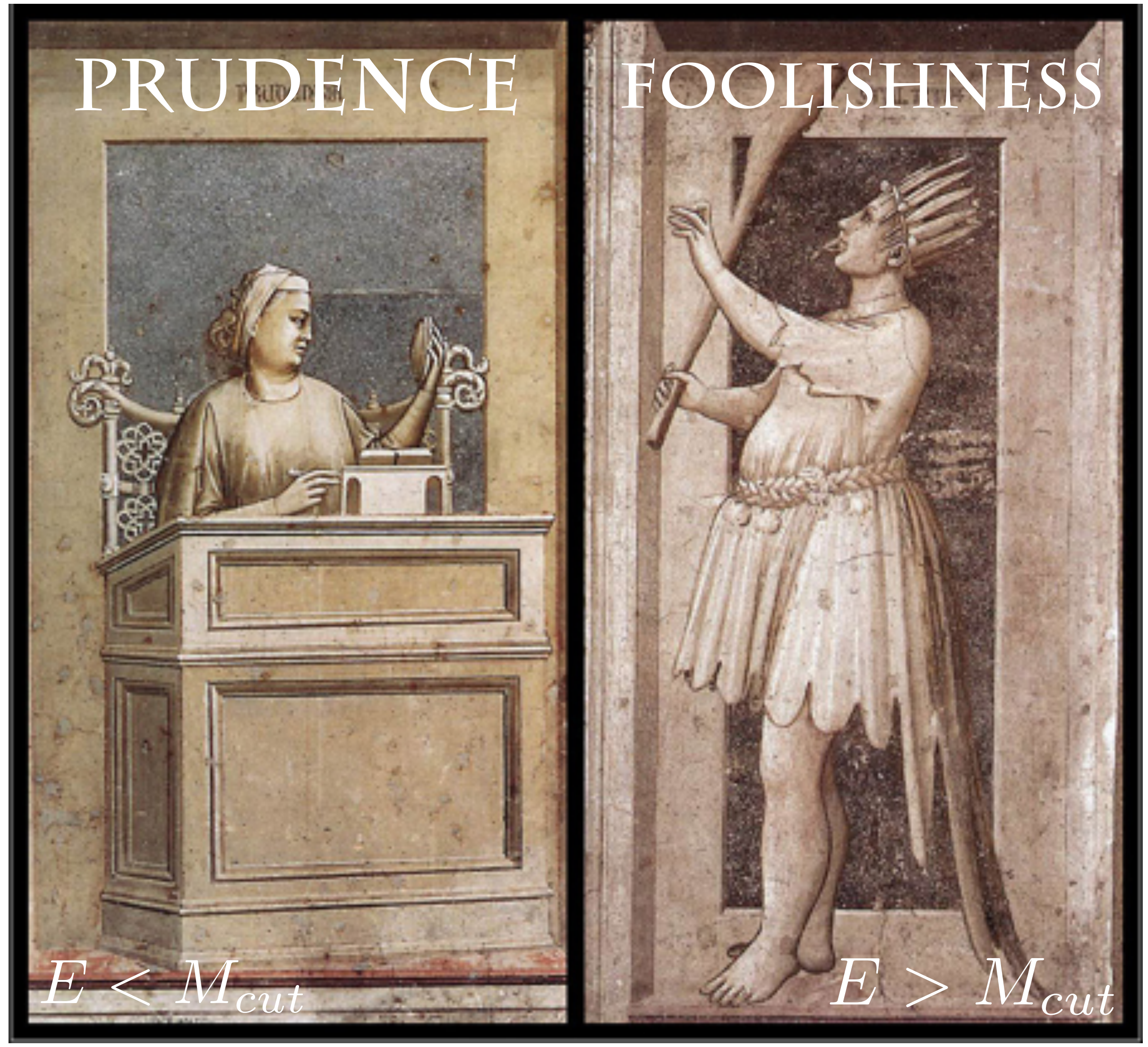
Comments on the EFT Validity



Francesco Riva (CERN)

Based on LHCHXSWG2 internal note
written by
Contino, Falkowski, Goertz, Grojean, and FR

includes multiple comments received by email and vidyo conference last Friday

Effective Field Theory

Expansion in physical scale of new physics Λ:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4}\mathcal{O}_j^{(8)} + \cdots$$

$\mathcal{O}_i^{(D)}$ = field operators of dimension-D

Wilson coefficients:

$$\boxed{c_i^{(D)} \sim (\text{coupling})^{n_i-2}}$$

n_i: number of fields in $\mathcal{O}_i^{(D)}$ independently of D

(can be easily seen by counting powers of $\hbar \neq 1$)

Cohen,Kaplan,Nelson'97; Luty'97
Giudice,Grojean,Pomarol,Rattazzi,'07

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Why EFT?

