Report:
impact studies for EIC
unpolarized TMDs and TMD evolution

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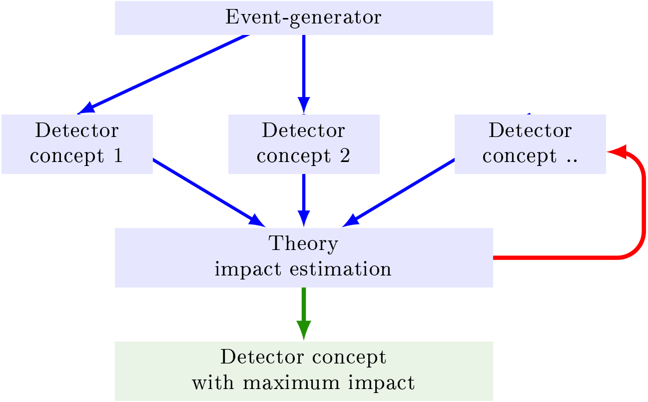


- Processes to study: TMD evolution, Sivers asymmetry (+ ...)
- **Current stage:** 1 iteration, unpolarized TMD data ⇒ TMD evolution (+ unpolarized TMD),
- **Most important:** Setup the framework

Data

Repository: https://github.com/VladimirovAlexey/EIC_YR_TMD
For this presentation I used data by Elke and Charlotte (10fb^{-1})
Usual TMD cut: $q_T < 0.25Q$, $Q > 2$ (and $z > 0.05$ for technical reasons)

- (high energy beam) 18×275 : 11146 points $\xrightarrow{\text{cut}}$ 1820 points
- (low energy beam) 5×50 : 9759 points $\xrightarrow{\text{cut}}$ 1841 points
- (compare to global analysis) ∼1000 points (∼ 450 DY + ∼550 SIDIS)

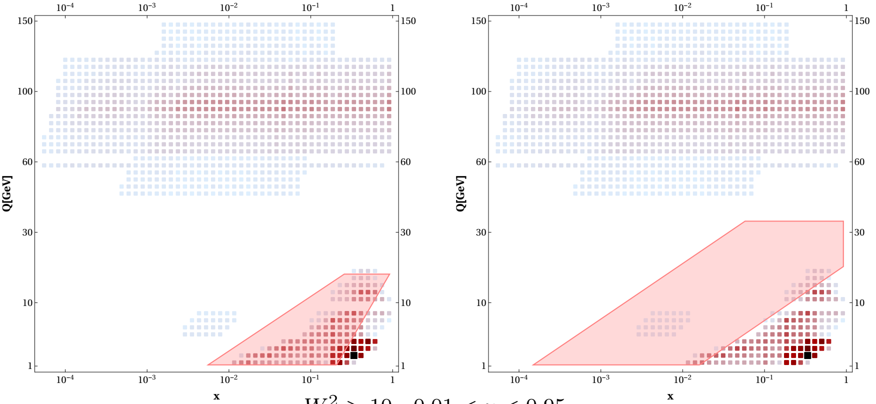
Data summary

- Kinematic cuts: Q^2> 1 GeV^2 and 0.01<y<0.95 and W^2>10 GeV^2
- Cuts on scattered lepton: p_e>0.5 GeV and -4<rapidity<4 (effectively satisfied by above, kinematic cuts)
- Cuts on hadrons: p_H>0.5 GeV and from PID:

rapidity	pion momentum [GeV]	kaon momentum [GeV]	proton momentum [GeV]
$-3.5 <$ rapidity < -1.0 (RICH)	$0.5 < p_H < 5.0$	$1.6 < p_H < 5.0$	$3.0 < p_H < 8.0$
$-1.5 <$ rapidity < -1.0 (dE/dx)	$0.2 < p_H < 0.6$	$0.2 < p_H < 0.6$	$0.2 < p_H < 1.0$
$-1.0 <$ rapidity < 1.0 (DIRC and dE/dx)	$0.2 < p_H < 4.0$	$0.2 < p_H < 0.7$	$0.2 < p_H < 1.1$
		$0.8 < p_H < 4.0$	$1.5 < p_H < 4.0$
$1.0 <$ rapidity < 3.5 (RICH)	$0.5 < p_H < 50.0$	$1.6 < p_H < 50.0$	$3.0 < p_H < 50.0$
$1.0 <$ rapidity < 1.5 (dE/dx)	$0.2 < p_H < 0.6$	$0.2 < p_H < 0.6$	$0.2 < p_H < 1.0$

- Unfolding with respect to events without cut on the scattered lepton (effectively momentum and rapidity cuts are applied due to kinematic cuts) and for hadrons without momentum cuts and with rapidity between -4 and 4.

