SIGILLBESKÄRNING

Sigillet ska beskäras på ett speciellt sätt. Här visar vi de be
skärningar av sigillet som är godkända. Notera att det finns
en beskärningsvariant som är den rekommenderade och som

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är t ex ceremoniella dokument och utbildningsbevis. Sigill i
originalutförande finns att ladda ner på www.lu.se/bildbank.
ttW production

- ttW is
  - a main source of same-sign charged leptons + multiple jets
  - one of the main backgrounds in ttH production (with leptonic H decays)
  - important background in 4-top production
  - relevant for SMEFT limit setting
- Hence, understanding it is important in the extraction of the top Yukawa coupling
- First data extractions show a slight tension: theory predicted a somewhat smaller cross section than needed

Normalisation factors of ttW background
\[
\lambda_{ttW}^{2l,Nj=2,3} = 1.56^{+0.30}_{-0.28}, \quad \lambda_{ttW}^{2l,Nj\geq4} = 1.26^{+0.19}_{-0.18}, \quad \lambda_{ttW}^{3l} = 1.68^{+0.3}_{-0.28}
\]

Ana Cueto’s talk this morning
"Constraint" at lowest order

- At lowest order in perturbation theory, \( ttW \) production is rather 'constraint'
  - Only two Feynman diagrams: W-boson is attached to a light quark line that attaches to the two colliding protons, while the top pair can only come from a gluon splitting

  \[ \begin{array}{c}
  q \\
  \downarrow \\
  W^\pm \\
  \uparrow \\
  \bar{q}' \\
  \downarrow \\
  t \\
  \uparrow \\
  \bar{t} \\
  \end{array} \]

- Hence, expect large higher order corrections, and possibly underestimation of theory uncertainties at lowest order(s), due to opening of new channels, new colour structures, new flavour structures, etc.
• Significant uncertainties due to scale variation
  • In particular: great variation due to choice for central value of scales
• Including soft-gluon resummation does not improve the picture
  [Broggio et al. (2019) & Kulesza et al. (2020)]
• For the true uncertainty an envelope over multiple scale choices seems necessary
• Clear sign of new structures/topologies opening at NLO
• ttZ (left) and ttH (right) production does show the expected uncertainty reduction — particularly related to the functional form of the central scale choice
Opening of new channels

- In the real-emission NLO QCD corrections to $ttW$, top pair production via gluon fusion enters.
- Not possible to generate this topology starting from LO and adding only parton-shower like emissions (soft-col approx).
- These are essentially "almost-finite" contributions that enhance the cross section.
- Dominant at large $p_T(t\bar{t})$:
  - Captured at LO accuracy in an NLO computation.
  - Captured at NLO accuracy in NLO multi-jet merging.
• Large dependence on the merging scale in total cross section
• Large merging scale choices results in non-smooth distributions
• Also for small merging scale choices, the new topologies are not treated correctly: they should not be part of the merging, since they are not IR soft/collinear enhanced (i.e., they have no shower equivalent)
Improved FxFx

- Include all particles in the clustering to find the "most-likely branching history"
- If, for a given event, it is more likely that a final state quark is clustered with the W-boson than with another QCD parton, that quark forms an "EW jet" and not a normal "QCD jet"
  - contributions from EW jets are finite (the W-boson mass screens the IR divergence)
  - EW jets should not be part of the merging procedure, and are included also below the merging scale
- New topology in ttW production can therefore be included at NLO accuracy in the complete phase space
Improved FxFx validation I

\[RF, Tsinikos (2021)\]

| $\mu_Q$ [GeV] | 25      | 50      | 75      | 100     | 125     |
|---------------|---------|---------|---------|---------|---------|
| $\sigma$ [fb] | $668.2(9)^{+54.7(+8.2\%)}_{-77.5(-11.6\%)}$ | $671.4(8)^{+60.0(+8.9\%)}_{-74.4(-11.1\%)}$ | $673.6(8)^{+60.1(+8.9\%)}_{-71.9(-10.7\%)}$ | $677.5(6)^{+60.8(+9.0\%)}_{-71.1(-10.5\%)}$ | $677.2(8)^{+59.1(+8.7\%)}_{-69.5(-10.3\%)}$ |
| $\mu_Q$ [GeV] | 150     | 200     | 250     | 300     | 350     |
| $\sigma$ [fb] | $679.2(6)^{+60.5(+8.9\%)}_{-69.7(-10.3\%)}$ | $679.1(6)^{+61.0(+9.0\%)}_{-69.5(-10.2\%)}$ | $678.8(6)^{+61.5(+9.1\%)}_{-69.6(-10.3\%)}$ | $678.3(6)^{+61.8(+9.1\%)}_{-69.6(-10.3\%)}$ | $678.1(6)^{+62.0(+9.1\%)}_{-69.7(-10.3\%)}$ |

- Hardly any dependence on the merging scale in the total cross section
  - from 25 - 350 GeV only percent-level differences
- well within scale uncertainties
Improved FxFx validation II

- Step at merging scale disappears
- Contributions from the EW jets in the ttW+1jet sample clearly visible below merging scale
- Large reduction in scale dependence at large $p_T(j_1)$ as compared to non-merged sample
Total cross section

- Rate about 17-19% larger than NLO_{QCD}
- Stabilisation of scale dependence
- As expected, adding 2nd jet at NLO in the merging does not change predictions significantly

Figure 5: Cross sections of various QCD perturbative orders of $t\bar{t}W$ production (left plot).

Percent deviation of the different central values with respect to their average (upper right ratio plot).

$K$-factors of the averaged central values with the combined scale uncertainties (lower right ratio plot).
Data comparison

- With the improved FxFx, the cross section increased significantly, bringing it closer to the data
  - uncertainty bands almost overlap
  - tension is resolved to a large extend
Conclusions

• There used to be a small tension for the total cross section of $t\bar{t}W$ production between theory and experiment
• From a theory point of view, $t\bar{t}W$ is special and very "constraint" at lowest order(s):
  • Large corrections from higher orders in QCD
  • Large corrections due to non-logarithmically enhanced radiation
  • Large corrections from formerly subleading EW corrections
• The improved FxFx merging allows for a consistent inclusion of NLO corrections to topologies opening at higher multiplicities
• For $t\bar{t}W$ production this increases the predicted cross section, resolving the tension between theory and experiment to a large extent