Beyond Top EFT

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with André Lessa (2312.00670, JHEP (2024))

Outline

SMEFT

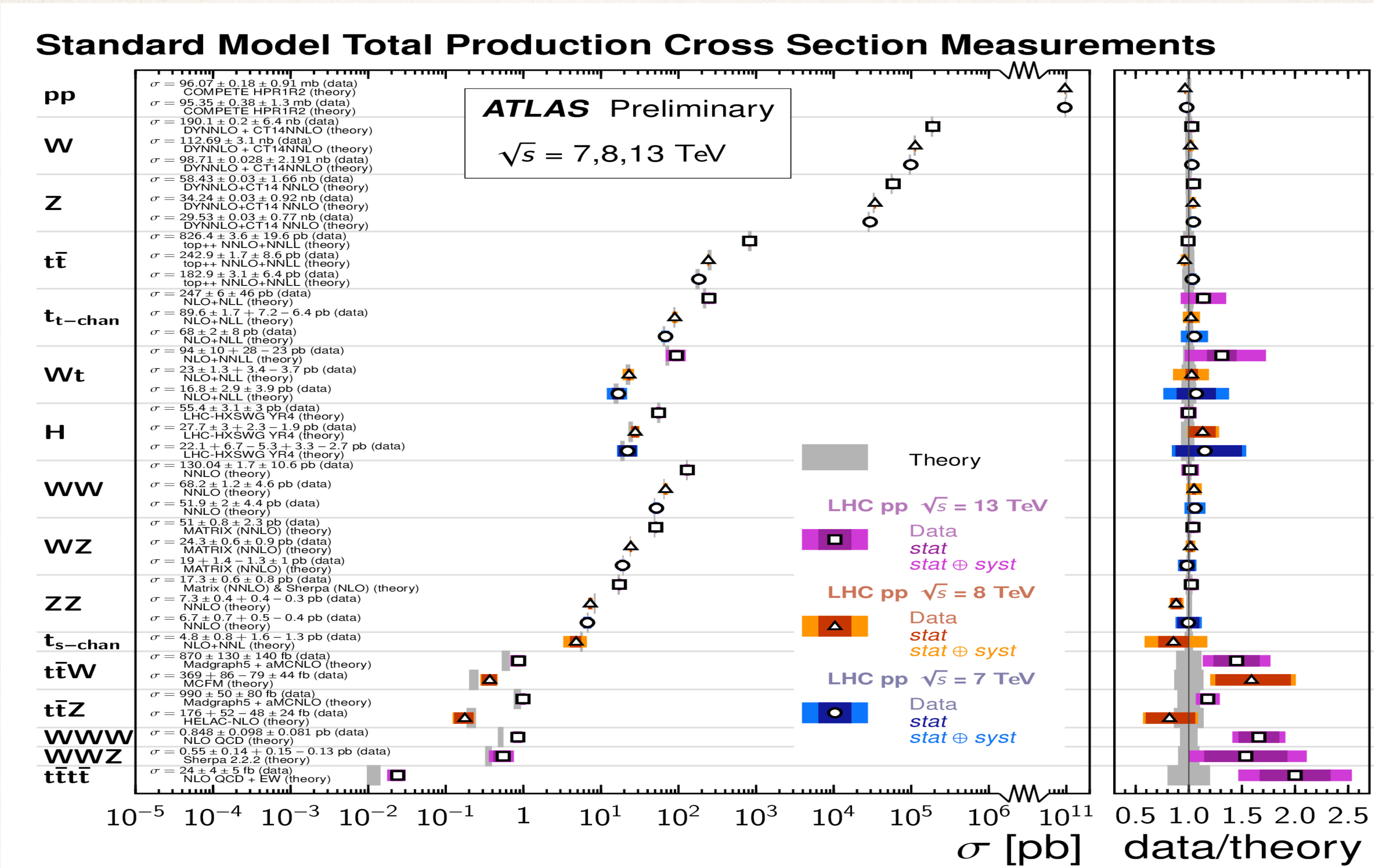
Validity of the EFT expansion

Going beyond SMEFT

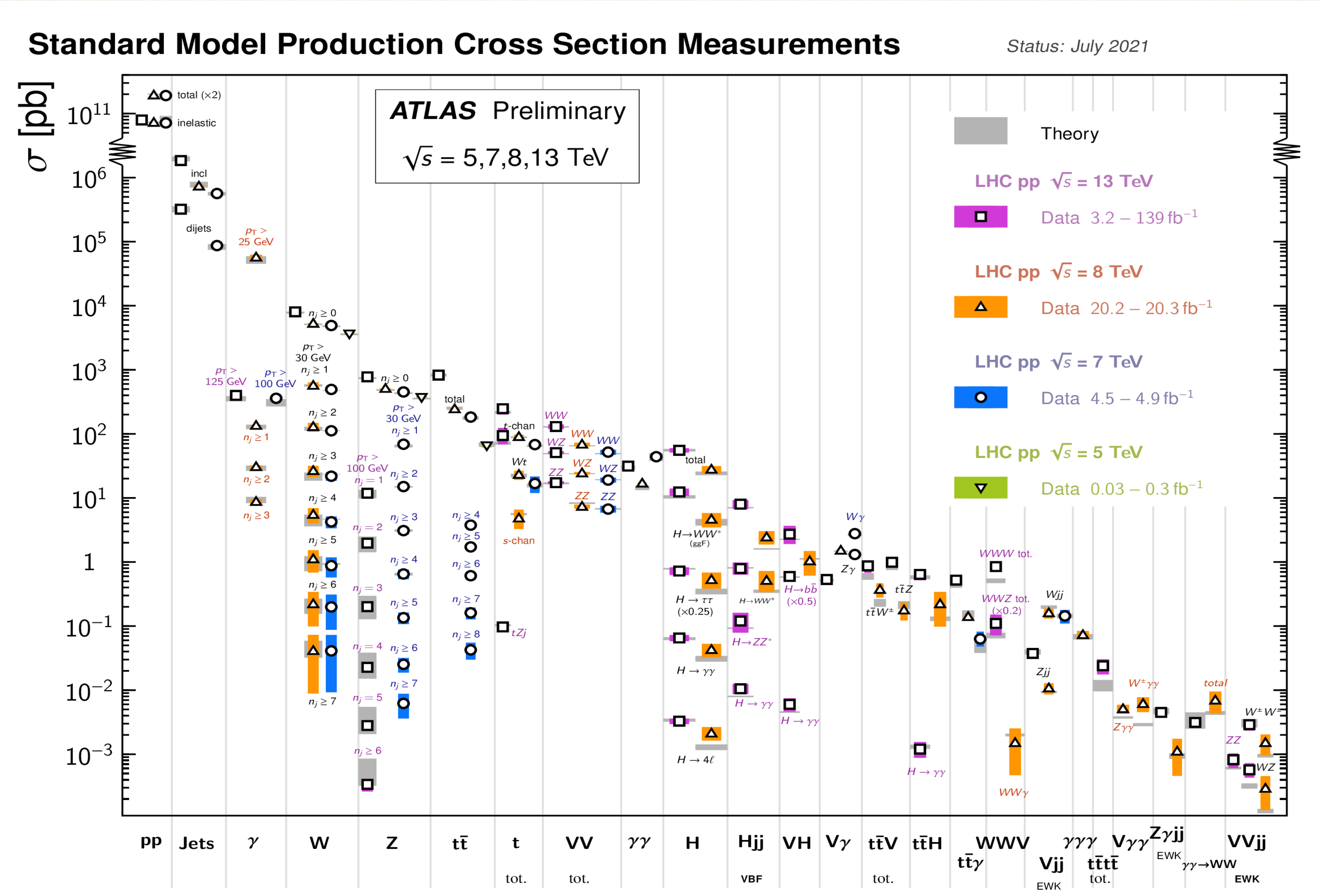
An example with Top physics

SMEFT

How well we know SMEFT? =
how well we know the SM

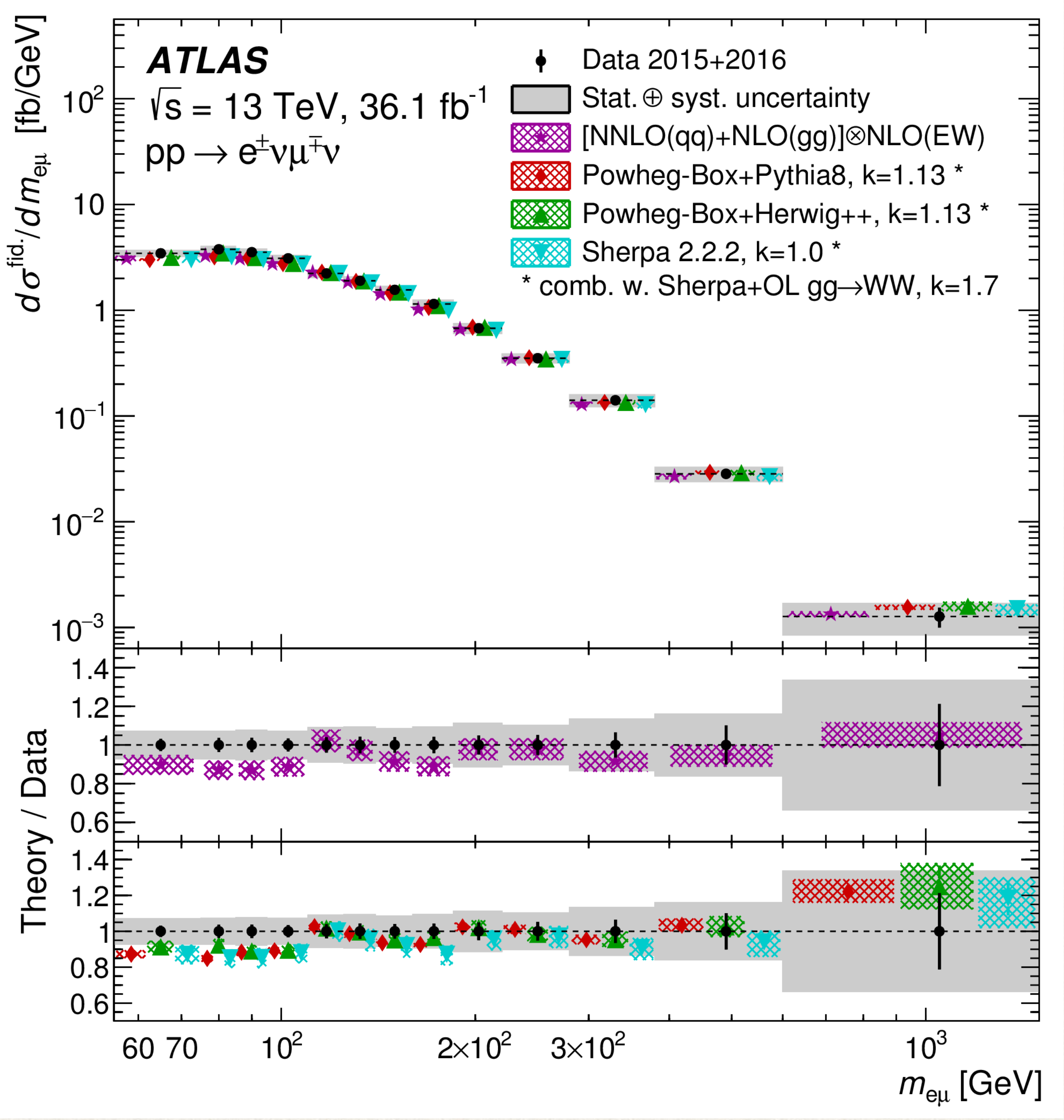


How well we know SMEFT? = how well we know the SM



Run3 and beyond

The LHC is a hadron machine, a **discovery** machine
yet it had to re-invent itself to become a **precision** machine



Precision LHC-> new opportunity

Traditional **resonant searches** have been so far unfruitful

On the other hand, more statistics and better understanding of the experiment allows diving into extreme kinematic regions

State-of-the-art

Global EFT analyses nowadays use
EWPT, LEP WW, LHC di/tri-boson
Higgs, Top, HTop, 4F from
LEP, Tevatron, LHC Run1 and Run2
