Constraining new physics with the current Higgs data

Admir Greljo

Institut "Jožef Stefan"

In colaboration with:
Ilja Doršner
Svjetlana Fajfer
Ivana Mustać
Jernej Fesel Kamenik

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Outline

- Higgs data
- Fitting procedure
- Light colored scalars and Higgs

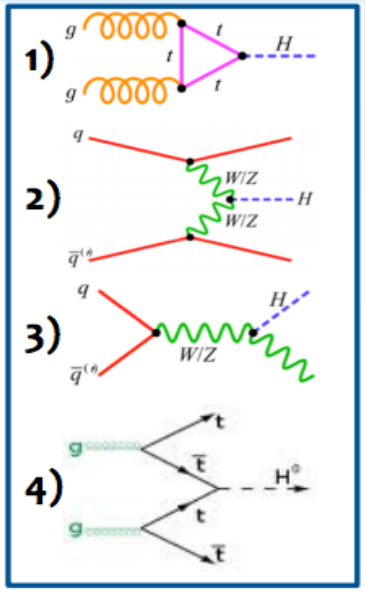
  arXiv:1208.1266 (JHEP 2012:130) - I. Doršner, S. Fajfer, A. Greljo, J. F. Kamenik
- Light vector-like quarks and Higgs

  arXiv:1304.4219 - S. Fajfer, A. Greljo, I. Mustać, J. F. Kamenik
- Conclusions

Higgs data and fitting procedure

- Decay chanels:
  - h->bb (BR_{SM}=0.569)
  - h->WW* (BR_{SM}=0.224)
  - h->ττ (BR_{SM}=0.063)
  - h->ZZ* (BR_{SM}=0.028)
  - h->γγ (BR_{SM}=0.0023)
  - h->Zγ (BR_{SM}=0.0016)
  - h->μμ (BR_{SM}=0.0002)

- Production mechanisms:
  - Gluon-gluon fusion (ggF) (σ_{SM_8TeV}=19.4 pb)
  - Vector-boson fusion (VBF) (σ_{SM_8TeV}=1.55 pb)
  - Associated production with gauge bosons (VH) (σ_{SM_8TeV}=1.07 pb)
  - Associated production with top (ttH) (σ_{SM_8TeV}=0.13)



- Signal strengths (μ): Experimental collaborations report number of signal events normalized to SM prediction for different search channels
- Several analysis categories for single decay mode
  - Generally target certain production mechanism
    - 0/1 – jets, VBF-tag, VH-tag, ttH-tag
  - Does not imply 100% purity

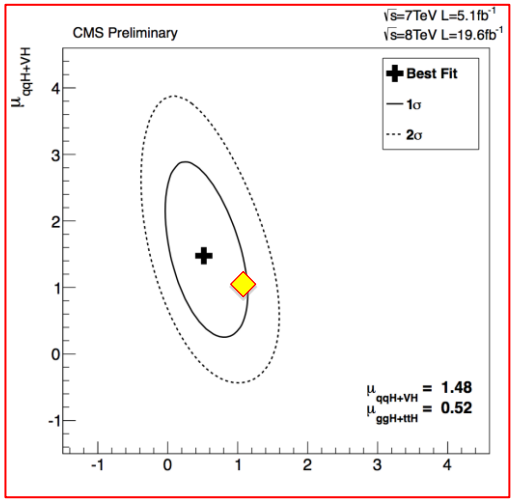
Higgs data and fitting procedure

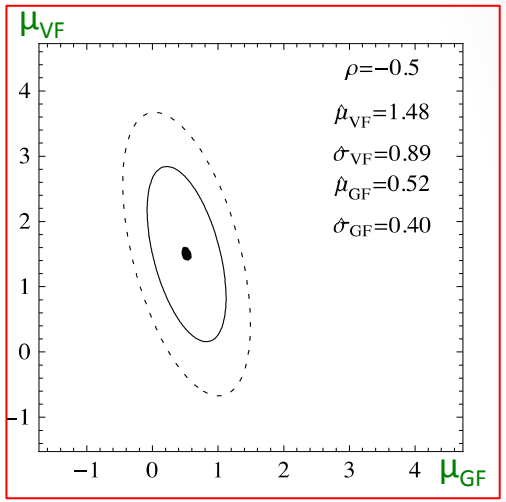
- Separation into GF=(ggF+tth) and VF=(VBF+VH)
  - Parameterize likelihood with

