artemide

updates

LHC EW precision sub-group meeting (pT W/Z benchmarking)

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	Sudakov	Non-Sudakov	Matching	Non-perturbative
arTeMiDe	μ_f, μ_{OPE} (c_2, c_4)	?	no matching	f_{NP}
Cute-MCFM	μ, μ_h, r	μ_R, μ_F (?)	Parameters of damping func. (?)	-
DYTURBO	Q	μ_R, μ_F	Parameters of Damping func.	f_{NP} (?)
NangaParbat	Q, μ_b	μ_R, μ_F	Still none (damping func.)	f_{NP}
RadISH	Q	μ_R, μ_F	Parameters of Damping func.	-
ResBos	C_1, C_2, C_3	μ_R, μ_F (?)	Damping func. (?)	f_{NP} (?)
Resolve	μ_S	μ_R, μ_F	Parameters of Damping func.	f_{NP} (?)
SCETlib	Δ_{resum}	Δ_{FO}	Profile scale Δ_{match}	(Cutoff variations) Δ_{Λ}

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Scales in TMD factorization

$$d\sigma \sim |C_V(\mu_f, Q)|^2 \, R^2[(\mu_f, \zeta_f) \to (\mu_i, \zeta_i), \mathcal{D}] \, F_1(\mu_i, \zeta_i) F_2(\mu_i, \zeta_i) \tag{1}$$

Factorization scales

Scale	"usual choice"	variation constant
μ_f	Q	C_2
ζ_f	$\zeta_f = Q$	–
μ_i	μ_b	C_3
ζ_i	μ_b^2	C_3

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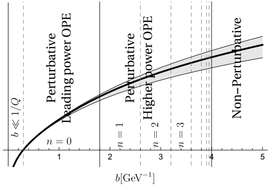
Extra scales due to small-b implementation

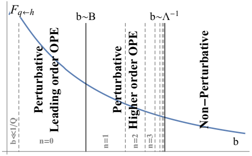
CS-kernel



$$\mathcal{D}(b) = \frac{-1}{2} K(b) = \overbrace{\mathcal{D}^{(0)}}^{\sim\langle 1\rangle} + \overbrace{b^2\mathcal{D}^{(1)}}^{\sim G_2} + b^4\mathcal{D}^{(2)} + \ldots$$

$$= \mathcal{D}^{(0)}(b^*) + \mathcal{D}_{NP}$$

TMDs



$$F(b) = \overbrace{F^{(0)}}^{\sim f(x)} + \overbrace{b^2 F^{(1)}}^{\sim \text{tw-4}} + b^4 F^{(2)} + \ldots$$

$$= F^{(0)}(b^*) f_{NP}$$

Scales in TMD factorization

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ζ_i	μ_b^2	C_3

Extra scales due to small-b implementation

Scale	"usual choice"	variation constant
μ_0	μ_b	C_1
μ_{OPE}	μ_b	C_3

Synopsis

Total: 3 factorization scales + 2 extra (due to implementation)
NangaParbat$_{\textbf{(to my b.und.)}}$: μ_f, $\mu_i = \sqrt{\zeta_i} = \mu_0 = \mu_{OPE}$
ResBos$_{\textbf{(to my b.und.)}}$: μ_f, $\mu_i = \sqrt{\zeta_i} = \mu_{OPE}$, μ_0

Scales in `artemide`

Factorization scales

Scale	"usual choice"	variation constant	aTMDe central	aTMDe variation
μ_f	Q	C_2	Q	C_2
ζ_f	$\zeta_f = Q$	–	$\zeta_f = Q$	–
μ_i	μ_b	C_3	μ (any reasonable)	" $\tilde{c}$ "
ζ_i	μ_b^2	C_3	ζ_μ	$\zeta_{\tilde{c}\mu}$

- The dependence on μ is absent **exactly**, by definition of ζ_μ.
- The variation band over $\tilde{c}$ is exactly null, by definition of ζ_μ.

