Minimally Extended SILH

Oleksii
Matsedonskyi

in collaboration with M.Chala,G.Durieux,C.Grojean,L.deLima

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Outline

- Motivation

- EFT formalism for Composite S+H

  - dimensional analysis
  - symmetry-based selection rules
  - UV selection rules
  - operator basis

- Benchmark CHS Scenarios

  - S physics
  - H physics

Motivation

- The first collider signals of a new heavy resonance can typically be explained by a variety of explicit models.

- Important to find an approach allowing to extract key information about the underlying physics without case by case study of all the explicit UV model.

- To do so, one can construct a simple unified framework which:

  1) describes only one new state with respect to the SM
  2) captures the predictions of a large set of explicit UV models
  3) reflects the key structural features of the underlying dynamics

Motivation

- Given no signal so far, we assume the simplest possibility - a new heavy spin-zero ElectroWeak singlet.

- The stated problem is difficult to solve in full generality, we limit ourselves to a large subclass of motivated TeV-scale new physics - Composite Higgs scenarios.

- Our construction is a minimal add-on to SILH* - the simplified framework describing the composite Higgs scenarios below the scale of other composite resonances.

*Giudice,Grojean,Pomarol,Rattazzi [0703164]

Framework

Assumptions:

- new resonance S has a spin 0
- S is an EW singlet
- S is the second lightest composite state
- S is a part of a new strong sector,
  - strong dynamics produces PNGB Higgs
  - Goldstone sym breaking and top mass from partial compositeness
  - rest of SM fields are elementary

Framework

- Mass spectrum

$m_\rho \sim g_\rho f$ cutoff, typical mass of composite states

$g_\rho \sim 1 - 4\pi$ typical coupling of composite states

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m_h PNGB Higgs, with a small mass provided by the Goldstone symmetry breaking

$\xi = v^2/f^2$

EW tuning

$\xi \lesssim 0.2$

Framework

- Power Counting

from L and $\hbar$ counting we get:

$$m_\rho^2 f^2 \left[\frac{S}{f}\right]^{\#_S} \left[\frac{H}{f}\right]^{\#_H} \left[\frac{y_q\, \bar{q}q}{m_\rho^2 f}\right]^{\#_{\bar{q}q}} \left[\frac{gA}{m_\rho}\right]^{\#_A} \left[\frac{p}{m_\rho}\right]^{\#_p}$$

generic composite states

SM coupling to the strong sector controlled by Yukawas and gauge couplings

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- Additional selection rules may be imposed on top of the simple dimensional analysis

Shift Symmetry and Partial Compositeness

- Goldstone symmetry can require a presence of symmetry breaking sources

partial compositeness:

$$\bar{q}_L H \psi_R$$

$$\bar{t}_R H \psi_L$$

SU(2)L | G-multiplet (e.g. SO(5))

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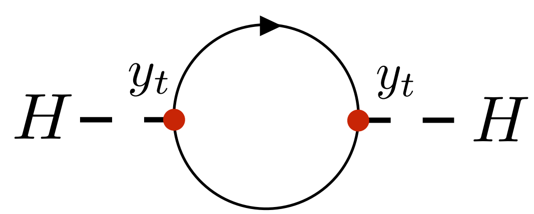
Higgs potential:



$$V_h = m_\rho^2 f^2 \frac{N_c y_t^2}{(4\pi)^2}\left(-\alpha\frac{|H|^2}{f^2} + \beta\frac{|H|^4}{f^4}\right),$$

analogous for PNGB S

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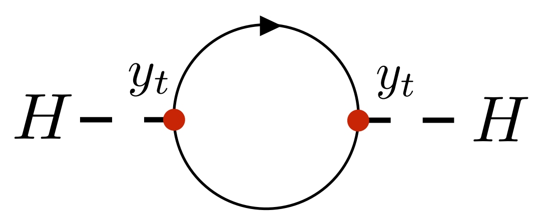

$$V_h = m_\rho^2 f^2 \frac{N_c y_t^2}{(4\pi)^2}\left(-\alpha \frac{|H|^2}{f^2} + \beta \frac{|H|^4}{f^4}\right) ,$$ analogous for PNGB S

mass hierarchy in PNGB S case: $$m_h^2 : M^2 : m_\rho^2 \;\sim\; \frac{N_c y_t^2}{(4\pi)^2}\xi : \frac{N_c y_t^2}{(4\pi)^2} : 1$$

Shift symmetry and Anomalies

- shift symmetry breaking by anomalies

  - coupling to SM gauge bosons $$\frac{N_f g_X^2}{(4\pi)^2}\frac{S}{f}X_{\mu\nu}\tilde{X}^{\mu\nu}$$

  - mass from the anomaly associated to strong sector gauge bosons $$m_\eta^2 \sim \frac{N_f}{N}m_\rho^2 \sim N_f\frac{g_\rho^2}{(4\pi)^2}m_\rho^2$$ $$g_\rho = \frac{4\pi}{\sqrt{N}}$$

$N_f\frac{g_\rho^2}{(4\pi)^2}$ with respect to generic power counting

UV selection rules

Known classes of explicit UV completions allow for additional selection rules, dictated by the internal structure of the UV completion. We will consider two possible completions:

- large-N theories
- N-site models (~5D)

UV selection rules: Large-N

- "loop" suppression in large-N theories for non-PNGB S

quarks and gluons at	$N\frac{g_S^2}{16\pi^2} \sim 1$	$\Rightarrow$	composite mesons	$g_\rho = \frac{4\pi}{\sqrt{N}}$	$m_\rho \neq f(N)$

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EFT valid only in the tuned region

parametrically large effects of the selection rules may be visible even with not too large scale separation

