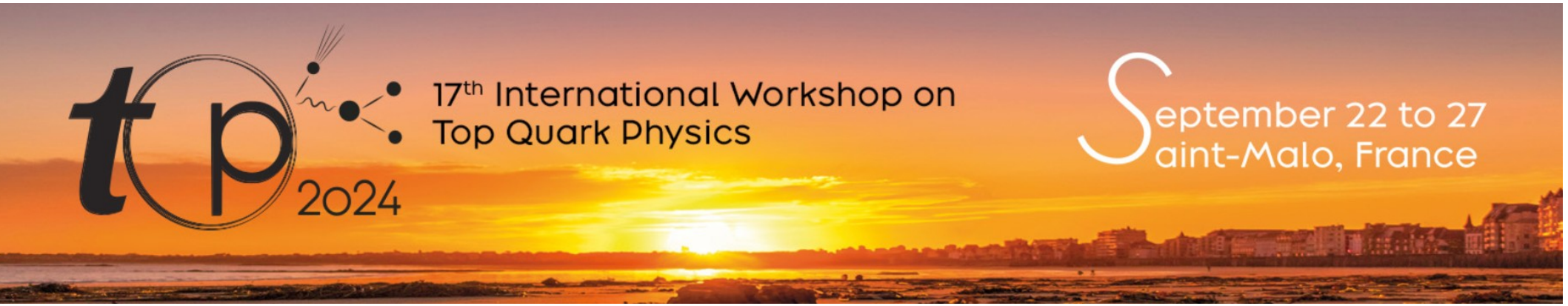


Experimental Summary

Abideh Jafari

Isfahan University
of Technology
IRAN

abideh.jafari@cern.ch: you know who to blame fo mistakes in this talk!

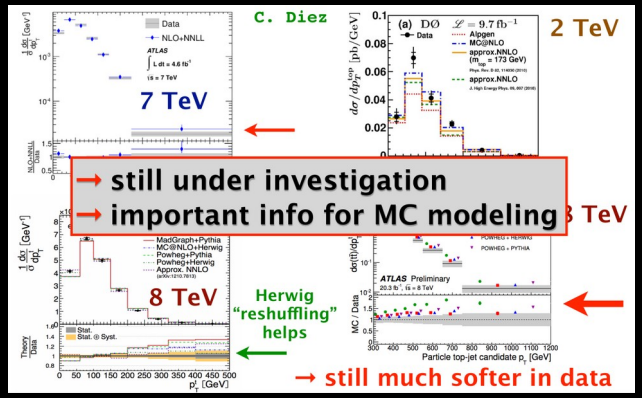
The happy faces already tell the summary of the workshop

The happy faces already tell the summary of the workshop

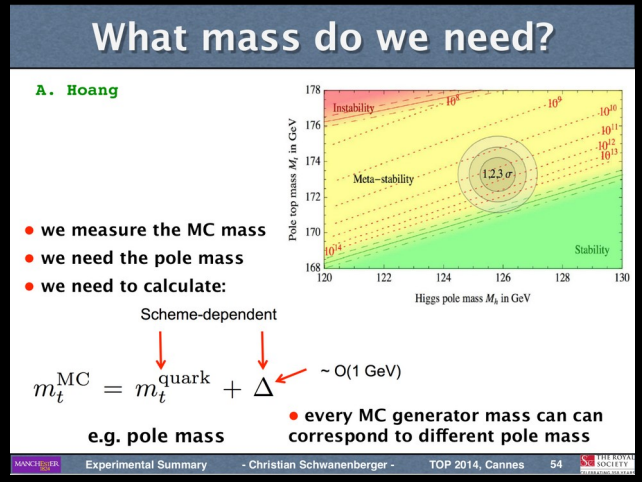
I'll share my very personal summary …

Inspired by Frederic and remembered Cannes

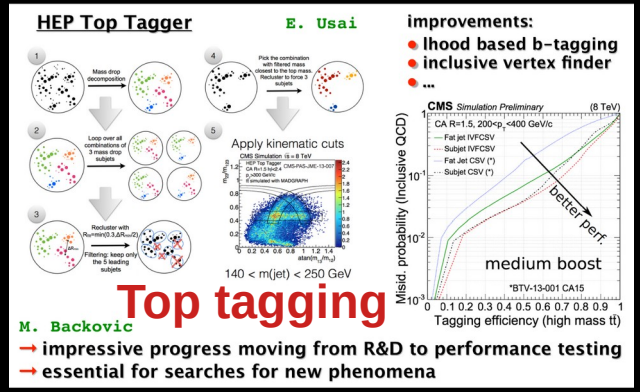
Inspired by Frederic and remembered Cannes

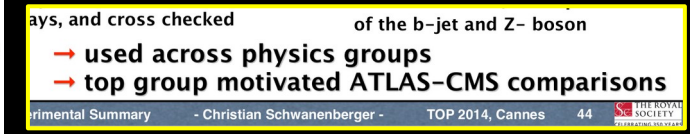


What mass do we need?



Search for ttZ and ttW

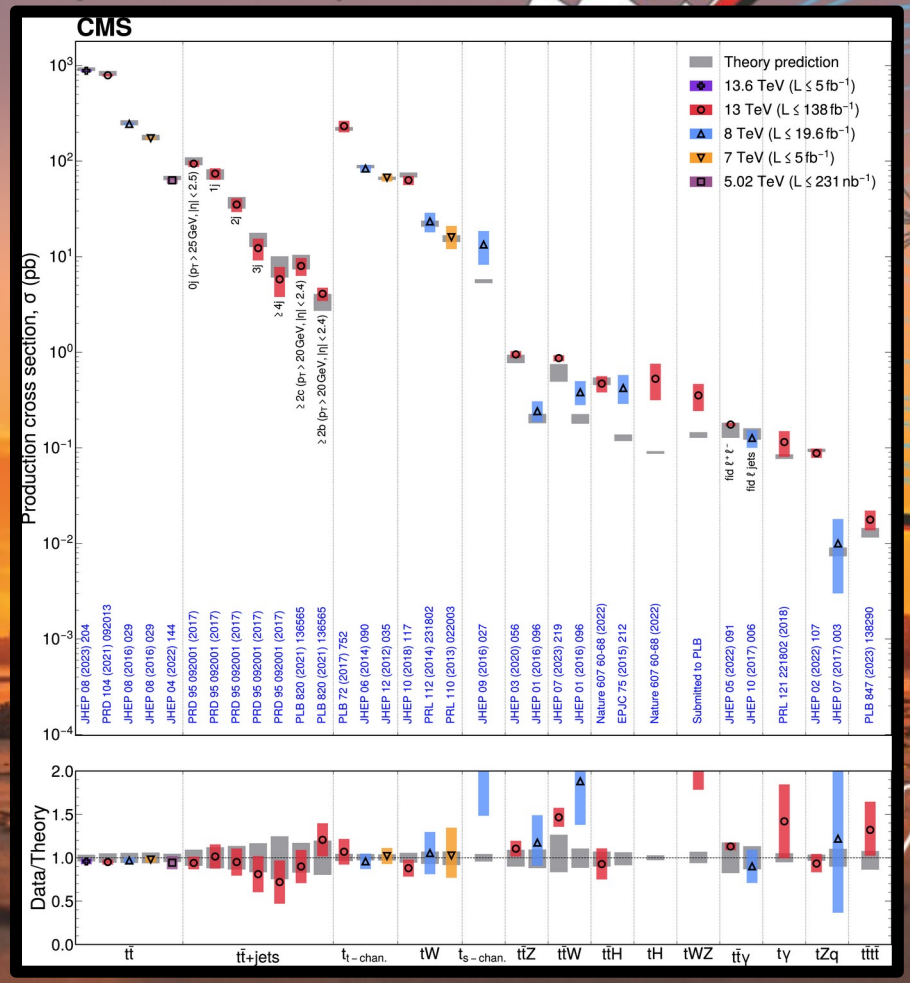




https://indico.in2p3.fr/event/10114/contributions/807/attachments/626/861/13_CSchwanenberger.pdf

17th International Workshop on Top Quark Physics

top 2024



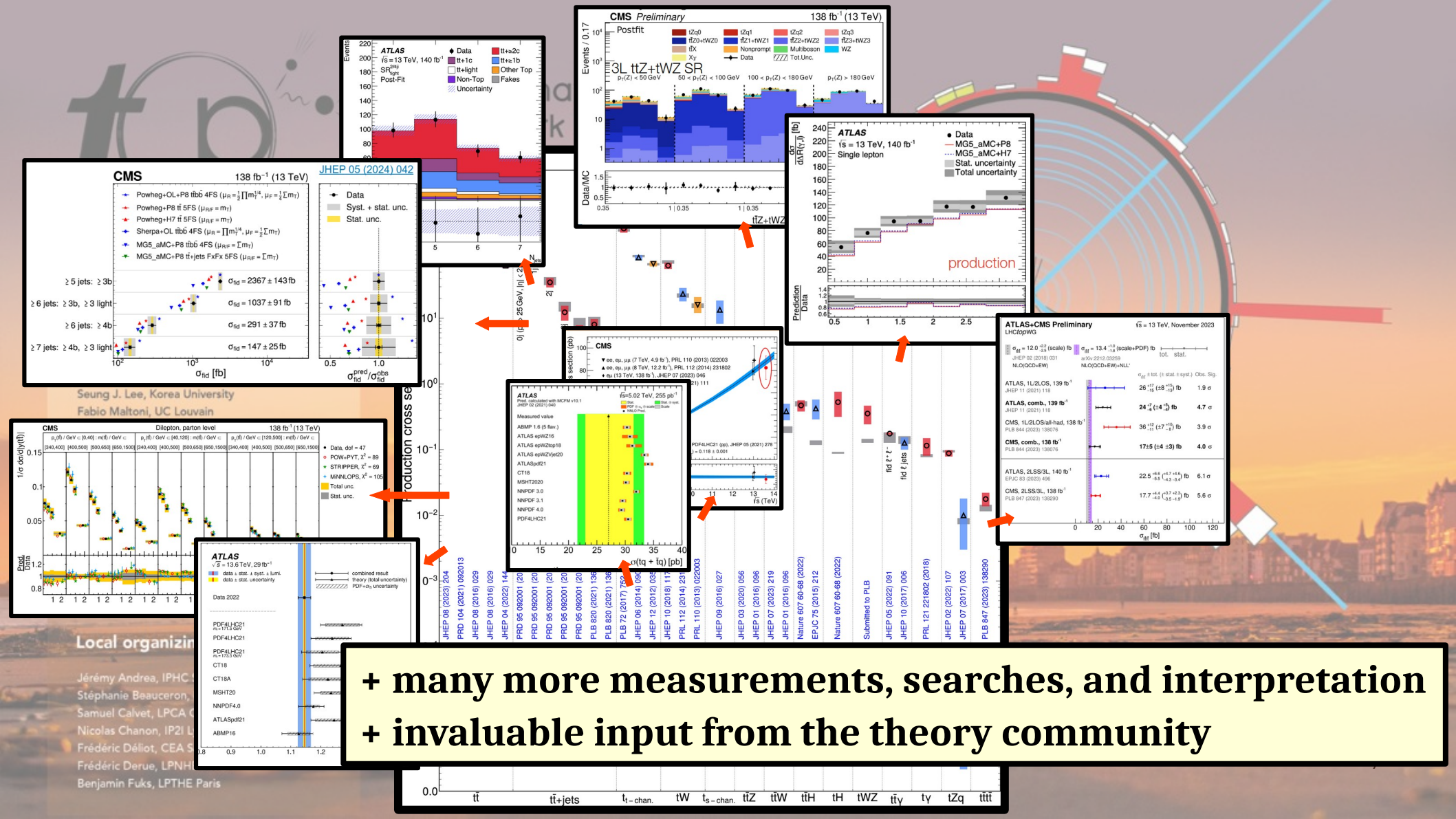
International advisory committee

Nedaa-Alexandra Asbah, CERN
Jorgen D'Hondt, University of Brussels
Alexander Grohsjean, Universität Hamburg
Andreas Jung, Purdue University, Chair
Seung J. Lee, Korea University
Fabio Maltoni, UC Louvain
Michelangelo Mangano, CERN
Alexander Mitov, Cambridge University
António Onofre, University of Minho/CF-UM-UP, LIP
Enrique Palecia, University of Oviedo
Reinhard Schwienhorst, Michigan State University
Roberto Tenchini, INFN Pisa
Wolfgang Wagner, University of Wuppertal
Małgorzata Worek, RWTH Aachen University

Local organizing committee

Jérémy Andrea, IPHC Strasbourg
Stéphanie Beauceron, LPNHE Paris
Samuel Calvet, LPCA Clermont
Nicolas Chanon, IP2I Lyon
Frédéric Déliot, CEA Saclay, Chair
Frédéric Derue, LPNHE Paris
Benjamin Fuks, LPTHE Paris

nber 22 to 27
Malo, France



+ many more measurements, searches, and interpretation

+ invaluable input from the theory community

Local organizing committee

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Stéphanie Beauceron, LPNHE Paris
Samuel Calvet, LPCA Clermont
Nicolas Chanon, IP2I Lyon
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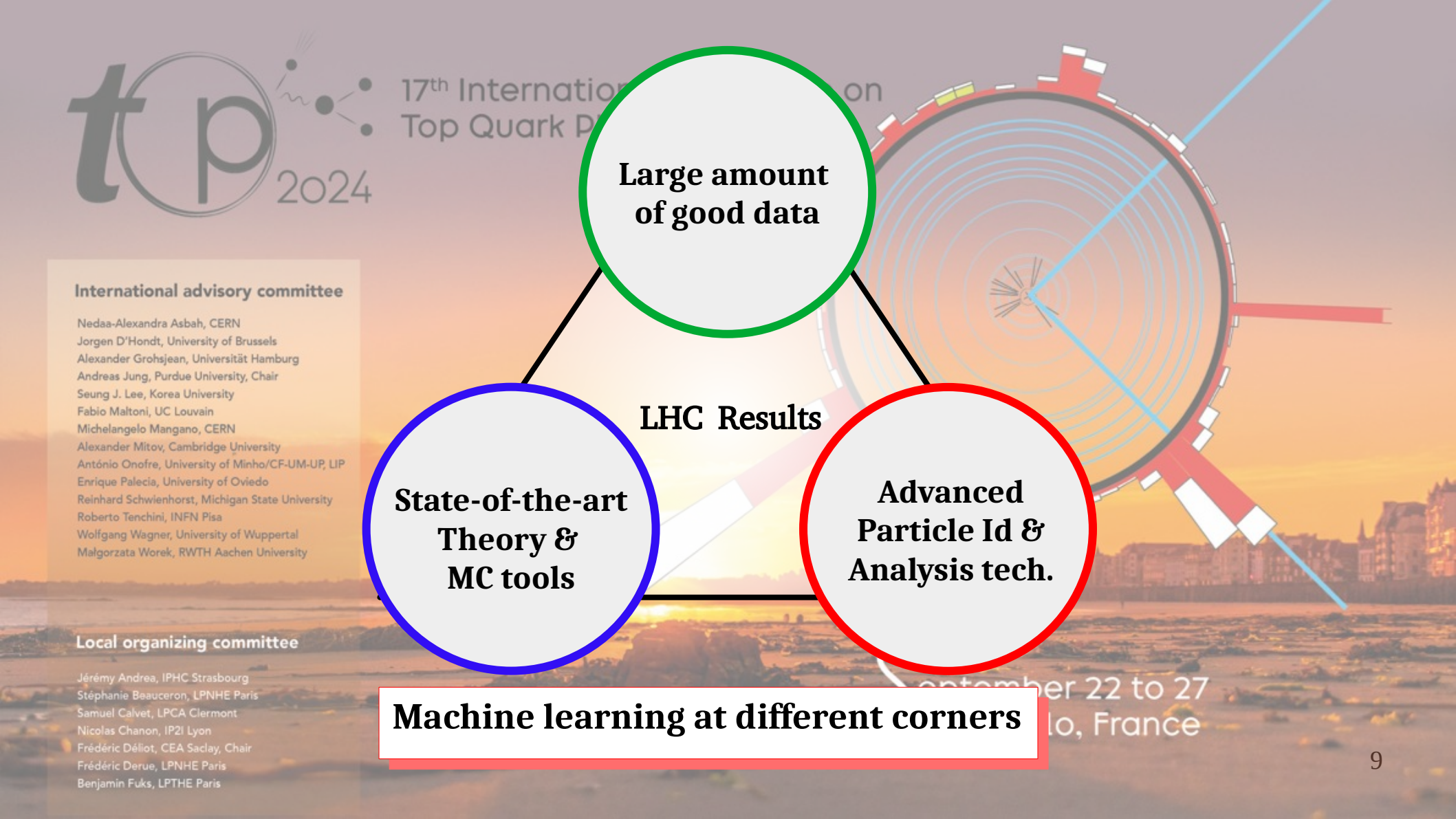
Frédéric Derue, LPNHE Paris
Benjamin Fuks, LPTHE Paris

eptember 22 to 27

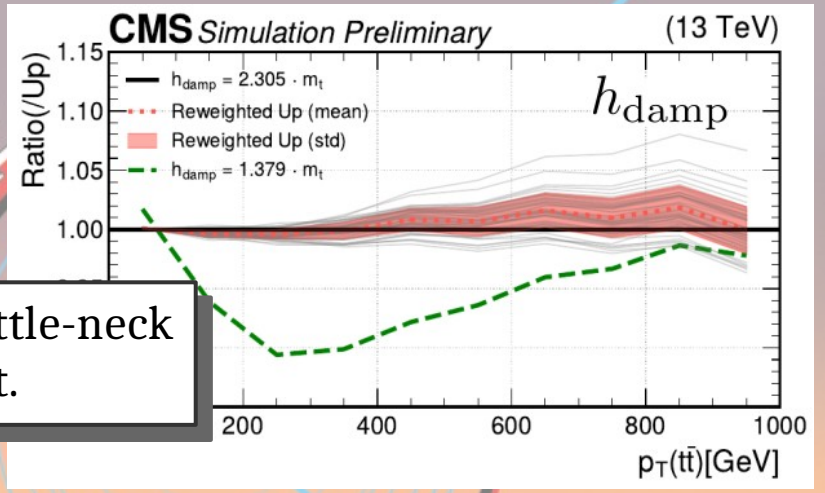
Thanks a lot to all for the excellent talks!


