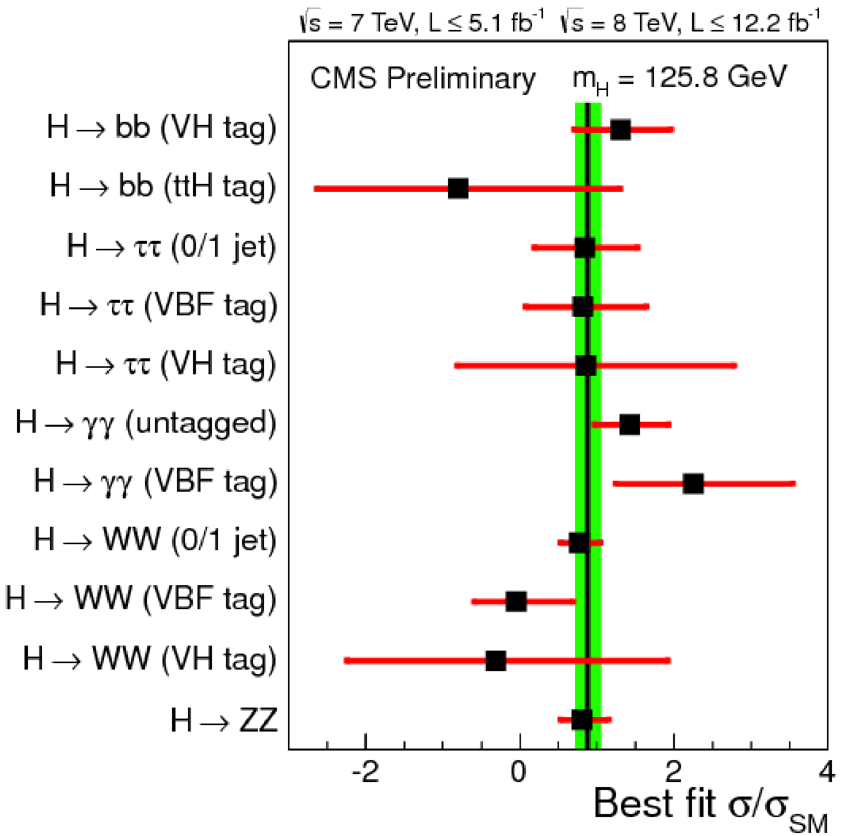
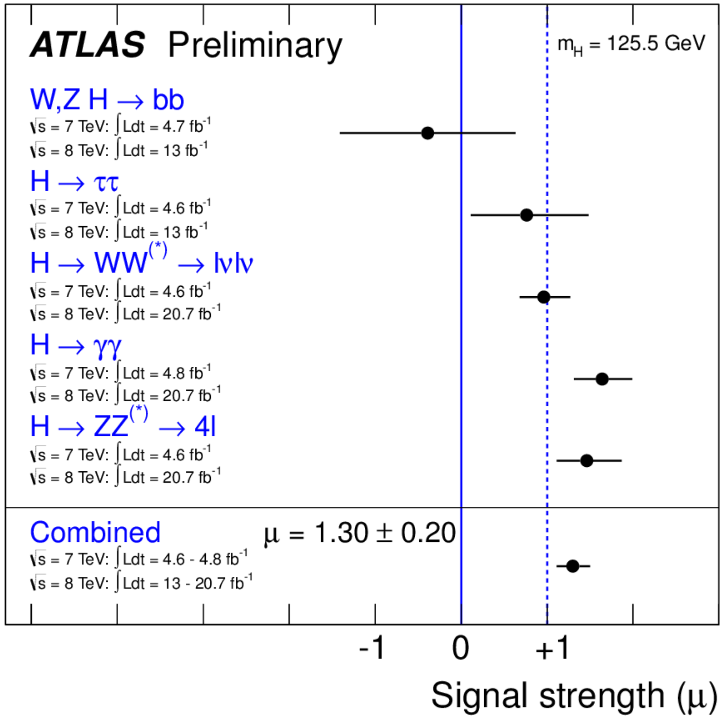
Implications of a 125 GeV Composite Higgs

Alex Pomarol, UAB *(Barcelona)*

A Higgs-like state has been discovered





with no significant deviations from a SM Higgs!

What does data tell us?

Light state: $\mathbf{m_H \approx 125\ GeV}$

If it has to do with EWSB: $\mathbf{m_H^2 = \lambda v^2}$

$\lambda \sim$ 0.26 (perturbative coupling)

Origin of the EWSB potential → a weakly-coupled theory

↳ **Is this the end of strong dynamics for the EWSB?**

Is this the end of strong dynamics for the EWSB?

Not really...

A light scalar can emerge from the strong sector due to symmetries:

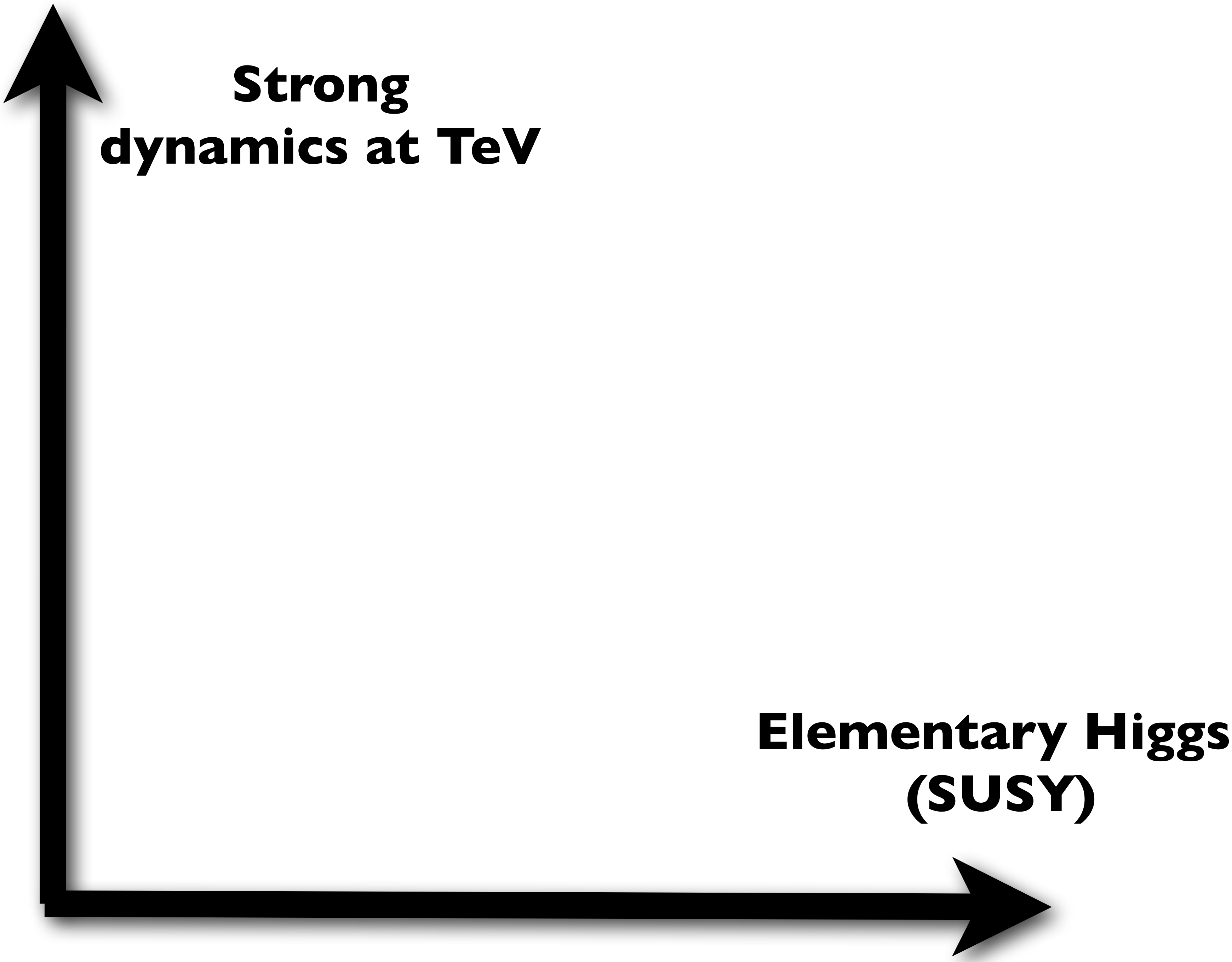
1) Supersymmetry

2) Scale invariance: Dilaton

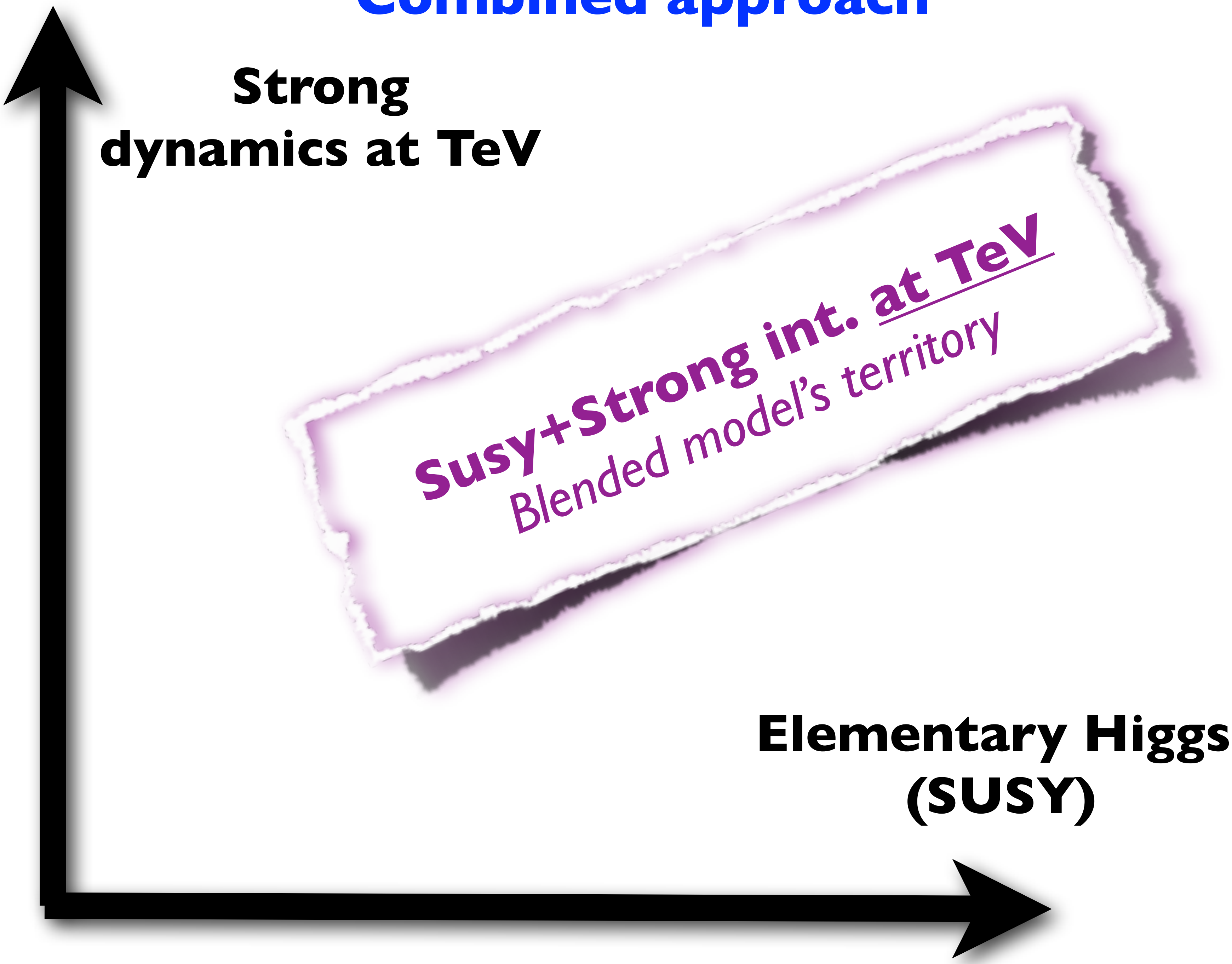
3) Global symmetries: Pseudo-Goldstones

1) Supersymmetry

Two schools with “orthogonal” approaches



Blended Models for EWSB: Combined approach



Why blending?

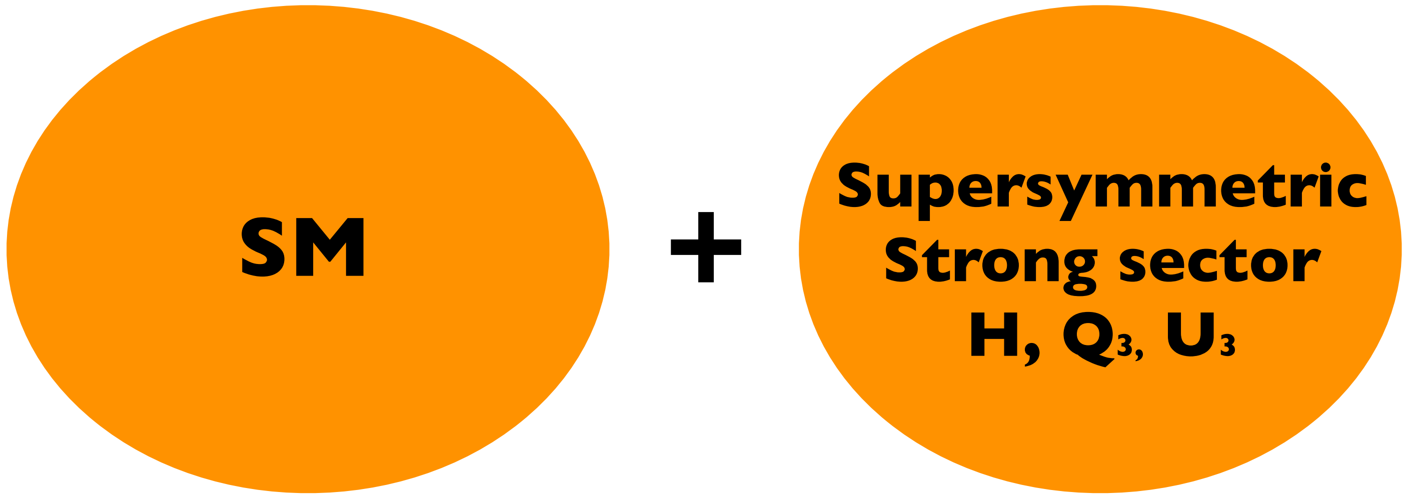
- MSSM needs a strong sector to break supersymmetry
  ↪ why not at the TeV?

