EFT analysis of aTGC @LHC

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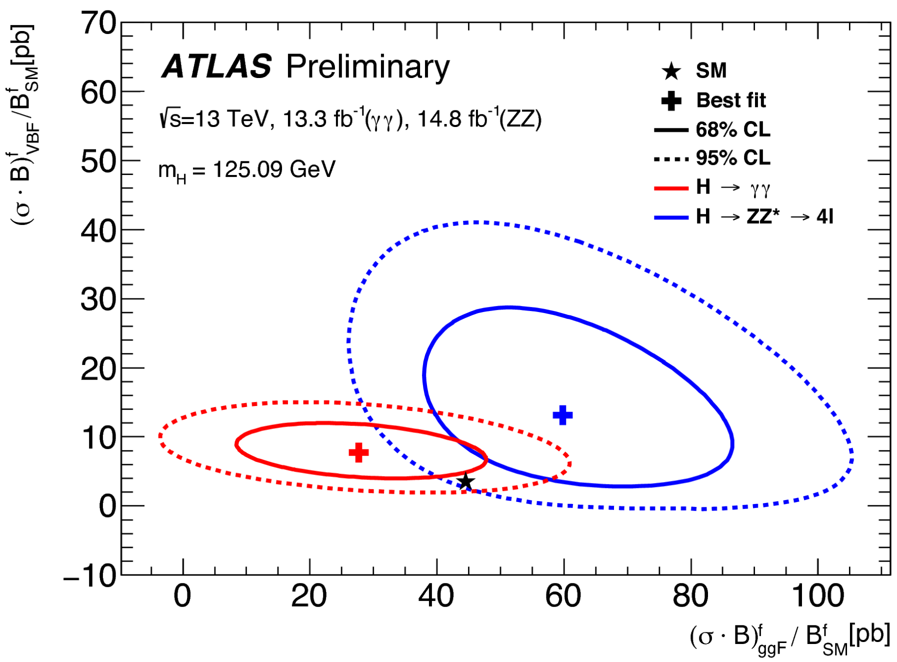
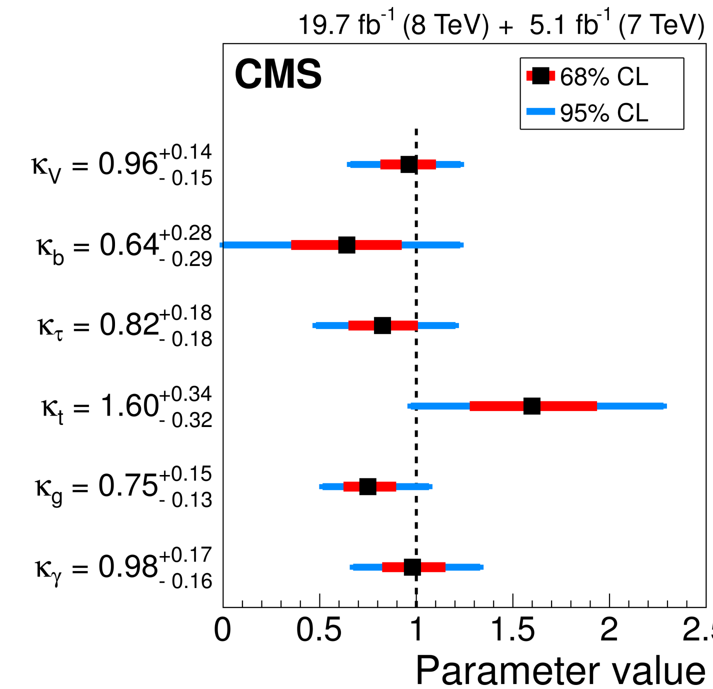
Planck 2017 — Warsaw

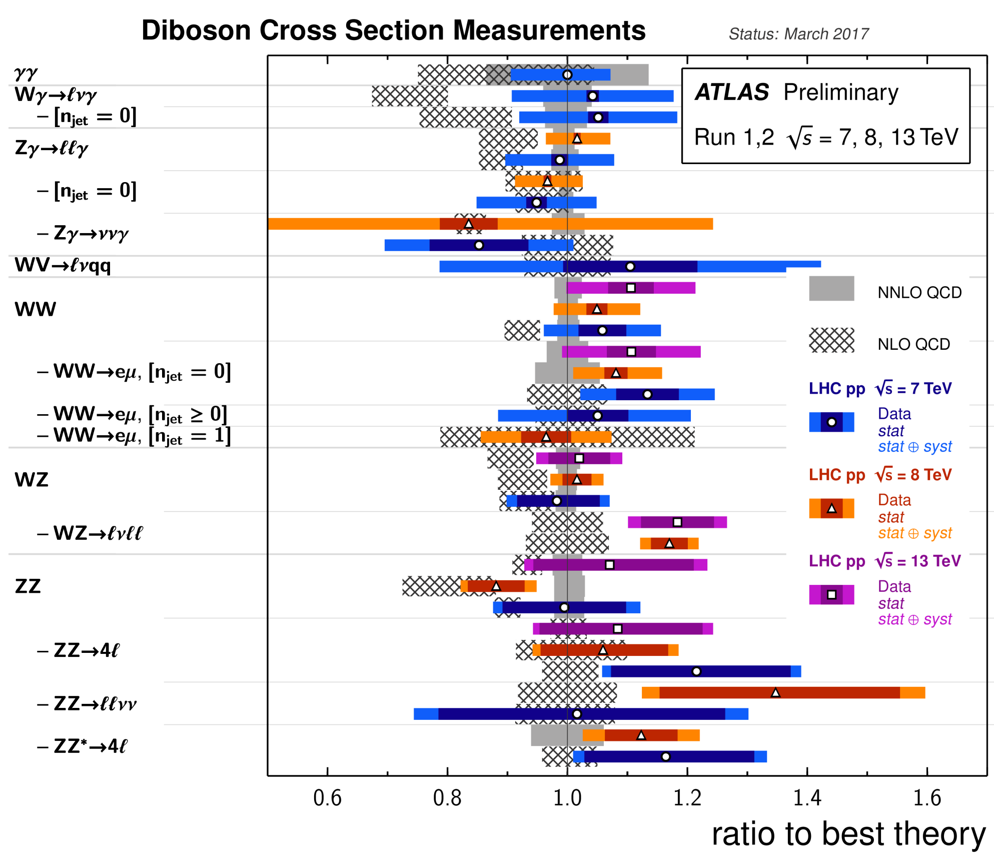
ma per seguir virtute e canoscenza
SISSA

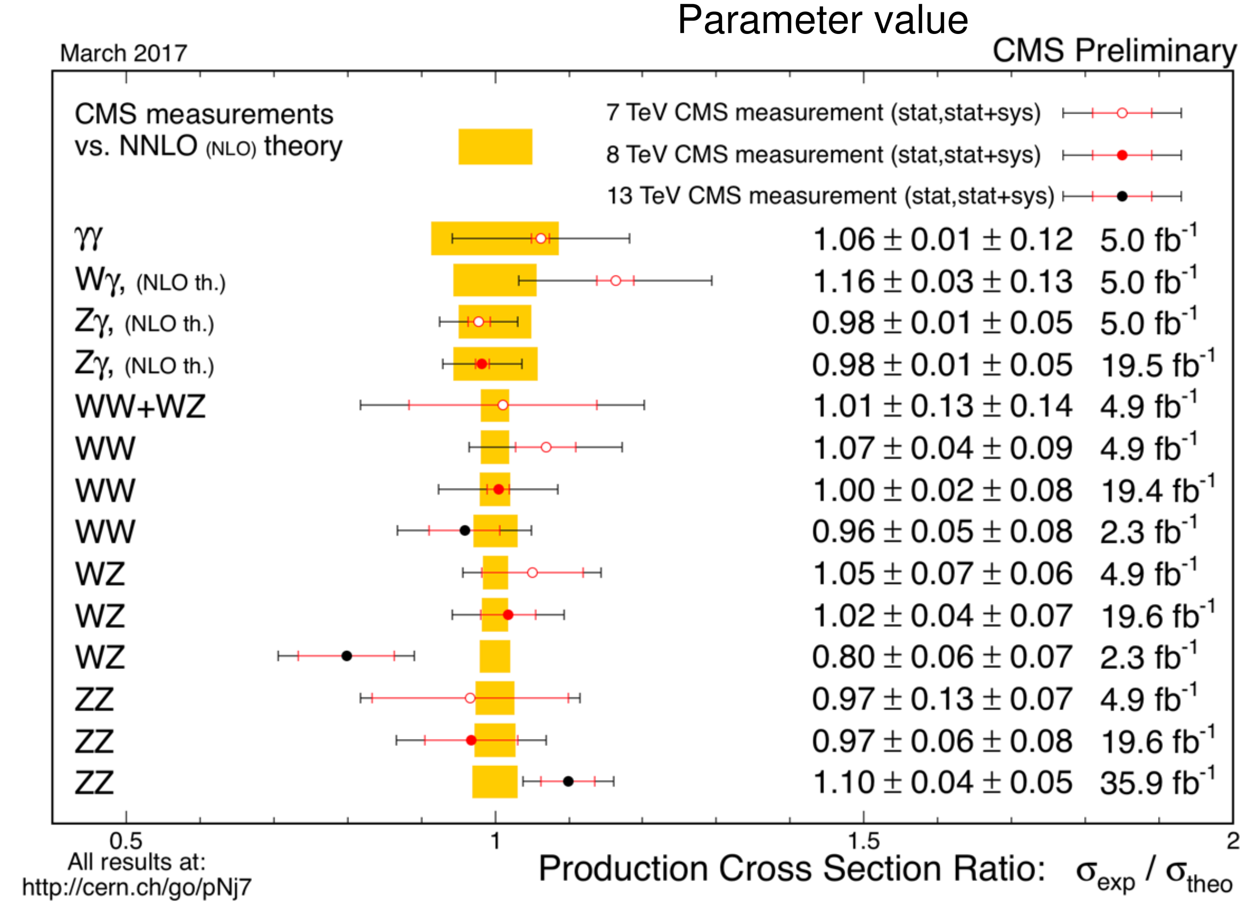
work in progress w/ Azatov, Reyimuaji and Venturini

