Precision Tests At High Energy

Francesco Riva - CERN

In collaboration with Liu, Pomarol, Rattazzi (appear next week)

Also Contino,Falkowski,Goertz,Grojean (YR4) and Biekotter,Knochel,Kraemer,Liu(2014)

Why EFT Parametrization?

Necessary for precision tests:

Motivation (SM test -> New Physics Search)

Organisation

(e.g. E/M expansion indicates hierarchy between departures from SM)

Self-Consistency Check

perturbativity of physical expansion (no need to invoke unitarity)

What is the problem?

Validity: $E/M \ll 1$

But experimental access to cE^2/M^2

Wilson coefficient

Can EFT validity be established model-independently?

No. Question on EFT validity depends on (broad) BSM hypotheses.

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 ip to v=246 GeV?

No, only to $E = m_W = \frac{g}{2}v \approx 81\ \mathrm{GeV}$

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

→ LHC relies on this

How can we know about couplings without resorting to simplified models?

EFT is actually an expansion in

* Scale
* Coupling
* Numerical coefficients

→O(1) naturally → for symmetries <<1

* Derivatives and fields → Powers of 1/M (matches units of energy)
* Every field → One power of coupling (matches units of $\hbar$)

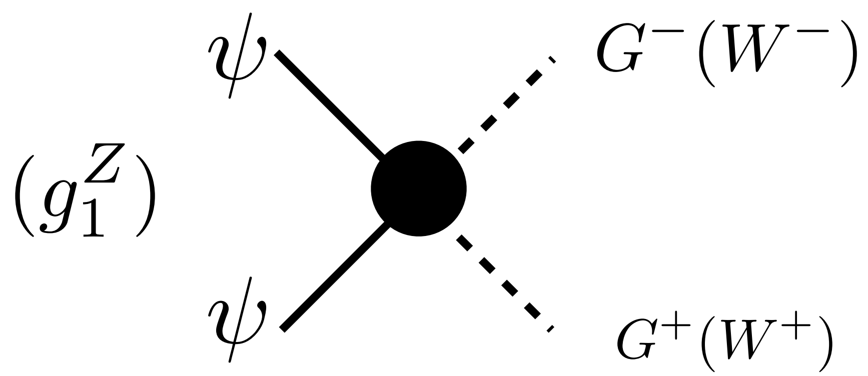
$$\mathcal{L}_{\rm eff} = \frac{M^4}{g_*^2}\mathcal{L}\left(\frac{D_\mu}{M}, \frac{g_H H}{M}, \frac{g_\Psi \Psi_{L,R}}{M^{3/2}}, \frac{g_V F_{\mu\nu}}{M^2}\right) \simeq \mathcal{L}_4 + \mathcal{L}_6 + \cdots$$

Exemples:

$$\frac{g_*^2}{M^2} H^\dagger D_\mu H \bar{\Psi}\gamma^\mu\Psi \quad (g_1^Z)$$

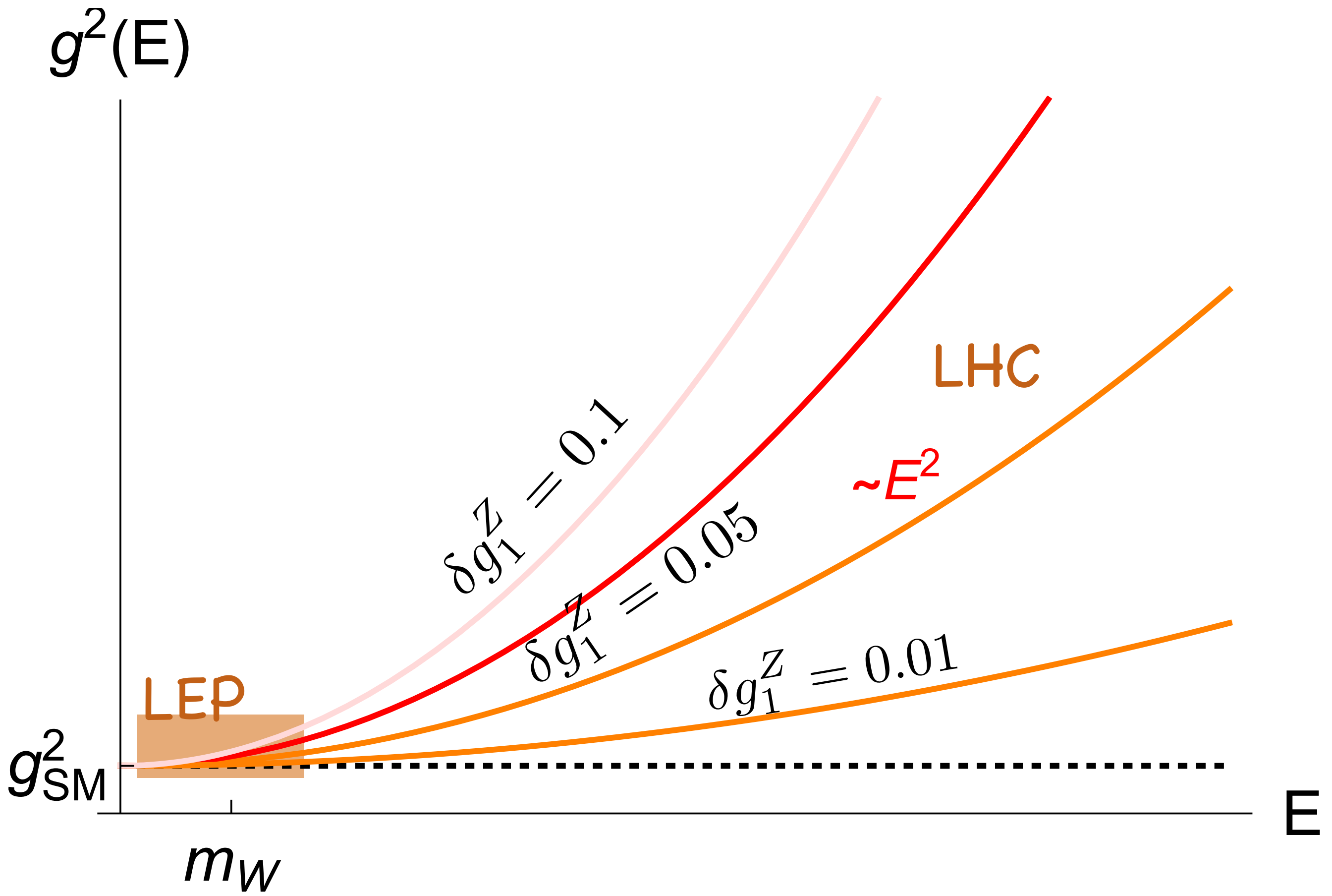
$$\frac{g_*}{M^2}\epsilon_{abc} W_\mu^{a\,\nu} W_{\nu\rho}^b W^{c\,\rho\mu} \quad (\lambda_\gamma)$$

When can LHC results be compared to LEP?



Anomalous Coupling Version

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



(see also Degrande et al'2013)

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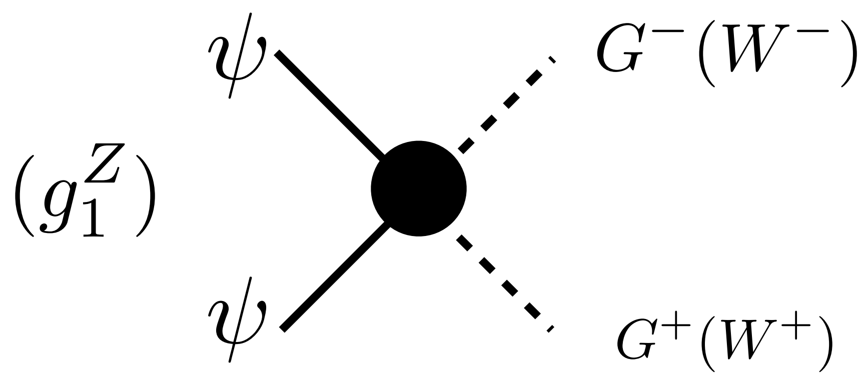

