

# PDF-bias and flavor dependence in TMD distributions

**Alexey Vladimirov**

in collaboration with:

**M.Bury, F.Hautmann, S.Leal-Gomes, I.Scimemi, P.Zurita**

based on [2201.07114]



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# DIS2022

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Inelastic Scattering and Related Subjects

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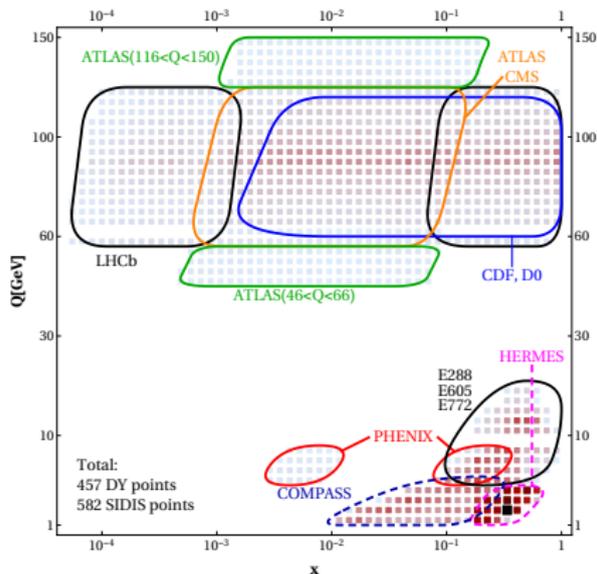
TMD phenomenology is very challenging and complex problem.  
There was a great progress in the last decade, but still many aspects are unstudied.  
They could be essentially important.  
**PDF-bias** is one of such aspects.

## Outline

- ▶ Definition of PDF-bias
- ▶ Evidence of PDF-bias
- ▶ Inclusion of PDF-uncertainty into TMD fits
- ▶ Role of the NP flavor-dependence



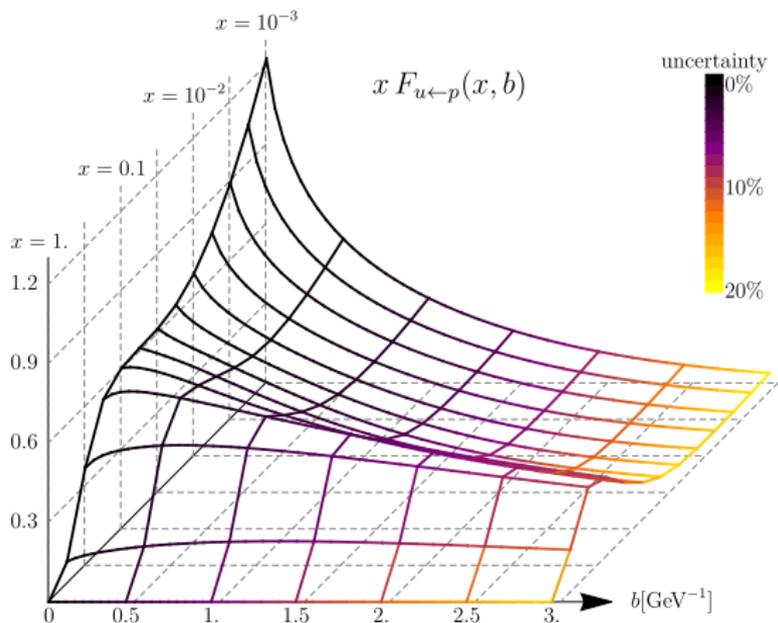
Same framework as in **SV19** [I.Scimemi,AV,1912.06532]



- ▶ Drell-Yan data
  - ▶ ATLAS, CMS, & LHCb (7, 8, 13 TeV)
  - ▶ CDF & D0
  - ▶ PHENIX
  - ▶ Fermi-Lab (E288, E605, E772)
- ▶ Theory
  - ▶ **TMD factorization**
  - ▶ N<sup>3</sup>LL (NNLO matching + N<sup>3</sup>LO evolution)
  - ▶  $\zeta$ -prescription
  - ▶ Position space
- ▶ artemide



