

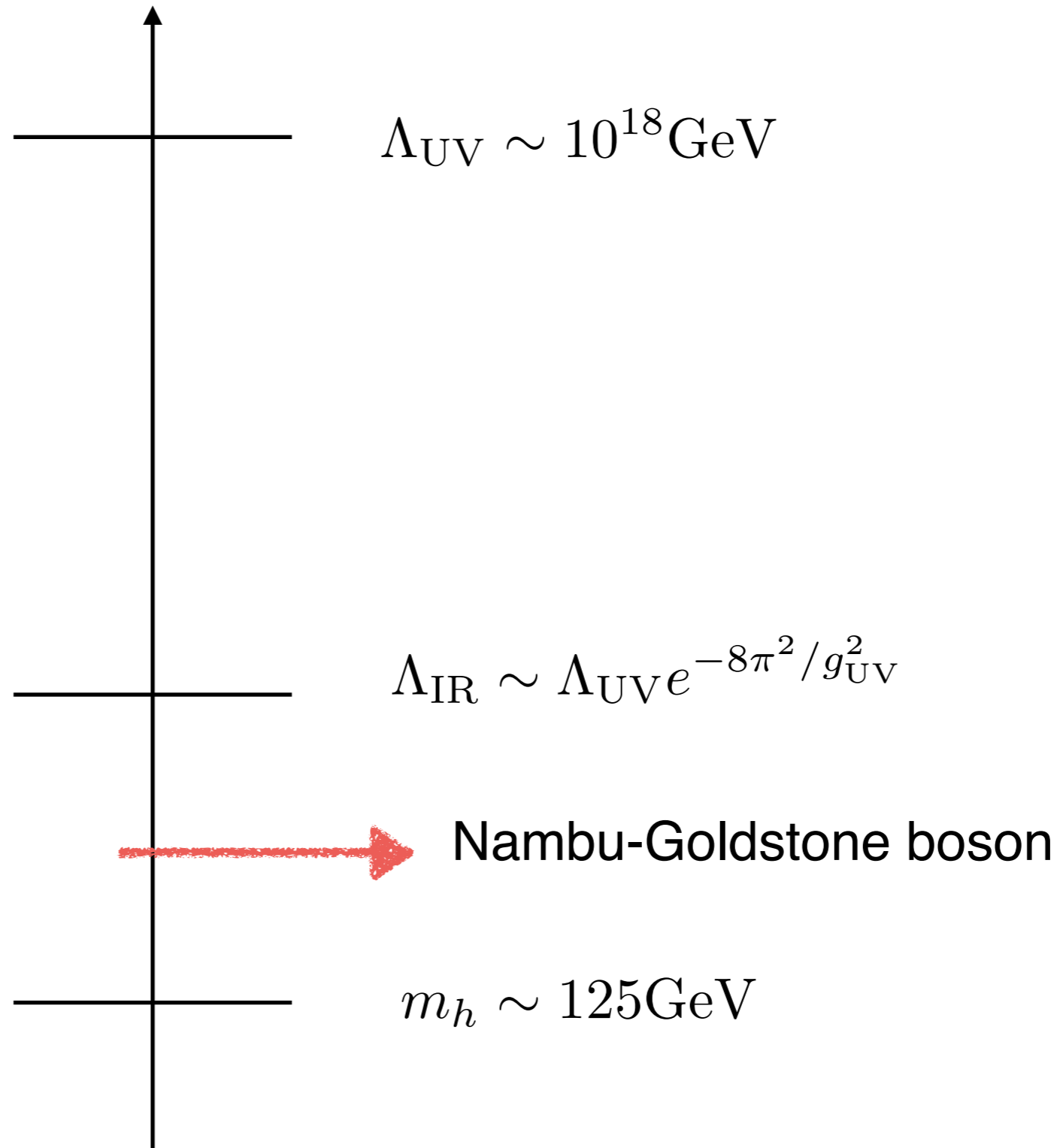
Composite Higgs Models at the LHC and Beyond

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What symmetry can tell us about
the composite Higgs Models?

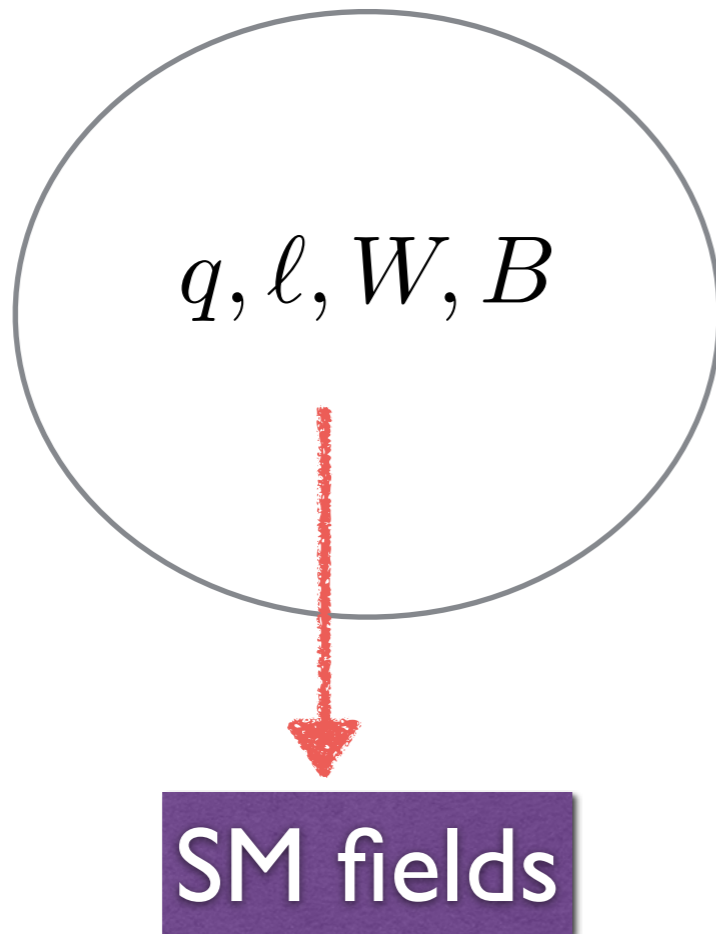
Compositeness



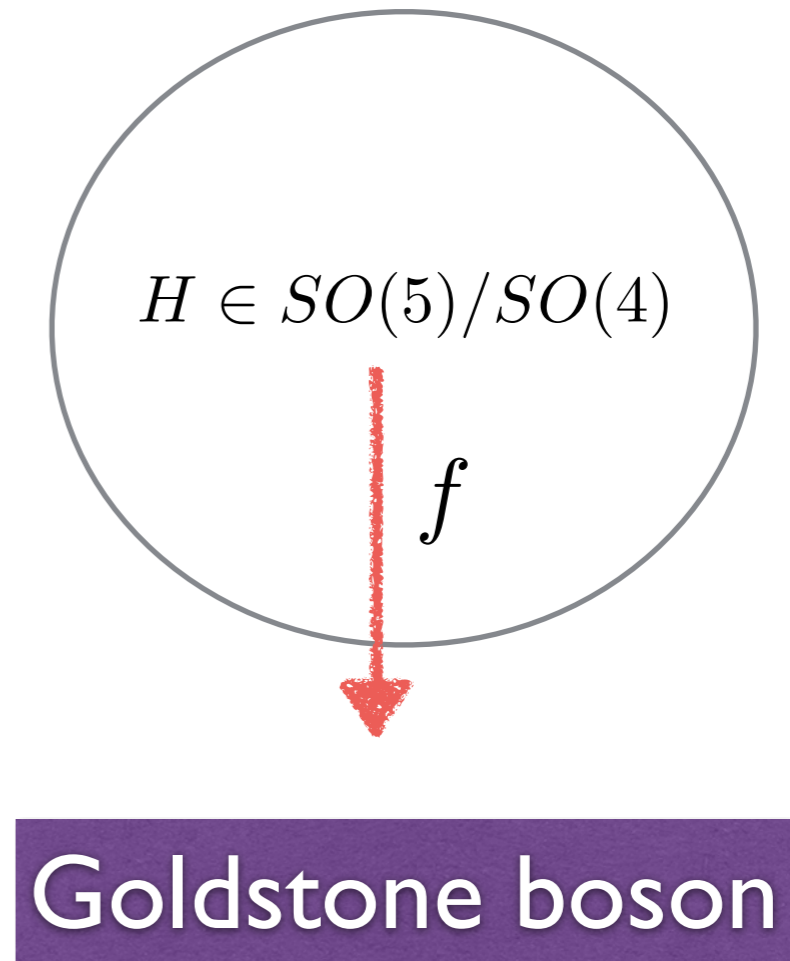
Enhanced shift symmetry!