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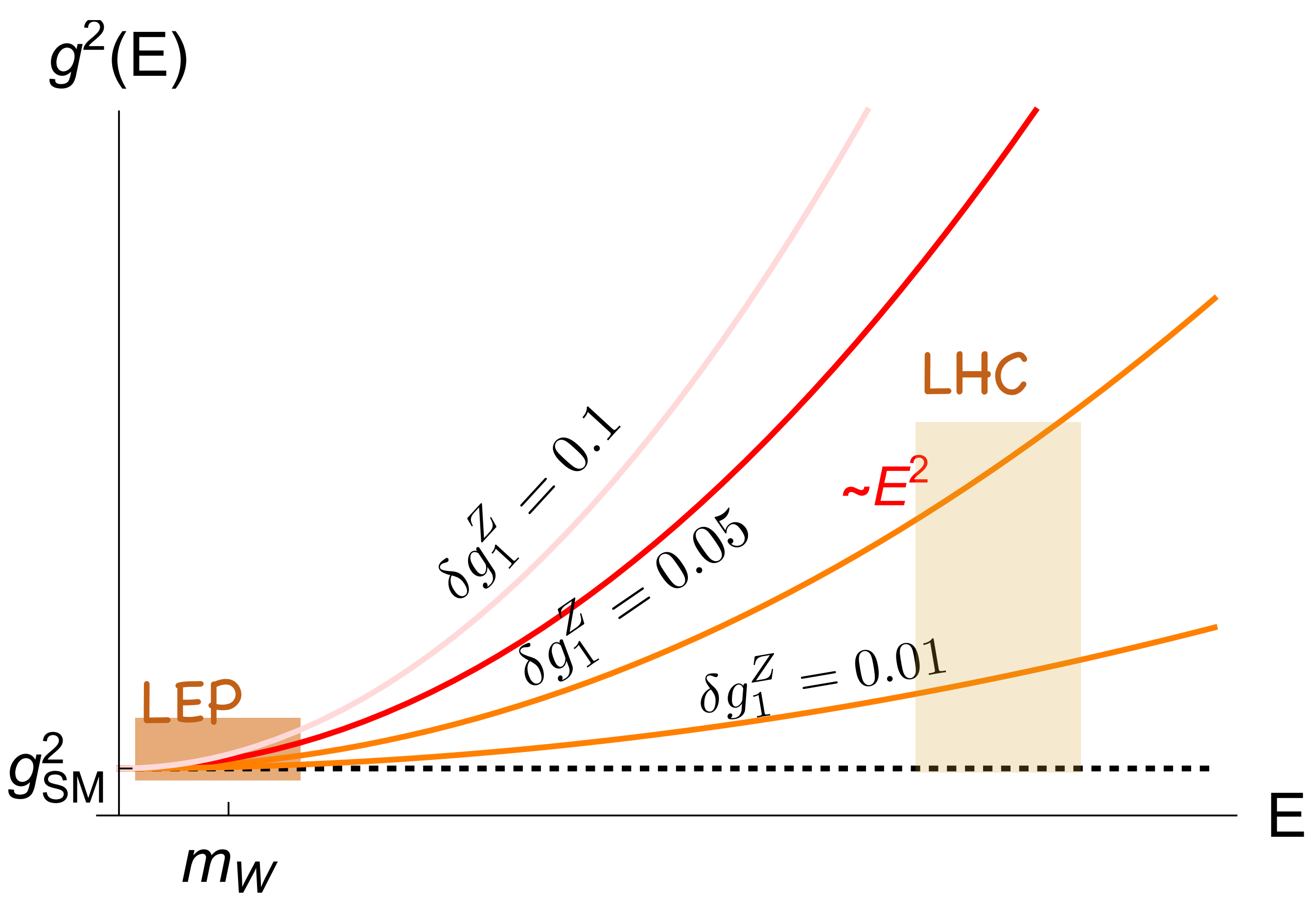

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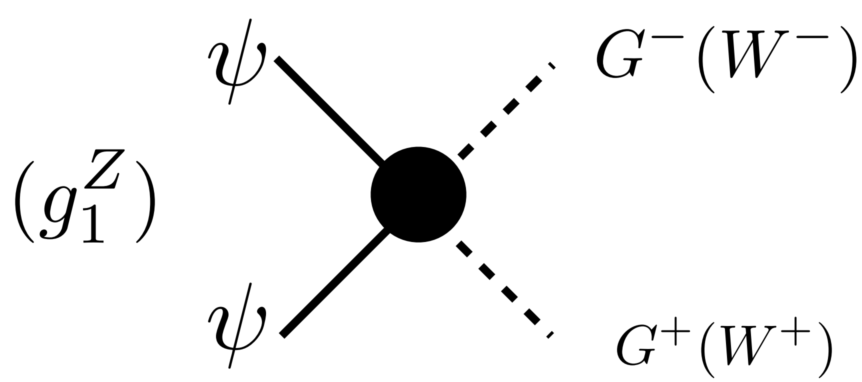

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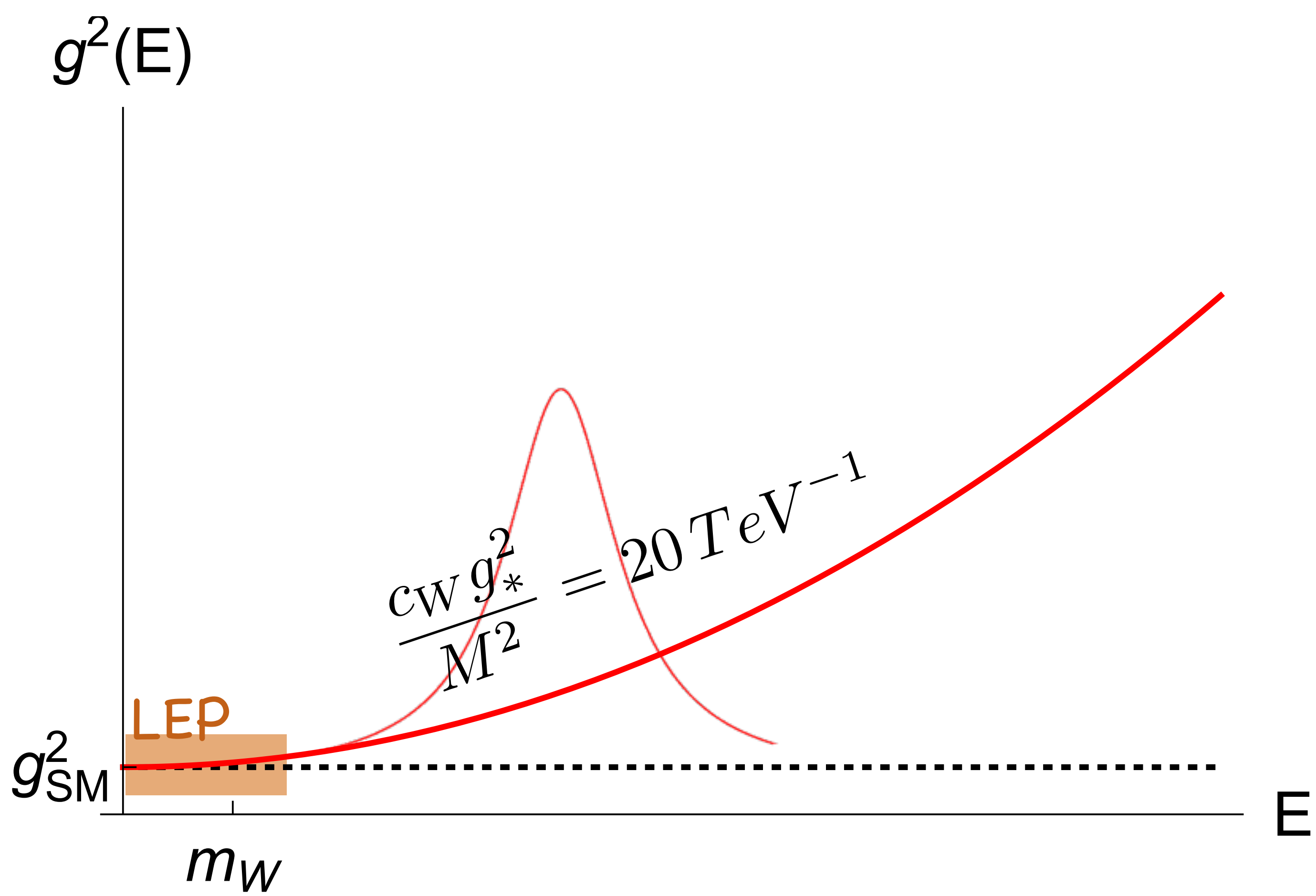
$$A \simeq g^2 \left(1 + \hat{c}\frac{g_*^2}{g^2}\frac{E^2}{M^2}\right) \equiv g^2(E)$$



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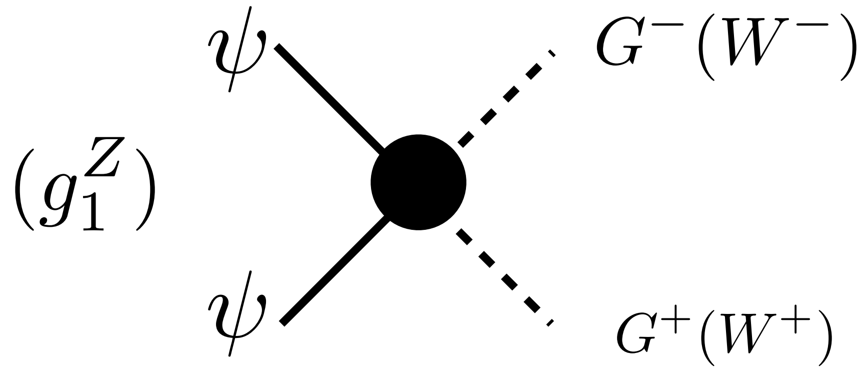