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Scales in `artemide`

Extra scales due to small-b implementation

Scale	"usual choice"	variation constant	aTMDe central	aTMDe variation
μ_0	μ_b	C_1	μ_b(effectively)	–
μ_{OPE}	μ_b	C_3	$\mu_{OPE} = \frac{2e^{-\gamma_E}}{b} + 2\text{GeV}$	C_4

Scales in artemide

Extra scales due to small-b implementation

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Resummed expression for CS-kernel

$$\mu^2 \frac{d}{d\mu^2}\mathcal{D}(b,\mu) = \frac{\Gamma_{\text{cusp}}}{2} \qquad \Longrightarrow \qquad \mathcal{D}(b,\mu) = \int_{\mu_0}^{\mu} \frac{d\mu'}{\mu'}\Gamma_{\text{cusp}}(\mu') + \mathcal{D}(b,\mu_0)$$

Fixed order: $$\mathcal{D}(b,\mu) = 2a_s C_F \mathbf{L}_\mu + a_s^2\left(\frac{\Gamma_1}{2}\mathbf{L}_\mu^2 + ...\right) + ... = \sum_{n=1}^{\infty} a_s^n \sum_{k=0}^{n} \mathbf{L}_\mu^k d^{(n,k)}$$

"Resummed": $$\mathcal{D}(b,\mu) = \sum_{n=0}^{\infty} a_s^n \sum_{k=0}^{n} (a_s\mathbf{L}_\mu)^k d^{(n+k,k)} = \sum_{n=0}^{\infty} a_s^n d_n(a_s\mathbf{L})$$

$$d_0 = -\frac{\Gamma_0}{2\beta_0}\ln(1-\beta_0 a_s \mathbf{L}_\mu)$$

Scales in **artemide**

Extra scales due to small-b implementation

Scale	"usual choice"	variation constant	aTMDe central	aTMDe variation
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"Resummed": $$\mathcal{D}(b,\mu) = \sum_{n=0}^{\infty} a_s^n \sum_{k=0}^{n} (a_s \mathbf{L}_\mu)^k d^{(n+k,k)} = \sum_{n=0}^{\infty} a_s^n d_n(a_s \mathbf{L})$$

- "resummation" corresponds to evolution to $\mu_0 = 2e^{-\gamma_E}/b$ (such that $\mathbf{L}_{\mu_0} = 0$)
- At large values of b $b \to b^*$
- **Pro:** very fast computation
- **Cons:** no variation constant

Scales in `artemide`

Scale	"usual choice"	variation constant	aTMDe central	aTMDe variation
μ_f	Q	C_2	Q	C_2
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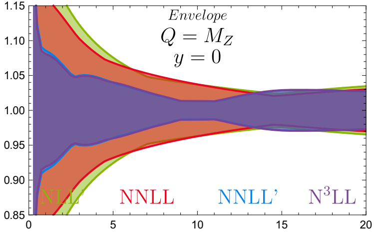
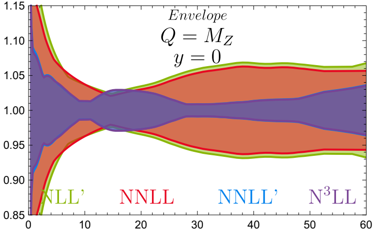
ζ_i	μ_b^2	C_3	ζ_μ	$\zeta_{\tilde{c}\mu}$

Scale	"usual choice"	variation constant	aTMDe central	aTMDe variation
μ_0	μ_b	C_1	μ_b(effectively)	no
μ_{OPE}	μ_b	C_3	μ_{OPE}	C_4

Variation over 8 points, $c_i \in [1/2, 2]$ (details in PT/W Feb 2021)

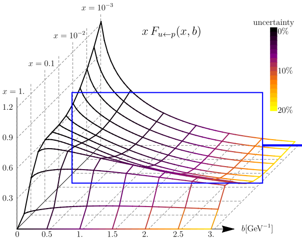


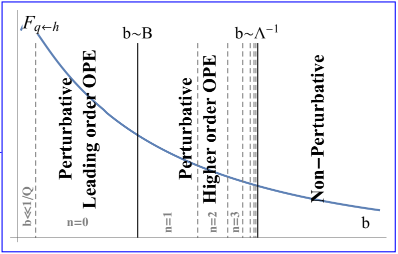


- Biggest contribution from μ_{OPE} (C_3)
- Envelope shown (to be symmetrized)

Uncertanties due to PDF
[2201.07114]

