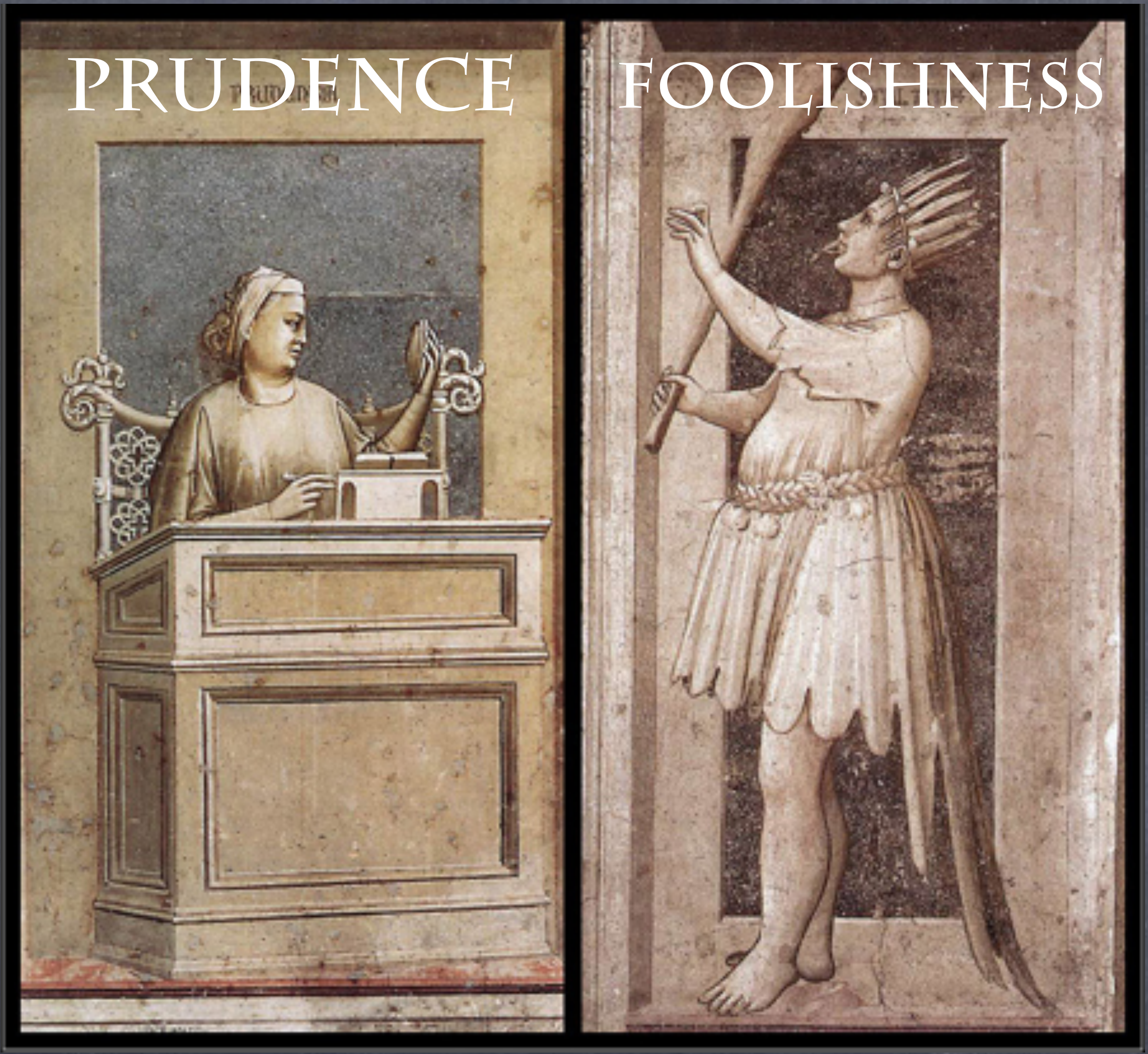
Precision Tests For the LHC



$E < M_{cut}$ $E > M_{cut}$

Francesco Riva (CERN)

In Collaboration with:

Pomarol, Gupta, Liu, Rattazzi, Falkowski, Biekötter, Knochel, Krämer

(1308.2803, 1405.0181, 1406.7320, 1411.0669,?)

Motivation (short)

- EFT as parametrization for precision tests (BSM inspired: interpretable as search)
- EFT as the very motivation for precision tests (and quantify results in comparison with other searches)
- Global analysis -> Global perspective for LHC Run 2

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Outline

1) The dim-6 Lagrangian, so far
2) Implications for Run2 - what we will not see
3) Implications for Run2 - what we might see

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- EFT as parametrization f
  (BSM inspired: in
- EFT as the very m
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1) The dim-6 Lagrangian, so far
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Motivation

Searches for New Physics

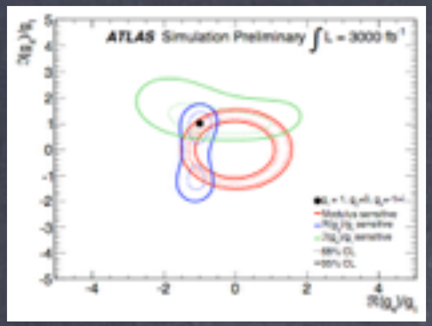
Direct

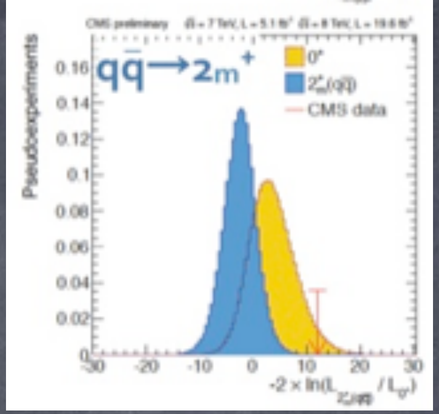
Precision

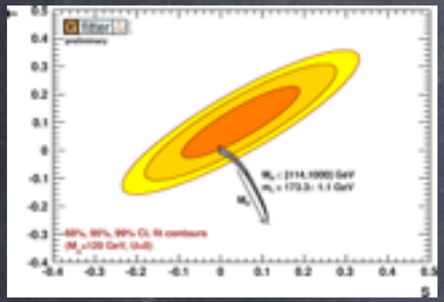
Motivation

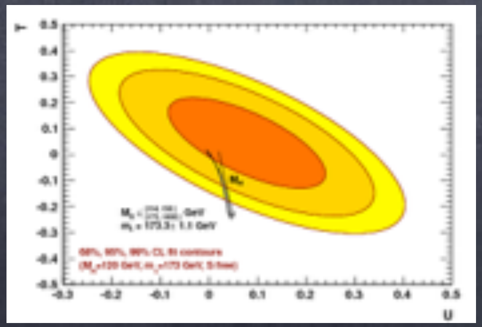
Searches for New Physics

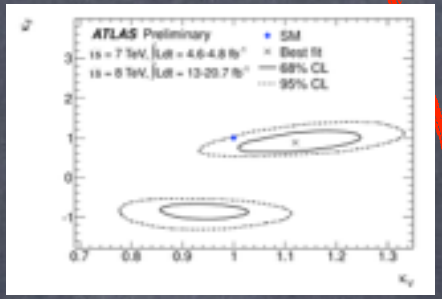
$\mathcal{L}^{SM}$

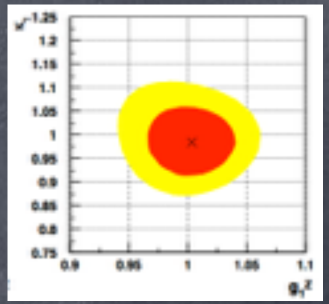


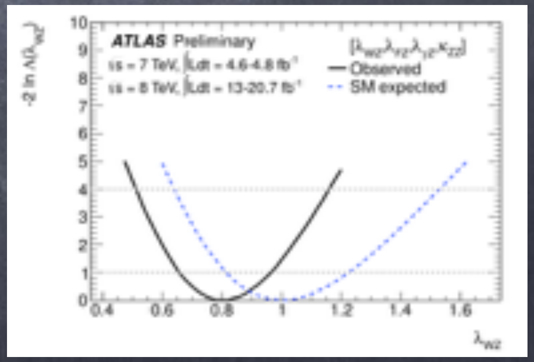


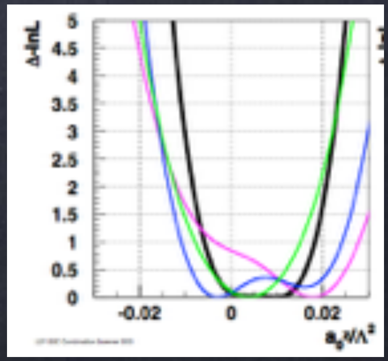




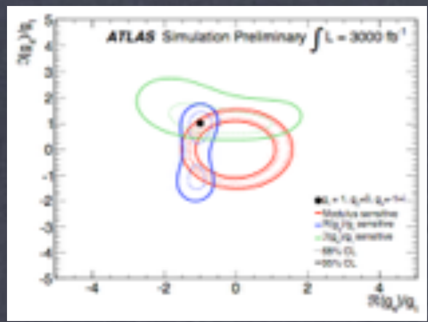


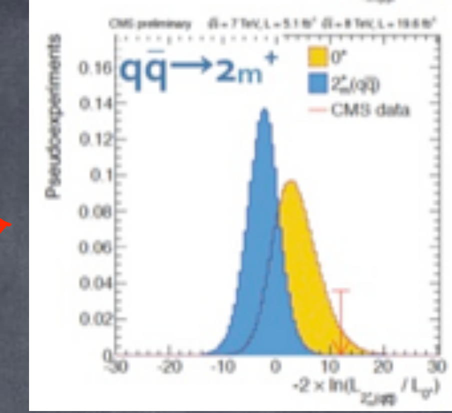




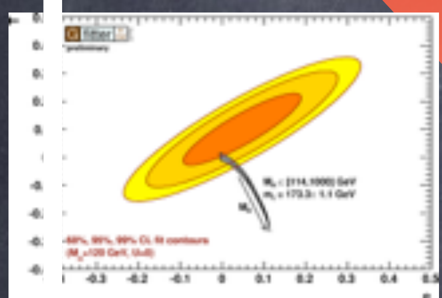


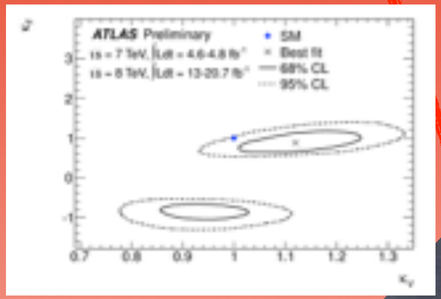
Motivation

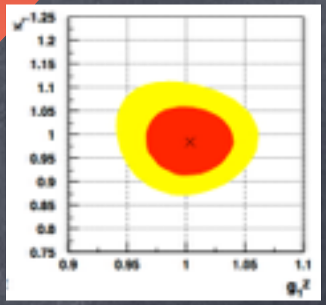


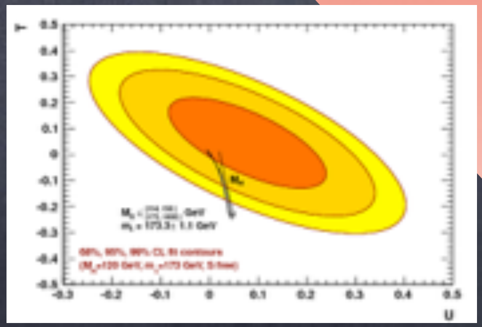


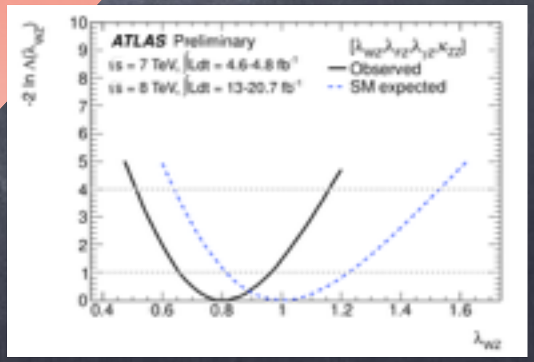
$\mathcal{L}^{SM}$











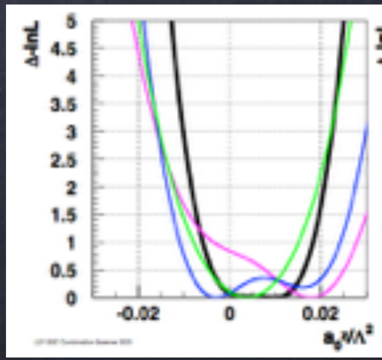
Expansion

1) E/Λ

2) H/f

3) Y_U, Y_D, Y_E

$\mathcal{L}^{UV}$



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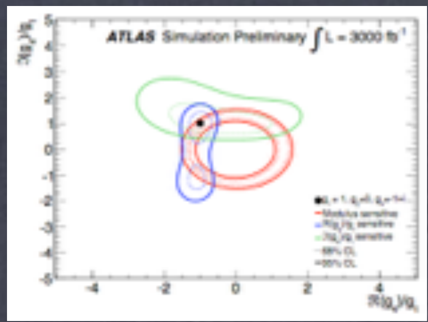
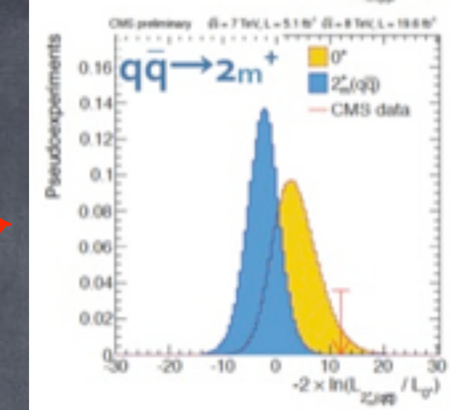
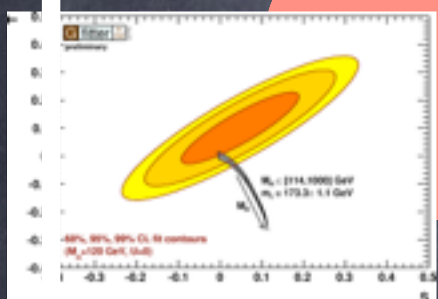
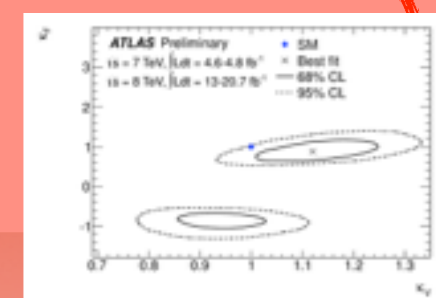


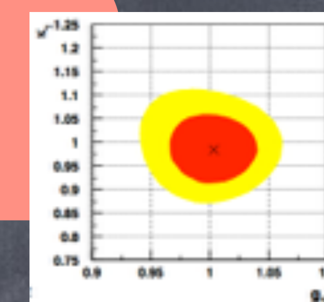


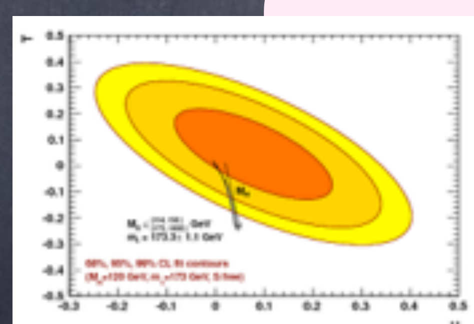
$\mathcal{L}^{SM} \equiv \mathcal{L}^4$



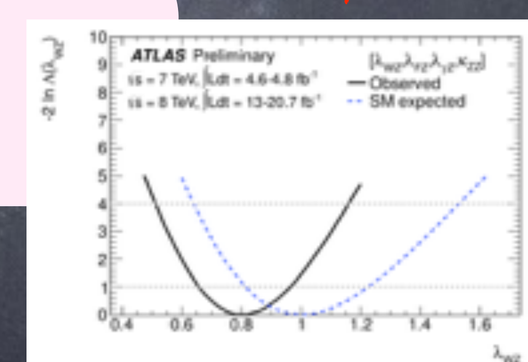
$\mathcal{L}^6$



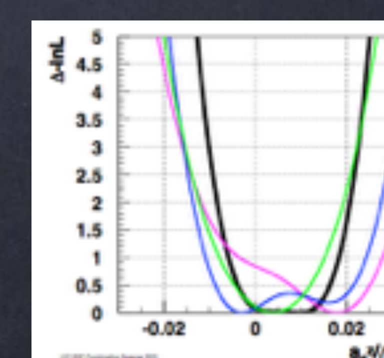




$\mathcal{L}^8$



$\mathcal{L}^{UV}$



Expansion

1) E/Λ

2) H/f

3) Y_U, Y_D, Y_E

Motivation

$$\mathcal{L}_{\rm eff} = \frac{\Lambda^4}{g_*^2}\mathcal{L}\left(\frac{D_\mu}{\Lambda}\,,\,\frac{g_* H}{\Lambda}\,,\,\frac{g_* f_{L,R}}{\Lambda^{3/2}}\,,\,\frac{g F_{\mu\nu}}{\Lambda^2}\right) \simeq \underbrace{\mathcal{L}_4}_{\rm SM} + \underbrace{\mathcal{L}_6}_{\sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i} + \cdots\,,$$

Buchmuller,Wyler'86;
Giudice et al '07
Grzadkowski et al'10

$$\boxed{\mathcal{L}^{SM} \equiv \mathcal{L}^4}$$

What defines SM?

