Off-shell single-top production in the Standard Model Effective Field Theory

based on arXiv:1903.11023

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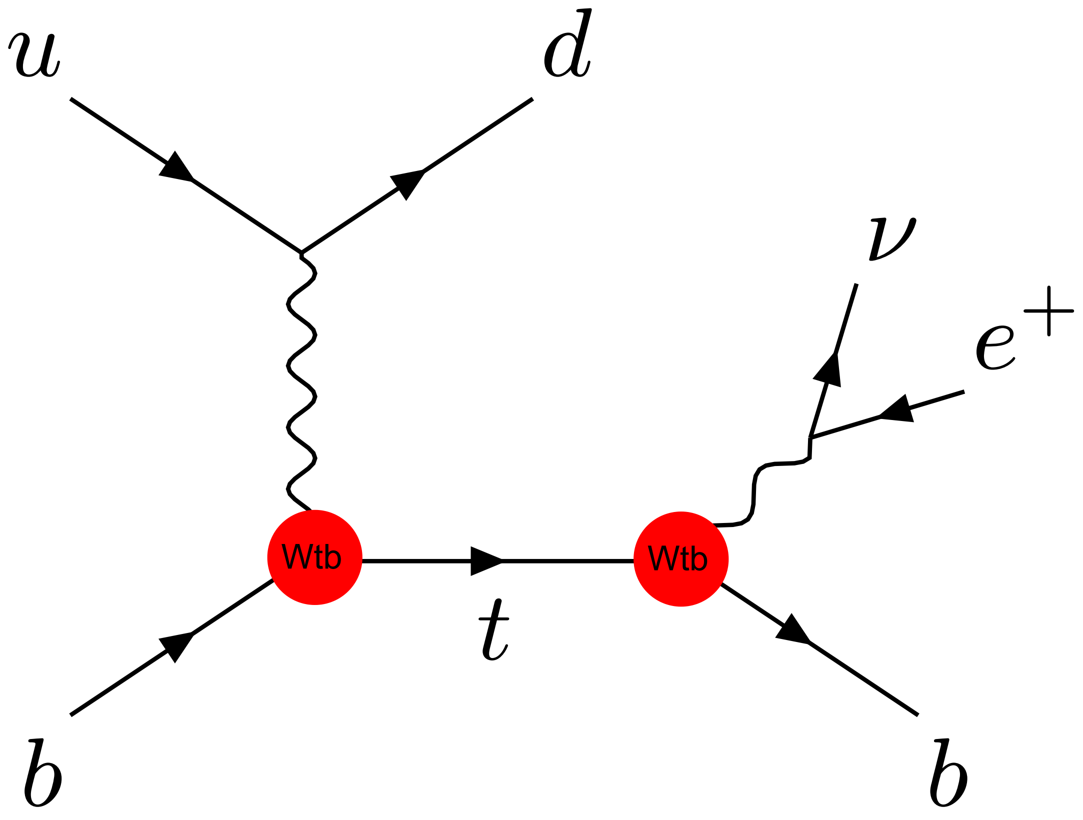
Features of t-channel single-top



- Double deep inelastic scattering: consistency check for PDFs; PDF transverse momentum dependence
- Access to V_{tb}: $\propto |V_{tb}|^2$
- Top-quark mass: m_{bl} lineshape
- As background with signature W, b + light jets
- Prime process to test V-A structure $\gamma^\mu P_L$

Status of SM theory predictions in a glimpse

- NLO: 4-flavor scheme, 5-flavor scheme, stable, on-shell, off-shell, ...

  NLO 4/5-flavor, on-shell (in MCFM): Campbell, Ellis, Tramontano '04; Campbell, Frederix, Frixione, Maltoni, Tramontano '09; Campbell, Ellis '12; (in POWHEG and aMC@NLO): Frederix, Re, Torrielli '12;
  NLO off-shell + non-resonant + parton shower: Prestel, Torrielli, Papanastasiou, Frederix, Frixione, Hirschi, Maltoni '13 '16;

- Threshold and transverse momentum resummation

  Kidonakis '12 '14 '16; Cao, Sun, Bin Yan, C.P. Yuan, F. Yuan '18; '19

- NNLO calculations *Brucherseifer, Caola, Melnikov '14 (on-shell); Berger, Gao, Yuan, Zhu '16 '17 (stable top)*

  "We found a difference of ~1% on the NNLO cross sections"

Parametrizing new physics has gone a long way

From *anomalous couplings*

$$-\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\big(V_L P_L + V_R P_R\big)\,t\,W_{\mu}^{-}\;-\frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}\big(g_L P_L + g_R P_R\big)\,t\,W_{\mu}^{-}$$

