Karlsruhe Institute of Technology

Theoretical summary

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TTP KIT

TOP2017

In contrast to many of you, I do not actively work on the top quark physics (my last paper with "top" in the title was 3 years ago), so my understanding of many things is, probably, outdated.

However, it is always interesting to come back after some time and reflect on the changes.

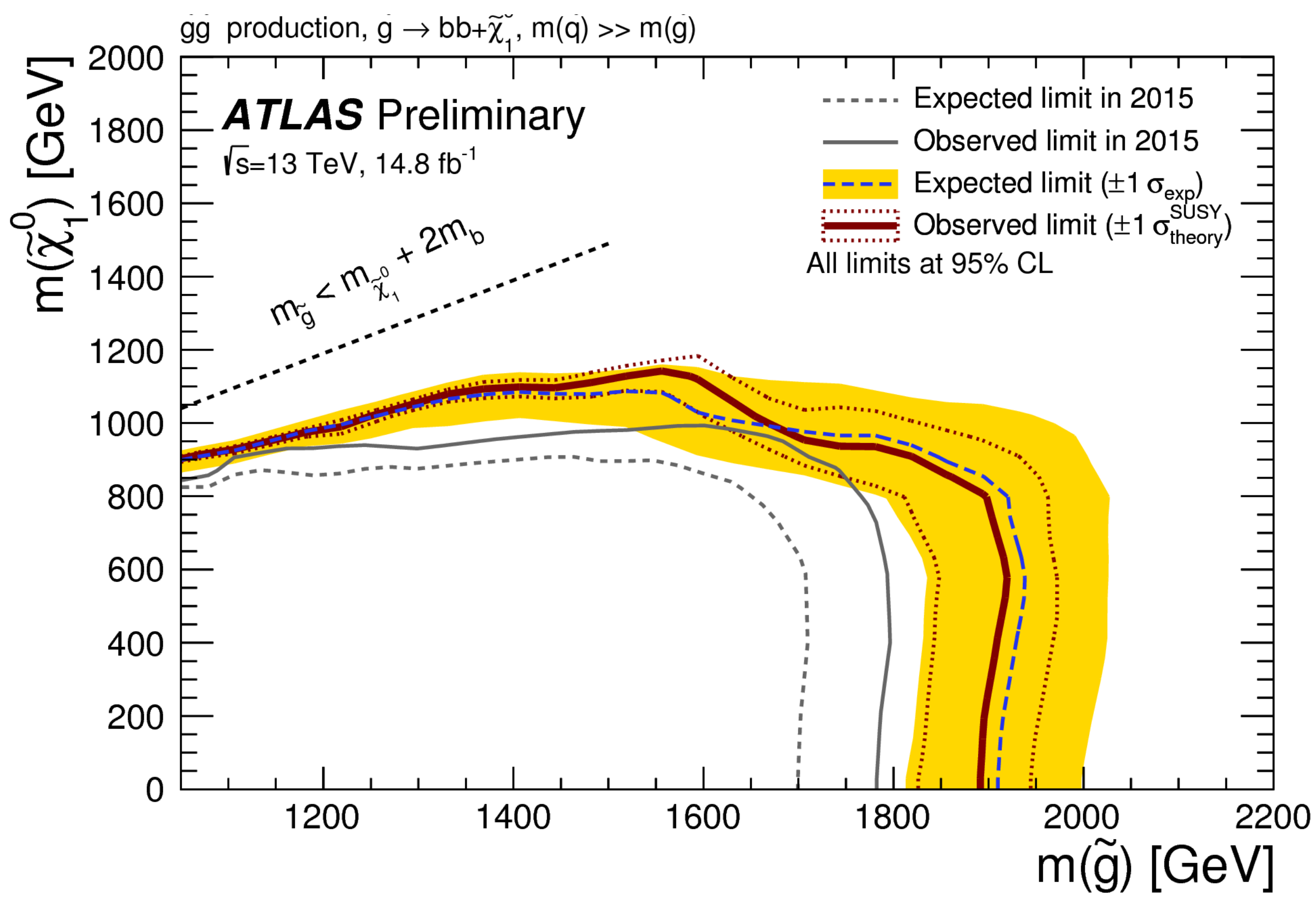
During this week, I got an impression that during the recent years, quite dramatic things happened both in theory and experiment in the top quark world.

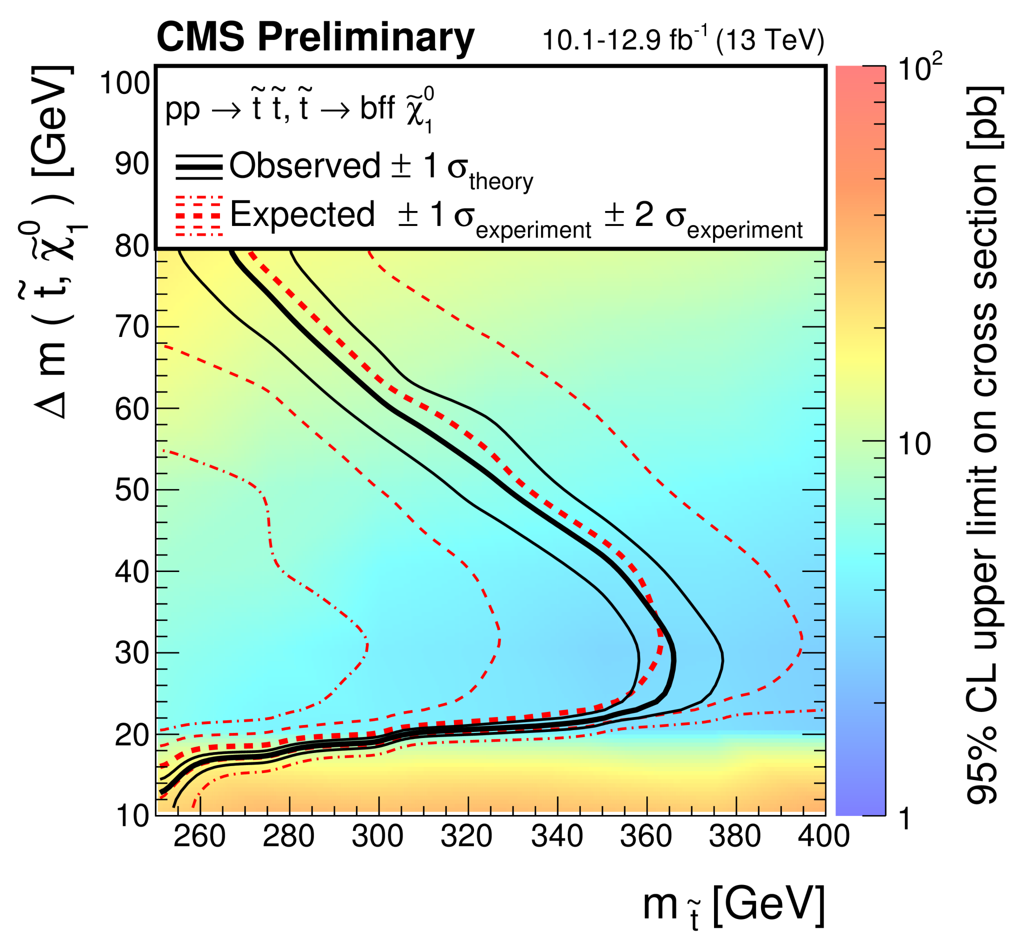
On the experimental side, it is an appearance of a very large data sample, that keeps many of you busy.

On the theory side, it is an emergence of high-precision predictions for multitude of processes with top quarks and the growing appreciation that great things can be done using them.

A large number of interesting results based on precise theoretical interpretation of equally precise measurements seems to be a hallmark of top quark physics right now -- and perhaps the future of the collider physics in the years to come.

ATLAS and CMS achieved spectacular results driving many models of physics beyond the Standard Model into regions of parameter space that are difficult to access at the LHC.   We need to think how to retrieve it from there.





Exclusion limits for stops and gluinos after ICHEP2016

One of the possible answers (or the only possible answer) is that future collider physics will be defined by searches for subtle effects -- precision physics at a hadron collider.

These subtle effects may arise in many ways; e.g. their originators can be too heavy to be seen, or they can be light but know how to blend into a background.

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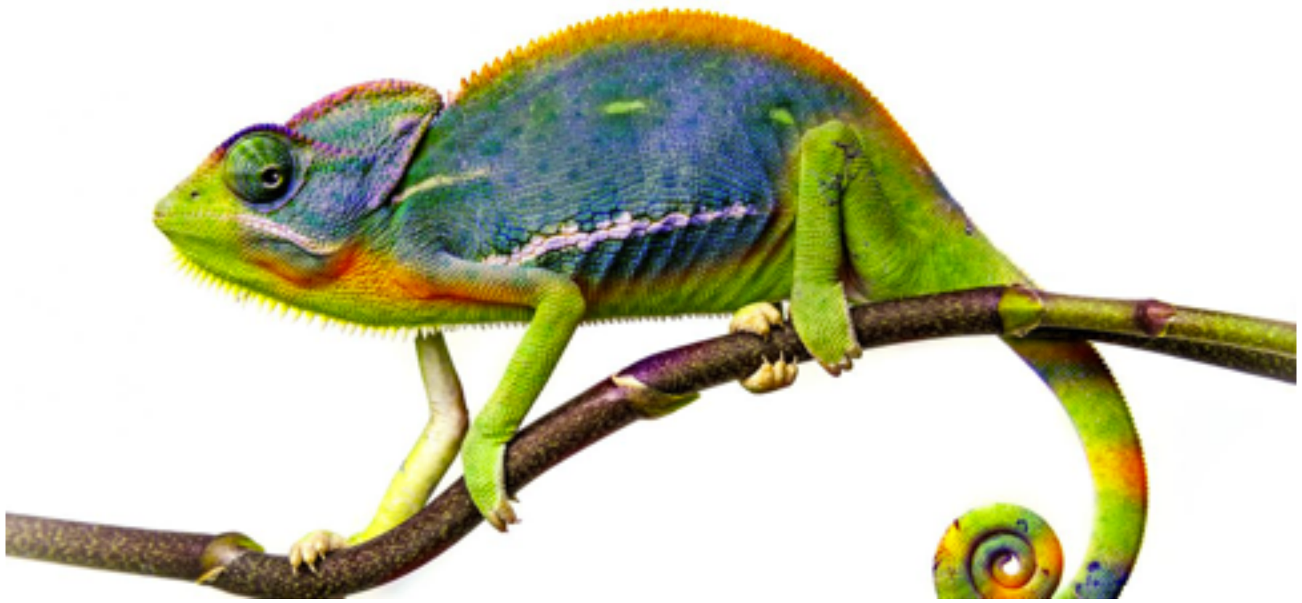
These subtle effects can arise in many ways; e.g. their originators can be too heavy to be seen, or they can be light but know how to blend into a background.

We will have to find a way to understand what they are.



The success of this endeavor requires several things:

- superb experimentation;

-- understanding which questions should be asked and where the interesting things can hide;

-- ability to describe hadron collisions from first principles with maximal attainable (and still sensible) precision;

Cross-talk between experts in different theory areas and experts in experiment is crucial; it is only this cross talk that will allow us to move forward towards the common goal -- finding physics beyond the Standard Model or at least constraining it from precision LHC measurements.

It is amazing to see how beautifully and efficiently this cross talk works in the top quark community.

This inter-connectivity seems to be required by the very nature of the top quark -- a particle that has something for everyone.

1) it is unusually heavy and interacts unusually strongly with the Higgs boson; in fact so strongly that it can destabilize our vacuum;

2) it is part of a flavor puzzle but its role in it is not at all clear;

3) it may be expected to talk directly to the Dark Side but we do not know how and if at all;

4) it has the capacity to annoy those of us who do not care about the top by directly interfering with searches for other interesting things at the LHC;

5) it is the only "free" color particle that we can observe and whose properties we, therefore, can describe in great detail from first principles.

For points 1-3: see the keynote by N. Craig and talks by Frugluele, Panico, Kilic, Takeuch at the mini-workshop

According to a “famous relativist”, top physics is just two numbers.... But why two? Even according to PDG there are many more ...

$$I(J^P) = 0(\tfrac{1}{2}^+)$$

Charge $= \frac{2}{3}\, e$ Top $= +1$

Mass (direct measurements) $m = 173.1 \pm 0.6$ GeV [a,b] $(S = 1.6)$

Mass from cross-section measurements) $m = 160^{+5}_{-4}$ GeV [a]

Mass (Pole from cross-section measurements) $m = 173.5 \pm 1.1$ GeV

$m_t - m_{\overline{t}} = -0.2 \pm 0.5$ GeV $(S = 1.1)$

Full width $\Gamma = 1.41^{+0.19}_{-0.15}$ GeV $(S = 1.4)$

$\Gamma\big(W b\big)/\Gamma\big(W q(q = b,\, s,\, d)\big) = 0.957 \pm 0.034$ $(S = 1.5)$

t-quark EW Couplings

$F_0 = 0.685 \pm 0.020$

$F_- = 0.320 \pm 0.013$

$F_+ = 0.002 \pm 0.011$

$F_{V+A} < 0.29$, CL = 95%

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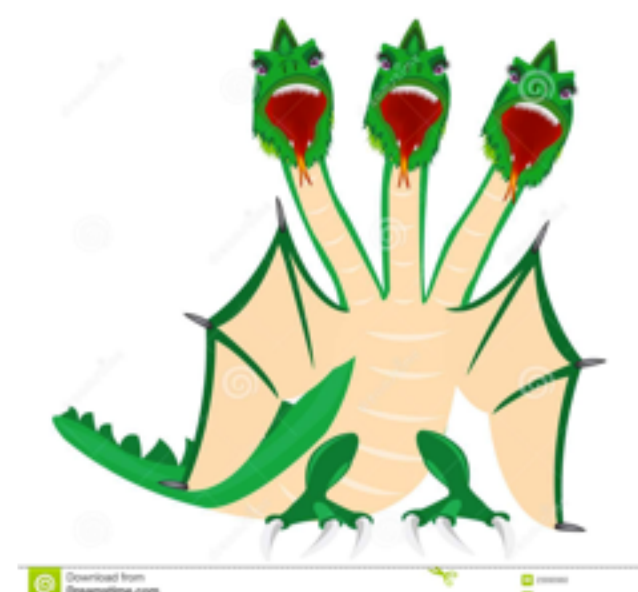
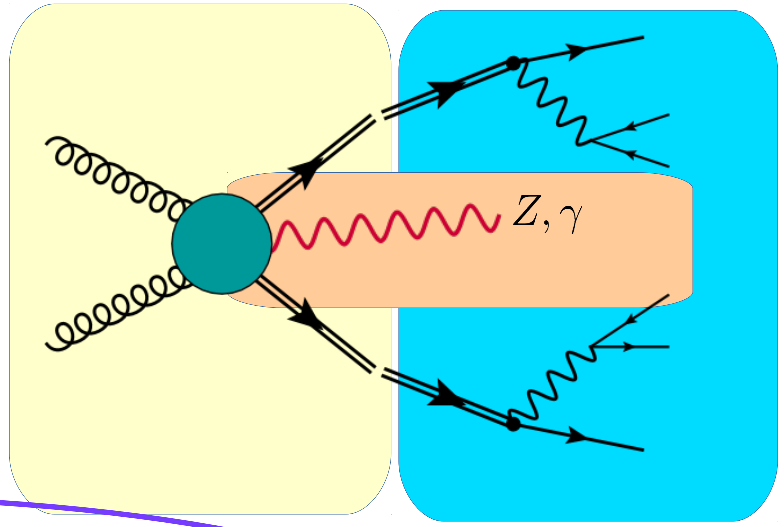


In fact it is the only quark (and the only particle for that matter) that officially got THREE(!) different masses according to PDG !

The situation becomes even more confusing if we consider the SM as a low-energy approximation to a true theory and give up the requirement of the renormalizability. Then, the number of “parameters” that play a role in top quark physics increases and becomes, essentially, infinite...

