



$t\bar{t}$ production at very high p_t : study of resummation effects using TMD approach

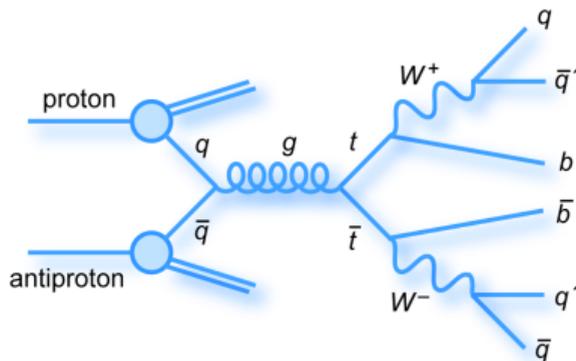
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DESY

November 2018



- Motivation: Resummation and factorization breaking in heavy quark production
- Top jet definition and topology of $t\bar{t}$ events
- $t\bar{t}$ predictions using TMDs

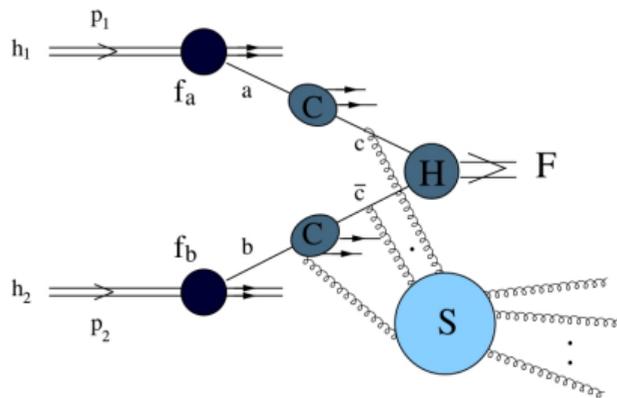


Motivation: Resummation effects & factorization breaking in $t\bar{t}$ events

Catani, S. et al. Transverse-momentum resummation for top-quark pair production at the LHC, JHEP 1811 (2018) 061

Catani, S. et al. Transverse momentum resummation for heavy quark hadroproduction, Nucl Phys, B890, arxiv 1408.4564

S.Catani, D.deFlorian, M.Grazzini
(arxiv:0008184)



At small q_t , fixed order calculations are divergent

When $q_t \ll M$ large logarithms corrections of the form $\alpha_s^n \ln^{2n} M^2/q_t^2$ originating soft and collinear emissions

- C** collinear radiation at scale $1/b$
- Sc** soft and flavor conserving collinear radiation $1/b \lesssim q_t \lesssim M$
- H** hard radiation at scale $q_t \sim M$

$$W_{ab}^F(s, Q, b) \sim C_{ca}(\alpha_s(b_0^2/b^2), z_1) C_{\bar{c}b}(\alpha_s(b_0^2/b^2), z_2) \sigma_{c\bar{c}}^F(Q^2, \alpha_s(Q^2)) S_c(Q, b)(\Delta)$$

Heavy quark production (colored final state): soft radiation at wide-angle start to appear, (through direct emission and interferences with initial-state radiation)

These effects start to appear at NLL in the resummation terms (Δ)

Motivation: Singular azimuthal correlations

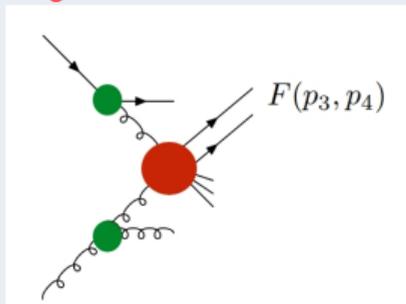
In azimuthal distributions, divergences arise from a single phase space point at

$$q_T = 0 \text{ (i.e. } \Delta\phi_{t\bar{t}} \sim \pi \text{)}$$

Origin of the singular behavior:

I Collinear radiation from initial state colliding

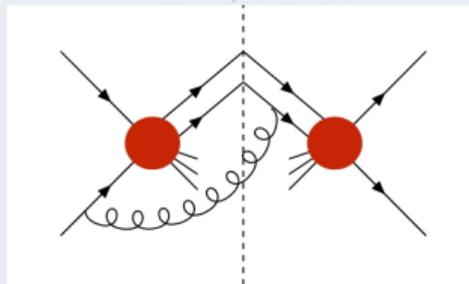
gluons M. Grazzini, Radcor 2017



$$gg \rightarrow F$$

II Soft wide-angle radiation in the case of final states containing coloured particles

M. Grazzini, Radcor 2017



initial-final state interaction which cause factorization breaking

Motivation

Summarizing ...

