Composite resonance effects on the EW chiral lagrangian at NLO

PRELIMINARY

J.J. Sanz-Cillero (UAM/CSIC-IFT)

In collaboration with:
A.Pich, J.Santos, I.Rosell
[1501.07249]; forthcoming

PRL 110 (**2013**) 181801 [arXiv:1212.6769]
JHEP 01 (**2014**) 157 [arXiv:1310.3121]
[arXiv:1501.07249 [hep-ph]]

Claude Monet 82

OUTLINE

1) Compositeness, non-linearity, chiral low-E counting

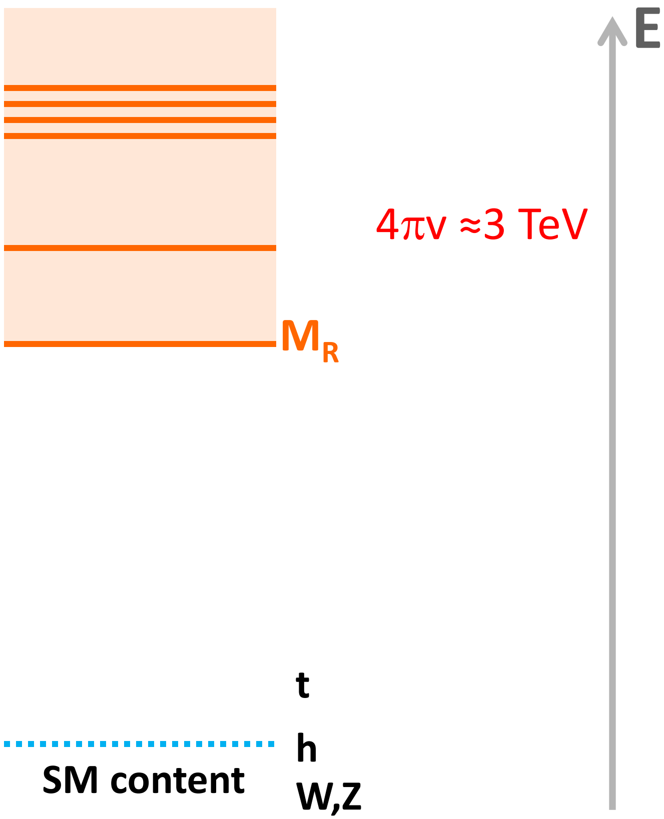
2) Custodial sym. & Resonances:

Contribution to the EFT @ NLO, i.e., $\mathcal{L}_{p4}$

3) Simple pheno:

Easy to avoid bounds with $M_R \sim 4\pi v \approx 3$ TeV

Composite theories:
the Resonance + EFT program



SM content

- **Bosons χ:**
  singlet h,
  EW Goldstones $U(\omega^a)$,
  bosones gauge
- **Fermion doublets ψ**