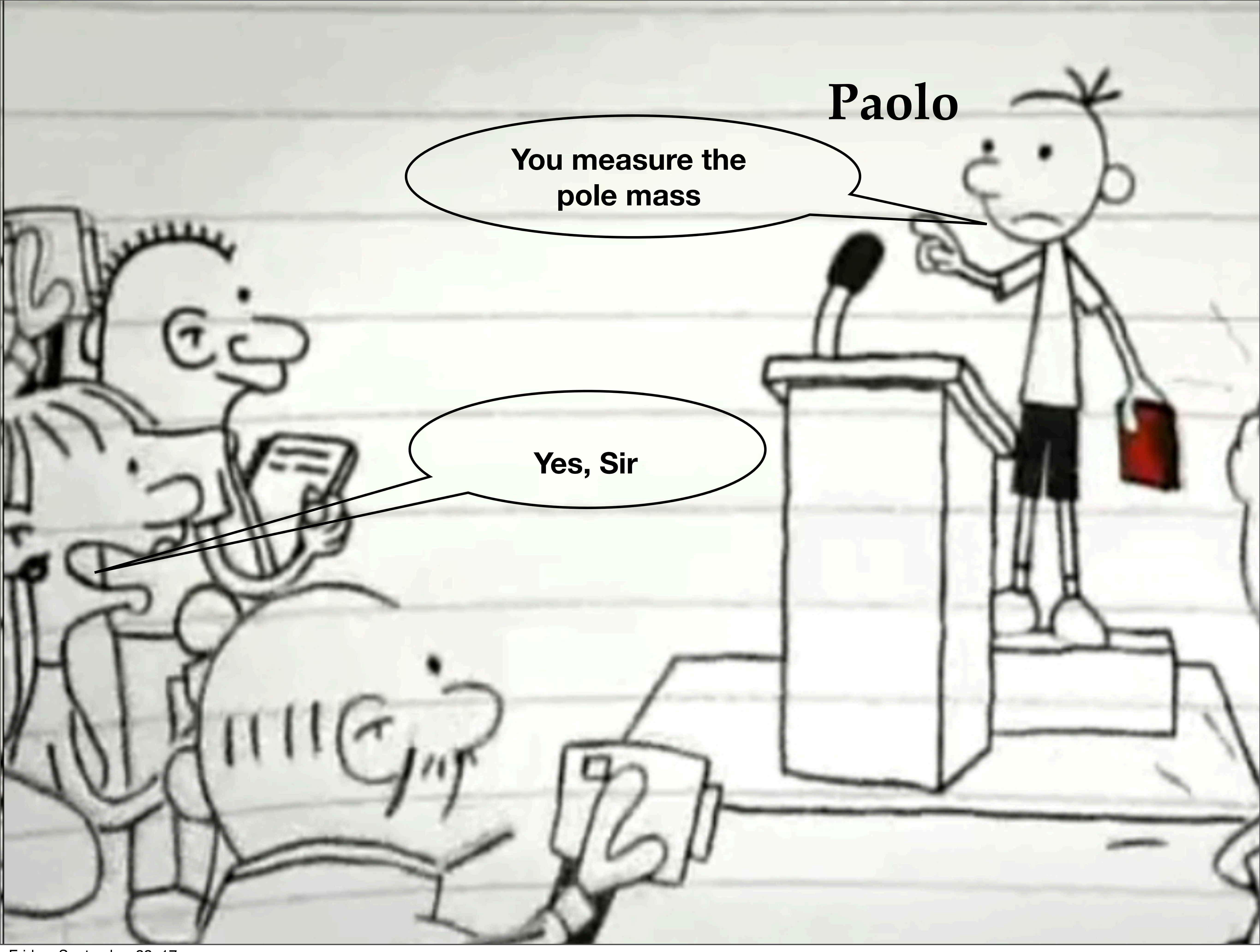
Reducing the number of these parameters back to something reasonable will require the discovery of the UV completion of the SM; a holy grail of the high-energy physics.

Can it be that the “famous relativist” already secretly knows it ... ?



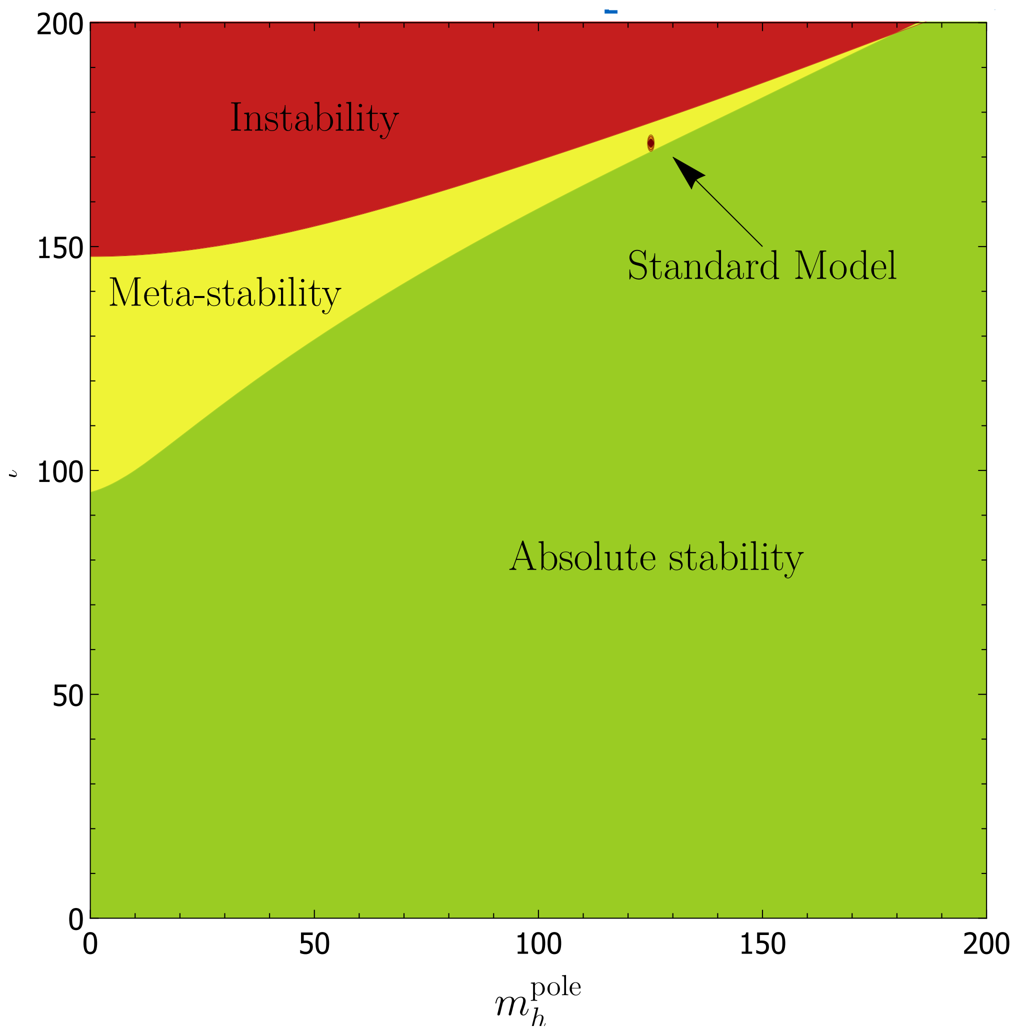
- There are (at least) 28 anomalous operators affecting production & decay dynamics
- A global (28-dimensional) approach is impossible

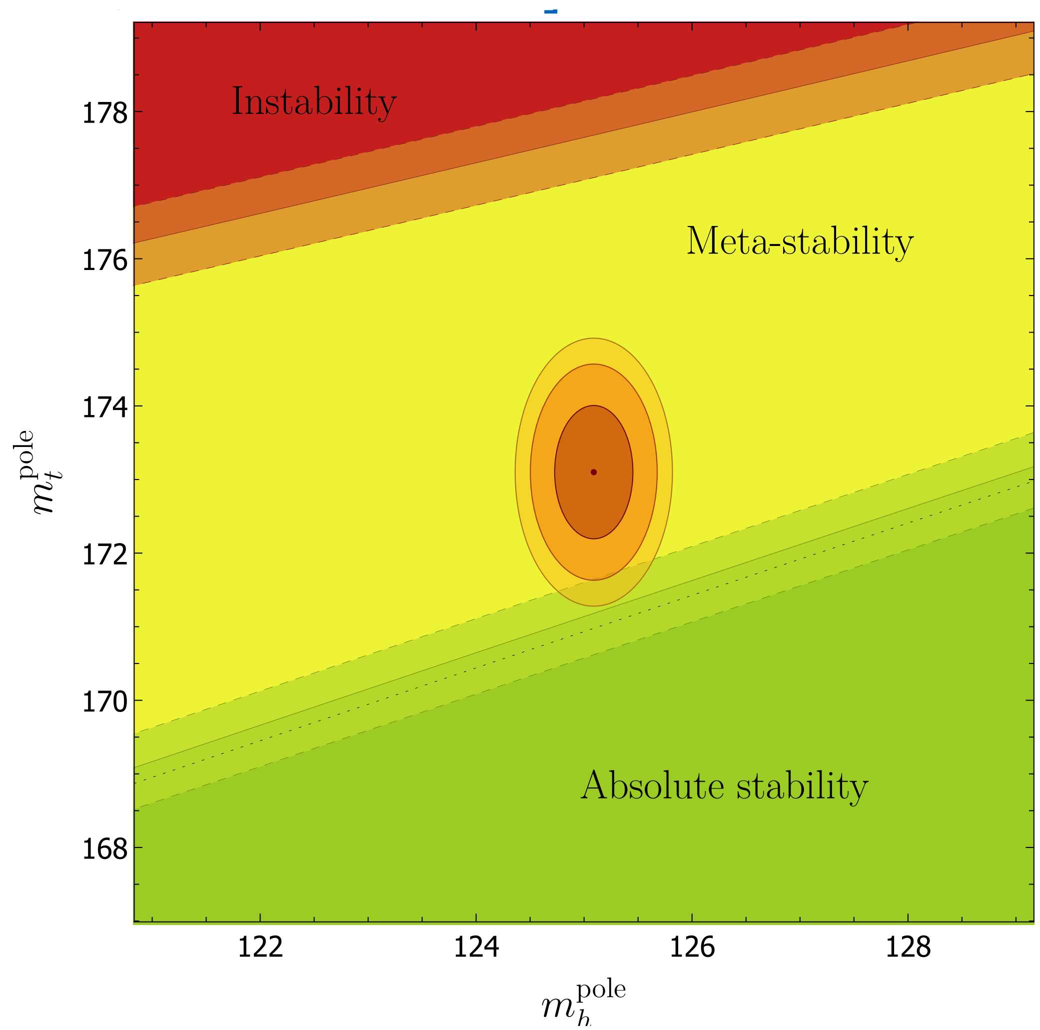
In what follows I will discuss what we know about parameters that affect the top quark physics and how we expect to learn more about them. I will start with the most important one -- the top quark mass.


Paolo
You measure the pole mass
Yes, Sir

The top quark mass: the beauty and the beast

See talks by P. Nason, N. Craig, A.Salvio





$$\tau_{SM} = \left(\frac{\Gamma}{V}\right)^{-1/4} = 10^{139^{+102}_{-51}} \text{ years}$$

$$m_t < 171 \text{ GeV}$$

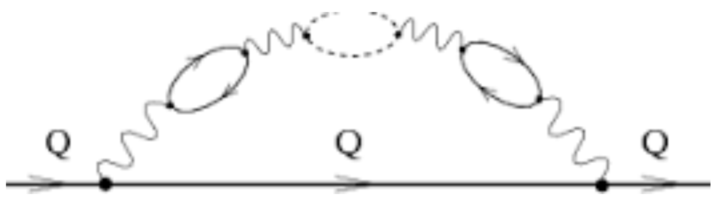
for the vacuum stability

Uncertainty equal parts m_t, α_s, threshold corrections

The top quark mass is measured very precisely ($m_t = 172.4(5)$ GeV) but there is an important question about what this result means since numerical differences between top quark masses defined in different perturbative schemes are known to be large (up to several GeV).

It is often stated that the ``Monte Carlo mass'' is measured by CMS and ATLAS but this notion is quite confusing.

There are two issues related to top quark mass measurements that are often lumped together :



1) "intrinsic" effects that make the notion of the top quark pole mass theoretically ill-defined; this problem was shown to be irrelevant for the LHC top quark mass determinations (O(100-200) MeV irreducible error). Recall, however, that to rule out metastability of our vacuum, the error on the mass should be below 250 MeV.

2) generic non-perturbative effects that affect the extraction of the top quark mass in experiments (MC mass is perhaps a short-hand notation for that).

Similar to a measurement of any other observable at hadron colliders, extraction of the top quark mass is affected by non-perturbative effects. This is an issue that exists even if a short-distance mass definition for the top quark mass is chosen.

Let us imagine an idealized situation where parton shower is not needed for the extraction of the top quark mass but an observable, from which the top quark mass is determined, is predicted with the standard QCD accuracy, i.e. up to power corrections.

$$\frac{\mathrm{d}\sigma}{\mathrm{d}M} \approx T(M, m_t, \alpha_s)\left[1 + c\left(\frac{\Lambda_{\rm QCD}}{M}\right)^n\right]$$

$$\delta m_t \sim \frac{c\,T}{\partial T/\partial m_t}\left(\frac{\Lambda_{\rm QCD}}{M^*}\right)^n$$

$$\frac{\partial T}{\partial m_t} \sim k\frac{T}{m}$$

$$\boxed{\delta m_t \sim \frac{c\,m_t}{k}\left(\frac{\Lambda_{\rm QCD}}{m_t}\right)^n}$$

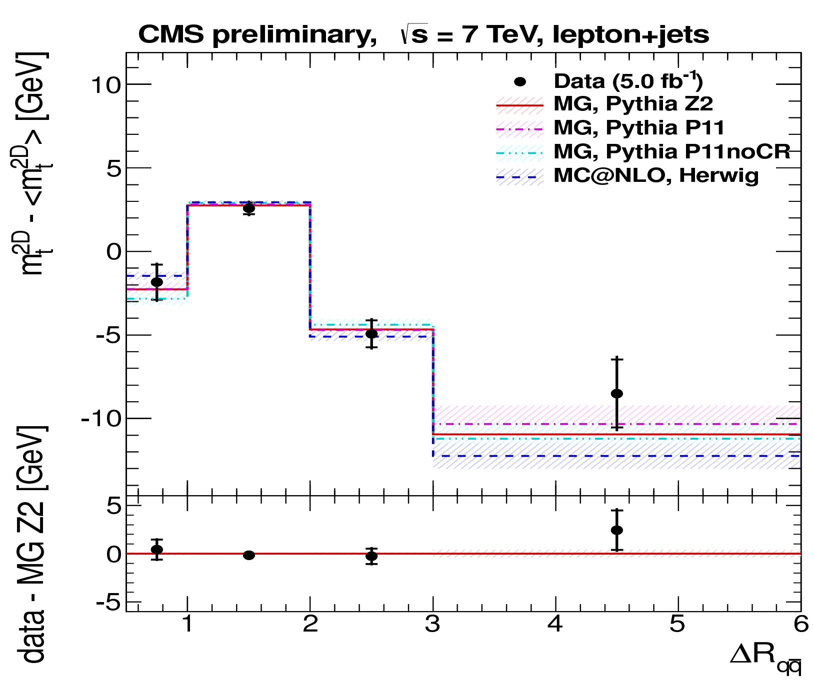
For a typical observable, k=1, n=1; this implies that the top quark mass can not be extracted with precision that is better than the non-perturbative QCD scale.