- LO EFT / anomalous couplings *Aguilar-Saavedra '08 '09; Bach, Ohl '12*
- Analysis and fit to observables, specific model interpretation *Cao, Bin Yan, Yu, Zhang '15*

to *SMEFT*

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{C_i}{\Lambda^2}\mathcal{O}_i$$

SMEFT: UV-model independent parametrization of NP

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar l_p\sigma^{\mu\nu}e_r)\tau^I\varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\,\varphi)(\bar l_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde G}$	$\varphi^\dagger\varphi\,\widetilde G^A_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar l_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q^{(3)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\,\varphi)(\bar l_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar q_p\sigma^{\mu\nu}T^A u_r)\widetilde\varphi\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\,\varphi)(\bar e_p\gamma^\mu e_r)$
$Q_{\varphi\widetilde W}$	$\varphi^\dagger\varphi\,\widetilde W^I_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar q_p\sigma^{\mu\nu}u_r)\tau^I\widetilde\varphi\, W^I_{\mu\nu}$	$Q^{(1)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\,\varphi)(\bar q_p\gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar q_p\sigma^{\mu\nu}u_r)\widetilde\varphi\, B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\,\varphi)(\bar q_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\widetilde B}$	$\varphi^\dagger\varphi\,\widetilde B_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar q_p\sigma^{\mu\nu}T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\,\varphi)(\bar u_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar q_p\sigma^{\mu\nu}d_r)\tau^I\varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\,\varphi)(\bar d_p\gamma^\mu d_r)$
$Q_{\varphi\widetilde WB}$	$\varphi^\dagger\tau^I\varphi\,\widetilde W^I_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar q_p\sigma^{\mu\nu}d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde\varphi^\dagger D_\mu\varphi)(\bar u_p\gamma^\mu d_r)$

Buchmueller, Wyler '86; Gradkowski, Iskrzynski, Misiak, Rosiek '10

- work up to including NLO EFT, on-shell *Zhang, Willenbrock '11; Franzosi, Zhang '15; Zhang '14 '16*
- connection to flavor physics and low energy precision measurements *Alioli, Cirigliano, Dekens, Vries, Mereghetti '17*
- most recently: partial NLO SMEFT, off-shell + PS *Beurs, Laenen, Vreeswijk, Vryonidou '18*

And the experiment?

ATLAS anomalous couplings: 1702.08309

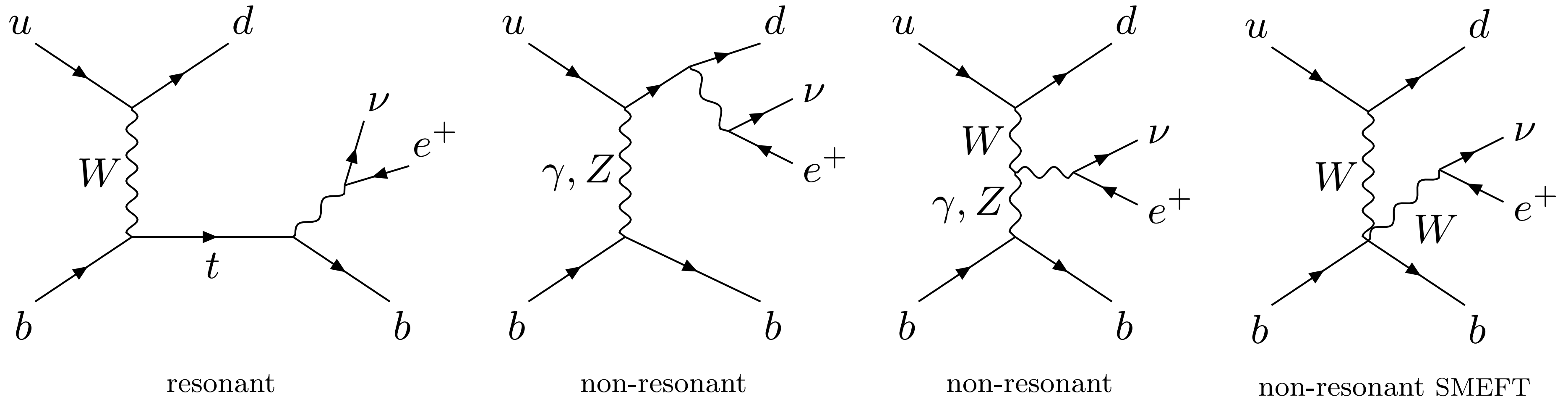
- SM NLO events: POWHEG BOX, 4f scheme, stable top, CT10 PDFs, scale choice A
- LO protos, CTEQ6 PDFs, scale choice B

CMS anomalous couplings: 1610.03545

- CompHEP LO generator
- "matching to simulate effective NLO approach"
- LO codes for everything else

