Higgs &
Electroweak Symmetry Breaking

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Christophe Grojean
CERN-TH & CEA-Saclay/IPhT
(christophe.grojean@cern.ch)

Higgs = “raison d’être” of LHC (/ILC?)

- 16 talks at this workshop have a title refering to the Higgs
- ~500 physics papers over the last 5 years have an introduction starting like
  - “The main goal of the LHC is to unveil the mechanism of electroweak symmetry breaking”,
  - “How the electroweak gauge symmetry is spontaneously broken is one of the most urgent and challenging questions before particle physics.”
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Reasons of a success

- last missing piece of the SM?
- at the origin of the masses of elementary particles?
- unitarization of WW scattering amplitudes?
- screening of gauge boson self-energies?

The source of the Goldstone's

symmetry breaking: new phase with more degrees of freedom

massive $W^\pm$, Z: 3 physical polarizations=eaten Goldstone bosons $\frac{SU(2)_L \times SU(2)_R}{SU(2)_V}$

$\Rightarrow$ Where are these Goldstone's coming from? $\Leftarrow$

what is the sector responsible for the breaking $SU(2)_L \times SU(2)_R$ to $SU(2)_V$?

with which dynamics? with which interactions to the SM particles?

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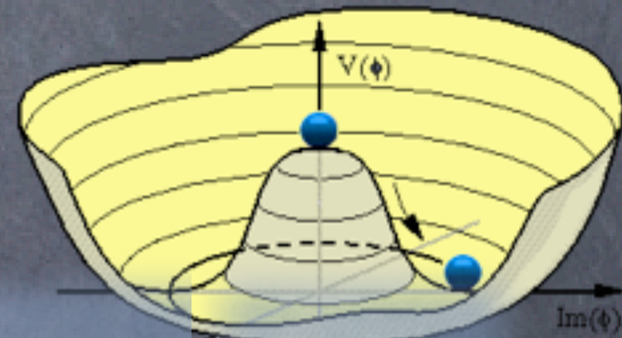
common lore: from a scalar Higgs doublet



$$H = \begin{pmatrix} h^+ \\ h^0 \end{pmatrix}$$

Higgs doublet = 4 real scalar fields

3 eaten Goldstone bosons ← → One physical degree of freedom the Higgs boson

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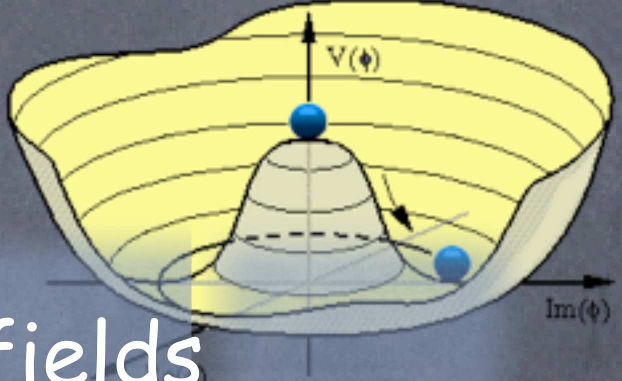

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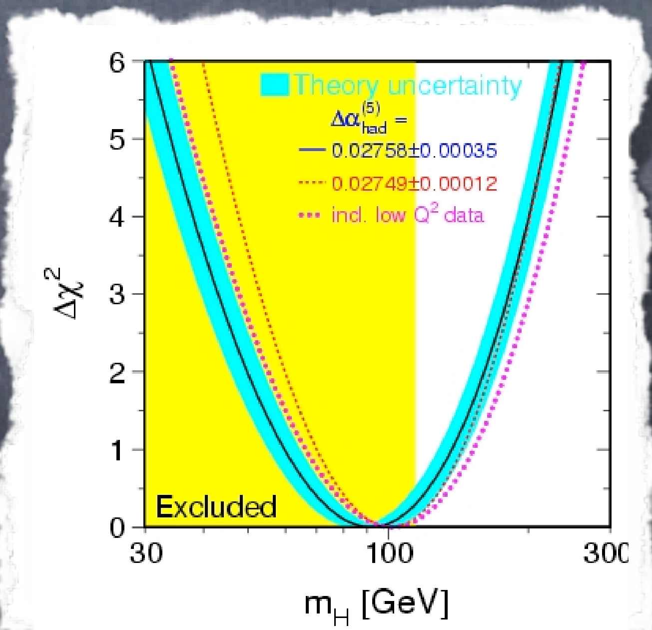
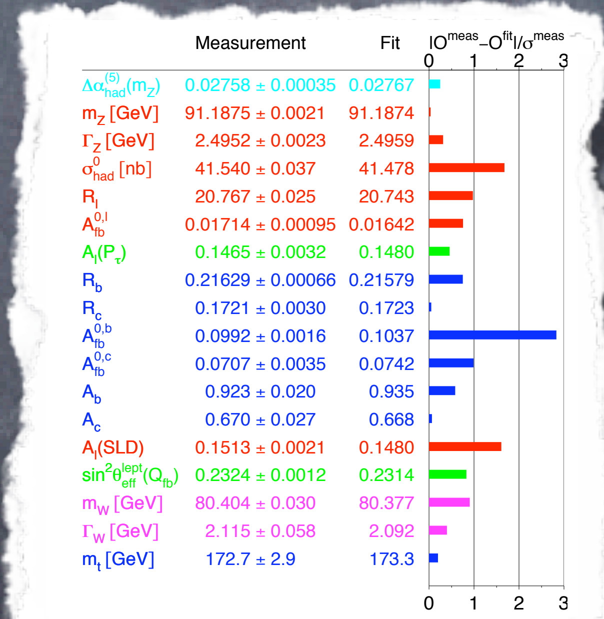
Good agreement with EW data