Composite Higgs models: Assumption I

Elementary



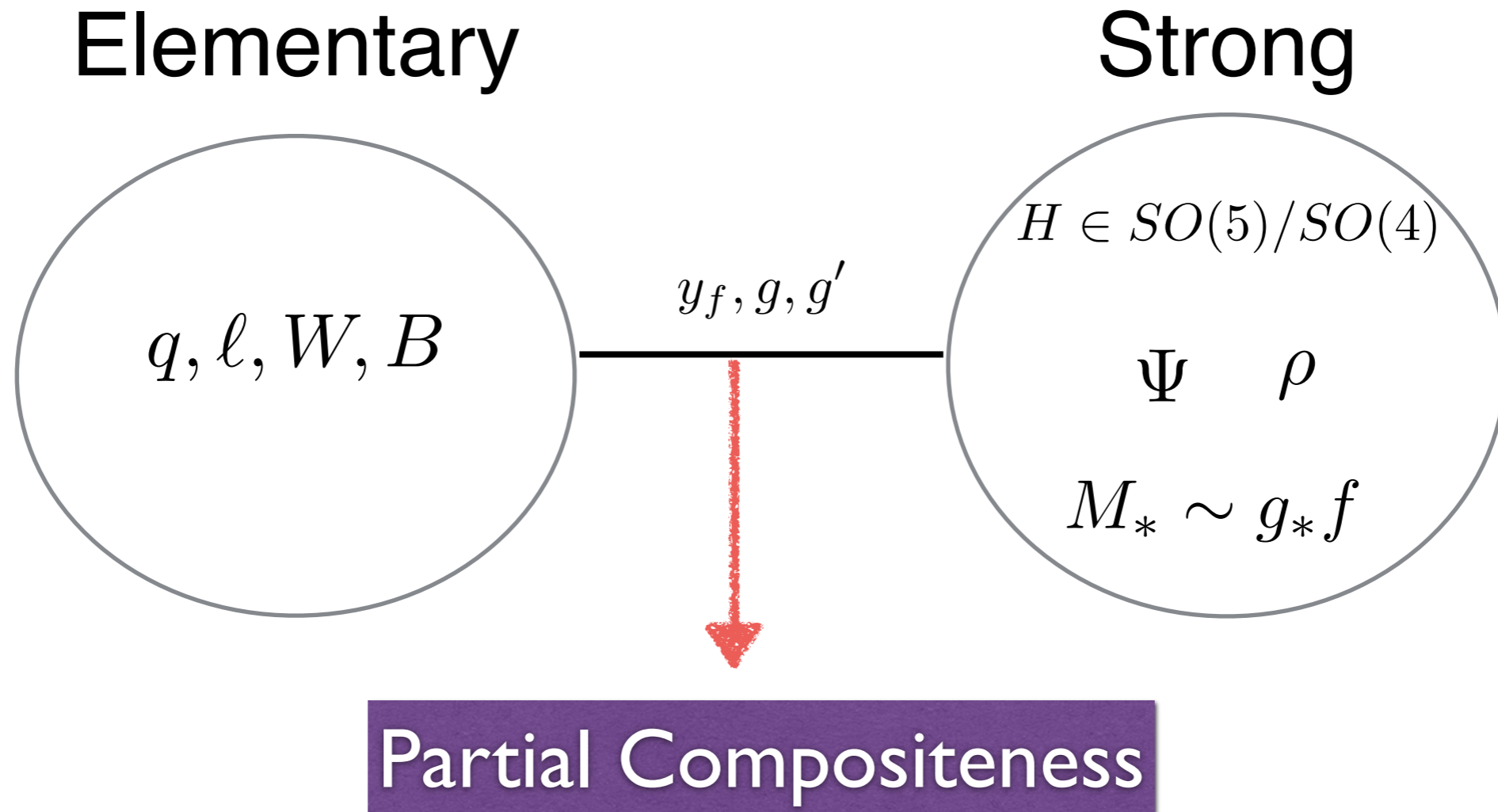
Strong



Kaplan, Georgi & Dimopoulos
Contino, Nomura and Pomarol
Agashe, Contino and Pomarol

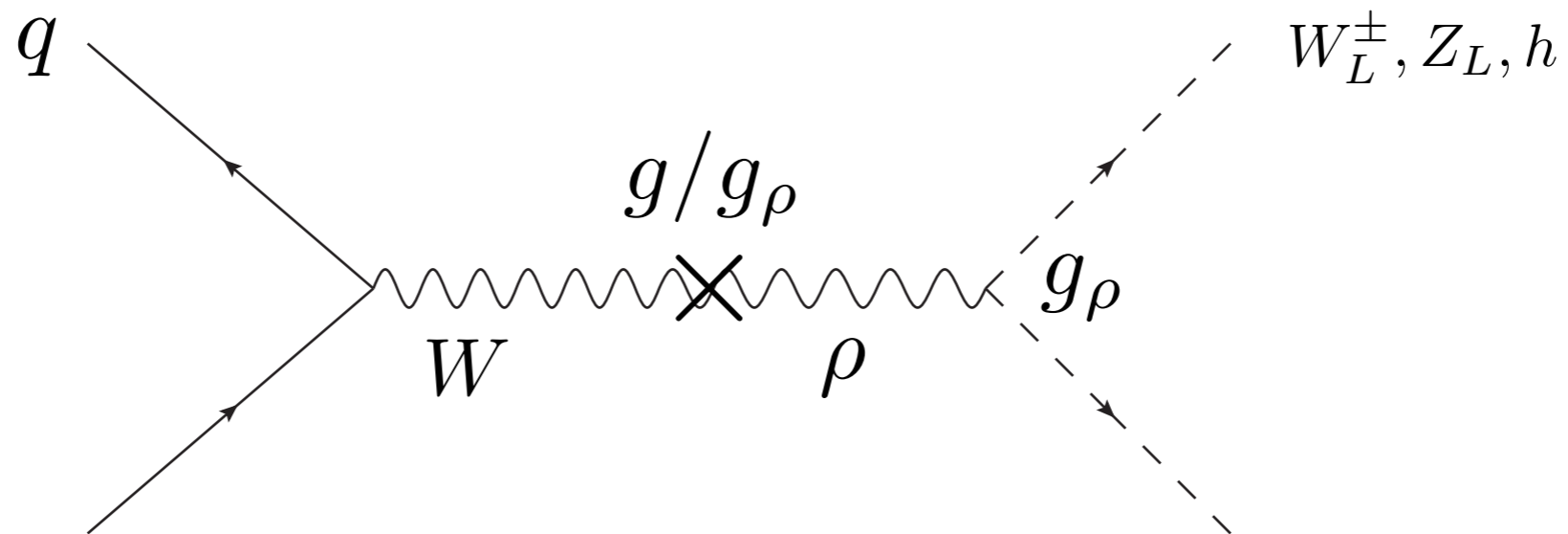
Non-linearly realized symmetry

Composite Higgs models: Assumption II



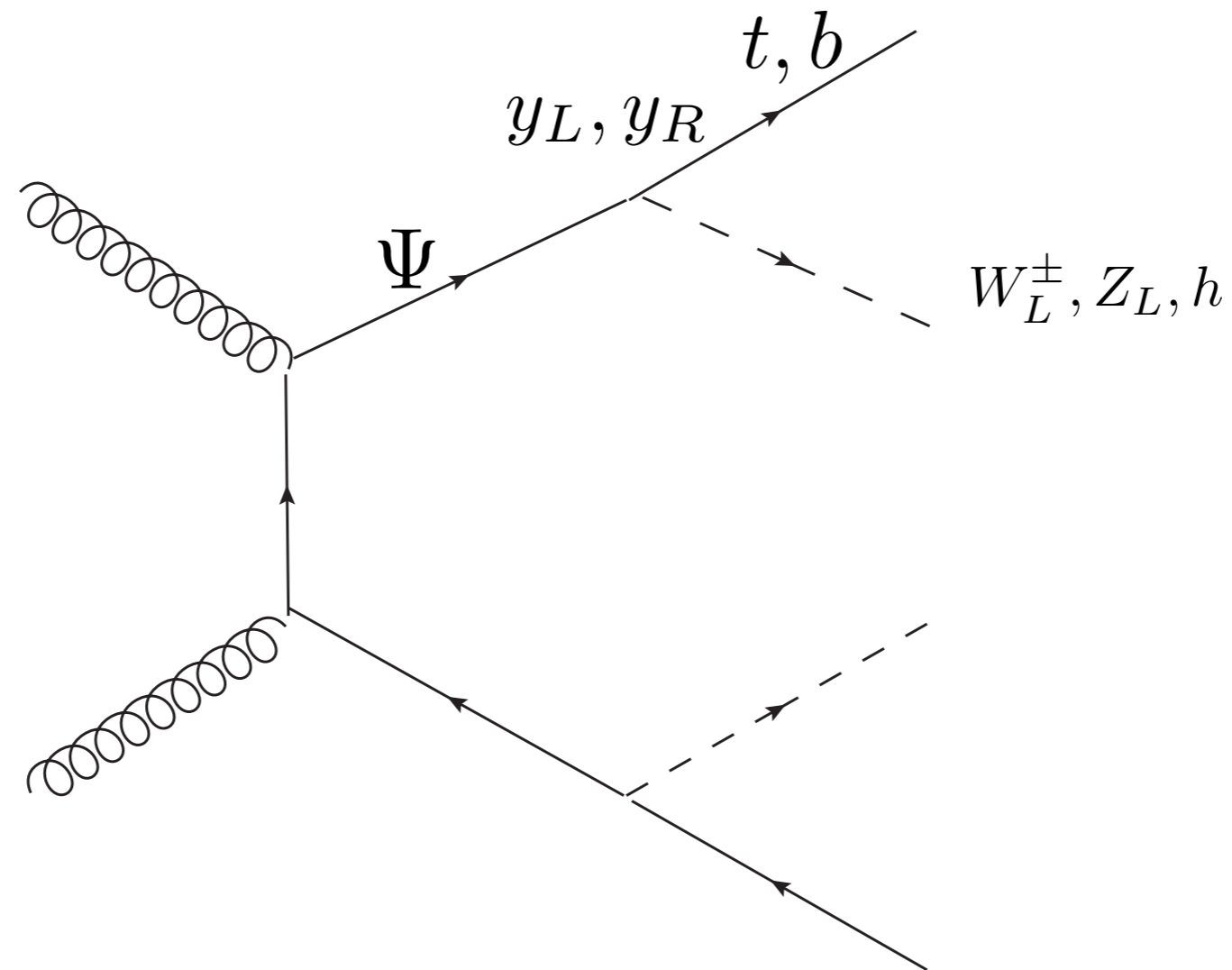
Direct Signatures

Direct searches: Spin-1



Dibosons provide the smoking gun!

