— New Frontiers in Theoretical Physics, Cortona 28-31 May 2014 —
XXXIV Convegno Nazionale di Fisica Teorica

Higgs Couplings and EW observables

Andrea Tesi

SCUOLA NORMALE SUPERIORE

INFN

mainly based on
Barbieri, T 1311.7493 , Barbieri, Buttazzo, Kannike, Sala, T 1304.3670

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vs. direct searches

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Is the Weak scale natural?

Hierarchy Problem and its consequences

If a scalar is coupled (with strength y) to a particle with mass M

$$\text{tuning} \equiv \Delta \sim \frac{y^2 M^2}{16\pi^2 m_h^2}$$

With a protection mechanism we don't care of higher energies

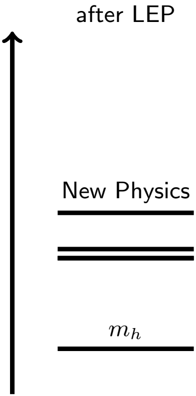
SUSY and Composite Higgs are compelling paradigms.

They realize a natural NP scale M.

$$M \lesssim 450\text{GeV}\sqrt{\Delta}$$

However...

However...



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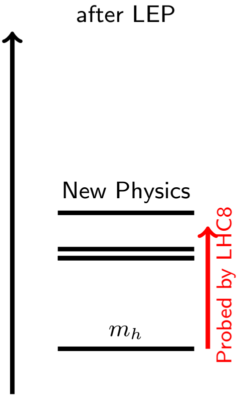

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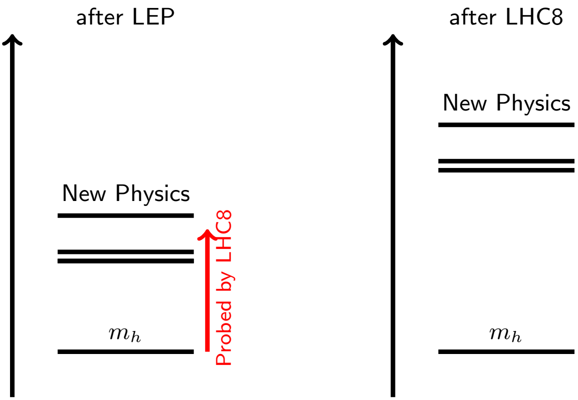
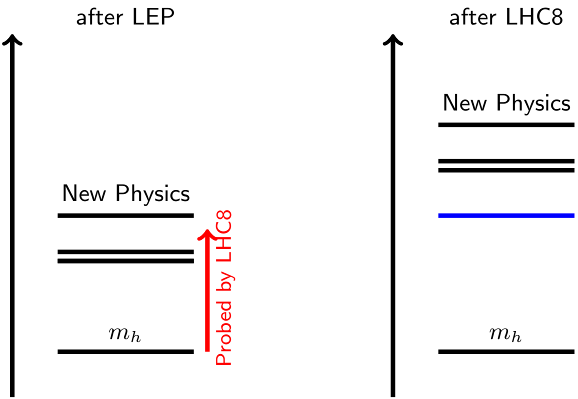


after LEP
New Physics
m_h
Probed by LHC8
after LHC8
New Physics
m_h

However...



Explicit models can have still room for natural scenarios

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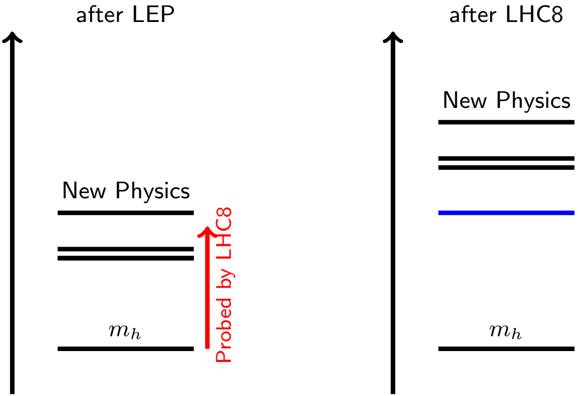

Explicit models can have still room for natural scenarios

In any case, after a period of direct searches,
precision measurements might help

Where to look indirectly for NP?

