ONE LOOP ELECTROWEAK CONSTRAINTS IN COMPOSITE HIGGS MODELS

R. Contino, M. Salvarezza, arXiv:1504.02750 [hep-ph]

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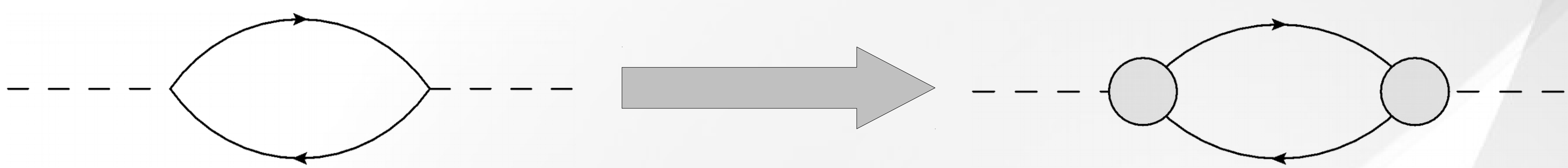
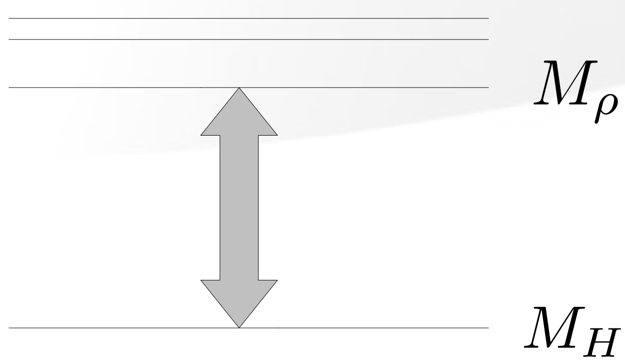
27th Rencontres de Blois
Particle Physics and Cosmology
03/06/2015

STRONG EWSB: COMPOSITE HIGGS MODELS

- A heavy (~TeV) strong sector triggers the EWSB: the Higgs Boson is **composite**



- **Problem**: big mass gap between the Higgs and the other resonances!



$$M_H = 126\, GeV$$

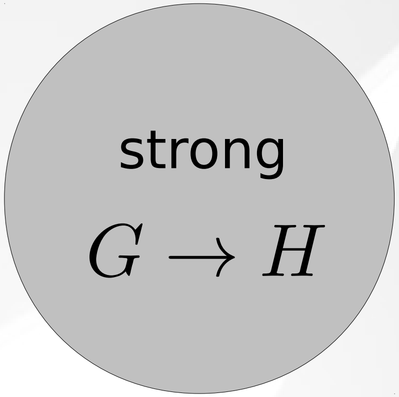
$$M_\rho \gtrsim TeV$$

STRONG EWSB: COMPOSITE HIGGS MODELS

- Learn from QCD: the Higgs as a **pseudo Nambu-Goldstone Boson** accounts naturally for such a picture

[Georgi, Kaplan, 1984]

- General recipe:
  - EFT for NGB Higgs: spontaneous symmetry breaking G → H at a scale f > v



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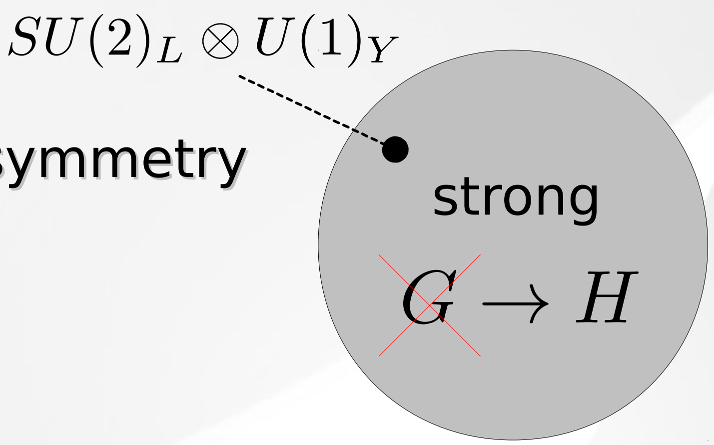