Motivation for precision tests: SM test → New Physics Search

Organisation e.g. E/Λ expansion = hierarchy between departures from SM

Self-Consistency Check Perturbativity $(E/\Lambda, \text{coupling} \times v/\Lambda) \ll 1$

E: relevant experiment energy

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(E: relevant experiment energy)

- Under what conditions does it faithfully describe some BSM at low-energy?
- When is it justified to truncate the EFT expansion at dimension-6? Exceptions?

Can validity of (truncated) EFT be established model-independently?

Problem: Expansion Validity: $E/\Lambda \ll 1$
Experimentally: better access to leading $c_i E^2/\Lambda^2$
Truncation depends on $c^{(8)}_i E^4/\Lambda^4$

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Example: Fermi theory $\frac{2}{v^2}\bar{\psi}_{\nu_\mu}\gamma^\mu\psi_\mu\bar{\psi}_{\nu_e}\gamma^\mu\psi_e$ is it valid up to v=246 GeV?

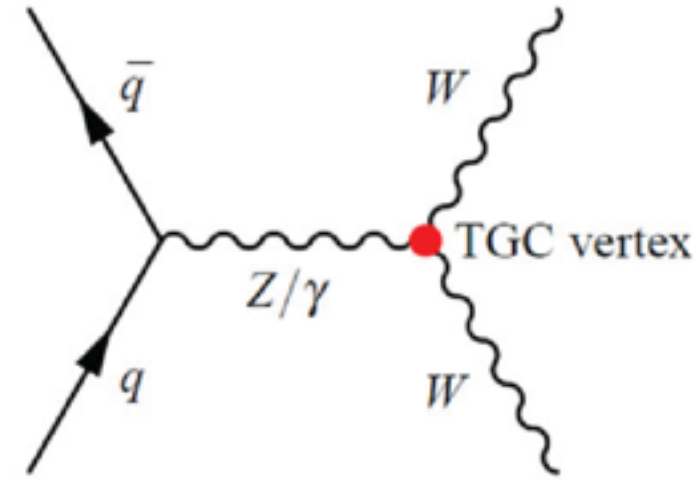
No, only to $E = m_W = \frac{g}{2}v \approx 81\ \mathrm{GeV}$ $\quad c_i^6 = c_i^8 = g^2$

* Weak couplings reduce the validity range of the EFT (as naively expected)
* Strong couplings extend it (for $g=4\pi$ Fermi theory ok up to $E\approx 3$ TeV!)

LHC High-P_T exemple

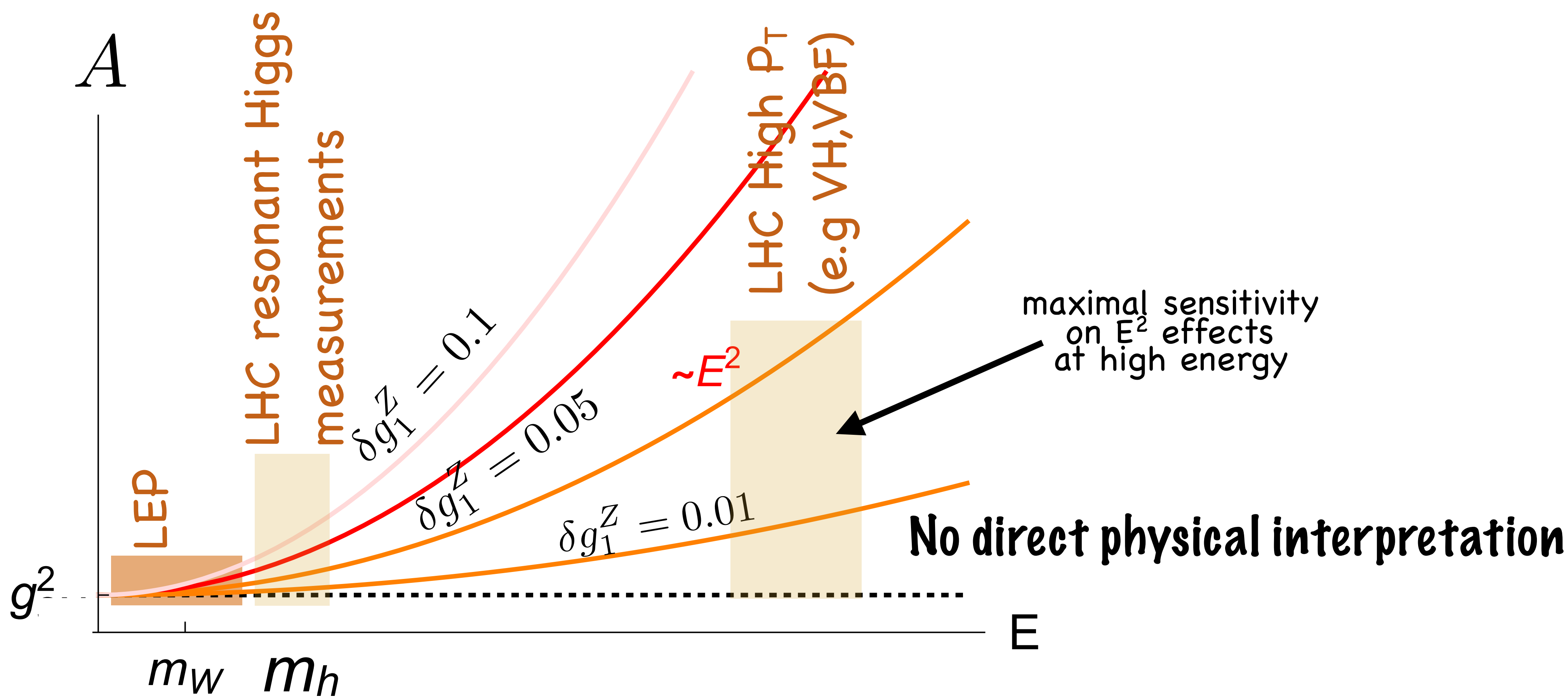
Anomalous Couplings:

- **Exemple:** $\delta g_1^Z Z^\nu W^{-\mu} W^+_{\mu\nu}$



$$A \simeq g^2 \left(1 + \frac{\delta g_1^Z}{g} \frac{E^2}{m_W^2}\right) \equiv g^2(E)$$

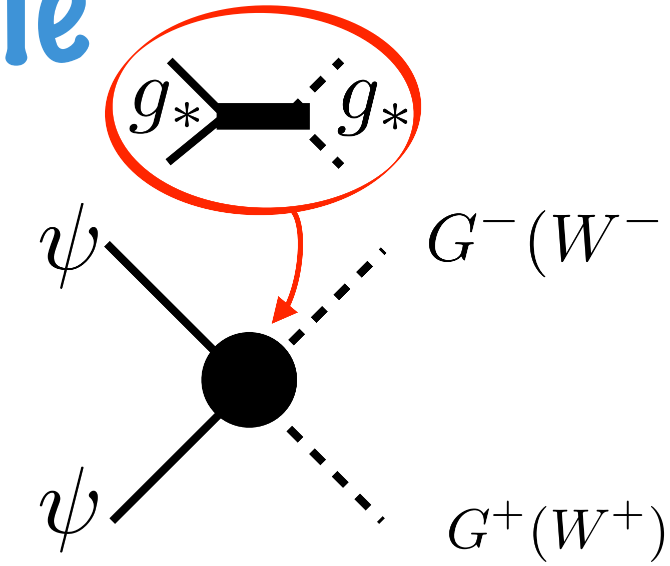
Same as LEP?



LHC High-P_T exemple

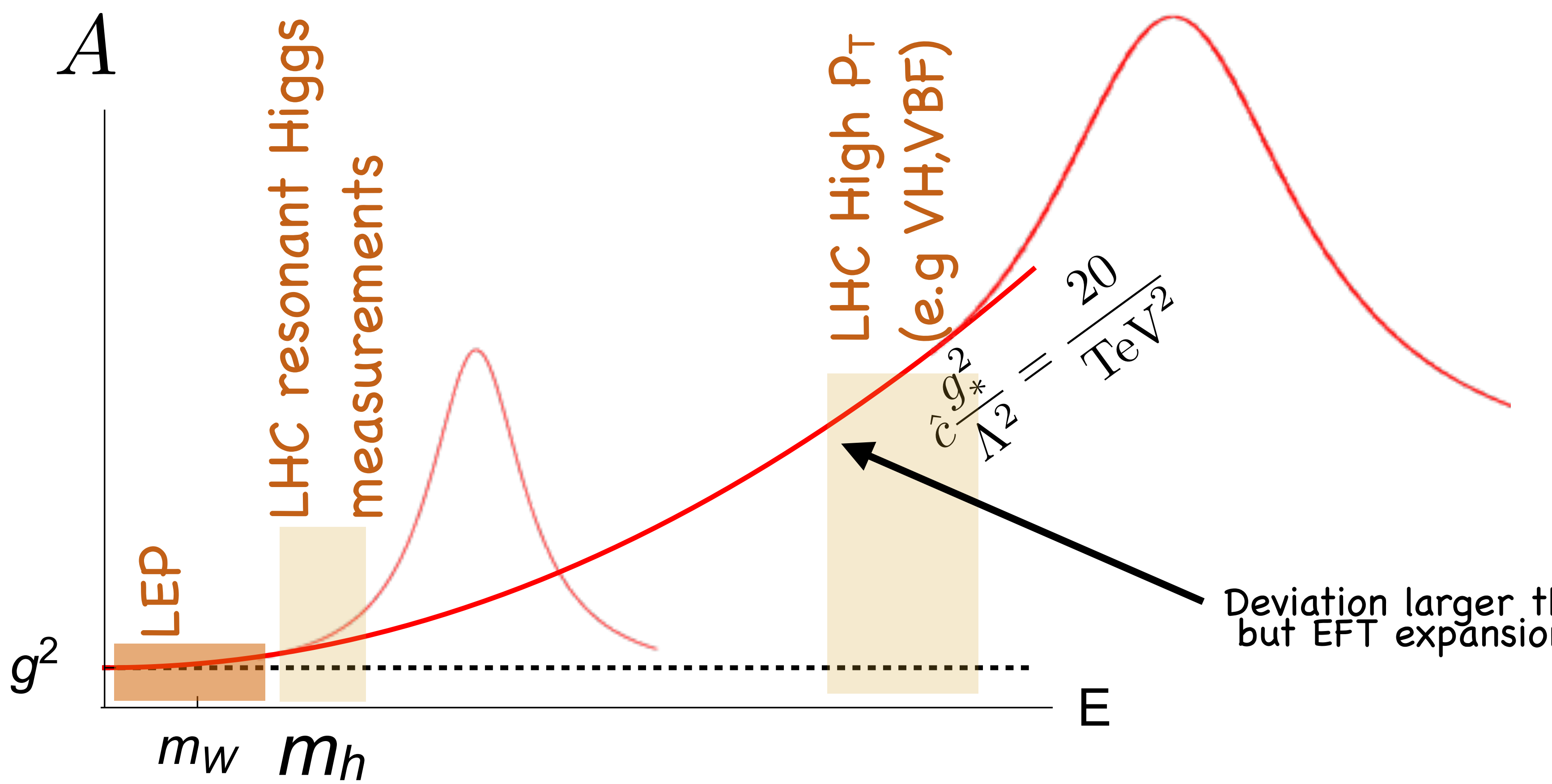
EFT:

- **Exemple:** $\frac{g_*^2}{\Lambda^2} H^\dagger D_\mu H \bar{\Psi}\gamma^\mu \Psi$



$$A \simeq g^2 \left(1 + \hat{c}\frac{g_*^2}{g^2}\frac{E^2}{\Lambda^2}\right)$$

Not Same as LEP



Although similar constraint as LEP on cg^{*2}/Λ^2, the LHC one consistent only for large g*>g

Broad BSM hypothesis

One new scale Λ - One (new) coupling g* - Symmetries

Giudice,Grojean,Pomarol,Rattazzi,'07

- Simple
- Captures most BSM scenarios (at least in some limit)
- For $0 \lesssim g_* \lesssim 4\pi$ interpolates from NDA to weakly coupled theories with $c_i \lesssim 1$

Georgi,Manohar

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Exemple:

$$\frac{c_T}{\Lambda^2}(H^\dagger \overleftrightarrow{D}_\mu H)^2 \qquad c^{(6)} \simeq \begin{cases} 0 \\ g_*^2 \end{cases}$$

If BSM custodial
If BSM not custodial

$$\frac{c^{(8)}}{\Lambda^4}(D_{\{\mu}H^\dagger D_{\nu\}}H)^2 \qquad c^{(8)} \simeq g_*^2$$

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$$\frac{c^{(8)}}{\Lambda^4}(D_{\{\mu}H^\dagger D_{\nu\}}H)^2 \qquad c^{(8)} \simeq g_*^2$$

- Gives physical meaning to assumption $c^{(6)} \simeq c^{(8)}$

  (not always the case: power counting keeps track of situations where this is a good assumption)

  - Expansion and truncation at dim-6 controlled by $\kappa^2 \equiv \frac{E_{max}^2}{\Lambda^2} \ll 1$