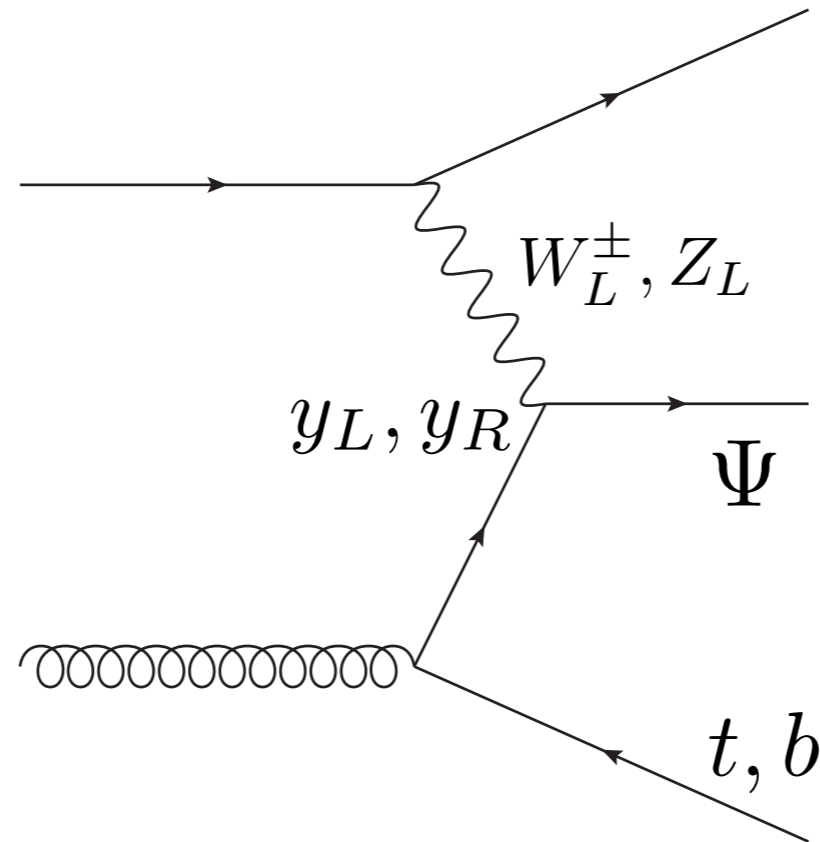
Direct searches: spin-1/2



Top partners

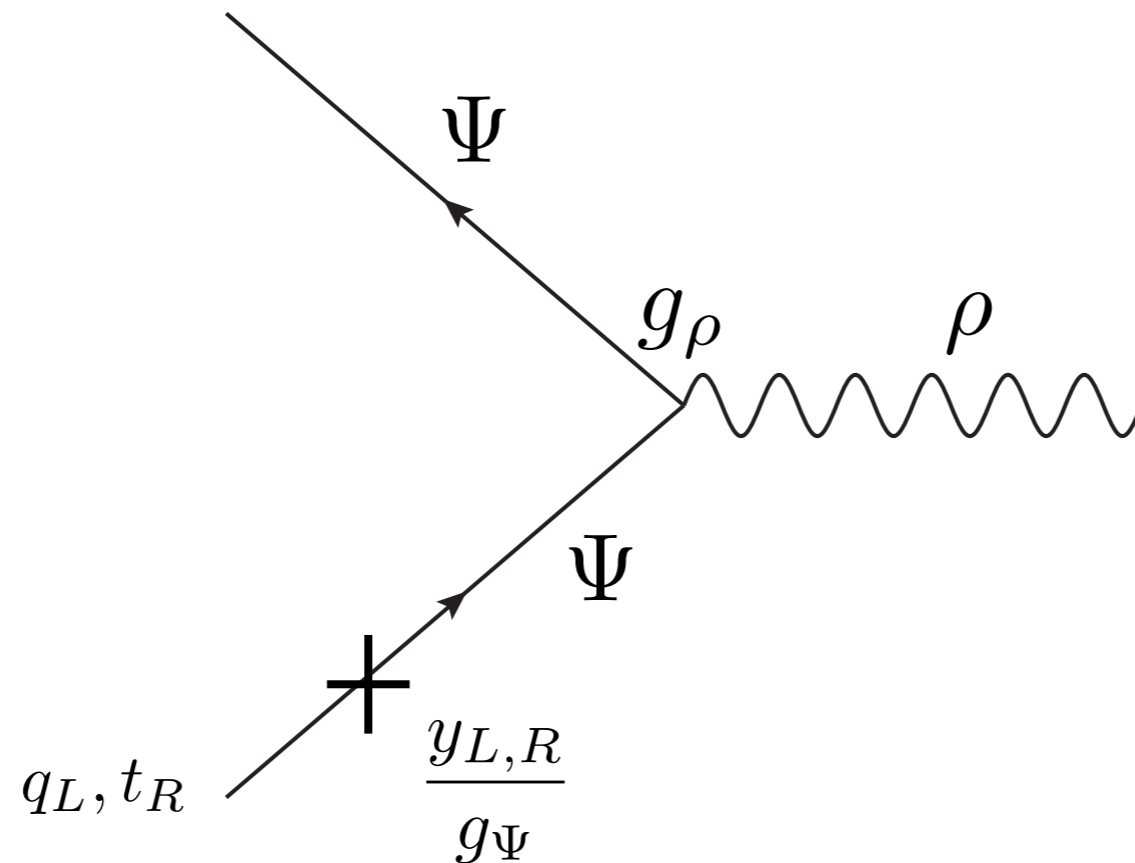
$$\Psi \equiv X_{5/3}, T, B$$

Direct searches: Single production



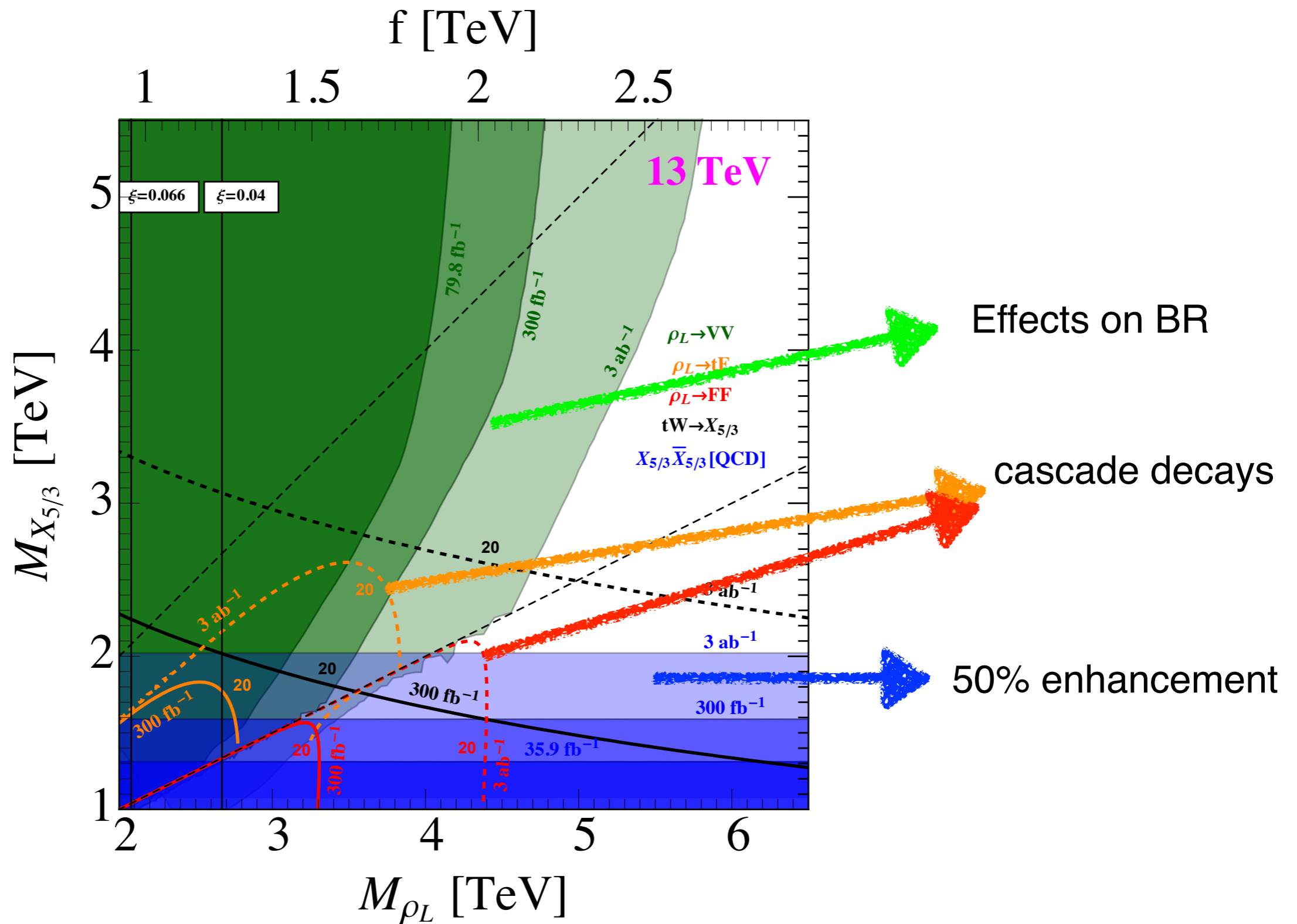
Lower mass threshold!

