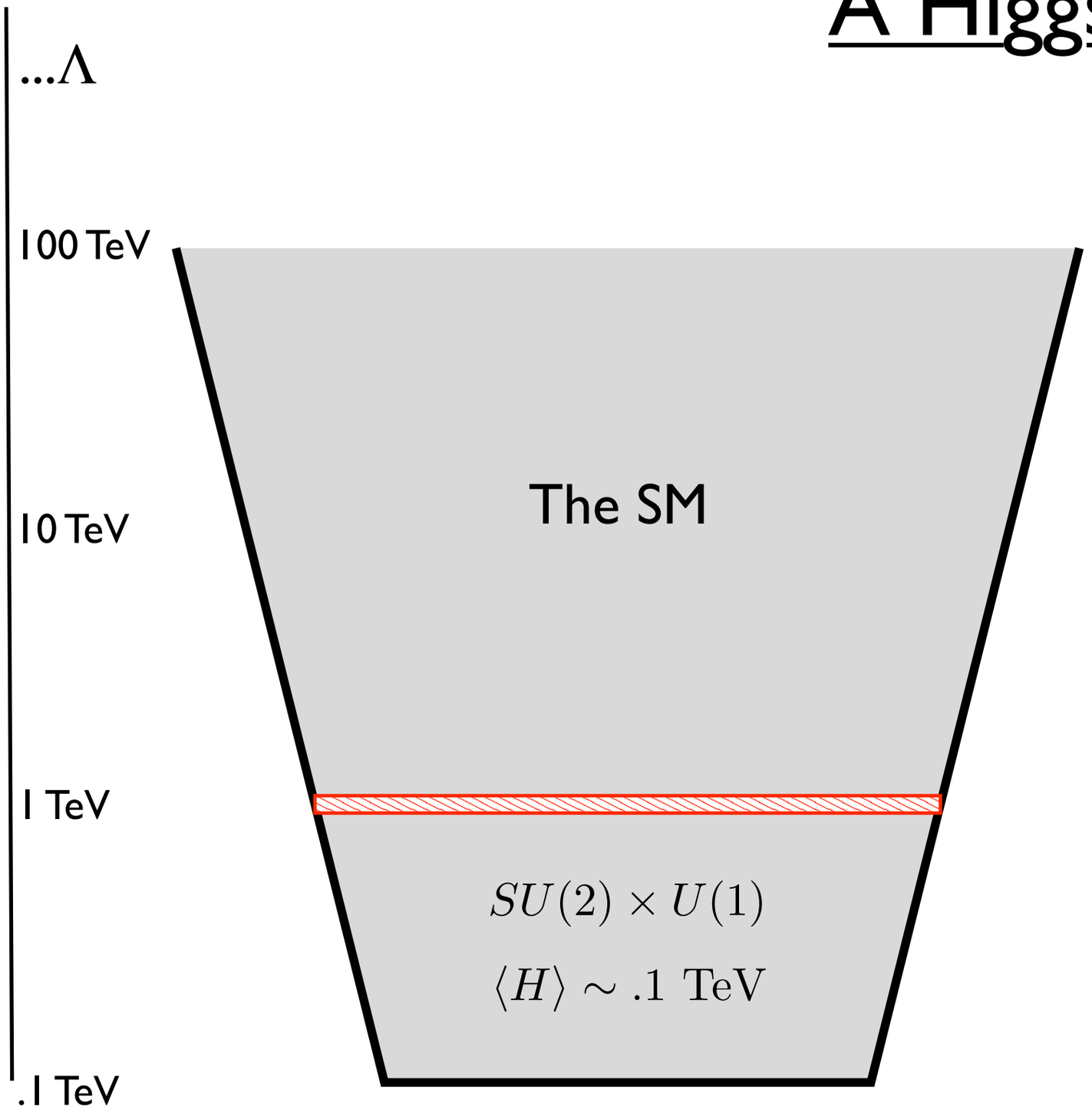
A Little Higgs with a Litte UV Completion with a Little...

Puneet Batra (Stanford University)
David E. Kaplan (The Johns Hopkins University)
work in progress

