

NLO QCD predictions for off-shell ttW production in association with a light jet at LHC

JHEP09(2023)026

Huan-Yu Bi, Manfred Kraus, **Minos Reinartz**, and Malgorzata Worek

Young Scientists Meeting of the CRC TRR 257, 17.10.2023, Siegen

Collaborative Research Center TRR 257



Particle Physics Phenomenology after the Higgs Discovery

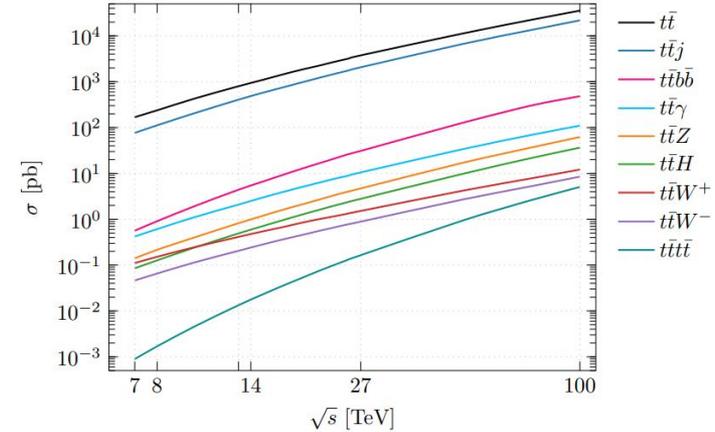
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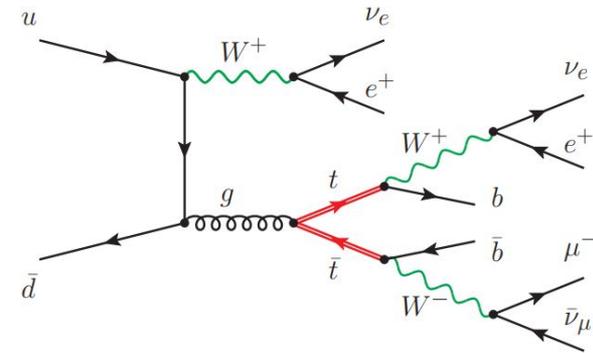
Motivation

- Rare process at LHC
- Charge asymmetries already at LO
- Background process to $t\bar{t}H$ and $t\bar{t}t\bar{t}$
- Irreducible background to same-sign dilepton searches
- Leading order only includes $q\bar{q}'$ initial states
- $g\bar{q}$ channels open up at NLO and gg at NNLO

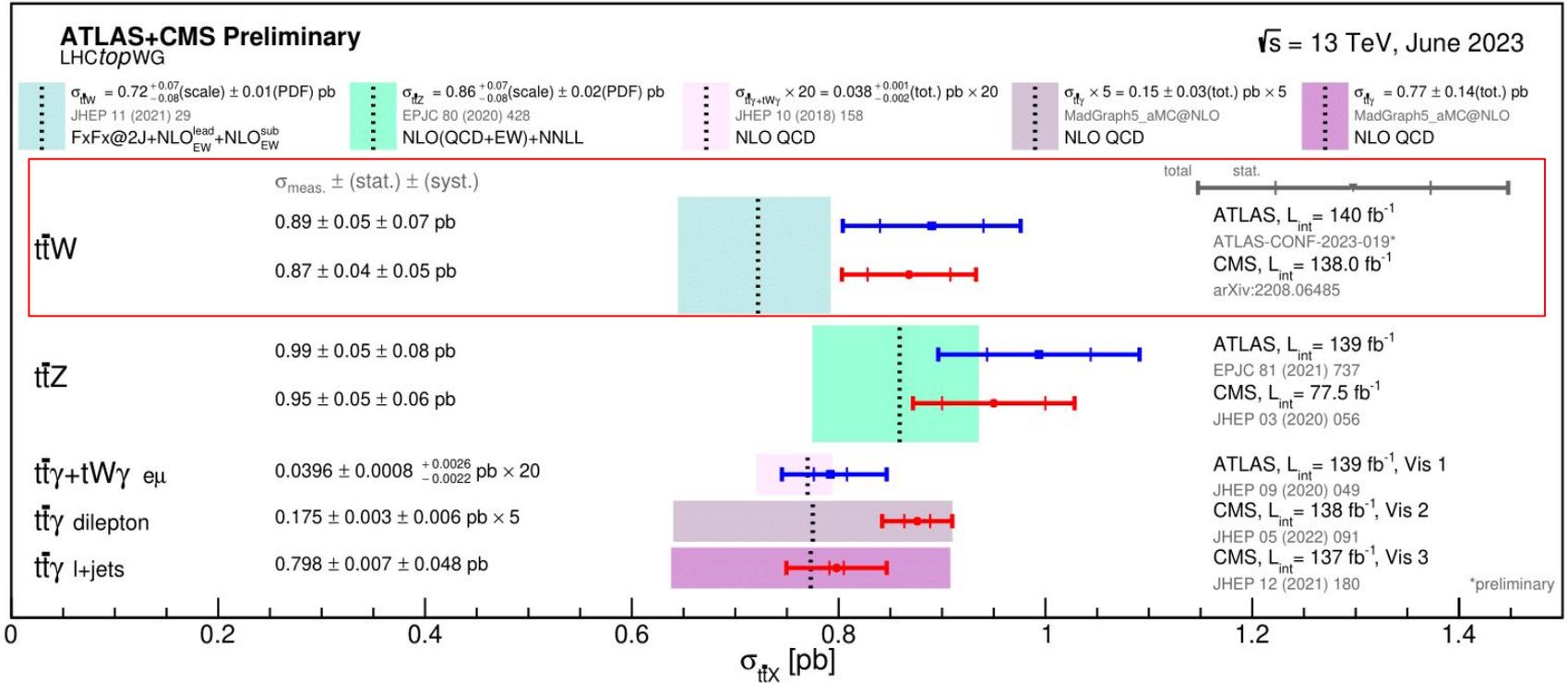
gg can be accessed in NLO $t\bar{t}Wj$ calculation



Report of the Topical Group on Top quark physics and heavy flavor production for Snowmass 2021