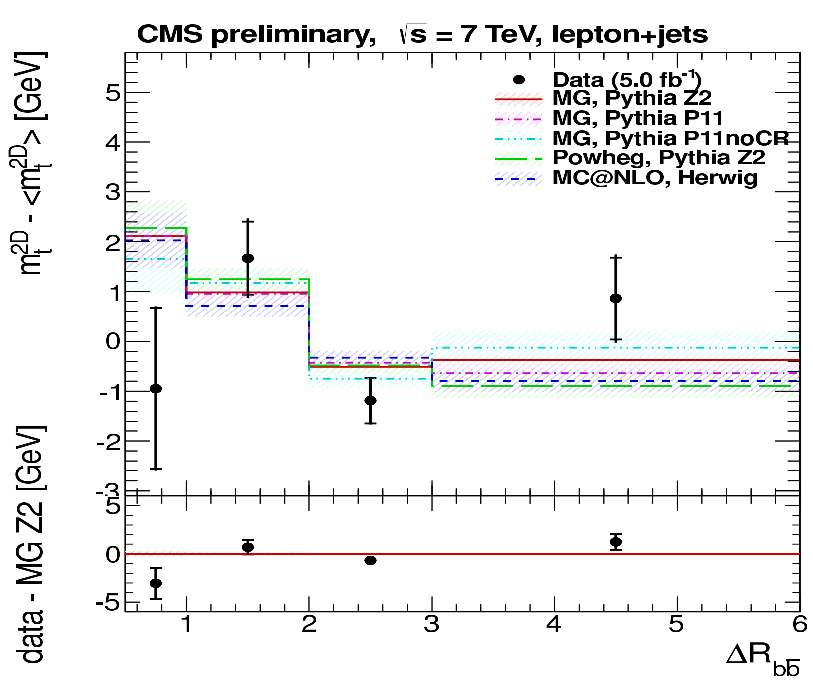
To improve on that, we need to carefully study observables that are used to extract the top quark mass and understand non-perturbative corrections to them.

Currently, the non-perturbative effects are estimated using existing parton showers (hadronization, underlying event, color reconnection etc.).

When we claim that we measure the mass of the quark with the uncertainty of O(600) MeV, we claim that
-we control kinematics of top decay products to a level of O(200) MeV
- we are sure that Nature has no means -- beyond already included in a parton shower -- to provide additional 200 MeV of energy to, say, a b-quark produced in a decay of a top.

This is a strong claim whose validity is hard to quantify. One possibility is to study the top quark mass as a function of the kinematic cuts, hoping to detect the inconsistencies.





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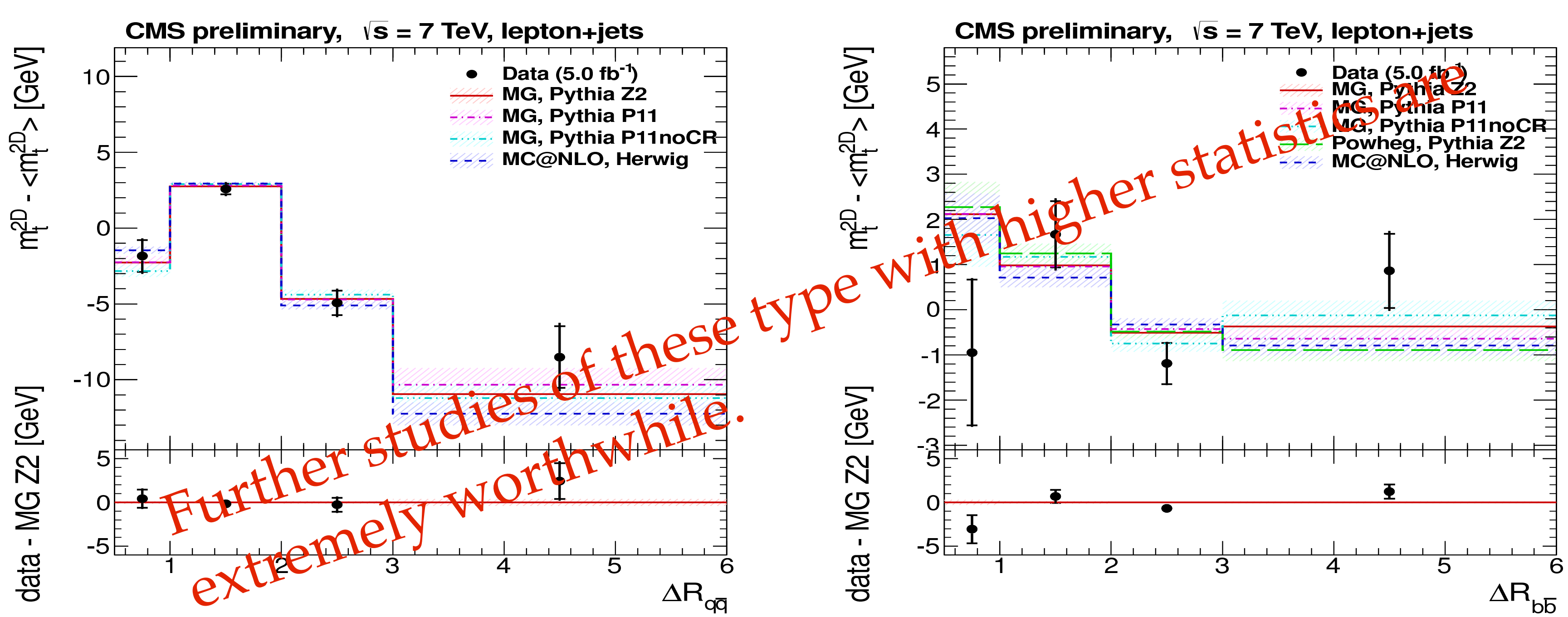


Further studies of these type with higher statistics are extremely worthwhile.

What is a MC mass? A simple answer is that the MC mass is the mass in the event generator. But this is not very helpful -- given how many MC's (and there versions) are there, the top quark will get more than three masses in the PDG booklet if you succeed in measuring them.

Consider the total cross section at leading order in perturbation theory. The matrix element computation and the PS computation should agree. Therefore, the MC mass is the pole mass.

$$\sigma_{ME}^{(0)} = \sigma_{PS}^{(0)} \rightarrow m_t^{\rm pole} = m_t^{\rm MC}$$

However, consider now a different scenario. Suppose that we infer the mass of the top quark from its decay products subject to shower. Parton showers apply IR cut-off to energies of generated partons; below that cut-off the radiation is treated non-perturbatively. Let us call this cut-off λ .

$$\langle E \rangle_{\rm PS} = \int_{\lambda}^{\omega_{\rm max}} \frac{{\rm d}\omega}{\omega}\, \omega + {\rm Hadronization} \qquad \langle E \rangle_{\rm ME} = \int_{0}^{\omega_{\rm max}} \frac{{\rm d}\omega}{\omega}\, \omega$$

$$\langle E \rangle_{\rm PS} = \langle E \rangle_{\rm ME} = m_{\rm pole} \qquad m_{\rm pole} = m_{\rm MC}(\lambda) + {\rm Hadronization}$$

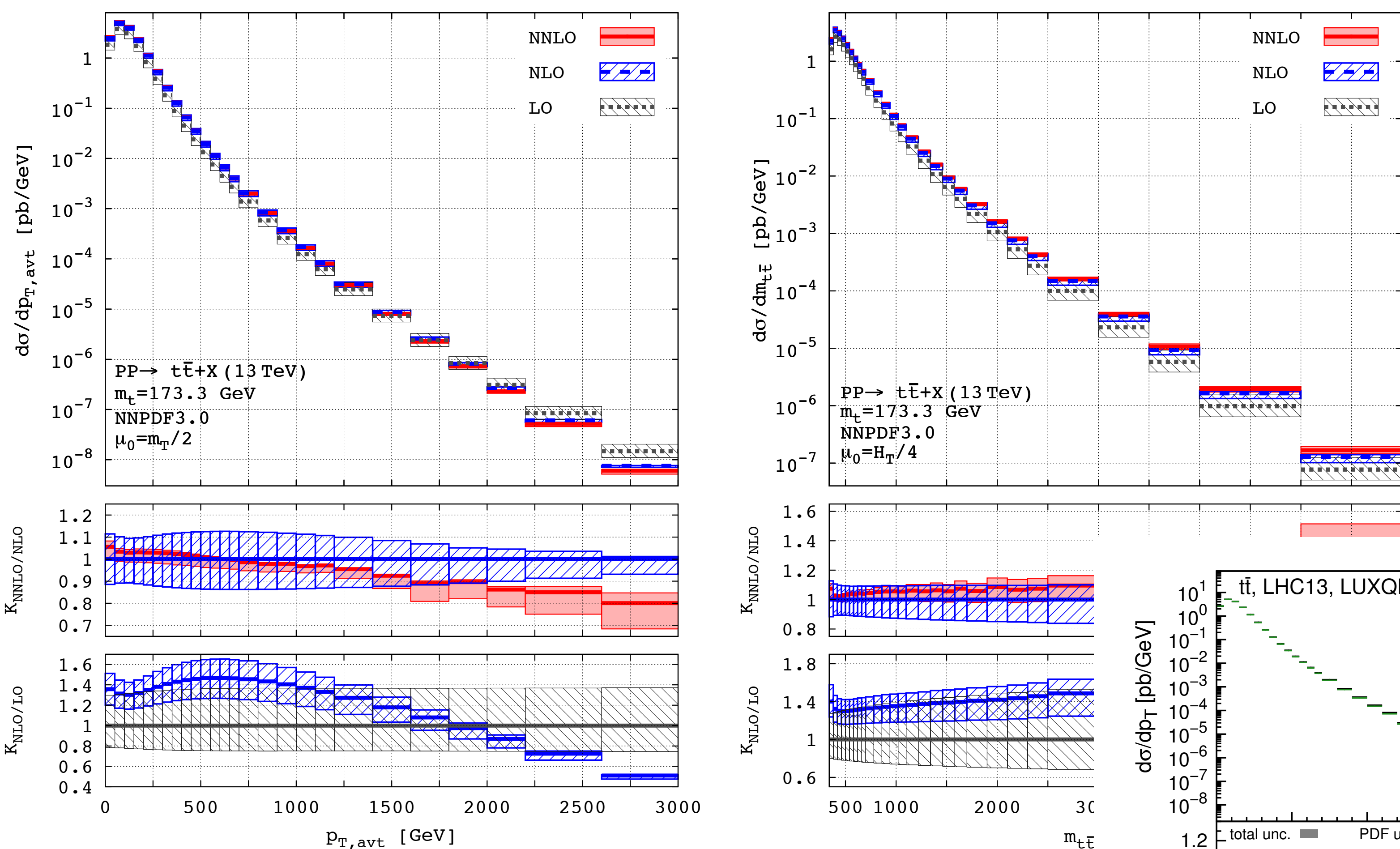
To what extent one can and needs to talk about MC masses, depends on the details of the measurement and, in particular, on how non-perturbative and perturbative radiations are combined. This is extremely confusing and I prefer to stay with the picture that non-pert. effects are there and that they need to be understood.

Simple processes: striving for perfection

Talks by A. Papanastasiou, D. Pagani, S. Schumann, A. Ferroglia, J. Gao, P. Nason, N. Craig

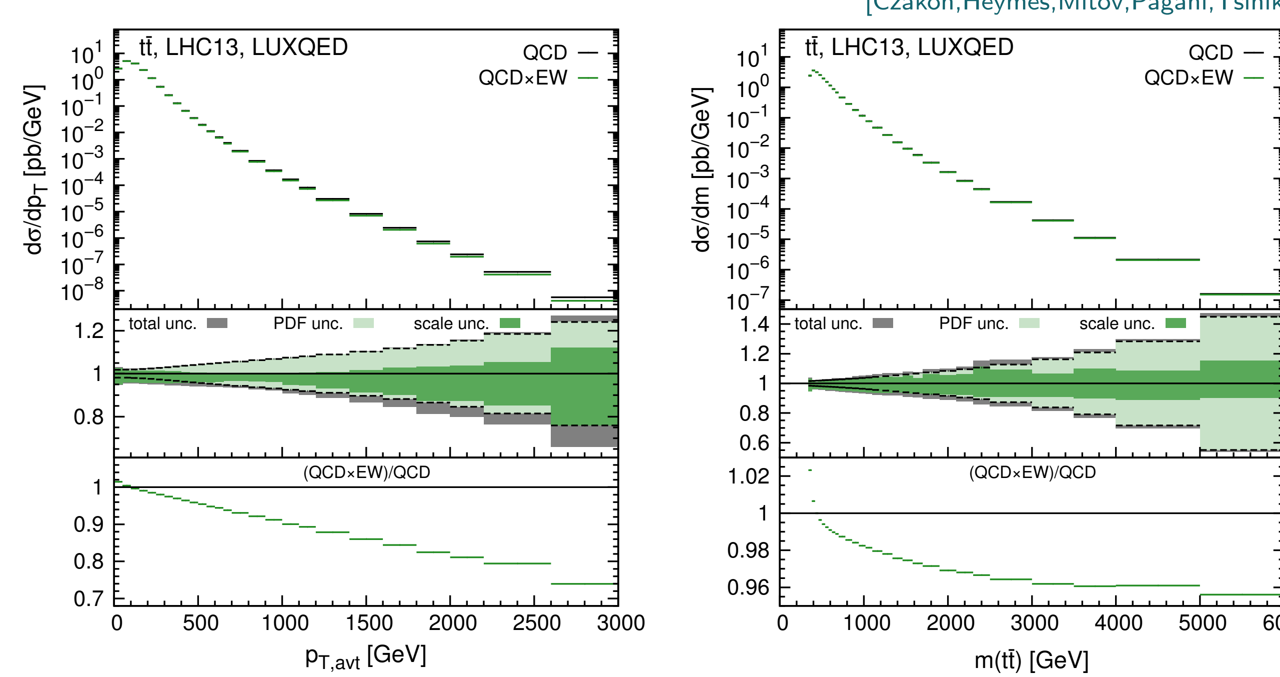
- fully-differential NNLO-QCD predictions for $t\bar{t}$ production

[Czakon,Heymes,Mitov '16]



NNLO QCD + NLO EW results are avilable for top pair production and the single top.

[Czakon,Heymes,Mitov,Pagani,Tsinikos,Zaro

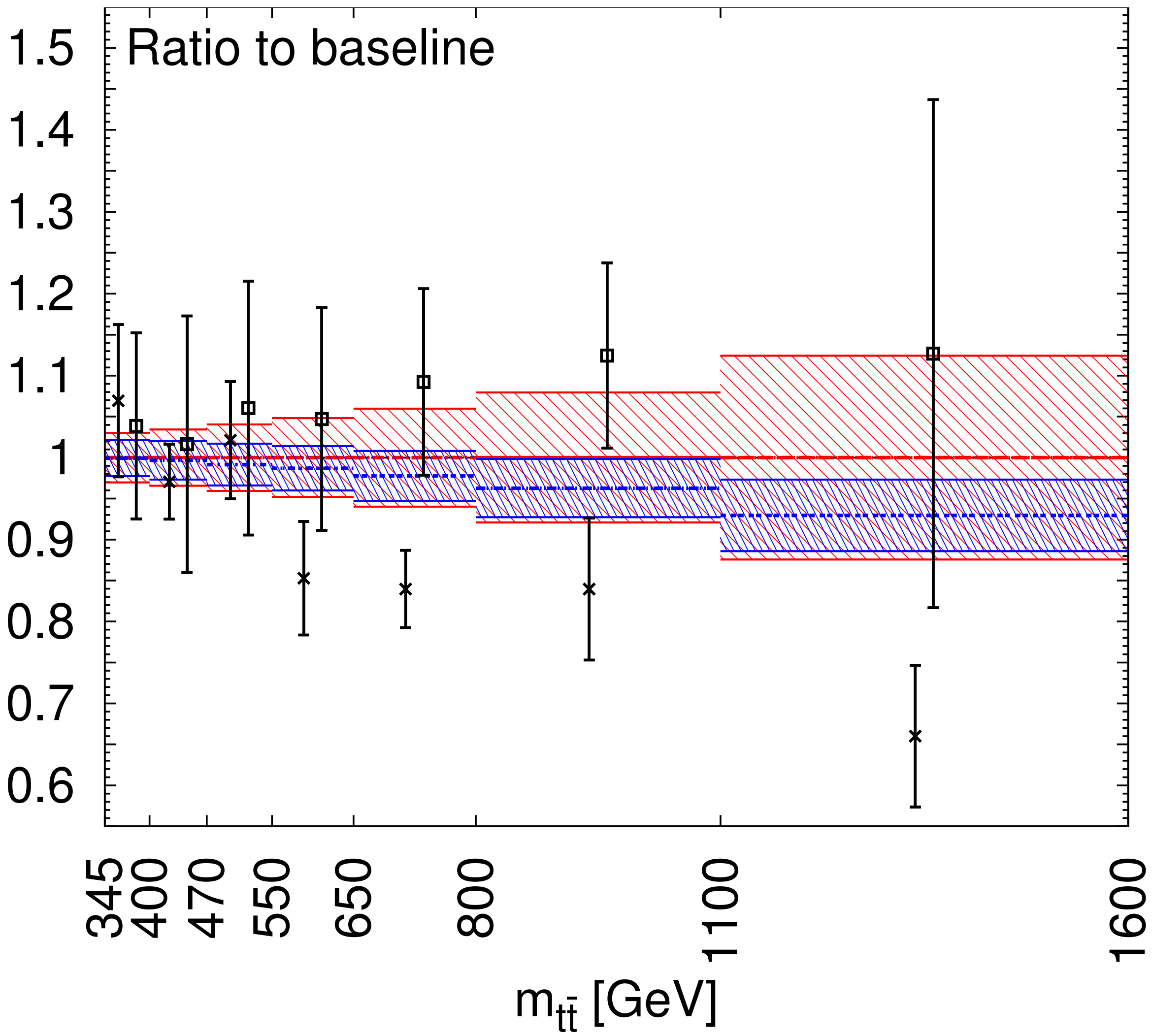


Clearly, landmark calculations. Useful to test cross sections and distributions. Adored by experimentalist. A question -- when we will get a NNLO for this or for that -- is one of the most frequently asked.

