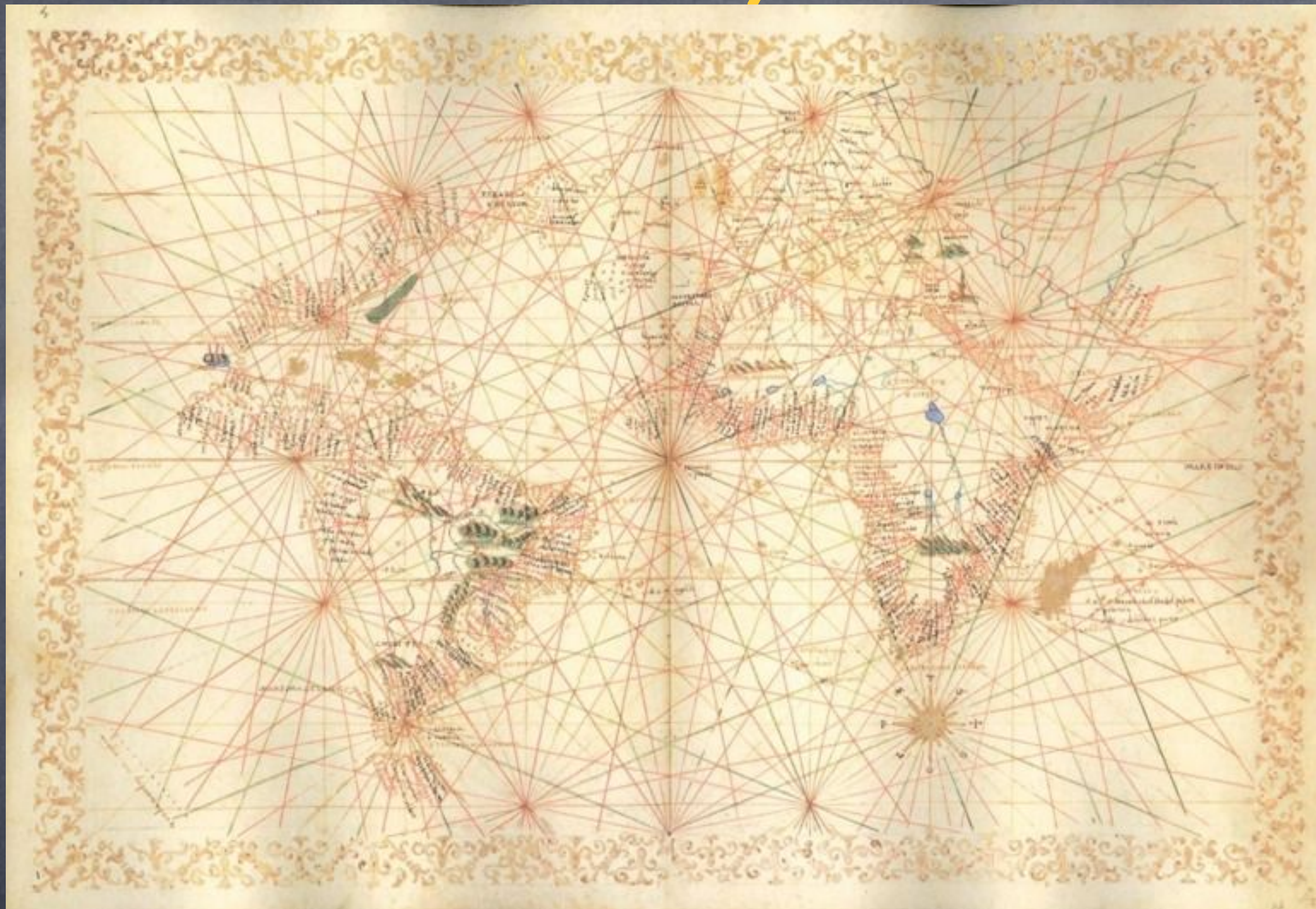
BSM Primary Effects



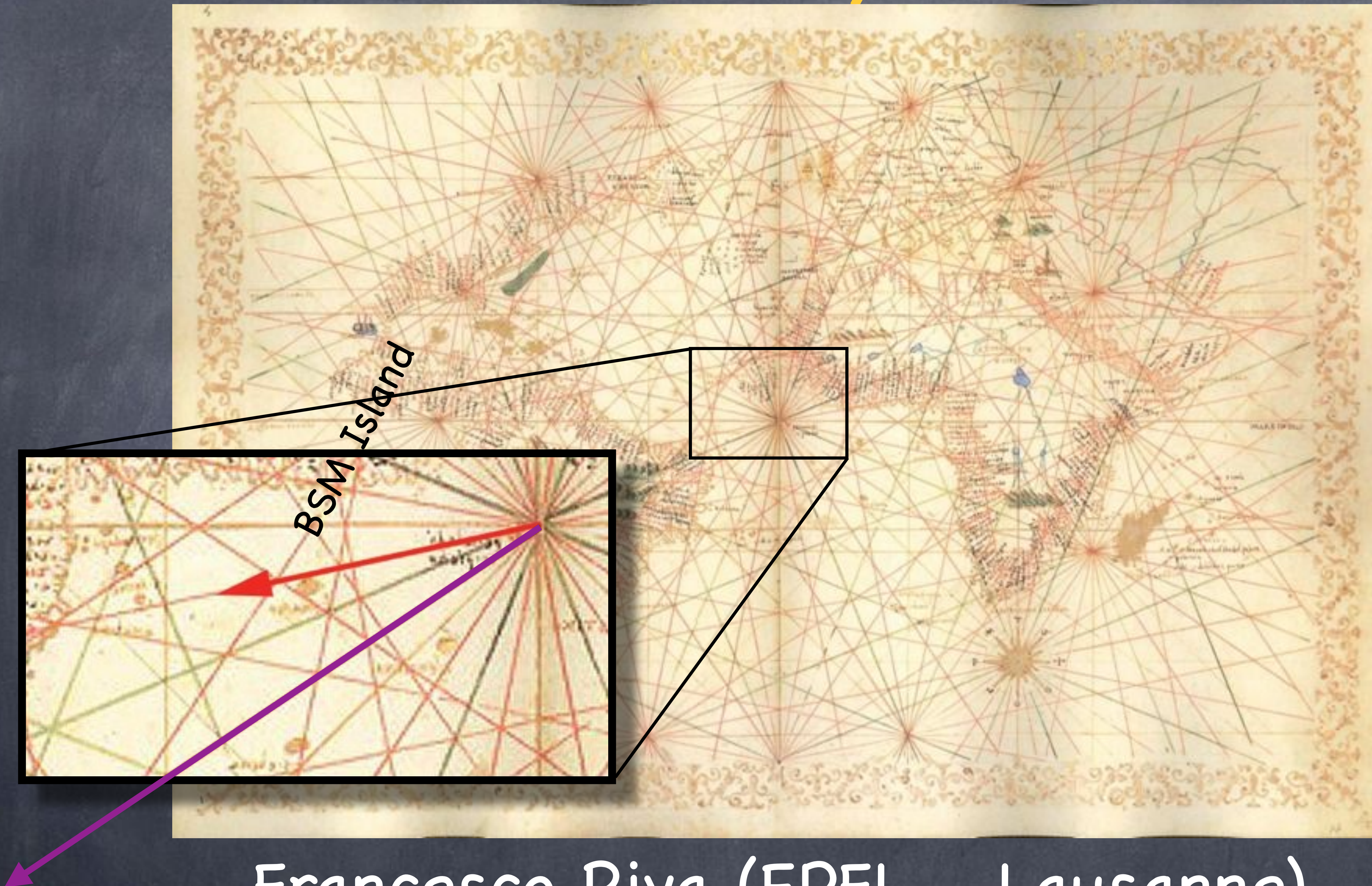
Francesco Riva (EPFL - Lausanne)

In Collaboration with:

Pomarol, Gupta, Liu, Falkowski, Sanz, Masso, Espinosa, Elias-Miro, Biekötter, Knochel, Kräme

(1308.2803 ,1308.1879, 1405.0181, 1406.7320, XXX)

BSM Primary Effects



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(1308.2803 ,1308.1879, 1405.0181, 1406.7320, XXX)

