First differential ttW cross section measurement at CMS

David Marckx (Ghent University)

on behalf of the CMS collaboration

29/03/2025
Moriond/EW2025
La Thuile, Italy

GHENT UNIVERSITY

NEW

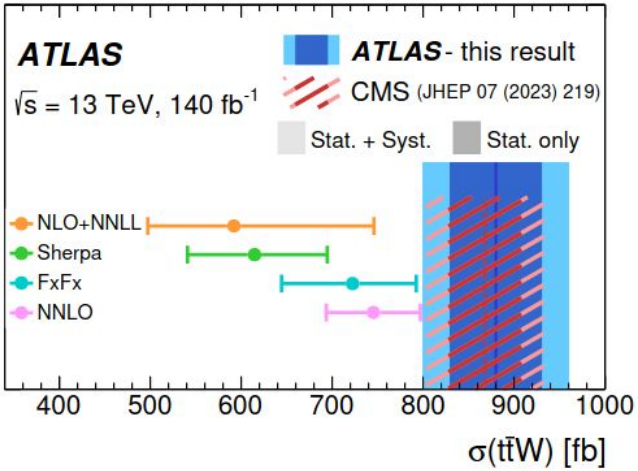
CMS-PAS-TOP-24-003

CMS Compact Muon Solenoid

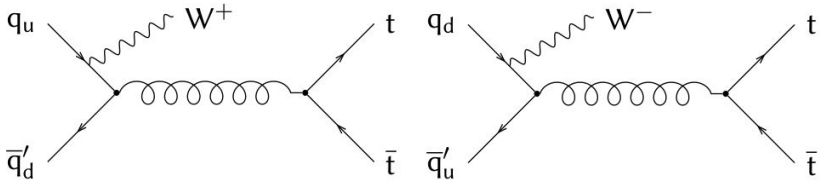
ttW: why?

[JHEP 05 (2024) 131]

- Both ATLAS and CMS have reported a higher cross-section than the current state-of-the-art MC predictions
- Tension remains, even at (approximate) NNLO!
- challenging from the theory perspective
- ttW is an important uncertainty in ttt(t), ttH, …



a seemingly simple process that produces a lot of question marks…
experimental input is needed!



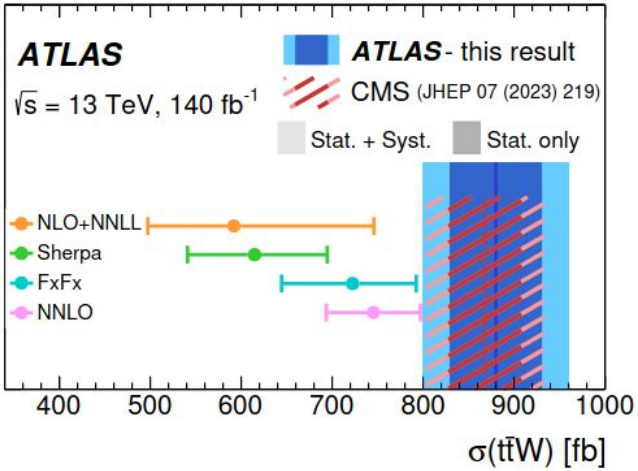
GHENT UNIVERSITY

David.Marcus.E.Marckx@cern.ch

ttW: why?

[JHEP 05 (2024) 131]

- Both ATLAS and CMS have reported a higher cross-section than the current state-of-the-art MC predictions
- Tension remains, even at (approximate) NNLO!
- challenging from the theory perspective
- ttW is an important uncertainty in ttt(t), ttH, …



a seemingly simple process that produces a lot of question marks…
experimental input is needed!

Goals of this analysis:

1. **First differential cross sections by CMS**
   in 2l and 3l channels
2. **First leptonic charge asymmetry of tops by CMS**
   in 3l channel, enhanced in ttW

