Recent Developements on PB-TMD fits

xFitter external meeting
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Overview

1. Introduction
2. PB-global Fit
3. Changing the scale on xFitter
4. Contribution of soft gluons on both PDFs and TMDs
5. Conclusion

Parton Branching (PB) method

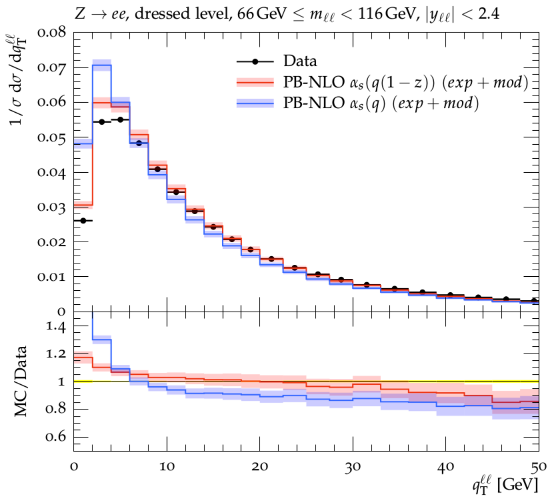
[Phys. Rev. D 100 (2019) no.7, 074027]
[Eur.Phys.J.C 82 (2022) 8, 755]
[Eur.Phys.J.C 82 (2022) 1, 36]
[Phys. Lett. B 822 136700 (2021)]
[JHEP 09 060 (2022)]

- Evolution of TMDs (and collinear PDFs) at LO, NLO & NNLO
- Resummation of soft gluons at LL and NLL (at NLL identical to CSS approach)
- unique feature: backward evolution fully determines the TMD shower: consistently treats perturbative and non-perturbative transverse momentum effects
- PB TMDs together with PB TMD parton shower allow very good description of measurements over wide kinematic range

PB-Fitting procedure in a nutshell

- Two angular ordered sets with different choice of scale in α_s:
- Set1: $\alpha_s(Q^2)$: identical to HERAPDF2.0
- Set2: $\alpha_s(p_t^2=Q^2(1-z)^2)$: to avoid the non-perturbative region at large $z \rightarrow Q_{cut}=1$ GeV.

[Phys. Rev. D 100 (2019) no.7, 074027]



TMD parametrization:

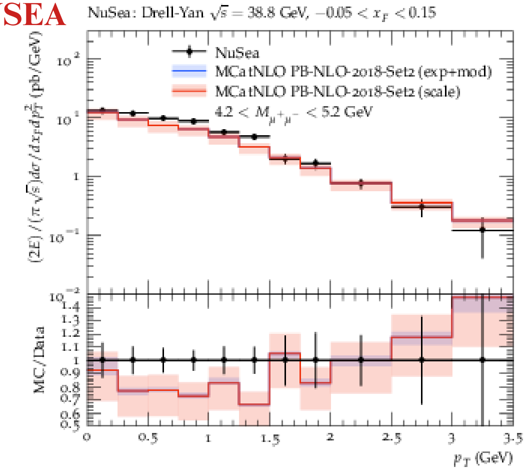
$$f_{0,b}(x, \mathbf{k}^2_{t,0}, \mu_0^2) = f_{0,b}(x, \mu_0^2) \cdot \exp(-|k^2_{T,0}|/2\sigma^2) \quad \sigma^2 = q_s^2/2 \;\; \& \;\; q_s = 0.5 \; GeV$$

Fitting procedure in a nutshell:

- parameterize collinear PDF at μ_0^2
- produce PB kernels for collinear & TMD distributions to evolve them to $\mu^2 > \mu_0^2$
  [Eur. Phys. J. C **74**, 3082 (2014)]
- perform fits to measurements using xFitter frame to extract the initial parametrization (with collinear coefficient functions at NLO)
- store the TMDs in a grid for later use in CASCADE3 [Eur. Phys. J. C **81**, no.5, 425 (2021)]
- plot collinear and TMD pdfs within TMDPLOTTER [arXiv:2103.09741]

