

Projected transverse momentum resummation in the top-antitop pair production at LHC

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based on the "Projected transverse momentum resummation in the top-antitop pair production at LHC", in preparation

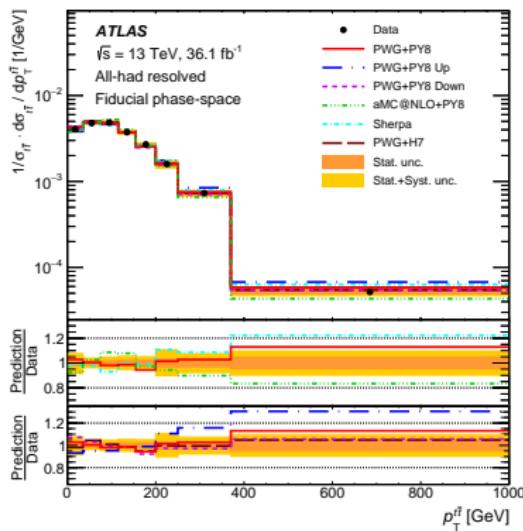
DIS2022

Experimental measurements

- Investigations on the process $pp \rightarrow t\bar{t} + X$:
 - m_t extractions;
 - Indirect exploration on new physics beyond SM;
 - ...
- Measurements on the inclusive cross section $\sigma(pp \rightarrow t\bar{t} + X)$
 - $\sqrt{s} = 5.02$
 1. ATLAS: [\[ATLAS:2021xhc\]](#)
 2. CMS: [\[1711.03143, 2112.09114\]](#)
 - $\sqrt{s} = 13 \text{ TeV}$
 1. ATLAS: [\[1910.08819, 2006.13076\]](#)
 2. CMS: [\[1911.13204\]](#)
 - ...

Experimental measurements

- Measurements on the differential cross sections $d\sigma(pp \rightarrow t\bar{t} + X)/d\mathcal{O}$
 1. ATLAS: [2006.09274, 2202.12134]
 2. CMS: [1904.05237, 2108.02803, 2008.07860]

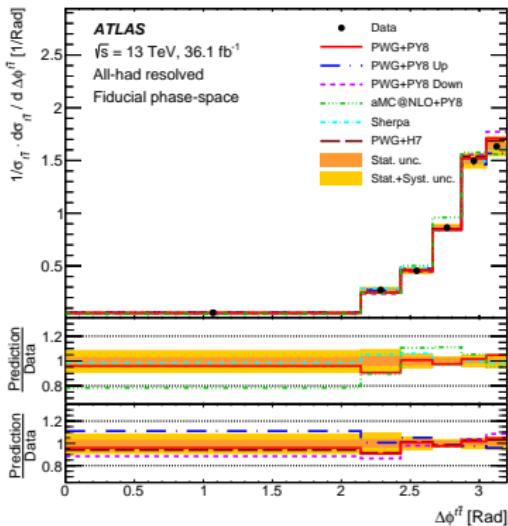


[2006.09274]

1. $P_T^{\bar{t}} \rightarrow \text{TM of } t\bar{t}$
2. QCD corrections from $\mathcal{O}(\alpha_s^m)$
3. TM resummation: reducing Theor. Err.

Experimental measurements

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1. Definition

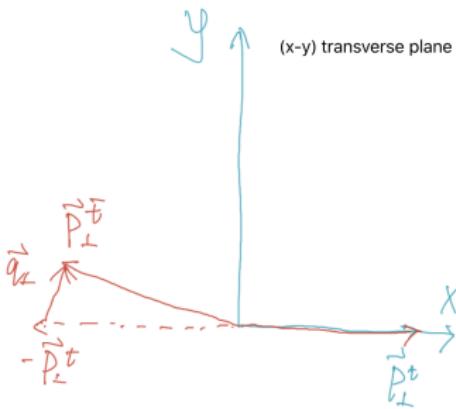
$$\Delta\phi^{t\bar{t}} = \arccos \left[\frac{\vec{p}_{t,\text{T}} \cdot \vec{p}_{\bar{t},\text{T}}}{|\vec{p}_{t,\text{T}}| |\vec{p}_{\bar{t},\text{T}}|} \right]$$

2. QCD corrections from $\mathcal{O}(\alpha_s^m)$
3. TM resummation: reducing Theor. Err.

$\Delta\phi^{t\bar{t}}$ and q_τ

- TM $\rightarrow 0$ limit:

$$\begin{aligned}\Delta\phi^{t\bar{t}} &= \arccos \left[\frac{\vec{p}_{t,T} \cdot \vec{p}_{\bar{t},T}}{|\vec{p}_{t,T}| |\vec{p}_{\bar{t},T}|} \right] \\ &= \pi - \frac{q_{t\bar{t},T}^y}{|\vec{p}_{t,T}|} + \dots\end{aligned}$$



- TM-y:

$$\frac{d\sigma_{t\bar{t}}}{d\Delta\phi^{t\bar{t}}} \rightarrow \frac{d\sigma_{t\bar{t}}}{d|q_{t\bar{t},T}^y|}$$

- General situation:

τ -2D unit vector on the (x,y) plane:
 $q_\tau = |\vec{q}_{t\bar{t},T} \cdot \vec{\tau}|$

$$\frac{d\sigma_{t\bar{t}}}{dq_\tau}$$

Derivations of its factorization and resummation

Theoretical progresses

- Fixed-order calculations
 - 1. NLO QCD: [Nucl. Phys. B 303 (1988)/Phys. Rev. D 40 (1989)/Nucl. Phys. B 351 (1991)/Nucl. Phys. B 373 (1992)]
 - 2. NNLO QCD: [Czakon:2013goa,Czakon:2015owf,Czakon:2016ckf,Czakon:2017dip]
[Czakon:2017wor,Catani:2019iny,Catani:2020tko]
 - 3. NNLO QCD+ t/\bar{t} decay:
[Gao:2012ja,Brucherseifer:2013iv,Catani:2019hip,Behring:2019iiv,Czakon:2020qbd]
 - 4. electroweak corrections
[Bernreuther:2010ny,Kuhn:2006vh,Bernreuther:2006vg,Kuhn:2013zoa,Hollik:2011ps]
[Pagani:2016caq,Gutschow:2018tuk,Denner:2016jyo,Czakon:2017wor]
 - 5. approximate NNNLO
[Kidonakis:2014isa,Kidonakis:2019yji]
 - 6.

Theoretical progresses

- Resummation from various kinematics

1. the mechanic threshold $M_{t\bar{t}} \rightarrow \hat{s}$

[Kidonakis:2009ev,Kidonakis:2014isa,Ahrens:2010zv,Ferroglio:2012ku,Ferroglio:2013awa]

[Pecjak:2016nee,Czakon:2018nun,Hinderer:2014qta]

2. the production threshold $M_{t\bar{t}} \rightarrow 2m_t$

[Beneke:2009ye,Beneke:2010da,Beneke:2011mq,Piclum:2018ndt,Ju:2020otc,Ju:2019mqc]

3. TM → This Work

[Kidonakis:2014pja,Kidonakis:2010dk,Zhu:2012ts,Li:2013mia,Catani:2014qha]

[Catani:2017tuc,Catani:2018mei]

4. the jettiness limit $\mathcal{T}_0 \rightarrow 0$ [Alioli:2021ggd]

5. MINNLO_{PS} [Mazzitelli:2020jio,Mazzitelli:2021mmm]

6.

Development of the TMR of DY channel

- Early investigations

[Dokshitzer:1978hw, Parisi:1979se, Curci:1979bg, Bassetto:1979nt, Collins:1981uk, Collins:1981va

[Kodaira:1982az, Catani:1988vd, Davies:1984hs, Kodaira:1981nh]

- The first all-order exponentiation of $\log[q_T/M_V]$

[Collins&Soper&Sterman1984]

- The momentum-space resummation

[Monni:2016ktx, Bizon:2017rah, Bizon:2019zgf, Bizon:2018foh, Ebert:2016gcn]

- Soft-collinear effective theory (SCET) → This Work

[Bauer:2000yr, Bauer:2001yt, Beneke:2002ph].

$\underbrace{\text{QCD} \rightarrow \text{SCET}}$
rapidity singularities

- Analytic regulator [Becher:2010tm].

- η regulator [Chiu:2011qc, Chiu:2012ir]

- Exponential regulator [Li:2016axz] → This Work

-

-

TMR of DY and $t\bar{t}$ production

- DY processes

[Collins:1984kg, Catani:2000vq, Bozzi:2005wk, Bozzi:2007pn, Ebert:2016gcn, Monni:2016ktx, Bizon:2017rah]
[GarciaEchevarria:2011rb, Becher:2011dz, Chiu:2011qc, Chiu:2012ir, Li:2016axz, Li:2016ctv,, Becher:2010tm]

$$\tilde{\sigma}_{\text{DY}}(\vec{b}_T) = \int d^2 \vec{q}_{T,\ell\bar{\ell}} \exp(-i \vec{b}_T \cdot \vec{q}_{T,\ell\bar{\ell}}) \frac{d\sigma_{\text{DY}}}{d\vec{q}_{T,\ell\bar{\ell}}} = \sum_{m=2, n=1} c_{m,n}^{\text{DY}} \alpha_s^m L_T^n + \sum_{m=2} \alpha_s^m d_m^{\text{DY}}.$$

Here $L_T = \ln(\vec{b}_T^2 Q^2)$. Exponentiating $L_T \rightarrow$ Resumming $\ln^m(qT)/qT$.

- $t\bar{t}$ production: [Zhu:2012ts, Li:2013mia, Catani:2014qha, Catani:2017tuc, Catani:2018mei]

$$\tilde{\sigma}_{t\bar{t}}(\vec{b}_T) = \sum_{m=2, n=1} \alpha_s^m \left[c_{m,n}^{t\bar{t}} + \tilde{c}_{m,n}^{t\bar{t}}(\phi_b) \right] L_T^n + \sum_{m=2} \alpha_s^m \left[d_m^{t\bar{t}} + \tilde{d}_m^{t\bar{t}}(\phi_b) \right],$$

where $L_T = \ln(\vec{b}_T^2 Q^2)$. Both L_T and ϕ_b give rise to $\ln^m(qT)/qT$.