inclusive and differential
and even flavour in some cases

So it's a game of matching hundreds of observables with a very large parameter space, and give a **consistent view** when all EFT directions are taken into account

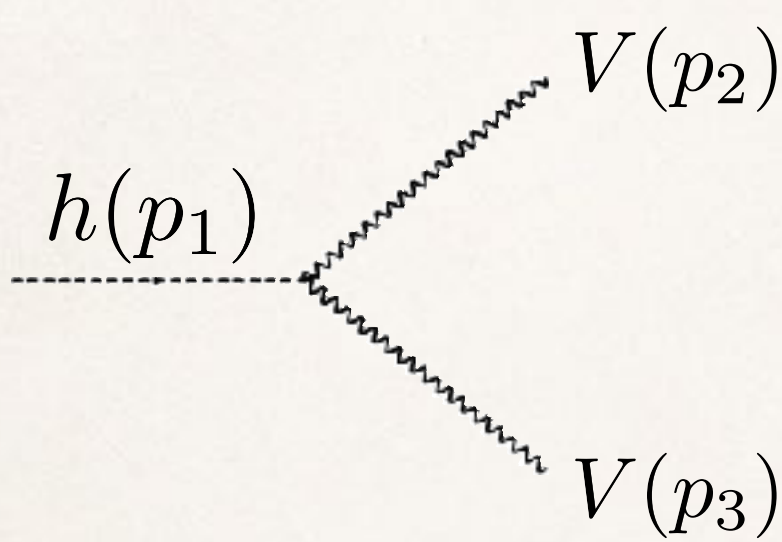
This is very tricky, theoretically and experimentally

The issue of validity

Differential information is key

Models offer richer kinematics than the kappa-formalism
and the EFT approach captures them

$$-\frac{1}{4} h\, g^{(1)}_{hVV} V_{\mu\nu} V^{\mu\nu} \quad -h\, g^{(2)}_{hVV} V_\nu \partial_\mu V^{\mu\nu} \quad -\frac{1}{4} h\, \tilde{g}_{hVV} V_{\mu\nu} \tilde{V}^{\mu\nu}$$

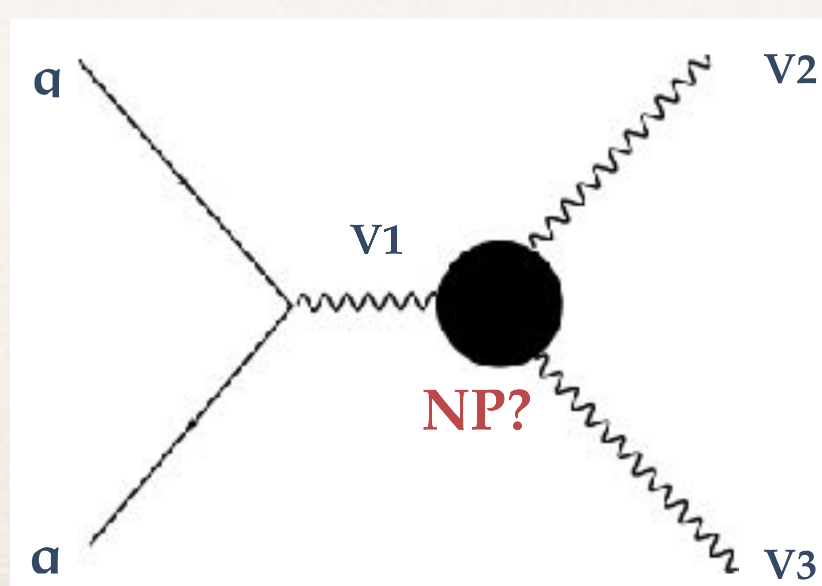


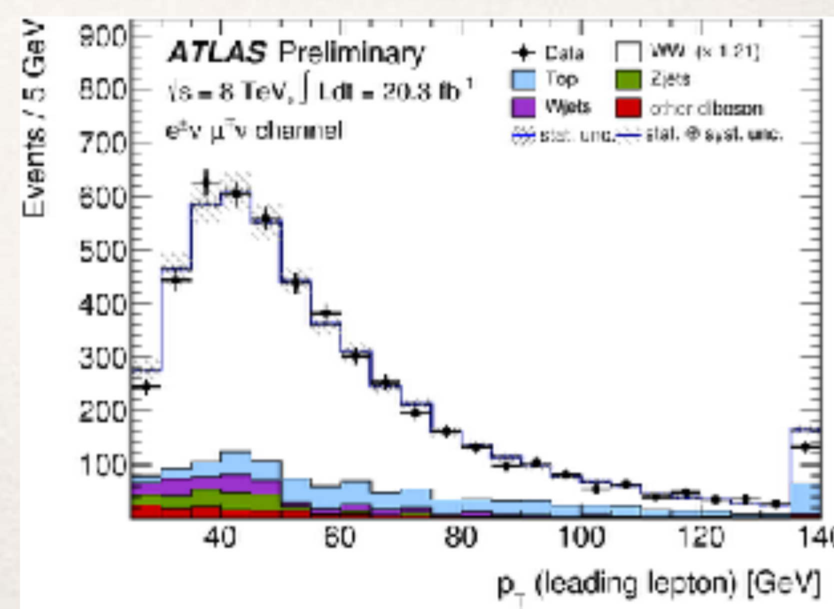
$$i\eta_{\mu\nu} \left(g^{(1)}_{hVV} \left(\frac{\hat{s}}{2} - m_V^2 \right) + 2 g^{(2)}_{hVV} m_V^2 \right)$$

$$-i g^{(1)}_{hVV} p_3^\mu p_2^\nu \quad -i \tilde{g}_{hVV} \epsilon^{\mu\nu\alpha\beta} p_{2,\alpha} p_{3,\beta}$$