$$\chi_1^2 = \sum_i \left(\mu^i_{GF} - \hat{\mu}^i_{GF},\ \mu^i_{VF} - \hat{\mu}^i_{VF} \right) \begin{pmatrix} \left(\hat{\sigma}^i_{GF}\right)^2 & \rho\hat{\sigma}^i_{GF}\hat{\sigma}^i_{VF} \\ \rho\hat{\sigma}^i_{GF}\hat{\sigma}^i_{VF} & \left(\hat{\sigma}^i_{GF}\right)^2 \end{pmatrix}^{-1} \begin{pmatrix} \mu^i_{GF} - \hat{\mu}^i_{GF} \\ \mu^i_{VF} - \hat{\mu}^i_{VF} \end{pmatrix}$$

  - Example:
    CMS h->γγ decay channel
  - From theory:

$$\mu^{h\to B}_{A\to h} = \frac{\sigma_{A\to h}}{\sigma^{SM}_{A\to h}} \frac{\mathcal{B}_{h\to B}}{\mathcal{B}^{SM}_{h\to B}}$$





- If the separation is not provided, use search categories
  - Estimate contribution from each production mode

$$\frac{\sigma_{A\to h}}{\sigma^{SM}_{A\to h}} = \xi_{ggF}\frac{\sigma_{ggF}}{\sigma^{SM}_{ggF}} + \xi_{VBF}\frac{\sigma_{VBF}}{\sigma^{SM}_{VBF}} + \xi_{VH}\frac{\sigma_{VH}}{\sigma^{SM}_{VH}} + \xi_{ttH}\frac{\sigma_{ttH}}{\sigma^{SM}_{ttH}}$$

  - Parameterize with likelihood

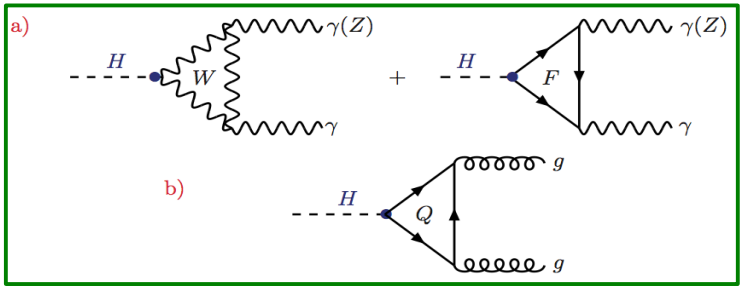
$$\chi_2^2 = \sum_j \left(\frac{\mu_j - \hat{\mu}_j}{\hat{\sigma}_j} \right)^2$$

- Total $\chi^2(\mu_i)=\chi_1^2+\chi_2^2$
- Express signal rates in terms of model parameters
- Minimize χ^2 to find the best fit point
- Find best fit regions as solutions to $\chi^2<\chi^2_{min}+\Delta\chi^2$
- $\Delta\chi^2$ - set by appropriate cumulative distribution function

Light colored scalars and Higgs phenomenology

arXiv:1208.1266 (JHEP 2012:130) - I. Doršner, S. Fajfer, A. Greljo, J. F. Kamenik

- Motivation (Grand Unified Theory)
  - Light colored scalars improve unification -
    - correlation with observable partial proton decay lifetimes
  - We find viable unification scenarios for two SU(5) models
    - 5-, 45- scalar and 24- dimensional fermion - P. Fileviez Perez (2007)
    - 5-, 15-, 45- scalar - I. Doršner and P. Fileviez Perez (2006), I. Doršner and I. Mocioiu (2008)
- Impact on Higgs phenomenology: Higgs portal! $\Phi^\dagger\Phi H^\dagger H$
- Loop induced Higgs decays
  - Sensitive to colored and/or charged massive particles
    a) $h\to\gamma\gamma$, $h\to Z\gamma$
    b) $gg\to h$