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





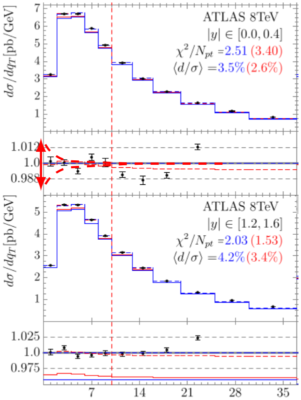
$$F(x,b) = \left[q(x) + \alpha_s\left(p(x)\ln(b^2\mu^2) + ...\right) + \alpha_s^2 ...\right] + b^2 ... + ...$$

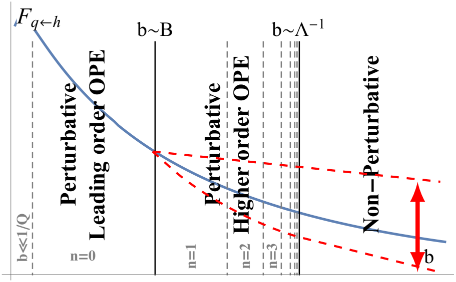
Lead.power OPE

Higher power OPE

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

The matching to PDF is important
But it is also a trap ⇒ PDF-bias





Enormous variation of f_{NP}
gives minor change in cross-section.
But **tiny modification of PDF shifts full curve.**

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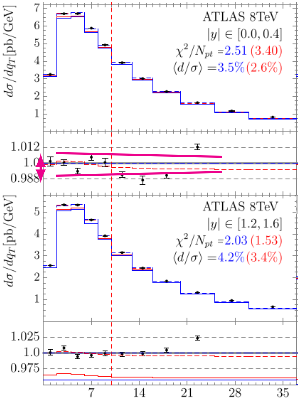

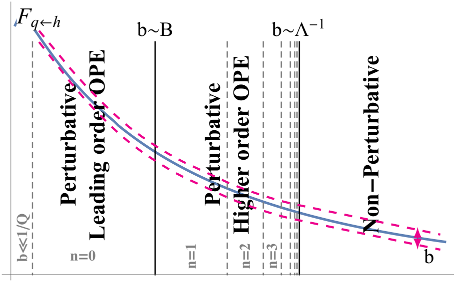

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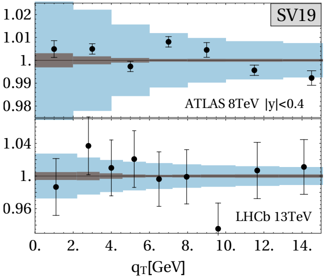
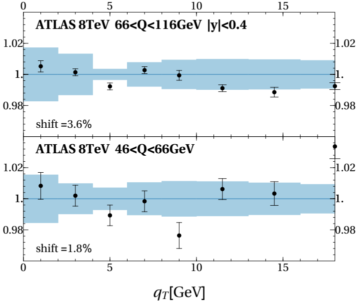
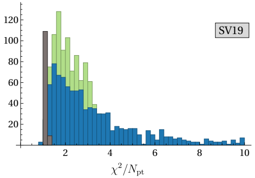
But **tiny modification of PDF shifts full curve.**

PDF-uncertanty
(NNPDF 1000 replicas)



Scale variation





PDF	χ^2_{DY}/N_{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

- Inadequate χ^2-distribution
- Large dependence on PDF

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SOLUTION: make f_{NP} flavor dependent

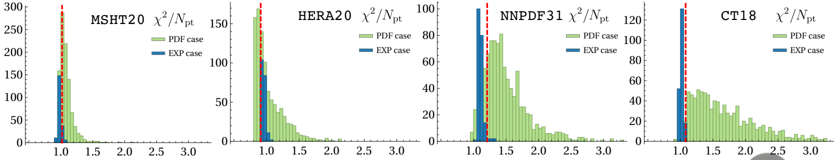
$$f^f_{NP}(x,b) = \exp\left(-\frac{\lambda^f_1 + x\lambda^f_2}{\sqrt{1+\lambda_0 x^2 b^2}} b^2\right), \qquad f = u, d, \bar{u}, \bar{d}, \text{rest}$$