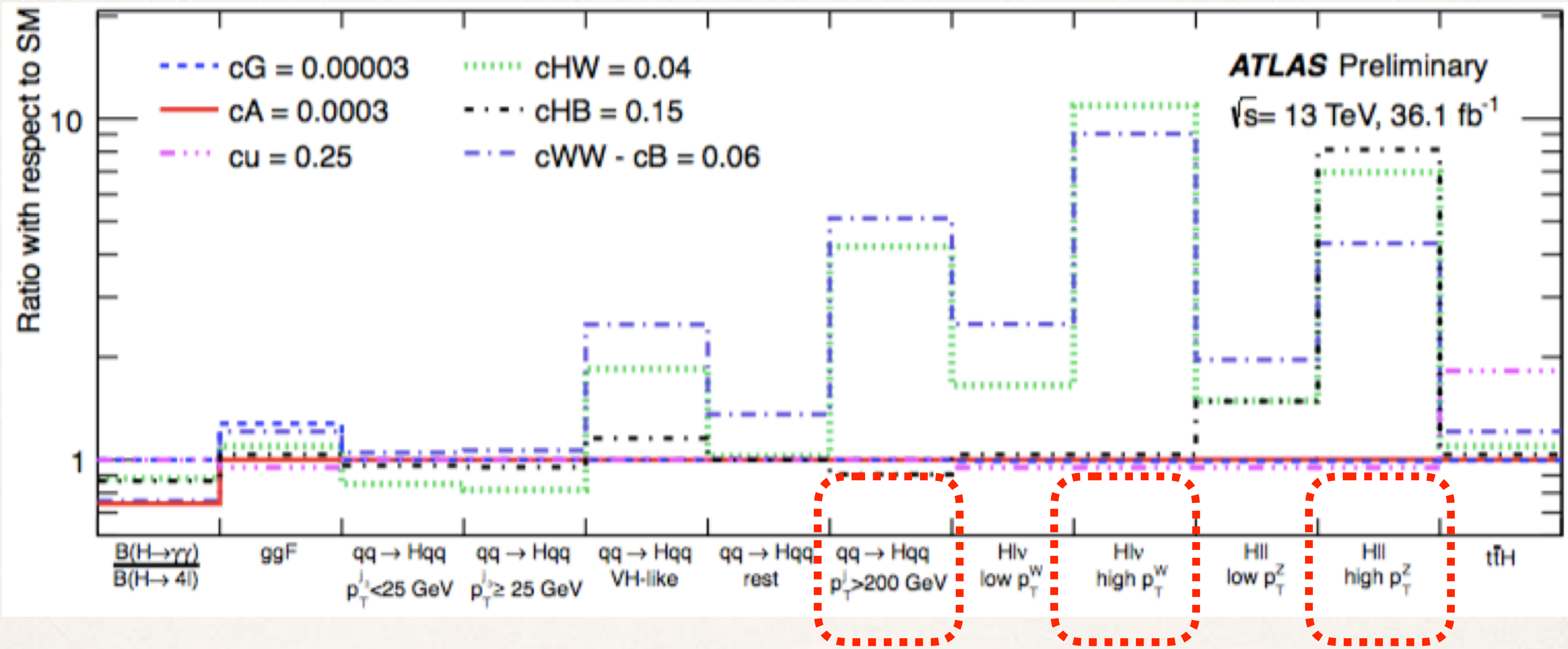
+ *off-shell pieces*

exploited in searches for anomalous **TGCs**





Too much of anything is bad



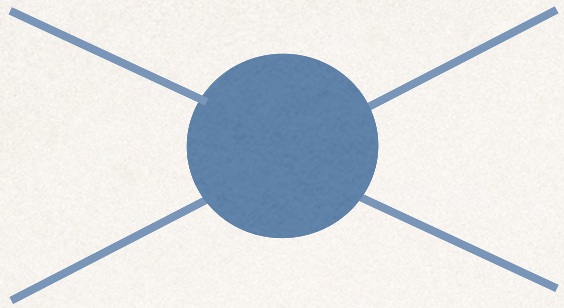
In these regions our theoretical/experimental understanding is weaker

e.g. WW at high-pT (large EW corrections)