TMR of the $t\bar{t}$ production

- Improving the fixed-order ingredients for $d\sigma_{t\bar{t}}/d\vec{q}_{T,t\bar{t}}$ [Nadolsky:2007ba, Catani:2010pd, Catani:2014qha, Catani:2017tuc]
 1. $\tilde{c}_{m,n}^{t\bar{t}}(\phi_b)$ and $\tilde{d}_m^{t\bar{t}}(\phi_b) \rightarrow \exp(im\phi_q)/|\vec{q}_{T,t\bar{t}}|$
 2. $L_T^m \rightarrow \ln^{m-1}(|\vec{q}_{T,t\bar{t}}|)/|\vec{q}_{T,t\bar{t}}| + \ln^{m-2}(|\vec{q}_{T,t\bar{t}}|)/|\vec{q}_{T,t\bar{t}}| + \dots$
 3. the azimuthal harmonics @ NLL' [Catani:2017tuc]
- Phase space combinations [Zhu:2012ts, Li:2013mia, Catani:2018mei].
 1. Azimuthally averaged spectra $d\sigma_{t\bar{t}}/dq_{T,t\bar{t}}$
 2. Exponentiating $L_T \rightarrow$ Resumming $\ln^m(qT)/qT$.
 3. NLL' in [Catani:2018mei] and N²LL in [Zhu:2012ts, Li:2013mia]
 4. IRC subtractions [Bonciani:2015sha, Catani:2019iny, Catani:2019hip, Catani:2021cbl].
 5. any other observables $q_\tau = |\vec{q}_{t\bar{t},T} \cdot \vec{\tau}| ???$

$$\frac{d\sigma_{t\bar{t}}}{dq_\tau}$$

the second candidate

Factorization

- QCD factorisation formula [Collins:1989gx]

$$\frac{d\sigma}{dM_{t\bar{t}}^2 d^2 \vec{P}_{t,\perp} dq_\tau} = \sum_{\text{sign}[P_t^z]} \frac{1}{16s(2\pi)^6} \int_{q_{\tau\parallel}^{\min}}^{q_{\tau\parallel}^{\max}} dq_{\tau\parallel} \delta(q_\tau - |q_{\tau\parallel}|) \int_{-\infty}^{\infty} dq_{\tau\perp}$$

$$\times \Theta_{\text{kin}} \int_{Y_{t\bar{t}}^{\min}}^{Y_{t\bar{t}}^{\max}} dY_{t\bar{t}} \frac{M_{\text{PS}}^2}{E_{t\bar{t}}|P_t^z|} \quad (1)$$

where $q_\tau = |\vec{q}_{t\bar{t},\text{T}} \cdot \vec{\tau}|$

$$Y_{t\bar{t}}^{\max} = -Y_{t\bar{t}}^{\min} = \sinh^{-1} \left(\sqrt{\frac{(M_{t\bar{t}} + s)^2}{4s(M_{t\bar{t}}^2 + \vec{q}_T^2)} - 1} \right)$$

$$\Theta_{\text{kin}} = \Theta \left[\sqrt{s} - \sqrt{\vec{q}_T^2 + M_{t\bar{t}}^2} - |\vec{q}_T| \right] \Theta \left[\sqrt{M_{t\bar{t}}^2 + \vec{q}_T^2} - \sqrt{m_t^2 + \vec{P}_{t,\perp}^2} - \sqrt{m_{\bar{t}}^2 + (\vec{P}_{t,\perp} - \vec{q}_T)^2} \right]$$

And

$$\begin{aligned} M_{\text{PS}}^2 &= \sum_{i,j} \int_0^1 \frac{dx_n}{x_n} \frac{dx_{\bar{n}}}{x_{\bar{n}}} f_{i/N}(x_n) f_{j/\bar{N}}(x_{\bar{n}}) \sum_{\rho} \int \prod_m^\rho d\Phi_{km} (2\pi)^4 \delta^4 \left(p_i + p_j - p_t - p_{\bar{t}} - \sum_m k_m \right) \\ &\quad \overline{\sum_{\text{s,c}} |\mathcal{M}(i+j \rightarrow t+\bar{t}+X)|^2} \end{aligned}$$

Factorization

- Expansion by regions [Beneke:1997zp,Jantzen:2011nz]

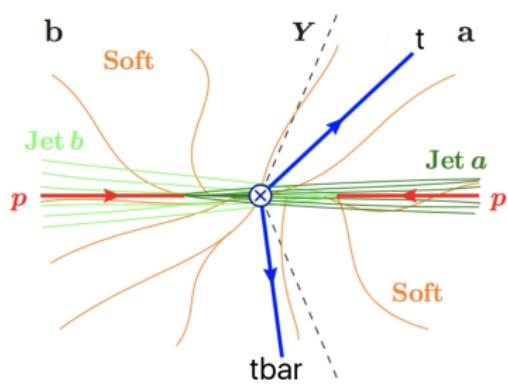
$$\text{Hard : } k_h \sim M_{t\bar{t}} [\mathcal{O}(\lambda_T^0), \mathcal{O}(\lambda_T^0), \mathcal{O}(\lambda_T^0)] ,$$

$$\text{Soft : } k_s \sim M_{t\bar{t}} [\mathcal{O}(\lambda_T), \mathcal{O}(\lambda_T), \mathcal{O}(\lambda_T)] ,$$

$$n = \text{col} : \quad k_n \sim M_{t\bar{t}} [\mathcal{O}(\lambda_T^2), \mathcal{O}(\lambda_T^0), \mathcal{O}(\lambda_T)] ,$$

$$\bar{n} = \text{col} : \quad k_{\bar{a}} \sim M_{t\bar{t}} \left[\mathcal{O}(\lambda_T^0), \mathcal{O}(\lambda_T^2), \mathcal{O}(\lambda_T) \right] .$$

where $\lambda_T \equiv |q_T|/M_{t\bar{t}}$



SCET+HQET

[Eichten:1989zy, Georgi:1990um, Grinstein:1990mi, Neubert:1993m]