Motivation

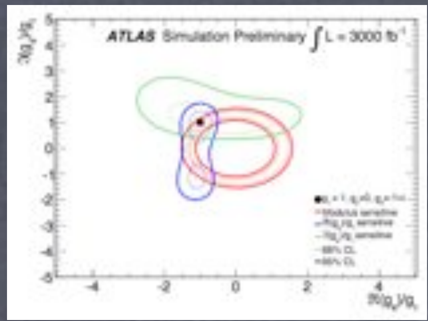
Searches for New Physics

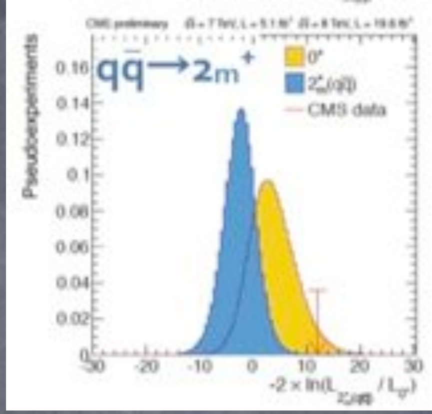
Direct

Precision

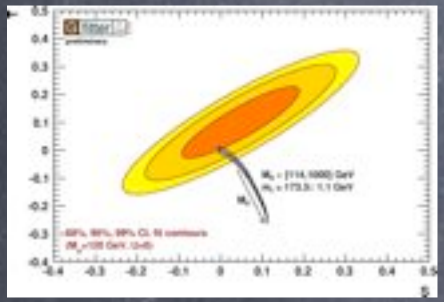
Motivation

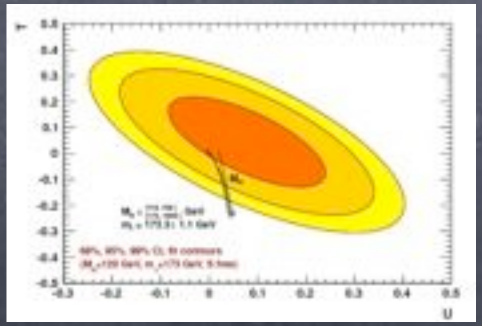
Searches for New Physics

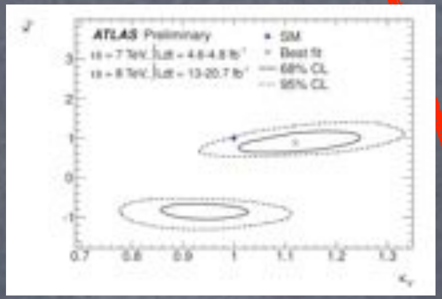


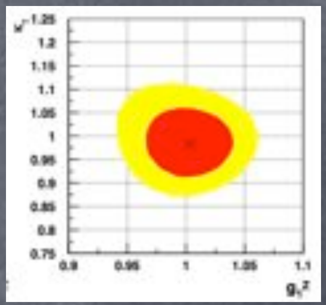


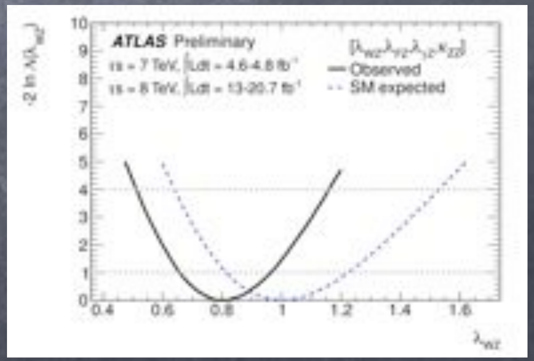
$\mathcal{L}^{SM}$

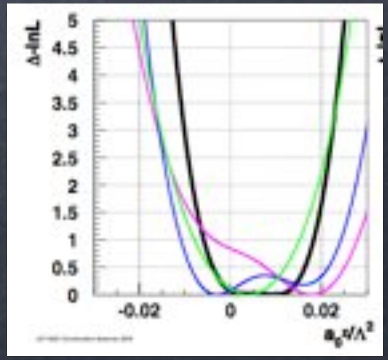




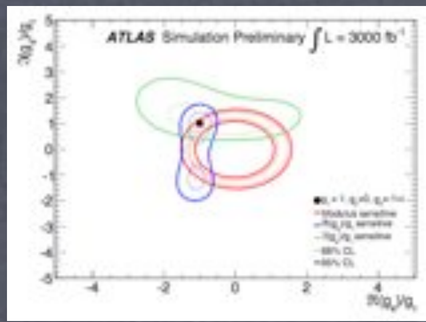


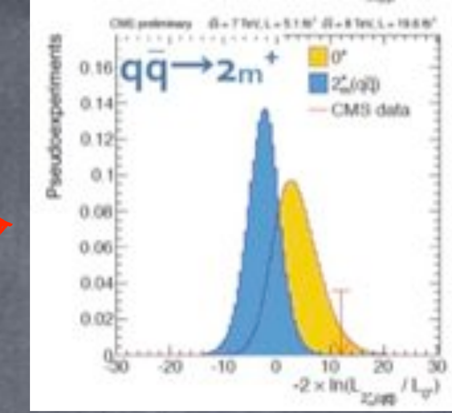




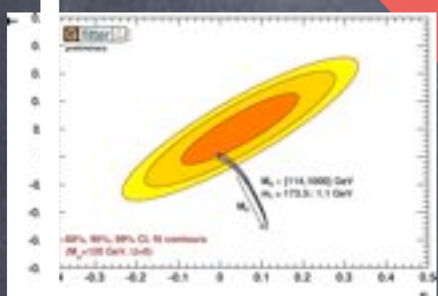


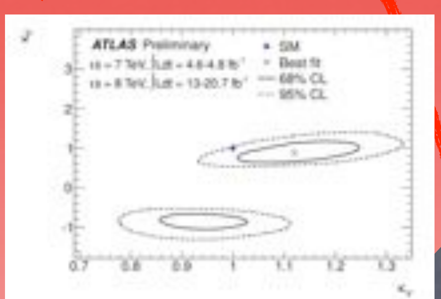
Motivation

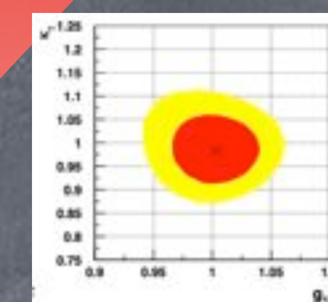


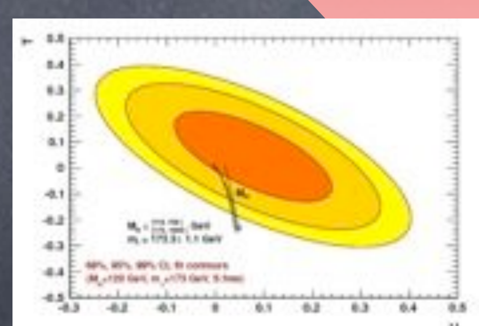


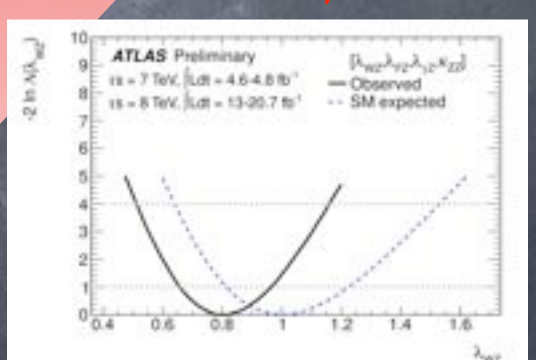
$\mathcal{L}^{SM}$

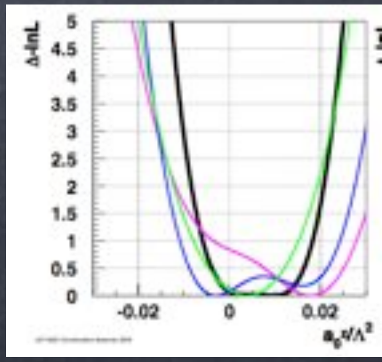












$\mathcal{L}^{UV}$

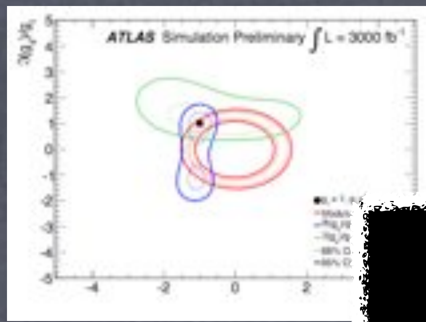
Expansion

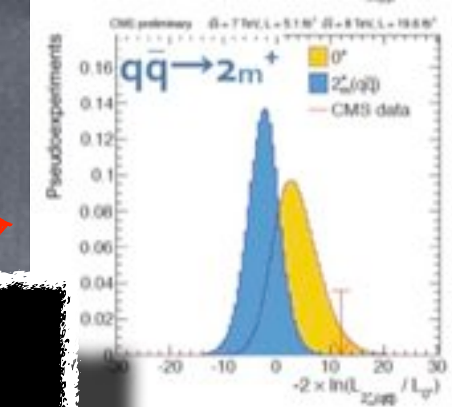
1) E/Λ

2) H/f

3) Y_U, Y_D, Y_E

Motivation

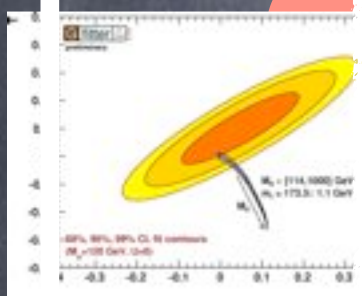


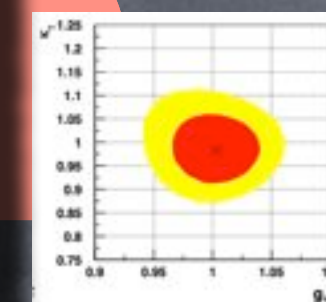


$\mathcal{L}^{SM} \equiv$

1) No direct findings: $M^i_{new} \sim \Lambda \gg m_W$

→ Expansion in D_μ/Λ



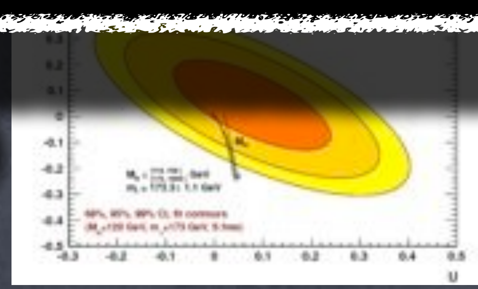


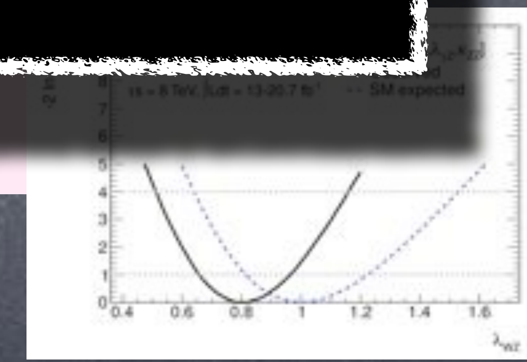
Expansion

1) E/Λ

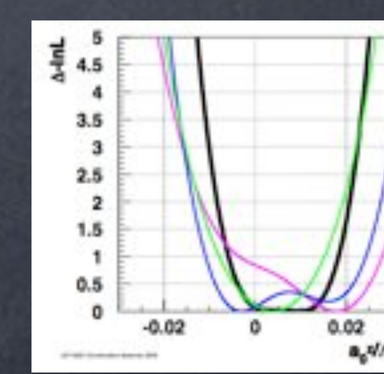
2) H/f

3) Y_U, Y_D, Y_E

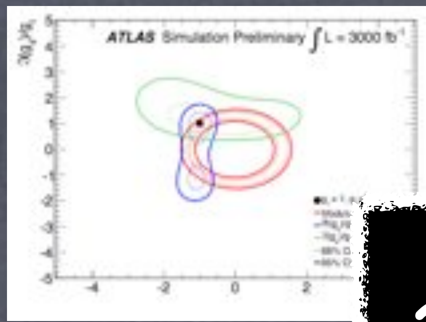


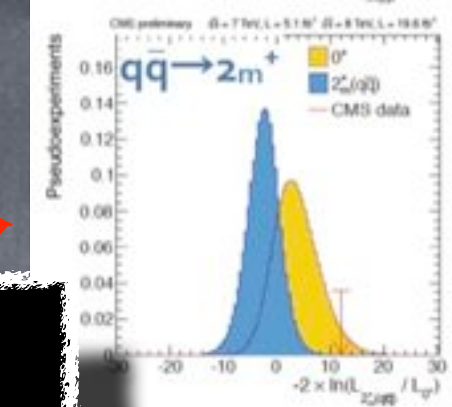


$\mathcal{L}^{UV}$

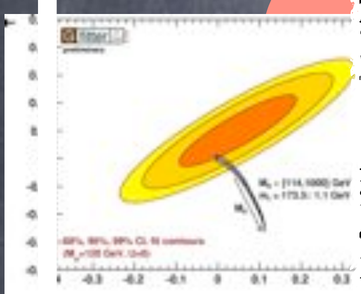


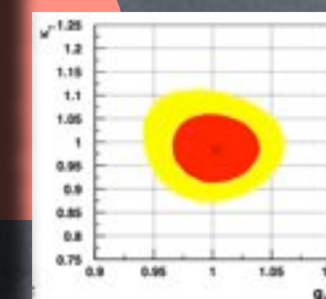
Motivation





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



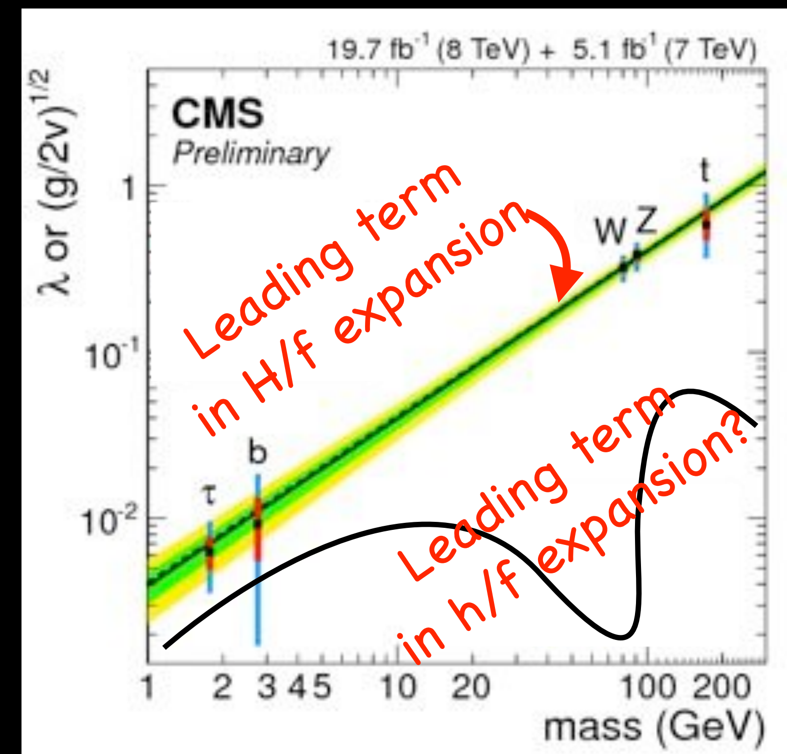


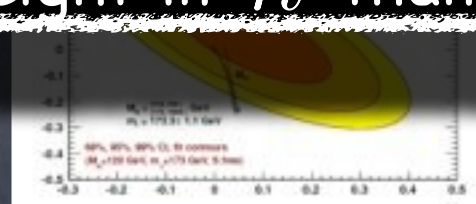
2) Higgs is excitation around EWSB vacuum

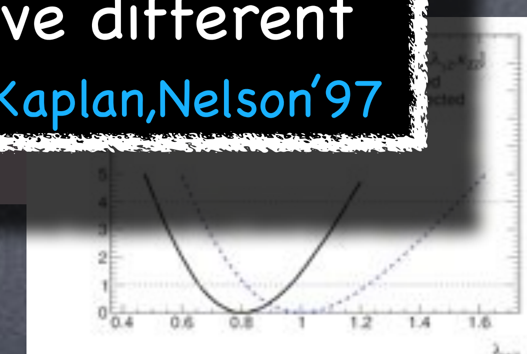
→ Expansion in H/f ($H \to v+h$)

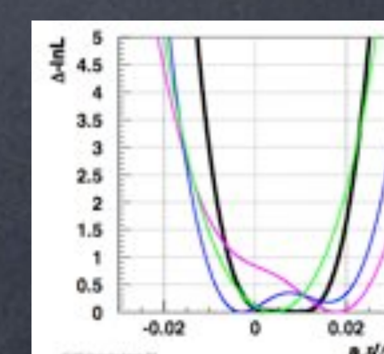
$$(f \equiv \Lambda/g_*)$$

Some BSM coupling (necessary, since fields have different weight in $\hbar$ than derivatives) e.g. Cohen,Kaplan,Nelson'97









Expansion

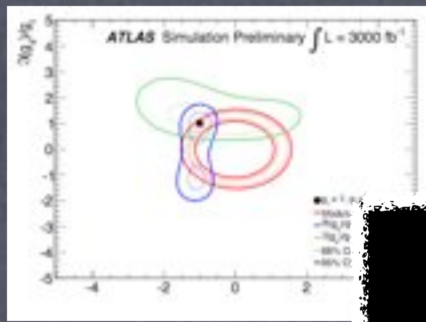
1) E/Λ

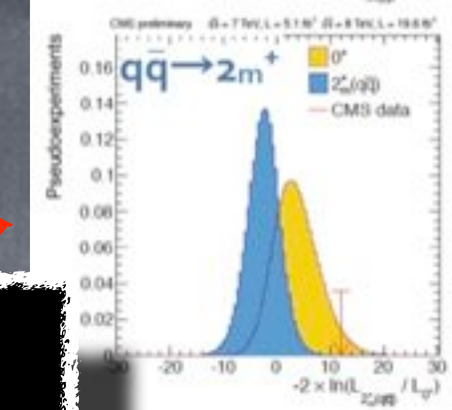
2) H/f

3) Y_U, Y_D, Y_E

$\mathcal{L}^{UV}$

Motivation



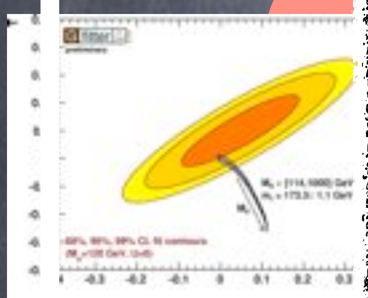


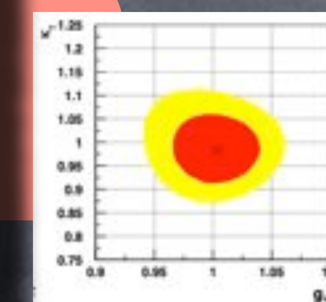
$\mathcal{L}^{SM} \equiv$

3) Flavor Violation tightly constrained
($K^0 - \bar{K}^0 \Rightarrow \Lambda > 10^6 \mathrm{GeV}$)