- In the MSSM is difficult to get a Higgs of 125 GeV (needs large susy breaking)
  ↪ extra contributions if the Higgs is composite

Examples:

Partly supersymmetric models:

Gherghetta,AP
Sundrum,
Redi,Gripaios
Gherghetta,Harling,Setzer



Some recent activity using
Seiberg dualities

Sparticles: **Higgsino and Stops**

Signal: $gg \to \tilde{t}\,\tilde{t} \to (t\,\tilde{H})\,(t\,\tilde{H})$

2) Spontaneously broken scale invariance

2) Dilatations

Not, a priori, guarantees a naturally light dilaton!

Under dilatations: $x \to \Lambda x$

Dilaton: $\pi \to \pi(\Lambda x) + \ln \Lambda$

or $\varphi = e^{\pi} \to \Lambda e^{\pi}$

A potential is allowed: $\int d^4x \, V = \int d^4x \, \kappa \varphi^4$ κ=const

Fubini 76

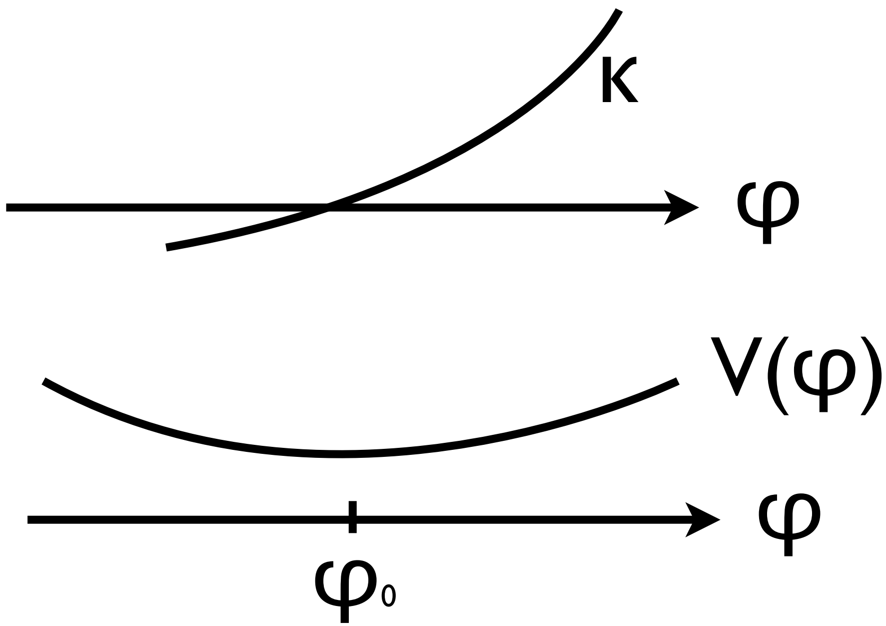
φ = const$\neq$0 only if κ=0 (tuning!)

Explicit breaking must be introduced to the CFT:

Add λO_d with $\beta(\lambda)\neq 0$

Now we have: $V(\varphi)=\kappa(\lambda(\varphi))\,\varphi^4$ (Coleman-Weinberg potential)

Non-trivial minimum if $\kappa(\lambda(\varphi))$ crosses zero:



Small dilaton mass → Flattish potential → slow running of κ → slow running of λ

λ must be an almost marginal deformation of the CFT

$\mathrm{Dim}[\lambda]=\varepsilon \rightarrow m_\varphi^2 \sim \beta(\lambda) \sim \varepsilon$ (Not like in QCD)

The AdS/CFT dictionary, tells us how to be realized in AdS spaces (RS-setup):

Rattazzi, Contino, A.P.

CFT_4 → AdS_5

Dilaton → Radion

$V(\varphi)$ → $T(\varphi)$ tension of the IR-brane

$O_{d\sim4}$ → Scalar in the bulk with mass ~ ε

$\lambda \neq 0$ → VEV for the scalar on the AdS boundary

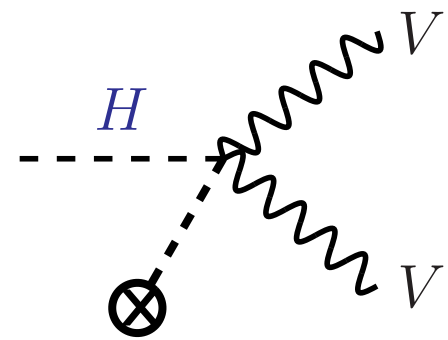
PGB in 5D!!

➥ **Model of a naturally light dilaton**

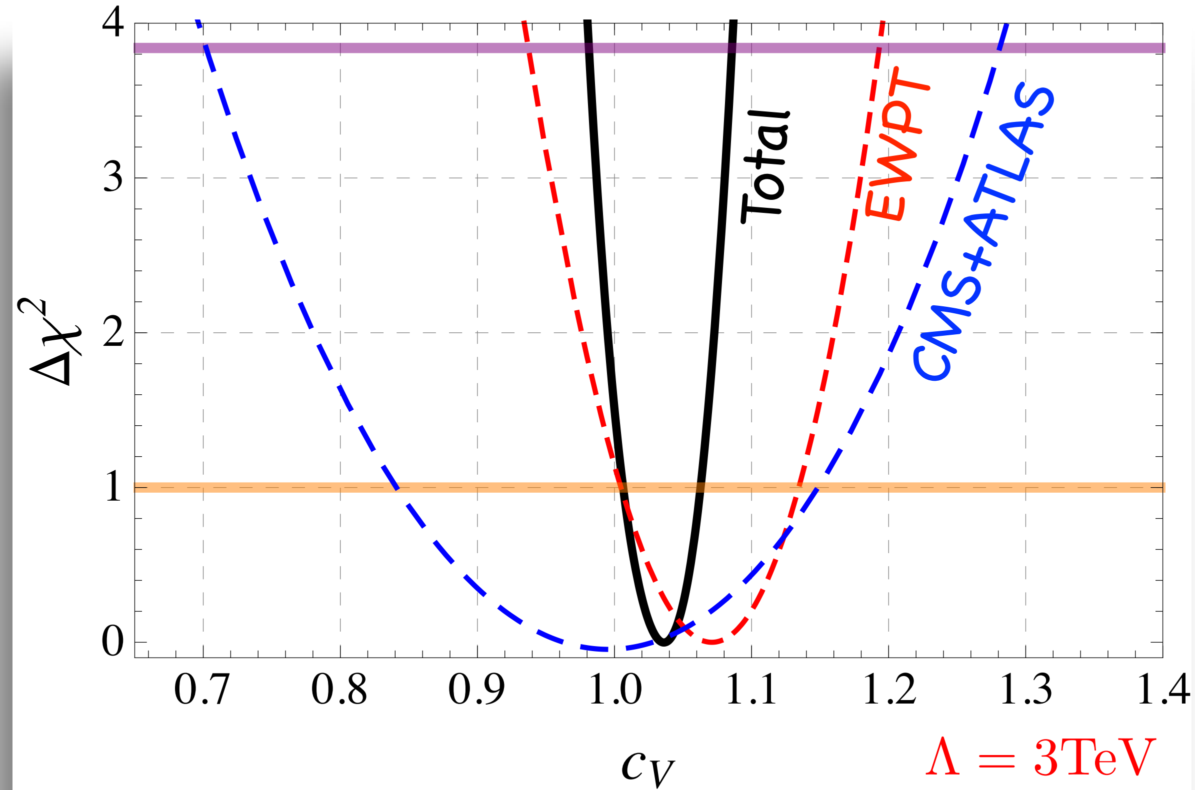
$$\mathbf{m_\varphi^2 \sim \varepsilon}$$

But present data is telling us that the 125 GeV state has to do with EWSB

Most genuine Higgs coupling:
(discloses its role in EWSB)



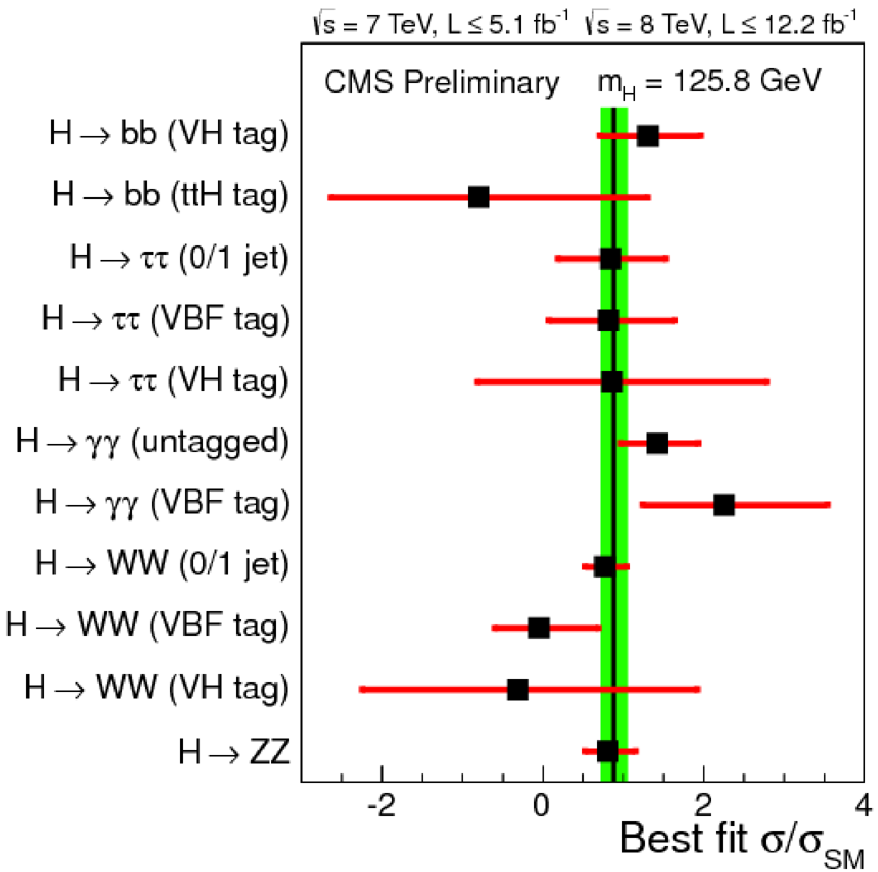
$$c_V = \frac{g_{hVV}}{g_{hVV}^{\rm SM}}$$

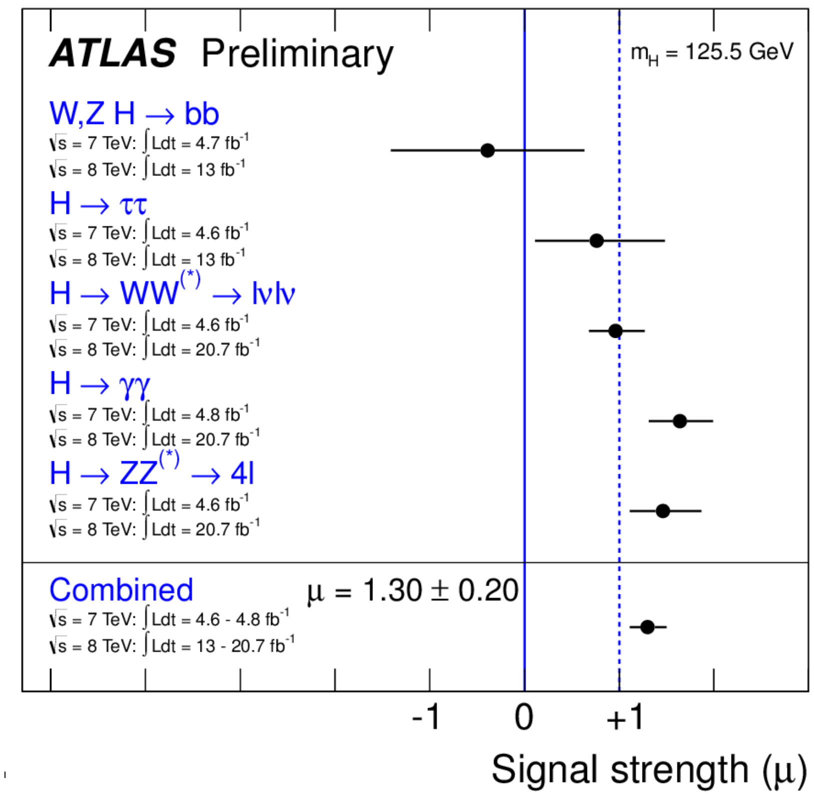


Falkowski,Riva,Urbano 13

it behaves as a Higgs doublet!

Furthermore no significant deviations from a SM Higgs!



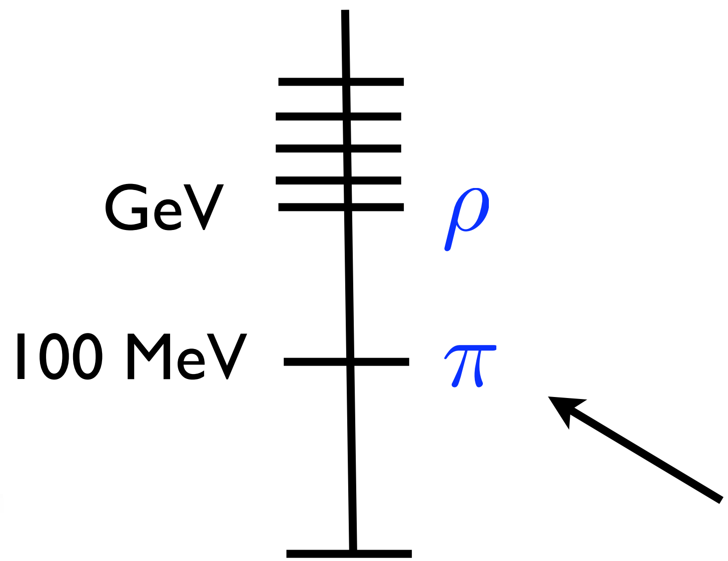


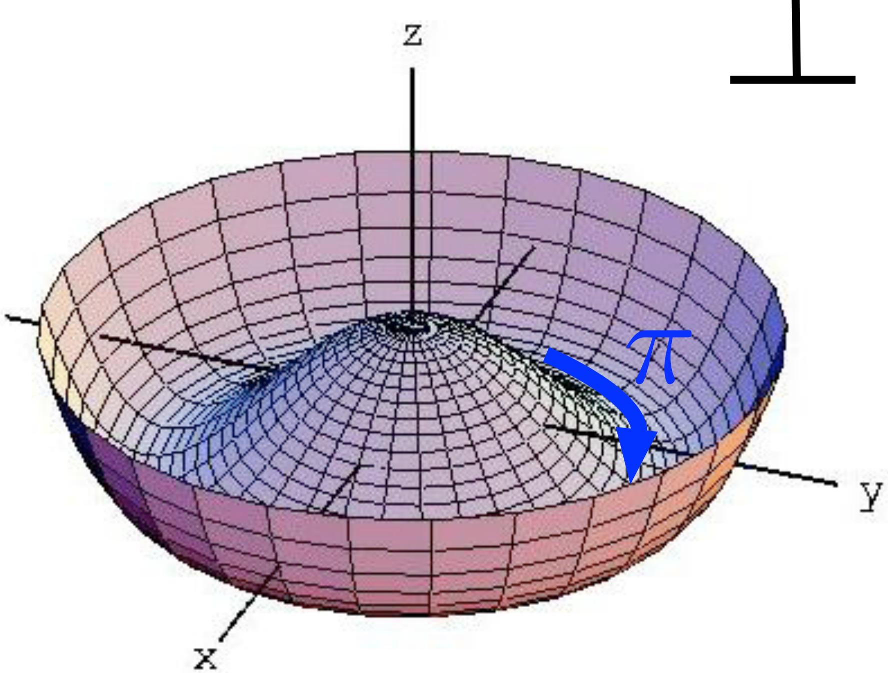
3) Higgs as a Pseudo-Goldstone boson (PGB)

