Phenomenology of a UV complete model

L Del Debbio

Higgs Centre for Theoretical Physics
University of Edinburgh

in collaboration with C Englert (Glasgow) and R Zwicky (Ed)

Criteria for UV completion

how can we build a BSM model given the lack of experimental evidence?

(1) Higgs boson is a pNGB

(2) top quark mass due to mixing with a composite state

global symmetry: $G_F \to H_F, \quad H_F \supset G_{\rm cus} \supset G_{\rm SM}$

$$G_{\rm cus} = {\rm SU}(3)_c \times {\rm SU}(2)_L \times {\rm SU}(2)_R \times U(1)_X$$
$$G_F/H_F \ni (1,2,2)_0$$

asymptotic freedom + unitary gauge group + several irreps (LH Weyl)

$$\text{fermions} \in mR_1 + 3R_2 + 3R_3$$
$$G_F = {\rm SU}(m) \times {\rm SU}(3) \times {\rm SU}(3)' \times {\rm U}(1) \times {\rm U}(1)'$$

[Ferretti &Karateev 13]

Ferretti's model - UV description

	$G_{\rm HC}$	$G_{\rm F}$				
	$SU(4)$	$SU(5)$	$SU(3)$	$SU(3)'$	$U(1)_X$	$U(1)'$
ψ	$\mathbf{6}$	$\mathbf{5}$	$\mathbf{1}$	$\mathbf{1}$	0	-1
χ	$\mathbf{4}$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$-1/3$	$5/3$
$\tilde{\chi}$	$\bar{\mathbf{4}}$	$\mathbf{1}$	$\mathbf{1}$	$\bar{\mathbf{3}}$	$1/3$	$5/3$

[Ferretti 14]

strong dynamics induces SSB of the global symmetry

$$\mathrm{SU}(5) \longrightarrow \mathrm{SO}(5)$$
$$\mathrm{SU}(3) \times \mathrm{SU}(3)' \longrightarrow \mathrm{SU}(3)_c$$

compute the spectrum

[plenary talk by Claudio]

Ferretti's model - composite Higgs model

$$\mathrm{SU}(5) \longrightarrow \mathrm{SO}(5) \supset \mathrm{SO}(4) \simeq \mathrm{SU}(2)_L \times \mathrm{SU}(2)_R$$

SM group: $T_L^a \in \mathrm{SU}(2)_L, \quad T_R^3 \in \mathrm{U}(1)$

$$\begin{aligned} 14\,\mathrm{NGB}: \quad & 1_0 + 2_{\pm 1/2} + 3_0 + 3_{\pm 1} \\ & \eta \qquad H \qquad \Phi_0 \quad \Phi_\pm \\ & \Pi = H + H^\dagger + \Phi_0 + \Phi_+ + \Phi_+^\dagger\,, \quad \Sigma = \exp\left(\frac{i\Pi}{f}\right) \\ & U = \Sigma\Sigma^T\,, \quad U \mapsto g U g^T \end{aligned}$$

using the notation $\phi^{m_L}_{m_R}$, exotic Higgses with $Q = m_L + m_R$:

$$\Phi_0 \supset (\phi_0^-, \phi_0^0, \phi_0^+)$$
$$\Phi_+ \supset (\phi_+^-, \phi_+^0, \phi_+^+)$$

[Georgi & Machacek 85]

Gauging the EW - pNGB potential

$$\mathcal{L}_{\rm eff} \supset \frac{f^2}{16}{\rm tr}\left[(D_\mu U)^\dagger D_\mu U\right]$$
$$D_\mu U = \partial_\mu U - igW^a_\mu \left[T^a_L, U\right] - ig' B_\mu \left[T^3_R, U\right]$$

Coleman-Weinberg potential due to the gauge bosons:

$$V_g = -Bf^4{\rm tr}\left[g^2 T^a_L U T^a_L U^\dagger + g'^2 T^3_R U T^3_R U^\dagger]\right]$$