(from an practical point of view)

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$$\mathcal{L}_{\rm eff} = \frac{\Lambda^4}{g_*^2}\mathcal{L}\left(\frac{D_\mu}{\Lambda}\,,\,\frac{g_* H}{\Lambda}\,,\,\frac{g_* f_{L,R}}{\Lambda^{3/2}}\,,\,\frac{g F_{\mu\nu}}{\Lambda^2}\right) \simeq \overset{SM}{\mathcal{L}_4} + \overset{\sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i}{\mathcal{L}_6} + \cdots\,,$$

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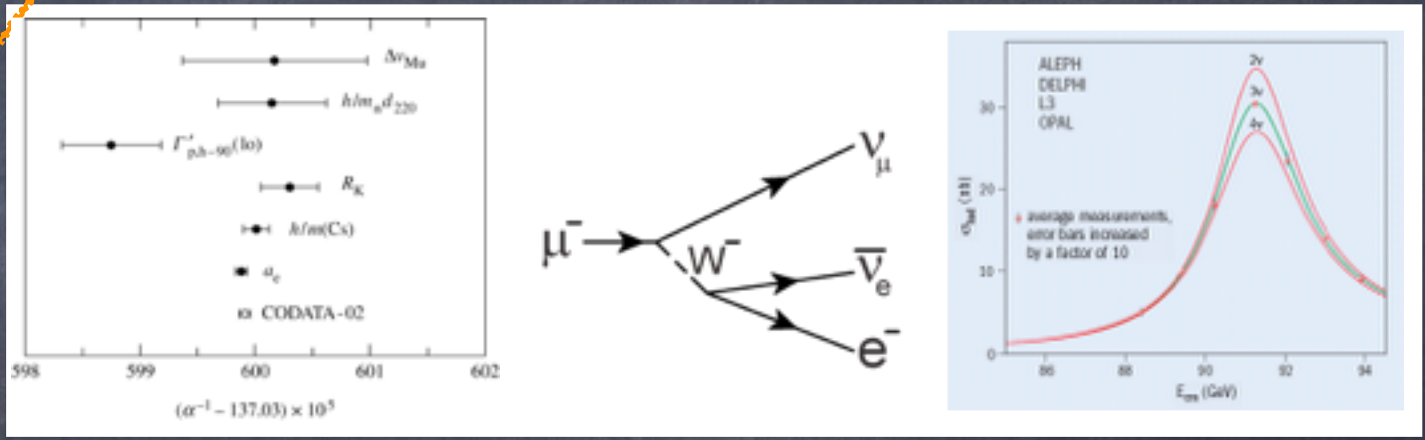
Fixed by 19 most precise experiments

What defines SM?

(from an practical point of view)

- Parameters: 19 in $\mathcal{L}_4 \equiv \mathcal{L}_{SM}$



Motivation

SM

$$\sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i$$

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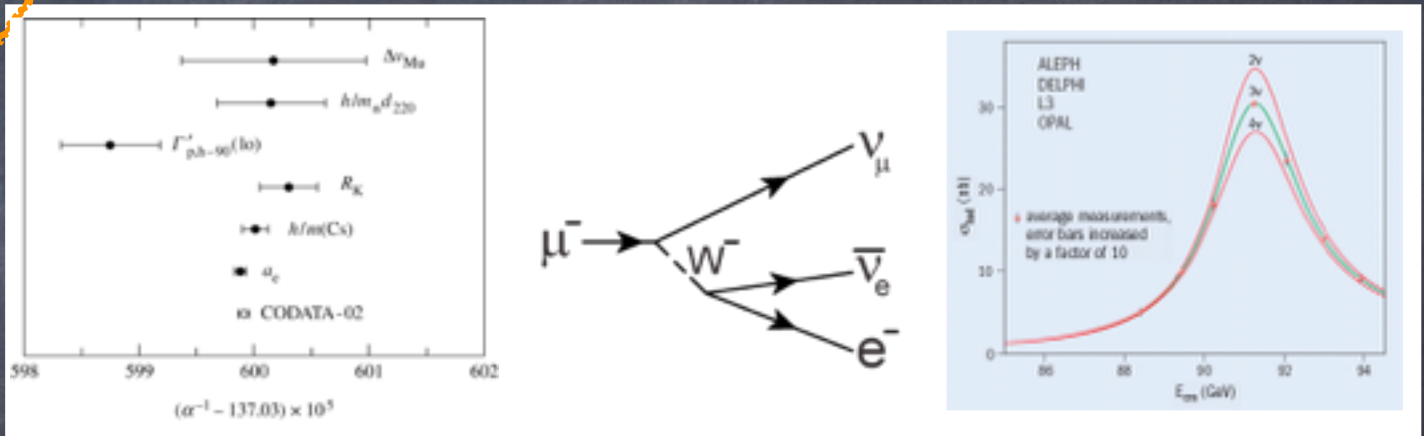
What defines SM?

(from an practical point of view)

- Parameters: 19 in $\mathcal{L}_4 \equiv \mathcal{L}_{SM}$
- Accidental relations (due to d=4 Lagrangian)

e.g. $$m_W = m_Z \cos\theta_W$$
$$g_{h\bar{f}f} = m_f/v$$

Fixed by 19 most precise experiments



Predictions for other experiments

Motivation

$$\mathcal{L}_{\rm eff} = \frac{\Lambda^4}{g_*^2}\mathcal{L}\left(\frac{D_\mu}{\Lambda}\,,\,\frac{g_* H}{\Lambda}\,,\,\frac{g_* f_{L,R}}{\Lambda^{3/2}}\,,\,\frac{gF_{\mu\nu}}{\Lambda^2}\right) \simeq \underbrace{\mathcal{L}_4}_{\rm SM} + \underbrace{\mathcal{L}_6}_{\sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i} + \cdots\,,$$

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$$\boxed{\mathcal{L}^{BSM} \simeq \mathcal{L}^6}$$

What defines BSM?

- Parameters: 76 dimension-6 ops.
- Accidental relations ?

Motivation

$$\mathcal{L}_{\rm eff} = \frac{\Lambda^4}{g_*^2}\mathcal{L}\left(\frac{D_\mu}{\Lambda}, \frac{g_* H}{\Lambda}, \frac{g_* f_{L,R}}{\Lambda^{3/2}}, \frac{g F_{\mu\nu}}{\Lambda^2}\right) \simeq \underbrace{\mathcal{L}_4}_{SM} + \underbrace{\mathcal{L}_6}_{\sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i} + \cdots,$$

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$$\boxed{\mathcal{L}^{SM} \equiv \mathcal{L}^4}$$

$$\boxed{\mathcal{L}^{BSM} \simeq \mathcal{L}^6}$$

This Talk: HIGGS PHYSICS
(one family, CP conserving)

What defines SM?

- Parameters: 1
- Accidental r
  (due to d=4 Lagrangian)

e.g.
$$m_W = m_Z \cos\theta_W$$
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What ...fines BSM?

- Parameters: ~~76~~ 17 dimension-6 ops.
- Accidental relations ?

PART 1: so far...

17 BSM Parameters:

(Counting independent dimension-6 terms
that can affect Higgs physics)

Notice: all Wilson coefficients evaluated at $\mu \sim m_W$

For running to UV see e.g.
Elias-Miro,Espinosa,Masso,Pomarol'13; (Alonso,Grojean),Jenkins,Manohar,Trott'13,Elias-Miro,Grojean,Gupta,Marzocca'13

Parameters for BSM: Higgs-only

Higgs Physics Only

$\langle h \rangle = v$

$v \leftarrow$	$\mathcal{O}_r = \lvert H\rvert^2 (D_\mu H)^\dagger (D^\mu H)$
$m_d \leftarrow$	$\mathcal{O}_{y_d} = y_d \lvert H\rvert^2 \bar{Q}_L H d_R$
$m_e \leftarrow$	$\mathcal{O}_{y_e} = y_e \lvert H\rvert^2 \bar{L}_L H e_R$
$m_u \leftarrow$	$\mathcal{O}_{y_u} = y_u \lvert H\rvert^2 \bar{Q}_L \widetilde{H} u_R$
$g_s \leftarrow$	$\mathcal{O}_{GG} = \frac{g_s^2}{4} \lvert H\rvert^2 G^A_{\mu\nu} G^{A\mu\nu}$
$g' \leftarrow$	$\mathcal{O}_{BB} = \frac{g'^2}{4} \lvert H\rvert^2 B_{\mu\nu} B^{\mu\nu}$
$g \leftarrow$	$\mathcal{O}_{WW} = \frac{g^2}{4} \lvert H\rvert^2 W^a_{\mu\nu} W^{a\mu\nu}$
$m_h \leftarrow$	$\mathcal{O}_6 = \lambda \lvert H\rvert^6$

In the vacuum <h>=v, operators $|H|^2 \times \mathcal{L}_{SM}$ only redefine SM parameters!

- Observable only in Higgs physics!

$$\frac{1}{g_s^2} G_{\mu\nu} G^{\mu\nu} + \frac{|H|^2}{\Lambda^2} G_{\mu\nu} G^{\mu\nu} = \left(\frac{1}{g_s^2} + \frac{v^2}{\Lambda^2} \right) G_{\mu\nu} G^{\mu\nu} + h \frac{2v}{\Lambda^2} G_{\mu\nu} G^{\mu\nu} + \ldots$$

Elias-Miro,Espinosa,Masso,Pomarol'13; Gupta,Pomarol,FR'14

Parameters for BSM: Higgs-only

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v	$\mathcal{O}_r = \lvert H\rvert^2 (D_\mu H)^\dagger (D^\mu H)$
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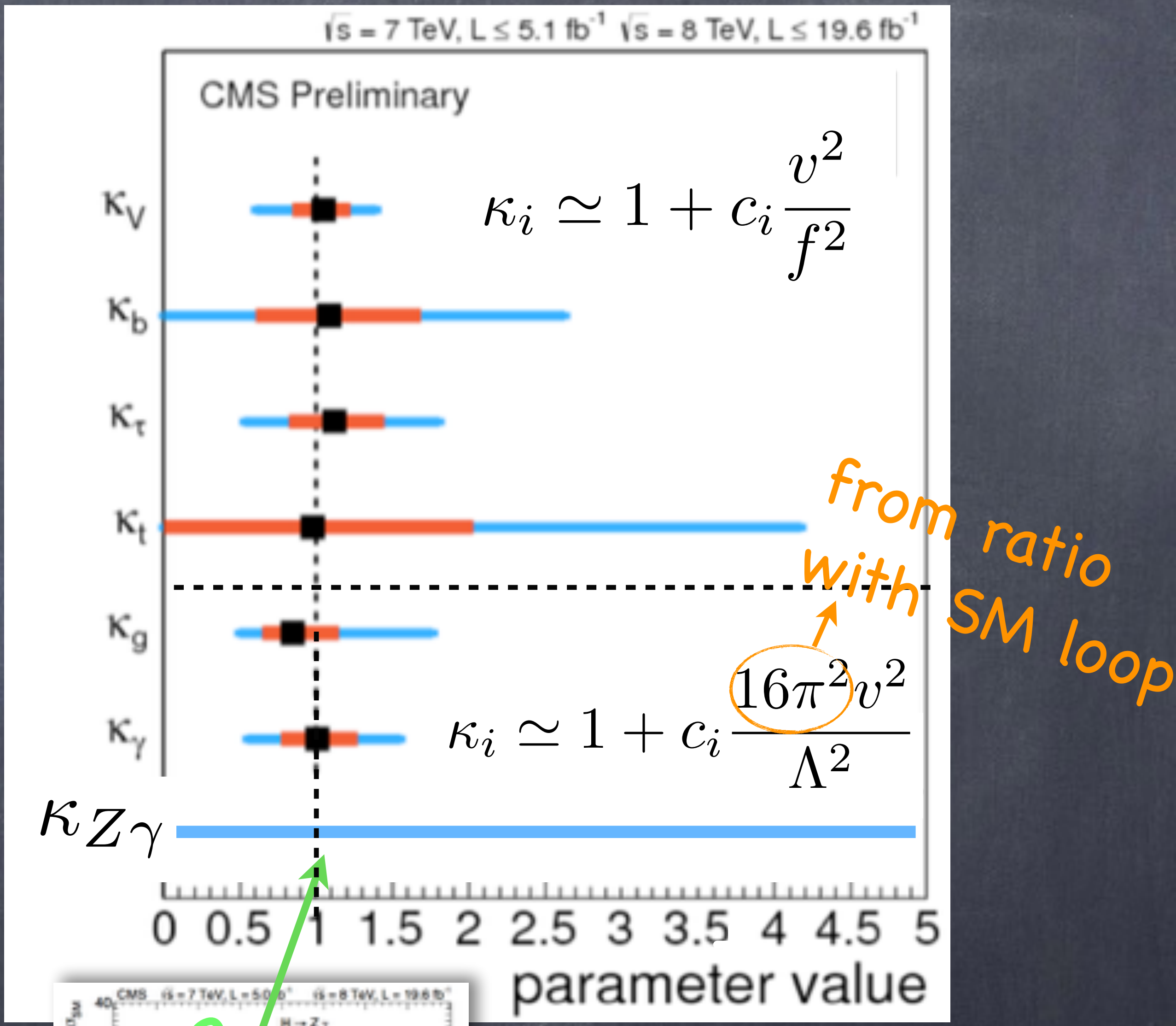
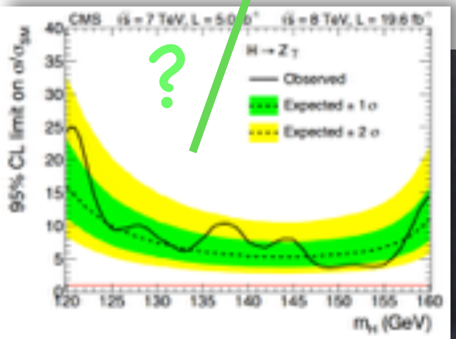
$\langle h \rangle = v$

$h^3?$





Elias-Miro,Espinosa,Masso,Pomarol13; Gupta,Pomarol,FR'14

Parameters for BSM: Higgs+EW

Higgs Physics Only	EW and Higgs physics
$\mathcal{O}_r = \|H\|^2 (D_\mu H)^\dagger (D^\mu H)$	$\mathcal{O}_{WB} = \frac{gg'}{4} (H^\dagger \sigma^a H) W^a_{\mu\nu} B^{\mu\nu}$
$\mathcal{O}_{y_d} = y_d \|H\|^2 \bar{Q}_L H d_R$	$\mathcal{O}_T = \frac{1}{2} \left(H^\dagger \overleftrightarrow{D}_\mu H \right)^2$
$\mathcal{O}_{y_e} = y_e \|H\|^2 \bar{L}_L H e_R$	$\mathcal{O}^u_R = (i H^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}_R \gamma^\mu u_R)$
$\mathcal{O}_{y_u} = y_u \|H\|^2 \bar{Q}_L \widetilde{H} u_R$	$\mathcal{O}^d_R = (i H^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}_R \gamma^\mu d_R)$
$\mathcal{O}_{GG} = \frac{g_s^2}{4} \|H\|^2 G^A_{\mu\nu} G^{A\mu\nu}$	$\mathcal{O}^e_R = (i H^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R \gamma^\mu e_R)$
$\mathcal{O}_{BB} = \frac{g'^2}{4} \|H\|^2 B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}^q_L = (i H^\dagger \overleftrightarrow{D}_\mu H)(\bar{Q}_L \gamma^\mu Q_L)$
$\mathcal{O}_{WW} = \frac{g^2}{4} \|H\|^2 W^a_{\mu\nu} W^{a\mu\nu}$	$\mathcal{O}^{(3)\,q}_L = (i H^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{Q}_L \sigma^a \gamma^\mu Q_L)$
$\mathcal{O}_6 = \lambda \|H\|^6$	$\mathcal{O}_L = (i H^\dagger \overleftrightarrow{D}_\mu H)(\bar{L}_L \gamma^\mu L_L)$
	$\mathcal{O}^{(3)}_L = (i H^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{L}_L \sigma^a \gamma^\mu L_L)$

Parameters for BSM: Higgs+EW

In the vacuum <h>=v, these operators can be measured!