[Elenitem:1993zv; Georgi:1993am; Christensen:1993mj], Neubert:1993m

[Beneke:2001ct, Beneke:2000yf, Beneke:2000ew, Beneke:2002rz, Beneke:2002ni Beneke:2002ph, Beneke:2002ni, Neubert:1993mb]

[Beneke:2002ii,
Beneke:2010da]

$$\mathcal{L}_{\text{SCT}_n} = \bar{\xi}_n \left(in \cdot D_n + i \not{D}_{n\perp} \frac{1}{i \bar{n} \cdot D} i \not{D}_{n\perp} \right) \frac{\not{p}}{2} \xi_n$$

$$-\frac{1}{2} \operatorname{Tr} \left\{ F_n^{\mu\nu} F_{\mu\nu}^n \right\}$$

$$\mathcal{L}_{\text{SCET}_s} = -\frac{1}{2} \text{Tr} \left\{ F_s^{\mu\nu} F_{\mu\nu}^s \right\} + \bar{q}_s i \not{D}_s q_s ,$$

$$\mathcal{L}_{\text{HQET}_V} = \bar{h}_V (i\partial \cdot v) h_V + \bar{\chi}_V (i\partial \cdot v) \chi_V ,$$

[1004.2489]

Factorization

- Factorization formula

$$\begin{aligned}
 \frac{d\sigma}{dM_{t\bar{t}} d^2\vec{P}_{t,\perp} dq_\tau} = & \int_{-\infty}^{\infty} db_{\tau\parallel} \cos(b_{\tau\parallel} q_\tau) \int_{\hat{Y}_{t\bar{t}}^{\min}}^{\hat{Y}_{t\bar{t}}^{\max}} dY_{t\bar{t}} \left\{ \mathcal{B}_{q_n}(\eta_n, |b_{\tau\parallel}|, \mu, \nu) \mathcal{B}_{\bar{q}_n}(\eta_{\bar{n}}, |b_{\tau\parallel}|, \mu, \nu) \right. \\
 & \times \text{Tr} \left[\mathbf{H}_{q_n \bar{q}_n}(m_t, \beta_{t\bar{t}}, x_t, \mu) \mathbf{S}_{q_n \bar{q}_n}(b_{\tau\parallel} \vec{r}, n, \bar{n}, v_t, v_{\bar{t}}, \mu, \nu) \right]_{\text{col}} + \mathcal{B}_{q_{\bar{n}}}(\eta_{\bar{n}}, |b_{\tau\parallel}|, \mu, \nu) \\
 & \times \mathcal{B}_{\bar{q}_n}(\eta_n, |b_{\tau\parallel}|, \mu, \nu) \text{Tr} \left[\mathbf{H}_{q_{\bar{n}} \bar{q}_n}(m_t, \beta_{t\bar{t}}, x_t, \mu) \mathbf{S}_{q_{\bar{n}} \bar{q}_n}(b_{\tau\parallel} \vec{r}, n, \bar{n}, v_t, v_{\bar{t}}, \mu, \nu) \right]_{\text{col}} \\
 & + \text{Tr} \left[\mathbf{H}_{g_n g_n}(m_t, \beta_{t\bar{t}}, x_t, \mu) \mathbf{S}_{g_n g_n}(b_{\tau\parallel} \vec{r}, n, \bar{n}, v_t, v_{\bar{t}}, \mu, \nu) \mathbf{B}_{g_n}(\eta_{\bar{n}}, b_{\tau\parallel} \vec{r}, \mu, \nu) \right. \\
 & \times \mathbf{B}_{g_{\bar{n}}}(\eta_{\bar{n}}, b_{\tau\parallel} \vec{r}, \mu, \nu) \Big]_{\text{col} \otimes \text{hel}_n \otimes \text{hel}_{\bar{n}}} \Big\}
 \end{aligned}$$

where $\beta_{t\bar{t}} = \sqrt{1 - 4m_t^2/M_{t\bar{t}}^2}$

- L_T -dominance

$$\frac{d\sigma}{dM_{t\bar{t}} d\Omega_t dq_\tau dY_{t\bar{t}}} = 2 \int_{-\infty}^{\infty} db_{\tau\parallel} \cos(b_{\tau\parallel} q_\tau) \left\{ \sum_{m=0} c_m L_T^m + \sum_{m=0} d_m [\text{sign}(b_{\tau\parallel})] L_T^m \right\}$$

- Resummation → RGE (virtuality) and RaGE (rapidity)

