Higgs Physics BSM: 8 closed doors, 8 (+3) open windows

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In Collaboration with:

Pomarol, Elias-Miro, Espinosa, Masso

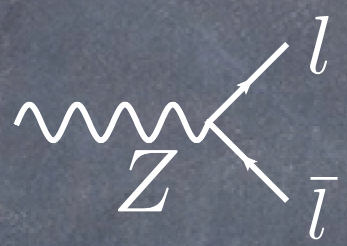
1308.1879, 1308.2803, xxx

Motivation

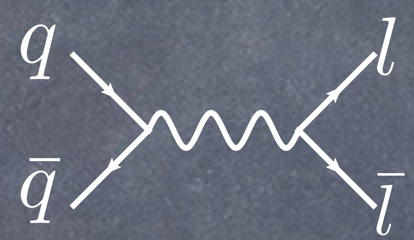
Understand legacy of previous experiments...

1/1000

LEP-I



LHC
KLOE



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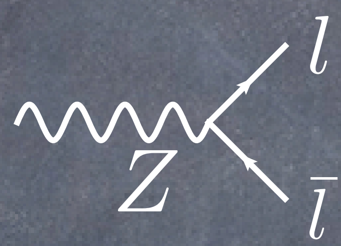

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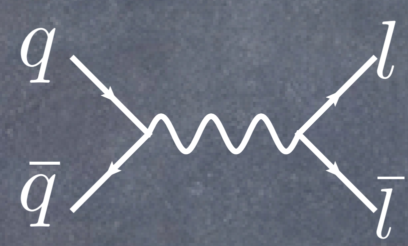

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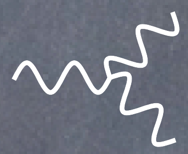
LEP-II

(TGC)



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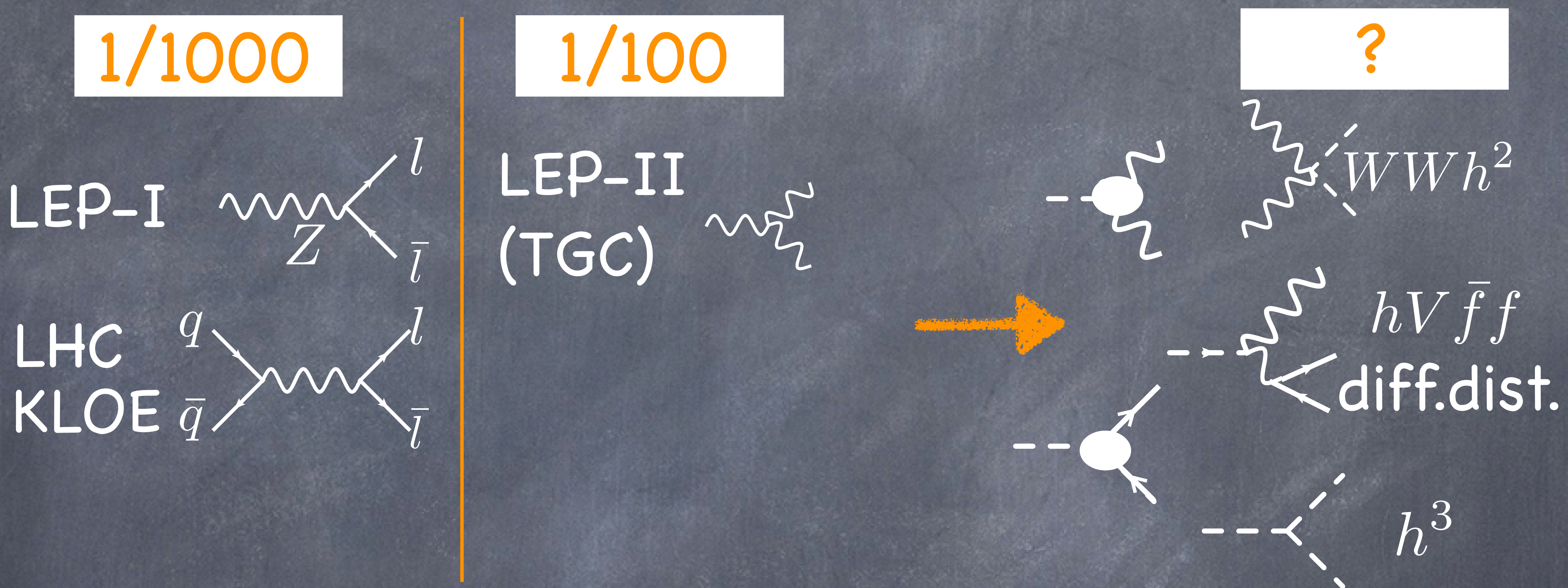


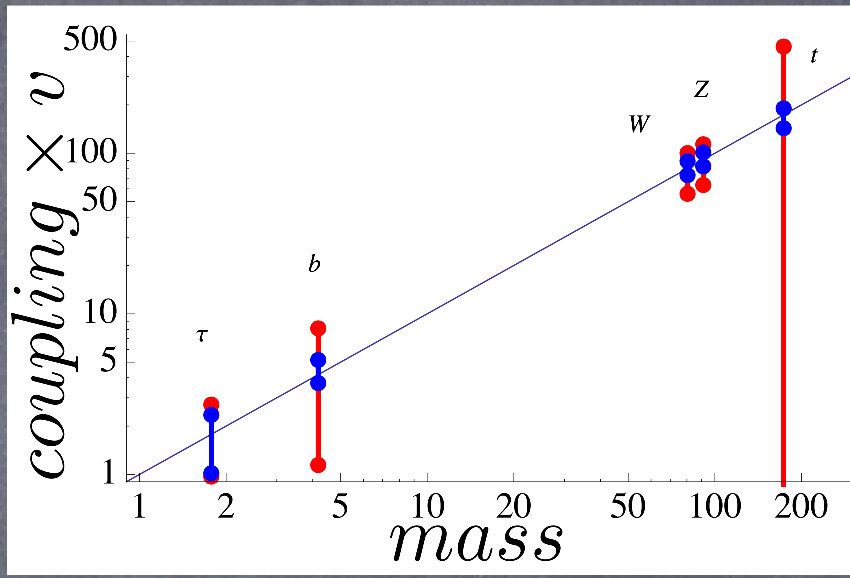
...to learn about Higgs physics:

How many free parameters to describe Higgs sector ?