    one source of th. error

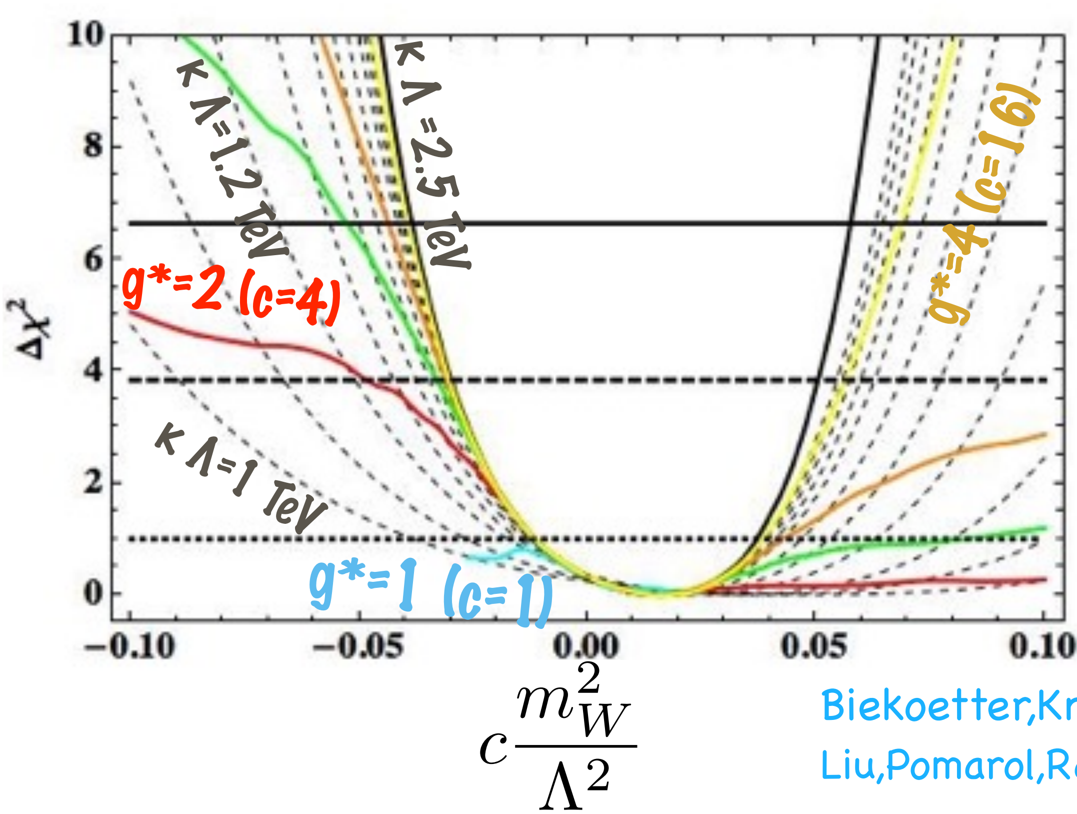
- Gives interesting range for $0 \lesssim |c^{(6)}| \lesssim (4\pi)^2$
- Allows results to be consistently presented in $(c, \kappa\Lambda)$ or $(g_*, \kappa\Lambda)$ plane

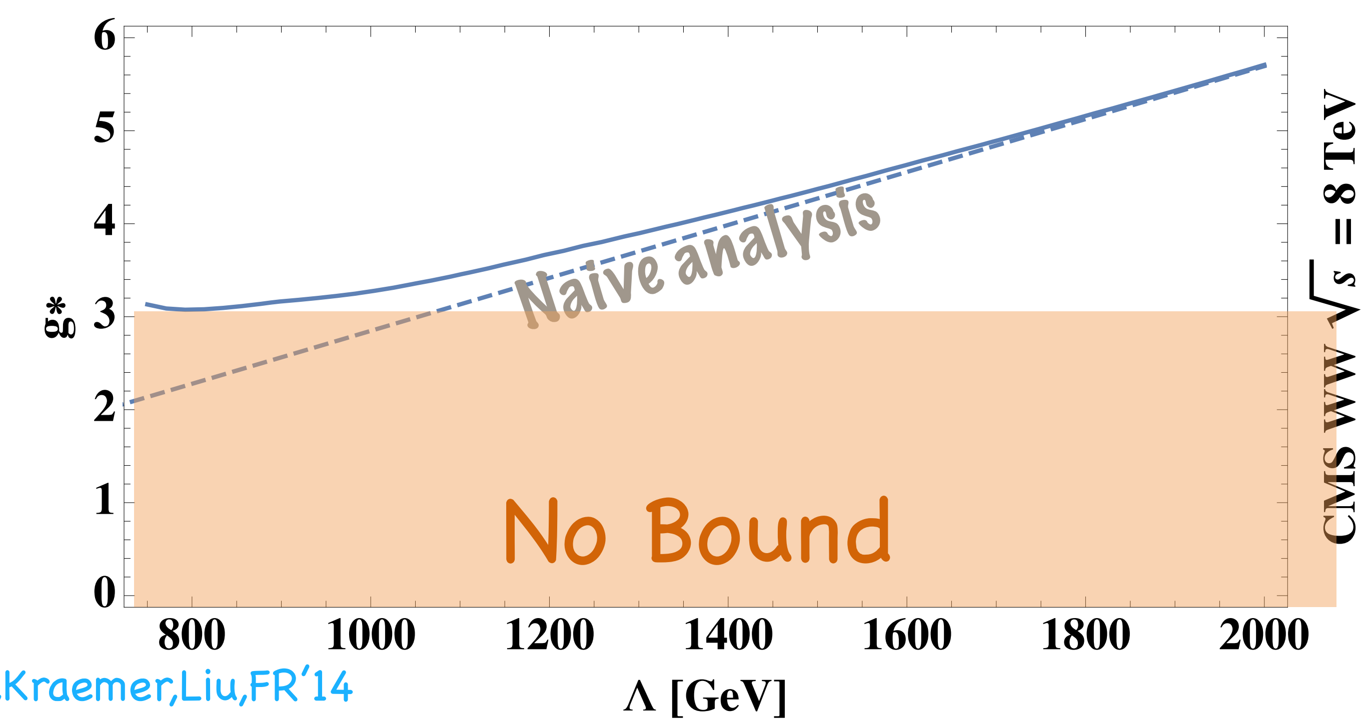
Why is this relevant?