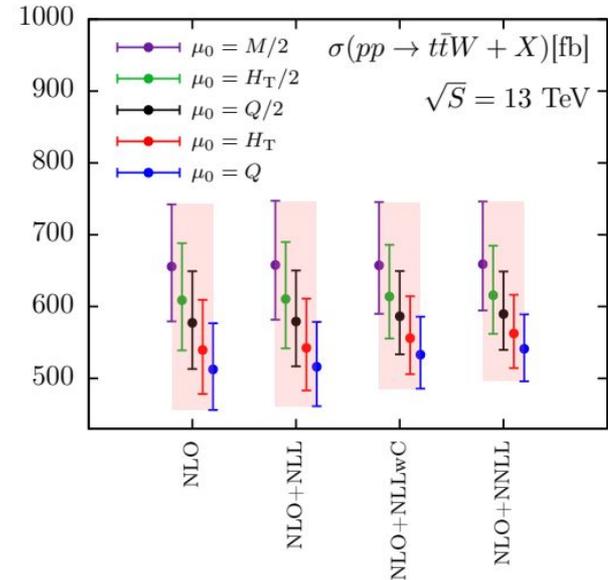
Experimental status



Theory status

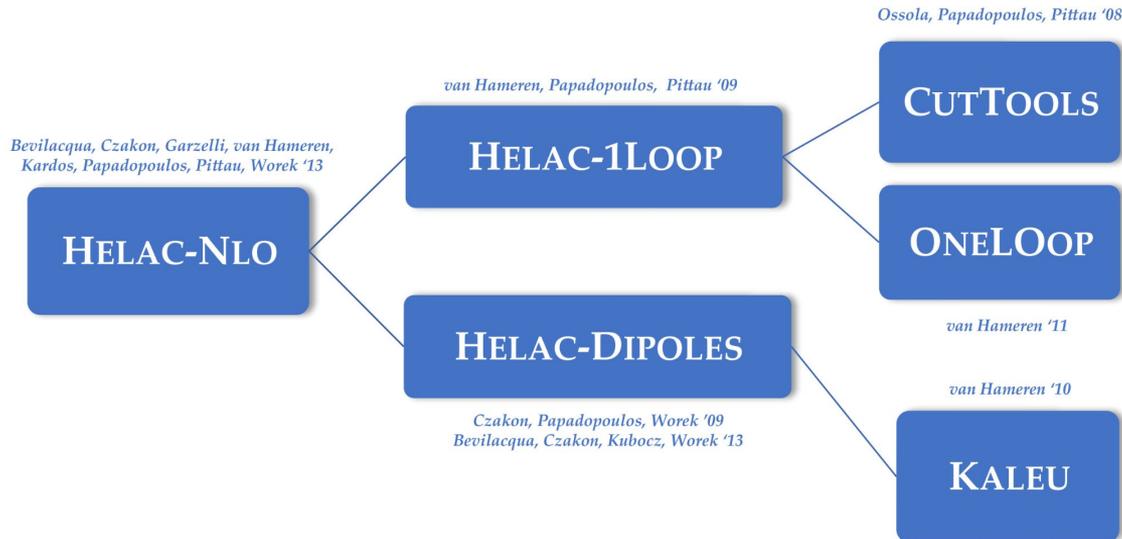
- Stable tops matched to parton shower
Cordero, Kraus, Reina '21
- NLO QCD and EW for stable tops
Frixione, Hirschi, Pagani, Shao, Zaro '15 / Frederix, Pagani, Zaro '17
- NLO QCD with off-shell effects
Bevilacqua, Bi, Hartanto, Kraus, Worek '20 / Denner, Pelliccioli '20
- NLO QCD and EW corrections with subleading contributions with off-shell effects
Ansgar Denner, Giovanni Pelliccioli '21 / Bevilacqua, Bi, Cordero, Hartanto, Kraus, Nasufi, Reina, Worek '21
- FxFx jet merging up to two jets with EW corrections and subleading contributions
Frederix, Tsirikos '21
- ttWj at NLO QCD with off-shell effects
Bi, Kraus, Reinartz, Worek '23
- Approximate NNLO QCD
Buonocore, Devoto, Grazzini, Kallweit, Mazzitelli, Rottoli, Savoini '23

● Soft-gluon resummation



Kulesza, Motyka, Schwartländer, Stebel, '18 '20 / Broggio, Ferroglia, Frederix, Pagani, Pecjak, Tsirikos '19

Computational framework



- Results are stored in modified [Les Houches Event Files](#) *Alwall et al '06* and [ROOT Ntuples](#) *Bern et al. '13*
- [HEPlot](#) for reweighting of scales, PDFs and change to more exclusive cuts

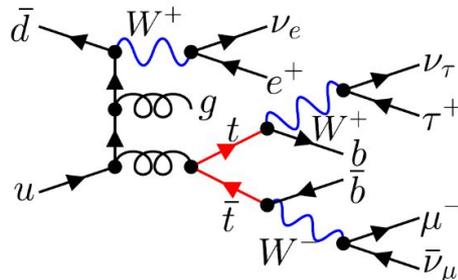
Bevilacqua (unpublished)

Setup of the calculation

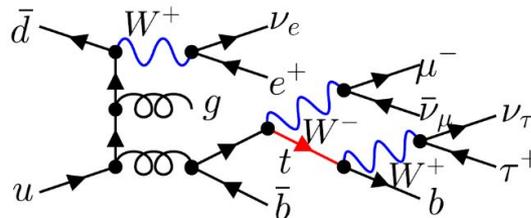
$$pp \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b \bar{b} j + X$$

- LHC with $\sqrt{s} = 13 \text{ TeV}$
- Diagonal CKM matrix
- 5-flavour scheme
- Top-width is a fixed parameter throughout the calculation $\Gamma_{t, \text{off-shell}}^{\text{NLO}} = 1.33254 \text{ GeV}$
- Full off-shell calculation = DR + SR + NR + interference + Breit-Wigner propagators

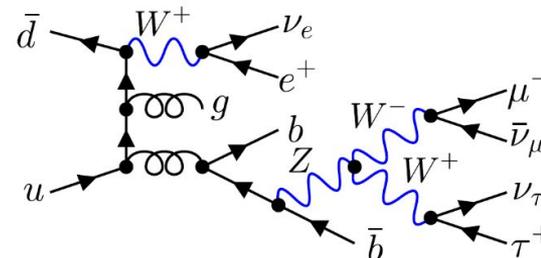
Double-resonant



Single-resonant



Non-resonant



Diagrams created with FeynGame
Harlander, Klein, Lipp '20

Bi, Kraus, Reinartz, Worek '23

Setup of the calculation

$$pp \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} j + X$$

- anti- k_T jet algorithm with $R = 0.4$ [Cacciari, Salam, Soyez '08](#)
- **charge-aware** b-jet recombination scheme with **exactly 2 b-jets**

$$bg \rightarrow b, \quad \bar{b}g \rightarrow \bar{b}, \quad b\bar{b} \rightarrow g, \quad bb \rightarrow b, \quad \bar{b}\bar{b} \rightarrow \bar{b}$$

- Inclusive event selection

- 3 scale choices: $\mu_0 = \mu_R = \mu_F = \frac{H_T}{2}$ $H_T = p_T(e^+) + p_T(\tau^+) + p_T(\mu^-) + p_T^{\text{miss}} + p_T(b_1) + p_T(b_2) + p_T(j_1)$

$$\mu_0 = \mu_R = \mu_F = \frac{E_T}{2} \quad E_T = \sqrt{m_t^2 + p_T^2(t)} + \sqrt{m_t^2 + p_T^2(\bar{t})} + \sqrt{m_W^2 + p_T^2(W)} + p_T(j_1)$$

$$\mu_0 = \mu_R = \mu_F = m_t + \frac{m_W}{2} \quad \mathcal{Q} = |M(t) - m_t| + |M(\bar{t}) - m_t| + |M(W) - m_W|$$

- PDF sets: NNPDF3.1 [NNPDF Collaboration '17](#), CT18 [CTEQ-TEA collaboration '19](#), MSHT20 [Bailey, Cridge, Harland-Lang, Martin, Thorne '20](#)