→ Minimal Flavor Violation expansion in
Y_U, Y_D, Y_E

D'ambrogio,Giudice, Isidori,Strumia'02



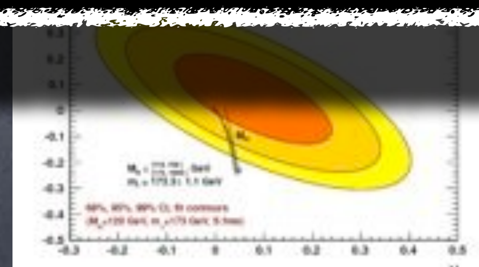


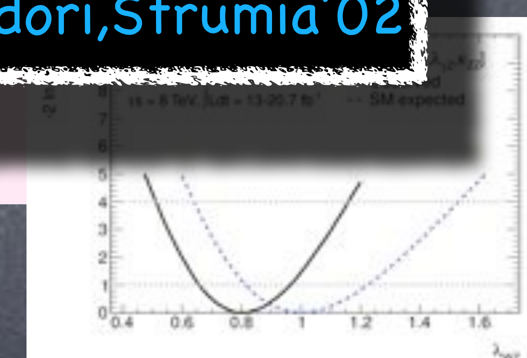
Expansion

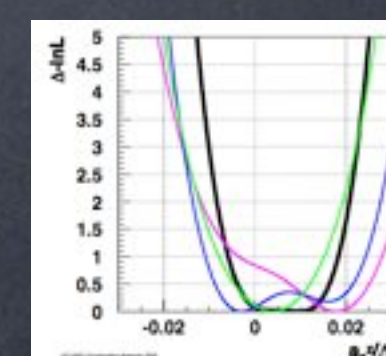
1) E/Λ

2) H/f

3) Y_U, Y_D, Y_E

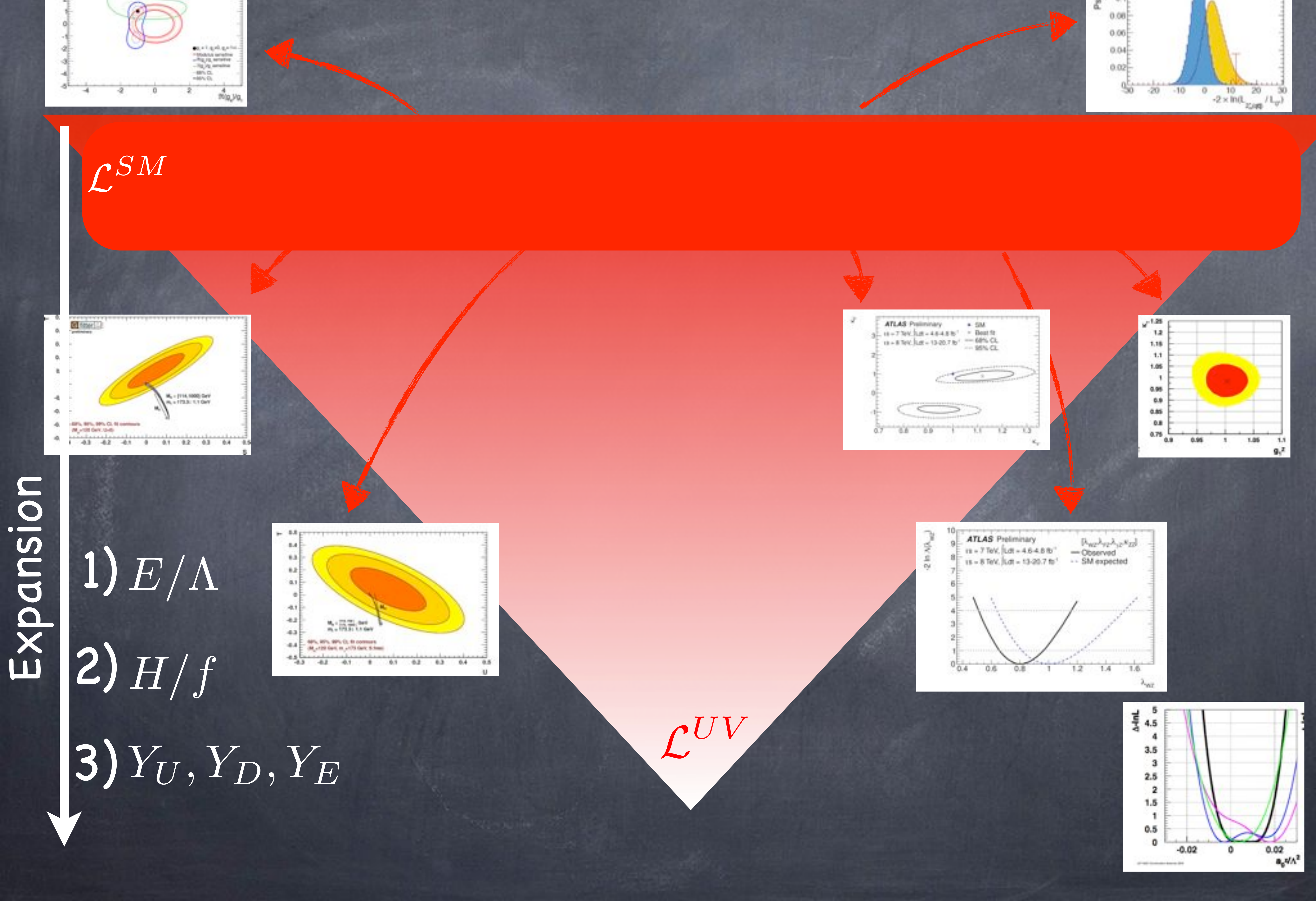






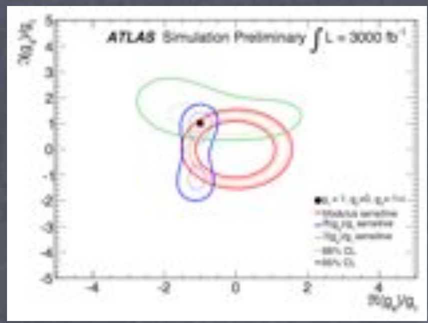
$\mathcal{L}^{UV}$

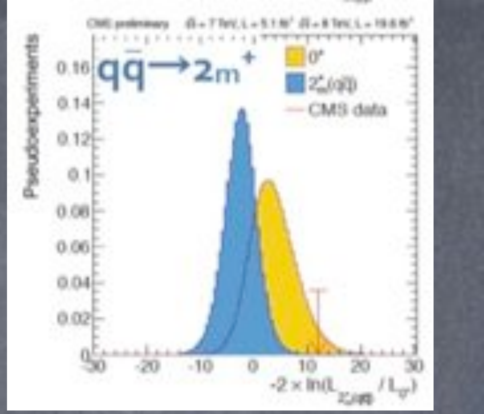
Motivation



$\mathcal{L}^{SM}$
$\mathcal{L}^{UV}$
Expansion
1) E/Λ
2) H/f
3) Y_U, Y_D, Y_E
ATLAS Simulation Preliminary
Pseudoexperiments
CMS data
ATLAS Preliminary
ATLAS Preliminary
Observed
SM expected

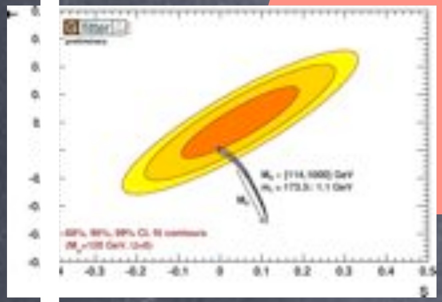
Motivation

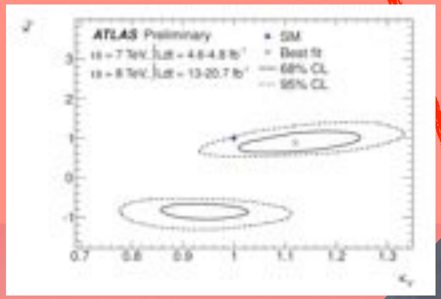


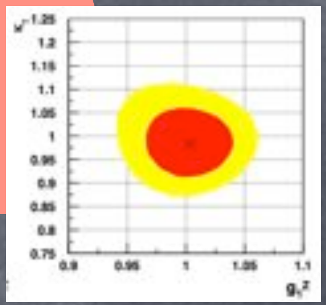


$\mathcal{L}^{SM} \equiv \mathcal{L}^4$

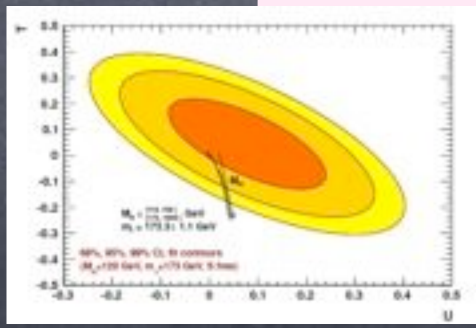
$\mathcal{L}^6$

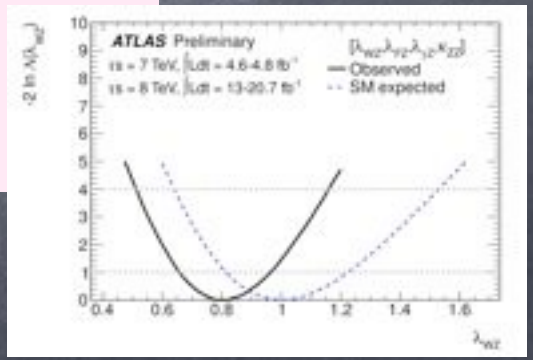




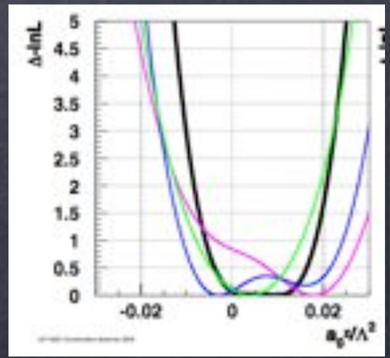


$\mathcal{L}^8$





$\mathcal{L}^{UV}$



Expansion

1) E/Λ

2) H/f

3) Y_U, Y_D, Y_E

Motivation

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

SM → $\mathcal{L}_4$; $\mathcal{L}_6 = \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i$

Buchmuller,Wyler'86;
Giudice et al '07
Grzadkowski et al'10
Alonso et al'13

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

- Parameters: 19
- Accidental relations (due to d=4 Lagrangian)

e.g. $m_W = m_Z \cos\theta_W$

$g_{h\bar{f}f} = m_f/v$

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

- Parameters: 76
- Accidental relations ?

e.g. $\delta_{Zff} = \delta_{Wff'}$

$$\delta g_1^Z = \frac{\delta g^Z}{g^Z_{SM}} = \frac{\delta g^{WW}}{2c^2_{\theta_W} g^{WW}_{SM}} = \frac{\delta g^{ZZ}}{2g^{ZZ}_{SM}} = \frac{\delta g^{\gamma Z}}{g^{\gamma Z}_{SM}}$$

Gupta,Pomarol,FR'14

- These relations are all is needed to disentangle linear vs. non-linear ~~$SU(2)$~~
- They represent the leading BSM effects: crucial to design future experiments

Motivation

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

SM → $\mathcal{L}_4$; $\sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i$ → $\mathcal{L}_6$

Buchmuller,Wyler'86;
Giudice et al '07
Grzadkowski et al'10
Alonso et al'13

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

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

- Parameters: 19
- Accidental r[elations]
(due to d=4 L[agr]angian)

e.g. $m_W = m_Z \cos\theta_W$

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

- Parameters: ~~76~~ 17
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e.g. $\delta_{Zff} = \delta_{Wff'}$

$$\delta g_1^Z = \frac{\delta g^Z}{g^Z_{SM}} = \frac{\delta g^{WW}}{2c^2_{\theta_W} g^{WW}_{SM}} = \frac{\delta g^{ZZ}}{2g^{ZZ}_{SM}} = \frac{\delta g^{\gamma Z}}{g^{\gamma Z}_{SM}}$$

Gupta,Pomarol,FR'14

- These relations are all is needed to disentangle linear vs. non-linear ~~$SU(2)$~~
- They represent the leading BSM effects: crucial to design future experiments

PART 1
17 BSM Parameters
(related to LEP and LHC Run1)