Resummation

$$\frac{d\sigma}{dq_T} \sim \sigma_{\text{Born}} \cdot \exp \left[\underbrace{\ln \lambda_T f_0(\alpha_s \ln \lambda_T)}_{(\text{LL})} + \underbrace{f_1(\alpha_s \ln \lambda_T)}_{(\text{NLL}, \text{NLL}')}, + \underbrace{\alpha_s f_2(\alpha_s \ln \lambda_T)}_{(N^2 \text{LL}, N^2 \text{LL}')}, + \underbrace{\alpha_s^2 f_3(\alpha_s \ln \lambda_T)}_{(N^3 \text{LL}, N^3 \text{LL}')}, + \dots \right] \quad (2)$$

$$\cdot \left\{ 1(\text{LL}, \text{NLL}); \alpha_s (\text{NLL}', \text{N}^2 \text{LL}); \alpha_s^2 (\text{N}^2 \text{LL}', \text{N}^3 \text{LL}); \alpha_s^3 (\text{N}^3 \text{LL}', \text{N}^4 \text{LL}); \dots \right\},$$

Logarithmic accuracy	$\mathcal{H}, \mathcal{S}, \mathcal{B}$	Γ_{cusp}	$\gamma_{t,h,s,b}$
NLL	$\mathcal{O}(\alpha_s^0)$	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s)$
$N^2 \text{LL}$	$\mathcal{O}(\alpha_s)$	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^2)$
$N^2 \text{LL}'$	$\mathcal{O}(\alpha_s^2)$	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^2)$
$a N^2 \text{LL}'$	$\mathcal{O}(\alpha_s^2)_{\log}$	$\mathcal{O}(\alpha_s^3)$	$\mathcal{O}(\alpha_s^2)$

Table: Needed accuracy of the fixed-order inputs to achieve a given logarithmic accuracy of the resummation, in accordance with eq. (2).

Resummation

- Matching procedure

$$\begin{aligned}\frac{d\sigma_{\text{mat}*}}{dq_\tau} &\equiv \left[\left(\frac{d\sigma_{\text{res}}}{dq_\tau} - \frac{d\sigma_s}{dq_\tau} \right) f_{\text{tran}}(q_\tau, \mu_{\text{mat}}, r_{\text{mat}}) + \frac{d\sigma_s}{dq_\tau} \right] \frac{d\sigma_{\text{FO}}/dq_\tau}{d\sigma_s/dq_\tau} \\ &= f_{\text{tran}}(q_{\text{tau}}, \mu_{\text{mat}}, r_{\text{mat}}) \left(\frac{d\sigma_{\text{res}}}{dq_\tau} \right) \left[\frac{d\sigma_{\text{FO}}/dq_\tau}{d\sigma_s/dq_\tau} \right]_{\text{exp}} + \bar{f}_{\text{tran}}(q_\tau, \mu_{\text{mat}}, r_{\text{mat}}) \frac{d\sigma_{\text{FO}}}{dq_\tau}\end{aligned}\quad (3)$$

- The transition function

$$f_{\text{tran}}(q_\tau, \mu_{\text{mat}}, r_{\text{mat}}) = \begin{cases} 1 & q_\tau < \mu_{\text{mat}} - r_{\text{mat}} \\ 1 - \frac{(q_\tau - \mu_{\text{mat}} + r_{\text{mat}})^2}{2r_{\text{mat}}^2} & \mu_{\text{mat}} - r_{\text{mat}} < q_\tau < \mu_{\text{mat}} \\ \frac{(q_\tau - \mu_{\text{mat}} - r_{\text{mat}})^2}{2r_{\text{mat}}^2} & \mu_{\text{mat}} < q_\tau < \mu_{\text{mat}} + r_{\text{mat}} \\ 0 & q_\tau + r_{\text{mat}} < \mu_{\text{mat}} \end{cases} \quad (4)$$

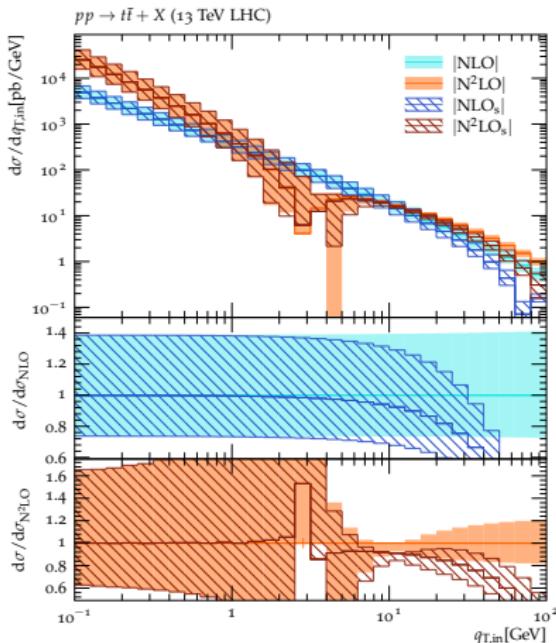
Numerical Results

- Observables

$$\begin{aligned} q_{T,\text{in}} &\equiv |\vec{q}_{\perp}^{t\bar{t}} \cdot \vec{\tau}| \text{ where } \vec{\tau} \parallel \vec{P}_{\perp}^t \\ q_{T,\text{out}} &\equiv |\vec{q}_{\perp}^{t\bar{t}} \cdot \vec{\tau}| \text{ where } \vec{\tau} \perp \vec{P}_{\perp}^t \\ \Delta\phi^{t\bar{t}} &= \pi - \arccos \left[\frac{\vec{p}_{t,\perp} \cdot \vec{p}_{\bar{t},\perp}}{|\vec{p}_{t,\perp}| |\vec{p}_{\bar{t},\perp}|} \right] \sim \frac{q_{T,\text{out}}}{|\vec{p}_{t,\perp}|} + \dots \end{aligned} \tag{5}$$