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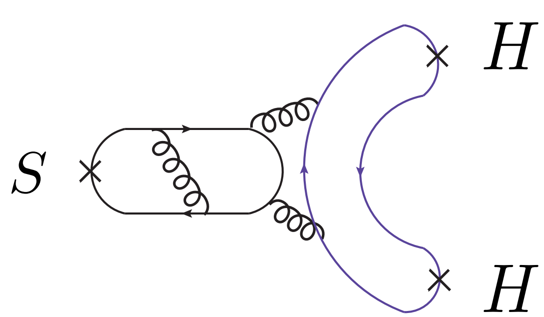
$$\frac{g_\rho^2}{(4\pi)^2}$$



$\sim 1/N$

Zweig rule in QCD, e.g. for $\phi \to \pi\pi\pi$

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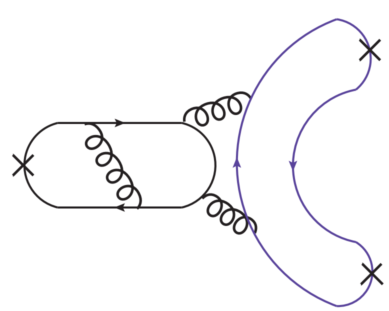
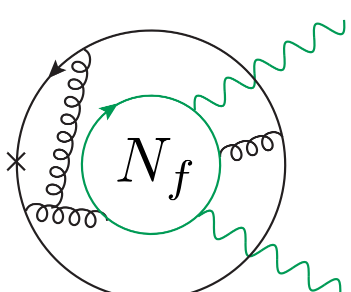
$\frac{g_\rho^2}{(4\pi)^2}$ S  H H $\sim 1/N$ Zweig rule in QCD, e.g. for $\phi \to \pi\pi\pi$

$N_f\frac{g_\rho^2}{(4\pi)^2}$ S  A_μ A_μ $\sim N_f/N$ not relevant in QCD because $N_f \sim N_c$

UV selection rules: N-sites

- "loop" suppression in N-site models

<u>mass spectrum:</u>

$\Lambda = 4\pi f$	cutoff
$m_\rho \sim g_\rho f$	one layer of composite states
M	PNGB or accidentally light S
m_h	PNGB Higgs

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<u>symmetry structure:</u>

SM | $e^{H/f}$ | $m_\rho \quad g_\rho$

tree-level int.out. of heavy composite states automatically leads to generic power counting <u>for the operators generated at tree level</u>

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E.g. the operator $SF_{\mu\nu}F^{\mu\nu}$ appears only at one-loop level

$$\left[\frac{g_\rho}{4\pi}\right]^2 \left[\frac{g}{g_\rho}\right]^2 \frac{S}{f} F_{\mu\nu}F^{\mu\nu}$$

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$N_f \frac{g_\rho^2}{(4\pi)^2}$ - same loop factor with respect to $\left[\frac{g}{g_\rho}\right]^2 \frac{S}{f} F_{\mu\nu}F^{\mu\nu}$ as in large-N

Automatic implementation of Minimal Coupling, suppressing the operators

$SX_{\mu\nu}X^{\mu\nu}$ $\quad$ $|H|^2 G_{\mu\nu}G^{\mu\nu},\ |H|^2\gamma_{\mu\nu}\gamma^{\mu\nu}$ $\quad$ $(D_\mu H)^\dagger \sigma^i (D_\nu H) W^{i\mu\nu},\ (D_\mu H)^\dagger (D_\nu H) B^{\mu\nu}$

Power Counting Rule

$$m_\rho^2 f^2 \left[\frac{N_c y_t^2}{(4\pi)^2}\right]^{\#_{\not L}} \left[\frac{N_f g_\rho^2}{(4\pi)^2}\right]^{\#_L} \left[\frac{y_q \bar{q} q}{m_\rho^2 f}\right]^{\#_{\bar{q}q}} \left[\frac{g_A A}{m_\rho}\right]^{\#_A} \left[\frac{S}{f}\right]^{\#_S} \left[\frac{H}{f}\right]^{\#_H} \left[\frac{\partial_\mu}{m_\rho}\right]^{\#_\partial}$$

- shift breaking by top loops
- MC, 1/N, or anomaly shift breaking “loop” suppression
- reconstruct SM fermion Yukawa couplings

Constructing the Operator Basis

- We focus on dim-5 operators (leading interactions with the SM fields)

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- It is consistent to consider a pair $\mathcal{L}_5^{(S+H)}$ and $\mathcal{L}_6^{(H)}$ (SILH), in a sense that after integrating out S at tree level from dimension >5 lagrangian there will be no contributions to dim-6 SILH operators.

$$S \to \frac{1}{M^2}\left[c|H|^2 + \ldots\right]$$

dim 1 dim 2 dim>2

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dim 1   dim 2   dim>2

- We assume that we start with an EFT, containing all the possible operators (including redundant), in which all the discussed symmetries and suppression rules are explicit, i.e. the operators obey the power counting. We want to reduce this set to a set which
  1) contains no redundancies
  2) follow the power counting

Constructing the Operator Basis

- Already the first assumption is not trivial

counter-example from SILH:
kinetic term of the Goldstone fields $U = \exp[i\chi/f]$ contains

$\mathrm{Tr}[D_\mu U (D^\mu U)^\dagger]$ $\longrightarrow$ c1 $|H|^2 |D_\mu H|^2$ + c2 $\partial_\mu |H|^2 \partial^\mu |H|^2$

order-1, shift preserving — order-1, shift breaking, correlated

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- In SILH basis the 1st operator is eliminated by a (shift-breaking) field redefinition,

  $$H \rightarrow H + \alpha |H|^2 H$$

  which does not lead to extra power counting breaking at the level of dim-6 operators

- At dim-5 level in H+S case one does not expect to generate correlated operators