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

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

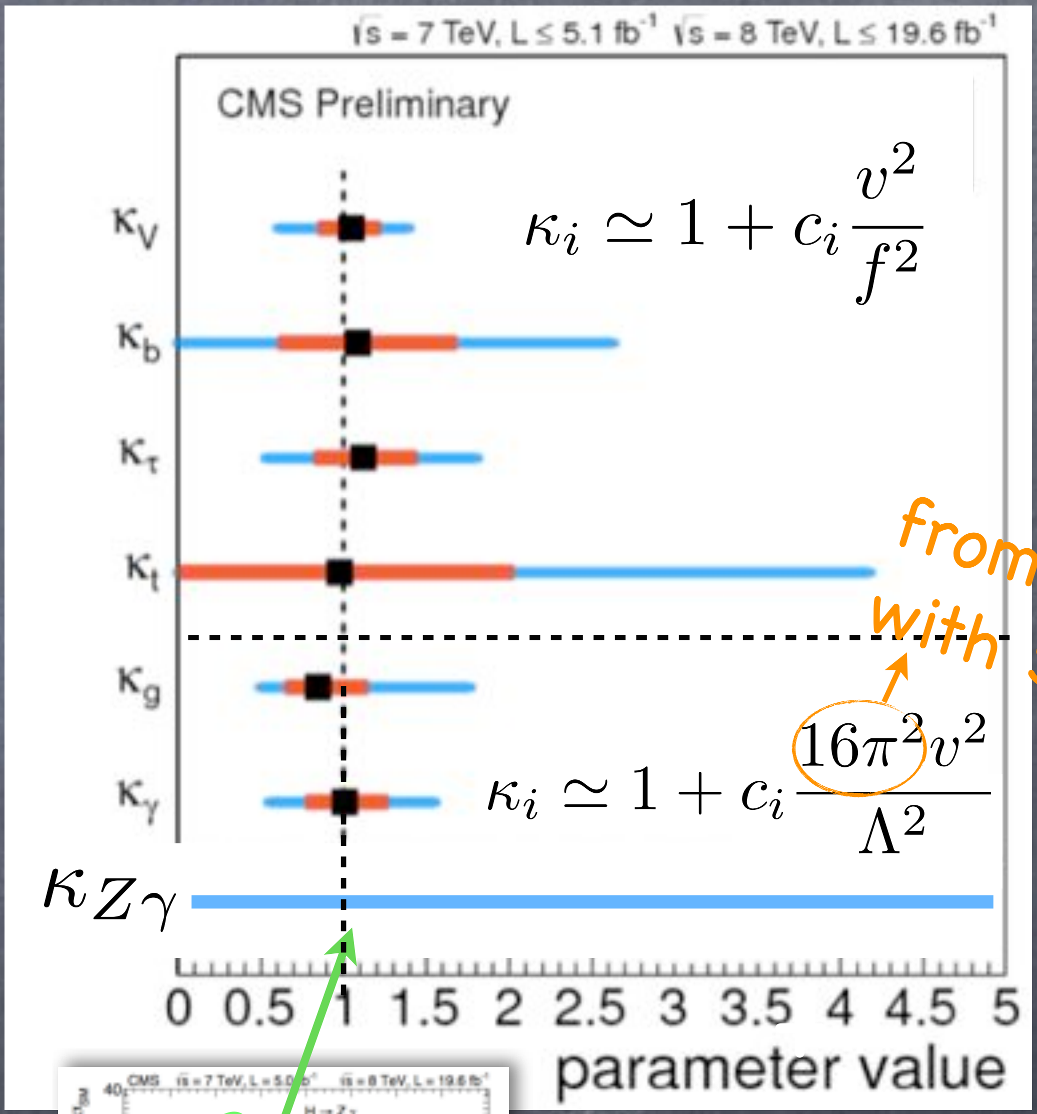
Parameters for BSM: Higgs-only

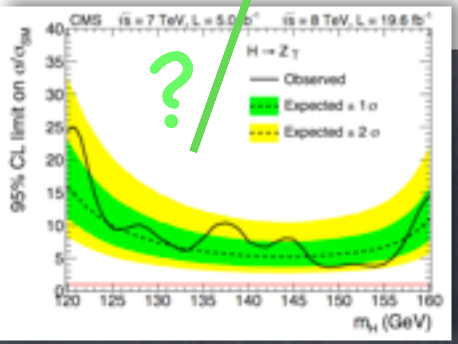
Higgs Physics Only

$\langle h \rangle = v$

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

h^3?





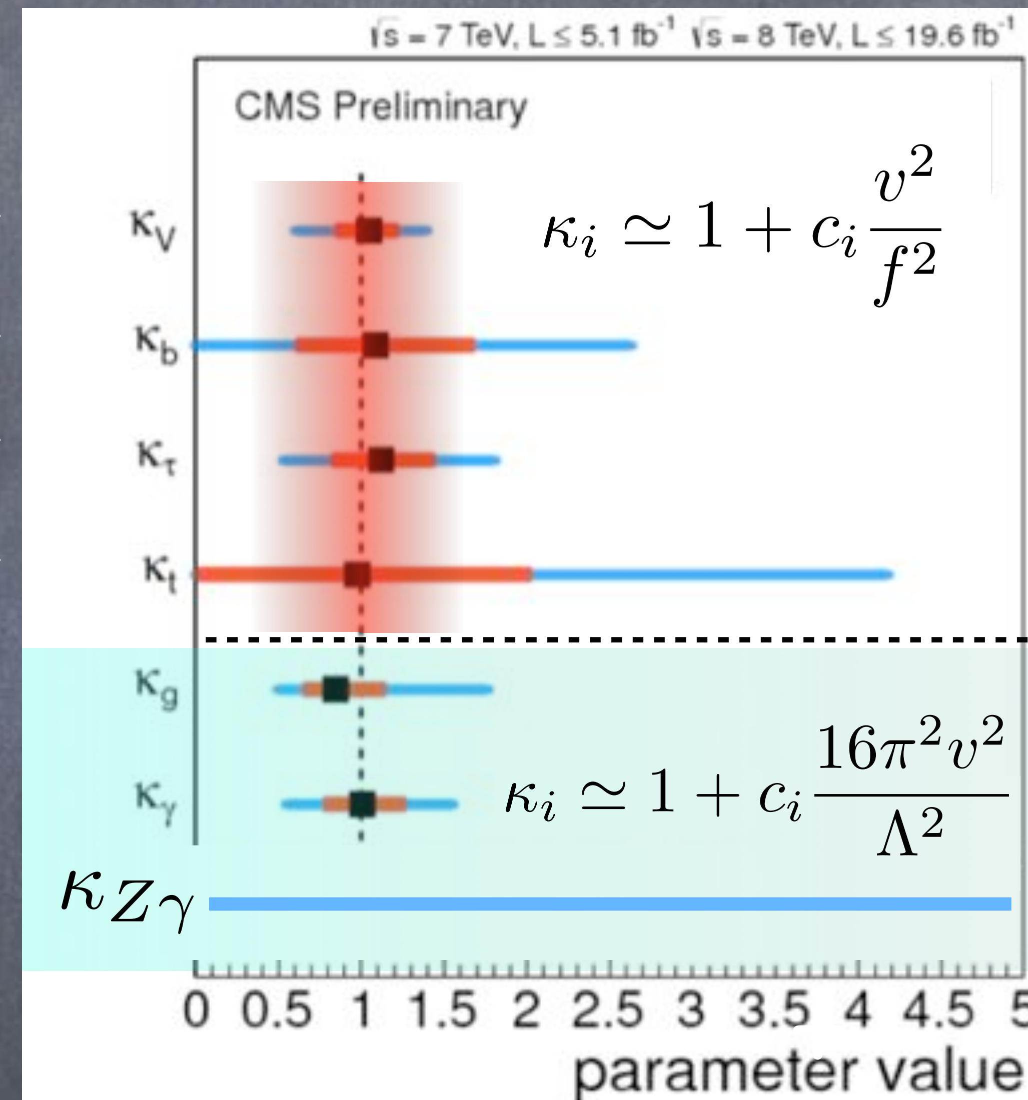
Elias-Miro, Espinosa, Masso, Pomarol13; Gupta, Pomarol, FR'14

Parameters for BSM: Higgs-only

Higgs Physics Only

$\langle h \rangle = v$

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



$$\kappa_i \simeq 1 + c_i \frac{v^2}{f^2}$$ ✗

$$\kappa_i \simeq 1 + c_i \frac{16\pi^2 v^2}{\Lambda^2}$$ ✓

Is the EFT expansion justified by these constraints?

$$c_{y_b} \frac{v^2}{f^2} \ll 1 \qquad c_{GG} \frac{m_h^2}{\Lambda^2} \ll 1$$

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

Parameters for BSM: Higgs+EW

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

Parameters for BSM: Higgs+EW

(see Adam's talk)

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

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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$\mathcal{O}^{(3)}_L = (iH^\dagger\sigma^a \overleftrightarrow{D}_\mu H)(\bar{L}_L\sigma^a\gamma^\mu L_L)$

7 of these operators modify:

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

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

Constrained by LEP1* $\sim$1/1000!

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

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

Parameters for BSM: Higgs+EW

(see Adam's talk)

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

7 of these operators modify:

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

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

Constrained by LEP1* ~1/1000!

EW and Higgs physics

$\mathcal{O}_{WB} = \frac{gg'}{4}(H^\dagger\sigma^a H)W^a_{\mu\nu}B^{\mu\nu}$
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$\mathcal{O}^{(3)}_L = (iH^\dagger\sigma^a \overleftrightarrow{D}_\mu H)(\bar{L}_L\sigma^a\gamma^\mu L_L)$

Impact of these operators in H-physics is irrelevant

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

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

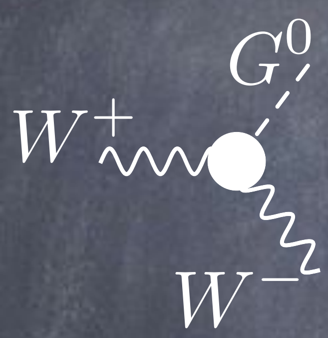
Parameters for BSM: Higgs+EW

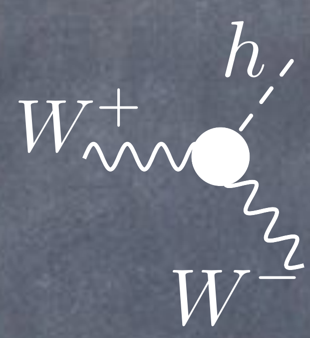
(see Adam's talk)

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

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

Hagiwara,Hikasa, Peccei,Zeppenfled'87





EW and Higgs physics

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

$$g\epsilon_{abc}W^{a\,\nu}_{\mu}W^{b}_{\nu\rho}W^{c\,\rho\mu}$$

Parameters for BSM: Higgs+EW
(see Adam's talk)

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

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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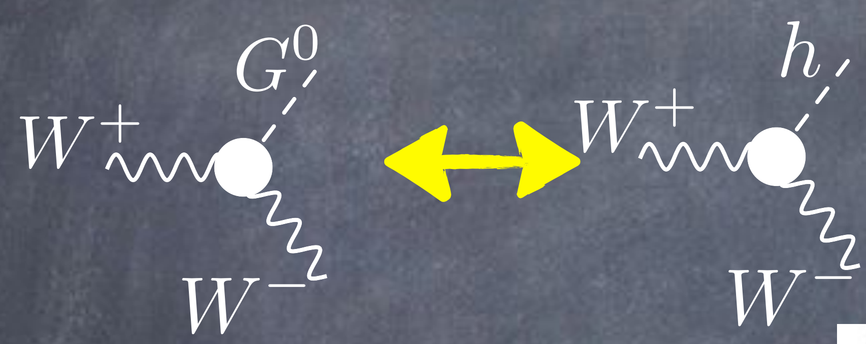
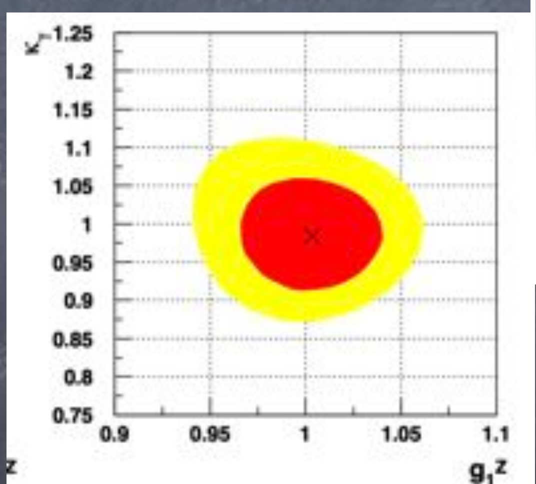
2 of these modify TGCs: $g^1_Z \quad \kappa_\gamma$

Hagiwara,Hikasa, Peccei,Zeppenfled'87



LEP2(ee->WW) constrained* ~5/100



➜ We can include these 2 combinations in H-physics studies (but recall connection with TGC!)

*= Non-Higgs operator $g\epsilon_{abc}W^{a\,\nu}_\mu W^b_{\nu\rho}W^{c\,\rho\mu}$ can interfere with extraction of bounds (see backup slides)

Falkowski,(Fichet,Mohan),FR,Sanz'14

Small Summary: Parameters

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

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

$$g^1_Z, \kappa_\gamma$$

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

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

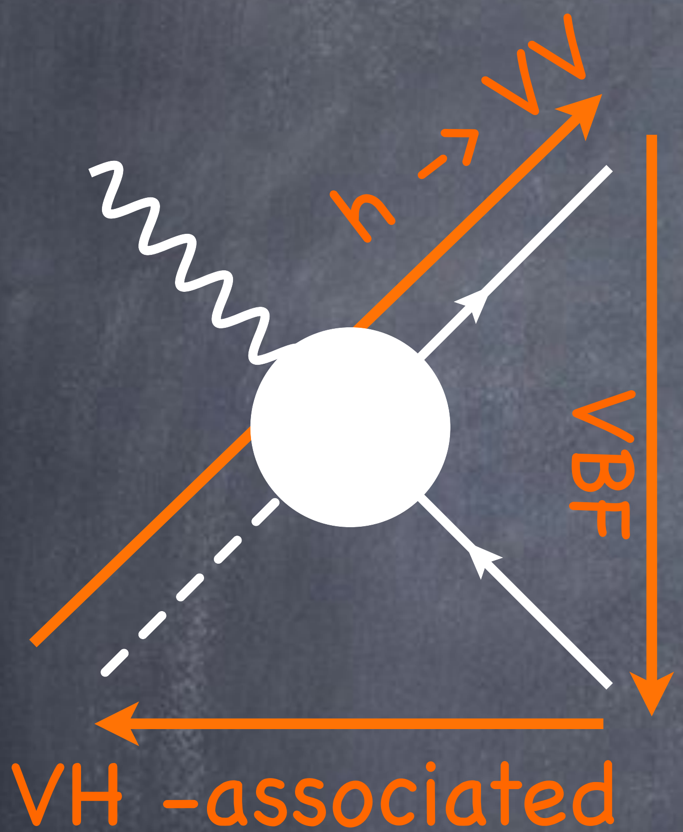
Gupta,Pomarol,FR'14

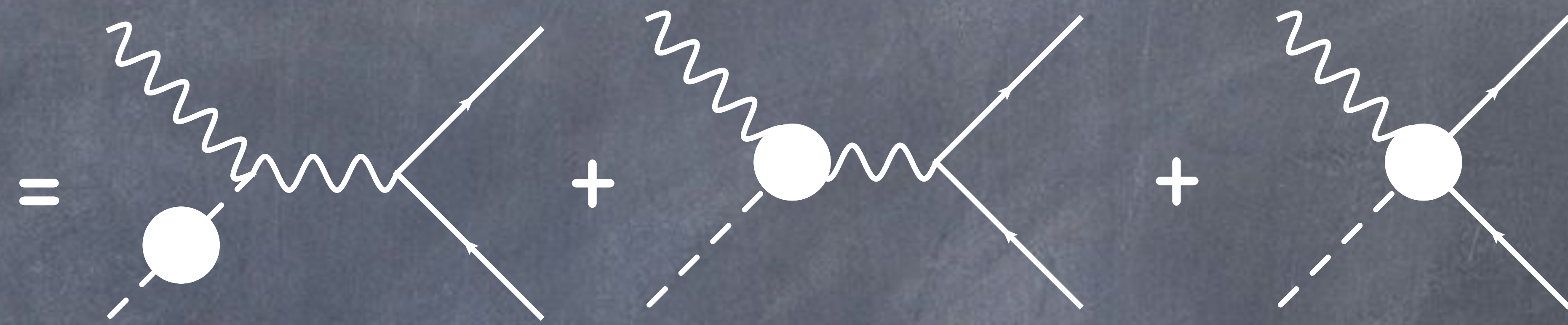
PART 2
Relations for Higgs physics at LHC Run2