How to present results/design future experiments?

Assumptions

1) A Higgs has been found: it is part of an EW doublet, responsible for EWSB



2) Nothing else has been found:

$$M^i_{new} \sim \Lambda \gg v$$

3) Minimal Flavor Violation (flavour universal, but effects can deviate)

4) B,L conserved at this level of precision: $\Lambda_{\not B}, \Lambda_{\not L} \gg \Lambda$

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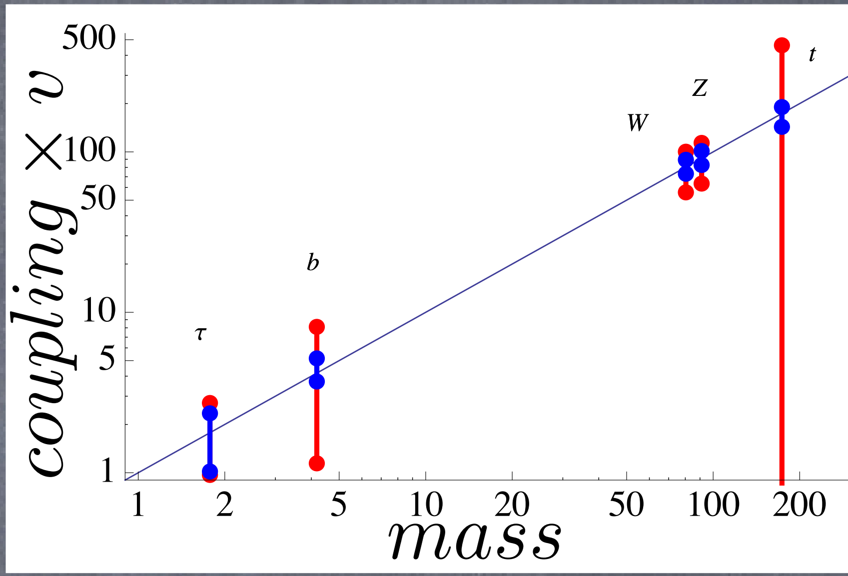

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EFT Description

Under these assumptions, ANY BSM theory can be described by (E/Λ) expansion:

$$\mathcal{L}(\phi_{\mathrm{SM}}) = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_6 + O\left(\frac{E}{\Lambda}\right)^4$$

- leading deviation $\mathcal{L}_6 \sim O\left(\frac{E}{\Lambda}\right)^2$ contains at most 59 terms (59 independent local dimension-6 operators)

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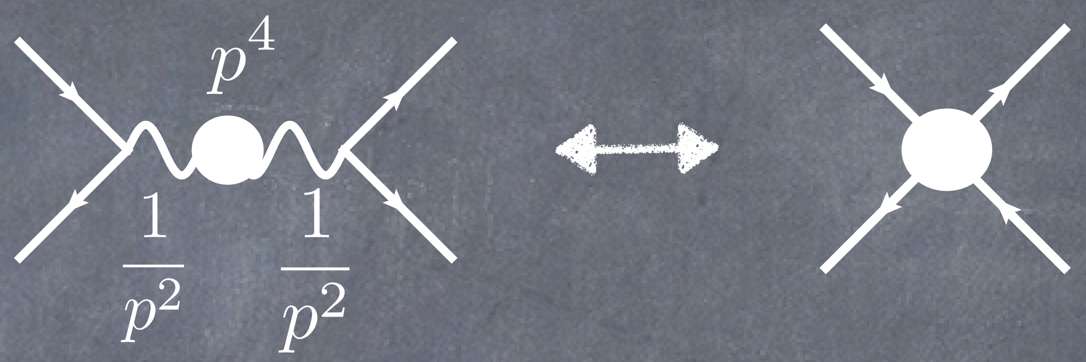
A particular theory produces only some.
Experimentally: keep all to parametrize BSM

