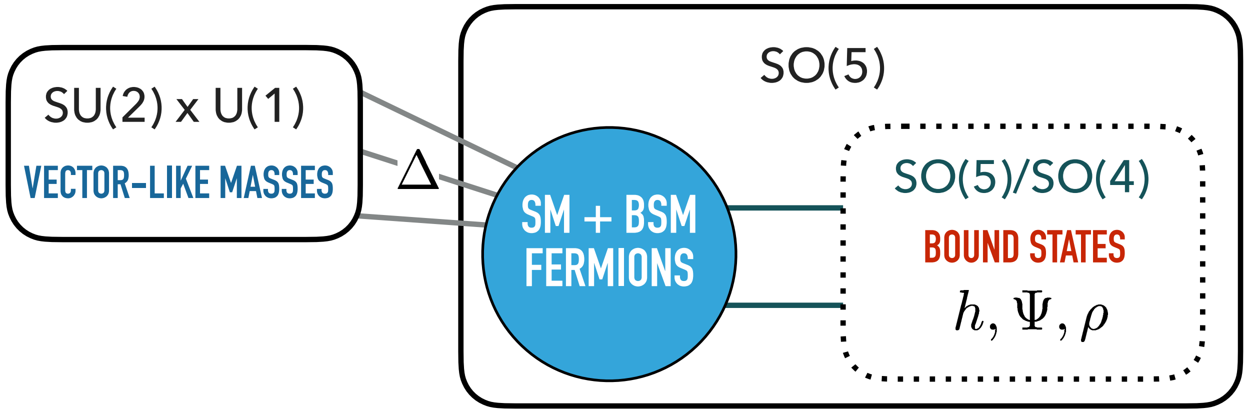
Minimal models with partial compositeness predict light top partners: their non-observation at the LHC cuts in parameter space previously unconstrained by LEP and worsens the fine-tuning.

FULL SO(5) MULTIPLETS

MAXIMAL SYMMETRY

- Solves **double tuning**, but still quadratic growth with **top partner** masses.
- **Trigonometric parity** unbroken, **needs cancellation** against gauge contribution.

SOFT BREAKING

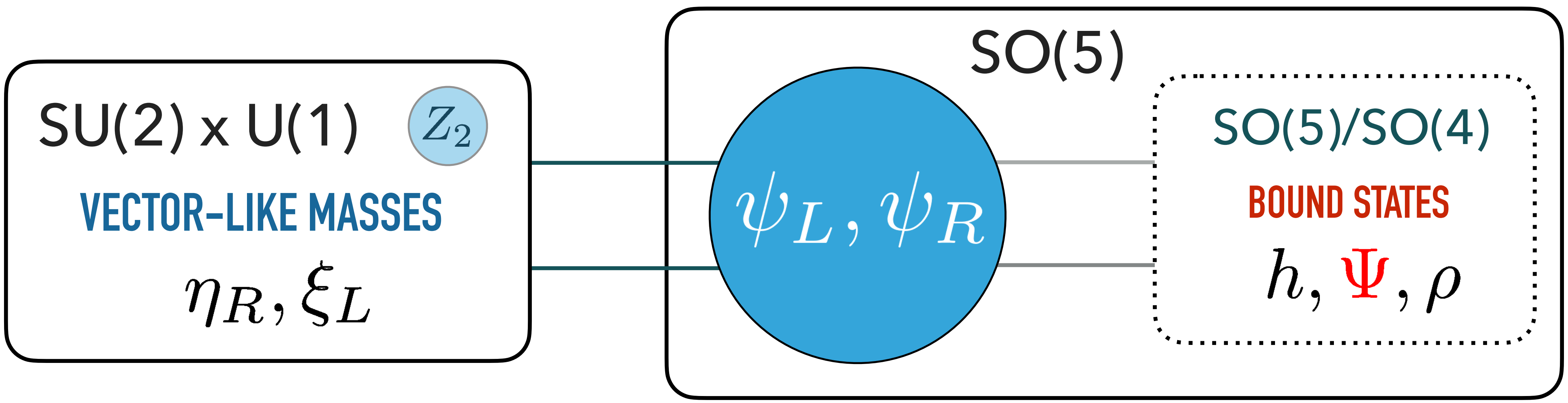


- Breaks correlation between h mass and **top partner mass**.
- Overall tuning still rather large as soft breaking does not solve **double tuning**.

SOFT BREAKING & MAXIMAL SYMMETRY

SB, Csaki, Goertz 2020

The idea is to enhance the symmetry both on the elementary and composite side to obtain a fully natural spectrum of resonances that is compatible with LHC.