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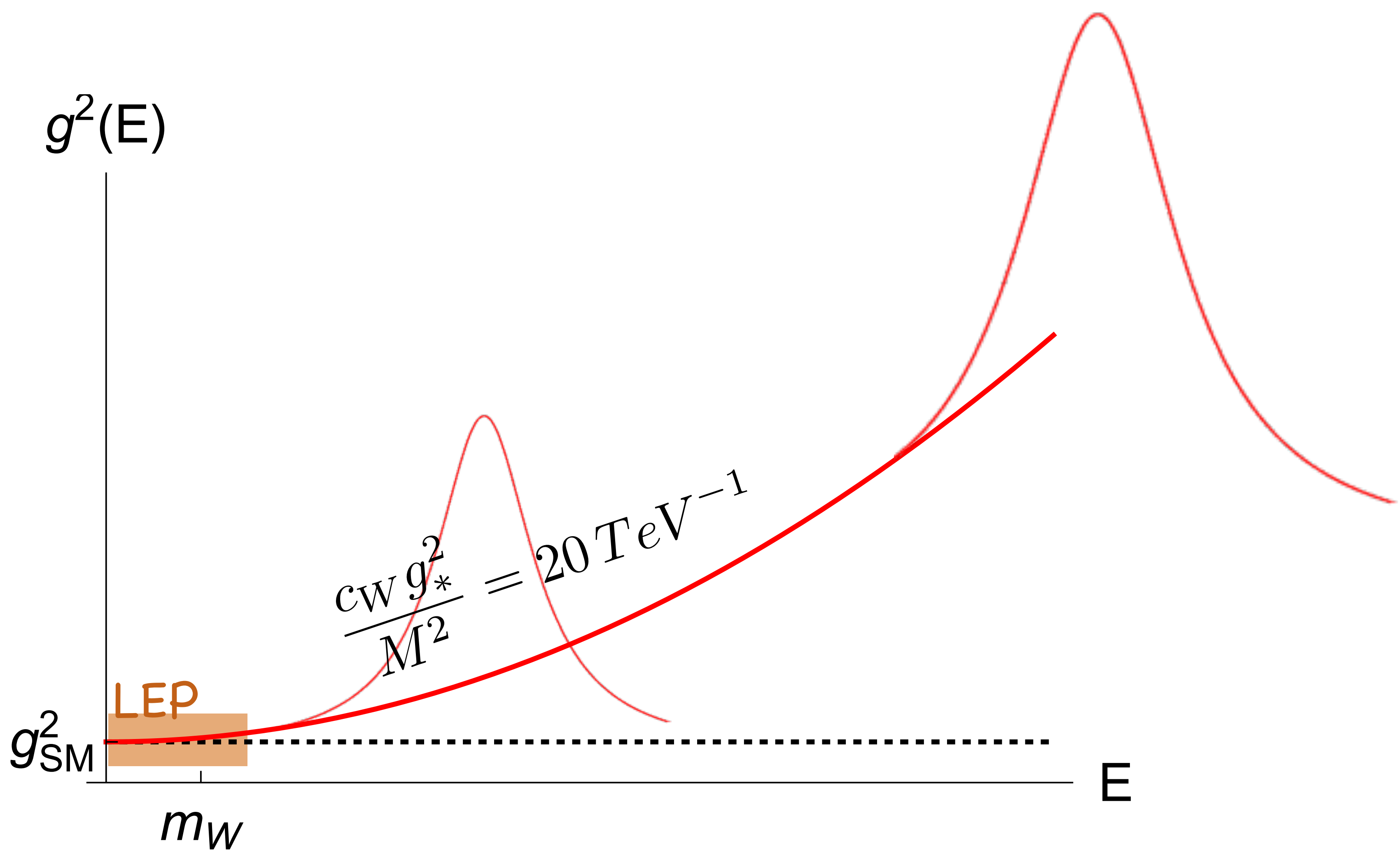

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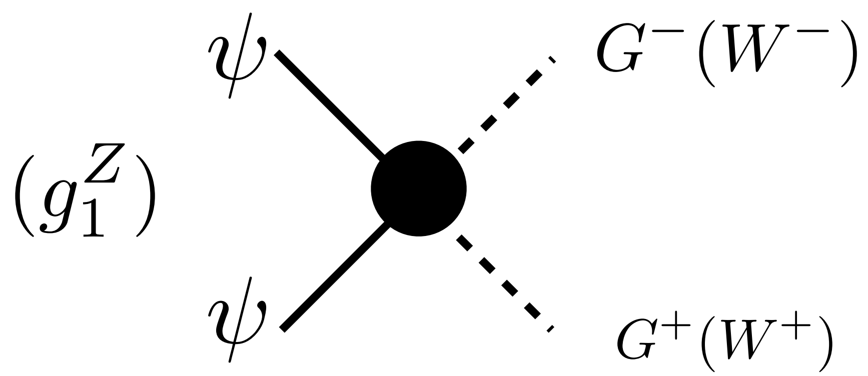

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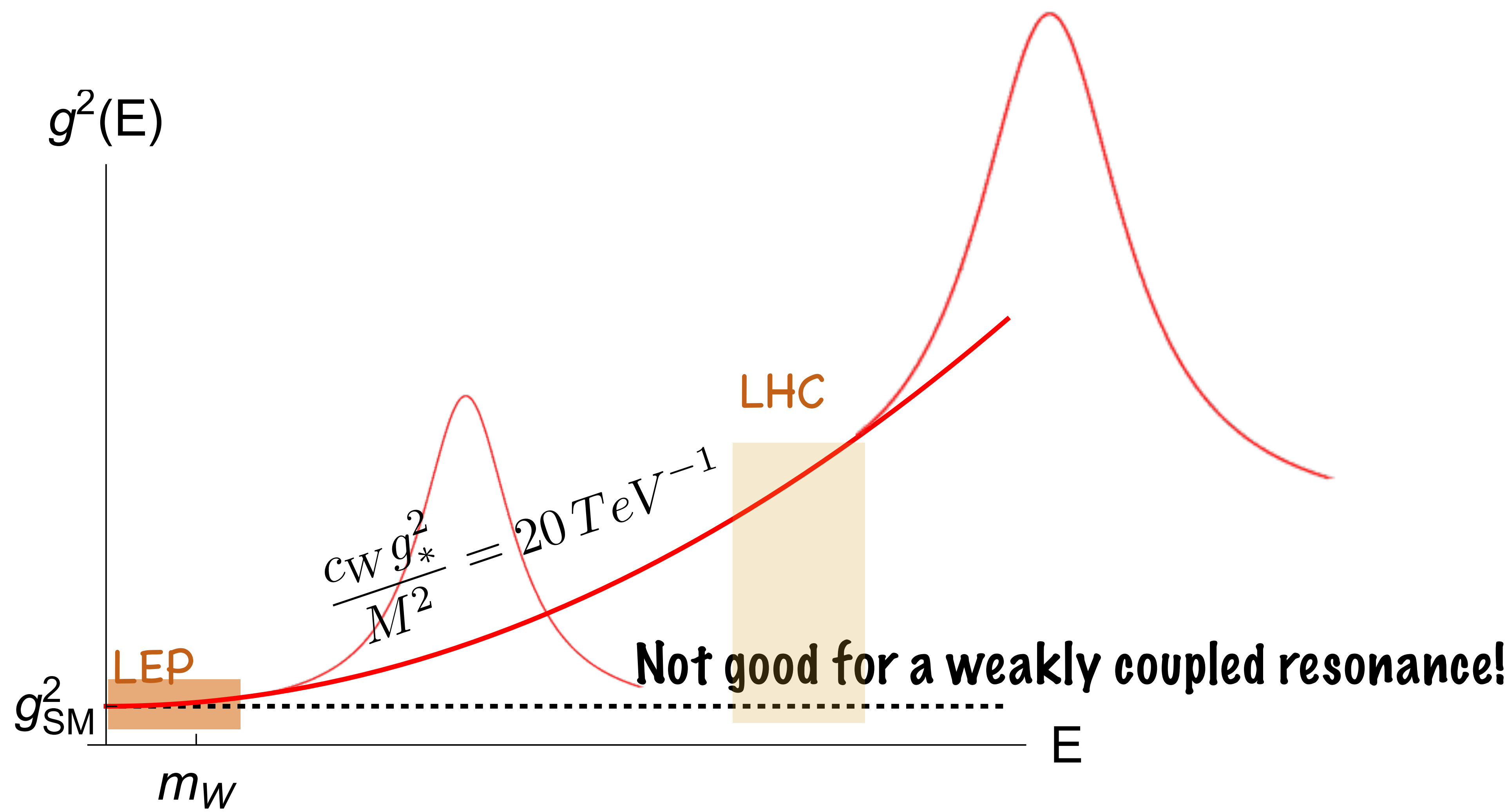