Buchmuller,Wyler'86;
Grzadkowski,Iskrzynski,Misiak,Rosiek'10

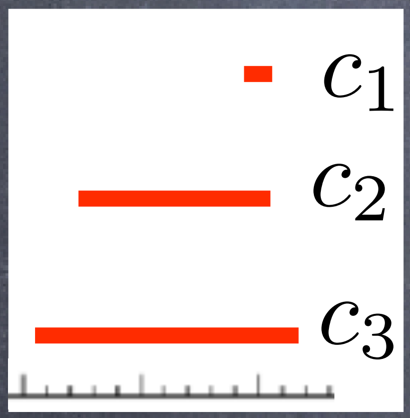
A Suitable Basis

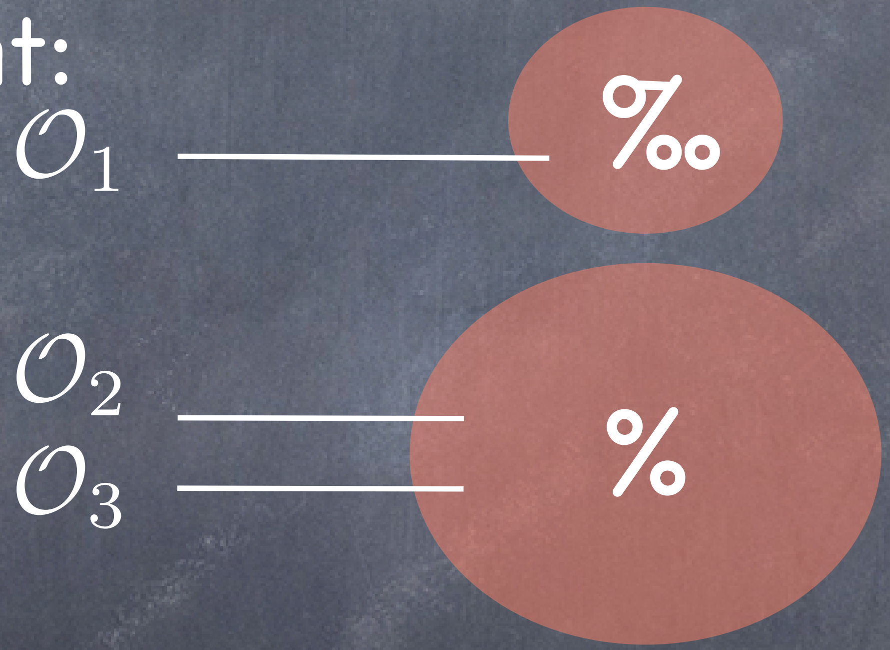
Many bases to express $\mathcal{L}_6$:



Connection with Experiment:

Physics basis-independent, but presentation of results more or less transparent:





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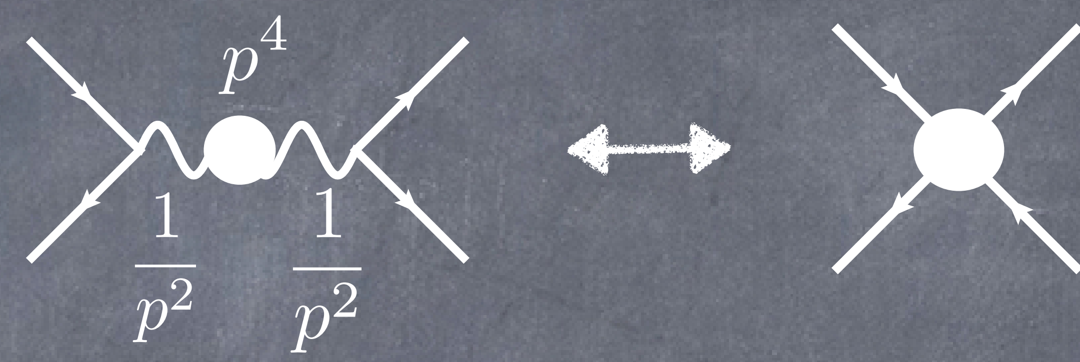

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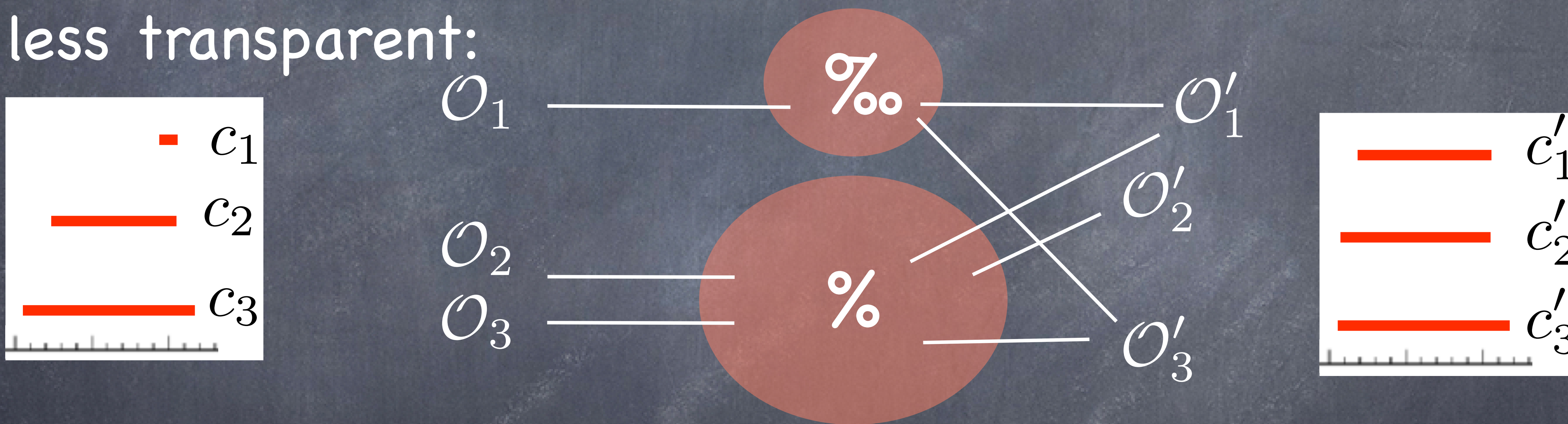

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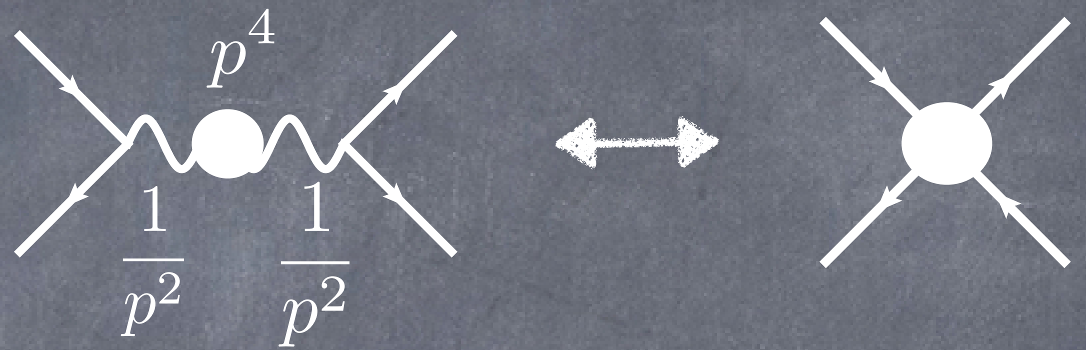