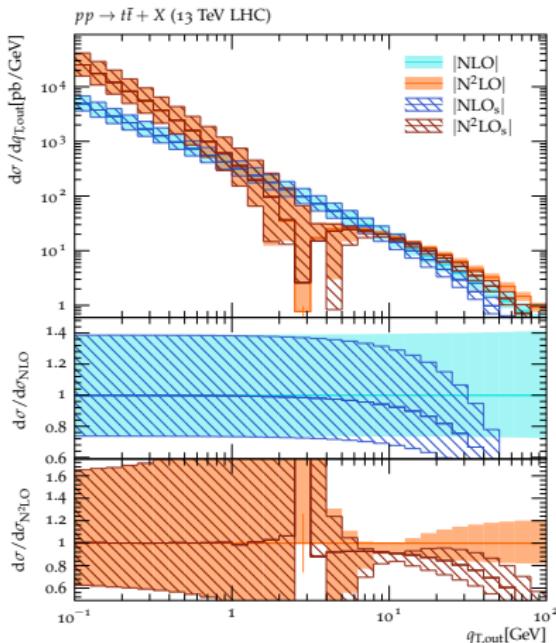
- $\mu_h = \nu_b = M_{t\bar{t}}$, $\nu_s = \mu_b = \mu_s = b_0/b_T$,
- Throughout this paper, we take all the input parameters (including electroweak coupling as well as the involved masses and widths) [\[PDG\]](#).
- The PDFs utilized in this work is NNPDF3.1 from [\[Ball:2017nwa\]](#).

Validation



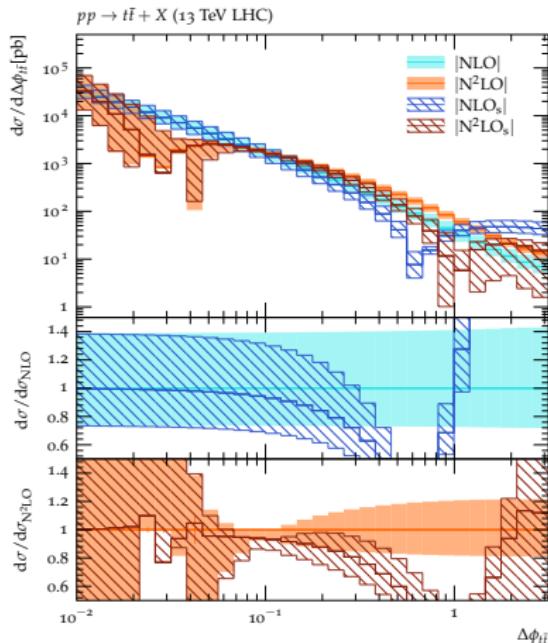
- $q_{T,\text{in}} \equiv |\vec{q}_{\perp}^{t\bar{t}} \cdot \vec{\tau}|$ where $\vec{\tau} \parallel \vec{P}_{\perp}^t$
- Uncertainties: matching scale $[2M_{t\bar{t}}, M_{t\bar{t}}/2]$
- Obvious agreements between approximate and exact results in $q_T \rightarrow 0$

Validation



- $q_{T,\text{out}} \equiv |\vec{q}_{\perp}^{t\bar{t}} \cdot \vec{\tau}|$ where $\vec{\tau} \perp \vec{P}_{\perp}^t$
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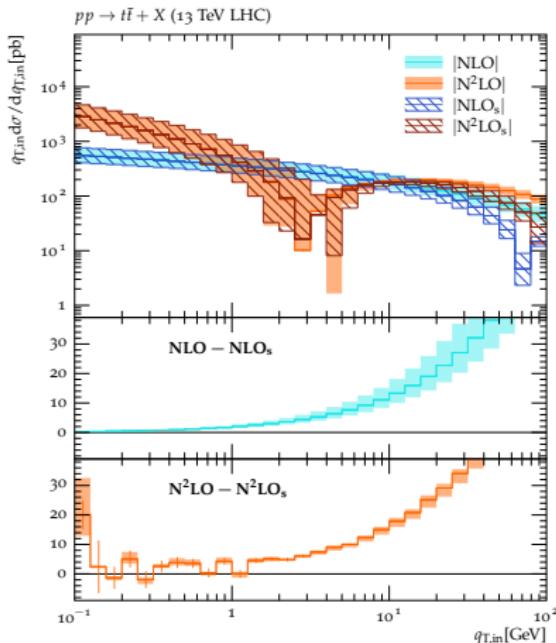
Validation



- $\Delta\phi^{t\bar{t}} = \pi - \arccos \left[\frac{\vec{p}_{t,\perp} \cdot \vec{p}_{\bar{t},\perp}}{|\vec{p}_{t,\perp}| |\vec{p}_{\bar{t},\perp}|} \right] \sim \frac{q_{T,\text{out}}}{|\vec{p}_{t,\perp}|} + \dots$