Cascade decays



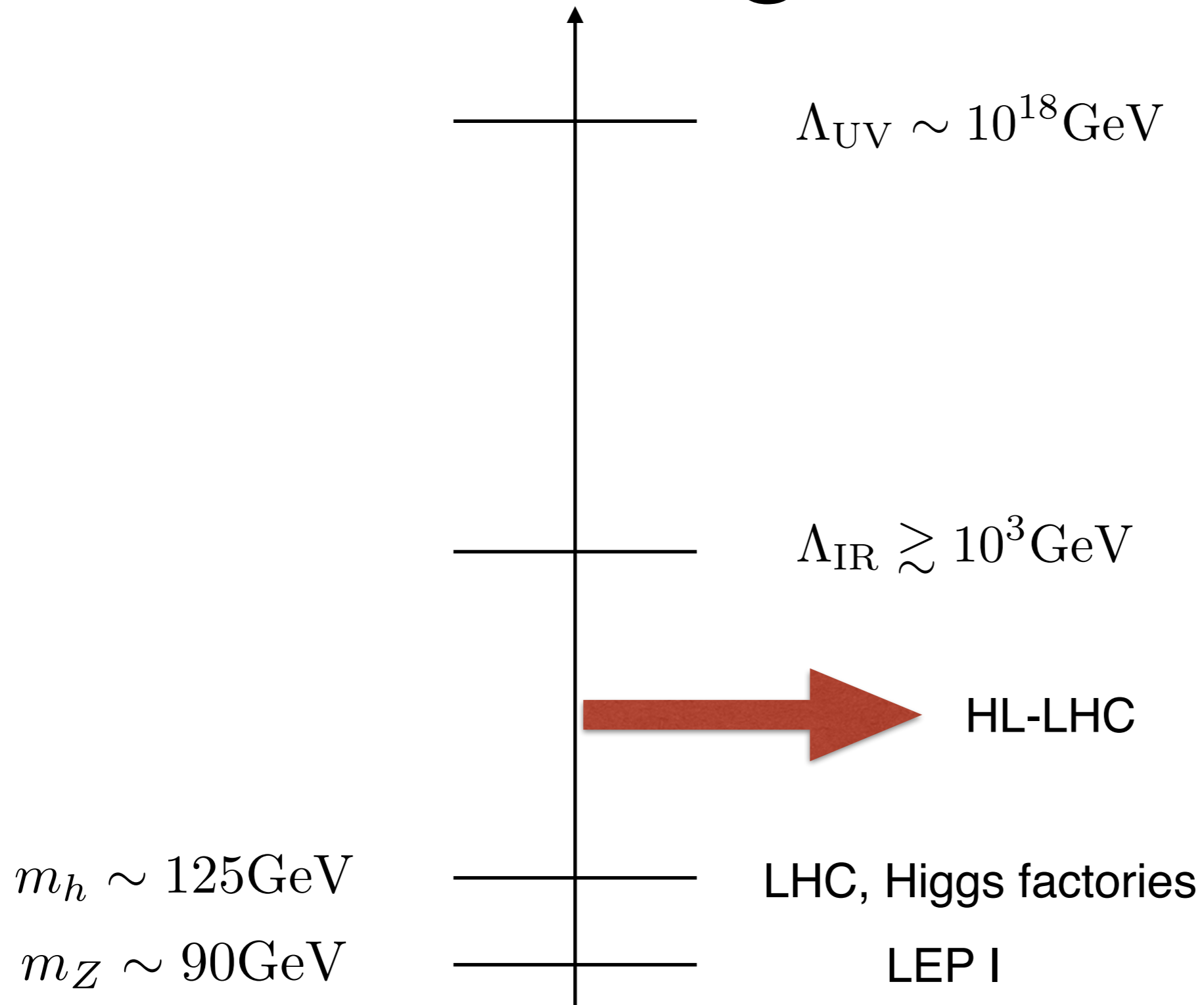
Have kinematical advantage!

Bounds and Projections

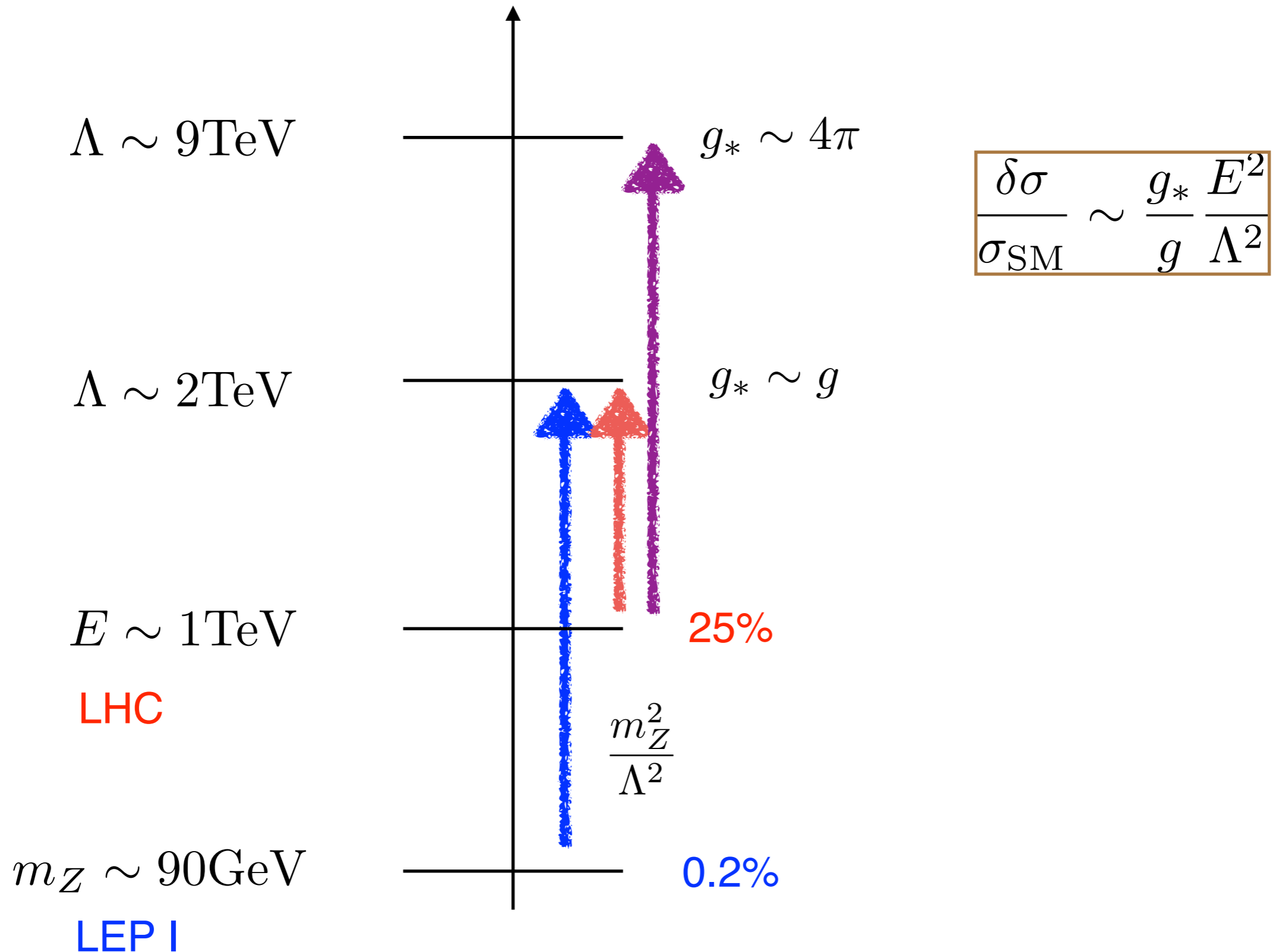


Indirect Signatures

Indirect Signatures



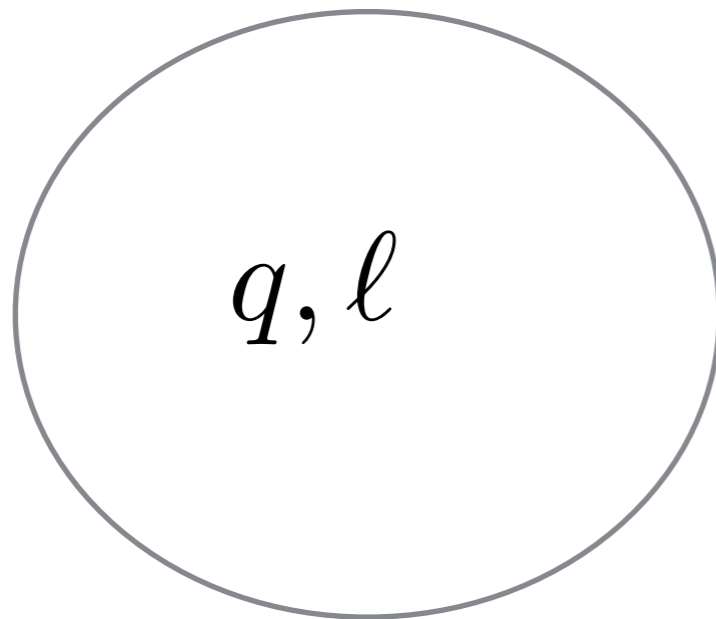
Precision to scale



Not realized in composite Higgs models!