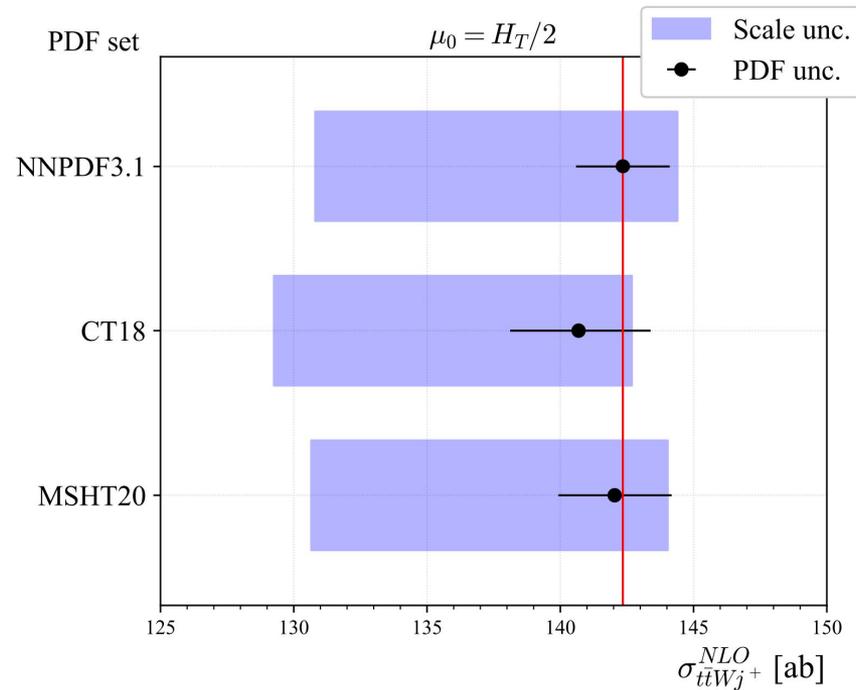
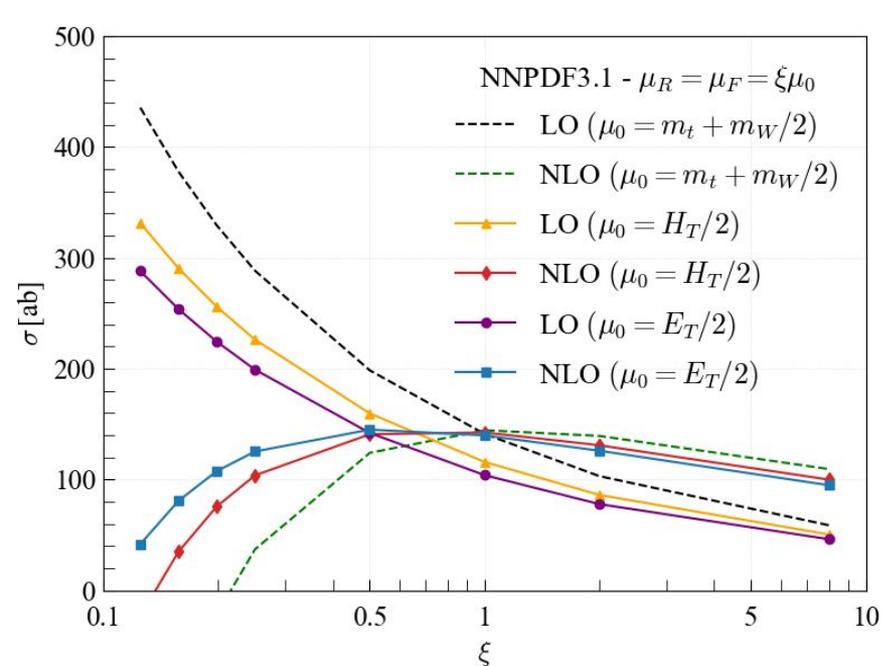
Fiducial cross-sections

PDF	μ_0	σ^{LO} [ab]	δ_{scale}	σ^{NLO} [ab]	δ_{scale}	δ_{PDF}	\mathcal{K}
NNPDF3.1	$H_T/2$	115.8	+38% -26%	142.3	+1.4% -8.1%	+1.2% -1.2%	1.23
	$E_T/2$	103.8	+37% -25%	139.7	+3.7% -9.9%	+1.2% -1.2%	1.35
	$m_t + m_W/2$	141.0	+41% -27%	144.3	+0.3% -14.1%	+1.2% -1.2%	1.02

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- LO results have about **40%** scale uncertainty
- NLO results have **10%** scale uncertainty and **1.2%** internal PDF uncertainties
- NLO results for different scale choices differ by up to **3%**
- LO cross-sections differ by about **36%**
- Differences in K-factor driven by LO result

Fiducial cross-section: Uncertainties



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Stability

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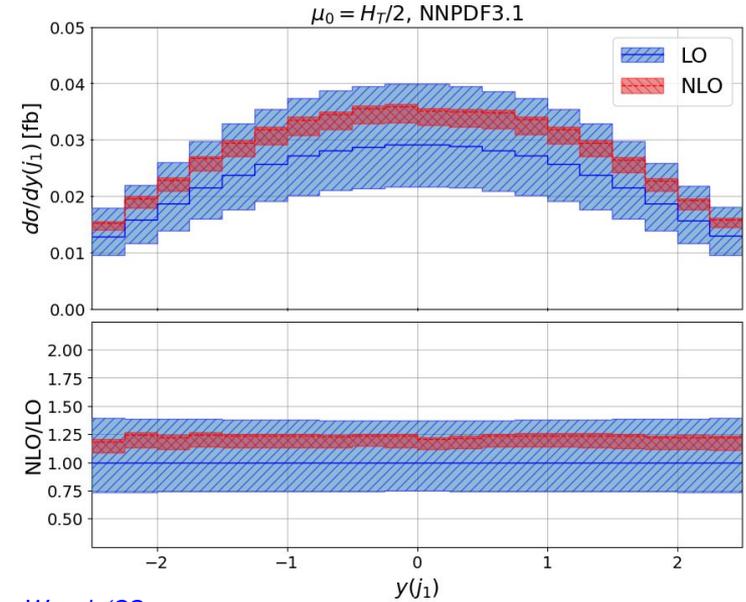
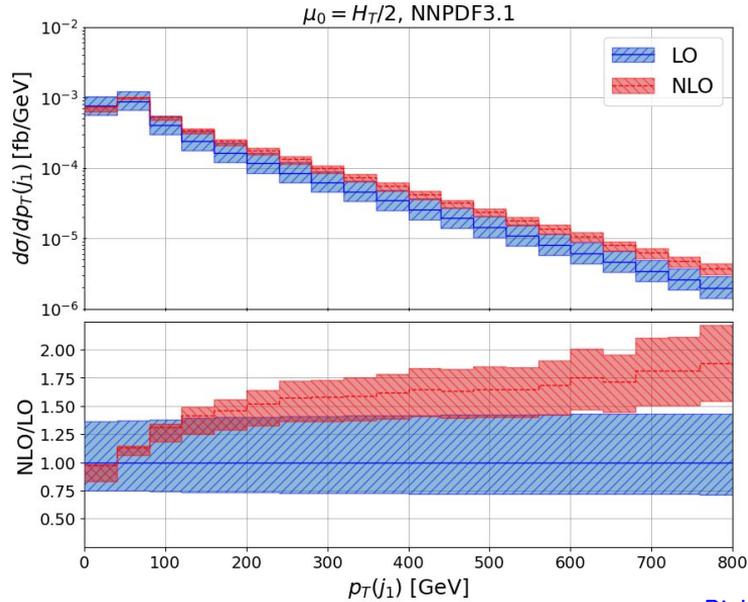
Results could depend on large logarithms introduced from cuts

- We study dependence on cuts for $p_T(j_1)$, $p_T(b)$ and p_T^{miss}
- Uncertainties keep similar relative size
- Size of K-factors changes slightly
⇒ driven by LO predictions

Results under great theoretical control!