DY p_T spectrum in a wide range of energies

NUSEA



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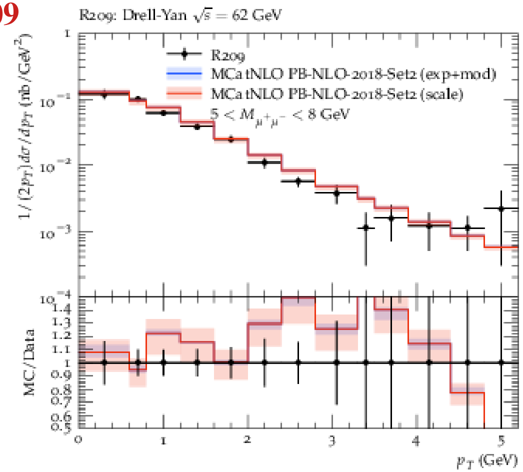
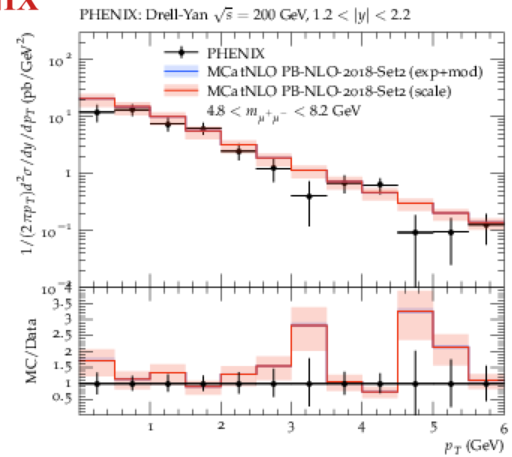
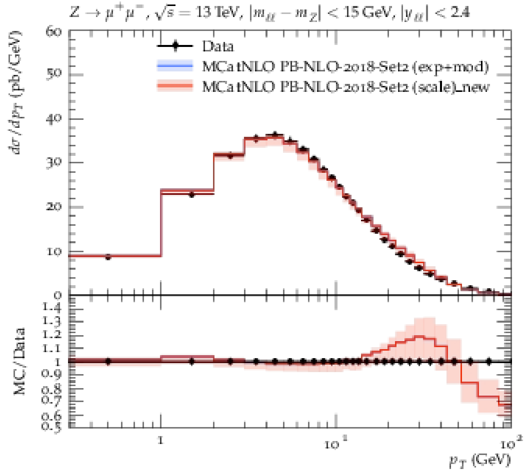


PHENIX



CMS



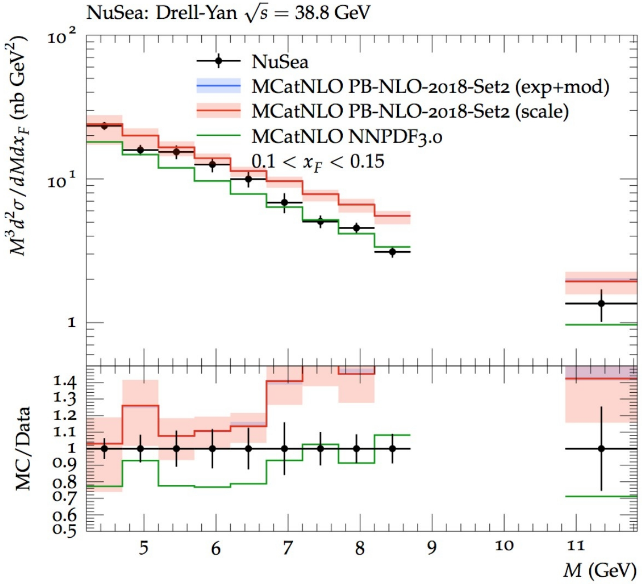
With the PB method we are able to describe the q_t of the DY pair at different centre of mass energies and different DY masses with the same set-up.
Hard process is produced with MC@NLO with corresponding collinear set.

Is there still any room for improvement? YES!

Motivation for global Fit

NuSea data studied with PB PDFs
→ generally well described by PB-TMD + NLO calculation
→ this deteriorates for region of highest masses

[Eur.Phys.J.C 80 (2020) 7]



Why?
DY mass is sensitive to collinear PDFs.
we enter the large-x region where the PDF used in the calculation, which are determined from fits to HERA inclusive data, are poorly constrained.

Treatment?
It can be improved by including different data sets in fits to constrain PDFs at large-x.
NNPDF3.0 obtained from global fit that include NuSea data.

