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

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Collaborative Research Center TRR 257
Particle Physics Phenomenology after the Higgs Discovery

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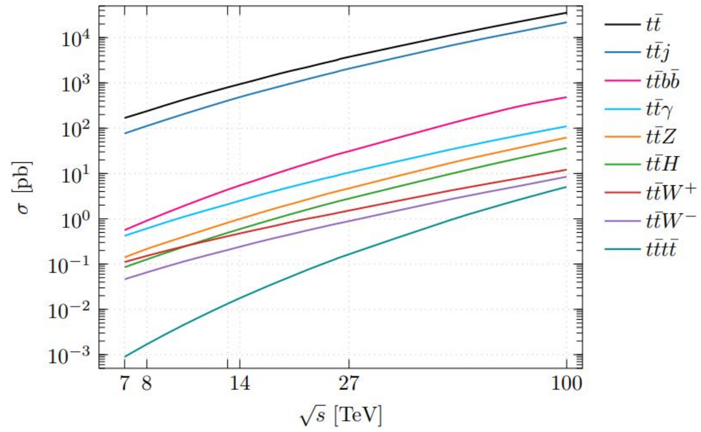
Motivation

- Rare process at LHC
- Background process to $t\bar{t}H$ and $t\bar{t}t\bar{t}$
- Irreducible background to same-sign dilepton searches
- Charge asymmetries are larger than $t\bar{t}$

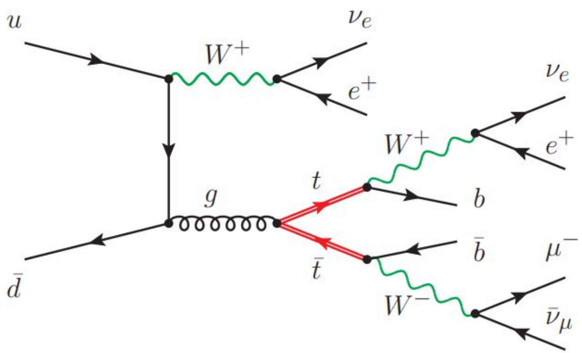
$$A_C^{\Delta|y|} = \frac{\sigma(\Delta|y|>0) - \sigma(\Delta|y|<0)}{\sigma(\Delta|y|>0) + \sigma(\Delta|y|<0)}, \qquad \Delta|y| = |y_t| - |y_{\bar{t}}|$$

- 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

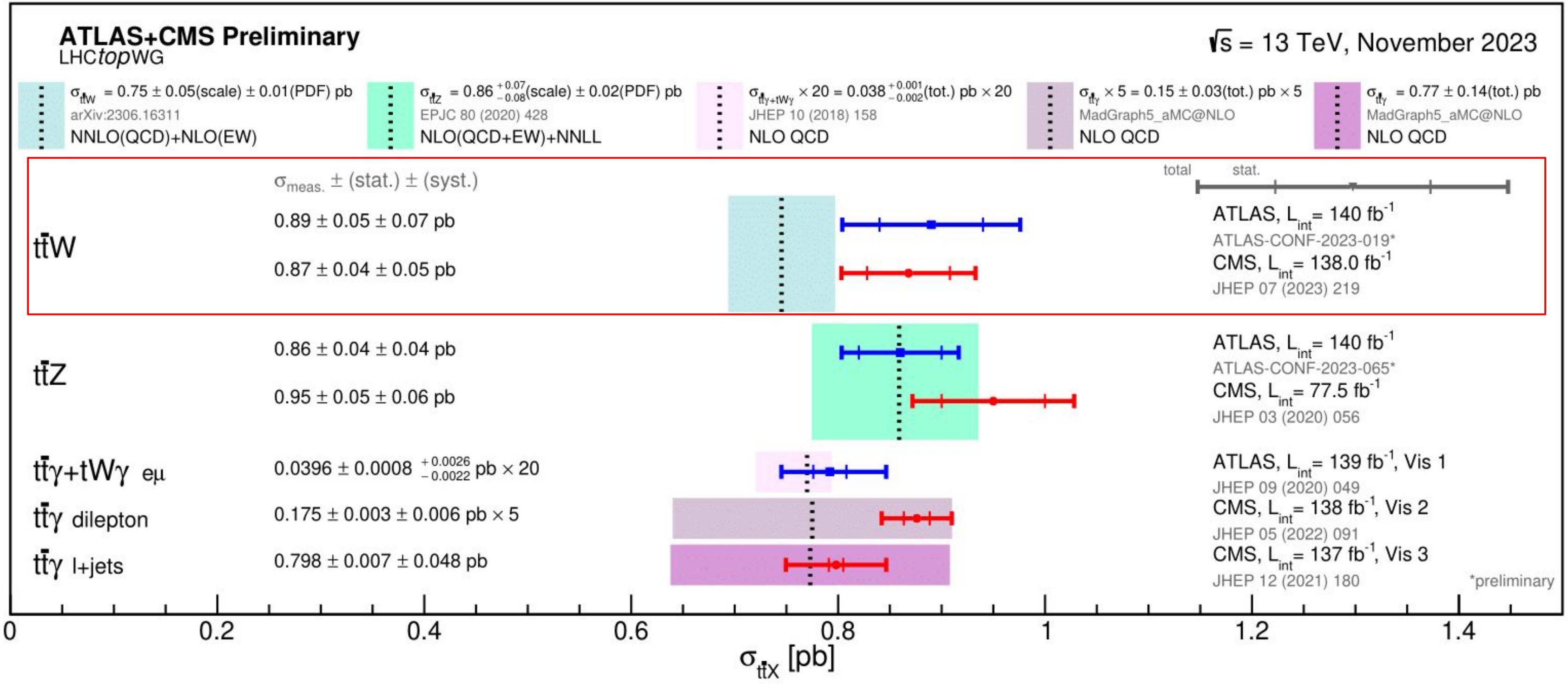


Report of the Topical Group on Top quark physics and heavy flavor production for Snowmass 2021