PDF	$p_T(j)$	σ^{LO} [ab]	δ_{scale}	σ^{NLO} [ab]	δ_{scale}	δ_{PDF}	\mathcal{K}
NNPDF	25	115.8	+43.8 (38%) -29.8 (26%)	142.3	+ 2.1 (1.4%) -11.5 (8.1%)	+1.8 (1.2%) -1.8 (1.2%)	1.23
	30	103.4	+39.4 (38%) -26.7 (26%)	130.8	+ 2.1 (1.6%) -11.5 (8.8%)	+1.6 (1.2%) -1.6 (1.2%)	1.27
	35	93.5	+35.8 (38%) -24.3 (26%)	121.2	+ 2.1 (1.7%) -11.4 (9.4%)	+1.4 (1.1%) -1.4 (1.1%)	1.30
	40	85.4	+32.9 (38%) -22.2 (26%)	112.9	+ 2.7 (2.4%) -11.1 (9.8%)	+1.3 (1.1%) -1.3 (1.1%)	1.32
CT	25	133.1	+54.8 (41%) -36.2 (27%)	140.7	+ 2.0 (1.4%) -11.4 (8.1%)	+2.7 (1.9%) -2.6 (1.8%)	1.06
	30	119.2	+49.3 (41%) -32.6 (27%)	129.4	+ 2.0 (1.6%) -11.4 (8.8%)	+2.5 (1.9%) -2.3 (1.8%)	1.08
	35	108.2	+45.0 (42%) -29.7 (27%)	119.9	+ 2.1 (1.7%) -11.2 (9.4%)	+2.3 (1.9%) -2.1 (1.7%)	1.11
	40	99.1	+41.4 (42%) -27.3 (28%)	111.7	+ 2.8 (2.5%) -11.0 (9.8%)	+2.1 (1.9%) -1.9 (1.7%)	1.13
MSHT	25	124.5	+51.7 (42%) -34.1 (27%)	142.0	+ 2.0 (1.4%) -11.4 (8.0%)	+2.1 (1.5%) -2.1 (1.5%)	1.14
	30	111.4	+46.6 (42%) -30.7 (28%)	130.6	+ 2.0 (1.6%) -11.4 (8.7%)	+1.9 (1.5%) -1.9 (1.4%)	1.17
	35	101.0	+42.5 (42%) -27.9 (28%)	121.0	+ 2.1 (1.7%) -11.2 (9.3%)	+1.7 (1.4%) -1.7 (1.4%)	1.20
	40	92.5	+39.1 (42%) -25.7 (28%)	112.8	+ 2.6 (2.3%) -11.0 (9.7%)	+1.6 (1.4%) -1.5 (1.3%)	1.22

Differential distributions

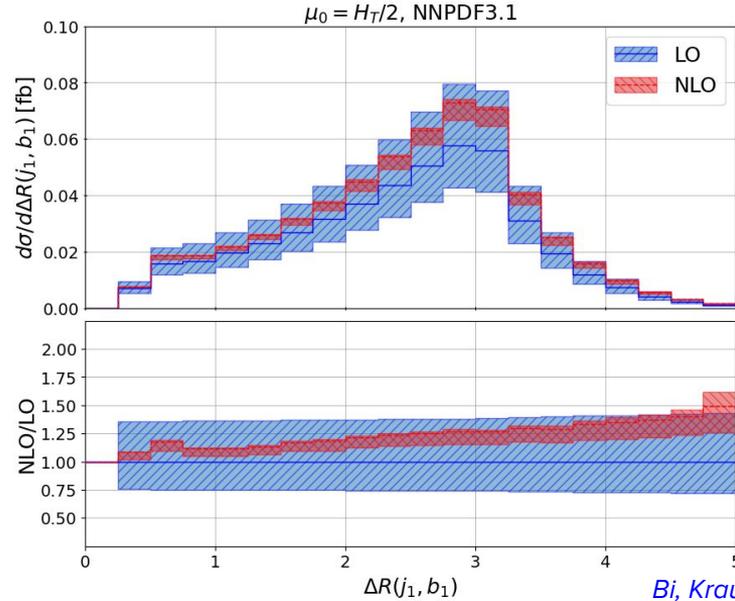


Bi, Kraus, Reinartz, Worek '23

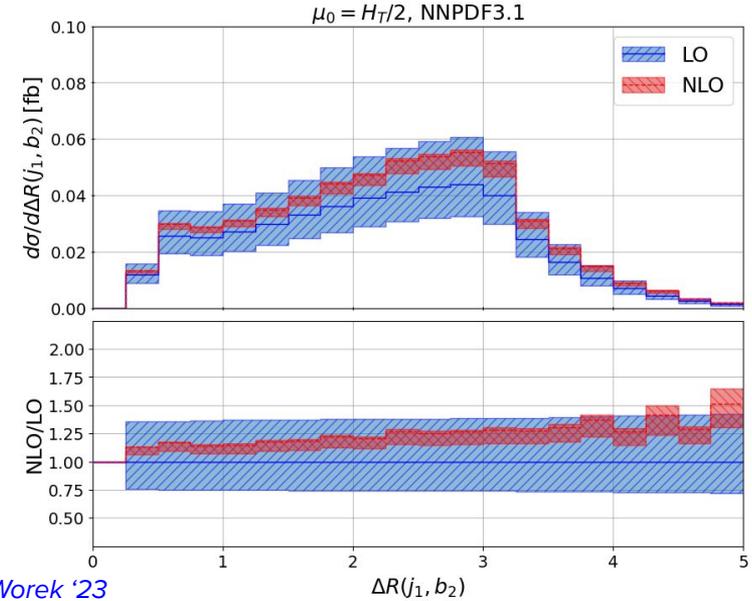
- 80% correction in tail outside of uncertainty
- Scale uncertainties are reduced from 40% at LO to below 18% at NLO
- Shows importance of NLO corrections for ttWj
- Similar observations for H_T

- Constant differential K-factor at about 20%
- Uncertainty reduced by factor 4 to 10%

Differential distributions



Bi, Kraus, Reinartz, Worek '23

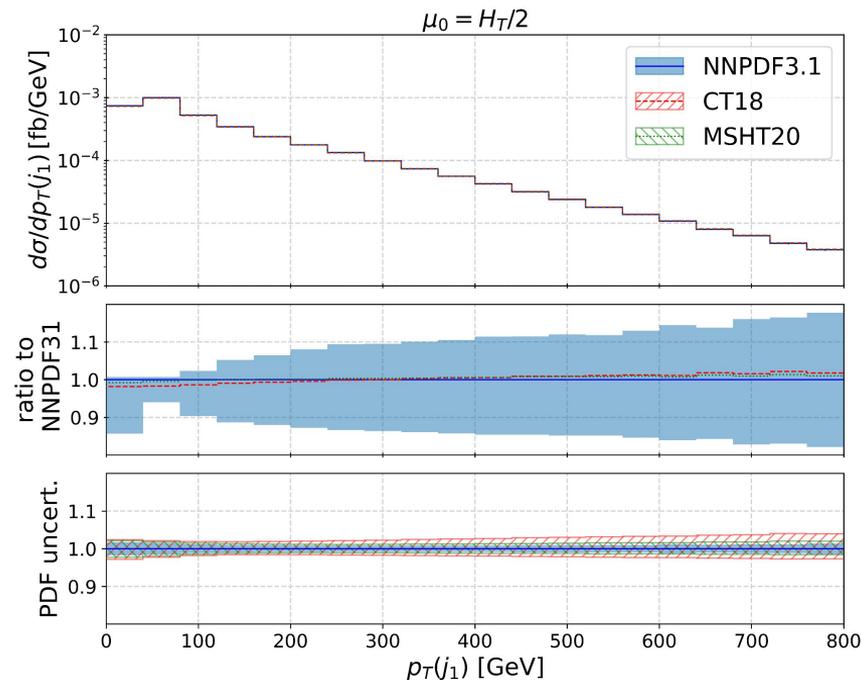


- Hardest b-jet and light jet are mostly produced back-to-back
- 2nd b-jet peak is smeared out
- Consistent with observation that light jet is emitted in **production in 90%** of cases

$$Q = |M(t) - m_t| + |M(\bar{t}) - m_t| + |M(W) - m_W|$$

Differential PDF uncertainties

- Small difference due to PDF set choice about 2%
- Internal PDF uncertainties go up to 4% level in the tail for CT18 and 2% for NNPDF3.1
- Both are negligible compared to NLO scale uncertainties at 18%