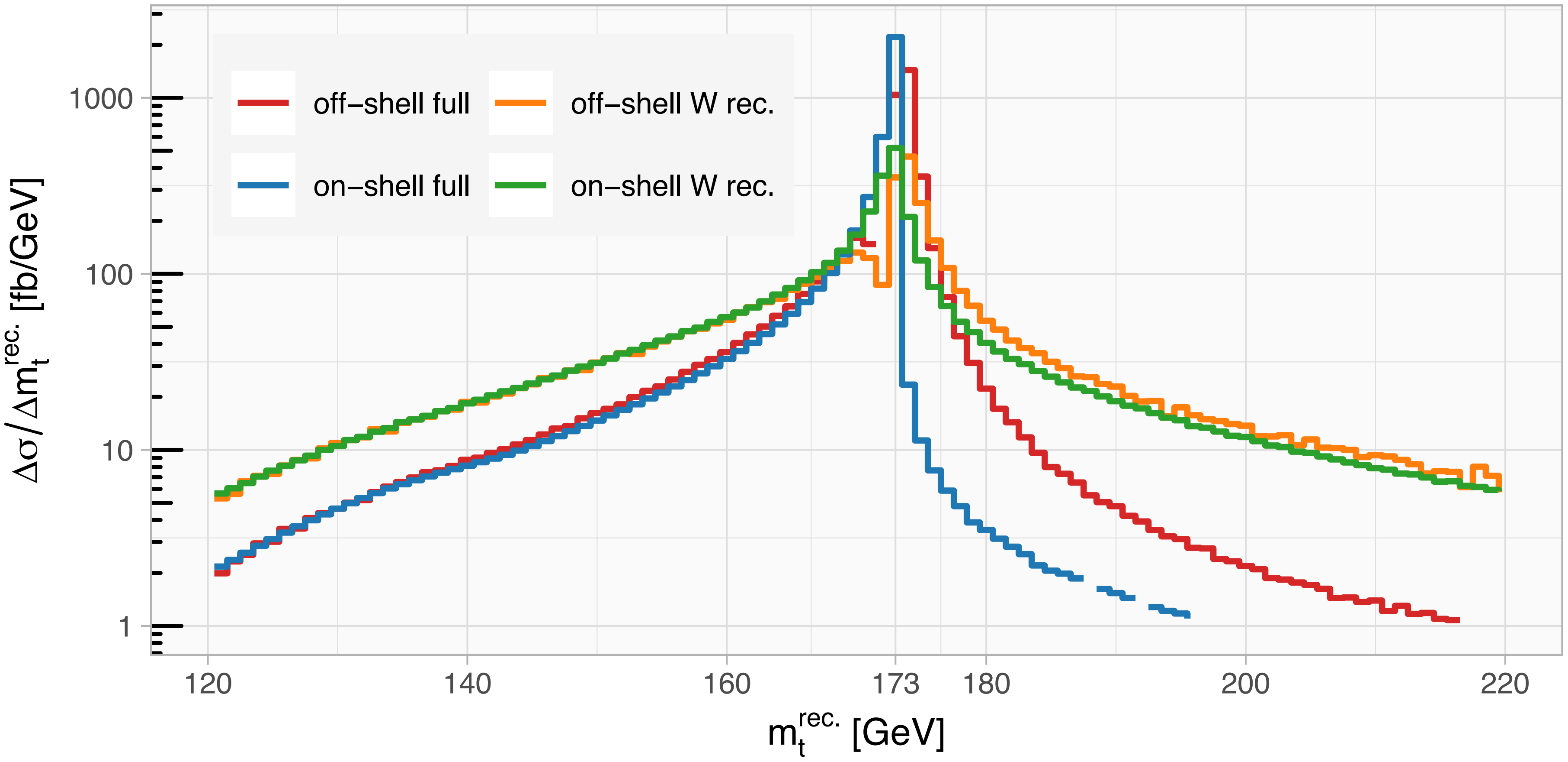
Our setup

- Fully consistent off-shell calculation at NLO SM and NLO SMEFT
- uses complex mass scheme; full decay chain (no approx. in decays)
- compares with data as closely as possible: DDIS scales

