Theory Summary of Top2016

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Context

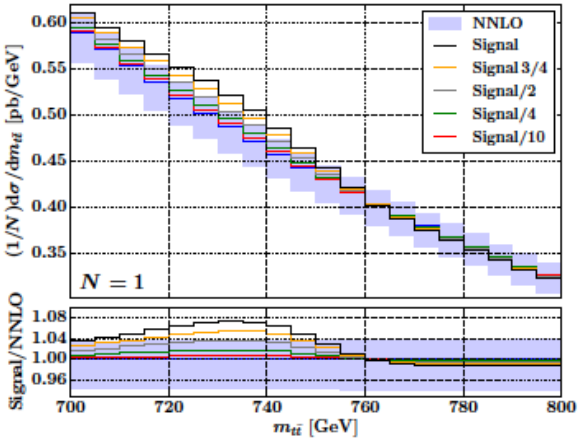
- The 2016 edition of Top20xy takes place in a markedly different environment:
  - The fantastic performance of the LHC is steadily moving the LHC physics program
    - From: detailed understanding of SM top quark
    - Towards: BSM implications.
- For the first time the Top20xy series of Workshop has significant emphasis on the interplay of top and BSM (think: "*what if the 750 GeV di-photon excess was real?*")
- The Workshop's idea is to facilitate work and discussions, thus helping address pressing problems in the description of (especially multi-TeV) top production, by:
  - SM theory and EXP provide answers regarding BSM,
  - BSM theory provides guidance about opportunities for EXP and SM theory:
    - The short-term, low-hanging fruit
    - The long-term end game for the LHC
- Overall there was a very good synergy!

The context in a single example: The 750 GeV resonance-that-wasn't and ttbar

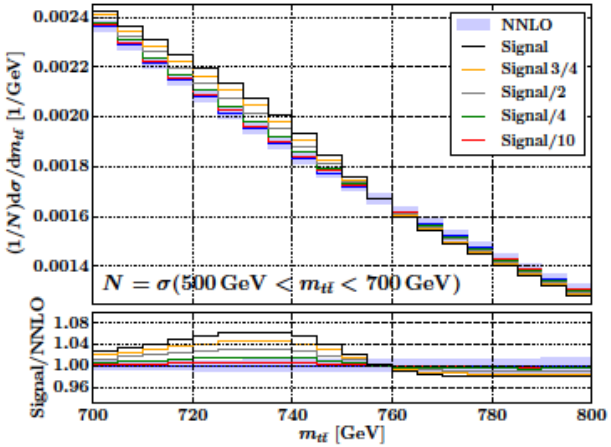
- We all know the answer to this mystery: statistics!
- Still, many lessons can be illustrated with/taken from, this example:

What does it take to find a not-so-prominent bump (or signal) in tt events?

signal vs. "plain" NNLO



vs. "turbo" NNLO (i.e. normalized NNLO)



- How well do we know the SM tt predictions?
  - Higher-order QCD effects
  - PDFs
  - Top mass
  - EW effects

Czakon, Heymes, Mitov 1608.00765

- BSM physics:
  - Motivation
  - Places to look
  - Possible signals to compute

- Both were fully covered at this conference and I'll discuss them in turn!

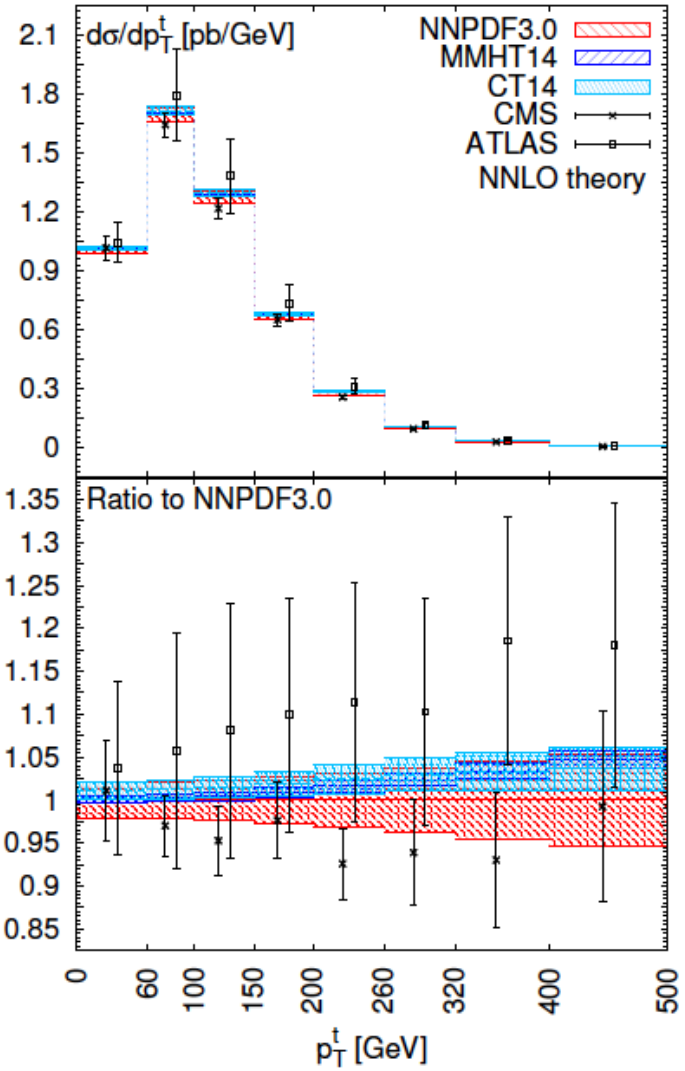
Quantifying the SM

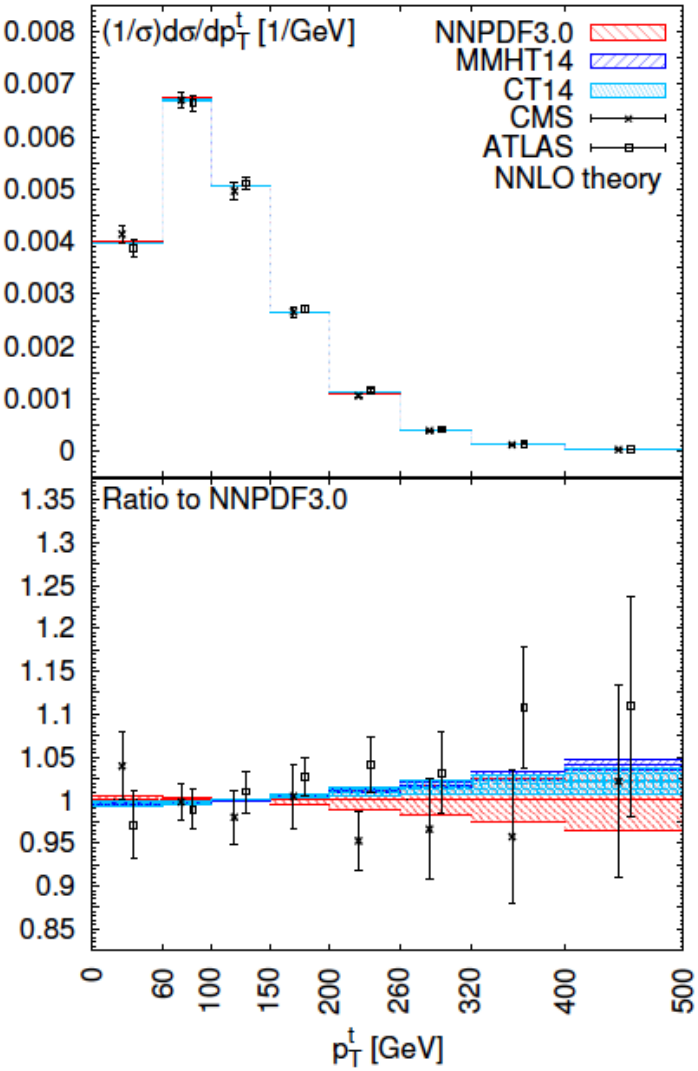
Precision top production: QCD corrections

- Inclusive stable top-production is in good shape
  - NNLO available for all 1-dim distributions (except $P_{T,tt}$ which is NLO)
  - Is there a $P_{T,top}$ discrepancy?