(doublet ⇔ ρ=1)





	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02767	
m_Z [GeV]	91.1875 ± 0.0021	91.1874	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	
σ^0_{had} [nb]	41.540 ± 0.037	41.478	
R_l	20.767 ± 0.025	20.743	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01642	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480	
R_b	0.21629 ± 0.00066	0.21579	
R_c	0.1721 ± 0.0030	0.1723	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1480	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.404 ± 0.030	80.377	
Γ_W [GeV]	2.115 ± 0.058	2.092	
m_t [GeV]	172.7 ± 2.9	173.3	

But the Higgs hasn't been seen yet...

"Myth or fact?" (H. Murayama)

How close to reality is the SM Higgs boson?

Deformations of the SM

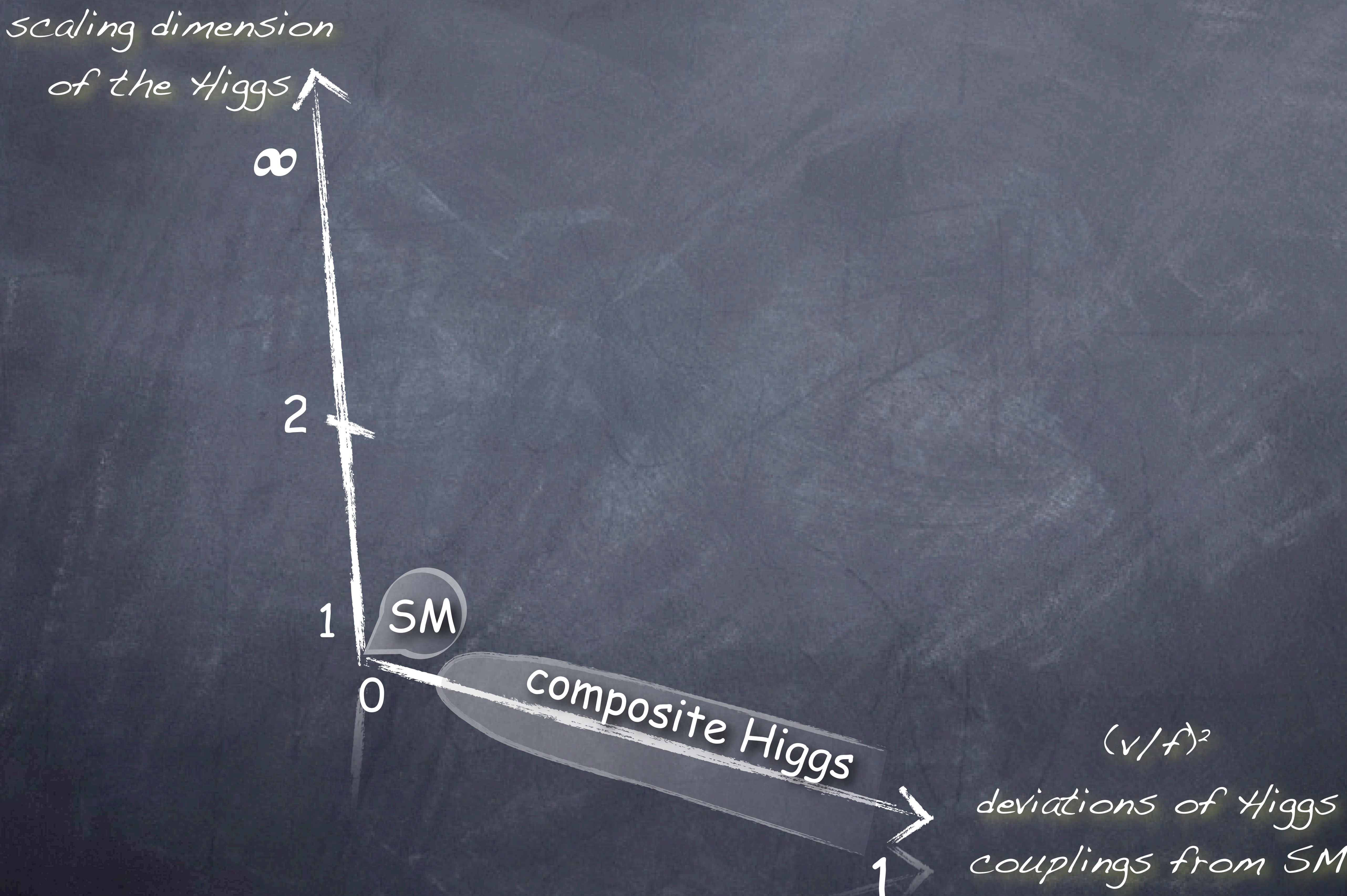
SM

Deformations of the SM

$(v/f)^2$

deviations of Higgs couplings from SM

Deformations of the SM



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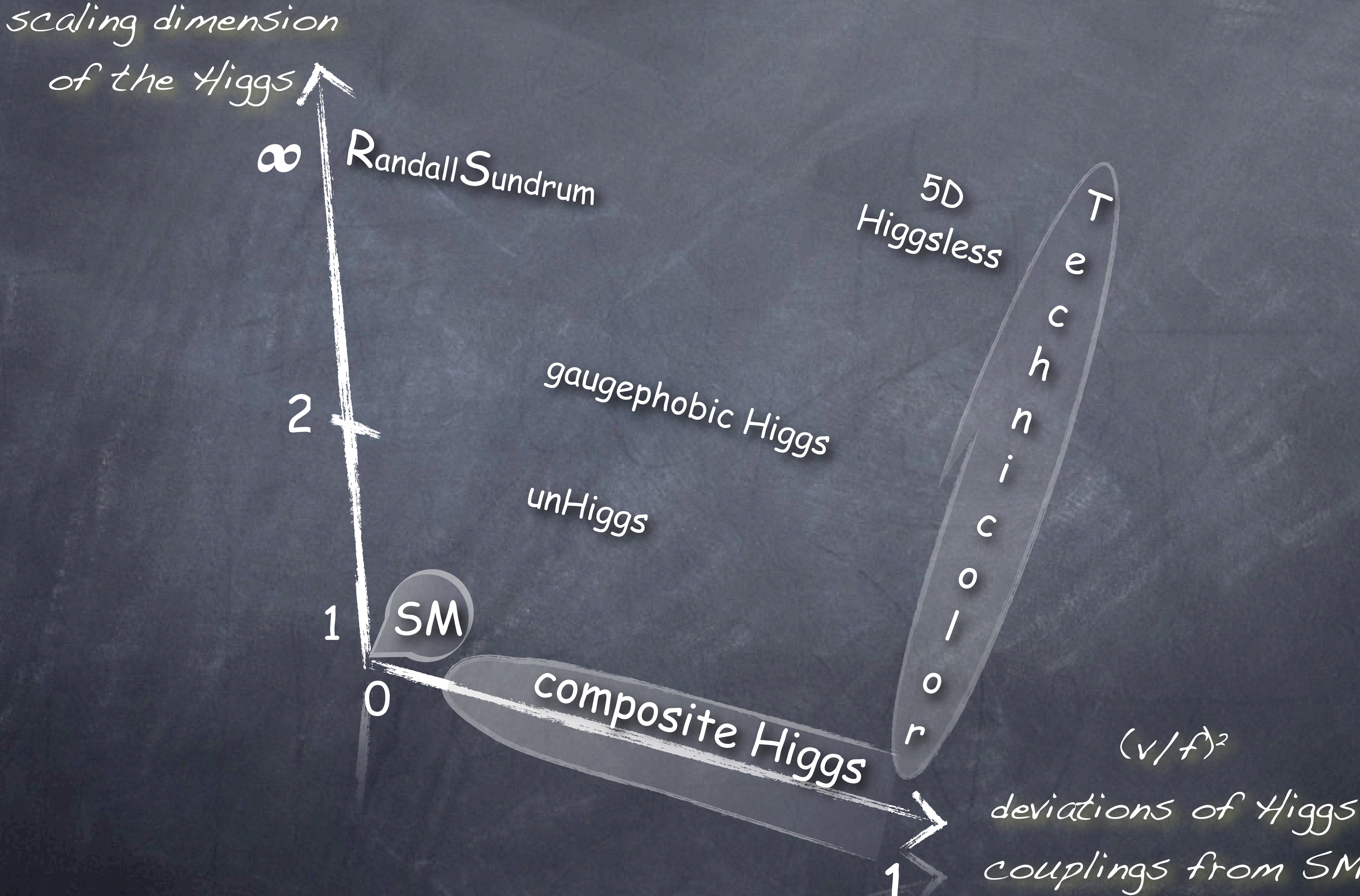