In $t\bar{t}$ events, singularities in the azimuthal correlations are present because:

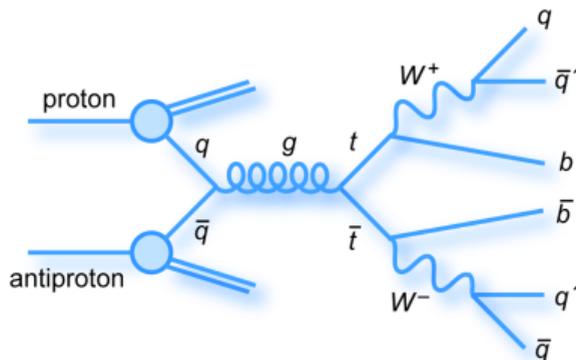
- the $t\bar{t}$ are mostly generated by $gg \rightarrow F$ processes, responsible for collinear and soft emissions
- final state coloured, responsible for soft wide angle radiations. (factorization breaking)

Similar signatures on coloured systems: $F = Vj$ and $F = jj$
but! $t\bar{t}$ case differs from non coloured systems (i.e $Z (W) + \text{jets}$) case
presented before by Jindrich Lidrych

$t\bar{t}$ events with high p_t could be scenarios sensitive to factorization breaking.

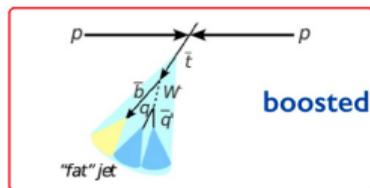
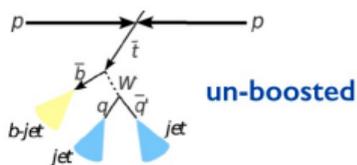
TMDs effects can be significant in resummation regions (coming from intrinsic k_t and parton showers)

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- **Top jet definition and topology of $t\bar{t}$ events**
- $t\bar{t}$ predictions using TMDs



Hadron definition of Top jets in the boosted regime

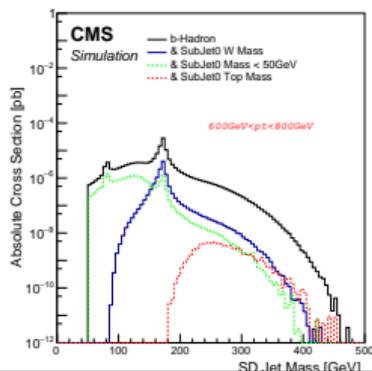
$t \rightarrow bW \rightarrow bq\bar{q} \Rightarrow$ hadronic decay of top (antitop) quarks ...



Soft Drop mass mechanism to reduce soft and collinear radiation and decluster the fat jets into two subjets
Why top jets instead top quarks? have similar hadronic signature that in the case of inclusive jets and $Z + jets$ see J.Lidrych and A.Bermudez presentations

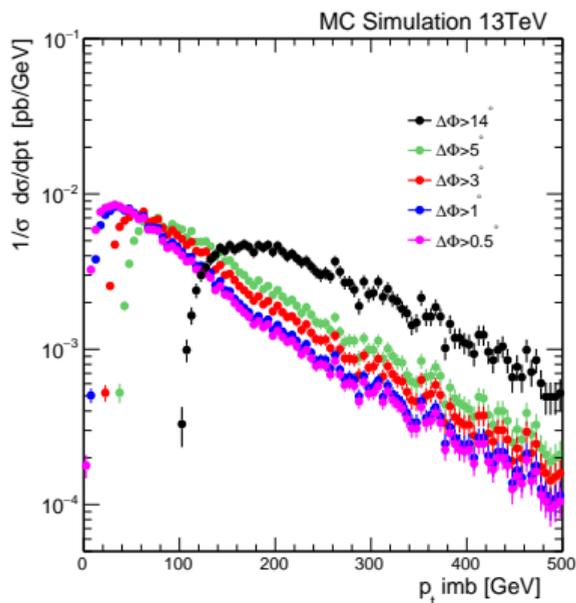
Hadron Definition of Top Jets

- $p_t > 400$ GeV
- B-Hadron inside fat jets
- First subjet should contain the decay products of the W-Boson ($50 < m_{sub0} < 150$ GeV)



p_t imbalance between top jets

Assuming that the two leading jets are the "top jets" candidates, the p_t imbalance between the two jets is reflecting how much is needed to have a angular separation larger than $\Delta\phi_R$



p_t^{imb} requiring a $\Delta\Phi_{min}$
($\Delta\Phi = \pi - \Delta\phi$)

i.e For having $\Delta\phi > 14^\circ$ (outside the back to back region) an extra radiation of $p_t \sim 100$ GeV is required.