B is a LEC, V_g provides a mass for the extra pNGBs in the spectrum

[Ferretti 16]

$$Bf^4 = C_{LR} \propto \int_0^\infty dq^2\, q^2\, \Pi_{LR}(q^2)$$
$$\left(q^2\delta_{\mu\nu} - q_\mu q_\nu\right)\Pi_{LR}(q^2) = \int d^4x\, e^{iqx}\, \langle J^L_\mu(x) J^R_\nu(0)\rangle$$

[Golterman & Shamir 15]

Partial compositeness

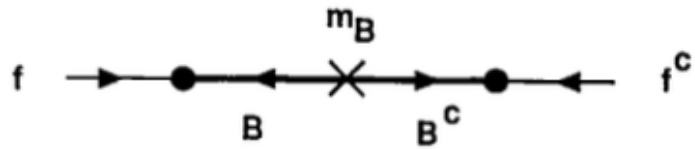
generates top quark mass, and EW symmetry breaking [Kaplan 85]

$$\mathcal{L}_{\rm UV} \supset \frac{\lambda_L}{\Lambda_{\rm UV}^{d_L-5/2}}\bar{q}_L\mathcal{O}_L + \frac{\lambda_R}{\Lambda_{\rm UV}^{d_R-5/2}}\bar{t}_R\mathcal{O}_R + \text{h.c.}$$

[Panico & Wulzer 15]

in the UV complete model:

$$\mathcal{L}_{\rm UV} \supset \frac{\lambda_L}{\Lambda_{\rm UV}^{d_L-5/2}}\bar{q}_L\mathcal{B}_R + \frac{\lambda_R}{\Lambda_{\rm UV}^{d_R-5/2}}\bar{t}_R\mathcal{B}_L + \text{h.c.}$$



q_L, t_R spurion fields, $\mathcal{B}_{L,R}$ hyperbaryon fields $(\chi\psi\chi)$, in the $(\mathbf{5},\mathbf{3})$ of H_F

[Golterman & Shamir 15]

Fermionic mass term

$$\mathcal{L}_{\rm eff} \supset \frac{M}{2}\bar{\Psi}\Psi + \lambda_q f \bar{q}_L \Sigma \Psi_R + \lambda_t f \bar{t}_R \Sigma^* \Psi_L + \dots$$

$$\lambda_q = \lambda_L \left(\frac{\Lambda}{\Lambda_{\rm UV}}\right)^{\gamma_L} \sqrt{Z_B}\,, \quad \lambda_t = \lambda_R \left(\frac{\Lambda}{\Lambda_{\rm UV}}\right)^{\gamma_R} \sqrt{Z_B}$$

$$\Psi = \frac{1}{\sqrt{2}} \begin{pmatrix} iB - iX \\ B + X \\ iT + iY \\ -T + Y \\ \sqrt{2} i R \end{pmatrix}$$

$(T,B) \in (\mathbf{3},\mathbf{2})_{1/6}\,, \quad R \in (\mathbf{3},\mathbf{1})_{2/3}\,, \quad (X,Y) \in (\mathbf{3},\mathbf{2})_{7/6}$

Fermionic mass term

X exotic state, with charge 5/3

$$\mathcal{L}_{\rm eff} \supset (\bar{t}_L, \bar{T}_L, \bar{Y}_L, \bar{R}_L) \cdot \mathcal{M}_T \cdot \begin{pmatrix} t_R \\ T_R \\ Y_R \\ R_R \end{pmatrix} + \dots$$

top quark mass:

$$\boxed{m_t/v = \sqrt{2}\frac{f}{M}\frac{1}{\sqrt{1+\lambda_q^2\frac{f^2}{M^2}}\sqrt{1+\lambda_t^2\frac{f^2}{M^2}}}}$$