Large amount of good data
LHC Results
State-of-the-art Theory & MC tools
Advanced Particle Id & Analysis tech.
Machine learning at different corners

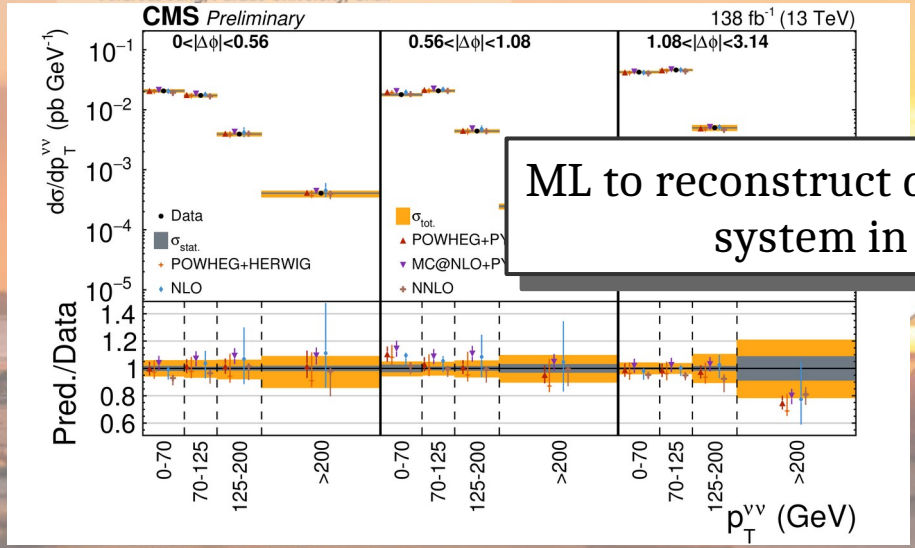
LHC Results

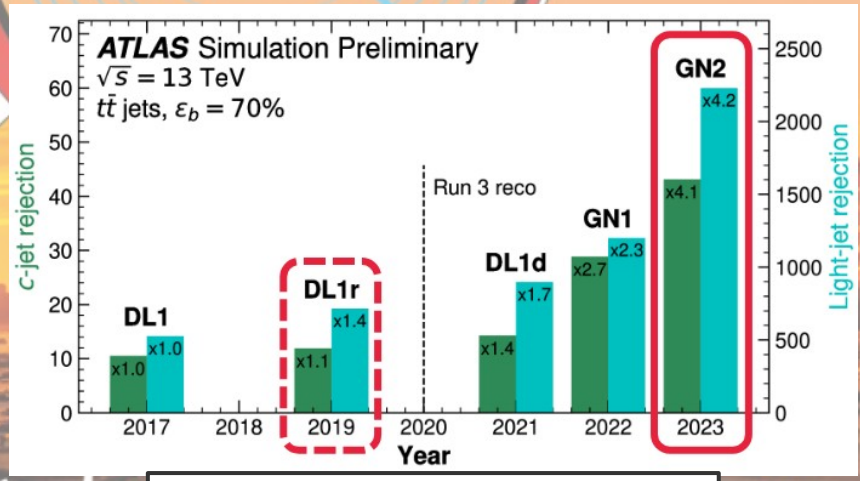
Advanced Particle Id & Analysis tech.

ML to overcome the bottle-neck of limited MC stat.



ML to reconstruct di-neutrino system in tt



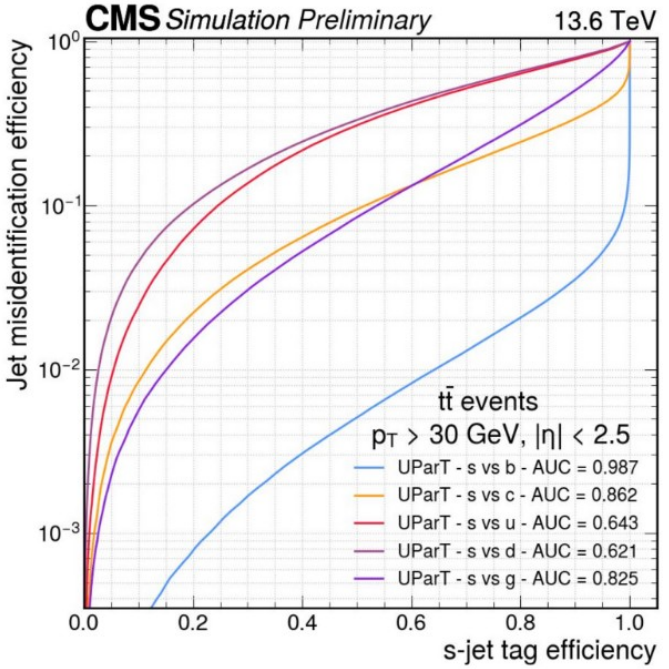


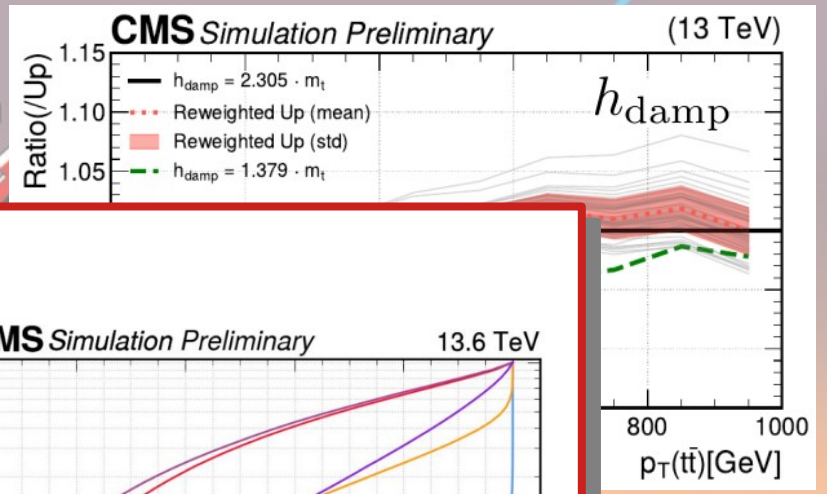
ML to boost identification of particles/jets

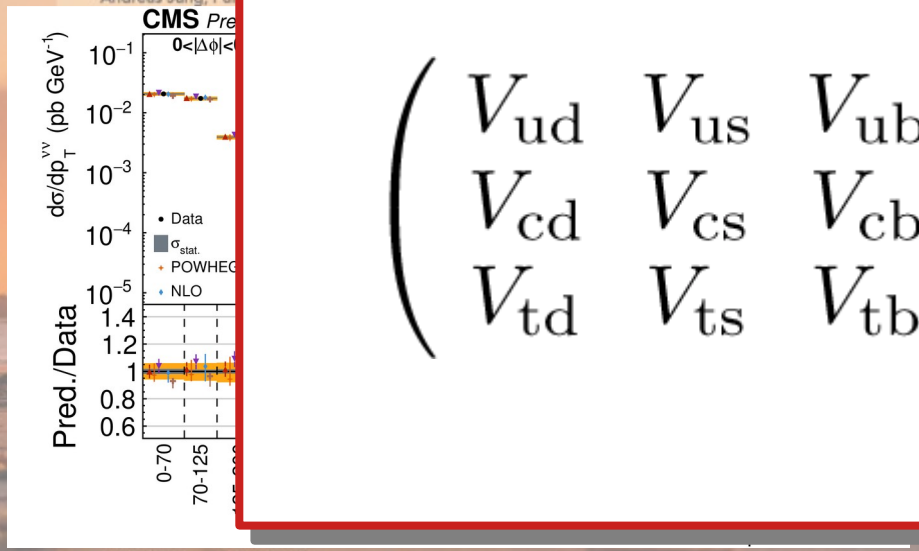
The first dedicated s-tagger!

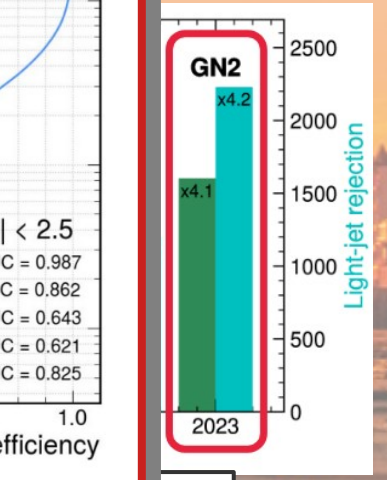
Exploited to **directly** measure $|V_{ts}|$?

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$





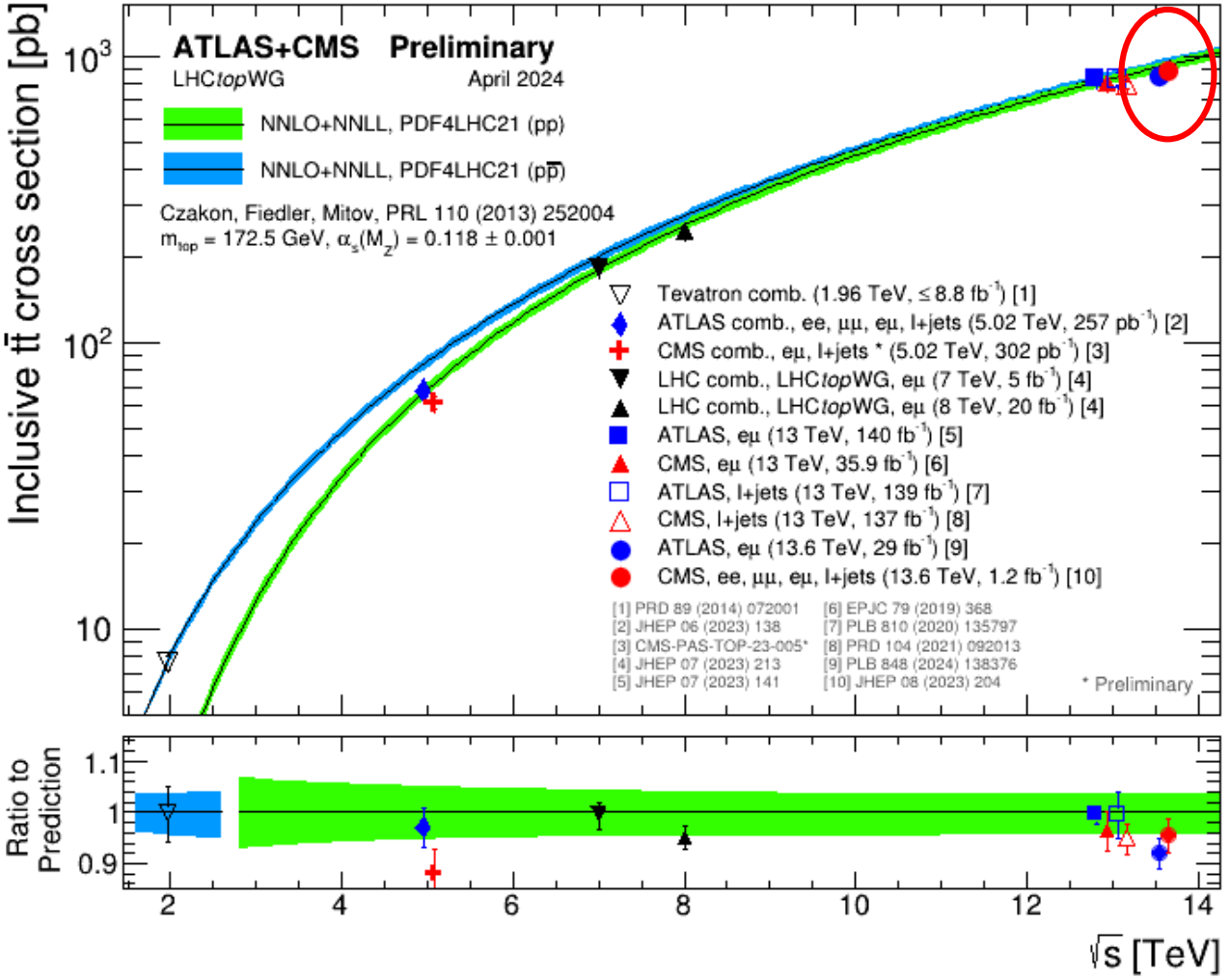




of particles/jets

Frédéric Derue, LPNHE Paris
Benjamin Fuks, LPTHE Paris

Top quarks arrived fast at the new energy frontier



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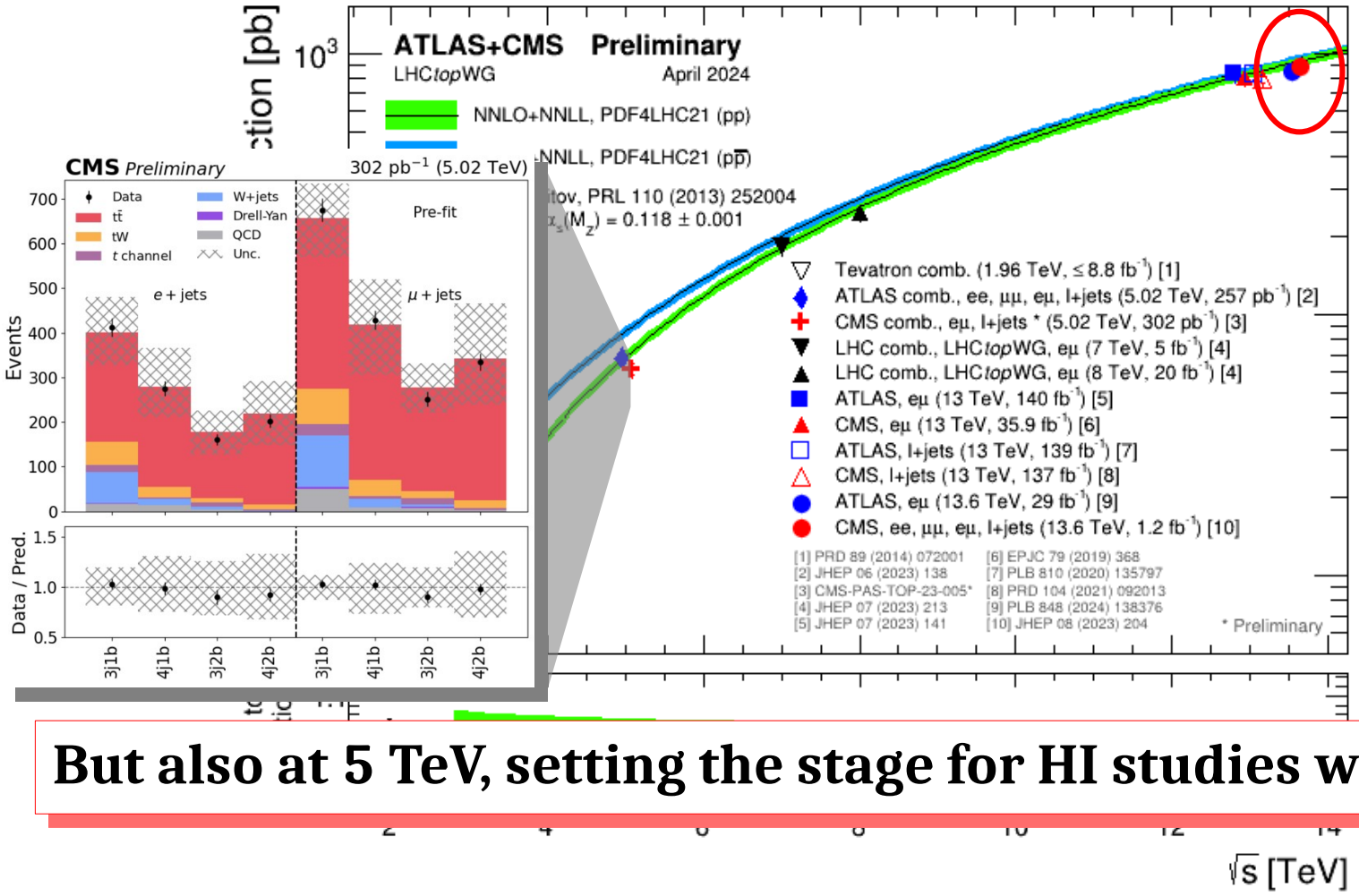
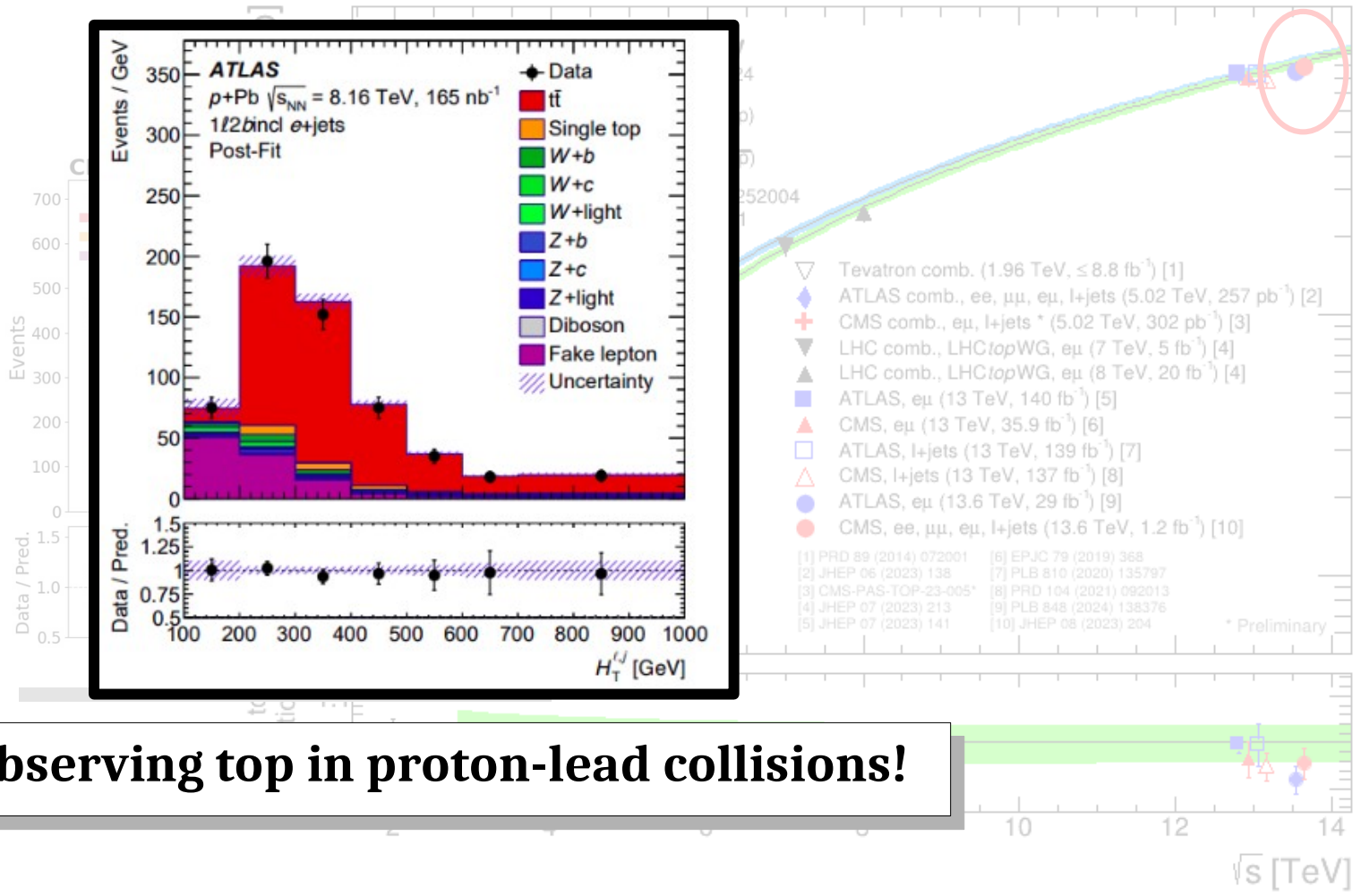


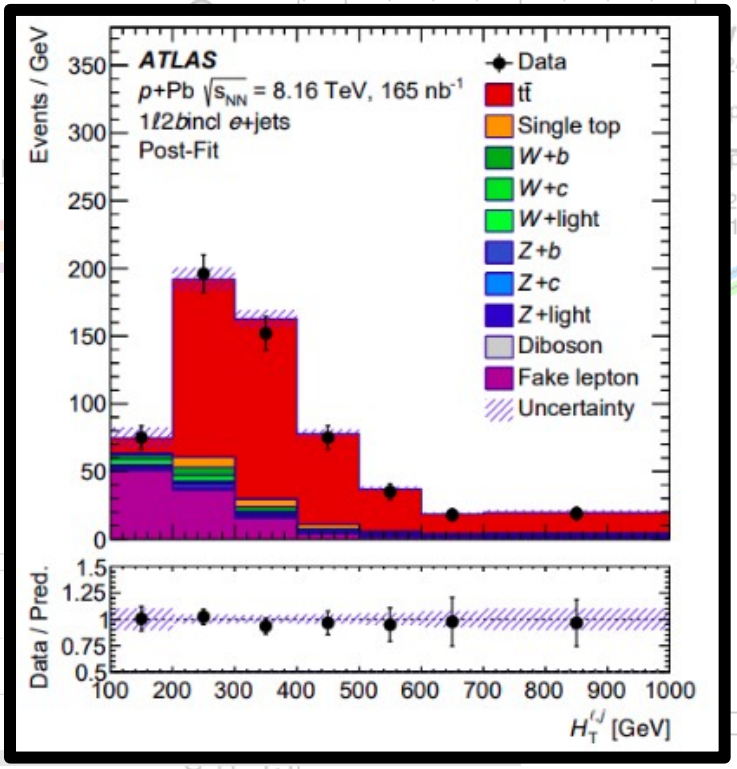
But also at 5 TeV, setting the stage for HI studies with top

Top quarks arrived fast at the new energy frontier

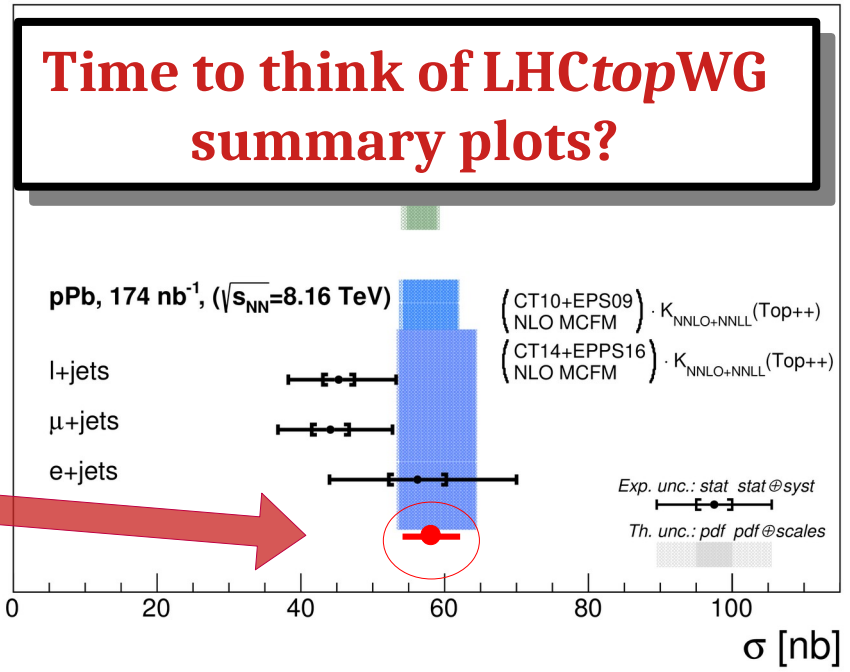


Observing top in proton-lead collisions!