7 of these operators modify:

$Z\bar{\nu}\nu \quad Z\bar{e}_L e_L \quad Z\bar{e}_R e_R$

$Z\bar{u}_L u_L \quad Z\bar{u}_R u_R \quad Z\bar{d}_L d_L \quad Z\bar{d}_R d_R$

All tightly constrained by LEP1
1/1000

EW and Higgs physics

$\mathcal{O}_{WB} = \frac{gg'}{4}(H^\dagger\sigma^a H)W^a_{\mu\nu}B^{\mu\nu}$
$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$
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$\mathcal{O}_L^q = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{Q}_L\gamma^\mu Q_L)$
$\mathcal{O}_L^{(3)\,q} = (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{Q}_L\sigma^a\gamma^\mu Q_L)$
$\mathcal{O}_L = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{L}_L\gamma^\mu L_L)$
$\mathcal{O}_L^{(3)} = (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{L}_L\sigma^a\gamma^\mu L_L)$

Preview:

(Gupta),Pomarol,FR'13-14; Falkowski,FR'14

*= if α, m_Z, m_W are used as input parameters, no other dim-6 operators affect LEP1 measurements!

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1/1000

EW and Higgs physics

$$\mathcal{O}_{WB} = \frac{gg'}{4}(H^\dagger \sigma^a H) W^a_{\mu\nu} B^{\mu\nu}$$

$$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$$

$$\mathcal{O}_R^u = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}_R \gamma^\mu u_R)$$

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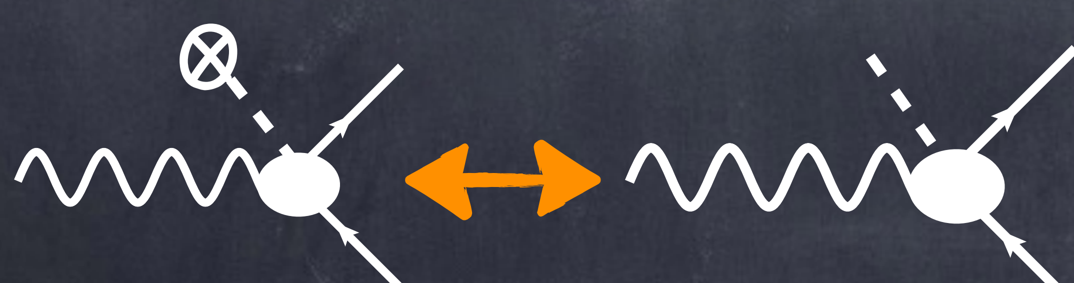
Preview:



Impact of these operators in H-physics is irrelevant

(Gupta),Pomarol,FR'13-14; Falkowski,FR'14

*= if α, m_Z, m_W are used as input parameters, no other dim-6 operators affect LEP1 measurements!

Parameters for BSM: Higgs+EW

In the vacuum <h>=v, these operators can be measured!

7 of these operators modify:

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$Z\bar{u}_L u_L \quad Z\bar{u}_R u_R \quad Z$

All tightly constra

1/1000

$$\frac{v^2}{f^2}\begin{pmatrix} \hat{c}'_{HL} \\ \hat{c}_{HL} \\ \hat{c}_{HE} \\ \hat{c}'_{HQ} \\ \hat{c}_{HQ} \\ \hat{c}_{HU} \\ \hat{c}_{HD} \\ \hat{c}_{ll} \end{pmatrix} = \begin{pmatrix} -1.9 \pm 1.1 \\ 1.1 \pm 0.7 \\ 0.1 \pm 0.6 \\ -4.7 \pm 1.9 \\ 0.2 \pm 2.0 \\ 7.0 \pm 6.9 \\ -31.3 \pm 10.3 \\ -4.7 \pm 3.5 \end{pmatrix} \cdot 10^{-3},$$

Falkowski,FR '14

EW and Higgs physics

$\mathcal{O}_{WB} = \frac{gg'}{4}(H^\dagger\sigma^a H)W^a_{\mu\nu}B^{\mu\nu}$
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Preview:

(Gupta),Pomarol,FR'13-14; Falkowski,FR'14

*= if α, m_Z, m_W are used as input parameters, no other dim-6 operators affect LEP1 measurements!

Parameters for BSM: Higgs+EW

In the vacuum <h>=v, these operators can be measured!

7 of these operators modify:

$Z\bar{\nu}\nu \quad Z\bar{e}_L e_L \quad Z\bar{e}_R e$

$Z\bar{u}_L u_L \quad Z\bar{u}_R u_R \quad Z$

All tightly constrai

1/1000

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Preview:

Impact of these operators in H-physics is irrelevant

(Gupta),Pomarol,FR'13-14; Falkowski,FR'14

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In the vacuum <h>=v, these operators can be measured!

2 of these modify TGCs: $\boxed{g_Z^1 \quad \kappa_\gamma}$

Hagiwara,Hikasa, Peccei,Zeppenfled'87

EW and Higgs physics

$\mathcal{O}_{WB} = \frac{gg'}{4}(H^\dagger\sigma^a H)W^a_{\mu\nu}B^{\mu\nu}$
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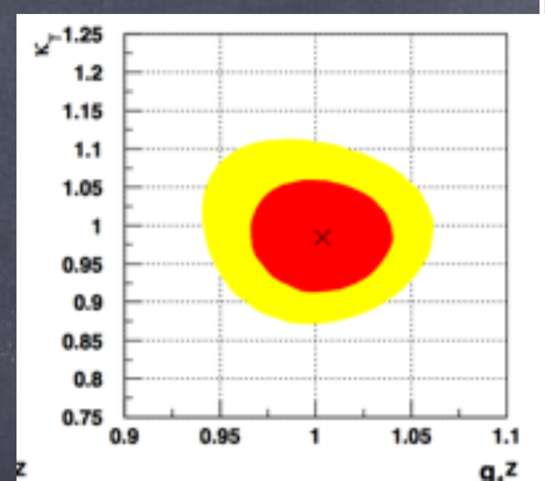
Hagiwara,Hikasa, Peccei,Zeppenfled'87

LEP2(ee->WW) constrained* $\sim$5/100



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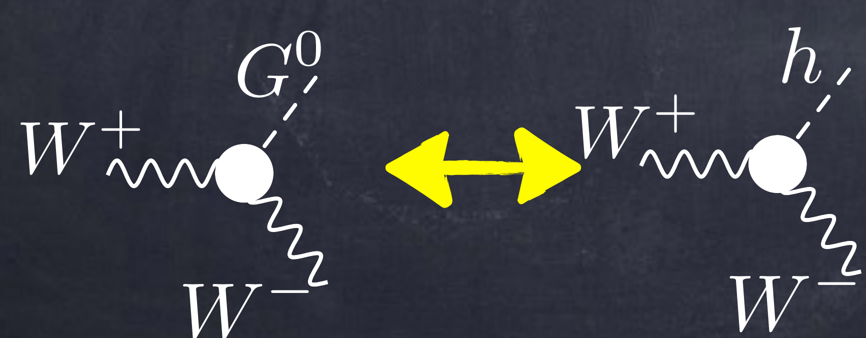

Small Summary: Parameters

$\mathcal{O}_r = \lvert H\rvert^2 (D_\mu H)^\dagger (D^\mu H)$
$\mathcal{O}_{y_d} = y_d \lvert H\rvert^2 \bar{Q}_L H d_R$
$\mathcal{O}_{y_e} = y_e \lvert H\rvert^2 \bar{L}_L H e_R$
$\mathcal{O}_{y_u} = y_u \lvert H\rvert^2 \bar{Q}_L \widetilde{H} u_R$
$\mathcal{O}_{GG} = \frac{g_s^2}{4} \lvert H\rvert^2 G^A_{\mu\nu} G^{A\mu\nu}$
$\mathcal{O}_{BB} = \frac{g'^2}{4} \lvert H\rvert^2 B_{\mu\nu} B^{\mu\nu}$
$\mathcal{O}_{WW} = \frac{g^2}{4} \lvert H\rvert^2 W^a_{\mu\nu} W^{a\mu\nu}$
$\mathcal{O}_6 = \lambda \lvert H\rvert^6$

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

g^1_Z, κ_γ

$\delta g_{ZeL}, \delta g_{ZeR}, \delta g_{Z\nu}, \delta g_{ZuL}, \delta g_{ZdL}, \delta g_{ZuR}, \delta g_{ZdR}$

Might as well use these as parameters, to keep relations between observables manifest!

- "BSM Primaries"

Gupta,Pomarol,FR'14

PART 2: Implications

BSM Relations 1

Relation Vff couplings:

- $\delta_{Zff} = \delta_{Wff'}$

W^+ DECAY MODES PDG

W^- modes are charge conjugates of the modes below.

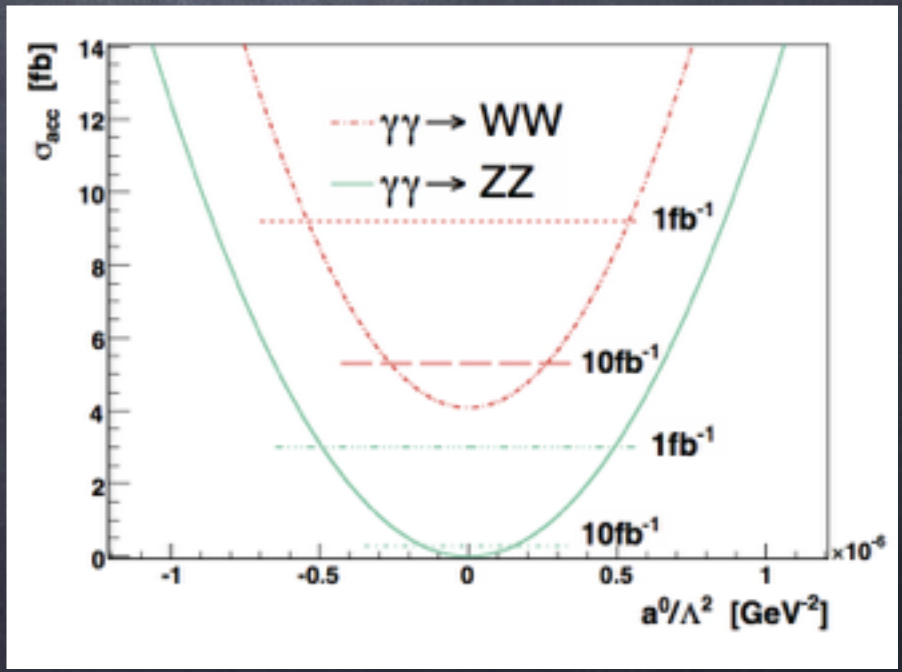
	Mode		Fraction (Γ_i/Γ)	Confidence level
Γ_1	$\ell^+\nu$	[a]	(10.80 ± 0.09) %	
Γ_2	$e^+\nu$		(10.75 ± 0.13) %	
Γ_3	$\mu^+\nu$		(10.57 ± 0.15) %	
Γ_4	$\tau^+\nu$		(11.25 ± 0.20) %	
Γ_5	hadrons		(67.60 ± 0.27) %	

Falkowski,FR'14

Relation VVV,VVVV couplings:

$$\delta g^{Z}_{WW} = \delta g^{WW}_{WW} = g^{ZZ}_{WW} = \delta g^{\gamma Z}_{WW}$$

$$\delta g^{\gamma\gamma}_{WW} = 0$$



Gupta,Pomarol,FR'14

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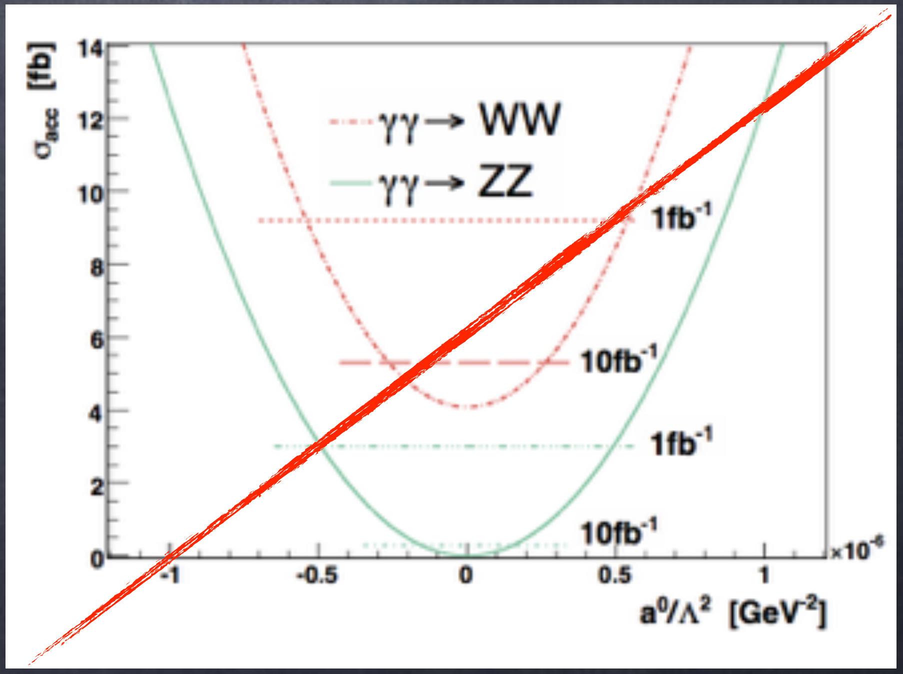

Gupta,Pomarol,FR'14

BSM Relations 2 - Run2

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

See e.g. Isidori,(Manohar),Trott'13
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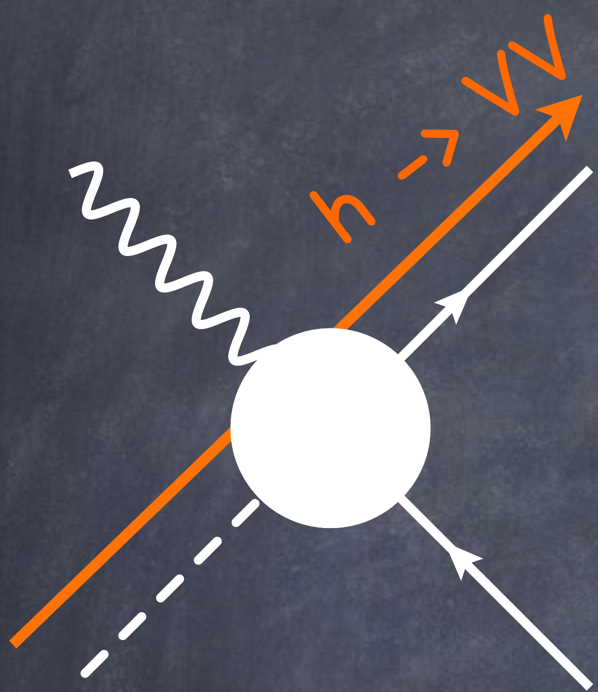
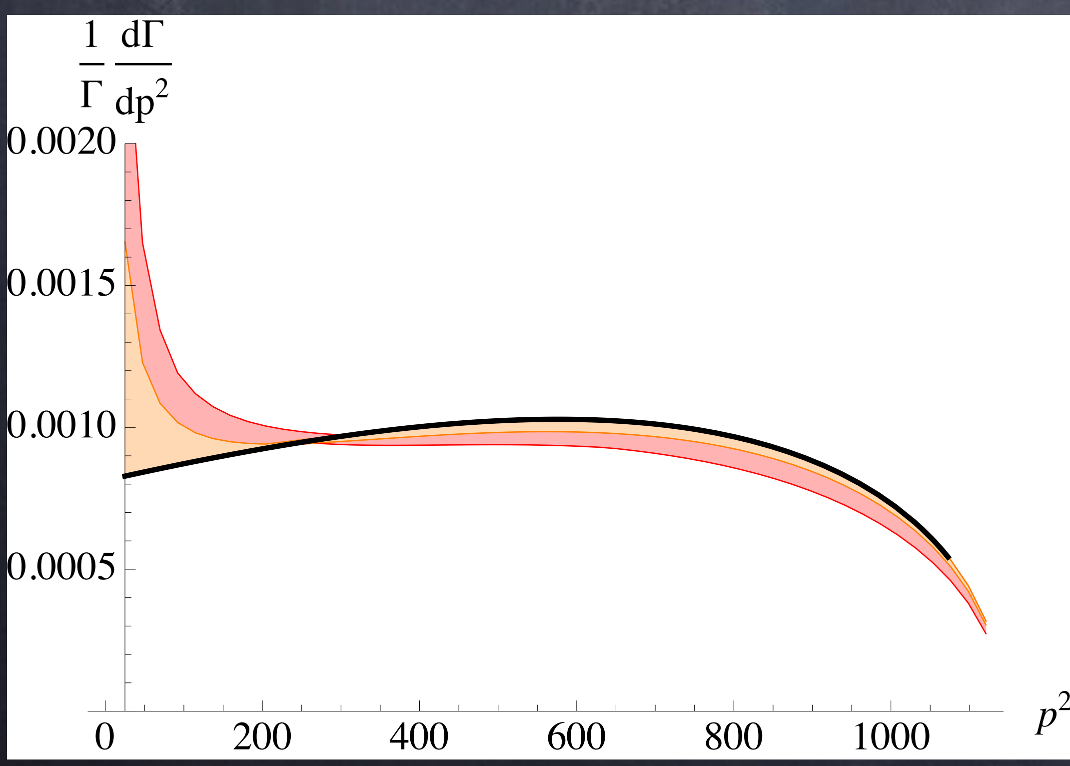