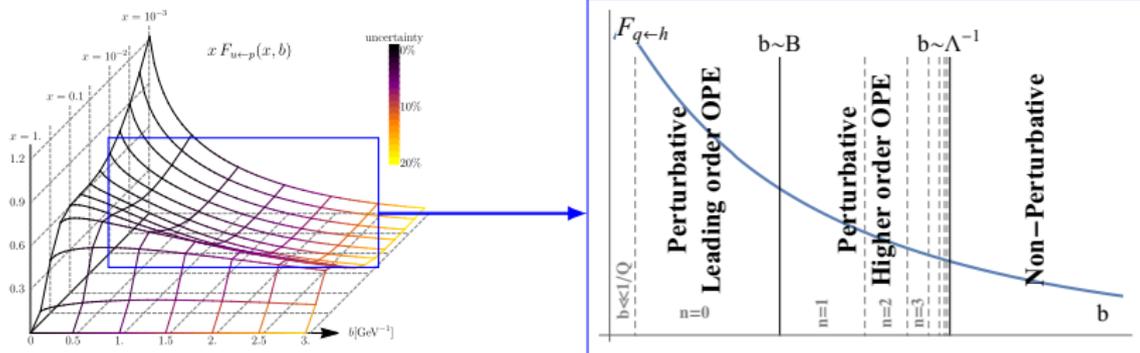
SV19 extraction [I.Scimemi,AV,1912.06532]



**Apparently (too) small uncertainty!**  
**This is due to PDF-bias**



TMD distributions are nonperturbative 3D functions  
**However, they match 1D PDFs at  $b \rightarrow 0$  boundary**



$$F(x, b) = [q(x) + \alpha_s (p(x) \ln(b^2 \mu^2) + \dots) + \alpha_s^2 \dots] + b^2 \dots + \dots$$

Lead.power OPE up  $N^3$ LO

Higher power OPE

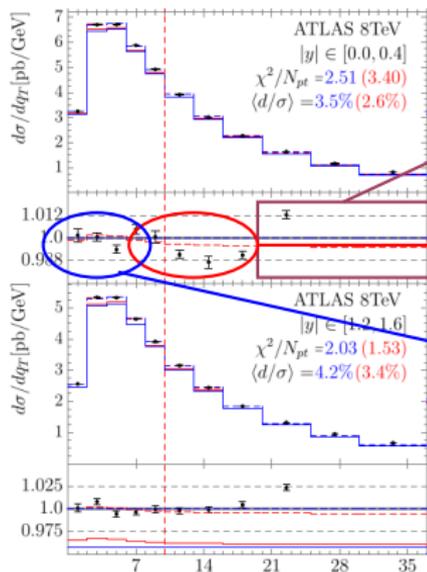
$$F(x, b) = C(x, b) \otimes q(x) f_{NP}(x, b)$$

Fitting ansatz



The matching to PDF is important, it guaranties agreement with the resummation

$$\frac{d\sigma}{dq_T} = \sigma_0 |C_V(Q)|^2 \int d^2b e^{i(q_T b)} F_1(x_1, b; Q) F_2(x_2, b; Q)$$