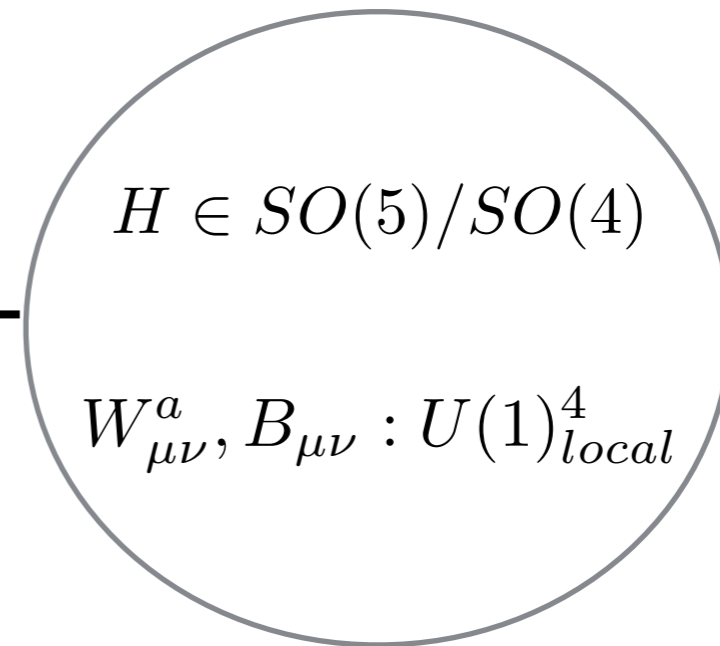
Strong multipole interactions

Elementary



y_f, g, g'

Strong

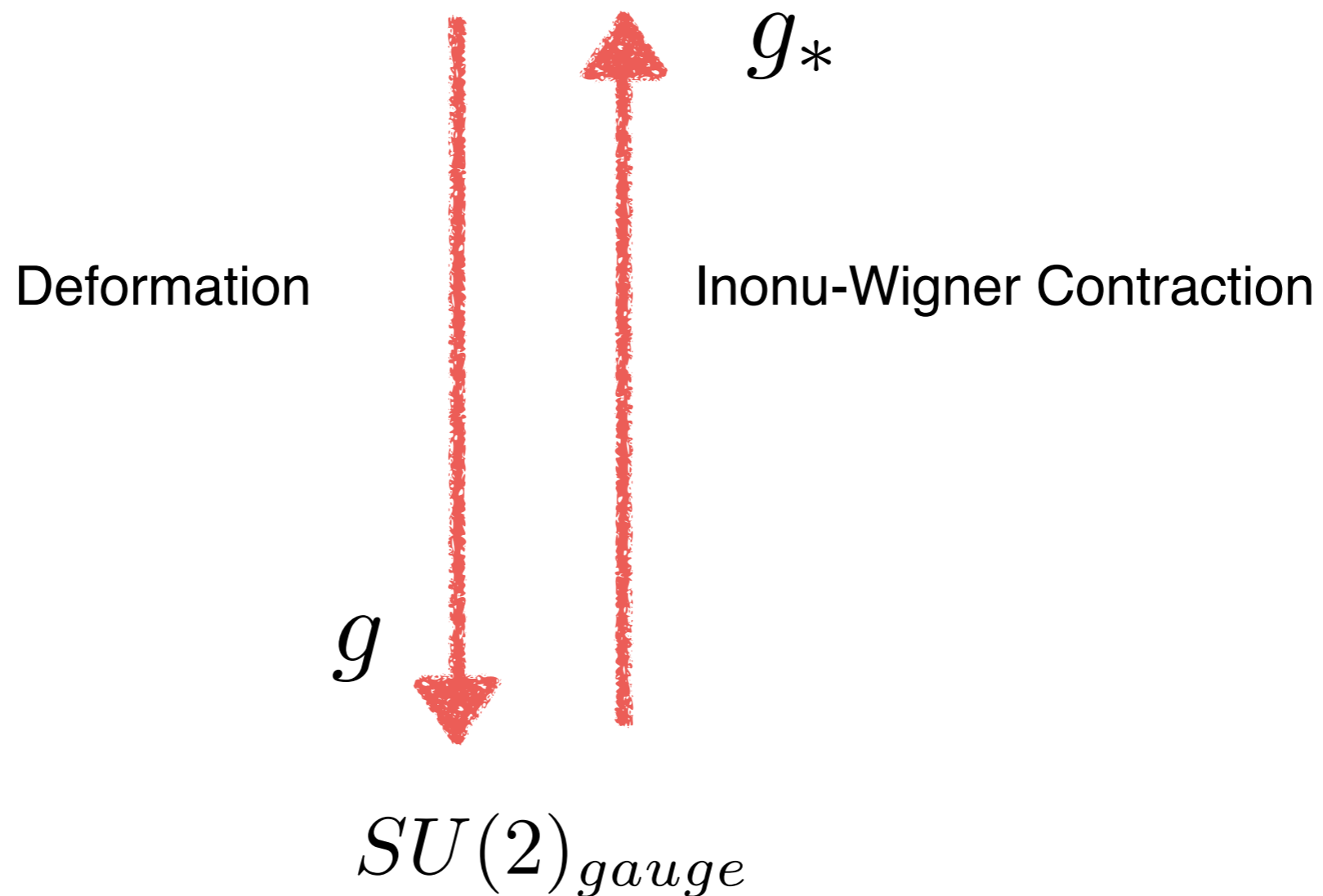


– New power-counting rules

$$W_{\mu\nu}^a, B_{\mu\nu} : g_*$$

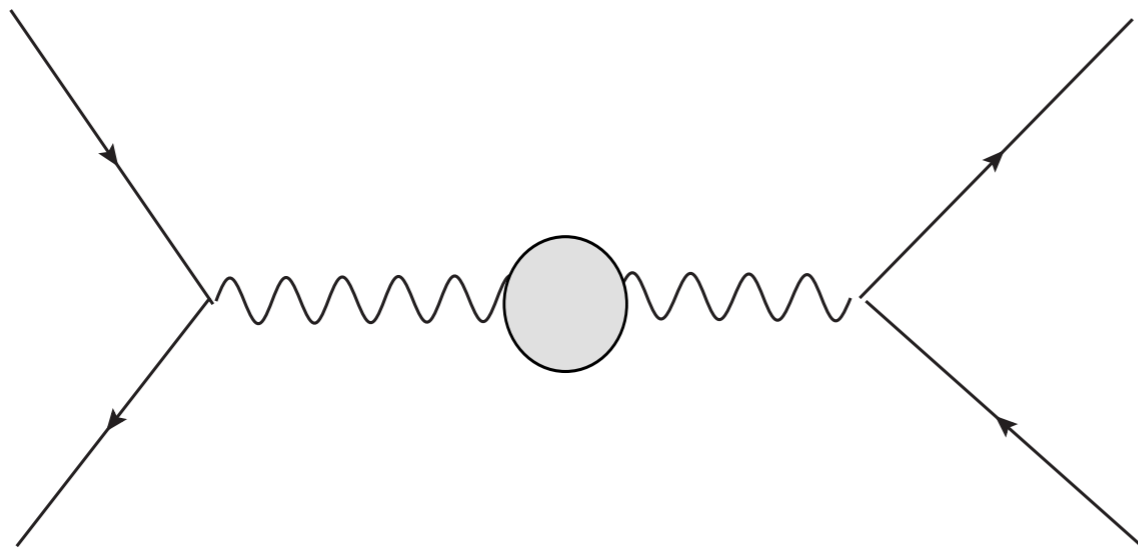
Gauge interactions as deformation

$$SU(2)_{global} \times U(1)_{local}^3$$



Strong multipole interactions

$$\mathcal{O}_{2W} = -\frac{1}{2m_*^2} D^\mu W_{\mu\nu}^a D_\rho W^{a\rho\nu} \Rightarrow c_{2W} \sim \frac{g^2}{g_*^2} \quad c_{2W} \sim 1$$