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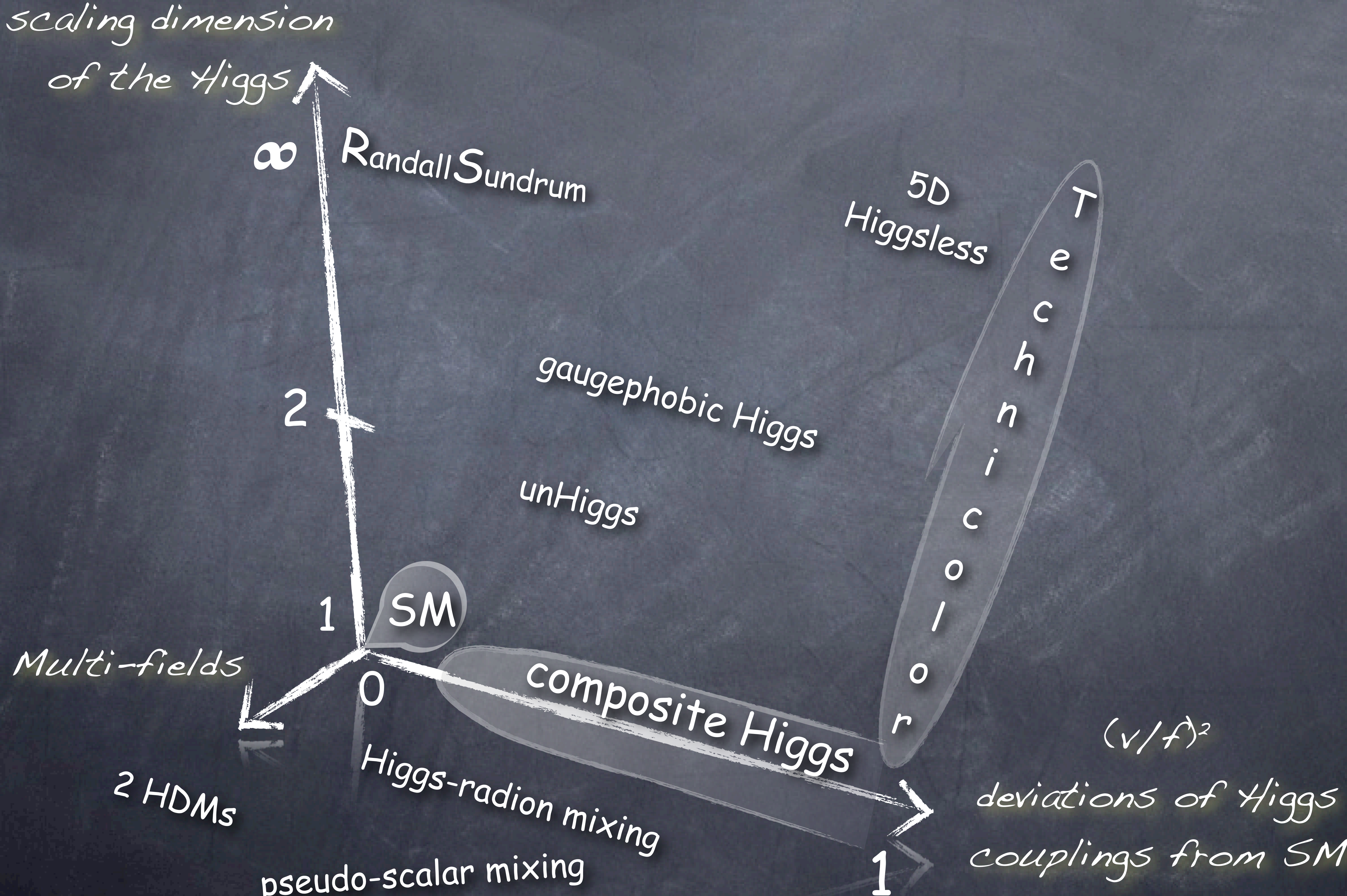
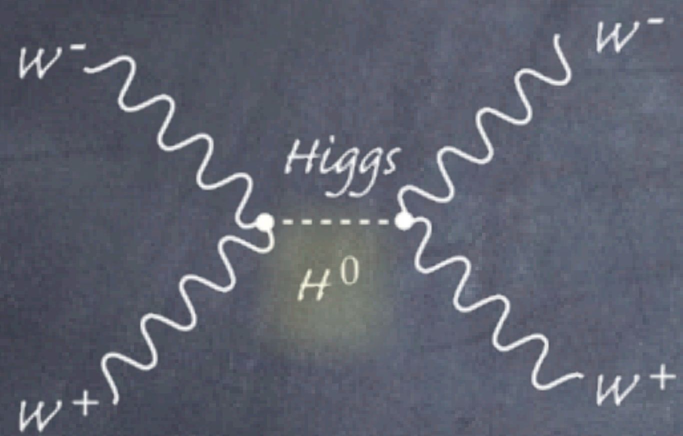