Power corrections

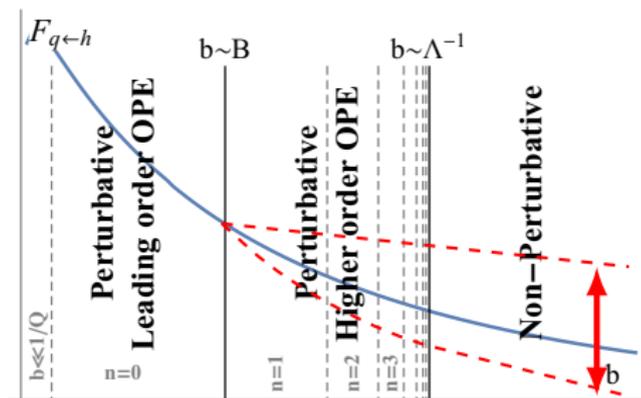
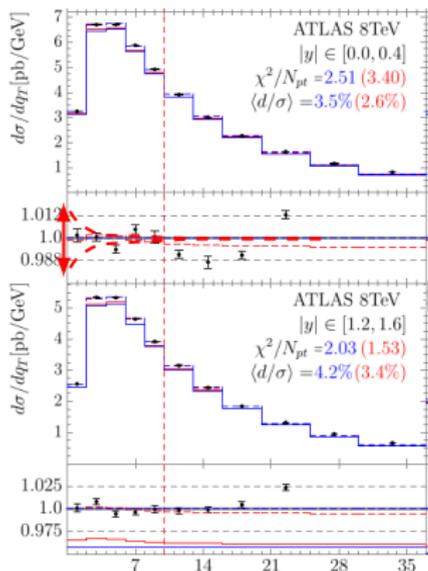
Resummation = "collinear mathing"

Nonperturbative TMDs



The matching to PDF is important, it guaranties agreement with the resummation  
 But it biases the shape for TMD distribution

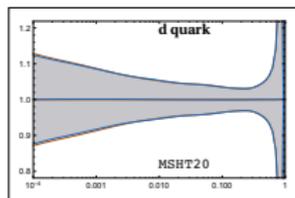
$$\frac{d\sigma}{dq_T} = \sigma_0 |C_V(Q)|^2 \int d^2b e^{i(q_T b)} F_1(x_1, b; Q) F_2(x_2, b; Q)$$



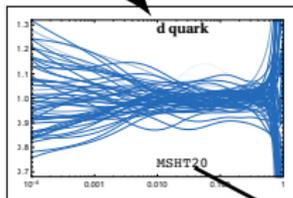
Variation of  $f_{NP} \Rightarrow$  few points in cross-section  
 Variation of PDF  $\Rightarrow$  full curve.



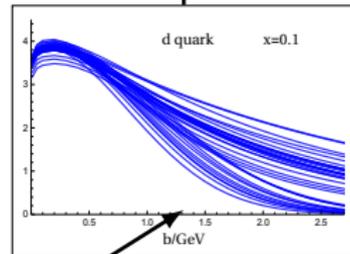
Obviously, one must include PDF uncertainty



replica's distribution



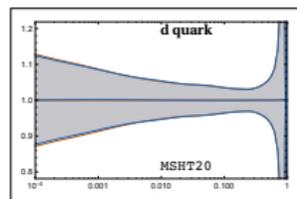
Compare to data



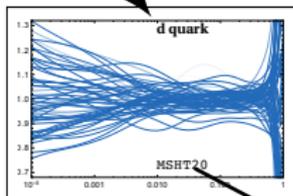
$$f(x, b) = C(x, b) \otimes q(x) f_{\text{NP}}(x, b)$$



Obviously, one must include PDF uncertainty **into the fit**  
Each PDF replica should be accompanied by its own  $f_{\text{NP}}$