LHC is performing great…









… but no new particles, no significant deviations in the data.

We should understand the consequences of that

Two complementary avenues towards achieving this goal:

a) Model building — paradigm change.

b) Detailed understanding of the real pressure — the LHC legacy.

must

We ~~should~~ understand the consequences of that

Two complementary avenues towards achieving this goal:

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b) Detailed understanding of the real pressure — the LHC legacy.

this talk

LHC searches suggest that there is a separation between the EW scale and the scale of new physics Λ.

$$\frac{M_W^2}{\Lambda^2} \ll 1$$

EFT approach is convenient to organize the lessons we learn from LHC.

What does the EFT approach buys for us? — SM EFT philosophy

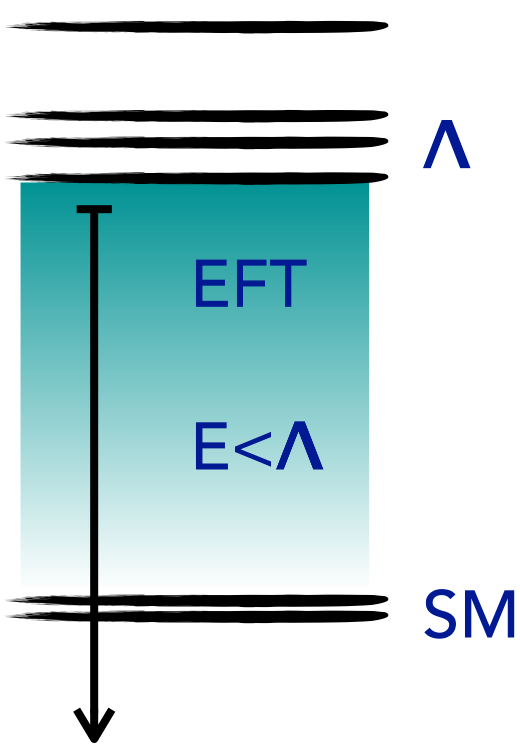
* Consistent framework for the parametrization of BSMs.

* Deformation of the SM in a way where the assumptions taken tend to be clear ("model independence").

* With suitable parameterizations one can learn about broad classes of models (e.g. SILH, univ. BSM, MFV, ...).

* The dim>4 operators connect further physics that are otherwise more independent (e.g. learn Higgs physics from LEP measurements, information about TGC from Higgs measurements, etc.).

* ...



Triple gauge couplings, what do we know?

In the SM, there is a single TGC which can be breakdown as

$$\mathcal{L}_{TGC} \;=\; ig\,(W^{+\,\mu\nu}W^{-}_{\mu}\,W^{3}_{\nu} + \,W^{\mu\nu}_{3}W^{+}_{\mu}W^{-}_{\nu}) \sim \partial WWW$$

where $W^3_\mu = c_\theta Z_\mu + s_\theta A_\mu$

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Beyond the SM, what ops. can we write at d=6 level? (weak coupling)

Only two type of **CP even** interactions are possible:

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2.- Different momentum and helicity interaction

1.- Deformation of existing TGC

a(nomalous)TGC of the 1st kind

$$\mathcal{L}_{TGC} = ig\, W^{+\,\mu\nu} W^-_\mu \,(c_\theta Z_\nu + s_\theta A_\nu) + ig\,(c_\theta Z^{\mu\nu} + s_\theta A^{\mu\nu}) W^+_\mu W^-_\nu$$

$$\downarrow$$

$$\mathcal{L}^{1st}_{aTGC} = ig\, W^{+\,\mu\nu} W^-_\mu \,(c_\theta\, \delta g_{1,z}\, Z_\nu + s_\theta\, \delta g_{1,\gamma}\, A_\nu) + ig\,(c_\theta\, \delta\kappa_z\, Z^{\mu\nu} + s_\theta\, \delta\kappa_\gamma\, A^{\mu\nu}) W^+_\mu W^-_\nu$$

Gaemers, Gounaris 78'

Hagiwara, Peccei, Zeppenfeld, Hikasa 86'

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gauge inv.

At d=6 level, gauge invariance implies $\delta\kappa_z = \delta g_{1,z} - s^2_\theta / c^2_\theta\, \delta\kappa_\gamma$

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aTGC of the 2nd kind

$$\mathcal{L}^{2nd}_{aTGC} = \lambda_z \frac{ig}{m_W^2} W^{+\,\mu_2}_{\mu_1} W^{-\,\mu_3}_{\mu_2} W^{3\,\mu_1}_{\mu_3}$$

All in all, we have 3 CP-even aTGC $\delta g_{1,z}\,,\ \delta\kappa_\gamma\,,\ \lambda_z$

Gaemers, Gounaris 78'
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Famous LEP-II % measurements

$$\delta g_{1,z} = -0.016^{+.018}_{-.020}$$
$$\delta\kappa_\gamma = -0.018 \pm 0.042$$
$$\lambda_z = -0.022 \pm 0.019$$

* Derived from diboson production.
* Fixed collision energy.
* EFT interpretation is straightforward.

LEP [1302.3415]

One can perform a global analysis of *all* SM dim6 operators.

After constraints from W/Z pole observables only **3** parameters to describe **possible deviations** of diboson production $\delta g_{1,z}\,,\ \delta\kappa_\gamma\,,\ \lambda_z$

These are matched into **4** unconstrained **Wilson coefficients**.

3<4 ⇒ flat direction — can be lifted with Higgs physics data.

EM, Espinosa, Masso, Pomarol [1308.1879]
Riva, Pomarol [1308.2803]
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Fit revisited in 1405.1617, 1411.0669

Working linearly w/ the aTGC the constraints are **O(10) weaker due to a flat direction** $\delta g_{1,z} \approx -\lambda$ **.**
Thus strong sensitivity to quadratic terms — EFT 🙁?!

Can be "lifted" by considering:

* Higgs observables — it bounds $g_{1,z}$
* other diboson c.m. energy — λ_z dep. scales different