Higgs-physics for Run2

Parametrization for off-shell Higgs physics as expansion in E, valid for linear/non-linear...

$$\mathcal{L}_h = \boldsymbol{\delta g^{h}_{VV}}\, v\, h V_\mu V^\mu + \boldsymbol{\kappa_{VV}} \frac{h}{v} V_{\mu\nu} V^{\mu\nu} + \boldsymbol{\delta g^{h}_{Vf}} \frac{h}{v} V_\mu \bar{f} \gamma^\mu f$$



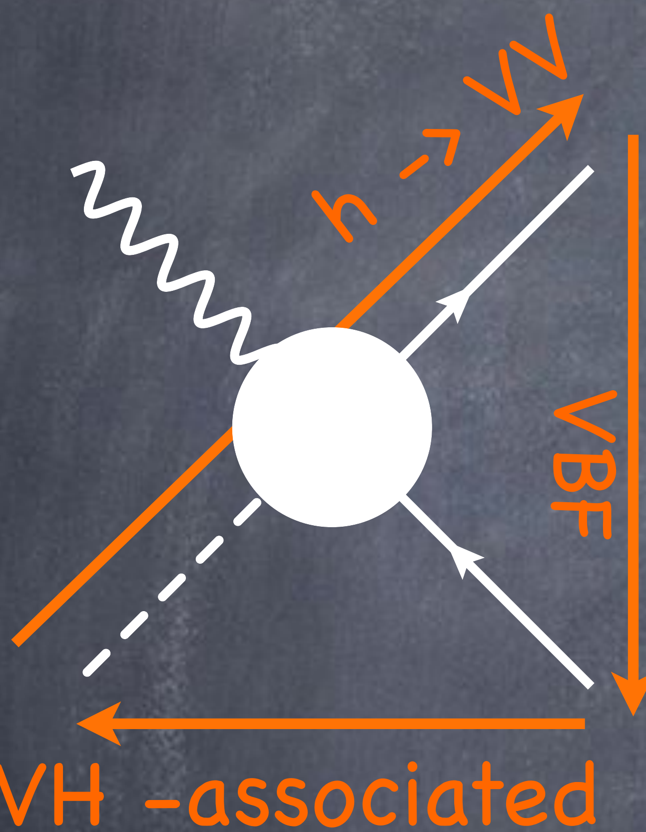


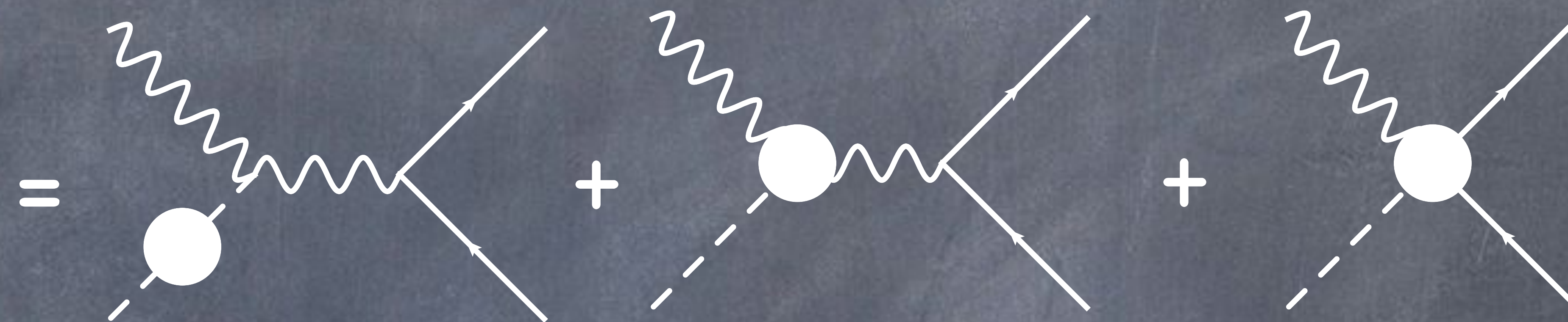
See Chen,Harnik,Vega-Morales'14 for contribution from hgammagamma

Higgs-physics for Run2

Parametrization for off-shell Higgs physics as expansion in E, valid for linear/non-linear...

$$\mathcal{L}_h = \boldsymbol{\delta g^h_{VV}}\, v\, h V_\mu V^\mu + \boldsymbol{\kappa_{VV}} \frac{h}{v} V_{\mu\nu} V^{\mu\nu} + \boldsymbol{\delta g^h_{Vf}} \frac{h}{v} V_\mu \bar{f} \gamma^\mu f$$





SM rescaling
(like Run1)

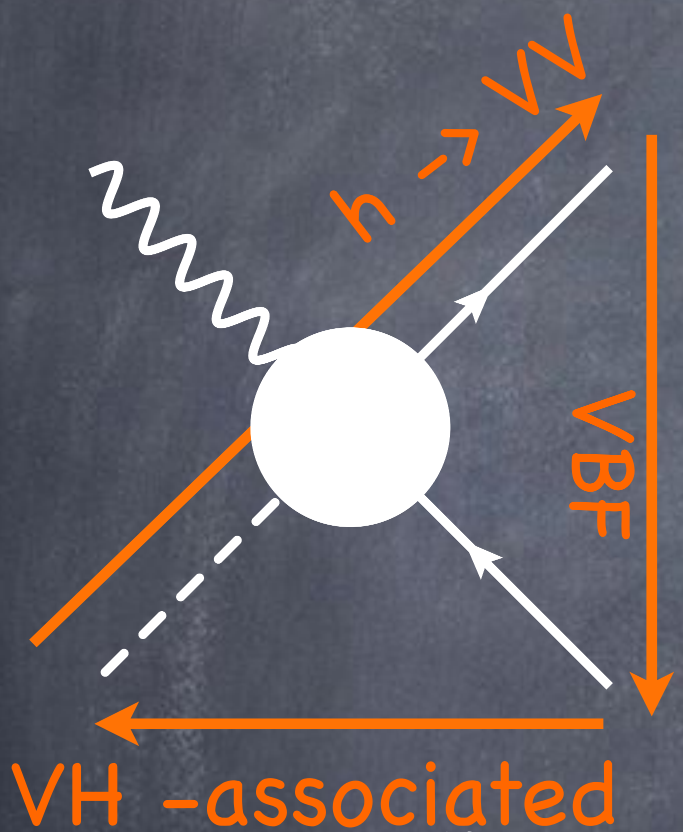
Grows with E
Generally not valid at E>M

Grows fast with E
(No V propagator)
Valid at E>M if large couplings
Can have flavour structure

See Chen,Harnik,Vega-Morales'14 for contribution from hgammagamma

Higgs-physics for Run2

Parametrization for off-shell Higgs physics:



$$\mathcal{L}_h = \boldsymbol{\delta g^h_{VV}}\, v\, h V_\mu V^\mu + \boldsymbol{\kappa_{VV}} \frac{h}{v} V_{\mu\nu} V^{\mu\nu} + \boldsymbol{\delta g^h_{Vf}} \frac{h}{v} V_\mu \bar{f} \gamma^\mu f$$

=

$\kappa_V, \kappa_b, \kappa_\tau, \kappa_t, \kappa_G, \kappa_{\gamma\gamma}, \kappa_{Z\gamma}, \kappa_{h^3}$ | g^1_Z, κ_γ

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

=

$$\frac{1}{v} \epsilon^{*\mu}(q)\, J^{V\,\nu}_f(p) \left[A^V_f\, \eta_{\mu\nu} + B^V_f\, (p \cdot q\, \eta_{\mu\nu} - p_\mu q_\nu) \right]$$

$$A^V_f = a^V_f + \widehat{a}^V_f \frac{m_V^2}{p^2 - m_V^2}$$

$$B^V_f = b^V_f \frac{1}{p^2 - m_V^2} + \widehat{b}^V_f \frac{1}{p^2}$$

LEP1 TGC

$$a^Z_f = 2\delta g^Z_f - 2\delta g^Z_1 (g^Z_f c_{2\theta_W} + eQ s_{2\theta_W}) + 2\delta\kappa_\gamma g' Y \frac{s_{\theta_W}}{c^2_{\theta_W}}$$

$$\widehat{a}^Z_f = 2 g^Z_f + \frac{g^Z_f v}{m_Z^2 c^2_{\theta_W}} \left(\delta g^h_{VV} + \delta g^Z_1 e^2 v - \delta\kappa_\gamma g'^2 v \right),$$

$$b^Z_f = 2 \frac{g^Z_f}{c^2_{\theta_W}} \left(-\delta\kappa_\gamma - \kappa_{Z\gamma} c_{2\theta_W} - 2\kappa_{\gamma\gamma} c^2_{\theta_W} \right),$$

$$\widehat{b}^Z_f = -2eQ_f t_{\theta_W} \kappa_{Z\gamma},$$

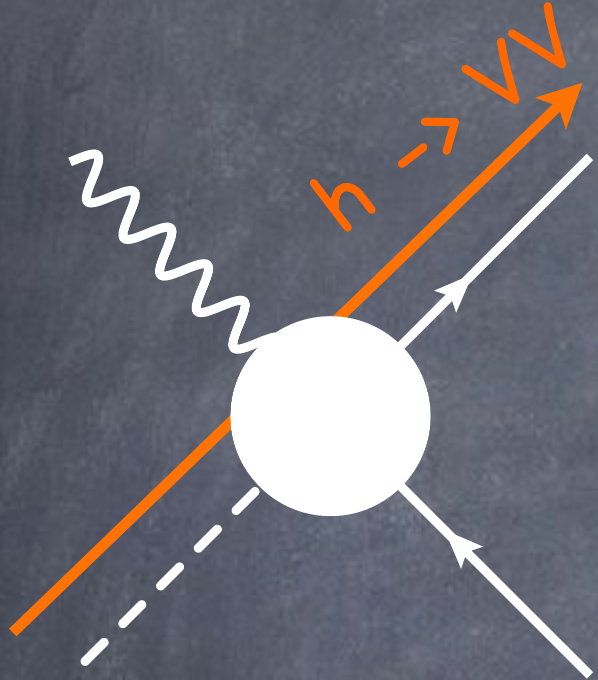
Other Higgs Processes

Pomarol,FR'13; Gupta et al. 'to Appear

BSM Relations for Run 2

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
Falkowski,Vega-Morales'14

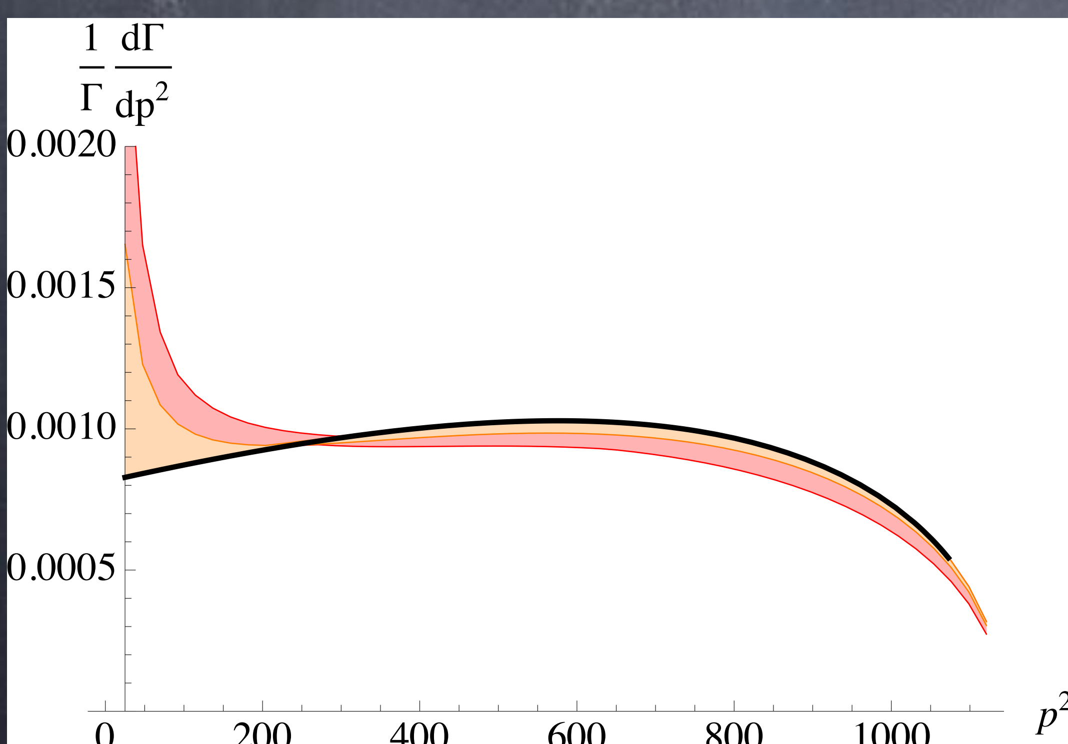


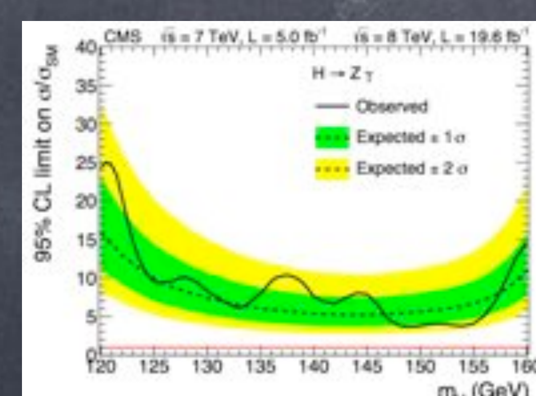
LEP 1

~~Related with Zff couplings~~

Related with Triple Gauge Coupling

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





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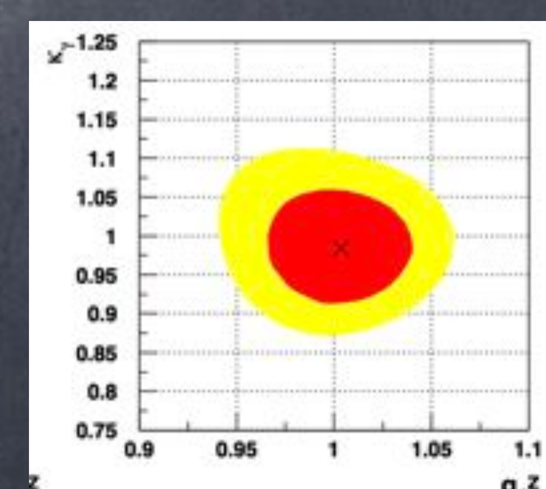