Bevilacqua, Bi, Hartanto, Kraus, Worek '20

Experimental status



LHC Top Working Group '23

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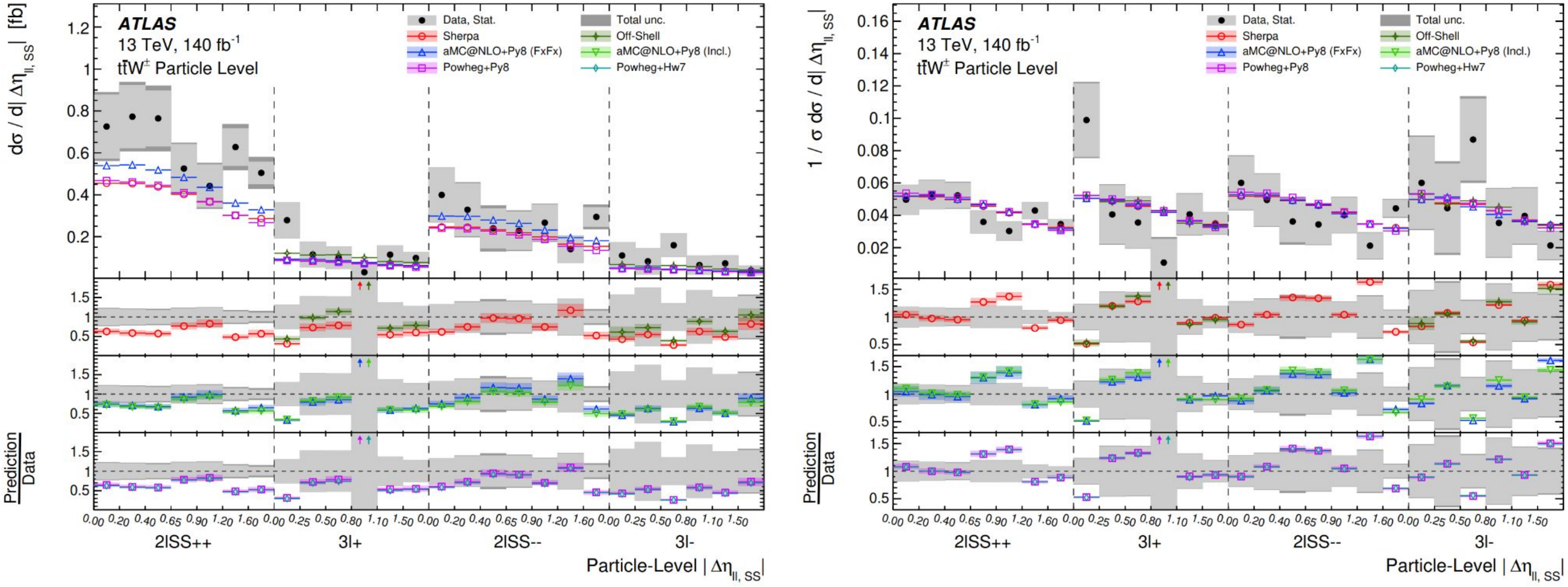
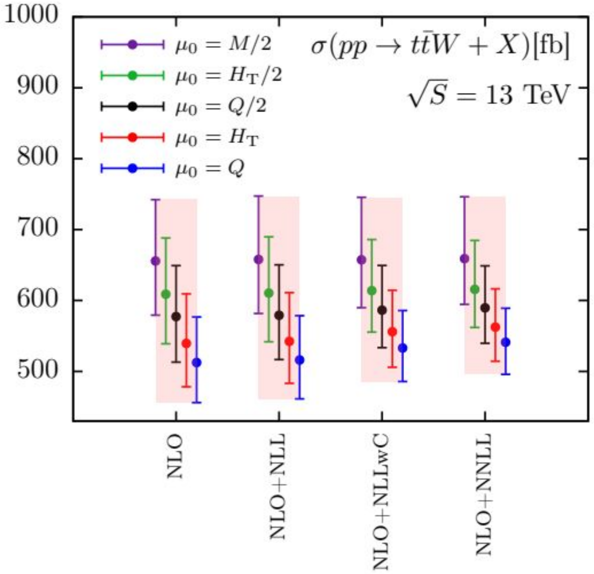


ATLAS Collaboration ‘24

Theory status

- NLO QCD + EW / Complete NLO for stable tops
  Frixione, Hirschi, Pagani, Shao, Zaro '15 /*Frederix, Pagani, Zaro '17*
- Stable tops matched to parton shower *Cordero, Kraus, Reina '21*
- NLO QCD with off-shell effects
  Bevilacqua, Bi, Hartanto, Kraus, Worek '20 / *Denner, Pellicciolli '20*
- NLO QCD and EW corrections with subleading contributions with off-shell effects
  Ansgar Denner, Giovanni Pellicciolli '21 / *Bevilacqua, Bi, Cordero, Hartanto, Kraus, Nasufi, Reina, Worek '21*
- FxFx jet merging up to two jets with EW corrections and subleading contributions *Frederix, Tsinikos '21*
- ttWj at NLO QCD with off-shell effects
  Bi, Kraus, Reinartz, Worek '23
- Approximate NNLO QCD + NLO EW
  Buonocore, Devoto, Grazzini, Kallweit, Mazzitelli, Rottoli, Savoini '23
- MECs to top quark decays Frederix, Gellersen, Nasufi '24