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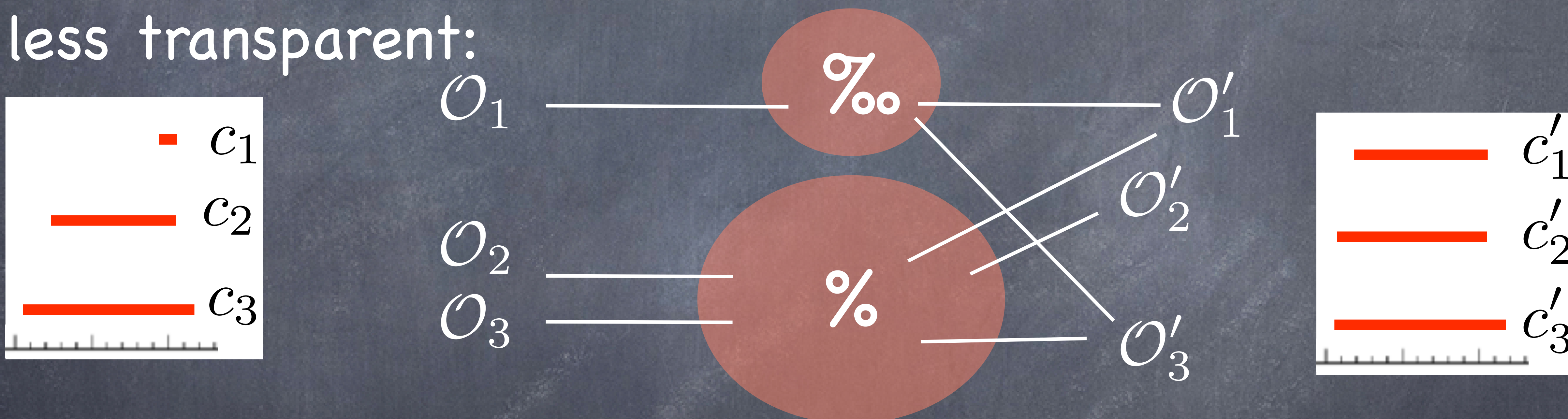
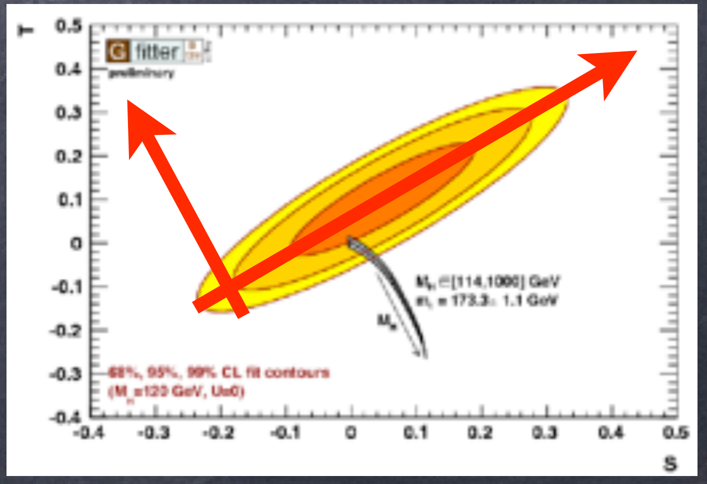


Connection with Theory:

Plausible symmetries of BSM sector must remain manifest



Higgs Physics

How many operators must be included?

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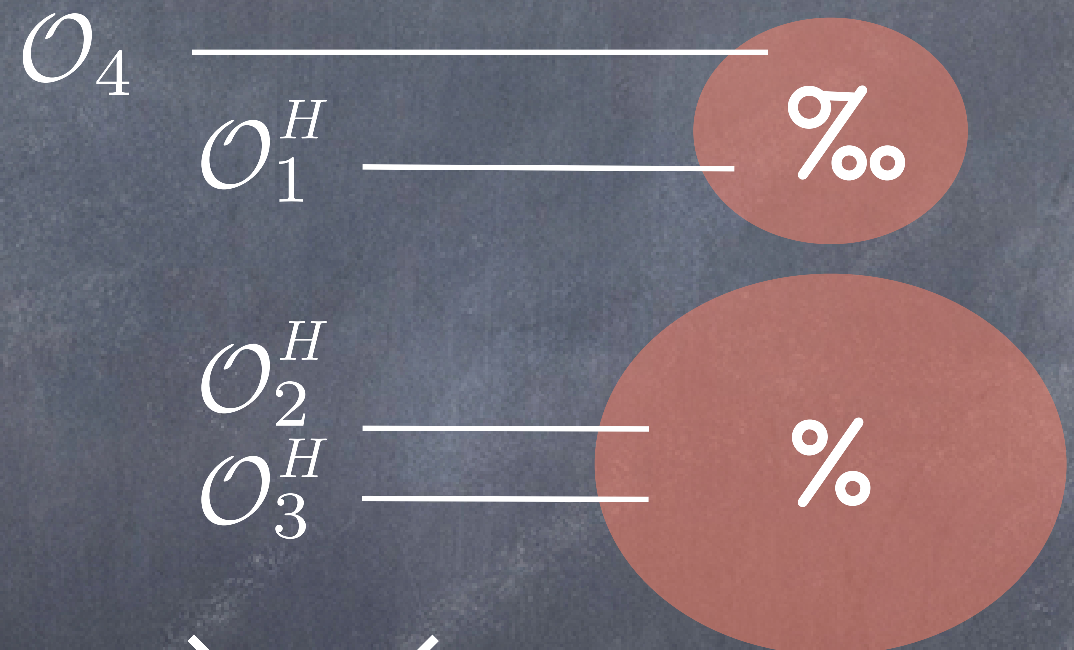
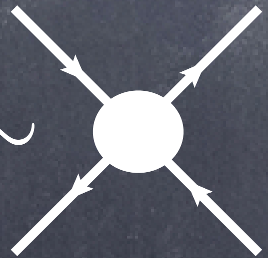