Custodial symmetry — $SU(2)_L \otimes SU(2)_R / SU(2)_{L+R}$

+

Resonance Lagrangian — V,A,S,P singlet & triplet

+

UV completion hypothesis — Sum-rules

↓

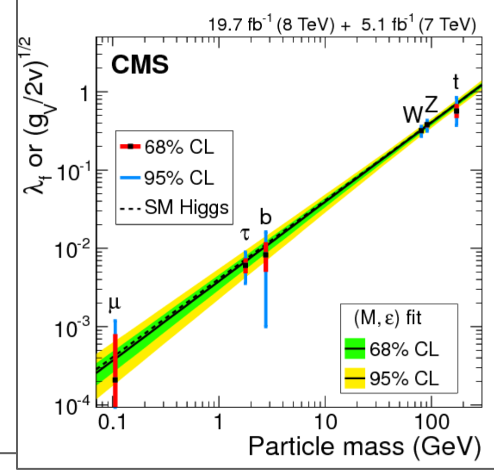
THIS WORK

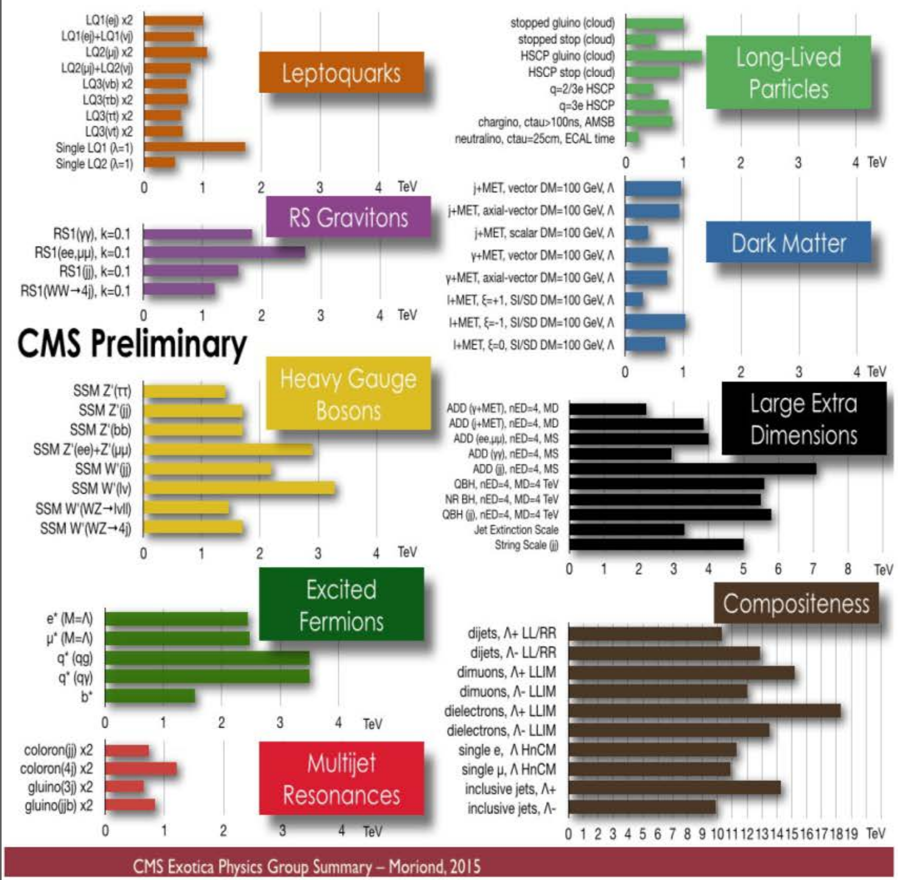
Resonance contributions to the NLO low-energy couplings → Tree-level / Loops