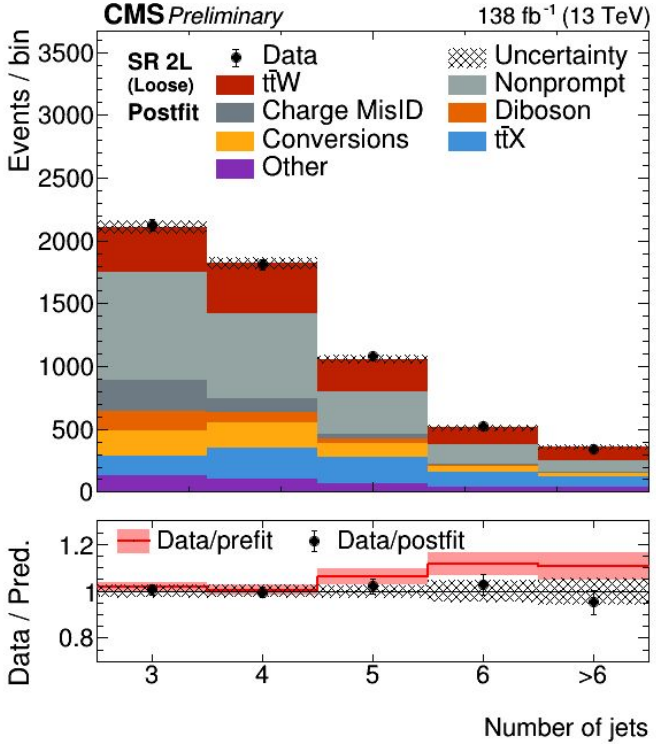
- Run 2 dataset (138 fb^{-1})
- recent ATLAS measurements: differential, charge asymmetry

GHENT UNIVERSITY

David.Marcus.E.Marckx@cern.ch

Differential measurements

- challenging backgrounds:
  - nonprompt, charge misID leptons, conversions, …
  - encode response matrix into systematic framework
  - 2 strategies were applied



GHENT UNIVERSITY

David.Marcus.E.Marckx@cern.ch

Differential measurements

- challenging backgrounds:
  - nonprompt, charge misID leptons, conversions, …
  - encode response matrix into systematic framework
  - 2 strategies were applied:

Counting strategy

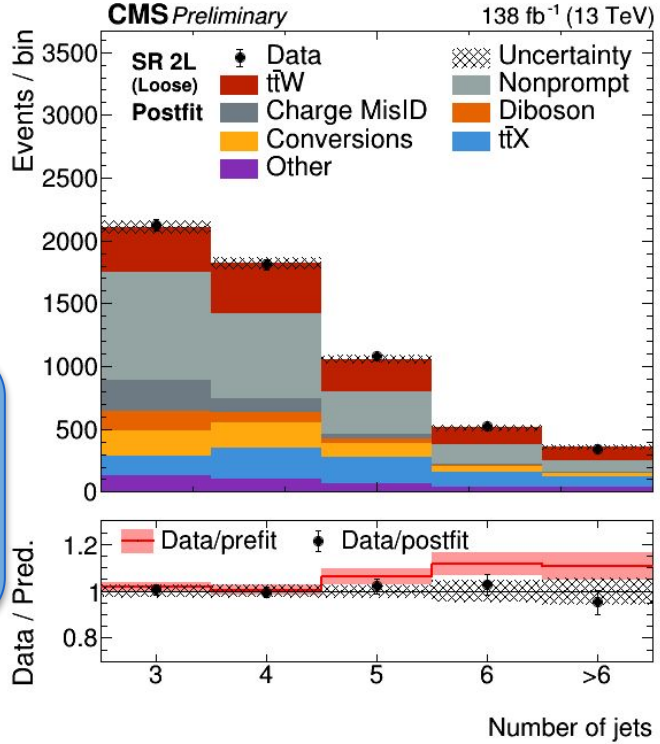
Focus on purity

- tight lepton selection
- lower signal acceptance
- no MVA

MVA strategy

Focus on signal acceptance

- loose lepton selection
- more background
- MVA



GHENT UNIVERSITY

David.Marcus.E.Marckx@cern.ch

Differential measurements

- challenging backgrounds:
  - nonprompt, charge misID leptons, conversions, …
  - encode response matrix into systematic framework
  - 2 strategies were applied:

Counting strategy

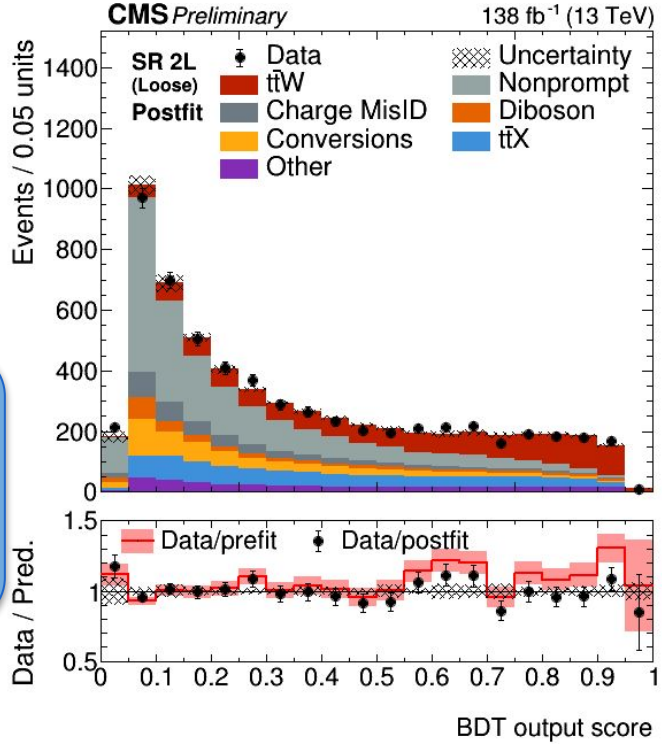
Focus on purity

- tight lepton selection
- lower signal acceptance
- no MVA

MVA strategy

Focus on signal acceptance

- loose lepton selection
- more background
- MVA



GHENT UNIVERSITY

David.Marcus.E.Marckx@cern.ch

Differential measurements

- challenging backgrounds:
  - nonprompt, charge misID leptons, conversions, …
  - encode response matrix into systematic framework
  - 2 strategies were applied:

Counting strategy

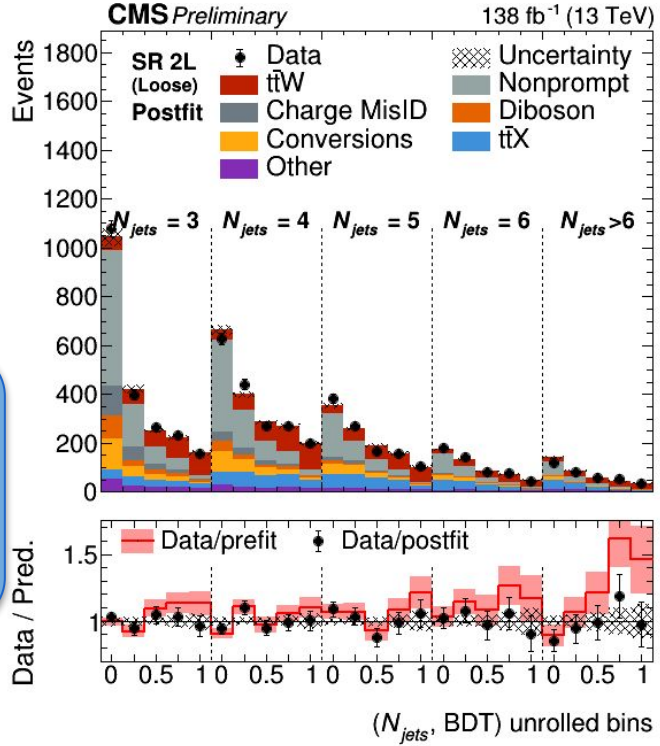
Focus on purity

- tight lepton selection
- lower signal acceptance
- no MVA

MVA strategy

Focus on signal acceptance

- loose lepton selection
- more background
- MVA



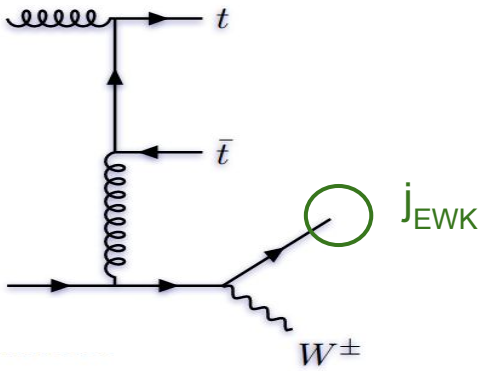
- 2D binning of the BDT and the variable of interest
  - separate signal from backgrounds
  - diagonalize the unfolding