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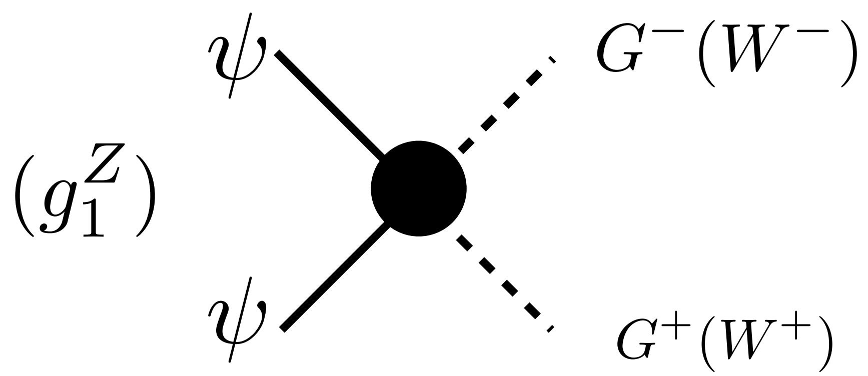

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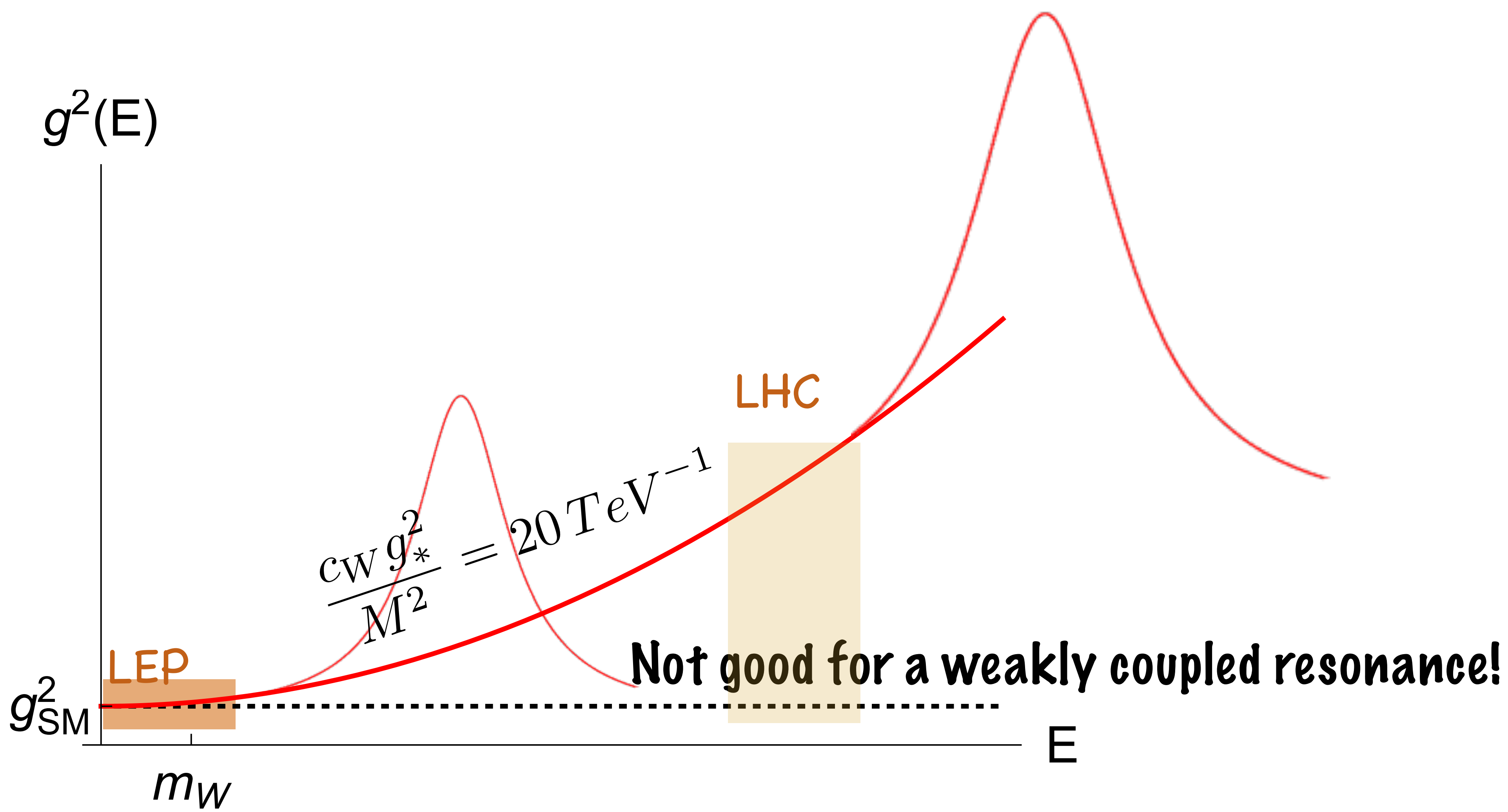
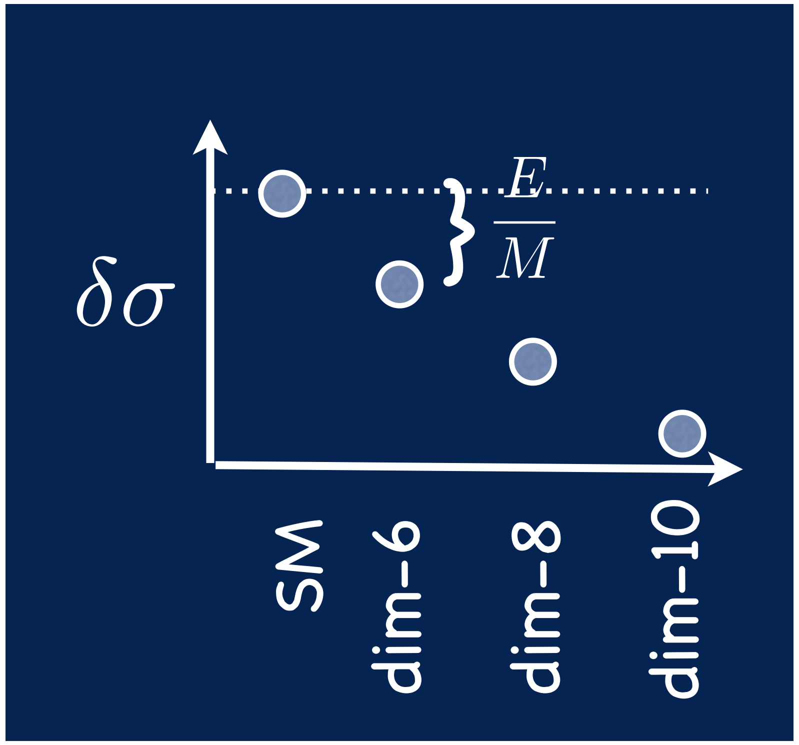
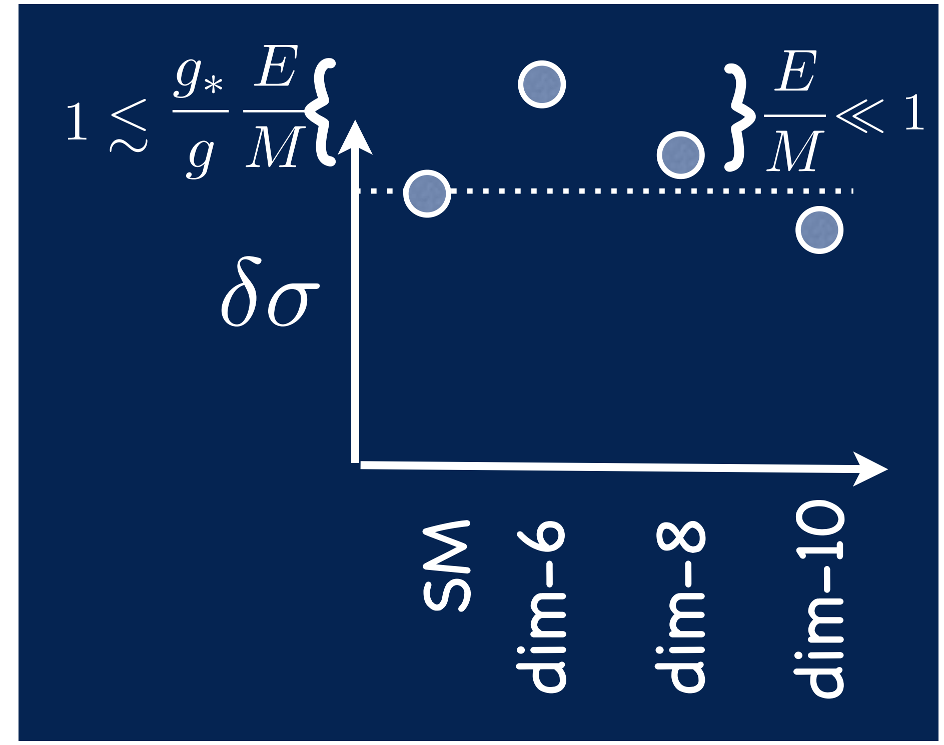


Although similar constraint as LEP on cg*²/M², the LHC one consistent only for large g*>g

But if BSM>SM, then the EFT brakes down?