Czakon, Hartland, Mitov, Nocera, Rojo, to appear

Absolute normalization





Normalized

- It does not appear there is $P_{T,top}$ discrepancy after the inclusion of NNLO

Precision top production: QCD corrections

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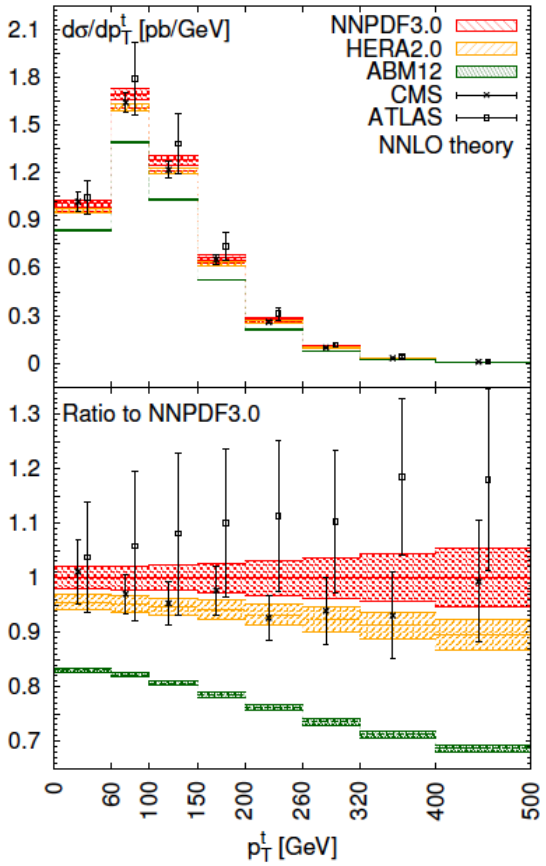
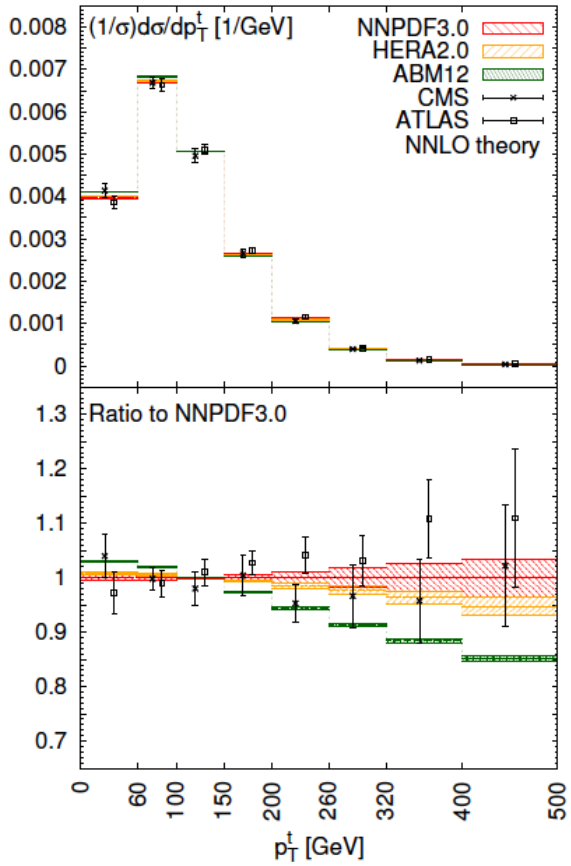




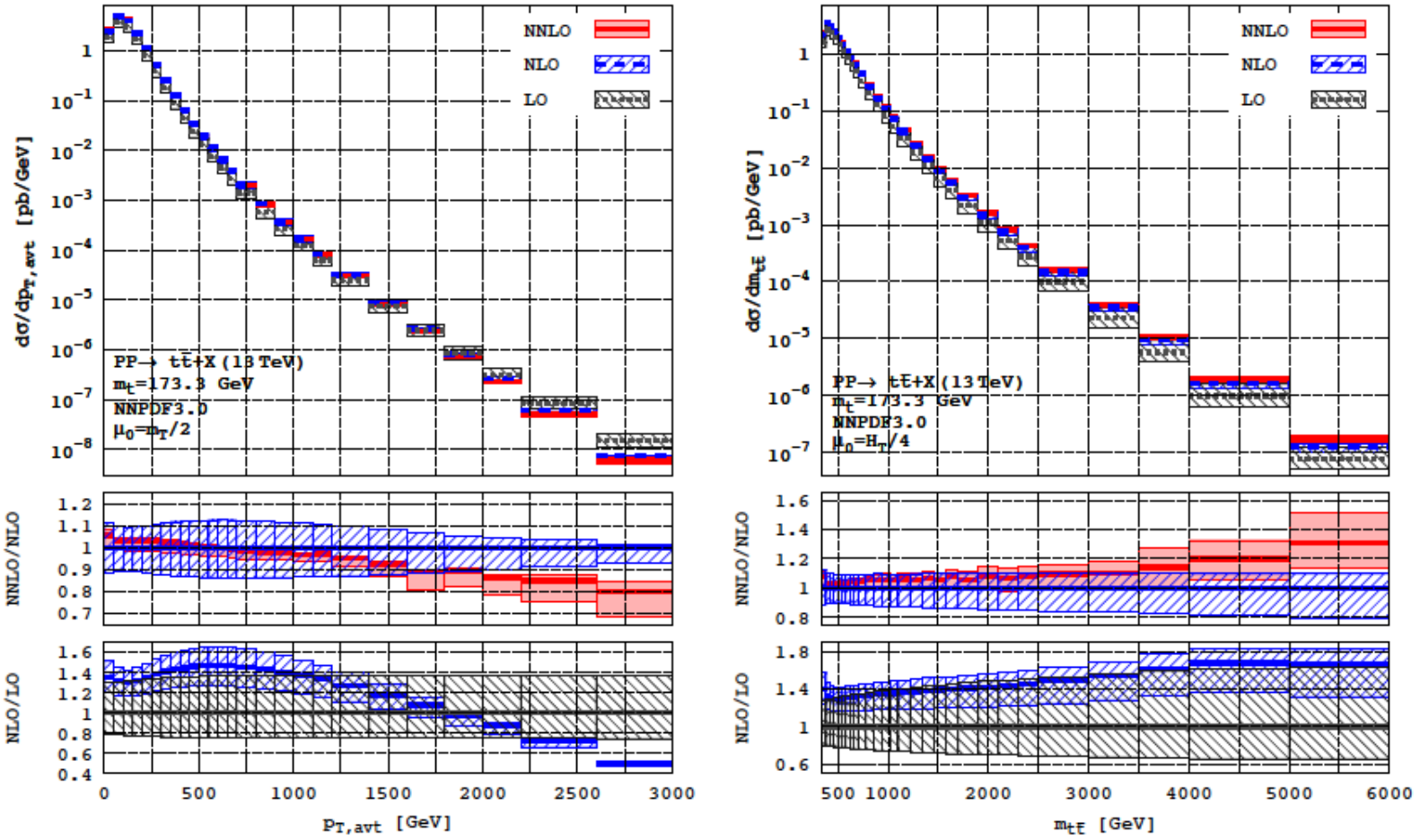
Normalized

- Similar conclusions from the ATLAS&CMS at 13 TeV will be very valuable and will help with MC development