5×50 18×275



$$W^2 > 10, \;\; 0.01 < y < 0.95$$

Picture is approximate!

Yet, we do not have different detectors and Sivers pseudo-data.
However, there are tasks/questions to theoreticians to answer.

- Prepare framework
  - Fast and accurate impact estimation for large data-sets
- Designation of most important kinematic regions
- Impact of y-cut
- Impact of systematic uncertainty
- ... (suggest)

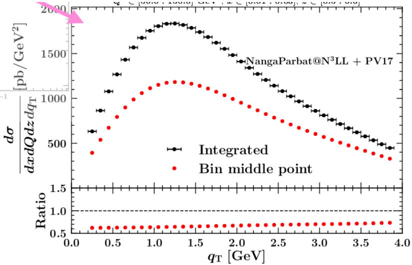
In what follows errors are:
statistical + acceptance error (by CVH),
+ uncorrelated sys.error ($\sim 3\%$)
+ correlated lum.error 1.5%.

Numerics is done by:

$\underbrace{\texttt{artemide}\text{(SV19 model)}}_{\text{Fortran TMD cross-section}} \rightarrow \underbrace{\texttt{harpy}}_{\text{interface}} \rightarrow \underbrace{\text{"elpis"}}_{\text{python } \chi^2\text{, data manipulation, etc.}} \leftarrow \underbrace{\text{iMinuit}}_{\text{python minimisation, Minos}}$

Analysis of TMD data is slooooowwww...

- Reweighing does not work $\Rightarrow$ run fitting
- SV19 analysis ($\sim$ 1000 points): error-estimation takes $\sim 3-5$ days
- Now, we deal with $\sim 3000-4000$ points, and many samples $\Rightarrow$ we must cut something
- Too much simplification gives unstable and inadequate result



(picture by Marco Radici)

I0-approximation

- Full-integration over Q
- Simplified (5 point) integration over p_T
- Central values for z and x

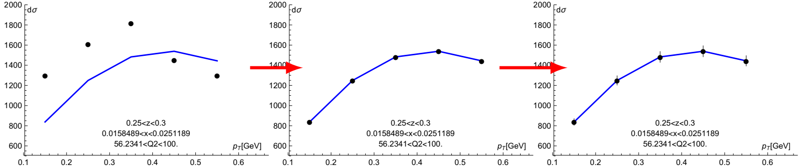
Timing:

- **Hesse:** $\sim$ 4-6 min for 12 param.
- **Minos:** $\sim$ 10 hours for 12 param.
- **Bootstrap (100 rep):** $\sim$ 13 hours for 12 param.

Theory driven pseudo-data

$$\sigma_{MC} \pm \delta\sigma_{\text{stat.}} \quad \Rightarrow \quad r \times \sigma_{th.} \pm w \times \delta\sigma_{\text{stat.}} \pm \delta\sigma_{\text{sys.}} (+ \text{corr.uncert.})$$

- r is RND with $\delta\sigma_{\text{stat.}}$
- w is $\sigma_{th.}/\sigma_{MC}$



Remainder

SIDIS cross-section within TMD factorization

$$\frac{d\sigma}{dp_T} = \sigma_0 |C_V(Q^2)|^2 \int d^2b e^{i(q_T b)} \left(\frac{Q^2}{\zeta_Q[\mathcal{D}]}\right)^{-\mathcal{D}(b,Q)} \sum_q e_q^2 F_{q\leftarrow h1}(x,b) D_{q\to h2}(z,b) \quad (1)$$

3 NP functions one for each kinematic variable + b or p_T

- TMD evolution ($\mathcal{D}$ ≡RAD) (Q,b)
- TMD PDF ($\equiv F$) (x,b)
- TMD FF ($\equiv D$) (z,b)

Perturbative+non-perturbative

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

- Perturbative input: NNLO
- $f_{NP}(\lambda)$ with $\lambda = \{\lambda_1, \lambda_2, ...\}$ parameters to fit (taken from SV19 =[I.Scimemi,AV,1912.06532])

