New directions in Electroweak Symmetry Breaking

Alex Pomarol , *Univ. Autonoma Barcelona*

After more than 35 years of collecting data,

we have learned that the SM is a very accurate theory!

although Weinberg 1967:

"...don't take it very seriously..."

Explains data at the per-mille level,

but it does not elucidate on the origin of the EW scale.

Beyond the SM

Addressing:

1. Origin of the EW scale (hierarchy problem):

   $$m_W \ll M_P$$

2. Flavor problem:
   - Origin of flavor
   - GIM-mechanism (or not large FCNC)

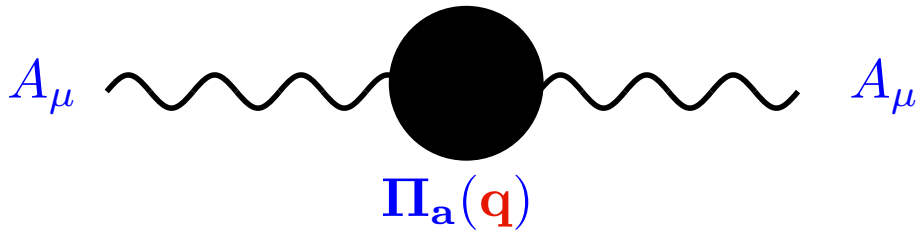
3. EW precision tests:

   Plenty of tests....

   but in certain cases, parametrization of the new physics effects in only 4 parameters: $\widehat{S}$, $\widehat{T}$, W , Y

"Universal" New Physics

• **Assume all New Physics effects in the self-energies of the SM gauge bosons:**



• **Assuming new physics scale $\Lambda_{\rm NP} \gg m_W$, such that we can expand in $q/\Lambda_{\rm NP}$:**

$$\mathbf{\Pi_a(q) = \Pi_a(0) + q^2 \Pi'_a(0) + \frac{q^4}{2} \Pi''_a(0) + ...}$$

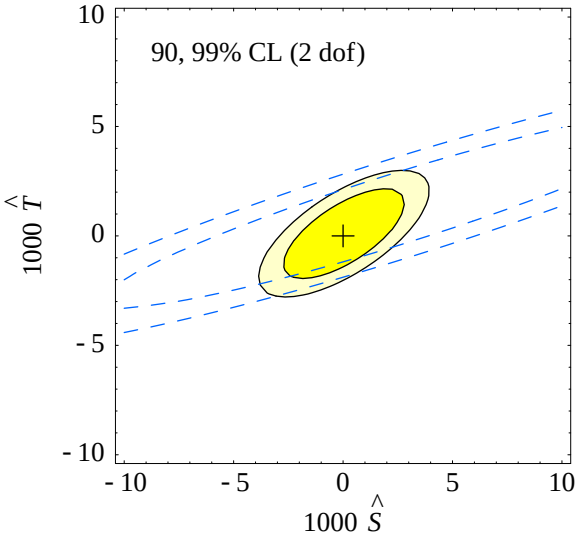
Four Independent Form Factors:

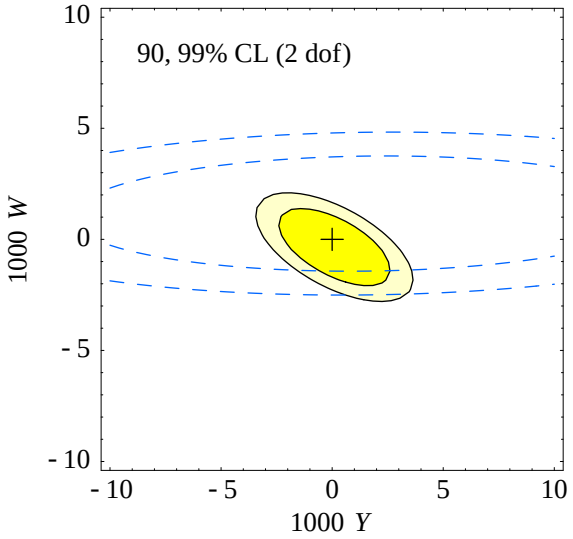
Barbieri,A.P.,Rattazzi,Strumia

		Form factors	custodial	$SU(2)_L$
$\widehat{S}$	$=$	$g^2\,\Pi'_{W_3B}(0)$	$+$	$-$
$\widehat{T}$	$=$	$\frac{g^2}{M_W^2}\,[\Pi_{W_3}(0)-\Pi_{W^+}(0)]$	$-$	$-$
W	$=$	$\frac{g^2M_W^2}{2}\,\Pi''_{W_3}(0)$	$+$	$+$
Y	$=$	$\frac{g'^2M_W^2}{2}\,\Pi''_{B}(0)$	$+$	$+$