Not necessarily.



Strong Coupling g*/g can undo energy expansion E/M

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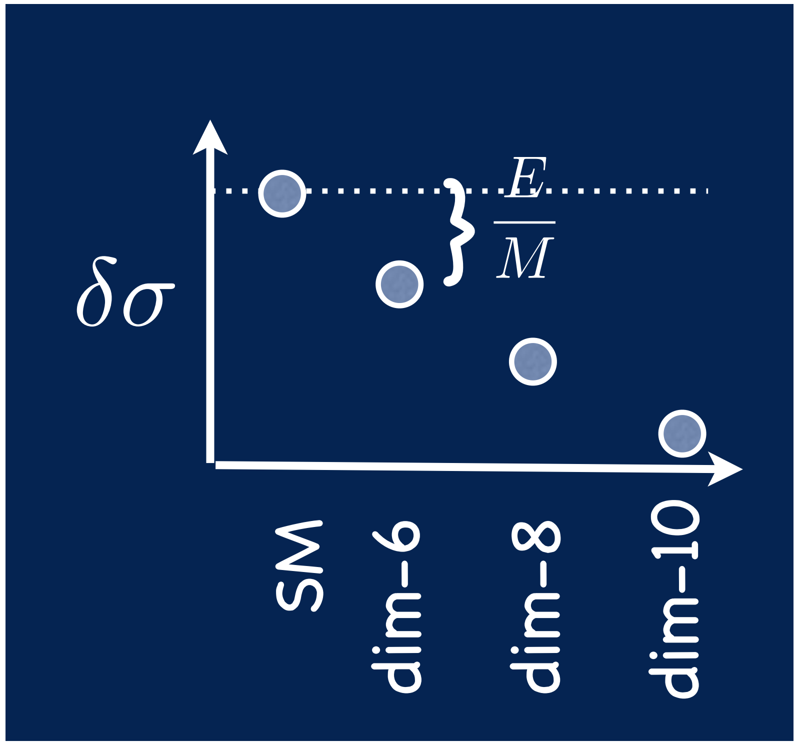

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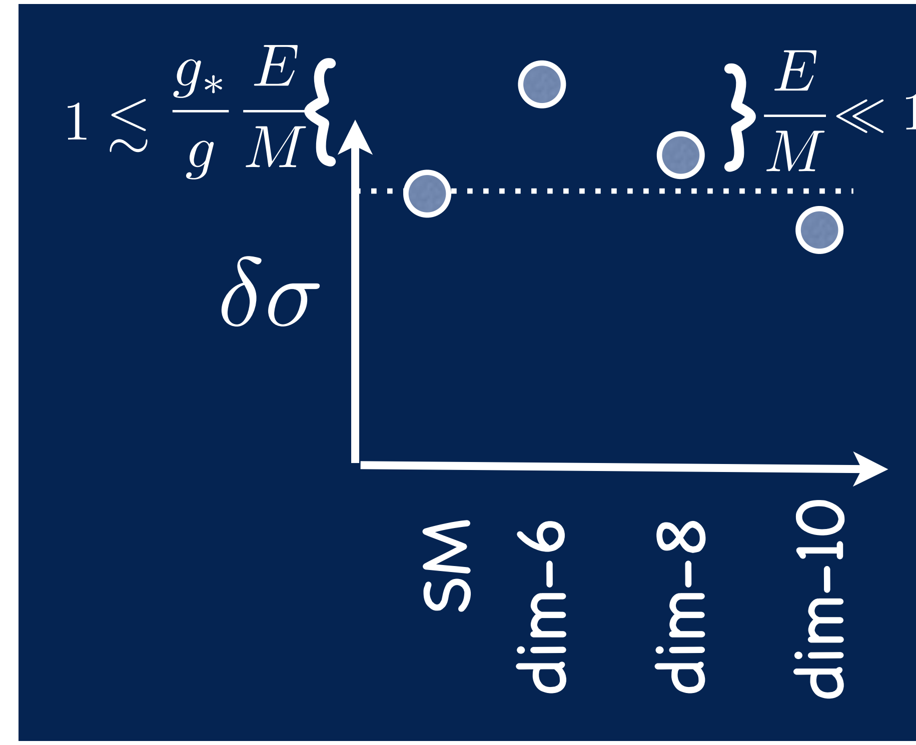
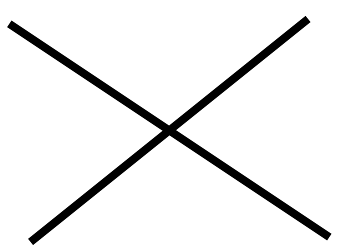
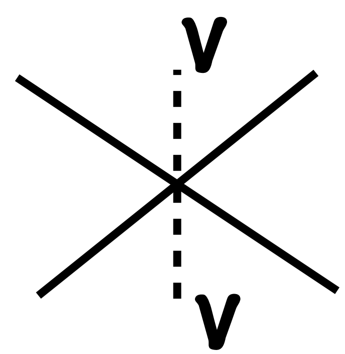


Strong Coupling g*/g can undo energy expansion E/M

Dim-6 vs. Dim-8 contributing to same vertex:

O_6





$O_8 \approx O_6\,(E/M)^2 \ll O_6$

$O_8 \approx O_6\,(g^* v/M)^2 \ll O_6$

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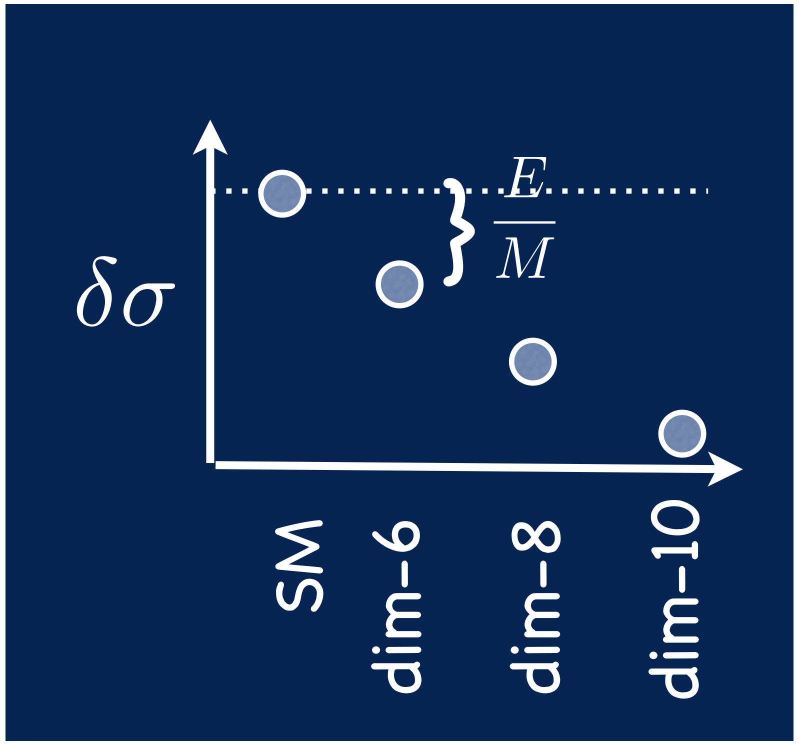

