Towards mini-global parton-branching TMD fits

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Parton Branching (PB) method

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[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

  → excellent description of the DY spectrum in a wide range of pT

  → also for jet multiplicity even much beyond reach of corresponding fixed-order calculation

Is there still any room for improvement? YES!

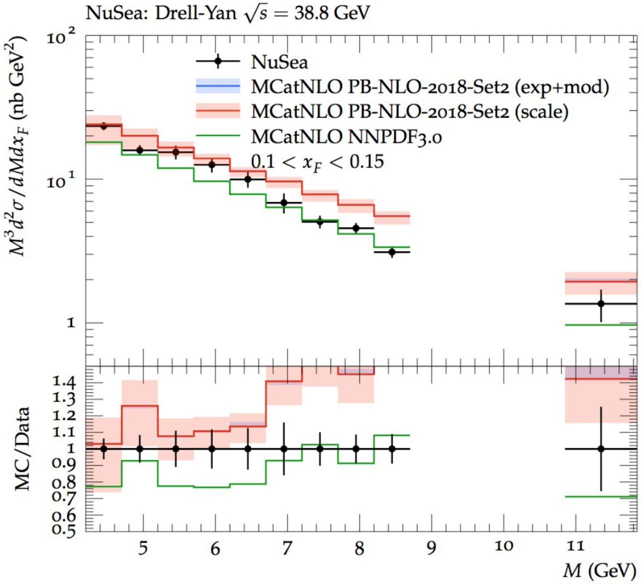
Motivation

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

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.

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



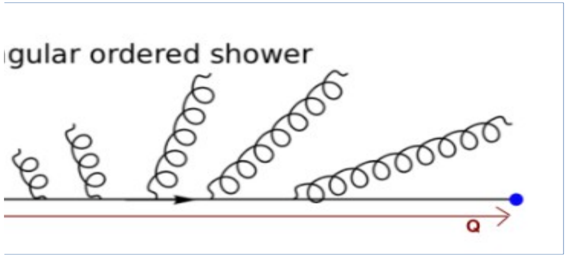
PB-Fitting procedure in a nutshell

- Two angular ordered sets with different choice of scale in α_s:
  - set1: α_s(evolution scale)
  - **set2**: α_s(transverse momentum): similar quality as the NLO + NNLL prediction in $p_t(z)$ description

Introducing "transverse momentum" instead of "evolution scale" suppresses further soft gluons at low kt.

- TMD parametrization:

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



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]

What data can help constraining quarks and gluons?

- Looking at various global fits lots of data can be added
- We start adding slowly additional data sets from HERA and CMS

→ Aiming for mini-global parton-branching TMD fits

We included some of the data sets already available in xFitter, taking care of TMD factorization.

HERA jets → Better constrains on large-x gluon → indirect information on gluon distribution and α_s
CMS DY data + W asymmetries → Better determination of quarks (strange sea).
Fixed target DY → Better constrains on the large-x PDF behavior (sensitive to sea quark distributions)

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

HERAPDF2.0-like parameterisation

$$xf(x) = A\,x^{B}(1-x)^{C}(1+Dx+Ex^{2})$$

→ Parameters obtained by parameterisation scan
→ additional parameters is required

$$xg(x) = A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g} \qquad (1+D_g x)$$