Higgs potential

$$V(h) = -\alpha f^2 \sin^2 \frac{h}{f} + \beta f^2 \sin^4 \frac{h}{f}$$

[Panico & Wulzer 15]

where

$$\alpha = C_{LR}(3g^2 + g'^2) + 2y^2 C_{\rm top} < 0$$
$$\beta = -2y^2 C_{\rm top}$$

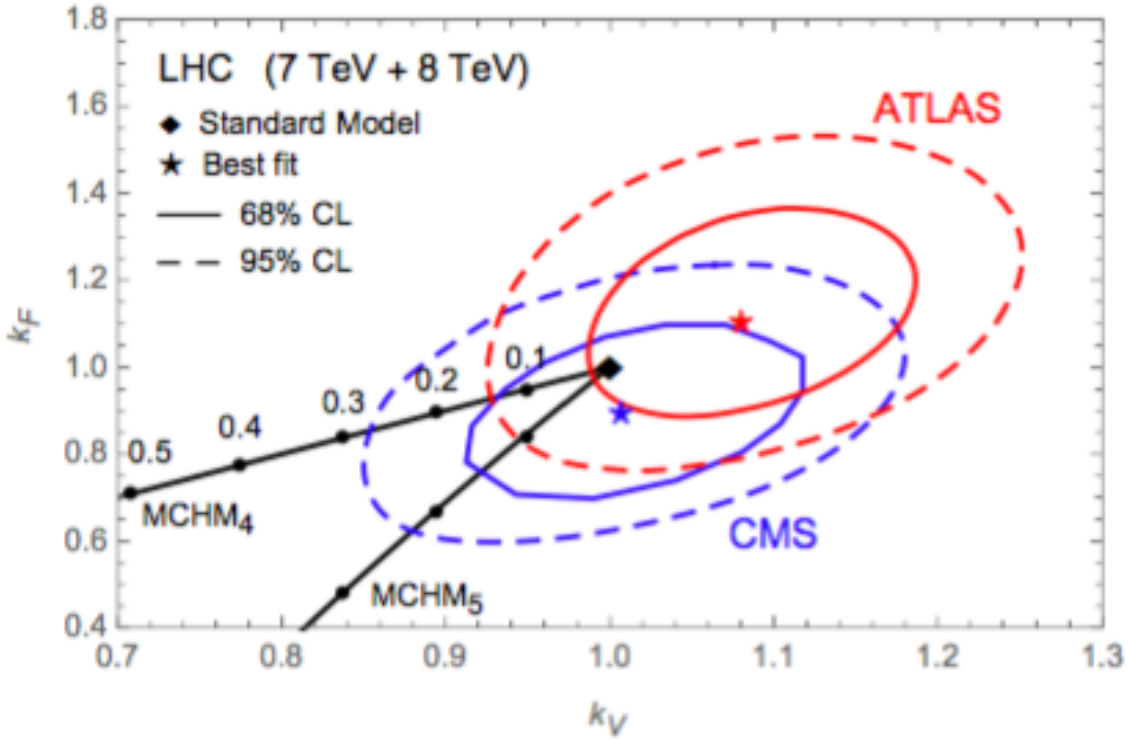
$$C_{\rm top} \propto \int \frac{d^4p}{(2\pi)^4} \frac{d^4q}{(2\pi)^4} \frac{p_\mu}{p^2} \frac{q_\nu}{q^2} \langle \bar{\mathcal{B}}_{Rk}(p) \gamma_\mu P_R \mathcal{B}_{Ri}(p) \bar{\mathcal{B}}_{Li}(q) \gamma_\nu P_L \mathcal{B}_{lk}(p) \rangle$$

[Golterman & Shamir 15]

$$\xi = v^2/f^2 = \alpha/(2\beta)$$
$$\alpha = \frac{1}{4} \frac{m_h^2}{v^2} \frac{\xi}{1-\xi}$$

Phenomenology I - modified coupling

Ferretti's model similar to generic MCHM5, $k \sim \sqrt{1-\xi}$ [Contino et al 06]