e.g. Higgs+jet at high-pTH

and the **EFT validity** needs to be taken into account

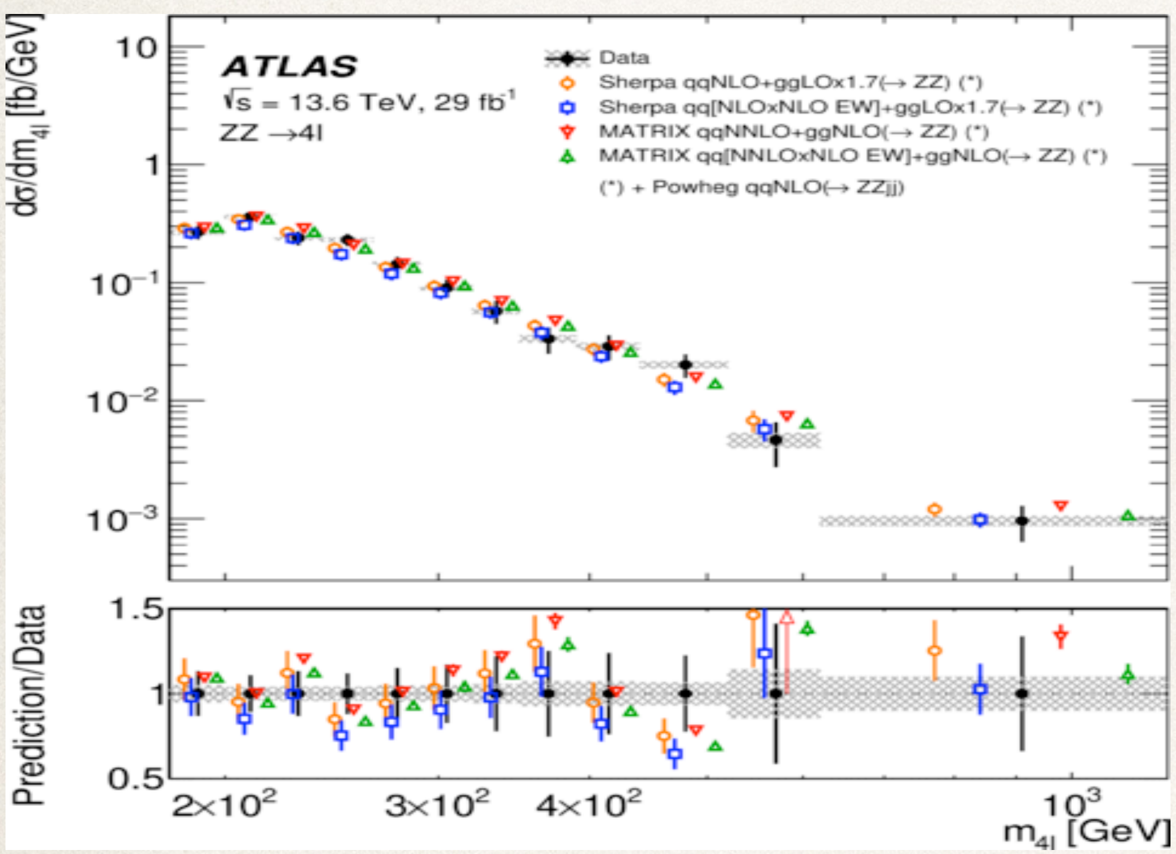
Validity is model-dependent



We place limits on *number of events*

$$\sigma_{NP} \propto c_{NP}^2 \left(\frac{\hat{s}}{\Lambda^2}\right)^n$$

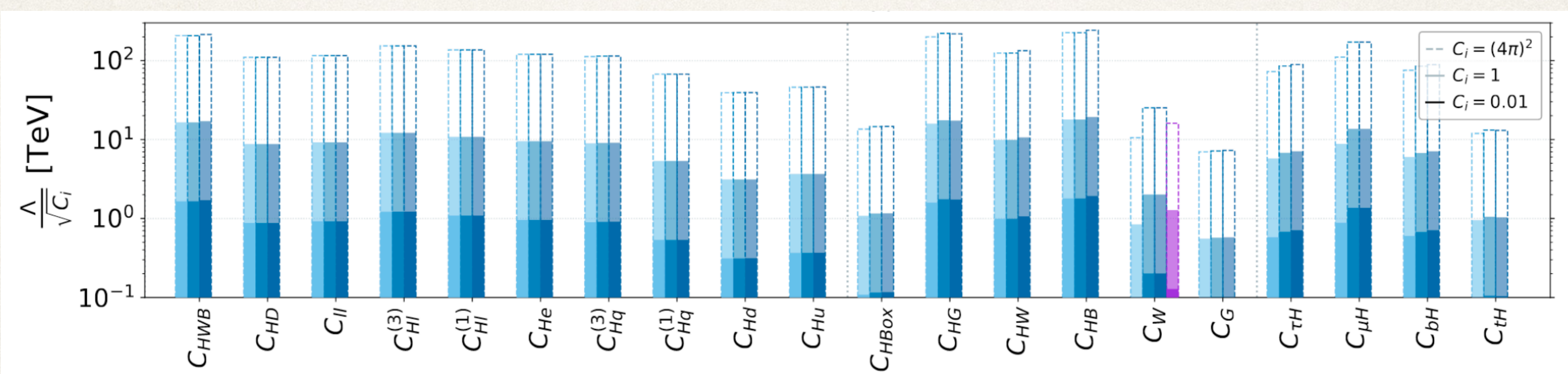
We require $\sqrt{\hat{s}} \gg \Lambda$



but there is a *coupling* in between

$$c_{NP} = \left(\frac{1}{16\pi^2}\right)^l \ldots \mathcal{O}(1)$$

limits then depend on the choice of c

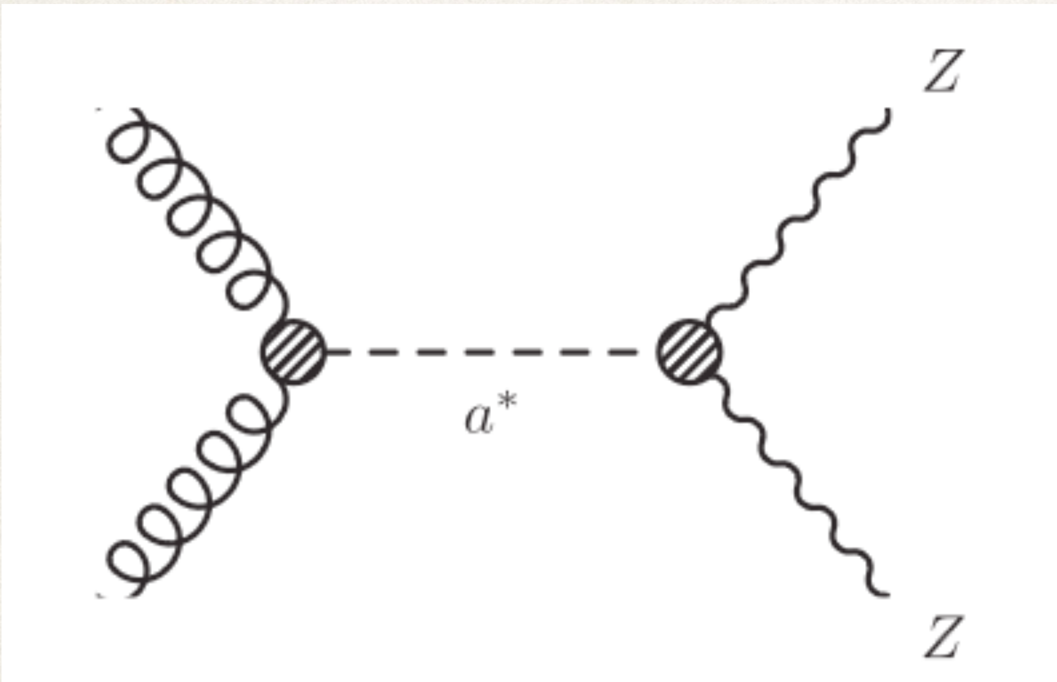


Beyond SMEFT

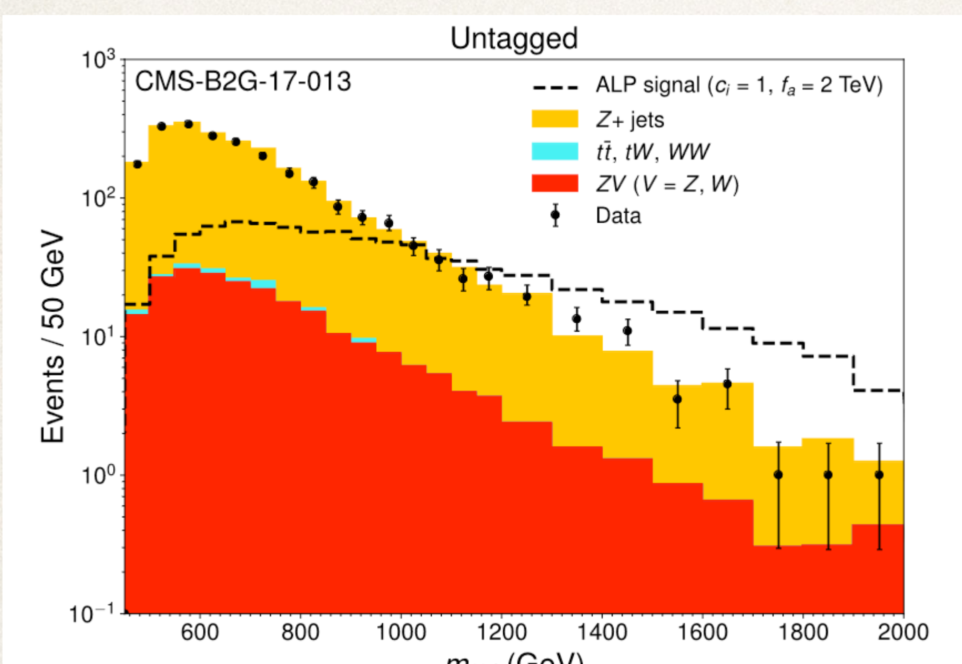
Further use of precise SM measurements to search for new physics

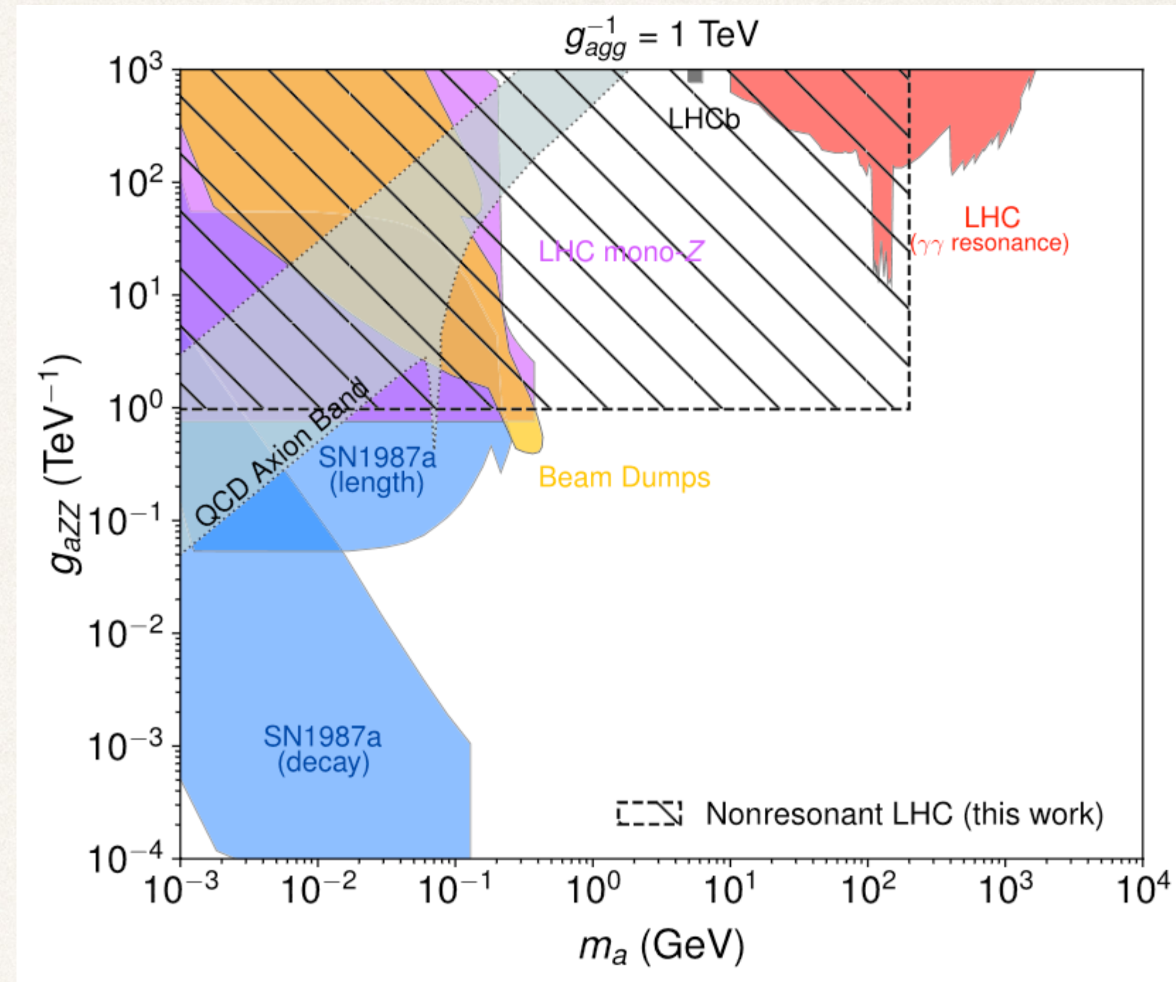
Non-resonant ALP

Gavela, No, VS, Troconiz
PRL 2020



$$\sigma_{V_1V_2} \propto g^2_{agg} g^2_{aV_1V_2} \hat{s} \sim \frac{\hat{s}}{f_a^4},$$