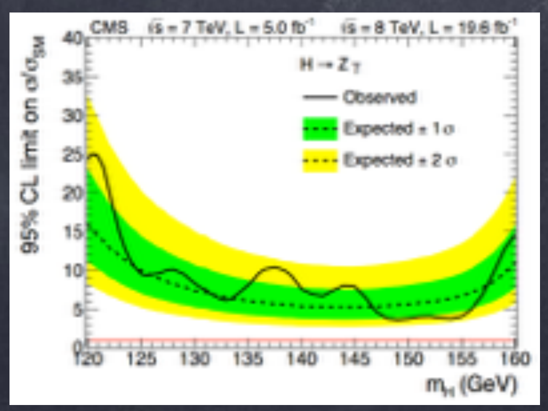
LEP 1

~~Related with Zff couplings~~

Related with Triple Gauge Coupling

Related with $h \to Z\gamma, \gamma\gamma$





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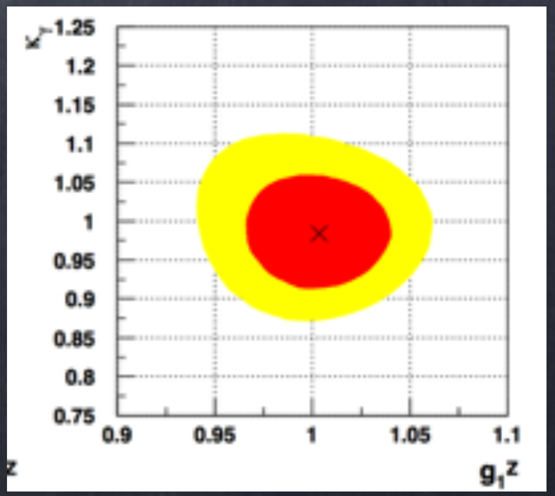

p^2>5 GeV

Pomarol,FR'13; See also: Beneke,Boito,Wang'14

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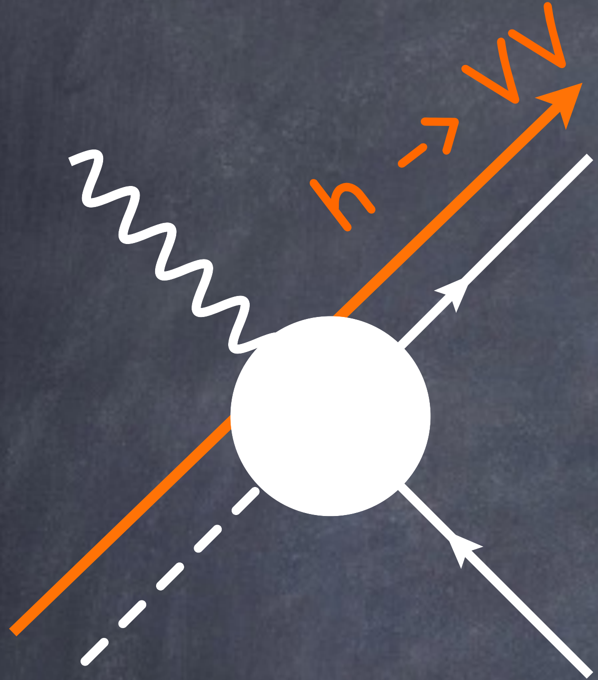

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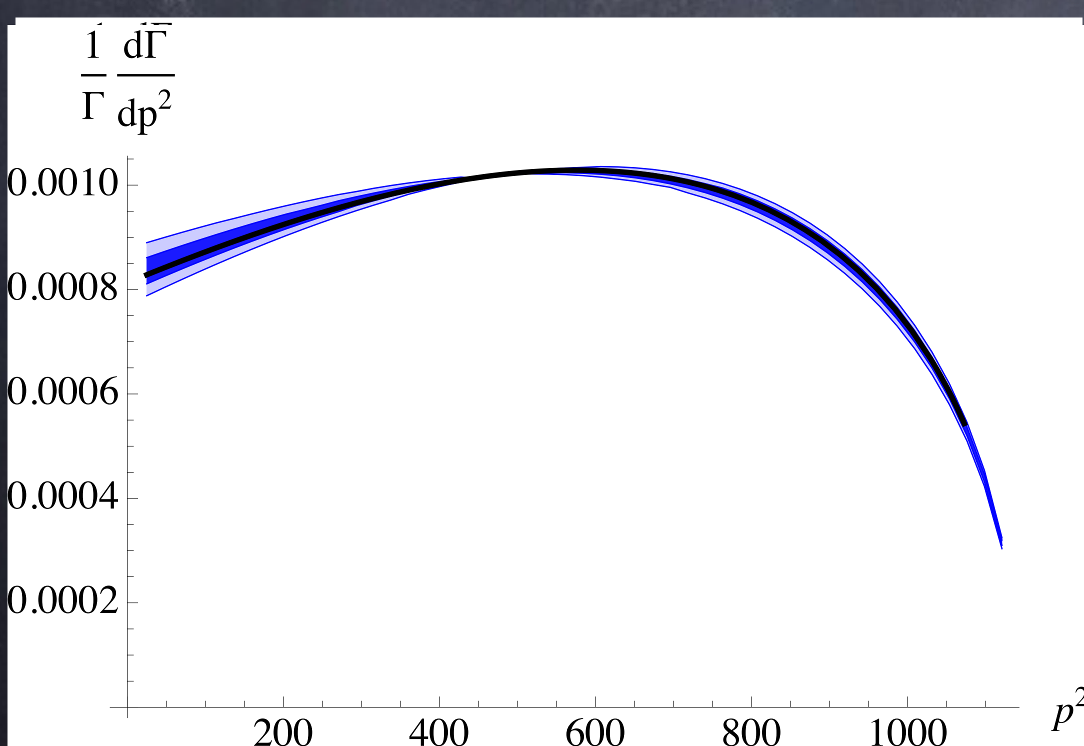

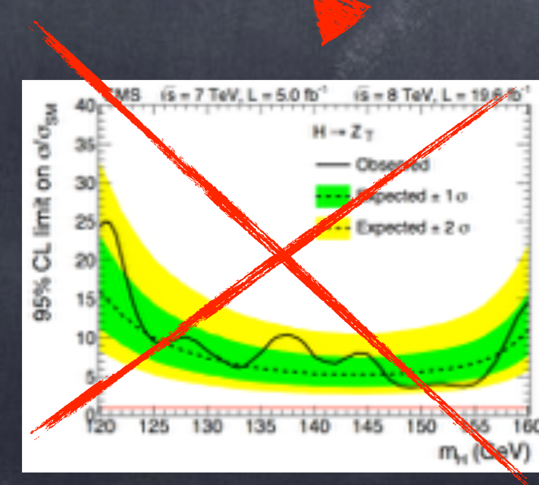

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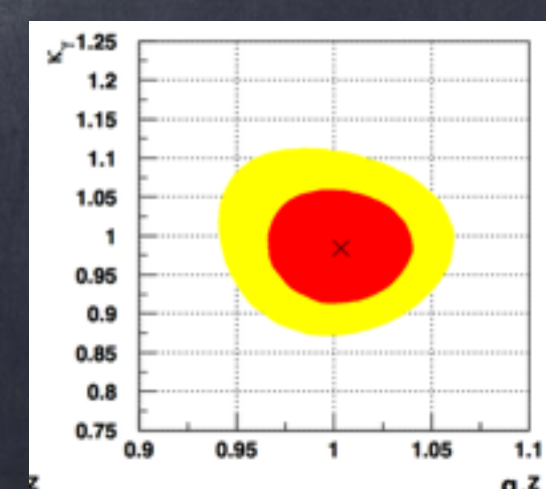

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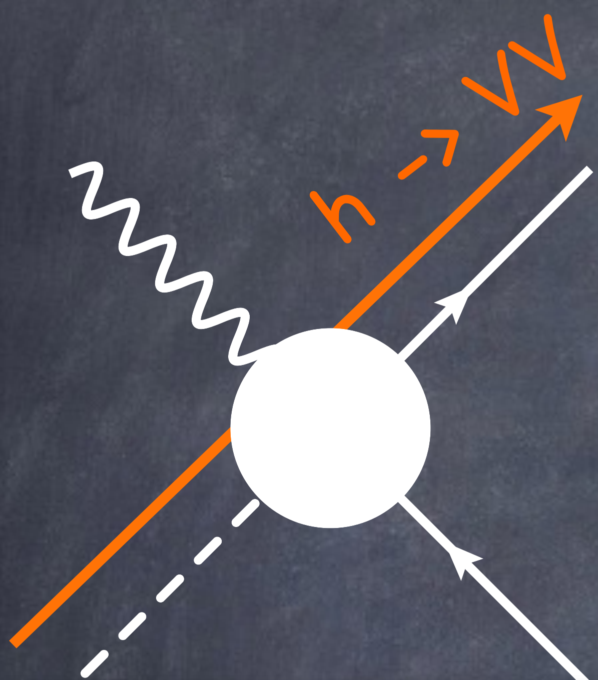

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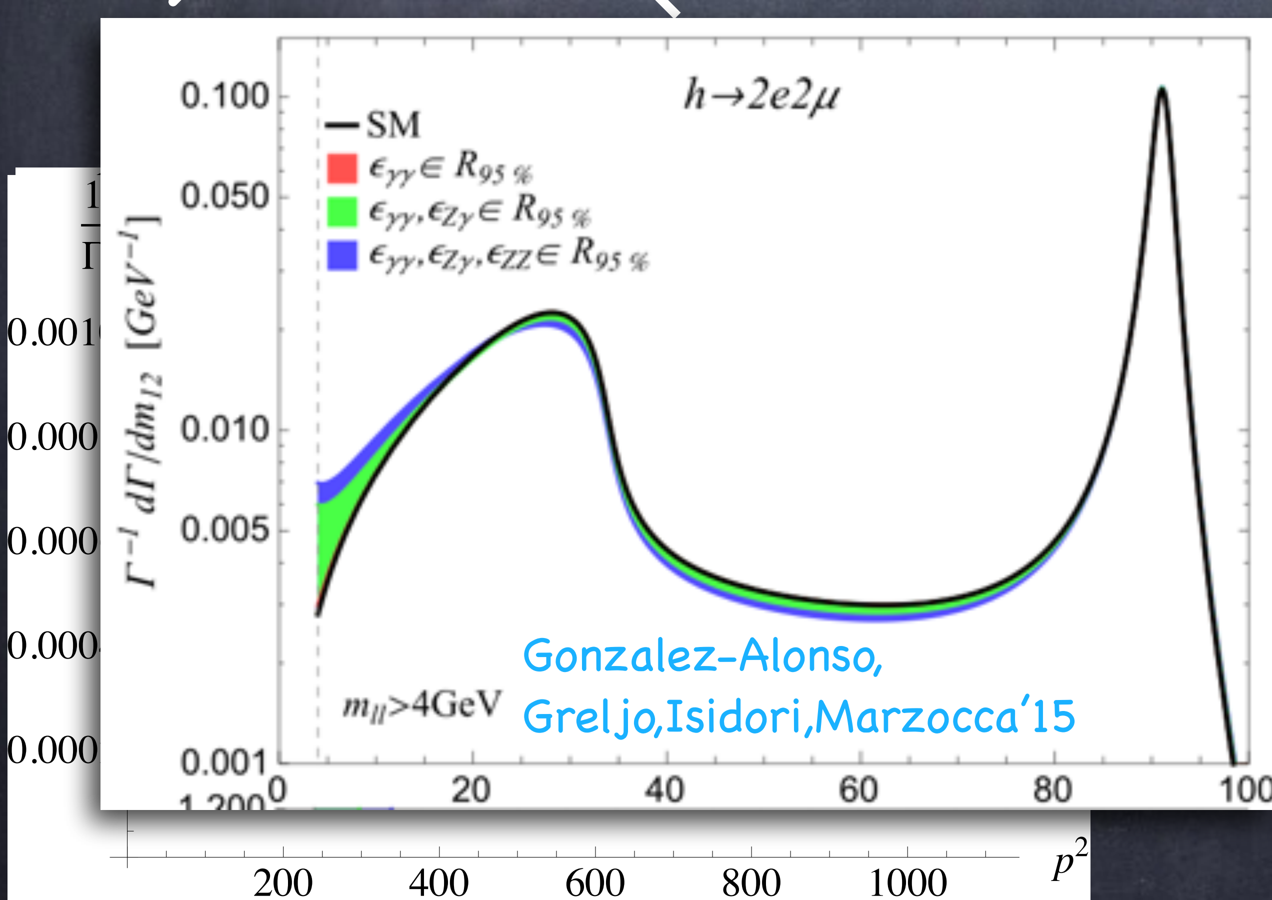

Gonzalez-Alonso, Greljo,Isidori,Marzocca'15

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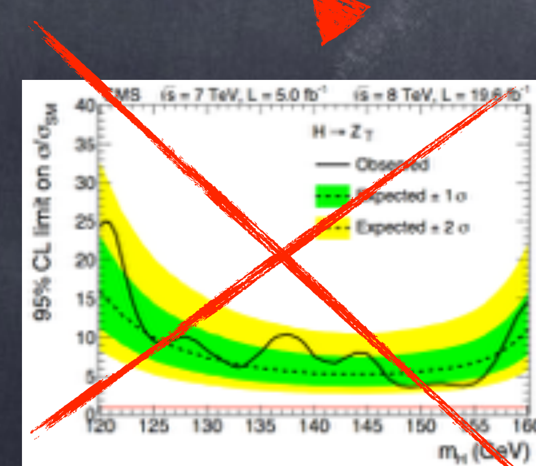

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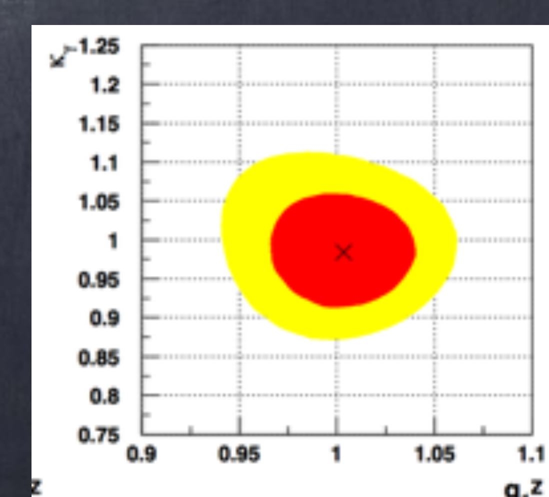

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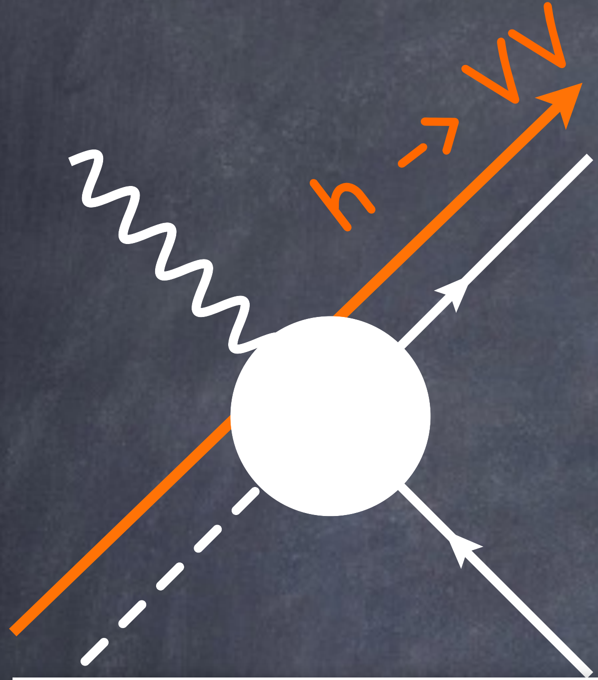