DY only (457 points)
SV19 model

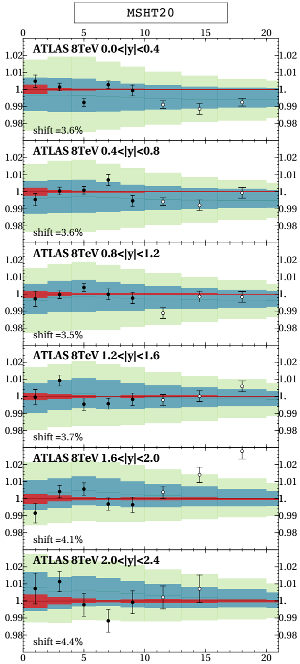
input PDF .	χ^2/N_{pt}
HERA20	0.97
NNPDF31	1.14
CT18	1.26
MSHT20	1.39

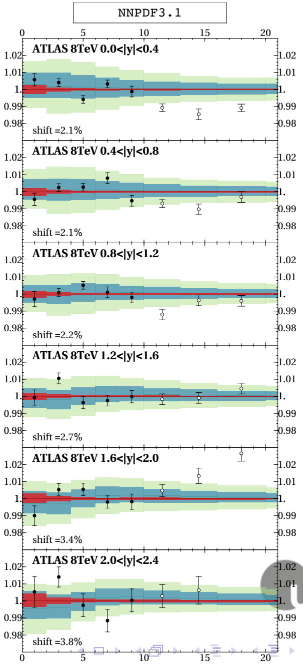
DY only (457 points)
flavor-dependent model

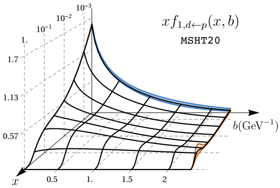
input PDF .	χ^2/N_{pt}
HERA20	0.91
NNPDF31	1.17
CT18	1.08
MSHT20	1.12

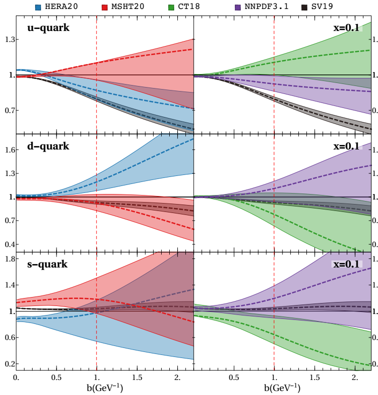


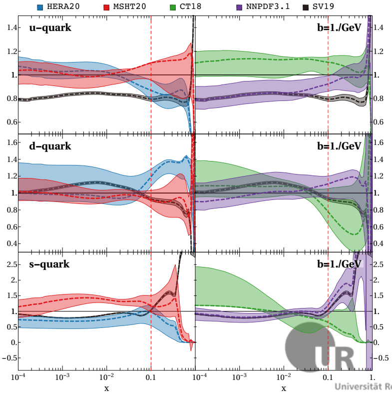
Similar fit-quality for different PDFs!


MSHT20
ATLAS 8TeV 0.0<|y|<0.4
shift =3.6%
ATLAS 8TeV 0.4<|y|<0.8
shift =3.6%
ATLAS 8TeV 0.8<|y|<1.2
shift =3.5%
ATLAS 8TeV 1.2<|y|<1.6
shift =3.7%
ATLAS 8TeV 1.6<|y|<2.0
shift =4.1%
ATLAS 8TeV 2.0<|y|<2.4
shift =4.4%


NNPDF3.1
ATLAS 8TeV 0.0<|y|<0.4
shift =2.1%
ATLAS 8TeV 0.4<|y|<0.8
shift =2.1%
ATLAS 8TeV 0.8<|y|<1.2
shift =2.2%
ATLAS 8TeV 1.2<|y|<1.6
shift =2.7%
ATLAS 8TeV 1.6<|y|<2.0
shift =3.4%
ATLAS 8TeV 2.0<|y|<2.4
shift =3.8%







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PDF-bias problem in TMD extraction

- PDF uncertainty is the **largest** one, in extraction and in predictions
- Flavor dependence of f_{NP} is needed for consistent extraction
  - Is it true NP flavor dependence of TMDs?
  - Is it a compensation of tensions within PDFs?

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