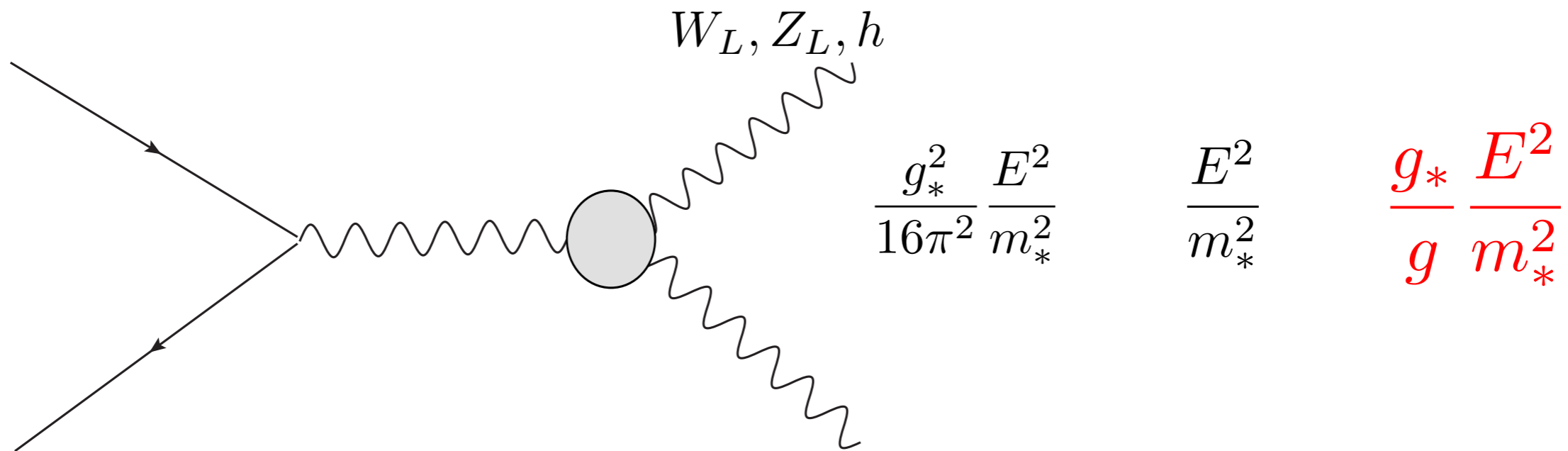


$$\sim \frac{g^2}{g_*^2} \frac{E^2}{m_*^2}$$

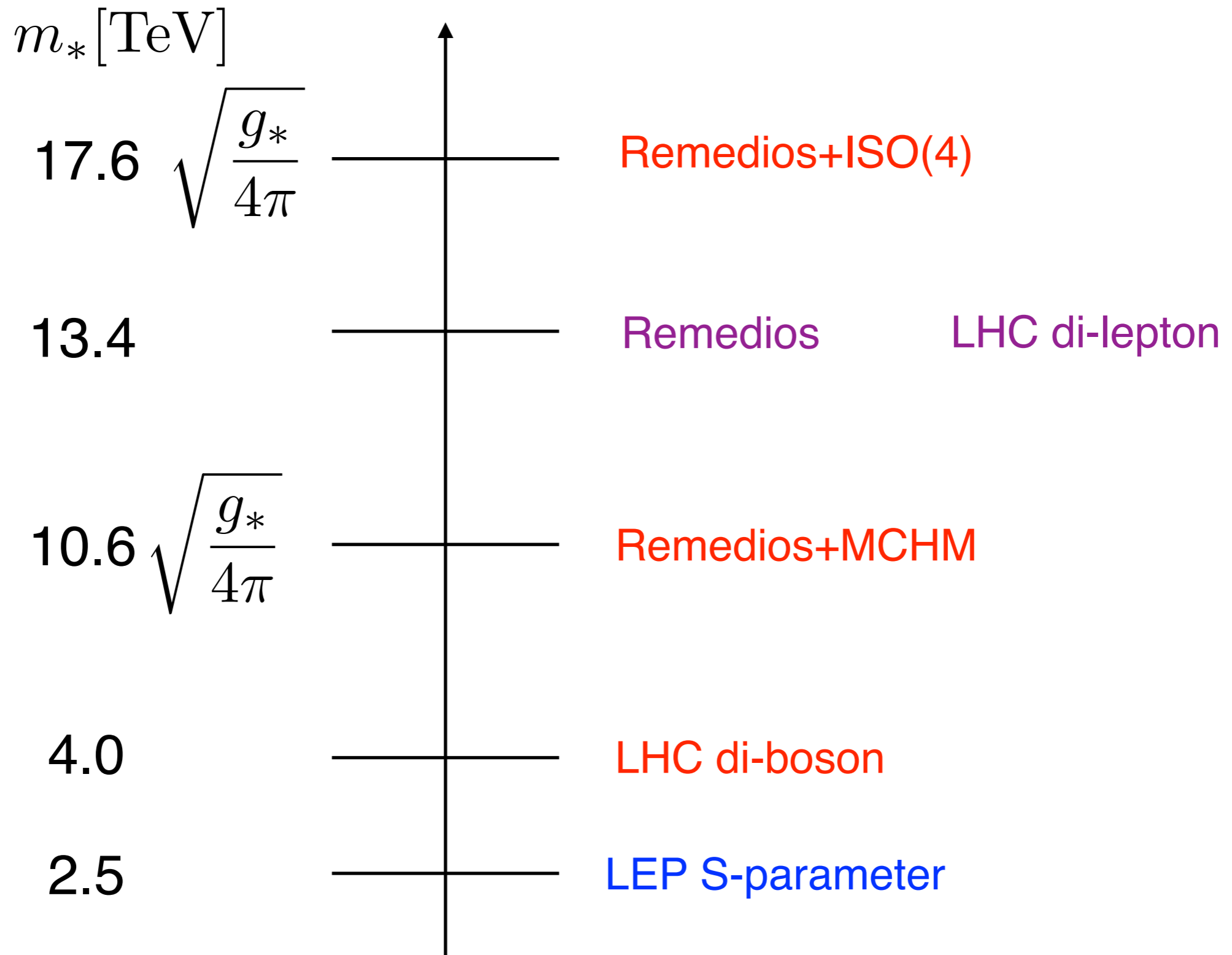
$$\frac{E^2}{m_*^2}$$

Strong multipole interactions

$$\mathcal{O}_{HW} = \frac{ig}{m_*^2} (D^\mu H)^\dagger \sigma^a (D^\nu H) W_{\mu\nu}^a \Rightarrow c_{HW} \sim \frac{g_*^2}{16\pi^2}, \quad 1 \quad \frac{g_*}{g}$$

