ML-based SIDIS Kinematic Reconstruction

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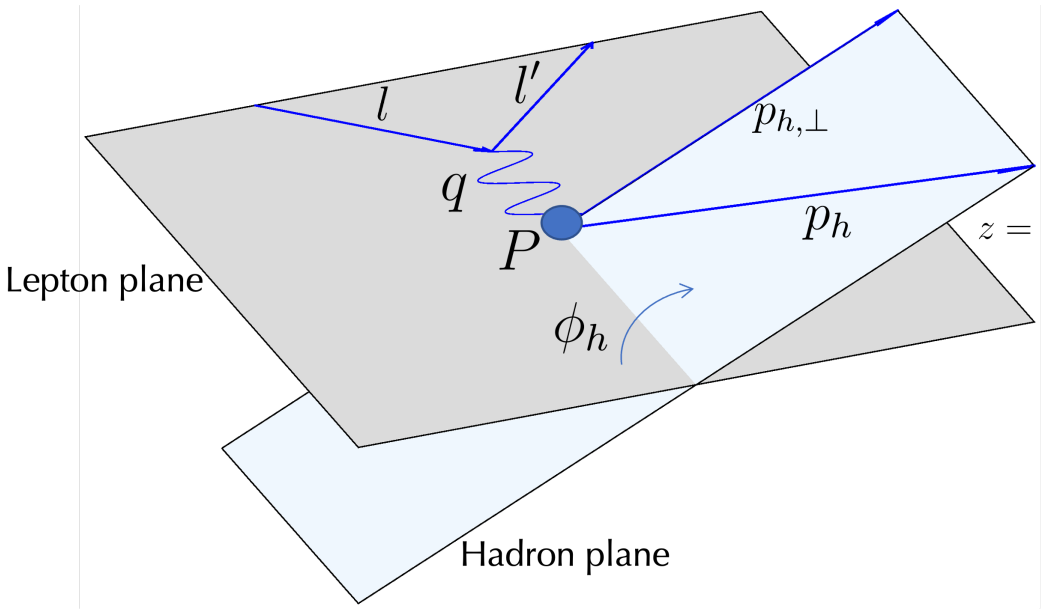
SIDIS kinematic reconstruction at EIC

- SIDIS reconstruction centered around reconstruction of virtual photon four-momentum, q
  - Past fixed target/HERA analyses: from scattered lepton, $q = l - l'$
- I previously presented results of hadronic final state and ML SIDIS kinematic reconstruction on ATHENA full sim. (DIS proceedings, https://inspirehep.net/literature/2158328)
- This talk: demonstration of the same method on ePIC full simulation, and aiming to publish results shown here



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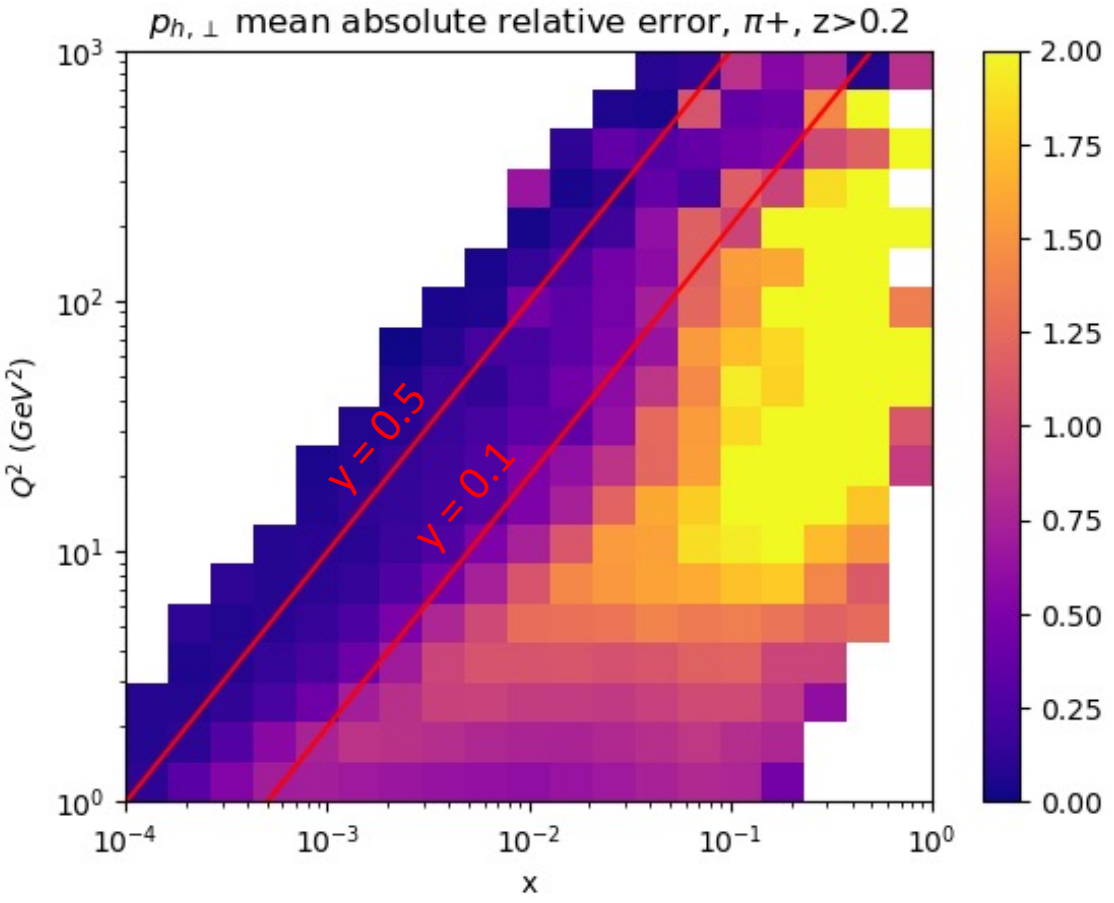
SIDIS kinematic resolutions with ePIC