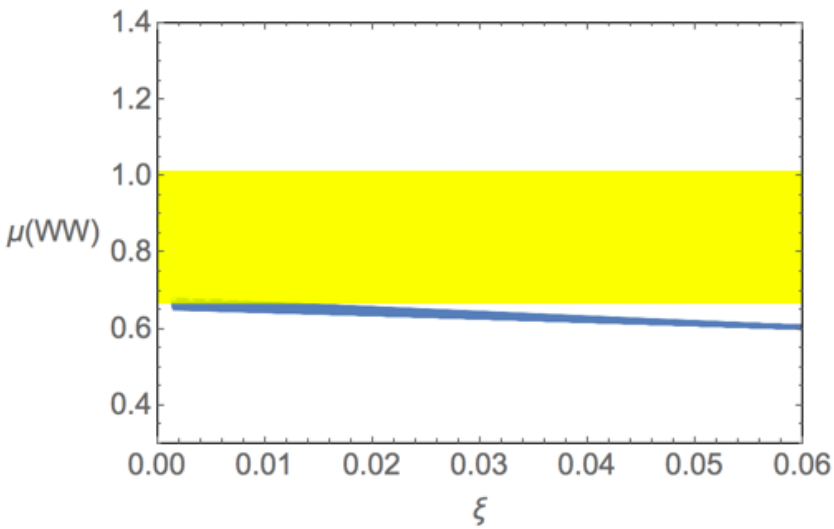
[Panico & Wulzer 15]

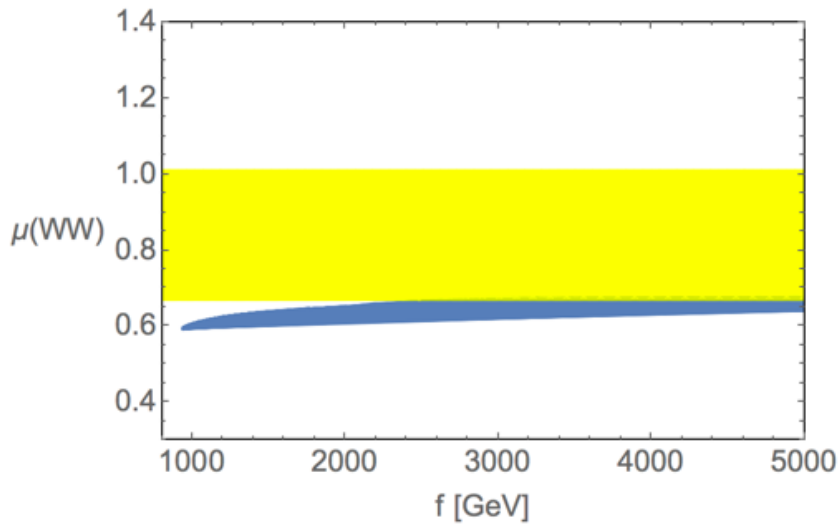
$$\boxed{\xi < 0.15, \quad \xi \to 0 \Longleftrightarrow \mathrm{SM}}$$

Phenomenology II - exotica

$M/\mathrm{TeV} \in [1.5, 3.5]$, $\lambda_t \in [0, 4\pi]$, using `Feynrules`, `MadEvent`