Example: $\delta G_F \sim$  deforms all SM relations

Higgs Physics

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- 2 non-Higgs operators also affect same observables

Minimal Independent set:

19

$$\mathcal{O}_H = \frac{1}{2}(\partial^\mu |H|^2)^2$$
$$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$$
$$\mathcal{O}_6 = \lambda |H|^6$$
$$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D^\mu} H\right) D^\nu W^a_{\mu\nu}$$
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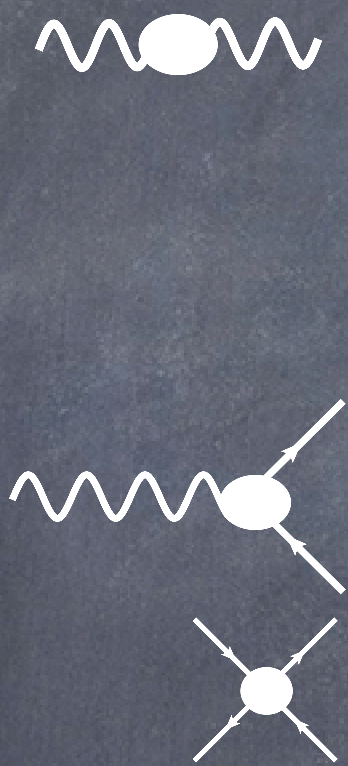
$\mathcal{O}_{y_u} = y_u \vert H\vert^2 \bar{Q}_L \widetilde{H} u_R + \text{h.c.}$	$\mathcal{O}_{y_d} = y_d \vert H\vert^2 \bar{Q}_L H d_R + \text{h.c.}$	$\mathcal{O}_{y_e} = y_e \vert H\vert^2 \bar{L}_L H e_R + \text{h.c.}$
$\mathcal{O}^u_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}_R \gamma^\mu u_R)$ $\mathcal{O}^q_L = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{Q}_L \gamma^\mu Q_L)$ $\mathcal{O}^{(3)\,q}_L = (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{Q}_L \sigma^a \gamma^\mu Q_L)$	$\mathcal{O}^d_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}^e_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R \gamma^\mu e_R)$
		$\mathcal{O}^{(3)\,l}_{LL} = (\bar{L}_L \sigma^a \gamma^\mu L_L)(\bar{L}_L \sigma^a \gamma_\mu L_L)$

Experimental Constraints: per-mille

BSM 5

$\langle H \rangle = v$



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Experiments 4

$\{m_W\}$

$\{A_l, R_l, \sigma^0_{\text{had}}, \Gamma_Z\}$

4

TeVatron: m_W

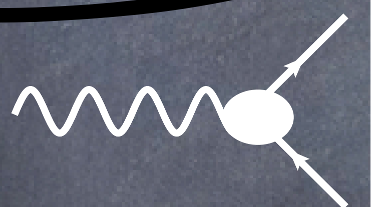
LEP-I$^{\text{(leptons)}}$: $\Gamma(Z \to l_L l_L, l_R l_R, \nu\nu)$

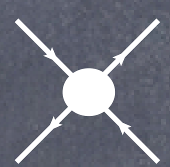
Experimental Constraints: per-mille

BSM 5

$\langle H \rangle = v$

$\mathcal{O}_W - \mathcal{O}_B$ unconstrained!





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Experimental Constraints: per-mille

BSM 5+4

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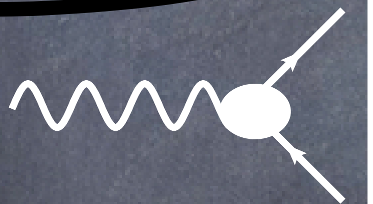

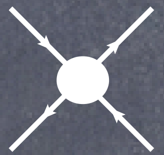

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$\{R_b, R_c, A_{FB}^{0,b}, A_{FB}^{0,c}, A_b, A_c\}$ 4

TeVatron: m_W

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LEP-I(hadr.): $\Gamma(Z \to u_{L,R} u_{L,R}, d_{L,R} d_{L,R})$

KLOE(β-decay)