replica's distribution

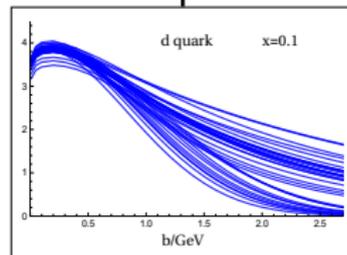


Fit  $f_{\text{NP}}$   
for each  
PDF replica

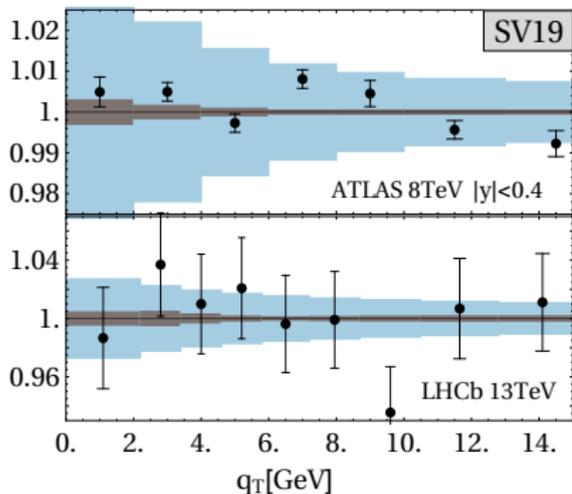
Very  
time  
consuming

$$f(x, b) = C(x, b) \otimes q(x) f_{\text{NP}}(x, b)$$

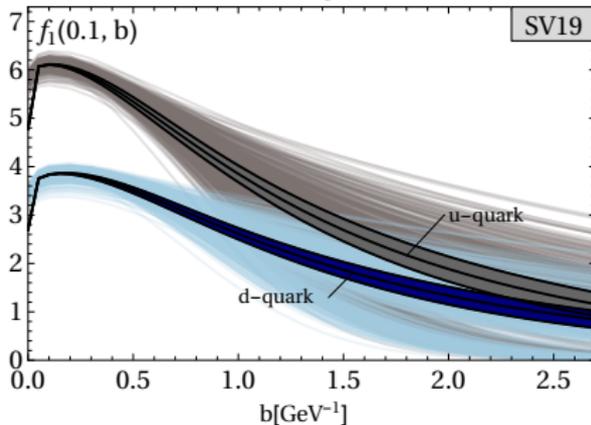
Compare to data



The PDF-band does not look too large  
 $\sim 1\%$  (in resummation regime)



A tiny variation of  $b = 0$  point  
**unbiases** large- $b$  values

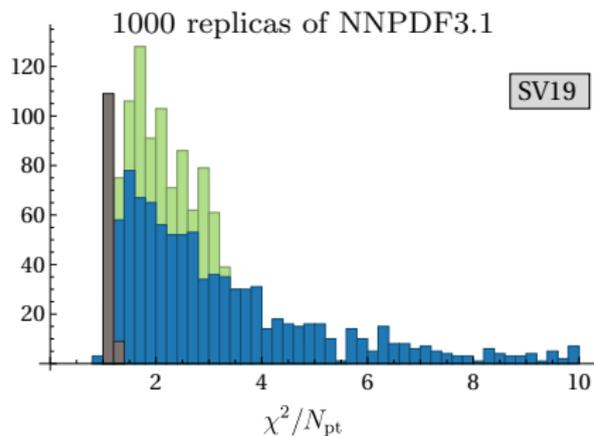


Is the PDF-bias resolved? **YES!**

**BUT...**



## Problems with statistical description



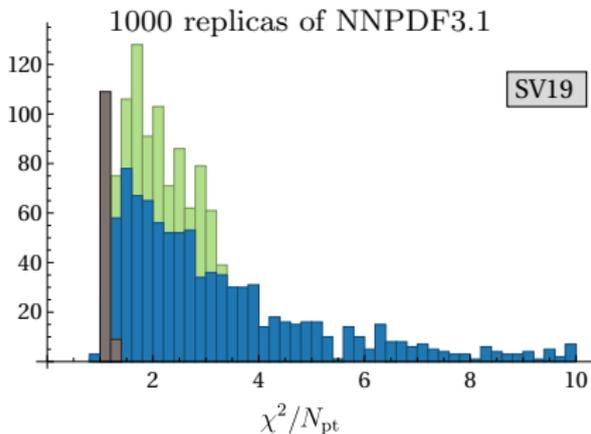
Many PDF replicas do not fit the data!

**Ideally:** fit TMD and PDF simultaneously (see talk by [P.Barry](#))

**Very challenging.**



## Problems with statistical description



We tried different PDF sets, but other sets were **even worse!**

PDF	$\chi^2_{\text{DY}}/N_{\text{pt}}$
HERA20	0.97
NNPDF3.1	1.17
MMHT14	1.34
CT14	1.59
PDF4LHC15	1.53
MSHT20	1.25
CT18	1.26
CJ15	1.82

Many PDF replicas do not fit the data!