Top quarks arrived fast at the new energy frontier



Time to think of LHC*top*WG summary plots?



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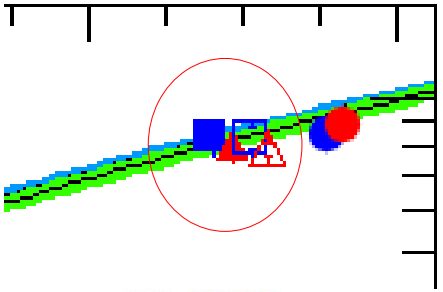
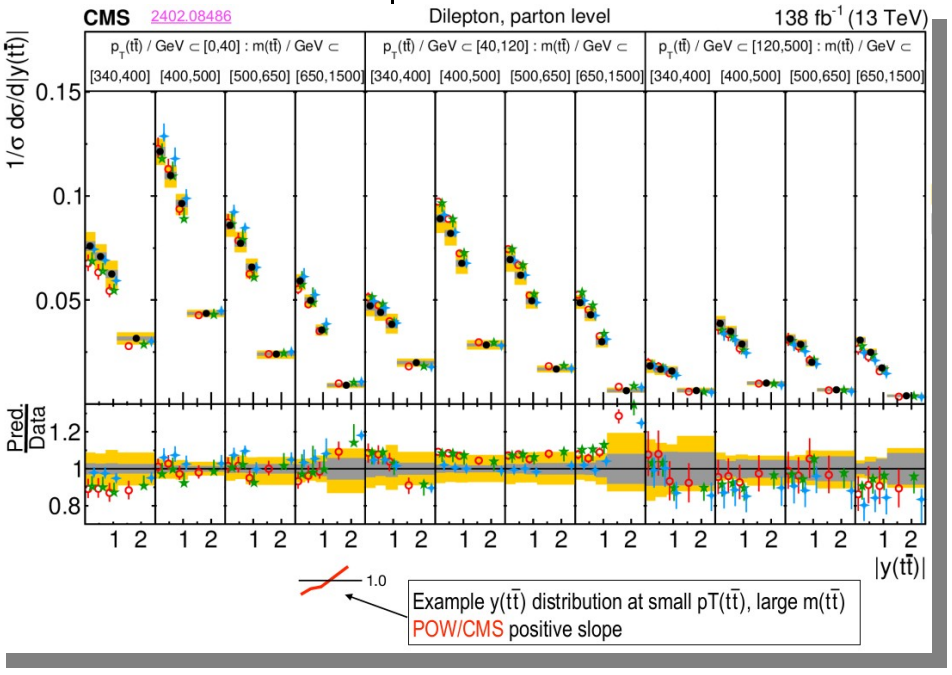


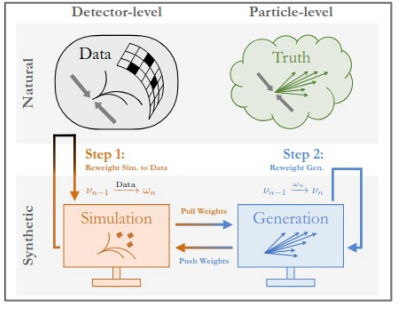
Providing deep tomography



Example: the old top p_T

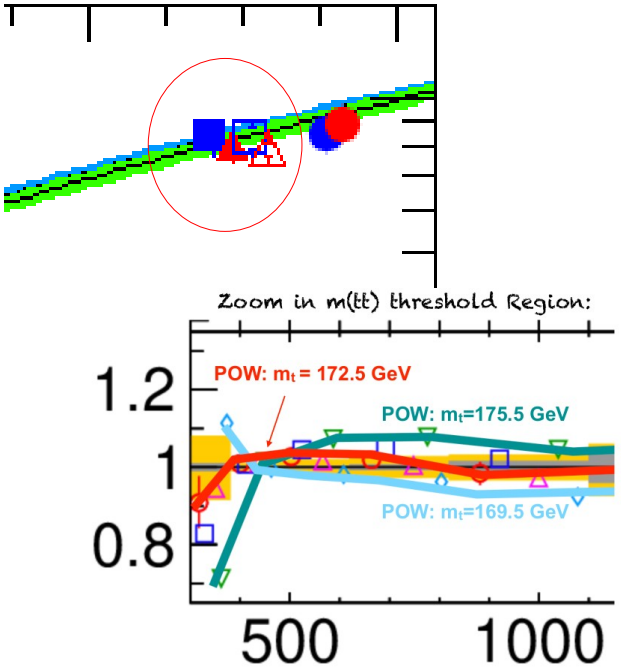
- Setteled to be mostly from missing higher order calc.
- Localizing with more granular measurements

Even deeper

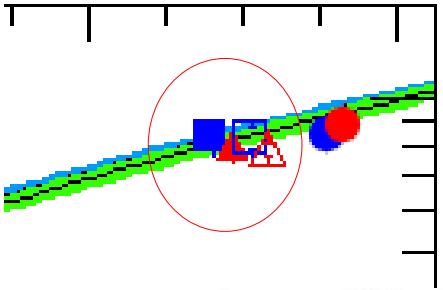


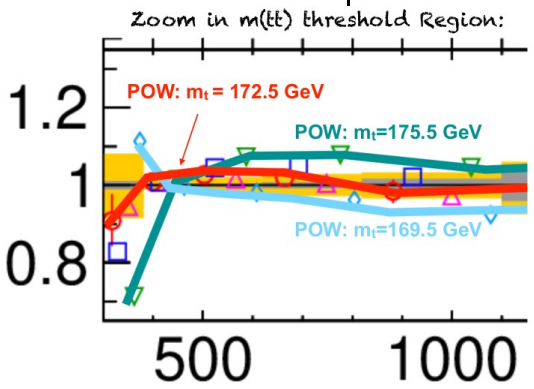
OmniFold

$d^m\sigma_{tt}/dx^m$



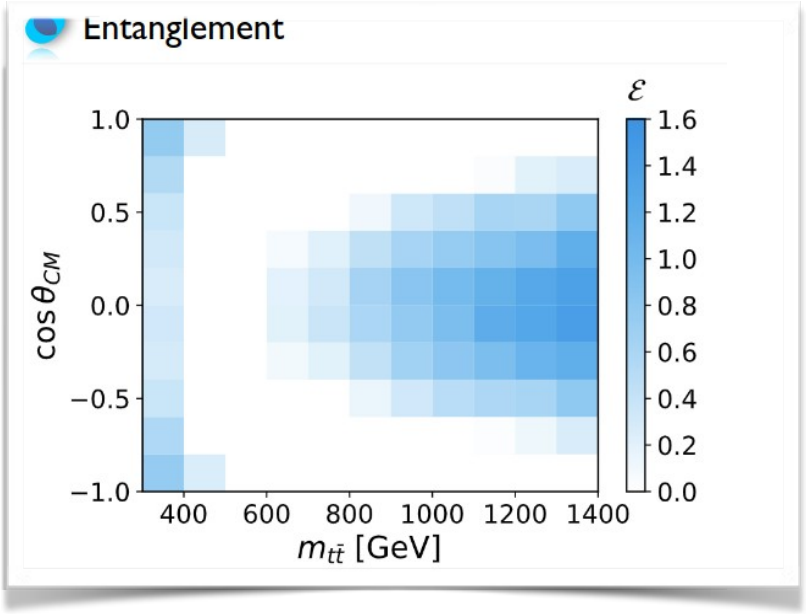
- Sensitivity to top mass O(1 GeV)
- Pathway to precise tt threshold scans in future





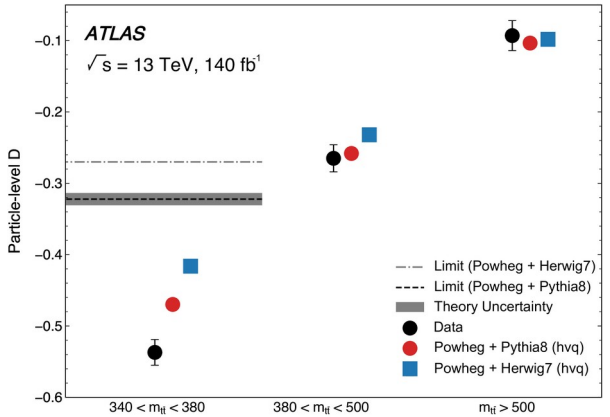
Great potential to various other cool physics analyses

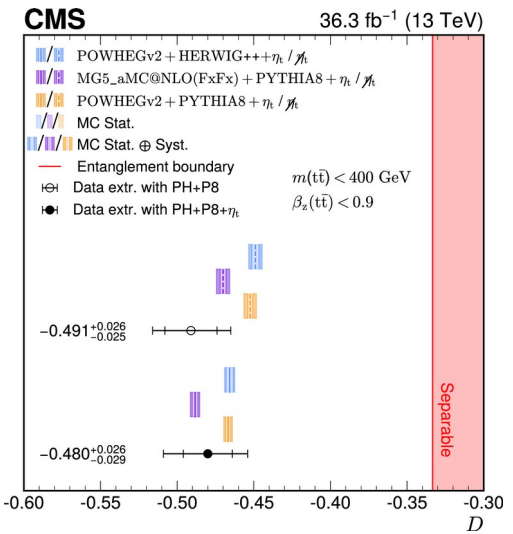
- Sensitivity to top mass O(1 GeV)
- Pathway to precise tt threshold scans in future

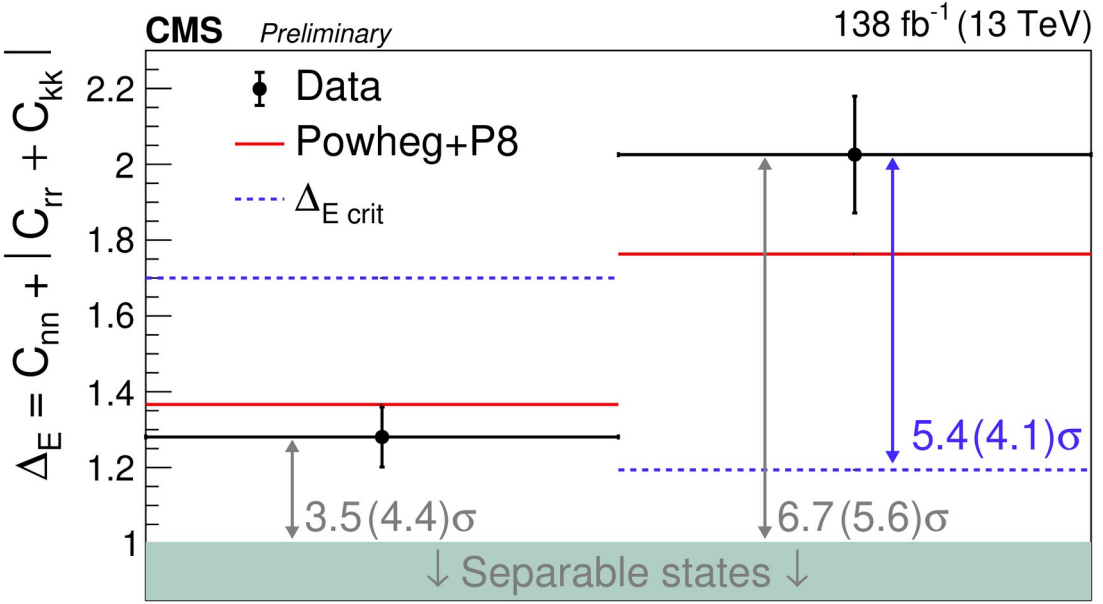


Step into quantum's shoes!

LHC Experiments observe quantum entanglement

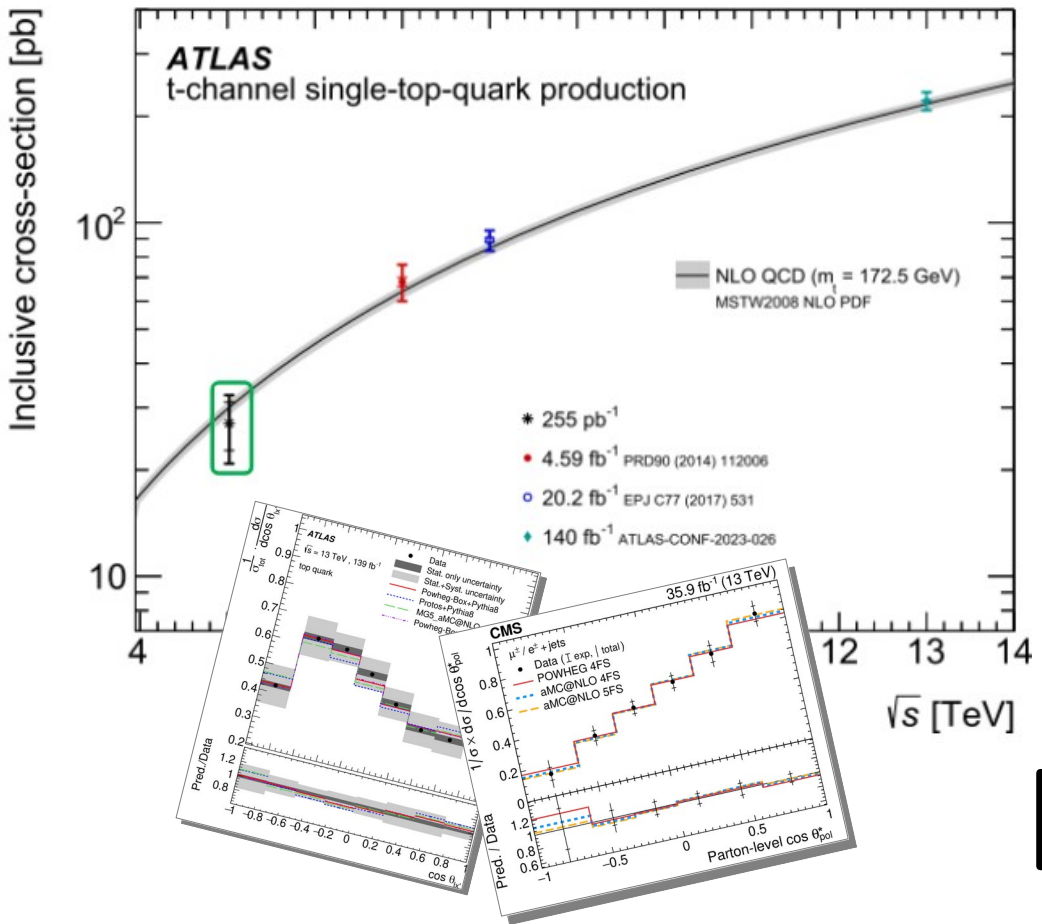






Reviving interest in spin correlation measurements!

What can single top add to the game?



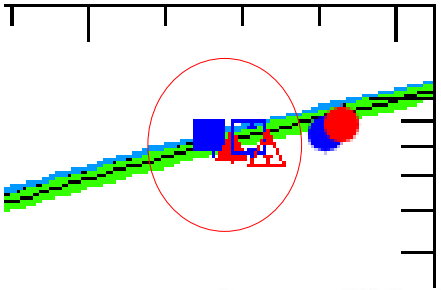
t-channel for bi (tri) partite entanglement

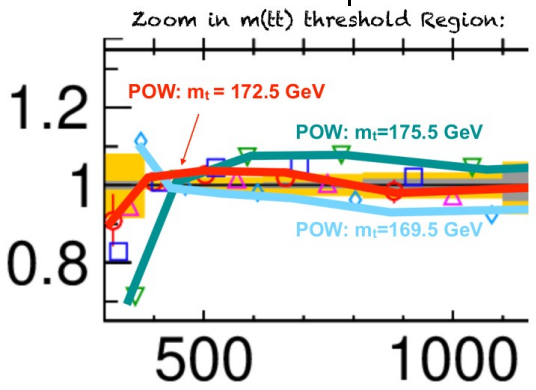
Remarks

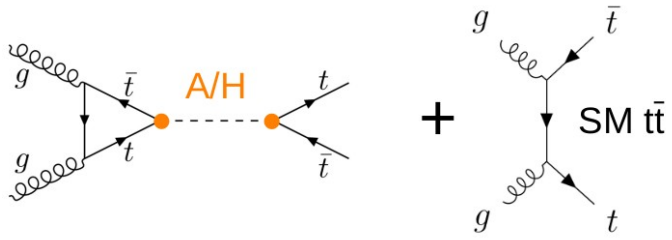
- ☑ Possible to measure right now entanglement between OAM and spin
- ☑ Possible to measure right now tripartite entanglement
- ☑ Doing the same as previously done, using available data

J.A.A.Saavedra

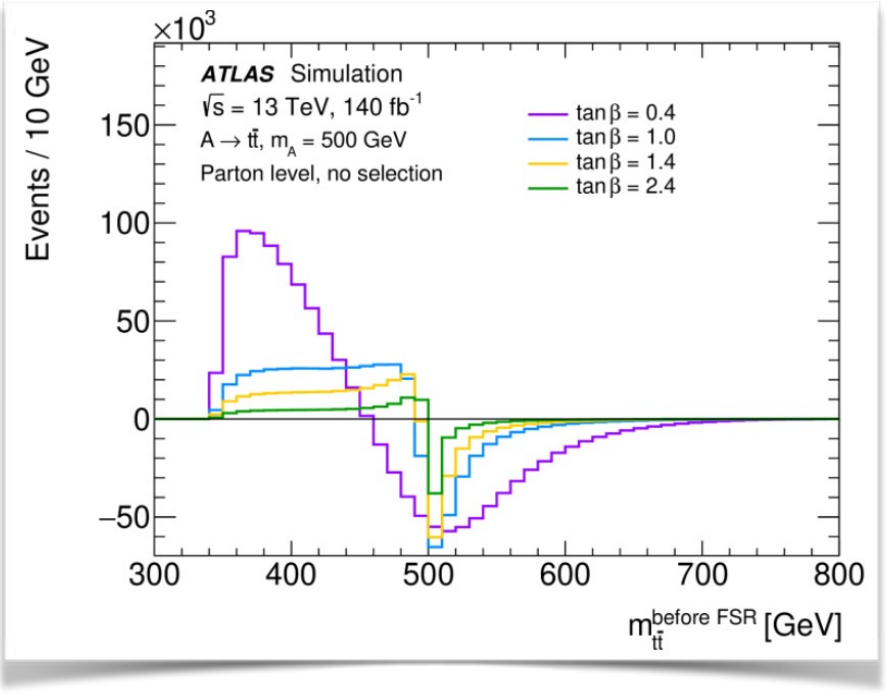
Call for new t-channel measurements ...