- Most, not all, PDF's describe the data well

Precision top production: QCD corrections

- We have now reliable predictions up to multi-TeV scales



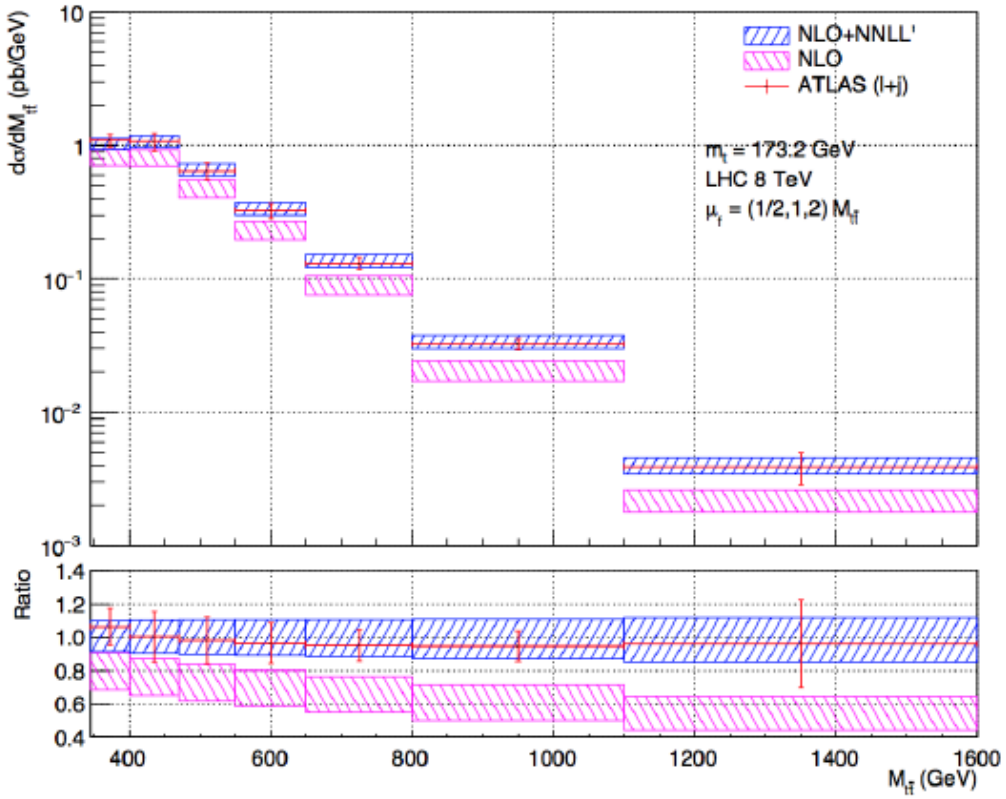
- Possible limitations?
  - Higher orders (i.e. resummation)
  - PDF
  - EW

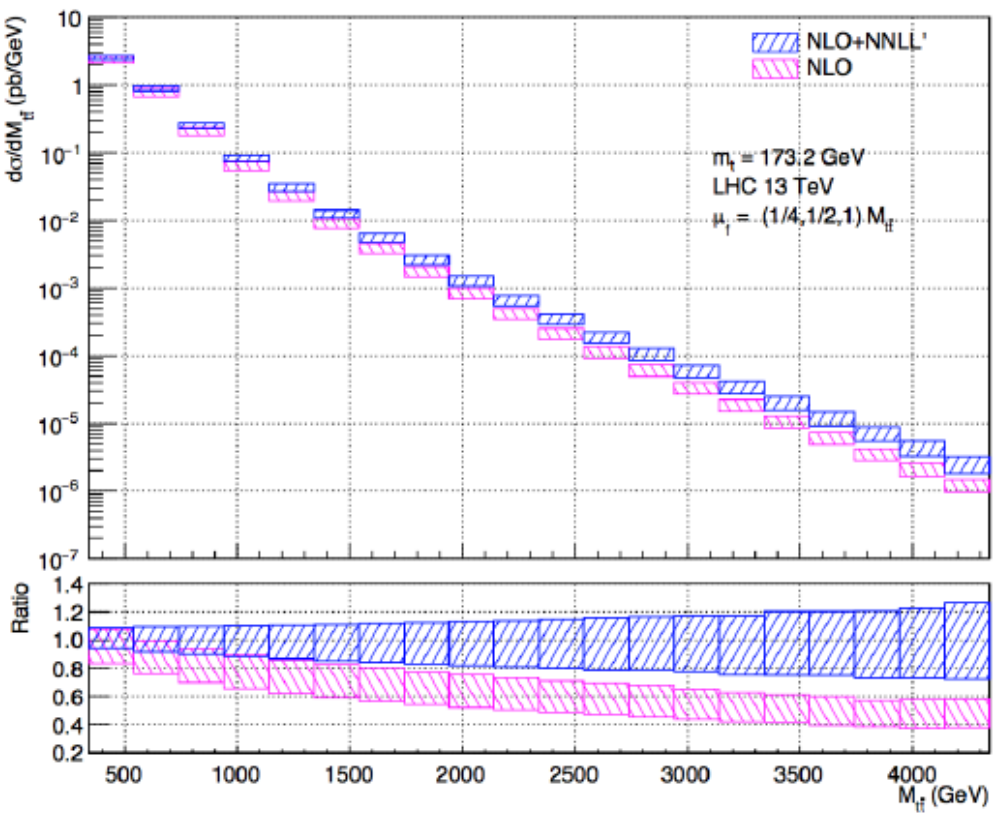
Precision top production: QCD corrections

- Soft-gluon resummation at NLO+NNLL

Pecjak, Scott, Wang, Yang `15

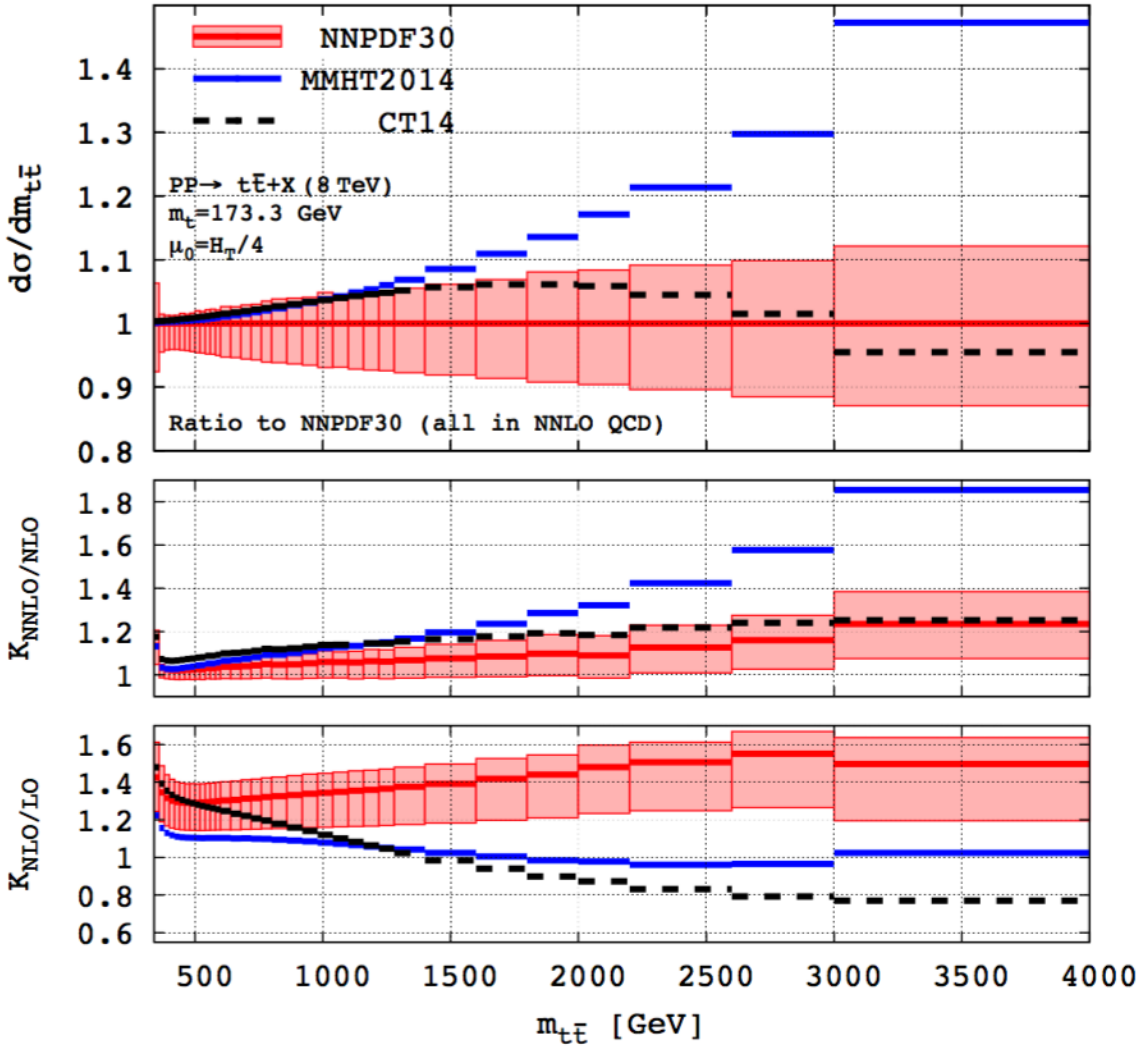
- Very nice result; the large effect is likely due to choice of scale (M_{tt}-based scales do not converge well Talk by Michael Czakon)