**Ideally:** fit TMD and PDF simultaneously (see talk by [P.Barry](#))

**Very challenging.**



## Missed ingredient: Flavor dependence of NP profile

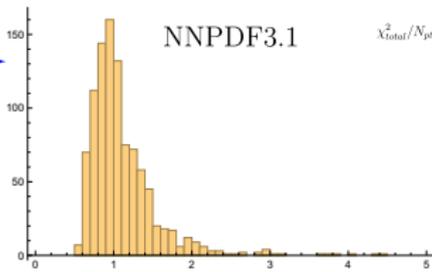
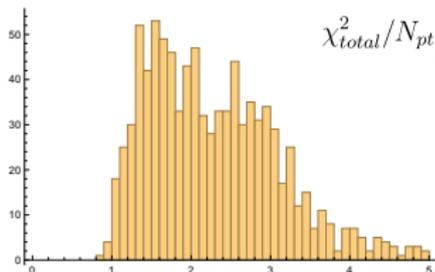
- ▶ Complicated profile (fine-tuned to central replica of NNPDF3.1)
- ▶ 5 parameters
- ▶ no-flavor dependence



- ▶ Simple profile
- ▶ Flavor dependent
- ▶ 2 parameters per flavor (+1 global)

$$f_{NP}(x, b) = \exp\left(-\frac{\lambda_1(1-x) + \lambda_2x + x(1-x)\lambda_5}{\sqrt{1 + \lambda_3x^{\lambda_4}b^2}}b^2\right)$$

$$f_{NP}(x, b) = \exp\left(-\frac{\lambda_1(1-x) + \lambda_2x}{\sqrt{1 + \lambda_0x^2b^2}}b^2\right)$$



## Missed ingredient: Flavor dependence of NP profile

DY only (457 points)

SV19 model

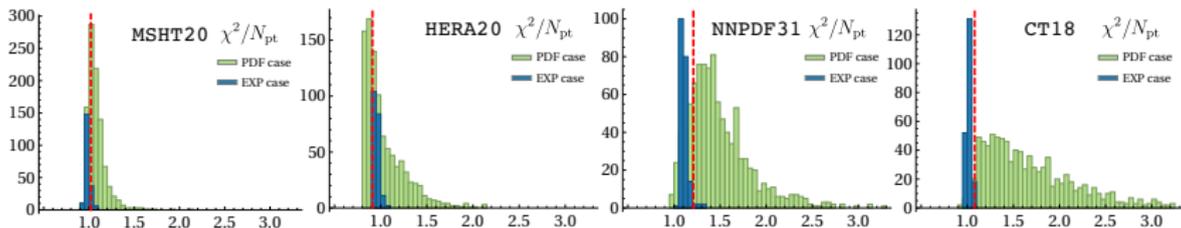
input PDF	$\chi^2/N_{pt}$
HERA20	0.97
NNPDF31	1.14
CT18	1.26
MSHT20	1.39



DY only (457 points)

flavor-dependent model

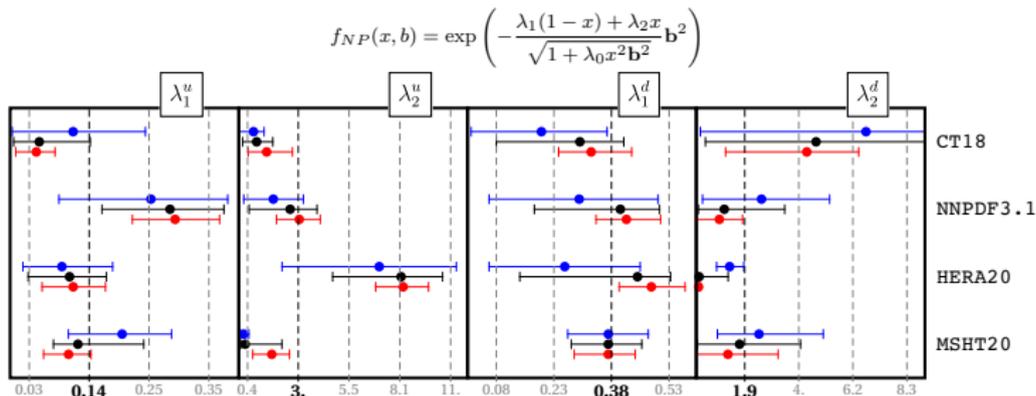
input PDF	$\chi^2/N_{pt}$
HERA20	0.91
NNPDF31	1.17
CT18	1.08
MSHT20	1.12