$\mathcal{L}_{\rm el} = \bar{\eta}_R M_R \psi_L + \bar{\xi}_L M_L \psi_R$ $\mathcal{L}_{\rm linear} = \lambda_L \bar{\psi}_L U \Psi_R + \lambda_R \bar{\psi}_R U \Psi_L$ $\mathcal{L}_{\rm mass} = M \bar{\Psi}_L V \Psi_R$

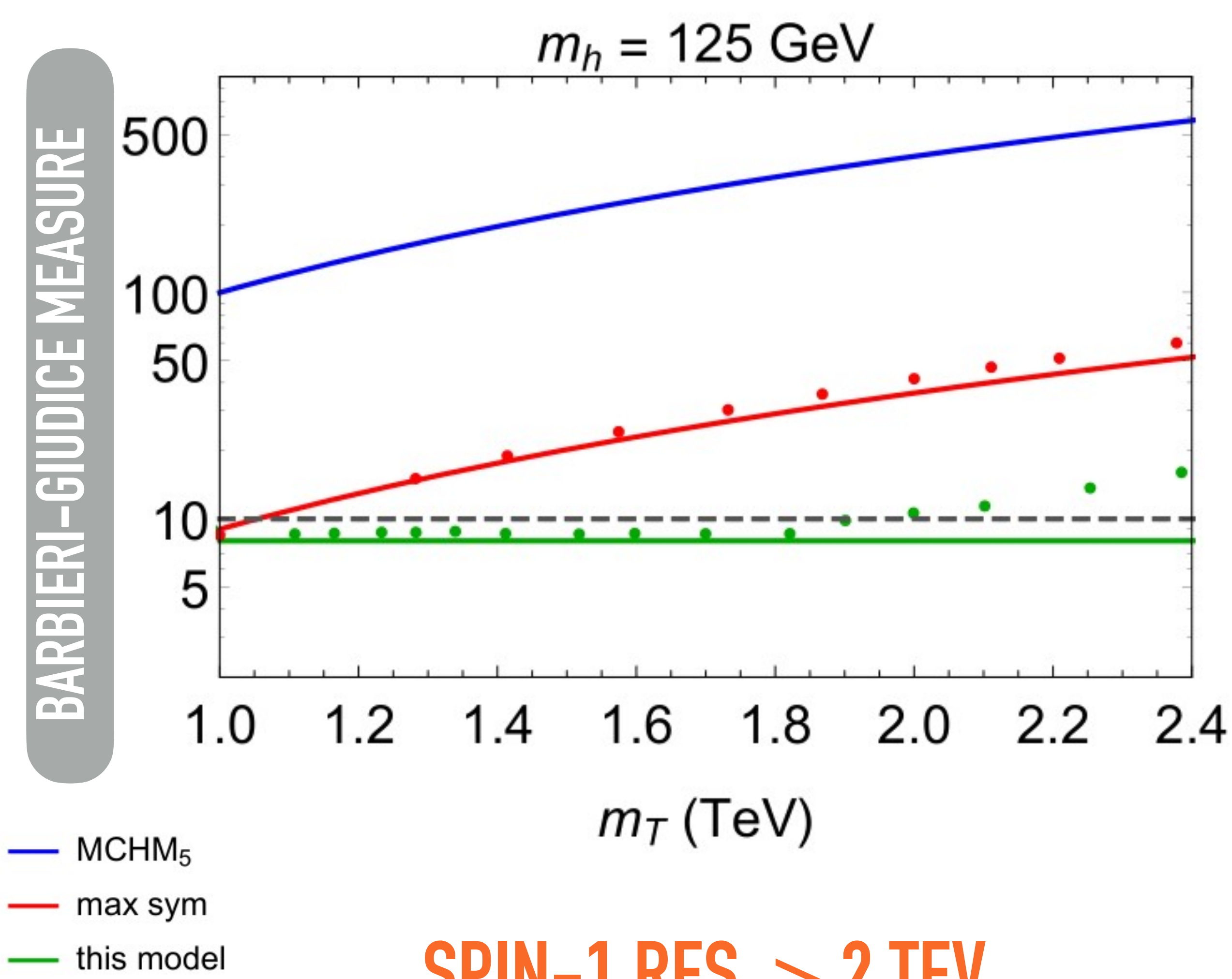
UV-BRANE LOCALIZED SPINORS | SO(5)-SYMMETRIC PARTIAL COMP. | SO(5)' MAXIMAL SYMMETRY

$\eta_R = (w_R, s_R) \quad \xi_L = (w'_L, v_L)$

*Successful combination requires simple modification of the minimal embedding for the VL fermions

SOFT BREAKING & MAXIMAL SYMMETRY

Natural spectrum above the LHC bounds compatible with a **light h boson**.



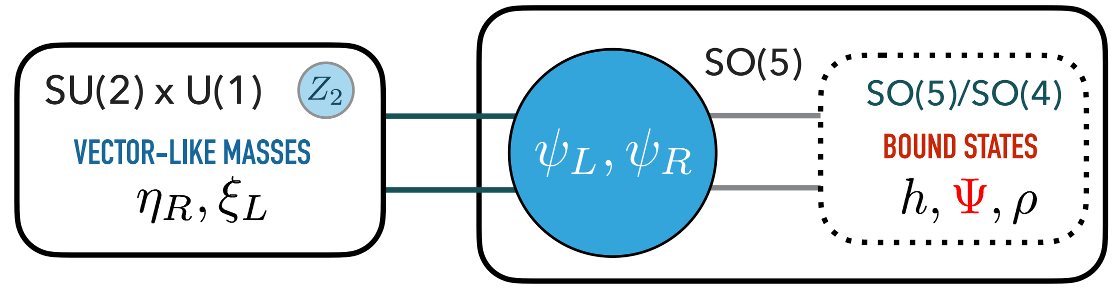
SPIN-1 RES. > 2 TEV

(> 3 TEV: 15)