SM Higgs as a peculiar scalar resonance

A single scalar degree of freedom with no charge under $SU(2)_L \times U(1)_Y$

$$\mathcal{L}_{\rm EWSB} = a\,\frac{v}{2}\,h\,{\rm Tr}\left(D_\mu\Sigma^\dagger D_\mu\Sigma\right) + b\,\frac{1}{4}\,h^2\,{\rm Tr}\left(D_\mu\Sigma^\dagger D_\mu\Sigma\right)$$

'a' and 'b' are arbitrary free couplings



$$\mathcal{A} = \frac{1}{v^2}\left(s - \frac{a^2\,s^2}{s-m_h^2}\right)$$

growth cancelled for
a = 1
restoration of
perturbative unitarity

For b = a^2: perturbative unitarity also maintained in inelastic channels

'a=1' & 'b=1' define the SM Higgs

$\mathcal{L}_{\rm mass} + \mathcal{L}_{\rm EWSB}$ can be rewritten as $D_\mu H^\dagger D_\mu H$

$$H = \frac{1}{\sqrt{2}}\,e^{i\sigma^a\pi^a/v}\begin{pmatrix} 0 \\ v+h \end{pmatrix}$$

h and π^a (ie W_L andZ_L) combine to form a linear representation of $SU(2)_L \times U(1)_Y$

Higgs properties depend on a single unknown parameter (m_H)

Continuous interpolation between SM and TC

$$\xi = \frac{v^2}{f^2} = \frac{(\text{weak scale})^2}{(\text{strong coupling scale})^2}$$

$\xi = 0$

SM limit

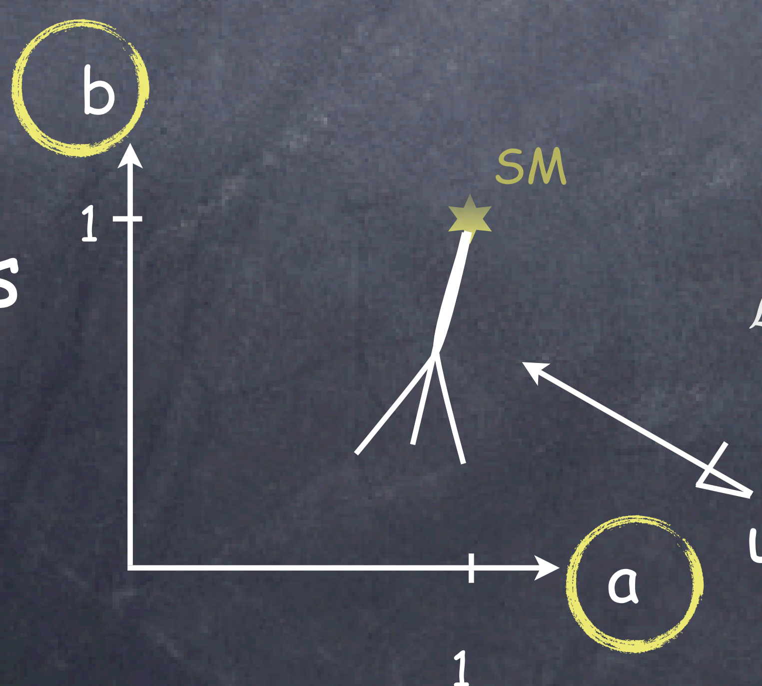
all resonances of strong sector, except the Higgs, decouple

$\xi = 1$

Technicolor limit

Higgs decouple from SM; vector resonances like in TC

Composite Higgs vs. SM Higgs



$$\mathcal{L}_{\rm EWSB} = \left(a\,\frac{v}{2}\,h \;+ b\,\frac{1}{4}\,h^2 \right) \mathrm{Tr}\left(D_\mu \Sigma^\dagger D_\mu \Sigma\right)$$