p^2>5 GeV

Pomarol,FR'13; Gupta et al' to Appear

BSM Relations for Run 2

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

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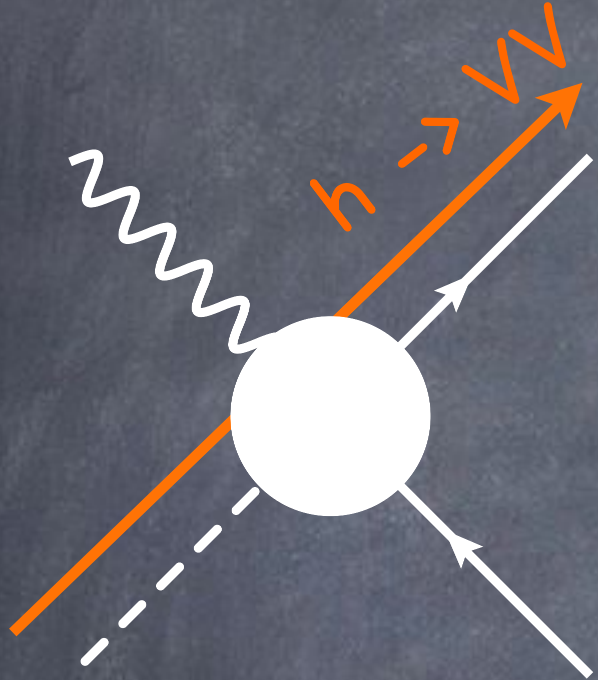

LEP 1

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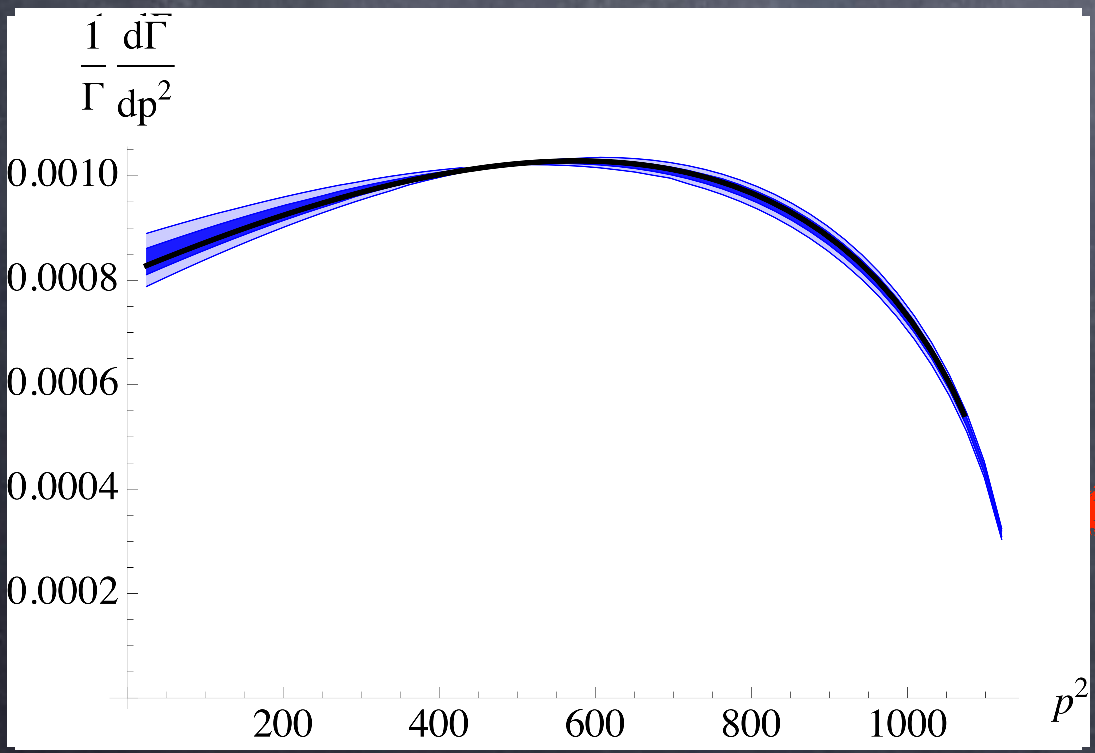

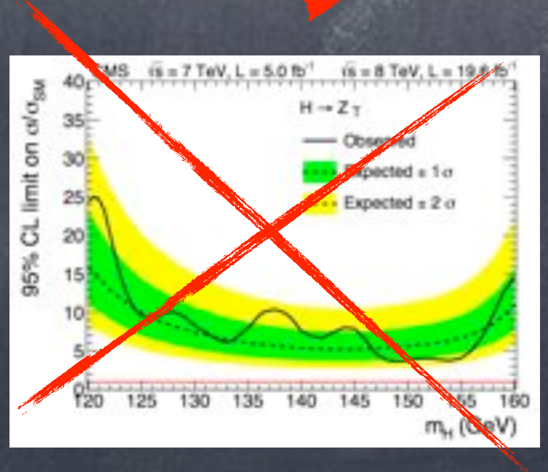

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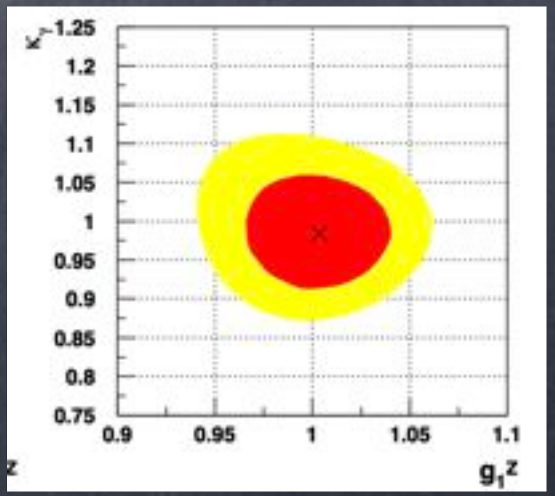

$p^2 > 5$ GeV

Pomarol,FR'13; Gupta et al' to Appear

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

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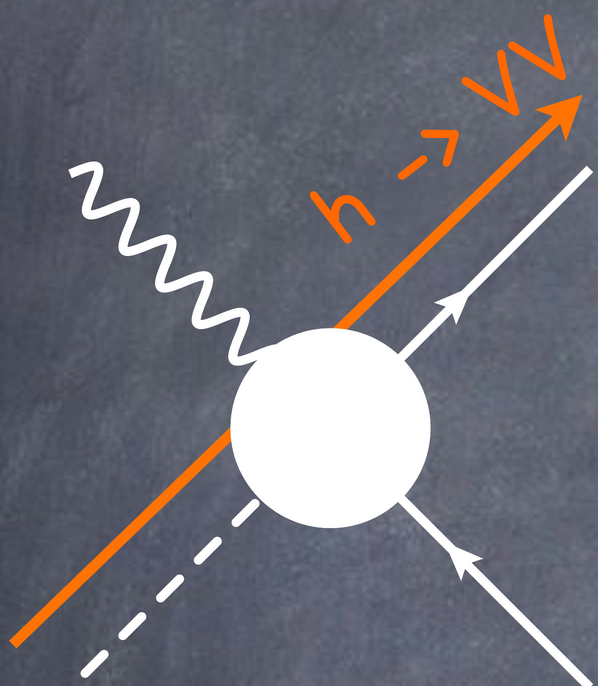


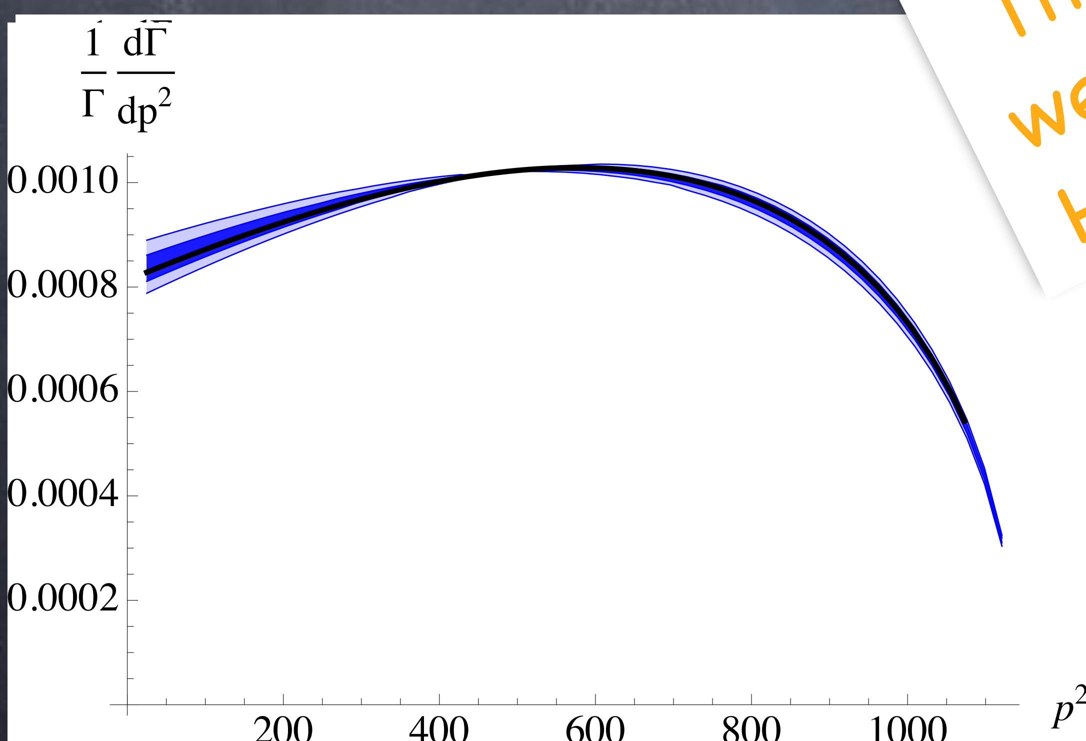
LEP 1

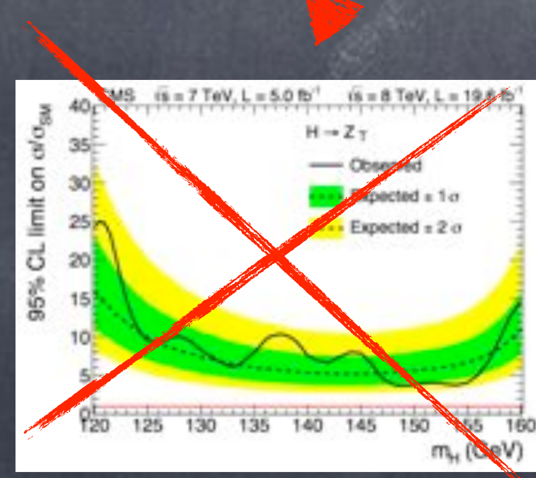
~~Related with Zff couplings~~

Related with Triple Gauge Coupling

Related wit ... γ

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





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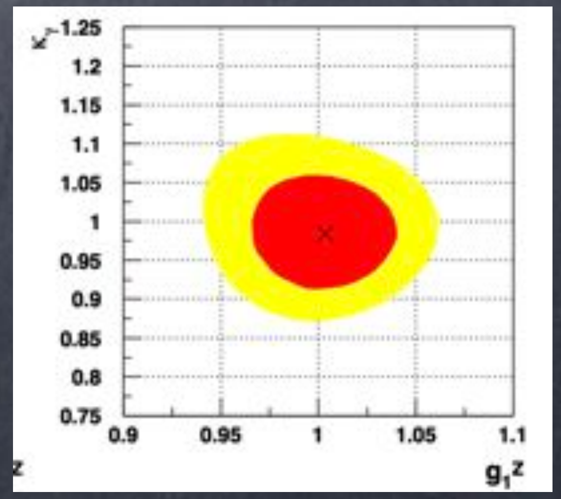


p^2>5 GeV

Pomarol,FR'13; Gupta et al' to Appear

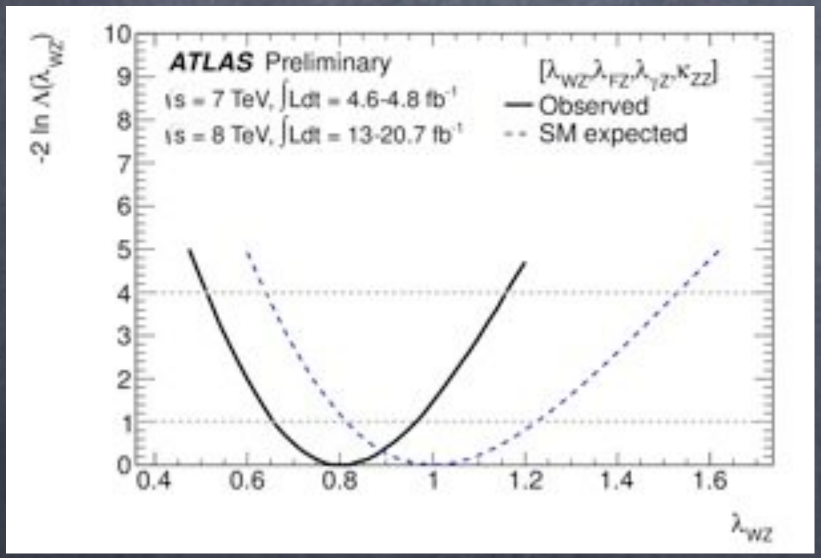
BSM Relations at Run 1

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!