3) Higgs as a composite PGB:

inspired by QCD where one observes
that the (pseudo) scalar are the lightest states

Spectrum:





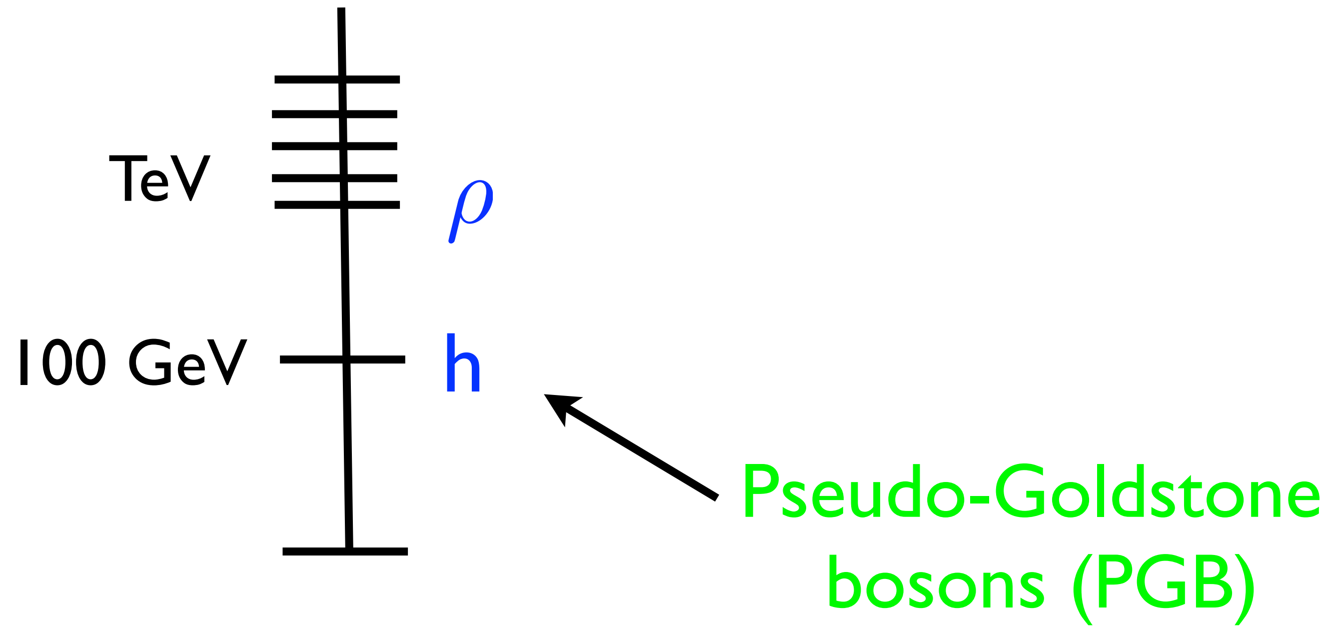
Are Pseudo-Goldstone bosons (PGB)

Mass protected by the global QCD symmetry!

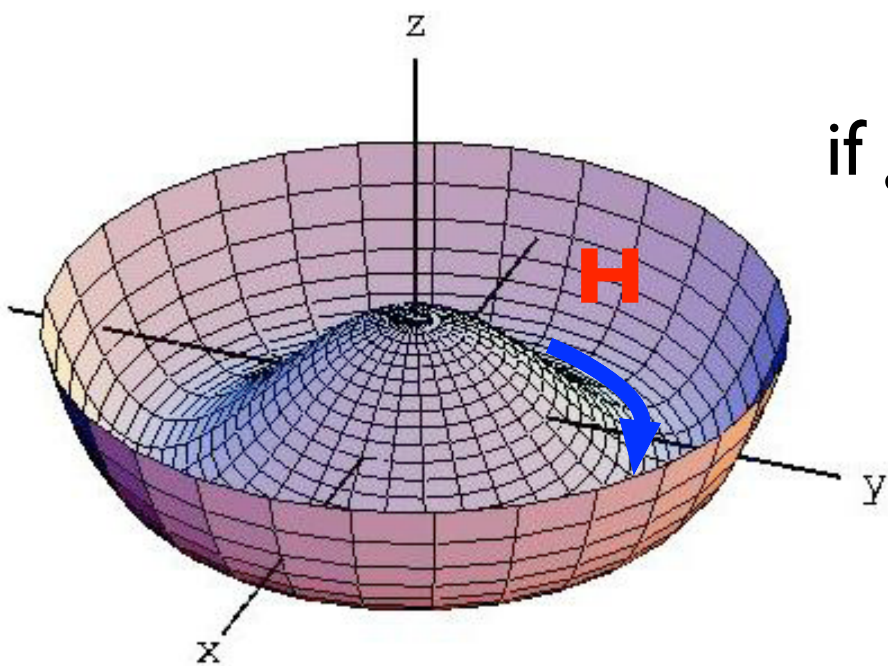
$$\pi \to \pi + \alpha$$

→ **Can the light Higgs be a kind of a pion from a new strong sector?**

We'd like the spectrum of the new strong sector to be:



Potential from some new **strong dynamics at the TeV**:



if global symmetry breaking

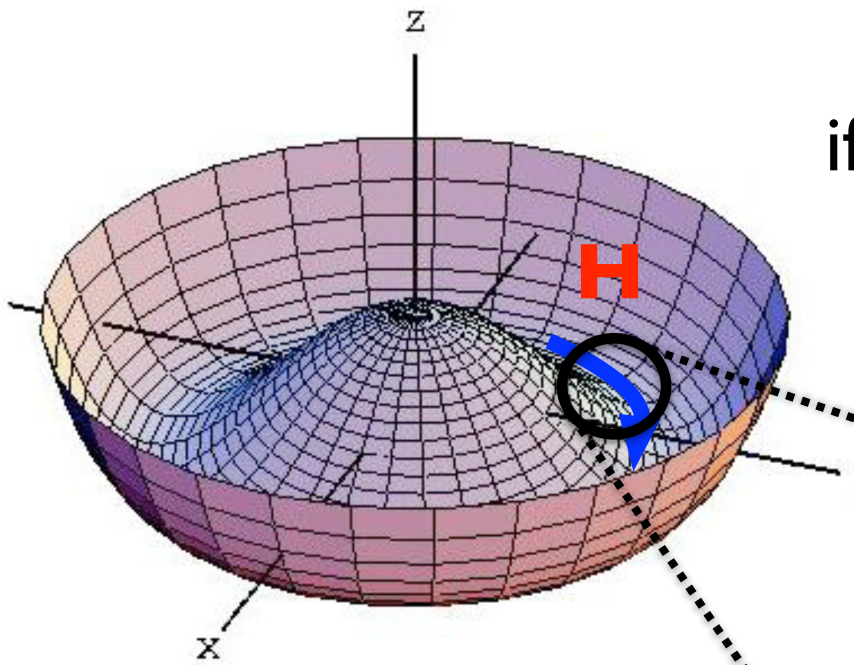
e.g. SO(5) → SO(4)

4 Goldstones

⇓

Higgs doublet

Potential from some new **strong dynamics at the TeV**:



if global symmetry breaking

e.g. SO(5) → SO(4)

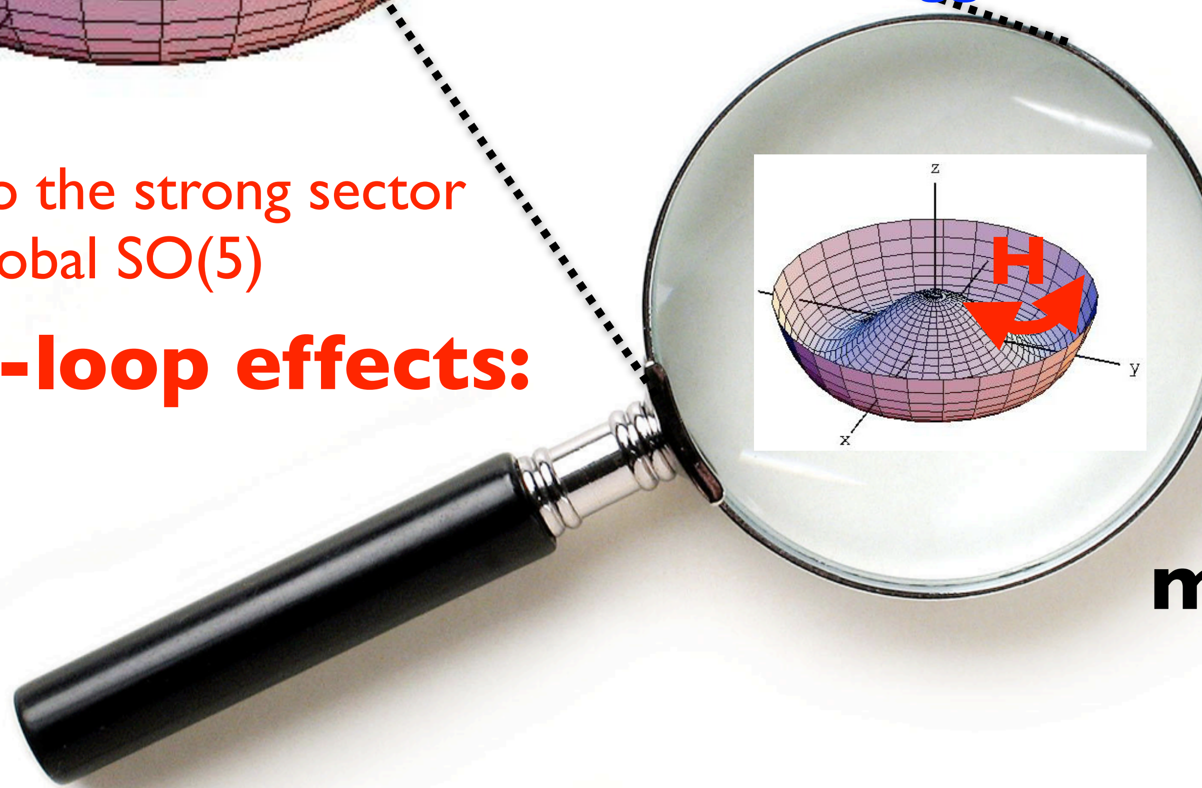
4 Goldstones

⇓

Higgs doublet

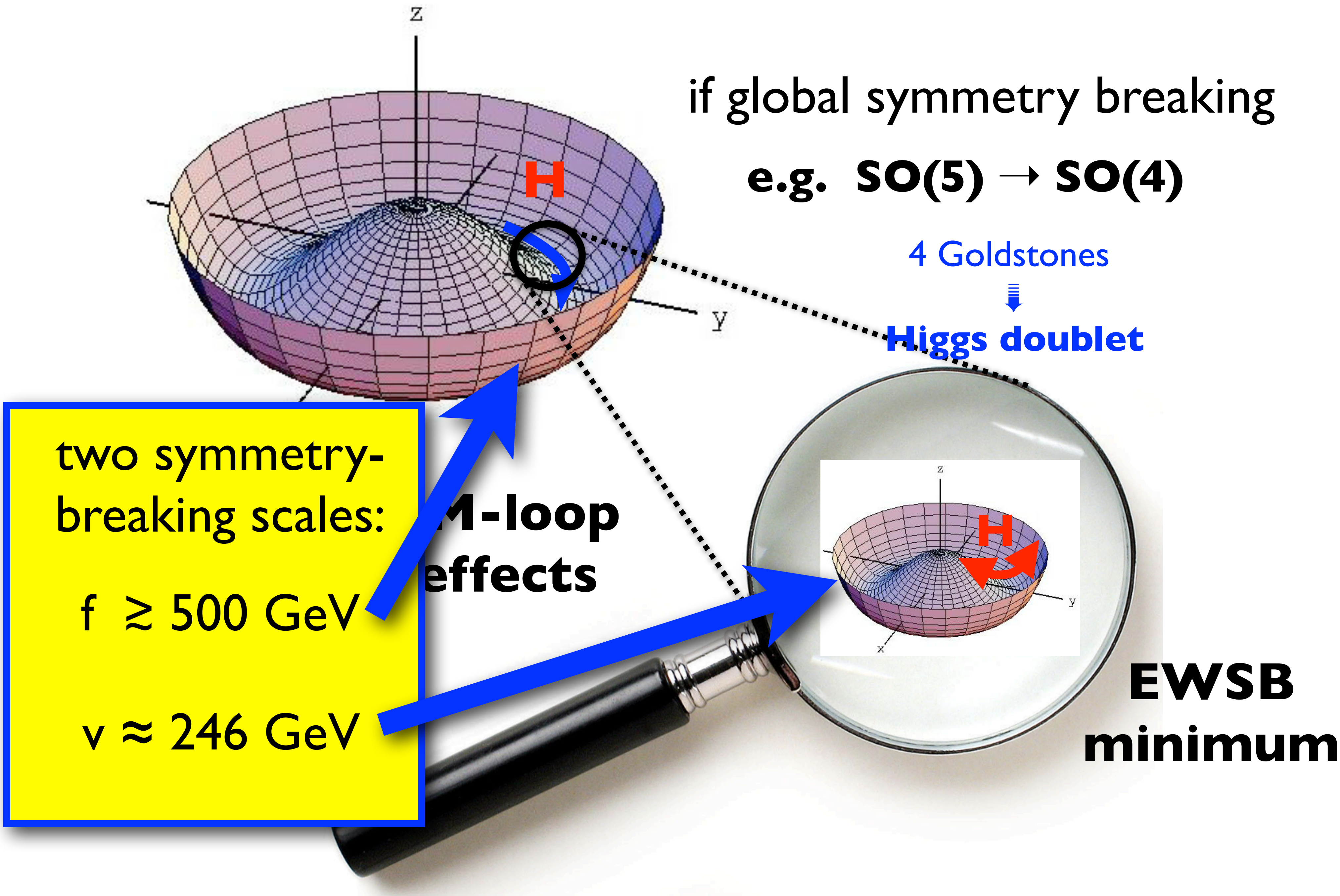
SM-field couplings to the strong sector
break the global SO(5)

SM-loop effects:



EWSB minimum

Potential from some new **strong dynamics at the TeV**:



Galloway, Evans, Luty, Tacchi 10

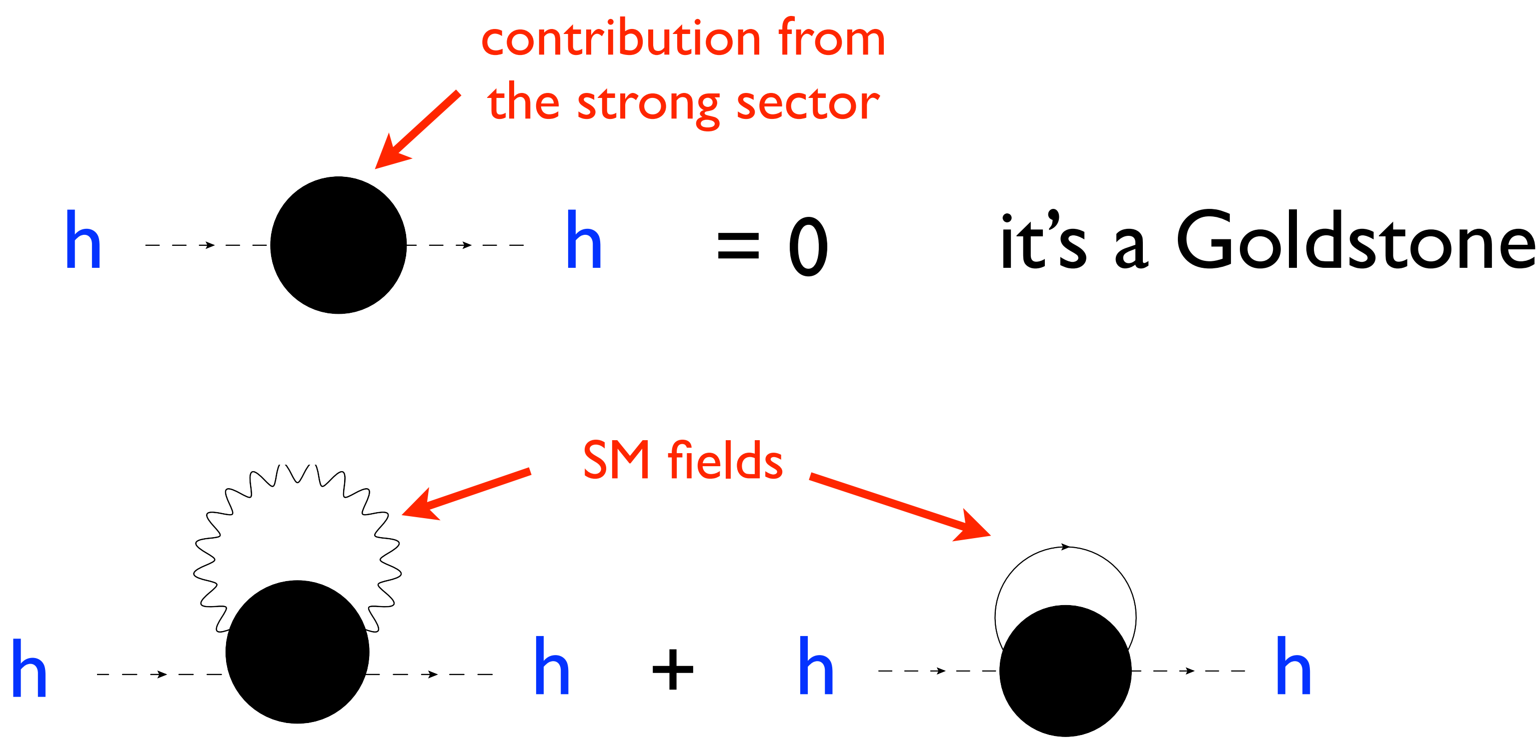
Example: Just replace in QCD **SU(3)$_c$** by **SU(2)$_c$**

2 flavors: ψ_L, ψ_R^c $2_L + 2_R = 4$ of SU(4)

if $\langle\Psi\Psi\rangle$ breaks SU(4)~SO(6) → SO(5)

5 Goldstones = **Higgs doublet**
and a singlet

Higgs Mass



$$\hookrightarrow \quad V(h) = \frac{g_{SM}^2 m_\rho^2}{16\pi^2} h^2 + \cdots$$

Difficult to get predictions due to the intractable **strong** dynamics**!**

A possibility to move forward has been to use the...

AdS/CFT approach

Strongly-coupled systems
in the Large N_c
Large $\lambda \equiv g^2 N_c$

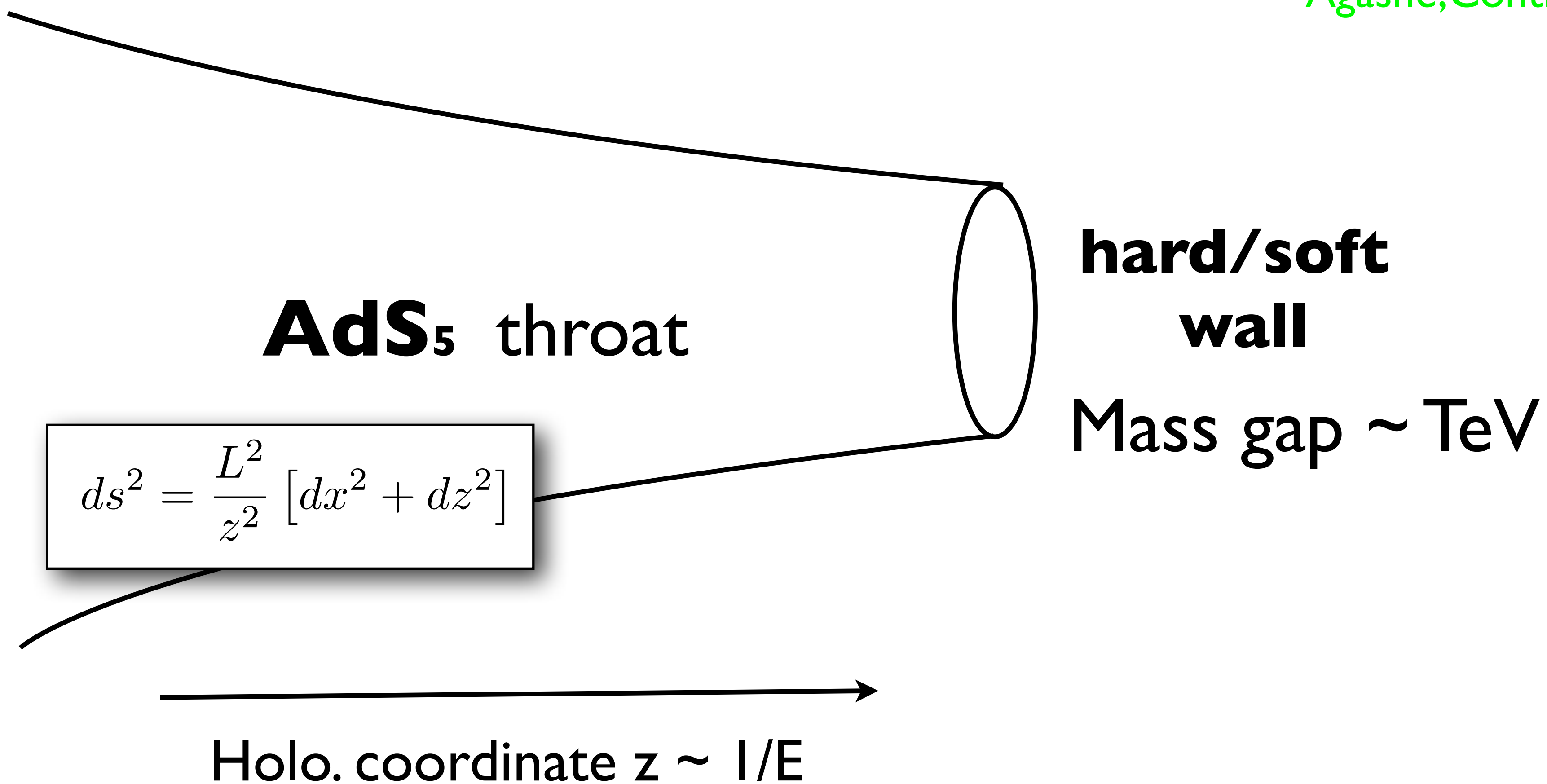
→

Weakly-coupled Gravitational systems in higher-dimensions

Very **useful** to derive properties of **composite states**
from studying weakly-coupled fields
in warped extra-dimensional models

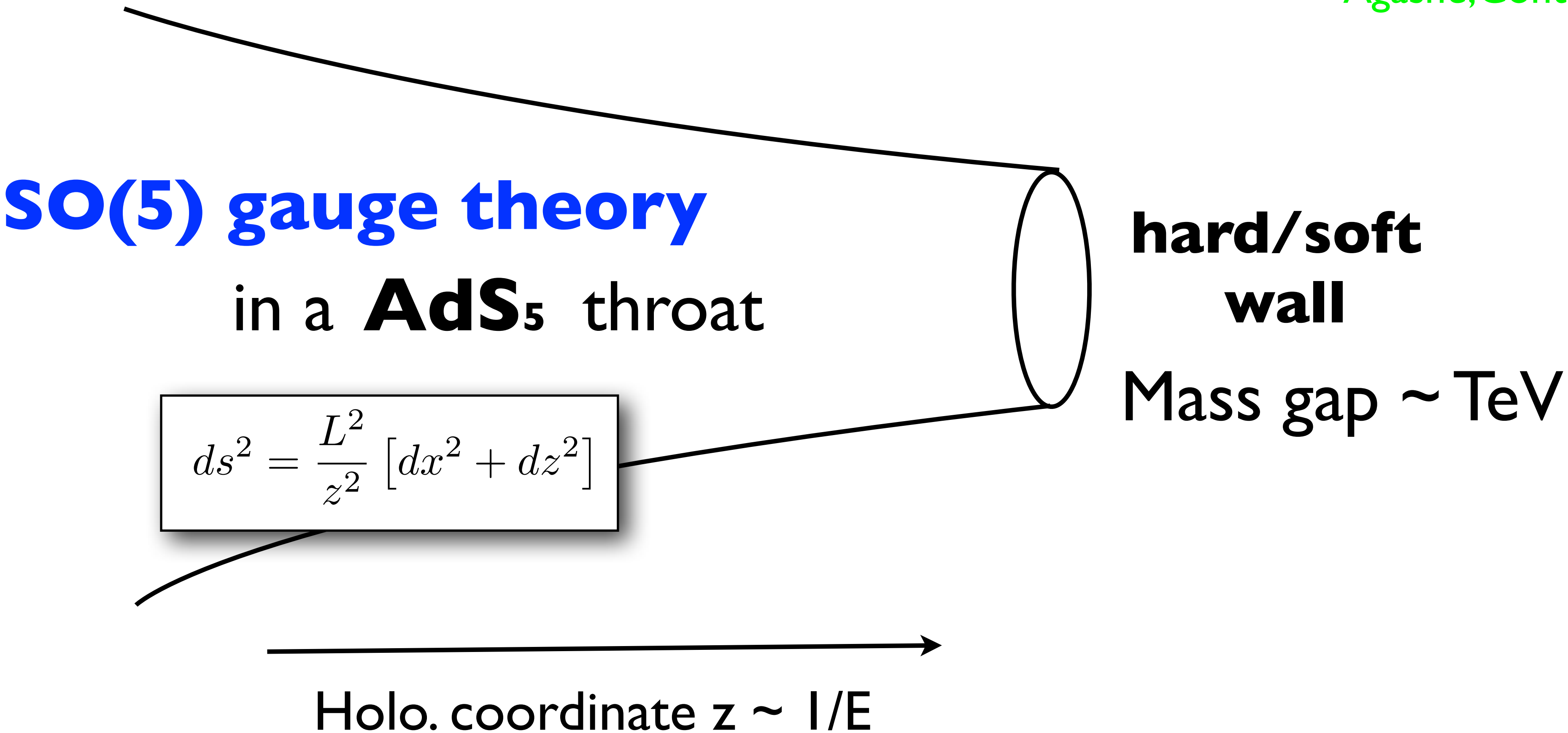
Holographic composite PGB Higgs model

Agashe, Contino, A.P.



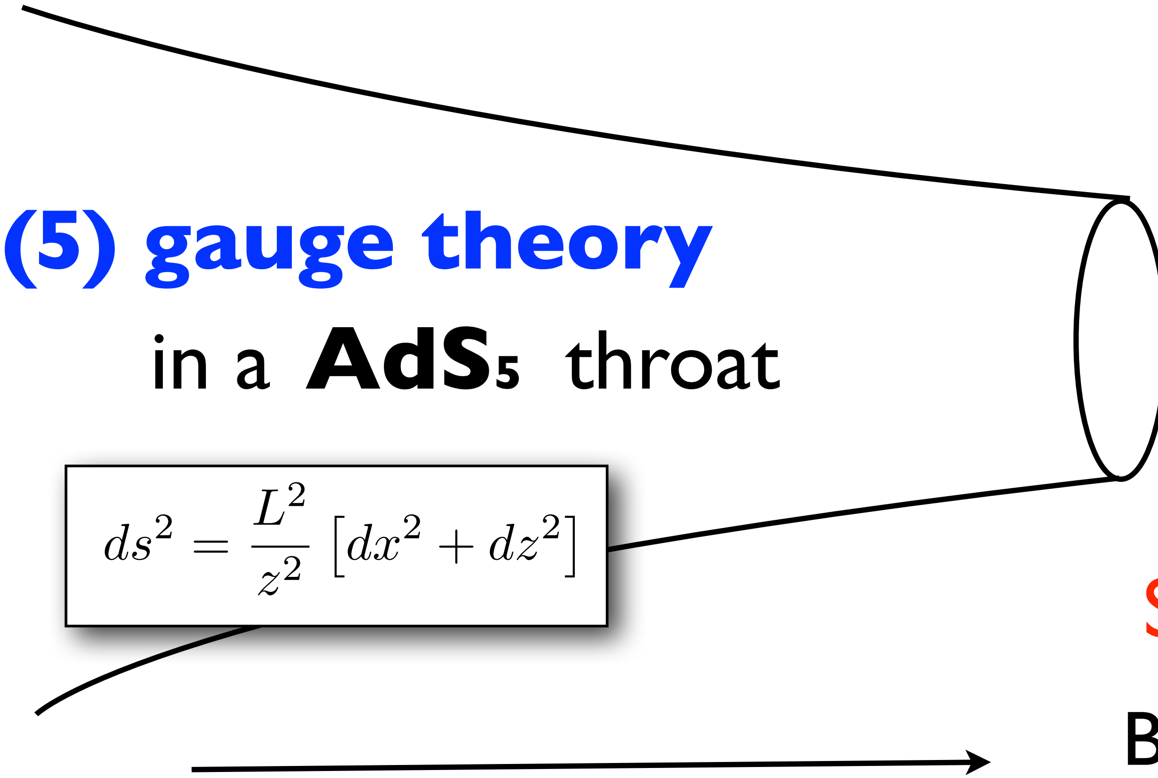
Holographic composite PGB Higgs model

Agashe, Contino, A.P.