- $p_T(t)$: EW corrections grow from +2% → -25% in range $[0, 3]$ TeV
- $p_T(t)$: EW corrections as significant as NNLO-QCD scale uncertainty
- smaller effects for $m_{t\bar{t}}$

These computations help us to constrain parton distribution functions, get the top quark (pole) mass and the strong coupling constant, hunt for broad(ish) resonances that decay to tops and interfere with continuum top pairs, and even help to exclude the existence of elusive stops.

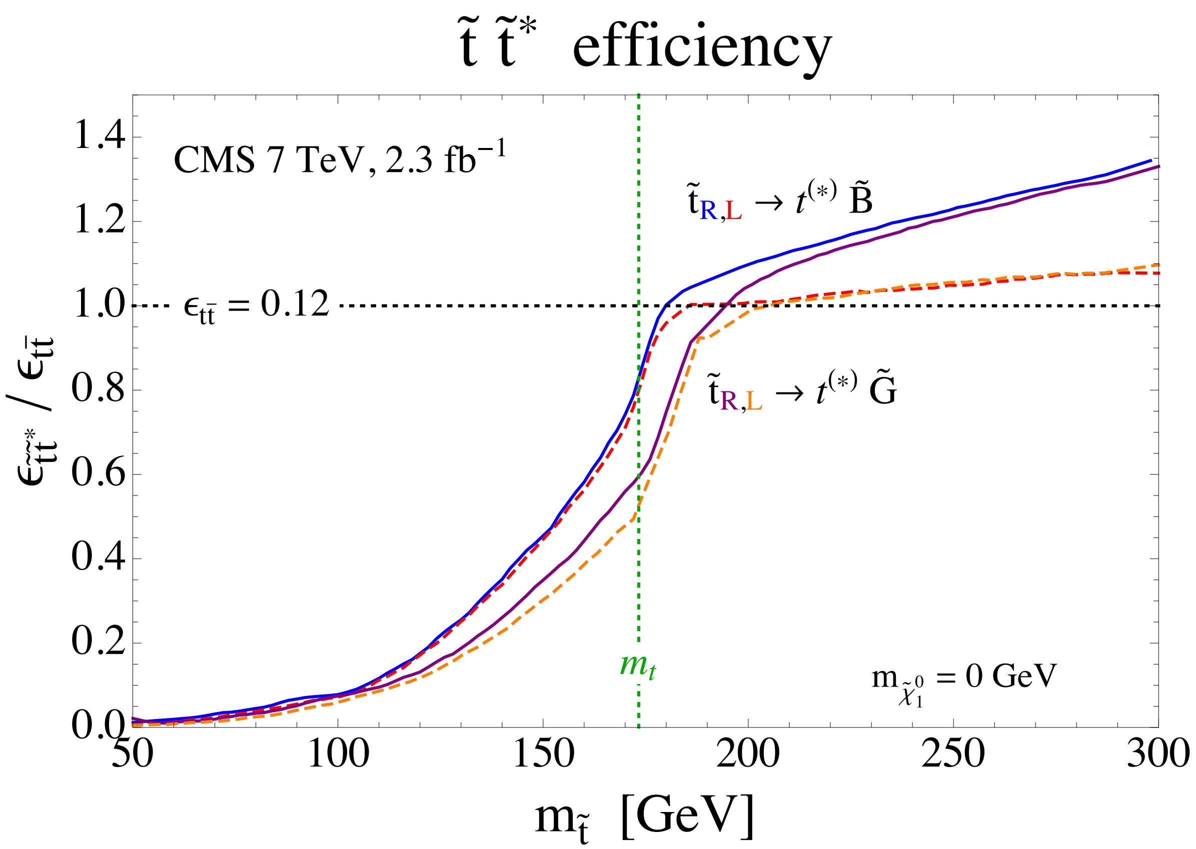
In other words, they are instrumental for generating physics knowledge that would have been impossible to obtain otherwise.



red: baseline-fit PDFs (NNPDF)
blue: PDFs after select top data included

$t\bar{t}$ cross section

[Czakon, Mitov, Papucci, Ruderman, Weiler '14]



Are there right renormalization and/or factorization scales? What are they? How do we find them? How is the scale uncertainty distributed?

Important outcomes of [1606.03350] : [Czakon,Heymes,Mitov '16]

- detailed study of scale dependence through NNLO at fixed order
- dynamical scales crucial in multi-TeV regimes, however, how to pick dynamical scale? (typically large differences between choices)
- based on criterion of best (fastest) perturbative convergence, across full ranges of distributions, the following scales were found to be optimal

$$\mu = \begin{cases} M_T/2, & \text{for } p_T(t),\ p_T(\bar{t}),\ p_T(t)_{\rm ave} \\ H_T/4, & \text{for all others studied } (y(t),\ m_{t\bar{t}},\ p_T(t\bar{t}), y_{t\bar{t}}) \end{cases}$$

- Note: $\sigma^{\rm NNLO}(\mu = H_T/4) \simeq \sigma^{\rm NNLO+NNLL}(\mu = m_t)$

It is important not to drive the question of choosing a "proper scale" beyond what is reasonable. By choosing "proper" scales we want to remove large higher order effects but we usually can't remove higher order effects that are O(1).

Clearly, one can remove any scale dependence from a perturbative computation at a given order, by solving the corresponding RG equation. We do not do that since scale uncertainty tells us something about the un-calculated higher-order terms; this is one of the very few ways we have to estimate them.

Proper scales depend on kinematics and parton composition of an event, e.g. tt +2 partons, tt+1 parton, tt+0 partons and their probable history of branchings. Parton showers know about this and employ "proper scales" in describing those branching histories.

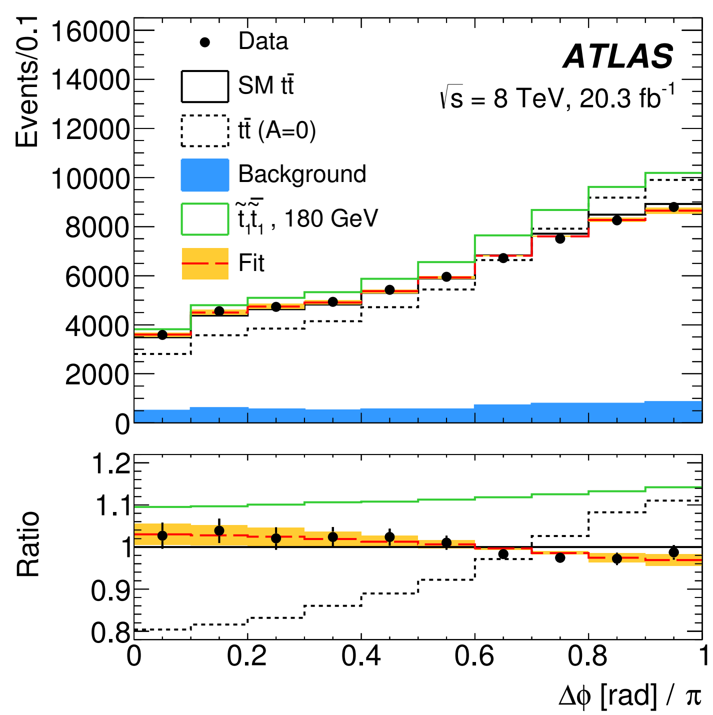
Simple processes: striving for reality

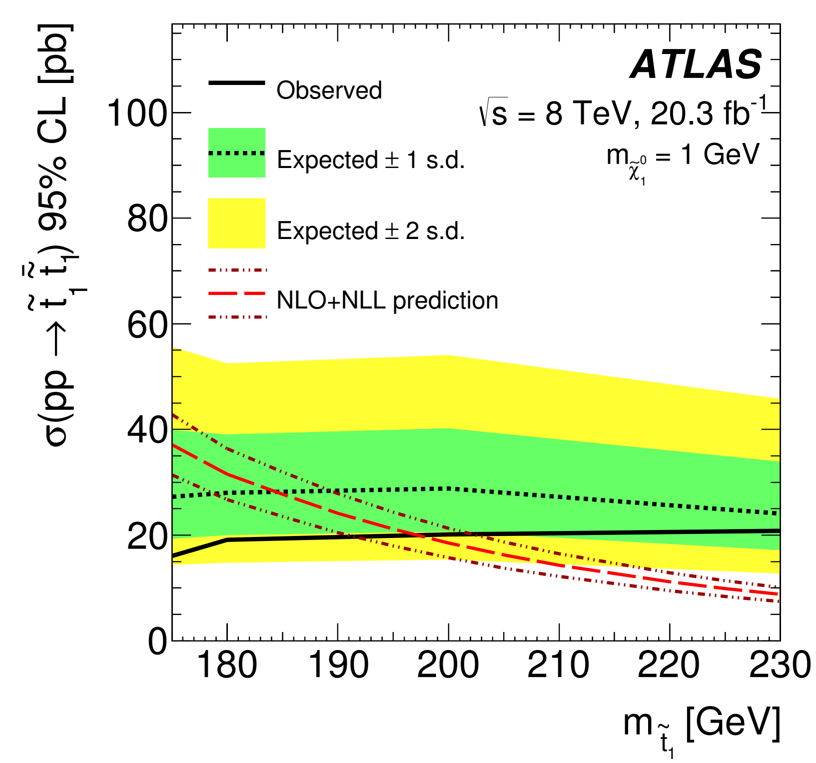
New trend -- an emergent opportunity to work with physical final states, i.e. use top quark decay products to define the process of interest. This point appeared in many talks and in different incarnations.

The basic approximation for studying the top quark processes is that of a narrow width approximation. This approximation is parametric; neglected corrections are suppressed by the width over mass ratio, O(1%). The NWA works always provided that you are not interested in the top quark invariant mass distribution -- effectively, the NWA integrates over all invariant masses.

Spin observables can be used to constrain top EFTs, see talks by L. Moore and N. Castro.

NLO computations for top pair production and single top in the narrow width approximation were performed long ago. They allow us to study top quark spin observables that can be inferred from kinematic properties of top decay products.