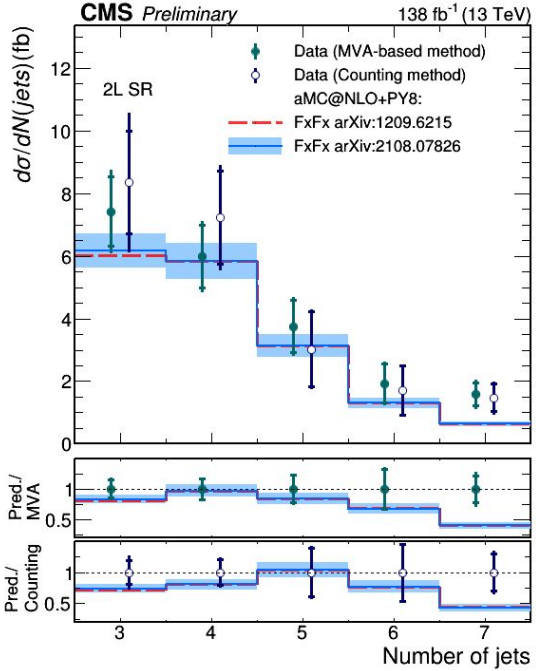
GHENT UNIVERSITY

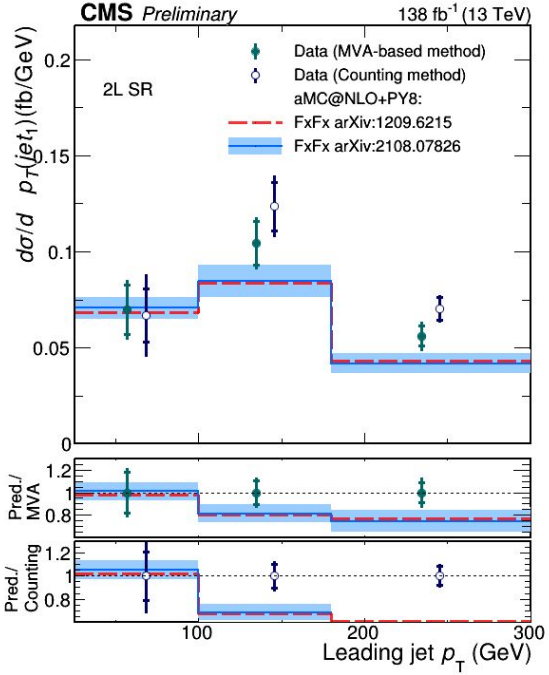
David.Marcus.E.Marckx@cern.ch

Differential measurements

- compare to Counting strategy
  - good agreement observed
  - consistent tension in absolute cross section
- compare results to improved FxFx merging model
  - exclude “EWK” jets from merging procedure 🫠
  - [JHEP11 (2023) 029]





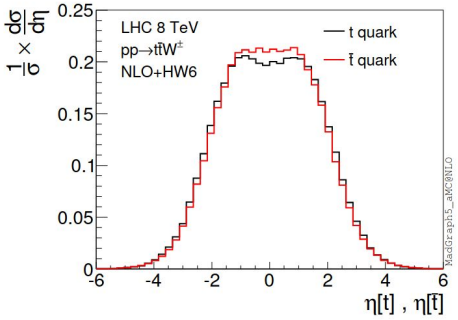


GHENT UNIVERSITY

David.Marcus.E.Marckx@cern.ch

Charge asymmetry

arXiv:1406.3262

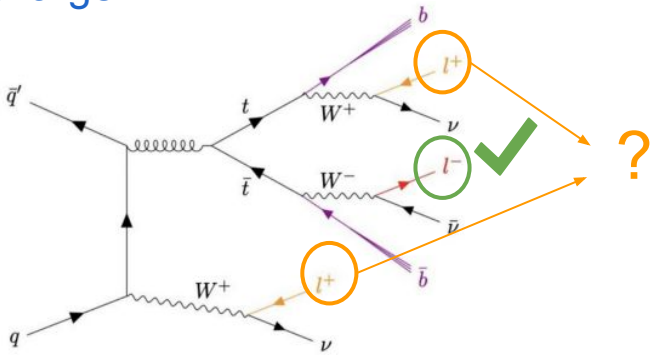


- **Work in three-lepton channel.**

$$A_c^{\ell} = \frac{N(\Delta y_{\ell} > 0) - N(\Delta y_{\ell} < 0)}{N(\Delta y_{\ell} > 0) + N(\Delta y_{\ell} < 0)}$$

- Machinery in place for this additional differential measurement
  - split signal in $\Delta y_{\ell} > 0$ and $\Delta y_{\ell} < 0$ components

- Need to select leptons coming from the top quarks.
  - $\ell^+ \ell^+\ell^-$: One lepton is already identified by its charge.
  - The other one is not so trivial.
  - Use a DNN to tag it.