Experimental Constraints: per-mille

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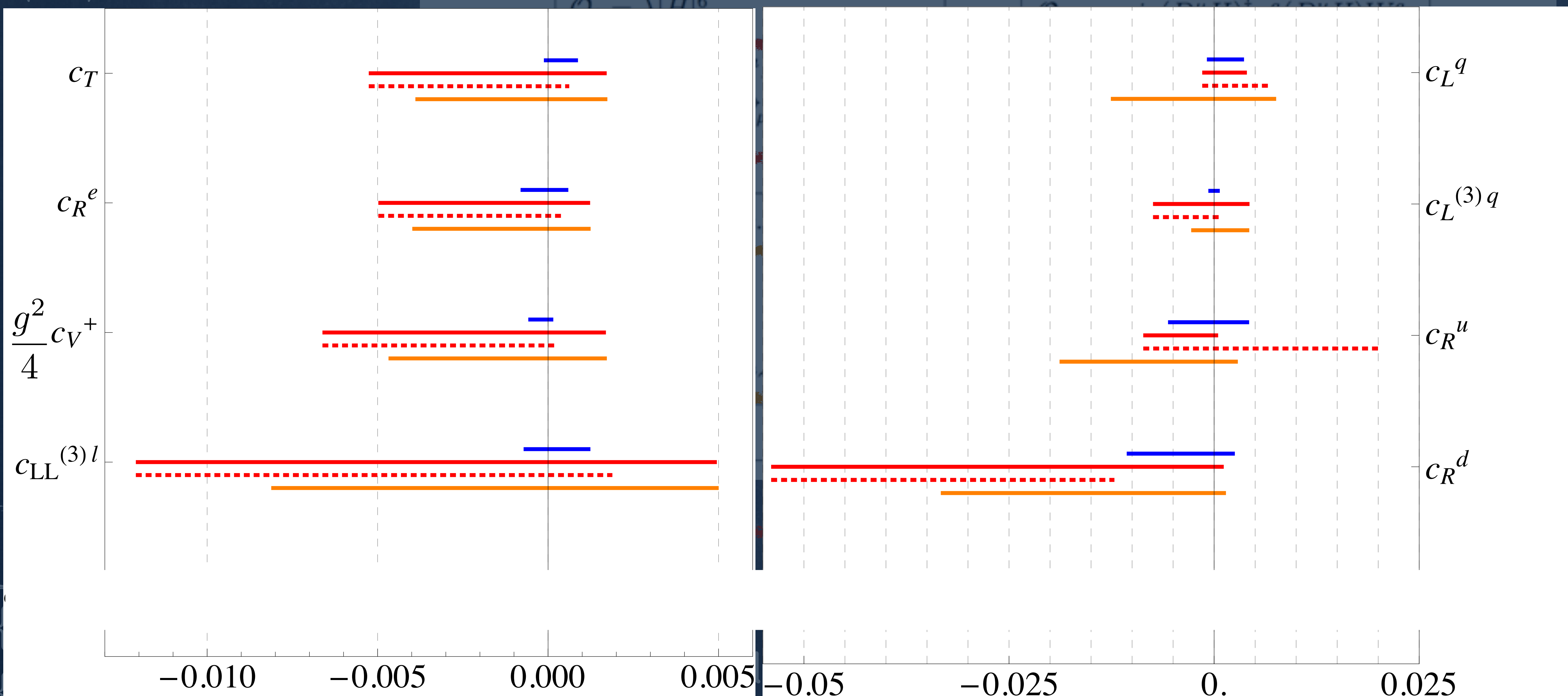

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LEP-I$^{(\text{hadr.})}$: $\Gamma(Z \to u_{L,R} u_{L,R}, d_{L,R} d_{L,R})$

KLOE$^{(\beta\text{-decay})}$

Experimental Constraints: per-cent

BSM 4

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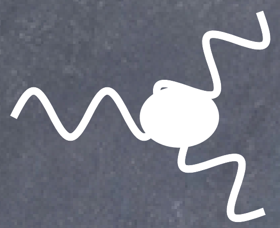

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[redacted]

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[redacted]		[redacted]

Experiments 3*

$\{g_1^Z, \kappa_\gamma, \lambda_\gamma\}$**

LEP-II$^{(ee\text{->}WW)}$

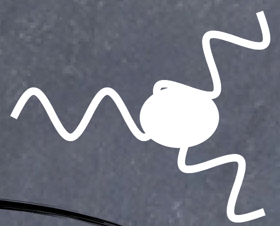
* other observables unaffected by deformations at dim-6

**combined fit for 3 observables not available from LEP; from LHC?

Experimental Constraints: per-cent

BSM 4

$\langle H \rangle = v$



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[redacted]

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[redacted]		[redacted]

Unconstrained:

$$4(\mathcal{O}_W - \mathcal{O}_B) - 4(\mathcal{O}_{HW} - \mathcal{O}_{HB}) + \mathcal{O}_{BB} = g^2 |H|^2 W^a_{\mu\nu} W^{a\,\mu\nu}$$

Experiments 3*

$\{g_1^Z, \kappa_\gamma, \lambda_\gamma\}$**

LEP-II$^{(ee\to WW)}$

* other observables unaffected by deformations at dim-6

**combined fit for 3 observables not available from LEP; from LHC?

Experimental Constraints: per-cent

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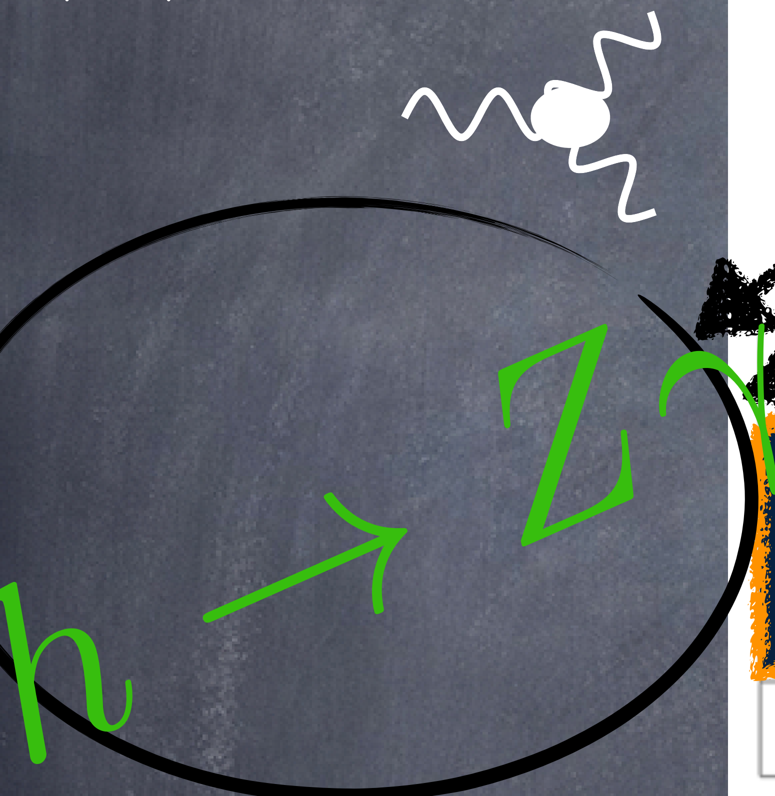