Higgs decay to WW

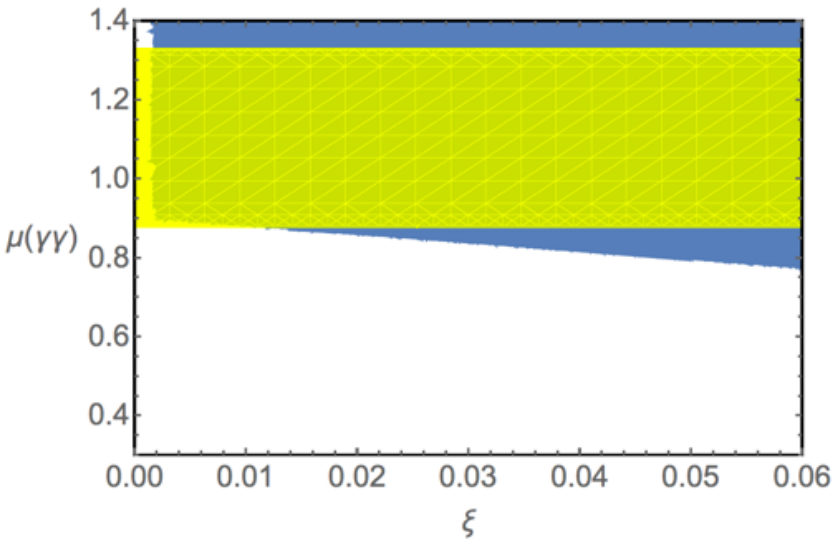


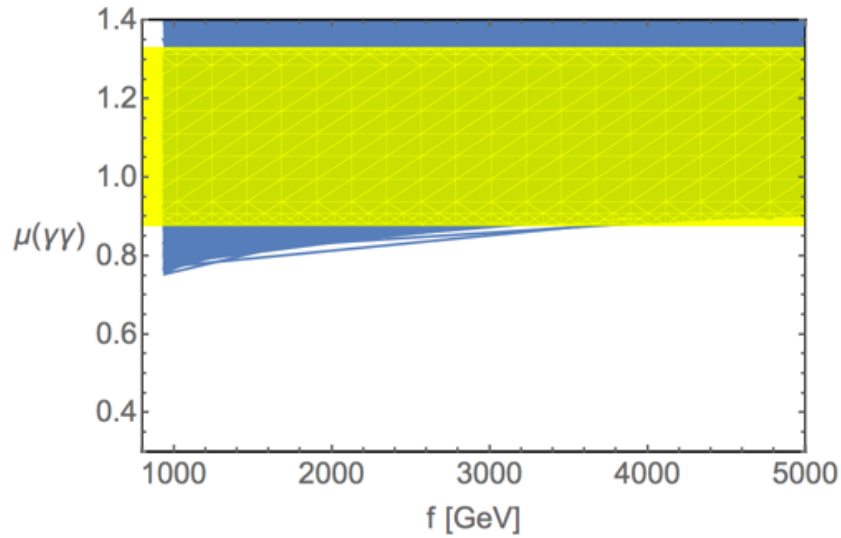


data from [Atlas & CMS 16]

Phenomenology III - exotica

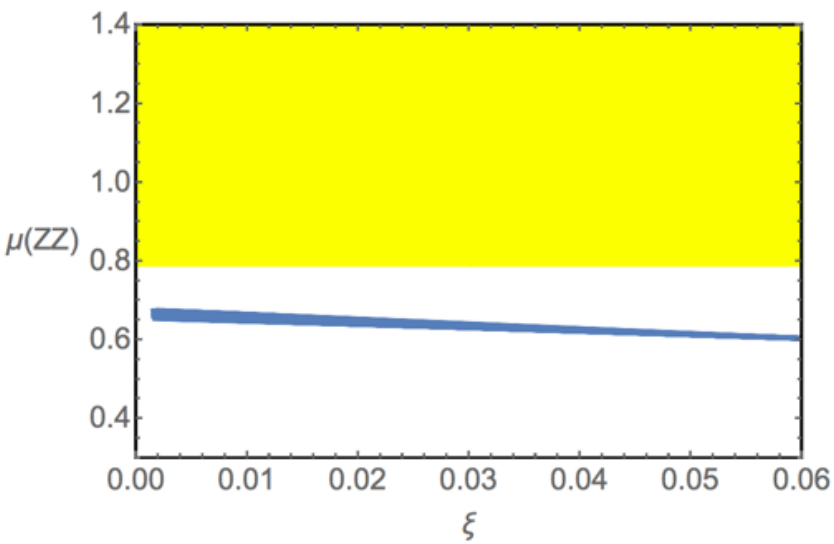
loop-induced Higgs decay to $\gamma\gamma$