- Soft-gluon resummation



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

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- NLO QCD + EW / Complete NLO for stable tops
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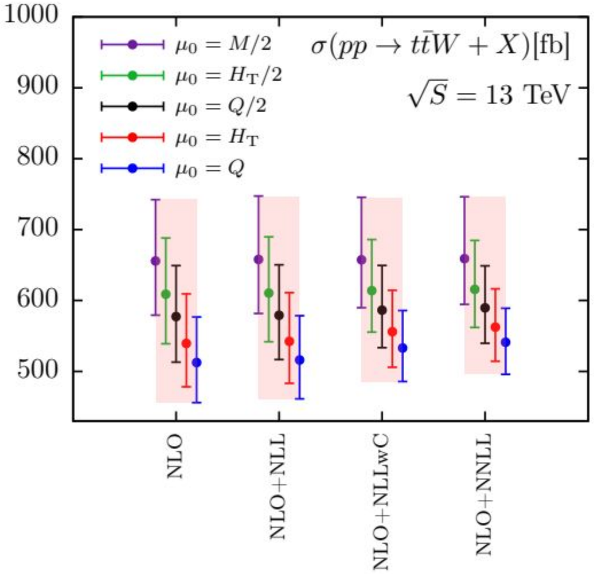
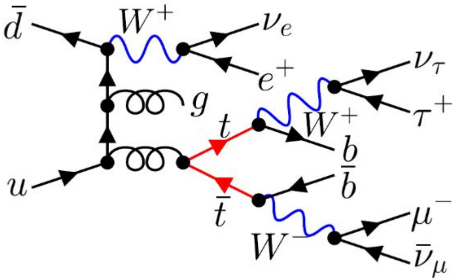


Kulesza, Motyka, Schwartländer, Stebel, '18 '20 / *Broggio, Ferroglia, Frederix, Pagani, Pecjak, Tsinikos '19*

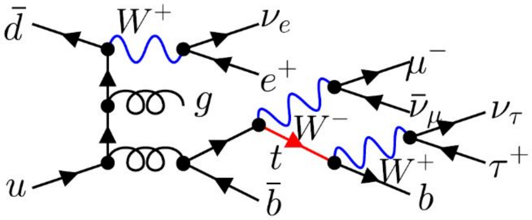
Setup of the calculation

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

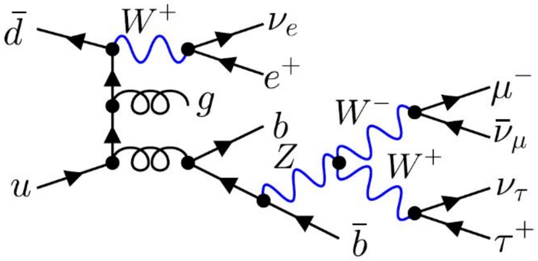
Double-resonant



Single-resonant



Non-resonant



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Diagrams created with FeynGame
Harlander, Klein, Lipp '20

Full off-shell calculation = DR + SR + NR + interference + Breit-Wigner propagators

Setup of the calculation

- LHC with $\sqrt{s} = 13\,\mathrm{TeV}$
- Diagonal CKM matrix
- 5 flavour scheme
- Top-width is a fixed parameter throughout the calculation $\Gamma^{\mathrm{NLO}}_{t,\,\text{off-shell}} = 1.33254\,\mathrm{GeV}$
- anti- k_T jet algorithm with R = 0.4 *Cacciari, Salam, Soyez '08*
- charge-aware b-jet recombination scheme with exactly 2 b-jets

$$bg \to b\,, \qquad \bar{b}g \to \bar{b}\,, \qquad b\bar{b} \to g\,, \qquad bb \to b\,, \qquad \bar{b}\bar{b} \to \bar{b}$$

- Inclusive event selection
- 3 scale choices:

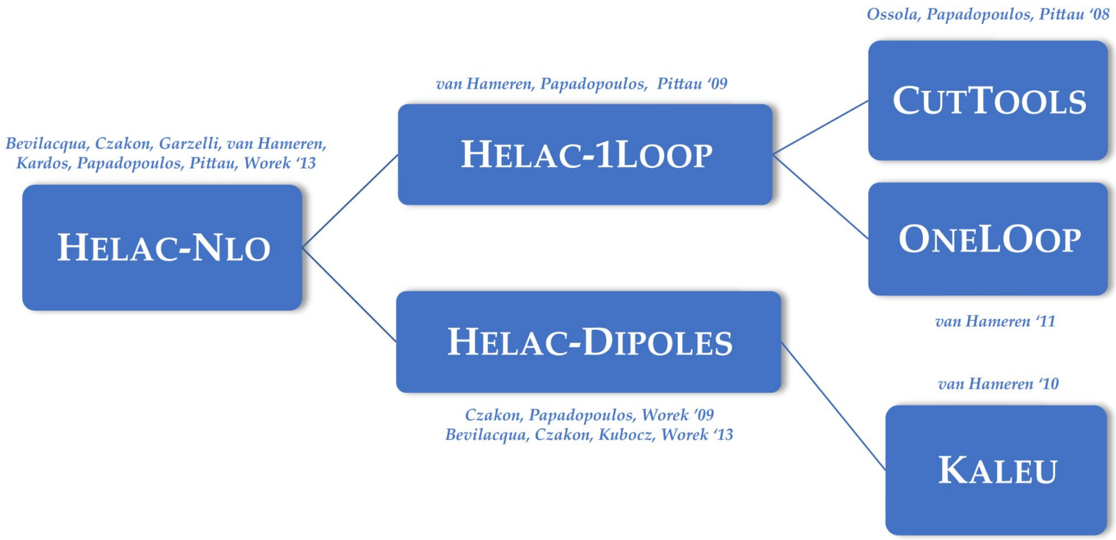
$$\mu_0 = \mu_R = \mu_F = \frac{H_T}{2}\,, \qquad H_T = p_T(e^+) + p_T(\tau^+) + p_T(\mu^-) + p_T^{miss} + p_T(b_1) + p_T(b_2) + p_T(j_1)$$

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

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

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

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)