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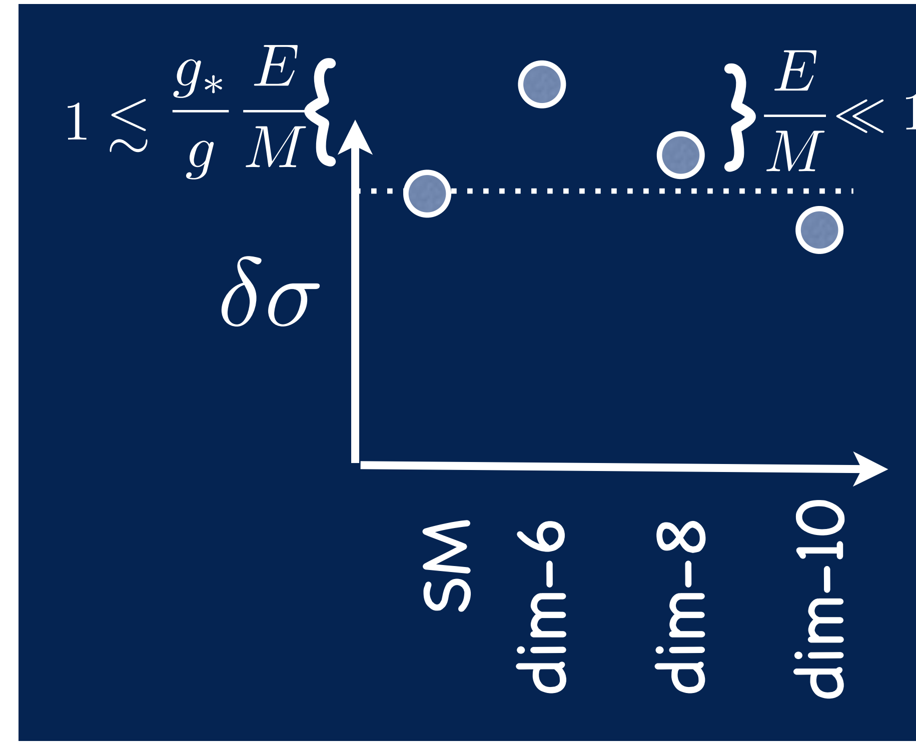

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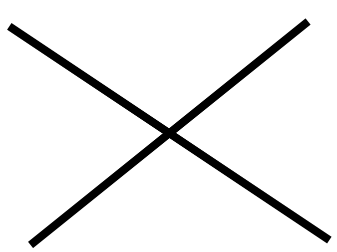
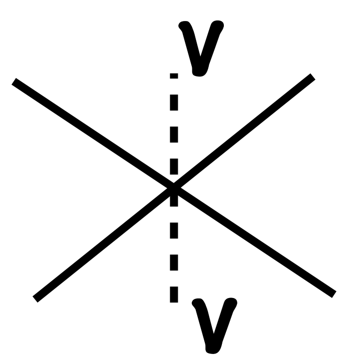




$O_8 \approx O_6\,(E/M)^2 \ll O_6$

$O_8 \approx O_6\,(g^* v/M)^2 \ll O_6$

→ In crossection dim-6^2 have the same powers of $(1/M^4)$ as dim-8xSM

...but more powers of g*!

→ It's always important to keep this dim-6^2 term:

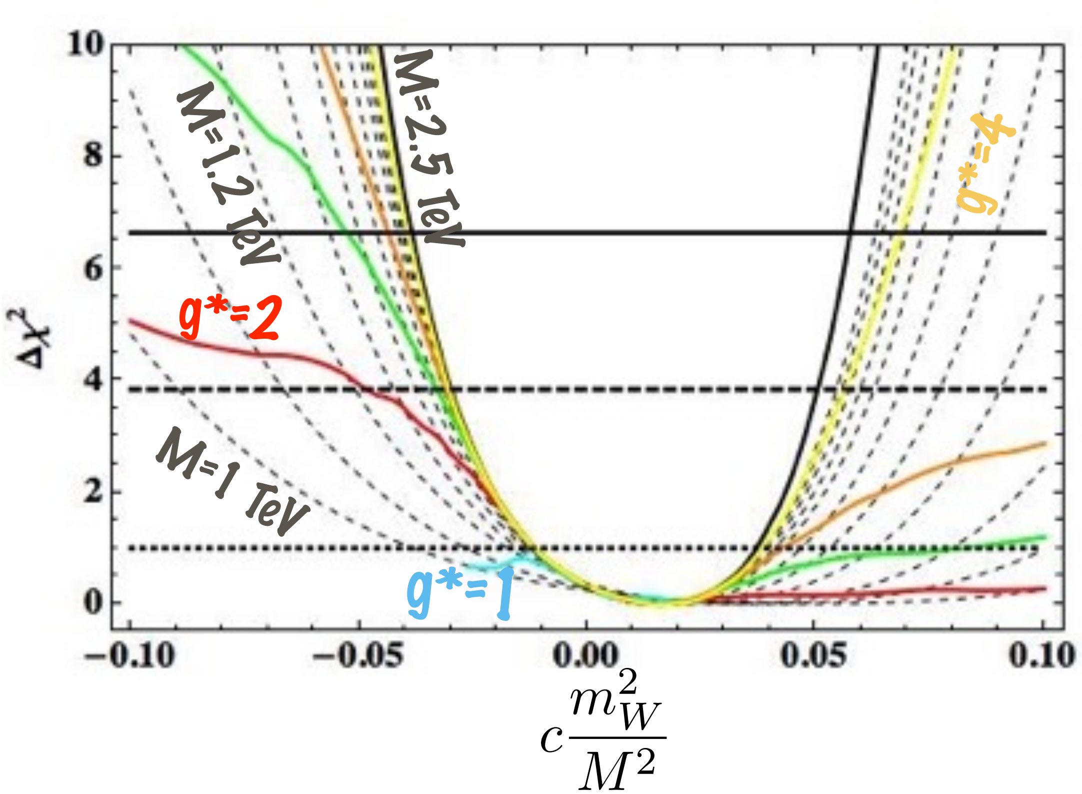
it's either small and negligible or large and requires strong coupling assumption

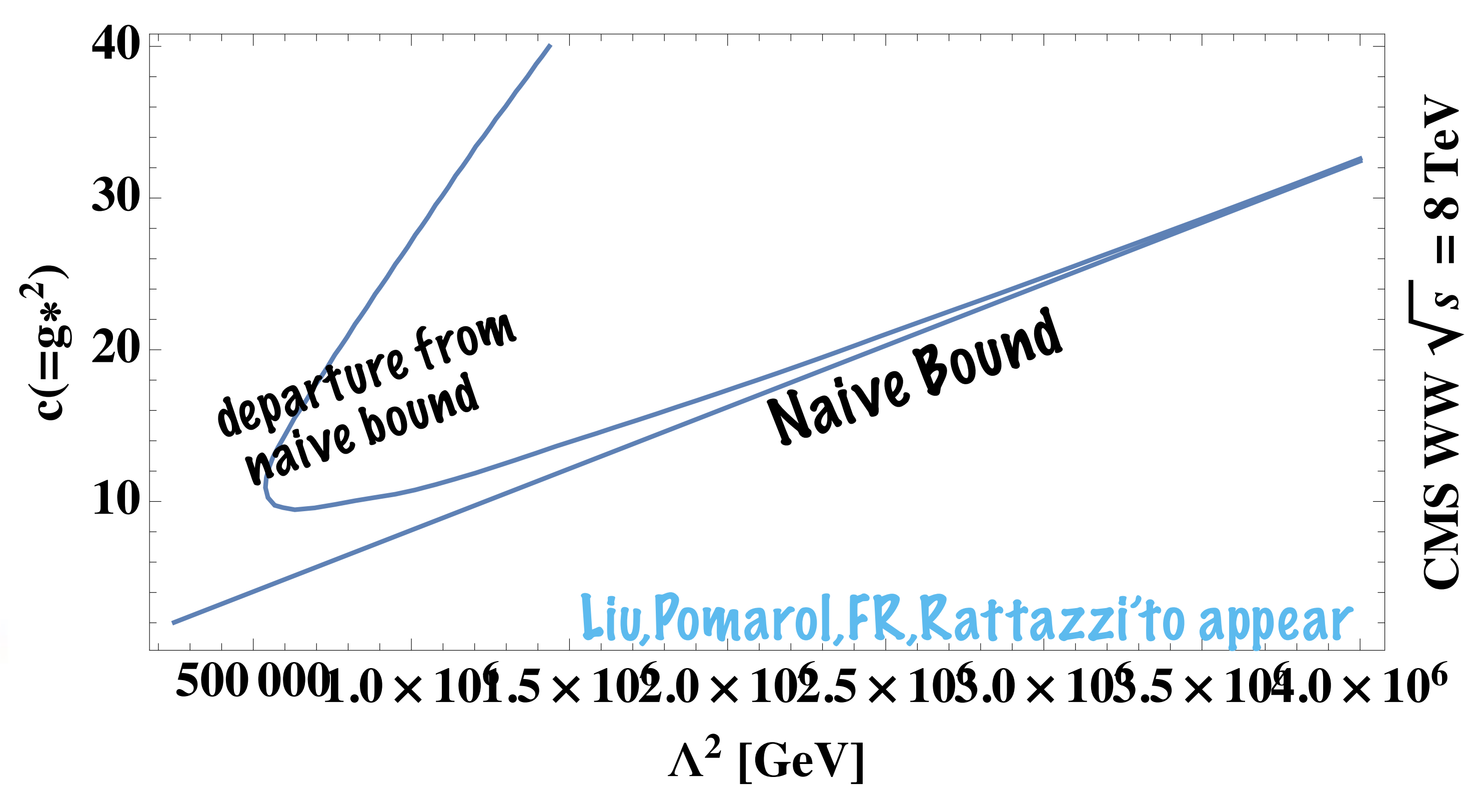
Recipe for incorporating this into an experimental analysis?