Results presentable in $(c, \kappa\Lambda)$ or $(g_*, \kappa\Lambda)$ plane

Procedure for analyses with large kinematic range:

- EFT validity condition can be imposed by repeating analysis with extra cut on $\sqrt{s} < \kappa\Lambda$ for different values of $\kappa\Lambda$ κ<1 measures how much error to tollerate
- Bounds on c/Λ^2 can be shown for different $c=g_*^2$ and in $(c,\kappa\Lambda)$ plane

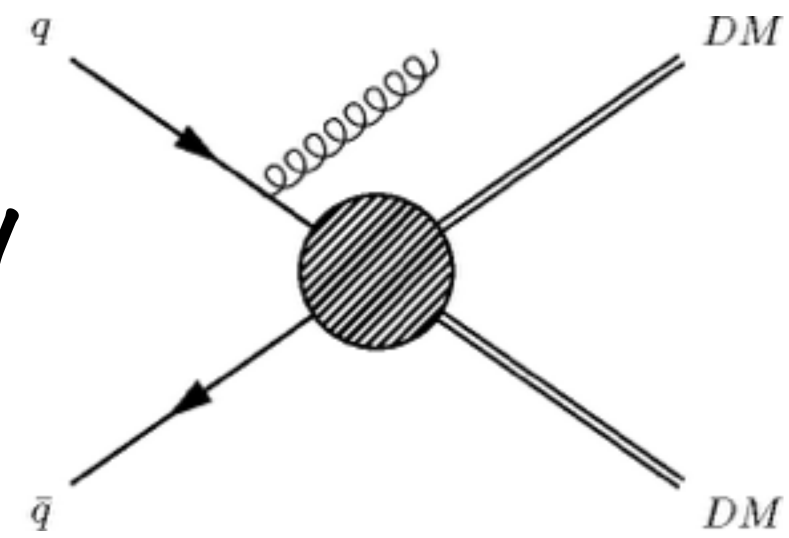




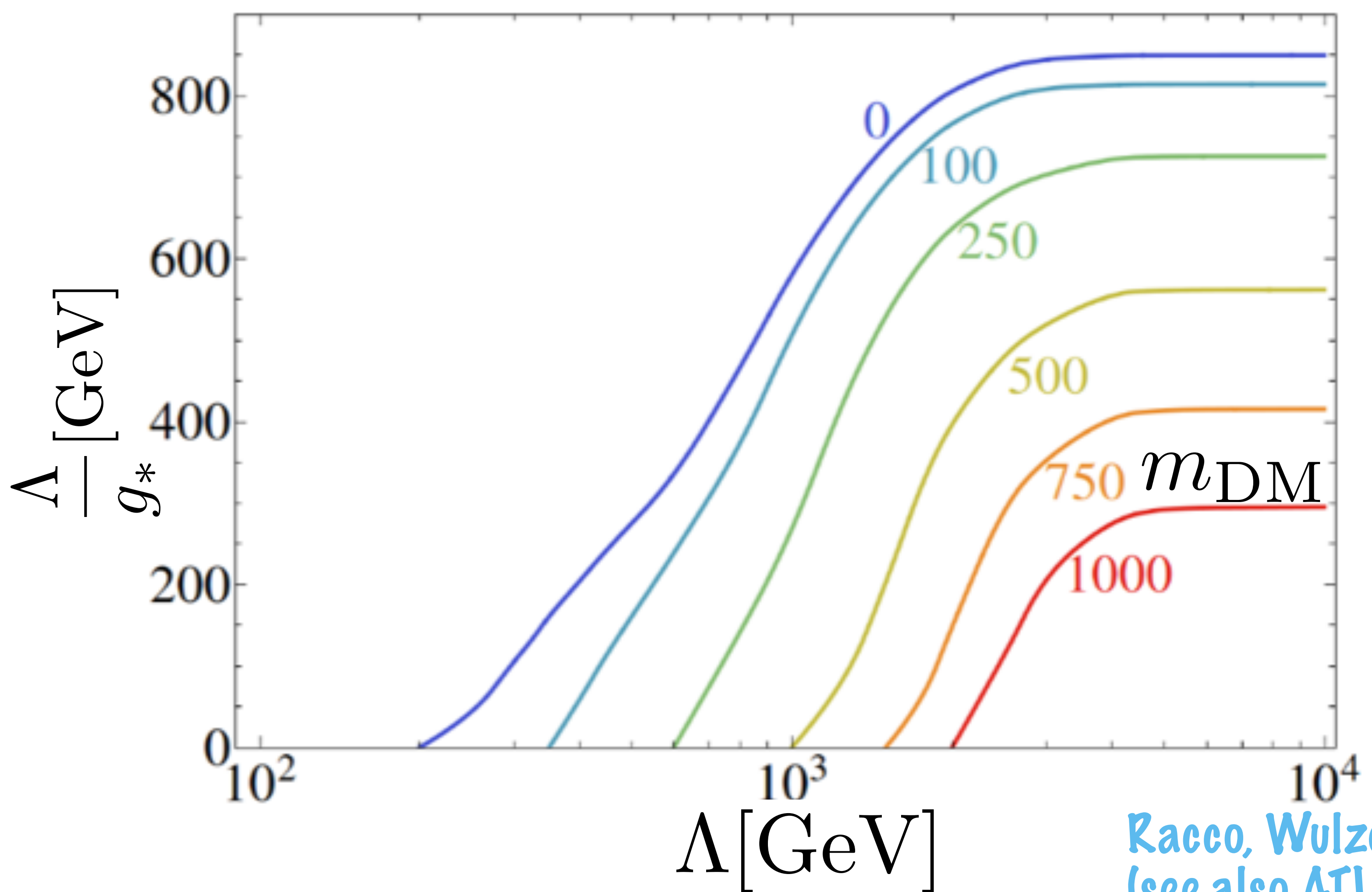
Biekoetter,Knochel,Kraemer,Liu,FR'14
Liu,Pomarol,Rattazzi,FR 'to appear