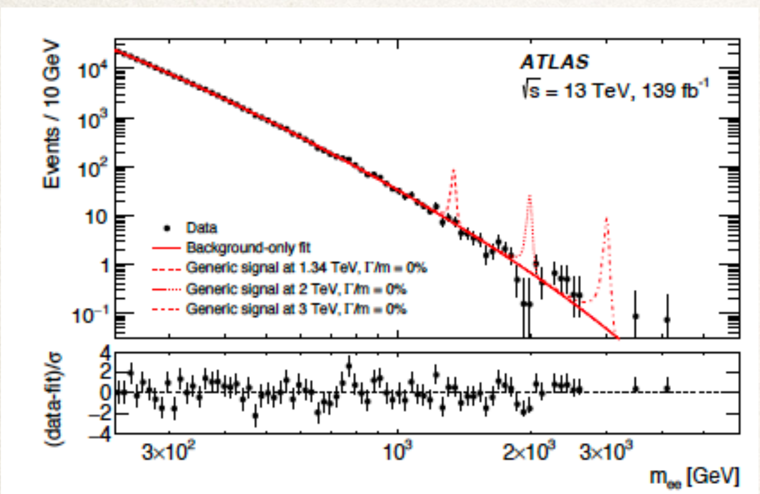


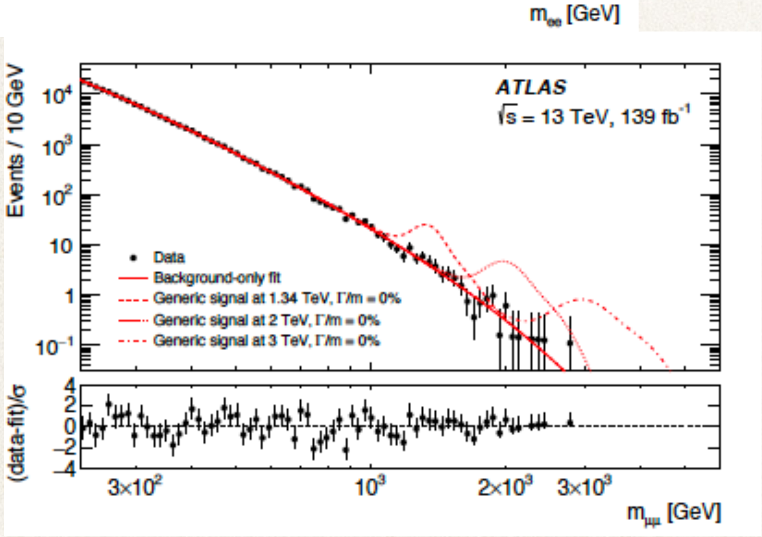
here we also have to deal with the validity issue: limit on f_a needs to be above the kinematic region we use to set the limit

we had to discard channels and certain bins

+Beyond SMEFT?

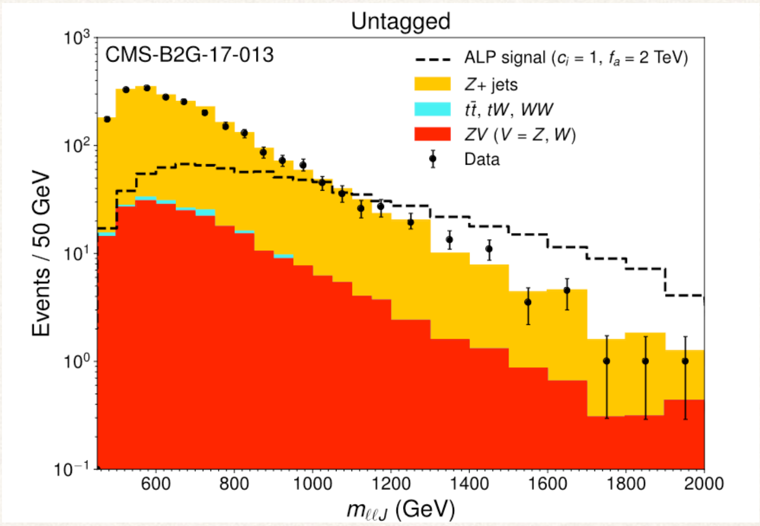
Is there something in between
resonant and non-resonant searches?

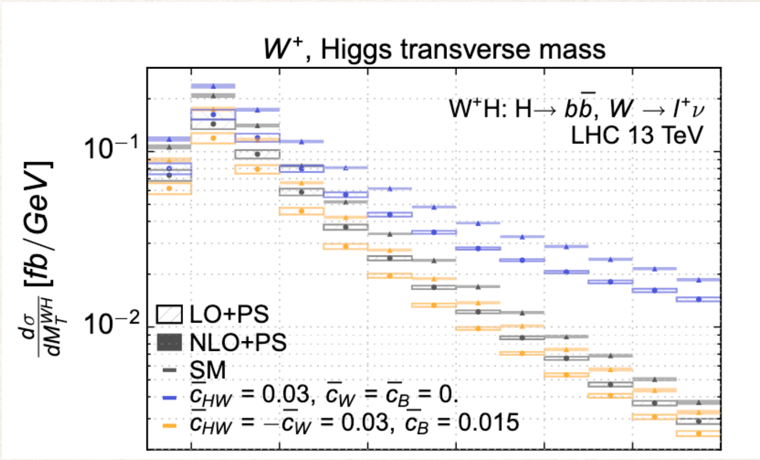




localized excess

?





excess tail

Going beyond SMEFT:
example with top SM measurements

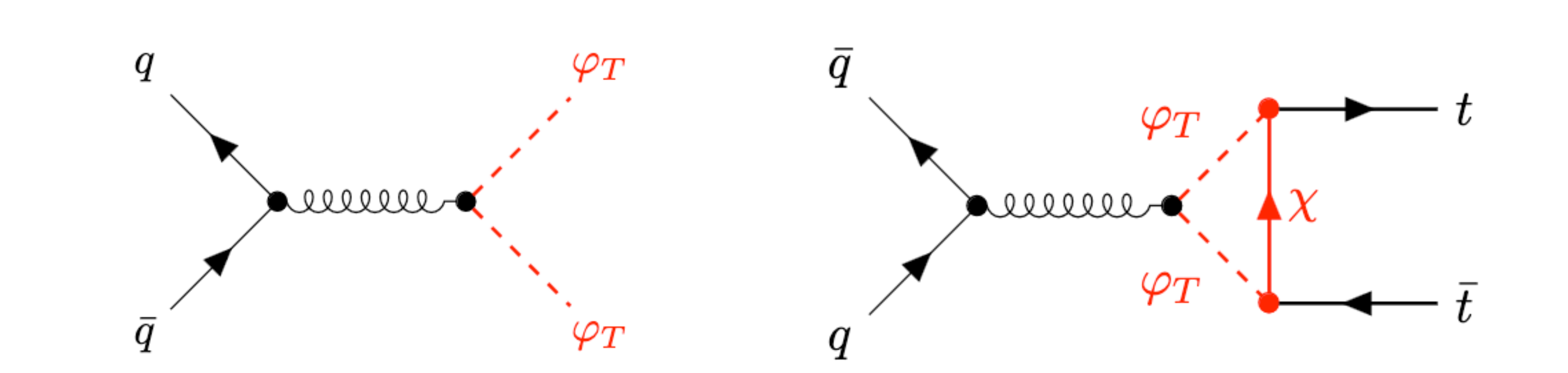
Dark Matter scenario

Let's study a simple scenario
Z2 symmetry, DM candidate, colored top partner
yDM=coupling SM to BSM

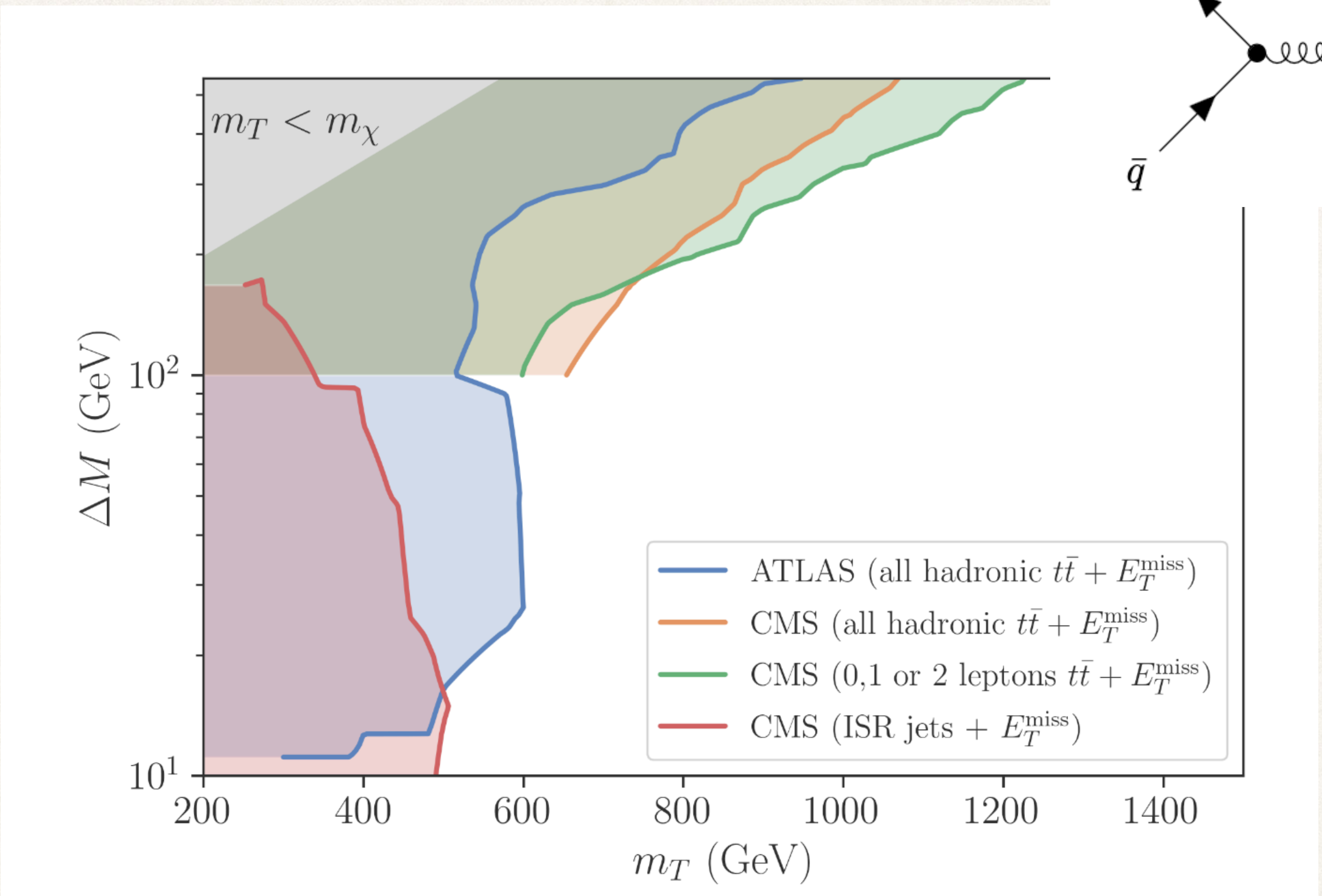
$$\mathcal{L}_{BSM} = \bar{\chi}\left(i\partial\!\!\!/ - \frac{1}{2}m_\chi\right)\chi + |D_\mu\varphi_T|^2 - m_T^2|\varphi_T|^2 - \left(y_{\rm DM}\varphi_T^\dagger\bar{\chi}t_R + h.c.\right)$$