Some results

Disclaimer 1: true picture is 4D
Disclaimer 2: model bias
Disclaimer 3: work in progress

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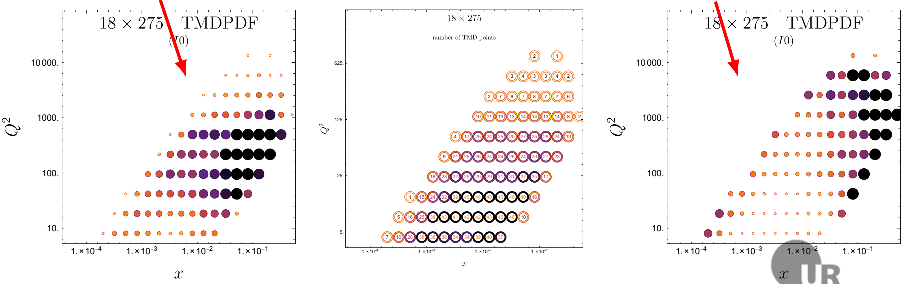
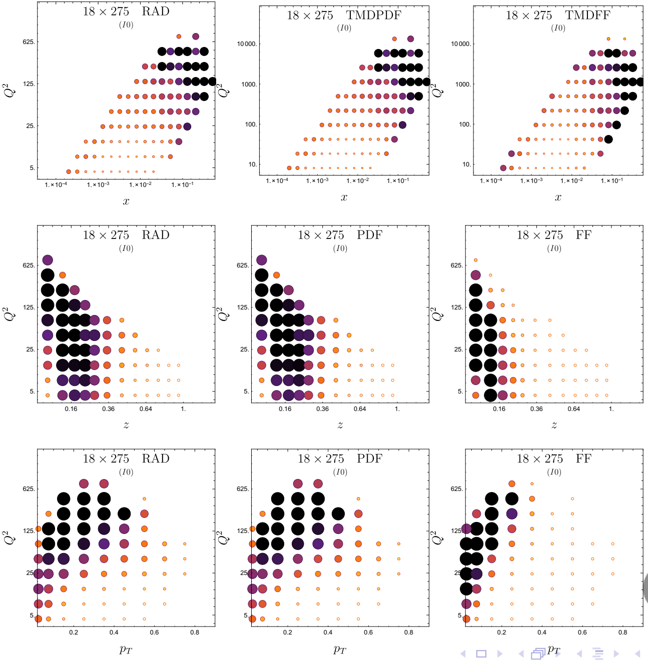
What is plot?!

$$\delta\chi^2_{\text{point},\lambda} = \frac{(\sigma(\lambda) - \sigma(\lambda \pm \delta\lambda))^2}{\delta\sigma^2} \tag{2}$$

size of circle $\simeq \sum_{\lambda,p\in\text{bin}} \delta\chi^2_{p,\lambda}$

size of circle $\simeq \frac{1}{N_{p\in\text{bin}}} \sum_{\lambda,p\in\text{bin}} \delta\chi^2_{p,\lambda}$




18 × 275 RAD (I0)
18 × 275 TMDPDF (I0)
18 × 275 TMDFF (I0)
18 × 275 RAD (I0)
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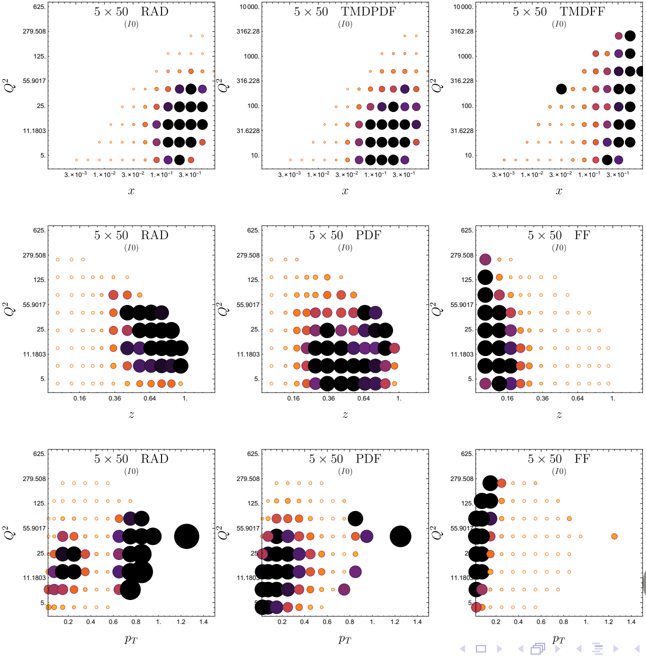
18 × 275 RAD (I0)
18 × 275 PDF (I0)
18 × 275 FF (I0)
Q^2
x
z
p_T