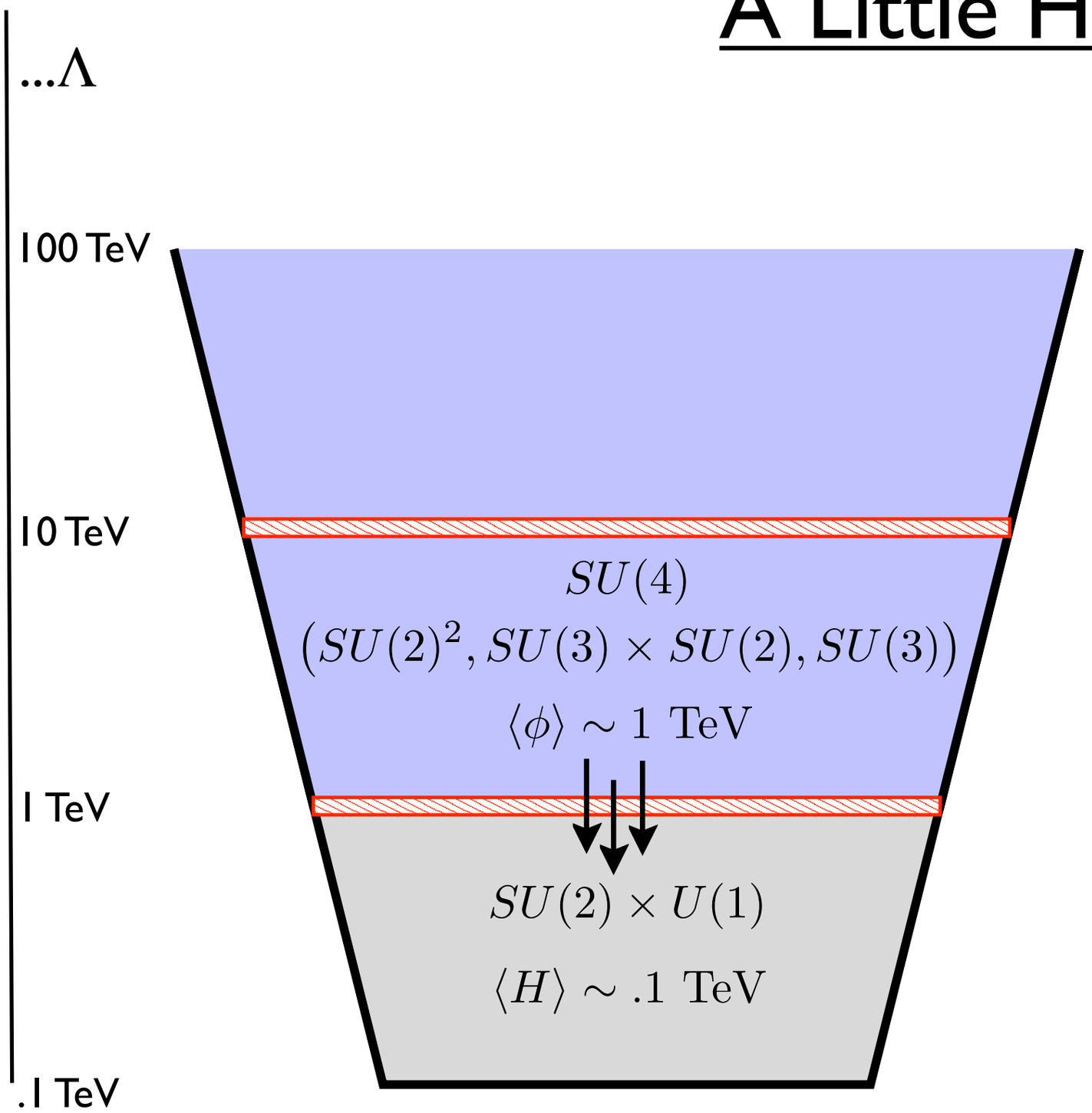
A Higgs



Scalars	Sensitivity
H	$\delta m_h^2 \sim \Lambda^2$

H is a fundamental scalar field

A Little Higgs

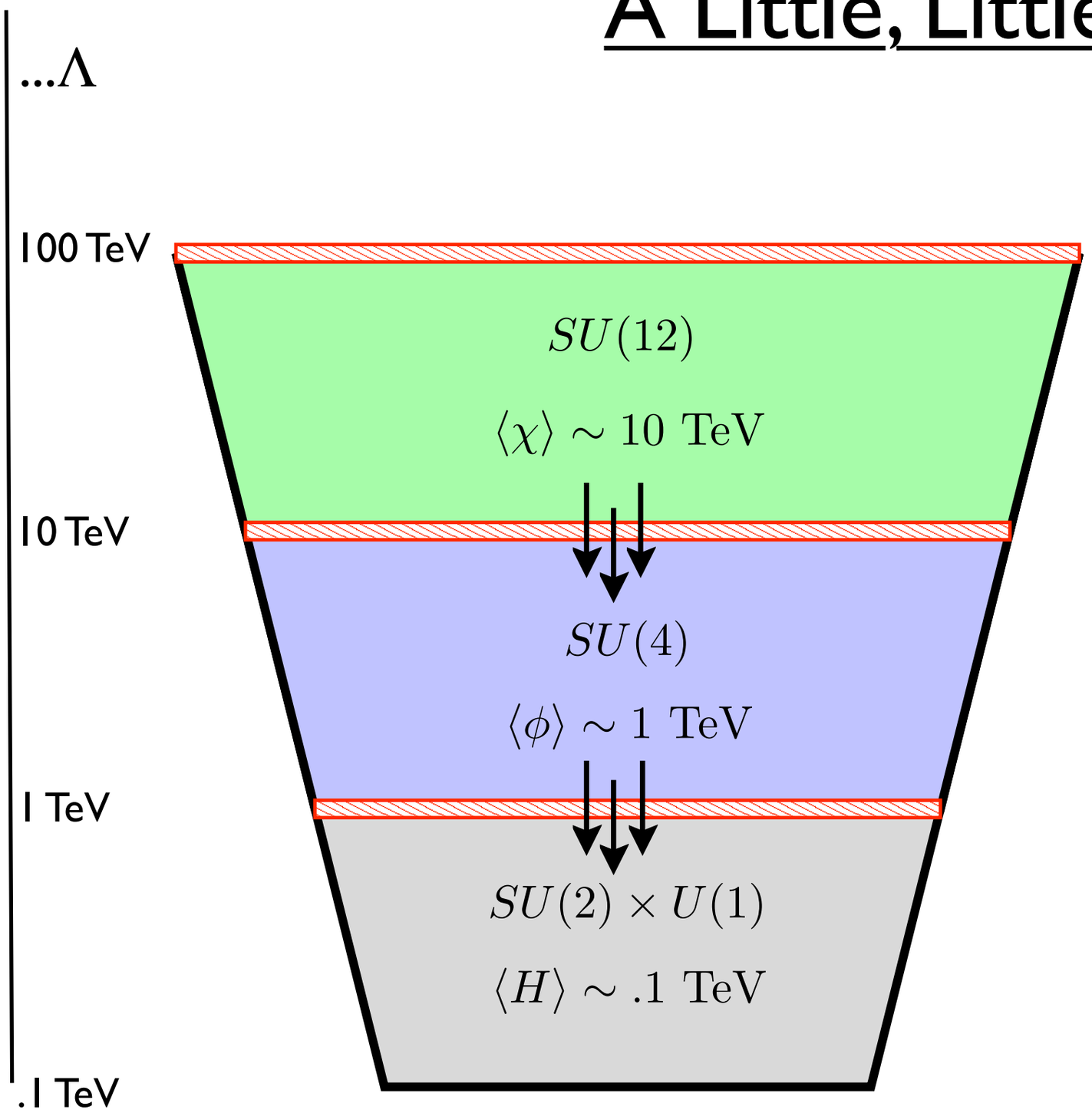


Scalars	Sensitivity
ϕ	$\delta m_\phi^2 \sim \Lambda^2$
H	$\delta m_h^2 \sim \langle \phi \rangle^2$

ϕ is a fundamental scalar field

H is a pseudo-goldstone boson that lives in ϕ

A Little, Little Higgs



Scalars	Sensitivity
χ	$\delta m_\chi^2 \sim \Lambda^2$
ϕ	$\delta m_\phi^2 \sim \langle\chi\rangle^2$
H	$\delta m_h^2 \sim \langle\phi\rangle^2$