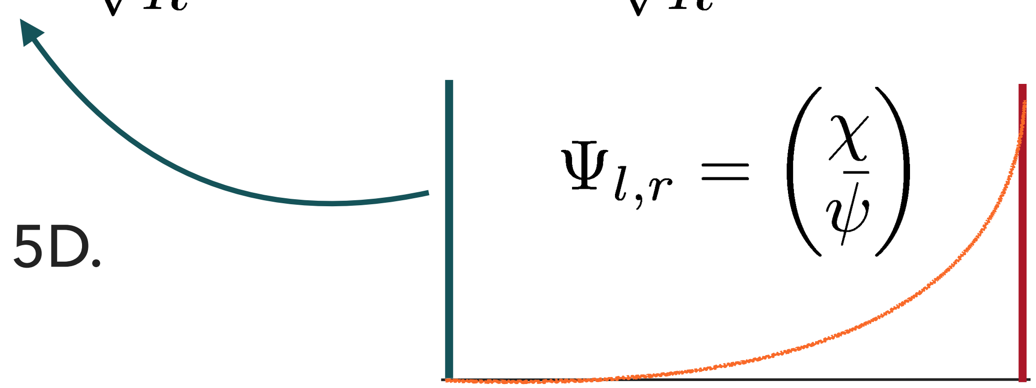
- Trigonometric parity broken in a controlled way: right misalignment no longer requires cancellation against gauge sector.
- Fine-tuning at the **10%** already implied by LEP and **almost flat** along mT.
- Soft breaking makes the h boson mass compatible with heavy partners by reducing β instead of raising *f*.
- Maximal symmetry provides the connection $\alpha \leftrightarrow \beta$ due to trig. parity and removes double tuning.

UNIVERSAL BOUNDARY CONDITIONS

All the features that we have employed have a simple interpretation in the holographic 5D setup.



$$S_{\rm UV} = \int d^4x \Big\{ -i\eta_R\sigma^\mu\partial_\mu\bar\eta_R - i\bar\xi_L\bar\sigma^\mu\partial_\mu\xi_L + \frac{1}{\sqrt{R}}\chi_l(R)\, M_R^\dagger\, \eta_R + \frac{1}{\sqrt{R}}\psi_r(R)\, M_L^\dagger\, \xi_L + \text{h.c.} \Big\}$$



1. Complete SO(5) multiplets are the fundamental objects one starts with in 5D.

- The spectrum of zero-modes (SM fermions) looks in fact incomplete because of static and specific boundary conditions.

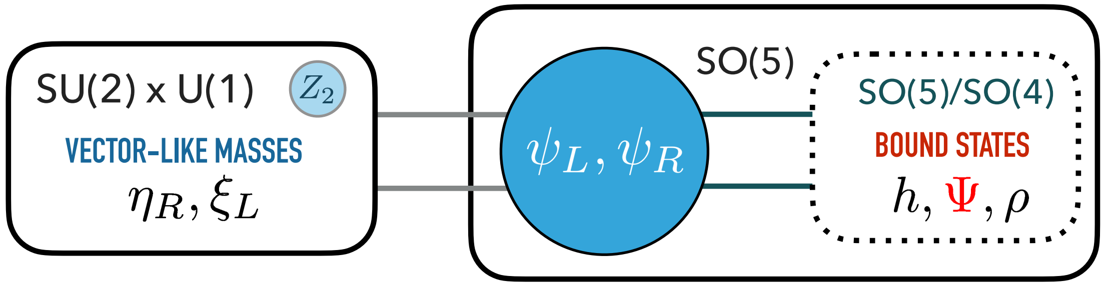
$$\begin{pmatrix} [-,+] & [+,+] \\ [-,+] & [+,+] \end{pmatrix} \oplus [-,+]$$

- Soft breaking means universal boundary conditions made dynamical by UV-localized action.

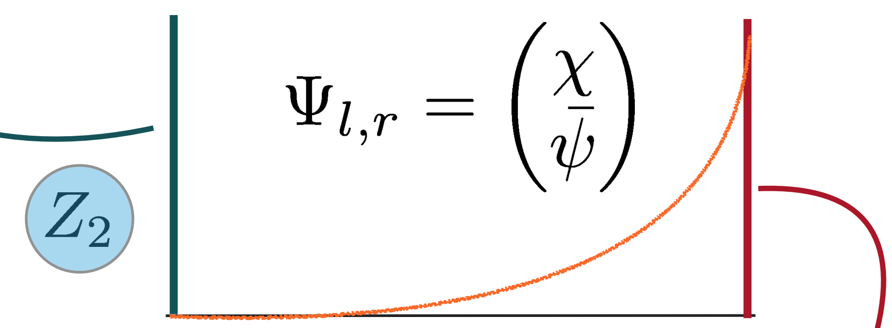
$$[+,+]$$

UNIVERSAL BOUNDARY CONDITIONS

All the features that we have employed have a simple interpretation in the holographic 5D setup.



$$S_{\rm UV} = \int \mathrm{d}^4x \Big\{ -i\eta_R\sigma^\mu\partial_\mu\bar{\eta}_R - i\bar{\xi}_L\bar{\sigma}^\mu\partial_\mu\xi_L + \frac{1}{\sqrt{R}}\chi_l(R)\, M_R^\dagger\, \eta_R + \frac{1}{\sqrt{R}}\psi_r(R)\, M_L^\dagger\, \xi_L + \text{h.c.} \Big\}$$