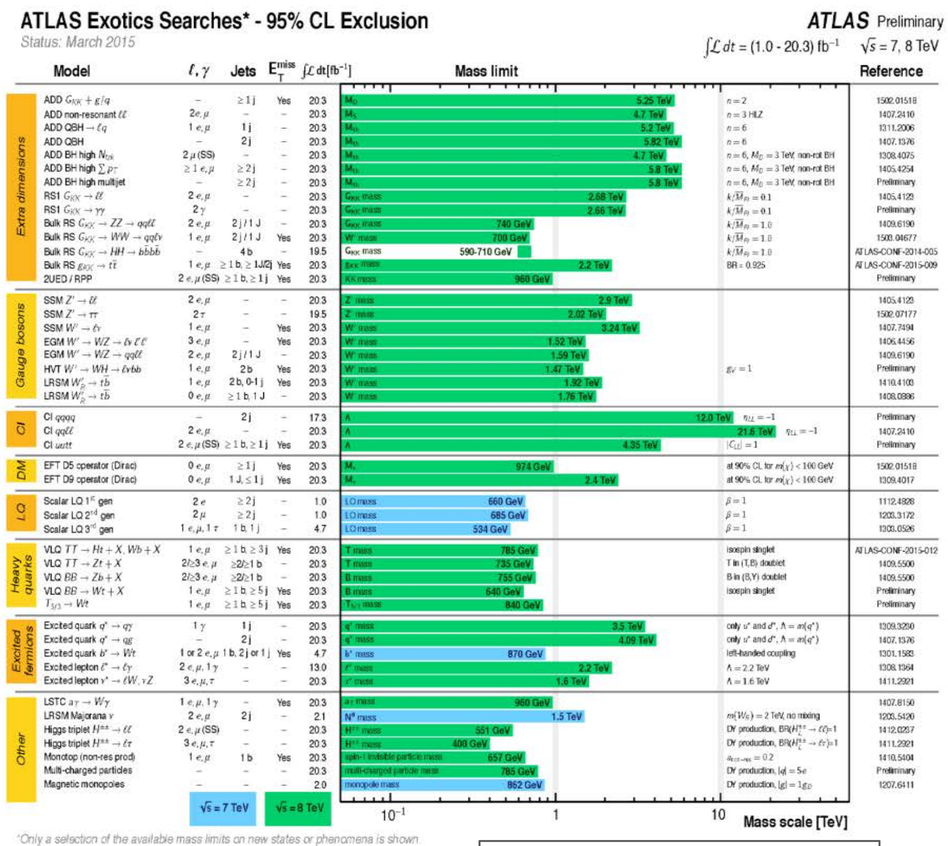
↓

Prediction for low-energy observables

Close to the SM







J. Alcaraz @ Blois 2015

What is the meaning of "close to the SM"?

- If Higgs (pseudo) Goldstone boson ➔ **Non-linearity for h + ω^a**

- **Chiral expansion** in non-linear EFT's: *

Finite pieces from loops (amplitude dependent) (+)

$$\mathcal{M}(2\to 2) \approx \frac{p^2}{v^2}\left[\, 1 \;+\; \left(\frac{c_k^r\, p^2}{v^2} \;-\; \frac{\Gamma_k\, p^2}{16\pi^2 v^2} \ln\frac{p}{\mu} \;+\; \dots \right) \;+\; \mathcal{O}(p^4) \right]$$

LO (tree) | **NLO (tree)** | **NLO (1-loop)**

Typical tree suppression $\sim 1/M_R^2$ (other states)

Typical loop suppression $\sim 1/(16\pi^2 v^2)$ (non-linearity)

THIS WORK

** Catà, EPJC74 (2014) 8, 2991
** Pich,Rosell,Santos,SC, [1501.07249]; 'forthcoming
** Pich,Rosell and SC, JHEP 1208 (2012) 106; PRL 110 (2013) 181801
(x) Contino,Salvarezza, [1504.02750]
(x) Contino,Marzocca,Pappadopulo,Rattazzi, JHEP 1110 (2011) 081

- Espriu,Yencho, PRD 87 (2013) 055017
- Espriu,Mescia, Yencho, PRD88 (2013) 055002
- Delgado,Dobado,Llanes-Estrada, JHEP1402 (2014) 121
- Delgado,Dobado,Herrero,SC,JHEP1407 (2014) 149
- Gavela,Kanshin,Machado,Saa, JHEP 1503 (2015) 043
- Guo,Ruiz-Femenia,SC, [1506.04204]
- Azatov, Contino,Di Iura,Galloway, PRD88 (2013) 7, 075019
- Azatov,Grojean,Paul,Salvioni, Zh.Eksp.Teor.Fiz. 147 (2015) 410, J.Exp.Theor.Phys. 120 (2015) 354

* Weinberg '79
* Manohar,Georgi, NPB234 (1984) 189
* Urech '95
* Georgi,Manohar NPB234 (1984) 189
* Buchalla,Catà,Krause '13
* Hirn,Stern '05
* Delgado,Dobado,Herrero,SC,JHEP1407 (2014) 149
* Pich,Rosell,Santos,SC, forthcoming

- Values of the NLO low-energy couplings?

- Resonances at $M_R \sim 4\pi v \approx 3$ TeV compatible with

  → LHC narrow resonance searches $M_R \gtrsim 1\text{–}2\ \mathrm{TeV}$ ✓

  → Strong limits on low-energy EFT operators $\Lambda_{\mathrm{eff}} \gtrsim 10\ \mathrm{TeV}$ (???)

Meaning?

→ Suppression of the EFT couplings ?