- Known problem since yellow report studies: electron method performance drops off significantly at low-y
  - Low-y : small electron energy loss
- Right: SIDIS transverse momentum resolution with $q = l - l'$
  - Tail of very poorly reconstructed events cut off here (require absolute error of pT < 1000%)
  - Reconstructed scattered electron taken with truth matching

ePIC 23.07.1, 18x275
Electron method



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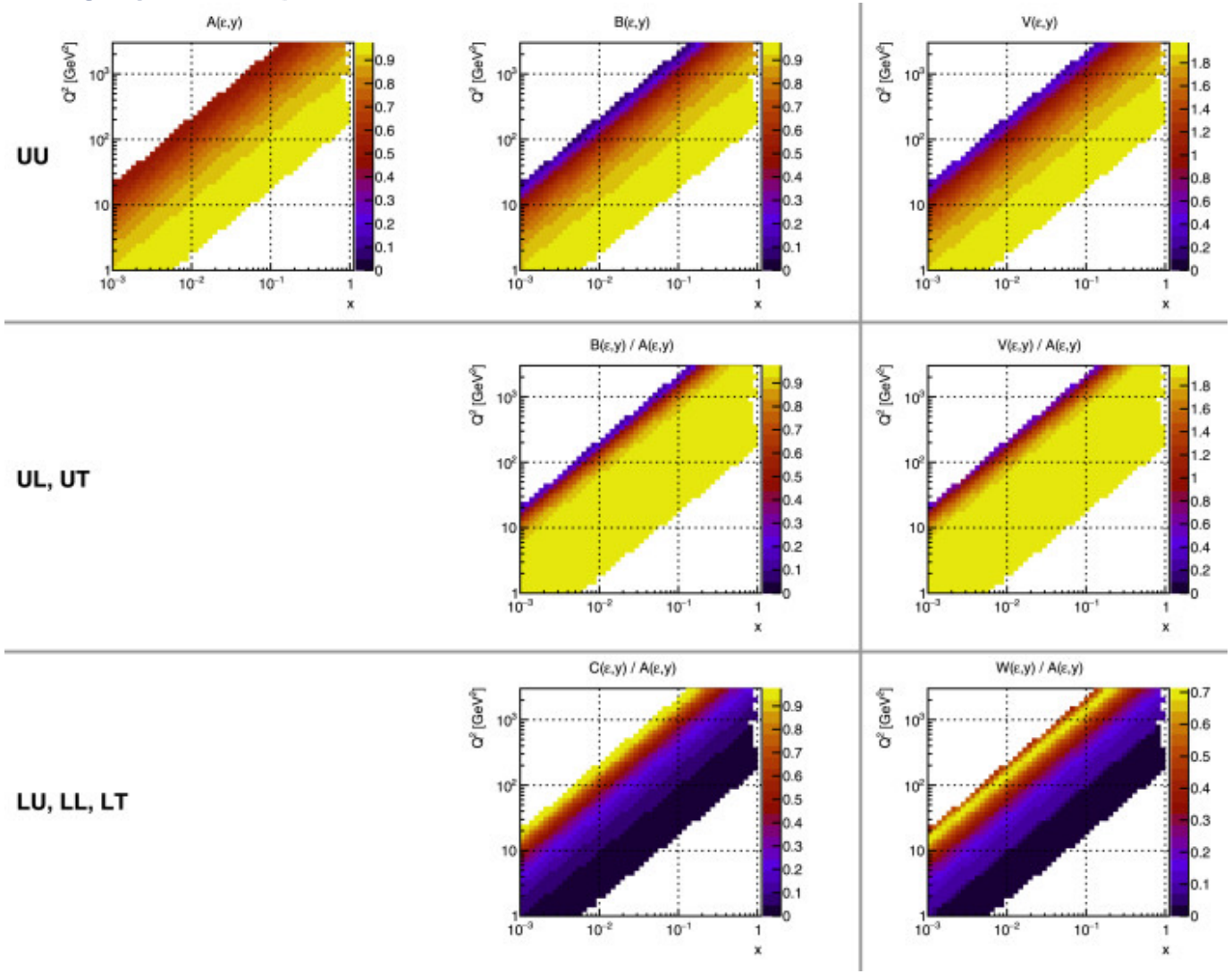
Low-y kinematic region at EIC