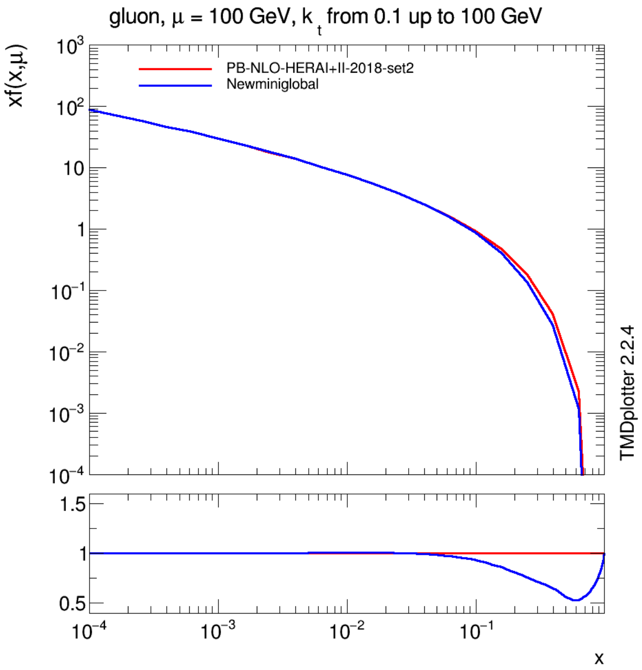
Data samples used in mini-global fit

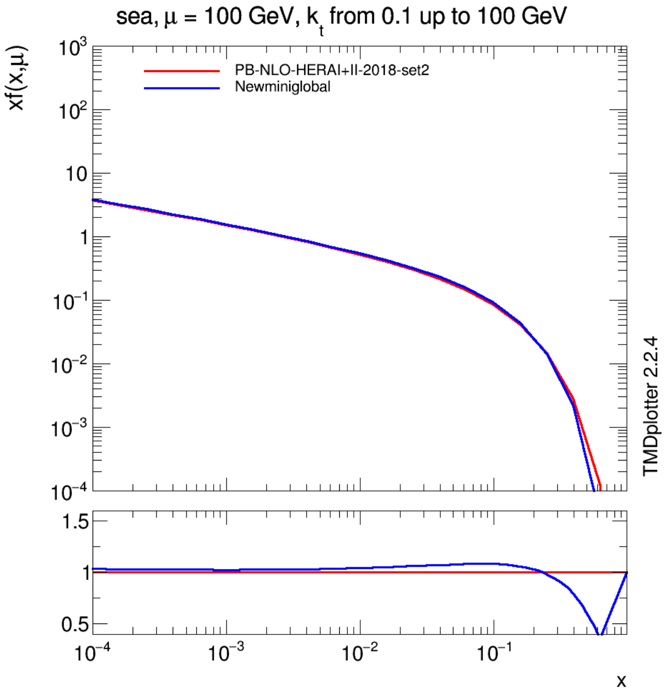
	Dataset	
HERA	HERA1+2 CCep	CC e+-p
	HERA1+2 CCem	NC e+-p
	HERA1+2 NCem	
	HERA1+2 NCep 820	
	HERA1+2 NCep 920	
	HERA1+2 NCep 460	
	HERA1+2 NCep 575	
HERA	ZEUS inclusive dijet 98-00/04-07 data	FastNLO jets
	H1 low Q2 inclusive jet 99-00 data	
	ZEUS inclusive jet 96-97 data	
	H1 normalised inclusive jets with unfolding	FastNLO ep jets normalised
	H1 normalised dijets with unfolding	
	H1 normalised trijets with unfolding	
Tevatron	CDF Z rapidity 2010	NC ppbar
	D0 W el nu lepton asymmetry ptl 25 GeV	CC ppbar
	D0 Z rapidity 2007	
	E866, high mass	NC pp
	E866, mid mass	
	E866, low mass	
LHC	CMS W muon asymmetry	CC pp
	CMS W muon asymmetry 8 TeV	NC pp
	CMS 7 TeV Z Boson rapidity 2	
	CMS 7 TeV Z Boson rapidity 3	
	CMS 7 TeV Z Boson rapidity 4	
	CMS 7 TeV Z Boson rapidity 5	