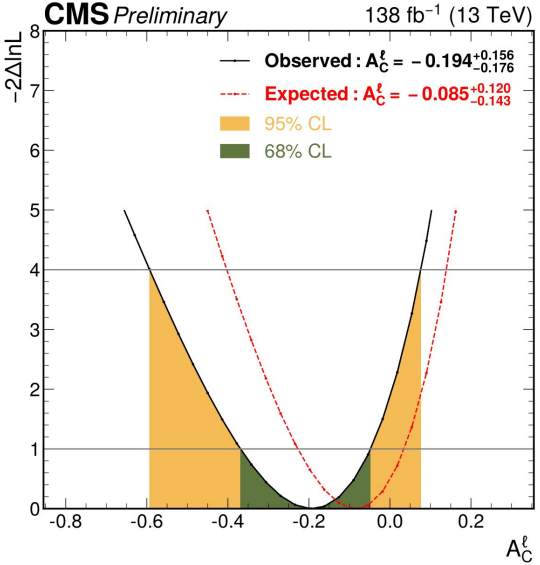
GHENT UNIVERSITY

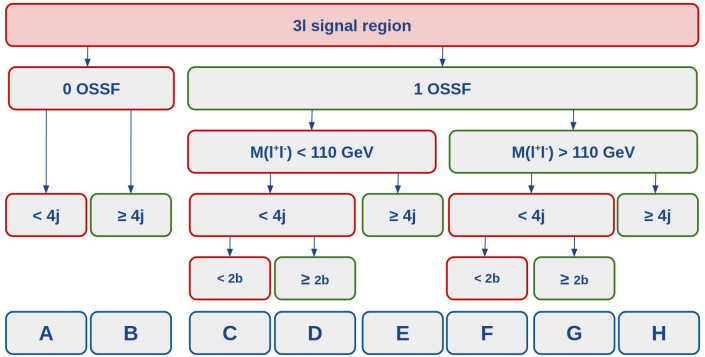
David.Marcus.E.Marckx@cern.ch

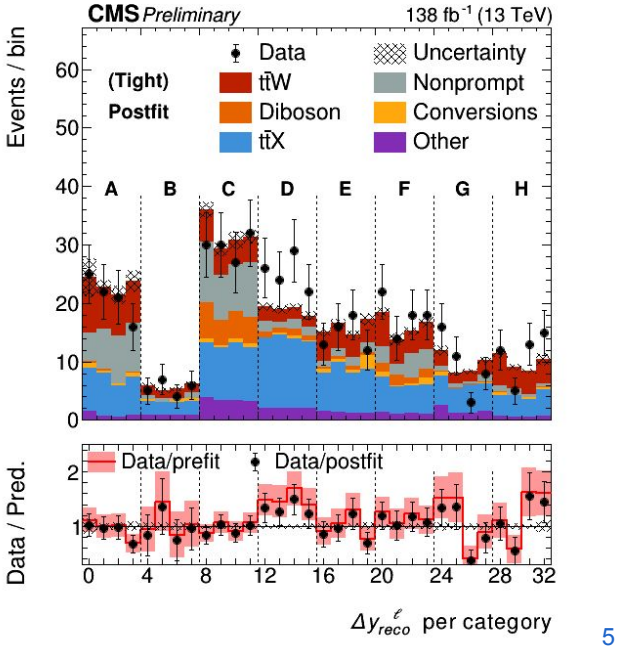
Charge asymmetry

- complex binning scheme is applied to control different background components 😷
- simultaneously extract A_c^{ℓ} and the signal strength

- results consistent with the SM are observed:





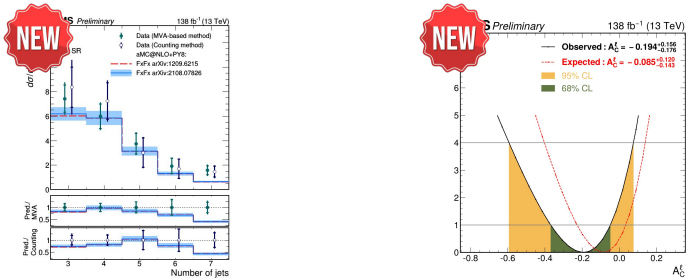


GHENT UNIVERSITY

David.Marcus.E.Marckx@cern.ch

Conclusions

- First CMS differential cross sections in ttW
- First CMS leptonic charge asymmetry in ttW



- Consistent tension in the observed absolute cross section of the process. A few soft differential trends are observed.