Limitations on multi-TeV top-pair production: PDF

- Talk by Michael Czakon



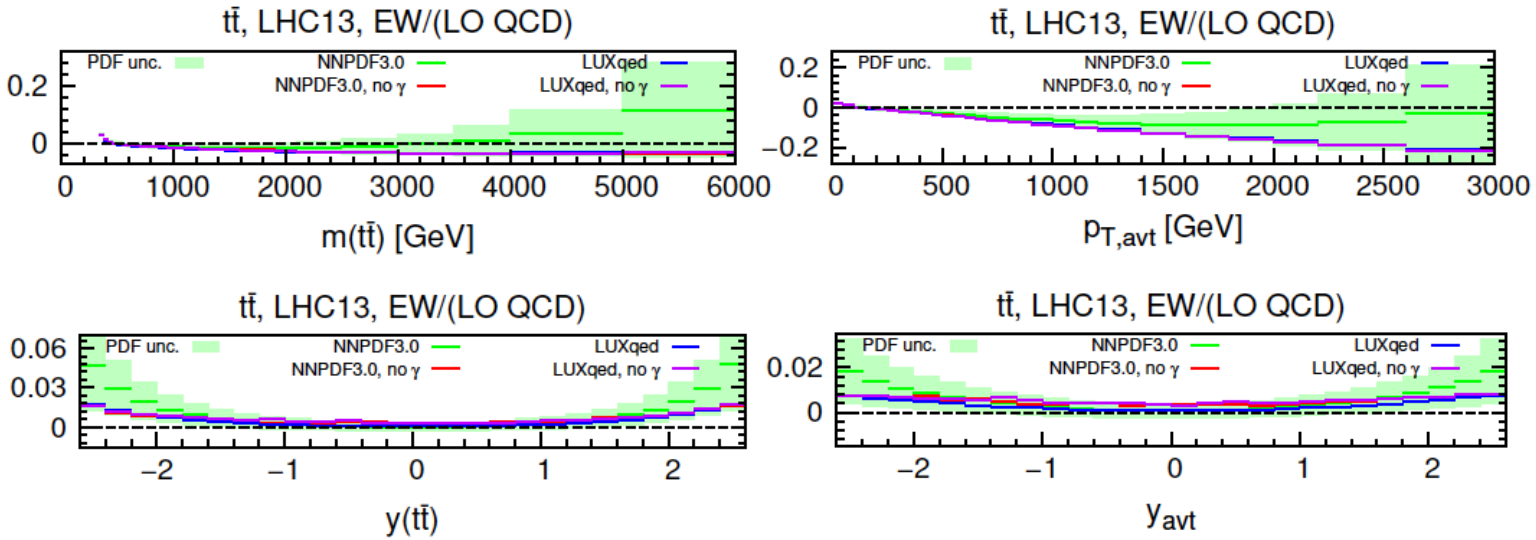
- The largest uncertainty (at present) for multi-TeV top production seems to be PDF uncertainty
- Can be reduced, in part, by refitting top data: use top/top-pair rapidity, not M_{tt}.

Limitations on multi-TeV top-pair production: PDF

- Luckily, one large potential PDF error went away (talks by Ioannis Tsinikos, Stefano Pozzorini)

NNPDF3.0QED vs LUXqed

Manohar, Nason, Salam, Zanderighi '16



- photon PDF impact ⟶ large in NNPDF3.0QED, negligible in LUXqed
- LUXqed ⟷ NNPDF3.0QED (no $\gamma(x, Q)$)
- LUXqed and NNPDF3.0QED in agreement within uncertainties

- The field appears to have unanimously accepted the smallness of the photon pdf

Related earlier work: Harland-Lang, Khoze, Ryskin, Martin

- Implications: tiny photon PDF error; large negative EW correction to ttbar at TeV scales
- Consistently merged NNLO QCD + NLO EW will be made public soon.

Czakon, Heymes, Mitov, Pagani, Tsinikos, Zaro, to appear

Top quark mass

Also talk by Michael Czakon

- Very important update on the top pole mass – MS-bar mass relation and contribution from renormalons.

Beneke, Marquard, Nason, Steinhauser arXiv:1605.03609
(uses the 4-loop result of):
Marquard, Smirnov, Smirnov, Steinhauser arXiv:1502.01030

- What's actually the issue?

- In the past it has been said that non-perturbative/renormalon corrections to mtop could be
  - O(1 GeV)
  - O(Λ_{QCD}≈300 MeV)

- Use of MS-bar (or other short-distance masses) has been proposed to "solve" the problem at the LHC and allow more precise mtop determination.

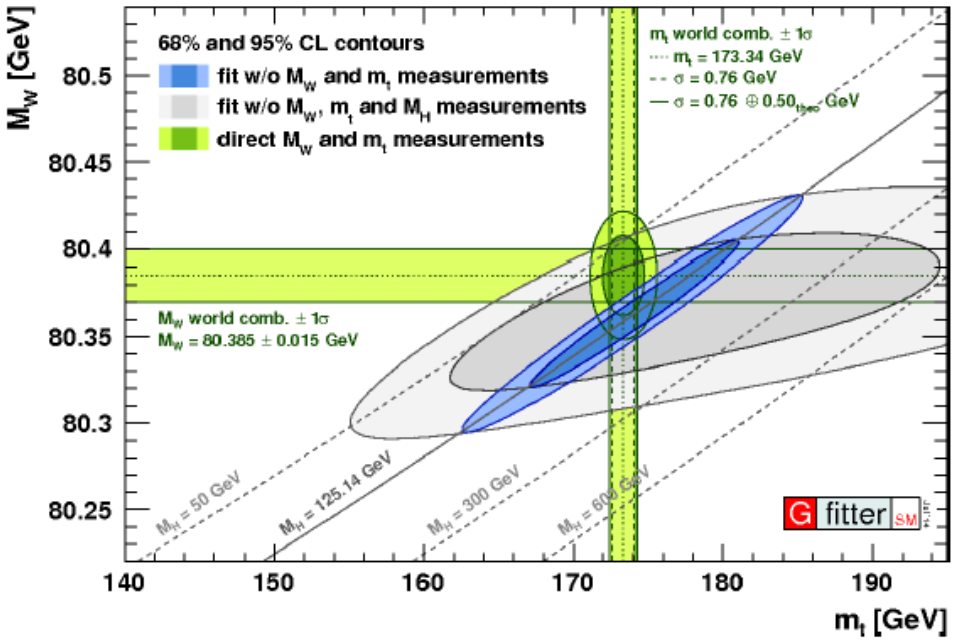
- But is this the case?