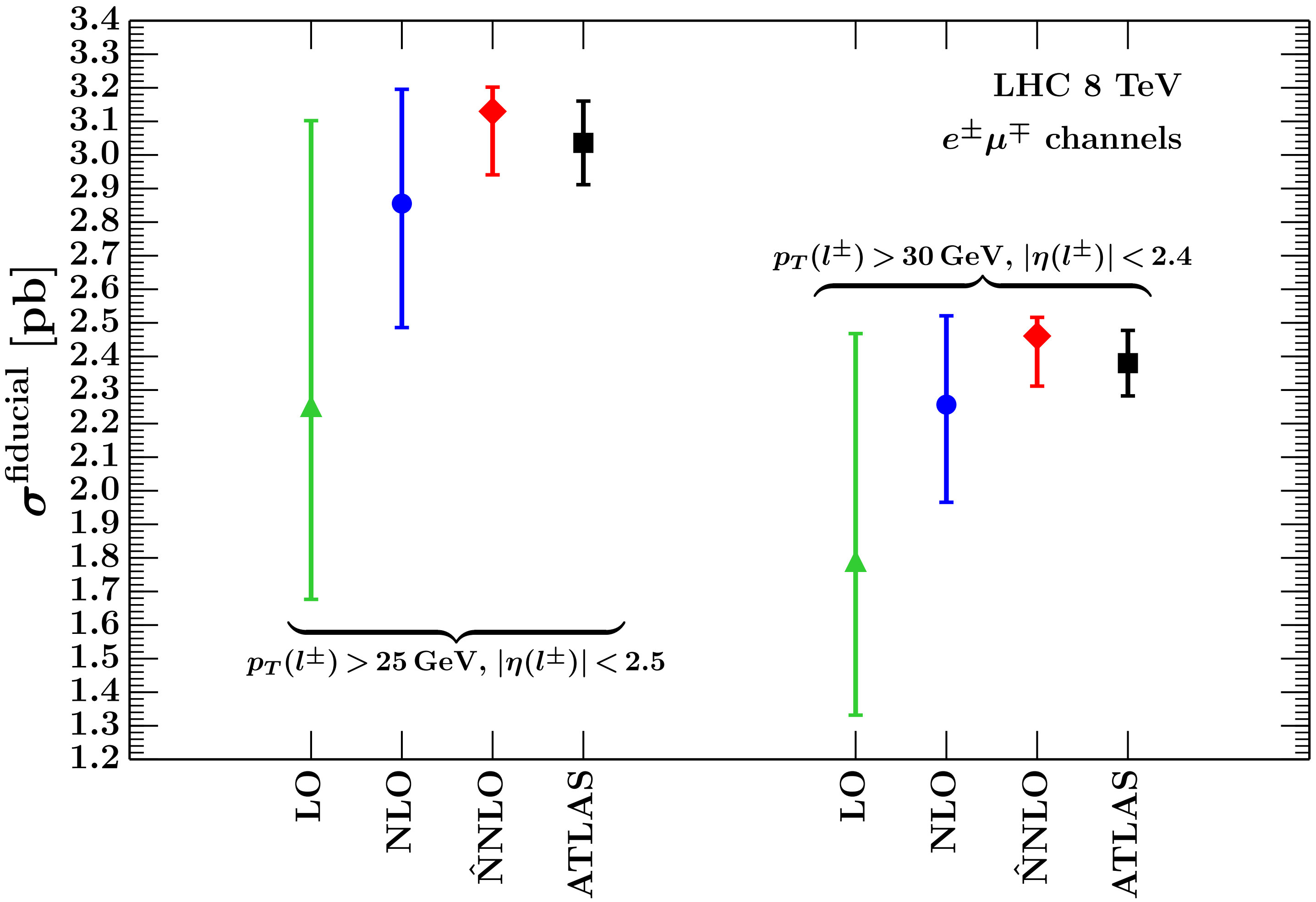


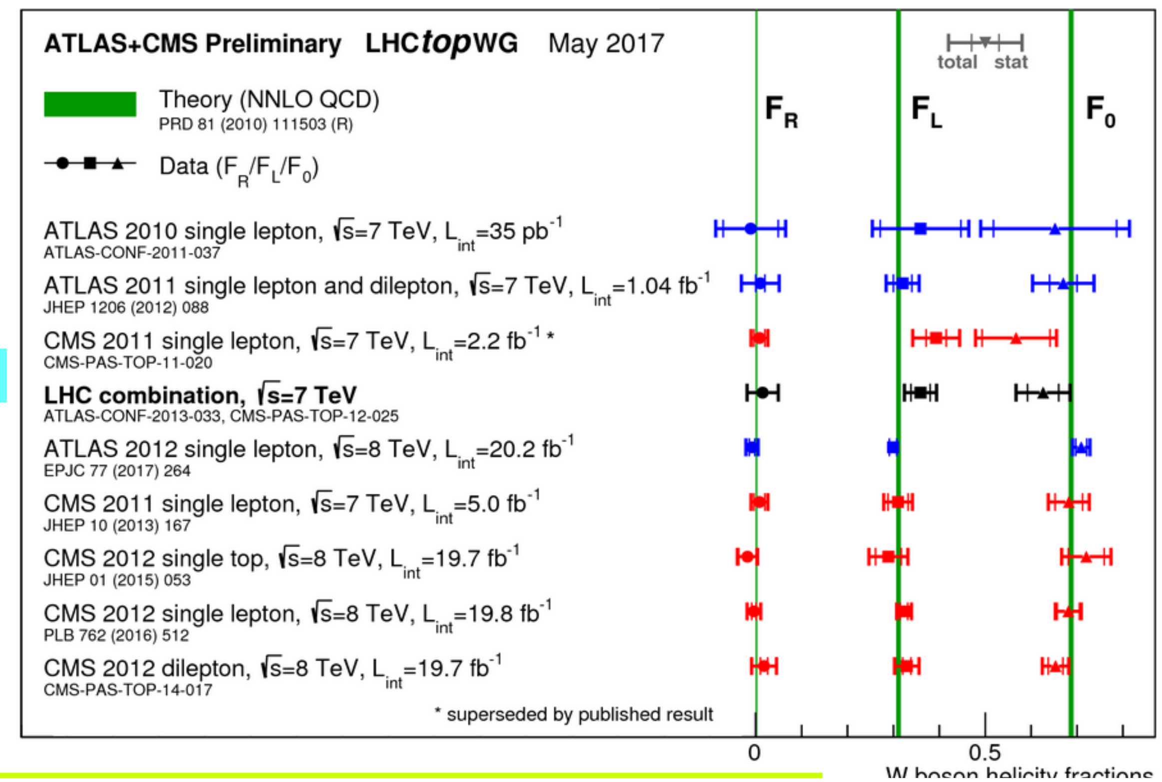


Little/no room left for light stops…

Similar approach can be taken at NNLO -- everything is available, at least as a matter of principle. Recent approximate result (approximate NNLO in top pair production and full NNLO in decay) allows one to compute fiducial cross sections and compare them directly to experimental results.

One of the interesting application of this result should be a re-evaluation of W-helicity fractions measurement for fiducial regions actually used in experiment.





$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}\left(1-\cos^2\theta^*\right) F_0 + \frac{3}{8}(1-\cos\theta^*)^2\ F_L + \frac{3}{8}(1+\cos\theta^*)^2\ F_R$$

When jet vetoes are involved, QCD corrections to fiducial and total cross sections become very different, so computations with top decays become indispensable. The case in point is the single-top production.

- fiducial volume (1 family)

  jet $p_T > 40\,\mathrm{GeV},\ |\eta| < 5$

  exactly 2 jets, 1 b-jet

  charged lepton $p_T > 30\,\mathrm{GeV}$

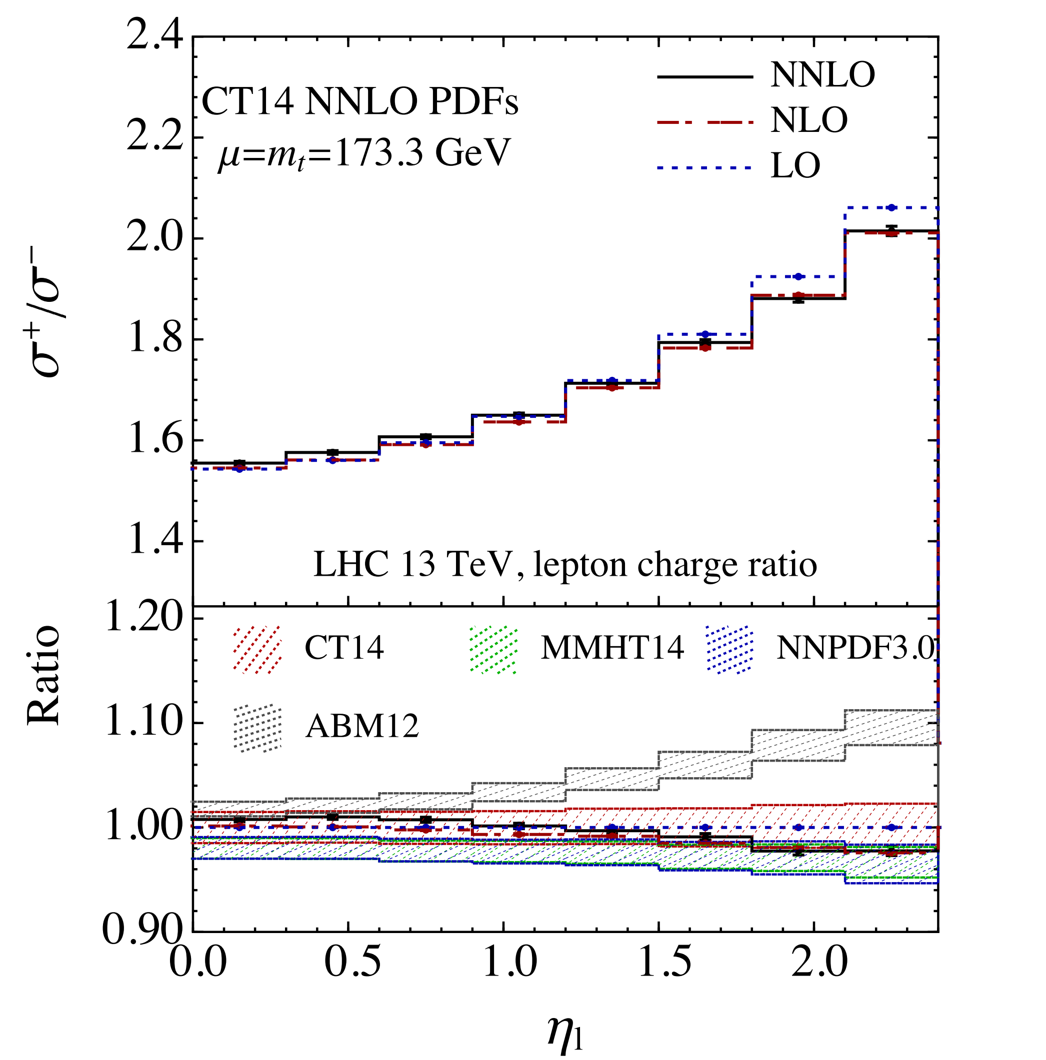
  $|\eta_b| < 2.4,\ |\eta_l| < 2.4$

- total rate **muF=muR=[m_t/2, 2m_t]**

fiducial [pb]		LO	NLO	NNLO
t quark	total	$4.07^{+7.6\%}_{-9.8\%}$	$2.95^{+4.1\%}_{-2.2\%}$	$2.70^{+1.2\%}_{-0.7\%}$
	corr. in pro.		-0.79	-0.24
	corr. in dec.		-0.33	-0.13
$\bar{t}$ quark	total	$2.45^{+7.8\%}_{-10\%}$	$1.78^{+3.9\%}_{-2.0\%}$	$1.62^{+1.2\%}_{-0.8\%}$
	corr. in pro.		-0.46	-0.15
	corr. in dec.		-0.21	-0.08

large negative corrections due to the jet veto condition

- lepton charge ratio as a function of pseudo-rapidity



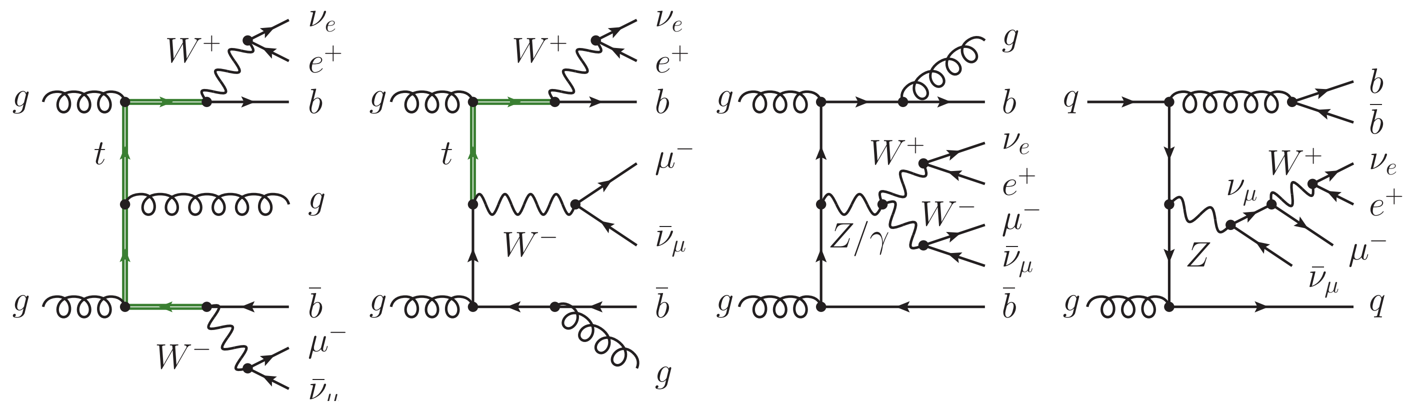
NNLO QCD corrections within 1%; good probe of u/d PDF ratio

Another exciting development are computations that go beyond the narrow width approximation; they fully include resonance and non-resonance contributions and their interferences through NLO QCD. The very appearance of these computations is the result of enormous progress in our ability to compute radiative corrections to hard scattering process -- none of these computations were possible even a decade ago (the NLO revolution).

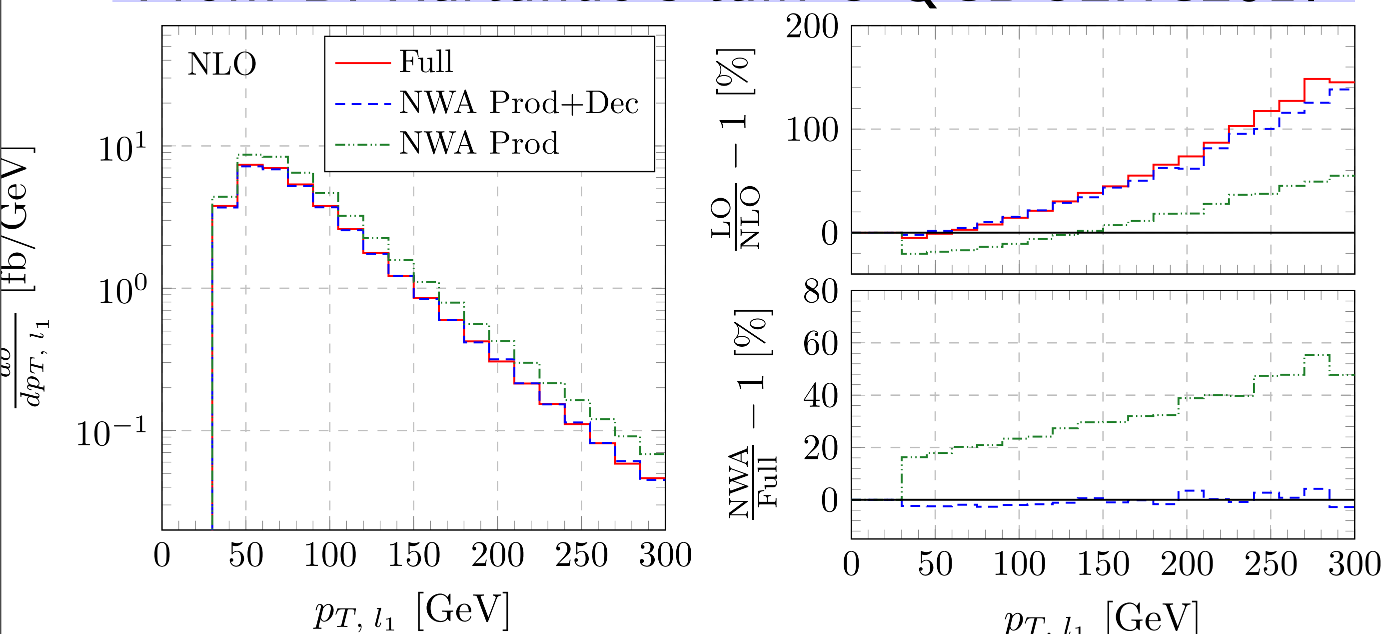
The off-shell effects are often small. However, it must be like that if you have chosen your top samples properly. So what is the virtue of going through all the pain to get them?

The point is that the very discussion of the "top quark production" introduces unphysical objects (tops) into our (ever more sophisticated) enterprise. Instead, fully off-shell computations allow us (you) to define top quarks (and related processes) operationally, using kinematics and selection cuts (no more things like diagram removal or diagram subtraction).   It is this feature that changes the quality of theoretical predictions and makes them infinitely closer to the real (experimental) world.

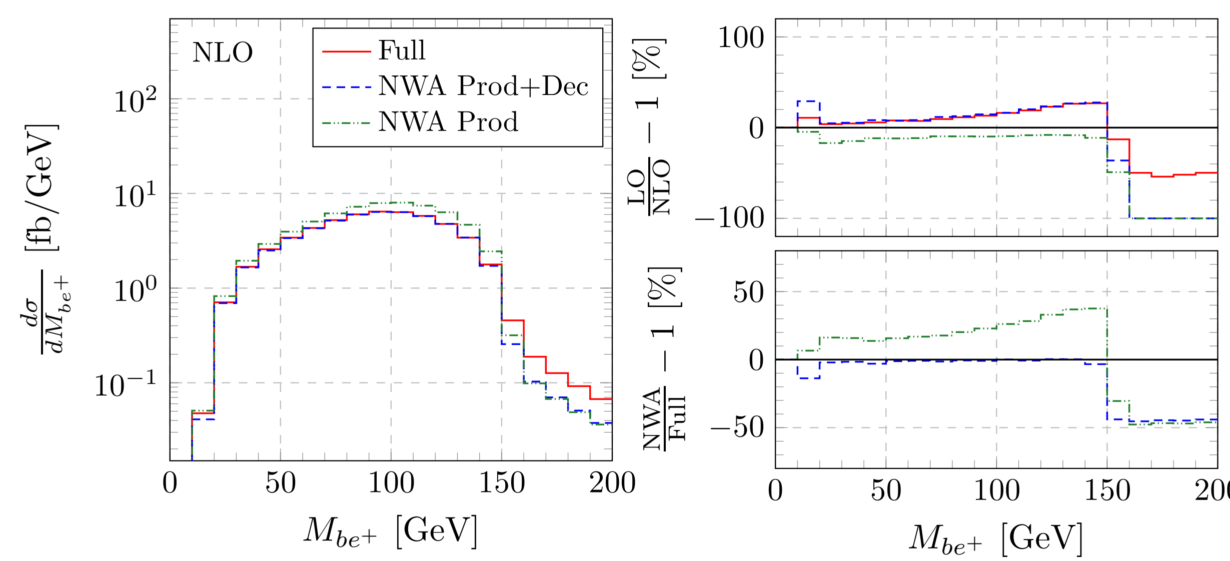
- NLO corrections to $e^+\nu_e\mu^-\bar{\nu}_\mu b\bar{b}+X$ known [5FS: Bevilaqua et al, Denner et al, Heinrich et al 4FS: Frederix, Cascioli et al]
- recently: NLO corrections to $e^+\nu_e\mu^-\bar{\nu}_\mu b\bar{b}j+X$ [Bevilaqua,Hartando,Krauss,Worek '15,16']



From B. Hartando's talk @ QCD@LHC2017



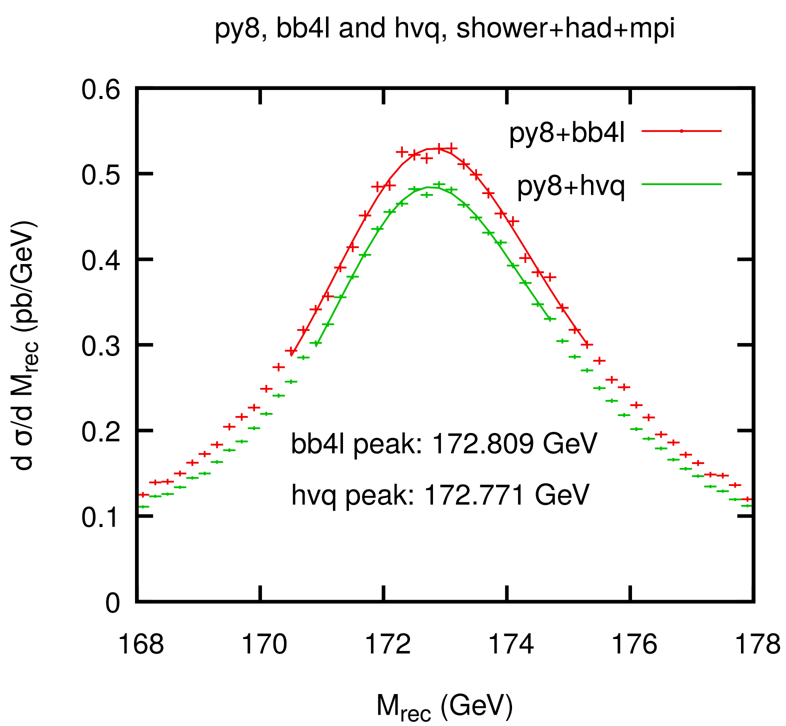
[Bevilaqua,Hartando,Krauss,Schulze,Worek – in preparation]



[Bevilaqua,Hartando,Krauss,Schulze,Worek – in preparation]

Another example where exact final states were recently introduced is the POWHEG resonance-aware parton shower matching. Results for bWbW production seem to confirm that the narrow width approximation with QCD corrections to the decay should be an adequate approximation for the extraction of the top quark mass from the reconstructed final state.