Total number of data point : 1501

Set1 → chi2/dof=1858/1484=1.25
Set2 → chi2/dof=1922/1484=1.29

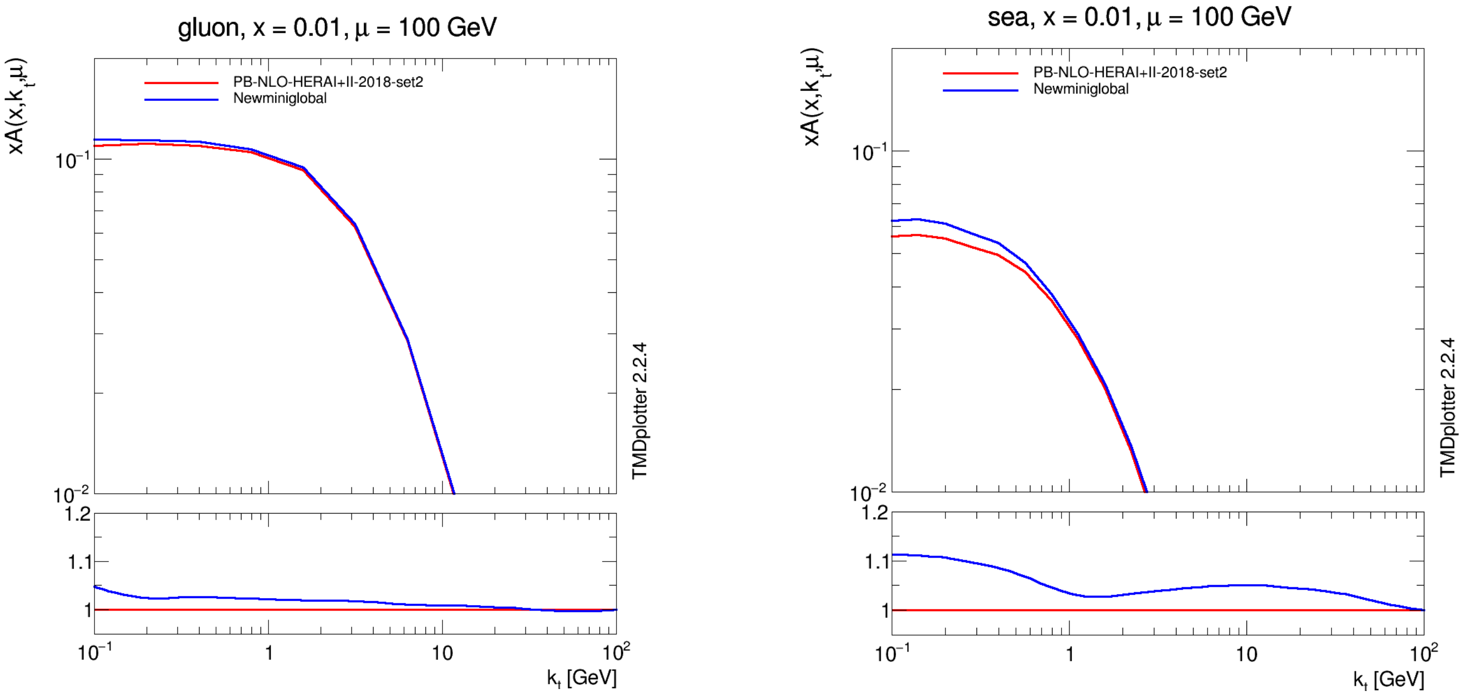
PDF comparison (miniglobal & HERA fits)





Full results already presented at DIS 2022

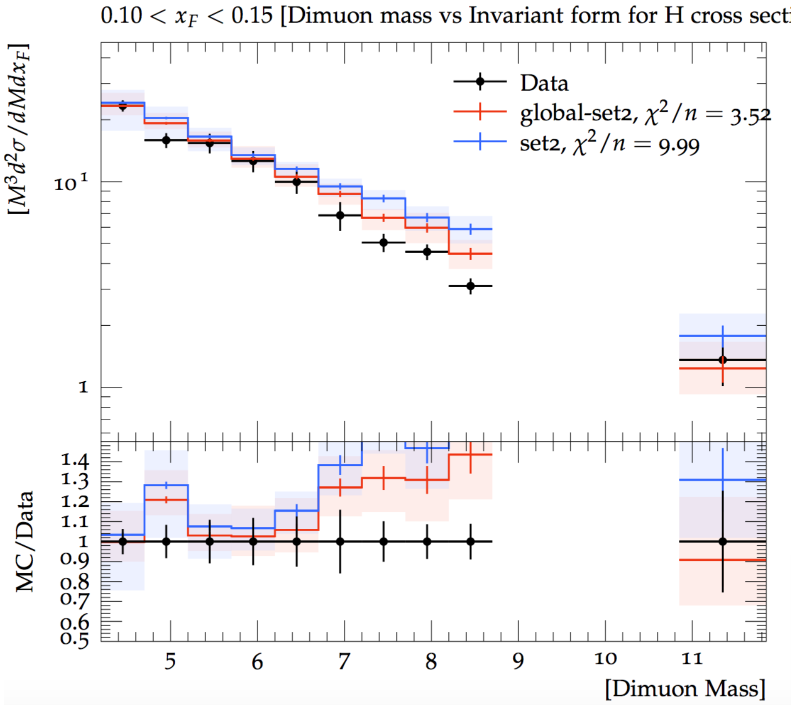
TMD comparison (miniglobal & HERA fits)



Different kt behaviour obtained from collinear splitting functions + collinear pdf
Difference essentially in low kt region
At small kt → few/no resolvable emissions → starting distribution at x plays an important role.
At large kt → Many emissions → no sensitivity to PDFs x-density

Does it work? Yes!

Shown PB-sets from mini-global fit were used to repeat previous studies where predictions were in general 10-20% away from measurements



Current status:

We couldn't include large-x data to set2! e.g. Fixed target DIS, EIC pseudo data

Possible reason:
Mismatch between the scale used in the coefficient functions and kernels

Treatment:
In PBset2 kernels $\mu_R^2=p_t^2$.
→ coefficient $\mu_R^2=p_t^2+Q^2$?