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Validation



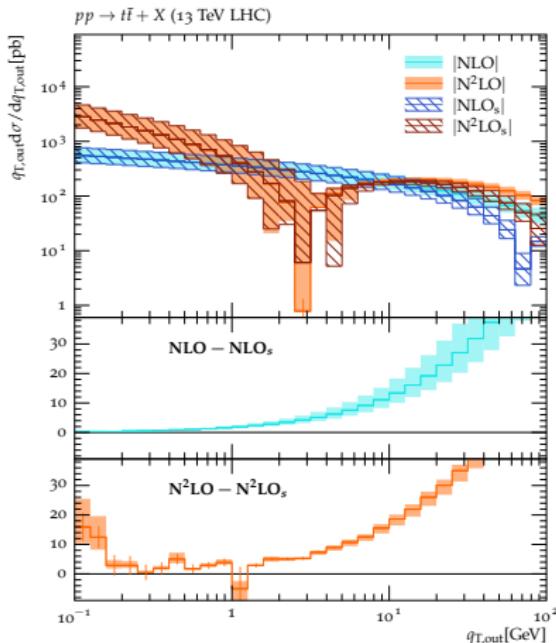
- $q_{T,\text{in}} \equiv |\vec{q}_{\perp}^{t\bar{t}} \cdot \vec{\tau}|$ where $\vec{\tau} \parallel \vec{P}_{\perp}^t$

$$\frac{d\sigma}{dq_{\tau}} \sim \sum_m \frac{\ln^m(q_{\tau})}{q_{\tau}} + \sum_m \ln^m(q_{\tau}) + \dots$$

$$\frac{d\sigma}{d \ln q_{\tau}} \sim \sum_m \ln^m(q_{\tau}) + \sum_m q_{\tau} \ln^m(q_{\tau}) + \dots$$

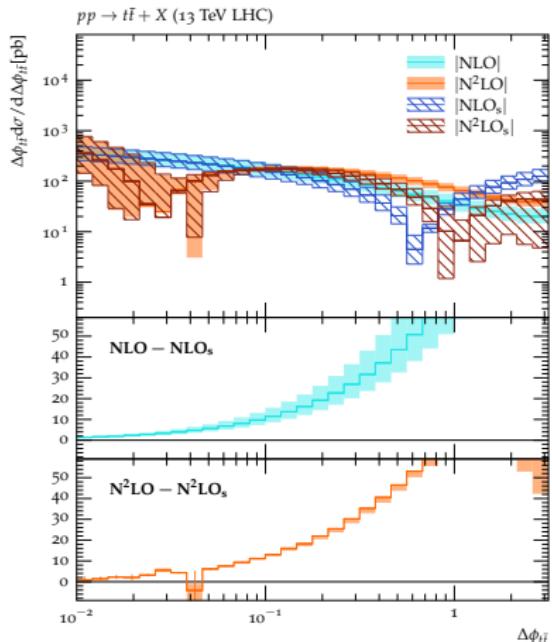
- Uncertainties: matching scale [$2M_{t\bar{t}}$, $M_{t\bar{t}}/2$]
- Obvious agreements between approximate and exact results at NLO,
- MC errors at N2LO

Validation



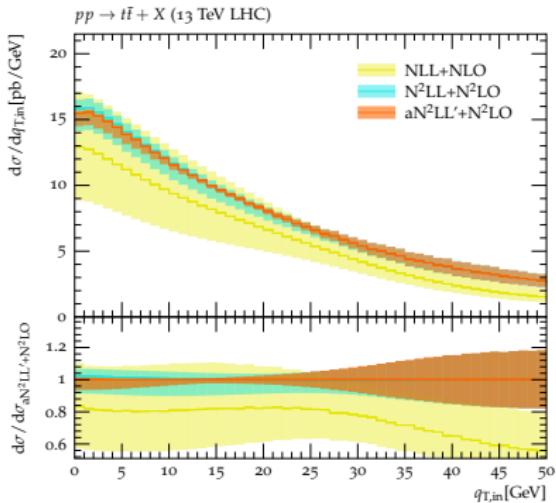
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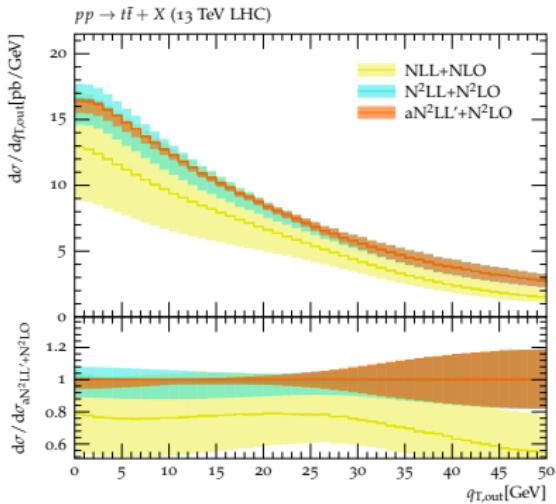
- $\Delta\phi^{t\bar{t}} = \pi - \arccos \left[\frac{\vec{p}_{t,\perp} \cdot \vec{p}_{\bar{t},\perp}}{|\vec{p}_{t,\perp}| |\vec{p}_{\bar{t},\perp}|} \right] \sim \frac{q_{T,\text{out}}}{|\vec{p}_{t,\perp}|} + \dots$
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- MC errors at N2LO