LEP 1

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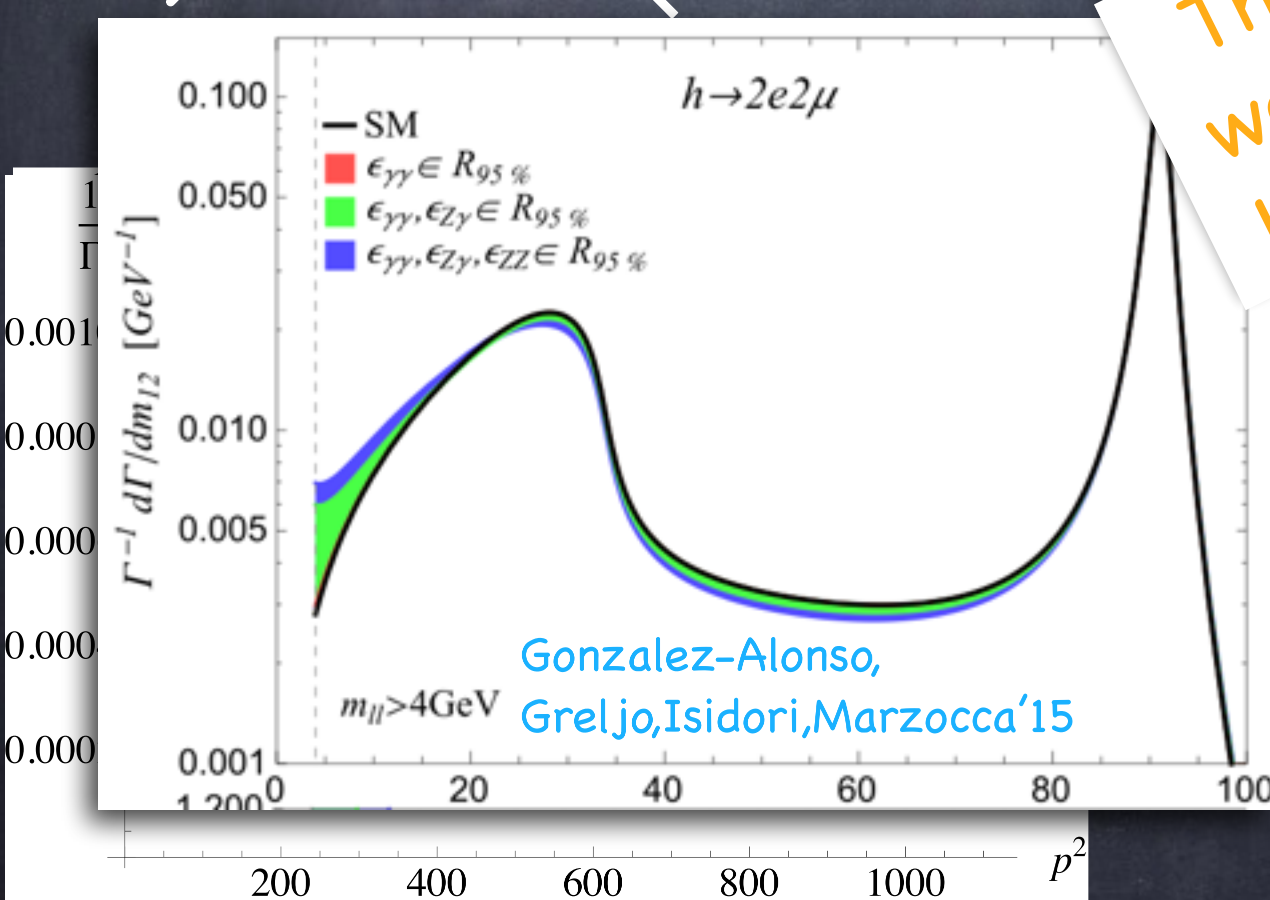
Related wi…

This is the sensitivity we are aiming to make H-physics competitive!



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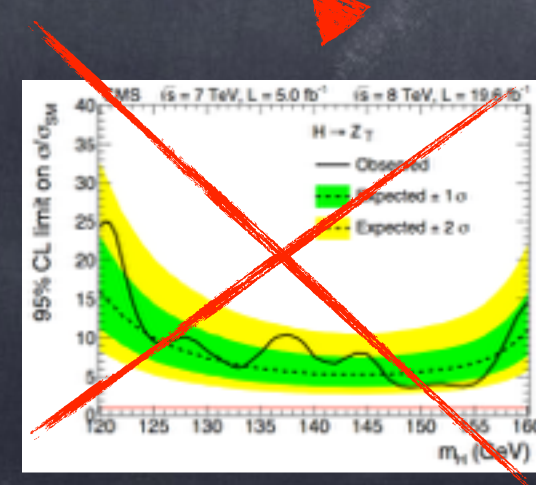

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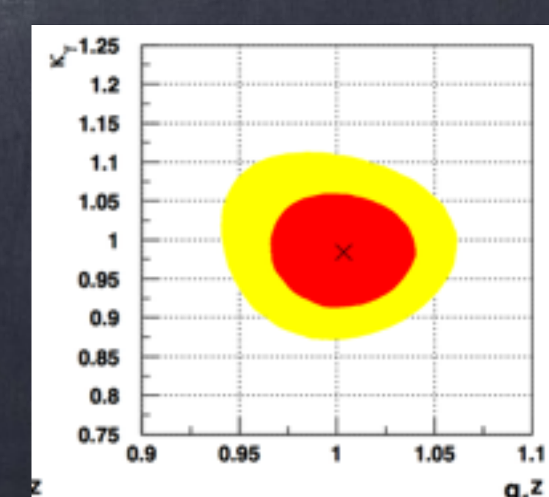

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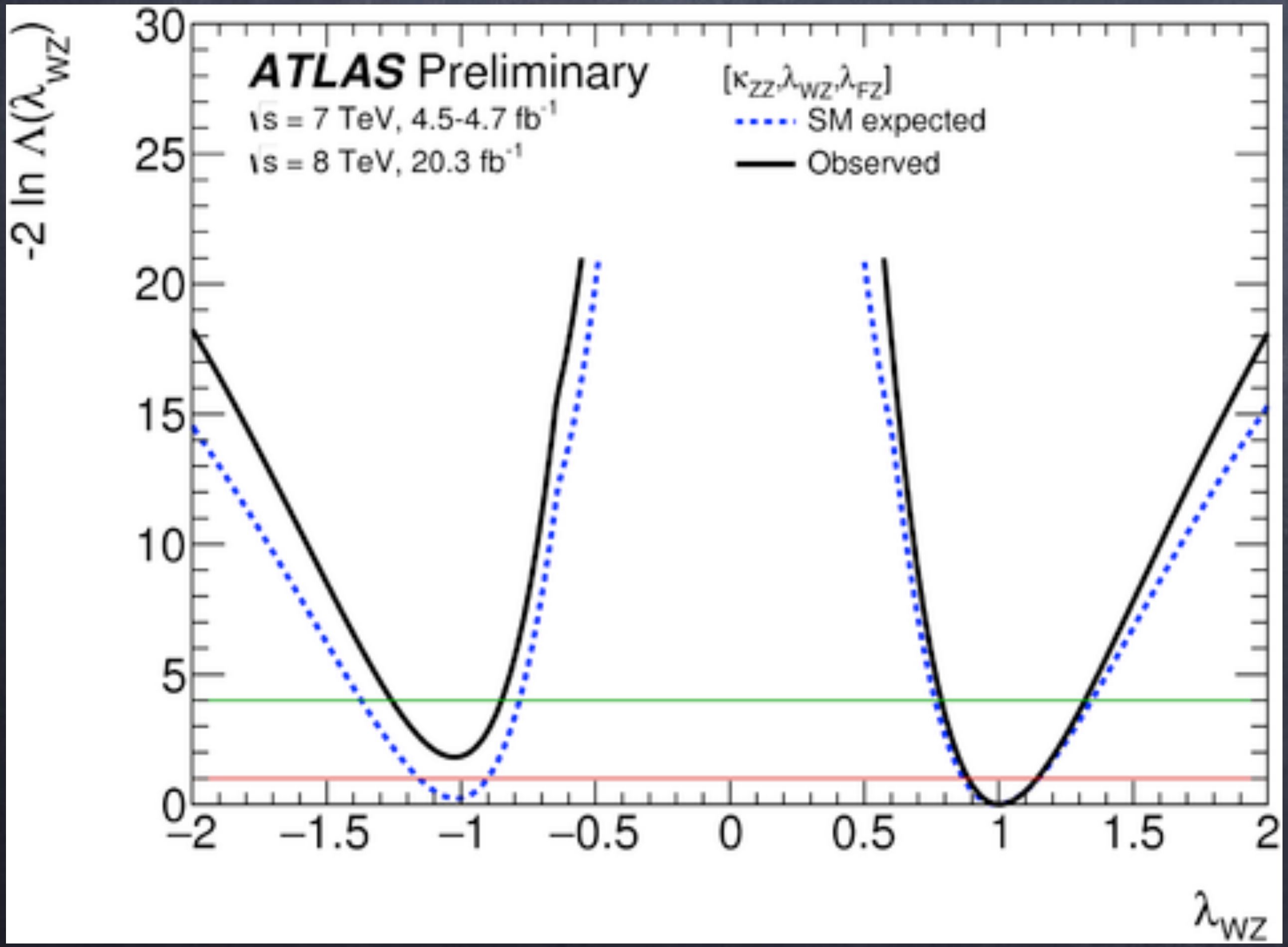
BSM Relations 3 - Run1

Custodial Symmetry in h decays h->VV* λ_{WZ}

- Off-Shell V
- $m_Z \neq m_W$

Integrated Decay Width already sensitive to p-dependence of hVV coupling!

$$\lambda_{WZ}^2 - 1 \simeq 0.6\delta g_1^Z - 0.5\delta\kappa_\gamma - 1.6\kappa_{Z\gamma}$$



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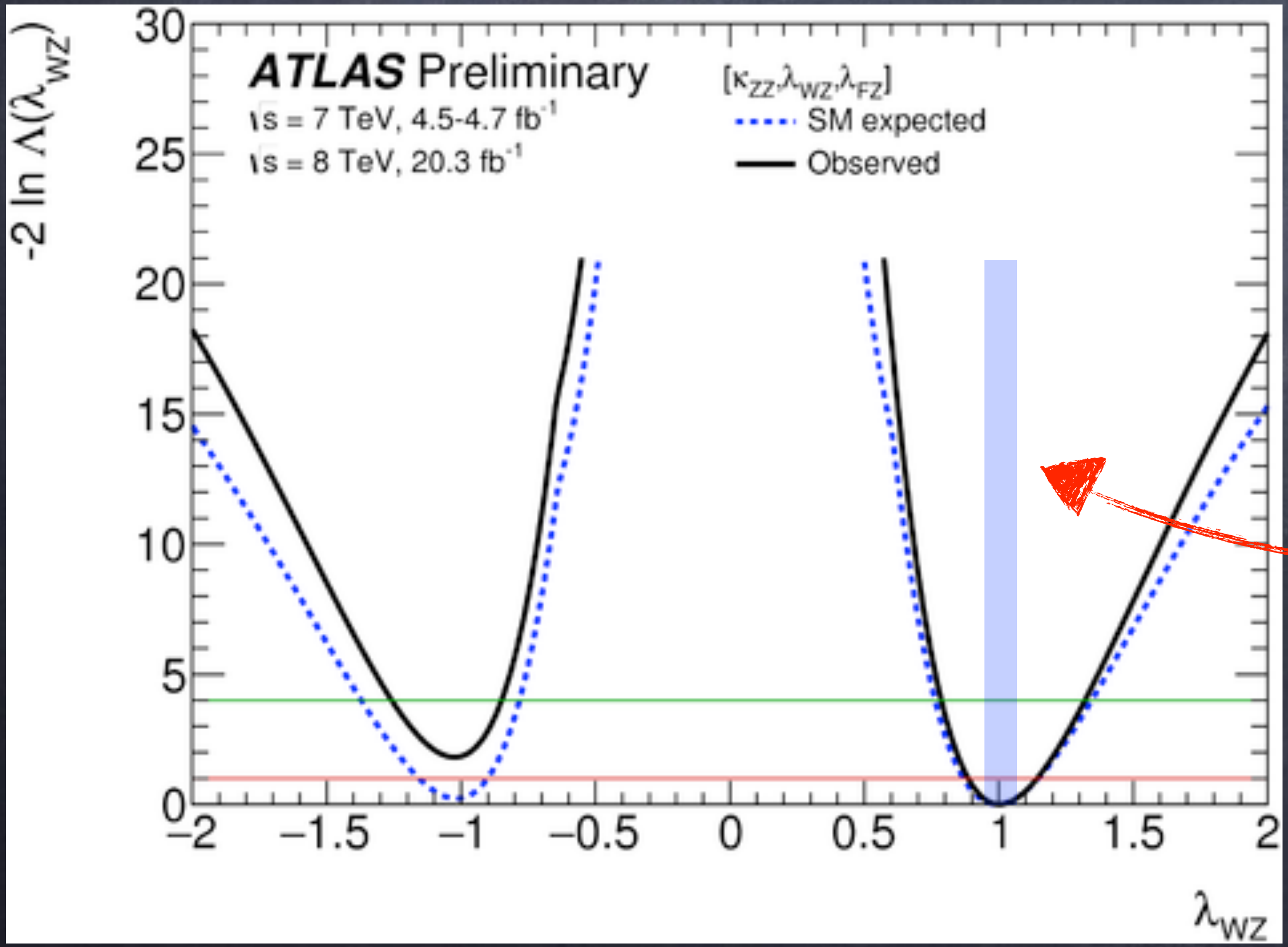