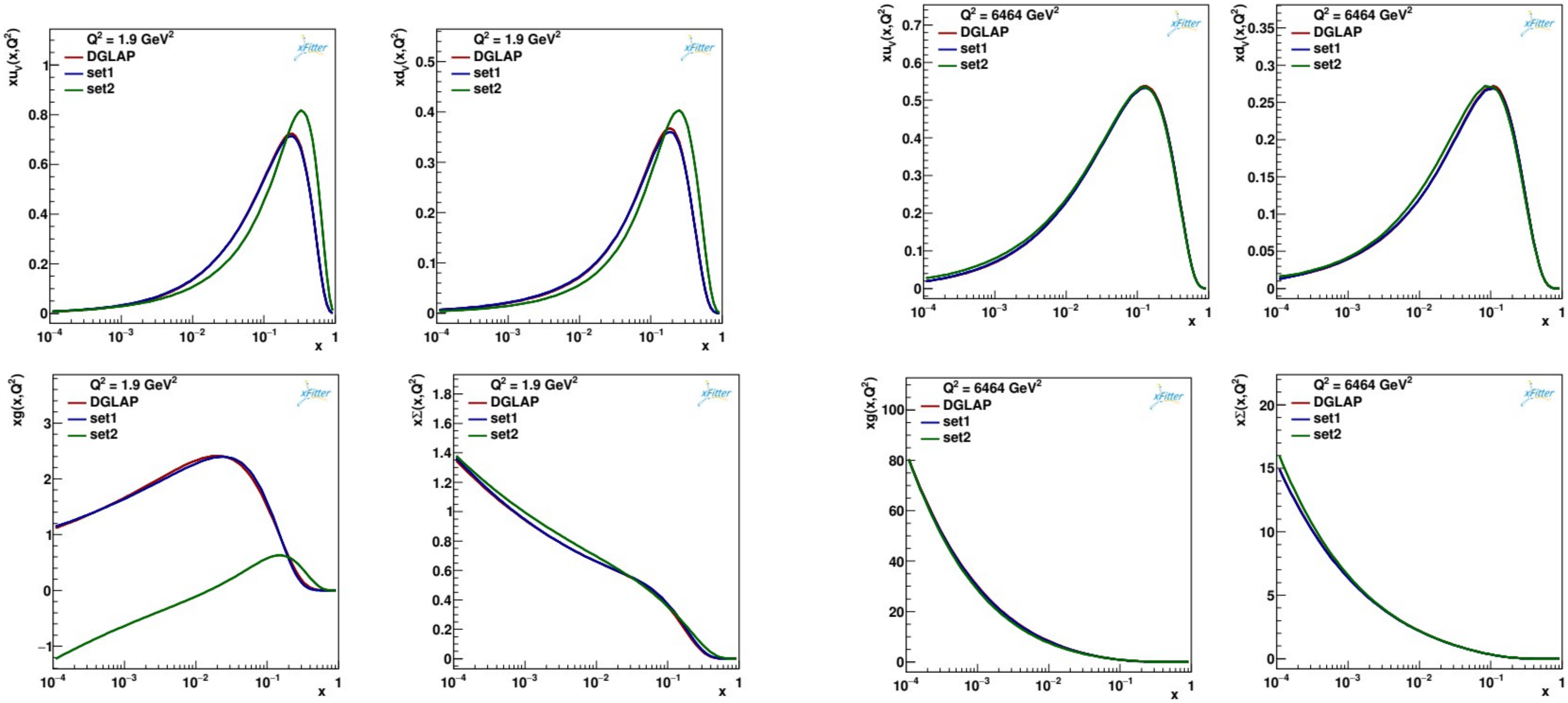
$$xu_v(x) = A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}(1+E_{u_v}x^2) \qquad +D_{u_v}x$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}} \qquad (1+D_{d_v}x)$$

$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}(1+D_{\bar{U}}x) \qquad \text{No } D_{\bar{U}}x \quad +E_{\bar{U}}x^2$$

$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}} \qquad (1+D_{\bar{D}}x)$$

Comparison of miniglobal sets

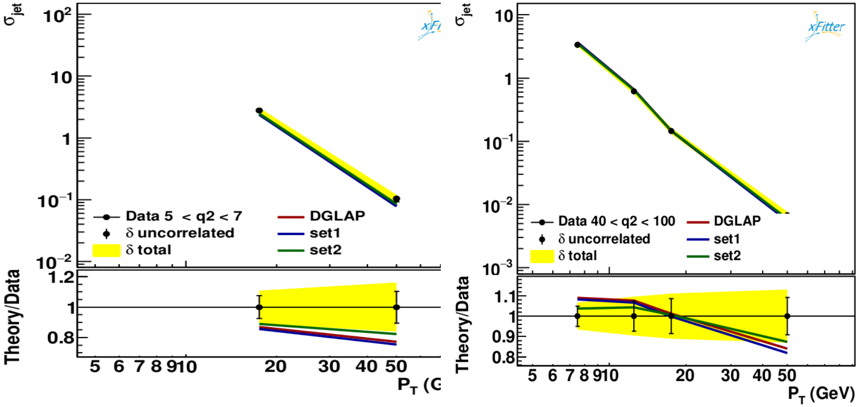


Collinear and PB set1 are very similar
Set2 has a very different gluon density coming from different scale of alpha_s
Differences are washed out at large scale