Holographic composite PGB Higgs model

Agashe, Contino, A.P.



SO(5) gauge theory

in a **AdS$_5$** throat

$$ds^2 = \frac{L^2}{z^2}\left[dx^2 + dz^2\right]$$

Holo. coordinate z ~ 1/E

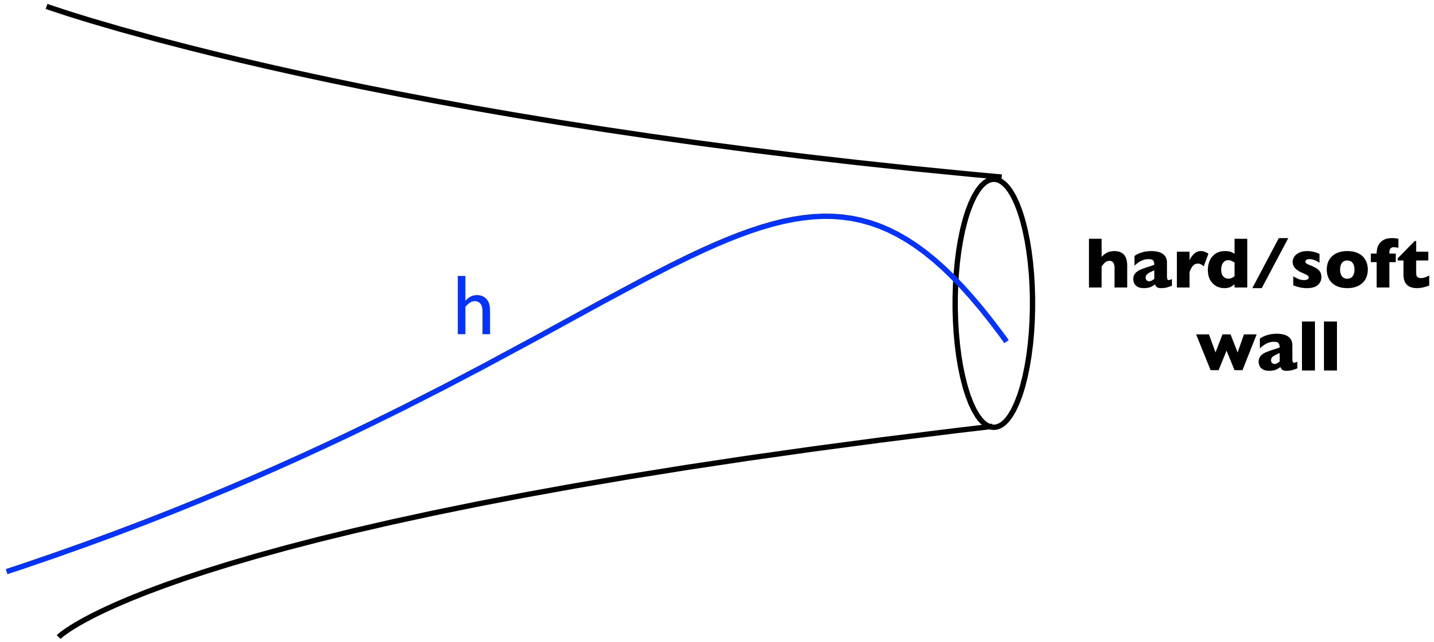
hard/soft wall

Mass gap ~ TeV

Symmetry : **SO(4)**

Breaking of symmetry by boundary conditions

Massless Spectrum



Higgs = 5th component
of the SO(5)/SO(4) gauge bosons

(Gauge-Higgs unification, Hosotani Mechanism,...)

➥ Normalizable modes = **Composite**

What about fermions?
(Main difficulty in composite models)

The fermionic sector: We have to choose the bulk symmetry representation of the fermions and b.c. giving only the 4D massless spectrum of the SM

Up-quark sector: $\mathbf{5}_{2/3}$ of $\mathrm{SO}(5)\times\mathrm{U}(1)_X$.

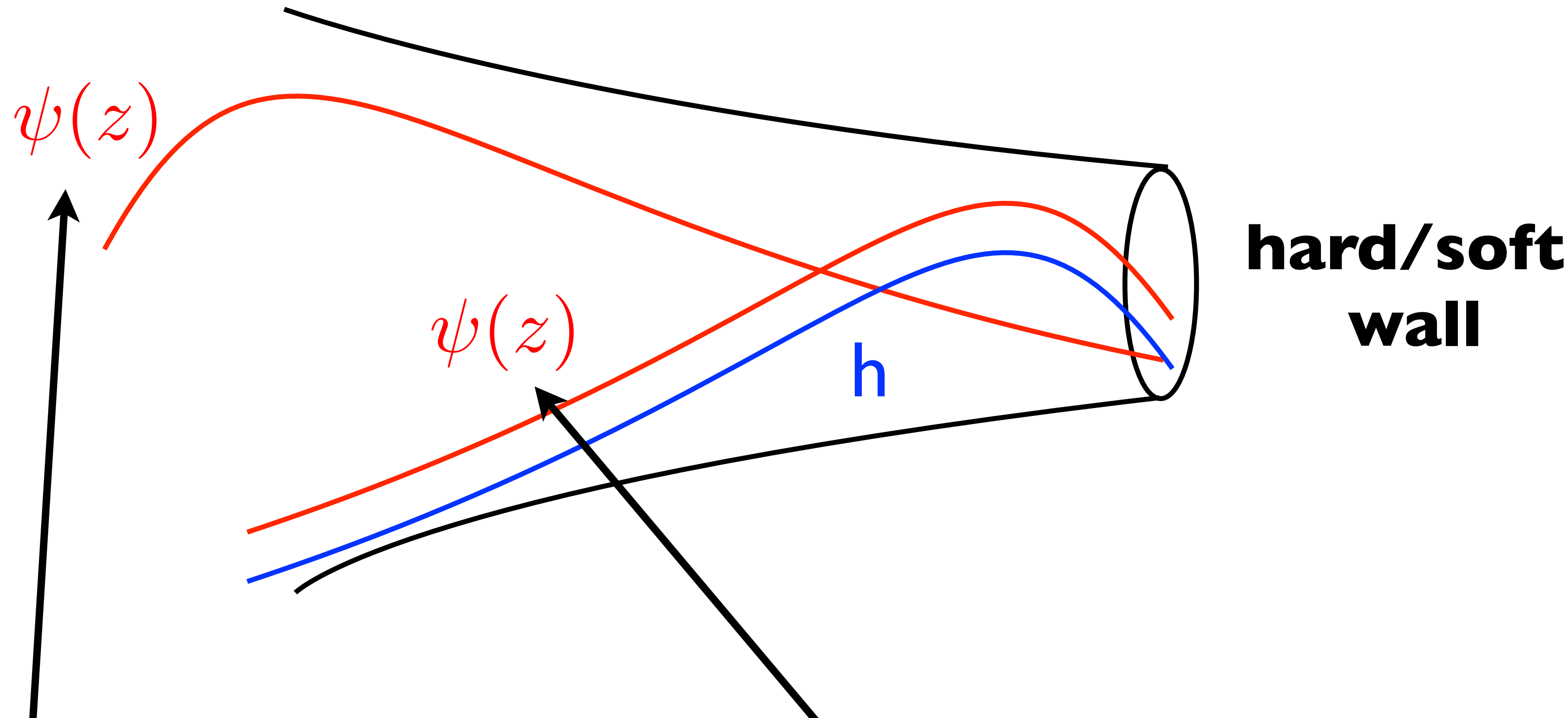
$$\xi_q = (\Psi_{q\,L}\ ,\Psi_{q\,R}) = \begin{bmatrix} (\mathbf{2},\mathbf{2})^{\mathbf{q}}_{\mathbf{L}} = \begin{bmatrix} q'_L(-+) \\ q_L(++) \end{bmatrix} & , & (\mathbf{2},\mathbf{2})^{\mathbf{q}}_{\mathbf{R}} = \begin{bmatrix} q'_R(+-) \\ q_R(--) \end{bmatrix} \\ (\mathbf{1},\mathbf{1})^{\mathbf{q}}_{\mathbf{L}}(--) & , & (\mathbf{1},\mathbf{1})^{\mathbf{q}}_{\mathbf{R}}(++) \end{bmatrix}$$

$$\xi_u = (\Psi_{u\,L}\ ,\Psi_{u\,R}) = \begin{bmatrix} (\mathbf{2},\mathbf{2})^{\mathbf{u}}_{\mathbf{L}}(+-) & , & (\mathbf{2},\mathbf{2})^{\mathbf{u}}_{\mathbf{R}}(-+) \\ (\mathbf{1},\mathbf{1})^{\mathbf{u}}_{\mathbf{L}}(-+) & , & (\mathbf{1},\mathbf{1})^{\mathbf{u}}_{\mathbf{R}}(+-) \end{bmatrix},$$

IR-bound. mass:

$$\widetilde{m}_u\, \overline{(\mathbf{2},\mathbf{2})}^{\mathbf{q}}_{\mathbf{L}}(\mathbf{2},\mathbf{2})^{\mathbf{u}}_{\mathbf{R}} + \widetilde{M}_u\, \overline{(\mathbf{1},\mathbf{1})}^{\mathbf{q}}_{\mathbf{R}}(\mathbf{1},\mathbf{1})^{\mathbf{u}}_{\mathbf{L}} + h.c.$$

Simple geometric approach to fermion masses



1st & 2nd family
(Elementary)

3rd family
(**Top** = Most Composite)

4D CFT Interpretation

Contino,AP

SM fermions Ψ are linearly coupled to a CFT operator:

$$\mathcal{L} = \lambda\,\Psi \cdot \mathcal{O}_\Psi + \mathcal{L}_{\rm CFT}$$

$$\mathrm{Dim}[\mathcal{O}_\Psi] = \frac{3}{2} + |M_\Psi + \frac{1}{2}|$$

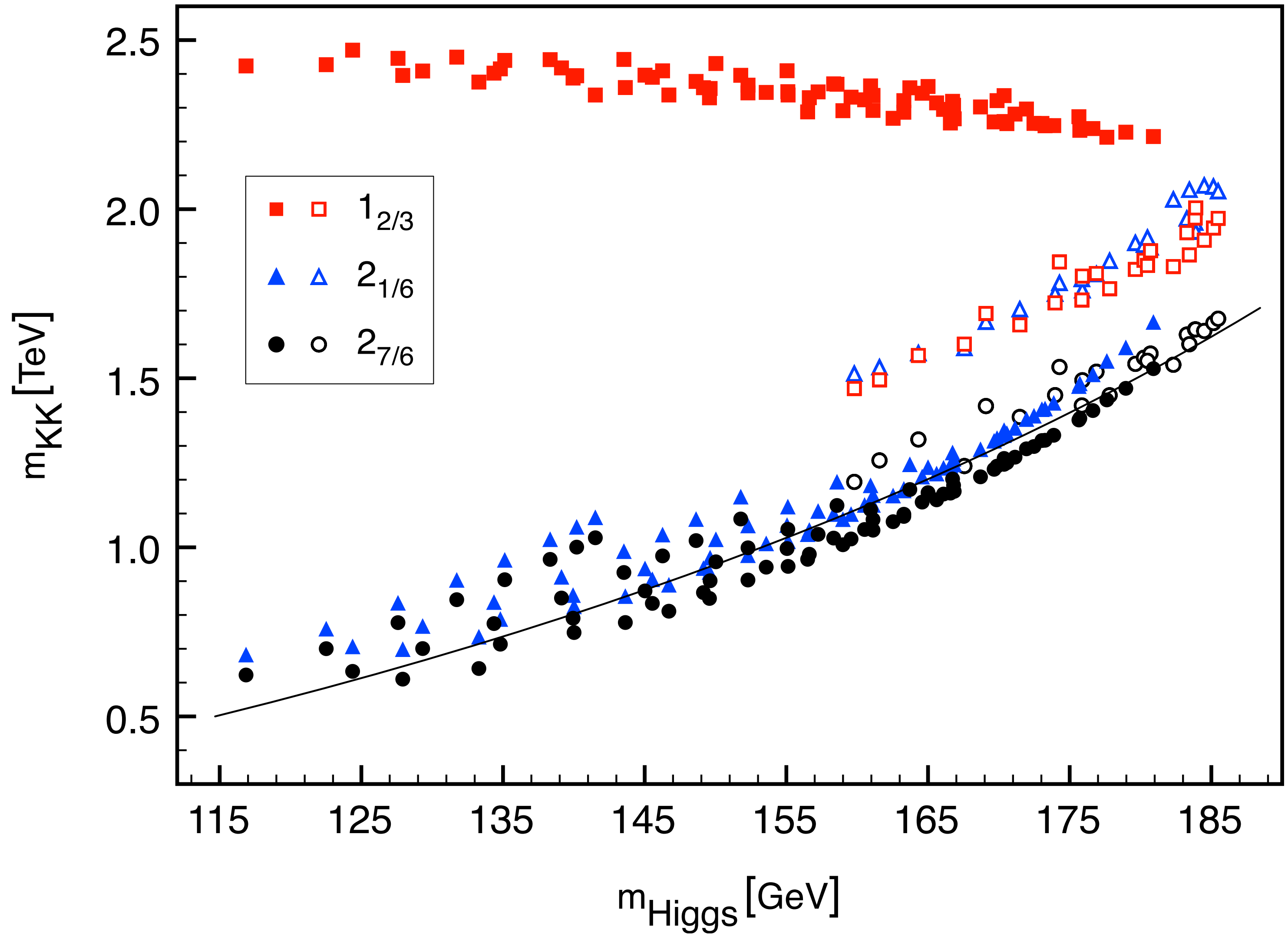
5D mass

$M_\Psi \geq 1/2 \rightarrow \gamma_\lambda \geq 0$ Irrelevant coupling

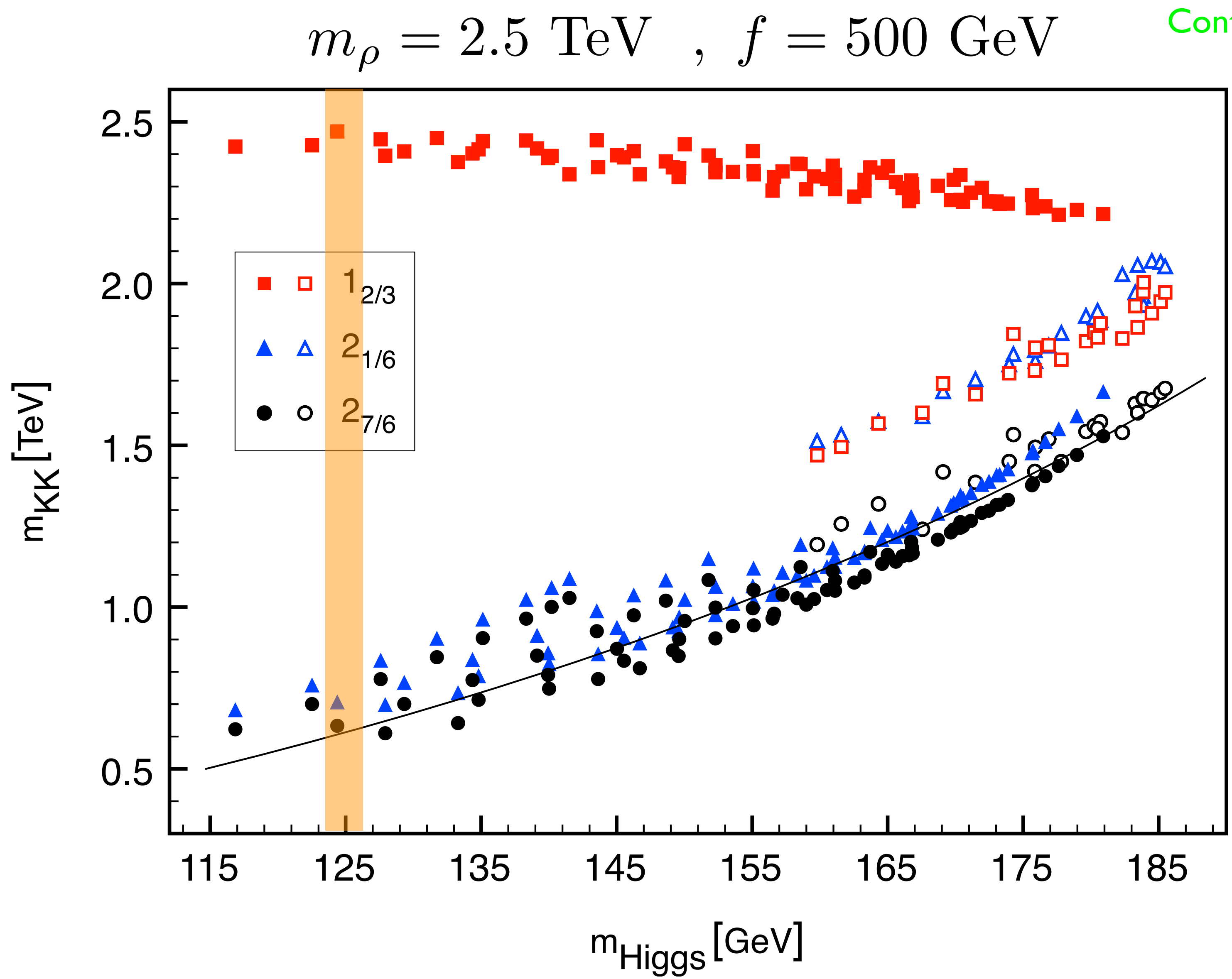
$|M_\Psi| < 1/2 \rightarrow \gamma_\lambda < 0$ Relevant coupling

$m_\rho = 2.5$ TeV , $f = 500$ GeV

Contino,DaRold,AP 07



Contino, DaRold, AP 07



For a 125 GeV Higgs, the fermionic **resonances** of the top are lighter ~ 600 GeV

Why this correlation?

$$m_h^2 \sim \frac{N_c}{\pi^2}\frac{m_t^2}{f^2}m_Q^2 \sim (125\ \mathrm{GeV})^2\left(\frac{m_Q}{700\ \mathrm{GeV}}\right)^2$$

But why the model can accommodate light resonances?

Is it natural?

Why this correlation?

$$m_h^2 \sim \frac{N_c}{\pi^2}\frac{m_t^2}{f^2} m_Q^2 \sim (125\ \text{GeV})^2 \left(\frac{m_Q}{700\ \text{GeV}}\right)^2$$

But why the model can accommodate light resonances?

Is it natural? ***Yes***

AdS/CFT dictionary: $\text{Dim}[\mathcal{O}_\Psi] = \frac{3}{2} + |M_\Psi + \frac{1}{2}|$

$$M_\Psi = -1/2 \quad \rightarrow \quad \text{Dim}[\mathcal{O}_\Psi] = 3/2$$

5D mass: free parameter

becomes a free field ~ decouple from the CFT

➥ in this limit, new light states

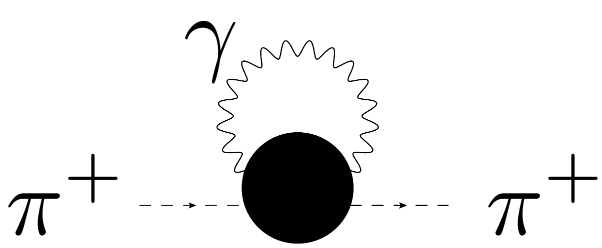
Simpler derivation of the connection:
Light Higgs - Light Resonance

Simpler derivation of the connection:
Light Higgs - Light Resonance

- Deconstruction: Matsedonskyi,Panico,Wulzer; Redi,Tesi 12
- "Weinberg Sum Rules": Marzocca,Serone,Shu; AP, Riva 12

➥ As Das,Guralnik,Mathur,Low,Young 67
for the charged pion mass:

$$m_{\pi^+}^2 - m_{\pi^0}^2 \simeq \frac{3\alpha}{2\pi} m_\rho^2 \log 2 \simeq (37\ \mathrm{MeV})^2$$



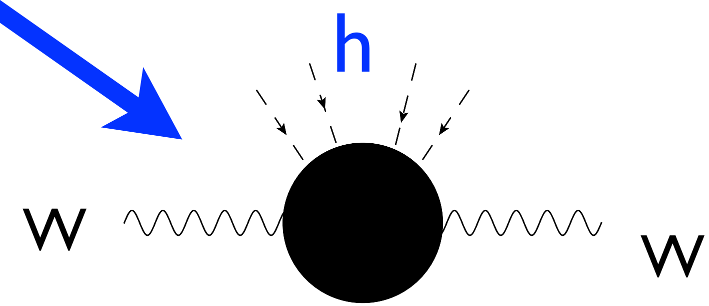
Exp. (35 MeV)²

quite successful!

Higgs potential

Gauge contribution (limit g'=0):

$$V(h) = \frac{9}{2}\int \frac{d^4p}{(2\pi)^4}\,\log \Pi_W$$



Encode the strong-sector contribution
to the gauge propagator
in the h-background

$$\Pi_W \simeq \frac{p^2}{g^2} + \frac{\sin^2 h/f}{2}\left[\langle J_{\hat{a}} J_{\hat{a}}\rangle - \langle J_a J_a\rangle\right]$$

Broken and **Conserved**
current-current correlators of the strong sector

Higgs Mass from Weinberg Sum Rules

Gauge contribution:

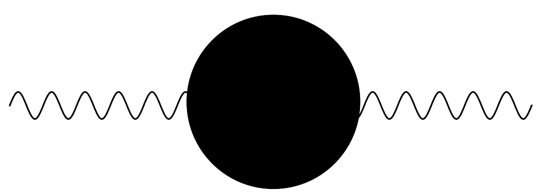
$$V(h) = \frac{9}{2}\int \frac{d^4p}{(2\pi)^4}\, \log \Pi_W \;=\; \frac{1}{2} m_h^2 h^2 + \cdots$$

$$\Rightarrow \quad m_h^2 \simeq \frac{9g^2}{2f^2}\int \frac{d^4p}{(2\pi)^4}\,\frac{\Pi_1(p)}{p^2}$$

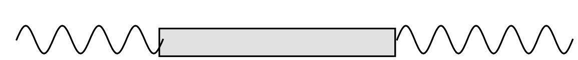
$$\Pi_1 = 2\left[\langle J_{\hat a} J_{\hat a}\rangle - \langle J_a J_a\rangle\right] = f^2 + 2p^2 \sum_n^{\infty} \frac{F_{a_n}^2}{p^2 + m_{a_n}^2} - 2p^2 \sum_n^{\infty} \frac{F_{\rho_n}^2}{p^2 + m_{\rho_n}^2}$$

Euclidean momentum

Large N



$$= \sum_n$$



$$F_{a_n} = \langle 0 | J_{\hat a} | a_n \rangle \qquad a_n \in \mathbf{4} \text{ of } SO(4)$$

$$F_{\rho_n} = \langle 0 | J_a | \rho_n \rangle \qquad \rho_n \in \mathbf{6}$$

Higgs Mass from Weinberg Sum Rules

Gauge contribution:

$$V(h) = \frac{9}{2}\int \frac{d^4p}{(2\pi)^4}\,\log \Pi_W \;=\frac{1}{2}m_h^2 h^2+\cdots$$

$$\Rightarrow \quad m_h^2 \simeq \frac{9g^2}{2f^2}\int \frac{d^4p}{(2\pi)^4}\frac{\Pi_1(p)}{p^2}$$

$$\Pi_1 = 2\left[\langle J_{\hat a}J_{\hat a}\rangle - \langle J_a J_a\rangle\right] = f^2 + 2p^2\sum_n^\infty \frac{F_{a_n}^2}{p^2+m_{a_n}^2} - 2p^2\sum_n^\infty \frac{F_{\rho_n}^2}{p^2+m_{\rho_n}^2}$$

Procedure:

1) Demand convergence of the integral:

$$\lim_{p^2\to\infty}\Pi_1(p)=0\ , \qquad \lim_{p^2\to\infty}p^2\Pi_1(p)=0\ ;$$ "Weinberg Sum Rules"

Higgs Mass from Weinberg Sum Rules

Gauge contribution:

$$V(h) = \frac{9}{2}\int \frac{d^4p}{(2\pi)^4}\,\log \Pi_W \;=\; \frac{1}{2}m_h^2 h^2 + \cdots$$

➥ $$m_h^2 \simeq \frac{9g^2}{2f^2}\int \frac{d^4p}{(2\pi)^4}\frac{\Pi_1(p)}{p^2}$$

$$\Pi_1 = 2\left[\langle J_{\hat a} J_{\hat a}\rangle - \langle J_a J_a\rangle\right] = f^2 + 2p^2\sum_n^\infty \frac{F_{a_n}^2}{p^2+m_{a_n}^2} - 2p^2\sum_n^\infty \frac{F_{\rho_n}^2}{p^2+m_{\rho_n}^2}$$

Procedure:

1) Demand convergence of the integral:

$$\lim_{p^2\to\infty}\Pi_1(p) = 0\,, \qquad \lim_{p^2\to\infty} p^2\Pi_1(p) = 0\,,$$ "Weinberg Sum Rules"

$$\left[\langle J_{\hat a} J_{\hat a}\rangle - \langle J_a J_a\rangle\right] \sim \frac{\langle \mathcal{O}\rangle}{p^{d-2}} + \cdots$$

Just from the OPE at large p

$d = \mathrm{Dim}[\mathcal{O}]$

➥ symmetry breaking operator

➥ WSR = demand d>4

Higgs Mass from Weinberg Sum Rules

Gauge contribution:

$$V(h) = \frac{9}{2}\int \frac{d^4p}{(2\pi)^4} \log \Pi_W \;=\; \frac{1}{2} m_h^2 h^2 + \cdots$$

$$\Rightarrow \quad m_h^2 \simeq \frac{9g^2}{2f^2}\int \frac{d^4p}{(2\pi)^4}\frac{\Pi_1(p)}{p^2}$$

$$\Pi_1 = 2\left[\langle J_{\hat{a}} J_{\hat{a}}\rangle - \langle J_a J_a\rangle\right] = f^2 + 2p^2 \sum_n^{\infty} \frac{F_{a_n}^2}{p^2 + m_{a_n}^2} - 2p^2 \sum_n^{\infty} \frac{F_{\rho_n}^2}{p^2 + m_{\rho_n}^2}$$

Procedure:

1) Demand convergence of the integral:

$$\lim_{p^2\to\infty} \Pi_1(p) = 0 \;, \qquad \lim_{p^2\to\infty} p^2\Pi_1(p) = 0 \;,$$ “Weinberg Sum Rules”

Just from the OPE at large p

e.g. in QCD:

$$\Pi_{LR}(p) \;=\; \Pi_V - \Pi_A \;\to\; \langle q\bar{q}\rangle^2/p^4$$

Higgs Mass from Weinberg Sum Rules

Gauge contribution:

$$V(h) = \frac{9}{2}\int \frac{d^4p}{(2\pi)^4} \log \Pi_W \;=\; \frac{1}{2} m_h^2 h^2 + \cdots$$

$$\Rightarrow \quad m_h^2 \simeq \frac{9g^2}{2f^2}\int \frac{d^4p}{(2\pi)^4}\frac{\Pi_1(p)}{p^2}$$

$$\Pi_1 = 2\left[\langle J_{\hat a} J_{\hat a}\rangle - \langle J_a J_a\rangle\right] = f^2 + 2p^2 \sum_n^\infty \frac{F_{a_n}^2}{p^2+m_{a_n}^2} - 2p^2 \sum_n^\infty \frac{F_{\rho_n}^2}{p^2+m_{\rho_n}^2}$$

Procedure:

1) Demand convergence of the integral:

$$\lim_{p^2\to\infty} \Pi_1(p) = 0 \,, \qquad \lim_{p^2\to\infty} p^2 \Pi_1(p) = 0$$ "Weinberg Sum Rules"

2) The correlators are dominated by the lowest resonances (minimal number to satisfy WSR)

Result: two resonances needed: ρ and a_1

$$\Pi_1(p) = \frac{f^2 m_\rho^2 m_{a_1}^2}{(p^2 + m_\rho^2)(p^2 + m_{a_1}^2)}$$

➥ $$m_h^2 \simeq \frac{9 g^2 m_\rho^2 m_{a_1}^2}{64\pi^2 (m_{a_1}^2 - m_\rho^2)} \log\left(\frac{m_{a_1}^2}{m_\rho^2}\right)$$

Similar result as the electromagnetic contribution
to the charged pion mass

Similarly, for the top contribution...