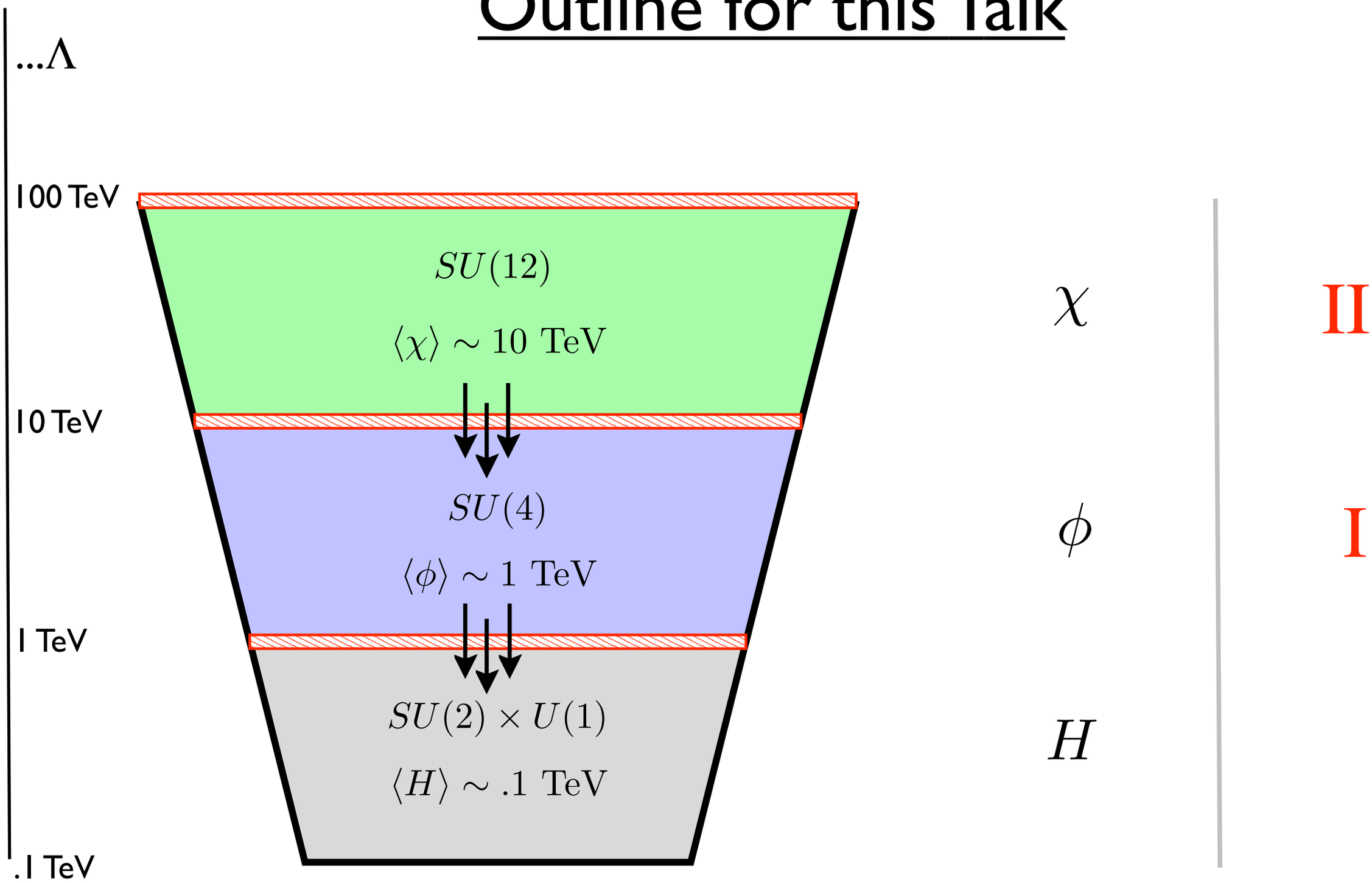
X is a fundamental scalar field
ϕ is a pseudo-goldstone boson that lives in X
H is a pseudo-goldstone boson that lives in ϕ

Above 10 TeV

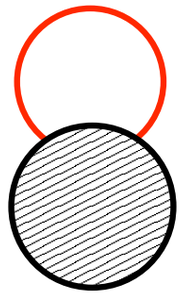
Energy	Physics
10 TeV	Precision Electroweak
100 TeV	Flavor Changing Neutral Currents
1000 TeV	CP Violation
10^{13} TeV	Proton Decay

- Another alternative to SUSY in these regions would be very interesting

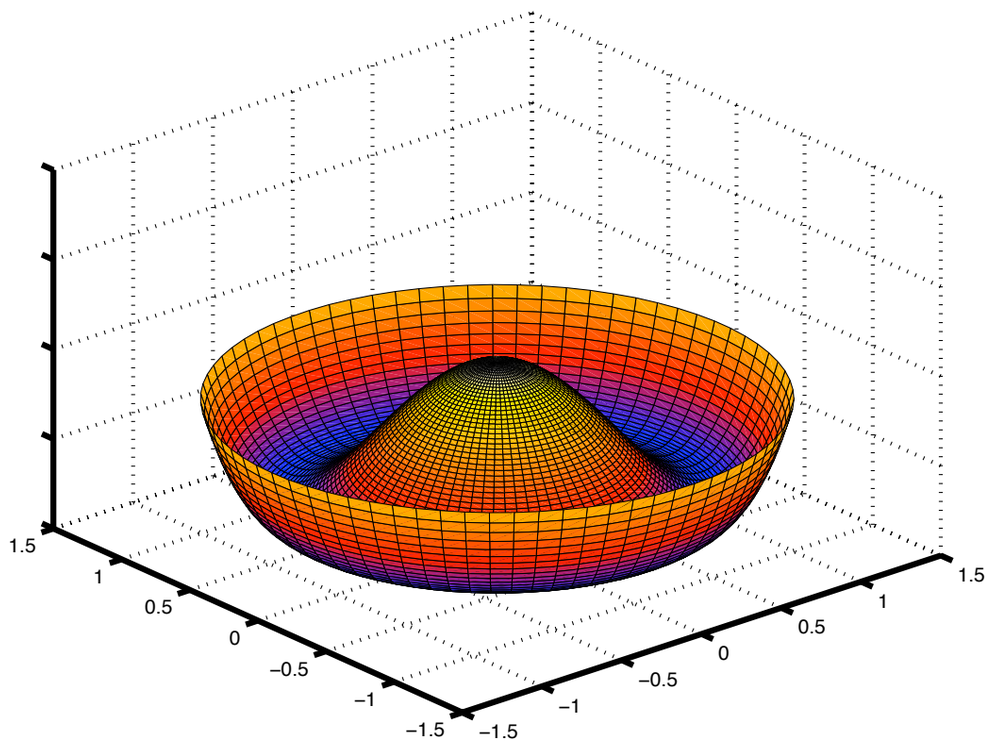
Outline for this Talk



Goldstone Bosons

Notation: 

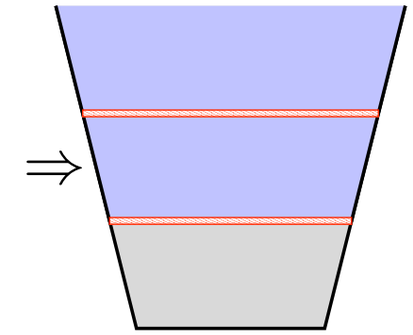
$$\Rightarrow V(\phi) = -m^2\left(\phi^\dagger\phi\right) + \lambda\left(\phi^\dagger\phi\right)^2$$

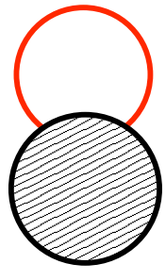


$$\langle\phi\rangle = \begin{pmatrix} 0 \\ 0 \\ f \end{pmatrix}$$

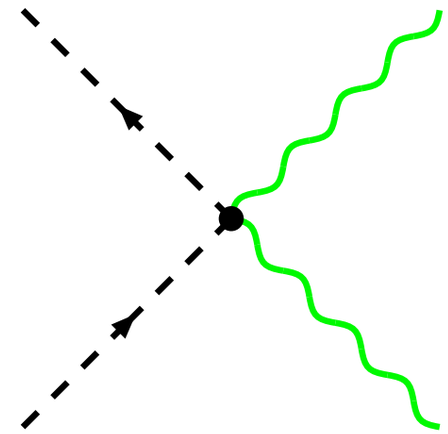
- SSB: SU(3) => SU(2)
- The Goldstone has no mass and no p-indepdent interactions
- Must introduce Gauge, Yukawa, and Quartic Interactions artfully

Gauge Interactions



-  try gauging the global SU(3) symmetry

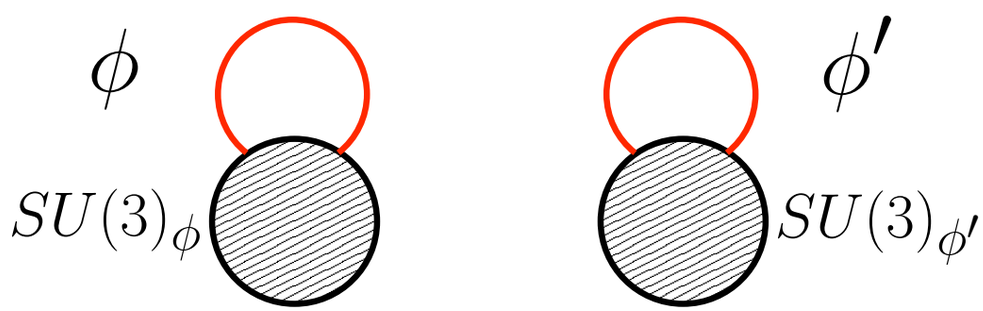
- new interactions, new vector bosons...