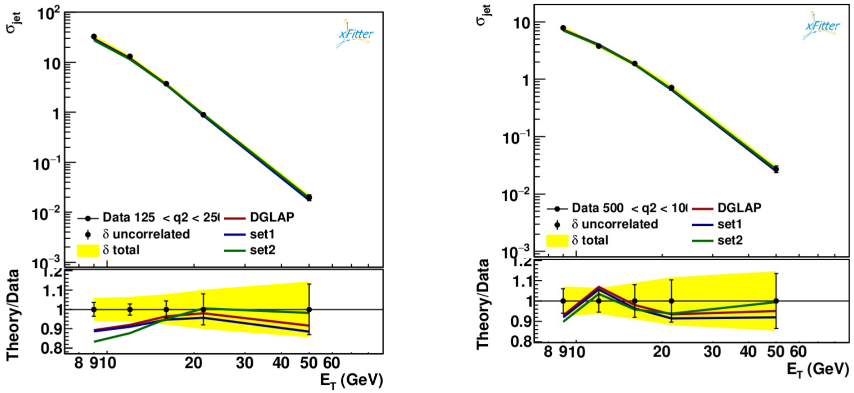
Comparison to jet data (examples)

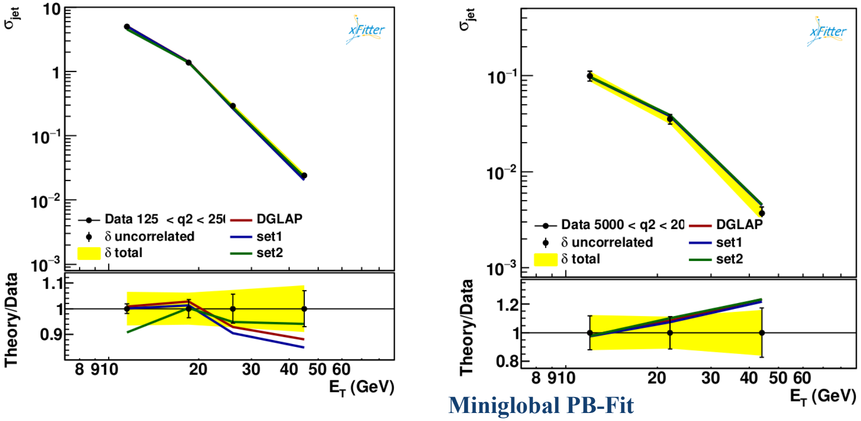
Jets – very interesting results for set2 for low Q2 and low pt –and "low" means even Q2 around 5 GeV2

H1_InclJets_LowQ2_99-00.dat



ZEUS_dijet_98-07.dat

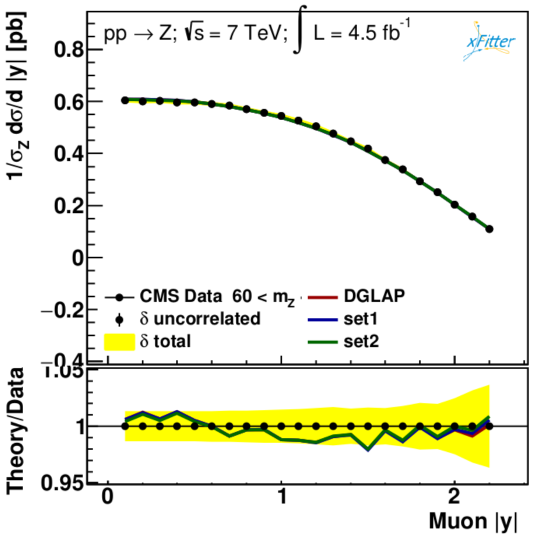




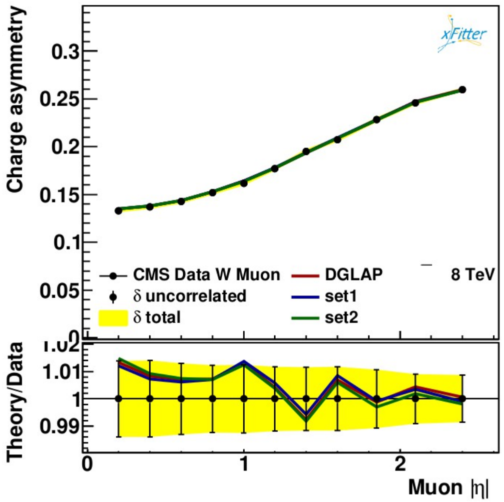
ZEUS_InclJets_HighQ2_96-97

Comparison to pp data (examples)

