Institute for Theoretical Particle Physics and Cosmology

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$t\bar{t}W^{\pm}$ at NLO in QCD: Full off-shell effects and precision observables

Eur. Phys. J. C 81, 675 (2021)

presented by Jasmina Nasufi during the 14$^{\rm nth}$ international workshop on Top-Quark Physics on September 15$^{\rm nth}$

Motivation

$$\boxed{pp \to t\bar{t}W^{\pm} \to \ell^{\pm}\nu_{\ell}\ell^{\mp}\nu_{\ell}\ell^{\pm}\nu_{\ell}b\bar{b} \qquad \ell^{\pm} = e^{\pm}, \mu^{\pm}}$$

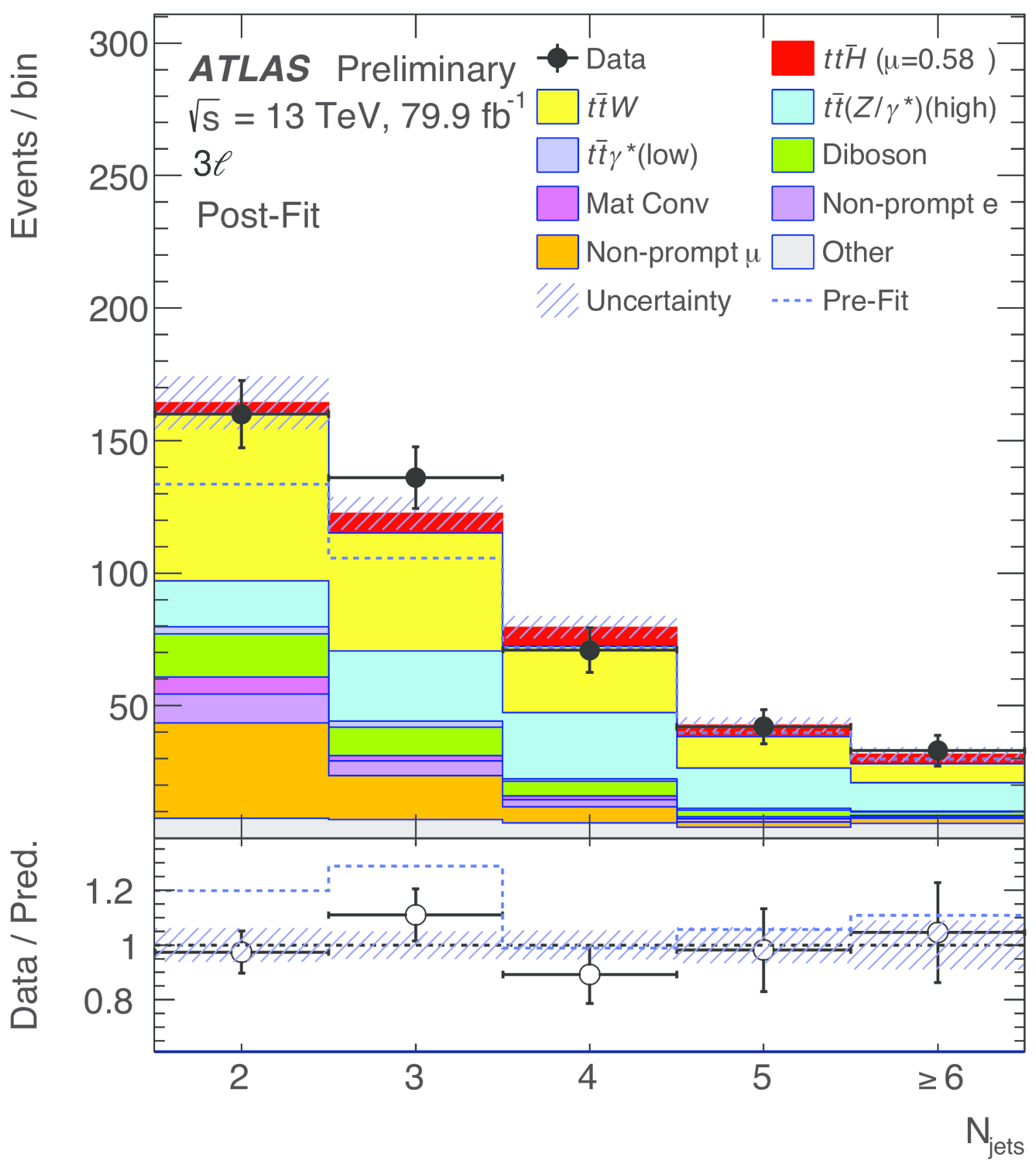


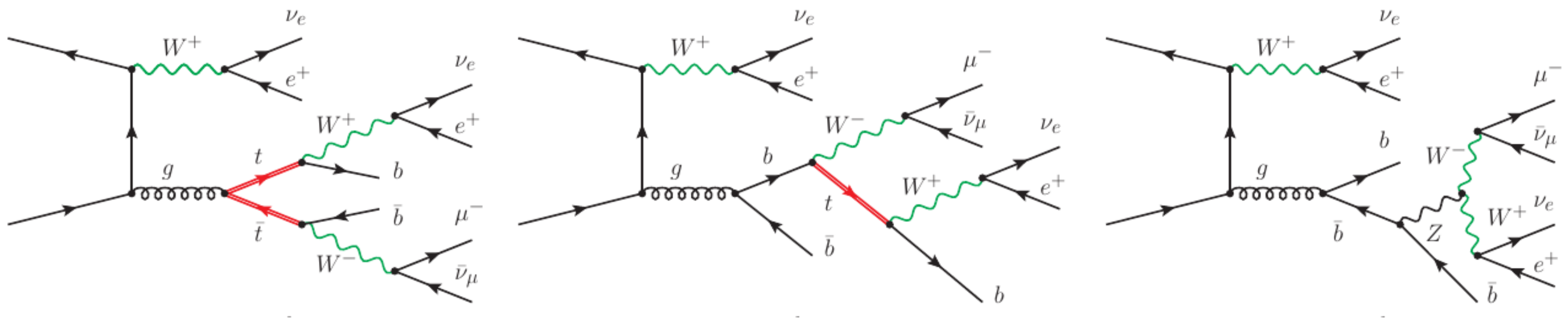
Fig. 1: Jet multiplicity distribution in the 3ℓ-channel. [1]

- Background to $t\bar{t}H$ in 3ℓ-channel [1]
- Discrepancy between theory and experiment
  - Overall Normalisation (30%-70% for very inclusive cuts)
  - Modelling of top decay
- Rare same sign lepton signature can be used to constrain BSM physics
- Phenomenologically relevant for top quark charge asymmetry [2]