If the hard process contain an extra radiation of p_{tmin} , then the region $\Delta\phi > \Delta\phi_R$ is filled by Parton Shower (or TMDs) (corresponding to low q_t region)

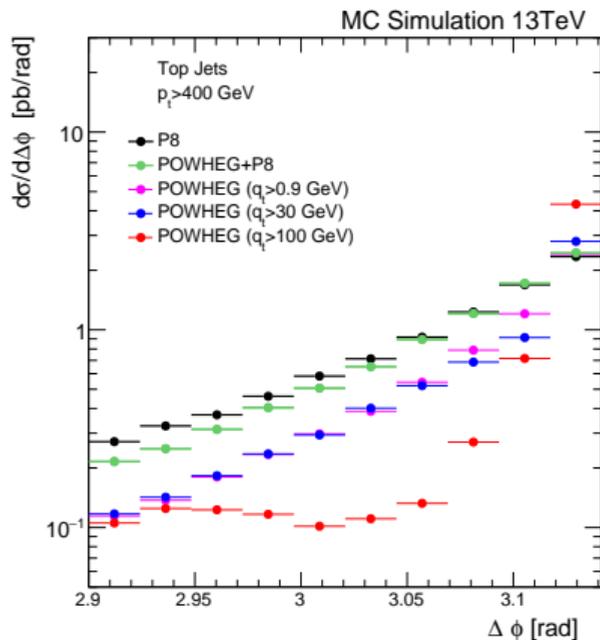
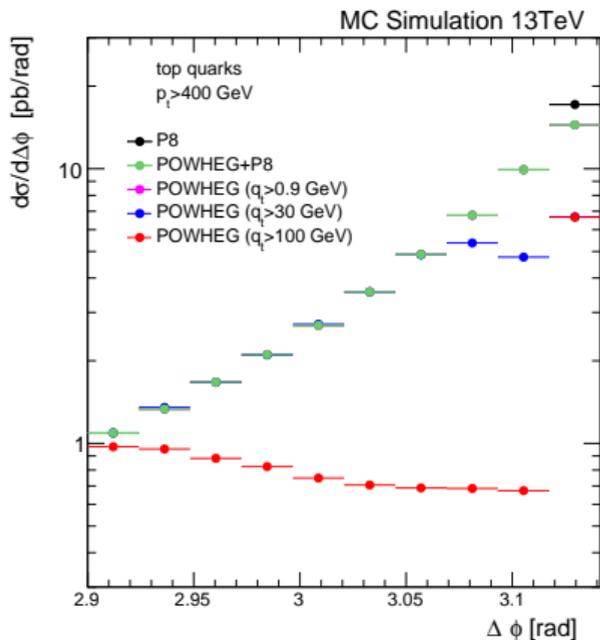
In this presentation, NLO $t\bar{t}$ predictions using POWHEG method are presented :

- POWHEG control the first emission contributing to the Sudakov Form Factor (it can be changed with the *ptsqmin* parameter)
- A q_T cut is applied to allow contributions from TMD and PS in the back to back region
- TMDs (and PS) are matched to POWHEG NLO predictions (POWHEG+CASCADE) and compared with results of POWHEG matched to PYTHIA8