Composite Higgs
universal behavior for large f
a=1-v/2f b=1-2v/f

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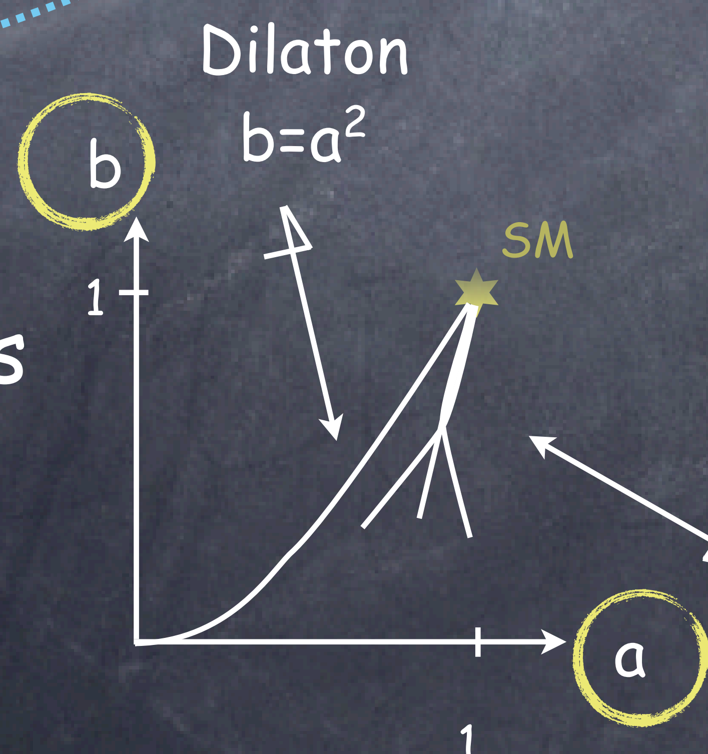
Composite Higgs vs. Dilaton



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Higgs: elementary vs. composite

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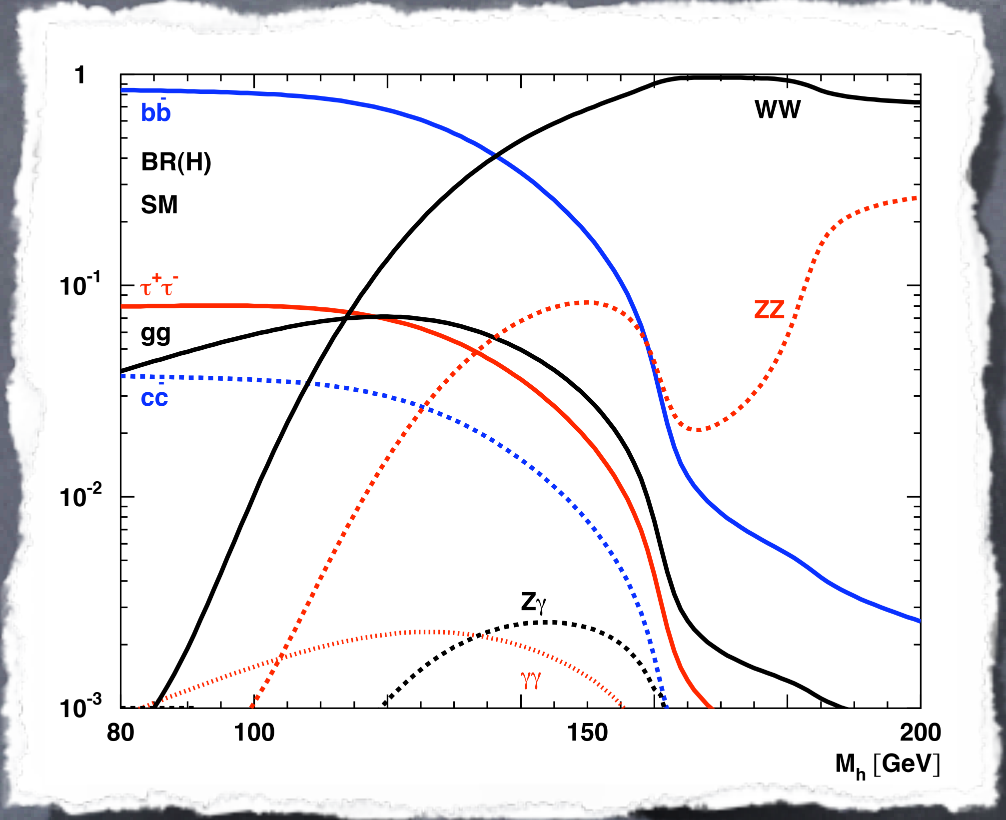