Some Recent Developments

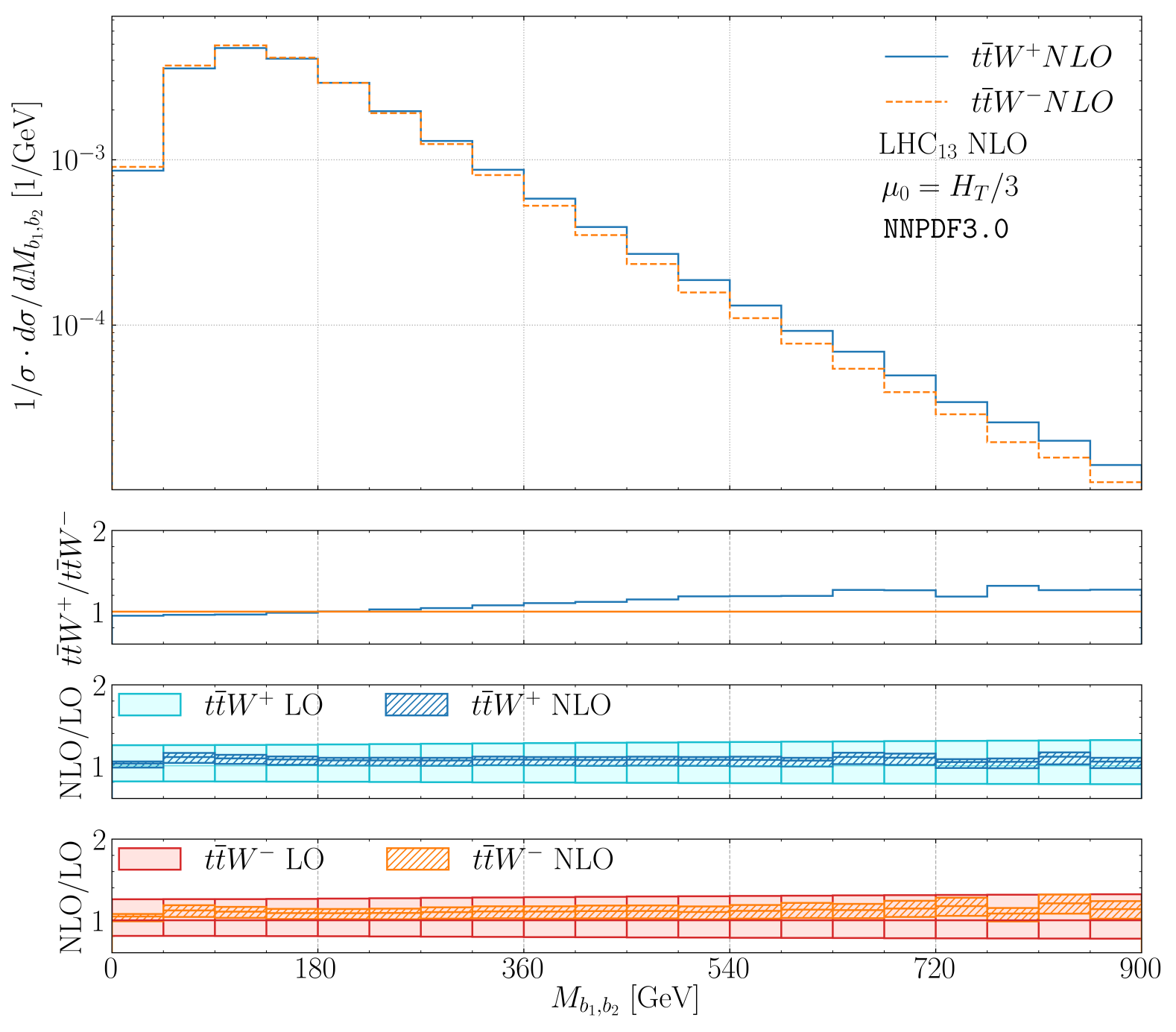
- First NLO QCD calculation with full off-shell effects in this channel completed in 2020 [5]
- Independent computation NLO QCD with full off-shell effects 2020 [6]
- This work (Eur. Phys. J. C 81, 675 (2021)), based on results from [5]
- Results for combined NLO QCD + EW with full off-shell effects [7]

Setup



- NLO QCD predictions with the HELAC-NLO Monte Carlo Program [3]
- Theoretical results → Modified Les Houches & ROOT event files. [4]
- **Modelling** : Full off-shell effects, Full Narrow-Width Approx. (NWA), NWA with LO decays (NWA$_{\rm LOdec}$).
- Analysis: 2 b-jets and 3 charged leptons with $p_T(\ell), p_T(j_b) > 25{\rm GeV}$, $|y(\ell)|, |y(j_b)| < 2.5$, $p_T^{miss} > 0{\rm GeV}$, $\Delta R(\ell j_b),\ \Delta R(\ell,\ell),\ \Delta R(j_b j_b) > 0.4$
- Two central scales: fixed $\mu_0 = m_t + m_W/2$ and dynamic $\mu_0 = H_T/3$ with $H_T = \sum_{vis} p_T + p_{T,miss}$
- Jets constructed via the the anti$-k_T$ jet algorithm with $R = 0.4$ from all final state partons with $|\eta| < 5$.
- NNPDF3.0 PDF set [8] with $N_F = 5$