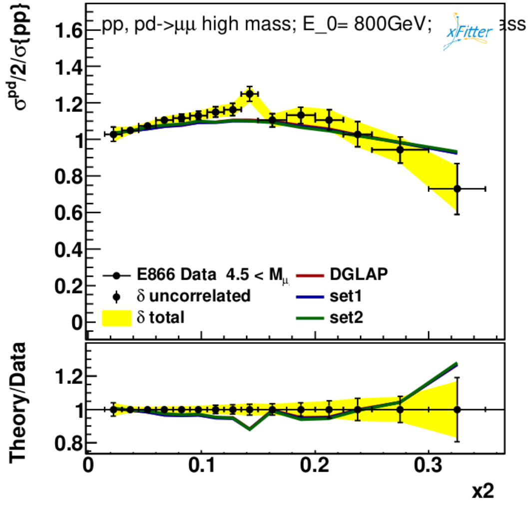
CMS DY Z mass peak



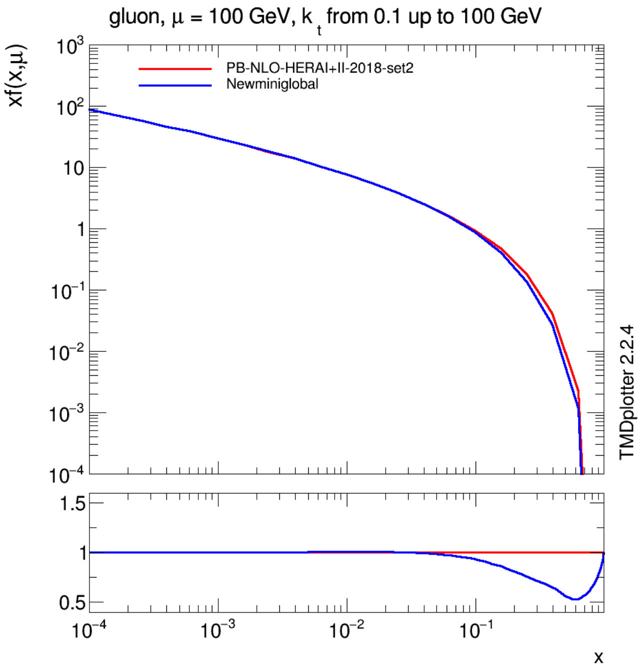
CMS W asymmetry 8 TeV

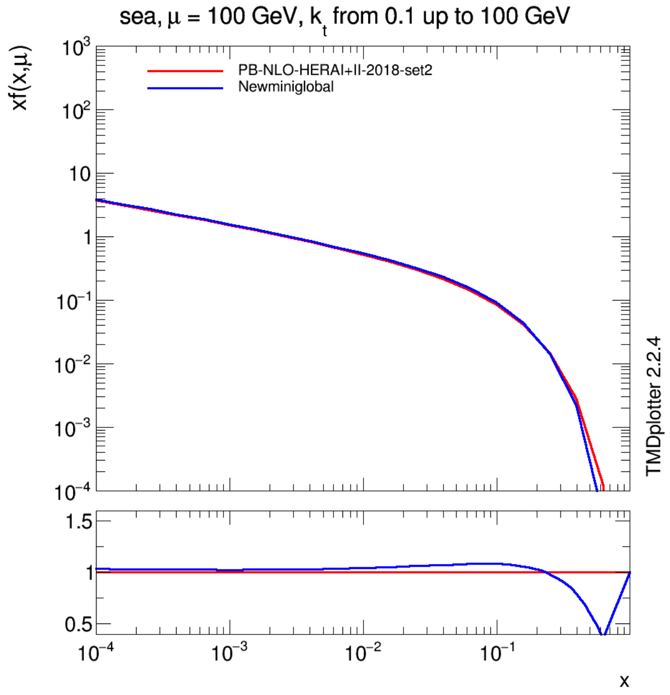


Fixed-target DY at high mass