- Low-y region important for measurement of SIDIS observables with unpolarized lepton beam
  - Right: depolarization factors of SIDIS observables in 18x275 configuration
- Necessary region for overlap with fixed-target kinematic space



From 2211.15746, *Precision studies of QCD in the low energy domain of the EIC*, 2023

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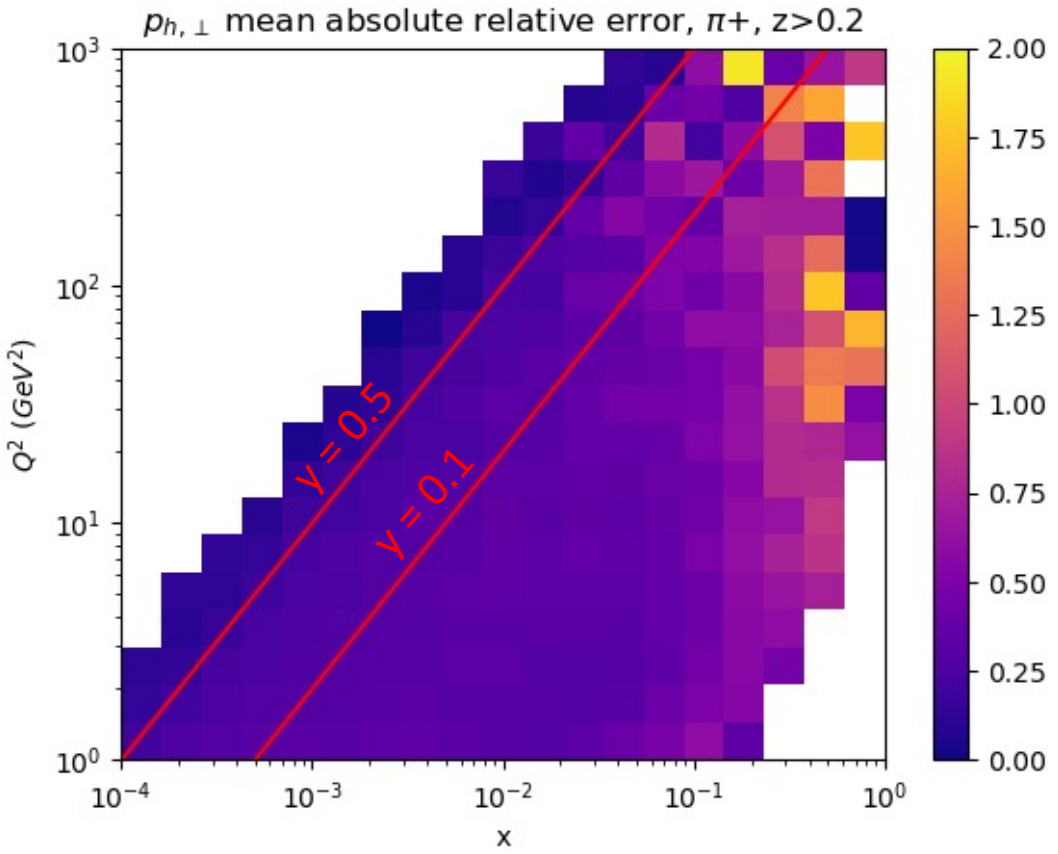
First hadronic final state method