5 × 50 RAD
(I0)
5 × 50 TMDPDF
(I0)
5 × 50 TMDFF
(I0)
5 × 50 RAD
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5 × 50 PDF
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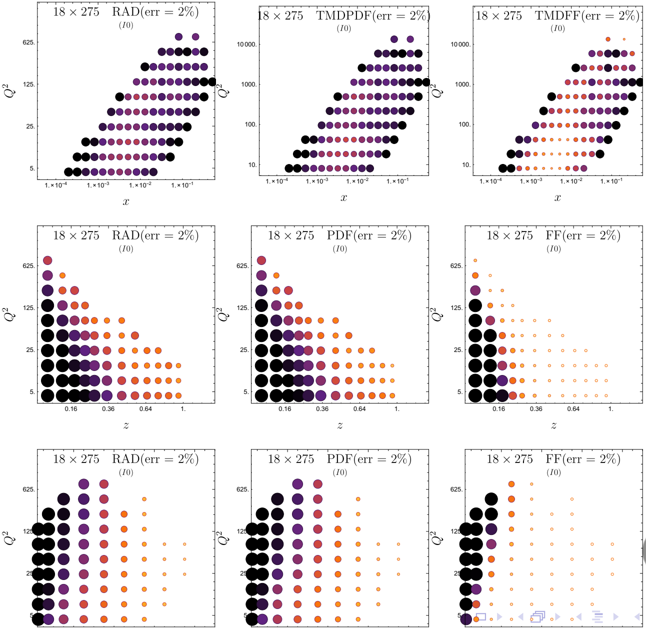
5 × 50 FF
(I0)
5 × 50 RAD
(I0)
5 × 50 PDF
(I0)
5 × 50 FF
(I0)
Q^2
x
z
p_T
625.
279.508
125.
55.9017
25.
11.1803
5.
10000.
3162.28
1000.
316.228
100.
31.6228
10.
3.×10⁻³ 1.×10⁻² 3.×10⁻² 1.×10⁻¹ 3.×10⁻¹
0.16 0.36 0.64 1.
0.2 0.4 0.6 0.8 1. 1.2 1.4

To inspect possible model-bias do the same plot with 2% error everywhere



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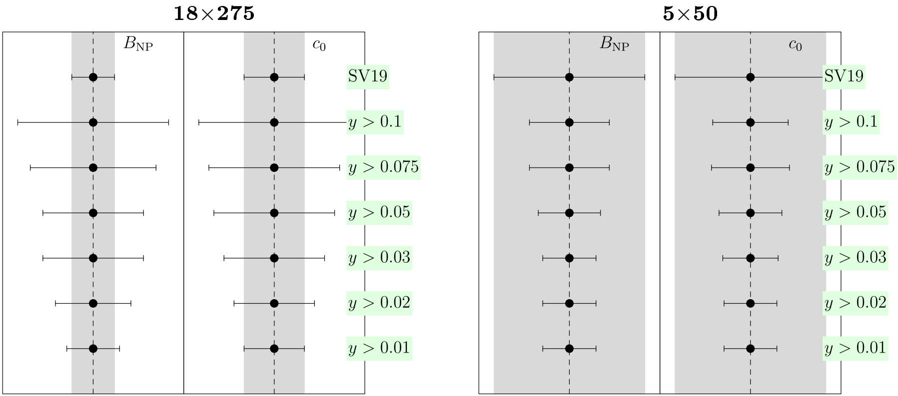
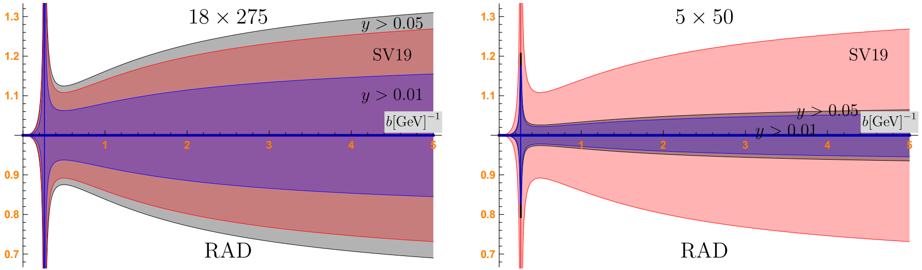
y-cut impact on **TMD evolution**



Not to forget!