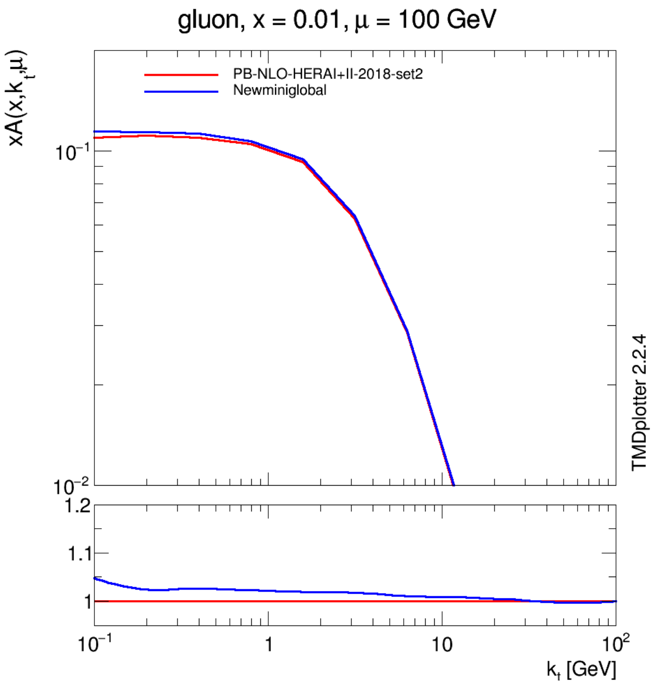


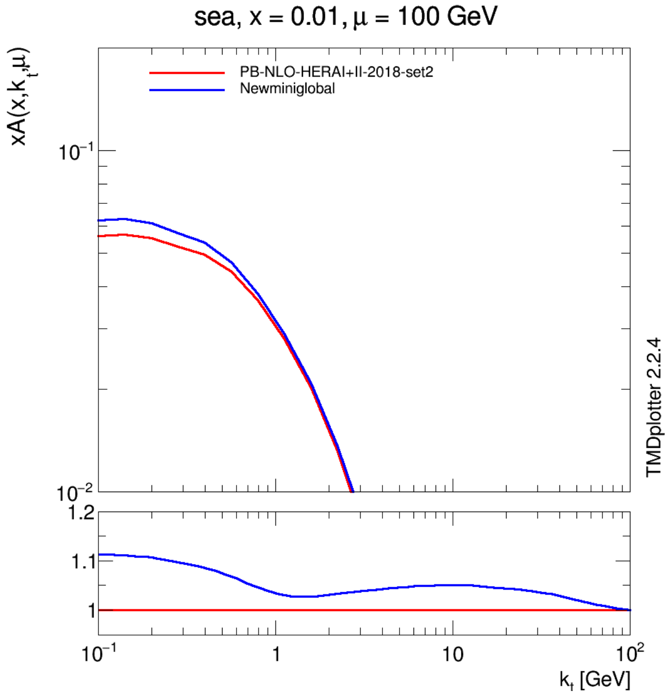
PDF comparison (miniglobal & HERA fits)





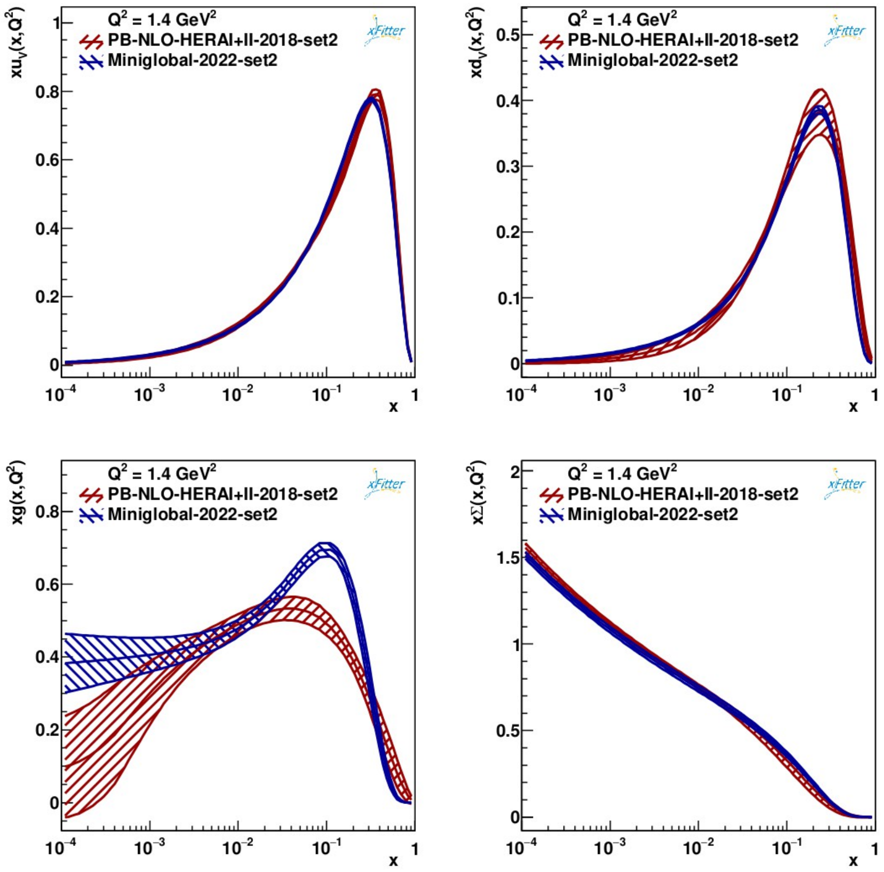
TMD comparison (miniglobal & HERA fits)