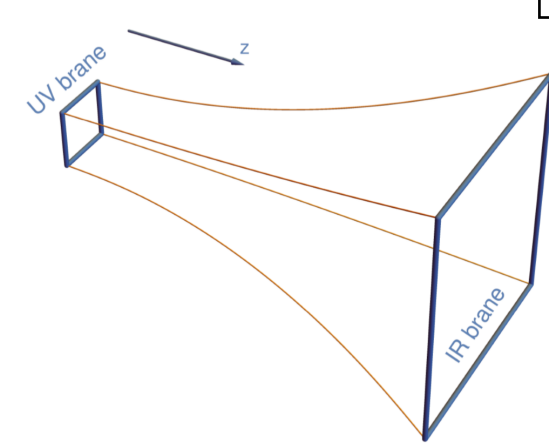


2. Maximal symmetry is implemented by requiring the IR-localized action to respect SO(5)'.

3. Similarly, the discrete symmetry is imposed on the UV brane and only broken in the IR.

4. The mass of the 4D vector-like fermions can be TeV-scale due to wave-function suppression: automatically at work for third generation quarks.

IR-localized terms are **SO(5)'** invariant



UNIVERSAL BOUNDARY CONDITIONS

$$\eta_R = (w_R, s_R) \quad \xi_L = (w'_L, v_L)$$

- If the brane-masses on the UV are too large, boundary conditions are no longer dynamical (decoupling): brane-localized spinors as Lagrange multipliers. Contino et al.'04

$$S_{\rm UV} = \int \mathrm{d}^4x \Big\{ -i s_R \sigma^\mu(x) \partial_\mu \bar{s}_R(x) + \frac{1}{\sqrt{R}} s_L(x,R)\, \mu_s\, s_R(x) + \text{h.c.} \Big\} \qquad \mu_s \sim \mathcal{O}(1)$$

- We can investigate the dynamical-to-static transition as a function of brane mass for the simplest case in which only the singlet state is active.

UV brane: $\bar{s}_R(x)$ Bulk: $\Psi^{\mathbf{1}}_l[+,+] = \begin{pmatrix} s_L(x,z) \\ \bar{\sigma}_R(x,z) \end{pmatrix}$ IR brane: empty

- Kaluza-Klein decomposition & normalization of the profiles:

$$\bar{s}_R(x) = \sum_n e_n \bar{\psi}_n(x) \quad s_L(x,z) = \sum_n g_n(z)\chi_n(x) \quad \bar{\sigma}_R(x,z) = \sum_n f_n(z)\bar{\psi}_n(x)$$

$$e_n^2 + \int_R^{R'} \mathrm{d}z\, a(z)^4 g_n(z)^2 = 1 \qquad \int_R^{R'} \mathrm{d}z\, a(z)^4 f_n(z)^2 = 1$$

UNIVERSAL BOUNDARY CONDITIONS

$\eta_R = (w_R, s_R)$ $\xi_L = (w'_L, v_L)$

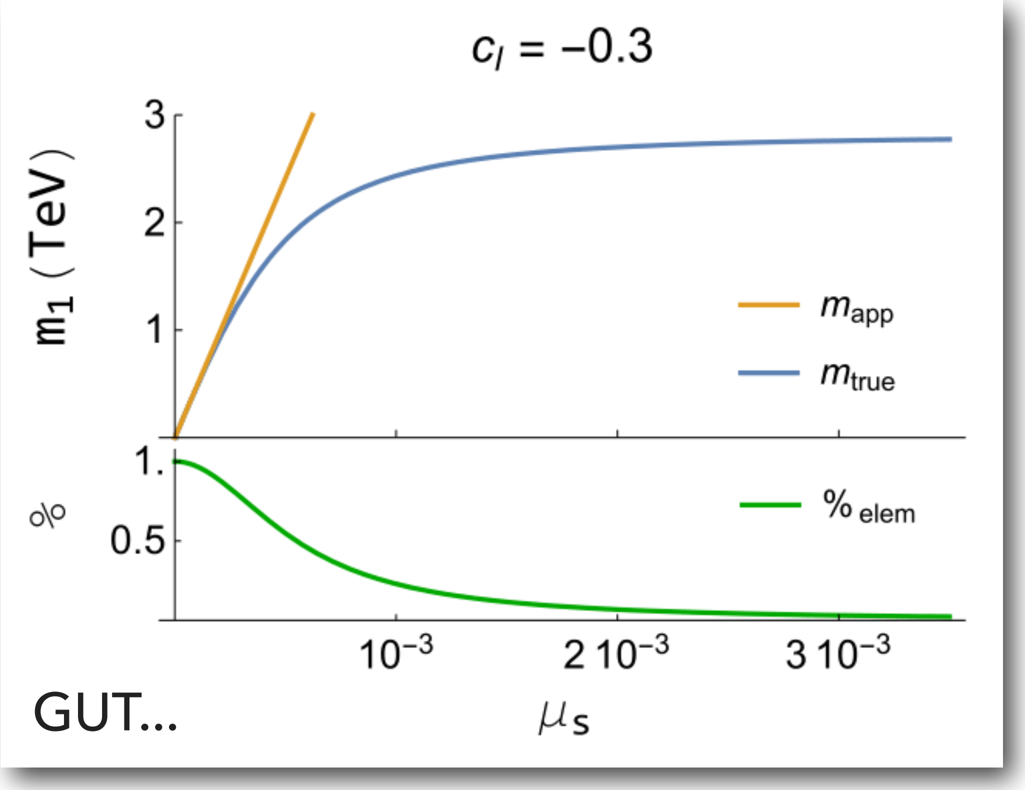
- The [+,+] boundary condition is perturbed by the presence of the UV action:

Csaki'03..

$$f_n(R') = 0, \quad f_n(R) = 0 \quad \rightarrow \quad f_n(R) - \frac{\mu_s^2}{m_n R} g_n(R) = 0$$

- Mass of the first Kaluza-Klein excitation:

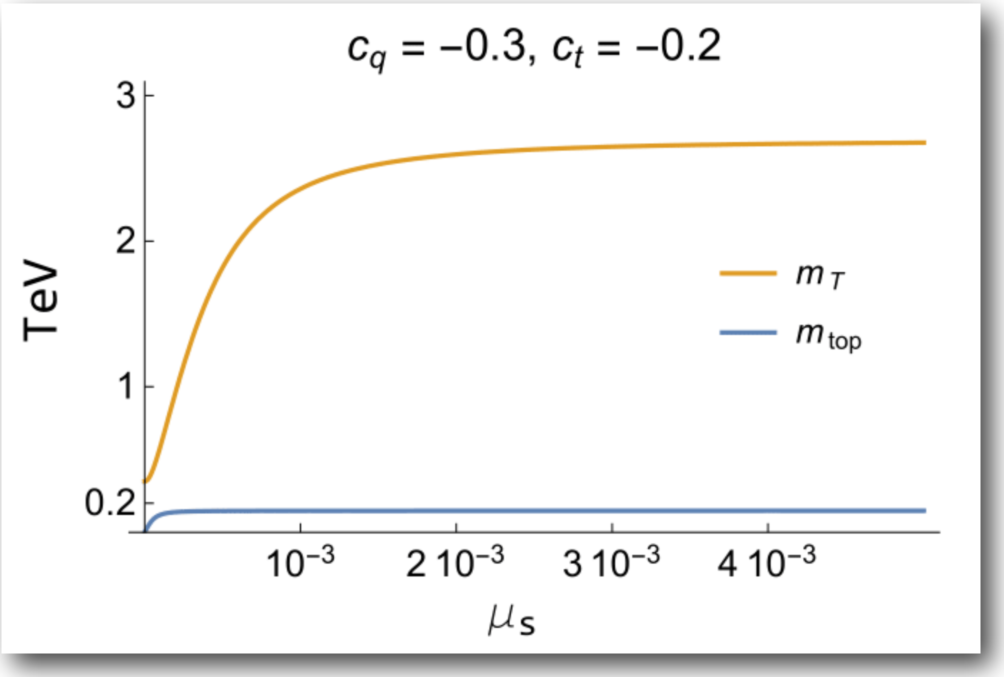
$$m_1^2 \sim \begin{cases} (2c_l - 1)\mu_s^2 R^{-2} \\ (1 - 4c_l^2)\mu_s^2 R'^{-2} \left(\frac{R}{R'}\right)^{-1-2c_l} \end{cases}$$



  - Would-be zero mode UV localized: light partially-elementary KK is unnatural.
  - Deep IR localization: TeV-scale KK with large overlap with UV-localized spinors.
  - Still too large brane masses: would-be zero mode migrates towards higher KK states and [-,+] is effectively recovered (light custodian).

UNIVERSAL BOUNDARY CONDITIONS

$$\eta_R = (w_R, s_R) \quad \xi_L = (w'_L, v_L)$$



- Wave-function suppression can produce partially-elementary KK states in case of deep IR localization: **third generation quarks**!
- The **top mass** can be reproduced in presence of partially-elementary KK states confirming the results of the 4D effective theory.
- The actual 5D calculation of the h potential is ongoing. SB, Bollig, Goertz, in prep.

CONCLUSION

- we have presented a new realization of composite h boson in which partial compositeness respects the global symmetry
- this removes the correlation between the h mass and the top partner masses, allowing for a light h boson with heavy top partners without raising the compositeness scale
- main source of tuning is not irreducible and can be largely cut down whenever other ingredients are added
- we have presented the combination of soft breaking with maximal symmetry which turns out to be a perfect match (double tuning, misalignment, fully softened potential)
- enhancing the symmetry on both the elementary and composite sides allows for a natural model to emerge: spectrum of resonances above 2 TeV is now compatible with minimal 10% tuning already implied by LEP

CONCLUSION

- all the ingredients of the 4D effective theory can be naturally realized in the 5D picture corroborating our results
- soft breaking corresponds to universal and dynamical boundary conditions that replace the static and specific ones in the original realization
- a partially-elementary KK state appears at low-energy in case of deep IR localization: automatic for third generation quarks (which in fact create the issue of top partners in the first place…)

THANK YOU!