Resummation



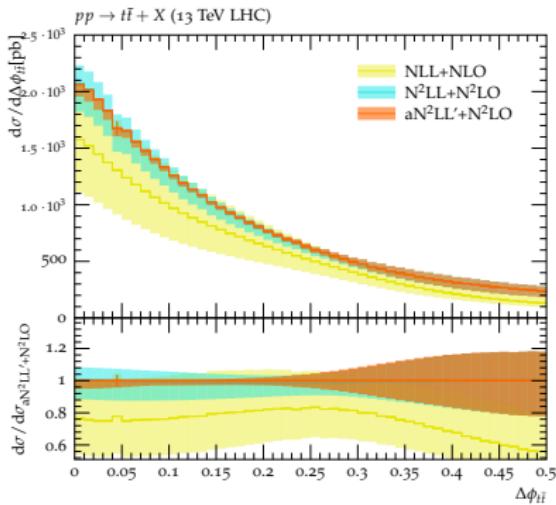
- Uncertainties: intrinsic scales $[2\mu, \mu/2]$
- Small q_T regime
 - The central values are close to each other.
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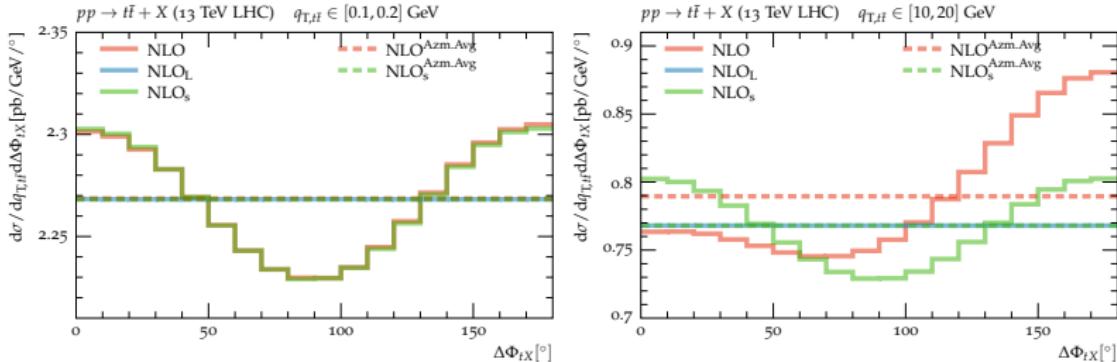
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Conclusion

- Within SCET+HQET, the q_τ spectra on the $t\bar{t}$ production are investigated from $\text{NLL} \rightarrow aN^2LL'$.
 - Akin to $|\vec{q}_\perp^{t\bar{t}}|$, q_τ is another observable insensitive to ϕ_b divergences
 - FO:
 1. Manifest agreements App v.s. QCD
 - Resummation:
 1. Obvious convergence with the increase in the accuracy
 2. $aN^2LL' \sim 5\%$ level theoretical uncertainty

Thanks for your attention

Backup

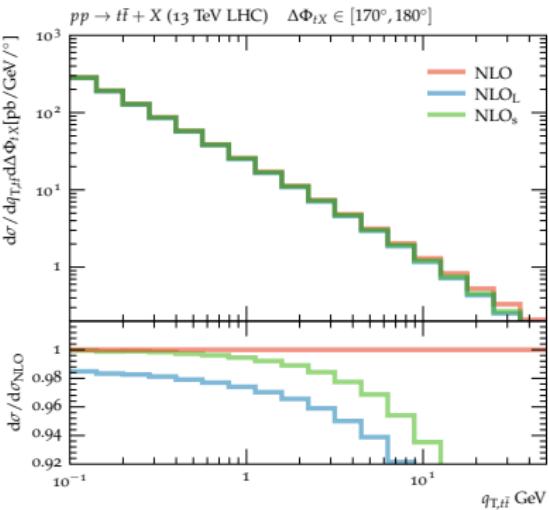
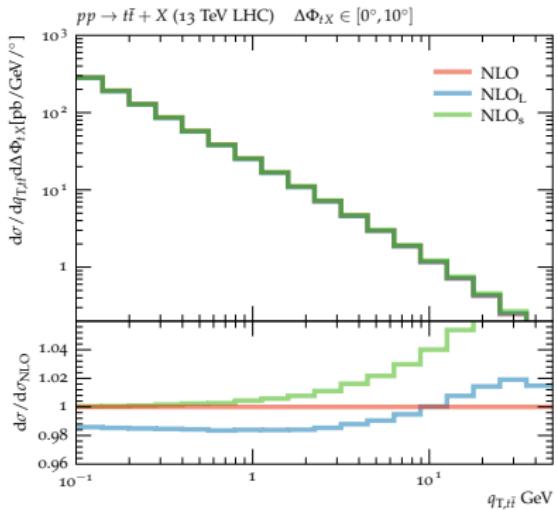


$t\bar{t}$ production: [\[Zhu:2012ts, Li:2013mia, Catani:2014qha, Catani:2017tuc, Catani:2018mei\]](#)

$$\tilde{\sigma}_{t\bar{t}}(\vec{b}_T) = \sum_{m=2, n=1} \alpha_s^m \left[c_{m,n}^{t\bar{t}} + \tilde{c}_{m,n}^{t\bar{t}}(\phi_b) \right] L_T^n + \sum_{m=2} \alpha_s^m \left[d_m^{t\bar{t}} + \tilde{d}_m^{t\bar{t}}(\phi_b) \right],$$

where $L_T = \ln(\vec{b}_T^2 Q^2)$. Both L_T and ϕ_b give rise to $\ln^m(qT)/qT$.

Backup



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