Similar fit-quality for different PDFs!



Flavor-dependence of  $f_{NP}$  helps to compensate tensions between PDF and TMD-data

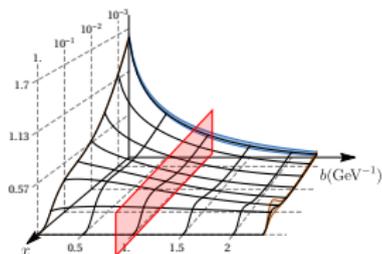
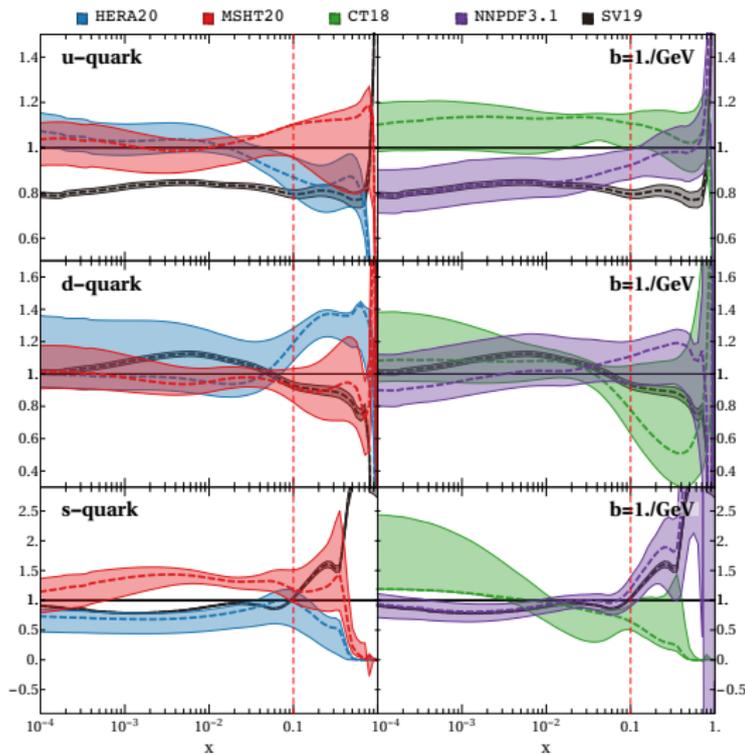


Parameters  $\lambda$  mostly agree in-between different PDFs, but usually one/two parameters are very different.