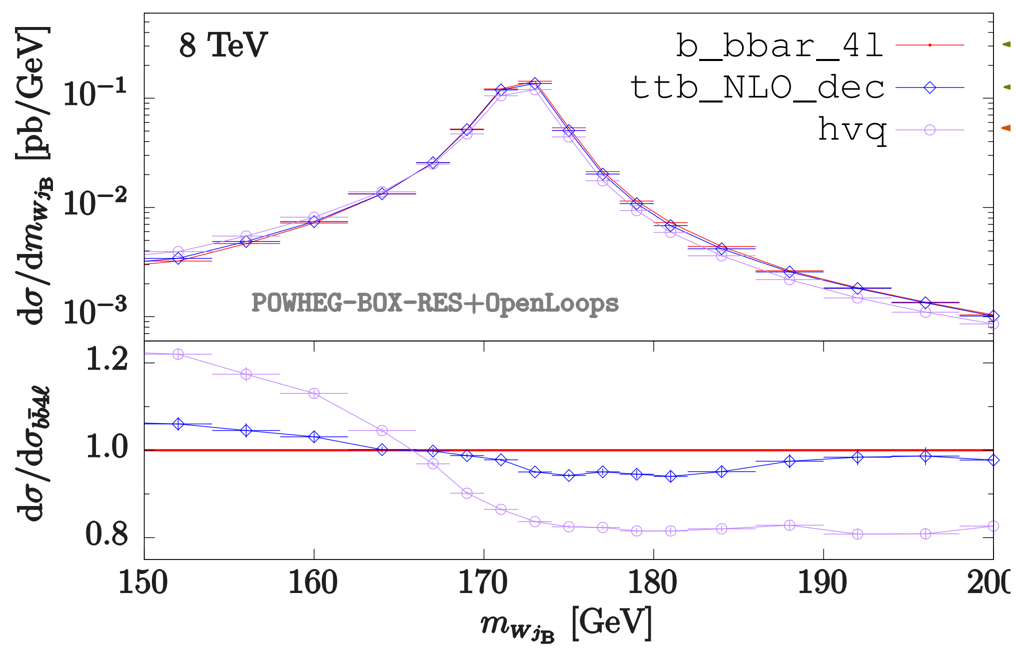
Can these implementations help to improve the precision of the top quark width measurement that use beyond-the-end-point events?

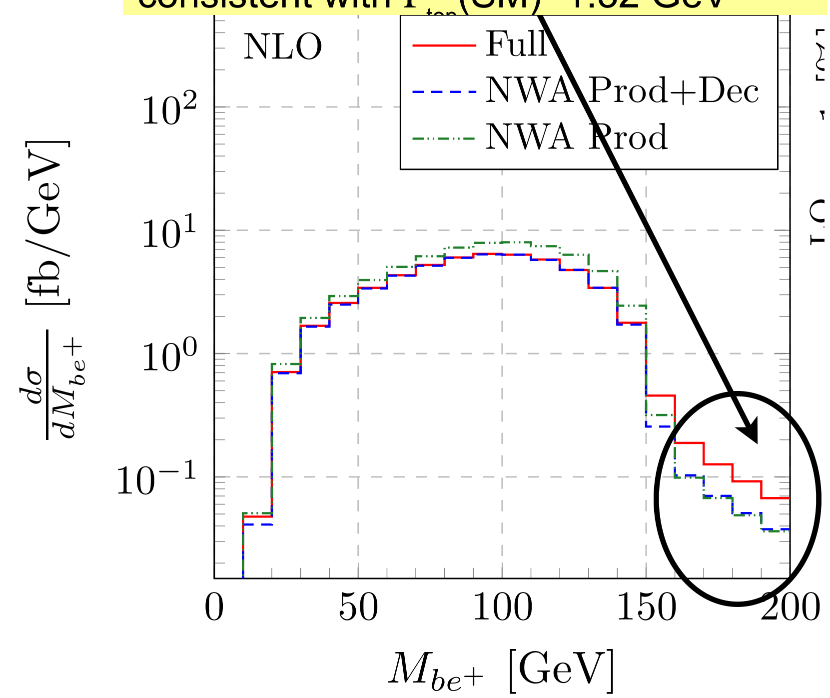


38 MeV mass difference

- $b\bar{b}4l$ Ježo, Lindert, Nason, Oleari, Pozzorini, P.N. 2016 Includes exact NLO matrix element for $pp \to l\bar{\nu}_l \bar{\ell}\nu_\ell b\bar{b}$, thus finite width effects and interference between radiation in production and decay is included.
  `User-Processes-RES/b_bbar_41`

Γ_{top} = 1.76 ± 0.33 (stat)$^{+0.79}_{-0.68}$ (syst) GeV
assuming m_{top}=172.5 GeV
consistent with Γ_{top}(SM)~1.32 GeV





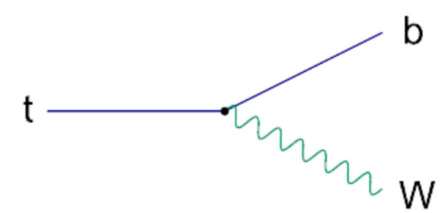
Top couplings: deciphering the unknown

Talks by M. Schulze, E. Vryonidou, C.Zhang, A. Ferroglia, L. Moore, J. Panico, J. Santiago

A systematic way to study top quark properties is provided by an EFT extension of the Standard Model. We add dim-6 operators to the SM Lagrangian and require that those operators satisfy all the symmetries of the SM. As the result -- dramatic increase in the number of couplings a.k.a. Wilson coefficients.

Process	O_{tG}	O_{tB}	O_{tW}	$O_{\varphi Q}^{(3)}$	$O_{\varphi Q}^{(1)}$	$O_{\varphi t}$	$O_{t\varphi}$	O_{4f}	$O_{\varphi G}$
$t \to bW \to bl^+\nu$	✓		✓	✓				✓	
$pp \to t\bar{q}$	✓		✓						
$pp \to tW$	✓		✓						
$pp \to t\bar{t}$	✓								
$pp \to t\bar{t}\gamma$	✓	✓	✓						
$pp \to t\gamma j$	✓	✓	✓						
$pp \to t\bar{t}Z$	✓	✓	✓						
$pp \to tZj$	✓	✓	✓						
$pp \to t\bar{t}W$	✓								
$pp \to t\bar{t}H$	✓						✓	✓	✓
$pp \to tHj$	✓		✓	✓			✓	✓	✓
$e^+e^- \to t\bar{t}$	✓	✓	✓	✓	✓	✓		✓	
(LO)$gg \to H, HH, Hj$	✓						✓		✓
(LO)$gg \to HZ$	✓			✓	✓	✓	✓		✓

Top decay

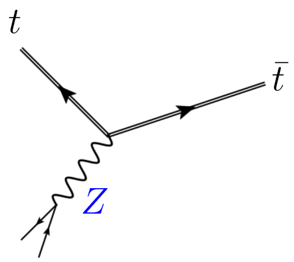


$$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi}W^I_{\mu\nu}$$

$$F_0 = \frac{m_t^2}{m_t^2 + 2m_W^2} - \frac{4\sqrt{2}C_{tW}v^2}{\Lambda^2}\frac{m_t m_W(m_t^2 - m_W^2)}{(m_t^2 + 2m_W^2)^2}$$

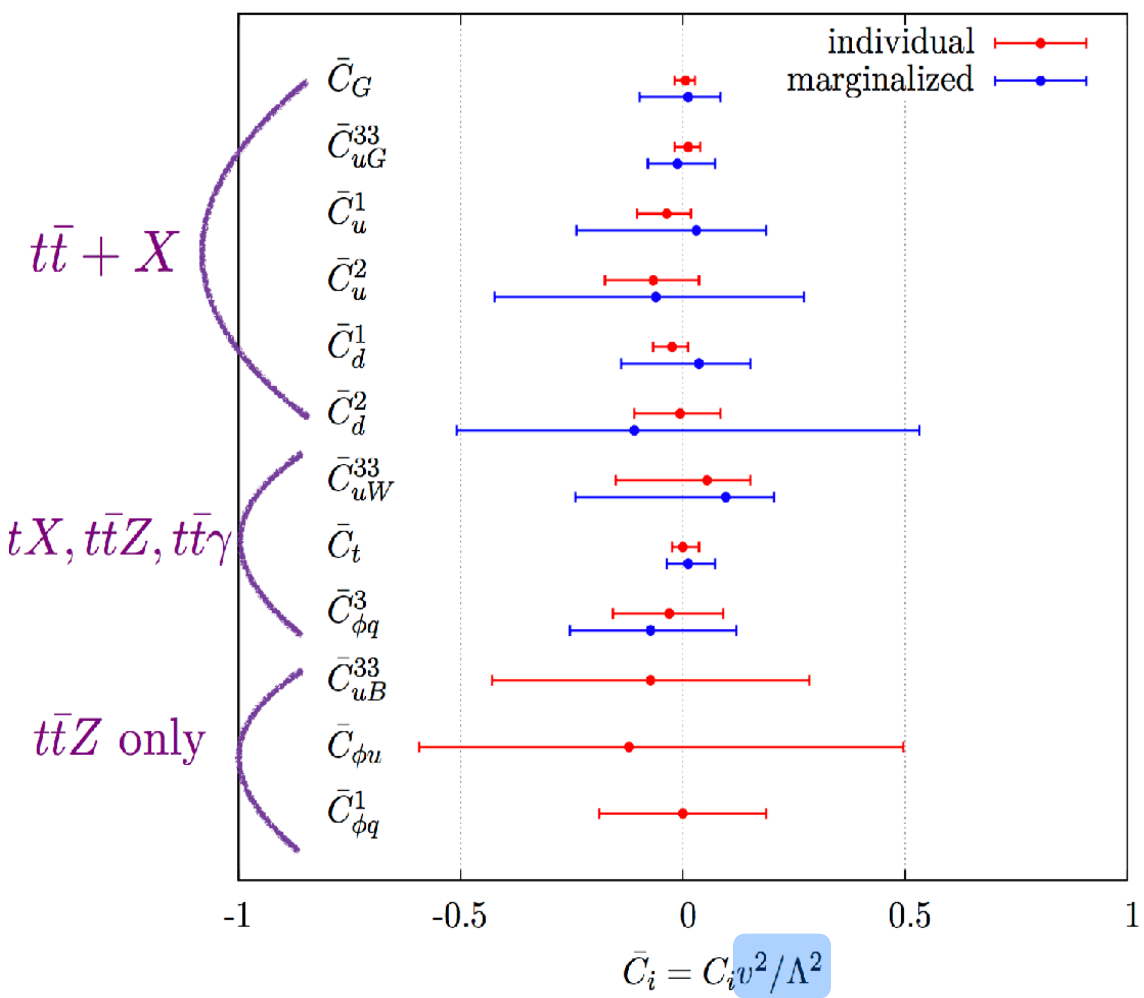
$$F_L = \frac{2m_W^2}{m_t^2 + 2m_W^2} + \frac{4\sqrt{2}C_{tW}v^2}{\Lambda^2}\frac{m_t m_W(m_t^2 - m_W^2)}{(m_t^2 + 2m_W^2)^2}$$

Note, however, that the EFT description is only relevant for strongly interacting UV completions, given the mass scales that have been directly probed at the LHC. In other words, not all your favorite models are covered by this description.



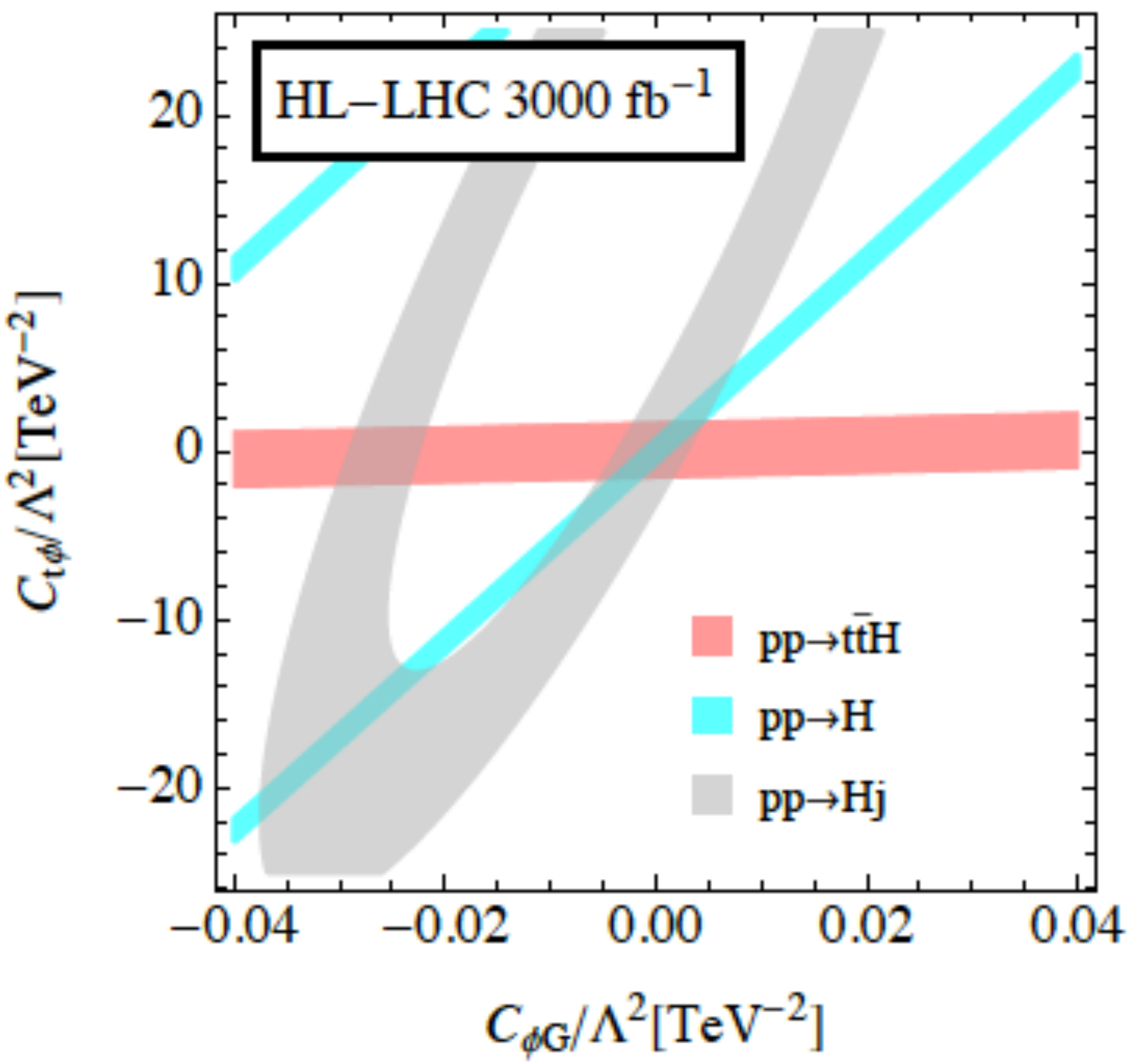
$$\mathcal{L}_{Ztt} = -\frac{g}{2c_W}\bar t \gamma^\mu \left(X^L_{tt}P_L + X^R_{tt}P_R - 2s_W^2 Q_t\right) t\, Z_\mu - \frac{g}{2c_W}\bar t \frac{i\sigma^{\mu\nu}q_\nu}{M_Z}\left(d_V^Z + i d_A^Z\gamma_5\right) t\, Z_\mu$$

$$d_V \approx \frac{\alpha}{\pi}\frac{v^2}{\Lambda^2}, \quad v \sim 250 \text{ GeV} \qquad \frac{\alpha}{\pi} \to 1, \quad \Lambda \sim 1 \text{ TeV} \Rightarrow \frac{\delta g}{g} \sim 5\%$$