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



Pomarol,FR'13

Pomarol,FR'13

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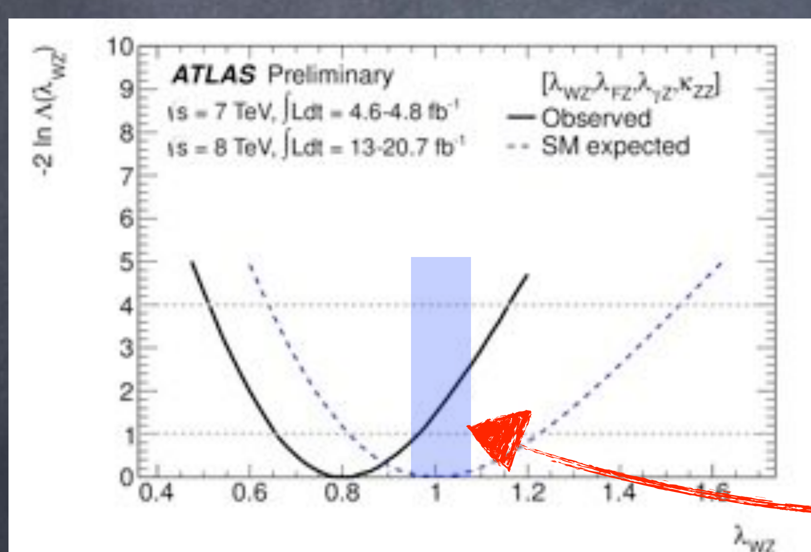
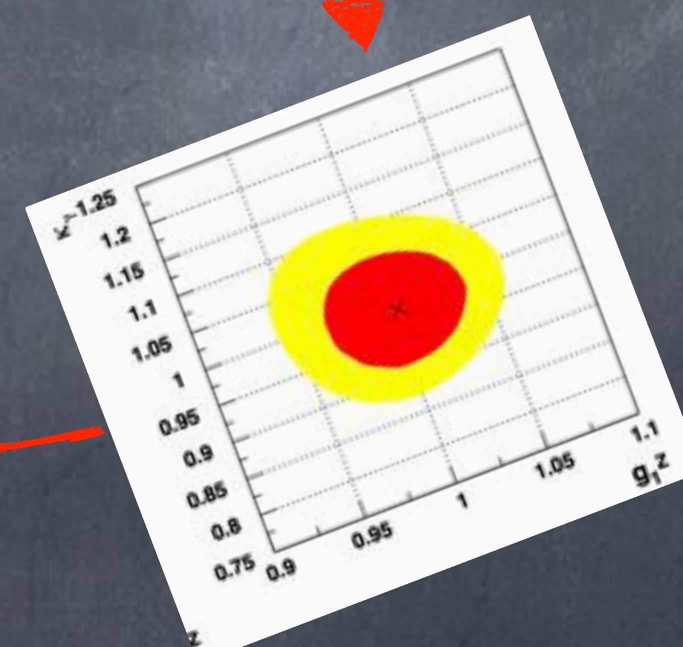


Pomarol,FR'13



Pomarol,FR'13

BSM Relations at Run 1

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!

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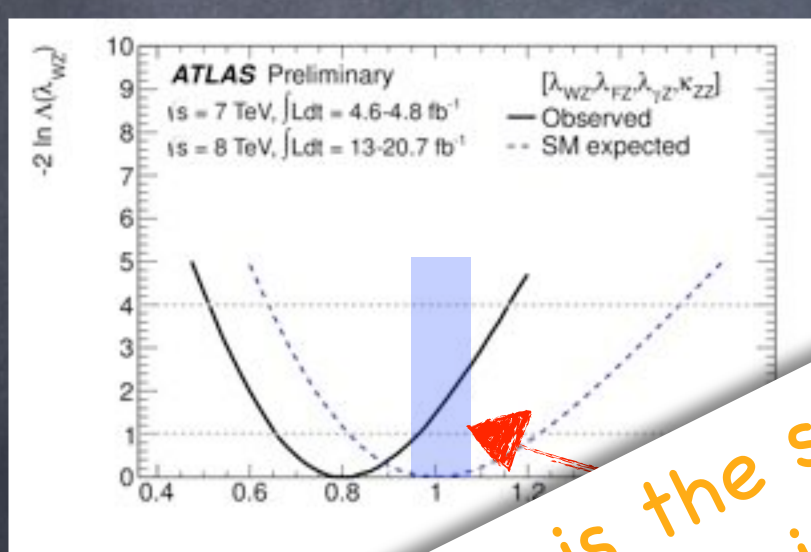
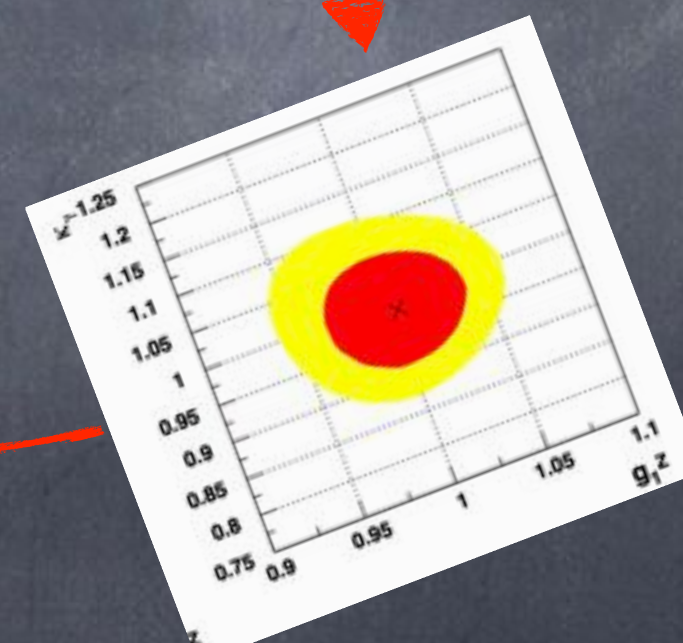
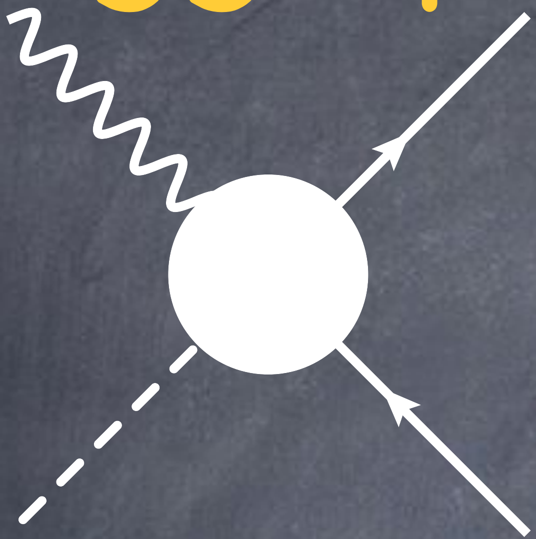




This is the sensitivity we are aiming to make H-physics competitive!

Pomarol,FR'13

Higgs physics at High Momentum?

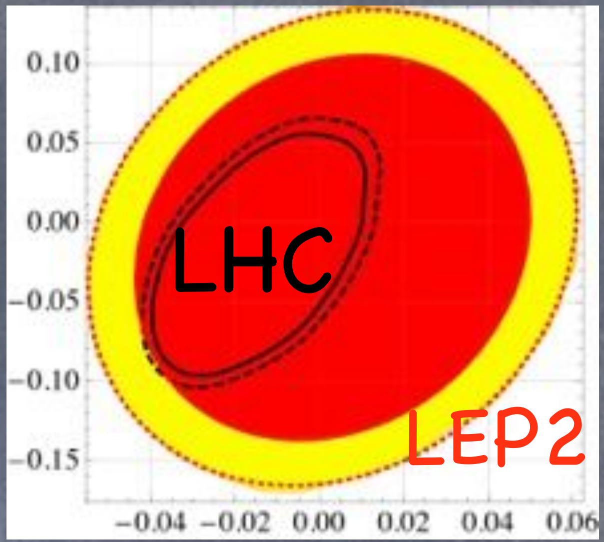


$$\mathcal{L}_h = \delta g^h_{VV} v\, h V_\mu V^\mu + \kappa_{VV} \frac{h}{v} V_{\mu\nu} V^{\mu\nu} + \delta g^h_{Vf} \frac{h}{v} V_\mu \bar{f} \gamma^\mu f$$

grow with Energy!

V*->VH associated

Higgs physics at LHC can compete with TGC at LEP

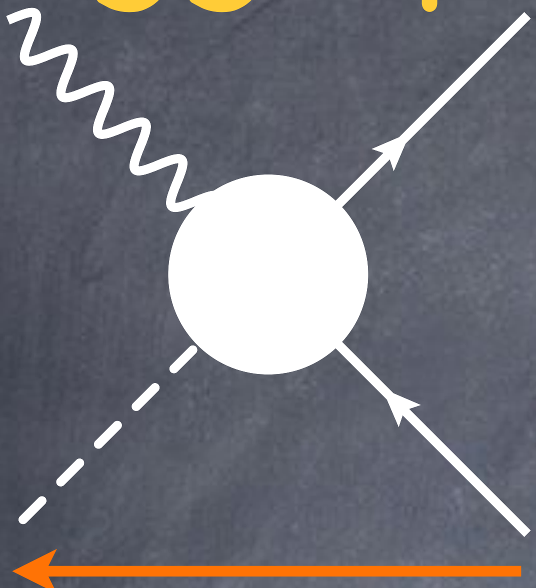


Isidori,Trott'13
Corbett,Eboli,
Gonzalez-Garcia,Fraile'12-13
Ellis,Sanz,You'14
Biekötter,Knochel,Krämer,Liu,FR '14
Beneke,Boito,Wang'14

$E \gg \Lambda^{exp}$

$\Lambda^{exp} \simeq 250\,\mathrm{GeV}$

Higgs physics at High Momentum?



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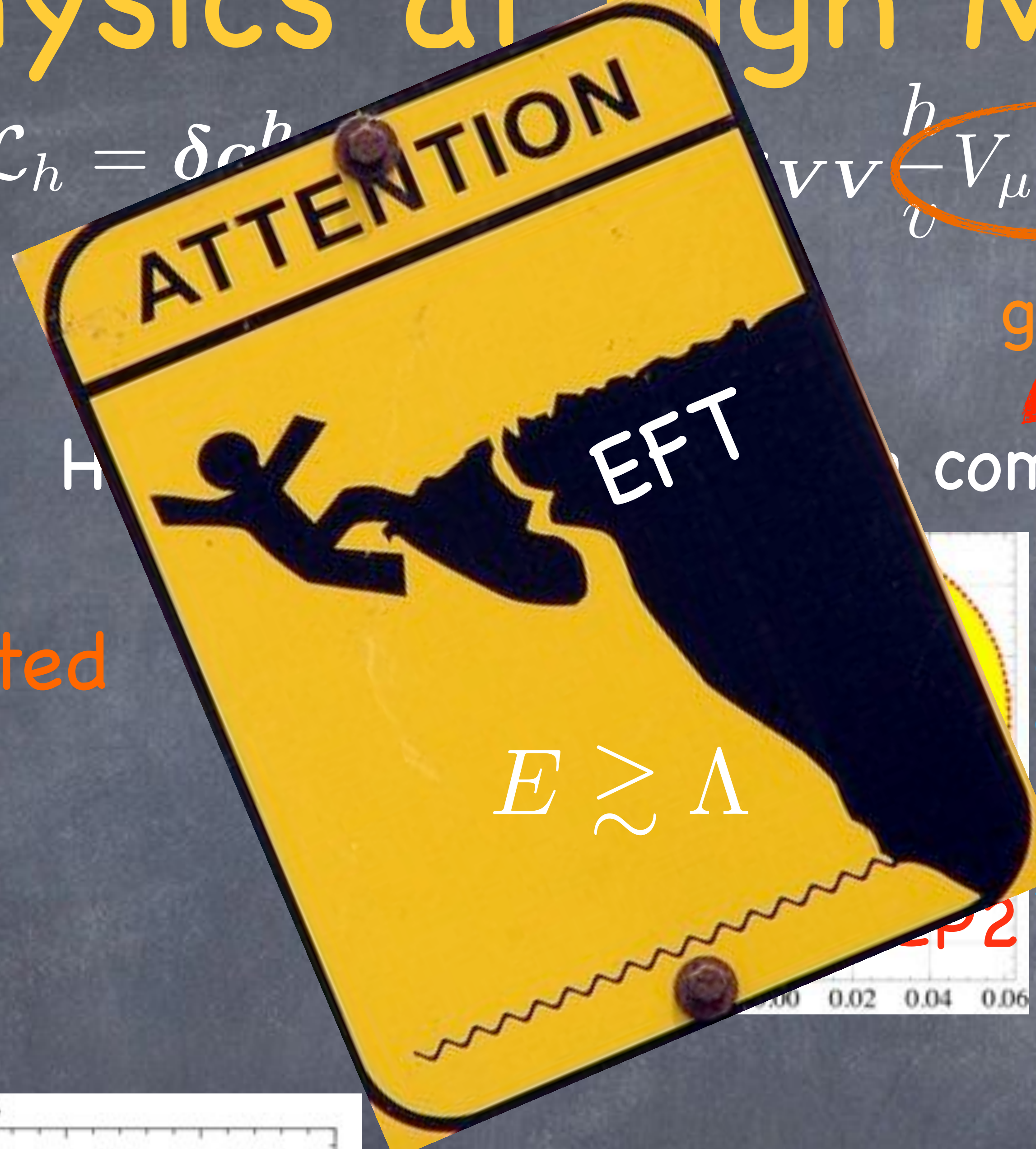
$$\mathcal{L}_h = \delta g^h \ldots VV \frac{h}{v} V_{\mu\nu} V^{\mu\nu} + \delta g^h_{Vf} \frac{h}{v} V_\mu \bar{f} \gamma^\mu f$$

grow with Energy!