# Realistic uncertainty band for unpolarized TMD

The final uncertainty band is  $\sim \times 5$  original SV19

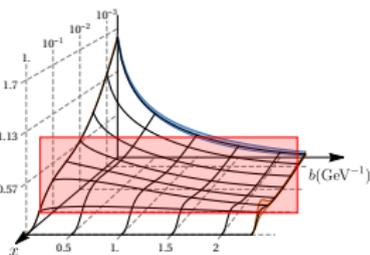
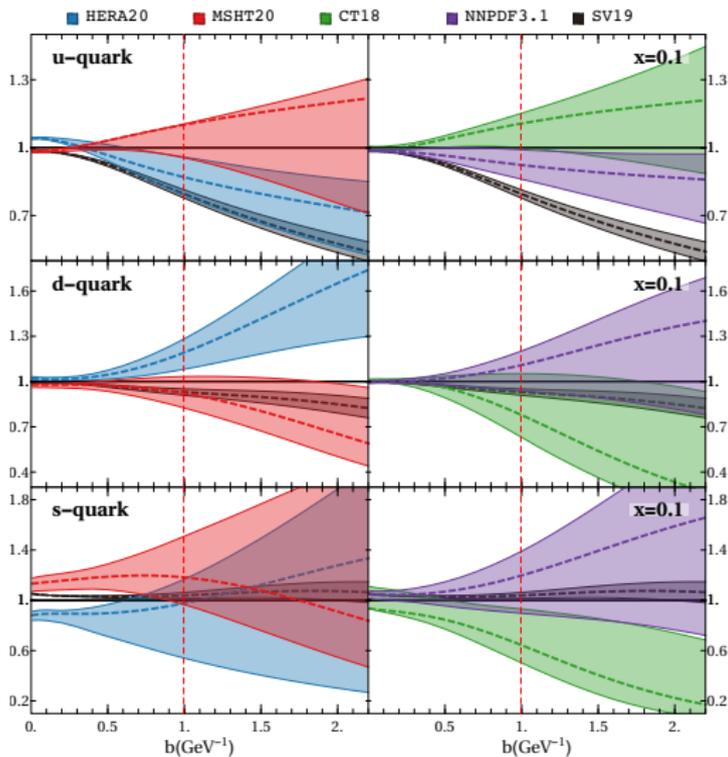


Main disagreement at large- $x$ .



# Realistic uncertainty band for unpolarized TMD

The final uncertainty band is  $\sim \times 5$  original SV19

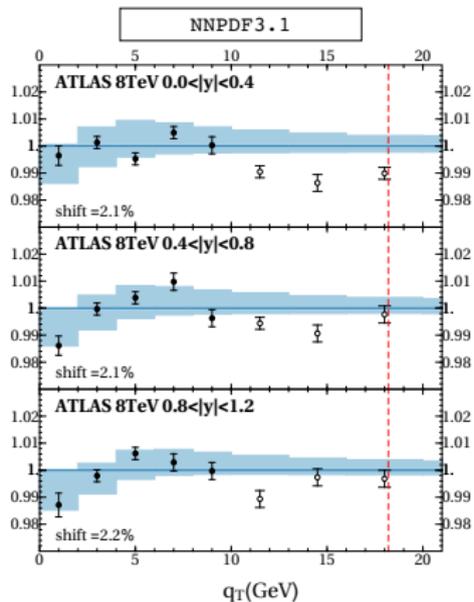
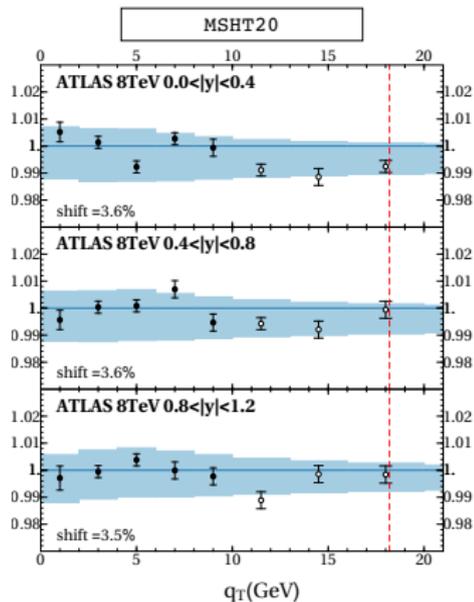


Not all TMDs  
(based on different PDFs)  
agree with each other.