In many cases, largest effect in the Higgs sector

$$\mathcal{L} \supset m_V^2\, V_\mu V^\mu c_V\, \frac{h}{v} - m_\psi\, \bar{\psi}\psi c_\psi \frac{h}{v} + \mathcal{L}_{\rm NP}(\Phi; M), \qquad c \simeq 1 - \# \frac{v^2}{M^2}$$

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LHC observables   Sensitive to both c_V and c_ψ, via signal rates

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LHC observables — Sensitive to both c_V and c_ψ, via signal rates

EW observables — Mainly sensitive to c_V, via oblique corrections

Focus on paradigmatic explicit models

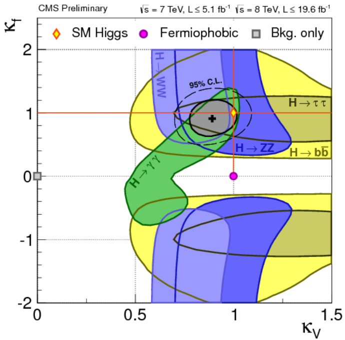
Natural SUSY	Composite Higgs
weak	strong

- What is the present scenario?
- Higgs couplings and EWPT (vs. direct searches)

[D'Agnolo, Kuflik, Zanetti; Gupta, Montull, Riva; Gupta, Rzehak, Wells; ...]

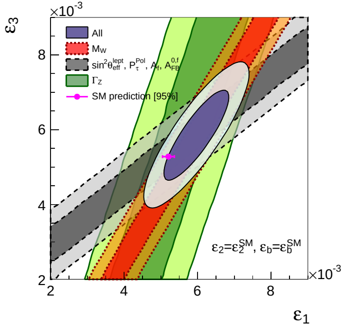
Some numbers...

Experimental status: fit



Agreement with SM within 1σ.
In principle room for sizeable deviations

$$\delta c_V \lesssim 15\%, \quad \delta c_\psi \lesssim 20\%$$



[Ciuchini, Franco, Mishima, Silvestrini '13]
New fit after Higgs discovery

$$\Delta\varepsilon_1 = (5 \div 8)10^{-4}$$

In the “near” future (2022)

300/fb LHC14

	ATLAS	CMS
$h \to \gamma\gamma$	0.16	0.15
$h \to ZZ$	0.15	0.11
$h \to WW$	0.30	0.14
$Vh \to Vb\bar{b}$	–	0.17
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$O(10\%)$

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...and in the far (20**)

HL-LHC (3000/fb)

$\delta c_V \lesssim 4 \div 5\%$

[ATLAS & CMS twiki]

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...and in the far (20**)

HL-LHC (3000/fb)	TLEP σ_{hZ}	TLEP Z-factory
$\delta c_V \lesssim 4 \div 5\%$	$\delta c_V < 1\%$	$\Delta\varepsilon_1 \lesssim 10^{-4}$
[ATLAS & CMS twiki]	[1308.6176]	[Mishima]

Science Fiction??

Models

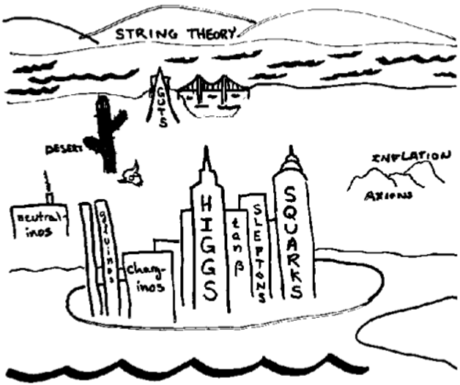
[a few paradigmatic examples]

Natural SUSY

Cohen et al '94
Dimopoulos, Giudice '95
...
Barbieri, Pappadopulo '09
Papucci et al '11
...

THE PARTICLE PHYSICISTS VIEW OF THE WORLD

[from D.B. Kaplan '97]



In the MSSM, light stops and gluinos **vs.** 126 GeV

$$-\frac{m_Z^2}{2} \simeq |\mu|^2 + m_{Hu}^2, \qquad m_h^2 \simeq m_Z^2 + \Delta_t^2$$

$$\Delta_t \gtrsim 85 \text{ GeV} \longrightarrow \text{stops} > 1 \text{ TeV}$$

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NMSSM as a better option for Natural SUSY,

$$W \supset \lambda S H_d H_u + f(S)$$

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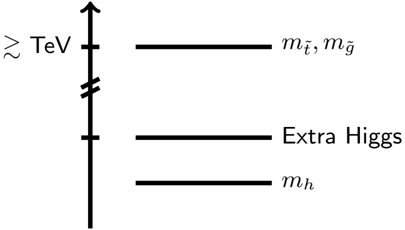
It allows the lightest particle to be an extra Higgs

$$\tilde{m} \longrightarrow \frac{2\lambda}{g}\tilde{m}$$

Simplified spectrum after LHC8



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[Hall,Pinner, Ruderman '11],[Gherghetta et al '12]