Constructing the Operator Basis

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- Generic S, operators with 2 derivatives, H and S

$$\mathcal{O}_1 = \frac{1}{f}|D_\mu H|^2 S \qquad \mathcal{O}_2 = \frac{i}{f}(H^\dagger D_\mu H)\partial^\mu S + \text{h.c.} \qquad \mathcal{O}_3 = \frac{1}{f}\partial_\mu |H|^2 \partial^\mu S$$

$$\mathcal{O}_4 = \frac{1}{f}(H^\dagger \Box H) S + \text{h.c.} \qquad \mathcal{O}_5 = \frac{1}{f}|H|^2 \Box S \qquad \mathcal{O}_6 = \frac{1}{f}\Box |H|^2 S$$

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- H shift symmetry preserving $\mathcal{O}_1$ can be expressed as two correlated shift breaking operators

$$\mathcal{O}_1 = \frac{1}{2}\left(\mathcal{O}_5 - \mathcal{O}_4\right)$$

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- H shift symmetry preserving $\mathcal{O}_1$ can be expressed as two correlated shift breaking operators

$$\mathcal{O}_1 = \frac{1}{2}(\mathcal{O}_5 - \mathcal{O}_4)$$

- the coefficients of $\mathcal{O}_{4,5}$ now break the power counting
- both can be eliminated by H and S e.o.m., generating e.g.

$$\sim \frac{M^2}{f} S |H|^2$$

Constructing the Operator Basis

- both can be eliminated by H and S e.o.m., generating e.g.

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- If we assign the unsuppressed coefficient M^2/f to the operator which affects the Higgs physics, not keeping track of all the correlations, the impact on Higgs physics will be overestimated

- If, instead, we enforce this coefficient to be loop suppressed, we will underestimate the processes initially mediated by $|D_\mu H|^2 S$

- $|D_\mu H|^2 S$ can not be eliminated in case of generic S. Hence one field redefinition is not used and one redundancy remains.

Constructing the Operator Basis

‣ Another type of problems for PNGB S, with operators $S^n|H|^{2m}$ with H and S without derivatives

- applying S or H e.o.m. we generate unsuppressed shift symmetry breaking

$$\frac{y_t^2}{16\pi^2}\frac{m_\rho^2}{f}S|H|^2 \;\to\; \frac{1}{f}SH^\dagger\Box H \;\;\text{or}\;\; \frac{1}{f}\Box S|H|^2$$

- because of the generic form of e.o.m.

$$\frac{y_t^2}{(4\pi)^2}S^m|H|^n+\Box S+\cdots=0$$

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$$\frac{y_t^2}{(4\pi)^2}S^m|H|^n+\Box S+\cdots=0$$

- Nor PNGB S nor H e.o.m. can't be used to eliminate $S^n|H|^{2m}$

- Generic S e.o.m. can be used, so the remaining unused field redefinition can be applied to eliminate e.g. $|D_\mu H|^2 S^2$

$$S^m+\Box S+\cdots=0$$

Constructing the Operator Basis

- resulting basis

- CP odd S

$$S X^2 \qquad S^{2,4} \qquad S\bar{q}Hq \qquad S^2|H|^2$$

- CP even generic S

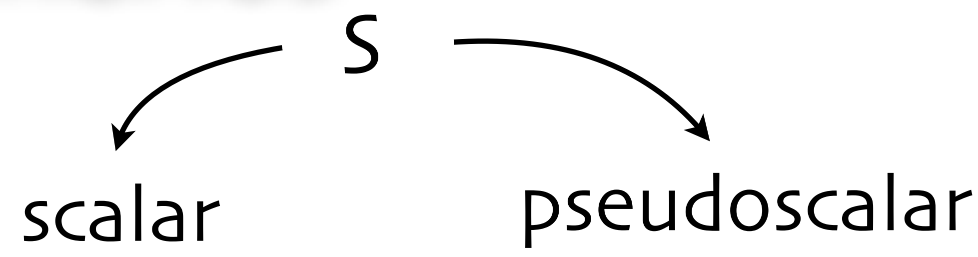
$$S X^2 \qquad S^{2,4} \qquad S\bar{q}Hq \qquad S^{3,5} \qquad S|D_\mu H|^2 \qquad S|H|^2 \qquad S^3|H|^2 \qquad S|H|^4$$

- CP even PNGB S

$$S X^2 \qquad S^{2,4} \qquad S\bar{q}Hq \qquad S^2|H|^2 \qquad S^{3,5} \qquad S|H|^2 \qquad S^3|H|^2 \qquad S|H|^4$$

- All the used field redefinitions of H and S are loop-suppressed, hence all the UV selection rules preserved