$\star$ **Useful parametrization!**

Global constraints on $\widehat{S}$, $\widehat{T}$, W, Y





m_h	$10^3\widehat{S}$	$10^3\widehat{T}$	$10^3 Y$	$10^3 W$
115	0.0 ± 1.3	0.1 ± 0.9	0.1 ± 1.2	-0.4 ± 0.8
800	-0.9 ± 1.3	2.0 ± 1.0	0.0 ± 1.2	-0.2 ± 0.8

In a generic "universal" model, no matter what the Higgs mass is, $\hat{S}$, $\hat{T}$, W and Y must be small, at the 10^{-3} level!

MSSM

1. Hierarchy problem..... *YES*
2. Flavor problem:
   - Origin of flavor..... *NO*
   - GIM-mechanism..... *YES, in certain models*
     (Gauge or moduli mediation of susy breaking)
   - EWPT: ..... *YES*

     Effects at the one-loop level

Recent "Problem" : Clash!

$$\begin{cases} 115\ \text{GeV} \leq m_h^2 \lesssim m_Z^2 + \frac{3h_t^4}{4\pi^2} v^2 \ln\left(\frac{m_{\tilde{t}}^2}{m_t^2}\right) \\ m_Z^2 = \frac{3h_t^2}{2\pi^2} m_{\tilde{t}}^2 \ln\left(\frac{M_S}{m_{\tilde{t}}}\right) + \ldots \end{cases}$$

A tuning of $\approx 5\%$ needed!

Recent Directions:

Higgs as Pseudo-Goldstone Boson (PGB)

Higgs as π in QCD:

Higgs mass protected by a global symmetry:

$$v \sim F_\pi \sim \frac{1}{4\pi} m_\rho \ (where\ m_\rho\ is\ the\ NP\ scale)$$

Problems in strong interactions:

CALCULABILITY!

↙ ↘

Little Higgs
(Collective breaking)

AdS/CFT
(Extra dimensions)

AdS/CFT Correspondence

Maldacena 98, Gubser,Klebanov,Polyakov 98

Relates strongly coupled 4D theories to

weakly coupled 5D theories in AdS

$\Rightarrow$ **Useful tool!**

Here,

Minimal Ingredients to get a realistic Composite PGB Higgs

arising from a 5D theory

Agashe,Contino,A.P.

Minimal

Composite

Higgs

Model

(MCHM similar, in spirit, to the MSSM)

Minimal Requirements for the Strongly Coupled Sector:

1. Delivers a Higgs as PGB
2. Custodial Symmetry: To guarantee $\hat{T} = 0$
3. $G_{\rm global} \ni G_{\rm SM}$

$$\Downarrow$$

$$G_{\rm global} = SO(5) \otimes U(1)_{B-L} \otimes SU(3)_c$$

Symetry Breaking pattern:

$$SO(5) \to SO(4) \simeq SU(2)_L \otimes SU(2)_R$$

10 genera. 6 genera.