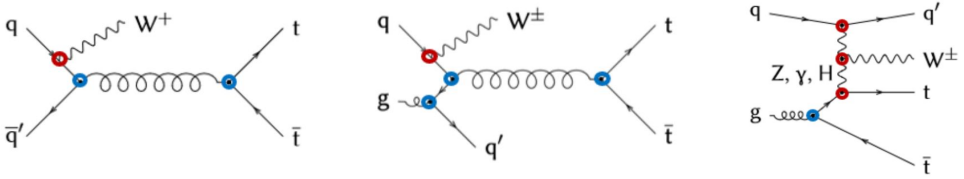
- With improvements in theory predictions, the tension in ttW will catch more attention.

- ATLAS and CMS have an exciting ride ahead with Run3 and HL-LHC!

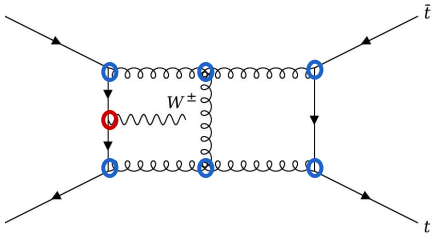
GHENT UNIVERSITY

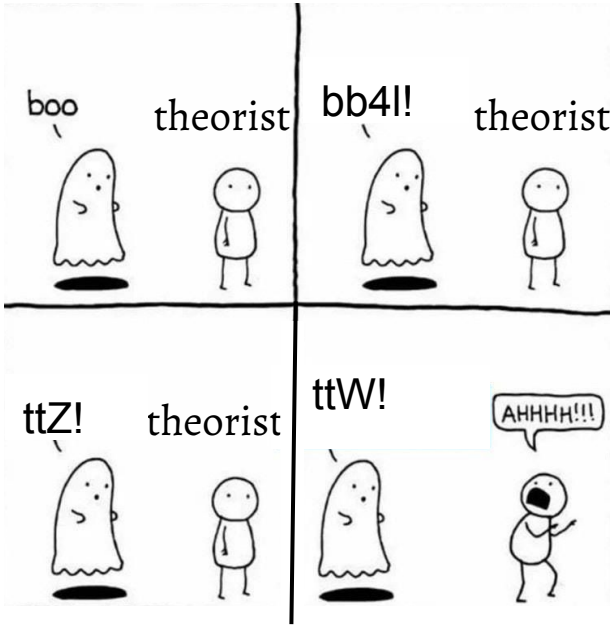
Challenges from the theory perspective

- significant higher order and EWK corrections
  - only quark induced at leading order
  - EWK t-W scattering corrections are surprisingly large (NLO2: -4%, NLO3: ~12%)



- complex loop diagrams with massive, charged and coloured objects
  - double loop diagrams





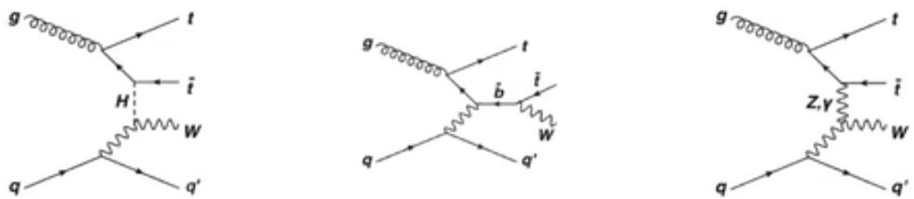
- Not clear what can explain the tensions beyond going to NNLO