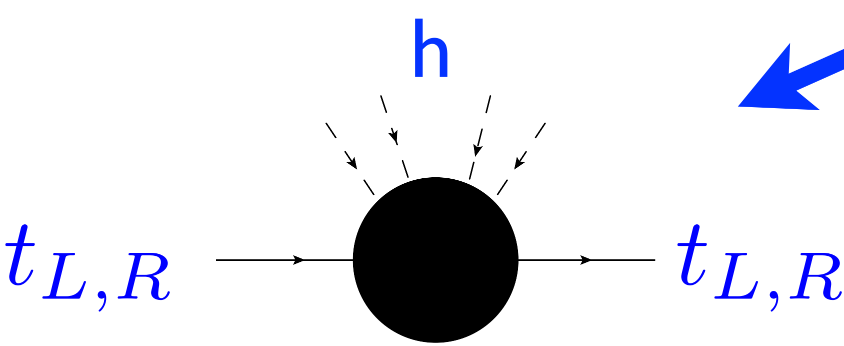
$$\mathcal{L} = \mathcal{L}_{\rm strong} + \mathcal{L}_{\rm SM} + J^{\mu}_{\rm strong} W_{\mu} + \mathcal{O}_{\rm strong} \cdot \psi_{\rm SM}$$

we must specify which rep of SO(5)

$$\mathrm{MCHM}_5 \;\equiv\; \mathrm{Rep}[\mathcal{O}] = 5$$

Top contribution to the Higgs potential:

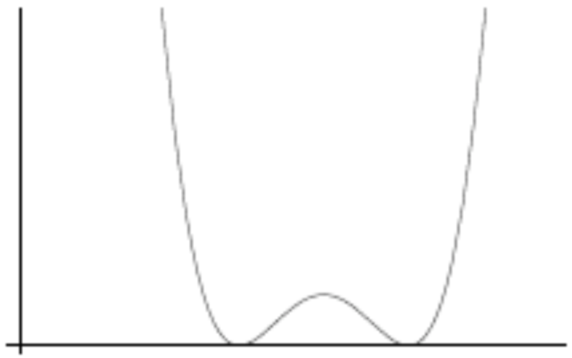
$$V(h) = -2N_c \int \frac{d^4p}{(2\pi)^4} \log\left[-p^2\left(\Pi^{t_L}\Pi^{t_R}\right) - |\Pi^{t_L t_R}|^2\right]$$



Encode the strong sector contribution
to the top propagator
in the h-background

$$V(h) = -2N_c \int \frac{d^4p}{(2\pi)^4} \log\left[-p^2\left(\Pi^{t_L}\Pi^{t_R}\right) - |\Pi^{t_L t_R}|^2\right]$$

$$= -m^2h^2 + \lambda_h h^4 + \cdots$$



Triggers EWSB!

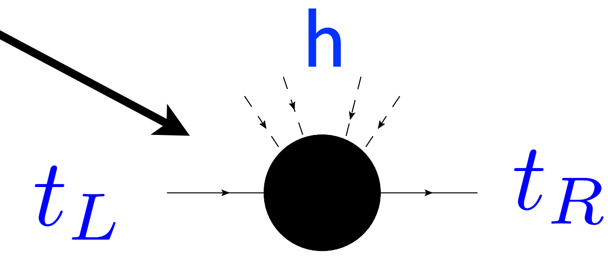
Higgs mass contribution:

$$m_h^2 \simeq \frac{8N_c v^2}{f^4} \int \frac{d^4p}{(2\pi)^4} \left[\frac{|M_1^t|^2}{p^2} + \frac{1}{4} \left(\Pi_1^{t_L} \right)^2 + \left(\Pi_1^{t_R} \right)^2 \right]$$

Higgs mass contribution:

$$m_h^2 \simeq \frac{8N_c v^2}{f^4} \int \frac{d^4p}{(2\pi)^4} \left[\frac{|M_1^t|^2}{p^2} + \frac{1}{4} \left(\Pi_1^{t_L}\right)^2 + \left(\Pi_1^{t_R}\right)^2 \right]$$

responsible
of the top mass



$$\left\{ \begin{aligned} \Pi_1^{t_L}(p) &= \Pi_{Q_1}^L(p) - \Pi_{Q_4}^L(p)\,, \\ \Pi_1^{t_R}(p) &= \Pi_{Q_1}^R(p) - \Pi_{Q_4}^R(p)\,, \\ M_1^t(p) &= M_{Q_1}(p) - M_{Q_4}(p)\,. \end{aligned} \right.$$

↪ fermion-fermion correlators

5=4+1 of SO(4):

$Q_1 \in \mathbf{1}$

$Q_4 \in \mathbf{4}$

Large N: $\Pi_{Q_4}^L(p) = \sum_n \frac{|F^L_{Q_4^{(n)}}|^2}{p^2 + m^2_{Q_4^{(n)}}}\,, \qquad \Pi_{Q_1}^L(p) = \sum_n \frac{|F^L_{Q_1^{(n)}}|^2}{p^2 + m^2_{Q_1^{(n)}}}\,,$

similarly for $\Pi^R_{Q_{4,1}}$ with the replacement $L \to R$, while

$$M_{Q_4}(p) = \sum_n \frac{F^L_{Q_4^{(n)}} F^{R*}_{Q_4^{(n)}} m_{Q_4^{(n)}}}{p^2 + m^2_{Q_4^{(n)}}}\,, \qquad M_{Q_1}(p) = \sum_n \frac{F^L_{Q_1^{(n)}} F^{R*}_{Q_1^{(n)}} m_{Q_1^{(n)}}}{p^2 + m^2_{Q_1^{(n)}}}\,.$$

Demanding again WSR:

$$\lim_{p\to\infty} M_1^t(p) \;=\; 0$$

$$\lim_{p\to\infty} p^n \Pi_1^{t_{L,R}}(p) = 0 \; (n = 0, 2)$$

... being fulfilled with the minimal set of resonances, two in this case, Q_1 and Q_4:

$$\Pi_1^{t_{L,R}} \;=\; |F_{Q_4}^{L,R}|^2 \frac{(m_{Q_4}^2 - m_{Q_1}^2)}{(p^2 + m_{Q_4}^2)(p^2 + m_{Q_1}^2)} \;,$$

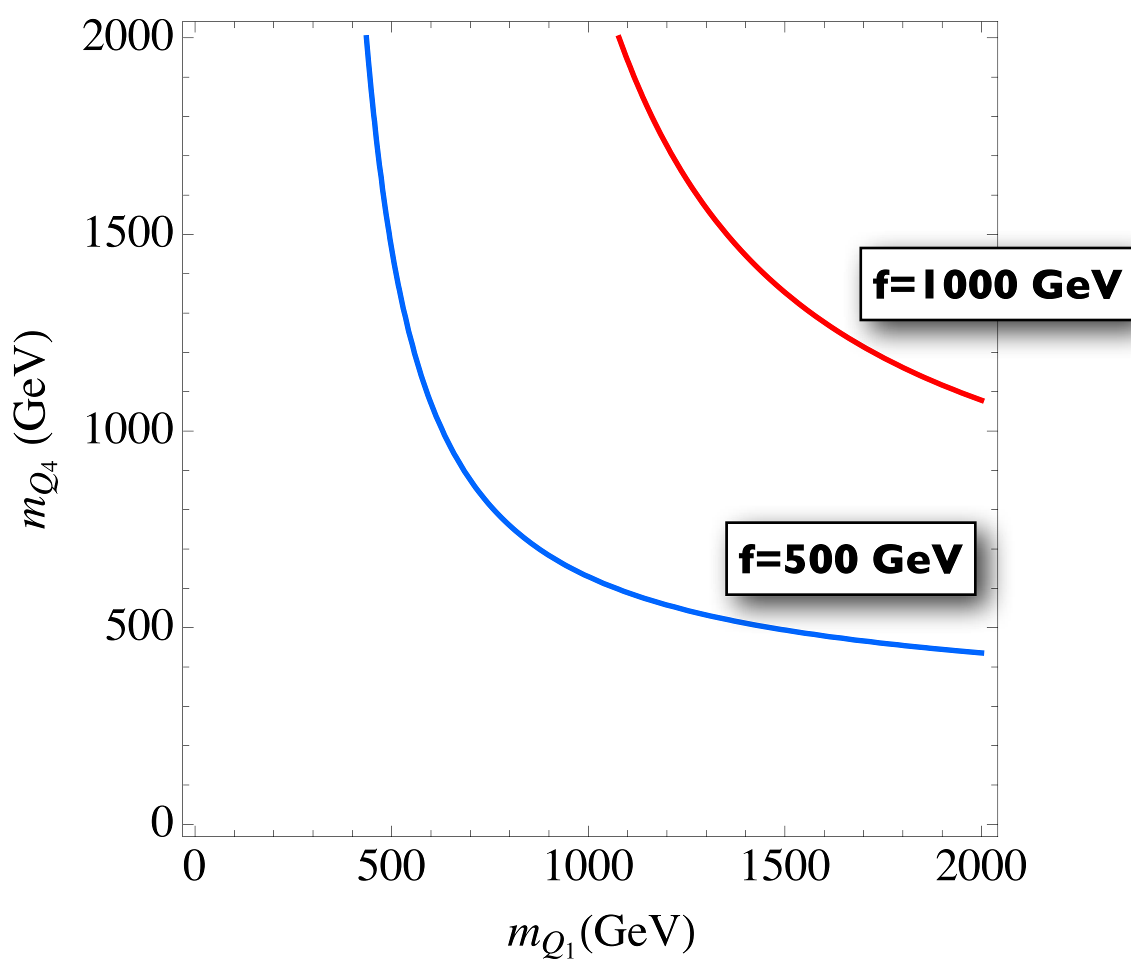
$$M_1^t(p) \;=\; |F_{Q_4}^{L} F_{Q_4}^{R*}| \frac{m_{Q_4} m_{Q_1} (m_{Q_4} - m_{Q_1} e^{i\theta})}{(p^2 + m_{Q_4}^2)(p^2 + m_{Q_1}^2)} \left(1 + \frac{p^2}{m_{Q_4} m_{Q_1}} \frac{m_{Q_1} - m_{Q_4} e^{i\theta}}{m_{Q_4} - m_{Q_1} e^{i\theta}}\right)$$

WSR + Minimal set of resonances (Q_1 and Q_4)
+ proper EWSB

$$m_h^2 \simeq \frac{N_c}{\pi^2}\left[\frac{m_t^2}{f^2}\frac{m_{Q_4}^2 m_{Q_1}^2}{m_{Q_1}^2 - m_{Q_4}^2}\log\left(\frac{m_{Q_1}^2}{m_{Q_4}^2}\right)\right]$$

AP,Riva 12

For a 125 GeV Higgs:

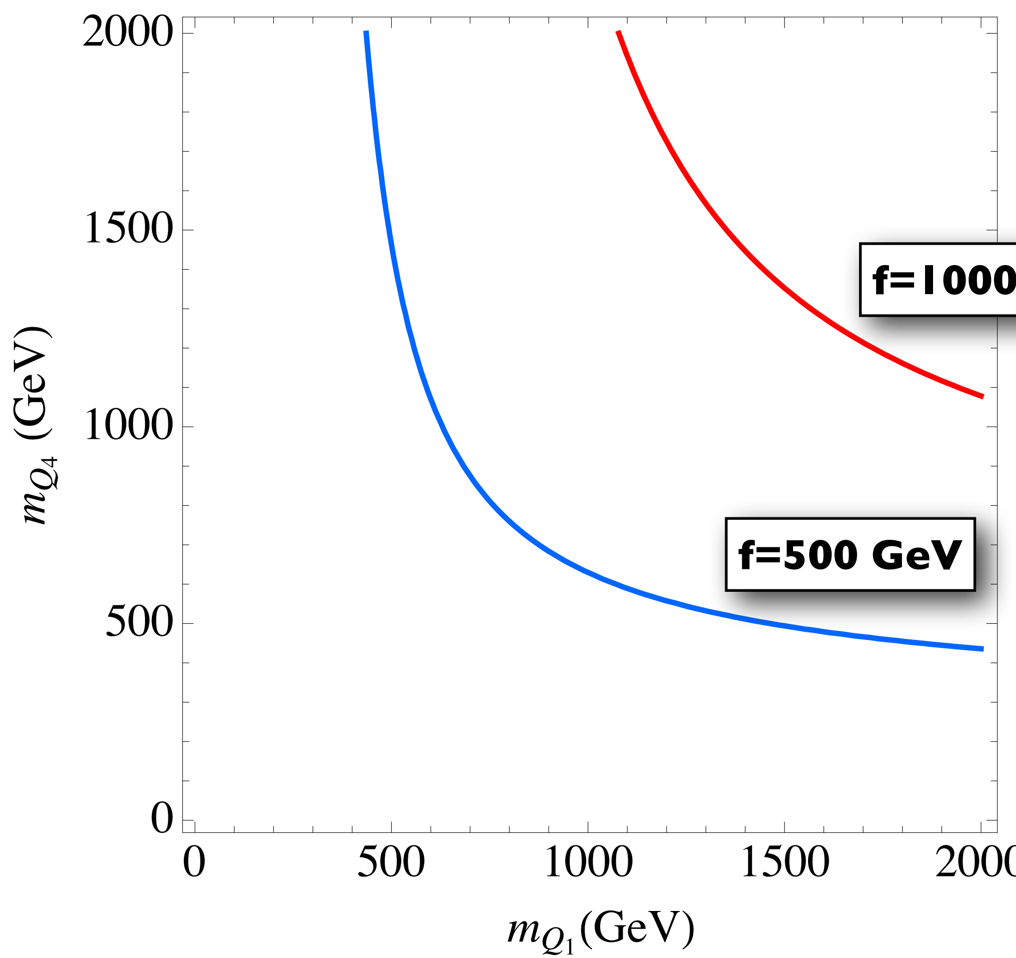


WSR + Minimal set of resonances (Q_1 and Q_4)
+ proper EWSB

$$m_h^2 \simeq \frac{N_c}{\pi^2}\left[\frac{m_t^2}{f^2}\frac{m_{Q_4}^2 m_{Q_1}^2}{m_{Q_1}^2 - m_{Q_4}^2}\log\left(\frac{m_{Q_1}^2}{m_{Q_4}^2}\right)\right]$$

AP,Riva 12

For a 125 GeV Higgs:



Fermionic resonances below 700 GeV

If the 125 GeV Higgs is composite...