$\hookrightarrow$ **4** Goldstone Bosons = **2** of $SU(2)_L$= Higgs

$\Downarrow$ gauging of $\mathrm{SU(2)_L}$

PGB

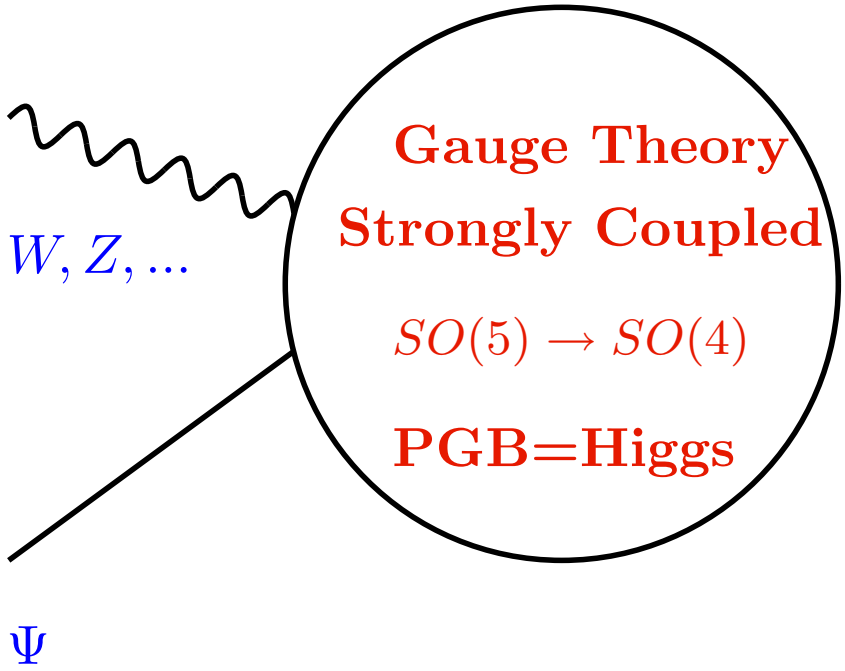
There is a nonzero potential (loop-level) $V(h)$