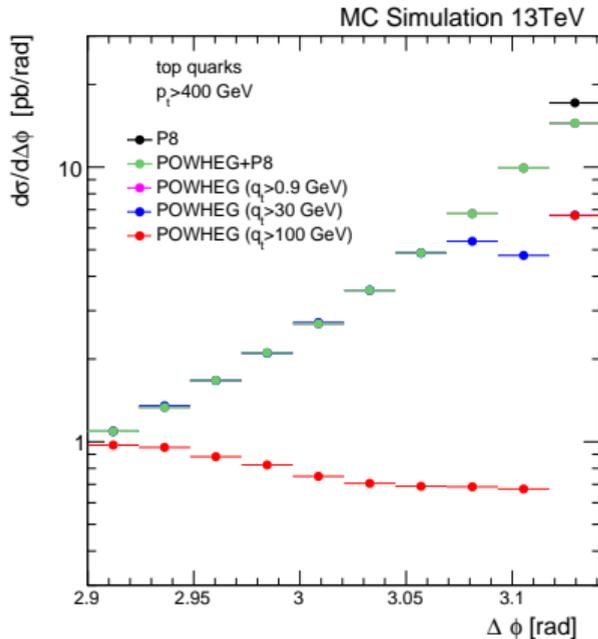
Top quarks & top jets $p_t > 400\text{ GeV}$

POWHEG+Pythia8 (without PS) for different q_{tsqmin} values are compared
(parton level & hadron level)

$\Delta\phi_{t\bar{t}}$ of tops quarks after the hard process is different than $\Delta\phi_{t\bar{t}}$ of the quarks before decaying $\Rightarrow \Delta\phi_{topjets}$ different behavior.

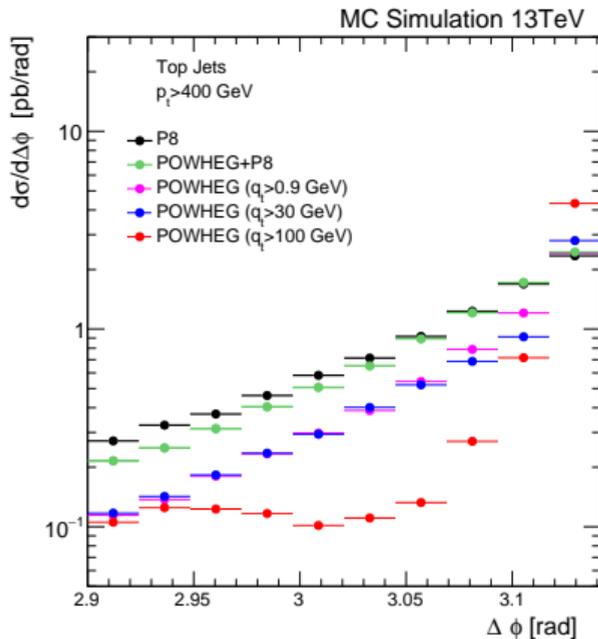


Top quarks & top jets $p_t > 400\text{ GeV}$



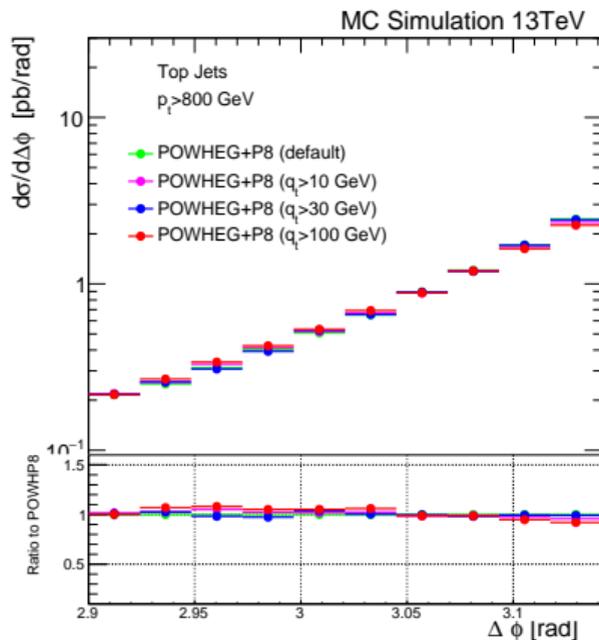
- The back to back region is sensitive to resummation effects (sensitive to extra contributions in the Born process)
- There is a difference between LO (P8) and NLO (POWHEG+P8) order predictions in the last bin (green and black curve)
- Requiring $q_t > 100\text{ GeV}$ in the Born process, this region must be filled by PS (or TMDs)