This spectrum allows us to focus only on the Higgs sector

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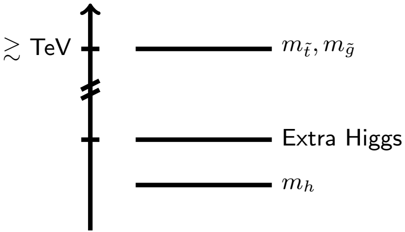

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NMSSM with light singlet

All Higgs couplings rescaled universally by $\cos\gamma$ (mixing between h and singlet)

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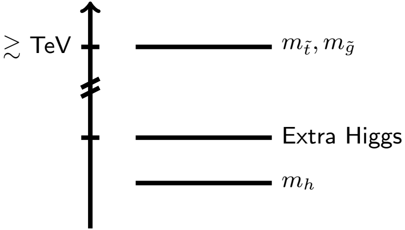

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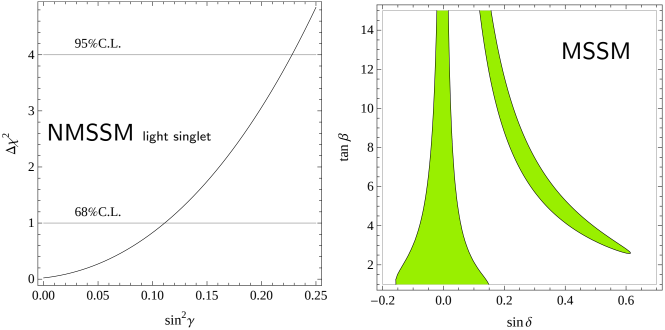
MSSM

Higgs couplings depend on $\tan\beta$ and δ (mixing between h and extra doublet)

Fitting the Higgs



We used the code of [Giardino, Kannike, Masina, Raidal, Strumia, 13]

	FIT	c_V
NMSSM light singlet	$\sin^2\gamma < .22$	$\sim 10\%$
MSSM	$\sin\delta\|_{\tan\beta=10} \lesssim 5\%$	$\sim .1\%$

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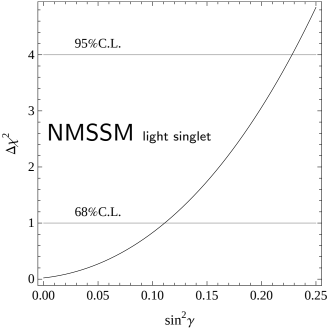

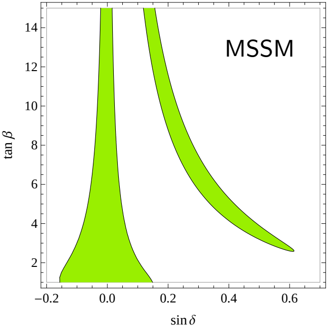

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MSSM more constrained than NMSSM by Higgs fit

NMSSM with light singlet and $\lambda = 0.8$

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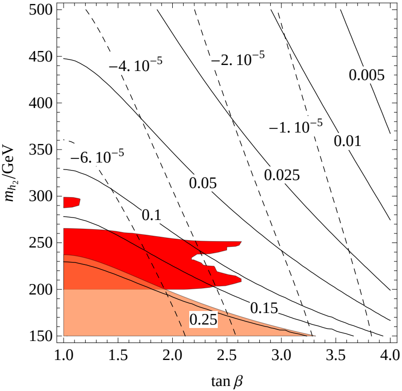
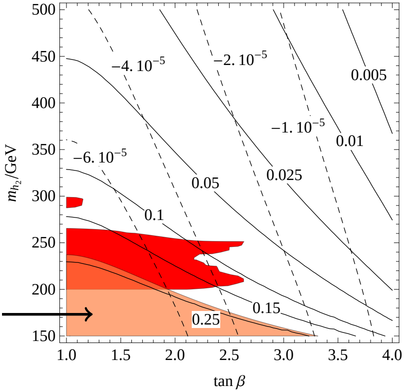