- General analysis:
  - Take $R_{gg}=\sigma_{ggF}/\sigma_{ggF}^{SM}$ and $R_{\gamma\gamma}=\Gamma_{h\to\gamma\gamma}/\Gamma_{h\to\gamma\gamma}^{SM}$ as fitting parameters
  - Express all signal rates in terms of R_{gg} and $R_{\gamma\gamma}$

$$\hat{\Gamma} = 0.915 + 0.085 R_{gg}$$

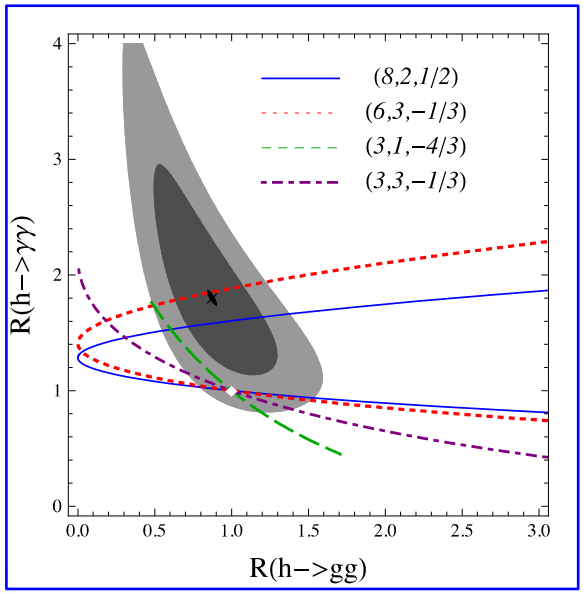
$$\mu_{GF}^{h\to\gamma\gamma} = \frac{R_{gg}}{\hat{\Gamma}} R_{\gamma\gamma},\ \mu_{VF}^{h\to\gamma\gamma} = \frac{R_{\gamma\gamma}}{\hat{\Gamma}},\ \mu_{GF}^{h\to ZZ,WW,\tau\tau} = \frac{R_{gg}}{\hat{\Gamma}},\ \mu_{VF}^{h\to ZZ,WW,\tau\tau} = \frac{1}{\hat{\Gamma}},\ \mu_{VH}^{h\to bb} = \frac{1}{\hat{\Gamma}}$$

Light colored scalars and Higgs phenomenology: Results

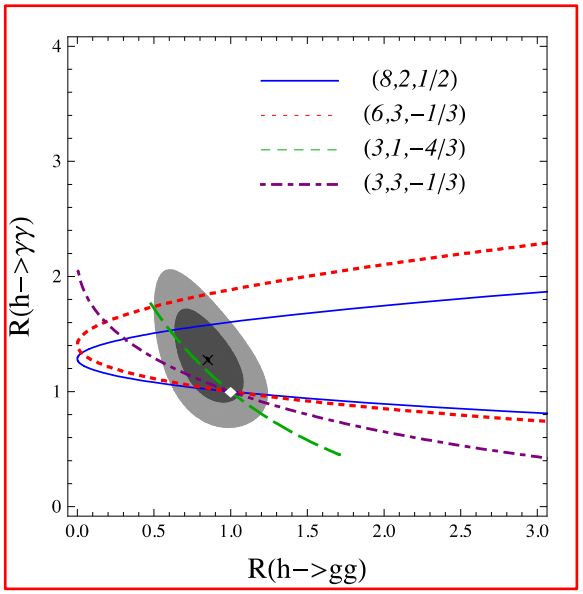
- Correlation between h→γγ and gg→h
- Specify representation
  - Dimension and index of color rep. $d(r_\phi)$ and $C(r_\phi)$
  - Electric charge (Q_ϕ)
- Single parameter $\lambda v^2/m_\phi^2$
  - Do one-dimensional χ^2, find allowed parameter region

$$\frac{\Gamma_{h\to\gamma\gamma}}{\Gamma^{SM}_{h\to\gamma\gamma}} = \left|1 - 0.0256\frac{\lambda v^2}{m_\phi^2}\sum_\phi d(r_\phi)Q_\phi^2\right|^2$$

$$\frac{\sigma_{ggF}}{\sigma^{SM}_{ggF}} = \left|1 + 0.256\frac{\lambda v^2}{m_\phi}\sum_\phi C(r_\phi)\right|^2$$



August 2012.



April 2013.