- Unlike LEP, energy unknown...
- Repeat analysis with extra cut on $\sqrt{s} < M$, for different values of M
  (if CoM energy unknown: similar techniques as DM monojet searches)

Racco,Wulzer,Zwirner'2015;
Brugisser,Mahbubani,FR,Urbano'to appear

- Bounds on c/M² can be shown for different g* using $c = g_*^2$ and in (g*,M) plane





→ Contains all information in terms of transparent physical parameters

Target:

Many interesting BSM theories are weakly coupled:

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

O(1) $\quad$ <1

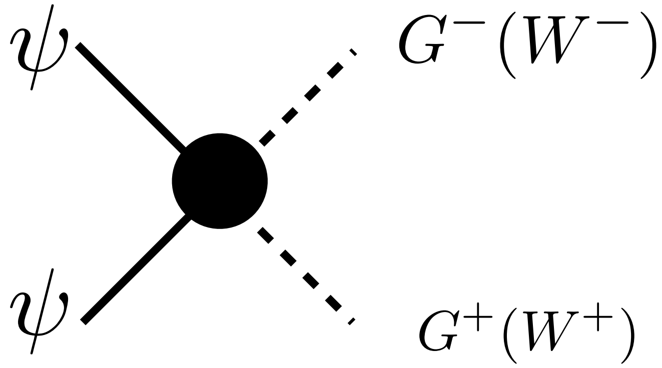
they require sensitivity to SM effects also at high energy!

This is the ultimate target for LHC experiments

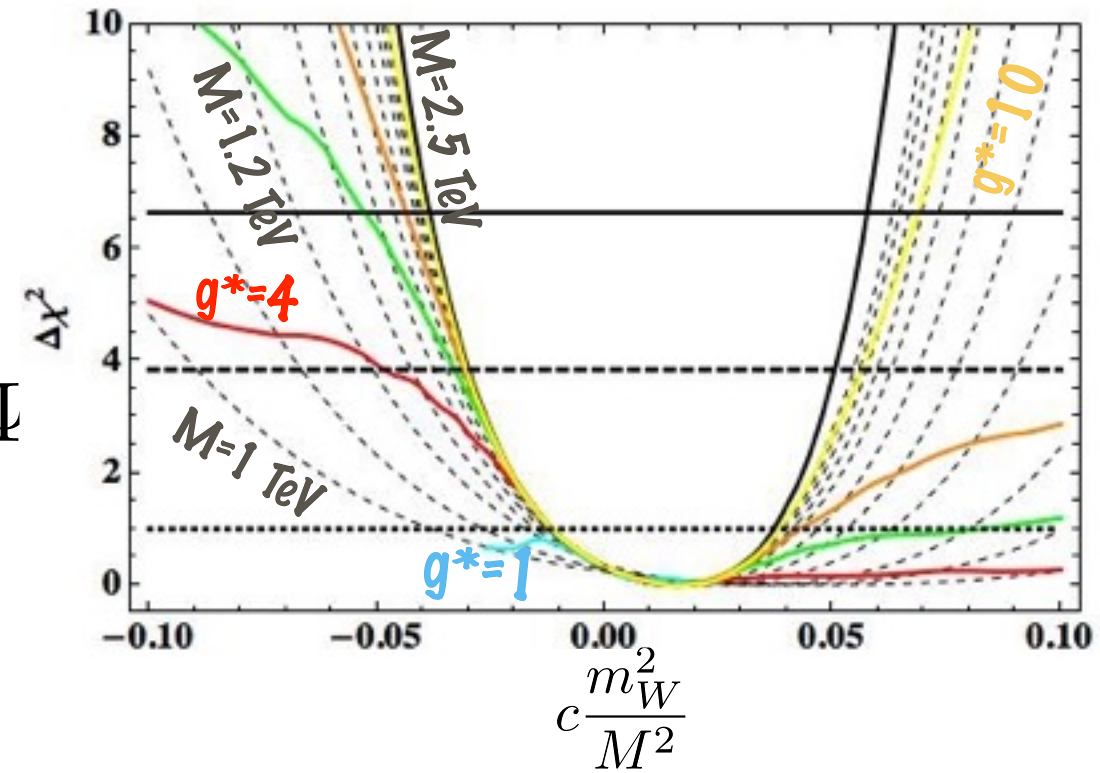
How does this apply to aGC?

LL

(g_1^Z)



$$c\,\frac{g_*^2}{M^2} H^\dagger D_\mu H \bar{\Psi}\gamma^\mu\Psi$$



→Strong Coupling necessary (otherwise no consistent bounds)

Improvable?

How does this apply to aGC?

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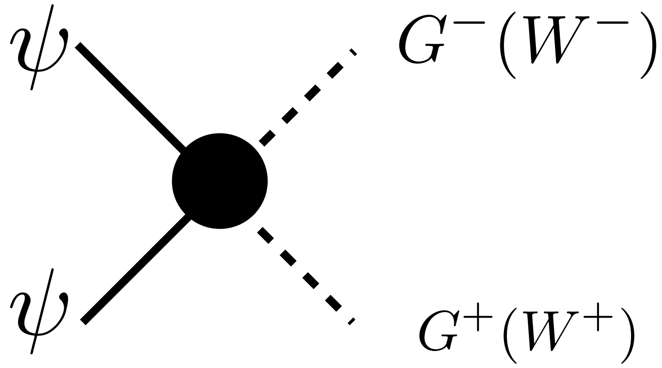

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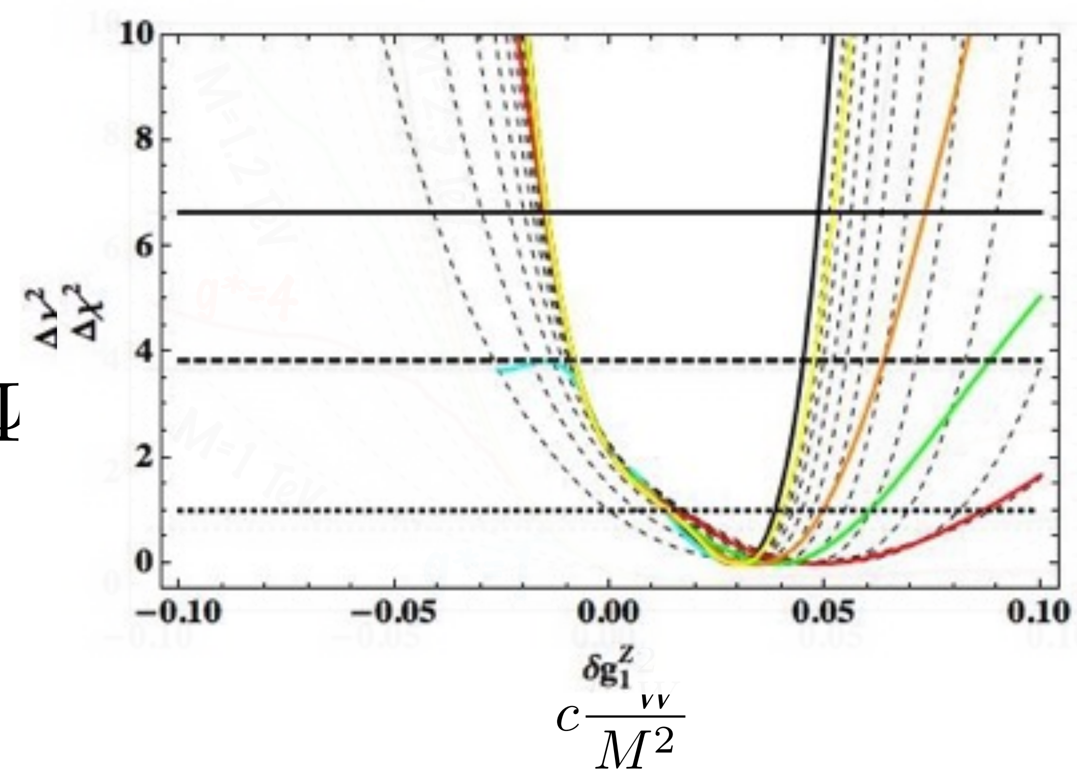