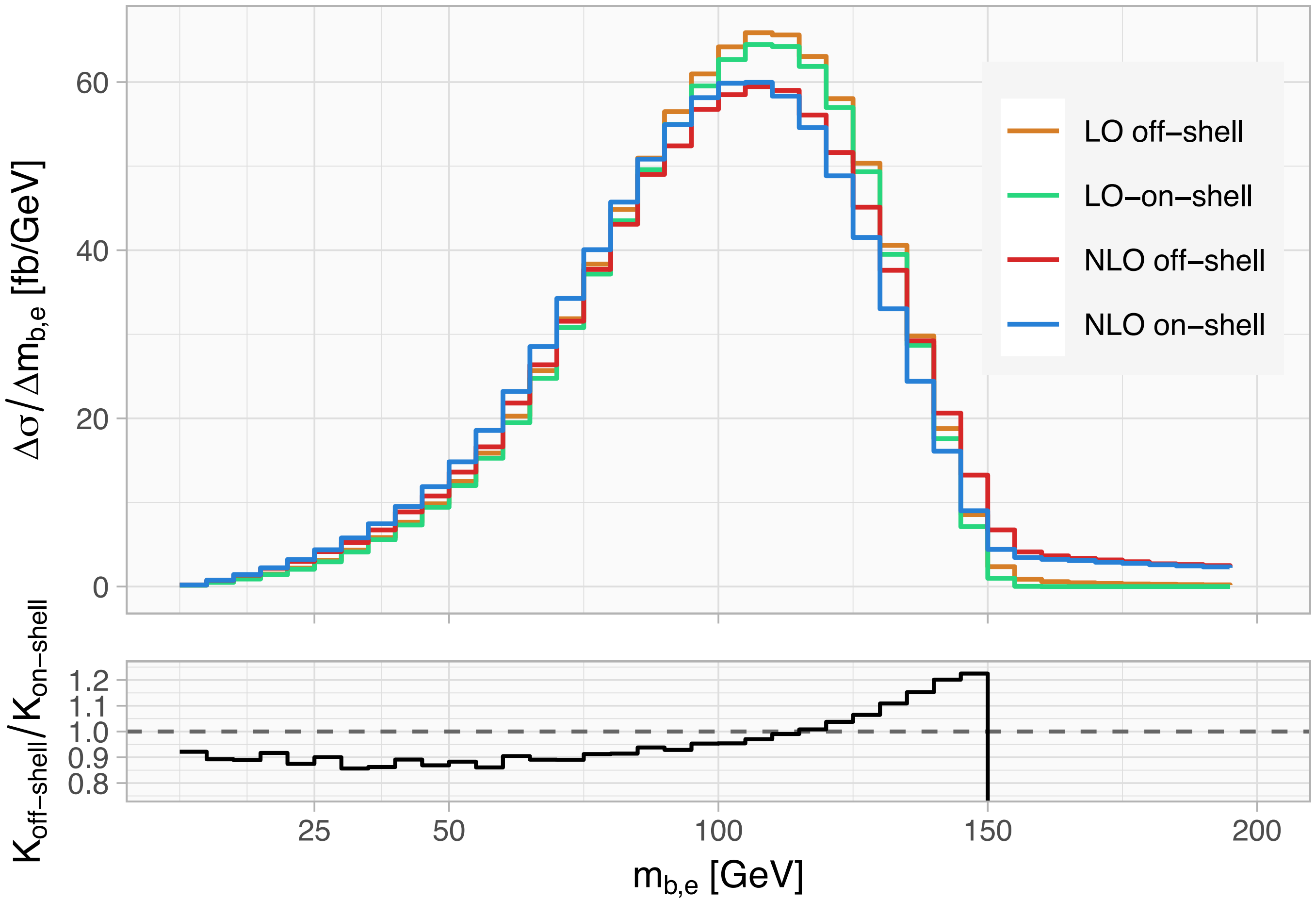


Inclusion of of eight SMEFT operators through NLO: two only enter at NLO

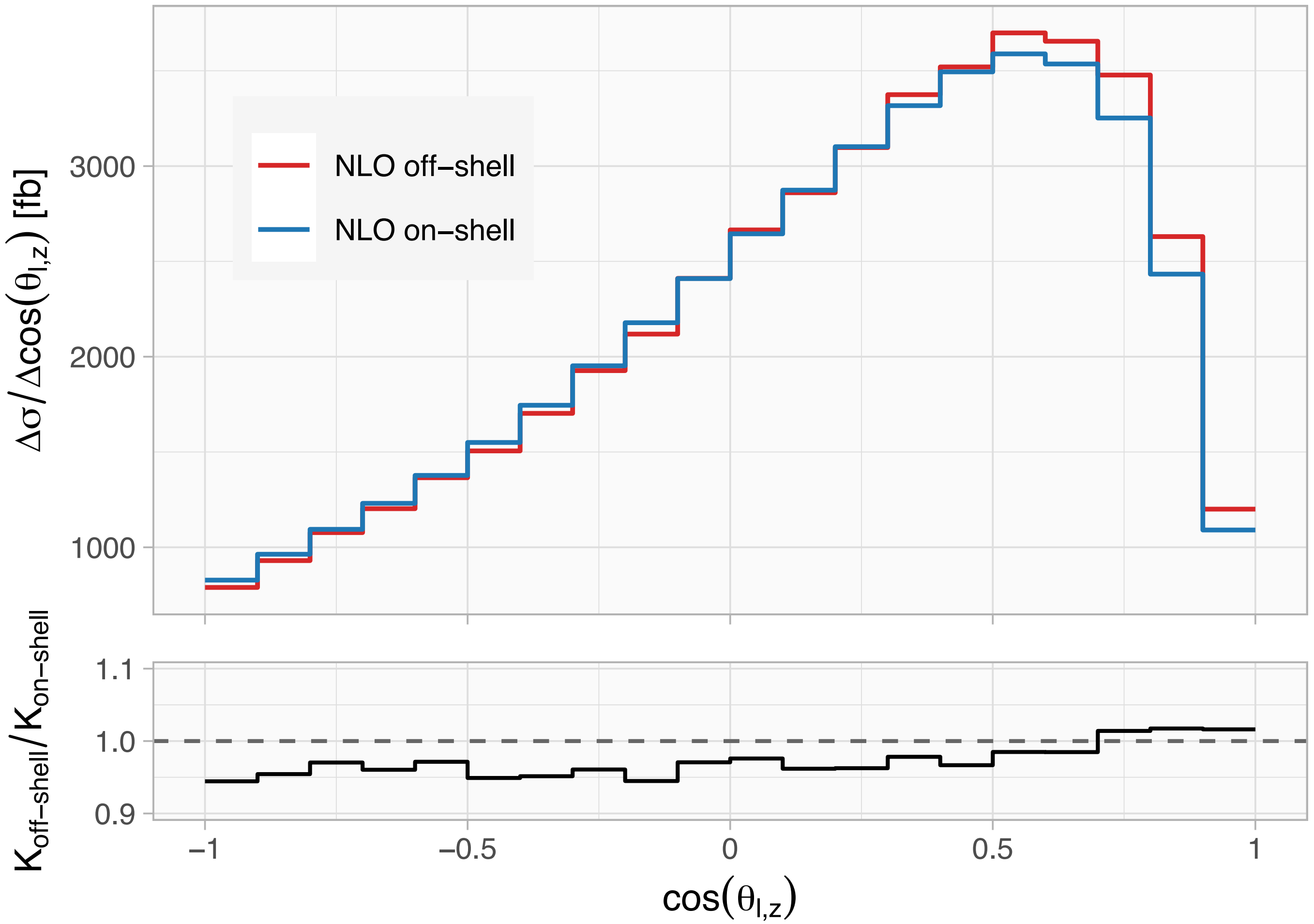