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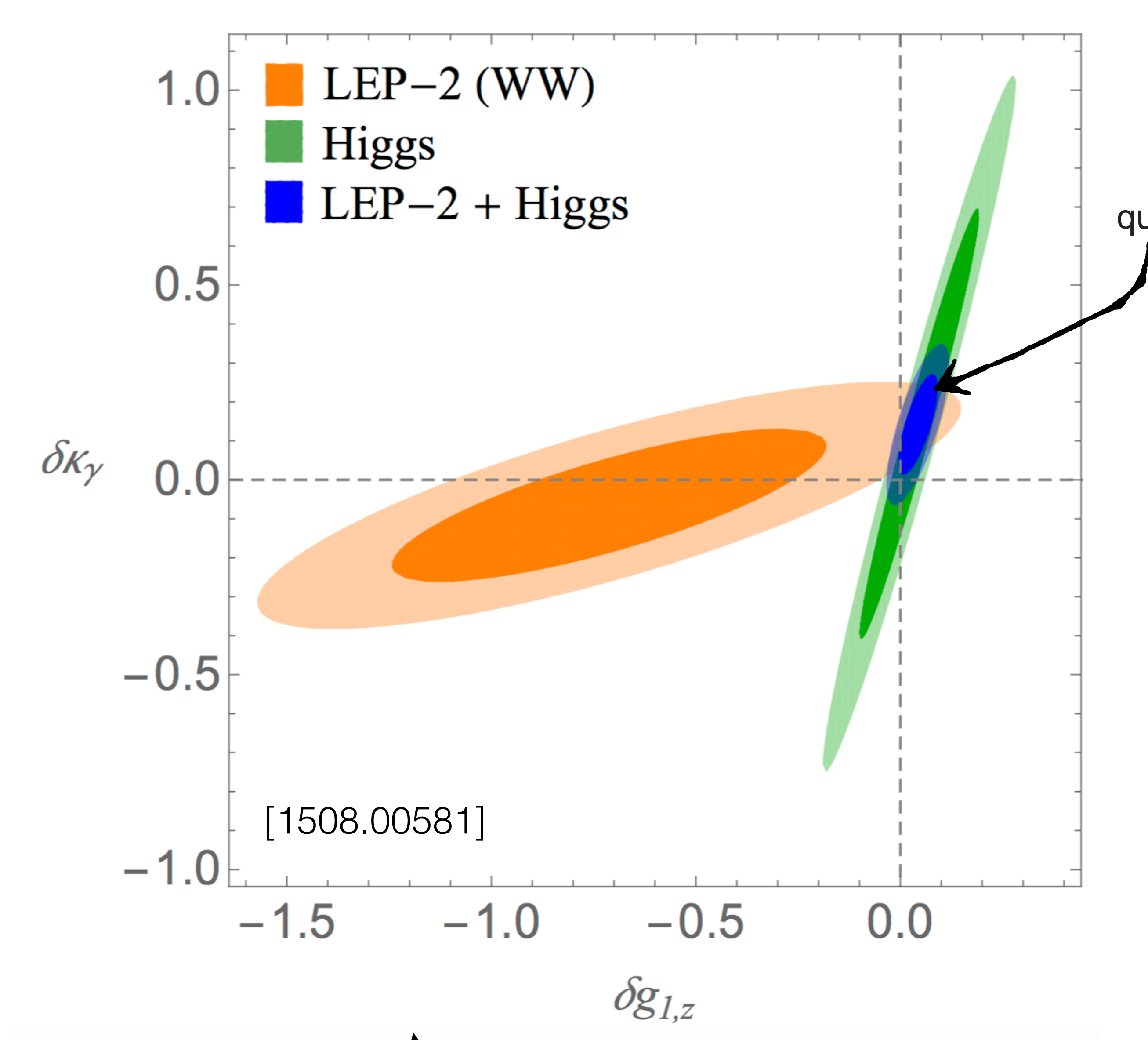

quadratic fit ≈ linear fit

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617, 1411.0669

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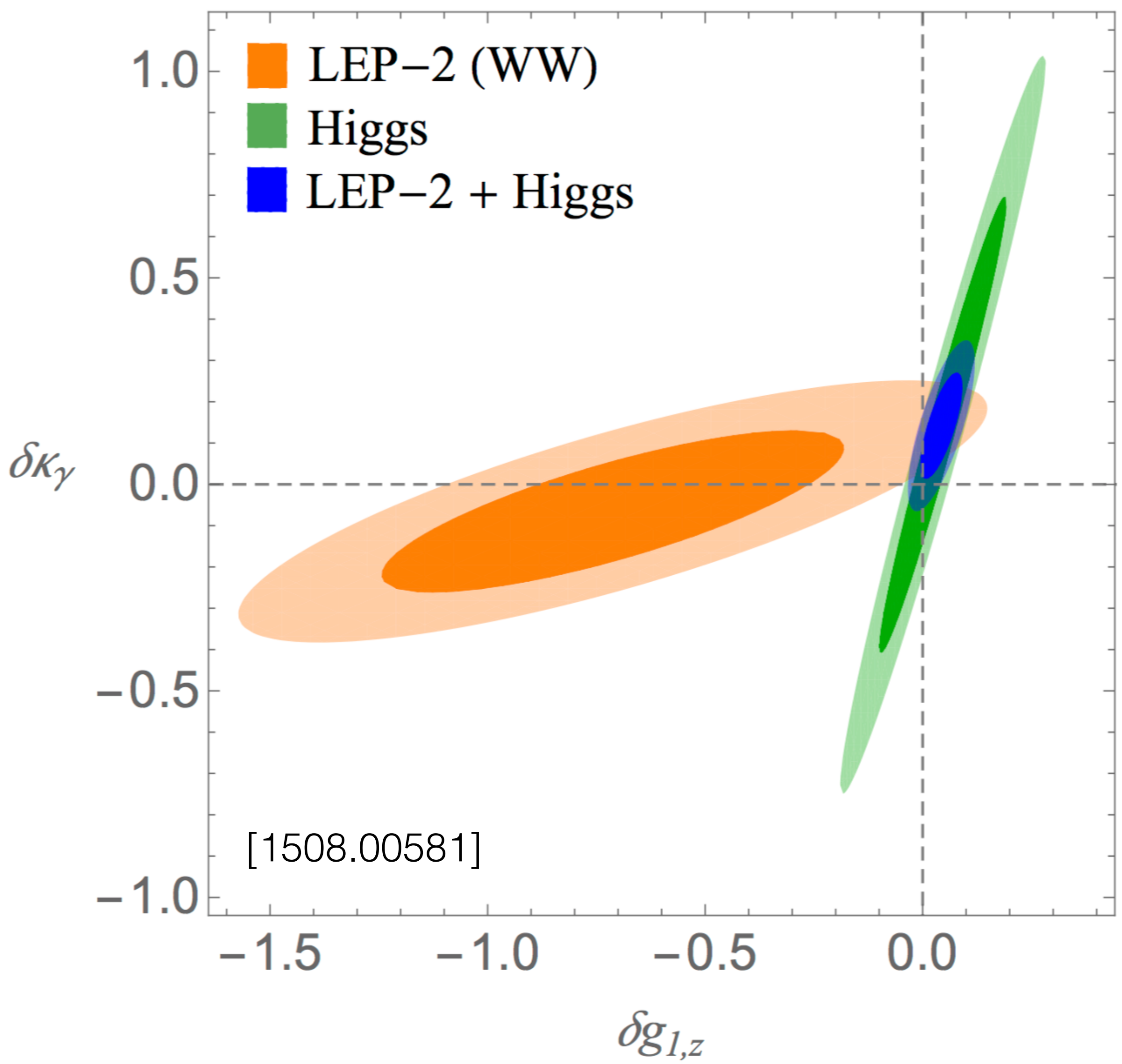

Schematically

HHBB
HHWB
HHWW
cW-cB
WWW

* **4** Higgs deformations
* **3** measurements
  hγγ, hZZ, hWZ, (hγZ)
* Each fermion decay/prod. mode has possible deformation.
* **4-3=1**

* **3** aTGC
* **2** measurements at linear level.
* **3-2=1**

After constraints from W/Z po

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TGC, diboson, EFT and the LHC

CMS [1703.06095]

In summary, our limits are consistent with the SM prediction and improve upon the sensitivity of the fully leptonic 8 TeV results [6, 7] and the combined LEP experiments [37, 42].