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

Uncertainty bound on PDF

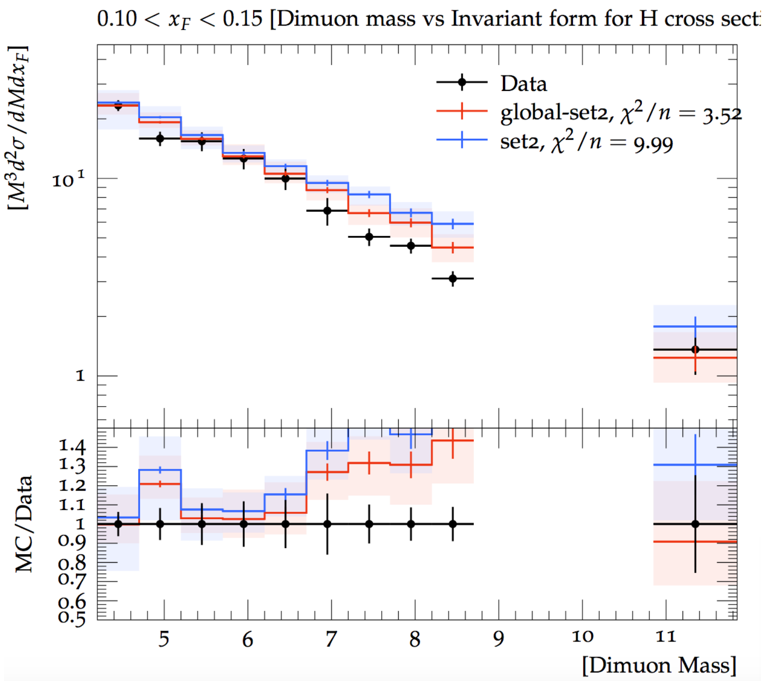


Smaller uncertainty!

Uncertainties are produced with replica method.

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



Summery & out look

- PB method implemented in xFitter → so far fits with HERA DIS
    - Studies of other processes at HERA and LHC gives more information

- Miniglobal fit leads to
    - better determination of PDFs
    - Smaller uncertainty bands

backup

The PB evolution equations for TMD parton densities $\mathcal{A}_a(x, \mathbf{k}, \mu^2)$ are given by [16]

$$\mathcal{A}_a(x,\mathbf{k},\mu^2) = \Delta_a(\mu^2)\mathcal{A}_a(x,\mathbf{k},\mu_0^2) + \sum_b \int \frac{d^2\mathbf{q}'}{\pi \mathbf{q}'^2} \frac{\Delta_a(\mu^2)}{\Delta_a(\mathbf{q}'^2)} \Theta(\mu^2 - \mathbf{q}'^2)\Theta(\mathbf{q}'^2 - \mu_0^2) \times \int_x^{z_M} \frac{dz}{z} P_{ab}^{(R)}(\alpha_s, z) \mathcal{A}_b\left(\frac{x}{z}, \mathbf{k} + (1-z)\mathbf{q}', \mathbf{q}'^2\right),$$