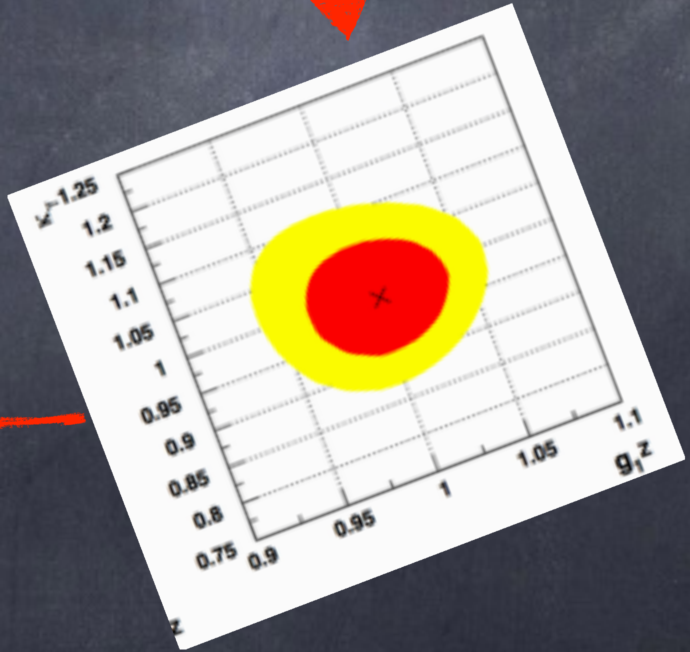

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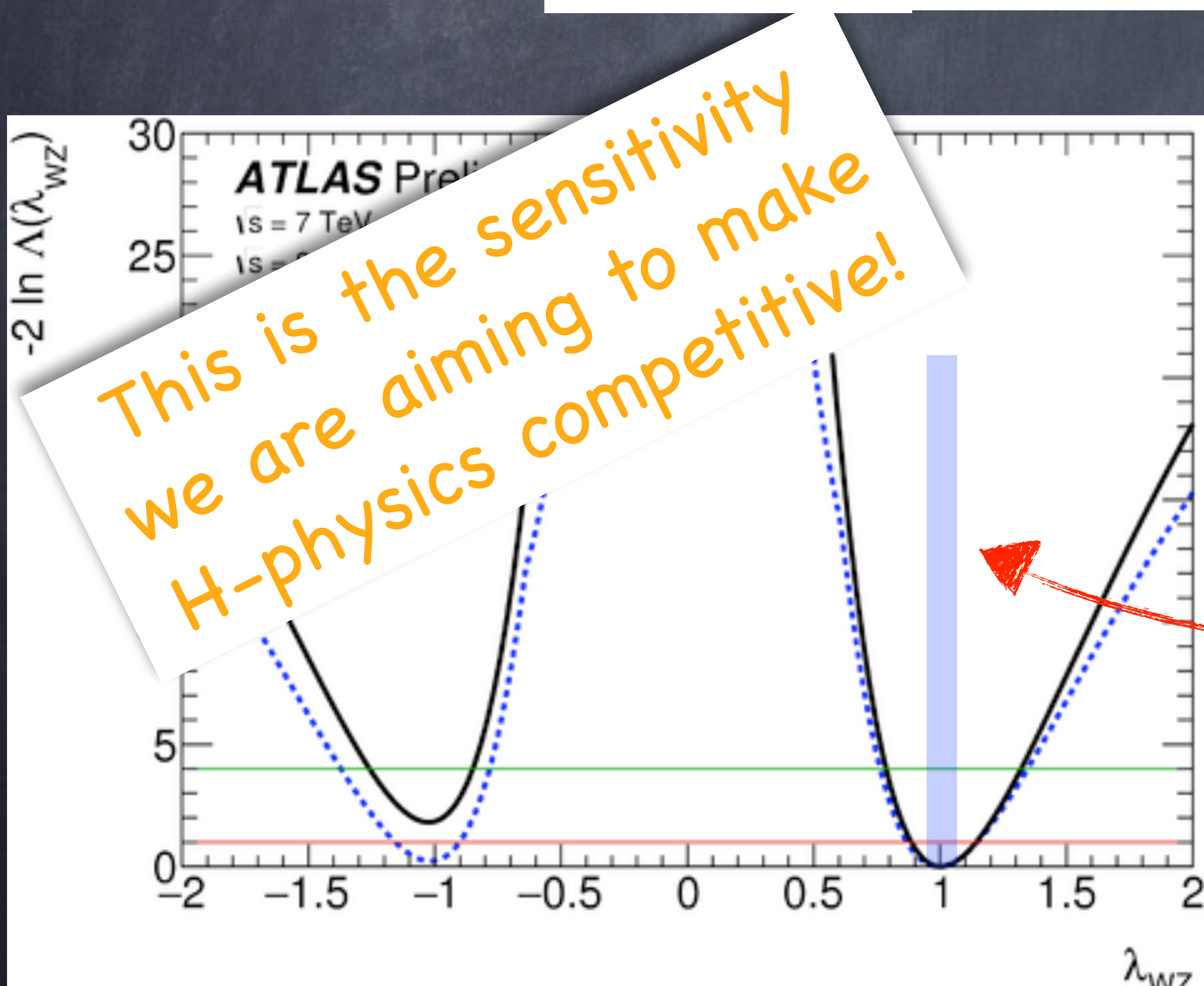

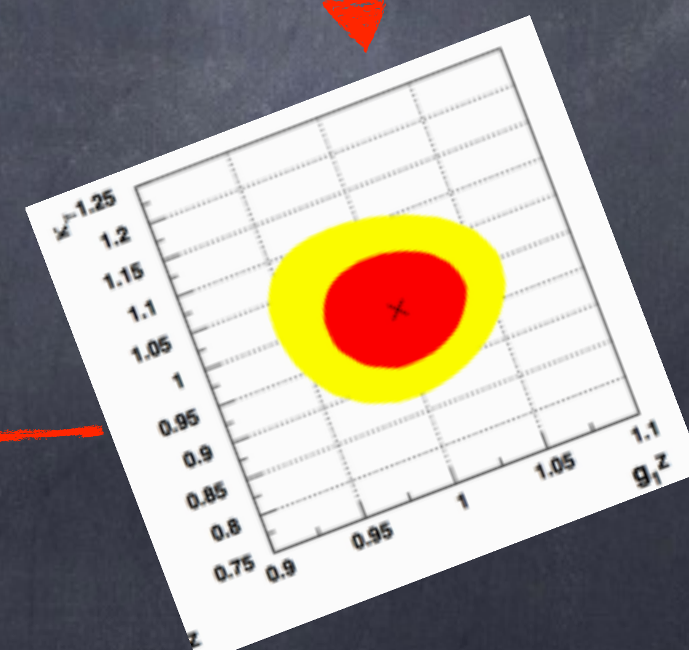

Pomarol,FR'13

So, what can we do at Run2?

- LHC genuinely exploring only Higgs-only operators (8)
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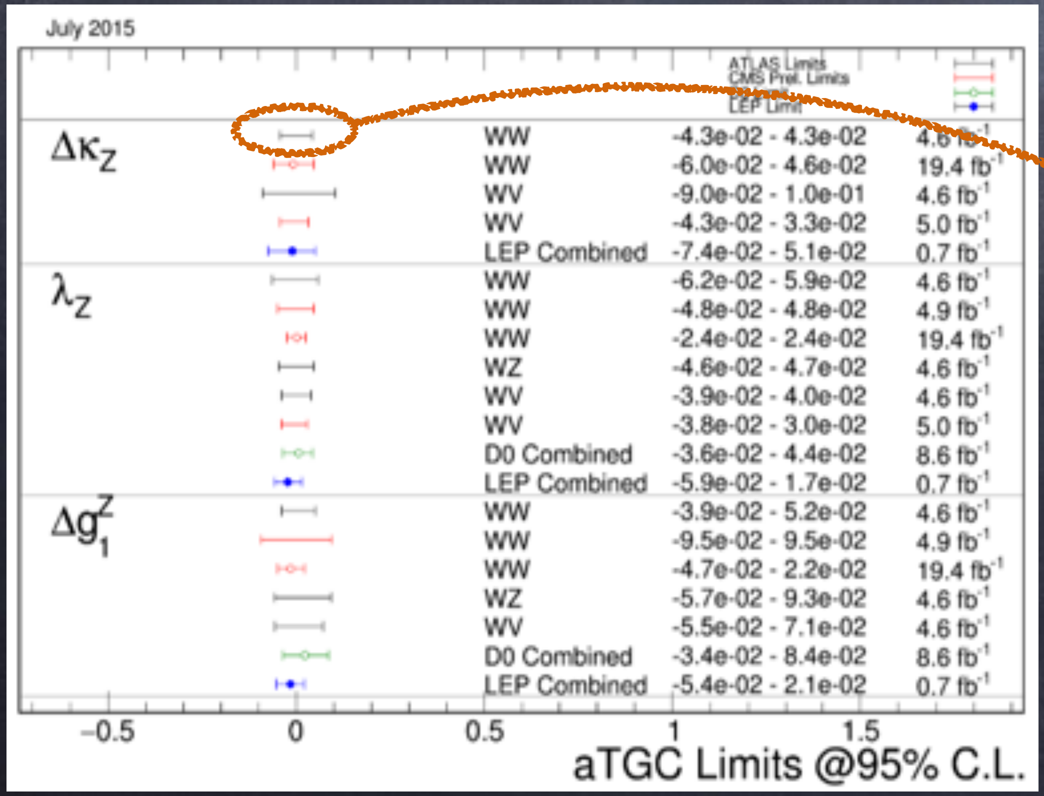
Can we not improve on any past measurement?



It seems that we already are...
but at what price? (in EFT terms)

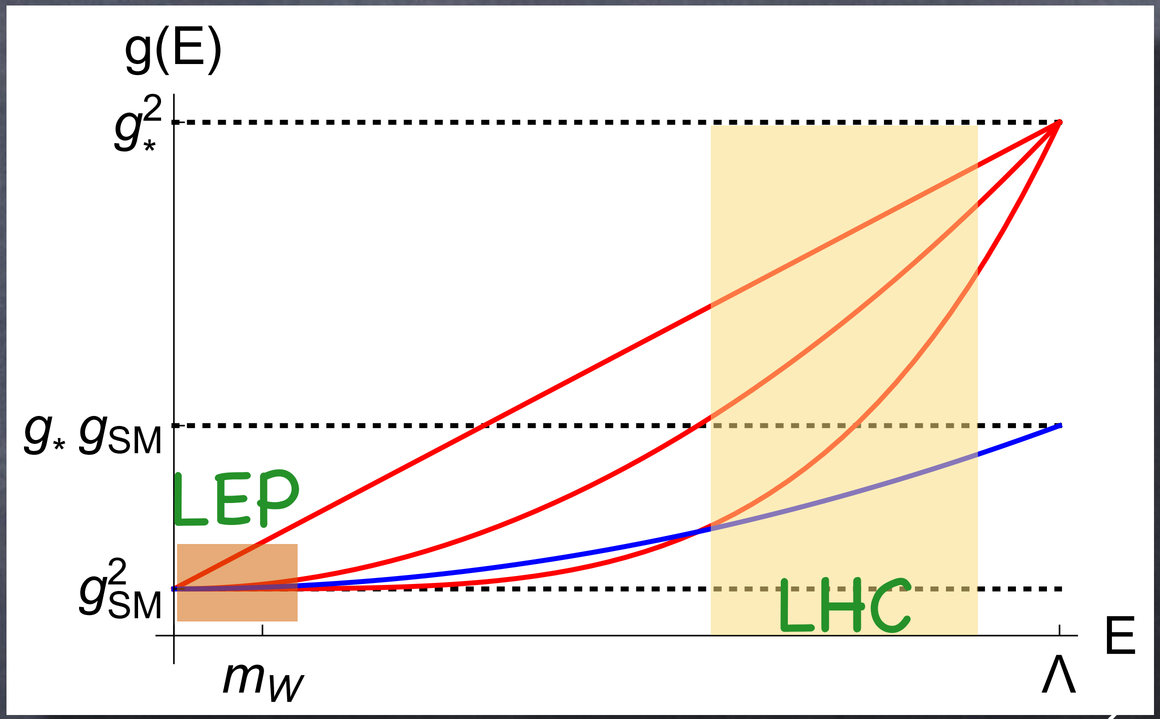
PART 3: Precision searches at high energy

What we can do at Run 2:

Disadvantage of LHC: Small sensitivity (w.r.t. SM) $\delta \sim O(1)$

Advantage of LHC: High Energy

- In some cases high-E can open the door to new (strong) couplings



Can be ≳1

Amplitude for $2 \to 2$ scattering $\mathcal{A} = g_{SM}^2 \left(1 + \frac{g_*^2(E)}{g_{SM}^2}\right)$

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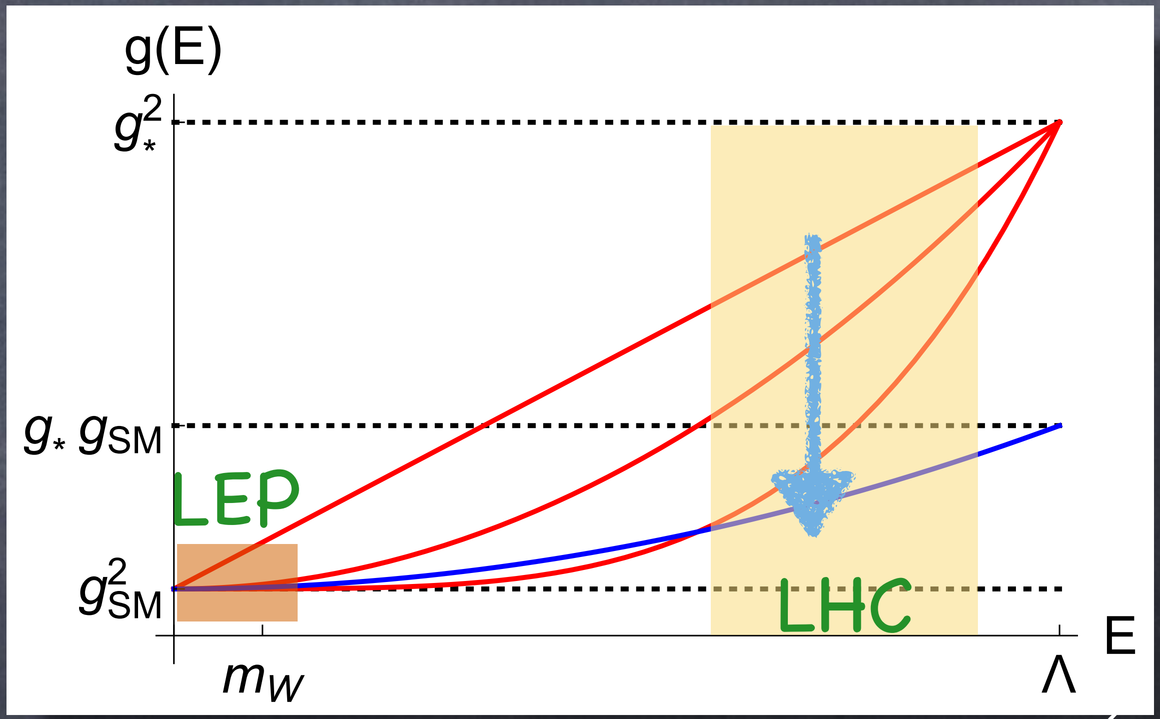

Want MINIMUM power of E, that gives access to g*

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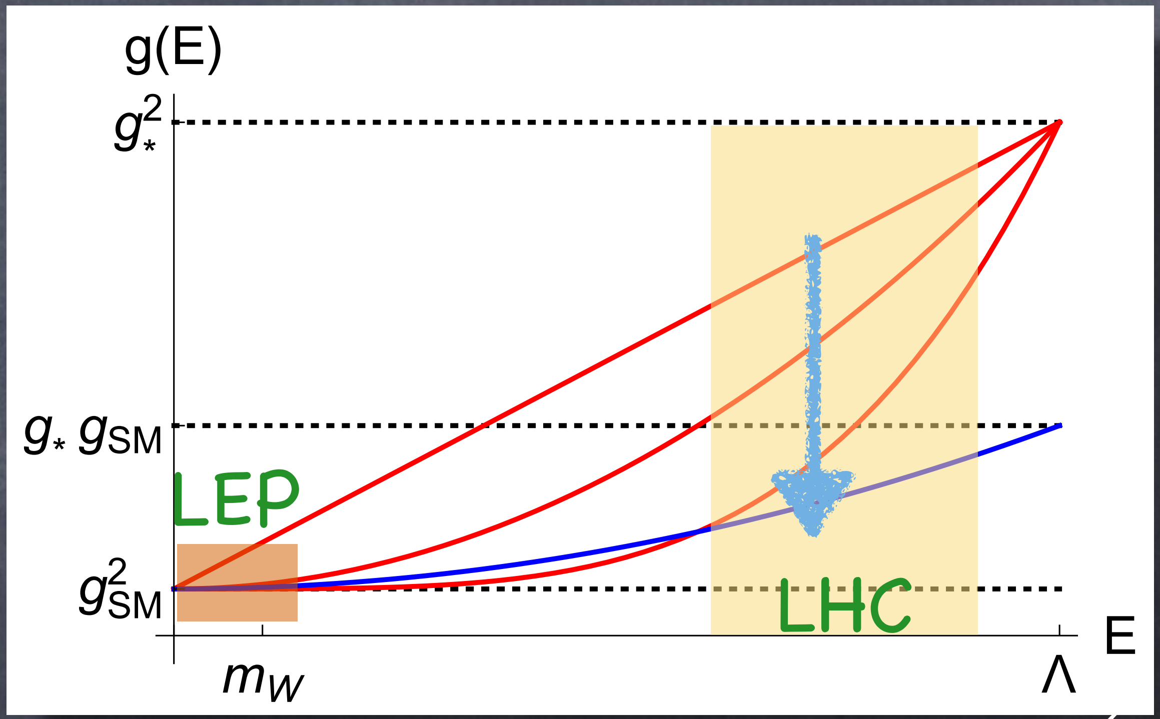

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- For this type of effects can LHC improve w.r.t. LEP

$\bar\psi\psi \to \bar\psi\psi$ $\qquad \bar\psi\psi \to VV, VH$ $\qquad VV \to VV, VH, HH$

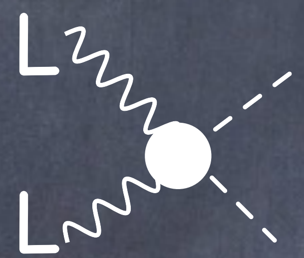
Strong Coupling for 2⟶2

SILH power counting: (forget Minimal Coupling, NPGB Higgs)

$$\mathcal{L}_{SILH} = \frac{\Lambda^4}{g_*^2}\mathcal{L}\left(\frac{D_\mu}{\Lambda}, \frac{g_* H}{\Lambda}, \frac{\lambda_{\rm el}\Psi_{L,R}}{\Lambda^{3/2}}, \frac{g F_{\mu\nu}}{\Lambda^2}\right)$$

- Only Higgs-Only operators are g* enhanced:

$$\frac{g_*^2}{\Lambda^2}(\partial_\mu |H|^2)^2 \longrightarrow$$



$$\sim g_*^2 \frac{E^2}{\Lambda^2}$$

...but small cross-section

Contino,Grojean,Moretti,Piccinini,Rattazzi'10
Azatov,Contino,Machado,FR' soon

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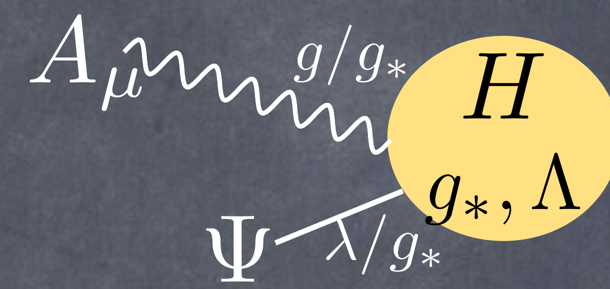

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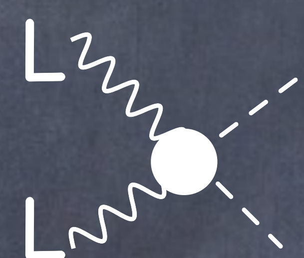

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(Partially) Strongly coupled fermions: $\epsilon_\Psi \lesssim 1$

$$\mathcal{L}_\Psi = \frac{\Lambda^4}{g_*^2}\mathcal{L}\left(\epsilon_\Psi \frac{g_* \Psi_{L,R}}{\Lambda^{3/2}}\right)$$

- Dijets $\bar\psi\psi \to \bar\psi\psi$

$$\sim g_*^2 \frac{E^2}{\Lambda^2}$$

$$\frac{\Lambda}{\epsilon_\Psi^2 g_*}$$

Model	Observed (TeV)
$\Lambda^+_{LL/RR}$ (LO)	10.3
$\Lambda^-_{LL/RR}$ (LO)	12.9
$\Lambda^+_{LL/RR}$ (NLO)	9.0
$\Lambda^-_{LL/RR}$ (NLO)	11.7
Λ^+_{VV} (NLO)	11.3

Eichten,Lane,Peskin'83;... ;Domenech,Pomarol;Serra'12

Strong Coupling for Vectors?