Cross Section Ratio $\mathcal{R} \equiv \sigma^{NLO}_{t\bar{t}W^+}/\sigma^{NLO}_{t\bar{t}W^-}$



	$\sigma^{t\bar{t}W^+}_{\rm NLO}$ [ab]	$\sigma^{t\bar{t}W^-}_{\rm NLO}$ [ab]
Full off-shell	$124.4^{+3\%}_{-6\%}$	$68.6^{+5\%}_{-7\%}$
NWA	$124.2^{+3\%}_{-6\%}$	$68.7^{+5\%}_{-7\%}$
NWA$_{LOdec}$	$130.7^{+10\%}_{-10\%}$	$72.0^{+11\%}_{-11\%}$

Comparing $t\bar{t}W^+$ and $t\bar{t}W^-$

- Similar NLO corrections $\mathcal{K} \equiv \sigma_{\rm NLO}/\sigma_{\rm LO} \sim 1.1$
- Similar theoretical scale uncertainty (see table)
- PDF uncertainty of oder 2% at NLO

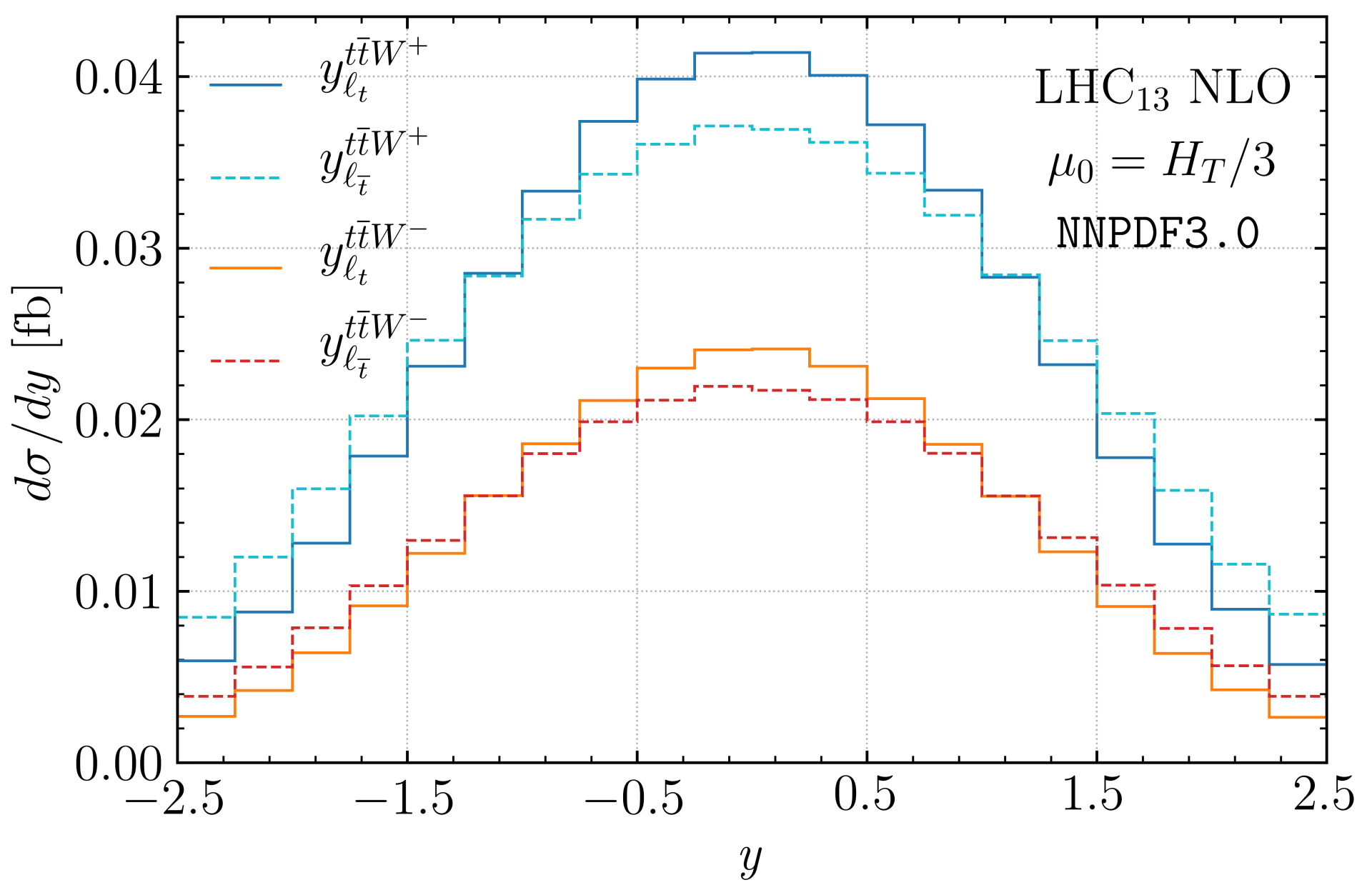
Correlated scales

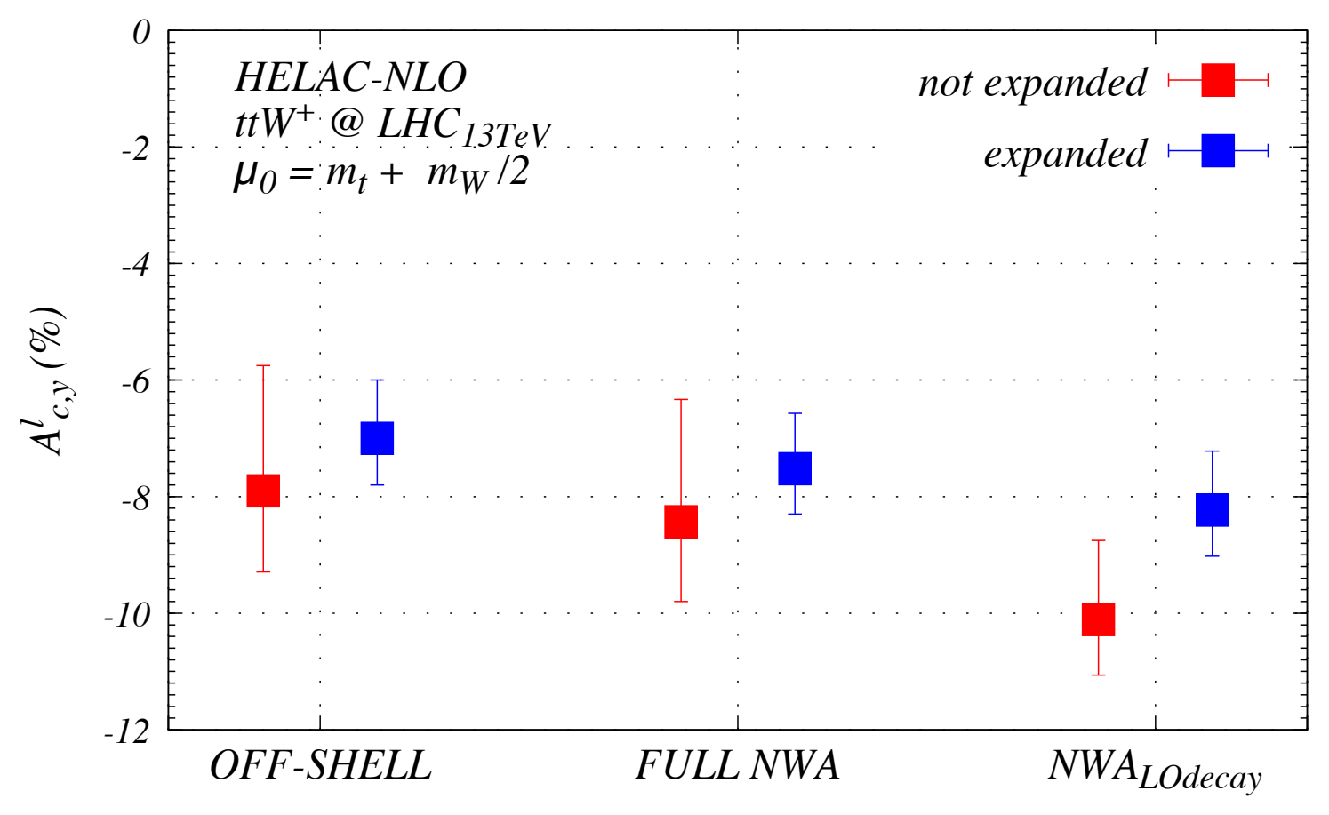
Due to the similarity between the NLO corrections and theo. uncertainties, the scales can be taken as correlated.