Scenarios



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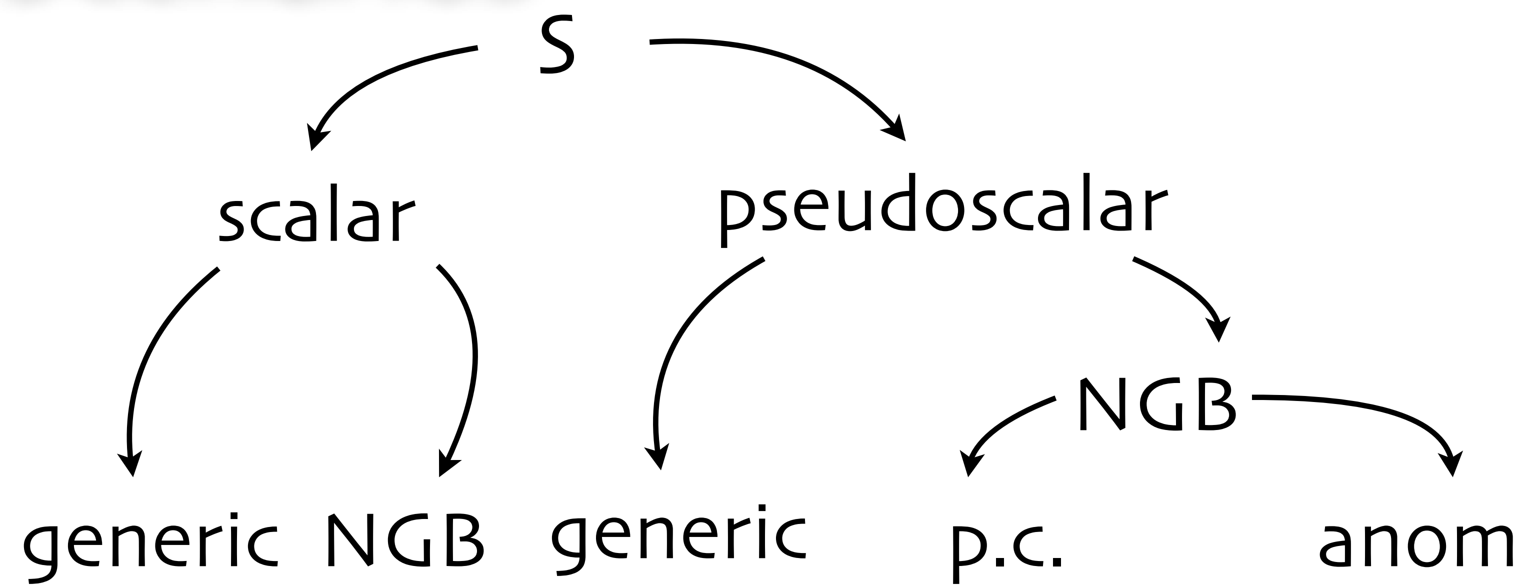
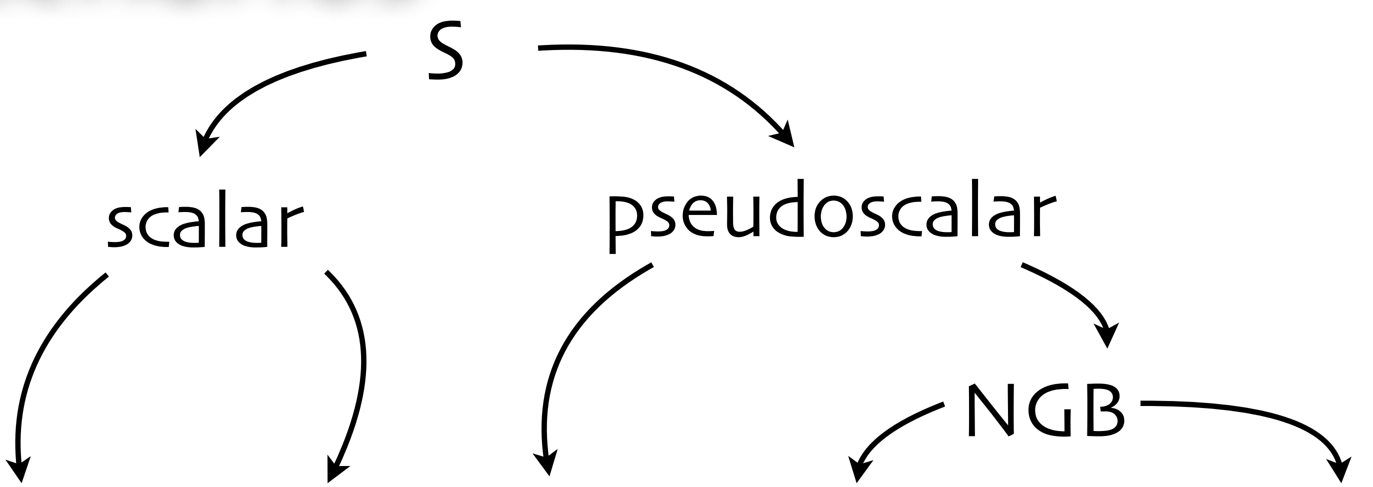


Scenarios

	S				
	scalar		pseudoscalar		
				NGB	
	generic	NGB	generic	p.c.	anom.
$k_X\, SX^2$	$\frac{g_X^2}{g_\rho^2}\frac{1}{f}$	$\frac{3y_t^2}{(4\pi)^2}\frac{g_X^2}{g_\rho^2}\frac{1}{f}$	$\frac{g_X^2}{g_\rho^2}\frac{1}{f}$	$\frac{3y_t^2}{(4\pi)^2}\frac{g_X^2}{g_\rho^2}\frac{1}{f}$	$\frac{N_f^{(X)} g_X^2}{(4\pi)^2}\frac{1}{f}$
$k_q\, S\bar{q}Hq$	$y_q\frac{1}{f}$	$y_q\frac{1}{f}$	$iy_q\frac{1}{f}$	$iy_q\frac{1}{f}$	—
$k_H\, S\vert D_\mu H\vert^2$	$\frac{1}{f}$	—	—	—	—
$k_{H1}\, S\vert H\vert^2\ ,\ k_{H2}\, S\vert H\vert^4/f^2\ ,\ k_{H3}\, S^3\vert H\vert^2/f^2$	$\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{f}$	$\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{f}$	—	—	—
$k_{H4}\, S^2\vert H\vert^2$	—	$\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{f^2}$	$\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{f^2}$	$\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{f^2}$	$\frac{\tilde{N}_f g_\rho^2}{(4\pi)^2}\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{f^2}$
$k_M\, S^2\ ,\ k_4\, S^4/f^2$	m_ρ^2	$\frac{3y_t^2}{(4\pi)^2}m_\rho^2$	m_ρ^2	$\frac{3y_t^2}{(4\pi)^2}m_\rho^2$	$\frac{\tilde{N}_f g_\rho^2}{(4\pi)^2}m_\rho^2$
$k_3\, S^3\ ,\ k_5\, S^5/f^2$	$\frac{m_\rho^2}{f}$	$\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{f}$	—	—	—