Composite Higgs/fermions:

$$\mathcal{L}_{H,\Psi} = \frac{\Lambda^4}{g_*^2}\mathcal{L}\left(\frac{D_\mu}{\Lambda}, \frac{g_* H}{\Lambda}, \frac{g_* \Psi_{L,R}}{\Lambda^{3/2}}, \frac{g F_{\mu\nu}}{\Lambda^2}\right)$$

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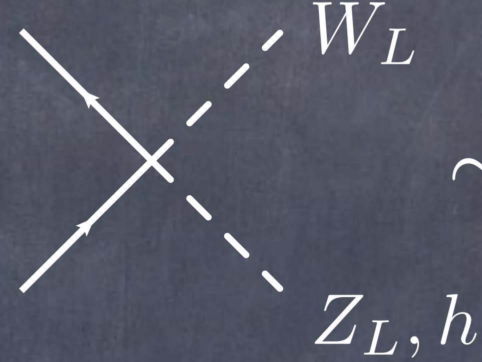

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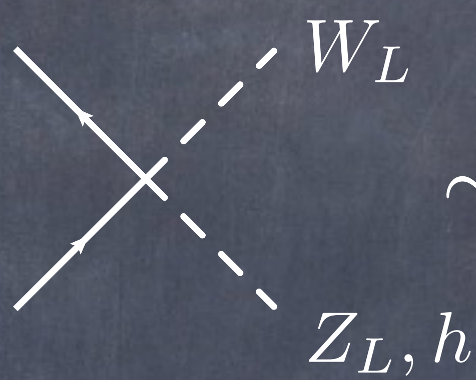

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(this also affects $Z\bar{\Psi}\Psi$ couplings at LEP1, but one -tuned- combination, corresponding to a shift of θ_W in all $Z\bar{\Psi}\Psi$ couplings, is invisible at LEP1 and is physically equivalent to)

Gupta,Pomarol,FR'14

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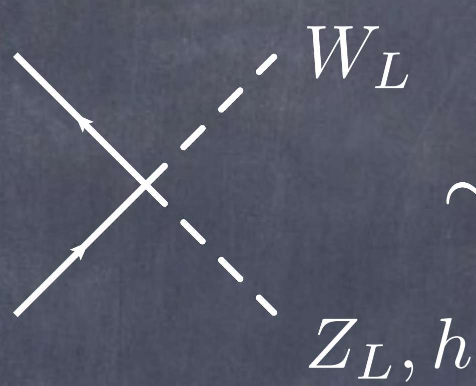

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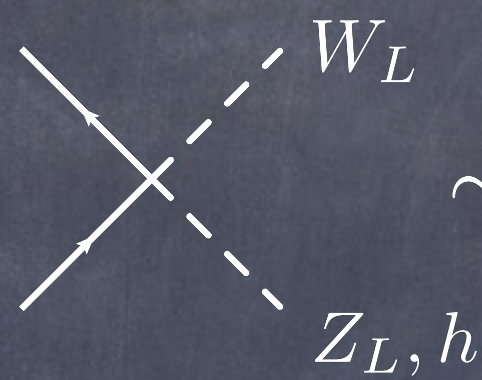

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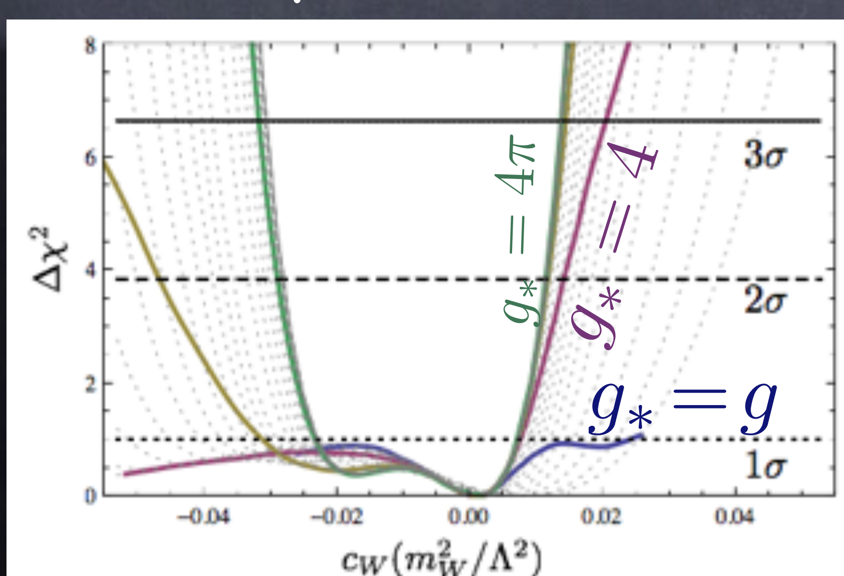
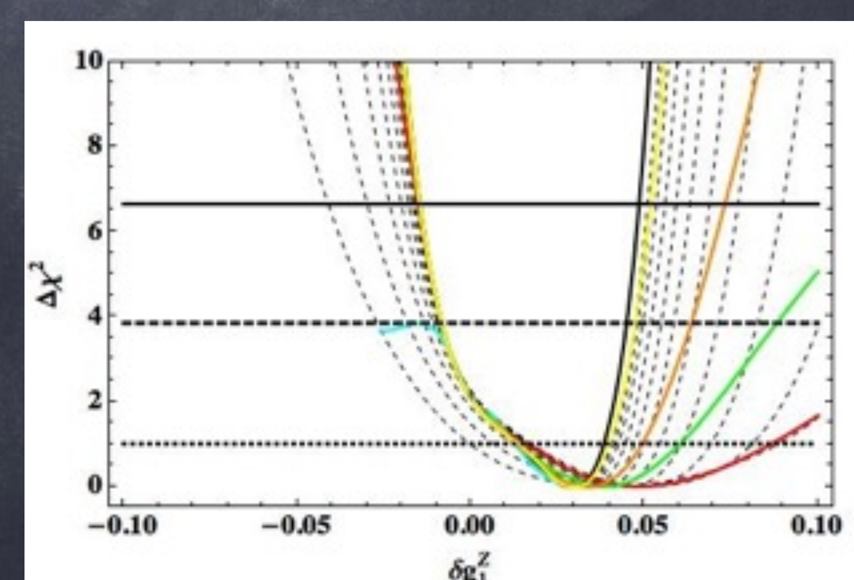
$\bar\Psi\Psi \to Vh$



Biekötter,Knochel,Krämer,Liu,FR '14

$\bar\Psi\Psi \to V_L V_L$



Liu,Pomarol,Rattazzi,FR 'to appear

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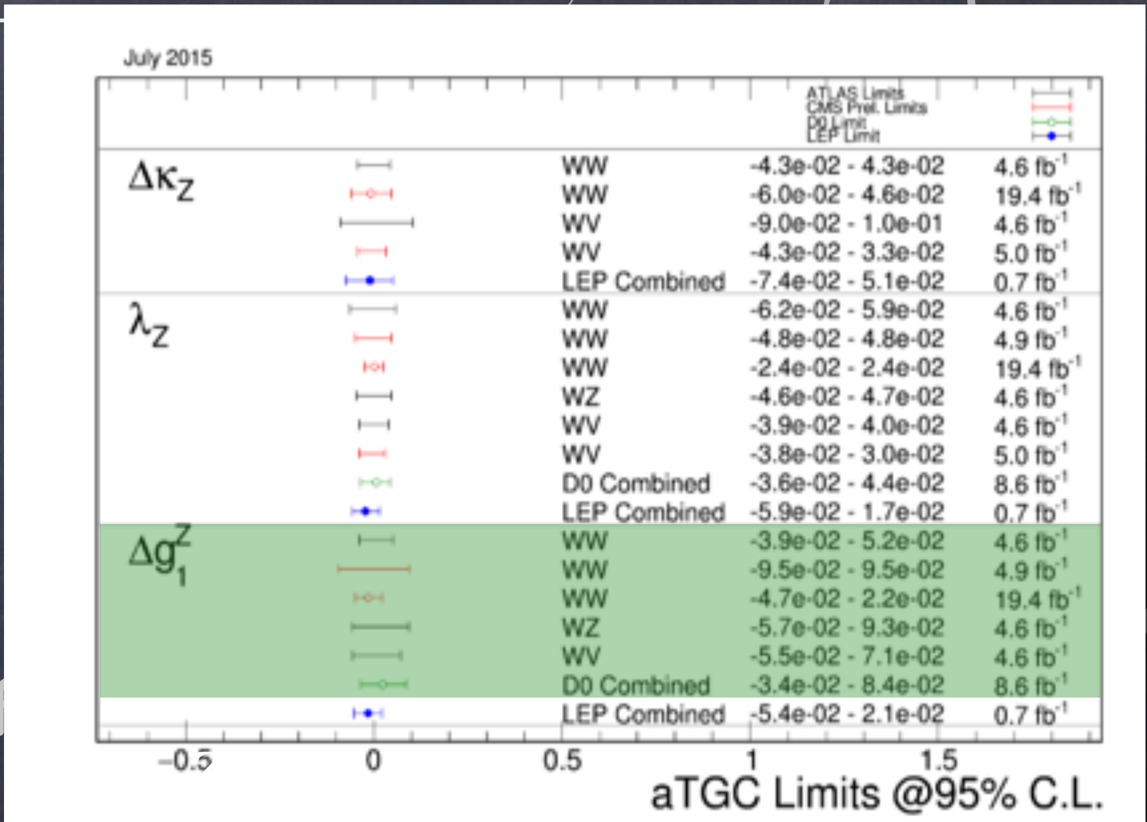

This is the scenario that these experiments are constraining

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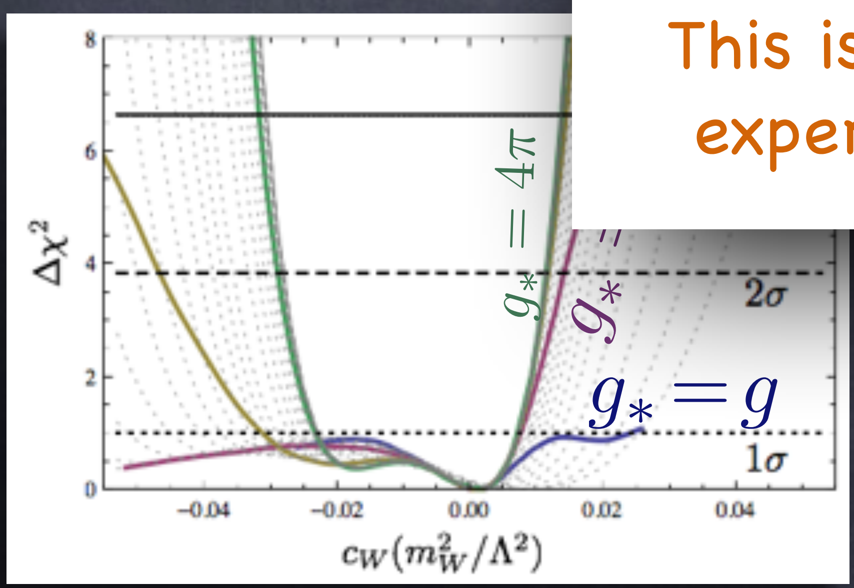

Biekötter,Knochel,Krämer,Liu,FR '14

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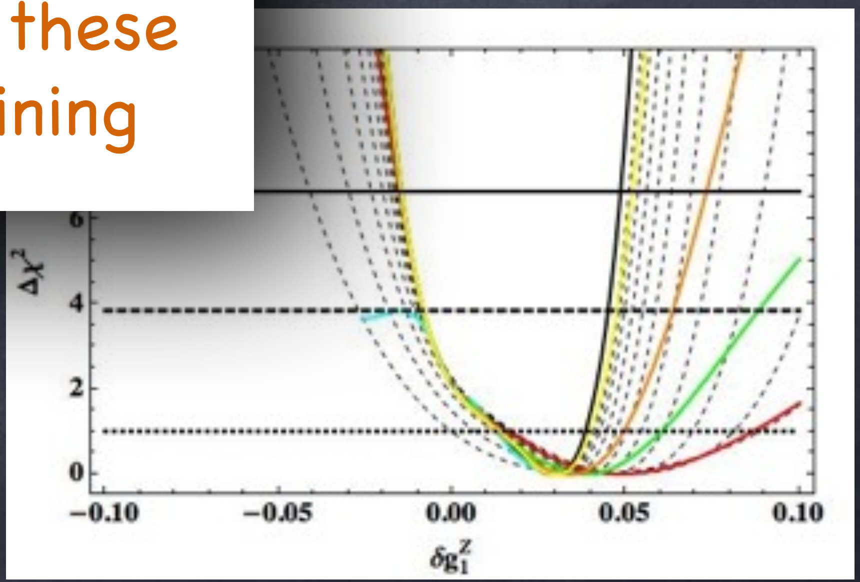

Liu,Pomarol,Rattazzi,FR 'to appear

Strong Coupling for Vectors?