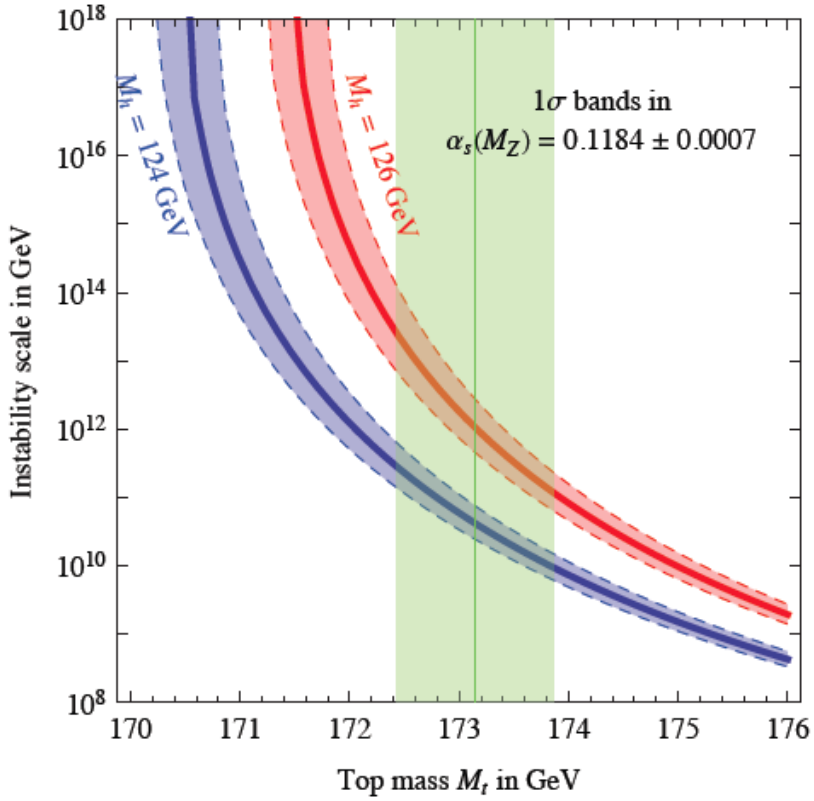
- The renormalon contribution is now estimated at 70 MeV. Absolutely negligible effect compared to the foreseeable error at the LHC. Error from MS-pole mass conversion 250 MeV.

- Conclusion?
  - One can use any mass one wants, but one should not expect added benefit from switching mass definitions! (at LHC; e+e- colliders are different story)
  - All LHC calculations are done in the pole scheme (and for a good reason!): the top decays and the ratio Γ_{top}/m_{top} ≈ 1% tells us why our description of tops is so good!

Top quark mass

- Why precision in m_{top}?
  - EW precision fits; fate of the Universe …





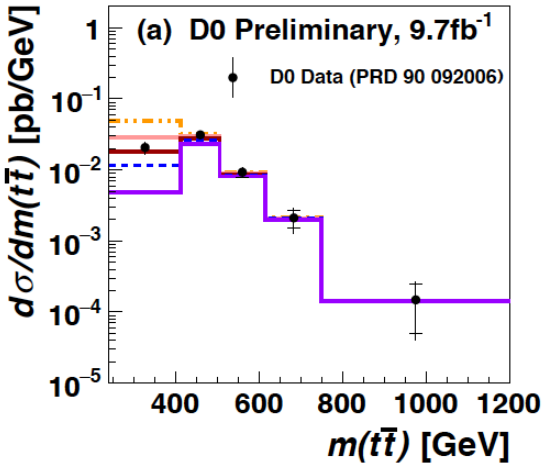
  - … it also starts to have some impact on LHC distributions:

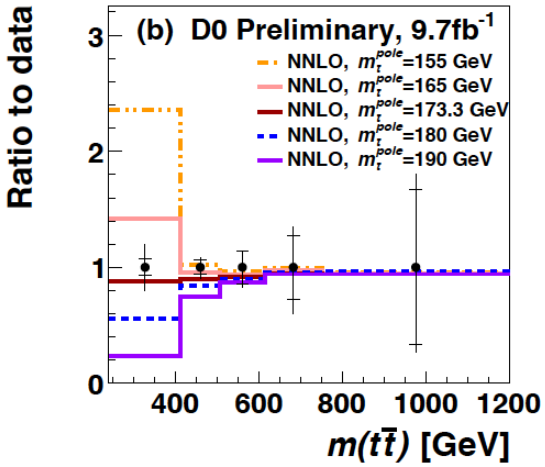
- The issue is non-trivial because of the significant spread O(3 GeV) among current most precise m_{top} measurements.

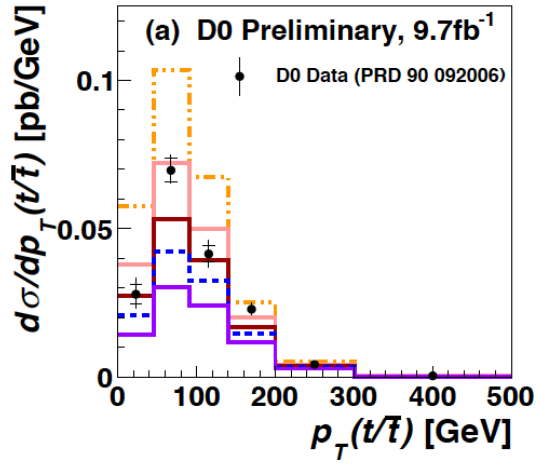
- Much work in the past; here are some recent/current developments:

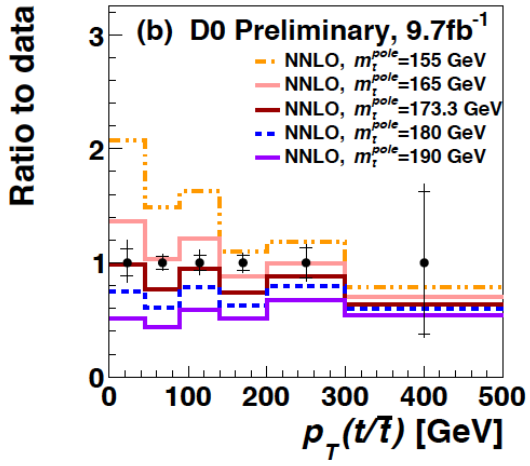
Top quark mass

- New methods and ideas about the extraction of m_t:
  - Comparing NNLO QCD with differential distributions measured by D0:

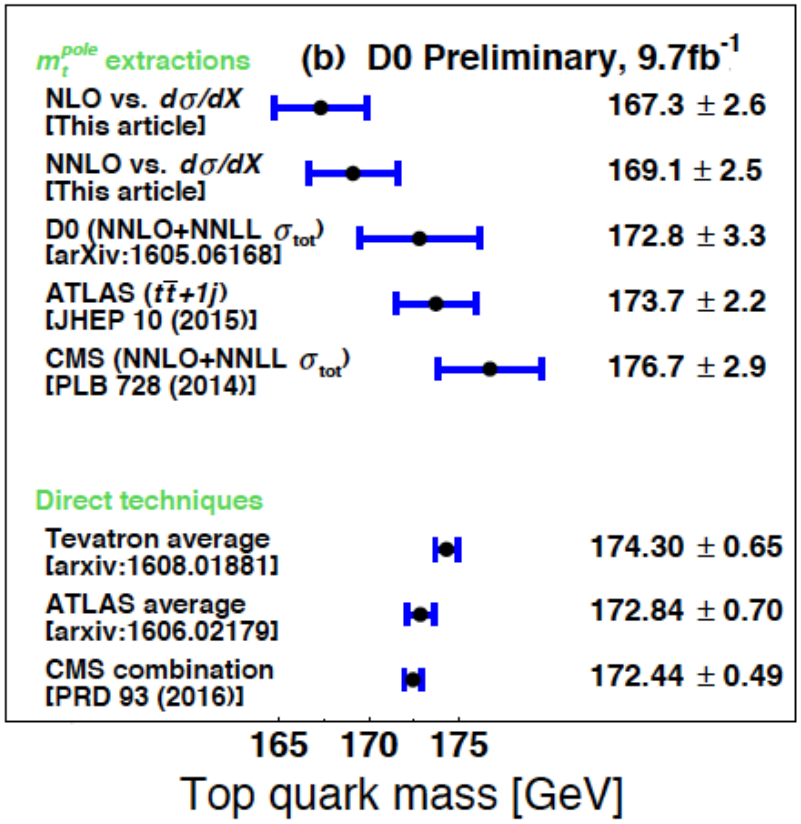








Talk by Reinhard Schwienhorst



- Interestingly, the error of the extracted mass is below the one of the total x-section.
- Promising approach, especially for the LHC