Bi, Kraus, Reinartz, Worek '23

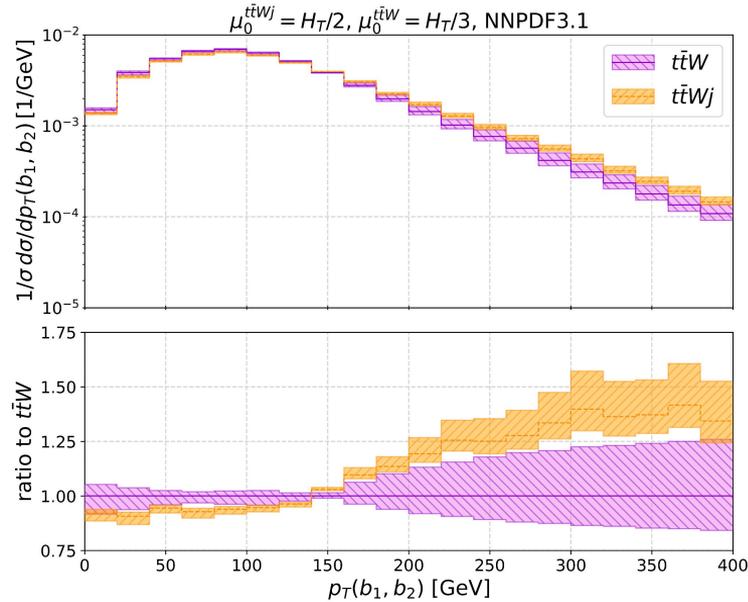
Additional jet activity in ttW

	$\sigma_{H_T/3}^{t\bar{t}W^+}$ [ab]	$\sigma_{H_T/2}^{t\bar{t}W^+j}$ [ab]	$\sigma_{E_T/3}^{t\bar{t}W^+}$ [ab]	$\sigma_{E_T/2}^{t\bar{t}W^+j}$ [ab]	$\sigma_{m_t+m_W/2}^{t\bar{t}W^+}$ [ab]	$\sigma_{m_t+m_W/2}^{t\bar{t}W^+j}$ [ab]
LO	216.6 ^{+24%} _{-18%}	115.8 ^{+38%} _{-26%}	198.7 ^{+23%} _{-18%}	103.9 ^{+37%} _{-25%}	202.6 ^{+24%} _{-18%}	141.0 ^{+41%} _{-27%}
NLO	254.6 ^{+2.8%} _{-5.9%}	142.3 ^{+1.4%} _{-8.1%}	249.6 ^{+4.6%} _{-6.8%}	139.7 ^{+3.7%} _{-9.9%}	252.3 ^{+4.5%} _{-6.8%}	144.3 ^{+0.3%} _{-14.1%}

Bi, Kraus, Reinartz, Worek '23

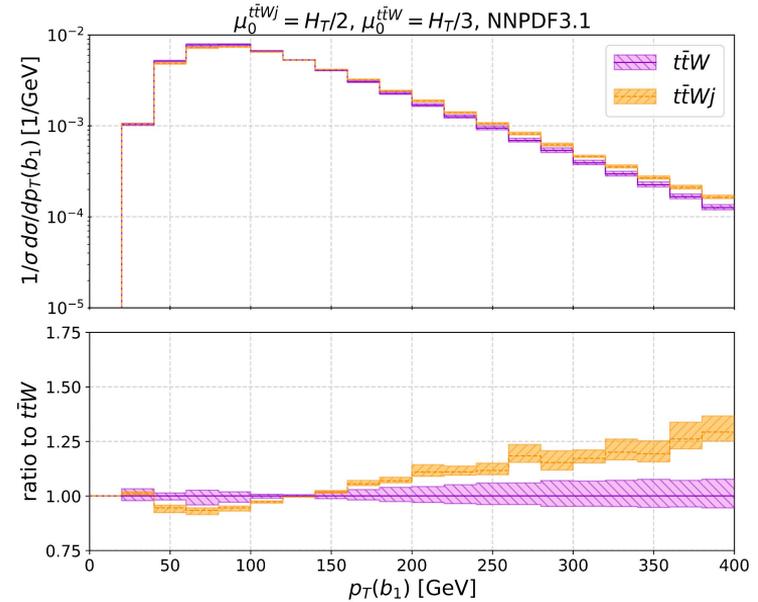
- ttWj contribution to inclusive NLO ttW sample is **50% - 70%** depending on scale choice and perturbative order
- Additional jet activity needs to be understood already at the integrated level for the ttW process
- NNLO corrections or merged samples should be used instead of NLO ttW
- For experiments additional jet activity affects reconstruction

Additional jet activity in ttW



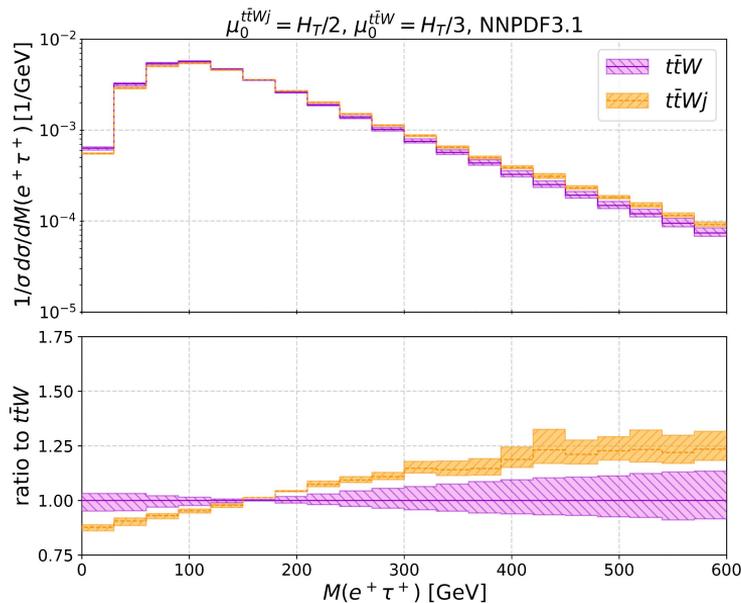
- Differences up to **42%** in tails well outside the uncertainty bands
- Uncertainties go up **25%** for $t\bar{t}W$ and **14%** for $t\bar{t}Wj$

Bi, Kraus, Reinartz, Worek '23



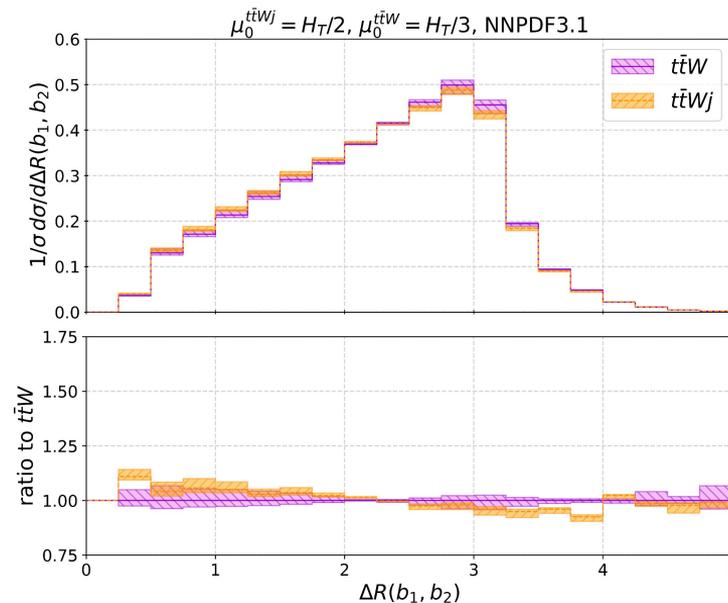
- Up to **30%** difference in tail
- Uncertainties for both processes similar at **6% - 8%**

Additional jet activity in ttW



- Difference is up to 24%
- Overall shape distortion up to 36%
- Uncertainty goes up from 2% - 5% in the beginning and up to 8% - 13% in the tail

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- ttW slightly prefers back-to-back emission of b_1 and b_2
- Shape distortion up to 20% with uncertainties covering 4% - 7%