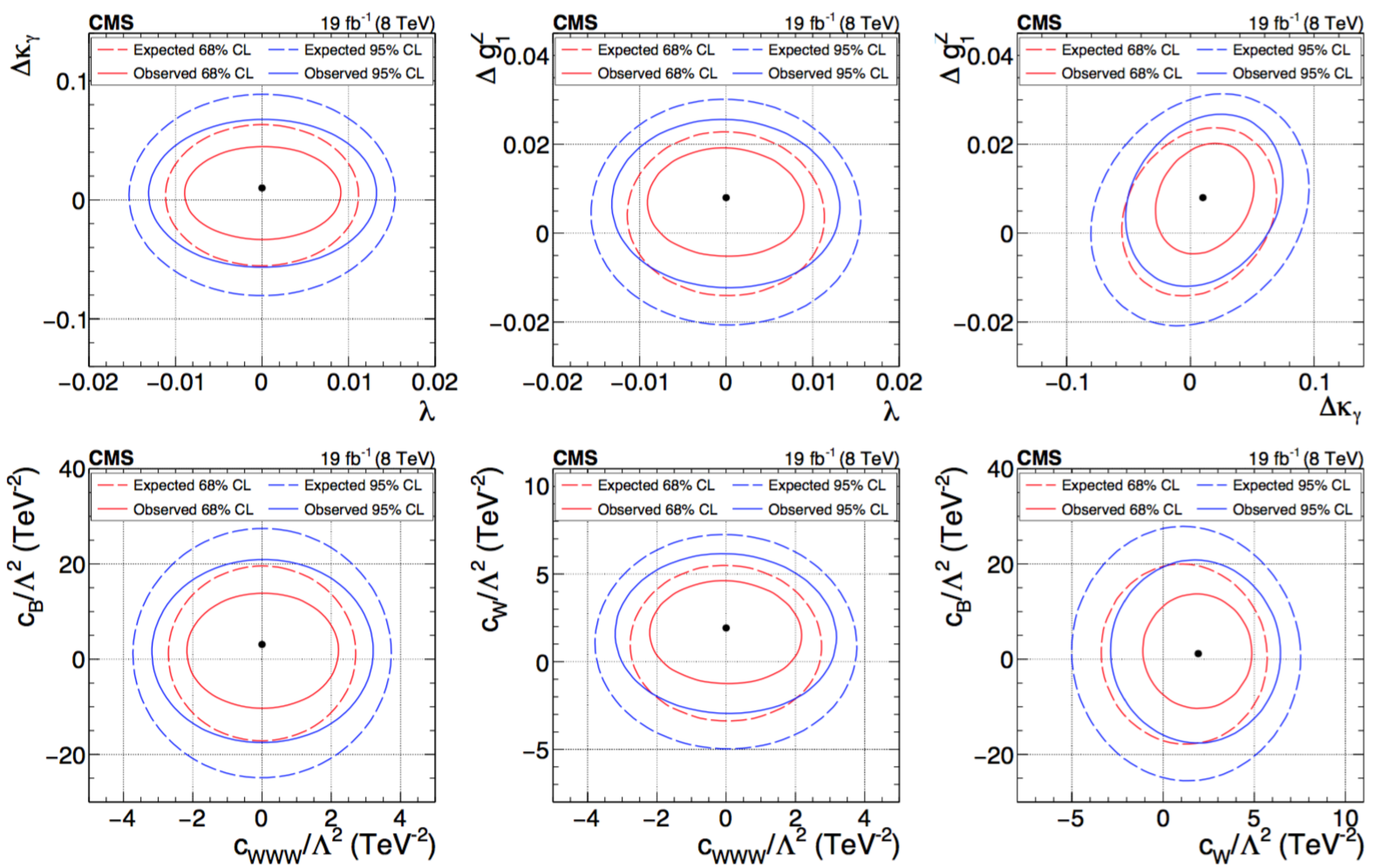
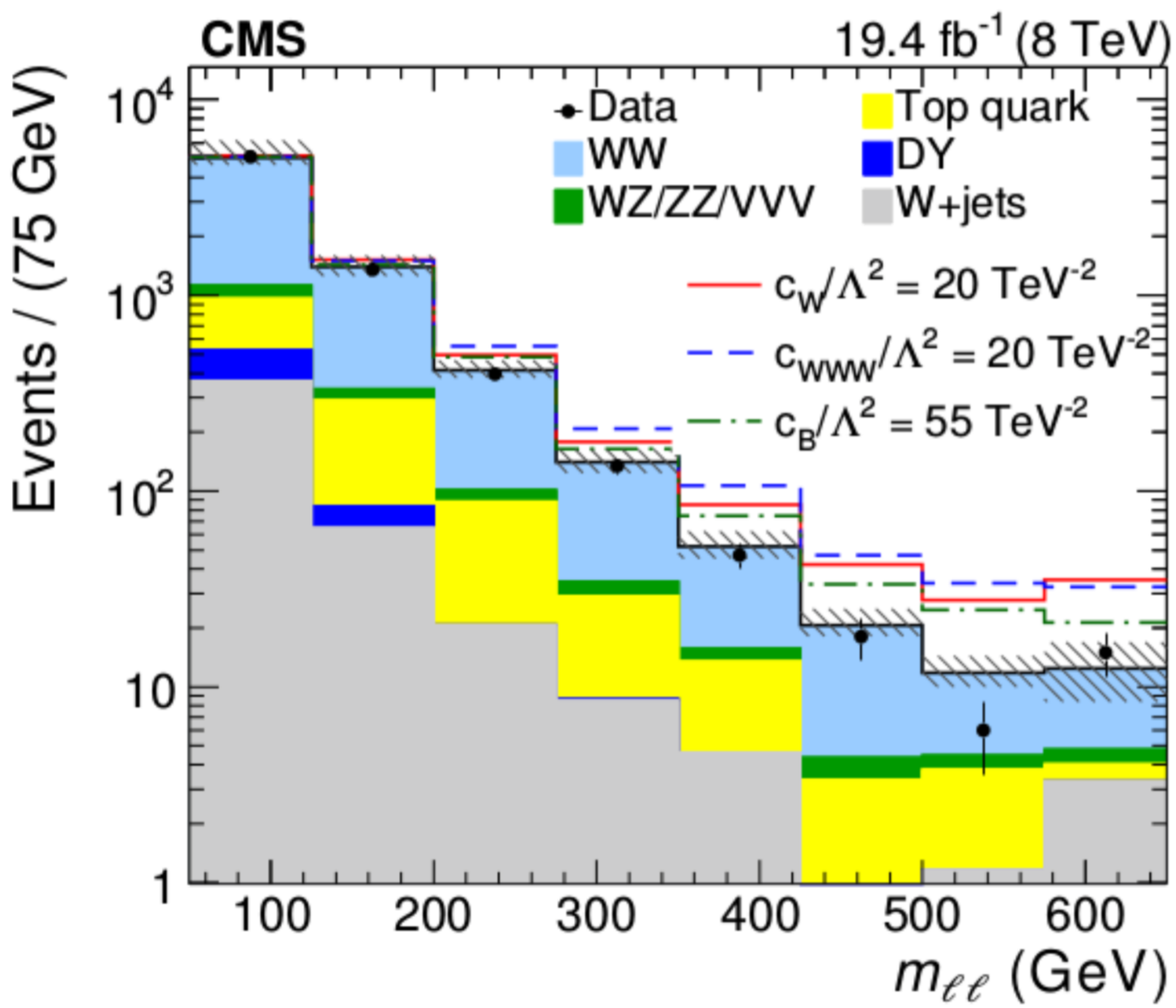
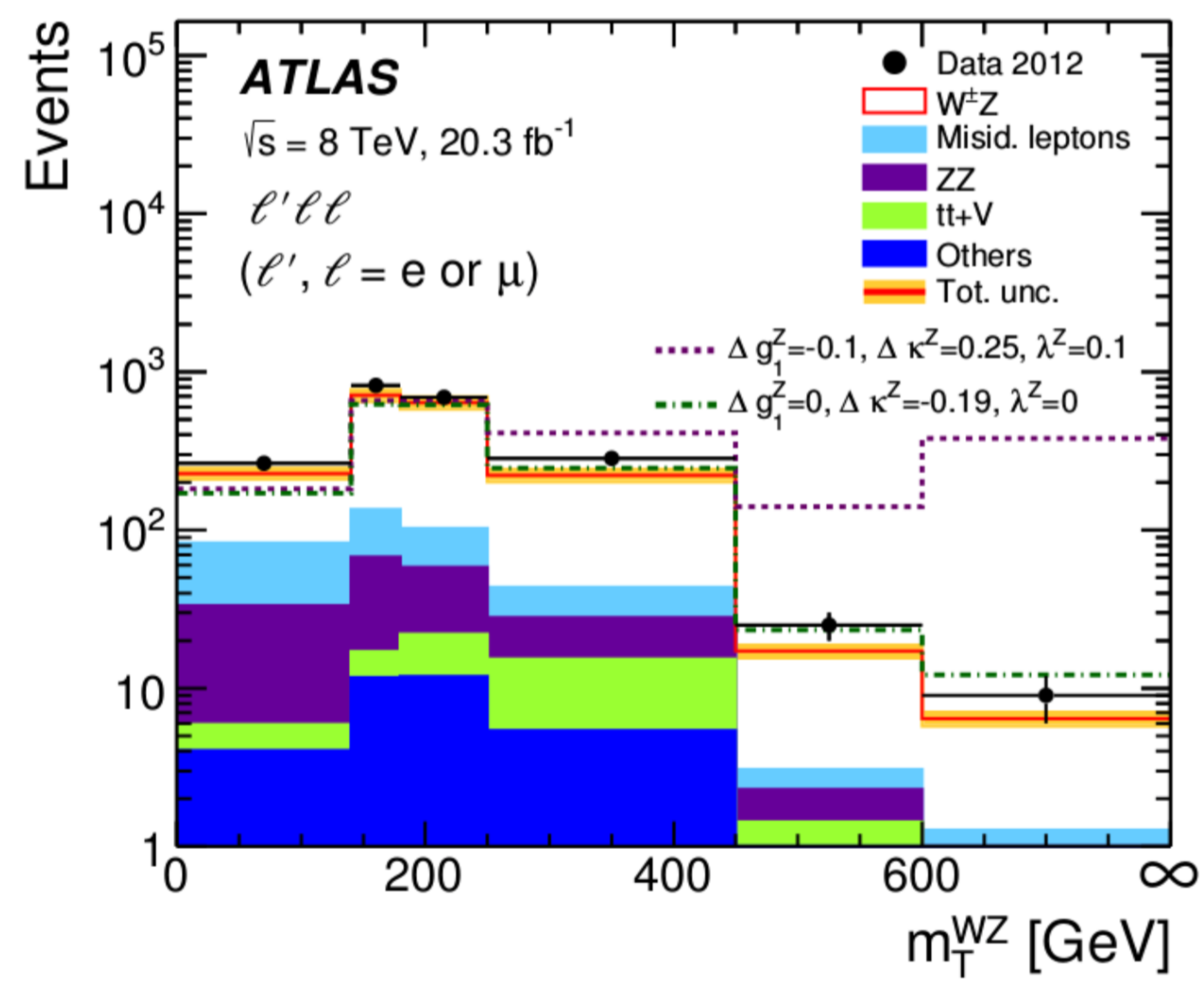


Figure 3: The 68 and 95% CL observed and expected exclusion contours in ΔNLL are depicted for three pairwise combinations of the aTGC parameters in the LEP parametrization (top) and in the EFT formulation (bottom). The black dot represents the best fit point.