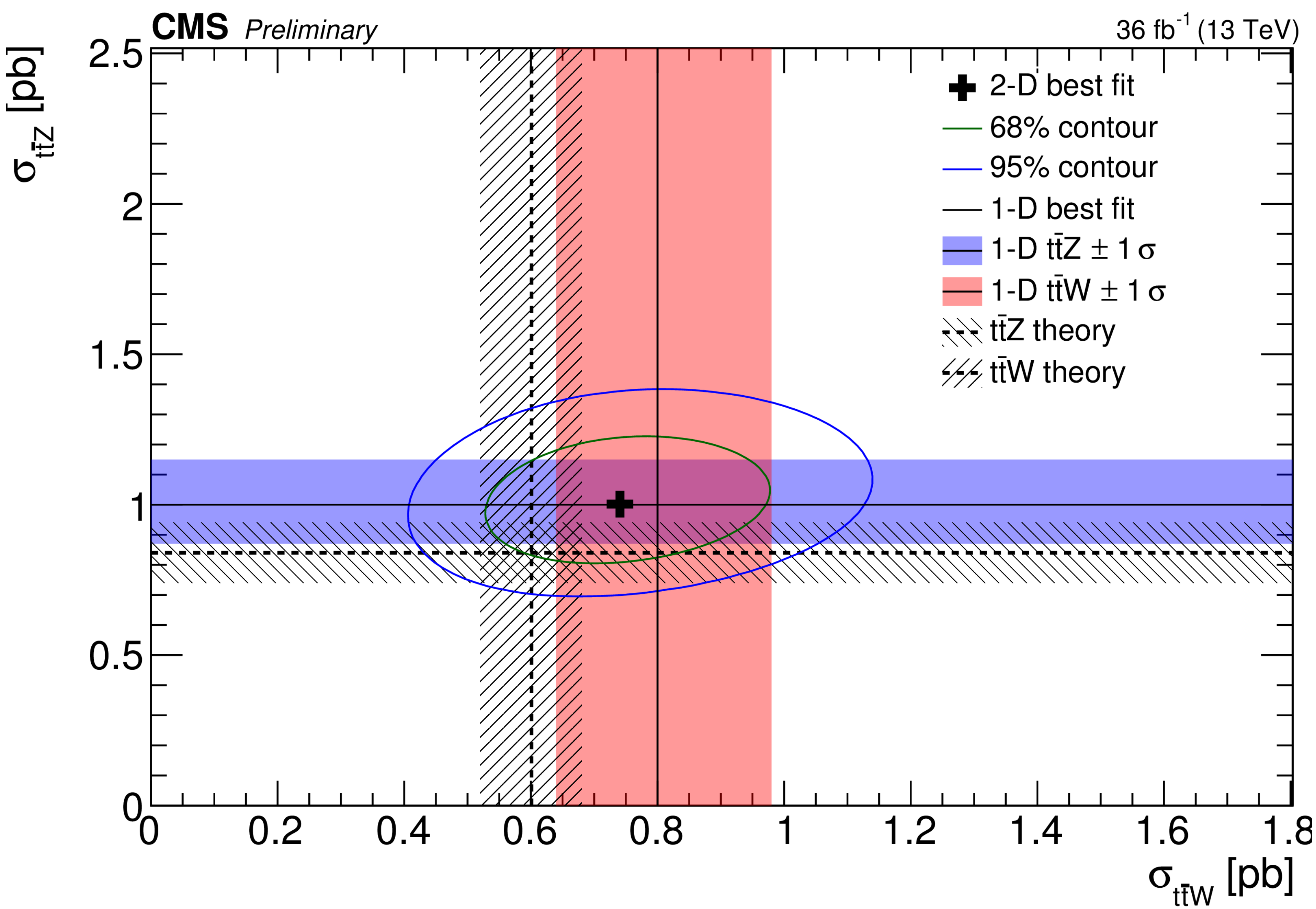
However, in composite models, deviations in ttH and ttV couplings can still be O(10-20) and O(10) percent respectively. This is an interesting number since experimental measurements with such a precision are almost already happening.

An overarching idea of the EFT approach is to perform a global fit of all the Wilson coefficients at once, using available data. An example of how this may eventually work is shown here, where three measurements over-constrain Wilson coefficients of two effective operators including one that describes modification of Higgs-Yukawa coupling; HL-LHC will allow for their precise determination.



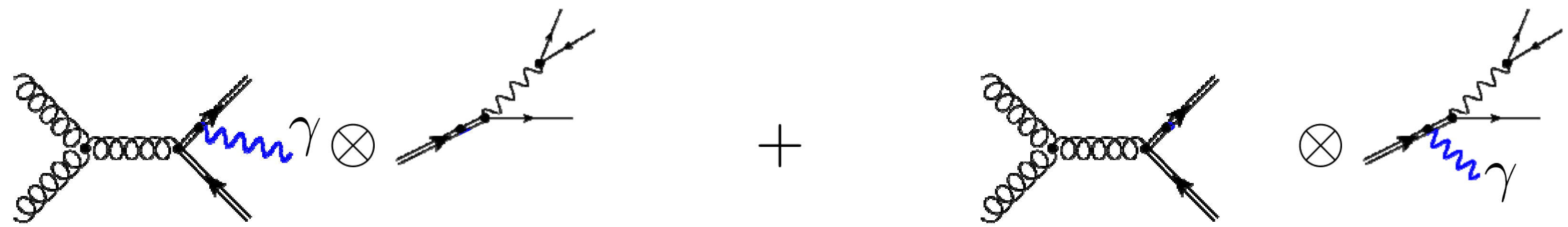
Maltoni, EV, Zhang arXiv:1607.05330

Experimental results for ttV cross sections are becoming O(10-30) percent accurate. Matching the theory prediction to such a precision requires working with physical final state and computing signals through NLO QCD.



Measuring the top-photon coupling from tT+photon sample forces us to recognize that top decays radiately. One needs to suppress this contribution using kinematic selection criteria.

- Feature: $t\bar{t} + \gamma$ introduces additional *radiative decays*

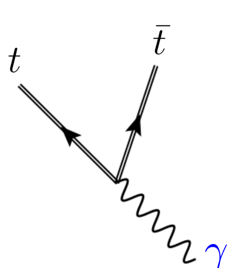


A) γ emission *before* top goes on-shell   *B)* γ emission *after* top goes on-shell

$$p_T^\gamma \geq 30\,\mathrm{GeV}$$

$$\sigma^{\mathrm{NLO}}_{\mathrm{prod}} = 61\,\mathrm{fb}$$
$$\sigma^{\mathrm{NLO}}_{\mathrm{decay}} = 77\,\mathrm{fb}$$

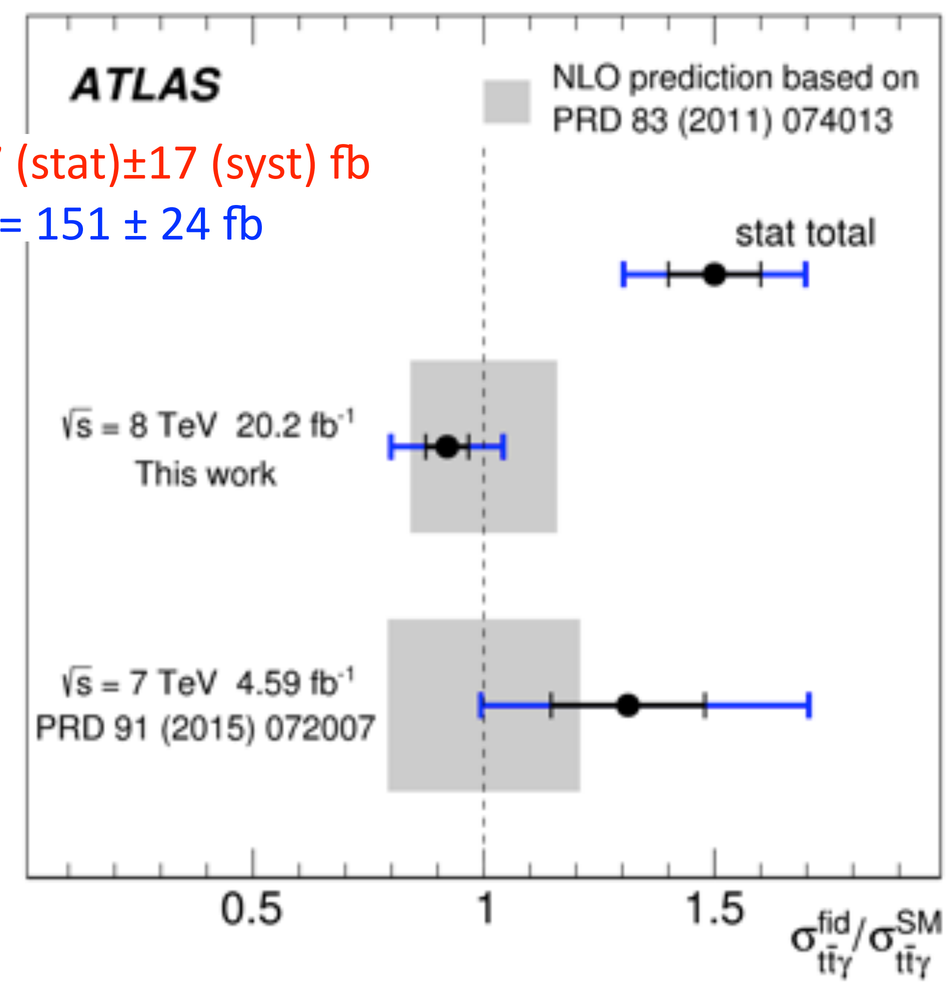
$$\sigma^{\mathrm{NLO}}_{\mathrm{total}} = 138\,\mathrm{fb}$$



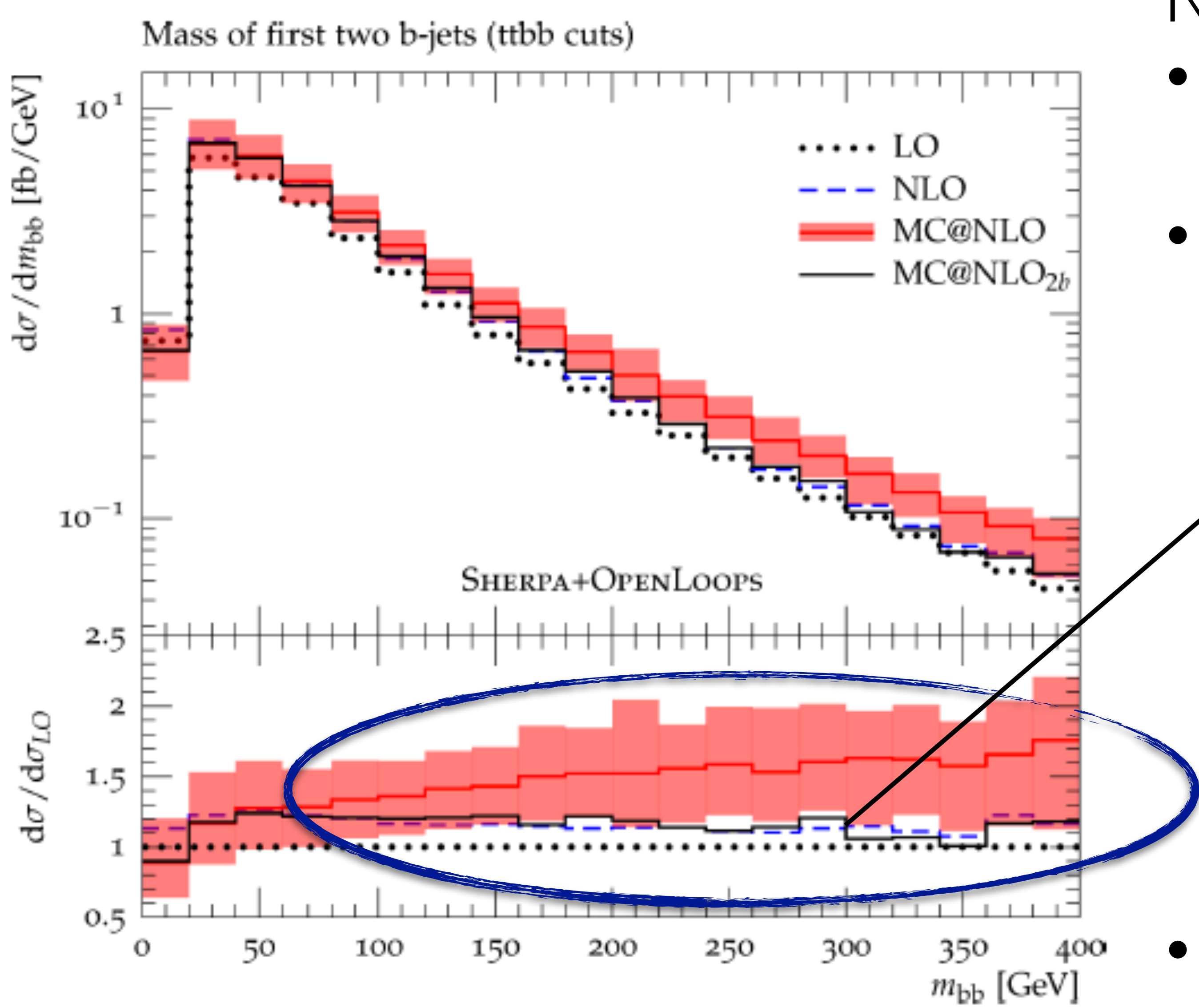
$$\mathcal{L}_{\gamma tt} = -eQ_t \bar{t}\gamma^\mu t\, A_\mu - e\bar{t}\,\frac{i\sigma^{\mu\nu}q_\nu}{m_t}\,(d_V^\gamma + i d_A^\gamma \gamma_5)\, t\, A_\mu\,.$$

σ_{fid} = 139±7 (stat)±17 (syst) fb

σ_{theory} = 151 ± 24 fb



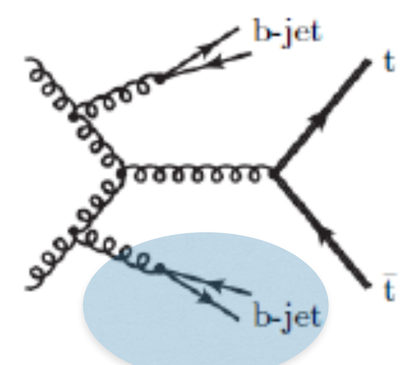
Searches for ttH(bb) final state require understanding of the ttbb background. This turns out to be quite difficult -- when fixed order computations are combined with parton showers excess in high-invariant mass bb pairs appears.