Exclusive samples for $t\bar{t}Wj$

(μ_R, μ_F)	$\sigma_{H_T/2}^{t\bar{t}W^+j}(N_j = 1)$ [ab]	$\sigma_{H_T/2}^{t\bar{t}W^+j}(N_j = 2)$ [ab]	$\sigma_{H_T/2}^{t\bar{t}W^+j}(N_j \geq 1)$ [ab]
(μ_0, μ_0)	$78.6^{+13\%}_{-48\%}$	$63.7^{+56\%}_{-34\%}$	$142.3^{+1.4\%}_{-8.1\%}$
(μ_R, μ_F)	$\delta\sigma_{H_T/2}^{t\bar{t}W^+j}(N_j = 1)$ [ab]	$\delta\sigma_{H_T/2}^{t\bar{t}W^+j}(N_j = 2)$ [ab]	$\delta\sigma_{H_T/2}^{t\bar{t}W^+j}(N_j \geq 1)$ [ab]
$(2\mu_0, 2\mu_0)$	+9.9 (+13%)	-21.4 (-34%)	-11.5 (-8.1%)
$(\mu_0/2, \mu_0/2)$	-37.4 (-48%)	+35.7 (+56%)	-1.6 (-1.1%)
$(2\mu_0, \mu_0)$	+9.0 (+11%)	-18.0 (-28%)	-9.0 (-6.3%)
$(\mu_0/2, \mu_0)$	-28.7 (-37%)	+27.8 (+44%)	-0.9 (-0.6%)
$(\mu_0, 2\mu_0)$	+3.5 (+4.5%)	-4.8 (-7.5%)	-1.2 (-0.8%)
$(\mu_0, \mu_0/2)$	-3.5 (-4.5%)	+5.5 (+8.6%)	+2.0 (+1.4%)

Summary

- NLO corrections small on integrated fiducial cross-section level
- Up to 80% NLO corrections in specific phase-space regions
- PDF uncertainties are negligible compared to scale uncertainties
- More than half ttW events are in association with a light jet
- Large shape distortion due to additional jet on differential level

Outlook

- Combine our ttW and $ttWj$ results into a merged sample

Thanks you for your attention!

Backup: Cuts and input parameters

- Cuts

$$p_T(\ell) > 25 \text{ GeV} ,$$

$$|y(\ell)| < 2.5 ,$$

$$p_T(j_b) > 25 \text{ GeV} ,$$

$$|y(j_b)| < 2.5 ,$$

$$p_T(j) > 25 \text{ GeV} ,$$

$$|y(j)| < 2.5 ,$$

$$\Delta R_{\ell\ell} > 0.4 ,$$

$$\Delta R_{b\ell} > 0.4 ,$$

$$\Delta R_{j\ell} > 0.4 ,$$

$$\Delta R_{bj} > 0.4 ,$$

$$\Delta R_{bb} > 0.4 ,$$

$$\Delta R_{jj} > 0.4 ,$$

- Input parameters

$$G_\mu = 1.166378 \cdot 10^{-5} \text{ GeV}^{-2} ,$$

$$m_t = 172.5 \text{ GeV} ,$$

$$m_W = 80.379 \text{ GeV} ,$$

$$\Gamma_W^{\text{NLO}} = 2.0972 \text{ GeV} ,$$

$$m_Z = 91.1876 \text{ GeV} ,$$

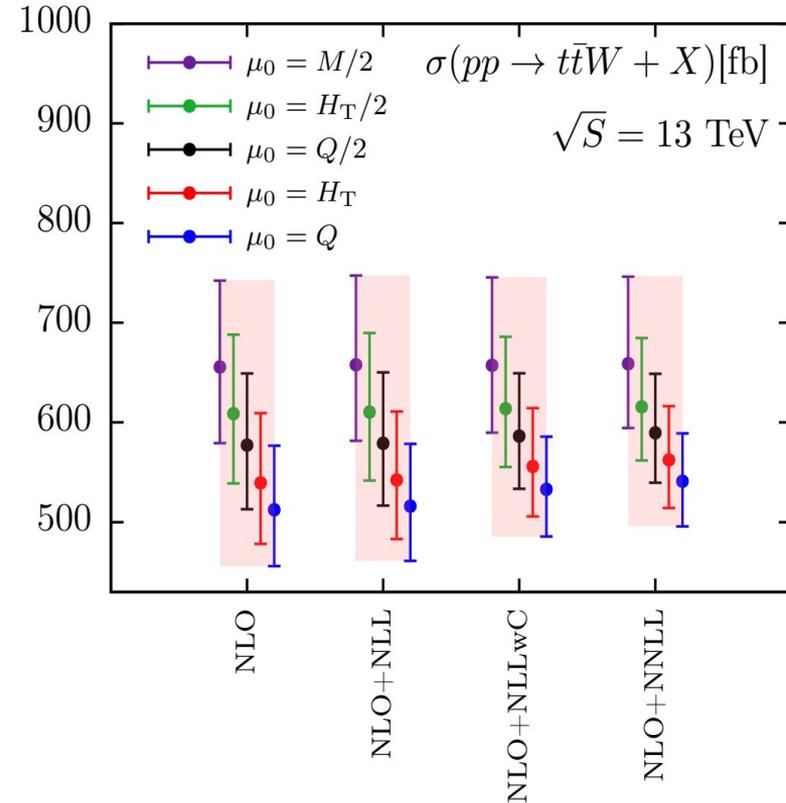
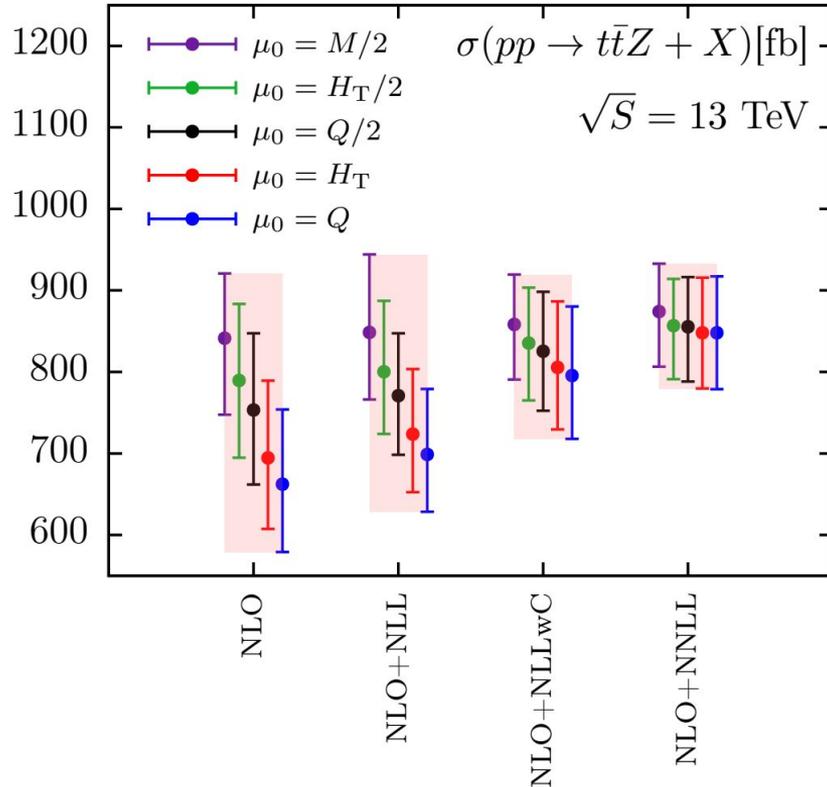
$$\Gamma_Z^{\text{NLO}} = 2.5074 \text{ GeV} .$$

$$\Gamma_{t, \text{off-shell}}^{\text{LO}} = 1.45766 \text{ GeV} ,$$

$$\Gamma_{t, \text{off-shell}}^{\text{NLO}} = 1.33254 \text{ GeV}$$

Backup: Resummation

Kulesza, Motyka, Schwartländer, Stebel, Theeuwes '20



Backup: Subprocesses

Leading order:

- 12 subprocesses with 1868 Feynman diagrams each

$$u\bar{d} / \bar{d}u \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} g,$$

$$c\bar{s} / \bar{s}c \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} g,$$

$$gu / ug \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} d,$$

$$g\bar{d} / \bar{d}g \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} \bar{u},$$

$$gc / cg \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} s,$$

$$g\bar{s} / \bar{s}g \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} \bar{c},$$