Scale choice in xFitter

$F_2(x,Q^2)$ at NLO/NNLO

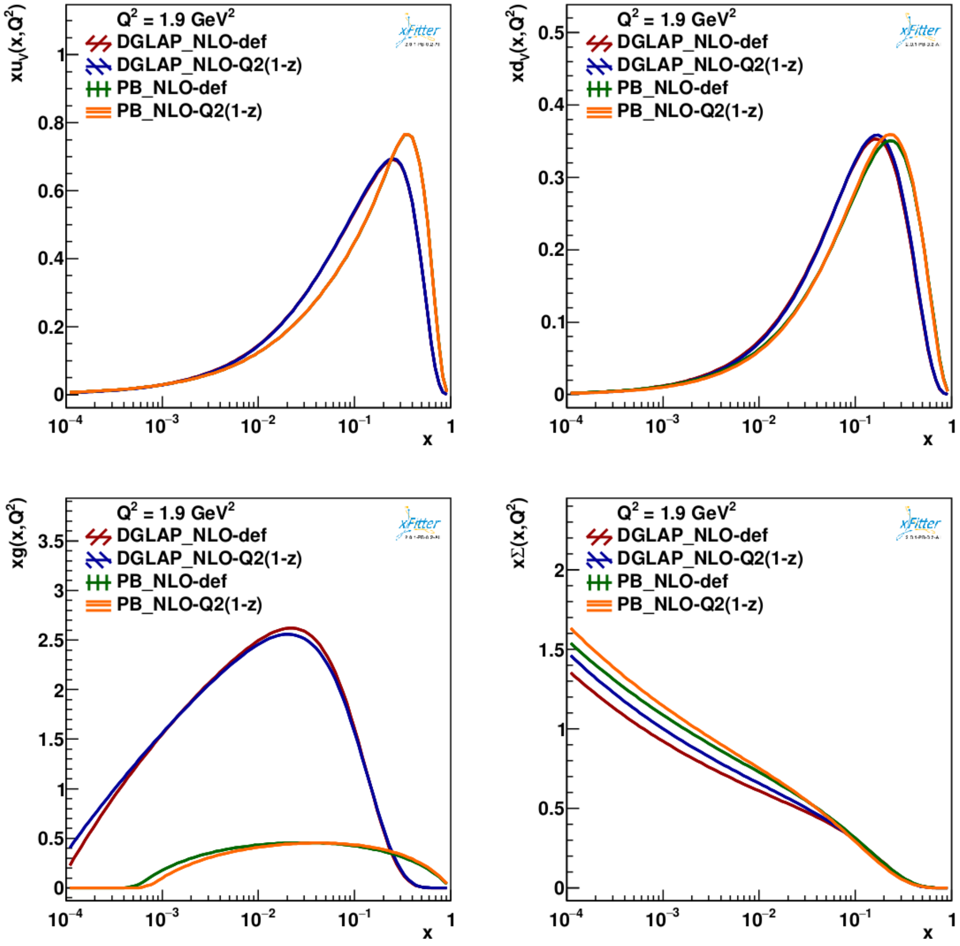
$$F_\lambda(x,Q^2) = \sum_k f_k \otimes C_k^\lambda = \sum_k \int_\chi^1 \frac{d\xi}{\xi} f_k(\xi,\mu) C_k^\lambda \left(\frac{\chi}{\xi}, \frac{Q}{\mu}, \frac{m_i}{\mu}, \alpha_s(\mu)\right)$$

the choice of scale is not unique, affects the accuracy of the predictions. Significant impact on the size of HO contributions

- In massless case: $\chi = x = \frac{Q^2}{2q \cdot p}$
  - Often renormalisation and factorization scales are taken: $\mu = Q$

- In massive case:
  - renormalization scale could also depend on transverse momentum of process
- Approximate with $\hat{t} \sim Q^2$, then $p_T^2 = (1-z)\hat{t} \sim (1-z)Q^2$ with $z = \frac{x}{\xi}$
- Set $\mu_R^2 = Q^2 + p_T^2 = Q^2 + Q^2(1-z)$
- Integral over ξ needs to be performed numerically to have access μ_R