Top quarks & top jets $p_t > 400\text{ GeV}$

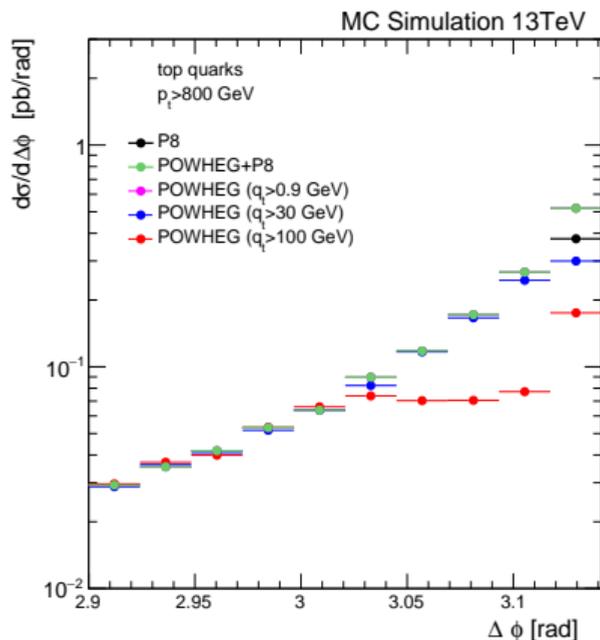
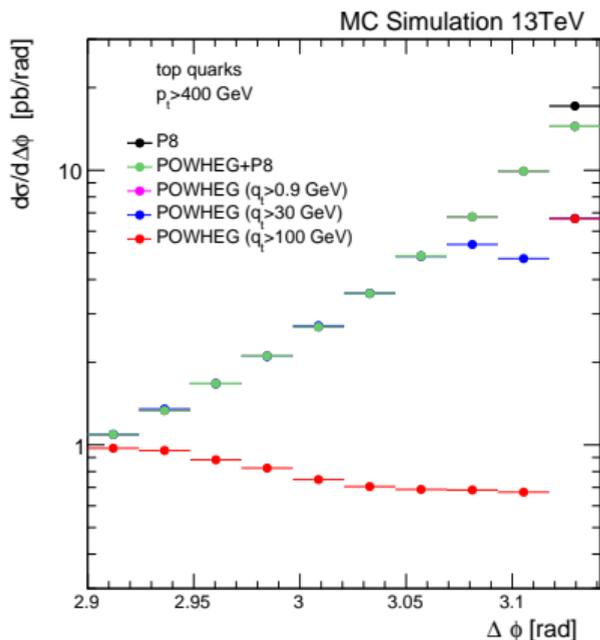


- Requiring $q_t > 100\text{ GeV}$ in the Born process, this region must be filled by PS (or TMDs)
- There is a difference between $\Delta\phi_{t\bar{t}}$ and $\Delta\phi_{topjets}$ (kinematics of jet clustering)
- **But!** Distributions still sensitive to the extra radiation required (in general similar behavior than the $t\bar{t}$ quark system)

Matching the POWHEG NLO predictions with PS (from Pyhia8), the results are independent to the $p_{t,qmin}$ values

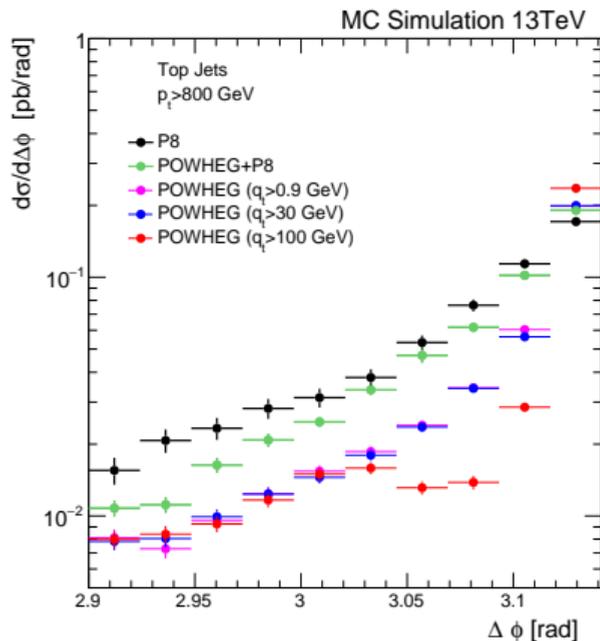
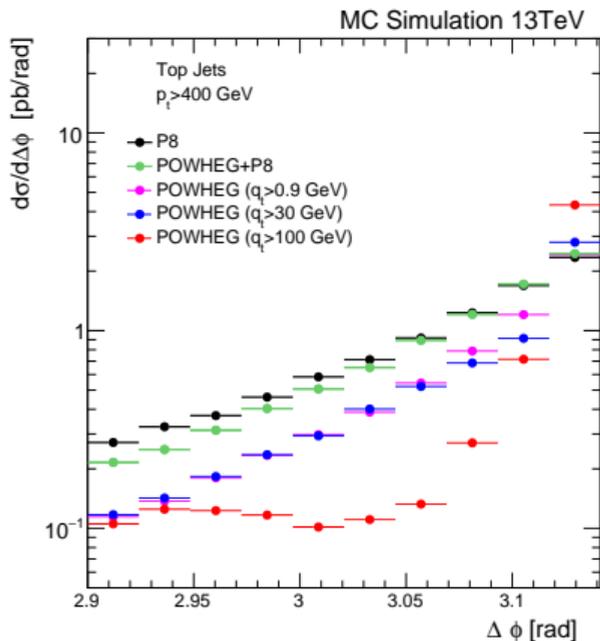