Backup: Subprocesses for real emission

Bi, Kraus, Reinartz, Worek '23

PARTONIC SUBPROCESS	NUMBER OF FEYNMAN DIAGRAMS	NUMBER OF CS DIPOLES	NUMBER OF NS SUBTRACTIONS
$gg \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} qq'$	16662	36	9
$qq' \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} gg$	16662	40	10
$qg \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} q'g$	16662	36	9
$qq' \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} qq'$	6240	12	3
$q\bar{q} \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} qq'$	6240	8	2
$qq' \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} b\bar{b}$	6240	16	4
$qq' \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} QQ'$	3120	8	2
$q\bar{q} \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} QQ'$	3120	4	1
$qQ' \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} qQ'$	3120	8	2
$b\bar{b} \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} qq'$	6240	12	3
$bq \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} bQ'$	6240	16	4
$bq \rightarrow e^+ \nu_e \mu^- \bar{\nu}_\mu \tau^+ \nu_\tau b\bar{b} bq'$	6240	16	4

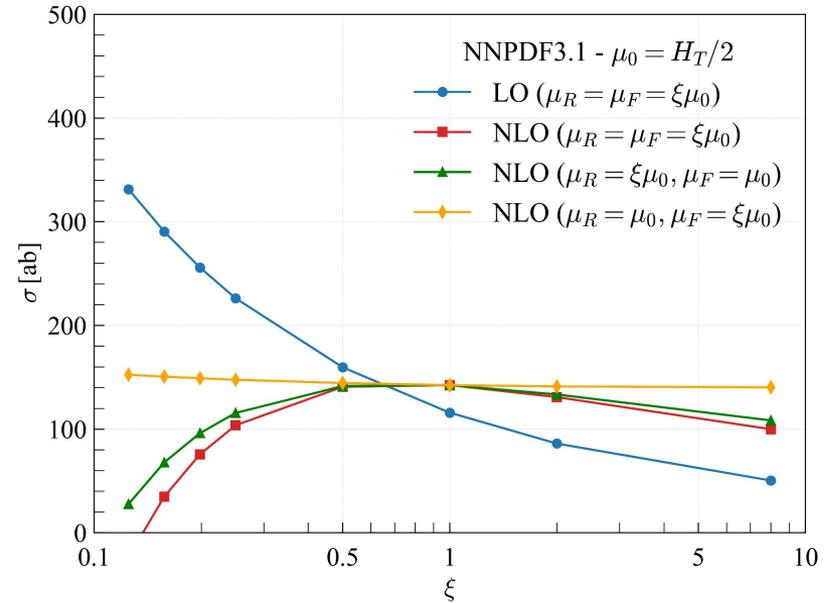
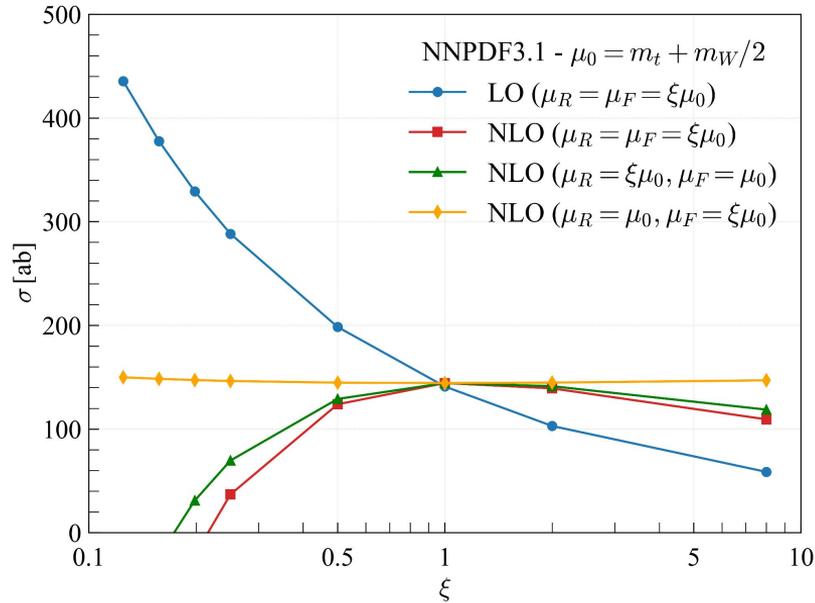
Backup: Stability

PDF	$p_T(b)$	σ^{LO} [ab]	δ_{scale}	σ^{NLO} [ab]	δ_{scale}	δ_{PDF}	\mathcal{K}
NNPDF	25	115.8	+43.8 (38%) -29.8 (26%)	142.3	+ 2.1 (1.4%) -11.5 (8.1%)	+1.8 (1.2%) -1.8 (1.2%)	1.23
	30	106.1	+40.2 (38%) -27.3 (26%)	129.8	+ 1.9 (1.4%) -10.4 (8.0%)	+1.6 (1.2%) -1.6 (1.2%)	1.22
	35	96.1	+36.4 (38%) -24.7 (26%)	117.3	+ 1.7 (1.4%) - 9.4 (8.0%)	+1.4 (1.2%) -1.4 (1.2%)	1.22
	40	86.1	+32.7 (38%) -22.2 (26%)	105.0	+ 1.5 (1.5%) - 8.4 (8.0%)	+1.3 (1.2%) -1.3 (1.2%)	1.22
CT	25	133.1	+54.8 (41%) -36.2 (27%)	140.7	+ 2.0 (1.4%) -11.4 (8.1%)	+2.7 (1.9%) -2.6 (1.8%)	1.06
	30	122.0	+50.2 (41%) -33.2 (27%)	128.3	+ 1.8 (1.4%) -10.3 (8.0%)	+2.5 (1.9%) -2.3 (1.8%)	1.05
	35	110.4	+45.5 (41%) -30.1 (27%)	115.9	+ 1.6 (1.4%) - 9.3 (8.0%)	+2.2 (1.9%) -2.1 (1.8%)	1.05
	40	99.0	+40.8 (41%) -27.0 (27%)	103.8	+ 1.5 (1.4%) - 8.3 (8.0%)	+2.0 (1.9%) -1.9 (1.8%)	1.05
MSHT	25	124.5	+51.7 (42%) -34.1 (27%)	142.0	+ 2.0 (1.4%) -11.4 (8.0%)	+2.1 (1.5%) -2.1 (1.5%)	1.14
	30	114.0	+47.4 (42%) -31.2 (27%)	129.6	+ 1.8 (1.4%) -10.3 (7.9%)	+1.9 (1.5%) -1.9 (1.5%)	1.14
	35	103.2	+42.9 (42%) -28.3 (27%)	117.0	+ 1.6 (1.4%) - 9.3 (7.9%)	+1.8 (1.5%) -1.7 (1.5%)	1.13
	40	92.5	+38.5 (42%) -25.4 (27%)	104.9	+ 1.5 (1.4%) - 8.3 (7.9%)	+1.6 (1.5%) -1.6 (1.5%)	1.13