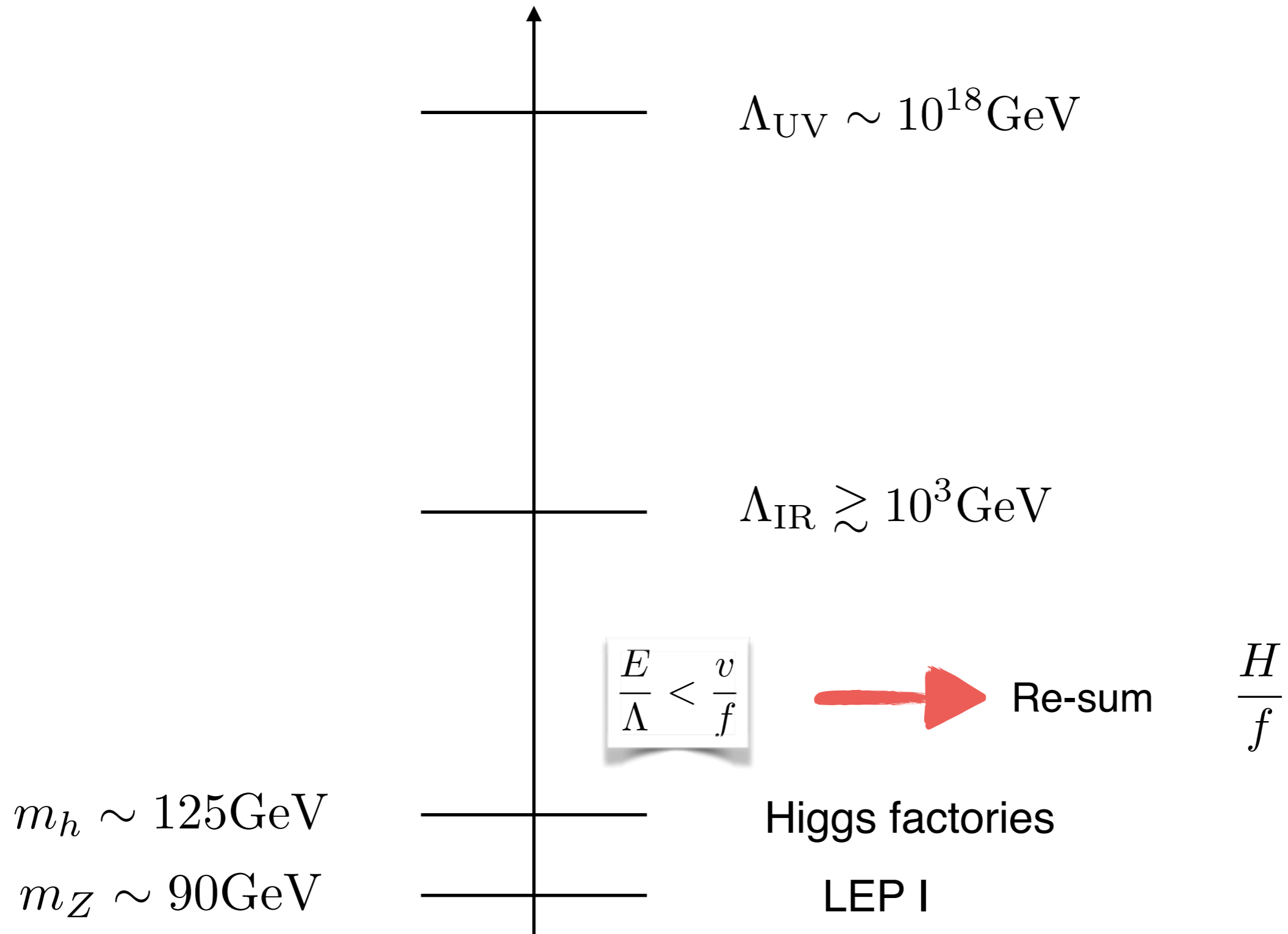


HL-LHC Reach

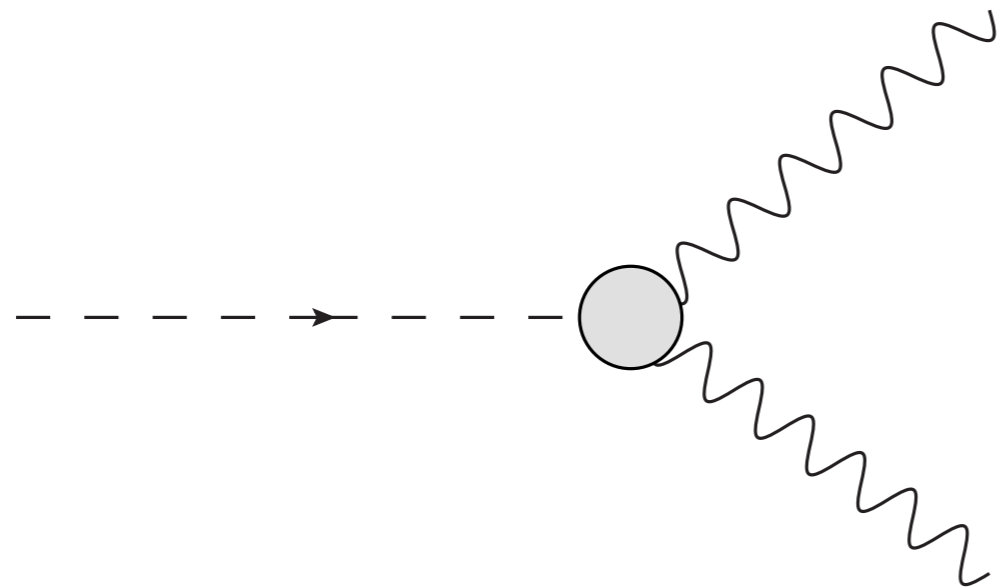


Beyond the LHC

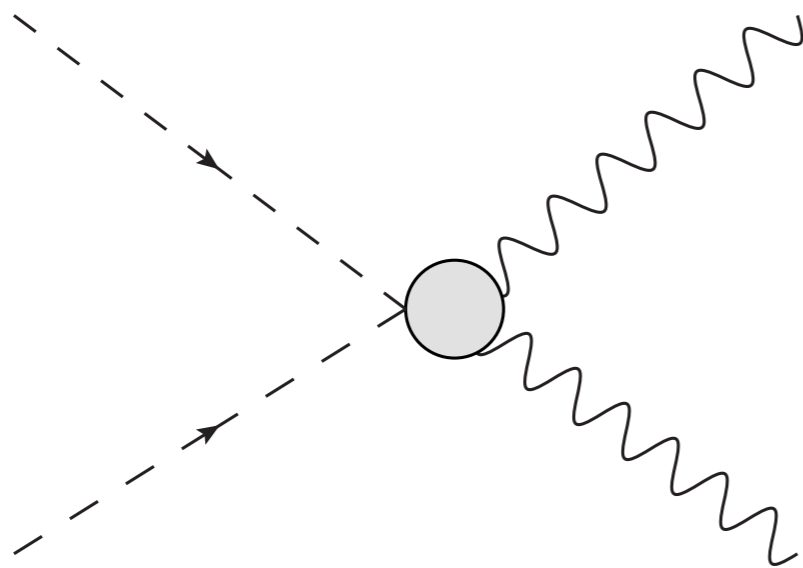
Future lepton colliders



Prediction from Higgs non-linearity



$$2a \frac{h}{v} \left(m_W^2 W_\mu^+ W^{-\mu} + \frac{1}{2} m_Z^2 Z_\mu Z^\mu \right)$$



$$b \frac{h^2}{v^2} \left(m_W^2 W_\mu^+ W^{-\mu} + \frac{1}{2} m_Z^2 Z_\mu Z^\mu \right)$$