H... compete with TGC at LEP



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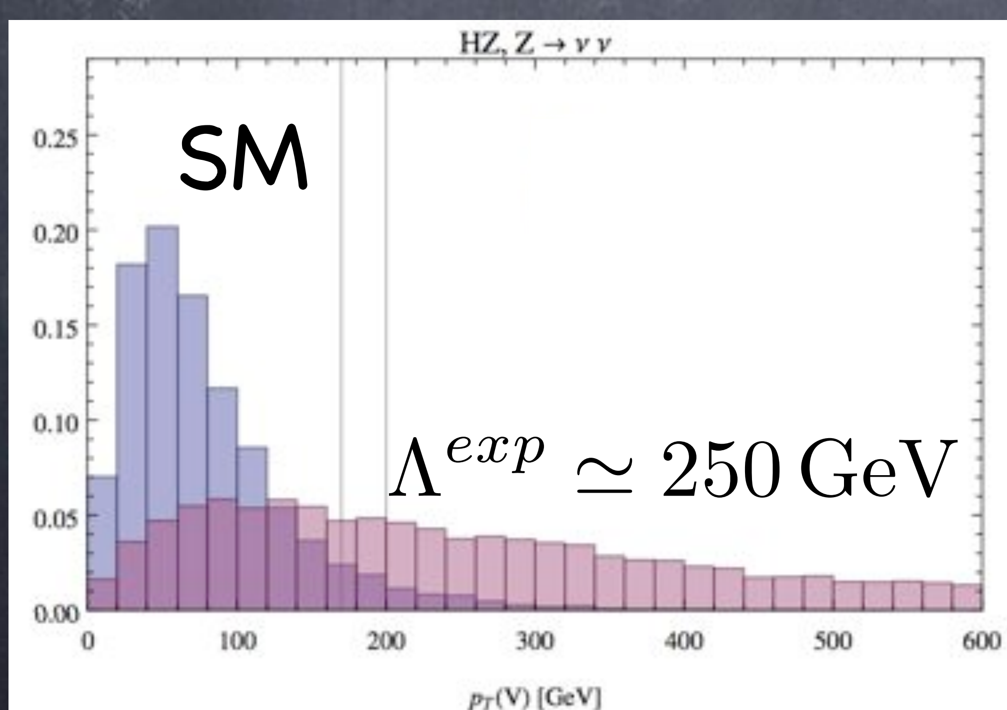
However:



Only operators that allow a (strong) coupling can be studied in regime

$$E \gg \Lambda^{exp}$$

Gupta,Pomarol,FR'14;
Biekötter,Knochel,Krämer,Liu,FR '14

Conclusions

- EFT: consistent framework to search for leading BSM effects

  Results must satisfy $E \ll \Lambda$ $v \ll f$

  (not always true, at present)

- Parametrization of BSM for Higgs physics:

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

2 $\{g_1^Z, \kappa_\gamma\}$

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

Conclusions

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→ Basis independent relations between EW and Higgs observables

→ These relation are the key to disentangle linear/non-linear Higgs

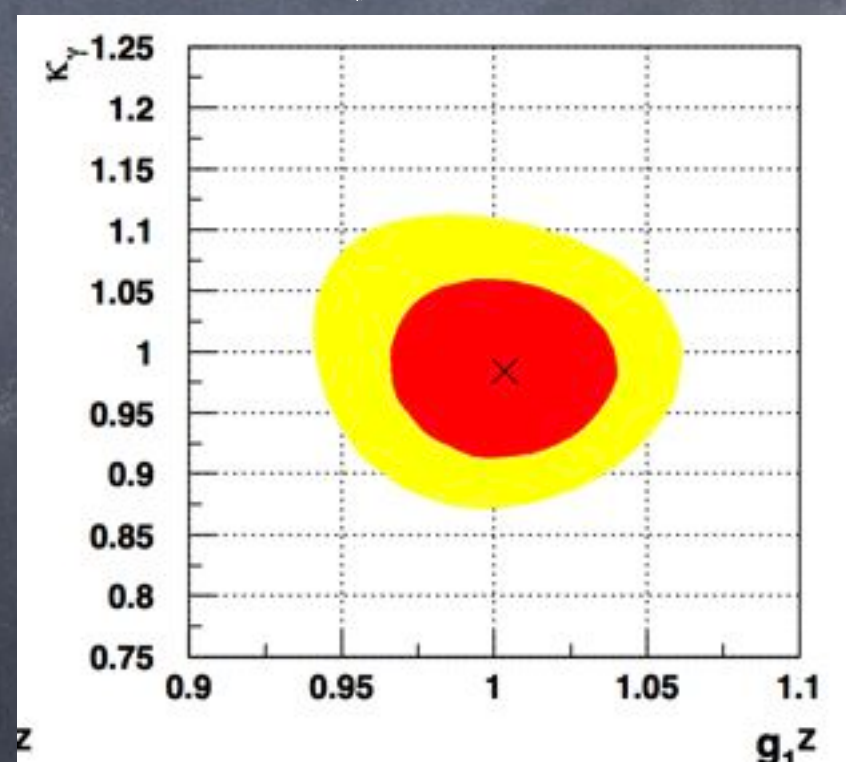
LEP2

2 Parameter fit

3 Parameter fit

Parameter	68% C.L.	95% C.L.	Correlations	
g_1^Z	$1.004^{+0.024}_{-0.025}$	[+0.954, + 1.050]	1.00	+0.11
κ_γ	$0.984^{+0.049}_{-0.049}$	[+0.894, + 1.084]	+0.11	1.00

LEP2 - Combined



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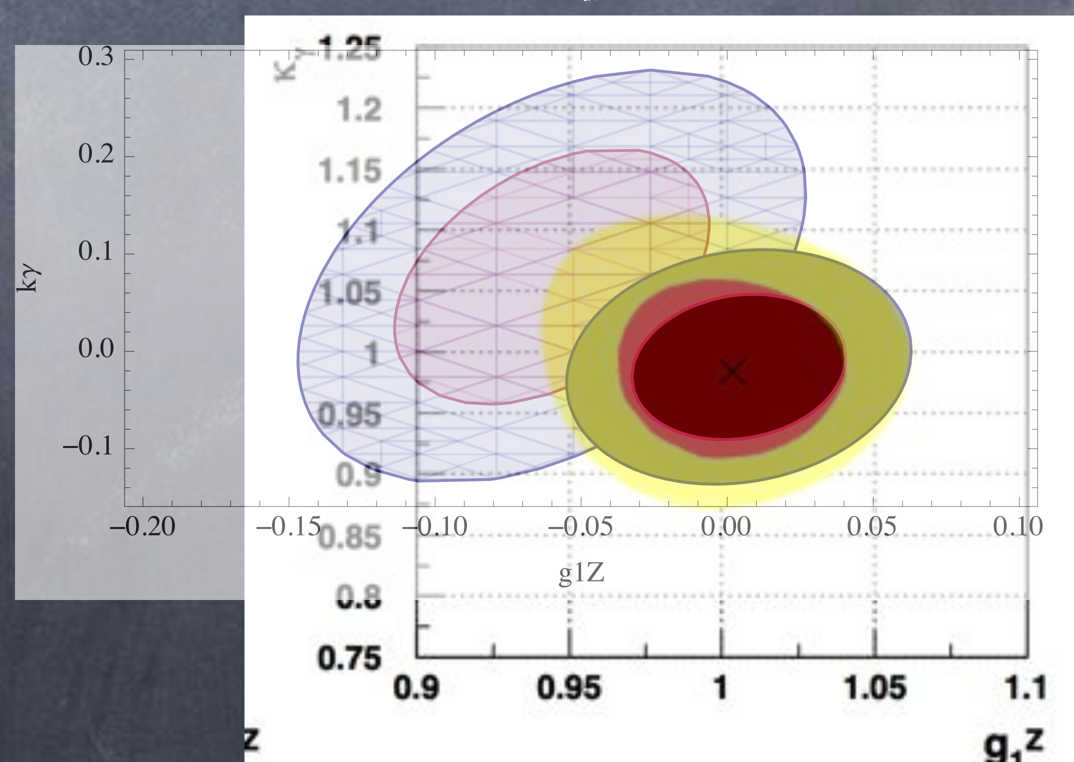
LEP2 - Combined

3 Parameter fit

Parameter	68% C.L.	95% C.L.	Correlations		
			Δg_1^Z	λ_γ	$\Delta\kappa_\gamma$
Δg_1^Z	$-0.060^{+0.031}_{-0.030}$	$[-0.118, \ +0.002]$	1.0	−0.55	−0.41
λ_γ	$0.038^{+0.031}_{-0.032}$	$[-0.027, \ +0.099]$	−0.55	1.0	−0.04
$\Delta\kappa_\gamma$	$0.077^{+0.070}_{-0.070}$	$[-0.050, \ +0.218]$	−0.41	−0.04	1.0

Delphi



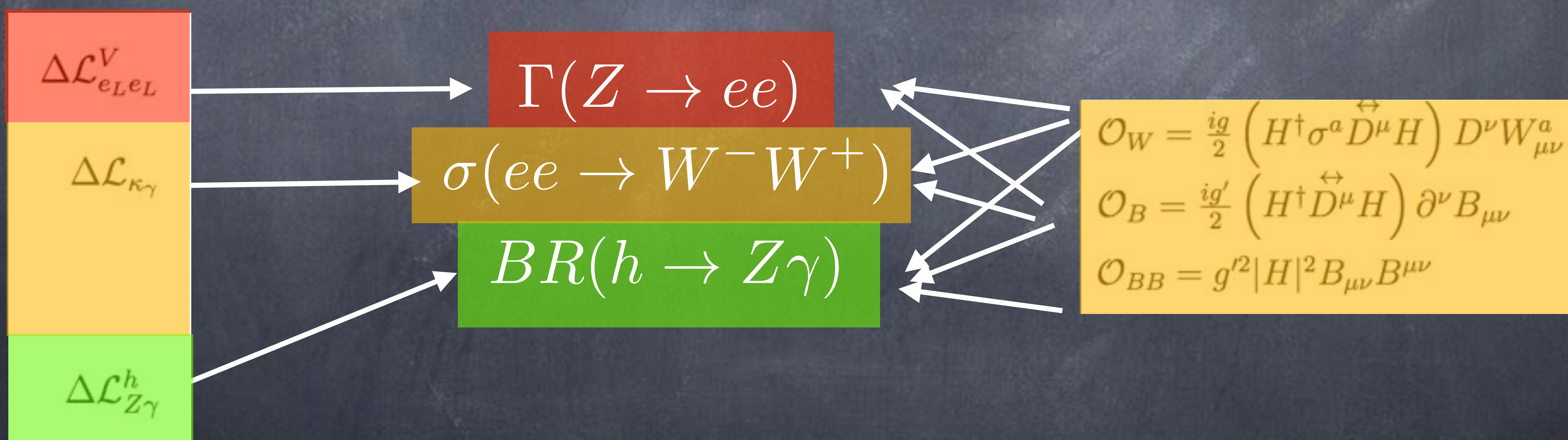
Parameters -> Relations

"BSM Primaries" Parametrization

- Mass eigenstate basis
- 1 to 1 with best experiments
- No theoretical correlation (orthogonal to other experiments)

Usual Operator Parametrization

- Gauge invariance manifest
- Physics unclear
- Large theo. correlations



Gupta,Pomarol,FR'14

Parameters -> Relations

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Usual Operator Parametrization

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Z and W couplings related also at dim-6 (and related to hVff from $h=\hat{h}+v$)

$$\Delta\mathcal{L}^{Z}_{e_L e_L} = \boldsymbol{\delta g^{Z}_{eL}}\frac{h^2}{v^2}\left[Z^{\mu}\bar{e}_L\gamma_\mu e_L - \frac{c_{\theta_W}}{\sqrt{2}}(W^{+\mu}\bar{\nu}_L\gamma_\mu e_L + \text{h.c.})\right]$$

$$\Delta\mathcal{L}_{\kappa_\gamma} = \frac{\boldsymbol{\delta\kappa_\gamma}}{v^2}\Big[ieh^2(A_{\mu\nu} - t_{\theta_W}Z_{\mu\nu})W^{+\mu}W^{-\nu} + Z_\nu\partial_\mu h^2(t_{\theta_W}A^{\mu\nu} - t^2_{\theta_W}Z^{\mu\nu}) + \frac{(h^2-v^2)}{2}\left(t_{\theta_W}Z_{\mu\nu}A^{\mu\nu} + \frac{c_{2\theta_W}}{2c^2_{\theta_W}}Z_{\mu\nu}Z^{\mu\nu} + W^{+}_{\mu\nu}W^{-\mu\nu}\right)\Big]$$

TGC related to h->WW,ZZ

$$\Delta\mathcal{L}^{h}_{Z\gamma} = \boldsymbol{\kappa_{Z\gamma}}\left(\frac{\hat{h}}{v} + \frac{\hat{h}^2}{2v^2}\right)\left[t_{\theta_W}A_{\mu\nu}Z^{\mu\nu} + \frac{c_{2\theta_W}}{2c^2_{\theta_W}}Z_{\mu\nu}Z^{\mu\nu} + W^{+}_{\mu\nu}W^{-\mu\nu}\right]$$

h->Zγ related to h->WW,ZZ

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