The effect of changing scale

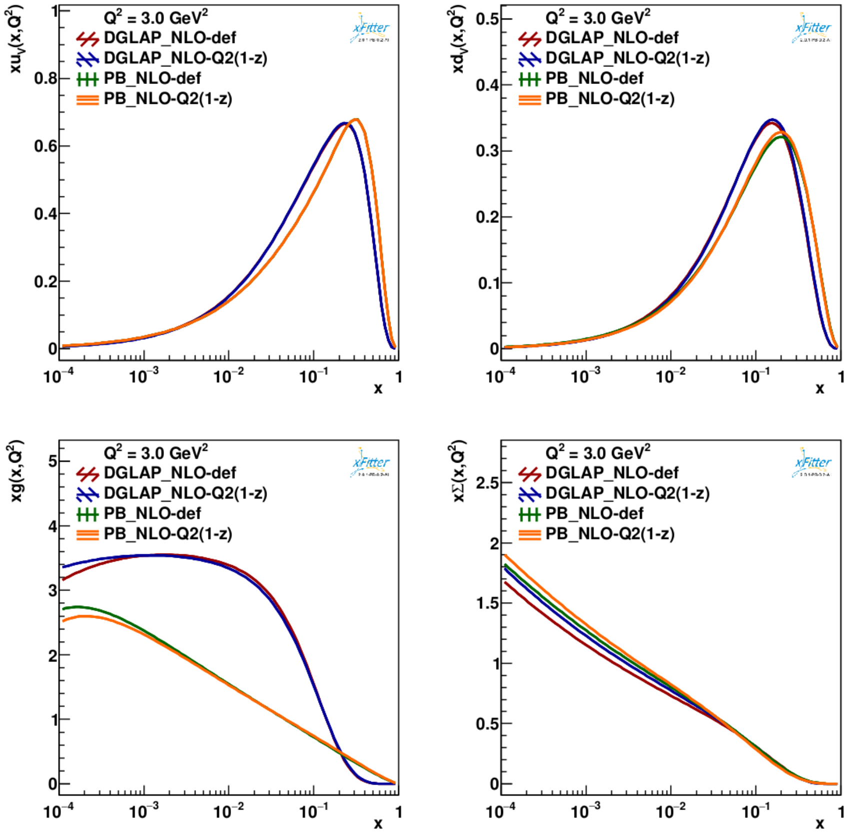


DGLAP-Default chi2/ndf=1357 / 1131
DGLAP-Q2(1-z) chi2/ndf=1351 / 1131

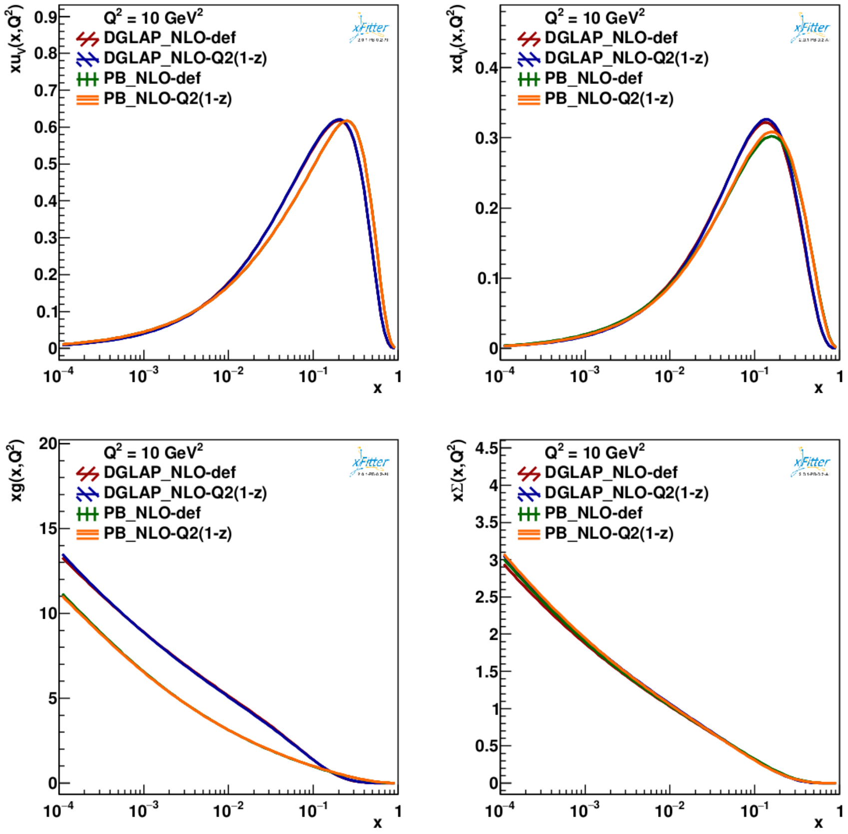
set2-Default chi2/ndf=1394 / 1131
set2-Q2(1-z) chi2/ndf=1375 / 1131

The effect of changing scale

Q^2=3 GeV^2



Q^2=10 GeV^2



Contribution of soft gluons to both PDFs and TMDs

PB method

Parton BR approach provides angular order evolution for TMD parton densities:

$$\widetilde{\mathcal{A}}_a(x,k_\perp^2,\mu^2) = \widetilde{\mathcal{A}}_a(x,k_\perp^2,\mu_0^2)\Delta_a(\mu^2,\mu_0^2) + \int \frac{\mathrm{d}'^2\mu_\perp}{\mu_\perp'^2}\Delta_a(\mu^2,\mu_\perp'^2)\Theta(\mu^2-\mu_\perp'^2)\Theta(\mu_\perp'^2-\mu_0^2)$$
$$\times \sum_b \int_x^{z_M} \mathrm{d}z P_{ab}^R(z,\alpha_s)\widetilde{\mathcal{A}}_b\left(\frac{x}{z},(k_\perp+(1-z)\mu'_\perp)^2,\mu_\perp'^2\right) ,$$