**Main question:**  
Is this flavor-dependence physical  
or just a compensation of  
imperfection of PDF?



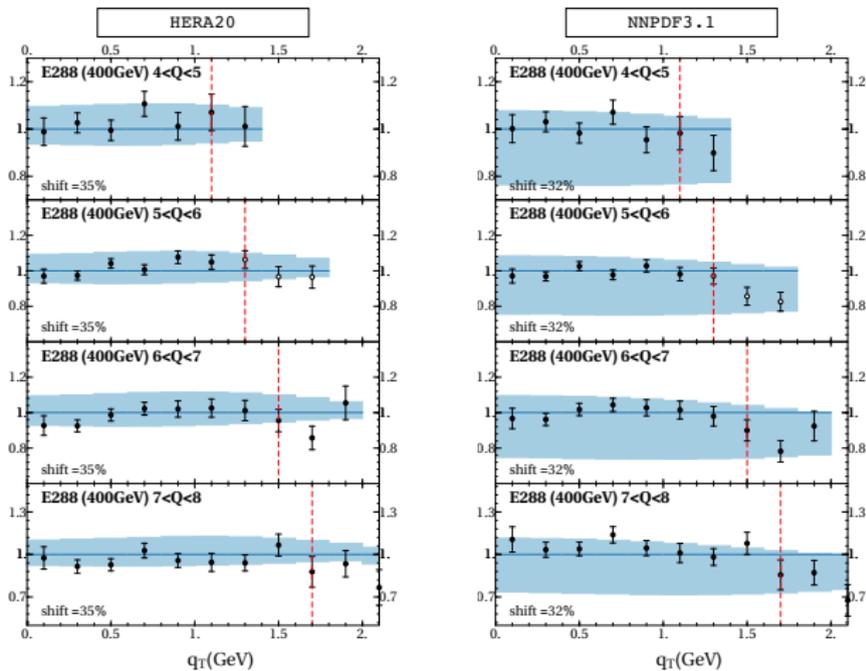
Unpolarized TMDPDF is the basement for further TMD phenomenology  
 PDF uncertainty is the biggest source of uncertainty in predictions



Prediction uncertainty is  $\sim 1\%$



Unpolarized TMDPDF is the basement for further TMD phenomenology  
 PDF uncertainty is the biggest source of uncertainty in predictions

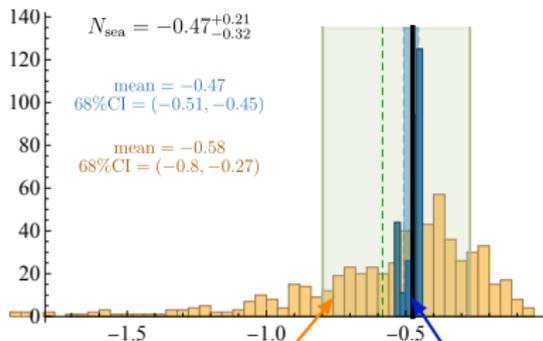


Prediction uncertainty is  $\sim 10 - 20\%$



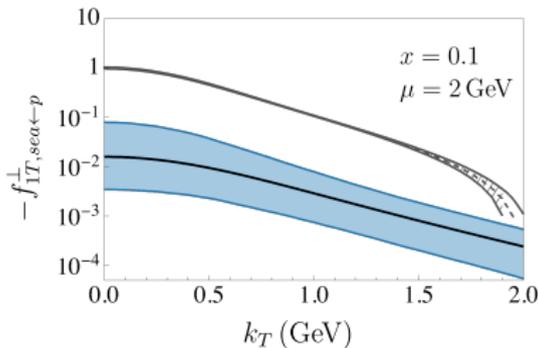
Unpolarized uncertainty became  $\sim 3 - 8$  times larger  
**All TMD extractions are concerned!**  
 Especially at lower-energy

Extraction of Sivers function [M.Bury,A.Prokudin,AV,2103.03270]



Band due to exp.unc.

Band due to uTMDPDF



How this picture will change once PDF band became 5 times larger?

TMD extraction vitally depends on PDF  $\Rightarrow$  PDF-bias  
To reduce the bias one must:  
1. Account for PDF uncertainty  
2. Incorporate NP flavor dependence

#### Future directions

- ▶ Extract PDF and TMD simultaneously
- ▶ SIDIS and FF-bias
- ▶ Propagation of increased unpolarized uncertainty to other TMD observables