LHC has surpassed the precision of LEP on TGC, but which theories are this bounds proving?

Most of its sensitivity comes from the tails, where the EFT description can break.





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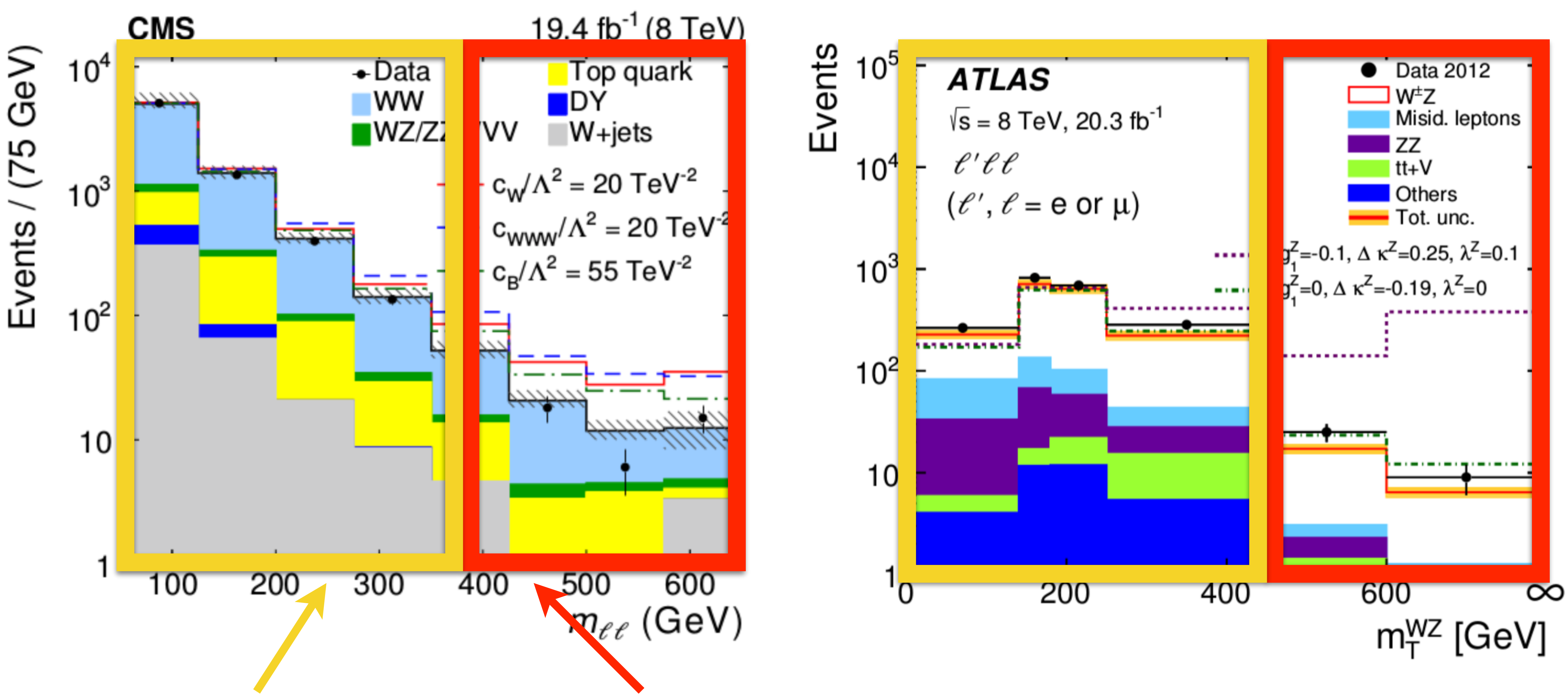


EFT with smaller cutoff may apply

Large cutoff, implies sensitivity to large coupling

Can we make sense of this LHC measurement in the EFT context?

namely, is there a consistent EFT where $W^3_{\mu\nu}$ is large?

There is an answer to the question that is interesting:

$$[\mathcal{G}]_{global} \rtimes [U(1)^{N_A}]_{local} \to [\mathcal{G}]_{local}$$

$$\mathcal{L}_{\rm SM}^{g=0} - \frac{1}{4g_*^2}{\rm tr}W_{\mu\nu}W^{\mu\nu} - \frac{1}{(g_*\Lambda)^2}{\rm tr}W^{\mu}{}_{\nu}W^{\nu}{}_{\rho}W^{\rho}{}_{\mu} + \cdots \longrightarrow \mathcal{L}_{\rm SM}^{g=\epsilon g_*} - \frac{1}{4g_*^2}{\rm tr}W_{\mu\nu}W^{\mu\nu} - \frac{1}{(g_*\Lambda)^2}{\rm tr}W^{\mu}{}_{\nu}W^{\nu}{}_{\rho}W^{\rho}{}_{\mu} + \cdots$$

Technically natural to have ***g<<g**** .

No sym. enhancement at ***ϵ=0***, num. of generators the same.

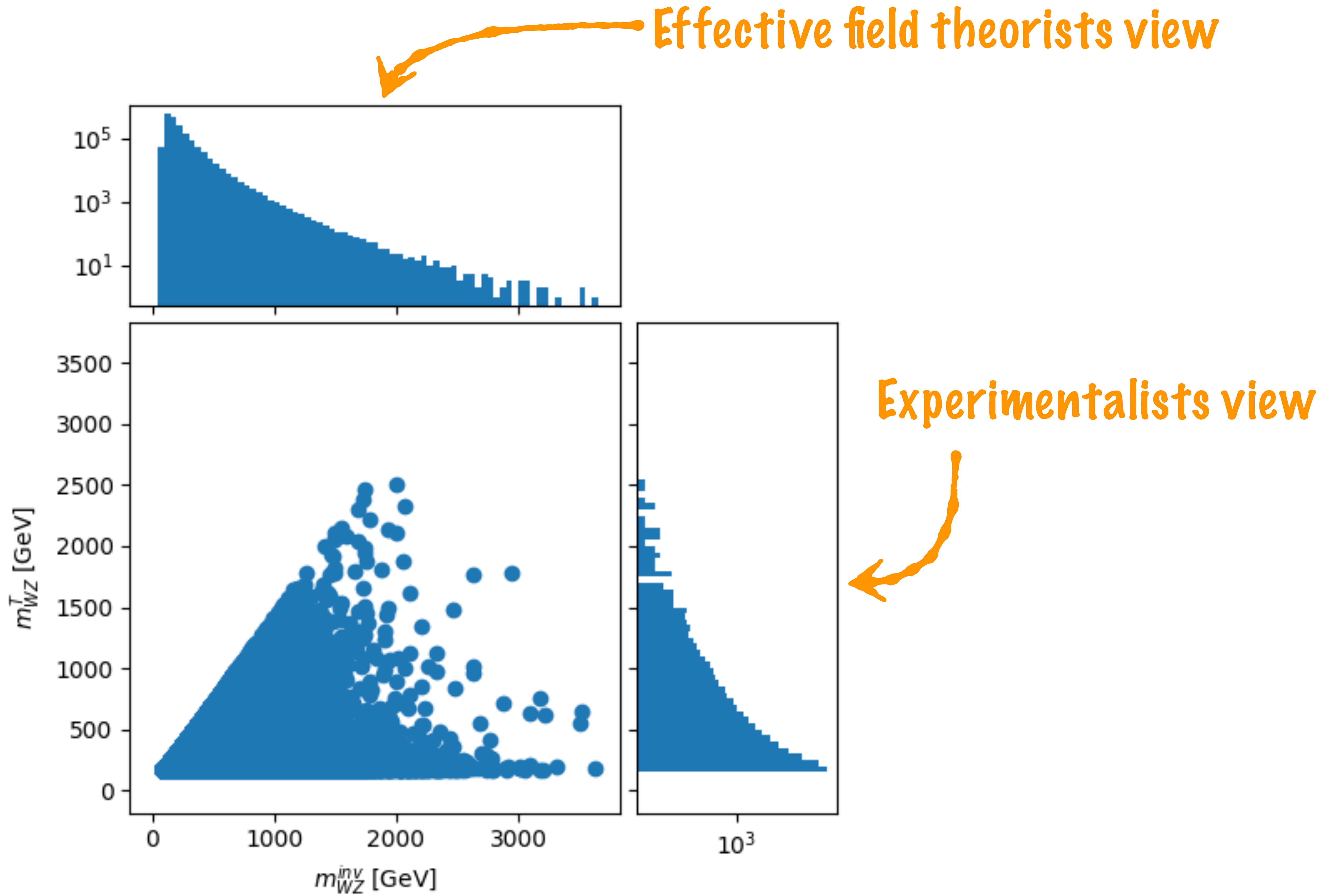
Analogous to Galilean -> Poincaré group: boosts are abelianized upon contracting Poincare to Galilean.