PARTIAL COMPOSITENESS

- Linear couplings between SM quarks and composite operators:

$$\mathcal{L} = \lambda_L \, \bar{q}_L^i \, \mathcal{O}_R^i + \lambda_R \, \bar{q}_R^i \, \mathcal{O}_L^i + \text{h.c.}$$

- Large hierarchies in the masses from RG-evolution with strong dynamics:

$$m_q \sim v \left(\frac{\Lambda}{\Lambda_{\text{UV}}} \right)^{\gamma_L + \gamma_R}$$

  - Very sensitive depending on the sign
  - Linear couplings allow large masses without reintroducing the HP

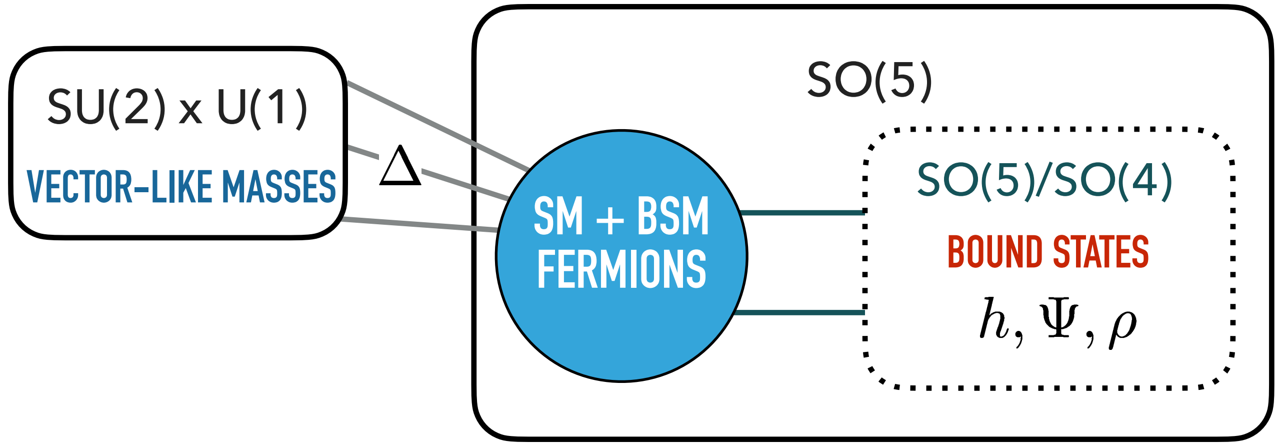
- Anomalous dimensions have simple interpretation in terms of bulk masses of the 5D field in which the chirality q is embedded:

$$\gamma = [\mathcal{O}] - 5/2 = c - 1/2$$

*Purely 4D models generically predict additional pNGBs, partial compositeness only works for top quark (the strong dynamics has to condense). Ferretti,Karateev'13

A SOFT COMPOSITE BEH

SB, Goertz 2019



MINIMAL EMBEDDING: s,v,w

- The SM fermions are completed to full SO(5) irreps:

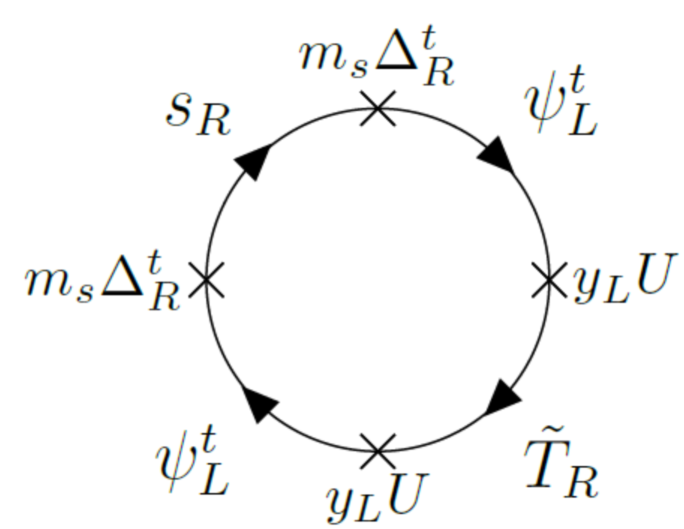
$$\Delta_L^\dagger q_L = \begin{pmatrix} q_L \\ 0 \\ 0 \end{pmatrix} \to \psi_L = \begin{pmatrix} q_L \\ w_L \\ s_L \end{pmatrix} \qquad \Delta_R^\dagger t_R = \begin{pmatrix} 0 \\ 0 \\ t_R \end{pmatrix} \to \psi_R = \begin{pmatrix} v_R \\ w_R \\ t_R \end{pmatrix}$$

$$\mathcal{L}_{\text{linear}} = \lambda_L \bar{\psi}_L U \Psi_R + \lambda_R \bar{\psi}_R U \Psi_L + \text{ h.c.}$$

- Explicit breaking moved from partial compositeness to elementary sector:

$$\mathcal{L}_{\text{el}} = m_v \bar{v} v + m_w \bar{w} w + m_s \bar{s} s$$
$$= m_v \bar{v}_L \Delta_L \psi_R + m_w \bar{\psi}_L \Gamma_w \psi_R + m_s \bar{s}_R \Delta_R \psi_L$$