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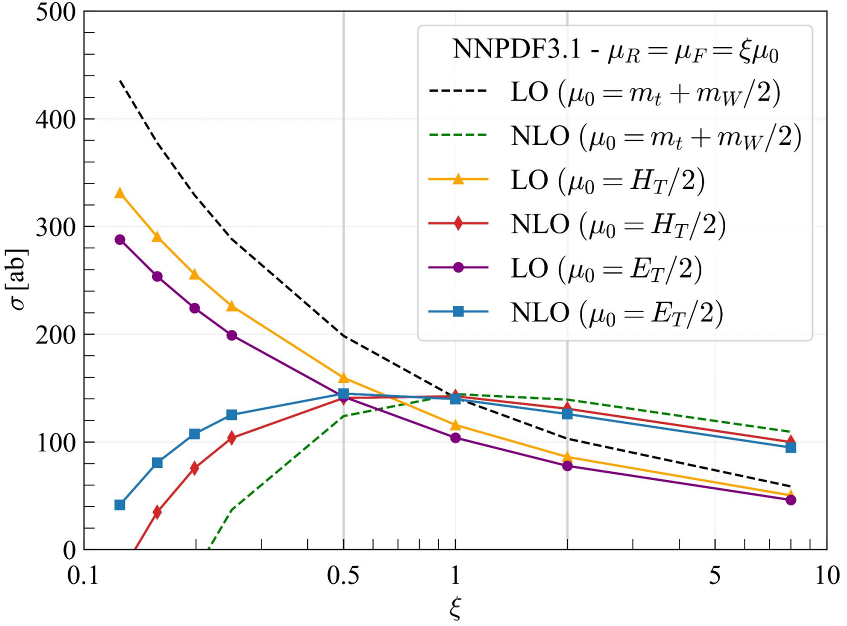
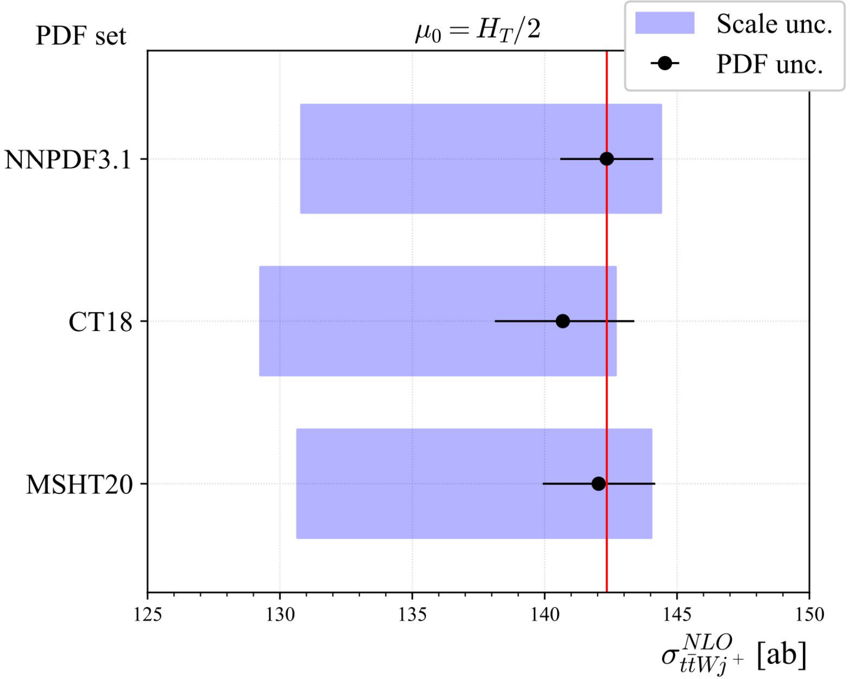
- LO results have about 40% scale uncertainty
- NLO results have 10% scale uncertainty and 1.2% internal PDF uncertainties
- NLO results for different scale choices differ by up to 3%
- LO cross-sections differ by about 36%
- Differences in K-factor driven by LO result

Fiducial cross-section: Uncertainties





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Stability

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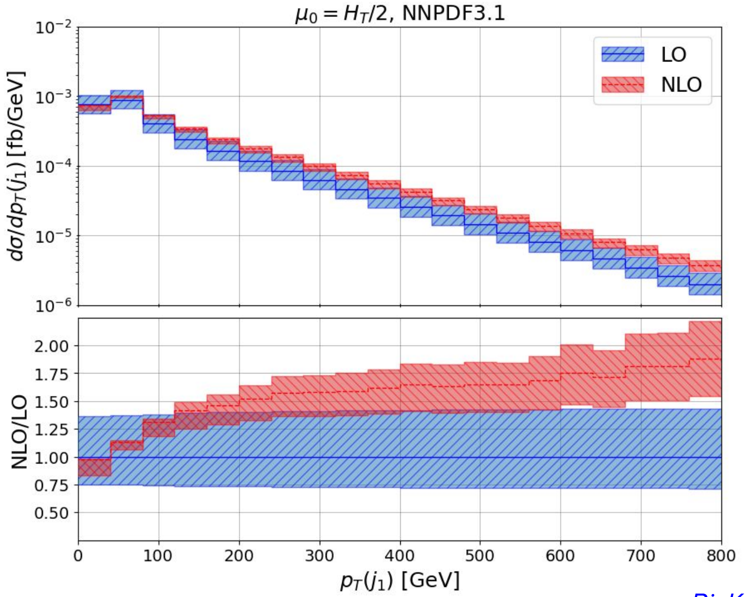
Results could depend on large logarithms introduced from cuts