$\hookrightarrow$ $SO(4) \to SO(3) \simeq SU(2)_{\mathrm{L+R}}$

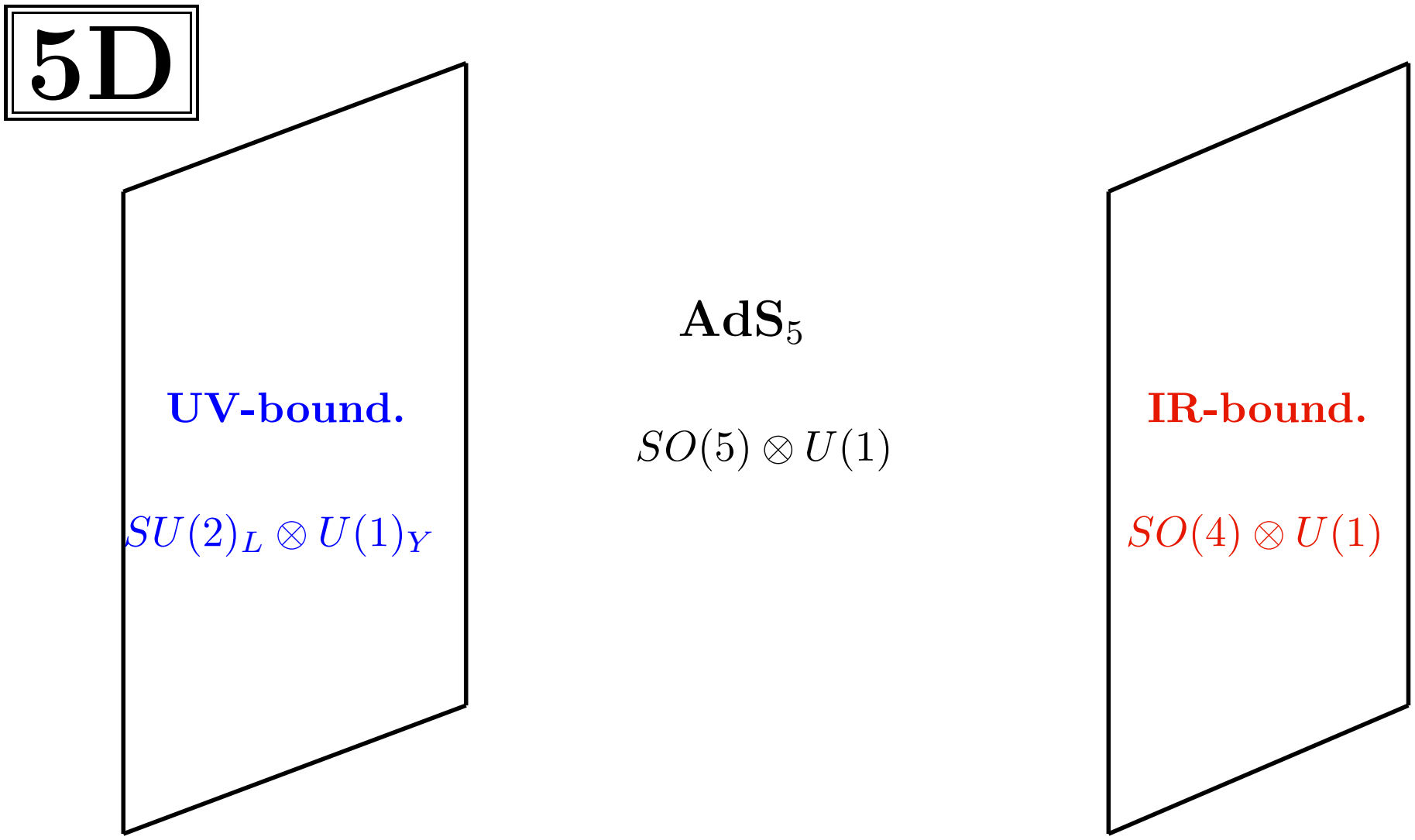