→ Suppression of the EFT operators ✓

Chiral expansion

(non-linear EFT)

Relaxed bounds $M_R \gtrsim 1\ \mathrm{TeV}$

'CHIRAL' COUNTING

- Assignment of the 'chiral' dimension: *

$$\mathcal{L}_{p^{\hat{d}}} \sim a_{(\hat{d})}\, p^{\hat{d}-N_F/2} \left(\frac{\overline{\psi}\psi}{v^2}\right)^{N_F/2} \sum_j \left(\frac{\chi}{v}\right)^j$$

with the low-energy scaling $\frac{\chi}{v} \sim \mathcal{O}(p^0)\,, \qquad \frac{\psi}{v} \sim \mathcal{O}\left(p^{\frac{1}{2}}\right)\,, \qquad \partial_\mu,\, m_\chi,\, m_\psi \sim \mathcal{O}(p)$

- **Low-energy EFT (ECLh) *** ➔ Classification of the operators according to `chiral' dimension:

$$\mathcal{L}_{ECLh} = \mathcal{L}_{p^2} + \mathcal{L}_{p^4} + \ldots$$

$\supset \mathcal{L}^{\mathrm{SM}}$

- **High-energy theory for Resonances + χ + ψ**

➔ General $\Delta\mathcal{L}_R$ `of O(p²)' **

$$\Delta\mathcal{L}_{\mathbf{R}} = \mathbf{F_R}\, \mathbf{R}\, \mathcal{O}_{\mathbf{p^2}}[\chi,\psi] + \ldots$$

* Weinberg, 79; Manohar,Georgi, NPB234 (1984) 189
* Gasser,Leutwyler '84 '85
* Hirn,Stern '05
* Buchalla,Catà,Krause '13
* Delgado,Dobado,Herrero,SC,JHEP1407 (2014) 149
* Henning,Lu,Murayama, [1412.1837]
* Pich,Rosell,Santos,SC, [1501.07249]; forthcoming

* Apelquist,Bernard '80
* Longhitano '80, '81
* Alonso,Gavela,Merlo,Rigolin,Yepes '12
* Brivio,Corbett,Eboli,Gavela,Gonzalez–Fraile,Gonzalez–Garcia,Merlo,Rigolin '13

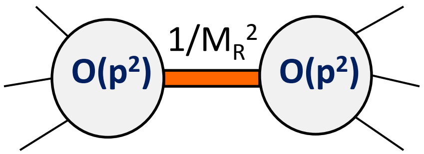
** Ecker et al. '89
** Cirigliano et al., NPB753 (2006) 139
** Pich,Rosell,Santos,SC, [1501.07249]; forthcoming

Res. contributions to the O(p^4) EFT couplings

1.) Only R operators O(p^2) : ** singlets V_1, A_1, S_1, P_1 + triplets V, A, S, P + ...

*[antisymetric-tensor formalism $R_{\mu\nu}$ for spin-1 Resonances **]*

2.) Tree-level contribution to the O(p^4) ECLh for p<<M_R:



$$e^{i\,S[\chi,\psi]_{\rm EFT}} = \int [dR]\, e^{i\,S[\chi,\psi,R]} \overset{\rm tree-level}{=} e^{i\,S[\chi,\psi,R_{\rm cl.}]}$$

$$\Delta\mathcal{L}_{p^4}^{\rm EFT} = \frac{1}{2M_R^2}\left(\langle\, \mathcal{O}_R\, \mathcal{O}_R\,\rangle - \frac{1}{N}\langle\, \mathcal{O}_R\,\rangle^2\right) \qquad (R=S,\,P)\,,$$

$$\Delta\mathcal{L}_{p^4}^{\rm EFT} = -\frac{1}{M_R^2}\left(\langle\, \mathcal{O}_R^{\mu\nu}\, \mathcal{O}_{R\,\mu\nu}\,\rangle - \frac{1}{N}\langle\, \mathcal{O}_R^{\mu\nu}\,\rangle^2\right) \qquad (R=V,\,A)\,,$$

$$\Delta\mathcal{L}_{p^4}^{\rm EFT} = \frac{1}{2M_{R_1}^2}\,(\mathcal{O}_{R_1})^2 \qquad (R_1=S_1,\,P_1)\,,$$

$$\Delta\mathcal{L}_{p^4}^{\rm EFT} = -\frac{1}{M_{R_1}^2}\,(\mathcal{O}_{R_1}^{\mu\nu}\, \mathcal{O}_{R_1\,\mu\nu}) \qquad (R_1=V_1,\,A_1)\,.$$