→ Contains all information in terms of transparent physical parameters, for transparent physical assumptions

Similar as DM mono-jet searches



Issue and solution well-known in DM community



Racco, Wulzer, Zwirner'15
(see also ATLAS - 1502.01518)

Important Remarks - Signal!

Higher Precision (around measurement) ⇔ NLO + terms higher order E/Λ
improve characterization of UV model

Important Remarks - no signal

$$A \simeq g^2 \left(1 + \hat{c}\frac{g_*^2}{g^2}\frac{E^2}{\Lambda^2}\right)$$

Higher Precision ⇹ Smaller Deviations ⇹ Improved Expansion Validity

(for constraints)

(weaker coupling or larger scale)

loop effects proportionally small,
more theories with dim-8 negligible**,

we are yet to observe the leading piece of the expansion.

**exceptions later

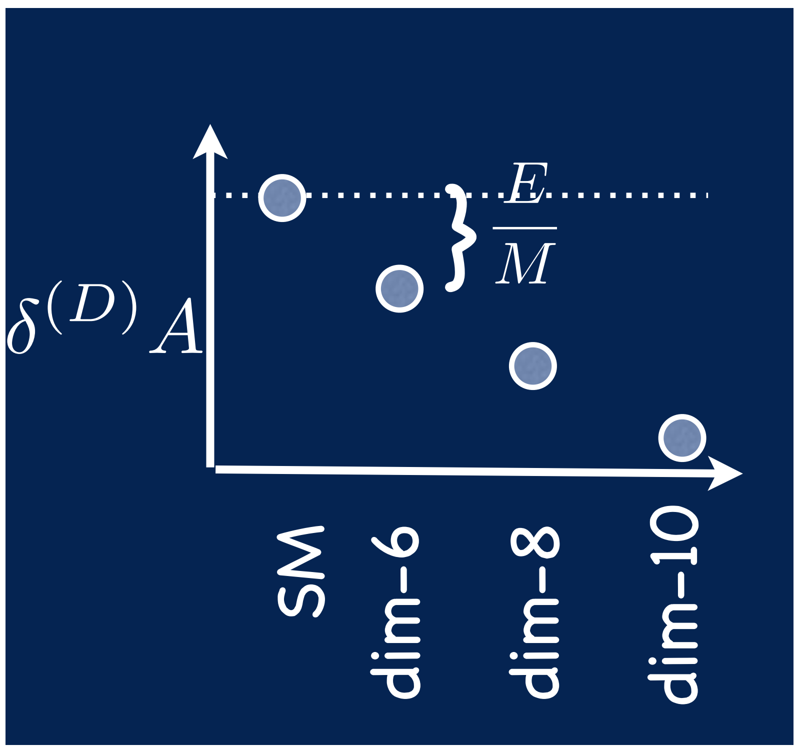
Important Remarks

$$A \simeq g^2 \left(1 + \hat{c}\,\frac{g_*^2}{g^2}\frac{E^2}{\Lambda^2}\right)$$