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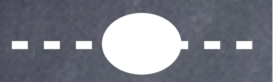
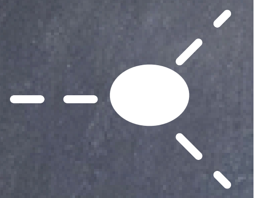
$H = h$





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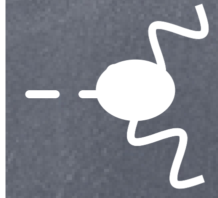

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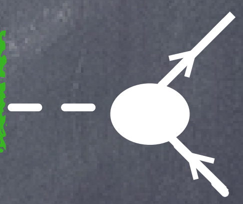

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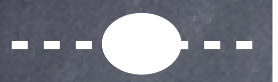
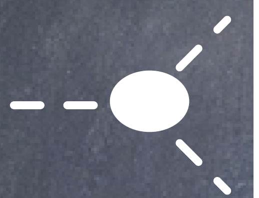
Terms $\sim |H|^2 \mathcal{L}_{SM}$ can only affect processes with h





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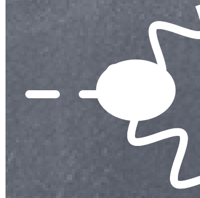

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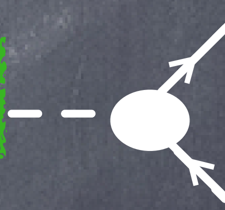

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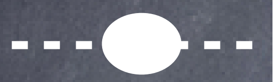

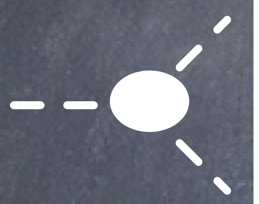

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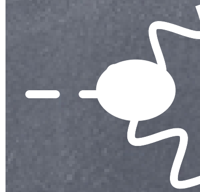

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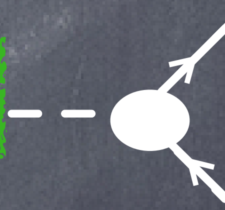

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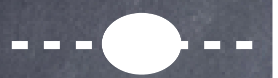

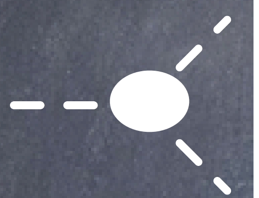

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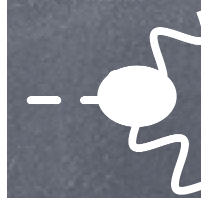

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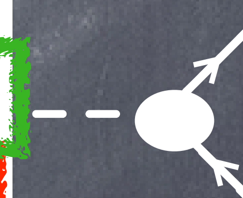

→ Unconstrained:

$WW, ZZ \to h$ (custodial)

$h^* \to hh$

$h \to \bar{f} f \quad f = \tau, b, t$

$h \to \gamma\gamma$

$gg \to h$

$h \to Z\gamma$

CP-Odd Terms?

$$\mathcal{O}_{B\widetilde{B}} = g'^2|H|^2 B_{\mu\nu}\widetilde{B}^{\mu\nu}\,, \qquad \mathcal{O}_{G\widetilde{G}} = g_s^2|H|^2 G^A_{\mu\nu}\widetilde{G}^{A\mu\nu}$$

$$\mathcal{O}_{H\widetilde{W}} = ig(D^\mu H)^\dagger\sigma^a(D^\nu H)\widetilde{W}^a_{\mu\nu}\,, \qquad \mathcal{O}_{H\widetilde{B}} = ig'(D^\mu H)^\dagger(D^\nu H)\widetilde{B}_{\mu\nu}$$

$$\mathcal{O}_{3\widetilde{W}} = \frac{1}{3!}g\epsilon_{abc}W^{a\,\nu}_{\mu}W^b_{\nu\rho}\widetilde{W}^{c\,\rho\mu}\,,$$

Counting similar to CP-even:

- 2 deformations in TGCs $\tilde{\kappa}_\gamma \quad \tilde{\lambda}_\gamma$
- 3 deformations in Higgs physics $h \to \gamma\gamma$, $gg \to h$, $h \to Z\gamma$

No interference with SM, nor with dim-6 CP-even

Results

- 17 operators with H could potentially affect Higgs physics
- Consider all experiments (2 operators must be added)
  - 8 Deformations of EW physics tightly constrained ‰
  - 3 TGCs modifications %
  - 8 Independent parameters affect Higgs Physics ONLY

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→ 8 Independent parameters affect Higgs Physics ONLY

-Unaffected by other bounds!