** Ecker et al. '89
** Cirigliano et al., NPB753 (2006) 139
** Pich,Rosell,Santos,SC, [1501.07249]; forthcoming

- Triplet V contribution in C & P-even strongly couple theories (full R Lagrangian in *)

$$\mathcal{L}_V = Tr\{V_{\mu\nu} \underbrace{\left(\frac{F_V}{2\sqrt{2}} f_+^{\mu\nu} + \frac{iG_V}{2\sqrt{2}}[u^\mu, u^\nu] + c_1^V \nabla^\mu J_V^\nu / v^2 + \ldots\right)}_{\mathcal{O}_V^{\mu\nu}}\}$$

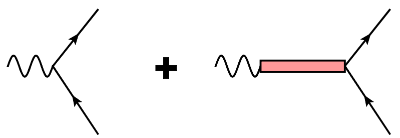
- Contribution from V,

to the EFT @ NLO: $$\mathcal{L}_{p^4}^{\text{from V}} = -i\frac{F_V G_V}{4M_V^2} Tr\{f_+^{\mu\nu}[u^\mu, u^\nu]\} - \frac{F_V c_1^V}{\sqrt{2}M_V^2} Tr\{f_+^{\mu\nu}\nabla_\mu J_{V\,\nu}/v^2\} + \ldots$$

$\frac{F_V G_V}{4M_V^2} \to$ i $(a_2 - a_3)/2$

$\frac{F_V c_1^V}{\sqrt{2}M_V^2} \to c^{\psi^2 h^0}_{10}$

- Impose UV constraints on $\mathcal{L}_R$, predict in the EFT: *, **



$$\mathcal{F}^v_{\omega\omega}(q^2) = 1 + \frac{F_V G_V}{v^2}\frac{q^2}{M_V^2 - q^2}$$

$$\mathcal{F}^v_{\psi\overline{\psi}}(q^2) = 1 - \frac{\sqrt{2}F_V c_1^V}{v^2}\frac{q^2}{M_V^2 - q^2}$$

$\xrightarrow{q^2 \to \infty} 0$

$\Rightarrow$

$(a_2 - a_3) = -v^2/(2M_V^2)$

$c^{\psi^2 h^0}_{10} = v^2/(2M_V^2)$

** Peskin,Takeuchi, PRL65 (1990) 96; PRD46 (1992) 381
** Orgogozo,Rychkov, JHEP1203 (2012) 046; 1306 (2013) 014
** Pich,Rosell, SC, PRL110 (2013) 181801; JHEP01 (2014) 157

* Pich,Rosell,Santos,SC, [1501.07249]; forthcoming

- Contributions to $Z \to \psi\overline{\psi} \quad (\text{with } \psi = t, b)$

- Ruled by the previous couplings

$$|\delta \mathbf{g}^{\mathbf{Z}\psi}| \stackrel{\text{EFT}}{=} \frac{\cos(2\theta)\, c_{10}^{\psi^2 h^0}\, m_Z^2}{v^2}$$

$$\stackrel{\text{from V}}{=} -\cos(2\theta)\, \frac{\mathbf{F_V c_1^V}}{\sqrt{2}v^2}\, \frac{m_Z^2}{\mathbf{M_V^2}}$$

$$\stackrel{\text{UV-complet.}}{=} \frac{\cos(2\theta)\, m_Z^2}{2\mathbf{M_V^2}}$$

- How strong are the bounds? Not difficult to make them* small enough**

$$\mathbf{M_V} \gtrsim \mathbf{1.5}\ \text{TeV} \longrightarrow |\delta \mathbf{g}^{\mathbf{Z}\psi}| \lesssim \mathbf{10^{-3}}$$

* Pich,Rosell,Santos,SC, fothcoming
** Agashe,Contino,Da Rold,Pomarol, PLB641 (2006) 62
** Efrati ,Falkowski,Soreq, [1503.07872]
** LEP [0511027]