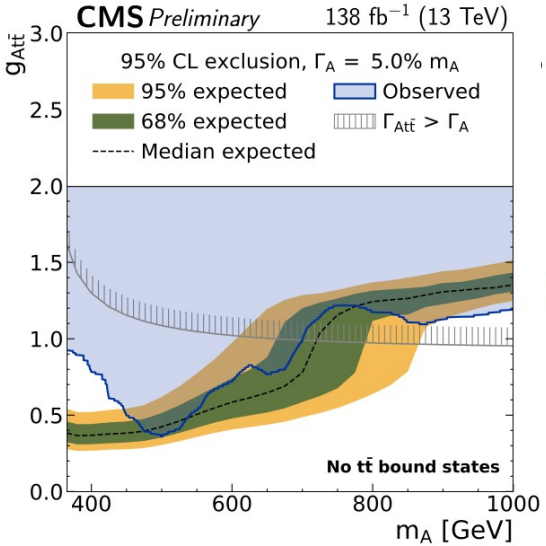


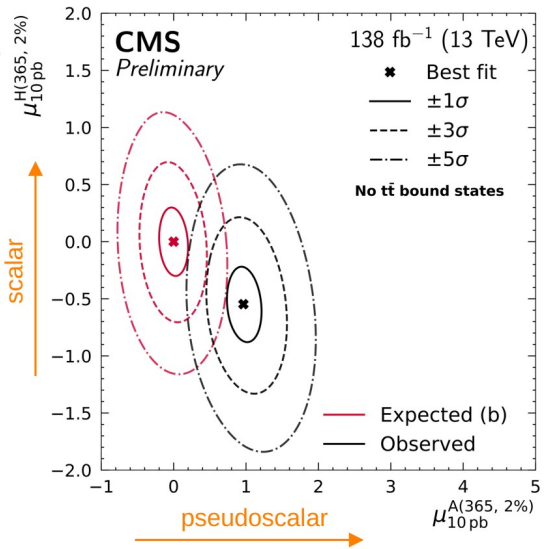
Great potential to various other cool physics analyses



The peak-dip structure in the mtt distribution indicates signs of new Higgs bosons

And we faced something unexpected near the threshold

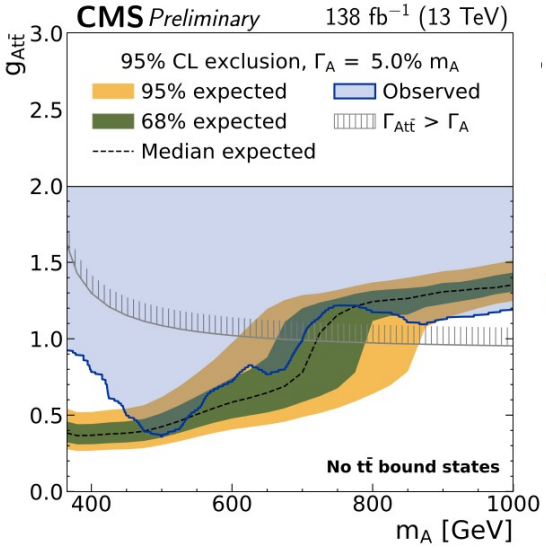


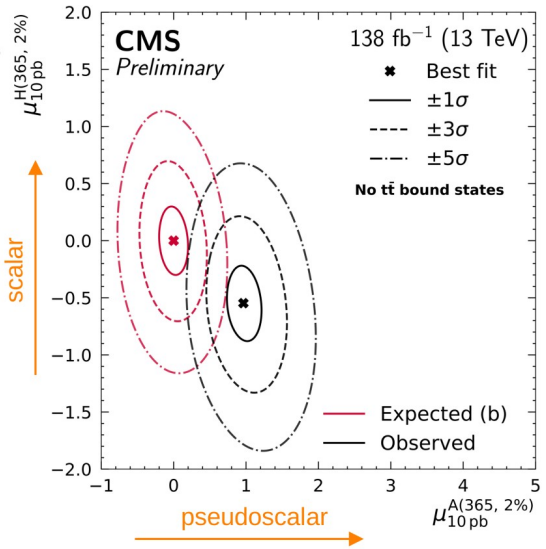


An excess with a significant above five sigma

- Favoring pseudoscalar over scalar
- “cross section” compatible with (inaccurate) predictions for toponium

And we faced something unexpected near the threshold





An excess with a significant above five sigma

- Favoring pseudoscalar over scalar
- “cross section” compatible with (inaccurate) predictions for toponium

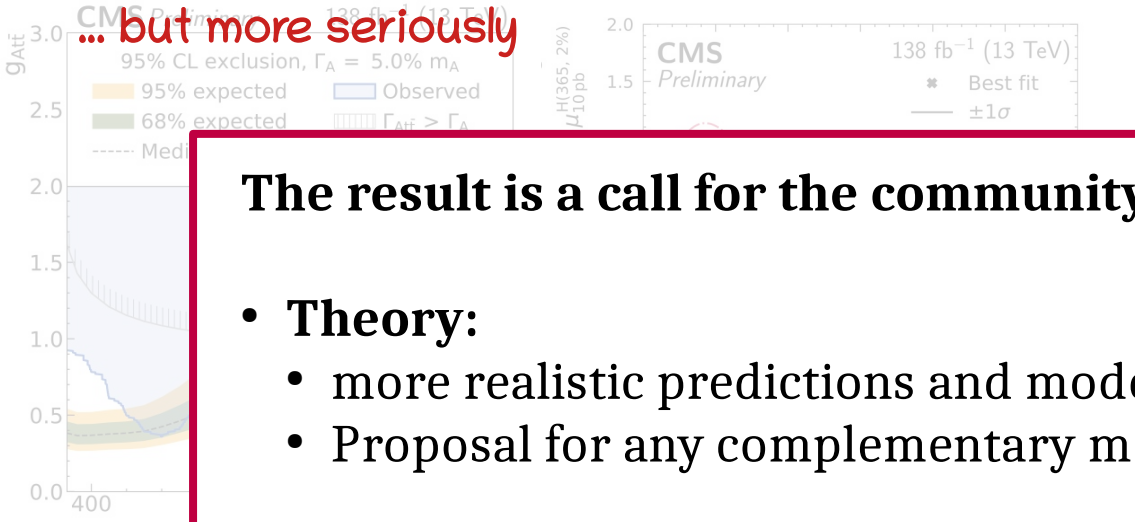
Have you discovered topnium?

CMS: we haven’t said that!

ATLAS: but you made a discovery!
With best regards to your PC

And we faced something unexpected near the threshold

… but more seriously



The result is a call for the community:

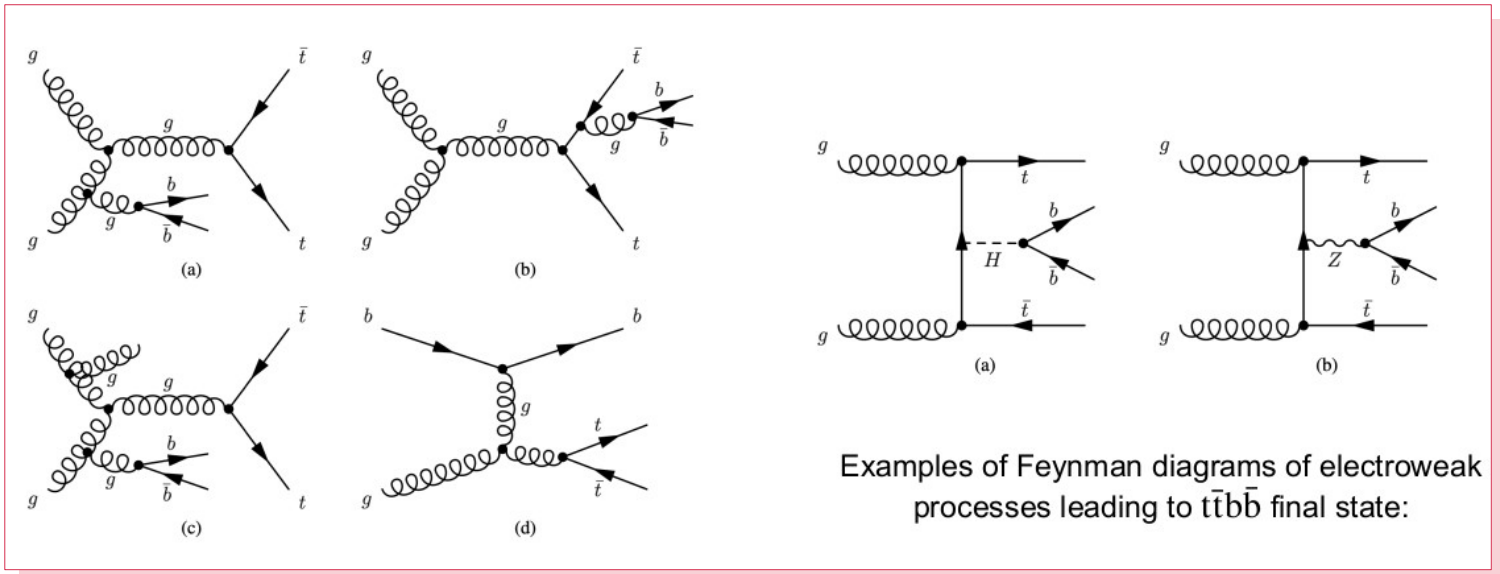
- **Theory:**
  - more realistic predictions and models at the threshold
  - Proposal for any complementary measurement?
- **Expriment:**
  - Information exchange and discussion
  - Does a similar analysis from ATLAS confirm the excess?

&

F·R·I·E·N·D·S

Associated production of top quark and heavy flavors (b/c)

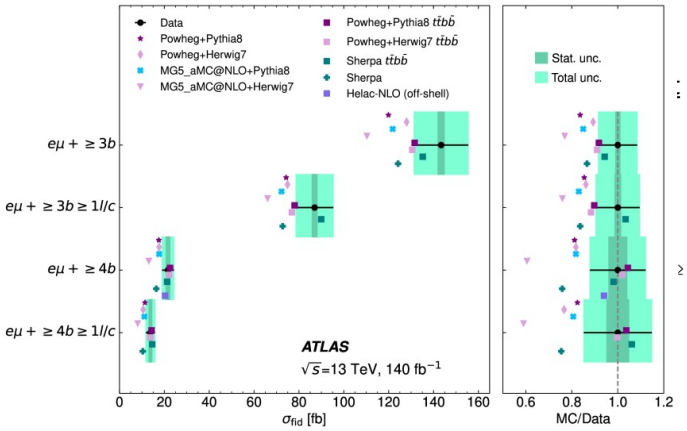
- Key information to understand QCD
- Background to other important processes, ttZ, ttH, BSM …

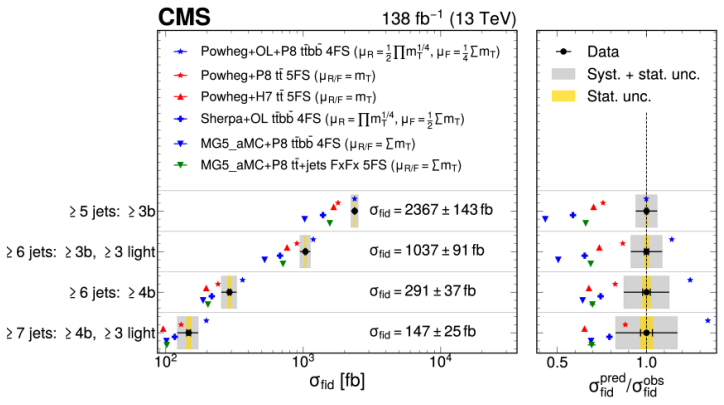


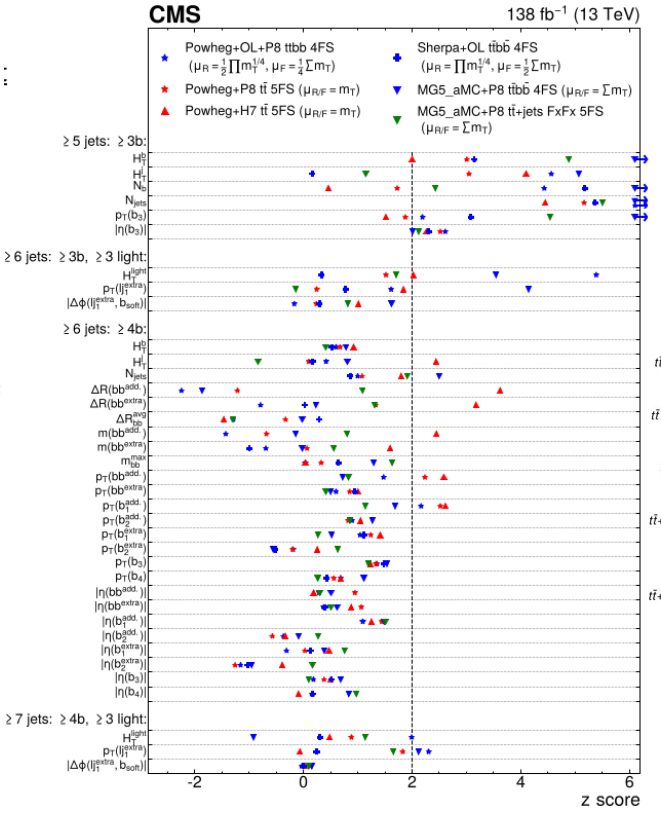
Crucial to study in Top physics groups:

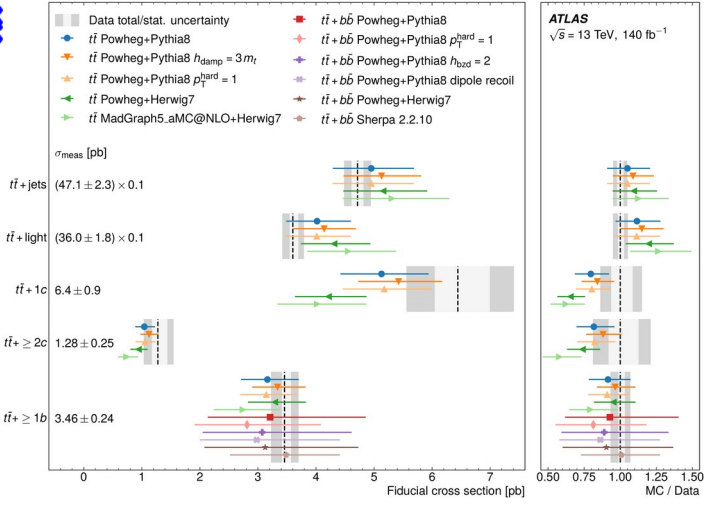
not get biased towards specific observables/phase spaces

Associated production of top quark and heavy flavors (b/c)









ttbb inclusive

ttbb differential

Similarly from ATLAS

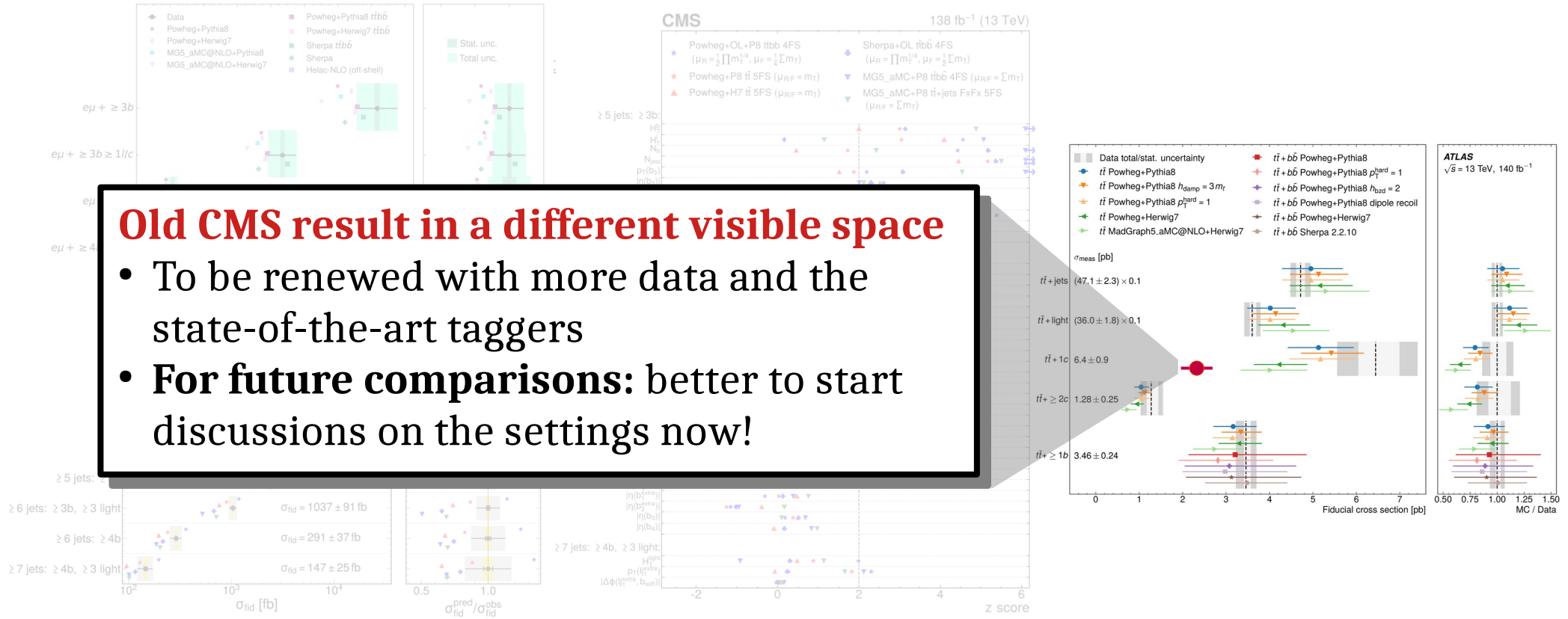
ttcc inclusive

CMS result is old

Associated production of top quark and heavy flavors (b/c)