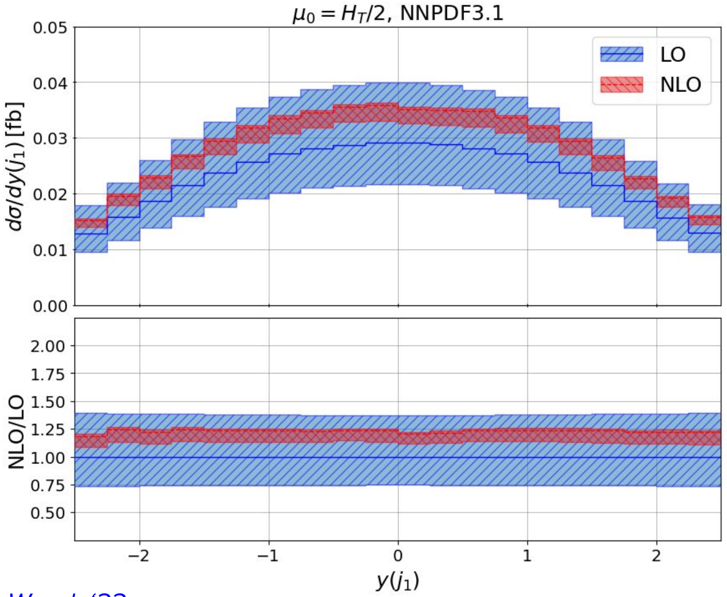
- We study dependence on cuts for $p_T(j_1)$, $p_T(b)$ and p_T^{miss}
- Uncertainties keep similar relative size
- Size of K-factors changes slightly
  ⇒ driven by LO predictions

Results under great theoretical control!

PDF	$p_T(j)$	$\sigma^{\rm LO}$ [ab]	$\delta_{\rm scale}$	$\sigma^{\rm NLO}$ [ab]	$\delta_{\rm scale}$	$\delta_{\rm PDF}$	$\mathcal{K}$
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





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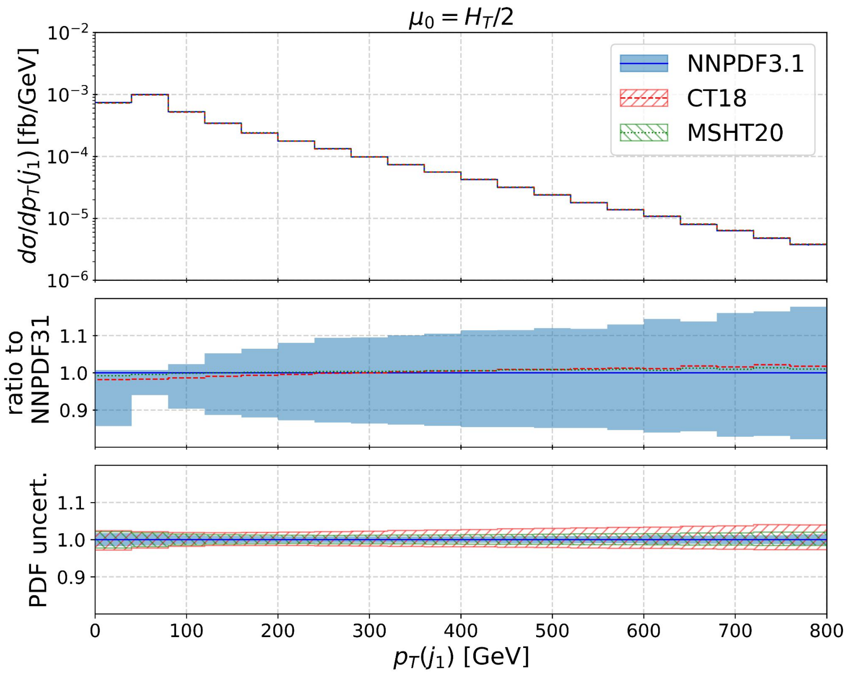
- 80% correction in tail outside of uncertainty
- Scale uncertainties are reduced from 40% at LO to below 18% at NLO
- Shows importance of NLO corrections for ttWj
- Similar observations for H_T

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

Differential 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%



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Additional jet activity in ttW

	$\sigma^{t\bar{t}W^+}_{H_T/3}$ [ab]	$\sigma^{t\bar{t}W^+j}_{H_T/2}$ [ab]	$\sigma^{t\bar{t}W^+}_{E_T/3}$ [ab]	$\sigma^{t\bar{t}W^+j}_{E_T/2}$ [ab]	$\sigma^{t\bar{t}W^+}_{m_t+m_W/2}$ [ab]	$\sigma^{t\bar{t}W^+j}_{m_t+m_W/2}$ [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	$254.6^{+2.8\%}_{-5.9\%}$	$142.3^{+1.4\%}_{-8.1\%}$	$249.6^{+4.6\%}_{-6.8\%}$	$139.7^{+3.7\%}_{-9.9\%}$	$252.3^{+4.5\%}_{-6.8\%}$	$144.3^{+\ 0.3\%}_{-14.1\%}$

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- 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

Additional jet activity in ttW

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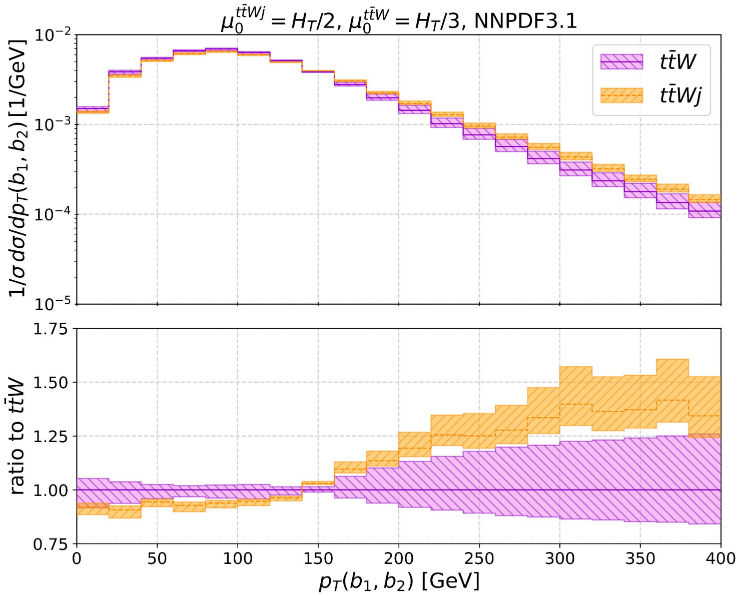