- Introduced in YR by Anselm: extending HERA kinematic reconstruction methods for (x,Q2,y) to constraining q

$$\left.\begin{aligned} (q_x, q_y) &= \text{HFS } \vec{p_T} \text{ || electron } \vec{p_T}, \\ Q^2 &= -q^2, \\ y &= \frac{P.q}{P.k} \end{aligned}\right\} (q_x, q_y, q_z, q_t)$$

- Q^2, y taken from hadronic final state (HFS) or hybrid reconstruction method (double-angle, Jacquet-Blondel, etc.)
- Transverse recoil from electron or HFS
- Quadratic formula to solve for remaining two components of q

ePIC 23.07.1, 18x275
Quadratic method, DA + electron recoil



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Machine learning approach

- Utilizing Particle Flow Networks (PFN, arXiv:1810.05165)
  - Deep sets architecture: operate on unordered, permutation invariant set
  - First demonstrated on jet tagging tasks at LHC
- Training PFN to directly reconstruct q
  - Unordered set: All HFS particles
  - Also utilize electron information
  - First shown on ATHENA full simulation (DIS 2022: https://inspirehep.net/literature/2158328, and AI4EIC 2022)

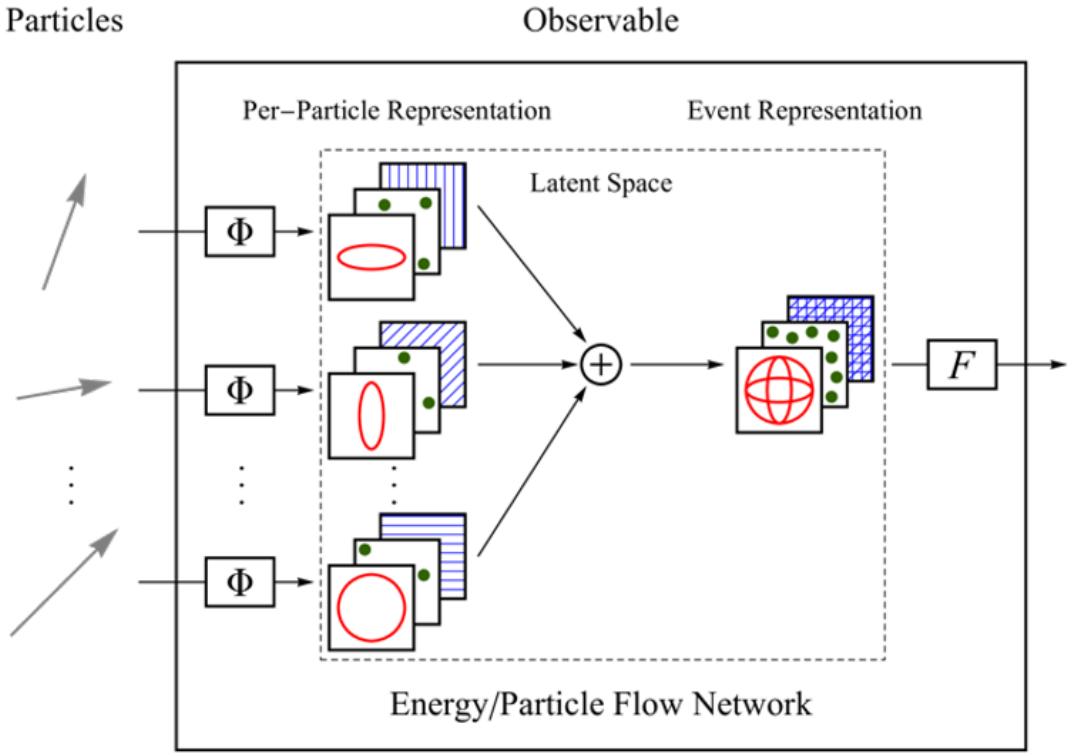

Diagram of Particle Flow Network, from arXiv:1810.05165

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Training details

- Utilized 2.6 million events from ePIC 23.07.1 campaign ($Q^2 > 1\ GeV^2$ sample), at ReconstructedParticle level
  - 1.6 million used for training, remaining 1 million for validation
  - Using MC truth matching to get scattered electron (analysis procedure in epic-analysis used to obtain electron and HFS)
- HFS particle information input to first layers: p_x, p_y, p_z, E
- Electron information input in latent space: $q_{x,ele}$, $q_{y,ele}$, $q_{z,ele}$, $q_{E,ele}$
- Inclusive DIS information input to latent space: -log10(x), log10(Q^2) from DA, Σ, electron methods
- Two networks trained: one reconstructing (q_x, q_y), and one reconstructing (q_z, q_E)