- This is EIC data vs. global data
- The model is "tuned" to lower-energies
- SV19 uncertainty estimation is done by replica method

y-cut impact on **TMD evolution**



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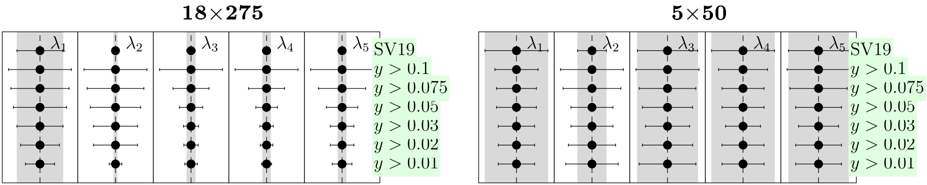
y-cut impact on **TMD PDF**



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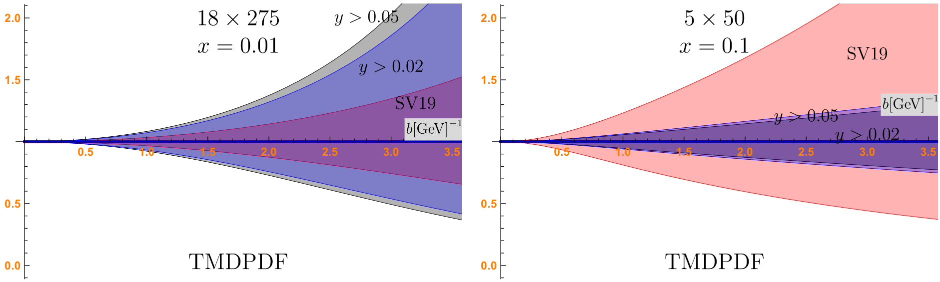
y-cut impact on **TMD PDF**



(difficult to compete with LHC) (DY data are not restrictive)

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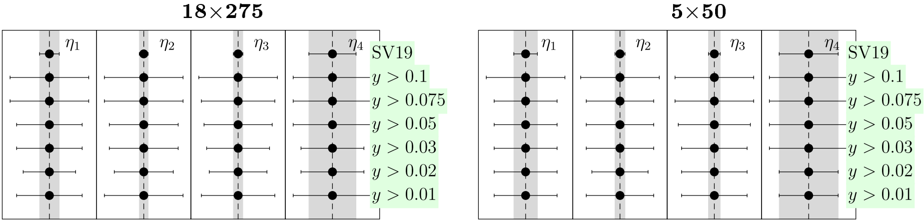
y-cut impact on **TMD FF**



UNCERTAINTIES WERE ESTIMATED BY DIFFERENT METHODS...

...under investigation...

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Conclusion

- Framework is setup
- Problem with uncertainty estimation
- Some first statements:
  - Important kinematic regions
  - $y > 0.02$ and systematics 2-4%
- Ready for smeared data
- (Almost) Ready for Sivers

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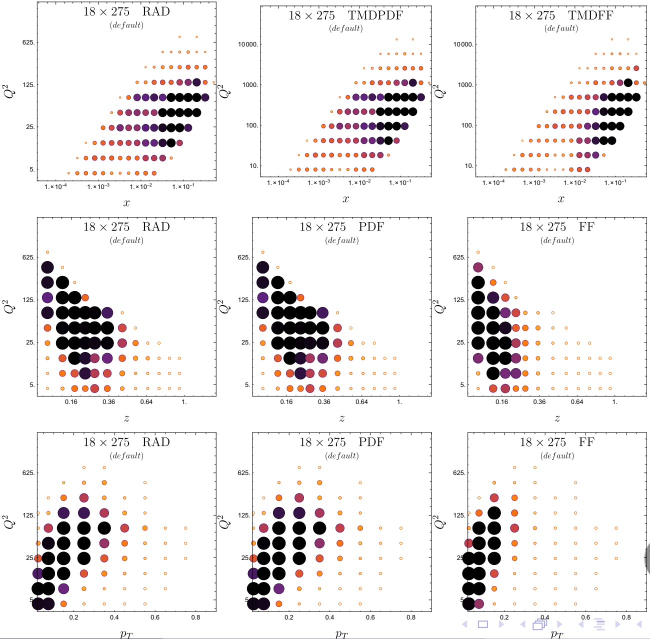
BACKUP