Old CMS result in a different visible space

- To be renewed with more data and the state-of-the-art taggers
- **For future comparisons:** better to start discussions on the settings now!



ttbb inclusive

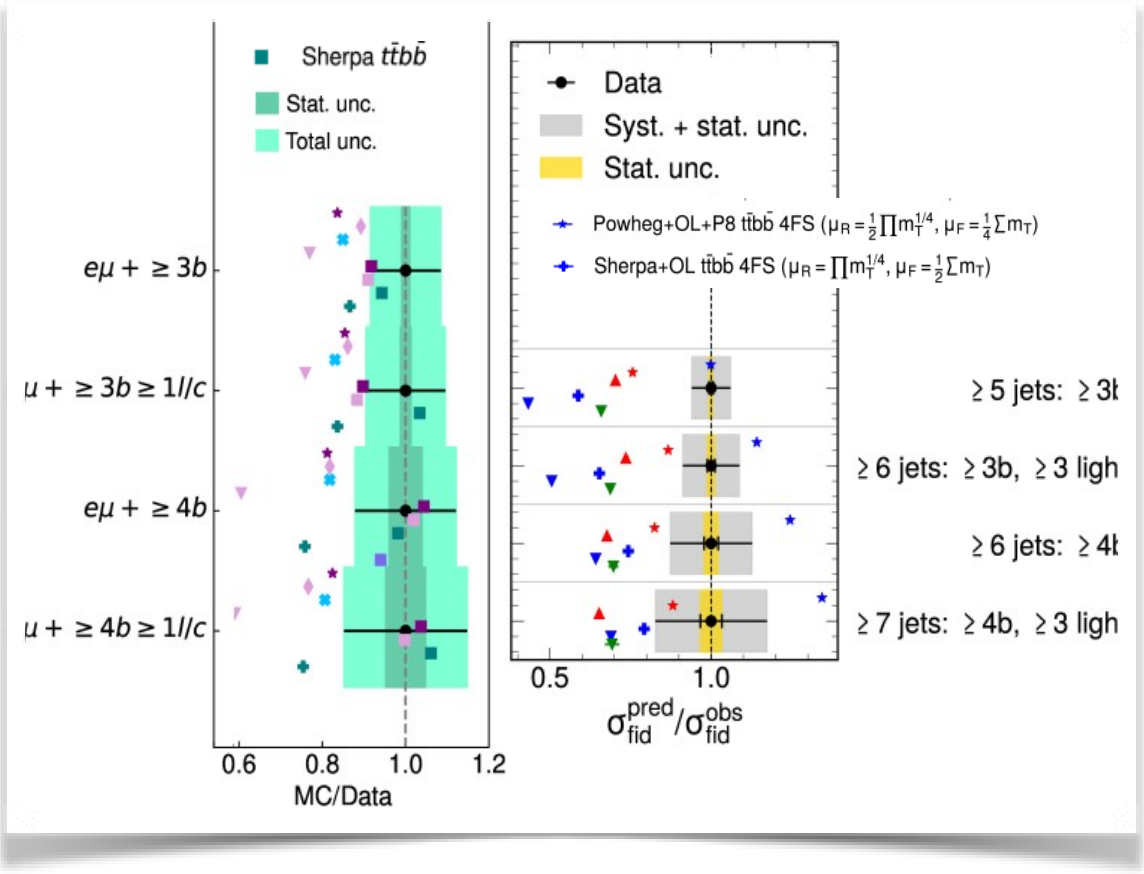
ttbb differential

Similarly from ATLAS

ttcc inclusive

CMS result is old

ATLAS-CMS comparison of ttbb measurements

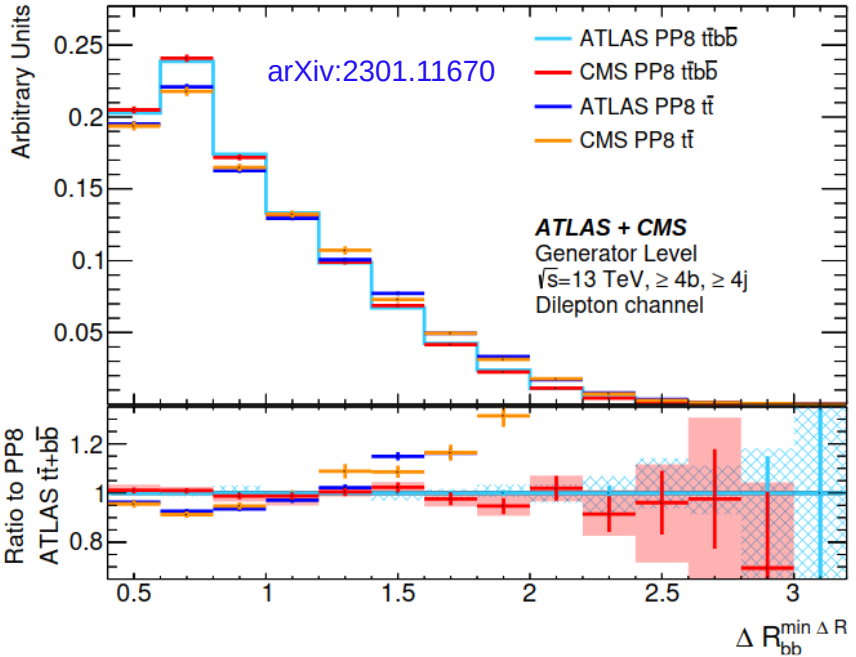


Observations

- Not exactly the same fiducial phase space
- Significant impact of scale choice
- Sherpa seems to work for ATLAS but not for CMS

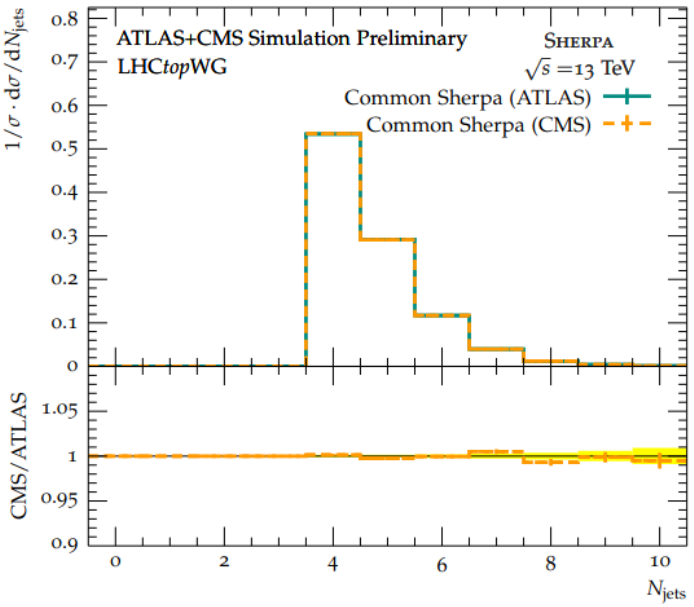
ATLAS-CMS comparison of ttbb measurements

Comparisons within the LHC Higgs WG



- No Sherpa comparison exists
- Different MC settings

Common MC samples LHC top WG



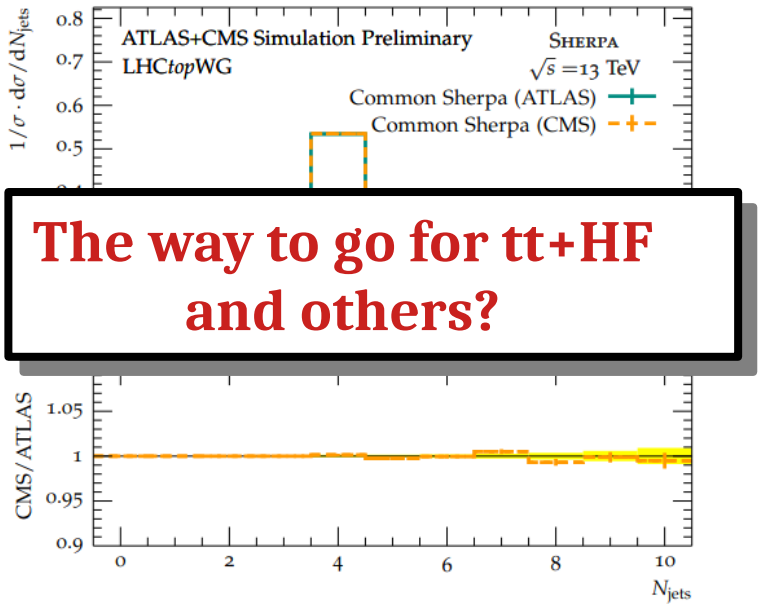
- Sherpa comparison
- Same MC settings, new observables and binnings possible

ATLAS-CMS comparison of ttbb measurements

Comparisons within the LHC Higgs WG

- No Sherpa comparison exists
- Different MC settings

Common MC samples LHC top WG

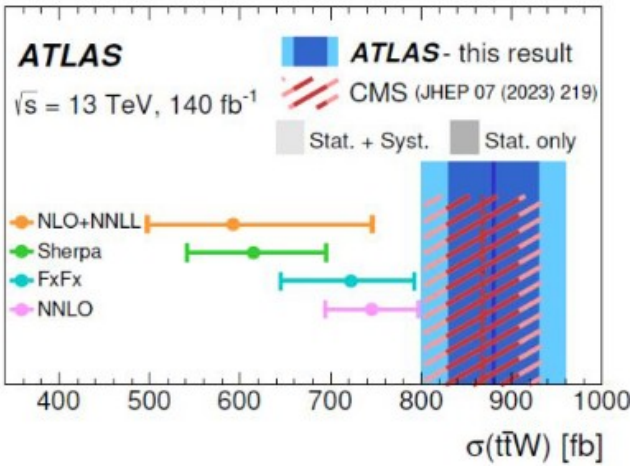


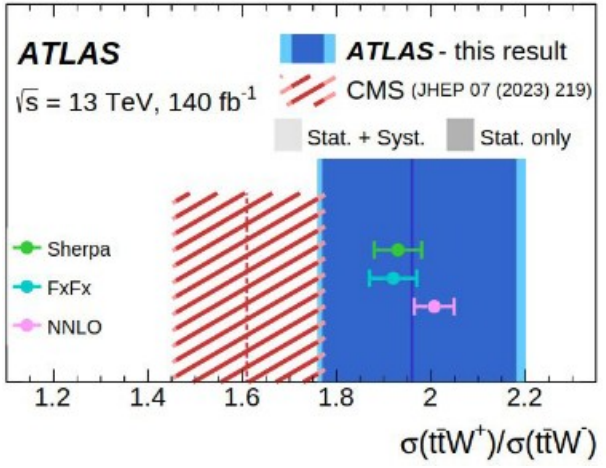
The way to go for tt+HF and others?

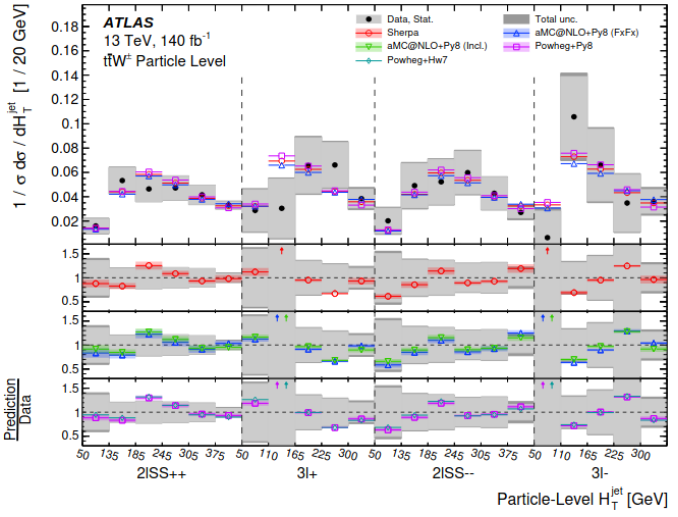
- Sherpa comparison
- Same MC settings, new observables and binnings possible

Associated production of top quarks and W boson

ttW





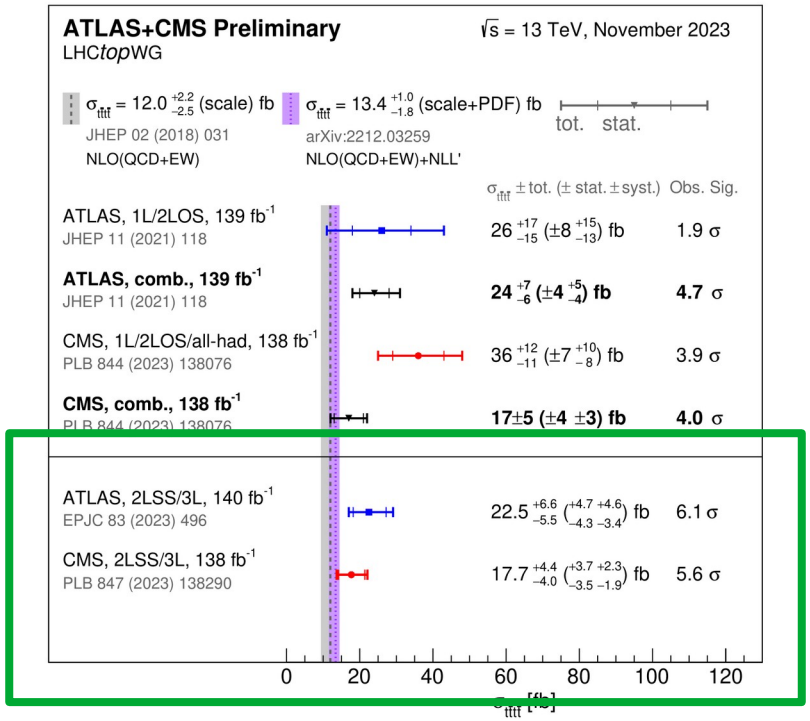


- Leading uncertainty in ttH and tttt measurements
- Underpredicted by theory
- Disagreement between the experiments for the asymmetry
- Not well model differentially (more data needed)

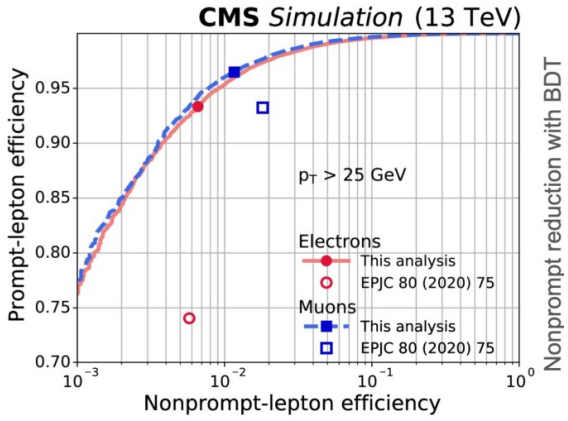
LHC-wide effort within the Top group!

The heaviest final state now observed in both experiment

tttt



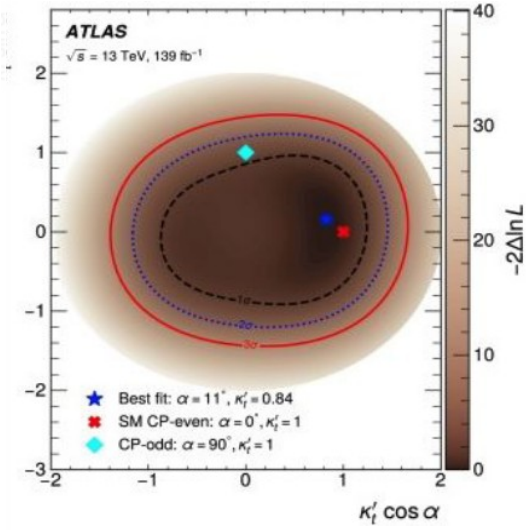
- Many channels analyzed
- Above 5σ sensitivity in SS/multilep
- Power of ML everywhere in the analyses

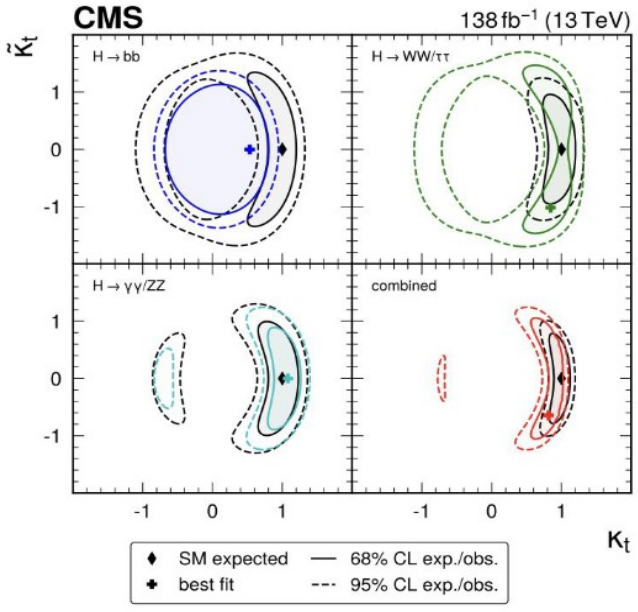


Already time to combine between ATLAS and CMS?

top+H

Direct access to top Yukawa in ttH and tH production



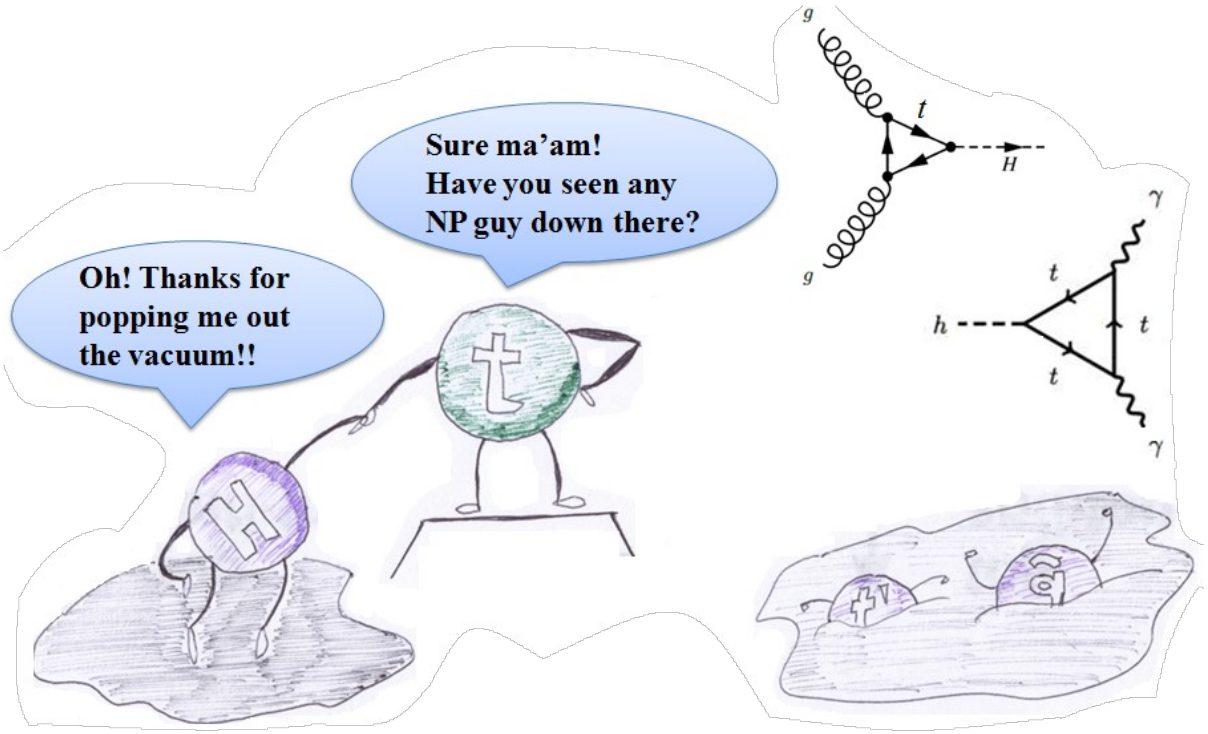


- ttH observed, upper limits on tH
- CP-odd Higgs: no evidence!
  - All Higgs decay modes contribute to the sensitivity