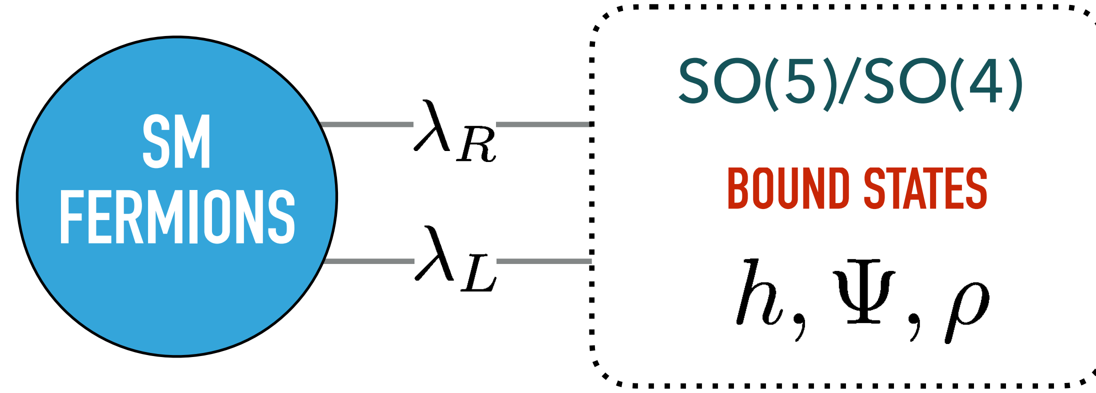
- Soft breaking changes the UV sensitivity: max divergence is log.



Note: the potential (especially in 5D) is anyways finite

TUNING

STANDARD MCHM5



- The **LO** potential contains only one trigonometric function: **trivial extrema** (no ewsb, or *technicolor*):

$$V_{\rm LO} \simeq \frac{3}{16\pi^2}(g_* f)^2 f^2 \lambda_{L,R}^2 \, {\rm Tr}\,(\Sigma\,\Gamma_{L,R}) \propto \, \sin^2(h/f) \qquad \Sigma = U^2 V$$

- Extra (double) tuning in order to **balance LO** and **NLO** potential:

$$|V_{\rm NLO}| \simeq \frac{\lambda_{L,R}^2}{g_*^2} \cdot |V_{\rm LO}| \quad \Rightarrow \quad \Delta_5 \simeq \frac{f^2}{v^2}\left(\frac{g_*}{\lambda}\right)^2 \sim 90\left(\frac{m_T}{1\,{\rm TeV}}\right)^2$$

$$m_h \sim \frac{m_T}{f} m_t$$

Panico, Redi, Tesi 2012

TUNING

$$V^\dagger T^a V = T^a, \quad V^\dagger T^{\hat a} V = -T^{\hat a}$$

MAXIMAL SYMMETRY is a symmetry of the strong sector that can emerge under certain assumptions.

Csaki et al.'17,'18

- Imposing maximal symmetry further constrains the structure of the LO potential, in particular **forbidding linear terms** in Σ :

$$V_{\rm LO} \simeq \frac{3}{16\pi^2} f^4 \lambda_L^2 \lambda_R^2\,{\rm Tr}\,(\Sigma\,\Gamma_L \Sigma\,\Gamma_R) \propto \sin^2(h/f)\cos^2(h/f)$$

- There is **unbroken Higgs parity** as long as fermions are concerned:

$$\sin^2(h/f) \leftrightarrow -\cos^2(h/f) \;\Rightarrow \xi \equiv \frac{v^2}{f^2} = 0.5$$

- Gauge contribution can however be important as well, and helps misalign the vacuum in the right way:

$$\Delta_{\rm max\ sym} \simeq \frac{f^2}{v^2} = 9\left(\frac{m_T}{1\,{\rm TeV}}\right)^2$$

DOUBLE TUNING IS REMOVED!

SOFT BREAKING AND MAXIMAL SYMMETRY

- The idea is to enhance the symmetry both on the elementary and composite side to obtain a fully natural spectrum of resonances that is compatible with LHC.

FIRST ATTEMPT

Take simplest embedding (s,v,w) + SO(5)' on the composite sector:

$$V_{\rm LO} \simeq \frac{3}{16\pi^2} f^2 \lambda_L \lambda_R\, m_w\, M\, {\rm Tr}(\Sigma\,\Gamma_w) \propto \sin^2(h/f)$$

$$\mathcal{L}_{\rm elem} = \cdots + m_w \bar\psi_L \Gamma_w \psi_R$$

$$\psi_L = \begin{pmatrix} q_L \\ w_L \\ s_L \end{pmatrix} \qquad \psi_R = \begin{pmatrix} v_R \\ w_R \\ t_R \end{pmatrix}$$

Linear term allowed by all the symmetries: **trigonometric parity** is **badly broken** and double tuning is reintroduced.

SOFT BREAKING AND MAXIMAL SYMMETRY

SUCCESSFUL COMBINATION

SB, Csaki, Goertz 2020

- It requires a simple modification of the minimal embedding: "splitting" w

$$\psi_L = \begin{pmatrix} q_L \\ w_L \\ s_L \end{pmatrix} \qquad \psi_R = \begin{pmatrix} v_R \\ w'_R \\ t_R \end{pmatrix}$$

- In general, the multiplets in which the different SM chiralities are embedded should not couple directly (trivially true without soft breaking):

$$\mathcal{L}_{\rm el} = m_w \bar{w}_R \Delta_w \psi_L + m'_w \bar{w}'_L \Delta_w \psi_R + m_v \bar{v}_L \Delta_v \psi_R + m_s \bar{s}_R \Delta_s \psi_L + \text{ h.c.}$$

- The chiralities that enter neither of the SO(5) multiplets can be grouped:

Z_2 $$\mathcal{L}_{\rm el} = \bar{\eta}_R M_R \psi_L + \bar{\xi}_L M_L \psi_R + \text{ h.c.} \qquad \eta_R = (w_R, s_R) \quad \xi_L = (w'_L, v_L)$$