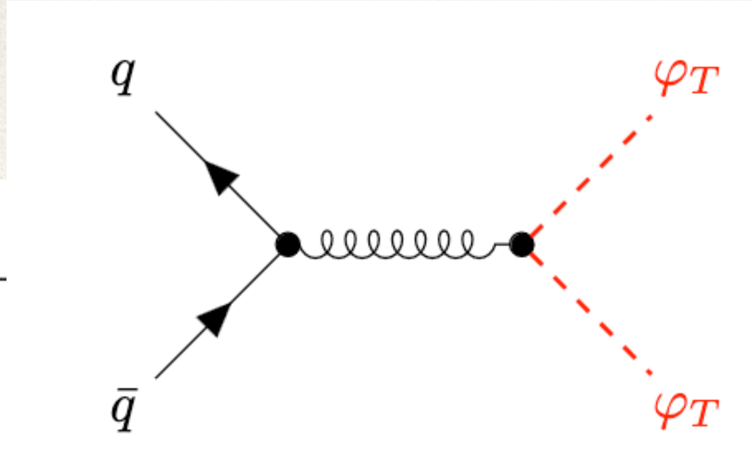
DM pheno: studied in Garny et al. 1802.00814, PRD

Would be produced **directly**
and contribute at one-loop in **top** SM measurements



Direct searches





Decays top partner to top and DM

Using recasting tool SModelS

scan for relevant analyses

compressed spectrum: ISR, limited coverage

Contributions to Top EFT

Compute explicitly all the one-loop integrals
leading momentum expansion, generates EFT Lagrangian

$$\mathcal{L}_{EFT} = m_t C_g\, G^A_{\mu\nu}\left(\bar{t}T^A\sigma^{\mu\nu}t\right) + C_q\left(\bar{t}_R T^A\gamma^\mu t_R\right)\left(\bar{Q}_L T^A\gamma^\mu Q_L + \bar{u}_R T^A\gamma^\mu u_R + \bar{d}_R T^A\gamma^\mu d_R\right)$$
$$+ C_q\left(\bar{t}_R T^A\gamma^\mu t_R\right)\left(\bar{Q}_{3,L} T^A\gamma^\mu Q_{3,L}\right) + C_{tR}\left(\bar{t}_R T^A\gamma^\mu t_R\right)\left(\bar{t}_R T^A\gamma^\mu t_R\right)$$

Relations among the EFT coefficients

Translation to SMEFT
in the Warsaw basis

$$C_g = y_t^{-1}\frac{C_{tG}}{\Lambda^2},$$
$$C_q = \frac{C_{tq}^{(8)}}{\Lambda^2} = \frac{C_{t(u/d)}^{(8)}}{\Lambda^2}$$
$$C_{tR} = \frac{C_{tt}^{(8)}}{\Lambda^2},$$

In the degenerate limit:

$$C_g \simeq -\frac{1}{2}\frac{g_s y_{DM}^2}{384\pi^2}\frac{1}{m_T^2}\,,\; C_q \simeq \frac{3}{2}\frac{g_s^2 y_{DM}^2}{576\pi^2}\frac{1}{m_T^2}\,,\; C_{tR} \simeq -\frac{1}{3}\frac{y_{DM}^4}{128\pi^2}\frac{1}{m_T^2}$$