Challenging mode (H→ bb, H→ multilep) benefit from Run3

In addition to new techniques and understanding backgrounds

Top quark's vital role in the Higgs discovery



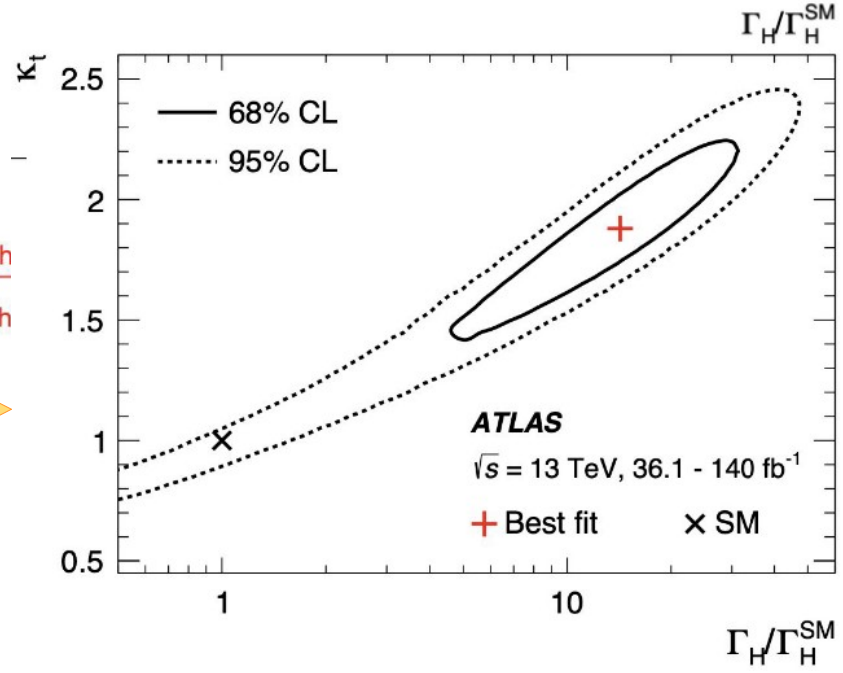
Courtesy to Fabio Maltoni

… and now in the Higgs identification

… more with four-tops

Target processes	
Off-shell measurement	
$pp \to t\bar{t}t\bar{t}$	
On-shell measurement	
Production	Decay
ggF, VBF, WH, ZH, $t\bar{t}H$, tH	$H \to \gamma\gamma$
$t\bar{t}H + tH$	$H \to b\bar{b}$
WH, ZH	$H \to b\bar{b}$
VBF	$H \to b\bar{b}$
ggF, VBF, $WH + ZH$, $t\bar{t}H + tH$	$H \to ZZ$
ggF, VBF	$H \to WW$
WH, ZH	$H \to WW$
ggF, VBF, $WH + ZH$, $t\bar{t}H + tH$	$H \to \tau\tau$
ggF+ $t\bar{t}H + tH$, VBF+ $WH + ZH$	$H \to \mu\mu$
Inclusive	$H \to Z\gamma$

$$R_\Gamma = \frac{\Gamma_H}{\Gamma_{H,SM}} = \frac{\mu_{\text{off-sh}}}{\mu_{\text{on-sh}}}$$

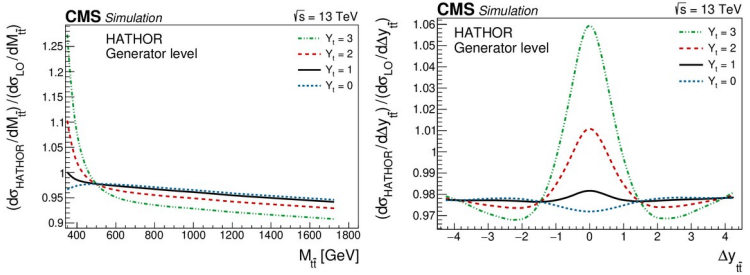


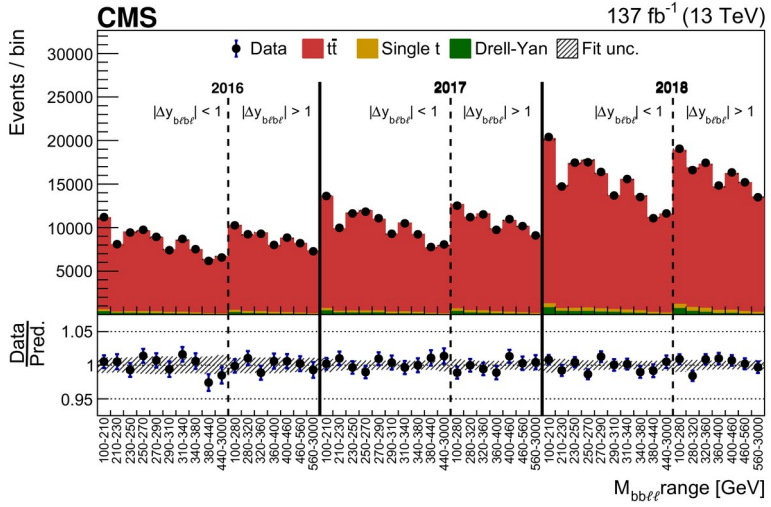
The Higgs boson width: Now considering virtual Higgs bosons in four tops

… more with four-tops

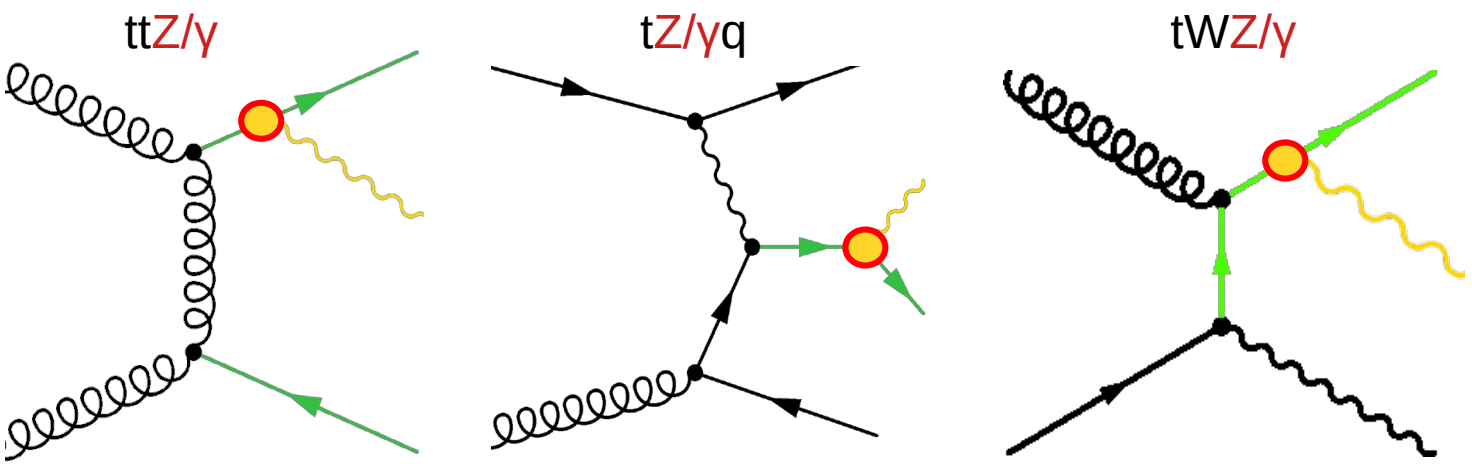
Can contribute even more?

Differential tt measurements



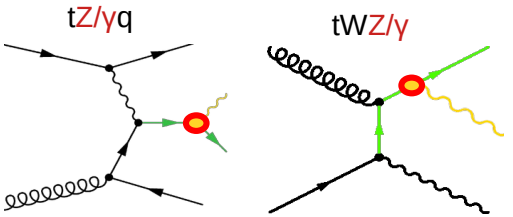


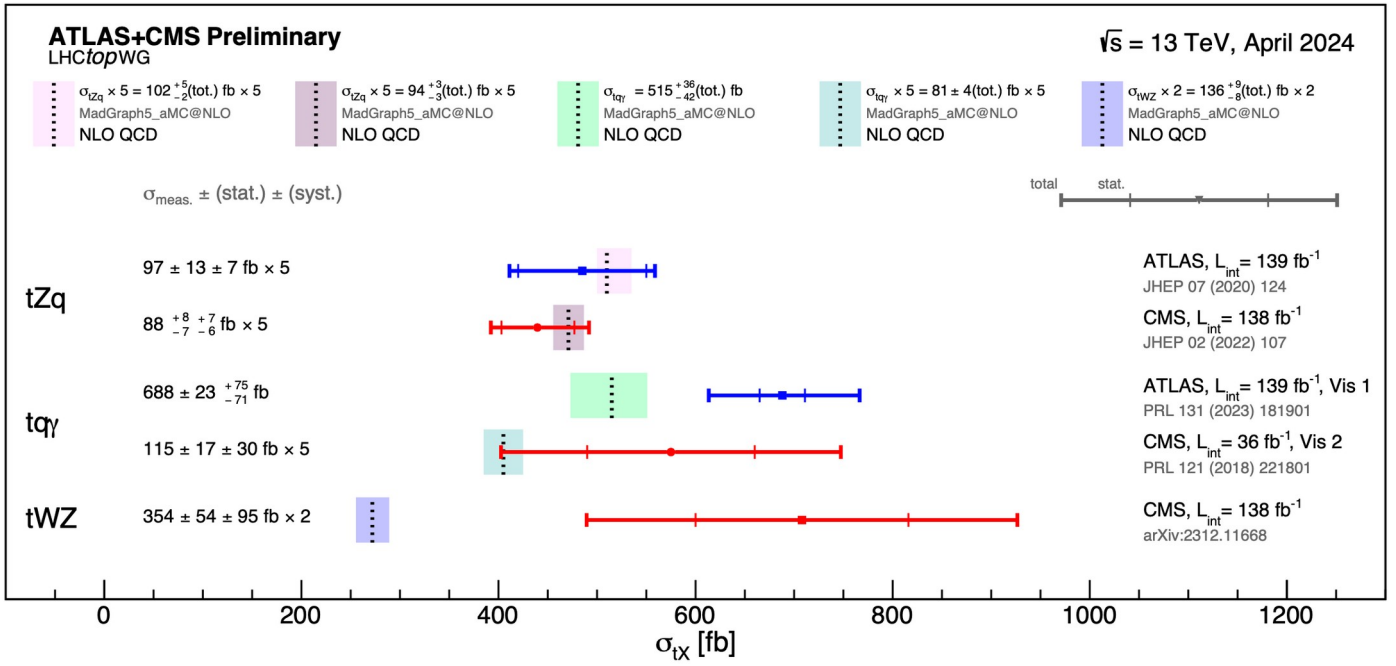
The Higgs boson width: Now considering virtual Higgs bosons in four tops



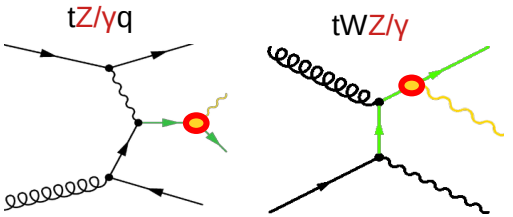
Sensitive to new top EWK interactions at tree level

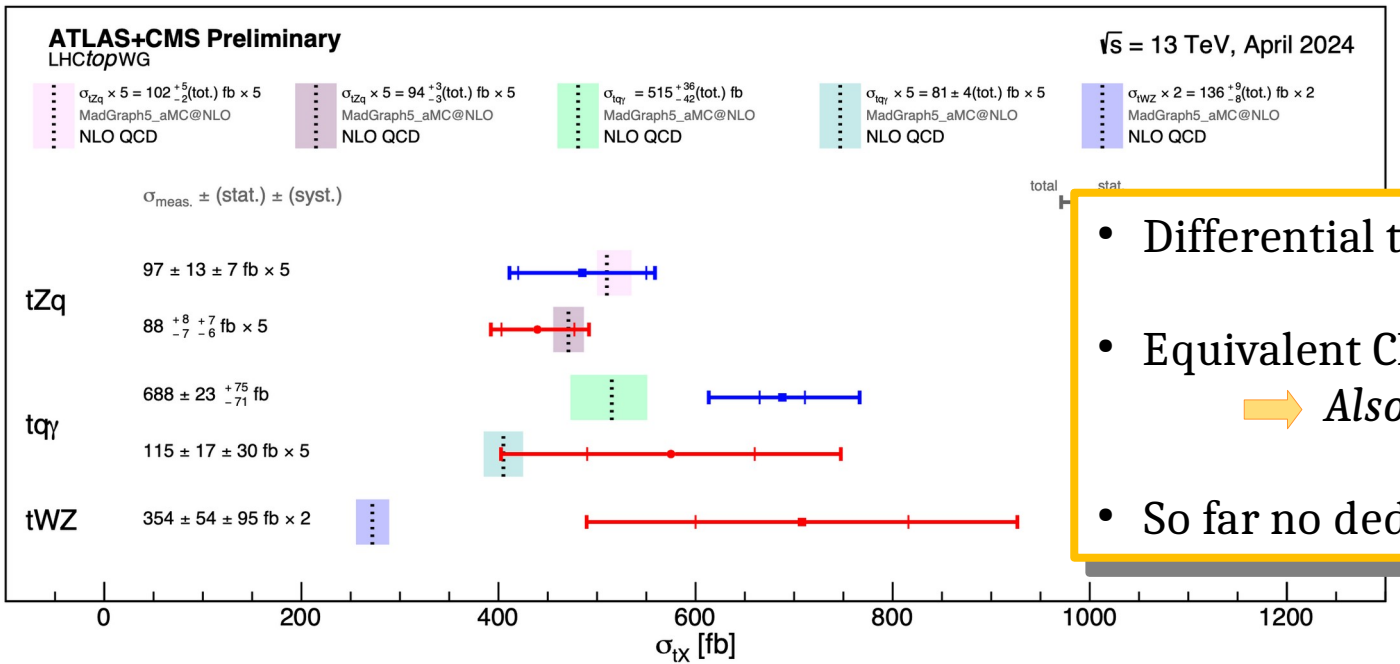
The associated single top production





The associated single top production

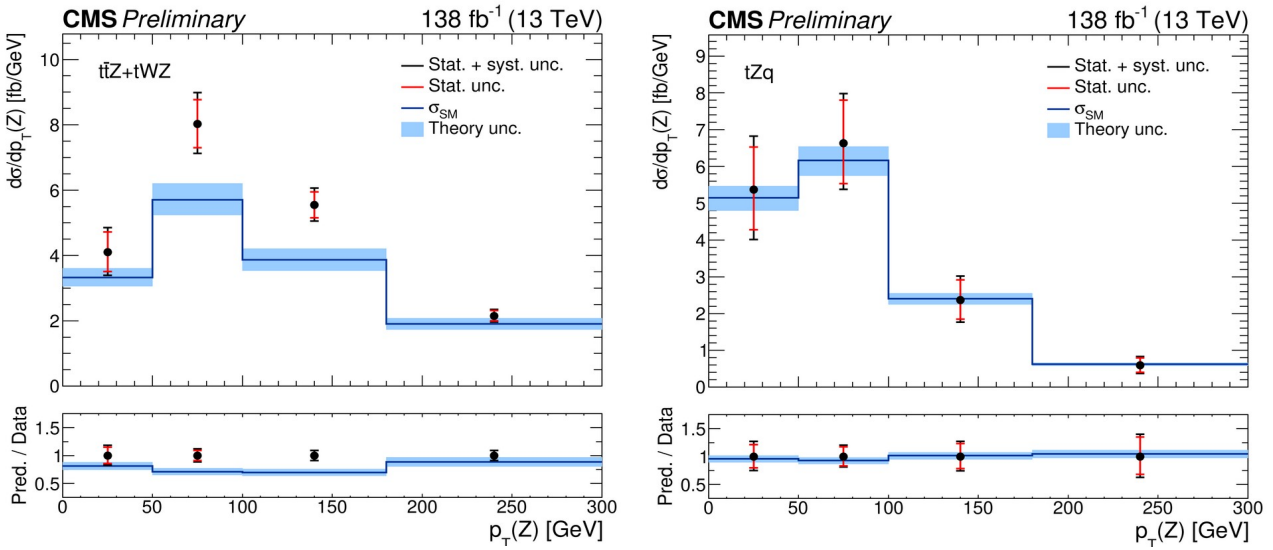




- Differential tZq results available
- Equivalent CMS tγq result expected
  - ➡ *Also to be measured differentialy*
- So far no dedicated tWγ measurement …

Simultaneous differential measurement of ttZ/tZq

Slightly less precise than dedicated measurements but …

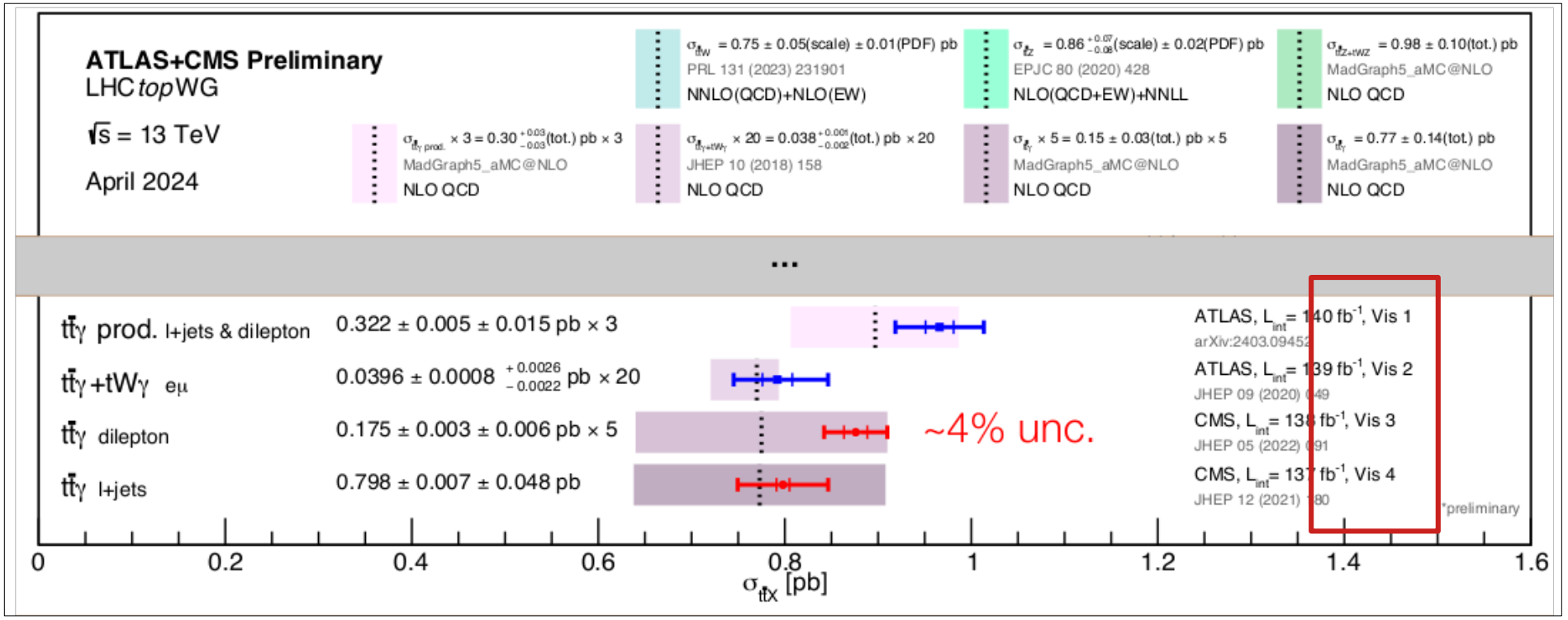


More suitable for EFT interpretation

- Consistent treatment of both process
- ttZ/tZq overlap in data and/or the systematic correlations

The photon-associated tt production

Detailed studies of photon origin: in top quark production or decays?