- gauge bosons acquire mass, $m_A^2 \sim g^2 f^2$, BUT 'eat' the single goldstone

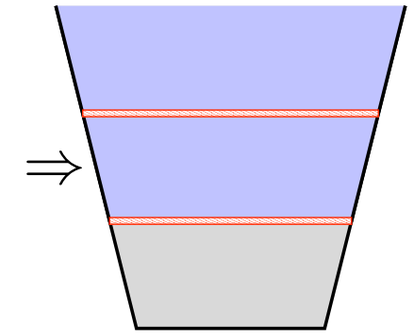
---

- resolution: double the number of Goldstones!



- one linear combination of Goldstones is eaten, one light doublet (H!) remains

Quantum Stability



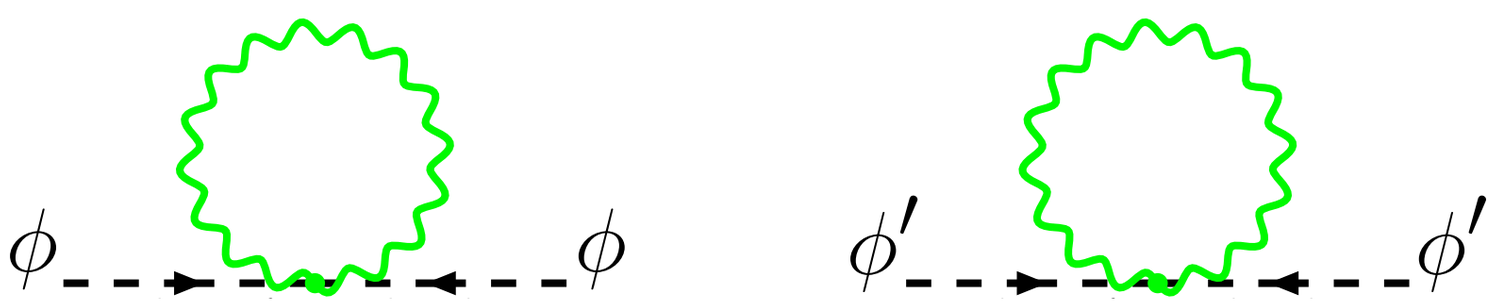
- Dimension-2 operators, $\Lambda^2 \phi^\dagger \phi'$, might give a large mass to H:

$$m_H \propto \Lambda \sim 10 \text{ TeV}$$

- Such Dimension-2 operators break BOTH

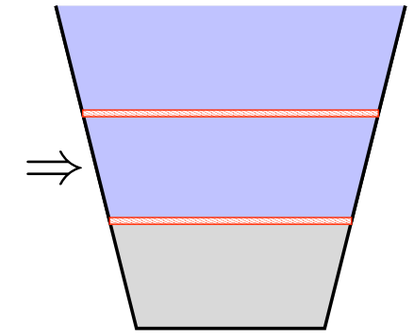
$$\left(SU(3)_\phi \;\&\; SU(3)_{\phi'}\right) \text{ AND } \left(U(1)_\phi \;\&\; U(1)_{\phi'}\right)$$

- BUT, gauge interactions preserve $\left(U(1)_\phi \;\&\; U(1)_{\phi'}\right)$

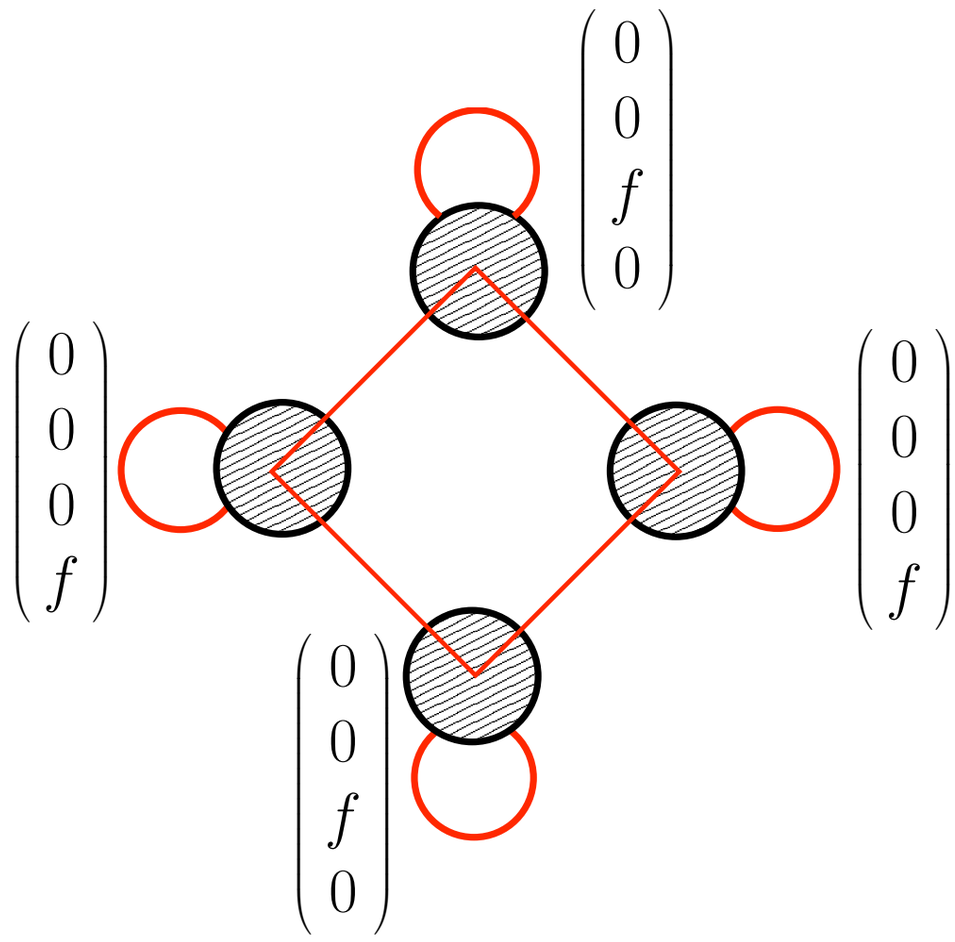


Scalar-Chiral symmetries forbid Quadratic Divergences to m_H^2

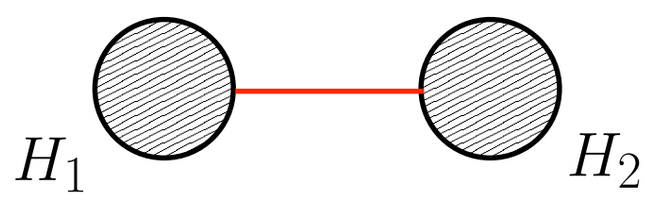
Quartic Interactions



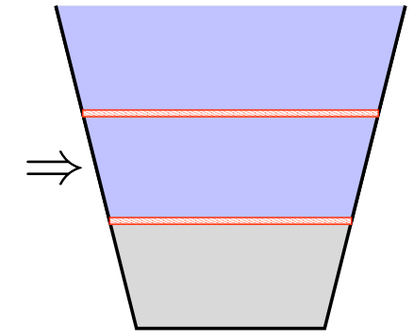
- A good tree-level quartic is hard to find!
- SU(4) works:



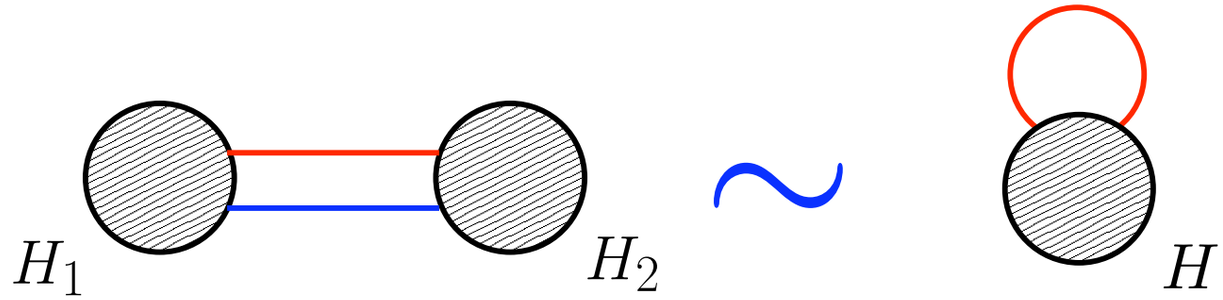
- At Low Energies: a two-Higgs Doublet Standard Model