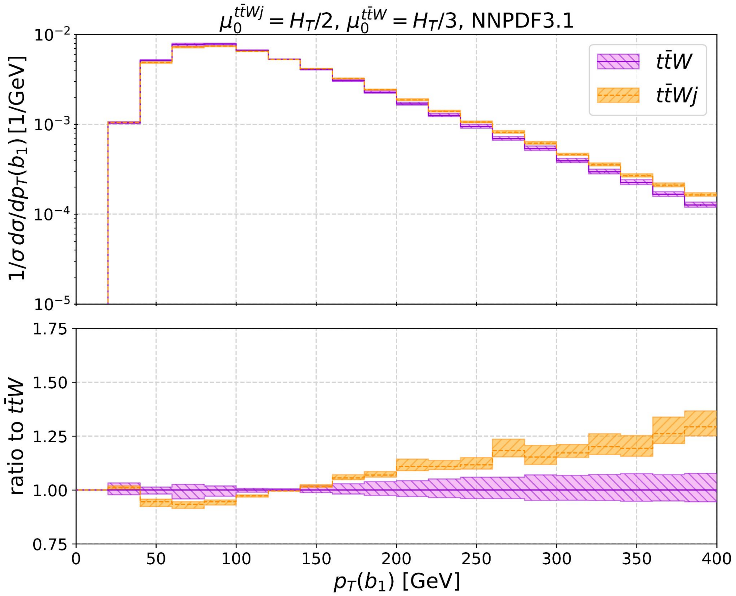

- Differences up to 42% in tails well outside the uncertainty bands
- Uncertainties go up 25% for ttW and 14% for ttWj

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

Additional jet activity in ttW

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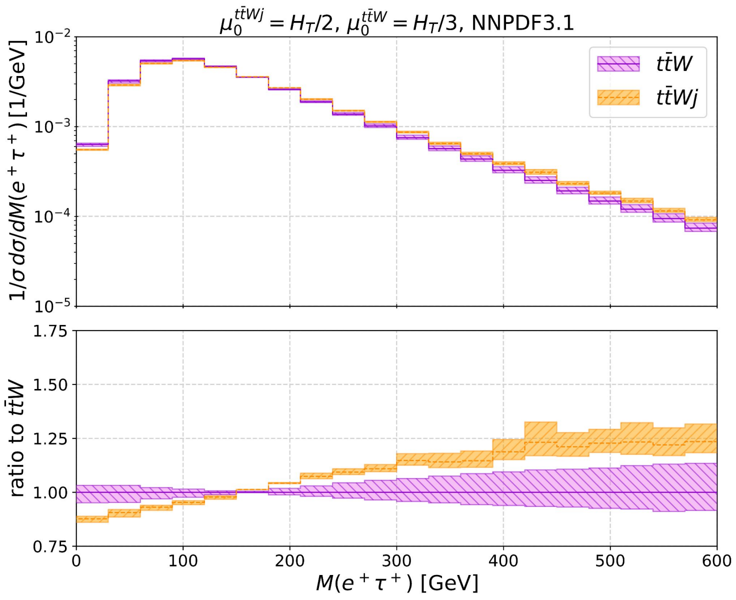
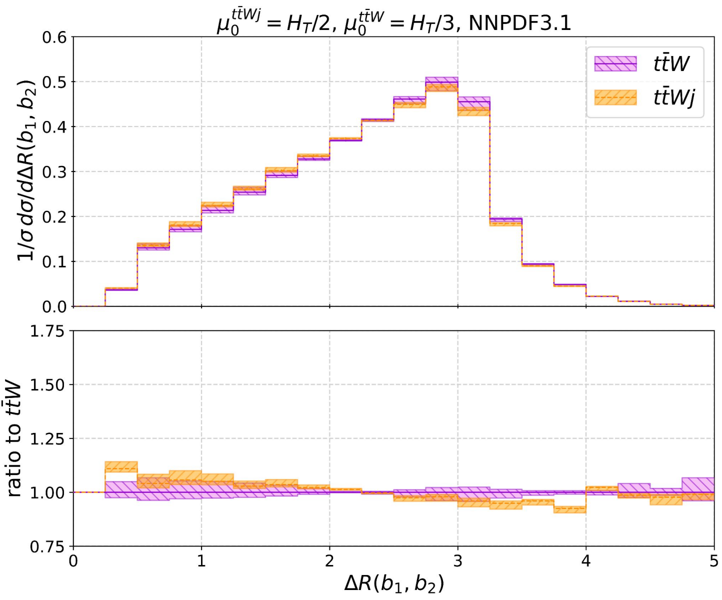




- Difference is up to 24%
- Overall shape distortion up to 36%
- Uncertainty goes up from 2% -5 % in the beginning and up to 8% - 13% in the tail

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

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
- Contribution of ttWj to ttW is about 50% - 70%
- Large shape distortion due to additional jet on differential level

Outlook

- Improve our off-shell ttW predictions by merging ttW + ttWj at NLO
- Compare different approaches like exclusive sums and MiNLO merging

Thank you for your attention!

Backup: Cuts and input parameters

- Cuts

$$
\begin{aligned}
p_T(\ell) &> 25~\text{GeV}\,, & |y(\ell)| &< 2.5\,,\\
p_T(j_b) &> 25~\text{GeV}\,, & |y(j_b)| &< 2.5\,,\\
p_T(j) &> 25~\text{GeV}\,, & |y(j)| &< 2.5\,,\\
\Delta R_{\ell\ell} &> 0.4\,, & \Delta R_{b\ell} &> 0.4\,,\\
\Delta R_{j\ell} &> 0.4\,, & \Delta R_{bj} &> 0.4\,,\\
\Delta R_{bb} &> 0.4\,, & \Delta R_{jj} &> 0.4\,,
\end{aligned}
$$