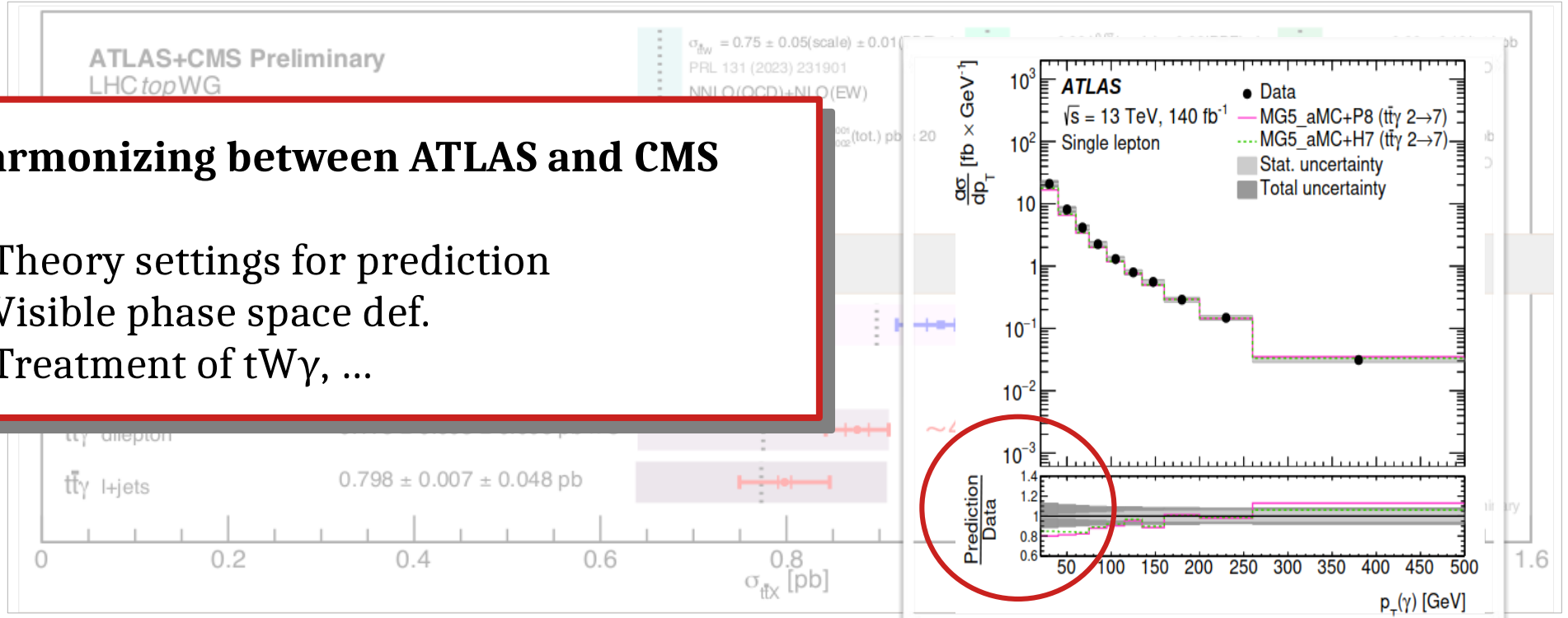


The photon-associated tt production

Detailed studies of photon origin: in top quark production or decays?

Harmonizing between ATLAS and CMS

- Theory settings for prediction
- Visible phase space def.
- Treatment of tWγ, …



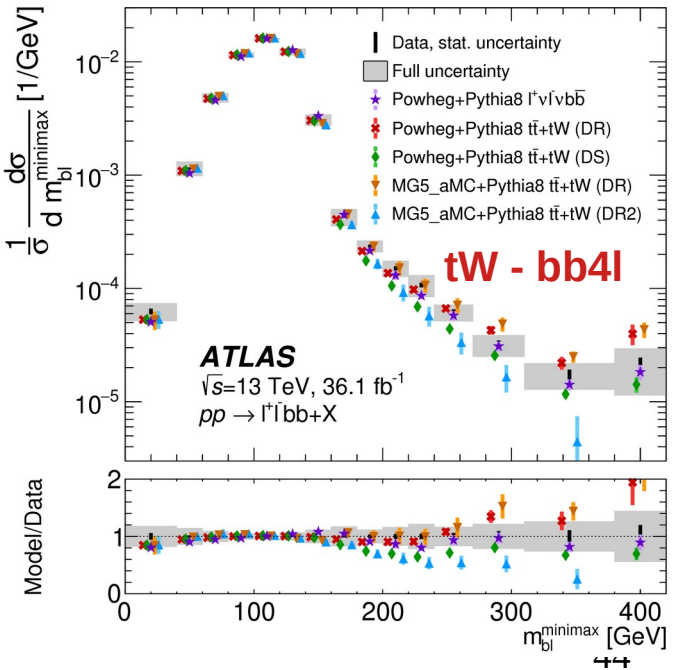
The continued topic of single-resonant processes

tW/tt

- Inteference/overlap of tW+V with tt+V beyond born level
- A long-lasting topic, major steps taken both from theory and experiment
- The available theory advancement are majorly used by experiments

- Off-shell effects needed to match the experimental precision
- For $t\bar{t} + tW$ production they are available at NLOPS in POWHEG BOX RES
- New developments (bb4l-dl and bb4l-sl):

What if a boson is added?

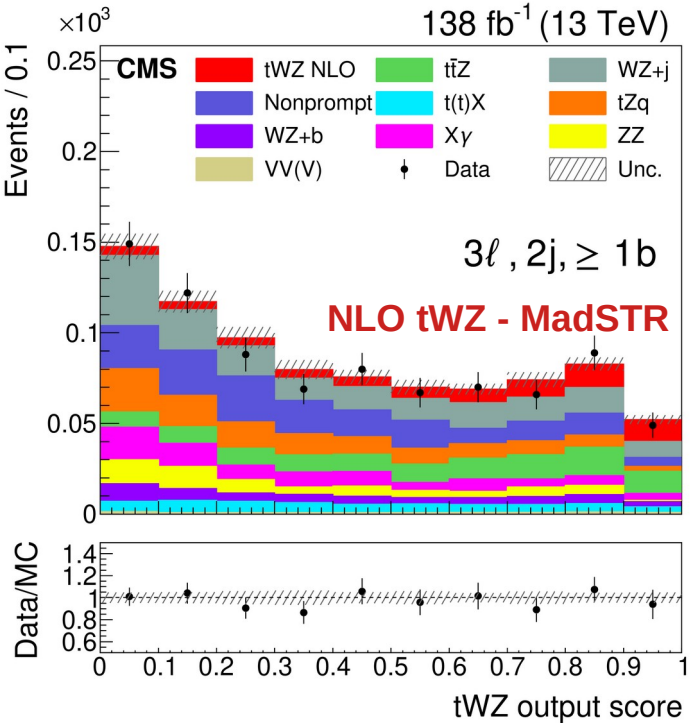


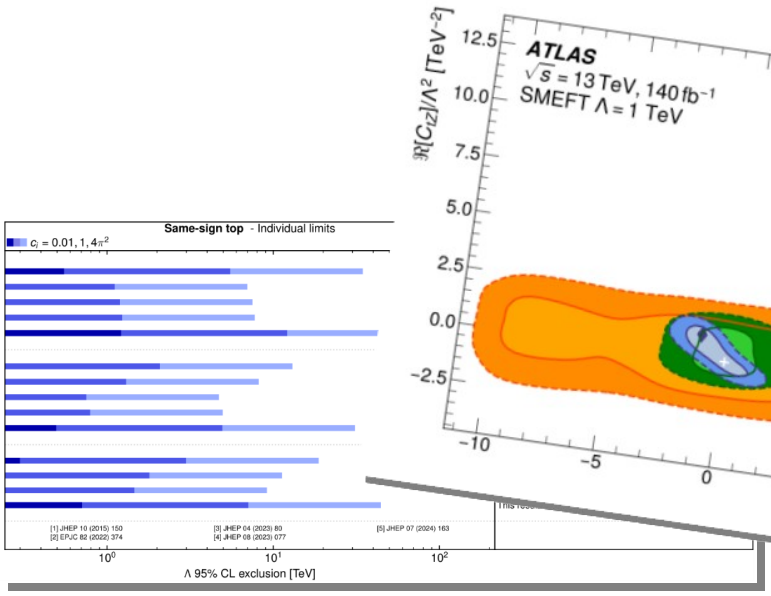
The continued topic of single-resonant processes

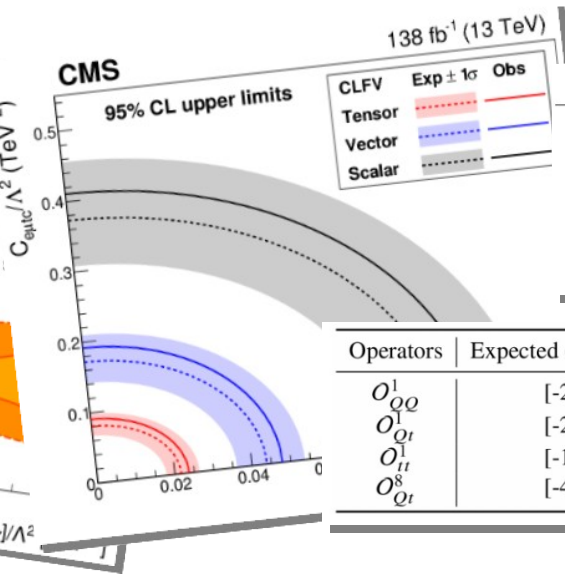
tWV/ttV

- Inteference/overlap of tW+V with tt+V beyond born level
- A long-lasting topic, major steps taken both from theory and experiment
- The available theory advancement are majorly used by experiments

- **Run3 data** brings possible sensitivity in tails
- **bb4l+V simulation** for detailed studies
- Particularly interesting for a proper **ttγ/tWγ** analysis given the unknowns that may do with the **photon origin**







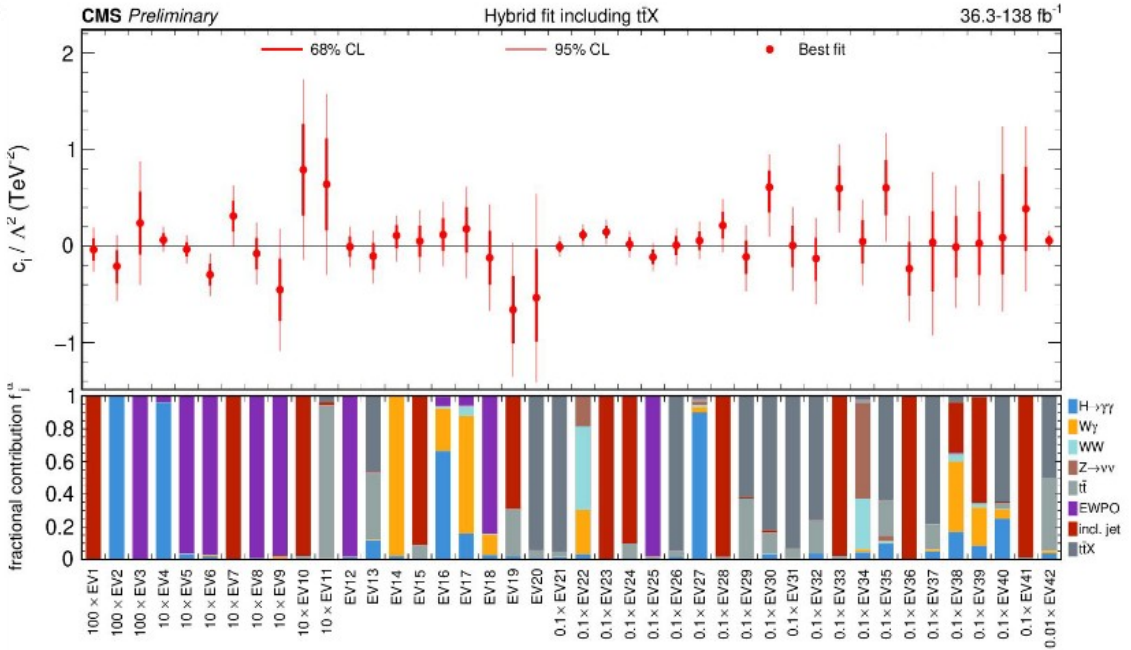
Operator	Expected C_k/Λ^2 (TeV^{-2})	Observed (TeV^{-2})
$\mathcal{O}^1_{tt}$	$[-2.0, 1.9]$	$[-2.2, 2.1]$
$\mathcal{O}^1_{QQ}$	$[-2.0, 1.9]$	$[-2.2, 2.0]$
$\mathcal{O}^1_{Qt}$	$[-3.4, 3.3]$	$[-3.7, 3.5]$
$\mathcal{O}^8_{Qt}$	$[-7.4, 6.3]$	$[-8.0, 6.8]$

Operators	Expected C_i/Λ^2 [TeV^{-2}]	Observed C_i/Λ^2 [TeV^{-2}]
O^1_{QQ}	[-2.5, 3.2]	[-4.0, 4.5]
O^1_{Qt}	[-2.6, 2.1]	[-3.8, 3.4]
O^1_{tt}	[-1.2, 1.4]	[-1.9, 2.1]
O^8_{Qt}	[-4.3, 5.1]	[-6.9, 7.6]

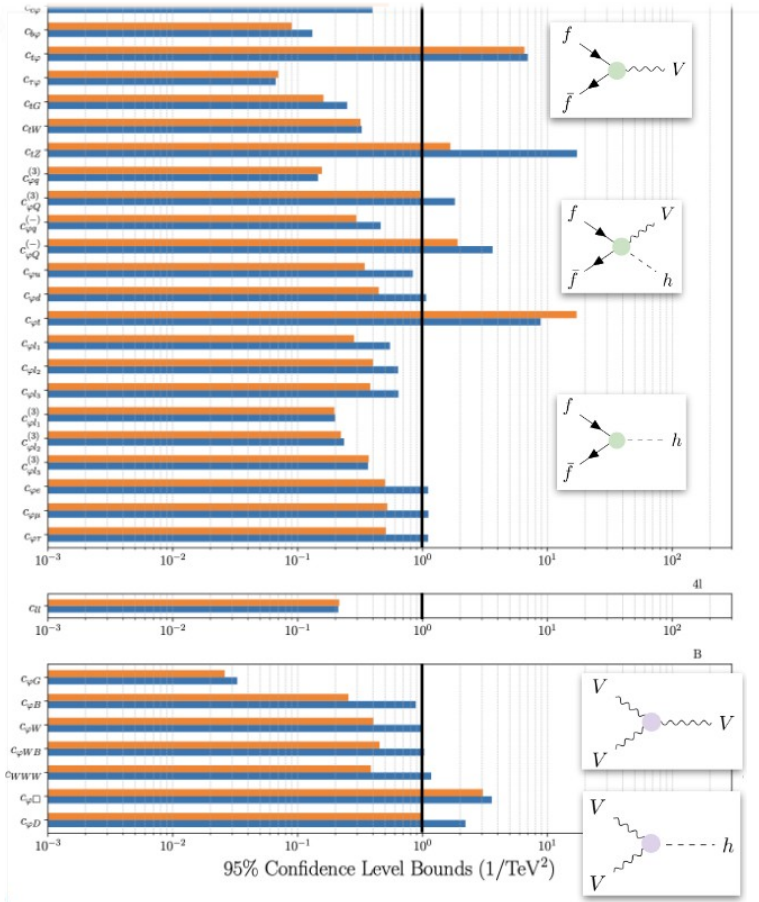
EFT interpretation: an adendum of the majority of analyses nowadays, if not **direct searches**

Global EFT fits

Huge effort on both theory and experiment side



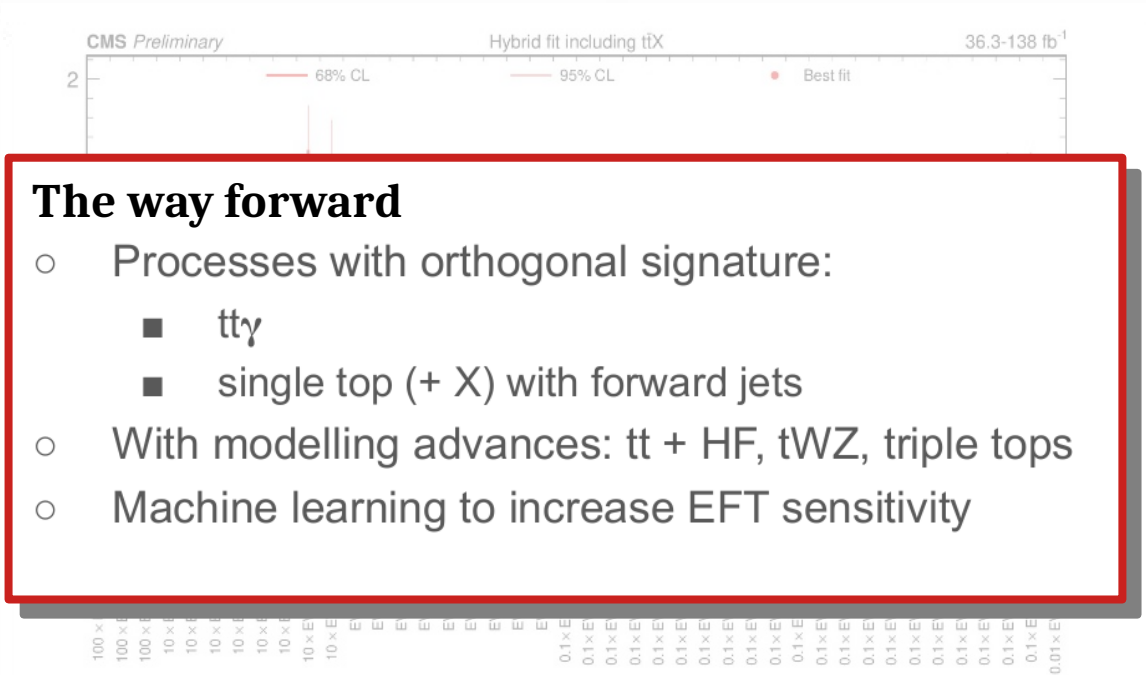
The first likelihood based a wide range of analyses