NOT WEIGHTED BY NUMBER OF POINTS



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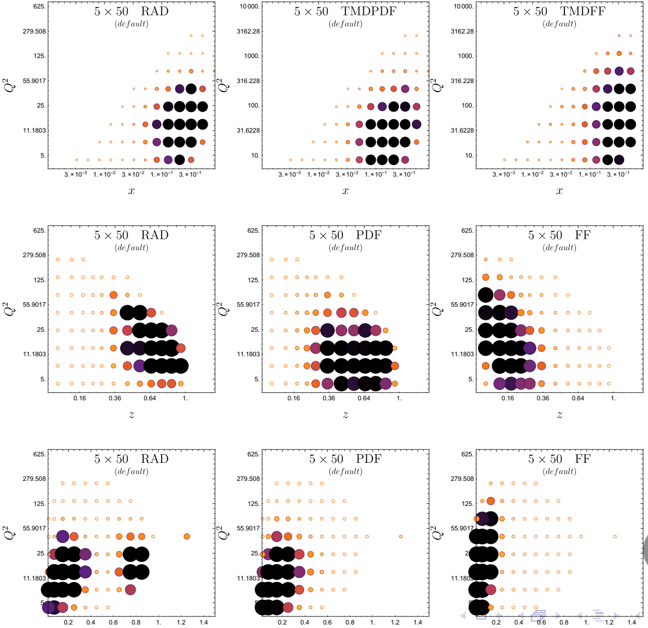
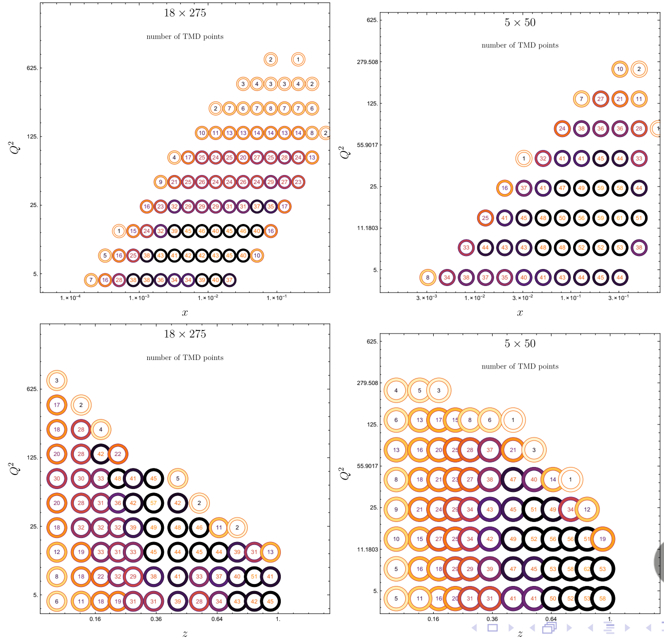


NUMBER OF POINTS IN A BIN



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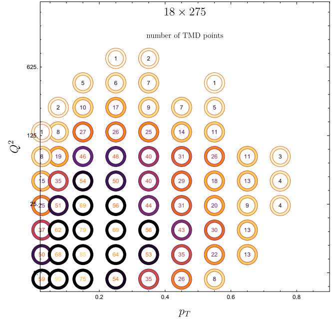
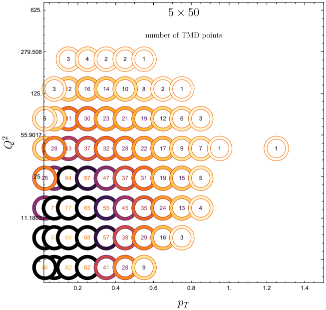
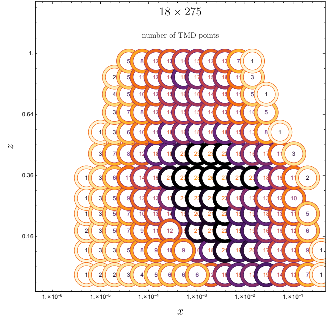
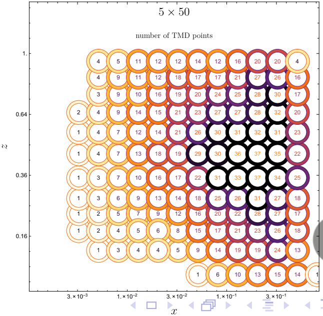
NUMBER OF POINTS IN A BIN