-No connection with other experiments

-Can be put in 1 to 1 correspondence with observables:

$WW, ZZ \to h$ (custodial invariant) $\quad h \to \gamma\gamma$

$h^* \to hh \quad gg \to h$

$h \to \bar{f}f \quad f = \tau, b, t \quad h \to Z\gamma$

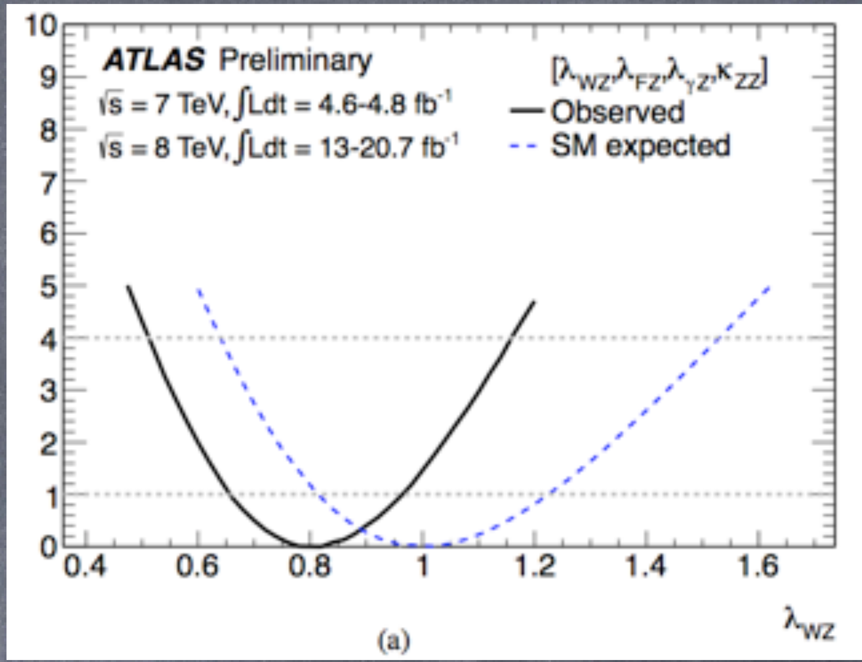
Appropriate parametrization: $\{\kappa_g, \kappa_\gamma, \kappa_V, \kappa_t, \kappa_b, \kappa_\tau, \kappa_{Z\gamma}, \kappa_{h^3}\}$

Implications

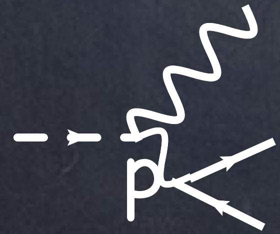
There is more (Higgs)physics that can be looked at, but is related to these 8+3+8

Ex1: Custodial Symmetry in h decays

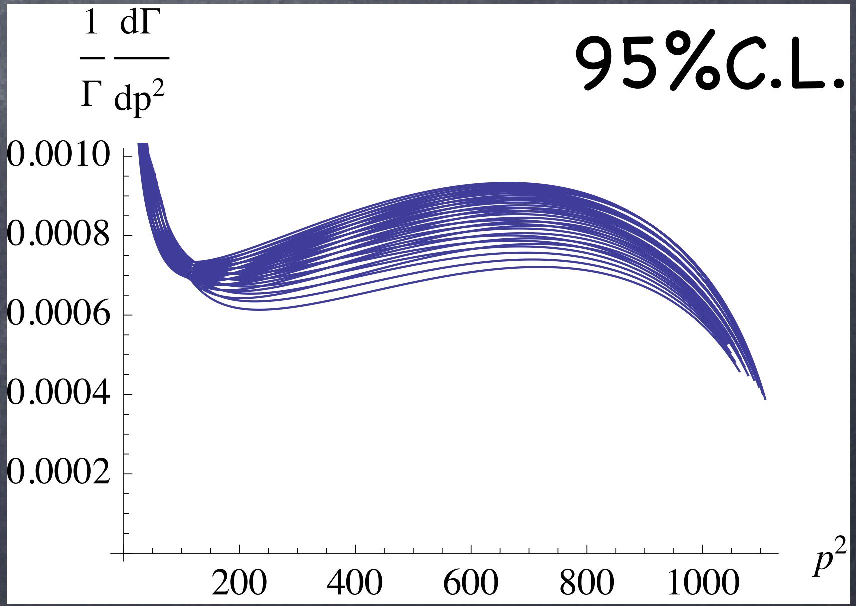
$$\lambda_{WZ}^2 - 1 \simeq s_{\theta_W}^2 \left[0.9 c_W - 2.6 c_B + 3\kappa_{HW} - 3.9\kappa_{HB}\right]$$
$$\simeq 0.8\delta g_1^Z - 0.1\delta\kappa_\gamma - 1.6\kappa_{Z\gamma} \in [-5, 6] \times 10^{-2},$$



Ex2: Deviations in different. distr. of $h \to Z\bar{f}f$: $h \to W\bar{f}f$



related with TGC deviations
(better measurable at LHC)



Riva,Pomarol'13

Conclusion

Most General BSM and Higgs Physics

~~8~~

3 $\{g_1^Z, \kappa_\gamma, \lambda_\gamma\}$

8 $\{\kappa_g, \kappa_\gamma, \kappa_V, \kappa_t, \kappa_b, \kappa_\tau, \kappa_{Z\gamma}, \kappa_{h^3}\}$

Results (CP-even and CP-Odd)

- ~~17~~ 21 operators with H could potentially affect Higgs physics
- Consider all experiments (~~2~~ 3 operators must be added since they affect the same observables)

→ 8 Deformations of EW physics tightly constrained ‰

→ 3 +2 TGCs modifications %

→ 8 +3 Unconstrained parameters can affect Higgs Physics

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Riva,Pomarol'13;
Elias-Miro,Espinosa,Masso,Pomarol'13;
See also Giudice,Grojean,Pomarol,Rattazzi'07