$SU(3)\times SU(2)\times U(1)$	$\lambda v^2/m_\phi^2$
$(\bar{\mathbf{3}},\mathbf{1},1/3)$	-0.3 ± 0.5
$(\bar{\mathbf{3}},\mathbf{1},-2/3)$	-0.4 ± 0.6
$(\mathbf{3},\mathbf{1},-4/3)$	-0.7 ± 0.6
$(\mathbf{3},\mathbf{2},1/6)$	-0.2 ± 0.3
$(\mathbf{3},\mathbf{2},7/6)$	-0.3 ± 0.3
$(\mathbf{3},\mathbf{3},-1/3)$	-0.2 ± 0.2
$(\bar{\mathbf{6}},\mathbf{1},-1/3)$	-0.06 ± 0.12
$(\bar{\mathbf{6}},\mathbf{1},2/3)$	-0.07 ± 0.12
$(\bar{\mathbf{6}},\mathbf{1},-4/3)$	-0.09 ± 0.12
$(\bar{\mathbf{6}},\mathbf{3},-1/3)$	-0.02 ± 0.04
	$-1.0<x<0.9$
$(\mathbf{8},\mathbf{2},1/2)$	-0.03 ± 0.05
	-1.22 ± 0.04

Light vector-like quarks and Higgs phenomenology

arXiv:1304.4219 - S. Fajfer, A. Greljo, I. Mustać, J. F. Kamenik

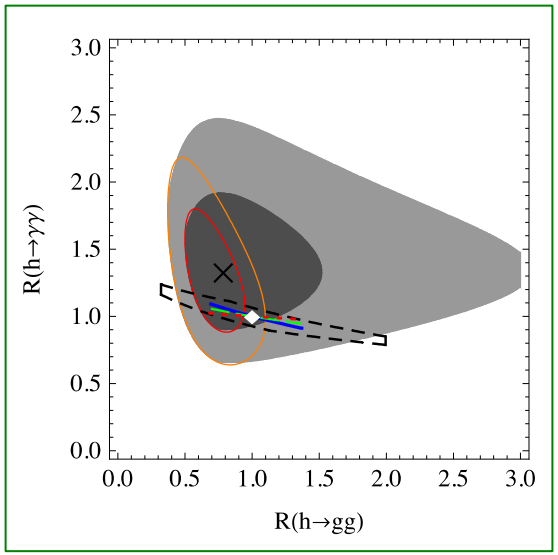
- Framework
  - Assume new lightest degree of freedom - vector-like quark (VLQ)
  - Consider weak representation of SM chiral quarks – mixing!
  - Study leading dimension five operators (5DO) $H^\dagger H \bar{q}_i Q,\ H^\dagger H \bar{Q} Q$
- Motivation
  - Models addressing EW hierarchy problem with Higgs being a pseudo-goldstone boson of a global symmetry
- Renormalizable models with VLQ
  - Updated constraints on flavor matrices
  - Lessons for Higgs: Hard to distinguish from SM!
- Including 5DO does not affect mass diagonalization! - $(v^2/2 - |H|^2)$
- The main consequences of 5DO
  - Direct di-Higgs coupling
    - possible implication for SM hierarchy
  - Modification of single Higgs - quark coupling
    - not related to weak currents!
- Visible effects:
  - Flavour diagonal Higgs couplings to light quarks
  - New heavy quarks in the loop

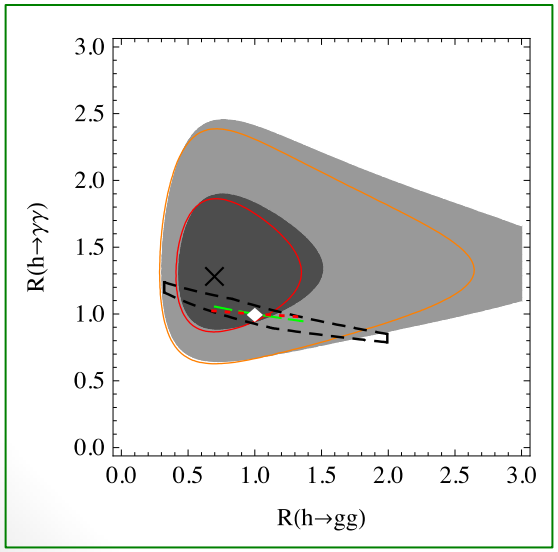
Light vector-like quarks and Higgs phenomenology