$$(m_T \simeq m_\chi)$$

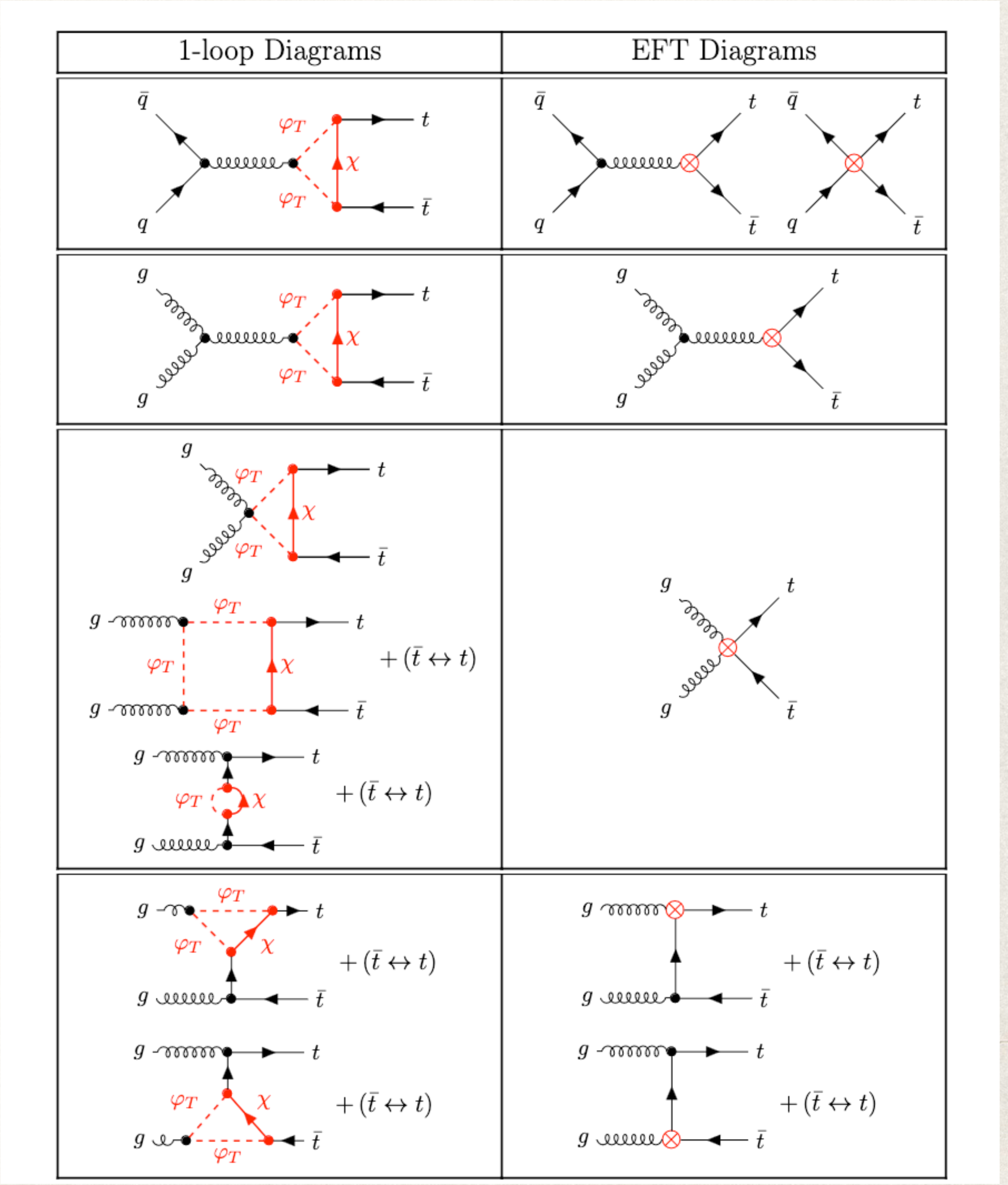
Matching and form factors

Want to compare the full loop predictions and the EFT equivalent

In practice one has to compute this matching

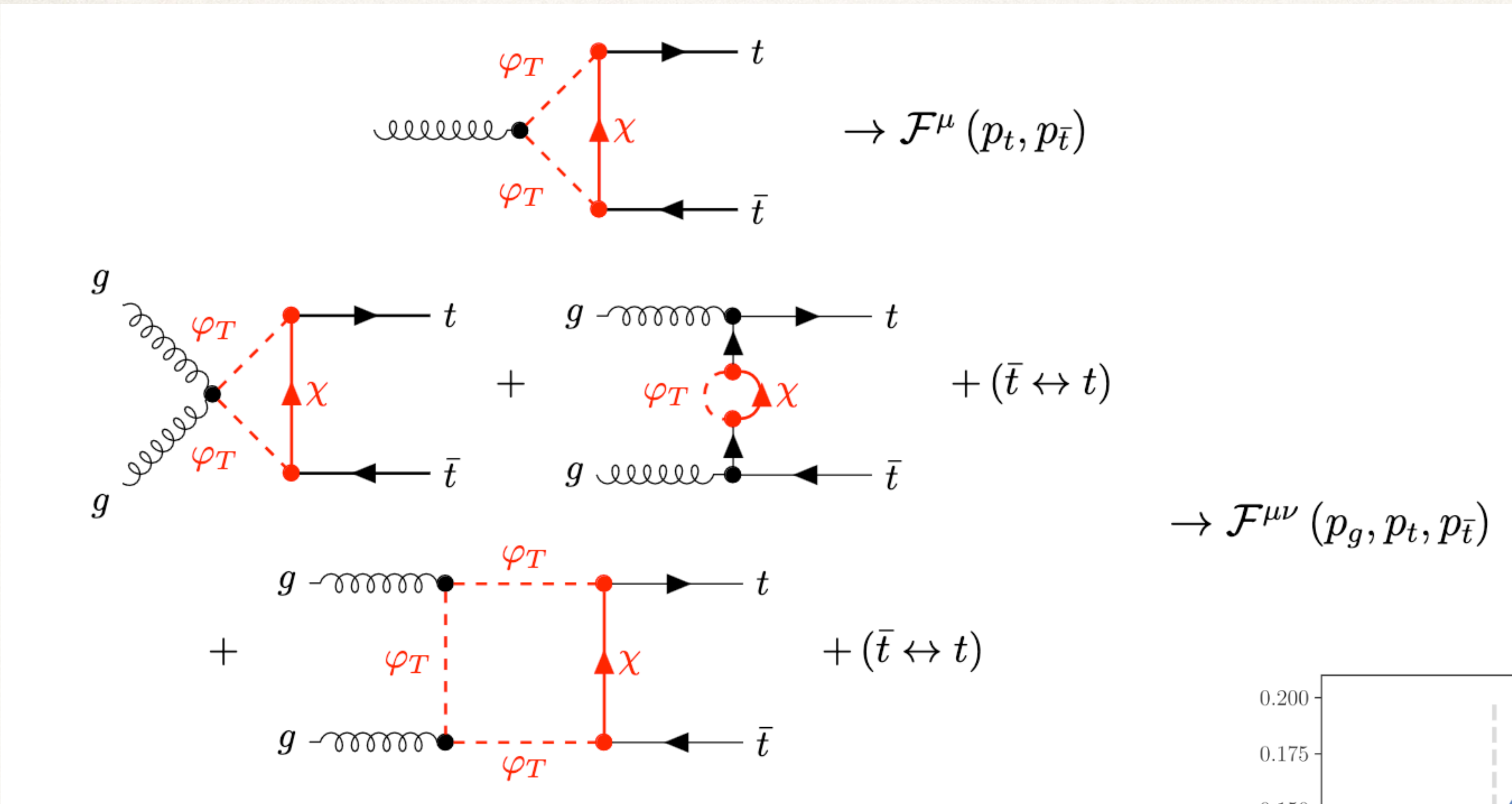
Not so trivial, becomes a bit technical: counterterms…

(all code and details in Zenodo)



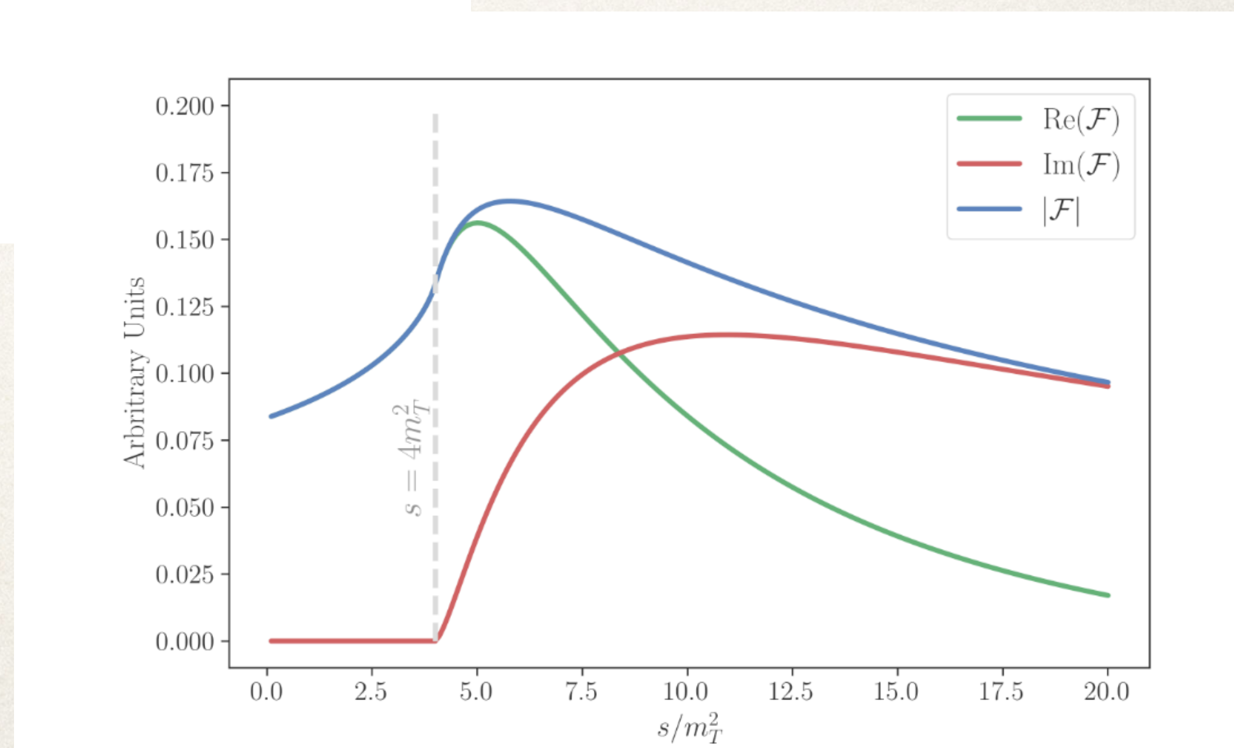
Contributions to ttbar final states

$$\mathcal{L}_{FF} = \pi^2 g_s y_{DM}^2 G_\mu \bar{t} \left[\mathcal{F}^\mu \left(p_t, p_{\bar{t}}\right)\right] t + \pi^2 g_s^2 y_{DM}^2 G_\mu G_\nu \bar{t} \left[\mathcal{F}^{\mu\nu} \left(p_g, p_t, p_{\bar{t}}\right)\right] t$$

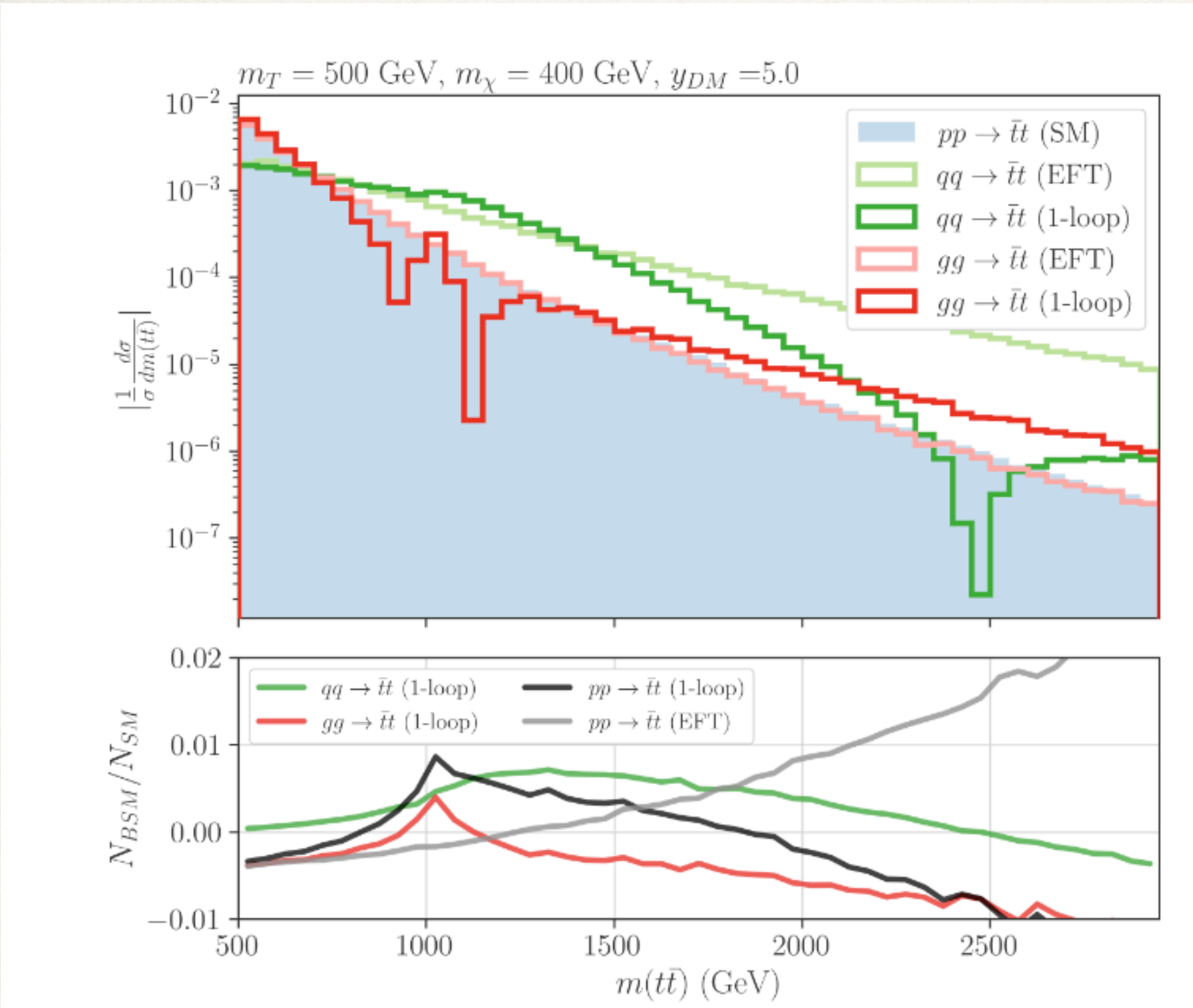


Two form factors contribute to ttbar

The kinematic behaviour at parton level shows a *broad bump* beyond sensitivity of resonant searches