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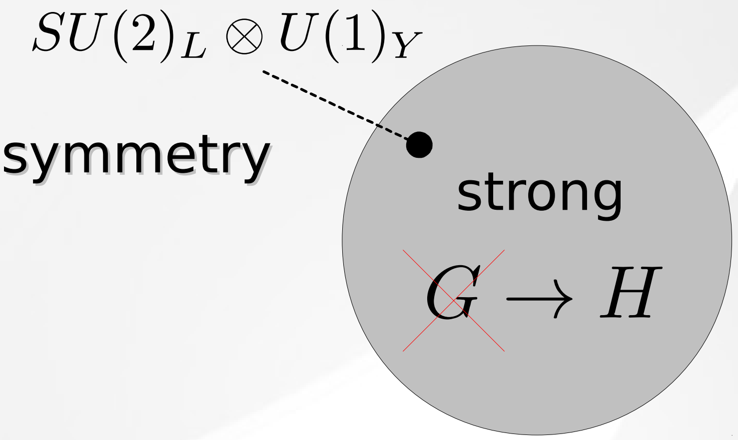

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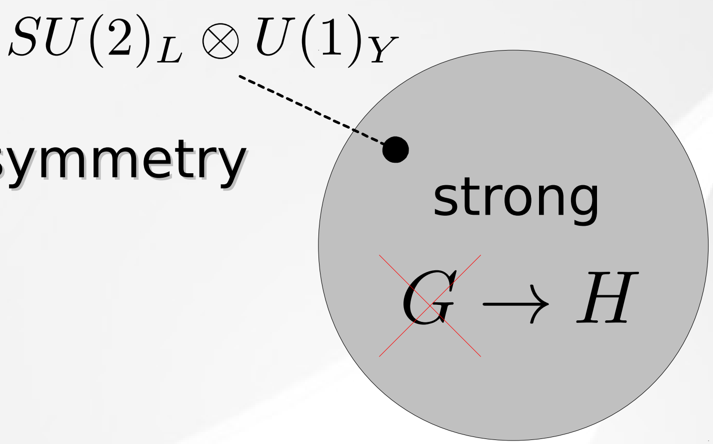

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- Separation of scales:

$$\xi = (v/f)^2$$

Decoupling: $\xi \to 0$

COMPOSITE HIGGS MODELS AND EWPT

- Oblique EWPO relevant for our purpose:

$$\epsilon_1 = \frac{1}{M_W^2}\left(A_{33}(0) - A_{W^+W^-}(0)\right) - M_Z^2 F'\left(M_Z^2\right)$$

$$\epsilon_3 = \frac{c}{s} F'_{3B}\left(M_Z^2\right) + c^2\left(F_{\gamma\gamma}(0) - F_{\gamma\gamma}\left(M_Z^2\right)\right) - c^2 M_Z^2 F'_{ZZ}\left(M_Z^2\right)$$

$$\Pi_{ij}\left(q^2\right) = A_{ij}(0) + q^2 F_{ij}\left(q^2\right)$$

[Altarelli, Barbieri, Caravaglios, 1993]

- Two sources of deviations $\Delta\epsilon_i = \epsilon_i - \epsilon_i^{SM}$
  - IR effect from modified Higgs dynamics
  - UV effect from composite resonances

COMPOSITE HIGGS MODELS AND EWPT

- IR effect on EWPO:

$\epsilon_3 \supset$

$\propto \xi \log\left(\frac{\Lambda}{M_H}\right)$

COMPOSITE HIGGS MODELS AND EWPT

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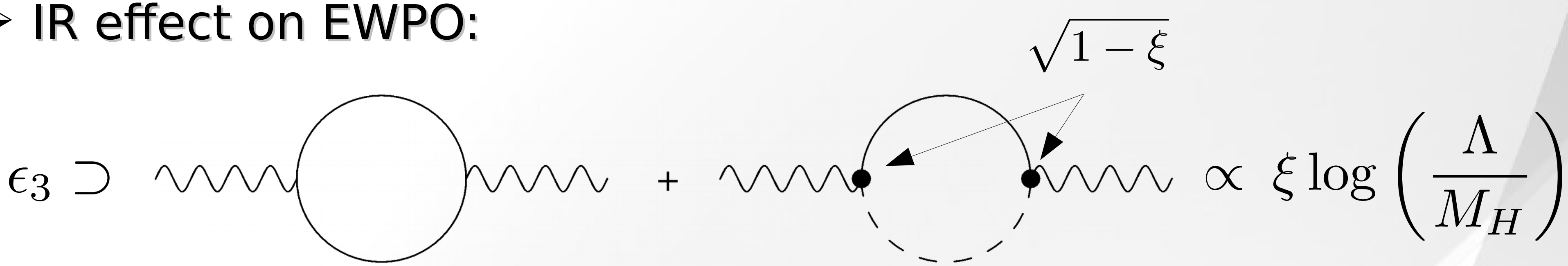

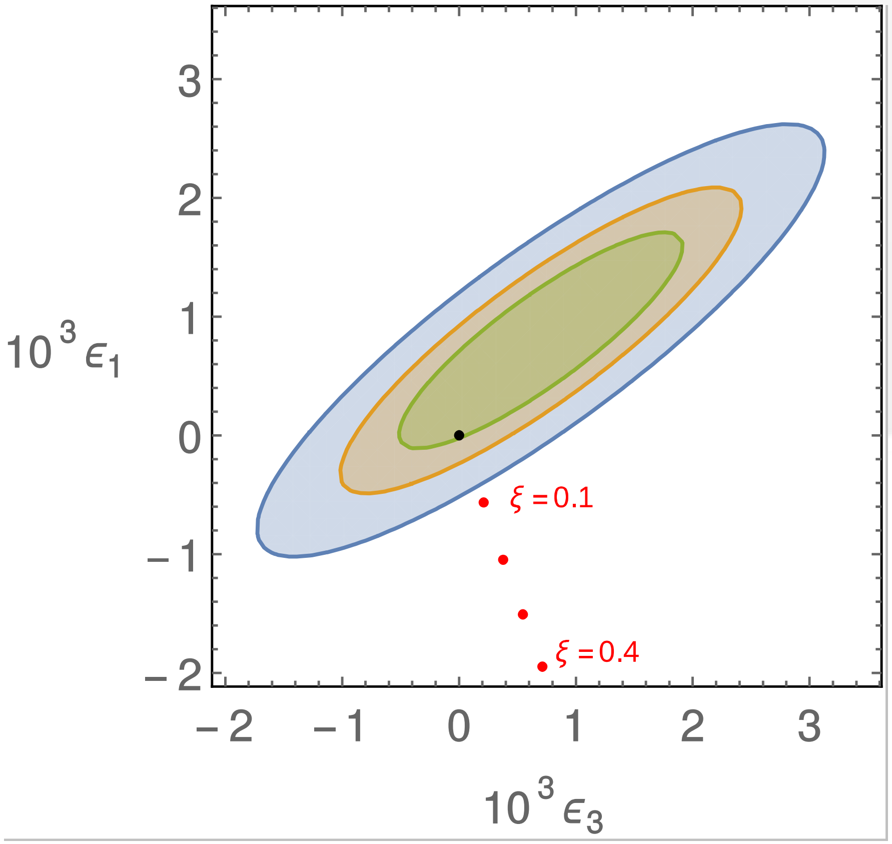

- Same effect for ϵ_1
- ~5-10% fine tuning on ξ required!
- Investigate if this picture can be improved (or not) with contributions from resonances

VECTOR RESONANCES LAGRANGIAN

- Introduce a single spin-1 resonance lighter than the others

Λ

M_ρ

M_H

VECTOR RESONANCES LAGRANGIAN

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$$\Lambda$$

$$M_\rho$$

$$M_H$$

- Goal:

Calculate the 1-loop contributions of such resonance to EWPO.

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Calculate the 1-loop contributions of such resonance to EWPO.