* "Generic" cases allow for additional "loop" suppression $N_f\frac{g_\rho^2}{(4\pi)^2}$

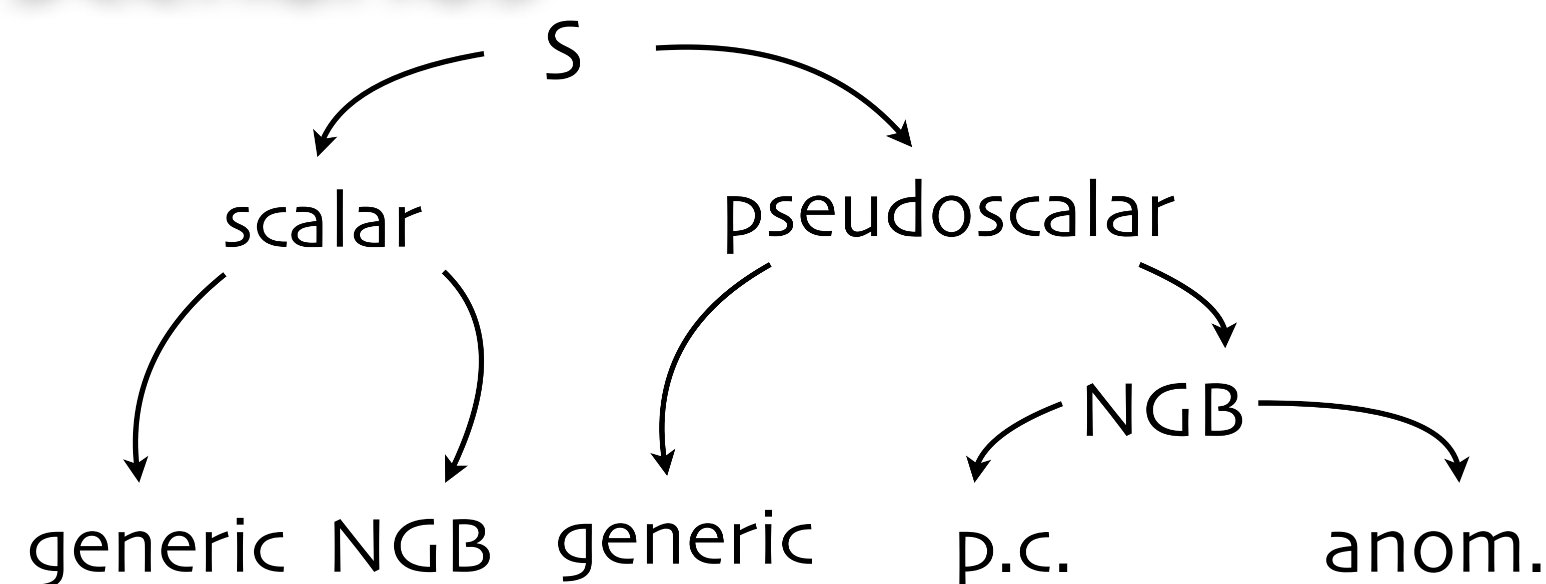
Scenarios



	generic	NGB	generic	p.c.	anom.
$k_X\, S X^2$	$\frac{g_X^2}{g_\rho^2}\frac{1}{f}$	$y_t^2/16\pi^2$	$\frac{g_X^2}{g_\rho^2}\frac{1}{f}$	$y_t^2/16\pi^2$	$N_f\, g_\rho^2/16\pi^2$
$k_q\, S\bar{q}Hq$	$y_q \frac{1}{f}$	$y_q \frac{1}{f}$	$i y_q \frac{1}{f}$	$i y_q \frac{1}{f}$	—
$k_H\, S\lvert D_\mu H\rvert^2$	$\frac{1}{f}$	—	—	—	—
$k_{H1}\, S\lvert H\rvert^2\ ,\ k_{H2}\, S\lvert H\rvert^4/f^2\ ,\ k_{H3}\, S^3\lvert H\rvert^2/f^2$	$y_t^2/16\pi^2$	$y_t^2/16\pi^2$	—	—	—
$k_{H4}\, S^2\lvert H\rvert^2$	—	$y_t^2/16\pi$	$y_t^2/16\pi^2$	$y_t^2/16\pi^2$	$N_f\, g_\rho^2/16\pi^2$
$k_M\, S^2\ ,\ k_4\, S^4/f^2$	m_ρ^2	$y_t^2/16\pi^2$	m_ρ^2	$y_t^2/16\pi^2$	$N_f\, g_\rho^2/16\pi^2$
$k_3\, S^3\ ,\ k_5\, S^5/f^2$	$\frac{m_\rho^2}{f}$	$y_t^2/16\pi^2$	—	—	—

* "Generic" cases allow for additional "loop" suppression $N_f \frac{g_\rho^2}{(4\pi)^2}$