If we integrate over the transverse momentum:

$$\widetilde{f}_a(x,\mu^2) = \widetilde{f}_a(x,\mu_0^2)\Delta_a(\mu^2,\mu_0^2) + \int_{\mu_0^2}^{\mu^2} \frac{\mathrm{d}\mu'^2}{\mu'^2}\Delta_a(\mu^2,\mu'^2)\sum_b \int_x^{z_M} \mathrm{d}z P_{ab}^R(z,\alpha_s)\widetilde{f}_b\left(\frac{x}{z},\mu'^2\right)$$

$$z_M = z_{\mathrm{dyn}} = 1 - q_0/\mu'$$

q_0=0.01 GeV

Z_M : soft gluon resolution parameter
For Z_M ~ 1 : we recover DGLAP

Factorizing to small and large Z regions

Sudakov form factors give the probability to evolve from one scale to another scale without resolvable branching. We introduce an intermadiate scale to divide the two regions with different treatments of the strong coupling

$$\Delta_a(\mu^2,\mu_0^2) \approx \exp\left(-\int_{\mu_0^2}^{\mu^2}\frac{\mathrm{d}\mu'^2}{\mu'^2}\left(\int_0^{z_M} k_a(\alpha_s)\frac{1}{1-z}\mathrm{d}z - d_a(\alpha_s)\right)\right)$$

$$z_{\mathrm{dyn}}(\mu') = 1 - q_0/\mu'$$

q_0:minimal emitted q_T for which a branching can be resolved

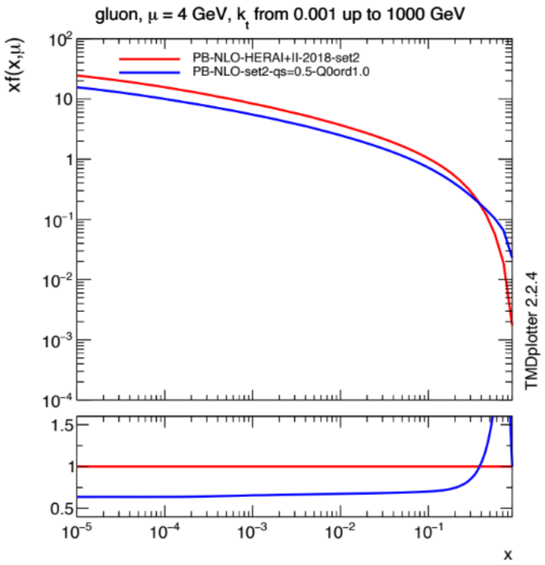
Perturbative	$z < z_{\mathrm{dyn}}$	$q_\perp > q_0$
Non-Perturbative	$z_{\mathrm{dyn}} < z < z_M$ ($z_M = 1-\epsilon$ with $\epsilon \ll 1$)	$q_\perp < q_0$

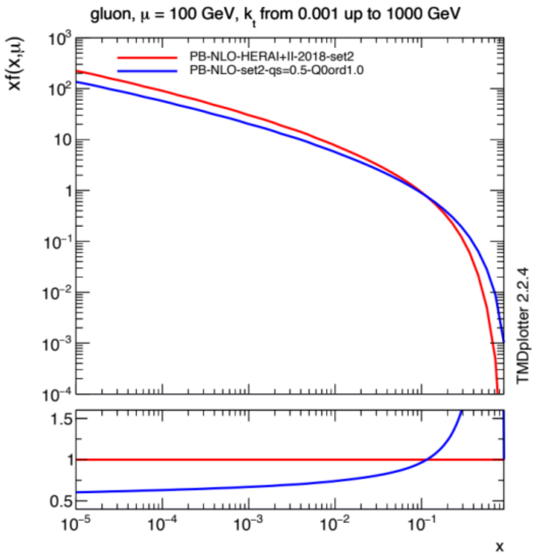
$$\Delta_a(\mu^2,\mu_0^2) = \exp\left(-\int_{\mu_0^2}^{\mu^2}\frac{d\mu'^2}{\mu'^2}\left[\int_0^{z_{\mathrm{dyn}}(\mu')} dz\frac{k_a(\alpha_s)}{1-z} - d_a(\alpha_s)\right]\right) \times \exp\left(-\int_{\mu_0^2}^{\mu^2}\frac{d\mu'^2}{\mu'^2}\int_{z_{\mathrm{dyn}}(\mu')}^{z_M} dz\frac{k_a(\alpha_s)}{1-z}\right).$$

$$\Delta_a(\mu^2,\mu_0^2) = \Delta_a^{(\mathrm{P})}\left(\mu^2,\mu_0^2,q_0\right)\cdot\Delta_a^{(\mathrm{NP})}\left(\mu^2,\mu_0^2,\epsilon,q_0^2\right)$$