The biggest global SMEFT fit: 50 WCs, 445 data points

Global EFT fits

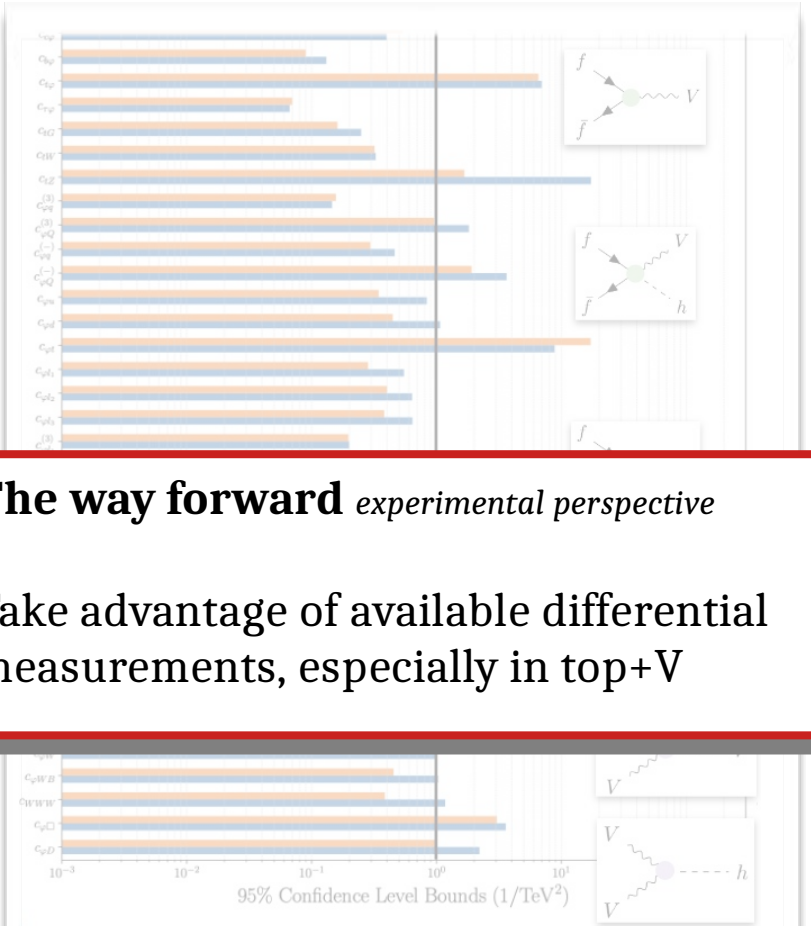
Huge effort on both theory and experiment side



The way forward

- Processes with orthogonal signature:
  - ttγ
  - single top (+ X) with forward jets
- With modelling advances: tt + HF, tWZ, triple tops
- Machine learning to increase EFT sensitivity

The first likelihood based a wide range of analyses

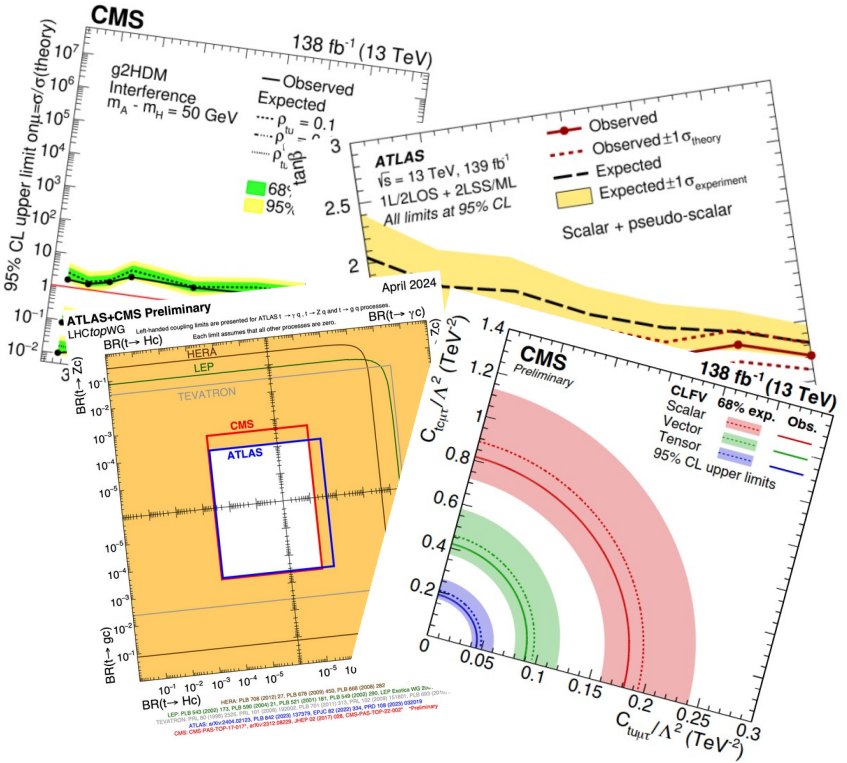


The way forward *experimental perspective*

Take advantage of available differential measurements, especially in top+V

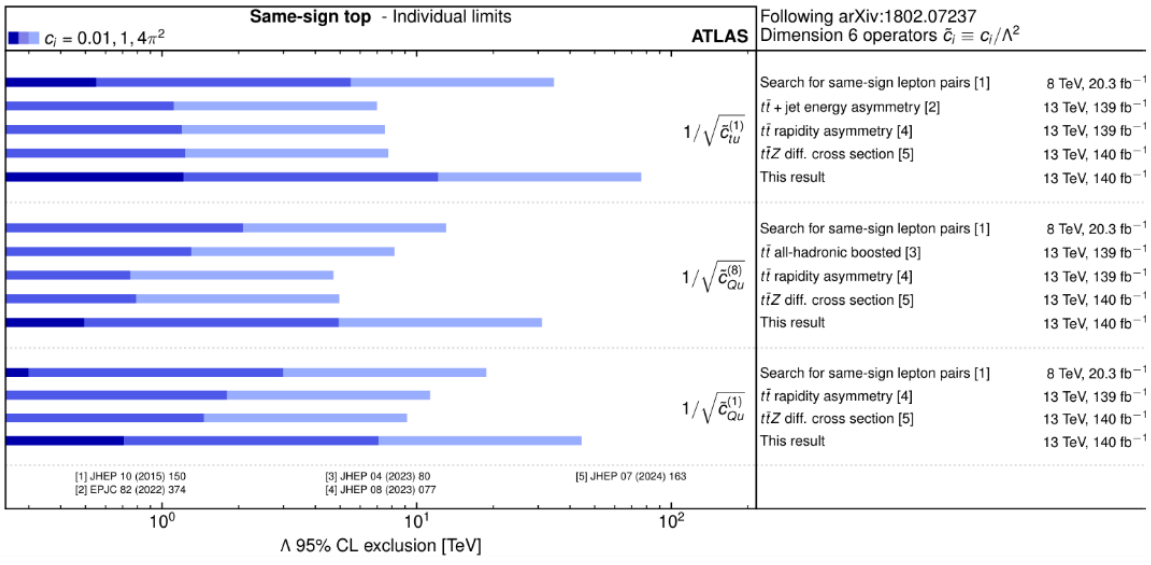
The biggest global SMEFT fit: 50 WCs, 445 data points

Searches with top quarks



FCNC, DM, 2HDM, cLFV...

New ATLAS result in search for same-sign tops

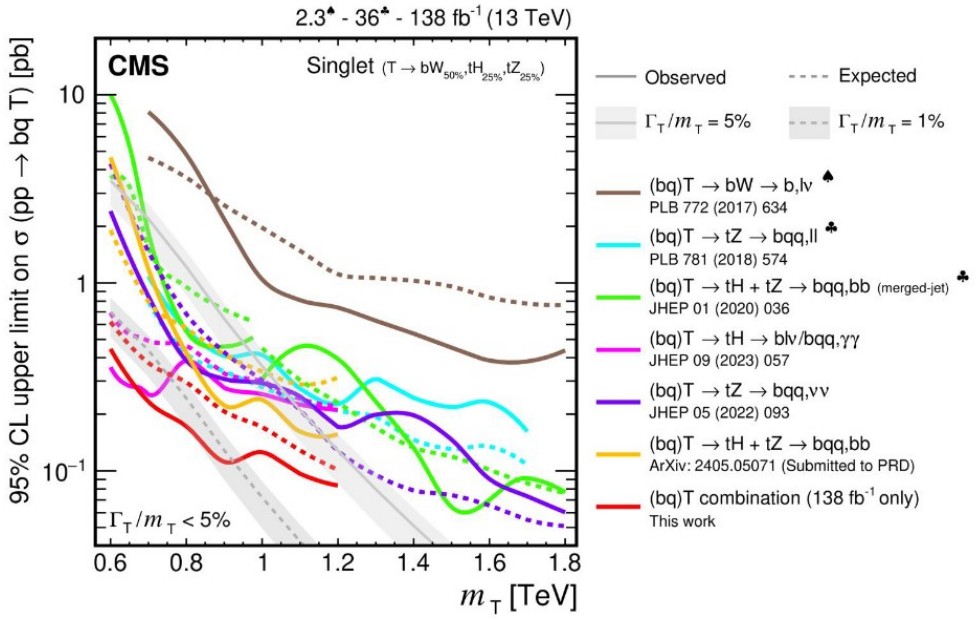


with bounds on 4-fermion WC's

Searches with top quarks

New ATLAS result in search for same-sign tops

Indirect impact of measurements where possible?

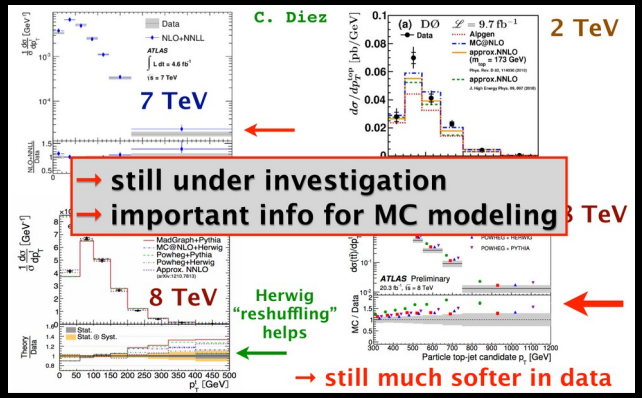


Bounds from current ttZ/tZq measurements?

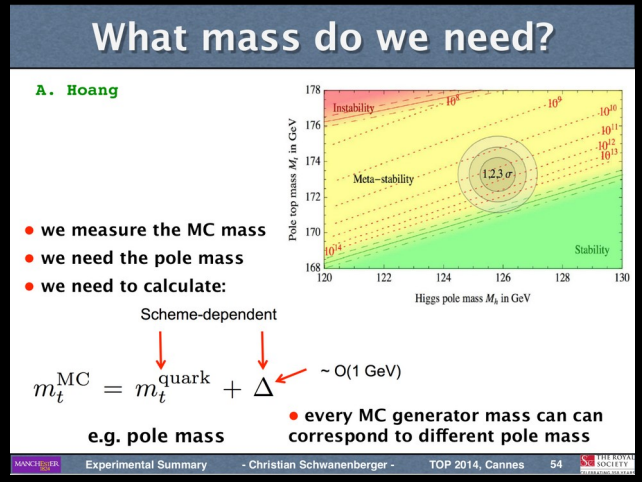
Maybe too weak: low Br, and low stat. in the tails

Measurements of ttZ/tZq with boosted Z → qq?

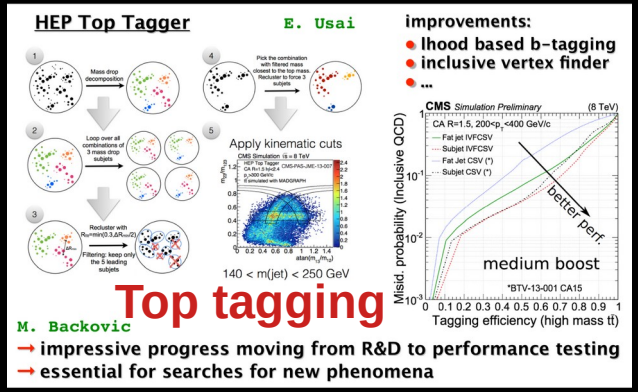
Inspired by Frederic and remembered Cannes

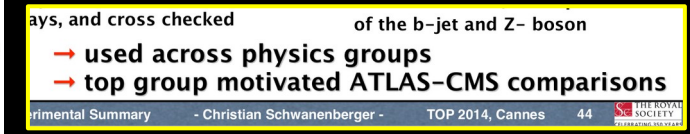


What mass do we need?



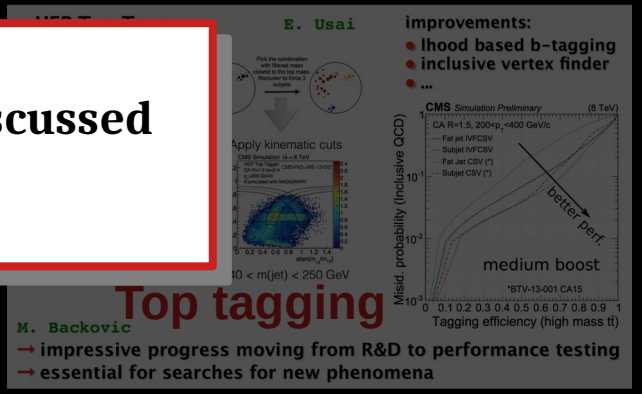
Search for ttZ and ttW





https://indico.in2p3.fr/event/10114/contributions/807/attachments/626/861/13_CSchwanenberger.pdf

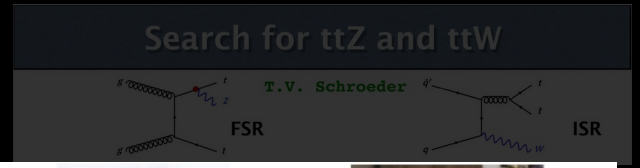
Inspired by Frederic and remembered Cannes



Impressive progress, advancing in *all* old-discussed topics and covering many more new ones

https://indico.in2p3.fr/event/10114/contributions/807/attachments/626/861/13_CSchwanenberger.pdf

And what happened since then …



* No photo available on Top2014 webpage

https://indico.in2p3.fr/event/10114/contributions/807/attachments/626/861/13_CSchwanenberger.pdf

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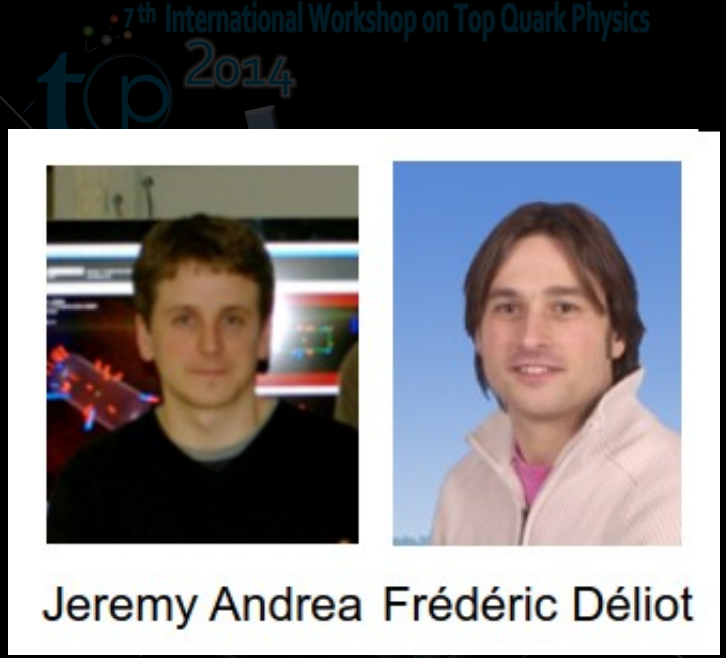

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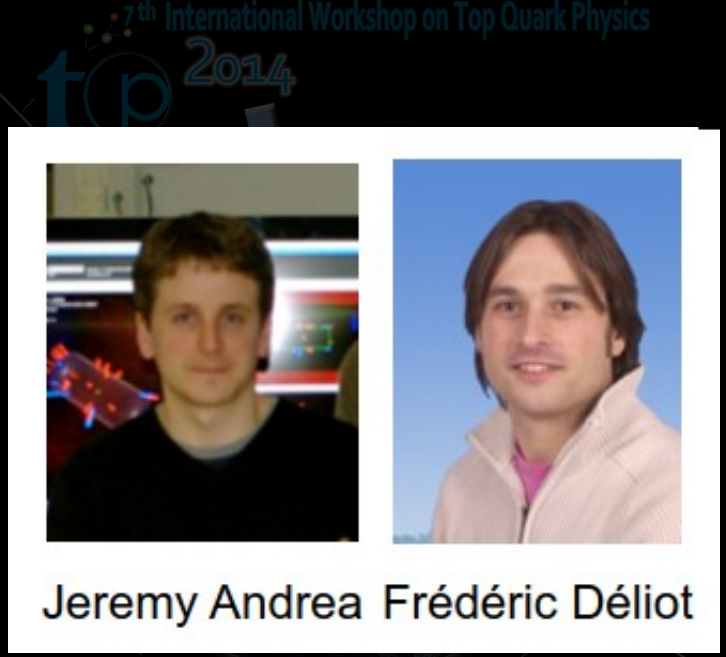
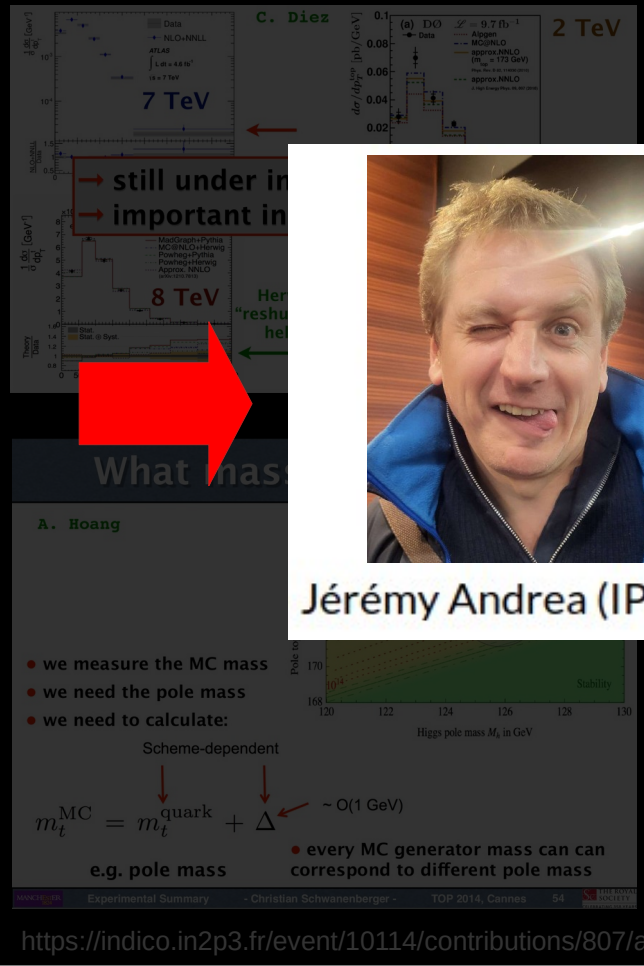
And what happened since then …





https://indico.in2p3.fr/event/10114/contributions/807/attachments/626/861/13_CSchwanenberger.pdf

Thank you!

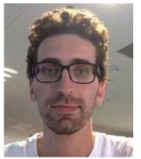
Jérémy Andrea (IPHC)

Samuel Calvet (LPC)

Frédéric Derue (LPNHE)

Benjamin Fuks (LPTHE)

Stéphanie Beauceron (LPNHE)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