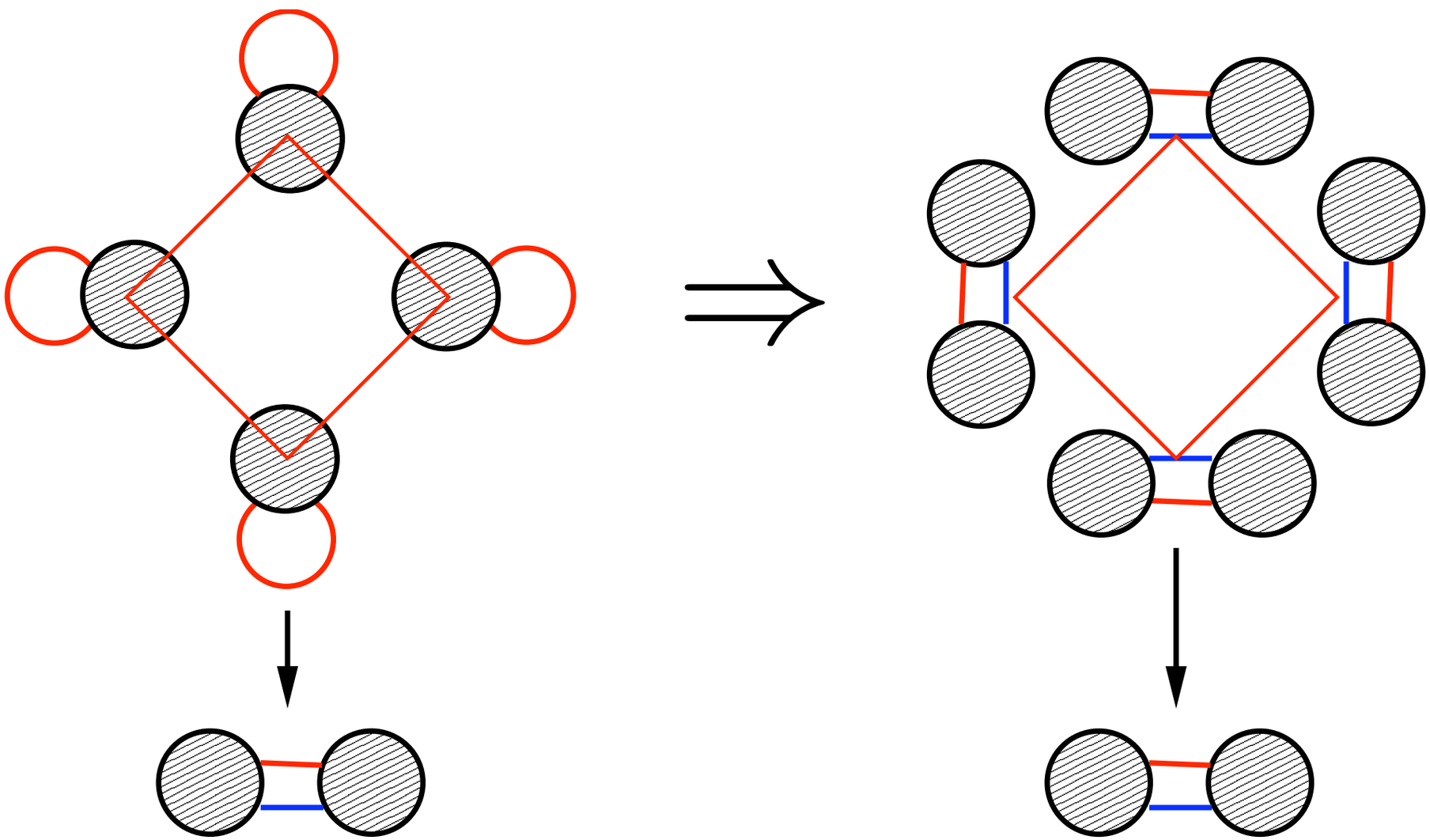
Iterative Structure



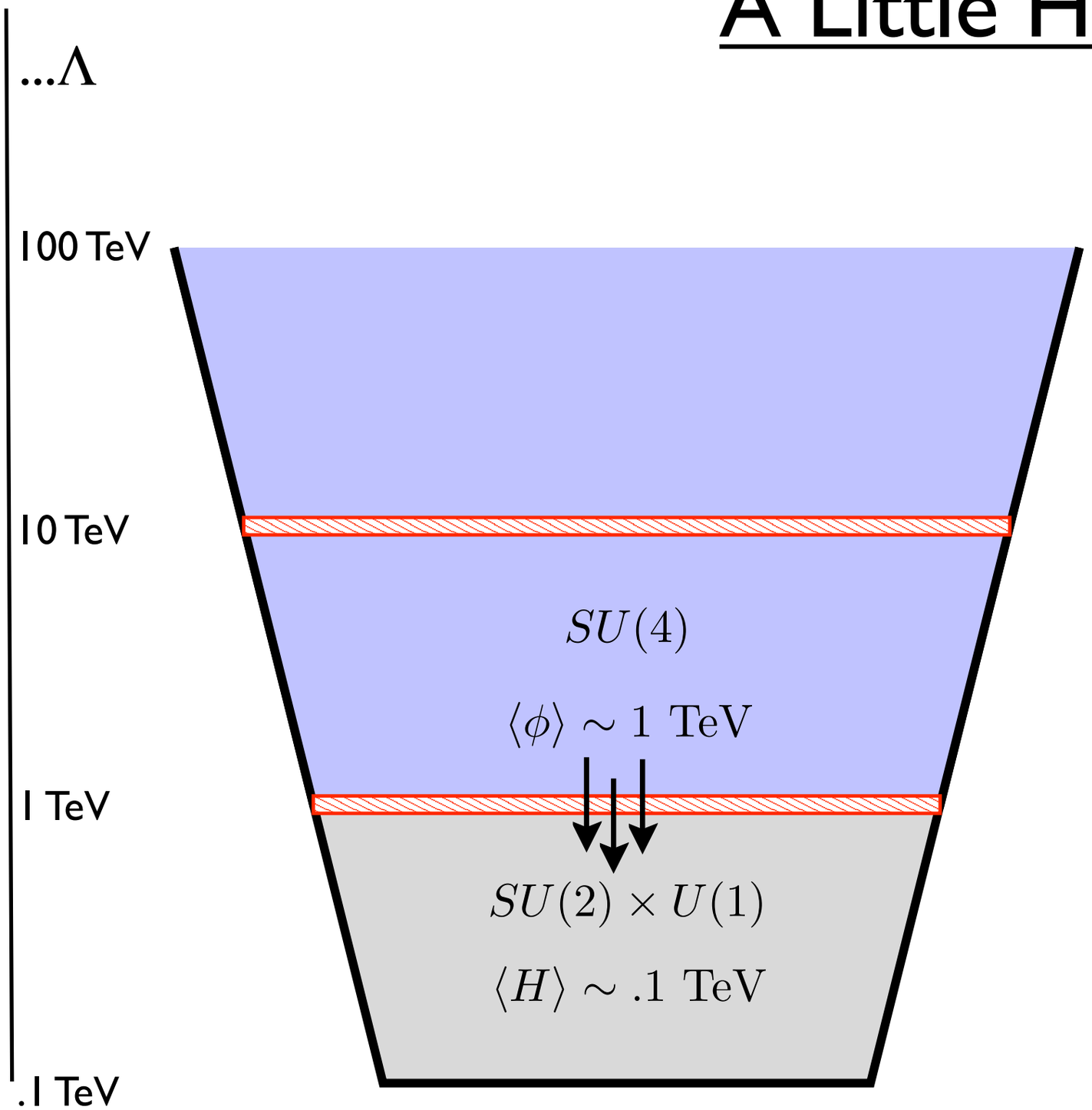
- Include $b_0 H_1^\dagger H_2$



- iterative pattern:



A Little Higgs

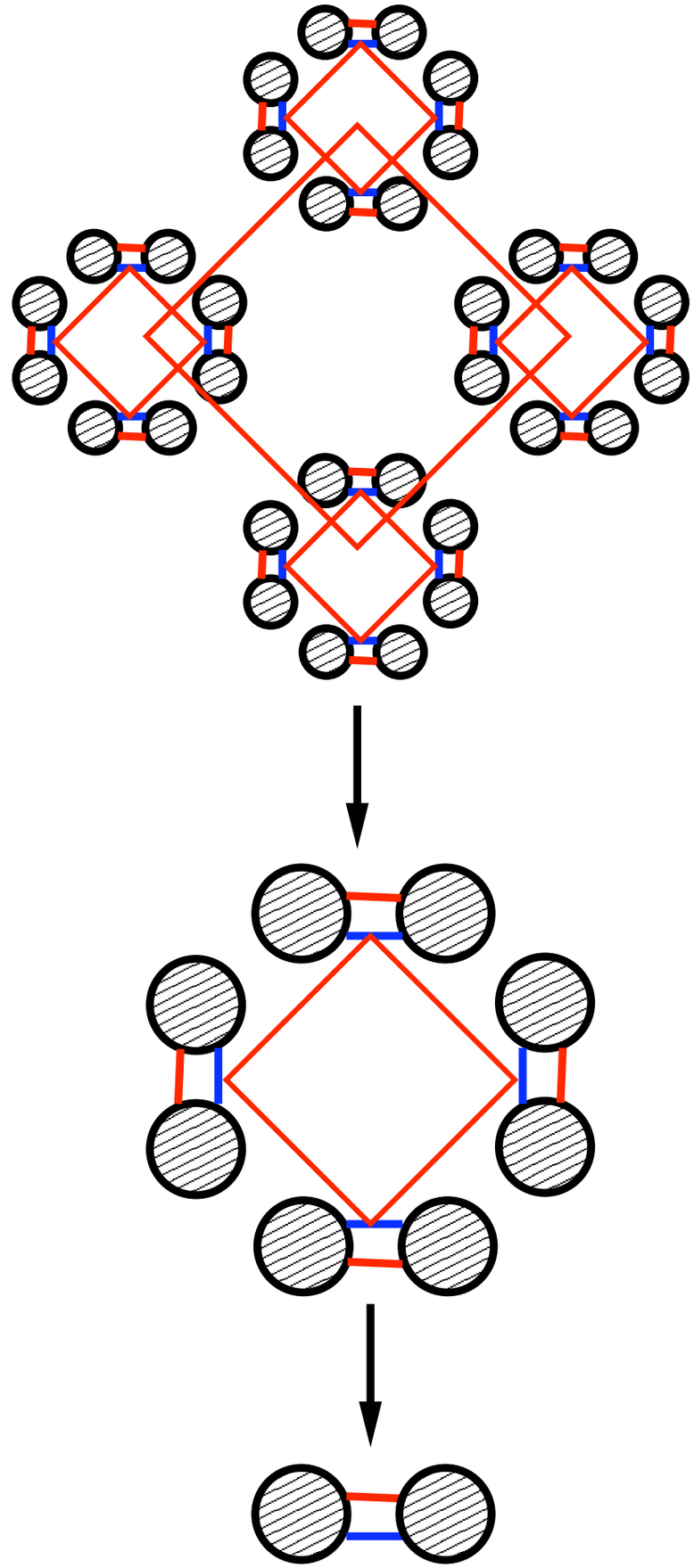


Scalars	Sensitivity
ϕ	$\delta m_\phi^2 \sim \Lambda^2$
H	$\delta m_h^2 \sim \langle\phi\rangle^2$