Inclusively: Off-shell effects $\mathcal{O}(\Gamma_t/m_t)$



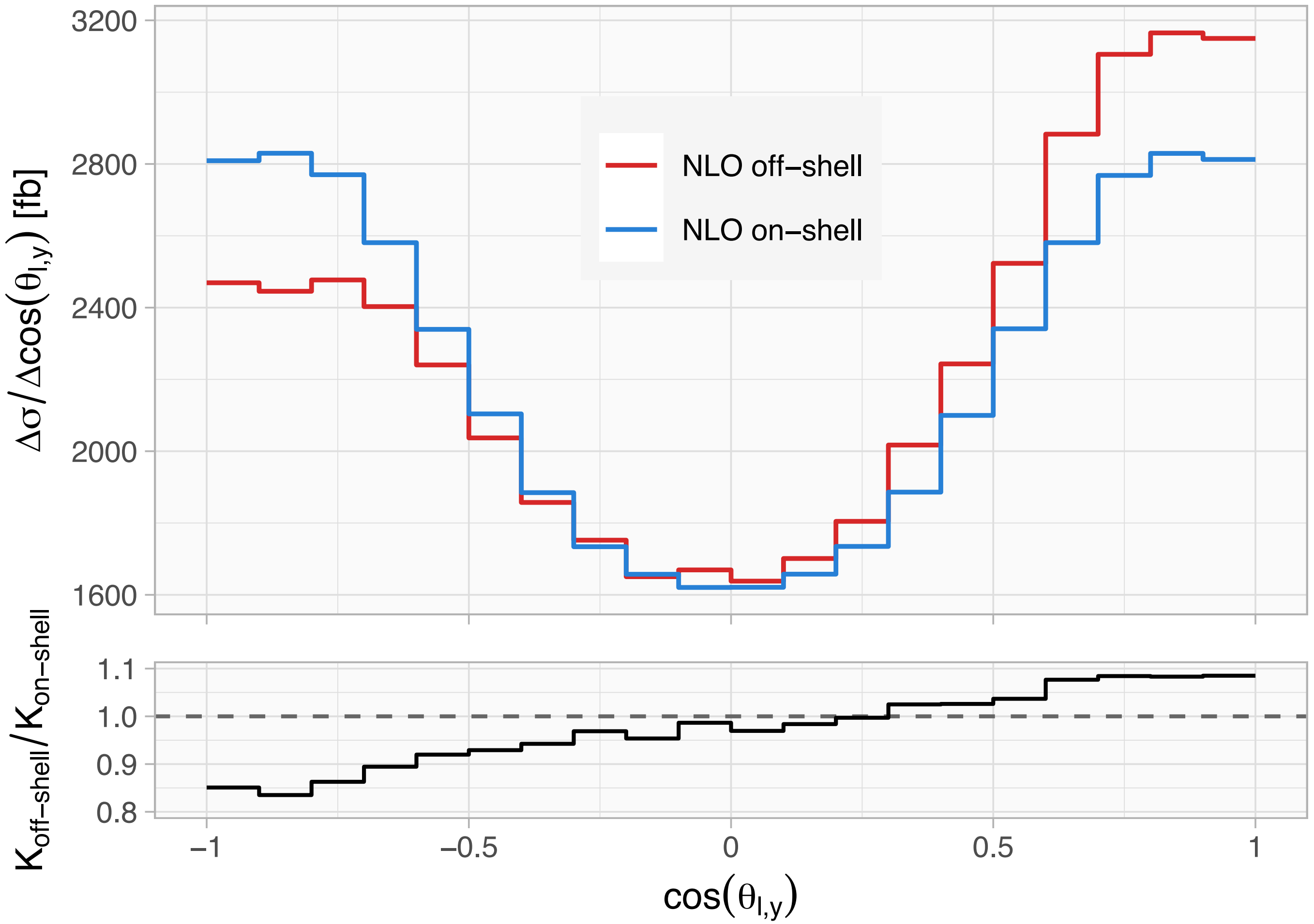
m_{bl} lineshape used for top-mass measurement