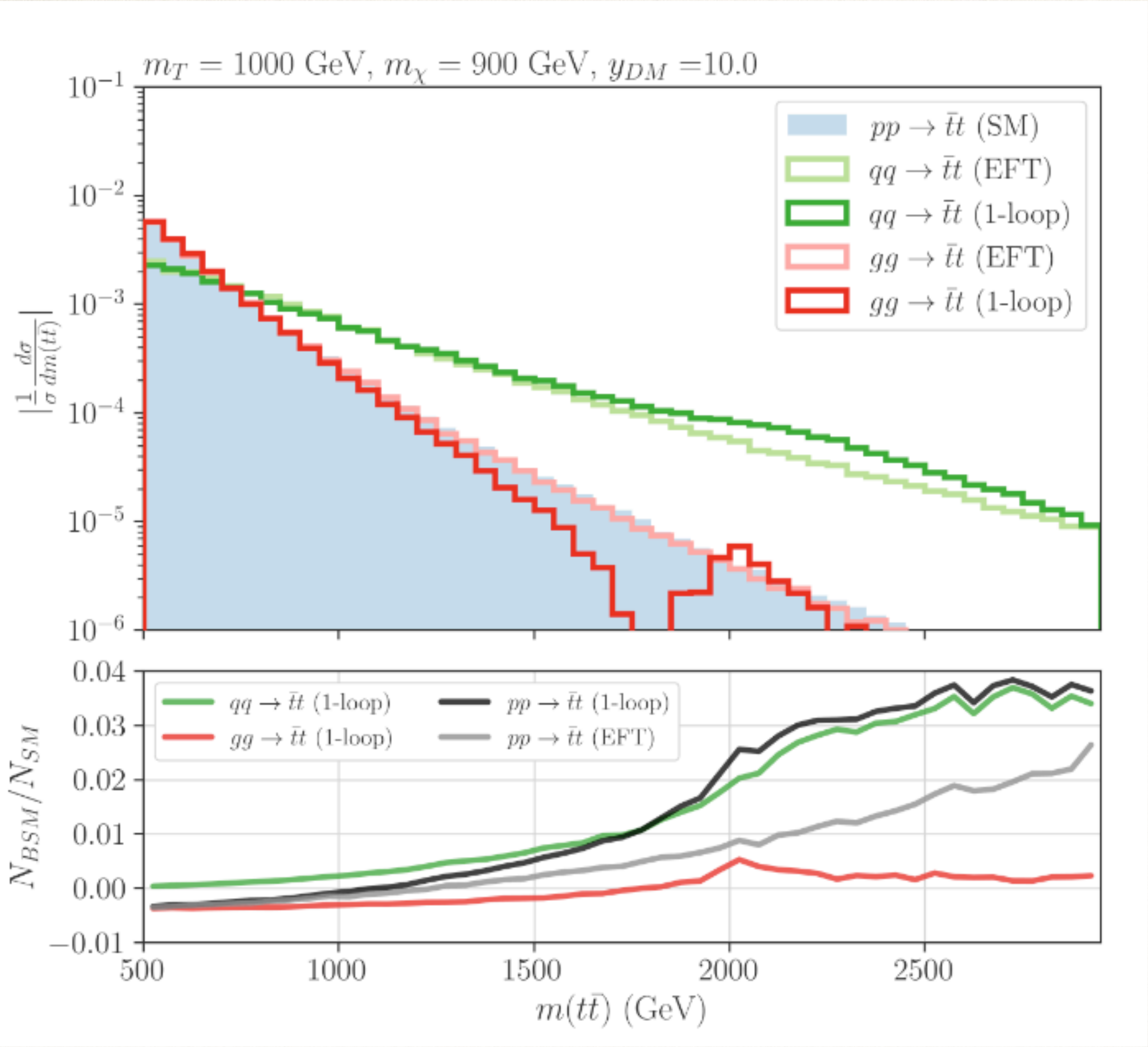
Invariant mass distribution: low mT



When convoluted with PDFs, the bump behaviour remains

And it is quite different from the SMEFT "equivalent"

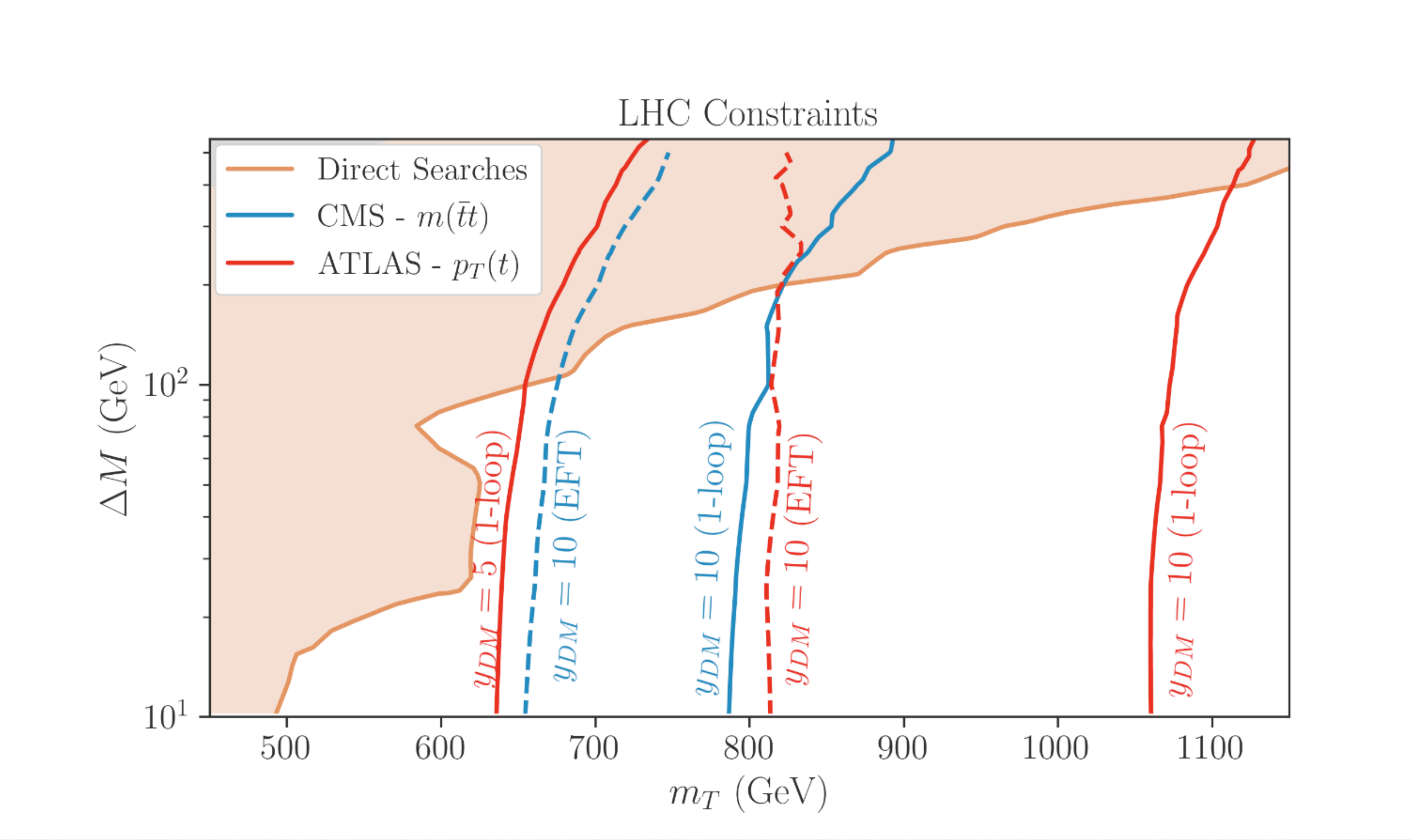
Invariant mass distribution: high mT



Even at relatively high masses, the difference 1-loop to SMEFT is noticeable

Depends on the kinematic reach on mtt

The *money plot*



Qualitative features, should carry over other cases

Direct vs indirect: compression of spectrum, MET

Loop vs EFT: gain in knowledge of the full form factor

Conclusions

The SM EFT is a very active area of research at the LHC motivated by the lack of direct evidence for new physics and increased precision in SM observables

The state-of-the-art in our understanding of SMEFT: global analyses including hundreds of observations and dozens of possible EFT deviations

Alternative interpretations on non-resonant phenomena, e.g. ALPs, provide a different view on the same data

With the same SM precision measurements, we can look at different kinematic regions (~broad bumps) that would be missed in resonant searches and in SMEFT tails search and are motivated by e.g. scenarios of DM