ϕ is a fundamental scalar field

H is a pseudo-goldstone boson that lives in ϕ

$SU(12)$
32 χ fields
$\langle \chi \rangle = F$
$F \sim 10$ TeV



$SU(4)$
8 ϕ fields
$\langle \phi \rangle = f$
$f \sim 1$ TeV

$SU(2)$
2 H fields
$\langle H \rangle = v$
$v \sim .1$ TeV

$\Lambda \sim 100$ TeV

$\frac{1}{10}$

$F \sim 10$ TeV

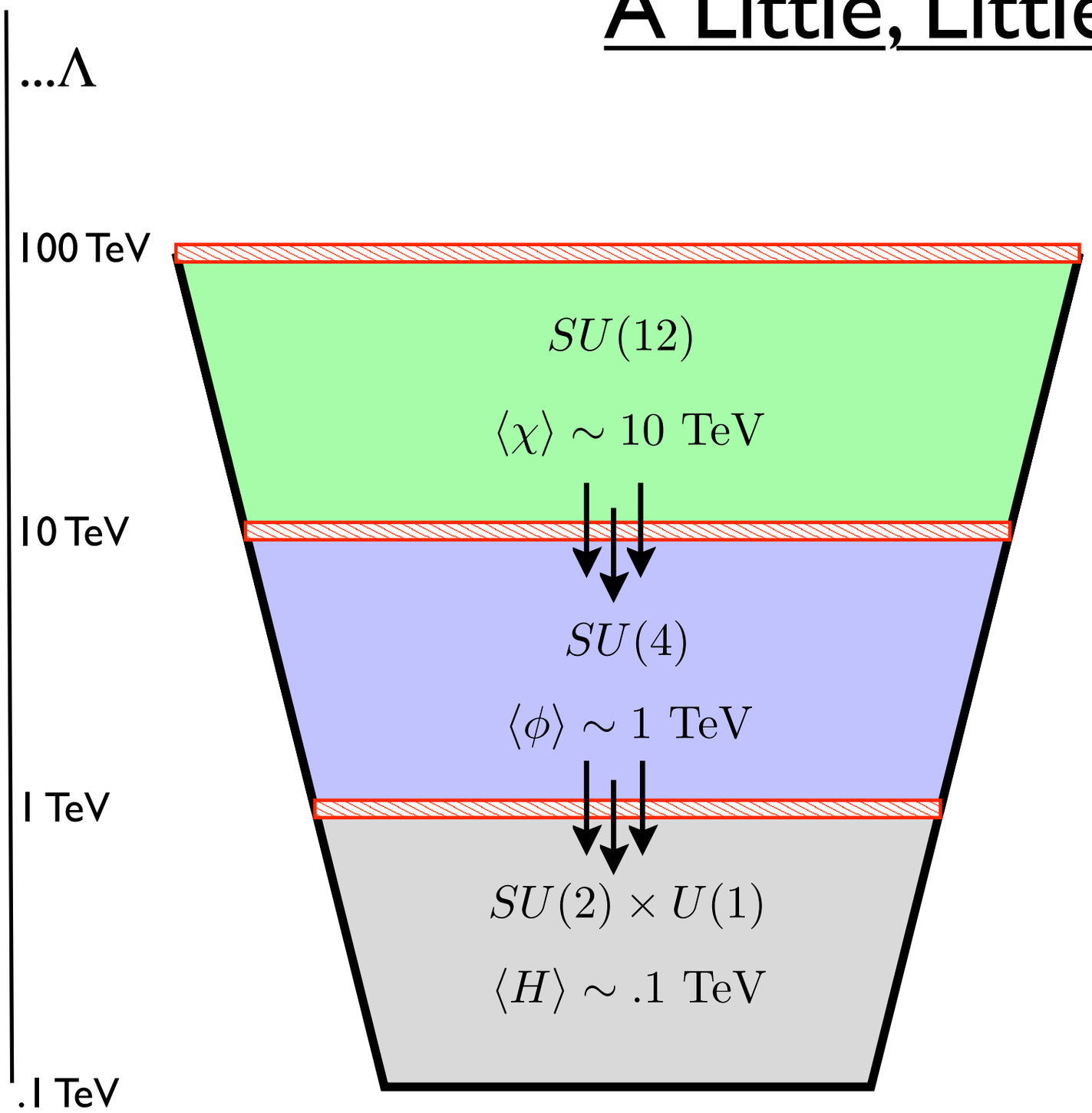
$\frac{1}{10}$

$f \sim 1$ TeV

$\frac{1}{10}$

$v \sim .1$ TeV

A Little, Little Higgs



Scalars	Sensitivity
χ	$\delta m_\chi^2 \sim \Lambda^2$
ϕ	$\delta m_\phi^2 \sim \langle\chi\rangle^2$
H	$\delta m_h^2 \sim \langle\phi\rangle^2$

X is a fundamental scalar field
ϕ is a pseudo-goldstone boson that lives in X
H is a pseudo-goldstone boson that lives in ϕ

A Scalar Tower

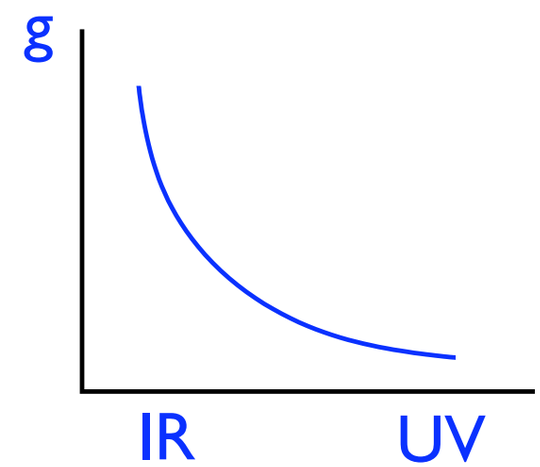
- SU(12) Can be embedded as well, in SU(44)

- Since quadratic divergences have been removed, logarithmic divergences and landau poles must now be addressed

- Full Structure:

	$SU(N)$	M Fields
$n=0$	2	2
$n=1$	4	8
$n=2$	12	32
$n=3$	44	128
n	$N_{n-1}+M_{n-1}$ $=2+\frac{2}{3}(4^n-1)$	4^n*2