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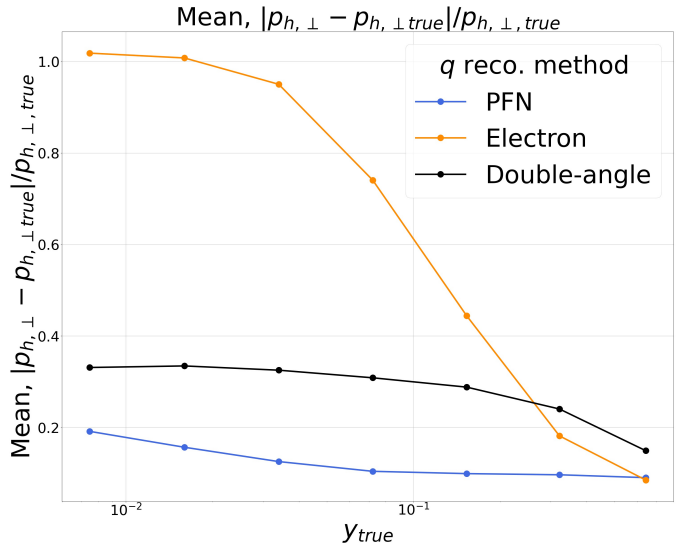
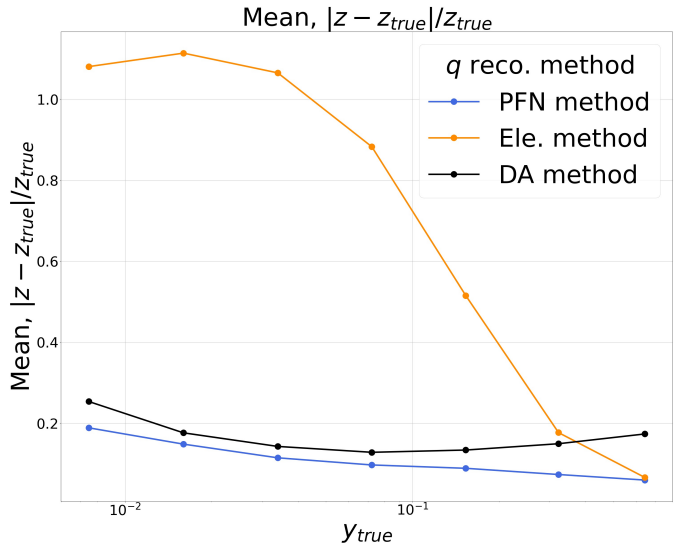
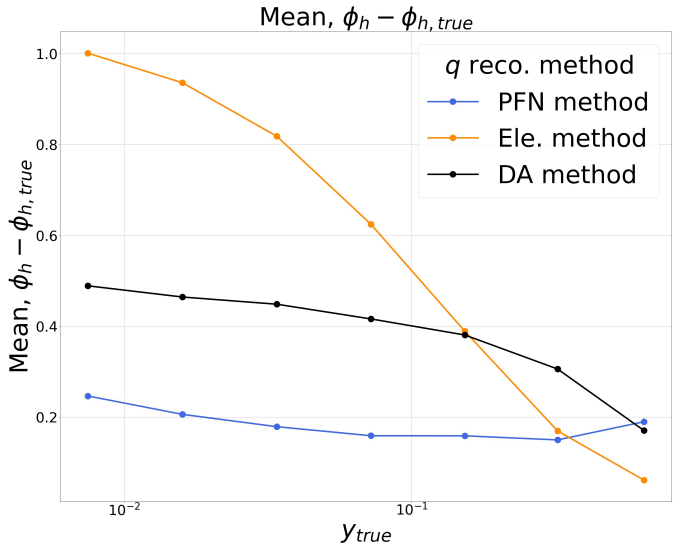
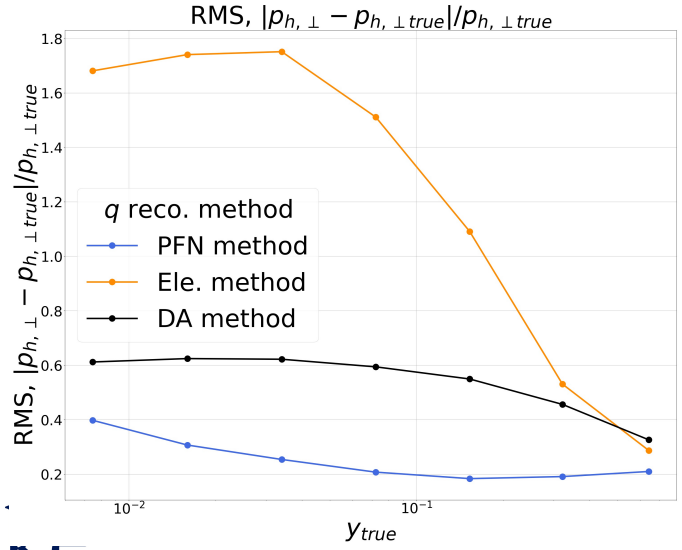
Results, ePIC full simulation 23.07.1