Top quark mass

- New methods and ideas about the extraction of m_t:
  - Update for the b-energy peak method:

    Agashe, Franceschini, Kim, Schulze arXiv:1603.03445

    - Computed with QCD corrections to top decay. Important correction; radiation modifies the results.
    - The main attraction of this, and similar to it, methods is that they decouple top productions from top decay.
    - m_{top} extraction is independent of BSM physics in top production

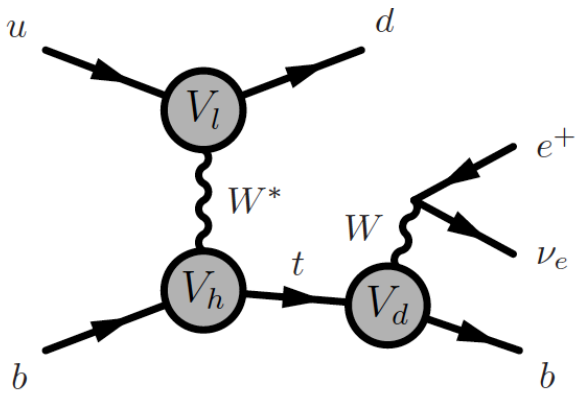
  - Calibration of the Pythia8 top quark "MC" mass in terms of the top quark pole mass

    Talk by Moritz Preisser

    - Compare Pythia8 with resummed analytic results in e+e- →tt
    - Interesting result; lots of discussions!
    - Possible issues:
      - Absorbs perturbative & non-perturbative effects unrelated to m_{top} proper
      - Applicability to hadron colliders
      - Process independence and universality

Single Top

Talk by F. Tramontano



- Received much less theoretical attention in the past!
  - Playground for MC development
  - Studies of 4/5 flavor schemes
  - Known at NLO
- NNLO corrections derived only recently (NWA, t-channel, 5-flavor scheme)
  - Differential x-section (stable top)

Brucherseifer, Caola, Melnikov '14

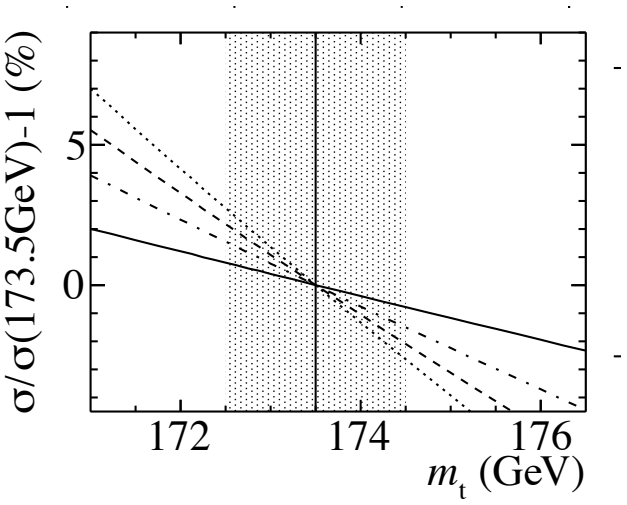
  - Fully differential (production + decay)

Berger, Gao, C.-P. Yuan, Zhu '16

- s-channel and tW-channel known at NLO and available through HATHOR for single top

Kant et al arXiv:1406.4403

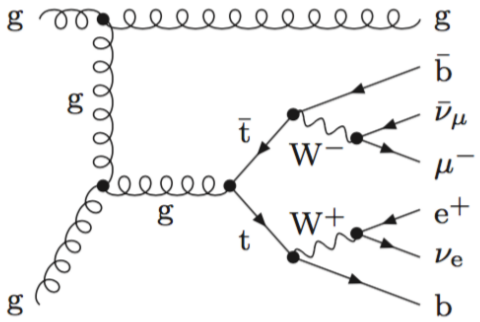
- Approx. NNLO available from Kidonakis

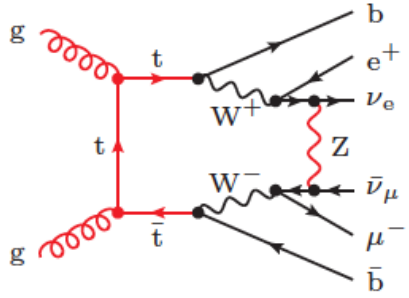


Precision top production: realistic final states

- Talks by M. Worek and S. Pozzorini

  - tt+j at NLO fully off-shell
  - Tt at NLO QCD+EW fully off-shell





  - These are some of the most complex calculations done to date!
  - We are moving towards full automation and exceptional capability at NLO

NLO EW Tools	first results	
RECOLA+COLLIER	$pp \to \ell^+\ell^- jj$	[arXiv:1411.0916]
	$pp \to (t\bar{t}) \to e^+\nu_e\mu^-\bar{\nu}_\mu b\bar{b}$	[arXiv:1607.05571]
	$pp \to e^+\nu_e\mu^-\bar{\nu}_\mu$	[arXiv:1605.03419]
	$pp \to e^+e^-\mu^+\mu^-$	[arXiv:1601.07787]
OPENLOOPS+ MUNICH/SHERPA	$pp \to W + 1,2,3$ jets	[arXiv:1412.5156]
	$pp \to \ell\ell/\ell\nu/\nu\nu + 0,1,2$ jets	[arXiv:1511.08692]
MADGRAPH5_AMC@NLO	$pp \to t\bar{t} + H/Z/W$	[arXiv:1504.03446]
	$pp \to t\bar{t}$	[arXiv:1606.01915]
GOSAM+ MADDIPOLE	$pp \to W + 2$ jets	[arXiv:1507.08579]

Benefits of automation

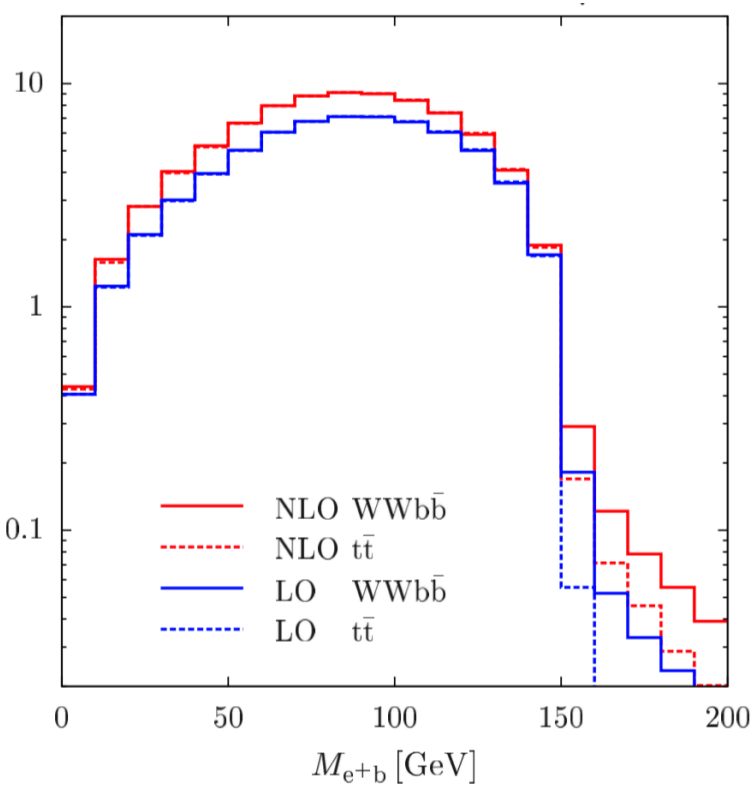
- NLO QCD+EW for multi-particle process, e.g. $pp \to WWb\bar{b}$ and $t\bar{t}+$ multijets
- NLO QCD+EW matching and mering with parton showers (still work in progress)