GHENT UNIVERSITY

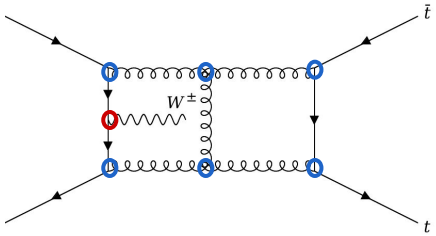
David.Marcus.E.Marckx@cern.ch

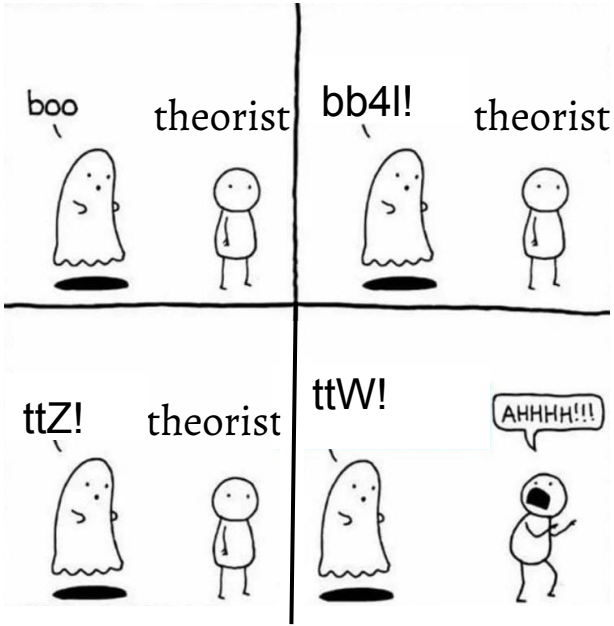
Challenges from the theory perspective

- significant higher order and EWK corrections
  - only quark induced at leading order
  - EWK t-W scattering corrections are surprisingly large (NLO2: -4%, NLO3: ~12%)



- complex loop diagrams with massive, charged and coloured objects
  - double loop diagrams





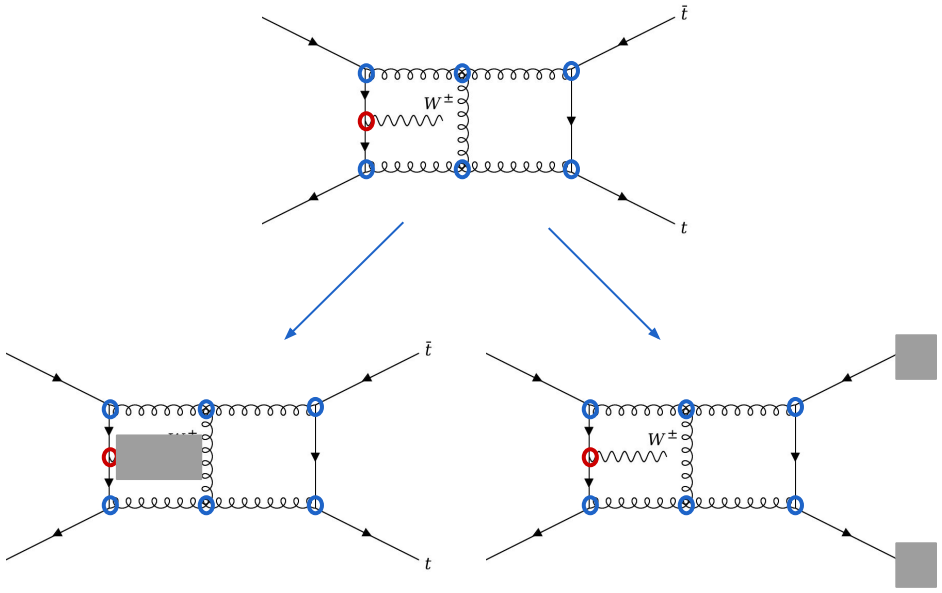
- Not clear what can explain the tensions beyond going to NNLO