- Estimates: $\Delta\epsilon_i^{(\rho)} \sim \frac{1}{16\pi^2}\xi \log\left(\frac{\Lambda}{M_\rho}\right)$ $\Delta\epsilon_i^{(\Lambda)} \sim \frac{1}{16\pi^2}\xi$
  - Not really a sizeable enhancement
  - Not an actual precise calculation
  - Rather a refined qualitative estimate

VECTOR RESONANCES LAGRANGIAN

- Coset G/H: focus on the minimal SO(5)/SO(4) Composite Higgs model

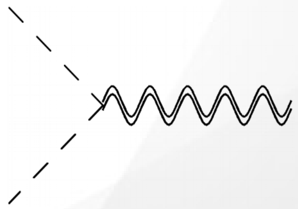
- Spin-1 resonance **in a (1,3)⊕(3,1) of $SU(2)_L \otimes SU(2)_R \sim SO(4)$**

- Two-derivatives lagrangian:

$$E^{\mu} = \pi D^{\mu} \pi + \dots$$

$$\mathcal{L}_{\rho} = \sum_{r=L,R} -\frac{1}{4 g_{\rho\, r}^2} \mathrm{Tr}\left[\rho^{r}_{\mu\nu} \rho^{r\, \mu\nu}\right] + \frac{1}{2} \frac{M_{\rho\, r}^2}{g_{\rho\, r}^2} Tr\left[\left(\rho^{r}_{\mu} - E_{\mu}\right)^2\right]$$

Mass + interactions:



$$+ \dots$$

- Interactions regolated by $a_{\rho} \equiv \frac{M_{\rho}}{g_{\rho} f} \sim 1$

VECTOR RESONANCES LAGRANGIAN

- Vector resonances **mix linearly** with EW gauge boson (**partial compositeness)**

$$\mathcal{L}_\rho \supset \frac{1}{2}\frac{M_\rho^2}{g_\rho^2} Tr\left[(\rho^\mu - E^\mu)^2\right] \supset M_\rho^2 \frac{g}{g_\rho}\rho^a_\mu W^{\mu a}$$

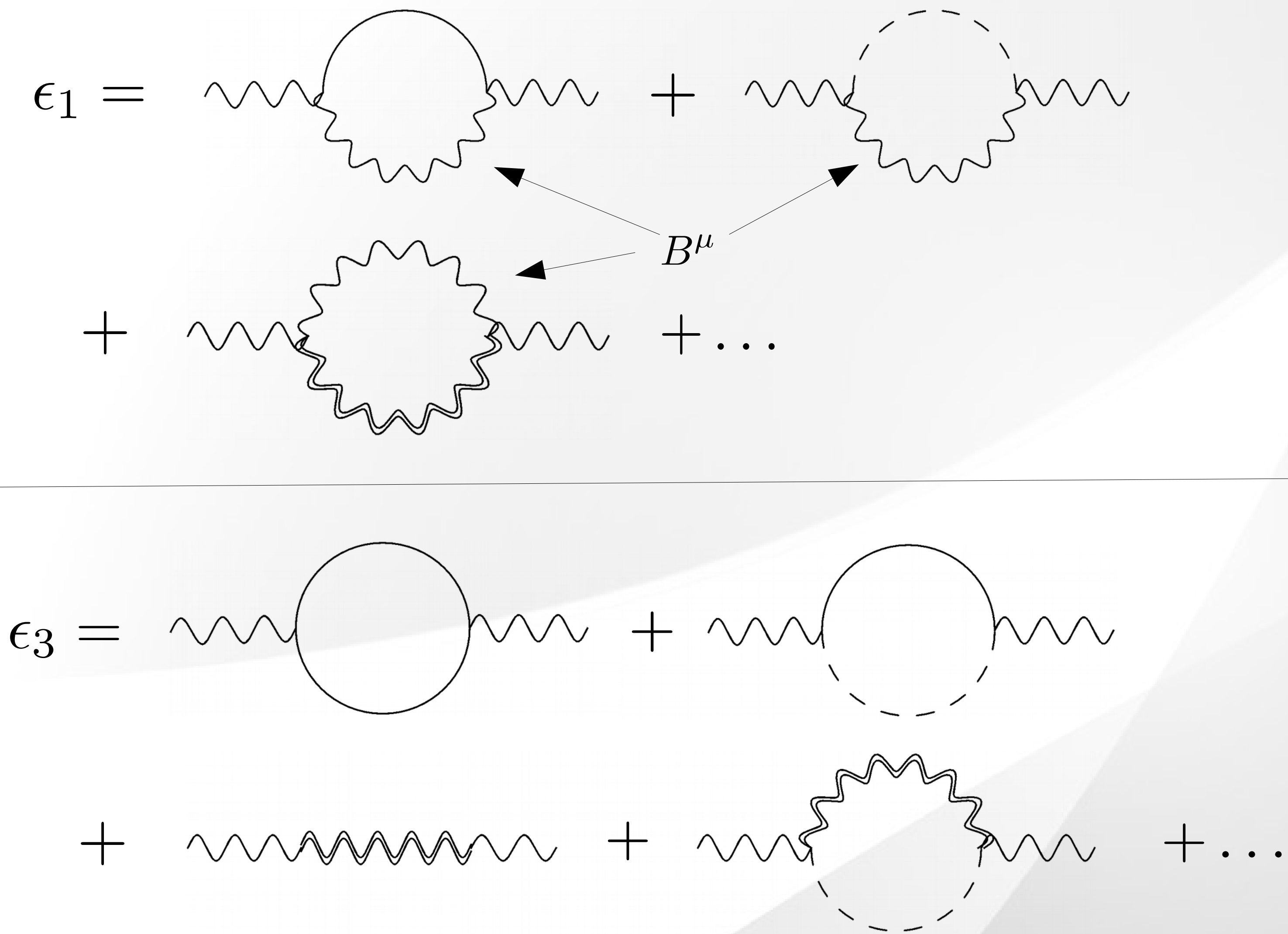
- Mixing is small and can be treated as a vertex