Liu, Pomarol, Rattazzi,Riva [1603.03064]

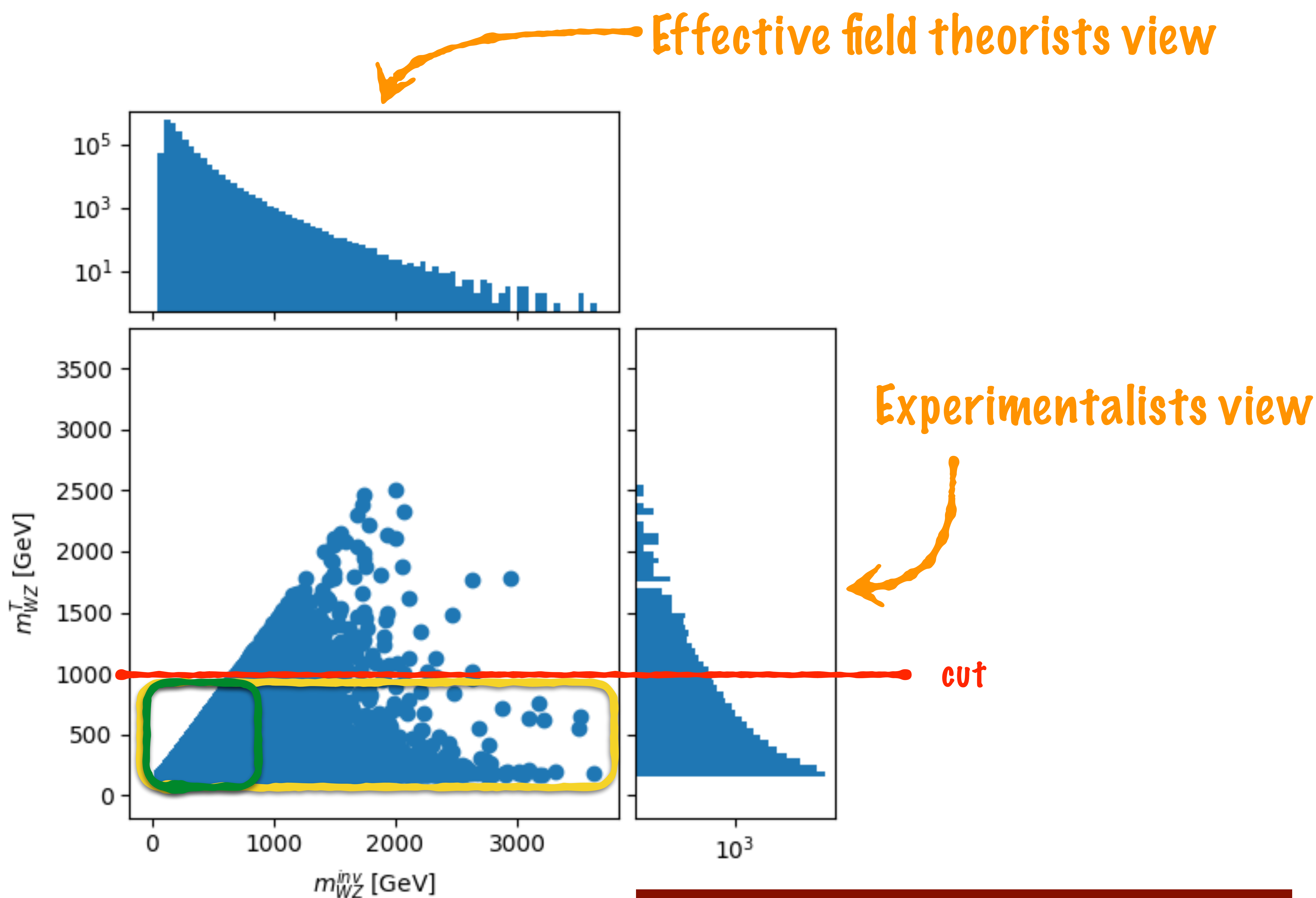
To prove less *exotic* theories we need better sensitivity

Two effects we may worry about the EFT measurement:

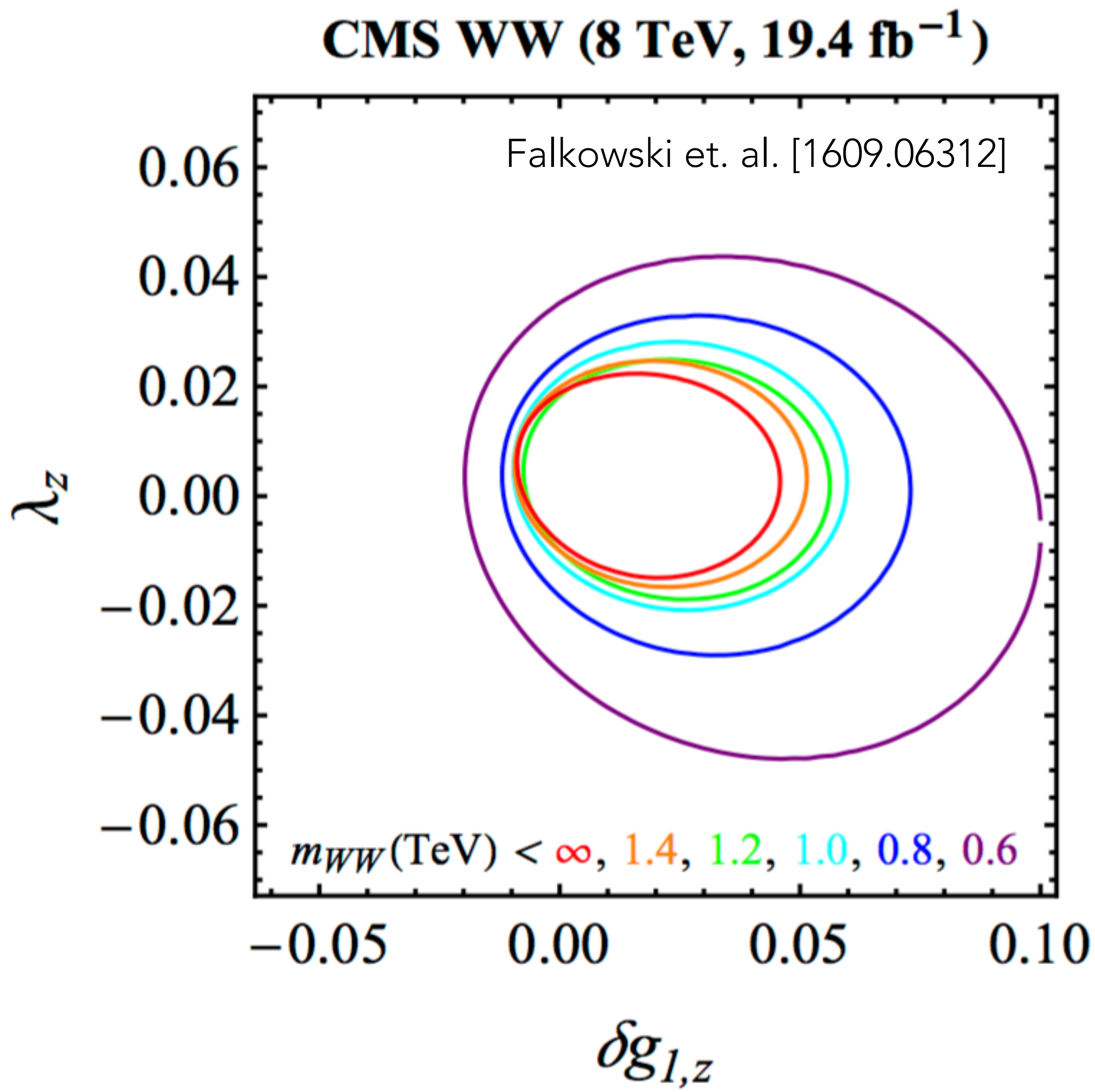
* Leakage of high invariant mass events
* Strong sensitivity to quadratic terms vs linear ones.