NMSSM with light singlet and $\lambda = 0.8$

Higgs fit →



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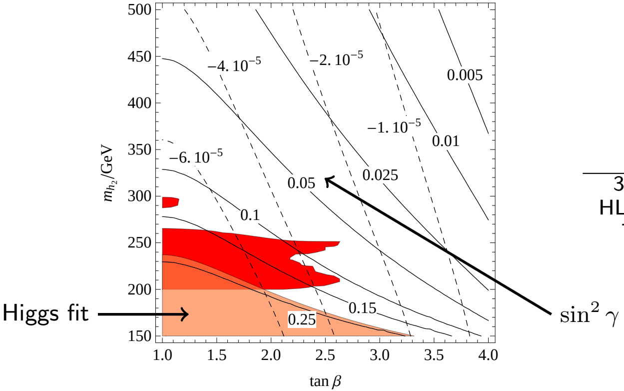

	$\sin^2\gamma$
300/fb	15%
HL-LHC	5%
TLEP	$< 1\%$

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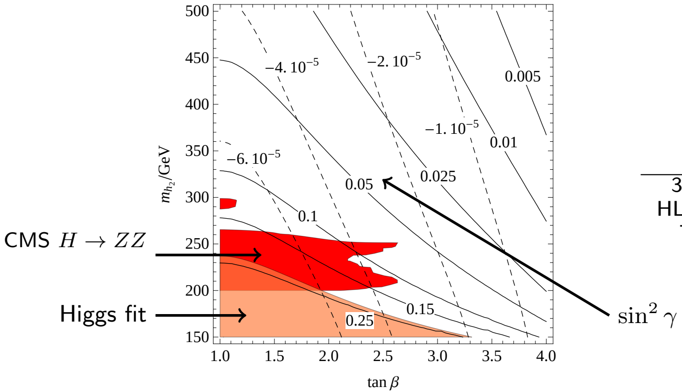

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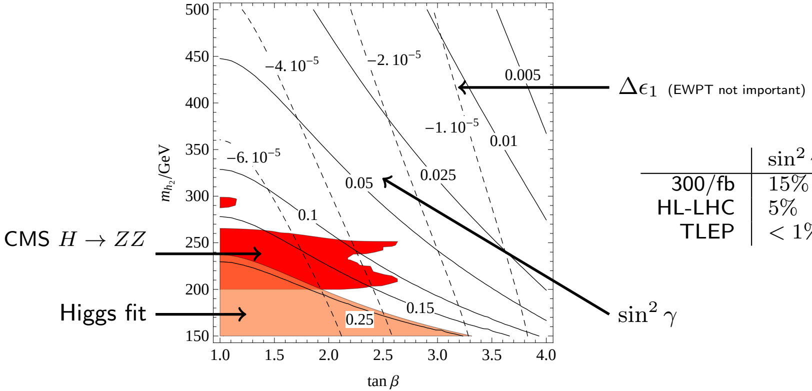

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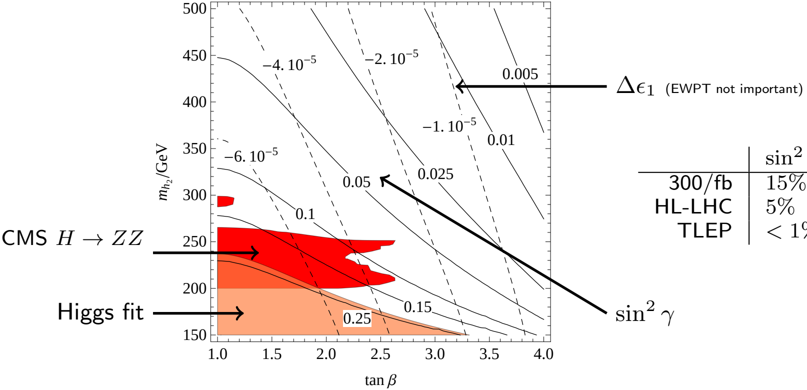

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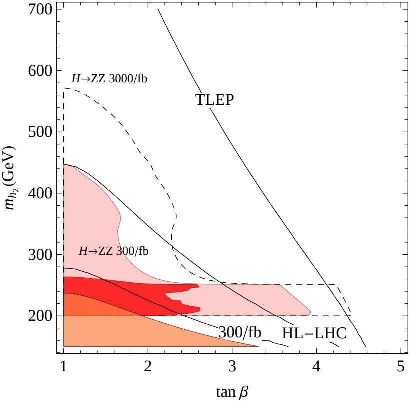
This is a natural region poorly constrained by precision measurements

- In the allowed region: $\mathrm{BR}(h_2 \to hh)$ [CMS-PAS-HIG-13-032]
- $H \to ZZ$ right place where to look for an excess
- At large λ the model is less attractive

