Signatures of dynamical scalars

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In collaboration with:
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SEVENTH FRAMEWORK PROGRAMME

MARIE CURIE ACTIONS

Moriond EW, March 17th 2015

invisibles
neutrinos, dark matter & dark energy physics

ift

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A urgent question

What dynamics is responsible for electroweak symmetry breaking?

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weakly interacting	**strong interacting**
linear realization of EWSB	non-linear realization of EWSB
e.g. SUSY	*e.g.* Technicolor, compositeness
an elementary scalar	a dynamical (composite) scalar

A urgent question

What dynamics is responsible for electroweak symmetry breaking?

weakly interacting

linear realization of EWSB

e.g. SUSY

an elementary scalar

strong interacting

non-linear realization of EWSB

e.g. Technicolor, compositeness

a dynamical (composite) scalar

Indirect approach: study the low-energy impact via **a model-independent effective Lagrangian**

linear EFT

non-linear (chiral) EFT

the two EFT give different predictions ➔ **SIGNATURES!**

Linear *vs.* non-linear EFT

linear EFT	non-linear (chiral) EFT
1 scalar field	2 scalar fields
$\Phi = \frac{1}{\sqrt{2}}\begin{pmatrix} \pi^1 + i\pi^2 \\ v + h + i\pi^3 \end{pmatrix}$ (GBs: π^1, π^2, π^3; BEH scalar: h)	$\mathbf{U} = e^{i\pi^a\sigma^a/v}$ h (gauge singlet!)
gauge doublet	
$D_\mu\Phi$ ↔	$D_\mu\mathbf{U}$ $\partial_\mu h$
$(v+h)$ ↔	$\mathcal{F}(h) = 1 + 2a\frac{h}{v} + b\frac{h^2}{v^2} + \ldots$
Exp. in canonical dimensions	Exp. in derivatives

Linear *vs.* non-linear EFT

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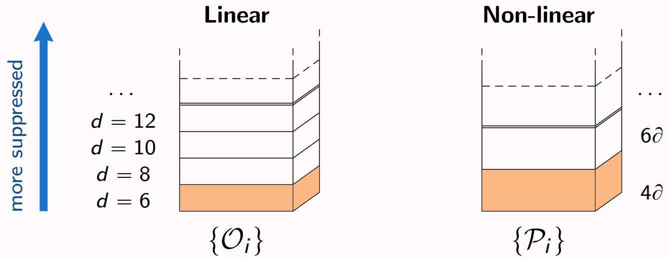
$\Phi = \frac{1}{\sqrt{2}}\begin{pmatrix}\pi^1 + i\pi^2\\ v + h + i\pi^3\end{pmatrix}$	$\mathbf{U} = e^{i\pi^a\sigma^a/v}$ h
gauge doublet BEH scalar	gauge singlet!
$D_\mu\Phi$ $\longleftrightarrow$	$D_\mu\mathbf{U}$ $\partial_\mu h$
$(v+h)$ $\longleftrightarrow$	$\mathcal{F}(h) = 1 + 2a\frac{h}{v} + b\frac{h^2}{v^2} + \dots$
Exp. in canonical dimensions	Exp. in derivatives

$$\Phi \to \frac{v+h}{\sqrt{2}}\mathbf{U}\begin{pmatrix}0\\1\end{pmatrix}$$

Linear *vs.* non-linear EFT

Two towers of operators:



Correspondence $\mathcal{O}_\mathbf{i} \to \mathcal{P}_\mathbf{j}$

Replace in $\mathcal{O}_i$: $\quad \Phi \to \dfrac{v+h}{\sqrt{2}}\mathbf{U}\begin{pmatrix}0\\1\end{pmatrix}$

Linear *vs.* non-linear EFT

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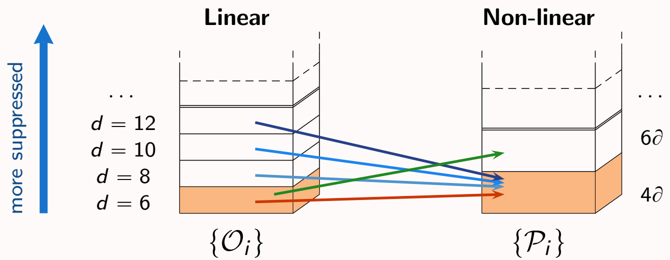