Effective field theorists view
Experimentalists view
10^5
10^3
10^1
3500
3000
2500
2000
1500
1000
500
0
m_{WZ}^T [GeV]
0
1000
2000
3000
m_{WZ}^{inv} [GeV]
10^3



leakage ≡ (yellow-green)/yellow



Looking at low categories only, LEP bounds are still stronger.

An obstruction to precision

$$\sigma \sim SM^2 + \frac{SM \times BSM_6}{\Lambda^2} + \frac{BSM_6^2}{\Lambda^4} + \frac{SM \times BSM_8}{\Lambda^4} + \cdots$$

Helicity selection rules. In some cases the interference term vanishes, at tree-level.

Which ops. can interfere?

Two groups of dim6 operators

[for any basis]

1) "Current-current ops.":

Those that **can** be resolved by the tree-level exchange of a spin s≤1 resonance.

2) "Loop ops.":

Those that **can't** be resolved by the tree-level exchange of a spin s≤1 resonance.

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Those that **can** be resolved by the tree-level exchange of a spin s≤1 resonance.

⇒ they can mediate processes with same helicity configuration as in the SM.

2) "Loop ops.":

Those that **can't** be resolved by the tree-level exchange of a spin s≤1 resonance.

⇒ require case by case analysis. (maybe can be classified with susy? spurion vev sucks helicity of the process and that's why some of them lead to MHV amplitudes…)

See Azatov, Contino, Machado, Riva [1607.05236] for thorough analysis — classification there is based on different logic.

$W^3_{\mu\nu}$ is of the second group — not obvious which helicity configurations can mediate

Dixon, Shadmi [9312363]: pioneering study in the context of QCD, $G^3_{\mu\nu}$.

It turns out that $W^3_{\mu\nu}$ does not lead to 2->2 amplitudes with same helicity as in the SM ⇒ thus interference vanishes.

Can we enlarge the sensitivity to $W^3_{\mu\nu}$ in the region where the EFT is valid?

We want to prove this term

* In general $\sigma = \sigma_{\rm SM} + \sigma_{\rm int} c + \sigma_{\rm BMS^2} c^2$

diboson measurements sensitive to this function

* We can look at the parameter $$\delta = \frac{\sigma_{\rm int}}{\sigma_{SM}} \times \frac{\sigma_{\rm int}}{\sigma_{\rm BMS^2}}$$

EFT 🙂?

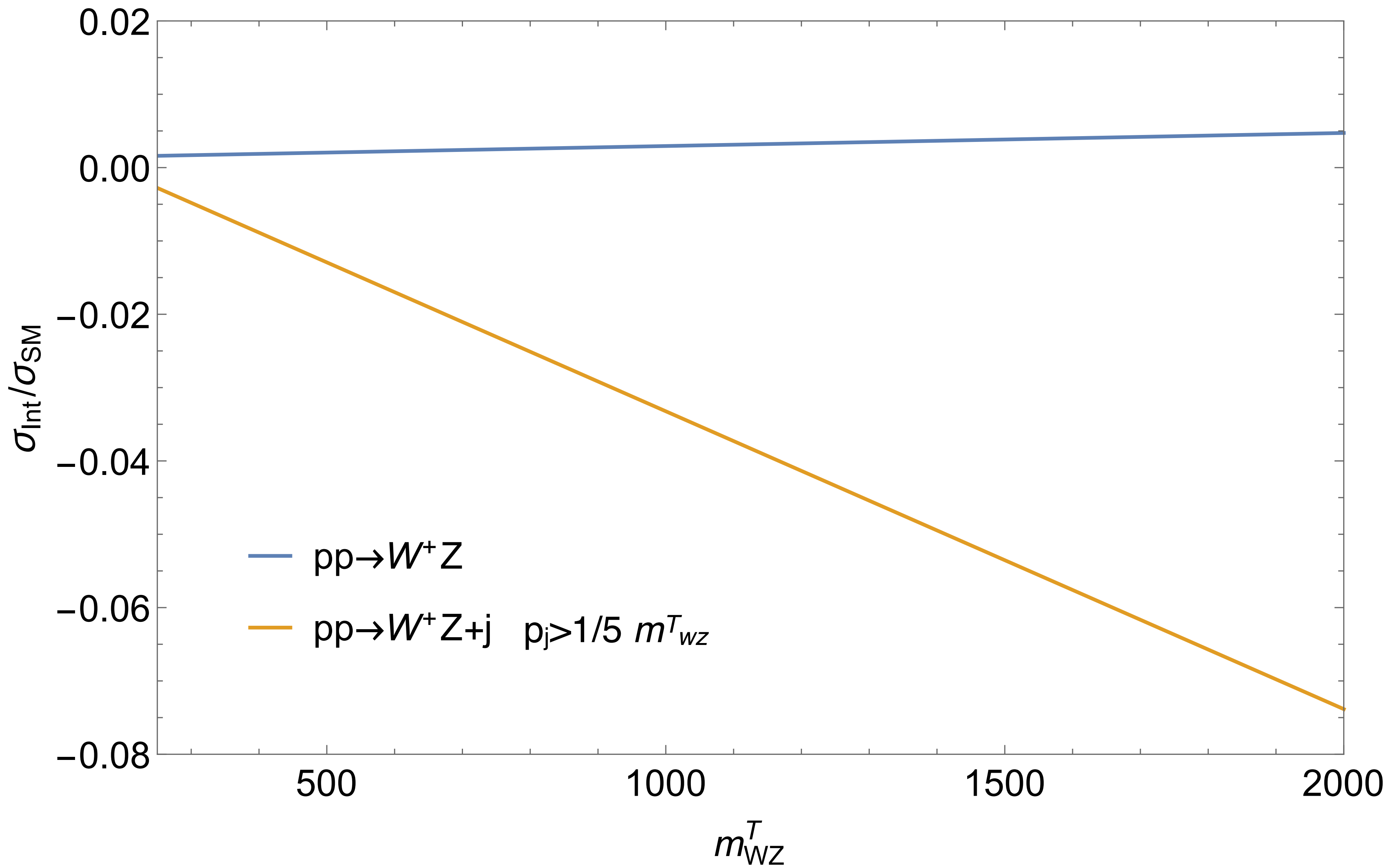
sensitive to NP?

* For the deviations of the SM cross sections less than $\Delta\sigma_{\rm obs} \leq \delta \times \sigma_{\rm SM}$ we are still dominated by the interference term.

⇒ **We should design searches that maximize δ**

$pp \rightarrow W^+Z+j$

* Sensitive to λ_z interference.

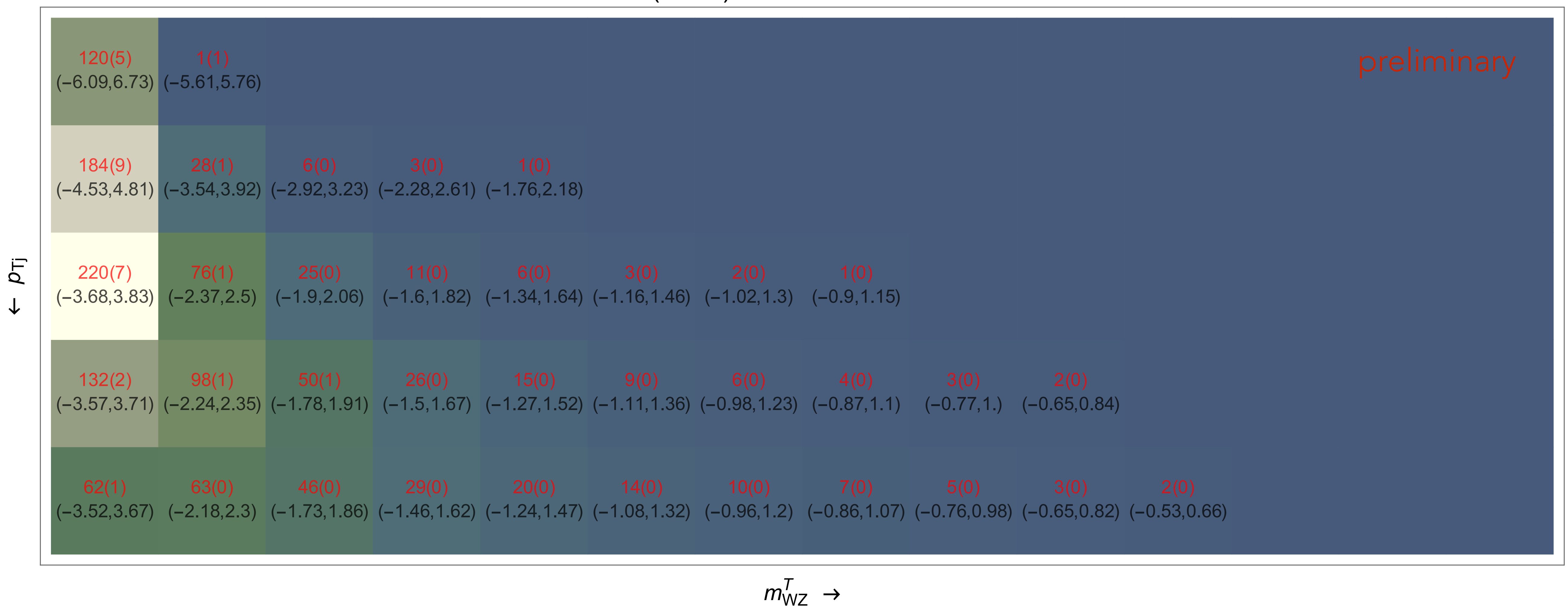


* Requiring extra hard jet helps in interference!