Scenarios



	scalar: generic	scalar: NGB	pseudoscalar: generic	pseudoscalar NGB: p.c.	pseudoscalar NGB: anom.
$k_X\, S X^2$	$\frac{g_X^2}{g_\rho^2}\frac{1}{f}$	$y_t^2/16\pi^2$	$\frac{g_X^2}{g_\rho^2}\frac{1}{f}$	$y_t^2/16\pi^2$	$N_f\, g_\rho^2/16\pi^2$
$k_q\, S\bar{q}Hq$	$y_q\frac{1}{f}$	$y_q\frac{1}{f}$	$iy_q\frac{1}{f}$	$iy_q\frac{1}{f}$	—
$k_H\, S\|D_\mu H\|^2$	$\frac{1}{f}$	—	—	—	—
$k_{H1}\, S\|H\|^2$, $k_{H2}\, S\|H\|^4/f^2$, $k_{H3}\, S^3\|H\|^2/f^2$	$y_t^2/16\pi^2$	$y_t^2/16\pi^2$	—	—	—
$k_{H4}\, S^2\|H\|^2$	—	$y_t^2/16\pi$	$y_t^2/16\pi^2$	$y_t^2/16\pi^2$	$N_f\, g_\rho^2/16\pi^2$
$k_M\, S^2$, $k_4\, S^4/f^2$	m_ρ^2	$y_t^2/16\pi^2$	m_ρ^2	$y_t^2/16\pi^2$	$N_f\, g_\rho^2/16\pi^2$
$k_3\, S^3$, $k_5\, S^5/f^2$	$\frac{m_\rho^2}{f}$	$y_t^2/16\pi^2$	—	—	—

- Pattern of an observed signal can be directly mapped to a corresponding scenario
- The Higgs physics can be affected as well, due to the mixing $S|H|^2$

Higgs Physics

- Generic CH effects lead to $\xi \lesssim 0.2$

- Higgs-scalar S mixing affects Higgs phenomenology. We concentrate on the effects which can be dominated by S and supersede the SILH effects

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		effect of scalar S		compositeness
		generic	PNGB	effects [+MC]
$\mathcal{O}_g$	$\frac{g_S^2}{v^2}\lvert H\rvert^2 G_{\mu\nu}G^{\mu\nu}$	$k_g k_{H1}\frac{3y_t^2}{(4\pi)^2}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M^2}\xi$	$k_g k_{H1}\frac{9y_t^4}{(4\pi)^4}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M^2}\xi$	$c_g\frac{3y_t^2}{(4\pi)^2}\frac{1}{g_\rho^2}\xi$
$\mathcal{O}_\gamma$	$\frac{g'^2}{v^2}\lvert H\rvert^2 B_{\mu\nu}B^{\mu\nu}$	$(k_W+k_B)k_{H1}\frac{3y_t^2}{(4\pi)^2}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M^2}\xi$	$(k_W+k_B)k_{H1}\frac{9y_t^4}{(4\pi)^4}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M^2}\xi$	$c_\gamma\frac{3y_t^2}{(4\pi)^2}\frac{1}{g_\rho^2}\xi$
$\mathcal{O}_W$	$\frac{ig}{2v^2}(H^\dagger\sigma^i\overleftrightarrow{D}_\mu H)(D_\nu W^{\mu\nu})^i$	$4k_W k_{H1}\frac{3y_t^2}{(4\pi)^2}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M^2}\xi$	$4k_W k_{H1}\frac{9y_t^4}{(4\pi)^4}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M^2}\xi$	$c_W\frac{1}{g_\rho^2}\xi$
$\mathcal{O}_B$	$\frac{ig'}{2v^2}(H^\dagger\overleftrightarrow{D}_\mu H)(\partial_\nu B^{\mu\nu})$	$-4k_W k_{H1}\frac{3y_t^2}{(4\pi)^2}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M^2}\xi$	$-4k_W k_{H1}\frac{9y_t^4}{(4\pi)^4}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M^2}\xi$	$c_B\frac{1}{g_\rho^2}\xi$
$\mathcal{O}_{HW}$	$\frac{ig}{v^2}(D_\mu H)^\dagger\sigma^i(D_\nu H)W^{i\mu\nu}$	$-4k_W k_{H1}\frac{3y_t^2}{(4\pi)^2}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M^2}\xi$	$-4k_W k_{H1}\frac{9y_t^4}{(4\pi)^4}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M^2}\xi$	$c_{HW}\frac{1}{g_\rho^2}\xi\left[\frac{g_\rho^2}{(4\pi)^2}\right]$
$\mathcal{O}_{HB}$	$\frac{ig'}{v^2}(D_\mu H)^\dagger(D_\nu H)B^{\mu\nu}$	$4k_W k_{H1}\frac{3y_t^2}{(4\pi)^2}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M^2}\xi$	$4k_W k_{H1}\frac{9y_t^4}{(4\pi)^4}\frac{1}{g_\rho^2}\frac{m_\rho^2}{M^2}\xi$	$c_{HB}\frac{1}{g_\rho^2}\xi\left[\frac{g_\rho^2}{(4\pi)^2}\right]$
$\mathcal{O}_q$	$\frac{1}{v^2}\bar{q}Hq\lvert H\rvert^2$	$y_q k_{H1}\left(k_q-\frac{k_H}{2}\right)\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{M^2}\xi$	$y_q k_{H1}k_q\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{M^2}\xi$	$c_q y_q\xi$
$\mathcal{O}_H$	$\frac{1}{2v^2}\partial_\mu\lvert H\rvert^2\partial^\mu\lvert H\rvert^2$	$k_{H1}\left(k_{H1}\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{M^2}-k_H\right)\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{M^2}\xi$	$k_{H1}^2\frac{9y_t^4}{(4\pi)^4}\frac{m_\rho^4}{M^4}\xi$	$c_H\xi$