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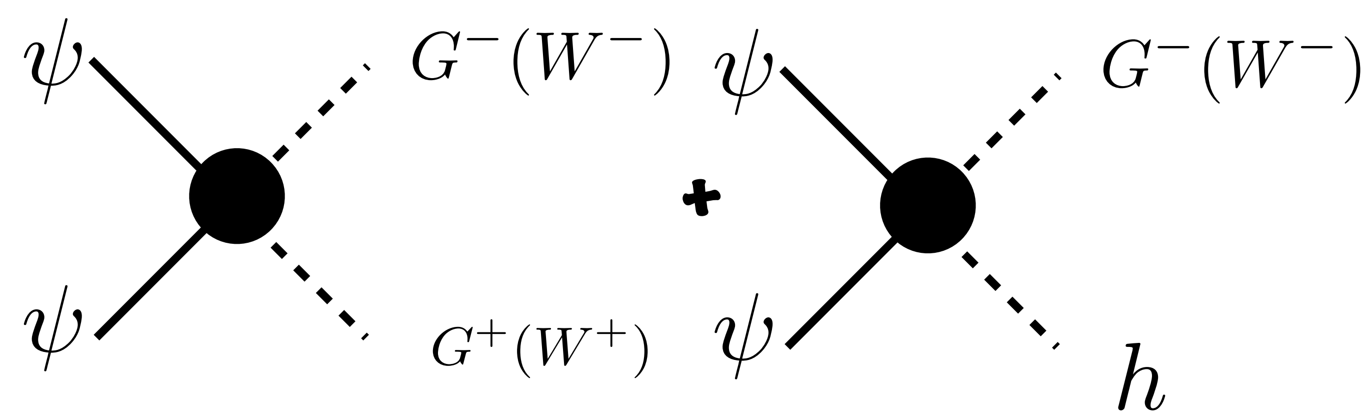
Improvable?

- Combination with Higgs physics



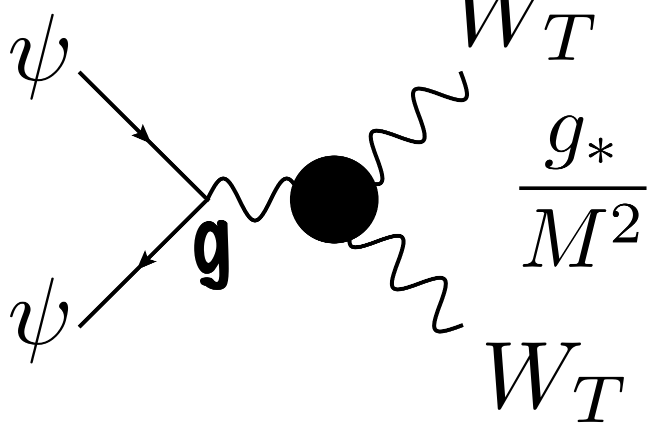
- Enhance signal through polarization tagging (In SM TT=10xLL)

Liu,Pomarol,FR,Rattazzi'to appear(see also Falkowski et al 2015 and Biekotter et al 2014)

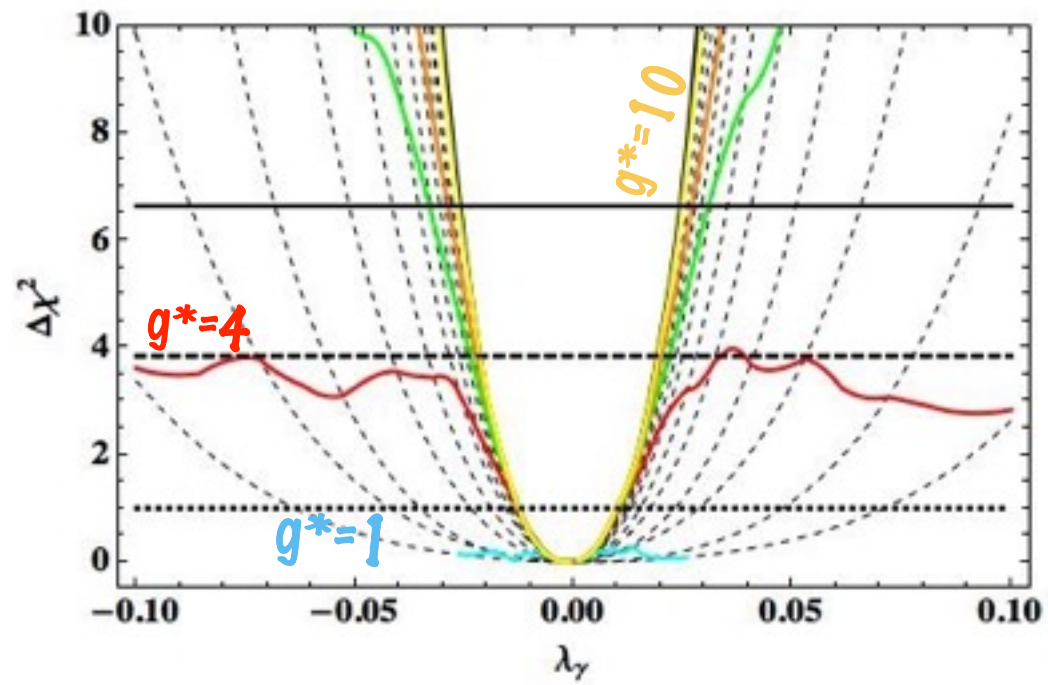
How does this apply to aGC?

TT

(λ_γ)



$$\frac{g_*}{M^2}\epsilon_{abc}W_\mu^{a\,\nu}W_{\nu\rho}^{b}W^{c\,\rho\mu}$$



→Strong Coupling necessary (otherwise no consistent bounds)

Liu,Pomarol,FR,Rattazzi'to appear

Important: only one power of g*!

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

Summary so far

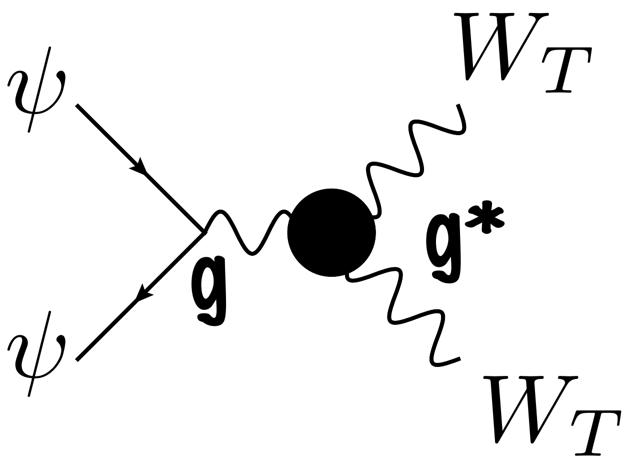
* Sensitivity to effects larger than SM at high-E
  → consistent with EFT only for strong coupling

* Recipe: Analysis of c/M^2 with different cutoffs
  Using $c=g*^2$ or $c=g*$, the results are presentable in $(g*,M)$-plane and contain all info

* This can be done consistently (quadratic terms in crossection can be kept) and no dimension-8 operators must be kept

...however:

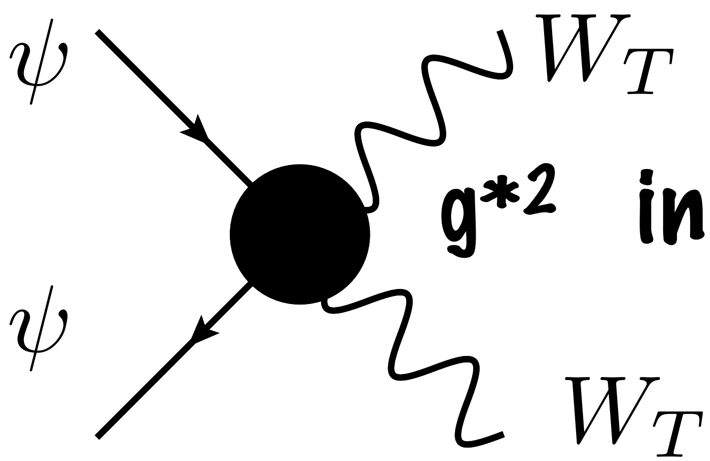
New Signals for aGC



always involves a weak coupling!

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

→



in some theories dimension-8 can have g*2

$$i\frac{g_*^2}{M^4}\bar{\psi}_{L,R}\gamma^\mu D^\nu \psi_{L,R} W^a_{\mu\rho} W^{a\,\rho}_{\nu}$$

$$A \simeq g^2 \left(1 + \hat{c}\frac{g_*^2}{g^2}\frac{E^4}{M^4}\right)$$

- → there are theories where this dominates
- → New effects with neutral vectors only (Z,photons) in final state
- → Modifications of helicity +- amplitude in TGCs
- → EFT expansion under control

Liu,Pomarol,FR,Rattazzi'to appear

Conclusions

* Sensitivity to dimension-6 effects larger than SM at high-E
  → consistent with EFT for strong coupling

* Recipe: Analysis of c/M^2 with different cutoffs
  Using $c=g_*^2$ or $c=g_*$, the results are presentable in (g_*, M)-plane and contain all info

* Target: higher sensitivity to effects comparable to the SM

* In the same class of theories, there are regions where dimension-8 can be consistently studied and dominate, despite EFT valid.