custodial symetry

4D

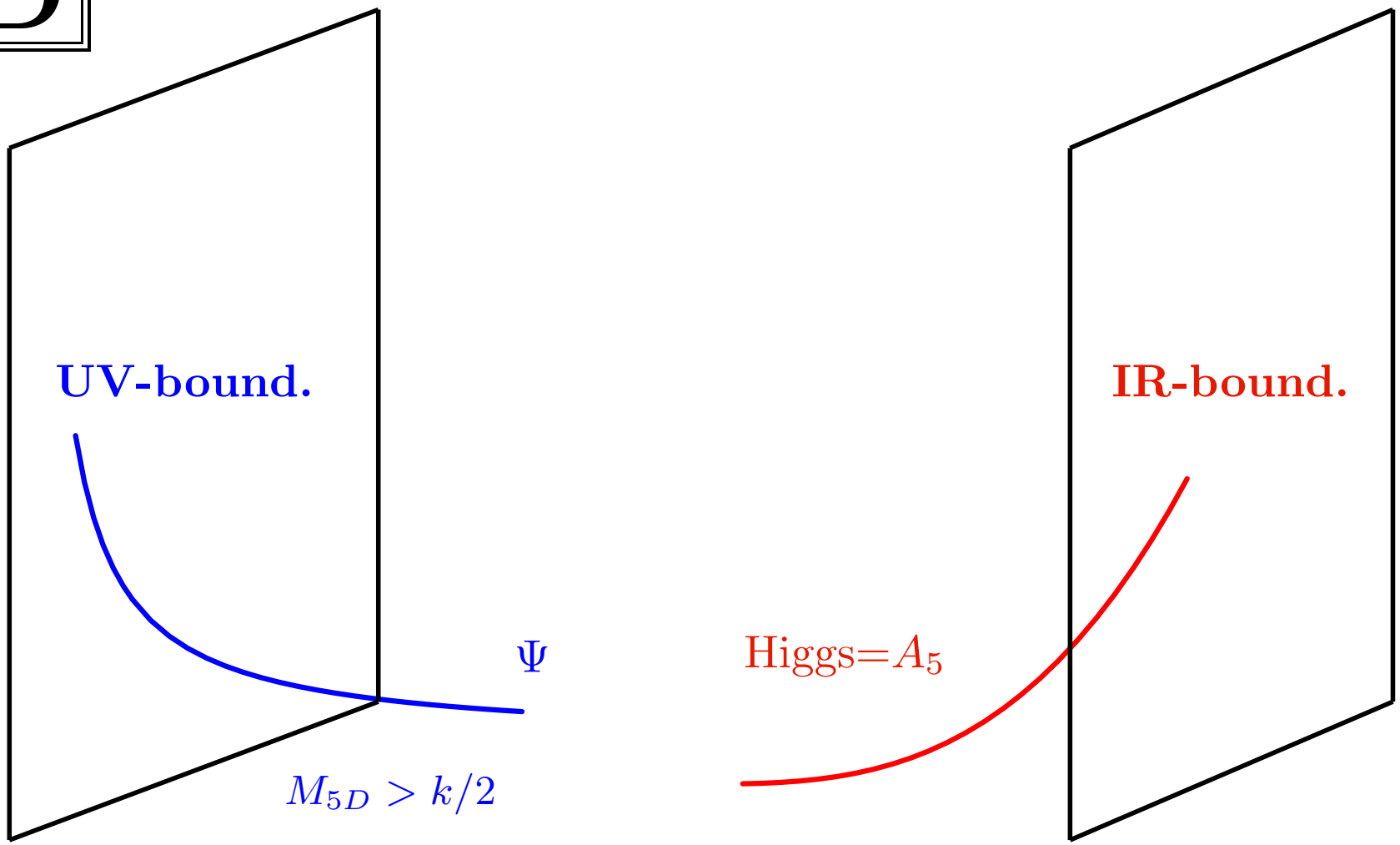
SM Fields:



By the AdS/CFT dictionary...


5D
UV-bound.
$SU(2)_L \otimes U(1)_Y$
$\mathbf{AdS}_5$
$SO(5) \otimes U(1)$
IR-bound.
$SO(4) \otimes U(1)$

5D

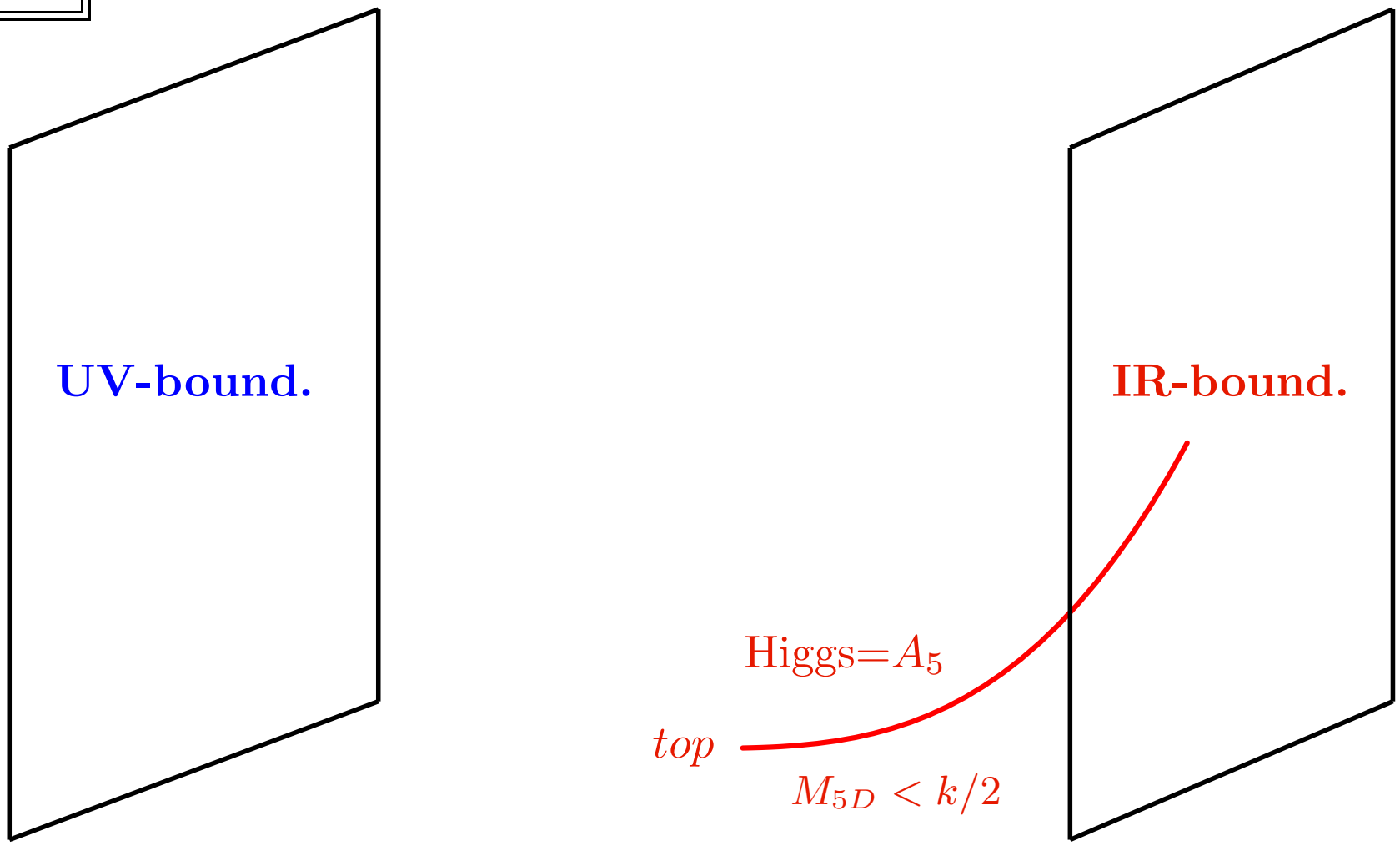


.

Small fermion masses from small wave-function overlapping and GIM-like mechanism

T.Gherghetta, A.P.

5D

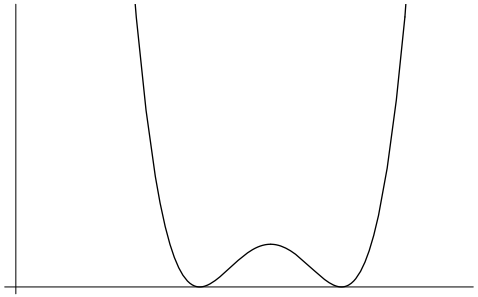


.

To get a large top mass: top_R composite as as the Higgs,
while top_L only partly composite (to avoid large deviations in $Z \to \bar{b}_L b_L$)

EWSB and Higgs mass

Dynamical question that can be answered since the Higgs potential is only determined by top+gauge loops:



$$V(h) = \alpha \cos\left(\frac{h}{F}\right) + \beta \sin^2\left(\frac{h}{F}\right)$$

α, β and F depend on 5D parameters (e.g. top 5D mass)

$$\Downarrow$$

$$\left(\frac{v}{m_\rho}\right)^2 \simeq \left(\frac{1}{10}\right)^2 \left[4 - \frac{\alpha^2}{\beta^2}\right] \qquad (v \ll m_\rho \text{ the gauge KK-state mass})$$

$$m_h^2 \simeq \frac{2\beta}{F^4} v^2 \sim (100 - 140 \text{ GeV})^2 \qquad \text{(light Higgs)}$$

EWPT

- $\hat{T}$=0 by the custodial symmetry
- W and Y small
- $\hat{S} \simeq 0.2 \left(\frac{v}{m_\rho}\right)^2 \leq 2 \cdot 10^{-3}$

$$\hookrightarrow \frac{v}{m_\rho} \leq \frac{1}{10}$$

Agashe, Contino

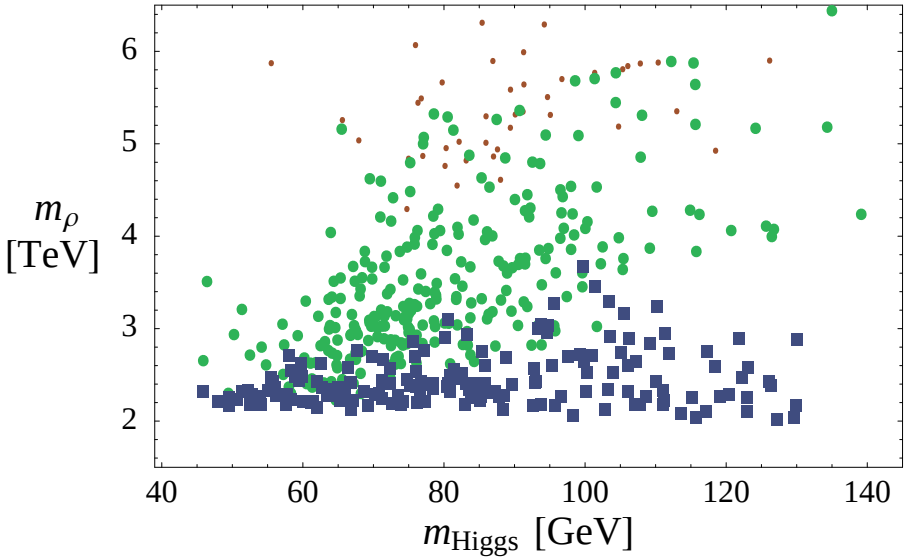
Including constraints from $Z \to \bar{b}b$, one needs