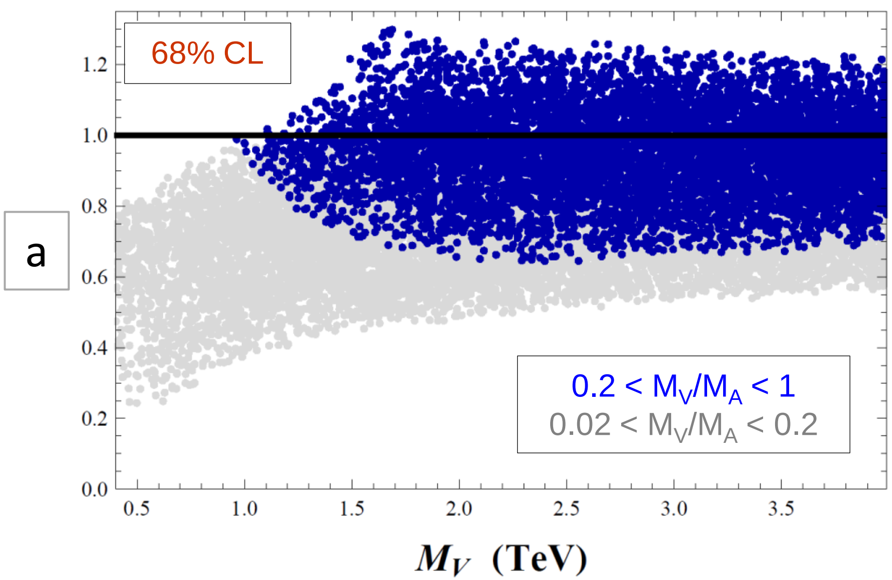
(S , T) oblique parameters:
ONE-LOOP results + UV-constraint

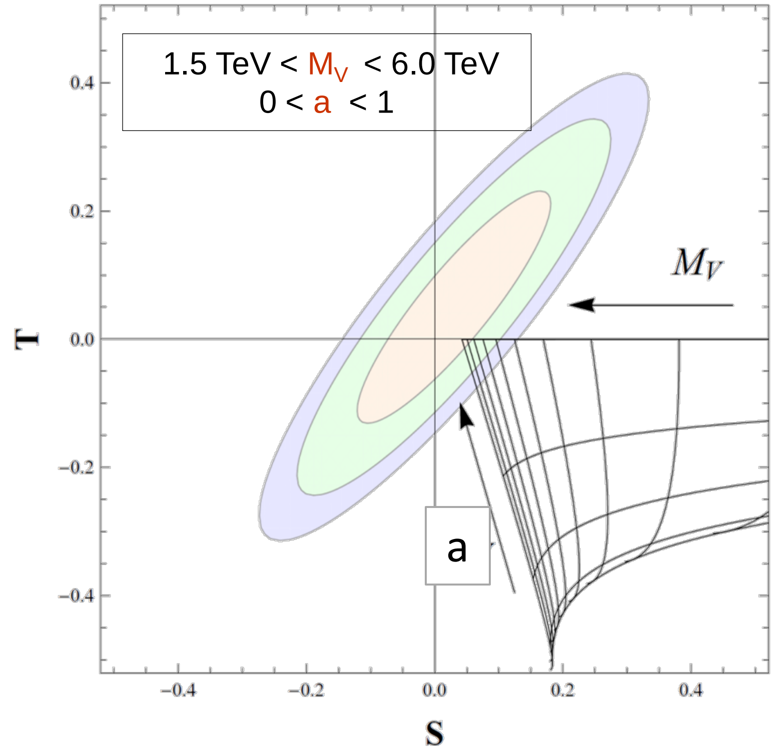
C & P-even

ii) NLO results: 1st and 2nd WSRs*

$1 > a > 0.94$
$M_A \approx M_V > 4$ TeV
(95%CL)

iii) NLO results: 1st WSR and $M_V < M_A$*





Similar conclusions, but softened

For M_V<M_A:

✓ M_A > 1 TeV at 68% CL.

* Pich,Rosell, SC, PRL 110 (2013) 181801; JHEP 01 (2014) 157

Conclusions

- **Chiral power counting** in the low-energy non-linear EFT (ECLh)

- Build **custodial-**invariant Lagrangian w/ light dof $\chi + \psi + R$

- **Low-energy matching:** Res. contributions to the EFT @ $O(p^4)$

- **UV-completion assumptions:** further constraints on the predictions

✓ **Tree-level predictions of the $O(p^4)$ low-energy couplings**

✓ **Natural suppression in low-energy observables for $M_R \sim 4\pi v \approx 3$ TeV**

- **$Z \to bb$: Ok for $M_V > 1.5$ TeV**
- **S & T param: Ok for $a \approx 1$ $M_V > 4$ TeV (1 TeV) for 1st+2nd WSR (only 1st WSR)**