- General fit - R_{gg}, $R_{\gamma\gamma}$, R_{bb}, $\Delta\gamma$

$$\hat{\Gamma} \equiv \frac{\Gamma_{tot}}{\Gamma_{tot}^{SM}} = 0.569 R_{bb} + 0.317 + 0.085 R_{gg} + \Delta\gamma$$

$$\mu_{GF}^{h\to\gamma\gamma} = \frac{R_{gg}}{\hat{\Gamma}} R_{\gamma\gamma}\,, \quad \mu_{GF}^{h\to ZZ,WW,\tau\tau} = \frac{R_{gg}}{\hat{\Gamma}}\,, \quad \mu_{VF}^{h\to\gamma\gamma} = \frac{R_{\gamma\gamma}}{\hat{\Gamma}} \quad \mu_{VF}^{h\to ZZ,WW,\tau\tau} = \frac{1}{\hat{\Gamma}}\,, \quad \mu_{VH}^{h\to\bar{b}b} = \frac{R_{bb}}{\hat{\Gamma}}.$$





- Four scenarios
- Correlation: (Ex: Singlet up-like VLQ)

$$R_{gg} = \frac{|0.68 r_y - 0.040|^2 + 0.057^2}{0.65^2} \qquad R_{\gamma\gamma} = \frac{|-8.3 + 1.8 r_y|^2}{|-6.5|^2}$$

  - Naturalness criteria $r_y = 1 - \frac{m_t^2}{m_{u'}^2}$
- Higgs data consistent with naturalness condition (even exhibit a slight preference) Ex: $r_y^t = 0.87 \pm 0.08$
- Indirect constraints on heavy partner's mass satisfying naturalness criteria: $m_{u'} > 360$ GeV @ 95% C.L.
- Complementary probe to direct searches
- More statistics needed!

Conclusions

- Higgs data is reviewed and fitting procedure is explained
- Impact of light colored scalars on Higgs phenomenology was studied in the light of new Higgs data
- Higgs data was used to study general set-up with dynamical VLQ and dimension five operators that attempts to address EW hierarchy problem

Thank you!

Back up

Higgs data summarized

(arXiv:1304.4219 - S. Fajfer, A. Greljo, I. Mustać, J. F. Kamenik)

Decay channel	Production mode	Signal strength	Comment
ATLAS			
$h \to ZZ^*$	Inclusive (87% ggF)	1.5 ± 0.4	[14, 21]
$h \to b\bar{b}$	VH	-0.4 ± 1.0	[14]
$h \to WW^*$	ggF+ttH	0.79 ± 0.35	Correlation $\rho = -0.3$, [14, 22]
	VBF+VH	1.6 ± 0.8	
$h \to \gamma\gamma$	ggF+ttH	1.60 ± 0.44	Correlation $\rho = -0.4$, [14, 23]
	VBF+VH	1.80 ± 0.87	
$h \to \tau\tau$	ggF+ttH	2.2 ± 1.6	Correlation $\rho = -0.5$, [14]
	VBF+VH	-0.3 ± 1.1	
CMS			
$h \to b\bar{b}$	VH	1.3 ± 0.7	[15]
$h \to WW^*$	0/1 jet (97% ggF)	0.76 ± 0.21	[24]
	VBF-tag (20% ggF)	0.0 ± 0.7	[15]
	VH	-0.3 ± 2.1	[15]
$h \to ZZ^*$	ggF+ttH	0.90 ± 0.45	Correlation $\rho = -0.7$, [25]
	VBF+VH	1.0 ± 2.3	
$h \to \gamma\gamma$	ggF+ttH	0.52 ± 0.40	Correlation, $\rho = -0.5$, [26]
	VBF+VH	1.5 ± 0.9	
$h \to \tau\tau$	0/1 jet (80% ggF)	0.73 ± 0.51	[27]
	VBF-tag (20% ggF)	1.37 ± 0.63	[27]
	VH	0.75 ± 1.5	[27]

Table I: LHC Higgs data used in the analysis.