A Scalar Tower

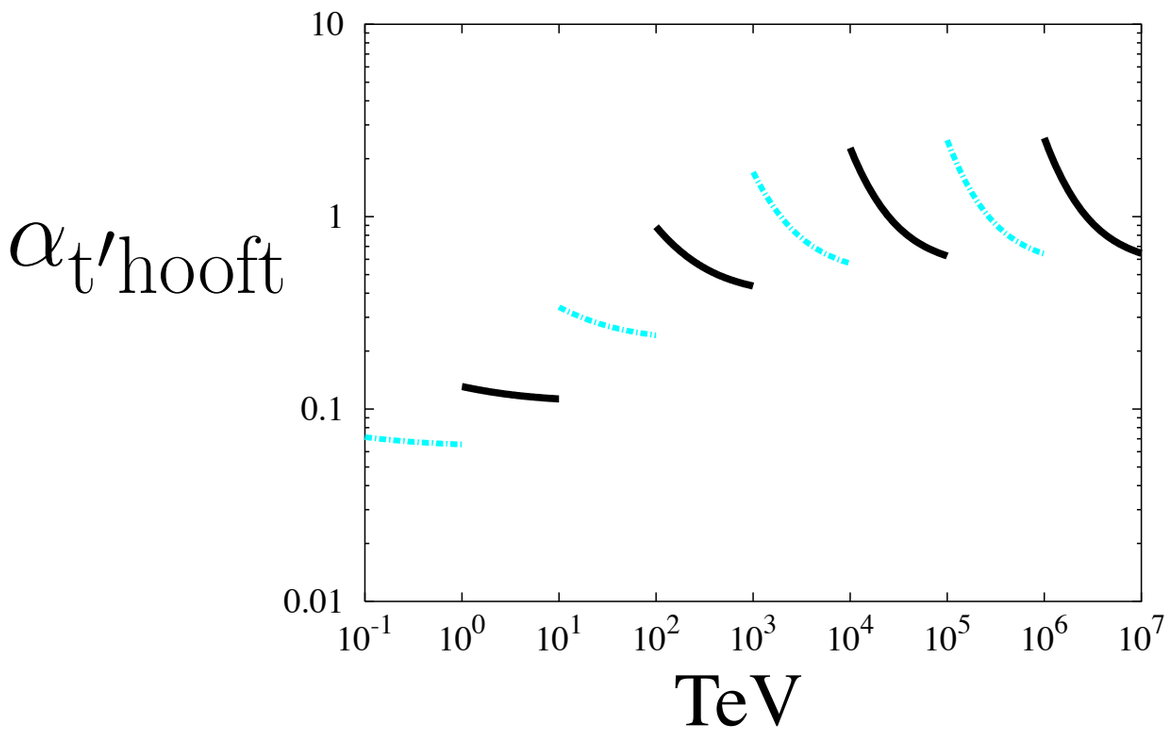


- The Gauge Coupling is really asymptotically free!

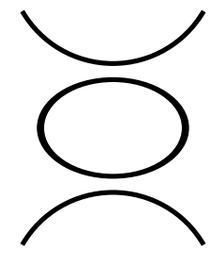
$$\alpha_{n+1}^{-1} = \alpha_n^{-1} - \frac{b_n}{2\pi}\log 10$$

$$b_n \sim \frac{19}{9}4^n \ll 0 \text{ as } n \to \infty$$

- Large-N Gauge theory, so $\frac{g^2 N}{4\pi} \equiv \alpha_{\text{t'hooft}}$ is important



- Even dimension-4 gauge operators $\Rightarrow 0$



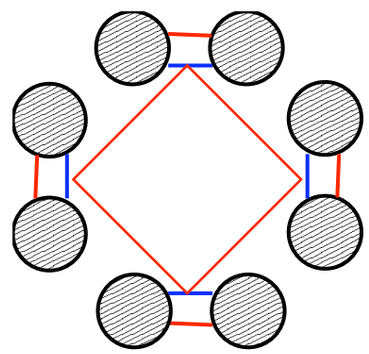
$$\sim g^4 N = \frac{\alpha_{\text{t'hooft}}^2}{N} \Rightarrow 0$$

Low Energy Characteristics

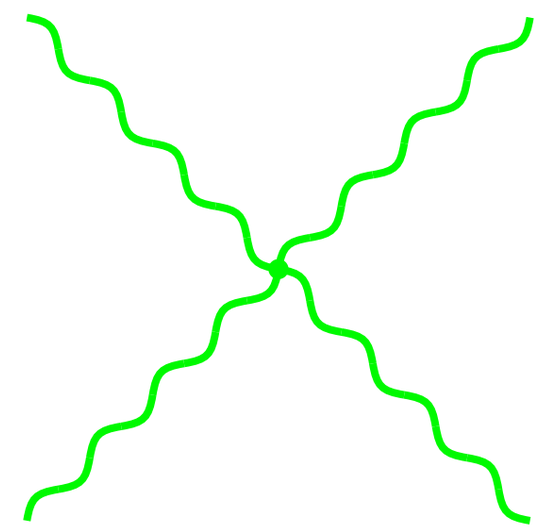
10 TeV

SU(12) Gauge Bosons, ...

"2HDM"
iterations

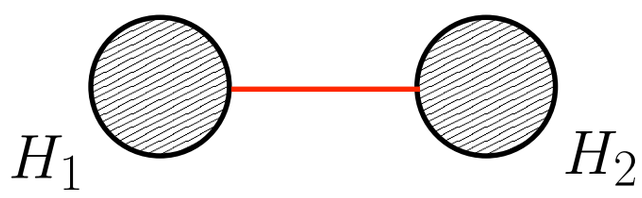


SU(4)/SU(2) Gauge Bosons
Radial modes
Scalar–Chiral couplings



1 TeV

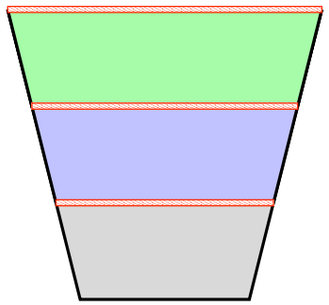
2HDM:



.1 TeV

Conclusions

- Little Higgs models can be stacked naturally and perturbatively.



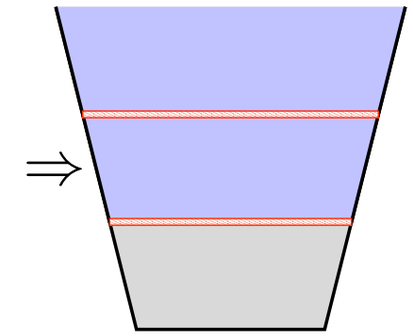
- 'Simple' Little Higgs models are easier to stack, due to the scalar-chiral symmetries

- Still to do: address flavor & hypercharge

- How high might such a stack climb?

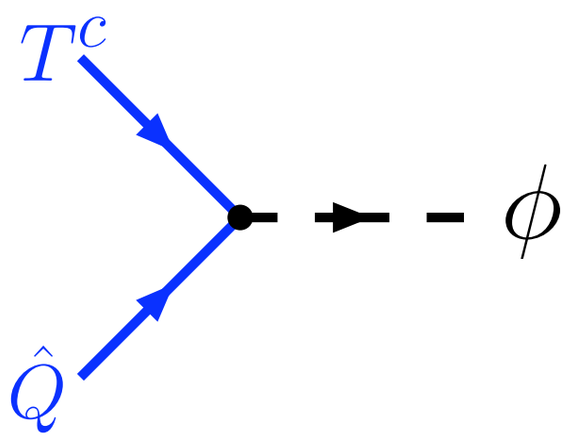
Supplemental Slides

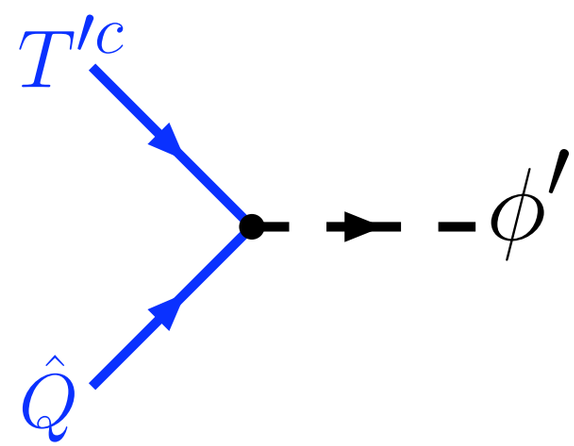
Yukawa Interactions



- Preserve the U(1) & SU(3) symmetries

$$y_\phi \phi \hat{Q} T^c + y_{\phi'} \phi' \hat{Q} T'^c \qquad \hat{Q} = \begin{pmatrix} Q \\ T \end{pmatrix}$$





- After the SU(3) breaking:

$$\Rightarrow m_T T T_M^C + y_t Q H t^c \qquad m_T \sim f \sim \ 1\mathrm{TeV}$$