Remedios the Beauty was not a creature of this world.
Gabriel Garcia Marquez

Strongly Coupled Transverse Vectors?

$$\mathcal{L}_{Rem} = \frac{\Lambda^4}{g_*^2}\mathcal{L}\left(\frac{\partial_\mu + igA_\mu}{\Lambda}, \frac{g_* F_{\mu\nu}}{\Lambda^2}\right)$$

- Lager than a genuinely composite vector...
- g* only irrelevant interactions (like a dipole)

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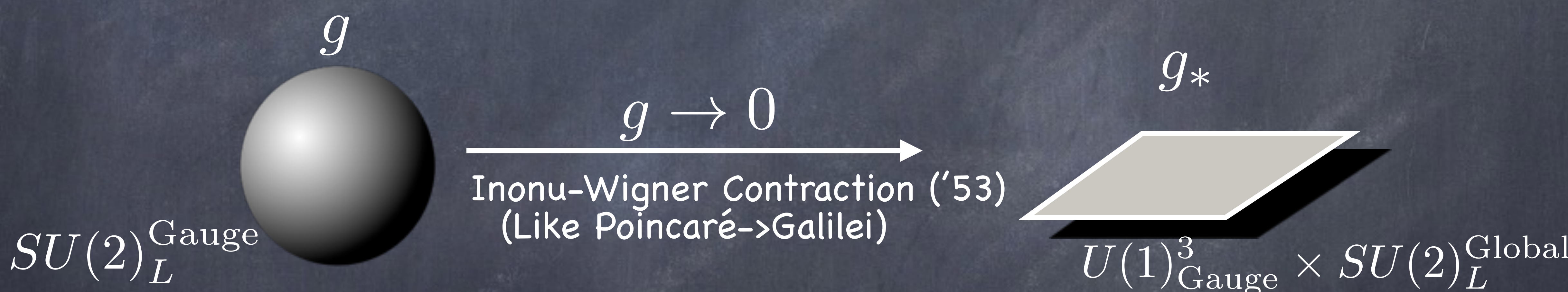

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g

$SU(2)_L^{\text{Gauge}}$

$$g \rightarrow 0$$

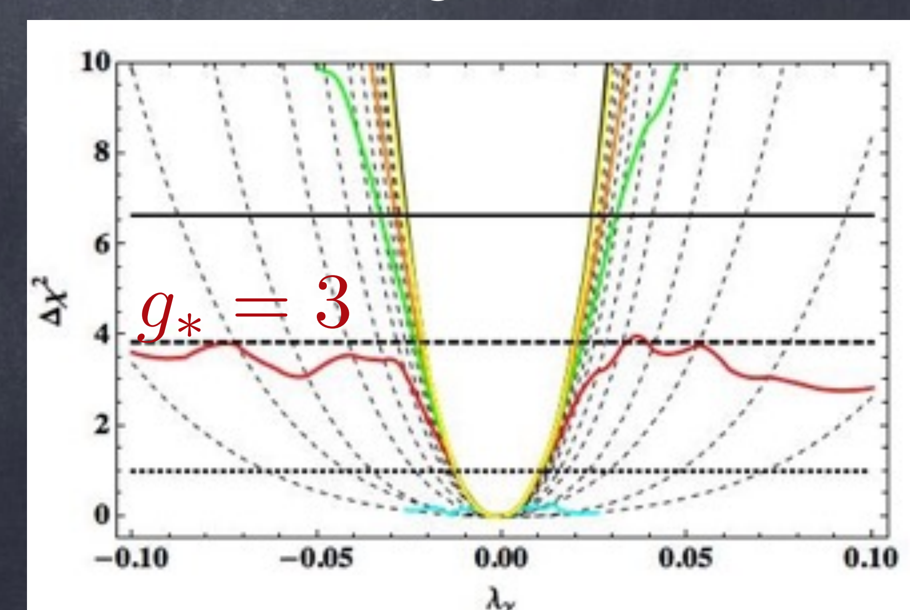
Inonu-Wigner Contraction ('53)
(Like Poincaré->Galilei)

g_*

$U(1)^3_{\text{Gauge}} \times SU(2)_L^{\text{Global}}$

$$\frac{g_*}{\Lambda^2}\epsilon_{abc} W_\mu^{a\,\nu} W_{\nu\rho}^b W^{c\,\rho\mu} \rightarrow$$

$$\sim g g_* \frac{E^2}{\Lambda^2}$$



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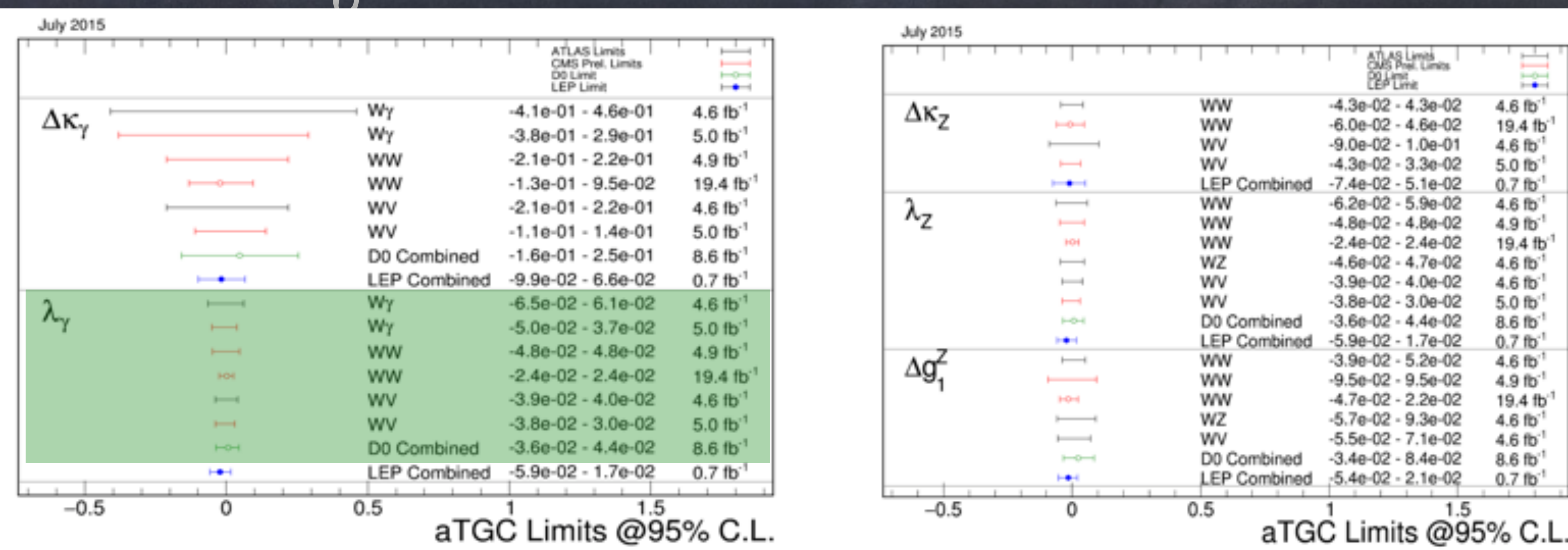

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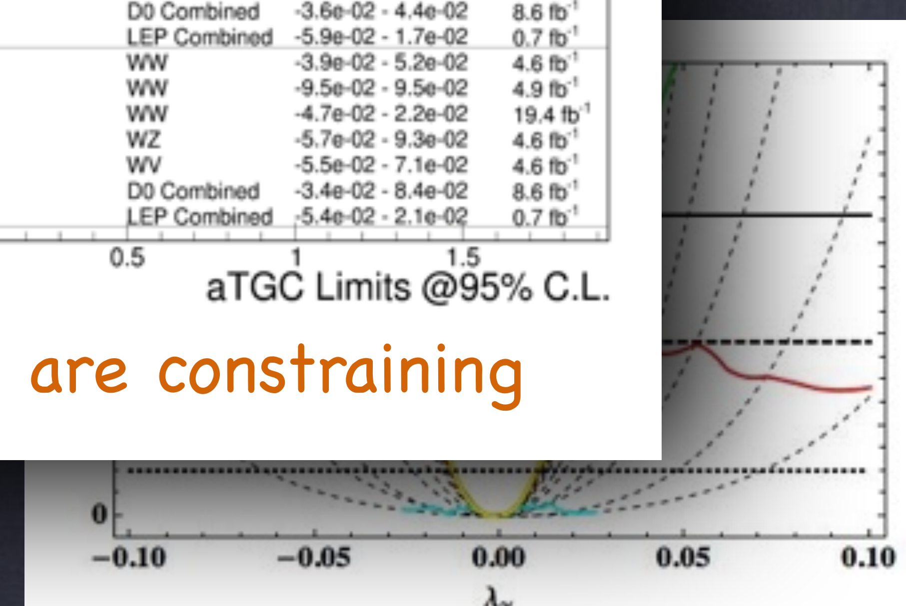

$(2)^{\text{Global}}_L$

$\frac{g_*}{\Lambda^2}\epsilon_{abc}$

W_T

Λ^2

Liu,Pomarol,Rattazzi,FR 'to appear

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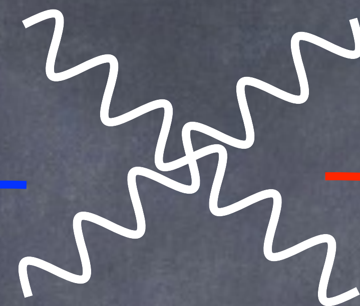
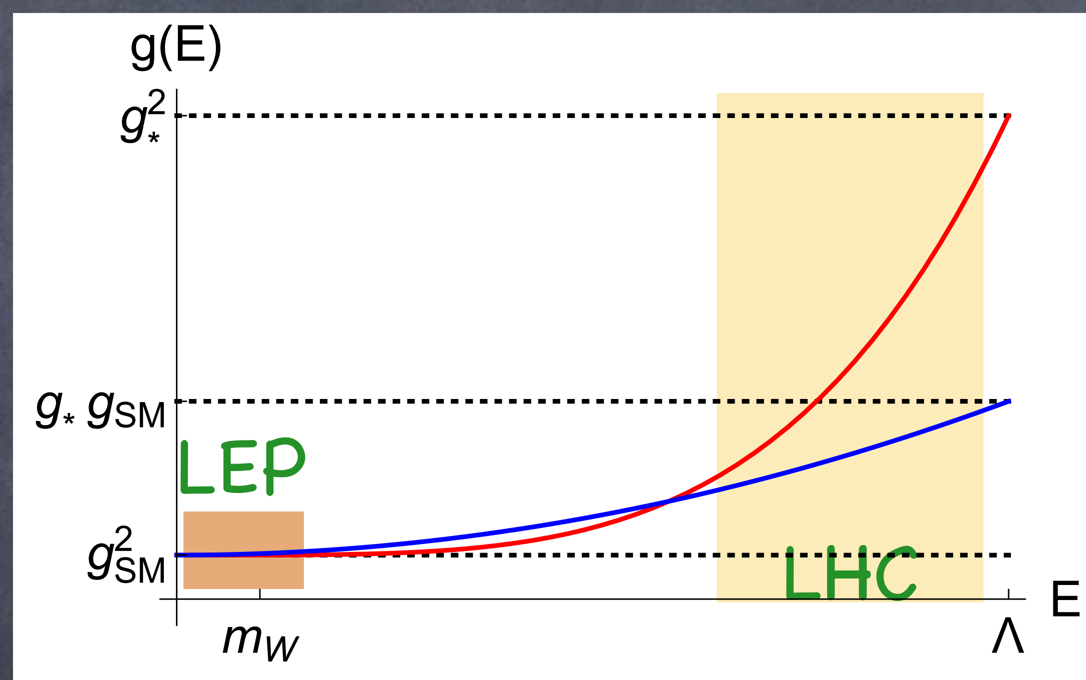
Vectors only?



$$\frac{g_*}{\Lambda^2}\epsilon_{abc}W_\mu^{a\,\nu}W_{\nu\rho}^{b}W^{c\,\rho\mu}$$

$$\frac{g_*^2}{\Lambda^2}(W_{\mu\nu})^4$$

$$\sim g g_* \frac{E^2}{\Lambda^2}$$



$$\sim g_*^2 \frac{E^4}{\Lambda^4}$$

Liu,Pomarol,Rattazzi,FR 'to appear (one day...)

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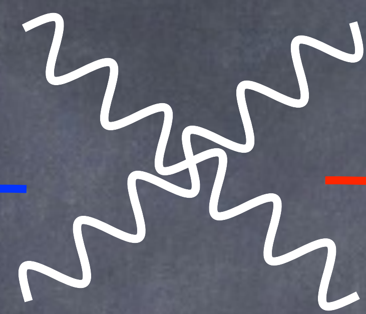

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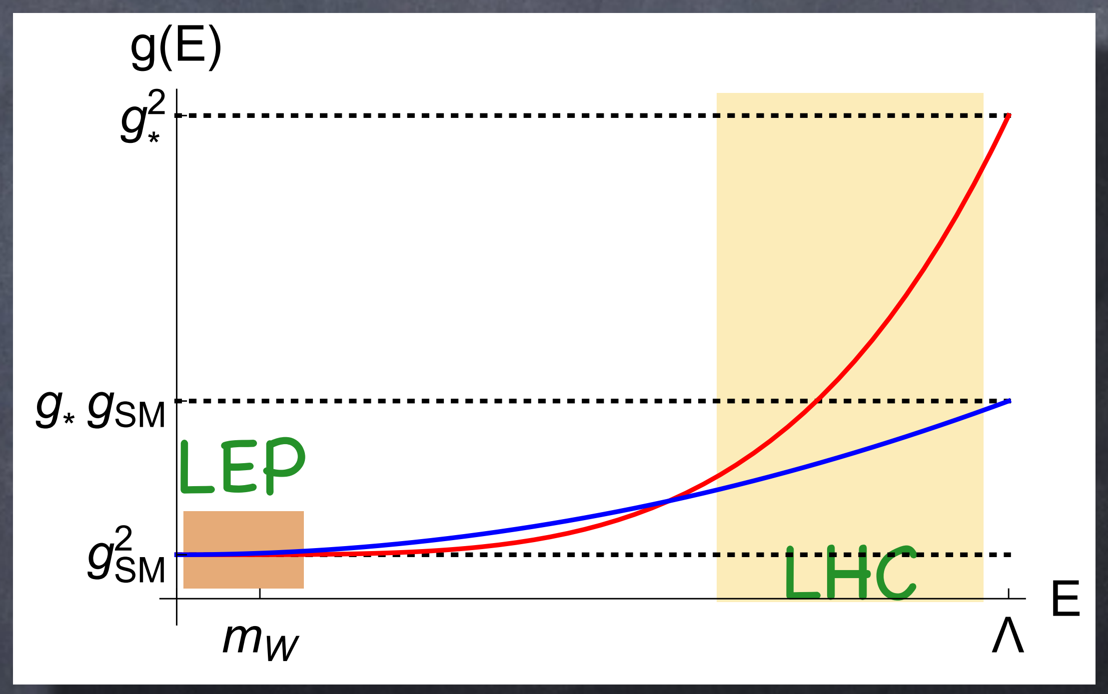

$$\sim g_*^2 \frac{E^4}{\Lambda^4}$$

- In the crossection, for $E^2/\Lambda^2 > g/g_*$:

SM^2<<dim-6 x SM << dim-6^2 = dim-8 x SM << dim-8^2

(after that, series converges...)

Liu,Pomarol,Rattazzi,FR 'to appear (one day...)

Conclusions

- EFT: motivation for SM precision tests
- Parametrization of BSM for Higgs/EW physics:

~~7~~ $\{\delta g_{ZeL}, \delta g_{ZeR}, \delta g_{Z\nu}, \delta g_{ZuL}, \delta g_{ZdL}, \delta g_{ZuR}, \delta g_{ZdR}\}$

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

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

(identification of a small number of relevant parameters necessary to focus on important physics, to design future experiments, to test SM EFT)

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(identification of a small number of relevant parameters necessary to focus on important physics, to design future experiments, to test SM EFT)

- LHC can improve w.r.t. LEP only for E-growing effects and only in theories with underlying strong coupling:

SILH | COMPOSITE FERMIONS | REMEDIOS

Conclusions

BSM, 2012:

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BSM, 2015:

Conclusions

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Generic SM
precision tests

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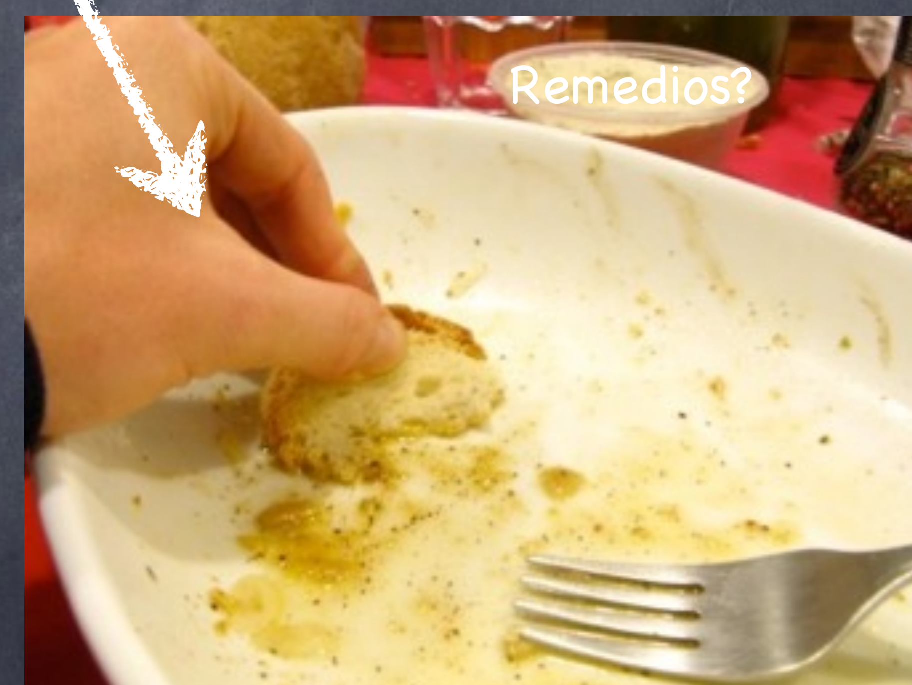

EFT: BSM Inspired precision searches ("fare la scarpetta")