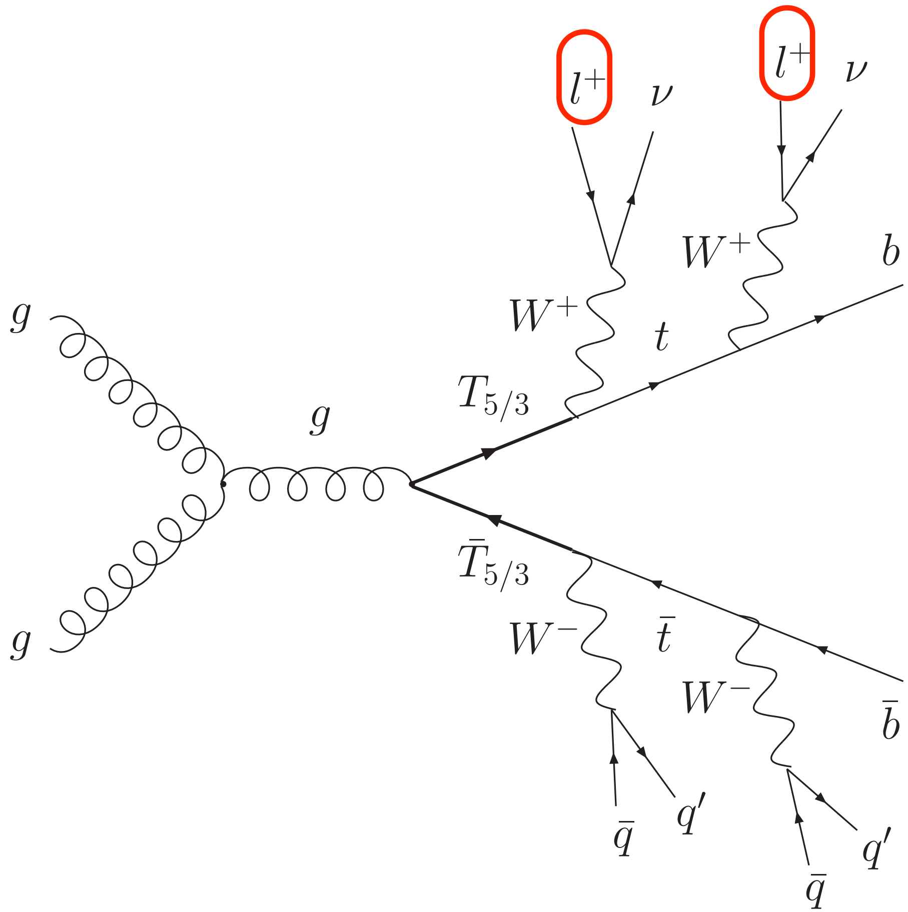
we must find at the LHC
color vector-like fermions in the **4** or **1** rep. of SO(4):

↓

EM charges: 5/3,2/3,-1/3

Color vector-like fermions with charge 5/3:

If this fermion is light, it can be double produced:

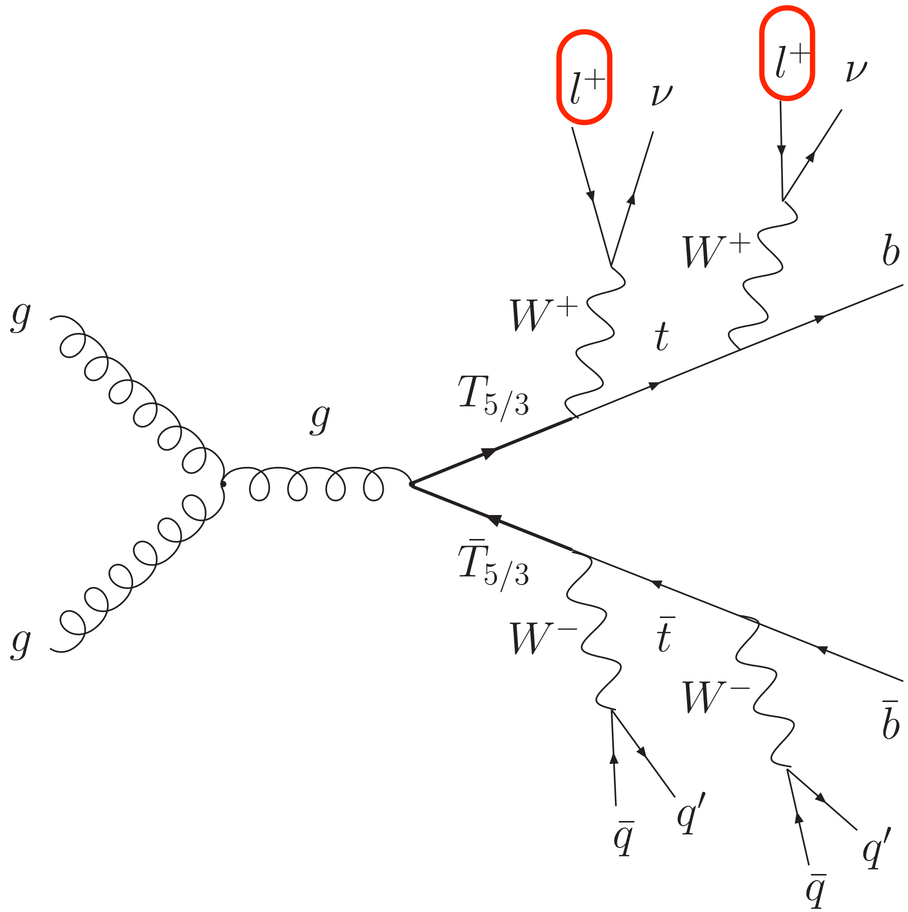


same-sign di-leptons

Contino,Servant
Mrazek, Wulzer
Aguilar-Saavedra,
Dissertori, Furlan,Moorgat,Nef

Color vector-like fermions with charge 5/3:

If this fermion is light, it can be double produced:



same-sign di-leptons

ATLAS-CONF-2012-130:

$$M_{T_{5/3}} \gtrsim 700 \text{ GeV}$$

Contino,Servant
Mrazek, Wulzer
Aguilar-Saavedra,
Dissertori, Furlan,Moorgat,Nef

Higgs couplings

Composite PGB Higgs couplings

Couplings dictated by symmetries (as in the QCD chiral Lagrangian)

Giudice,Grojean,AP,Rattazzi 07

AP,Riva 12

$$\frac{g_{hWW}}{g_{hWW}^{\rm SM}} = \sqrt{1-\frac{v^2}{f^2}}$$

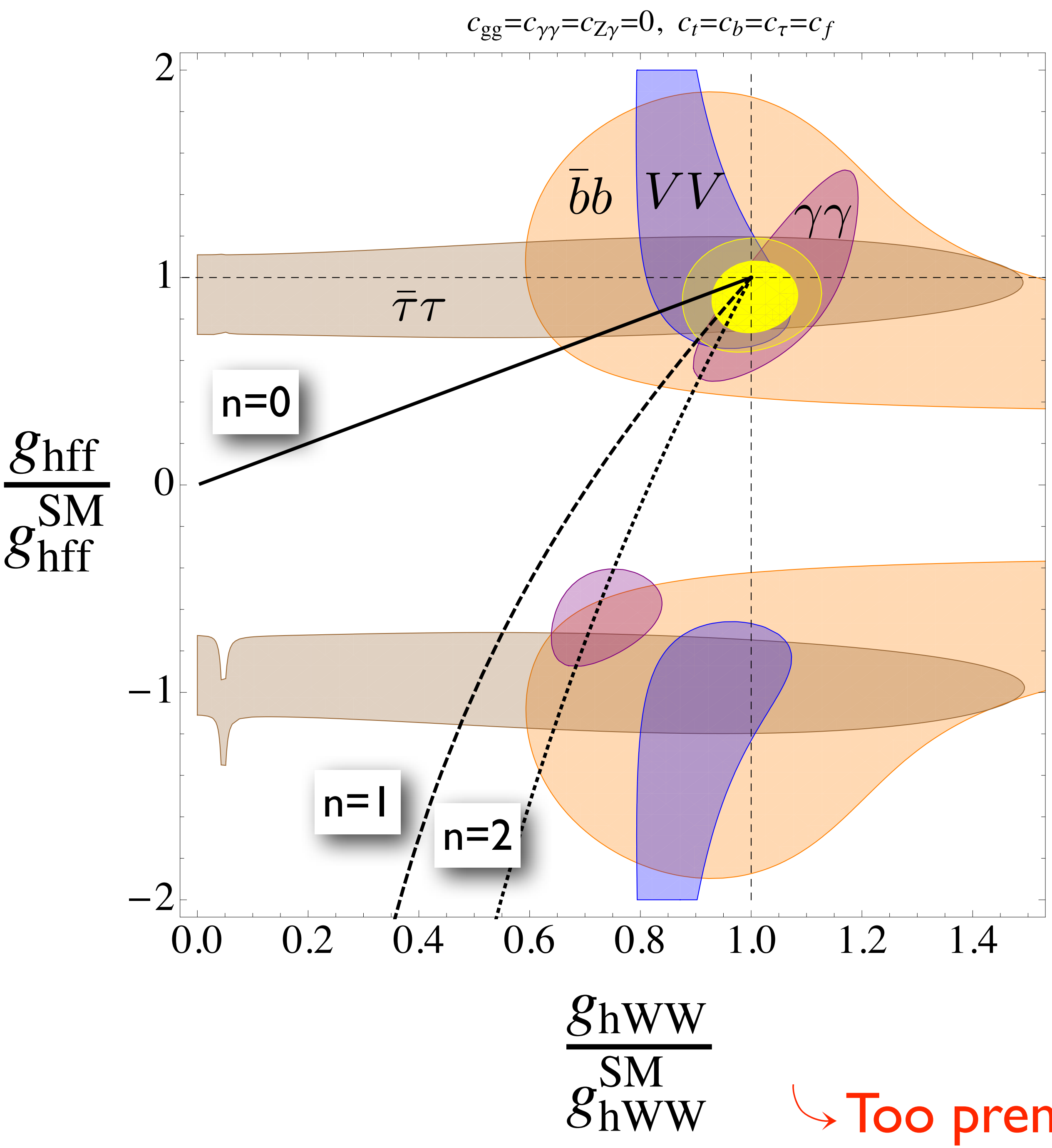
f = Decay-constant of the PGB Higgs

$$\frac{g_{hff}}{g_{hff}^{\rm SM}} = \frac{1-(1+n)\frac{v^2}{f^2}}{\sqrt{1-\frac{v^2}{f^2}}}$$

$n = 0, 1, 2, \ldots$

$n = 1$ ← $\mathrm{MCHM}_{5,10}$

small deviations on the h$\gamma\gamma$(gg)-coupling due to the Goldstone nature of the Higgs



Falkowski,Riva,Urbano 13

↪ Too premature to see deviations for v/f~1/2!

Other symmetry-breaking patterns G→H:

G	H	PGB
SO(5)	SO(4)	4=(2,2)
SO(6)	SO(5)	5=(2,2)+(1,1)
	O(4)xO(2)	8=(2,2)+(2,2)
SO(7)	SO(6)	6=(2,2)+(1,1)+(1,1)
	G_2	7=(1,3)+(2,2)
...	...	...

Other symmetry-breaking patterns G→H:

G	H	PGB
SO(5)	SO(4)	4=(2,2)
SO(6)	SO(5)	5=(2,2)+(1,1)
	O(4)xO(2)	8=(2,2)+(2,2)
SO(7)	SO(6)	6=(2,2)+(1,1)+(1,1)
	G_2	7=(1,3)+(2,2)
...	...	...

One doublet
+ Singlet

Gripaios, AP, Riva, Serra

SB of minimal TC:
Just by replacing
$SU(3)_c$ by $SU(2)_c$

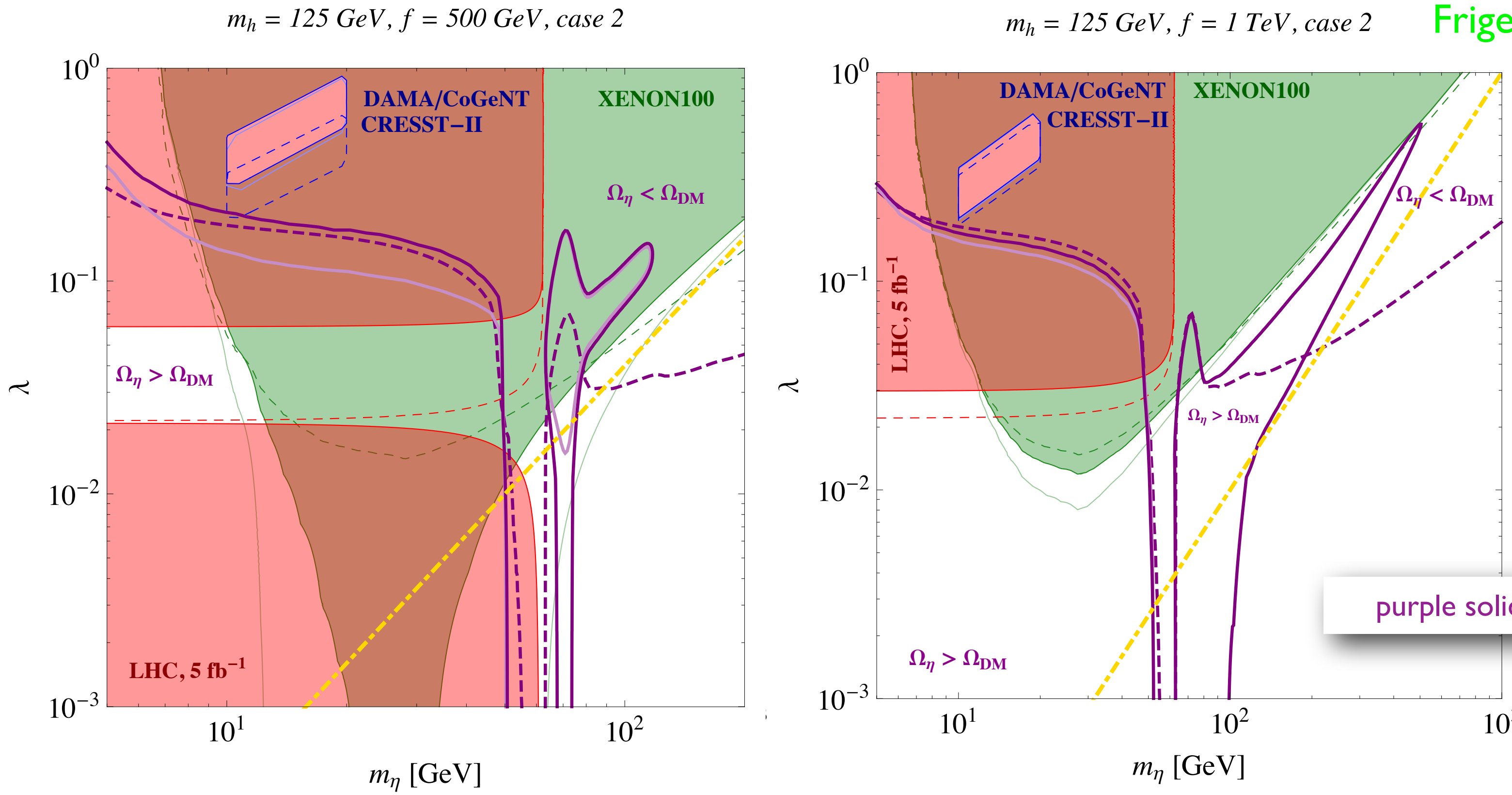
Galloway, Evans, Luty, Tacchi 10

If SO(6)→SO(5) breaking pattern: Doublet h +Singlet η

<u>New player in the game:</u>

- Mass of eta very model-dependent: depends on how the $SO(2) \subset SO(6)$ is explicitly broken
- If extra parity $\eta \to -\eta$ (e.g. if O(6)): η <u>can be Dark Matter</u> !

Frigerio,AP,Riva,Urbano 12



purple solid line: proper relic density

Conclusions

Strong dynamics still possible at the TeV:

- Composite Higgs as a PGB a natural possibility
  (Higgs mass at the loop level)

- A 125 GeV composite Higgs **implies** either from AdS/CFT, Weinberg Sum rules, deconstructed models:

  Fermionic colored vector-like **resonances**
  (either Q_{EM}=5/3,2/3,-1/3) with masses
  ~ 700 GeV

- It gives clear predictions for the Higgs couplings and their deviations from the SM

Hope to see them at the LHC !