Cascioli et al: arXiv:1309.5912

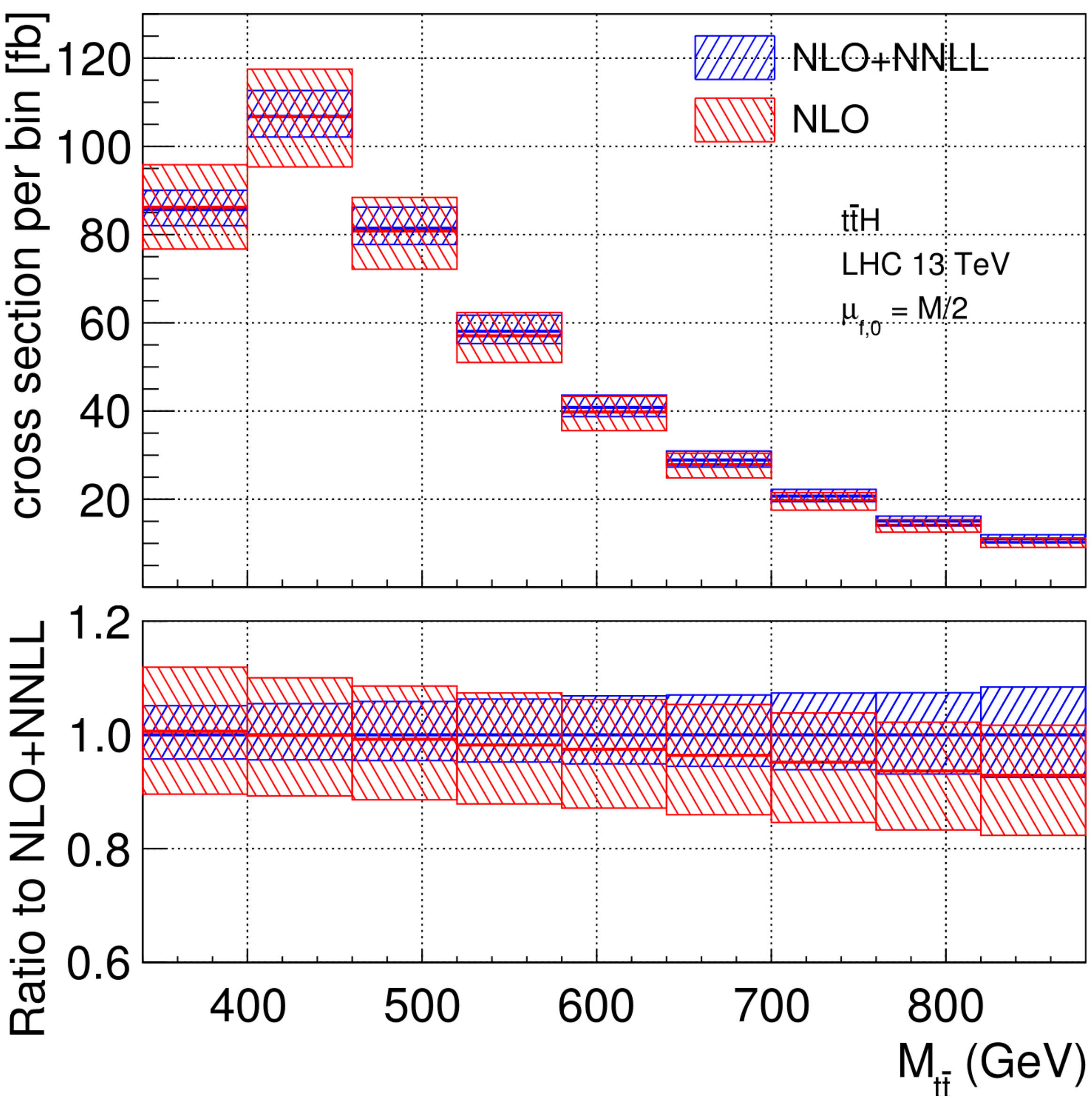
NLO+PS findings:

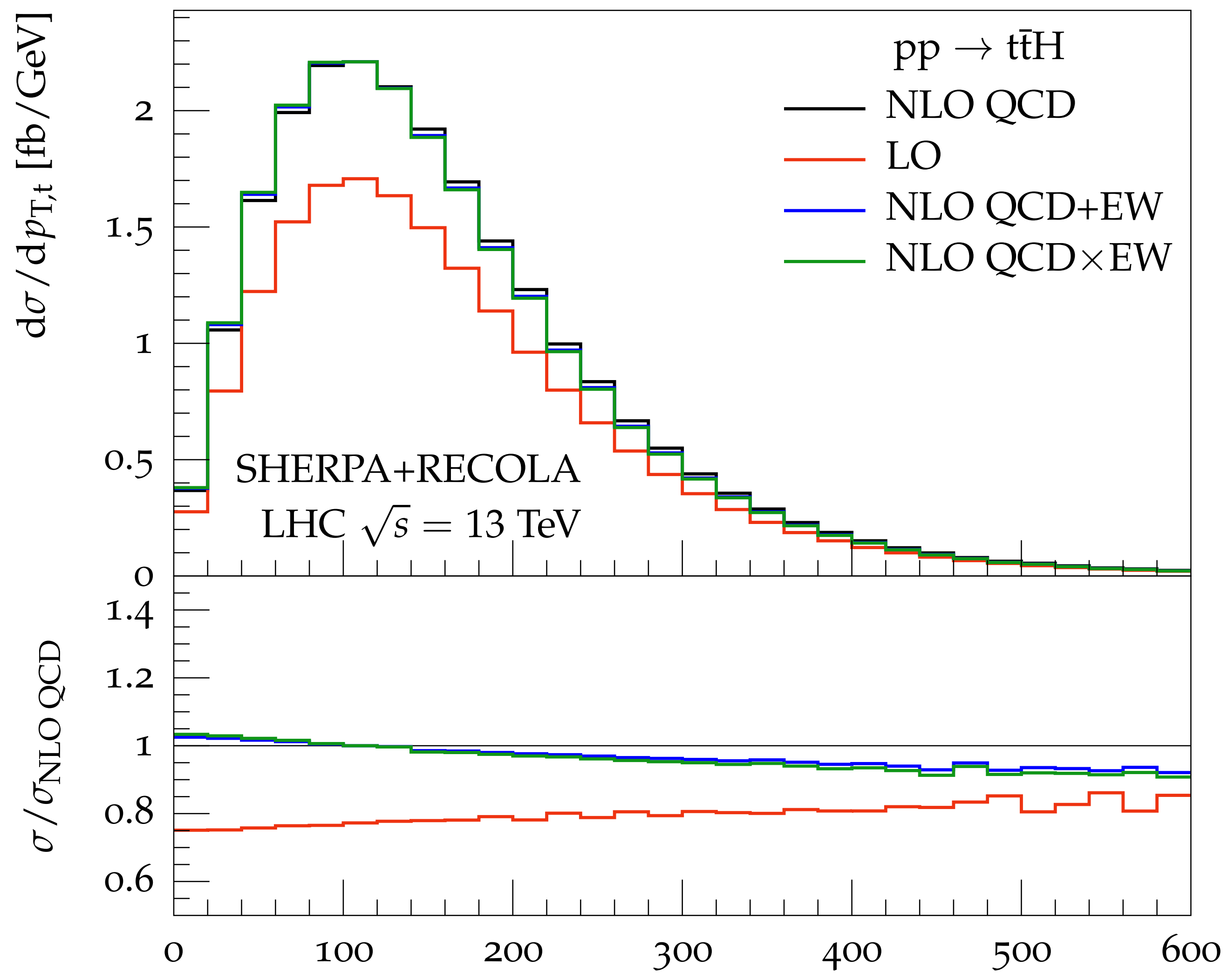
- Large enhancement wrt fixed-order in the Higgs region (~30%)
- Due to secondary g → bb splittings in the shower (eliminated when turning off g to bb in the shower)



- Need to carefully assess matching & shower uncertainties for the **sensitive** b-observables

To extract the coupling, the ttH signal should also be known precisely. The resummed (soft emissions) result for ttH final state is now available, as well as the mixed NLO QCD + EW corrections. All in all, theoretical computations for ttH seems to be progressing fast and already reach a very impressive degree of sophistication.





[Biedermann et al. Eur. Phys. J. C **77** (2017) 492]

A. Broggio, AF, G. Ossola, B.D. Pecjak, R. Sameshima, L.L. Yang

Conclusions

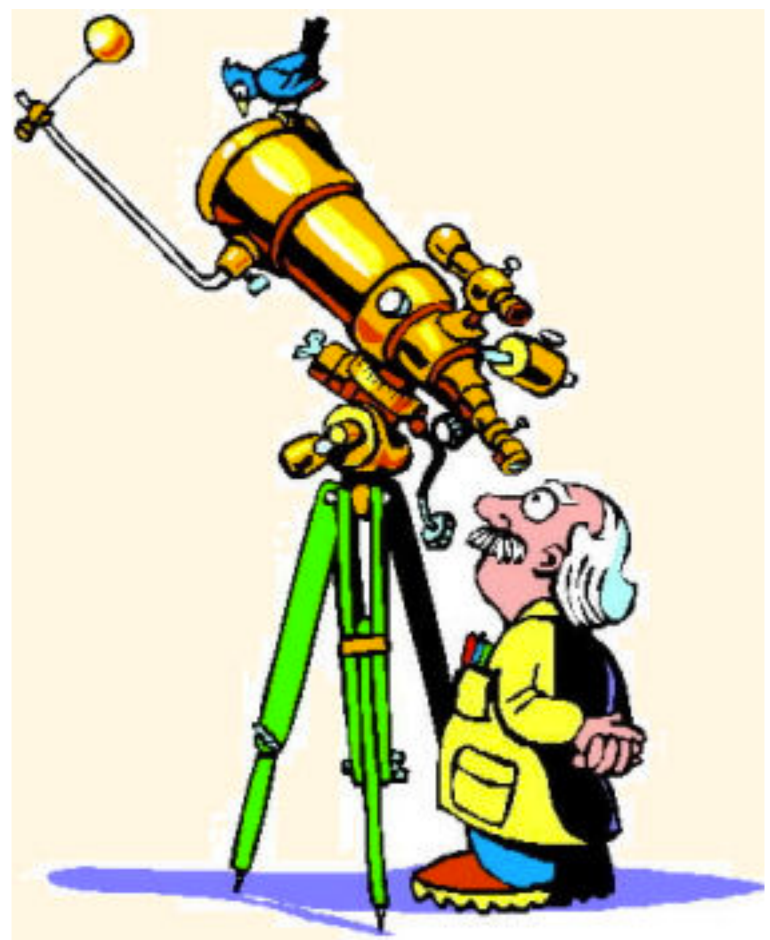
Progress in connecting top quark signals at the LHC with the underlying Lagrangians has been enormous.

We are able to provide theoretical predictions for fiducial volume cross sections at various levels of sophistication; they can be directly contrasted with experiments.

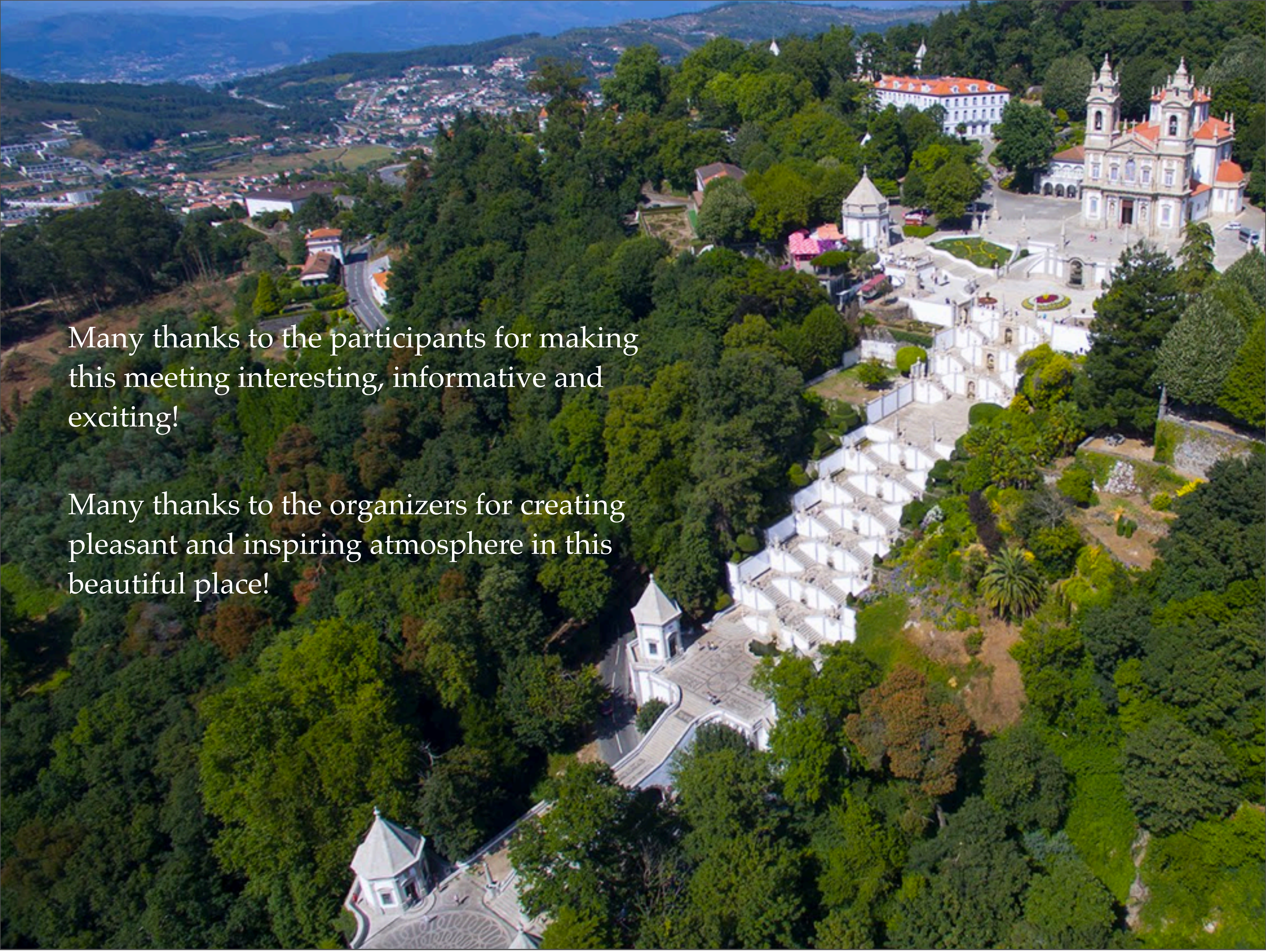
We have learned how to use these results to look for physics beyond the Standard Model, sometimes in unorthodox ways.

We are exploring the many top quark couplings in a systematic way and will continue to do so in a close collaboration between theorists and experimentalists.

Conclusions



I guess the only problem is that top quark physics is still too complex, it involves too many numbers. As I said at the beginning of this talk, our grand goal is to reduce them to a bare minimum. Hopefully, we will see the day when the top quark will be indeed described by just two numbers, confirming what the wise "famous relativist" knew all along.


Many thanks to the participants for making this meeting interesting, informative and exciting!
Many thanks to the organizers for creating pleasant and inspiring atmosphere in this beautiful place!