Higgs Physics

- effect of generic S on $h \to gg$

		effect of scalar S		compositeness effects [+MC]
		generic	PNGB	
$\mathcal{O}_g$	$\frac{g_S^2}{v^2}\|H\|^2 G_{\mu\nu}G^{\mu\nu}$	$k_g k_{H1} \frac{3y_t^2}{(4\pi)^2} \frac{1}{g_\rho^2} \frac{m_\rho^2}{M^2} \xi$	$k_g k_{H1} \frac{9y_t^4}{(4\pi)^4} \frac{1}{g_\rho^2} \frac{m_\rho^2}{M^2} \xi$	$c_g \frac{3y_t^2}{(4\pi)^2} \frac{1}{g_\rho^2} \xi$
$\mathcal{O}_q$	$\frac{1}{v^2} \bar{q} H q \|H\|^2$	$y_q k_{H1} \left(k_q - \frac{k_H}{2}\right) \frac{3y_t^2}{(4\pi)^2} \frac{m_\rho^2}{M^2} \xi$	$y_q k_{H1} k_q \frac{3y_t^2}{(4\pi)^2} \frac{m_\rho^2}{M^2} \xi$	$c_q y_q \xi$
$\mathcal{O}_H$	$\frac{1}{2v^2} \partial_\mu \|H\|^2 \partial^\mu \|H\|^2$	$k_{H1} \left(k_{H1} \frac{3y_t^2}{(4\pi)^2} \frac{m_\rho^2}{M^2} - k_H\right) \frac{3y_t^2}{(4\pi)^2} \frac{m_\rho^2}{M^2} \xi$	$k_{H1}^2 \frac{9y_t^4}{(4\pi)^4} \frac{m_\rho^4}{M^4} \xi$	$c_H \xi$

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$\mathcal{O}_q$	$\frac{1}{v^2}\bar{q}Hq\|H\|^2$	$y_q k_{H1}\left(k_q - \frac{k_H}{2}\right)\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{M^2}\xi$	$y_q k_{H1} k_q \frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{M^2}\xi$	$c_q y_q \xi$
$\mathcal{O}_H$	$\frac{1}{2v^2}\partial_\mu\|H\|^2\partial^\mu\|H\|^2$	$k_{H1}\left(k_{H1}\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{M^2} - k_H\right)\frac{3y_t^2}{(4\pi)^2}\frac{m_\rho^2}{M^2}\xi$	$k_{H1}^2 \frac{9y_t^4}{(4\pi)^4}\frac{m_\rho^4}{M^4}\xi$	$c_H \xi$

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- SM top loop contribution to $h \to gg$ is modified by order ξ due to the Higgs compositeness effects in the operators $\mathcal{O}_q$ and $\mathcal{O}_H$
- S effect becomes dominant for $M^2/m_\rho^2 \lesssim 3y_t^2/g_\rho^2$

Higgs Physics

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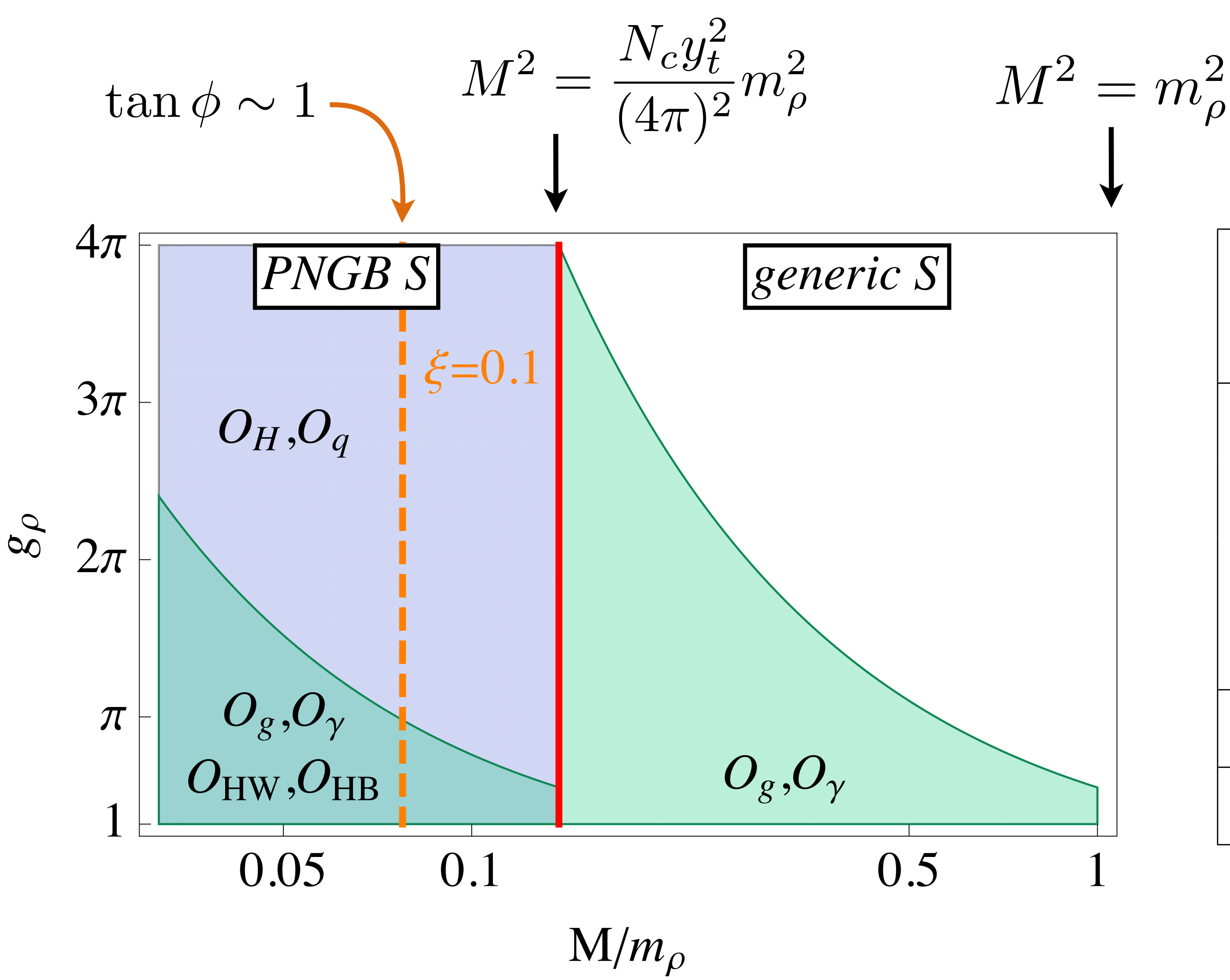