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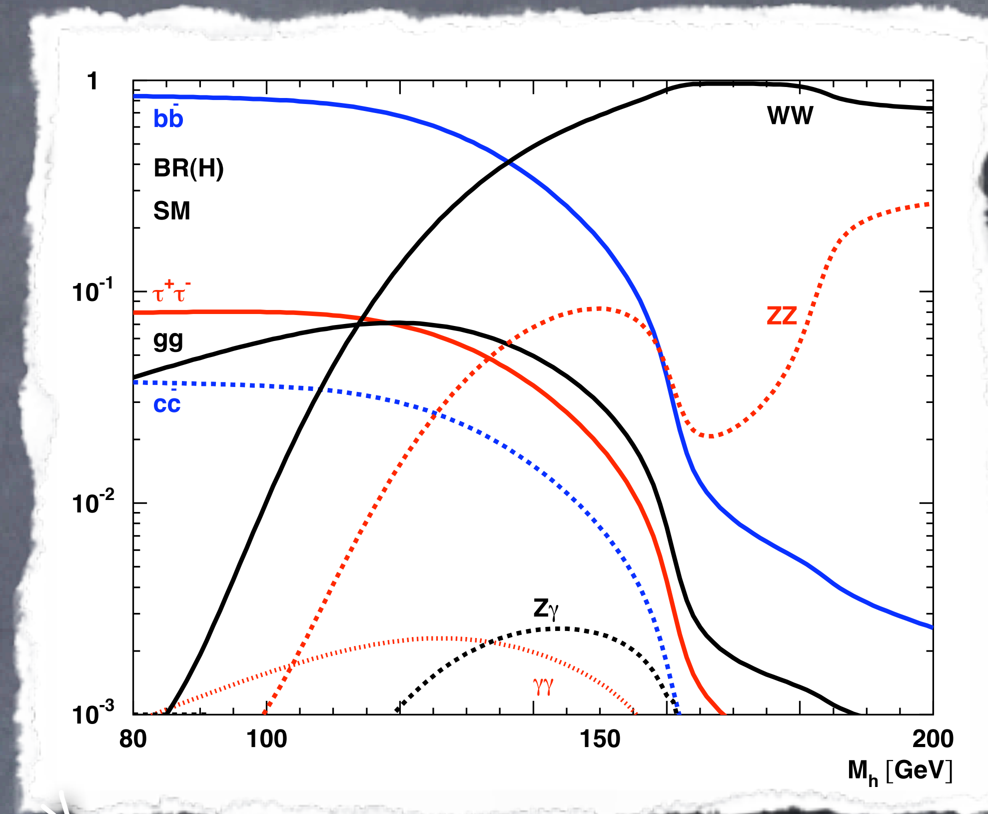