GHENT UNIVERSITY

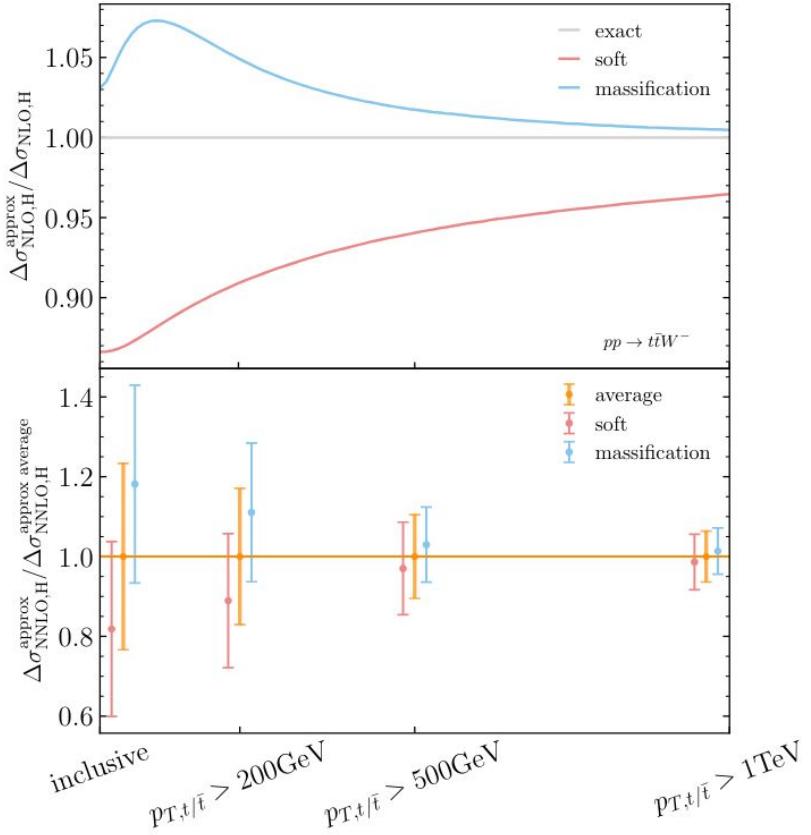
David.Marcus.E.Marckx@cern.ch

ttW@NNLO: the 2-loop approximation

arxiv2306.16311



soft W massification

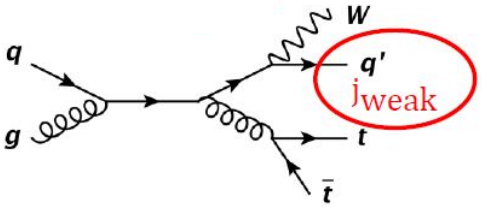


GHENT UNIVERSITY

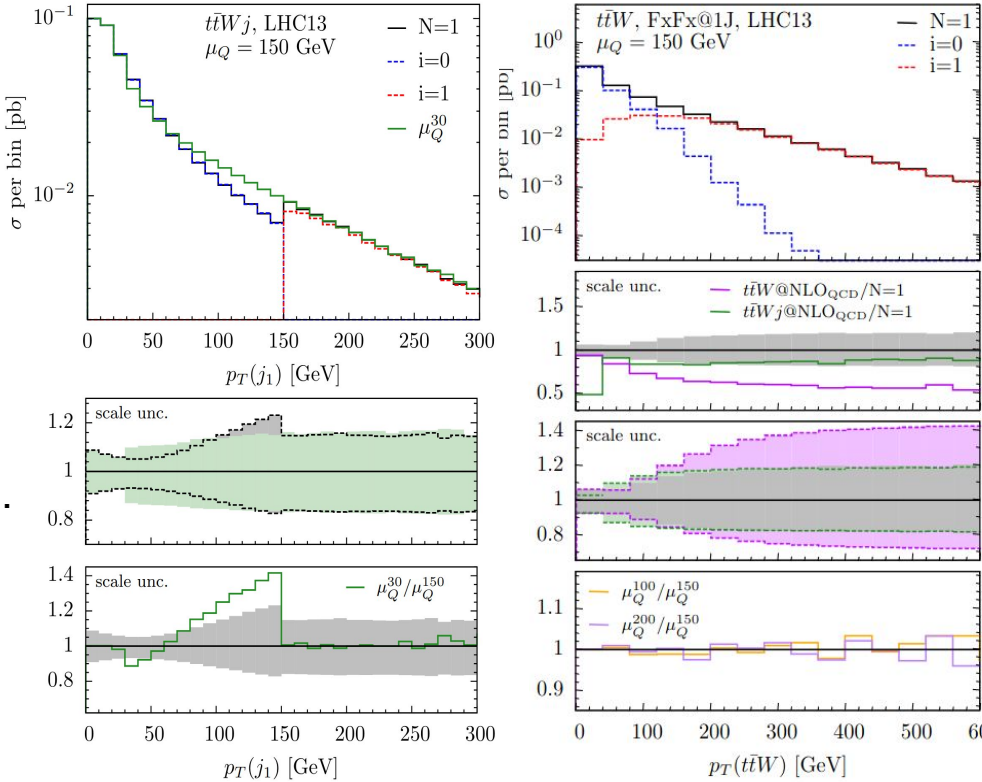
David.Marcus.E.Marckx@cern.ch

State-of-the-art MC: improved FxFx merging

- NLO QCD FxFx@2j + NLO EWK
- MadGraph with new FxFx merging [JHEP11 (2023) 029]



- treats EWK jets by ME below merging scale.
- better description of low p_T jets
- Many other ongoing efforts



GHENT UNIVERSITY

David.Marcus.E.Marckx@cern.ch