- The use of the dynamical resolution scale is important to reach the same sudakov form factor of the CSS formalism.
- I will show how the non-perturbative Sudakov affects both the PDF and the TMDs by allowing really soft emissions.

role of soft gluons with PDFs





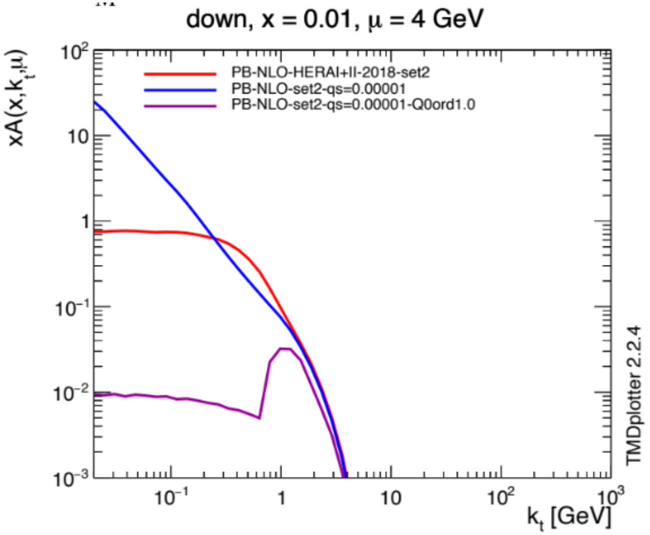
Red: PB-TMD (Zm~1 : Non-pert Sudakov already included)

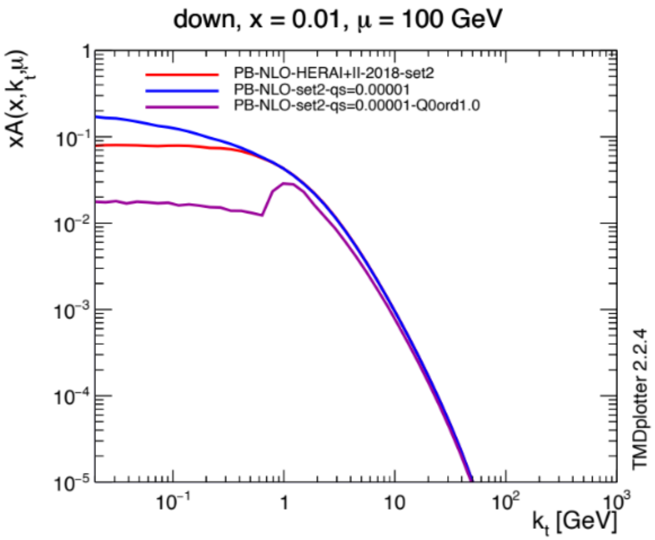
Blue: PB-TMD with q0=1.0 GeV (No Non-pert Sudakov)

The distributions obtained from PB-NLO-2018 set2 with $z_M \rightarrow 1$ are significantly different from those applying $z_M = z_{dyn}$, illustrating the importance of soft contributions even for collinear distributions.

role of soft gluons in TMDs

The effect of the z_M cutoff is even more visible in TMDs!





$$z_M = z_{\rm dyn} = 1 - q_0/\mu'$$

Red: PB-TMD, q_s=0.5 (Zm~1: Non-pert Sudakov)

- The non-pert sudakov allows the radiation of very soft gluons with $z_M \to 1$
- For the region $q_t < q_0$ { α_s will become large, and a special treatment is needed: we freeze α_s for $q_t < q_0$ at $\alpha_s(q_0)$; there are still low k_T contributions, which come from adding vectorially all intermediate emissions }

Blue: PB-TMD, q_s=0.0 (Zm~1: Non-pert Sudakov + No intrinsic kt)

- Effect of the intrinsic k_T distribution is much reduced at large scales

Purple: PB-TMD with q_0=1 GeV, q_s=0 (No Non-pert Sudakov + No intrinsic k_t)

- Emissions below q_0=1 GeV are not allowed

Summery & out look

- PB method implemented in xFitter
    - First fit with the HERA data → extended to global fit
    - For better determition of PDF, still large-x data need to be included

- New scale is defined in xFitter: It decreases χ^2 for both DGLAP and PB fit

- The importance of the non-perturbative region, which is automatically included in the PB approach by the requirement to reproduce DGLAP, is investigated for both collinear and TMDs.

Thanks a lot