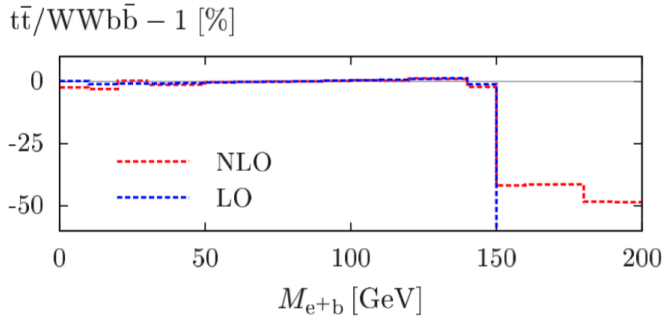
Precision top production: realistic final states

- Talks by M. Worek and S. Pozzorini

  - These complete NLO calculations allow precise test of various common assumptions and approximations:

    - Effects beyond NWA are substantial in some kinematic regions



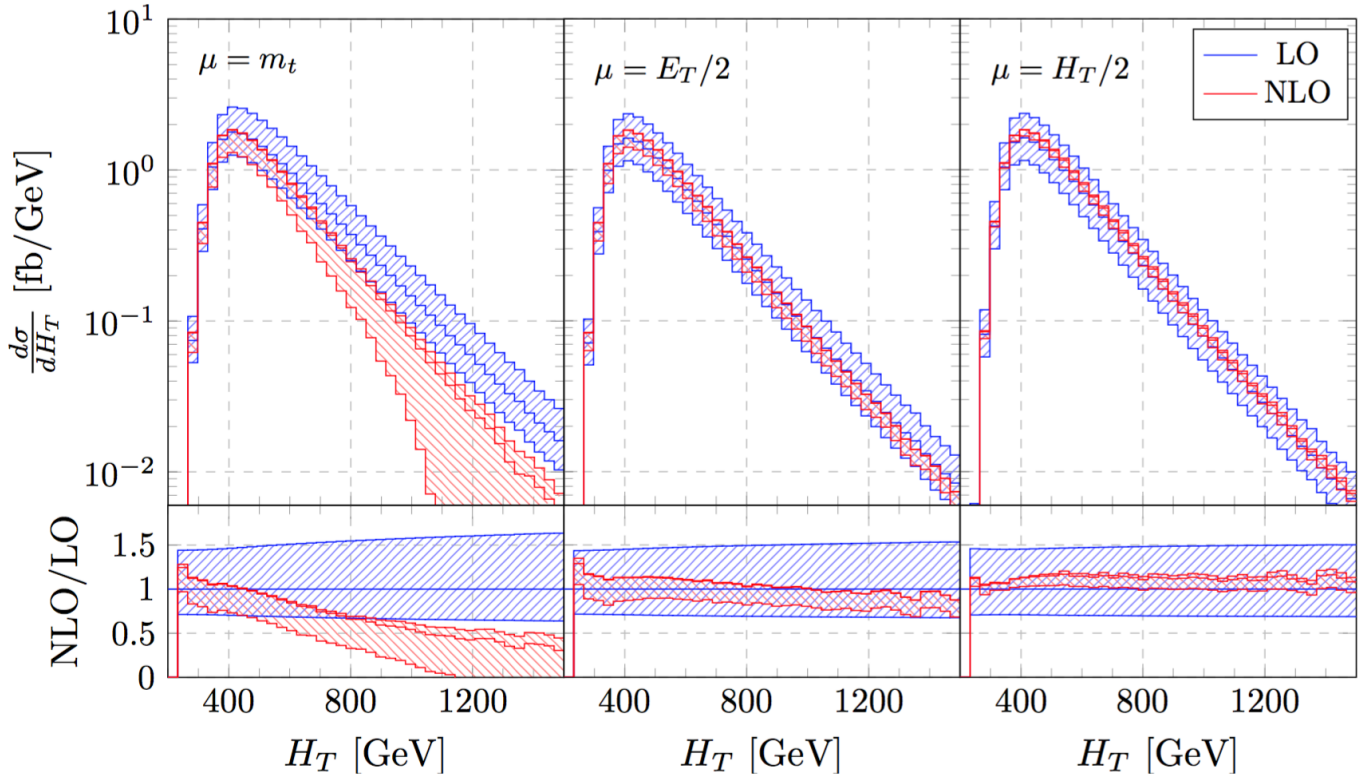


A. Denner, S. Dittmaier, S. Kallweit,
B. S. Pozzorini, M. Schulze '12

  - Important applications:
    - endpoint m_{top} measurement is dominated by this effect!

Precision top production: realistic final states

- Talks by M. Worek and S. Pozzorini
  - Additional features:
  - Flexible dynamic scales calculations. Comparison with the NNLO findings?



Bevilacqua, Hartanto, Kraus, Worek, arXiv:1609.01659

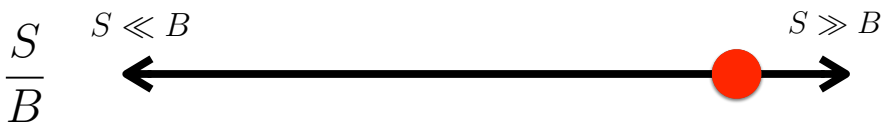
  - Flexible outputs: ntuples.
  - Important impact on m_{top} for various measurements (endpoint & tt+jet)

Being inspired by BSM Physics

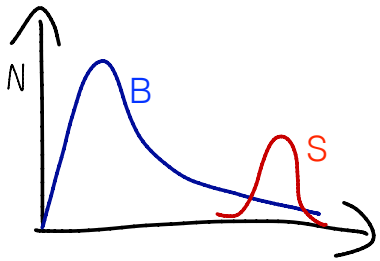
BSM and top

- What better inspiration than being told:
  - Top is truly special
  - Your work and expertise is very much needed!
  - Without your work important discoveries may not happen!

signal v. background

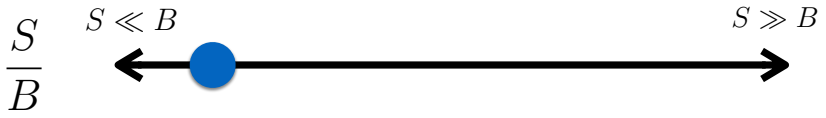


usually we try to separate new physics from the background

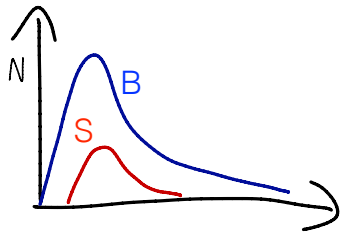


A. Weiler

signal v. background



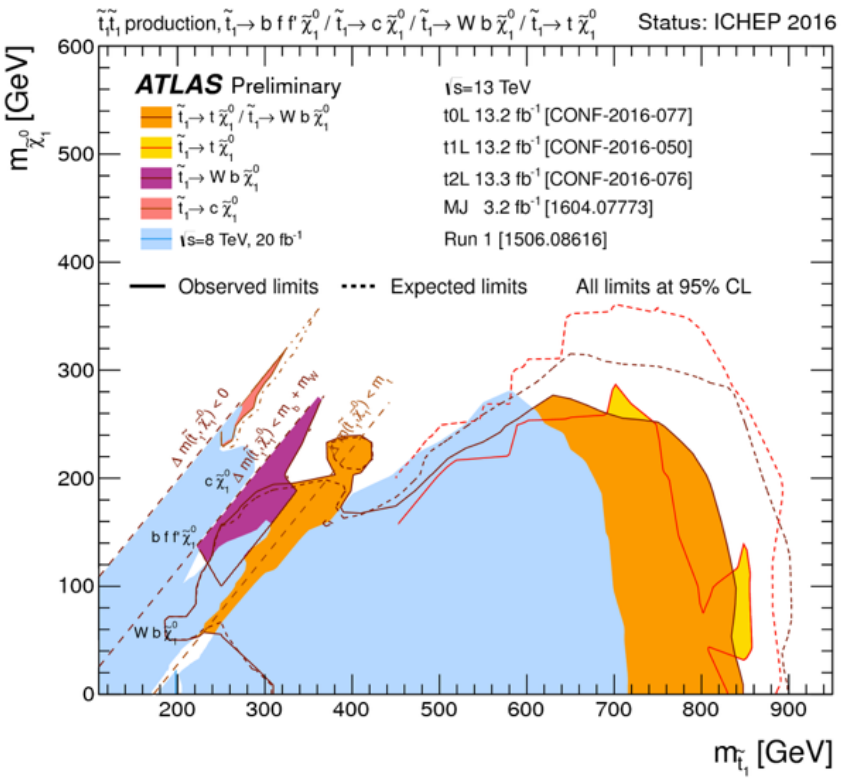
Sometimes we can learn about new physics by precisely studying the background