PDF	p_T^{miss} [GeV]	σ^{LO} [ab]	δ_{scale}	σ^{NLO} [ab]	δ_{scale}	δ_{PDF}	\mathcal{K}
NNPDF	0	115.8	+43.8 (38%) -29.8 (26%)	142.3	+ 2.1 (1.4%) -11.5 (8.1%)	+1.8 (1.2%) -1.8 (1.2%)	1.23
	10	114.6	+43.4 (38%) -29.5 (26%)	140.9	+ 2.0 (1.4%) -11.4 (8.1%)	+1.7 (1.2%) -1.7 (1.2%)	1.23
	20	111.2	+42.1 (38%) -28.6 (26%)	137.1	+ 2.0 (1.5%) -11.2 (8.2%)	+1.7 (1.2%) -1.7 (1.2%)	1.23
	30	105.9	+40.1 (38%) -27.2 (26%)	131.0	+ 1.9 (1.5%) -10.8 (8.3%)	+1.6 (1.2%) -1.6 (1.2%)	1.24
CT	0	133.1	+54.8 (41%) -36.2 (27%)	140.7	+ 2.0 (1.4%) -11.4 (8.1%)	+2.7 (1.9%) -2.6 (1.8%)	1.06
	10	131.7	+54.2 (41%) -35.8 (27%)	139.3	+ 2.0 (1.4%) -11.3 (8.1%)	+2.7 (1.9%) -2.5 (1.8%)	1.06
	20	127.8	+52.6 (41%) -34.8 (27%)	135.5	+ 1.9 (1.4%) -11.1 (8.2%)	+2.6 (1.9%) -2.5 (1.8%)	1.06
	30	121.7	+50.1 (41%) -33.1 (27%)	129.4	+ 1.9 (1.5%) -10.7 (8.3%)	+2.5 (1.9%) -2.4 (1.8%)	1.06
MSHT	0	124.5	+51.7 (42%) -34.1 (27%)	142.0	+ 2.0 (1.4%) -11.4 (8.0%)	+2.1 (1.5%) -2.1 (1.5%)	1.14
	10	123.2	+51.2 (42%) -33.7 (27%)	140.6	+ 2.0 (1.4%) -11.3 (8.0%)	+2.1 (1.5%) -2.1 (1.5%)	1.14
	20	119.5	+49.7 (42%) -32.7 (27%)	136.8	+ 1.9 (1.4%) -11.0 (8.1%)	+2.1 (1.5%) -2.0 (1.5%)	1.14
	30	113.8	+47.3 (42%) -31.2 (27%)	130.7	+ 1.9 (1.4%) -10.7 (8.2%)	+2.0 (1.5%) -1.9 (1.5%)	1.15
MSHT	40	106.3	+44.2 (42%) -29.1 (27%)	122.6	+ 1.8 (1.5%) -10.2 (8.3%)	+1.8 (1.5%) -1.8 (1.5%)	1.15

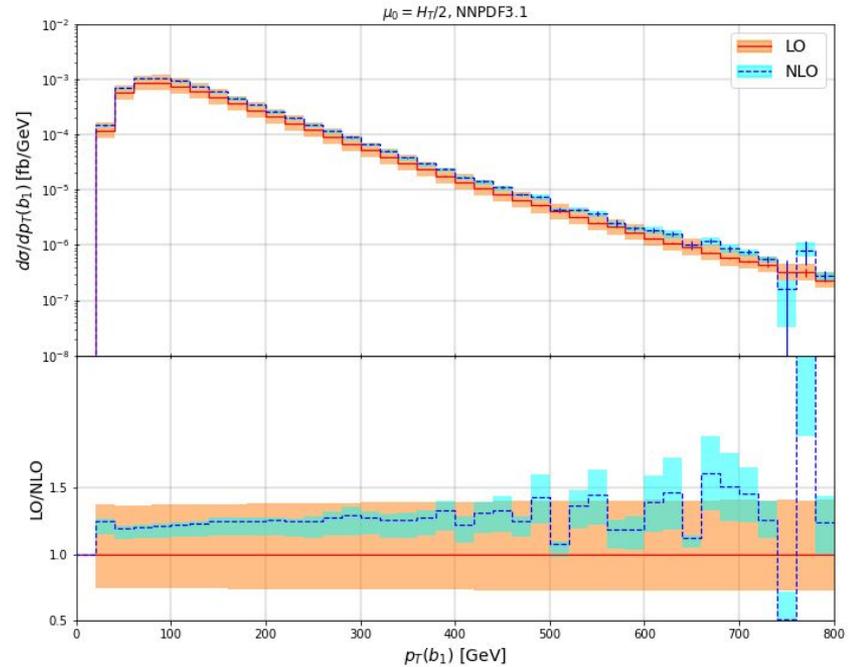
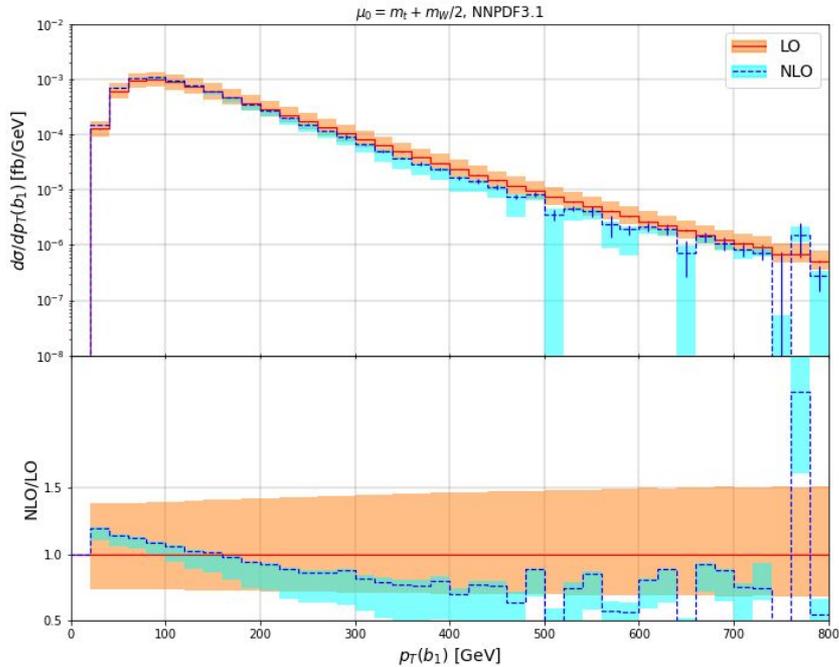
Bi, Kraus, Reinartz, Worek '23

Backup: Dependence on scales



Bi, Kraus, Reinartz, Worek '23

Backup: Differential distributions for fixed scale



Backup: Exclusive samples in ttW

(μ_R, μ_F)	$\sigma_{H_T/2}^{t\bar{t}W^+}(N_j = 0)$ [ab]	$\sigma_{H_T/2}^{t\bar{t}W^+}(N_j = 1)$ [ab]	$\sigma_{H_T/2}^{t\bar{t}W^+}(N_j \geq 0)$ [ab]
(μ_0, μ_0)	$104.6^{+20\%}_{-44\%}$	$141.9^{+41\%}_{-27\%}$	$246.4^{+5.0\%}_{-7.0\%}$
(μ_R, μ_F)	$\delta\sigma_{H_T/2}^{t\bar{t}W^+}(N_j = 0)$ [ab]	$\delta\sigma_{H_T/2}^{t\bar{t}W^+}(N_j = 1)$ [ab]	$\delta\sigma_{H_T/2}^{t\bar{t}W^+}(N_j \geq 0)$ [ab]
$(2\mu_0, 2\mu_0)$	$+21.1 (+20\%)$	$-38.4 (-27\%)$	$-17.2 (-7.0\%)$
$(\mu_0/2, \mu_0/2)$	$-45.7 (-44\%)$	$+58.1 (+41\%)$	$+12.4 (+5.0\%)$
$(2\mu_0, \mu_0)$	$+19.1 (+18\%)$	$-32.3 (-23\%)$	$-13.2 (-5.3\%)$
$(\mu_0/2, \mu_0)$	$-40.0 (-38\%)$	$+46.6 (+33\%)$	$+6.6 (+2.7\%)$
$(\mu_0, 2\mu_0)$	$+4.1 (+3.9\%)$	$-7.8 (-5.5\%)$	$-3.8 (-1.5\%)$
$(\mu_0, \mu_0/2)$	$-3.1 (-2.9\%)$	$+8.7 (+6.1\%)$	$+5.6 (+2.3\%)$