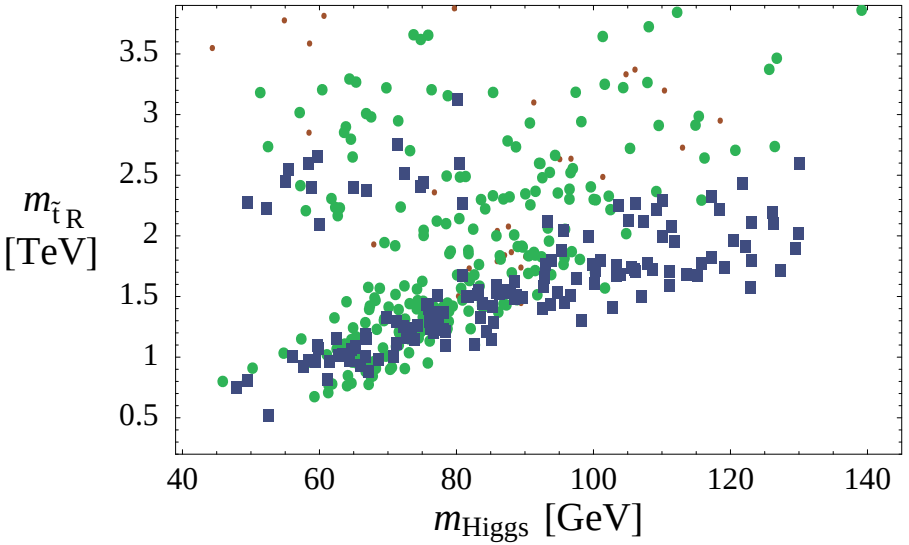
$$\frac{v}{m_\rho} \leq \frac{1}{30}$$

Certain adjustment needed between the α and β at the $5-10\%$

Work in progress...

Successful EWSB and EWPT





Always a light Higgs $m_h \lesssim 140$ GeV!

Resonances (KK) for all SM fields $m \sim 2$ TeV

Search for b_R^* and t_R^* at the LHC!

MCHM

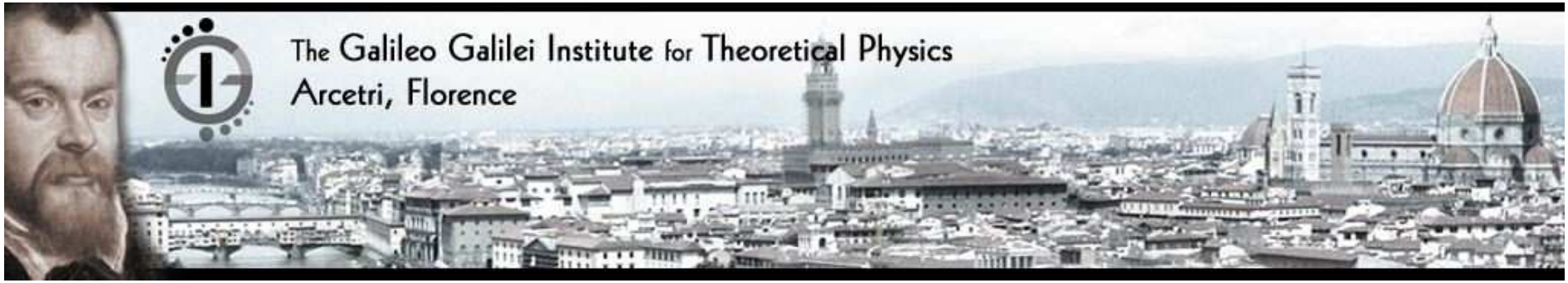
1. Hierarchy problem:..... *YES* *Randall,Sundrum*
2. Flavor problem:
   - Origin of flavor..... *YES, the smallness of* m_f
   - GIM-mechanism..... *YES*
3. EWPT: .....*YES, with a mild tuning* 10%

Conclusions

- Models for EWSB are quite constrained (at the $\sim 1/1000$ level)
- MSSM already in jeopardy...
- Serious alternatives: Higgs as a PGB, e.g. , MCHM

Origin of EWSB still an open question (till the LHC).
I hope it will create a lot of discussions...

..... in the New Institute:



BEST WISHES!