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❶ Decorrelation effects

From the HISZ linear basis

Hagiwara,Ishihara,Szalapski,Zeppenfeld (1993)

$$\mathcal{O}_B = ig' D^\mu \Phi^\dagger \, B_{\mu\nu} \, D^\nu \Phi$$

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Chiral basis

$D^\nu \mathbf{U}$ → $\mathcal{P}_2$; $\partial^\nu h$ → $\mathcal{P}_4$

$$\mathcal{P}_2 = ig' B_{\mu\nu} \, \mathrm{Tr}(\sigma^3 [D^\mu \mathbf{U}^\dagger, D^\nu \mathbf{U}]) \mathcal{F}_2(h) \qquad \mathcal{P}_4 = ig' B_{\mu\nu} \, \mathrm{Tr}(\sigma^3 D^\mu \mathbf{U} \mathbf{U}^\dagger) \partial^\nu \mathcal{F}_4(h)$$

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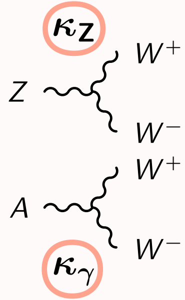
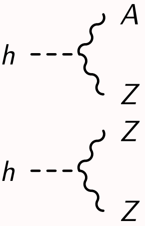


$Z_{\mu\nu} W^{+\mu} W^{-\nu}$

$A_{\mu\nu} W^{+\mu} W^{-\nu}$



$A_{\mu\nu} Z^\mu \partial^\nu h$

$Z_{\mu\nu} Z^\mu \partial^\nu h$

Decorrelated signals!

❶ Decorrelation effects

From the HISZ linear basis

Hagiwara, Ishihara, Szalapski, Zeppenfeld (1993)

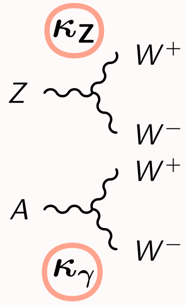
$$\mathcal{O}_W = ig\, D^\mu \Phi^\dagger\, W_{\mu\nu}\, D^\nu \Phi$$

Chiral basis

$D^\nu \mathbf{U}$ $\qquad$ $\partial^\nu h$

$$\mathcal{P}_3 = ig\, \mathrm{Tr}(W_{\mu\nu}[D^\mu \mathbf{U}^\dagger, D^\nu \mathbf{U}])$$

$$\mathcal{P}_5 = ig\, \mathrm{Tr}(W_{\mu\nu} D^\mu \mathbf{U}\mathbf{U}^\dagger)\partial^\nu \frac{h}{v}$$



$Z_{\mu\nu} W^{+\mu} W^{-\nu}$

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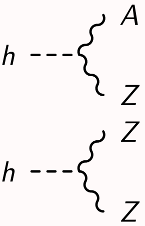

$A_{\mu\nu} Z^\mu \partial^\nu h$

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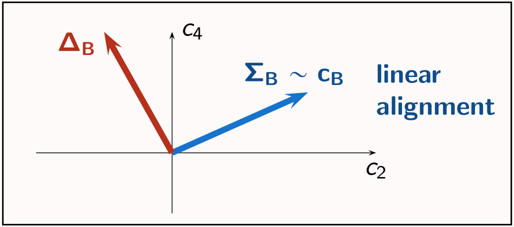
Decorrelated signals!

❶ Global fit from TGV + Higgs data



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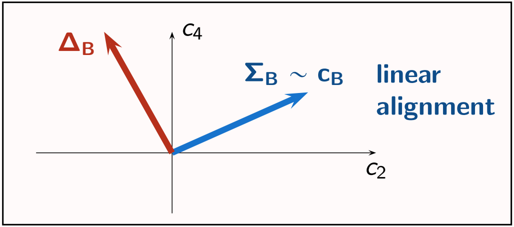
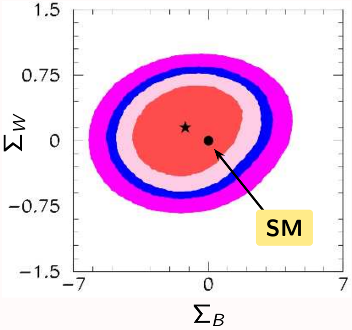


χ^2 dependence after marginalizing over the other chiral parameters

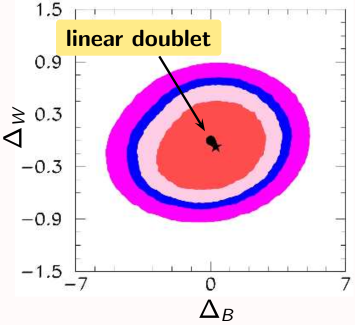
Datasets: TGV (LEP) and HVV couplings (D0+CDF+ATLAS+CMS).