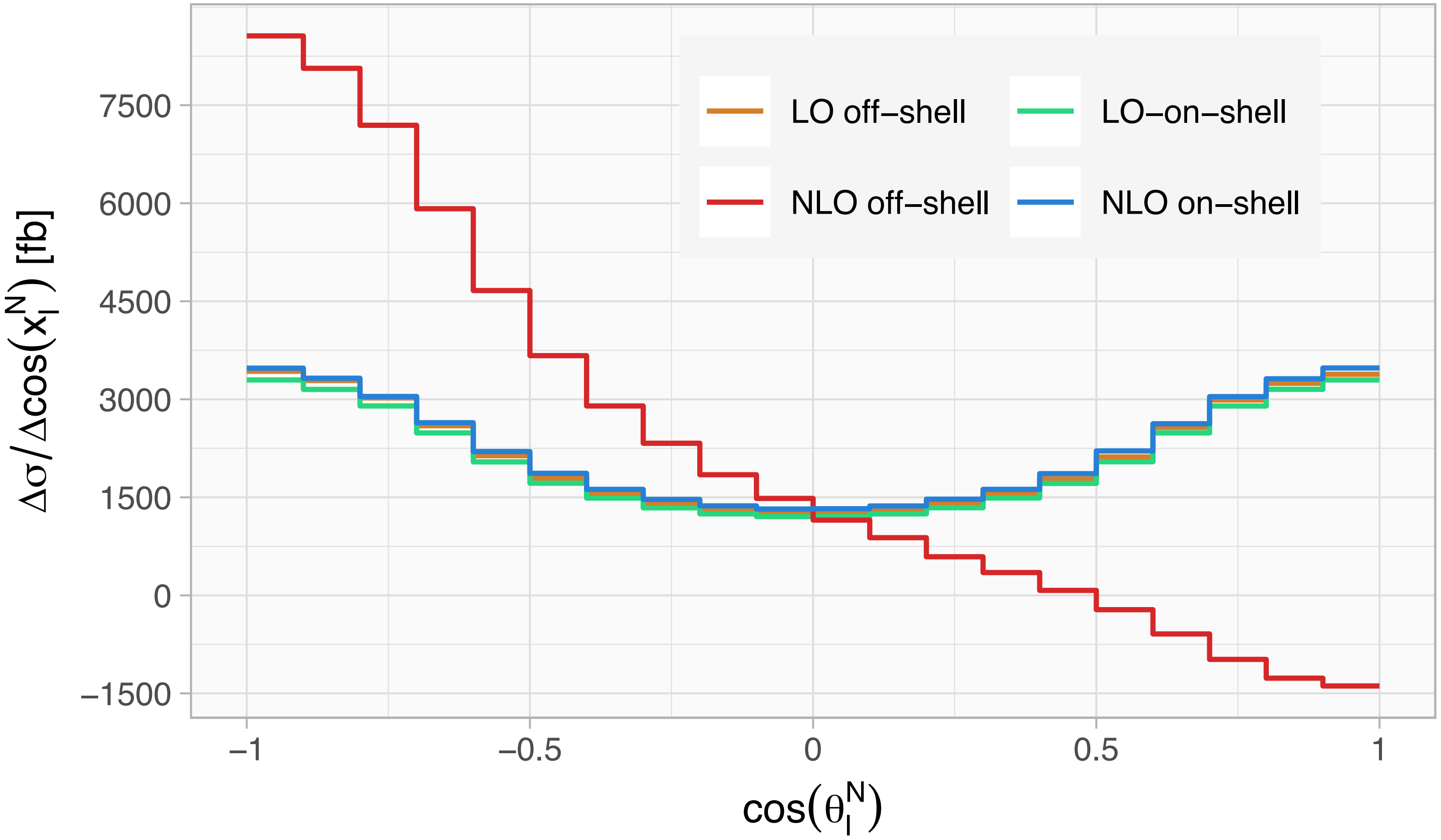
Angle between spectator jet and lepton



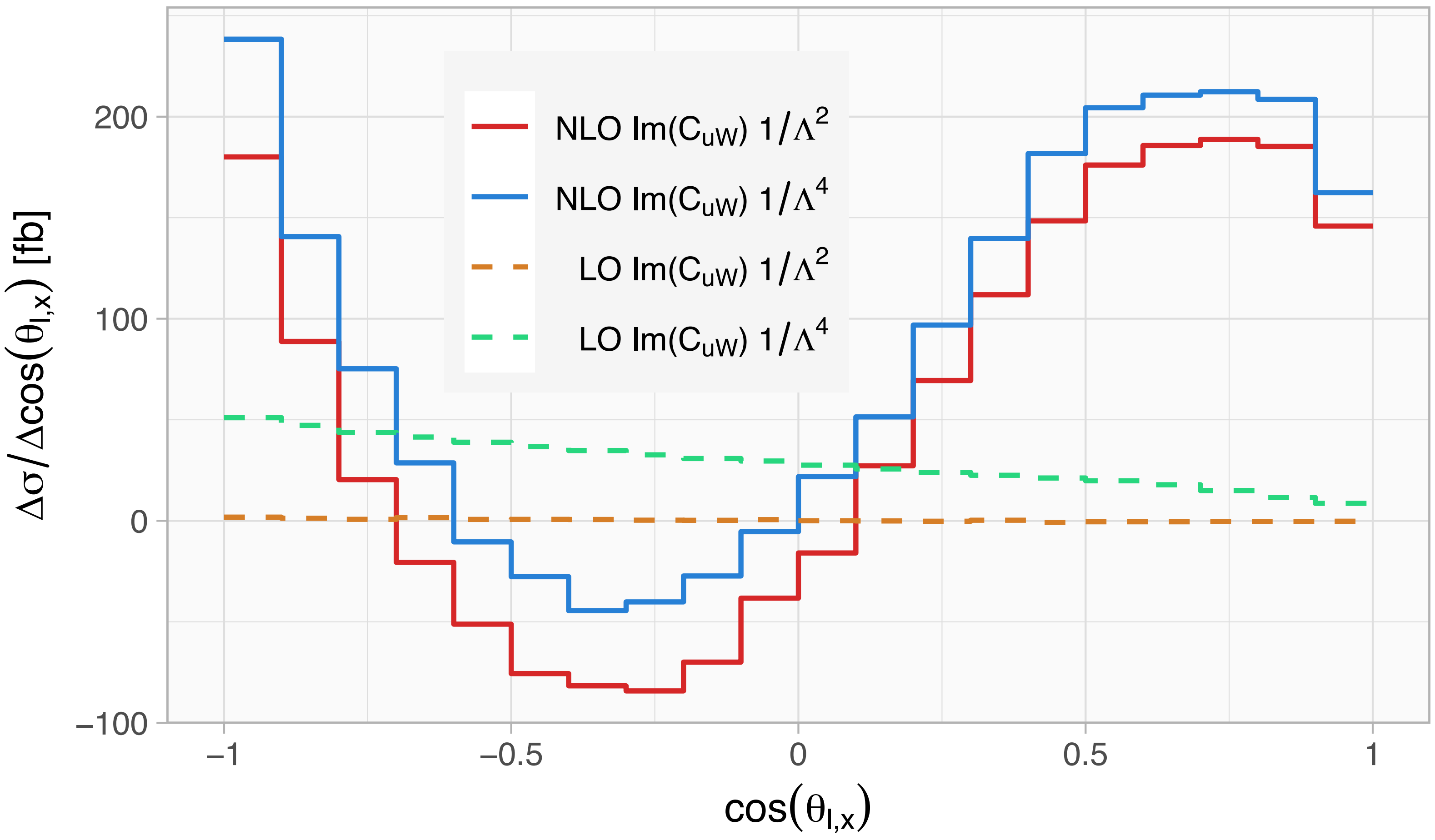
Another angle sensitive to new physics



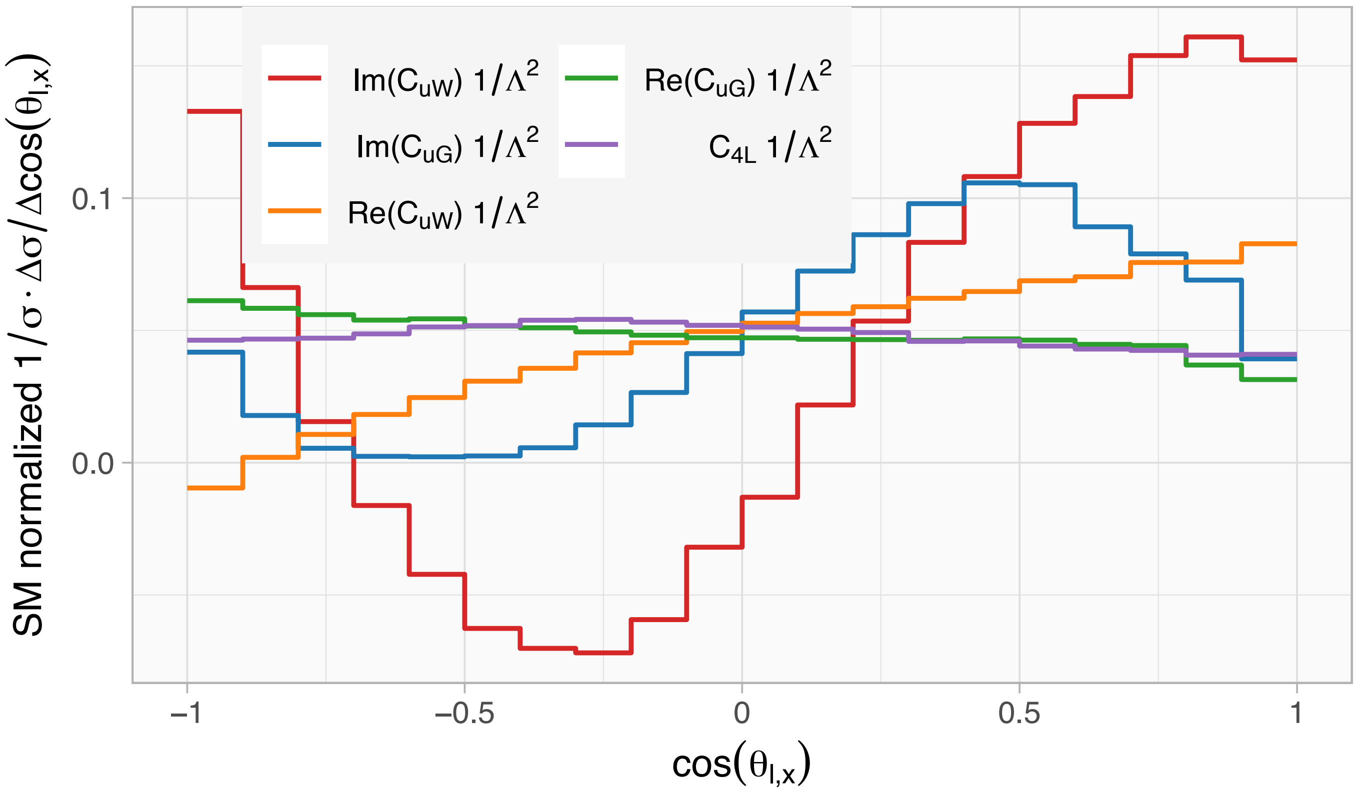
Fixed order infrared sensitivity propagating to observables



One of the most interesting structures: $\mathfrak{Im} C_{uW}$



Example of the whole spectrum...



$$\mu_X \frac{\mathrm{d}}{\mathrm{d}\mu_X} \begin{pmatrix} \mathcal{Q}_{uG}^{33} \\ \mathcal{Q}_{uW}^{33} \end{pmatrix} = \frac{\alpha_s}{4\pi} C_F \begin{pmatrix} 1 & 0 \\ 2 & 2 \end{pmatrix} \begin{pmatrix} \mathcal{Q}_{uG}^{33} \\ \mathcal{Q}_{uW}^{33} \end{pmatrix}$$

Conclusions

Unified and consistent NLO SM + NLO SMEFT framework for t-channel analyses

- analytical implementation im MCFM 8.3 ⇒ fast, easy and hackable
- off-shell top in the complex mass scheme: full semi-leptonic decay, no approximations in decays
- eight operators, two sets with non-vanishing anomalous dimension and mixing at NLO
- compare with data as closely as possible: DDIS scales
- strict SMEFT mode: $1/\Lambda^2$ and extended mode with partial $1/\Lambda^4$ terms

shipping with pre-packaged analysis framework, b-tagging (mcfm.fnal.gov)