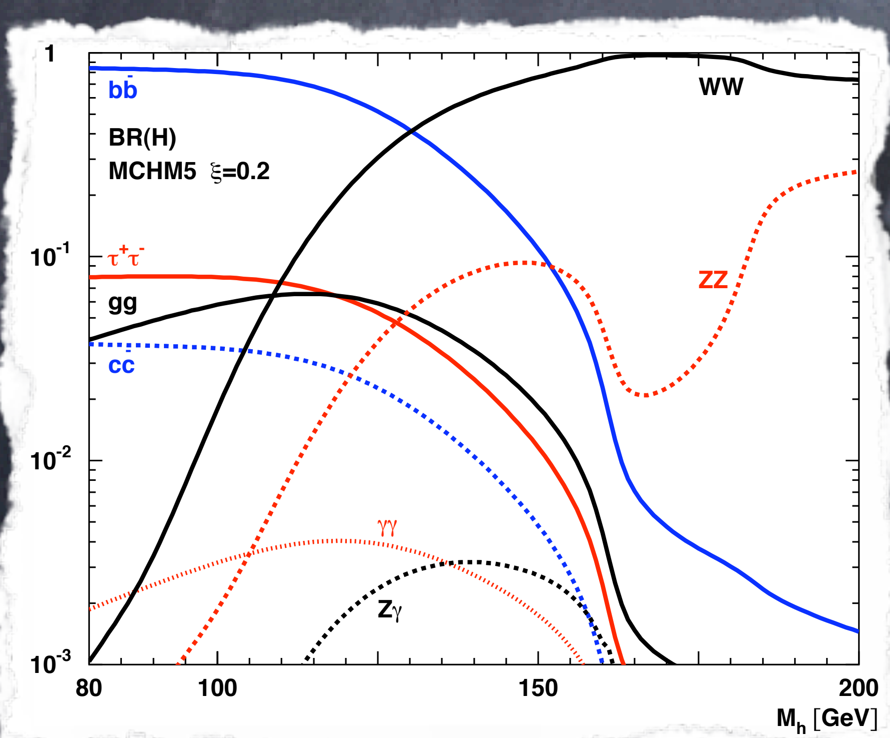
composite Higgs

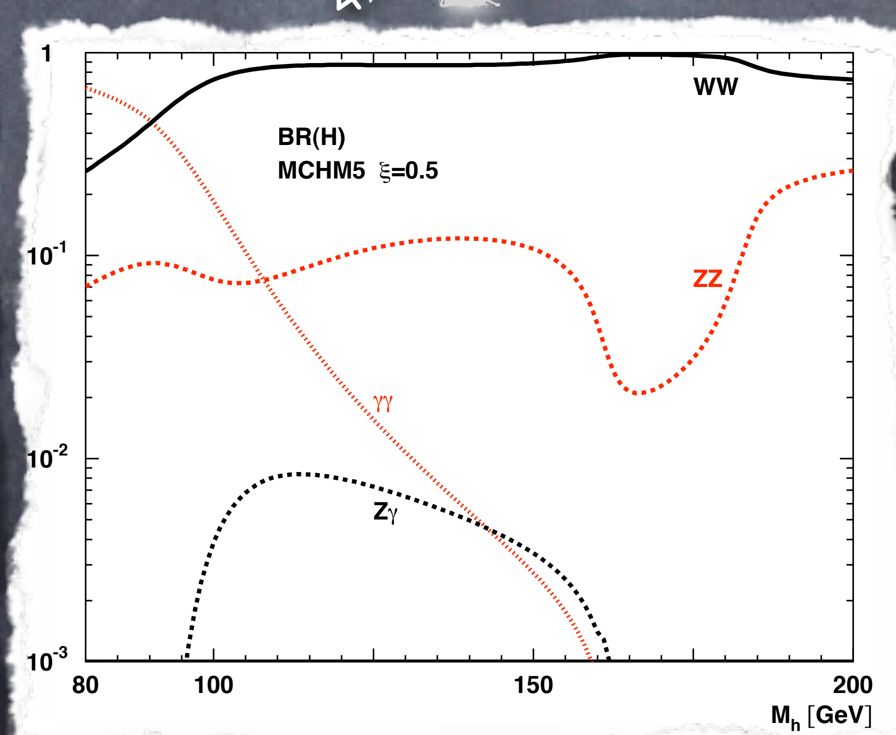
decay rates depends only
on m_H & Higgs compositeness scale ($4\pi f$)

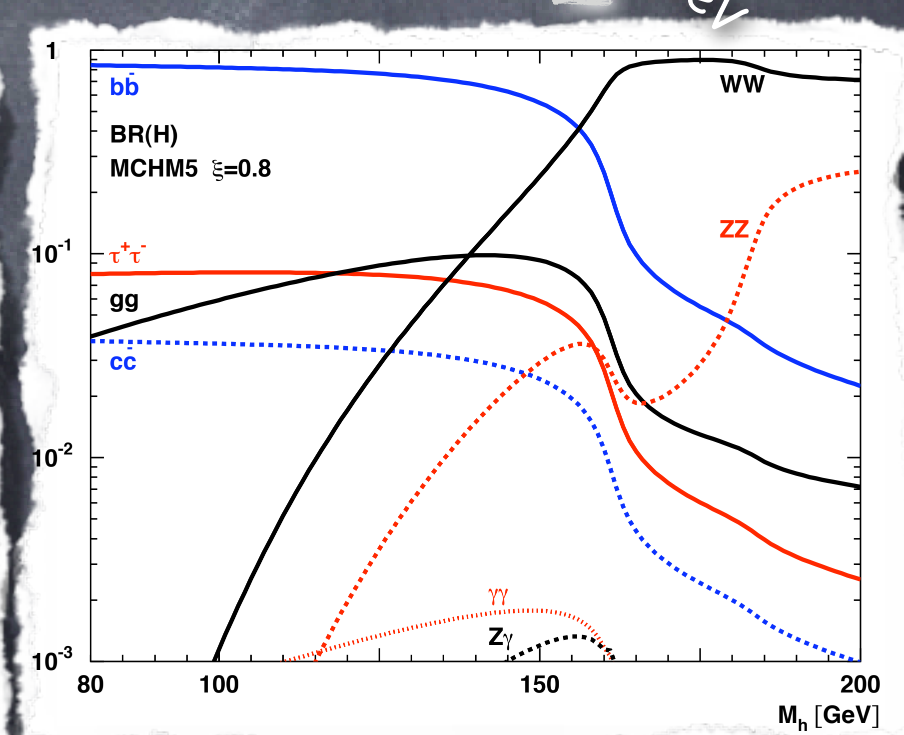
$4\pi f$~7 TeV

$4\pi f$~4.4 TeV

$4\pi f$~3 TeV







EWSB @ LWSC'10: 20 talks

Higgs couplings

- **Higgs** BRs — *Kohei Yoshida*, *Hiroaki Ono*
- ZZH and γZH couplings (including CP) — *Pankaj Sharma*, *Tao Han*
- **WWH couplings** — *Yosuke Takubo*
- Higgs self-couplings — *Jumping Tian*
- Higgs-top sector — *Tomohiko Tanaba*, *Sven Heinemeyer*
- Higgs-neutrinos couplings — *Shinya Kanemura*
- Higgs/Dark matter couplings — *Shigeki Matsumoto*

- Higgs mass measurement — *Henge Li*, *Jean-Yves Hostachy*
- Higgs production — *K. Ikematsu*, *Daisuke Harada*
- Luminosity measurement — *Ivanka Bozovic-Jelisavcic*
- Triple gauge boson couplings — *Yu Matsumoto*, *Mamta*
- Little Higgs models — *Yosuke Takubo*
- New physics searches — *C. Grojean*, *Mikael Berggren*

Conclusions

LHC is prepared to discover the "Higgs"

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