What happens when increasing the p_t top quarks with $p_t > 800\text{ GeV}$



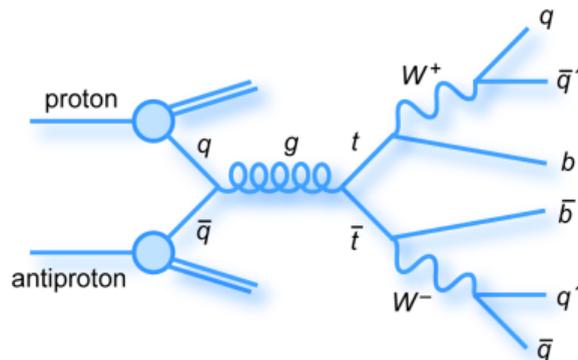
The region sensitive to emission of $p_T \sim 100\text{ GeV}$ is smaller ($\Delta\pi > 3.05\text{ rad}$)
 \Rightarrow higher q_T needed for having the back to back region filled by PS (TMDs)

What happens when increasing the p_t , top jets with $p_t > 800\text{ GeV}$



Similar behavior observed than at parton level, when increasing the p_t

- Motivation: Resummation and factorization breaking in heavy quark production
- Top jet definition and topology of $t\bar{t}$ events
- $t\bar{t}$ predictions using TMD and TMD shower



TMD formalism and application

details given in A.Lelek and A.Bermudez presentations

Collinear and TMD parton densities from fits to precision DIS measurements in the parton branching method *arXiv* : 1804.11152

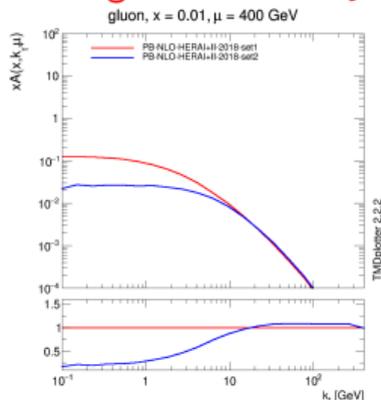
POWHEG is matched to CASCADE using $ptsqmin$ of 10000GeV^2 ($q_T > 100\text{GeV}$)

PB method to determine the transverse momentum dependent (TMD)

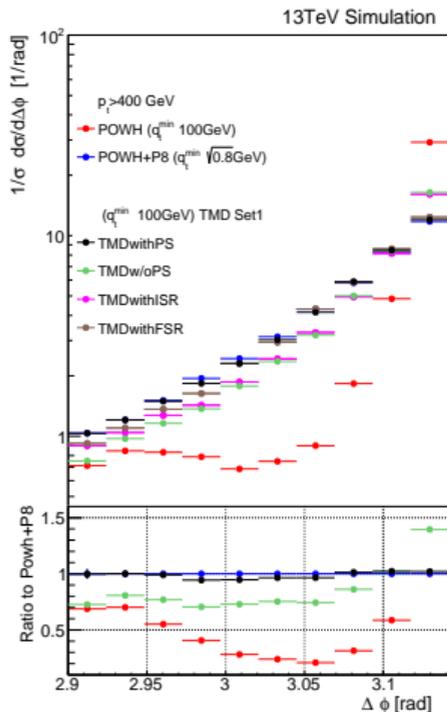
Two different scenarios for TMDs are compared:

Set1: $\alpha_s(\mu^2)$, Set2: $\alpha_s((1-z)^2\mu^2)$ **expected some differences at $\mu \sim 400\text{ GeV}$**