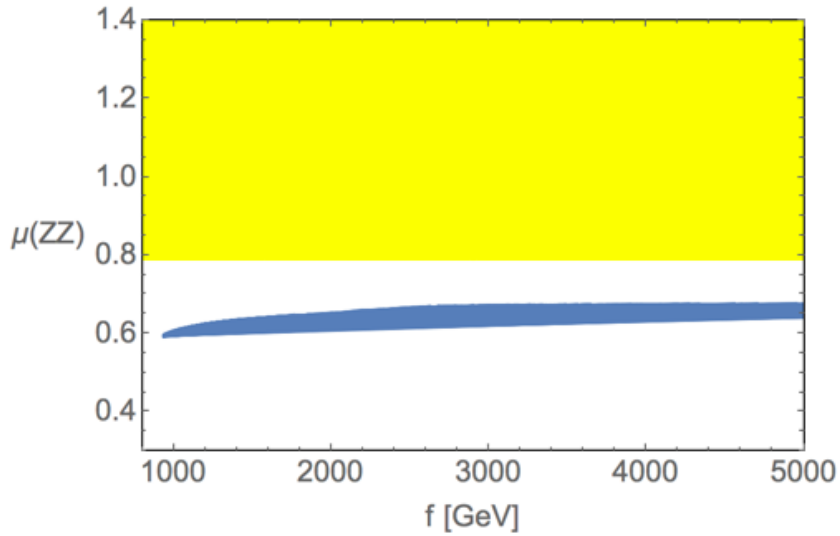




Phenomenology IV - exotica

Higgs decay to ZZ





some tension in this channel

Scope for lattice simulations

Ferretti's model is not ruled out by LHC Run1 data

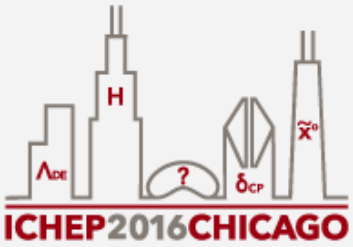
Strong constraints from a lattice computation of α and β

Estimate the precision required in order to have an impact on pheno

The lattice simulation is a difficult computation... [Svetitsky, Jay later today]

... and needs to be extrapolated to the chiral limit

Ferretti? or someone else? ... theoretical tools, new observables



38th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

AUGUST 3 - 10, 2016
CHICAGO

Fri 05/08

Print | PDF | Full screen | Detailed view | Filter

09:00	**Search for a high mass diphoton resonance using the ATLAS detector (15' + 5')**	*Bruno Lenzi*
	Chicago 7	09:00 - 09:20
	Searches for BSM physics in diphoton final state at CMS (15' + 5')	*Chiara Ilaria Rovelli*
	Chicago 7	09:20 - 09:40
	The Diphoton Excess in a Relaxion Framework (12' + 3')	*Michael Fedderke et al.*
	Chicago 7	09:40 - 09:55
10:00	**Dark sector shining through 750 GeV dark Higgs boson at the LHC (12' + 3')**	*pyungwon ko et al.*
	Chicago 7	09:55 - 10:10
	The NMSSM lives - with the 750 GeV diphoton excess (12' + 3')	*Krzysztof Rolbiecki et al.*
	Chicago 7	10:10 - 10:25
	Measuring the diphoton coupling of a 750 GeV resonance at the LHC (12' + 3')	*Christophe Royon et al.*
	Chicago 7	10:25 - 10:40
	Supersymmetric Models and the 750 GeV diphoton resonance (12' + 3')	*qaisar shafi*
	Chicago 7	10:40 - 10:55
11:00	**Higgs-radion Interpretation of the 750 GeV di-photon excess at the LHC (12' + 3')**	*Jack Gunion*
	Chicago 7	10:55 - 11:10