- Relevant four-derivative operators (additional tree-level contribution to $\Delta\varepsilon_3$):

$$\alpha_{2\,r} Tr\left[\rho^r_{\mu\nu} f^{\mu\nu}\right] \qquad \left(f^{\mu\nu} = e^{-i\pi^a T^{\hat{a}}} F^{\mu\nu} e^{i\pi^a T^{\hat{a}}}\right)$$

CALCULATION OF EW OBSERVABLES

- Some diagrams:



CALCULATION OF EW OBSERVABLES

- Final expressions for the case of a single ρ:

$$\left(a_\rho \equiv \frac{M_\rho}{g_\rho f}\right)$$

$$\Delta\epsilon_1 = -\frac{3g'^2}{32\pi^2}\xi\left[\log\left(\frac{\Lambda}{M_Z}\right) + f_1\left(\frac{M_H^2}{M_Z^2}\right)\right]$$

$$+\frac{3g'^2}{32\pi^2}\xi\frac{3}{4}a_\rho^2\left[\log\left(\frac{\Lambda}{M_\rho}\right) + \frac{3}{4}\right]$$

IR Composite Higgs boson contribution

$$\Delta\epsilon_3 = \frac{g^2}{96\pi^2}\xi\left[\log\left(\frac{\Lambda}{M_Z}\right) + f_3\left(\frac{M_H^2}{M_Z^2}\right)\right]$$

$$+g^2\xi\left(\frac{1}{4g_\rho^2} - \alpha_2\right) - \frac{g^2}{96\pi^2}\xi\left[\frac{3}{4}\left(a_\rho^2 + 28\right)\log\left(\frac{\Lambda}{M_{\rho L}}\right) + \frac{41}{16}a_\rho^2 + 1\right]$$

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UV Resonance contribution

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Any sign →

PARAMETER SPACE CONSTRAINTS

- Fix parameters:

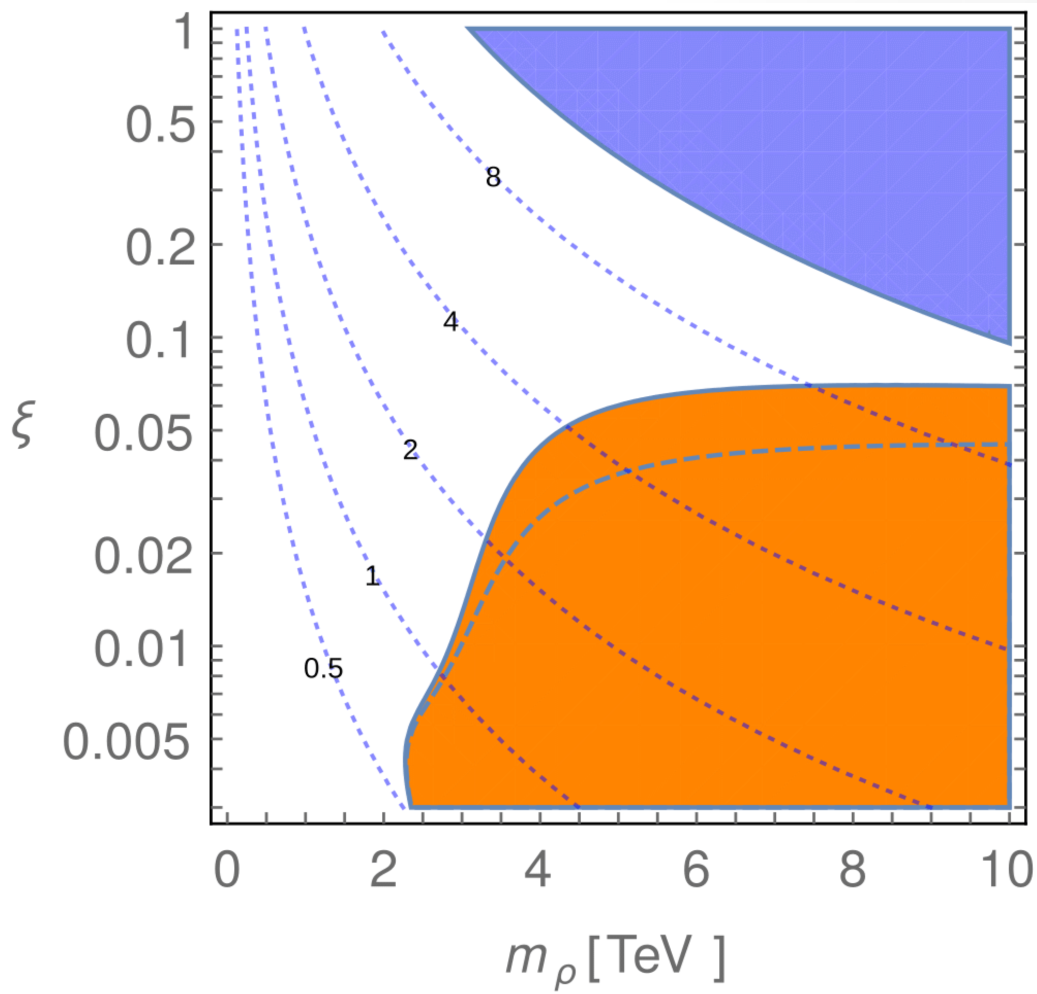
$$\alpha_2 = 0$$

$$a_\rho = 1$$

$$\Lambda = 3M_\rho$$

- Constrain (ξ, M_ρ) @ 95% CL

PARAMETER SPACE CONSTRAINTS



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IR + tree level ρ

IR + one loop ρ

$g_\rho > 4\pi$

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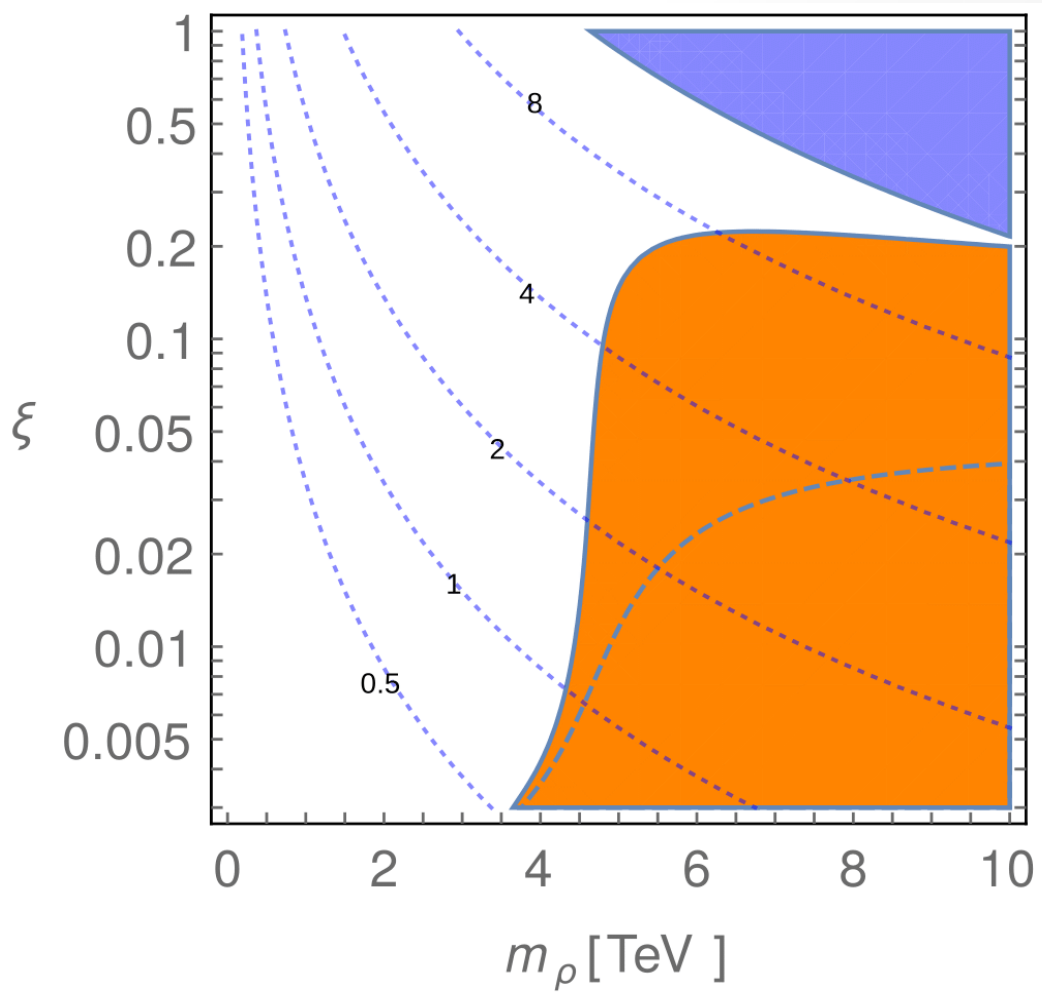

- Fix parameters:

$$\alpha_2 = 0$$

$$a_\rho = 1.5$$

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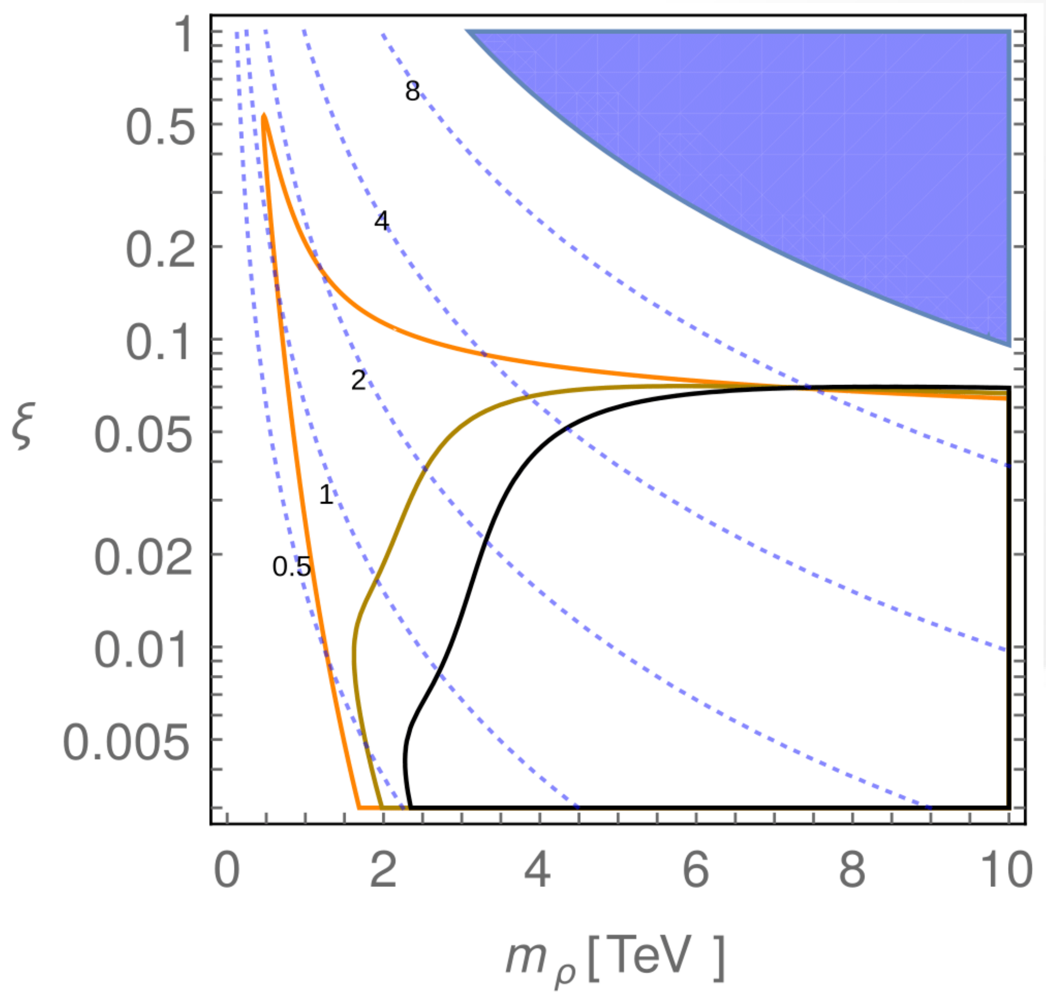
PARAMETER SPACE CONSTRAINTS



- Fix parameters:

$$\alpha_2 = 0,\ 1/8g_\rho^2,\ 1/4g_\rho^2$$

$$a_\rho = 1$$

$$\Lambda = 3M_\rho$$

- Constrain (ξ, M_ρ) @ 95% CL

- Black: $\alpha_2 = 0$
- Dark yellow: $\alpha_2 = 1/8g_\rho^2$
- Orange: $\alpha_2 = 1/4g_\rho^2$

TO DO (ALMOST DONE)

- Aim at a first “complete” description of EWPT in composite Higgs
  - Vector resonances
  - Fermionic resonances
- Include many constraints
  - Oblique EWPO
  - $Zb\bar{b}$ coupling
  - Higgs potential
  - Top mass
  - Z mass

D. Ghosh, M. Salvarezza, F. Senia, L. Silvestrini, *in preparation*

CCWZ LAGRANGIAN FOR SO(5) → SO(4)

➢ CCWZ: natural formalism for spontaneously broken effective theories, chiral expansion is built-in.

- **Global G invariance** → **Local H invariance**

[Callan, Coleman, Wess, Zumino, 1977]

➢ Building blocks:

$$d_\mu = d_\mu^a T^{\hat{a}} = T^{\hat{a}} \left[\frac{\sqrt{2}}{f} \partial_\mu \pi^a + \frac{1}{f\sqrt{2}} \epsilon^{abc} \pi^b \left(W_\mu^c + \delta^{c3} B_\mu \right) + \dots \right]$$

$$E_\mu = E_\mu^a T^a = T^a \left[\frac{1}{2f^2} \left(\epsilon^{abc} \pi^b \partial_\mu \pi^c + \pi^a \partial_\mu \pi^4 - \pi^4 \partial_\mu \pi^a \right) + W_\mu^a + \dots \right]$$

$$d_\mu \xrightarrow[g \in SO(5)]{} h(x) d_\mu h^\dagger(x)$$

$$E_\mu \xrightarrow[g \in SO(5)]{} h(x) d_\mu h^\dagger(x) - i h \partial_\mu h^\dagger$$

$$h \in SO(4)$$

$$\mathcal{L} = \mathcal{L}\left(d_\mu, E_\mu\right)$$

$d_\mu,\ E_\mu$ ↔ 1 derivative