SOFT BREAKING AND MAXIMAL SYMMETRY

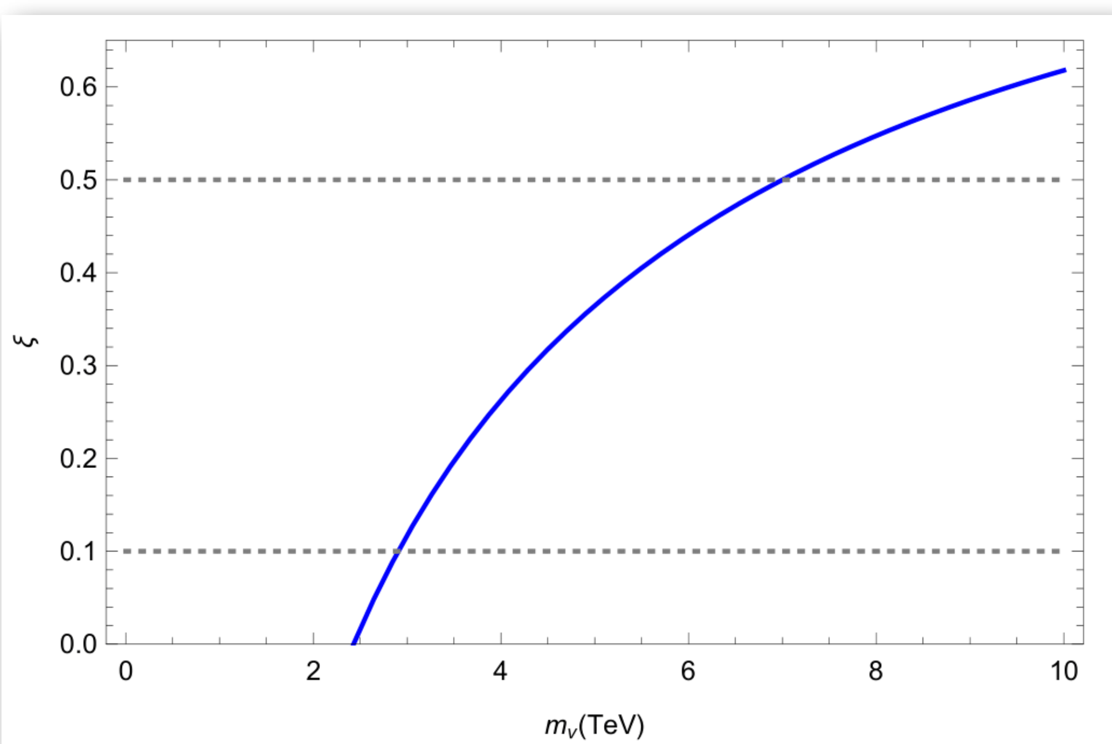
SUCCESSFUL COMBINATION

$$\Gamma_L = M_L^\dagger M_L$$
$$\Gamma_R = M_R^\dagger M_R$$

- We can again estimate the LO order potential by means of spurion analysis:

$$V_{\rm LO} \simeq \frac{3}{16\pi^2}\lambda_L^2\lambda_R^2 f^4 \sum_{i,j=1}^{\infty} {\rm Tr}(\Sigma\,\Gamma_L^i\Sigma\,\Gamma_R^j) \propto c_2\sin^2(h/f) + c_4\sin^4(h/f)$$

the sum just reconstructs massive VL propagators



- **Double tuning** is solved.
- Trigonometric parity broken in a **controlled way**:

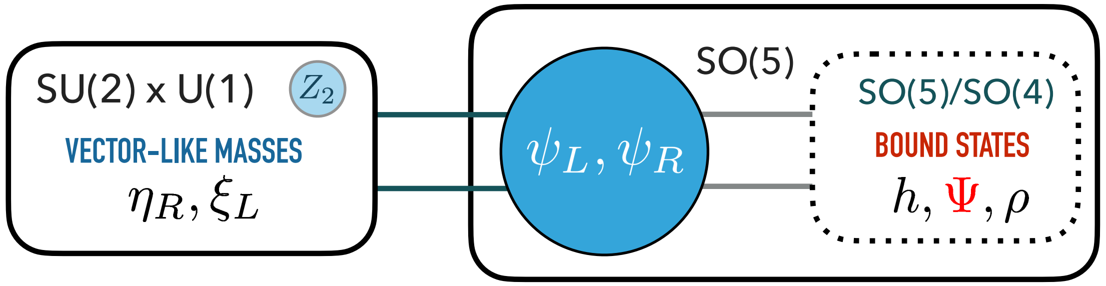
$$\xi = 0.5 \;\Leftrightarrow\; (m_v^2 - m_w'^2)m_w^2 = 0$$

- The vacuum **can be misaligned** already within the fermion sector.

SMALL SUMMARY II

Soft breaking and maximal symmetry turn out to be a perfect match pushing the tuning back to the 10% of the pre-LHC.

ESSENTIALS OF THE SETUP



1. Soft breaking: SO(5)-symmetric partial compositeness requires the elementary fermions to appear as complete SO(5) multiplets.

2. Maximal symmetry: the composite resonances come as complete SO(5) multiplets as well and the symmetry is enlarged to SO(5)'.

3. Discrete parity in the elementary sector.

4. The vector-like masses of BSM fermions are at the TeV scale to avoid decoupling ("coincidence problem"?).