A. Weiler

Talk by A. Weiler

BSM and top



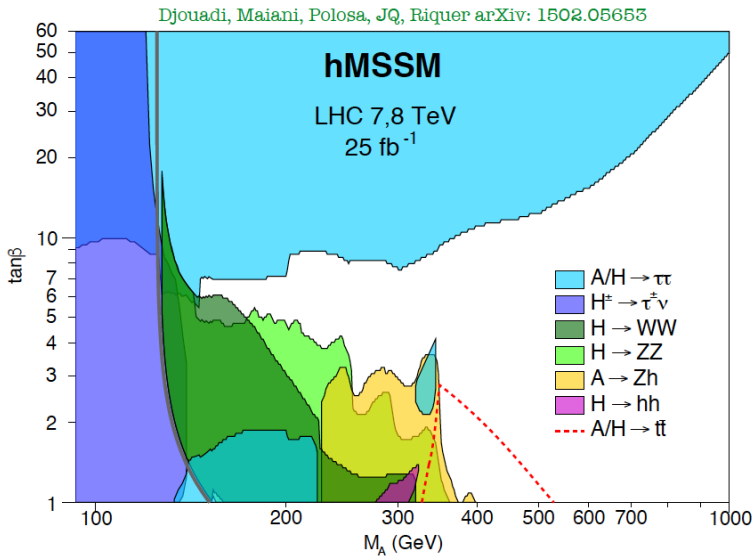
- Talk by Franceschini
  - LHC: 100 fb^{-1} by end-next year
  - New Higgs and EW states are a priority
  - Challenges:
    - Compressed spectra (i.e. little energy released above SM) e.g. stop chimneys
    - Dilution: there could be many decay channels and the decay rate is diluted – each one of them small – and so hard to see!
  - Messages:
    - We can look for straightforward deviations (bumps) but it may become harder.
    - More and more favored approach: look for BSM that hides in SM.
    - Not just top production but also top decay can contain new physics.

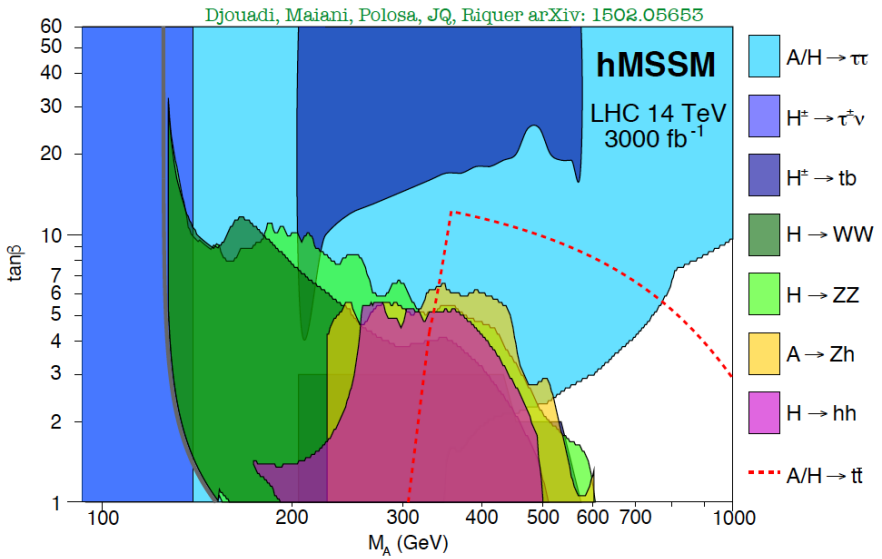
BSM and top

- Talk by M. McCullough Top and Naturalness
  - The naturalness idea connects Top+Higgs and so, naturally, leads to top partners.
    - Light stop is a major example
    - But it may be much more complicated: at LHC scales the top connection may not be apparent!
- Talk by Y. Kats BSM hiding in top (and applications of idea of Naturalness)
  - pp→ tT +2 jets is a fairly generic signature (whatever the model)!
- Talk by Matthew Buckley DM and top
  - top could naturally be connected to DM so signatures like pp-> tt+$E_{T,mis}$ are generic and well motivated.
- Talk by Reuven Balkin models with composite DM are well motivated.

BSM and top

- Talk by J. Quevillon generic scalars and top at LHC
  - Many things can happen, obviously; it is possible to even have effects that do not affect total rates (due to interferences)!
  - H,A → top is enhanced within MSSM by latest searches
  - Interferences: can be super important.





- Talk by Vignaroli
  - yet another example "why top is special"
- It all naturally looks like tt signal!

New Particles with preferred couplings to 3rd gen. quarks

- VLQs (top-partners)
- New vector resonances (kkg, W', Z', ..)
- New composite scalars

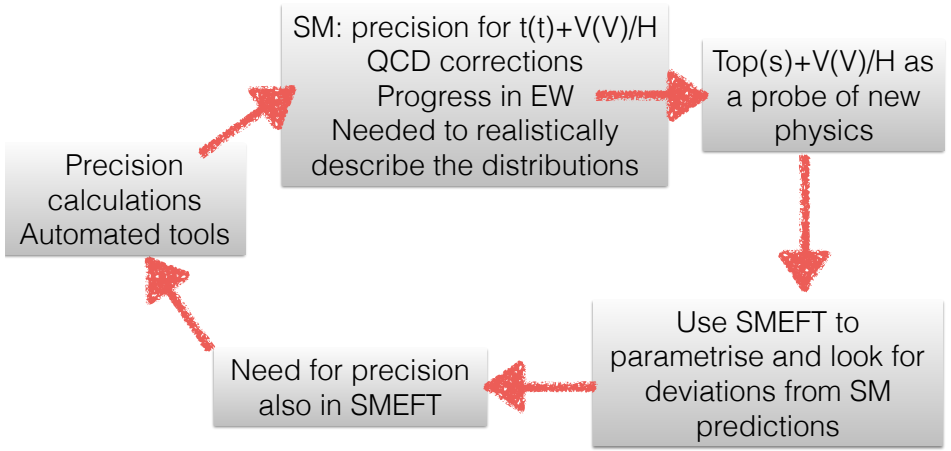
Rich BSM phenomenology with tops in the final state

Computing BSM effects is not a problem!

- We need to be doing good BSM+SM Calculations (a message from J. Quevillon's talk).
  - How to do that? EFT context — talks by Eleni Vryonidou & Gauthier Durieux
- Vryonidou: SMEFT@NLO

Franzosi, Zhang 1503.08841
Bylund, Maltoni, Tsinikos, Vryonidou, Zhang 1601.08193
Maltoni, Vryonidou, Zhang 1607.05330

  - Extend SM (preferably at NLO) with a set of EFT operators
  - new operators can bring steady rise in distributions (not just bumps)



- top-quark FCNCs: first global EFT analysis at NLO in QCD presented by Durieux

Durieux, Maltoni, Zhang '14

- Alternative frameworks: TopFitter

A. Buckley et al: 1506.08845 and 1512.03360

Conclusions

- Many developments in tt theory
  - Precision
  - Usability
  - Flexibility

- Improvements are happening at a constant pace; this allows cross-checks and validation with experiment

- Some highlights:
  - NNLO in single top
  - Top P_T discrepancy still present in MC's but resolved at NNLO?
  - Ongoing work in m_{top} extractions. But can we expect great improvements any time soon?

- What to expect?
  - NNLO top pair with NNLO decays (in NWA) (hopefully soon)
  - More differential top NNLO results;
  - Flexible formats

- Where else can we benefit?
  - Talk more to BSM colleagues!
  - There is tremendous TOP expertise around! It should be used in searches
  - Searches can provide insight into places to search and compute.
  - Evidently this will be a process; we'll look for ways to channel it and we need to keep open minds!