NMSSM Higgs sector

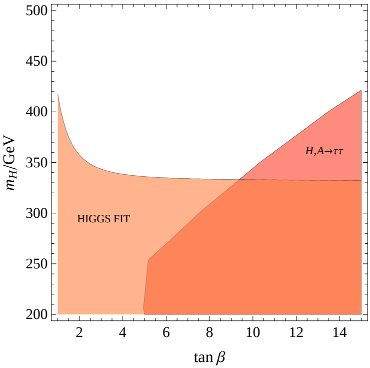
Using data from [Brownson, Craig et al '13] and extrapolation



with Dario Buttazzo and Filippo Sala for "What Next?"

MSSM

Higgs couplings powerful constraint (EWPT irrelevant)



- LHC8, $m_H > 350$ GeV @ 95% CL
- @ large-$\tan\beta$ direct searches $H, A \to \tau\tau$ important
- LHC14 will close the parameter space of this picture

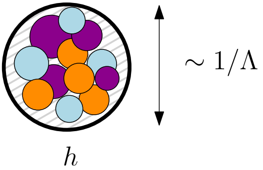
Composite Higgs

Georgi, Kaplan '84

Agashe, Contino, Pomarol '04

Contino, Da Rold, Pomarol '06

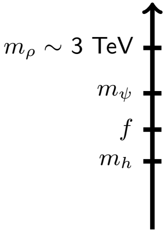
...



Effective description
below the compositeness scale

Why light and natural?

Higgs as pseudo-GB of a strong sector with SO(5)/SO(4) symmetry



- Separation of scales $f > v$
- Composite fermions $m_\psi = g_\psi f$ needed to trigger EWSB
- Higgs mass set by top yukawa and g_ψ

$$m_h^2 = C \frac{N_c m_t^2}{2\pi^2} g_\psi^2$$

- Tuning (for 126 GeV Higgs)

$$\Delta \sim \frac{m_\psi^2}{v^2} \geq \frac{f^2}{v^2}$$

Top partners have been actively searched for: $m_\psi > 700\ \mathrm{GeV}$

Higgs couplings

Tree-level effects mainly sensitive to v/f

$$f \geq 550 \text{ GeV} \qquad \boxed{c_V \sim 10\%}$$

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EWPT

$$\widehat{S} = -\frac{g^2}{96\pi^2}(1-c_V^2)\log\frac{\Lambda}{m_h}, \qquad \widehat{T} = -(1-c_V^2)\frac{3\alpha}{8\pi c_w^2}\log\frac{\Lambda}{m_h}$$

Assuming no other contribution, precision on $c_V \sim 5\%$

[Ciuchini, Franco, Mishima, Silvestrini '13]

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It is possible to find UV contributions that relax this bound
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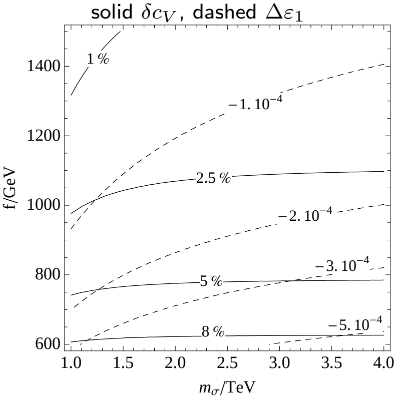
At present, Composite Higgs has natural islands allowed by precision tests

We can simulate the physics of Composite Higgs by a (computable) LΣM

$$1 - c_V^2 = \sin^2\theta = \xi - \frac{m_h^2}{m_\sigma^2} + O(\xi\frac{m_h^2}{m_\sigma^2})$$

$$\Delta\varepsilon_1 = -\sin^2\theta \frac{3\alpha}{8\pi c_w^2}\left[\log\frac{m_\sigma}{m_h} + c_1(m_h) + O(\frac{m_Z^2}{m_\sigma^2})\right]$$



Both Higgs couplings and EW can have strong impact

300/fb	$\delta c_V < 6\%$
HL-LHC	$\delta c_V < 2 \div 3\%$
TLEP	$\delta c_V < 1\%$
TLEP	$\Delta\epsilon_1 < 10^{-4}$ [Mishima]

Complementary info on top-partners mass: $m_\psi \gtrsim 3 \times f \times (\frac{g_\psi}{3})$

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Higgs couplings right place to see indirect effects in future
EWPTs play a role only in strongly coupled scenarios