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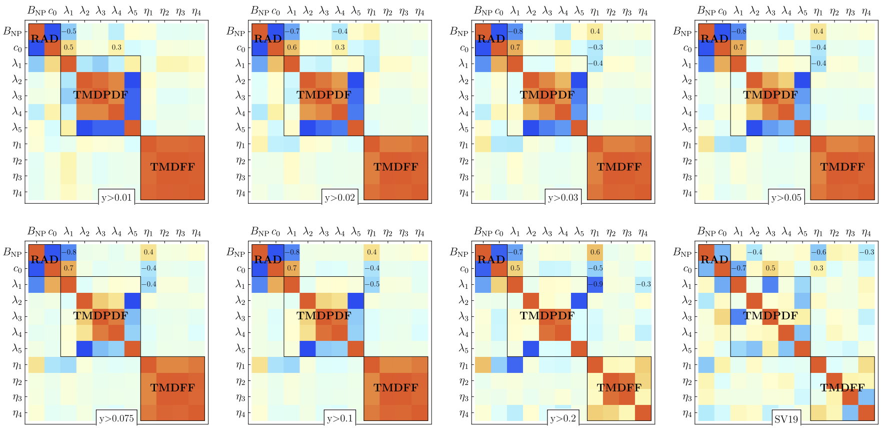
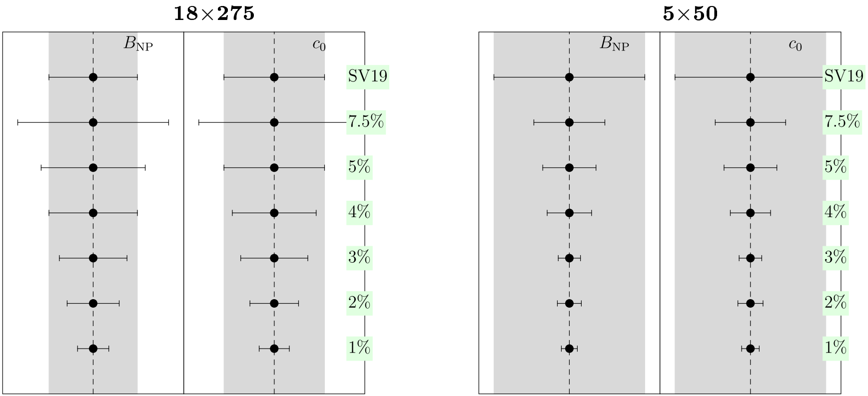
y-cut impact on correlation



Conclusion

- Small y is important **especially for the evolution**
- $y > 0.02$ is OK

systematic error impact on **TMD evolution**



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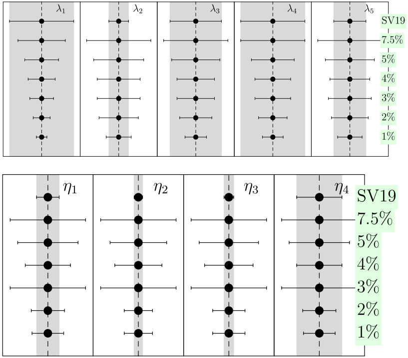
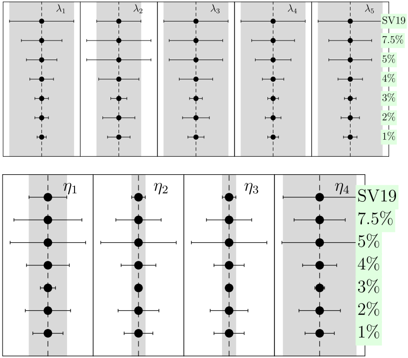
systematic error impact on **TMD evolution**

18×275



5×50



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