$\mathcal{O}_g$	$\frac{g_S^2}{v^2}\lvert H\rvert^2 G_{\mu\nu}G^{\mu\nu}$	
$\mathcal{O}_\gamma$	$\frac{g'^2}{v^2}\lvert H\rvert^2 B_{\mu\nu}B^{\mu\nu}$	$h \to gg, h \to \gamma\gamma$
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$\mathcal{O}_{HB}$	$\frac{ig'}{v^2}(D_\mu H)^\dagger(D_\nu H)B^{\mu\nu}$	
$\mathcal{O}_q$	$\frac{1}{v^2}\bar{q}Hq\lvert H\rvert^2$	$h\bar{q}q,\ h \to gg, h \to \gamma\gamma$
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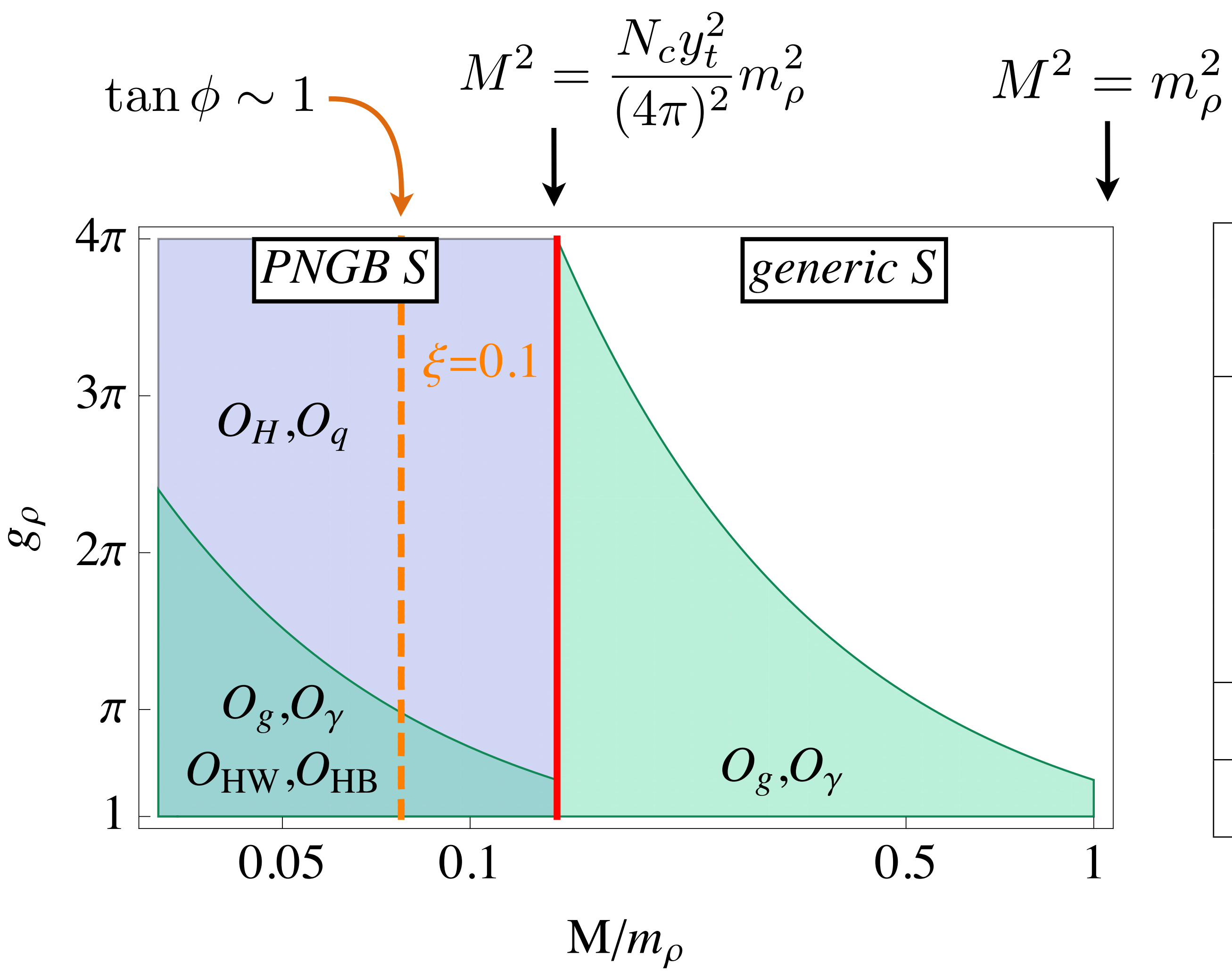

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- S effects get stronger for smaller S masses and lower g_ρ

- The PNGB S has the largest impact on the Higgs physics because of the larger expected mixing: both $S|H|^2$ and S^2 are loop suppressed, hence the suppression cancels out from the mixing angle

Summary

- We provided a simple description of a new composite scalar accompanying the composite Higgs, extending the SILH framework

- We derived the relations between the patterns of S and H couplings and the structure of the underlying theory

- The proposed strategy can be extended to higher order operators, theories with extra symmetries, light S scenarios

Thank you!