$$\mathcal{R} \equiv \sigma^{NLO}_{t\bar{t}W^+}/\sigma^{NLO}_{t\bar{t}W^-} = 1.81 \pm 0.03({\rm scale}) \pm 0.03({\rm PDF})$$

NNLO $(2\% - 3\%)$ precision independent of modelling!

Charge Asymmetries $A^t_{c,\eta},\ A^t_{c,y},\ A^{\ell}_{c,y}$





$$A_{c,y} = \frac{\sigma\left(\Delta|y| > 0\right) - \sigma\left(\Delta|y| < 0\right)}{\sigma\left(\Delta|y| > 0\right) + \sigma\left(\Delta|y| < 0\right)} \qquad \Delta|y| \equiv |y_{\ell_t}| - |y_{\ell_{\bar{t}}}|$$

- Final results with full off-shell effects are given in terms of *expanded* asymmetries:

  $A^t_{c,\eta,exp}\ [\%] = 3.70^{+12\%}_{-11\%},\ A^t_{c,y,exp}\ [\%] = 2.62^{+15\%}_{-13\%},\ A^{\ell}_{c,y,exp}\ [\%] = -7.00^{+14\%}_{-11\%}$
- Modelling impacts central value and theoretical uncertainties.

Conclusions

- Off-shell effects impact phase space regions.
- **Cross section ratio** $\mathcal{R}$ exhibits enhanced perturbative stability → 2% − 3% error (!) independently of modelling
- **Top charge asymmetries** were revisited, calculated for NLO QCD with full off-shell effects → expanded vs unexpanded asymmetries
- **NLO corrections** neccesary, LO understimates the theoretical uncertainties for these observables.

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[1] ATLAS-CONF-2019-045

[2] F. Maltoni, M. Mangano, I. Tsinikos, and M. Zaro, Phys. Lett. B 736, 252 (2014), 1406.3262.

[3] G. Bevilacqua, M. Czakon, M. V. Garzelli, A. van Hameren, A. Kardos, C. G. Papadopoulos, R. Pittau and M. Worek, Comput. Phys. Commun. **184** (2013) 986.

[4] Bern, Dixon, Febres, Cordero, Hoeche, Ita, Kosower, Maitre 2014

[5] G. Bevilacqua, H.-Y. Bi, H. B. Hartanto, M. Kraus, and M. Worek, JHEP 08, 043 (2020), 2005.09427

[6] A. Denner, G. Pelliccioli (2020), 2007.12089.

[7] A. Denner and G. Pelliccioli (2021), 2102.03246

[8] R. D. Ball et al. (NNPDF), JHEP 04, 040 (2015), 1410.8849.