SMEFT

Non-linearity

$$\frac{1-b}{4(1-a)}$$

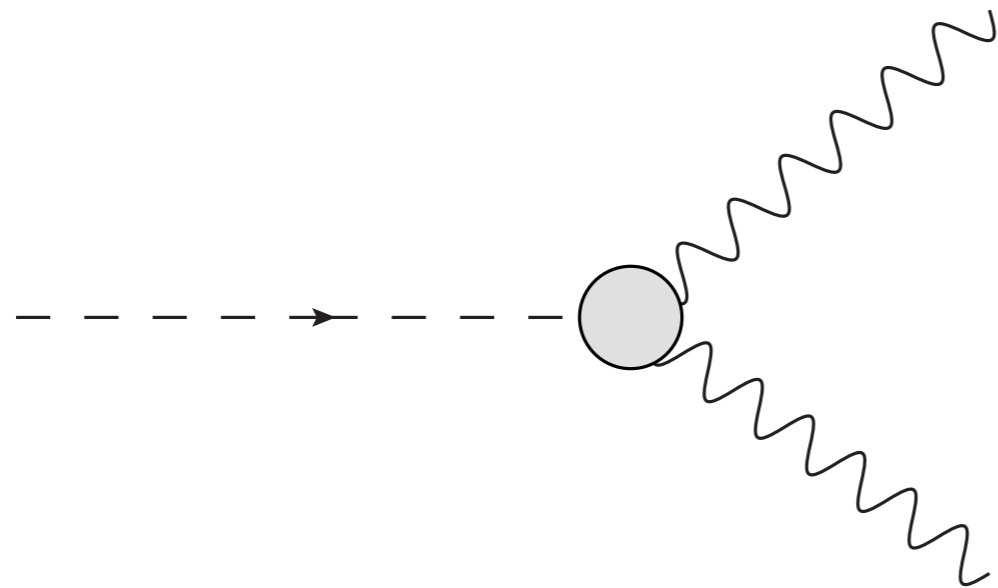
1

$$\frac{\xi}{2(1-\sqrt{1-\xi})} \sim 1 - \frac{1}{4}\xi$$

R. Contino et al '13

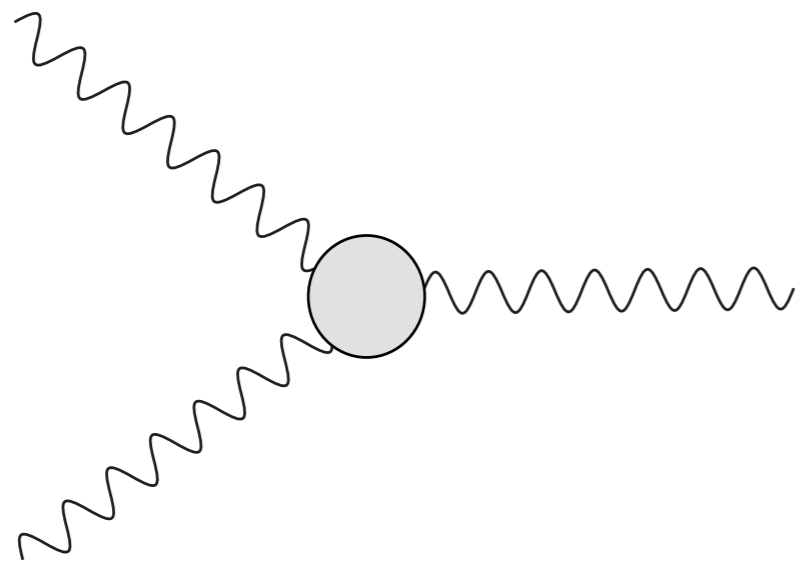
D. Liu, I. Low and Z. Yin '18

Predictions from Higgs non-linearity



$$C_2^h \frac{h}{v} Z_{\mu\nu} Z^{\mu\nu}$$

$$C_4^h \frac{h}{v} Z_{\mu\nu} A^{\mu\nu}$$



$$\delta\kappa_\gamma i e W_\mu^+ W_\nu^- A^{\mu\nu}$$

SMEFT

Non-linearity

$$\frac{2c_w^2 C_2^h - c_{2w} C_4^h / t_w}{\delta\kappa_\gamma}$$

$$1$$

$$\cos\theta = \sqrt{1 - \xi}$$

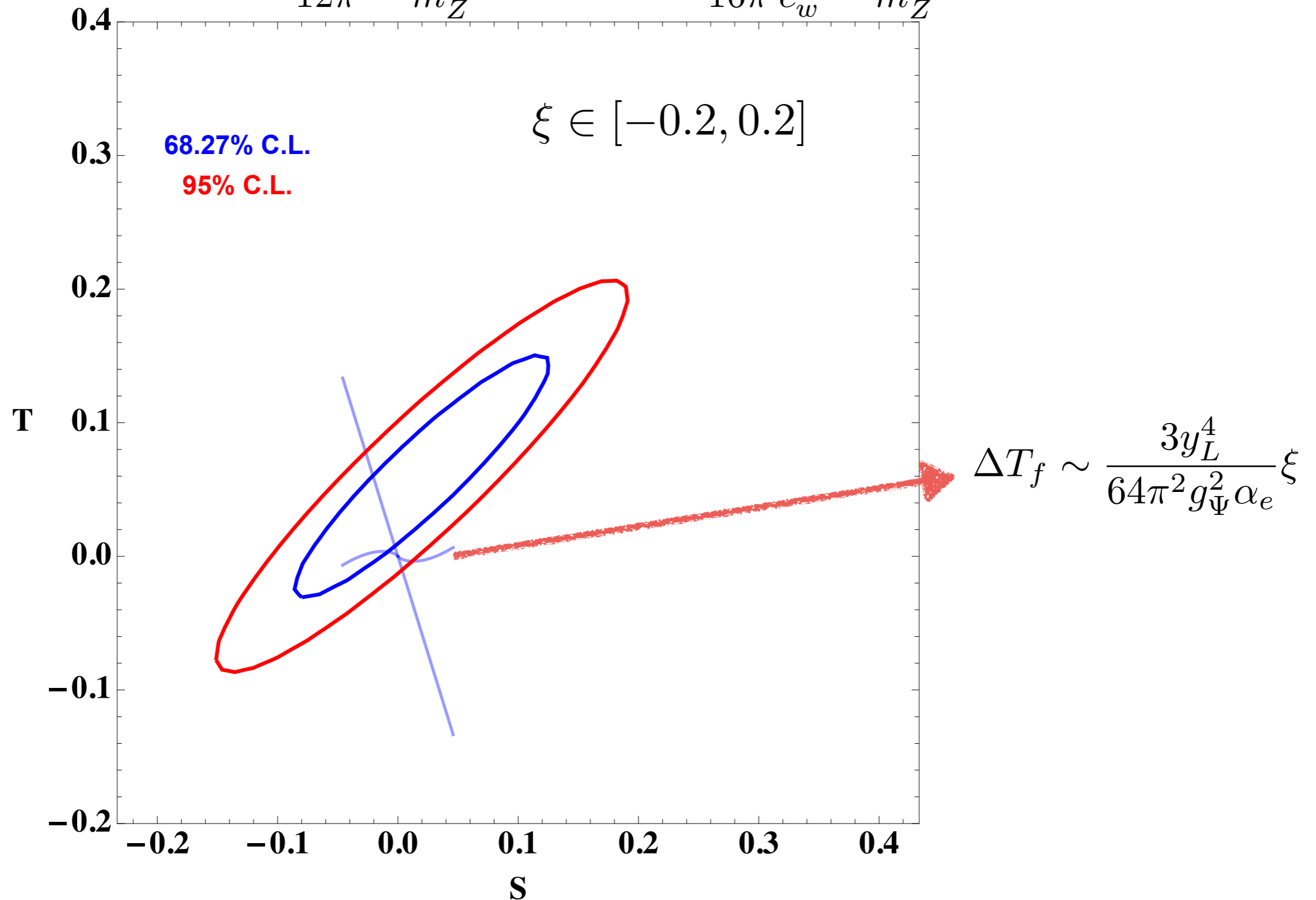
Conclusion

- Symmetry can tell us a lot about composite Higgs models.
- New symmetries lead to new power-counting rule.

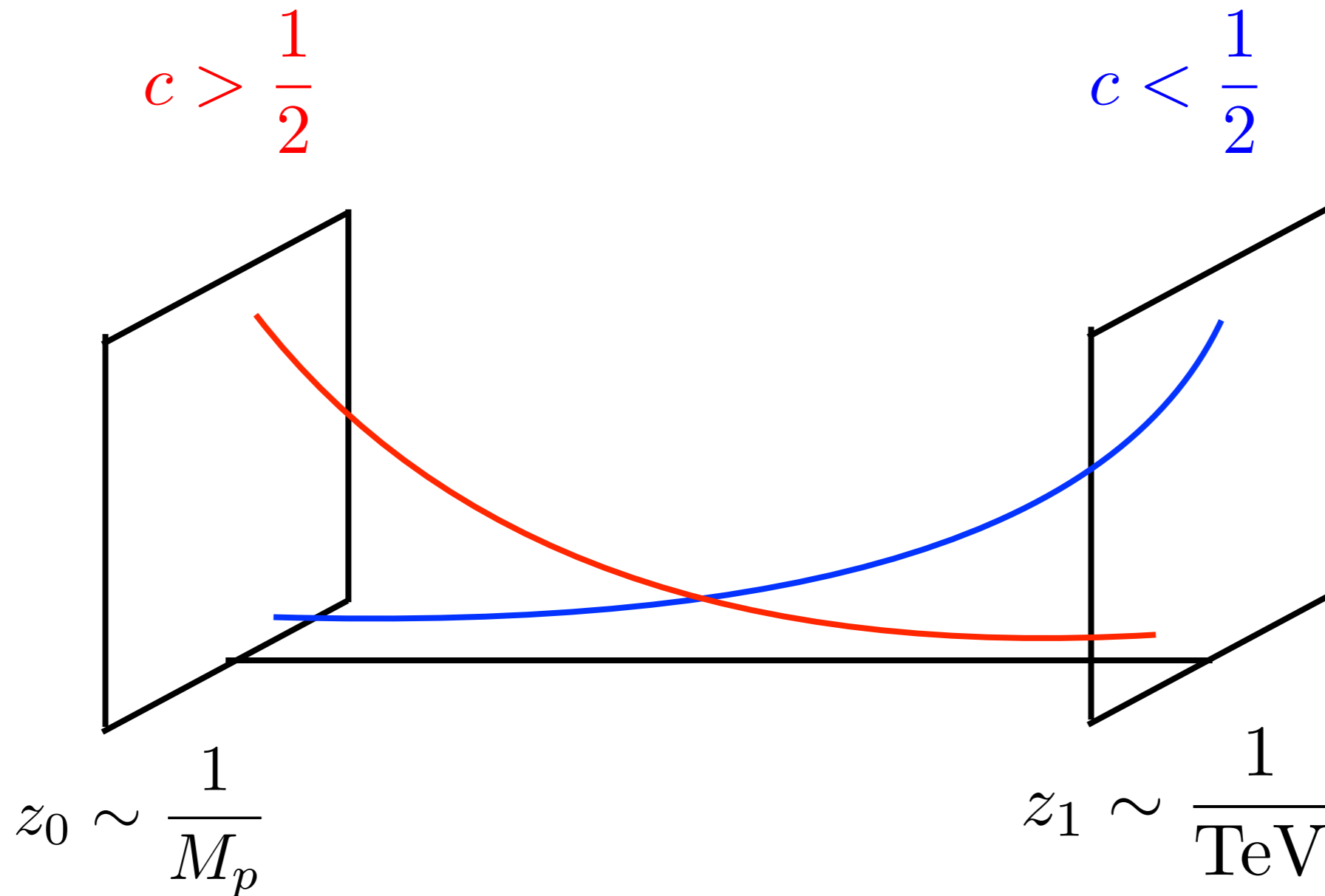
Back-up Slides

Lesson from Electroweak Precision Test

$$S_H = \frac{\xi}{12\pi} \ln \frac{\Lambda^2}{m_Z^2}, \quad T_H = -\frac{3}{16\pi} \frac{\xi}{c_w^2} \ln \frac{\Lambda^2}{m_Z^2}$$



Partial compositeness: AdS



Randall and Sundrum 99'
Davoudiasl, Hewett and Rizzo 99'
Pomarol 99'
Grossman and Neubert 99'
Gherghetta and Pomarol 00'

$$c = \frac{M_\Psi}{k}$$

Partial compositeness: CFT

$$y_L \bar{q}_L^{I_L} \mathcal{O}_{I_L} + y_R \bar{q}_R^{I_R} \mathcal{O}_{I_R}$$

$$d_{\mathcal{O}} = \frac{3}{2} + |c + \frac{1}{2}|$$

$$y_{L,R}^{\text{IR}} \sim y_{L,R}^{\text{UV}} \left(\frac{\Lambda_{\text{IR}}}{\Lambda_{\text{UV}}} \right)^{d_{\mathcal{O}_{L,R}} - \frac{5}{2}}$$

Scale Hierarchy turn to coupling hierarch