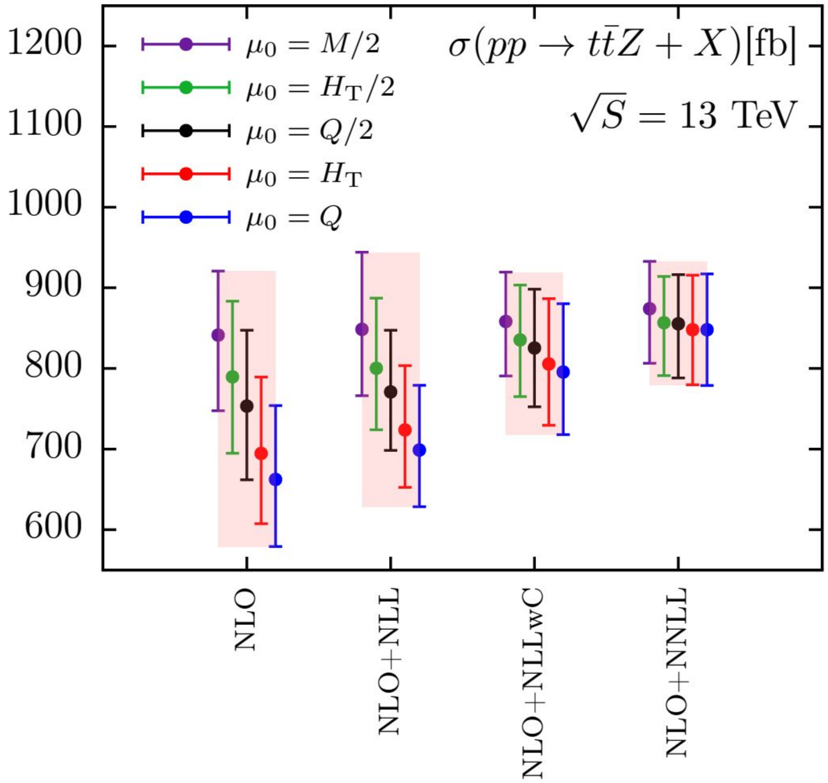
- Input parameters

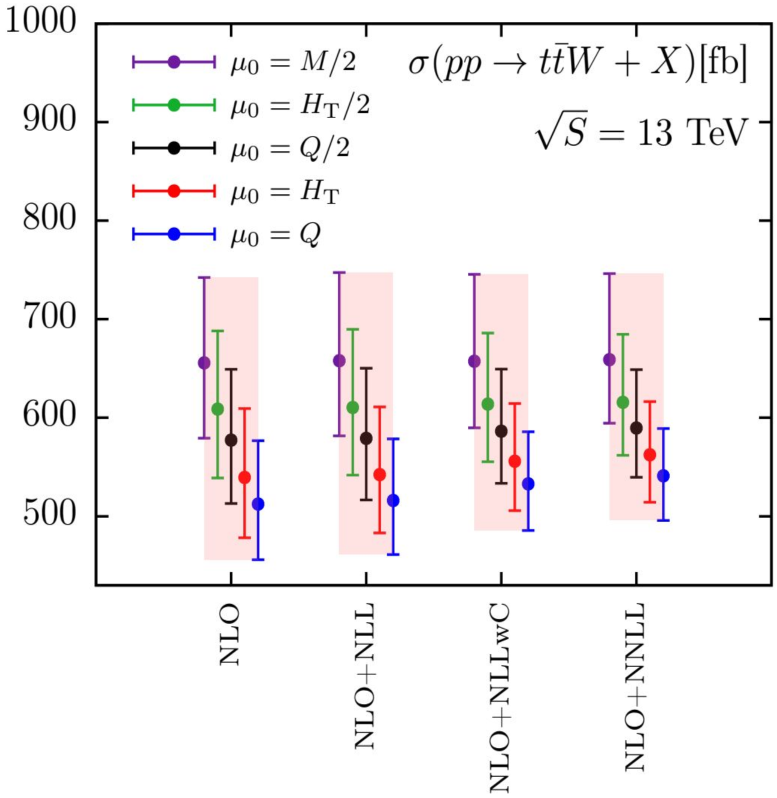
$$
\begin{aligned}
G_\mu &= 1.166378 \cdot 10^{-5}\,\text{GeV}^{-2}\,, & m_t &= 172.5\,\text{GeV}\,,\\
m_W &= 80.379\,\text{GeV}\,, & \Gamma_W^{\text{NLO}} &= 2.0972\,\text{GeV}\,,\\
m_Z &= 91.1876\,\text{GeV}\,, & \Gamma_Z^{\text{NLO}} &= 2.5074\,\text{GeV}\,.
\end{aligned}
$$

$$
\Gamma^{\text{LO}}_{t,\,\text{off-shell}} = 1.45766\,\text{GeV}\,, \qquad \Gamma^{\text{NLO}}_{t,\,\text{off-shell}} = 1.33254\,\text{GeV}
$$

Backup: Resummation

Kulesza, Motyka, Schwartländer, Stebel, Theeuwes ‘20





Backup: Subprocesses

Leading order:

- 12 subprocesses with 1868 Feynman diagrams each

$$u\bar{d} \;/\; \bar{d}u \to e^+\nu_e\,\mu^-\bar{\nu}_\mu\,\tau^+\nu_\tau\,b\bar{b}\,g\,, \qquad c\bar{s} \;/\; \bar{s}c \to e^+\nu_e\,\mu^-\bar{\nu}_\mu\,\tau^+\nu_\tau\,b\bar{b}\,g\,,$$

$$gu \;/\; ug \to e^+\nu_e\,\mu^-\bar{\nu}_\mu\,\tau^+\nu_\tau\,b\bar{b}\,d\,, \qquad g\bar{d} \;/\; \bar{d}g \to e^+\nu_e\,\mu^-\bar{\nu}_\mu\,\tau^+\nu_\tau\,b\bar{b}\,\bar{u}\,,$$

$$gc \;/\; cg \to e^+\nu_e\,\mu^-\bar{\nu}_\mu\,\tau^+\nu_\tau\,b\bar{b}\,s\,, \qquad g\bar{s} \;/\; \bar{s}g \to e^+\nu_e\,\mu^-\bar{\nu}_\mu\,\tau^+\nu_\tau\,b\bar{b}\,\bar{c}\,,$$