Azatov, EM, Reyimuaji, Venturini

Azatov, EM, Reyimuaji, Venturini

$\delta/(\Delta\sigma/\sigma)$ and 95% CL interval



CL obtained integrating over lower bin categories.

LHC @14TeV
pTj: veto <50, [50,100], [100,300], [300,500], >500
mwzT: [100,200], …, [900,1000], [1000,1200], [1200,1500], [1500,2000], [2000,2500], >2500

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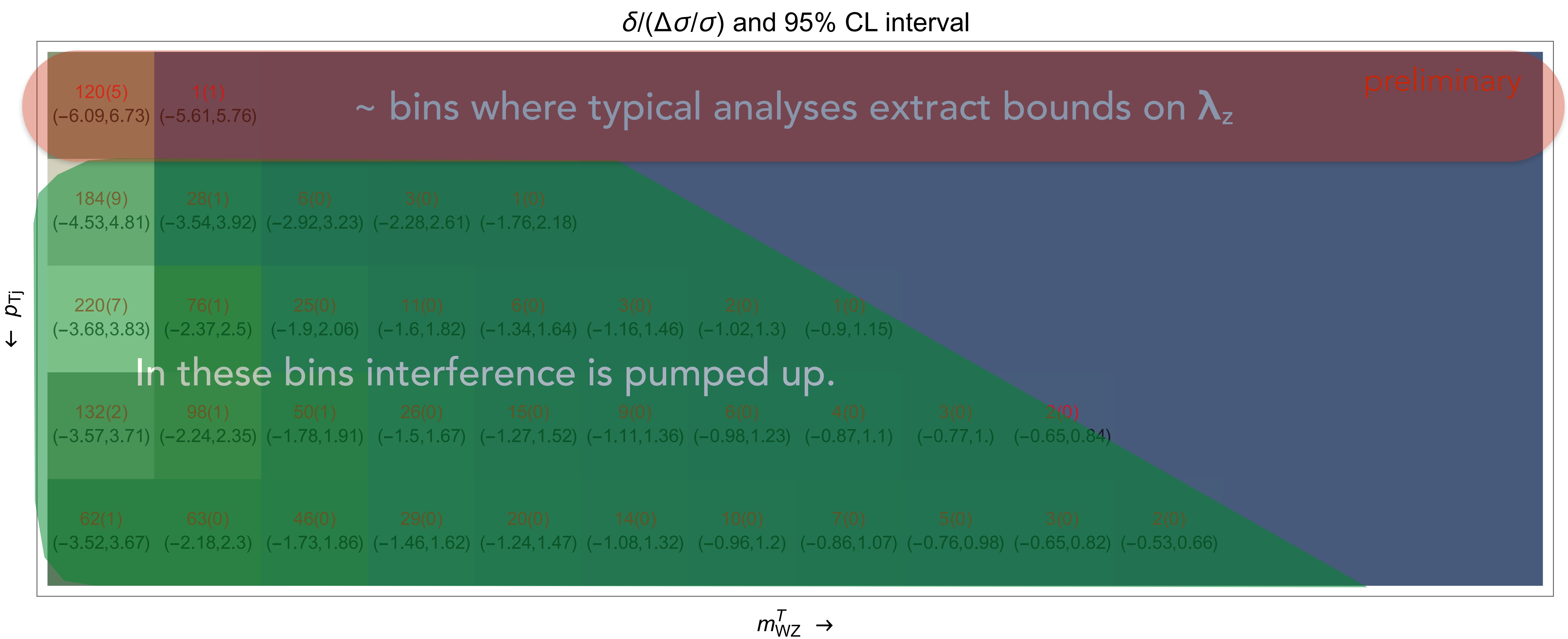

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Summary

* At LHC we must be careful with EFT interpretation.

* Analysis of aTGC. The main motivation is bottom up, better sensitivity to NP from diboson measurement.

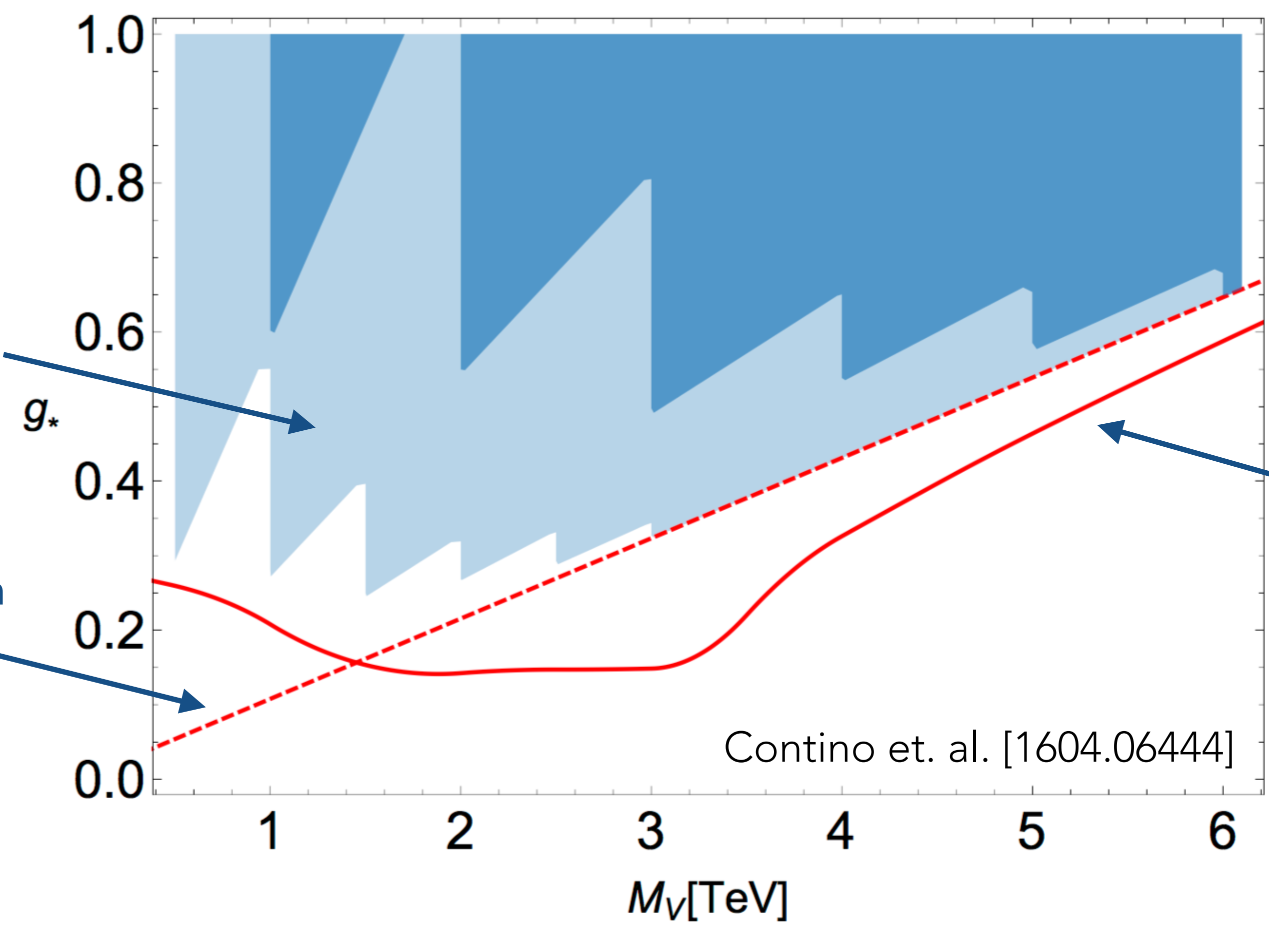
* Larger sensitivity to interference term is more *EFT save*:
less dependence on quadratic terms and dim8 ops — field redefinitions of $O(1/\Lambda^2)$ differ at $O(1/\Lambda^4)$.

* For λ_z , 2->3 process is more sensitive to 2->2 process.

Example

conservative EFT
limit by cutting m_{inv}
on simulated x-sec.

naive EFT interpretation
would fail here



BSM model