Different TMDs give different k_t distributions

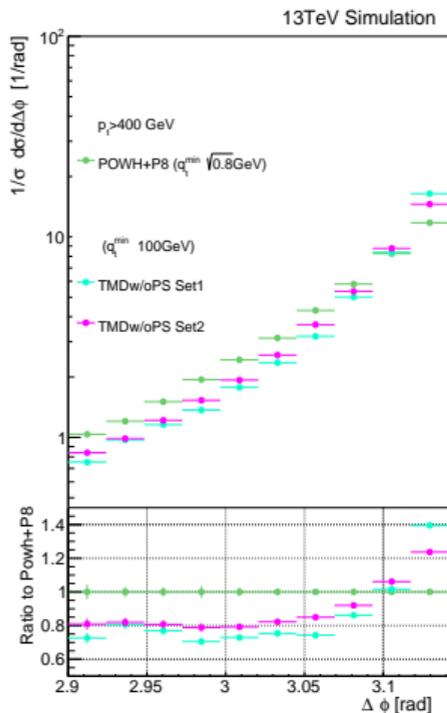


CASCADE-lhe is matched with POWHEG ($q_t^{min} = 100 \text{ GeV}$)

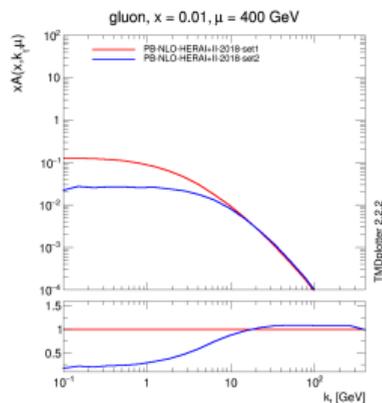


- For this plot, TMD with Set1 scenario is used.
- There is considerable effect in the most back to back region from TMDs (looking at the TMD results without PS)
- TMDs (with PS) is able to fill the back to back region to similar values from (P8+Powheg) matching

CASCADE-Ihe is matched with POWHEG ($q_F t^{min} = 100 \text{ GeV}$). Set1 vs Set2 TMDs without including Parton Shower

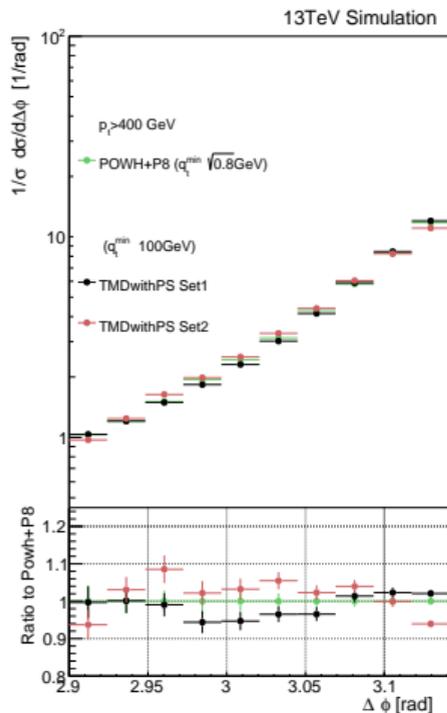


- There is a difference between the two sets of the TMDs (about $\sim 20\%$)



Noticeable effect of the TMDs

CASCADE-lhe is matched with POWHEG ($q_t^{min} = 100$ GeV). Set1 ,Set2 TMDs with Parton Shower



- The difference between the two sets of TMDs is changed $\sim 20\% \rightarrow \sim 10\%$ including TMDs parton shower
- The PS reduce the effects of TMDs, and predictions are similar to the predicted by matching POWHEG with P8.

High p_t top jets are sensitive to resummation effects in the limit when $\Delta\phi \rightarrow \pi$, and could have signature of factorization breaking due to interaction of initial-final shower with coloured partons as final state of the Bron level processes.

- Matching TMD (derived as a result of Parton Branching methods, and with PS) with NLO collinear ME, i.e POWHEG, for predicting $t\bar{t}$ production at high p_t regimes, give similar results and compatibles with the predictions from POWHEG+PYTHIA
- There is TMD dependence visible in the most back to back region ($\sim 20\%$)
- Further applications of CASCADE-lhe will be given in the tutorial on Friday

Thanks for your attention!