BSM can be > 1 for g*/g>Λ/E>>1

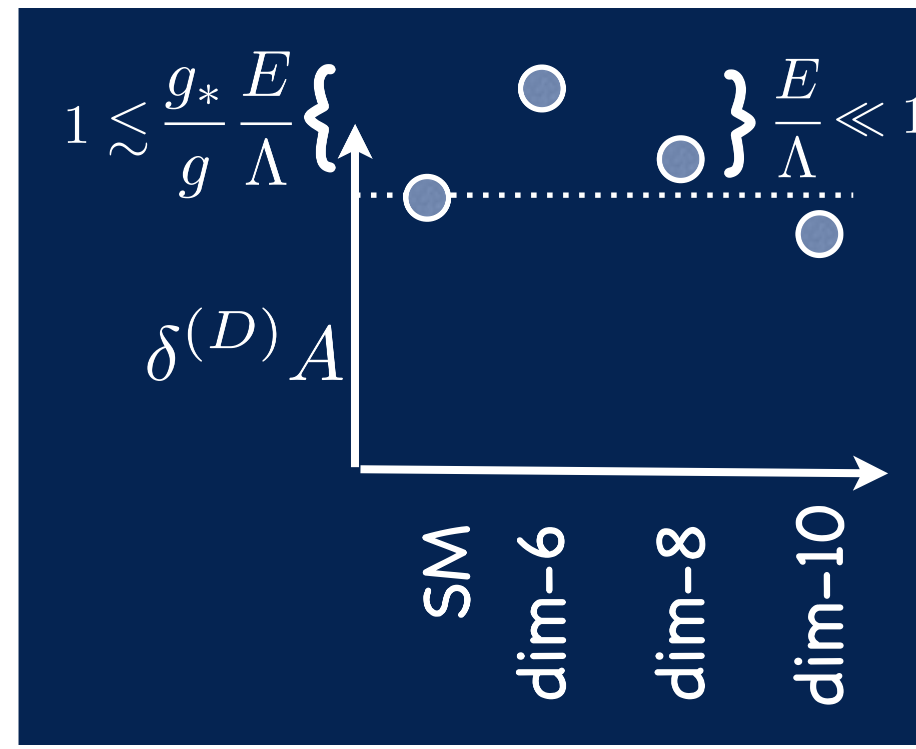
EFT valid

Small Deviations from SM



→Interpretation possible for small or large coupling

Large Deviations from SM



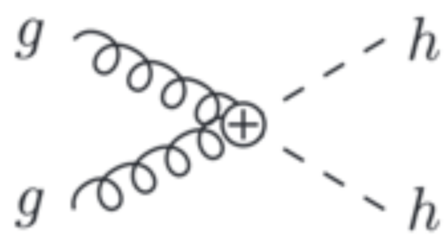
Interpretation possible **ONLY** for strong coupling (EFT expansion still valid)

Exceptions

1 - Symmetries/Selection rules can suppress dim-6 but allow dim-8

Exemple: If H is a PNGB:

$$H \to H + \alpha$$



$\epsilon\, |H|^2 G^a_{\mu\nu} G^{a,\mu\nu}$ ✗

$D_\lambda H^\dagger D^\lambda H G^a_{\mu\nu} G^{a,\mu\nu}$ ✓

Azatov,Contino,Panico,Son'15

(See extended discussion in notes)

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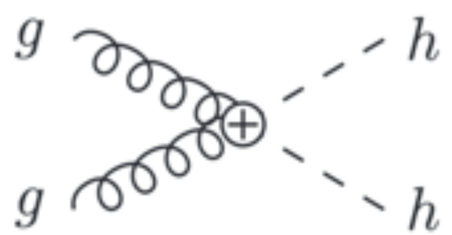

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2 - Accidental zeros at Leading order

For some processes dim-6 just do not contribute, but dim-8 do

(Exemple: s-channel neutral gauge boson pair-production)

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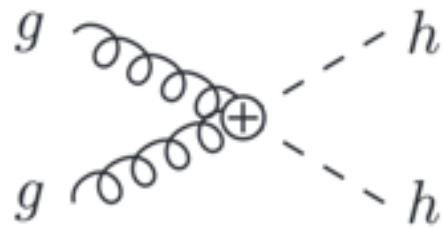

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3 - Fine tuning

Unexpected, not capturable by power counting

Unstable under RGE (opposite to symmetries)

(See extended discussion in notes)

Conclusions

* EFT necessary to parametrize departures from SM
  - Better precision, stronger constraints, applicable to wider classes of theories, better the expansion!
* Question of EFT validity relies on generic BSM hypotheses to relate value of Wilson coefficients $c_i^{(6)}$ and $c_i^{(8)}$ to physical BSM quantities
* Simple concrete framework (one scale Λ,one coupling g*,symmetries):
  - Control over parameters in expansion → truncation justified
  - Analyses with different cuts in experiment energy, allow to show constraints in physical (g*,κΛ) or (c,κΛ) plane
  - Regions with BSM>SM (ubiquitous in LHC searches) EFT-allowed in strong coupling limit
* Dim-8 can generically be neglected unless symmetry structure suppresses dim-6: this interesting cases can be studied case-by-case