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

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<tr>
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<tbody>
<tr>
<td>$-3.5 &lt; \text{rapidity} &lt; -1.0$ (RICH)</td>
<td>$0.5 &lt; p_H &lt; 5.0$</td>
<td>$1.6 &lt; p_H &lt; 5.0$</td>
<td>$3.0 &lt; p_H &lt; 8.0$</td>
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<tr>
<td>$-1.5 &lt; \text{rapidity} &lt; -1.0$ (dE/dx)</td>
<td>$0.2 &lt; p_H &lt; 0.6$</td>
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<td>$0.2 &lt; p_H &lt; 1.0$</td>
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<tr>
<td>$-1.0 &lt; \text{rapidity} &lt; 1.0$ (DIRC and dE/dx)</td>
<td>$0.2 &lt; p_H &lt; 4.0$</td>
<td>$0.2 &lt; p_H &lt; 0.7$</td>
<td>$0.2 &lt; p_H &lt; 1.1$</td>
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- 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.
\[ W^2 > 10, \ 0.01 < y < 0.95 \]

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:

- **artemide**(SV19 model) $\rightarrow$ **harpy** $\rightarrow$ "**elpis"** $\rightarrow$ iMinuit
  - Fortran TMD cross-section
  - interface
  - $\chi^2$, data manipulation, etc.
  - python
  - minimisation, Minos
Analysis of TMD data is slowowww...

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

(picture by Marco Radici)
Theory driven pseudo-data

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

- \( r \) is RND with \( \delta\sigma_{\text{stat.}} \).
- \( w \) is \( \sigma_{\text{th.}}/\sigma_{MC} \)
Remainder
SIDIS cross-section within TMD factorization

\[
\frac{d\sigma}{dp_T} = \sigma_0 |C_V(Q^2)|^2 \int d^2 b e^{i(q_T b)} \left( \frac{Q^2}{\zeta Q[D]} \right)^{-D(b,Q)} \sum_q e_q^2 F_q \leftrightarrow h_1(x, b) D_q \rightarrow h_2(z, b)
\]  

(1)

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

- TMD evolution ($D \equiv$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
Inspecting the most important regions

What is plot?!

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

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

\[ y \text{-cut: } y > 0.05 \quad x = 0.01 \]
\[ y \text{-cut: } y > 0.02 \]

TMDPDF
(difficult to compete with LHC)

TMDPDF
(DY data are not restrictive)

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y-cut impact on TMD FF

**18×275**

- $\eta_1$
- $\eta_2$
- $\eta_3$
- $\eta_4$

SV19
- $y > 0.1$
- $y > 0.075$
- $y > 0.05$
- $y > 0.03$
- $y > 0.02$
- $y > 0.01$

**5×50**

- $\eta_1$
- $\eta_2$
- $\eta_3$
- $\eta_4$

SV19
- $y > 0.1$
- $y > 0.075$
- $y > 0.05$
- $y > 0.03$
- $y > 0.02$
- $y > 0.01$

**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
NOT WEIGHTED BY NUMBER OF POINTS

1. \times 10^{-4} \ 1. \times 10^{-3} \ 1. \times 10^{-2} \ 1. \times 10^{-1}

5. \ 25. \ 125. \ 625.

1. \times 10^{-4} \ 1. \times 10^{-3} \ 1. \times 10^{-2} \ 1. \times 10^{-1}

10. \ 100. \ 1000. \ 10 000.

0.16 \ 0.36 \ 0.64 \ 0.8

5. \ 25. \ 125. \ 625.

0.2 \ 0.4 \ 0.6 \ 0.8

5. \ 25. \ 125. \ 625.

TMD.SIDIS

artemide

June 1, 2020 21 / 26
NOT WEIGHTED BY NUMBER OF POINTS
NUMBER OF POINTS IN A BIN

18 × 275
number of TMD points

5 × 50
number of TMD points

TMD.SIDIS
artemide
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NUMBER OF POINTS IN A BIN

18 × 275

18 × 275

5 × 50

5 × 50
Conclusion

- Small $y$ is important especially for the evolution
- $y > 0.02$ is OK
systematic error impact on TMD evolution

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