Backup: Subprocesses for real emission

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Partonic Subprocess	Number Of Feynman Diagrams	Number Of CS Dipoles	Number Of NS Subtractions
$gg \to e^+\nu_e\, \mu^-\bar{\nu}_\mu\, \tau^+\nu_\tau\, b\bar{b}\, qq'$	16662	36	9
$qq' \to e^+\nu_e\, \mu^-\bar{\nu}_\mu\, \tau^+\nu_\tau\, b\bar{b}\, gg$	16662	40	10
$qg \to e^+\nu_e\, \mu^-\bar{\nu}_\mu\, \tau^+\nu_\tau\, b\bar{b}q'g$	16662	36	9
$qq' \to e^+\nu_e\, \mu^-\bar{\nu}_\mu\, \tau^+\nu_\tau\, b\bar{b}\, qq'$	6240	12	3
$q\bar{q} \to e^+\nu_e\, \mu^-\bar{\nu}_\mu\, \tau^+\nu_\tau\, b\bar{b}\, qq'$	6240	8	2
$qq' \to e^+\nu_e\, \mu^-\bar{\nu}_\mu\, \tau^+\nu_\tau\, b\bar{b}\, b\bar{b}$	6240	16	4
$qq' \to e^+\nu_e\, \mu^-\bar{\nu}_\mu\, \tau^+\nu_\tau\, b\bar{b}\, QQ'$	3120	8	2
$q\bar{q} \to e^+\nu_e\, \mu^-\bar{\nu}_\mu\, \tau^+\nu_\tau\, b\bar{b}\, QQ'$	3120	4	1
$qQ' \to e^+\nu_e\, \mu^-\bar{\nu}_\mu\, \tau^+\nu_\tau\, b\bar{b}\, qQ'$	3120	8	2
$b\bar{b} \to e^+\nu_e\, \mu^-\bar{\nu}_\mu\, \tau^+\nu_\tau\, b\bar{b}\, qq'$	6240	12	3
$bq \to e^+\nu_e\, \mu^-\bar{\nu}_\mu\, \tau^+\nu_\tau\, b\bar{b}\, bQ'$	6240	16	4
$bq \to e^+\nu_e\, \mu^-\bar{\nu}_\mu\, \tau^+\nu_\tau\, b\bar{b}\, bq'$	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
	40	99.0	+37.5 (38%) −25.5 (26%)	122.8	+ 1.9 (1.5%) −10.3 (8.4%)	+1.5 (1.2%) −1.5 (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
	40	113.8	+46.9 (41%) −31.0 (27%)	121.4	+ 1.8 (1.5%) −10.2 (8.4%)	+2.4 (1.9%) −2.2 (1.8%)	1.07
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
	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

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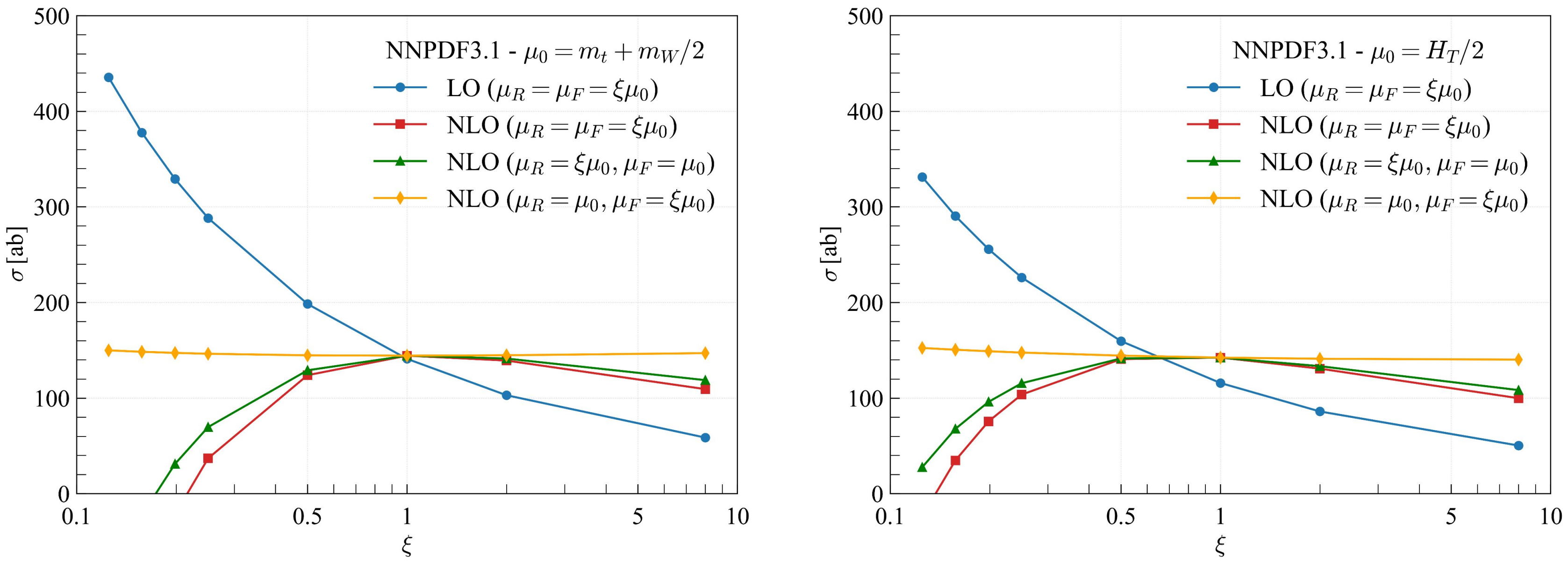
Backup: Dependence on scales



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Backup: Exclusive samples for ttW

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

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Backup: Exclusive samples for ttWj

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

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