Colored areas:
68%, 90%, 95%, 99% CL

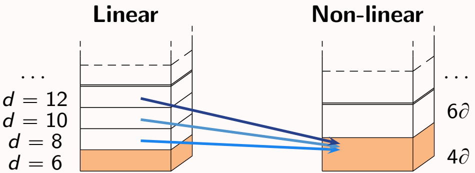
A BSM sensor



A linear vs non-linear discriminator



❷ Characteristic signals



$$\varepsilon^{\mu\nu\rho\lambda}\left(\Phi^\dagger \overleftrightarrow{\mathbf{D}}_\rho\Phi\right)\left(\Phi^\dagger\sigma_i \overleftrightarrow{\mathbf{D}}_\lambda\Phi\right)W^i_{\mu\nu}$$

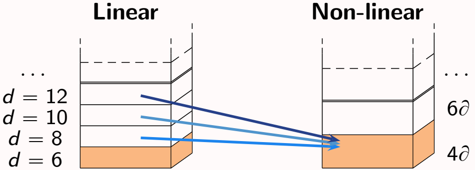
$d = 8$ NNLO in linear

↓

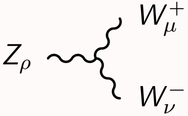
$$\mathcal{P}_{14} = g\varepsilon^{\mu\nu\rho\lambda}\,\mathrm{Tr}(\mathbf{TV}_\mu)\,\mathrm{Tr}(\mathbf{V}_\nu W_{\rho\lambda})\mathcal{F}_{14}(h)$$

4∂ NLO in chiral

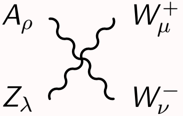
❷ Characteristic signals



$\mathcal{P}_{14}$ ➔



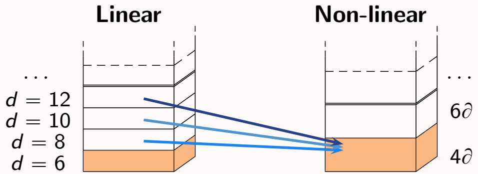
$$-\frac{g^3 c_{14}}{2c_\theta}\varepsilon^{\mu\nu\rho\lambda}\partial_\mu W^+_\nu W^-_\rho Z_\lambda + \text{h.c.}$$



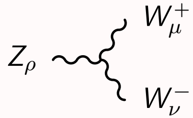
$$-\frac{2eg^3 c_{14}}{c_\theta}\varepsilon^{\mu\nu\rho\lambda} W^+_\mu W^-_\nu Z_\lambda A_\rho + \text{h.c.}$$

If comparable in size to other NLO effects ➔ non-linearity signature!

❷ Characteristic signals



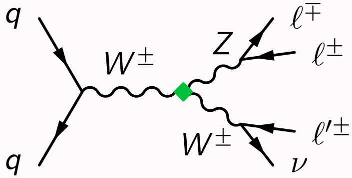
$\mathcal{P}_{14}$ ➔



$$-\frac{g^3 c_{14}}{2c_\theta}\varepsilon^{\mu\nu\rho\lambda}\partial_\mu W^+_\nu W^-_\rho Z_\lambda + \text{h.c.}$$

the anomalous TGC g_5^Z

can be hunted @ the LHC!



Summary

New physics underlying electroweak symmetry breaking can be studied in a model-independent way via EFTs.

linear and **non-linear** EFTs predict significantly different patterns of low-energy signals

- **correlation/decorrelation** effects
- distinct **characterizing signatures**

More on chiral lagrangians with a light dynamical h:

bosonic basis CP even	Phys.Lett.B722 330
bosonic basis CP odd	JHEP 1410 44
bosons+fermions basis	Nucl.Phys.B880 552
interesting signatures from $(\Box h)(\Box h)$ operators	JHEP 1412 004
connection to specific composite Higgs models	JHEP 1412 034