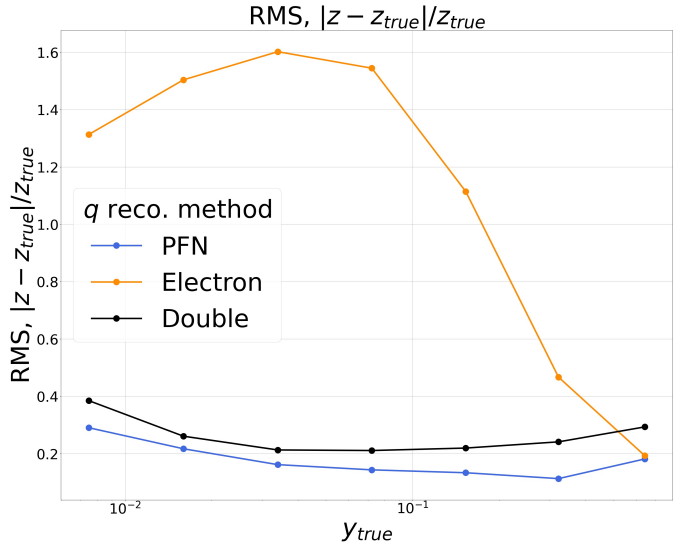
SIDIS kinematic resolutions, $Q^2 > 1GeV^2$, π^+, $z > 0.2$ ePIC 23.07.1

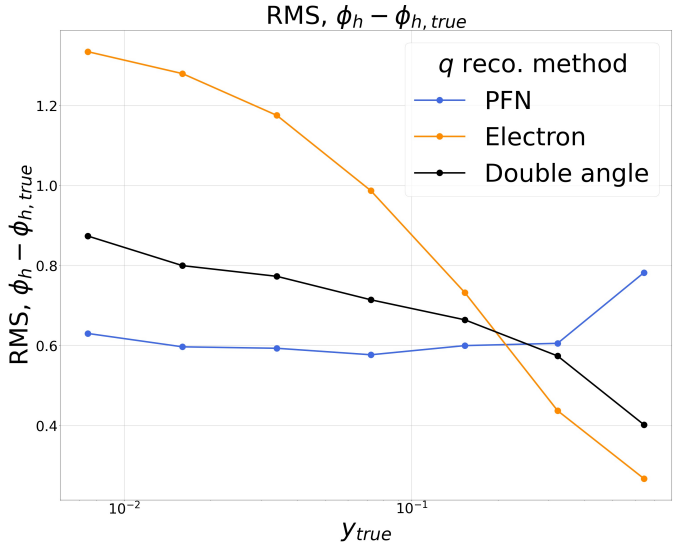












Future steps

- Aiming to monitor the performance of these approaches on each large-statistics ePIC simulation campaign
- Training data already prepared with epic-analysis – goal is to make trained models accessible through this analysis framework for further use in the SIDIS WG (implemented with ONNX)
- Essential to conduct further study of performance of these methods when QED radiative effects considered

Conclusion

- Constraining (q_z,q_t) using (y,Q^2) from hybrid HFS-electron methods significantly improves reconstruction at low-y
  - Will need to investigate the impact of QED radiative corrections once this is included in ePIC simulation campaigns
- Training Particle Flow Networks to reconstruct virtual photon four momentum using scattered electron and all HFS particles outperforms other method across all y
- We would like to submit a write-up of these methods and results on ePIC 23.07.1 for publication (JINST or similar)

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Backup

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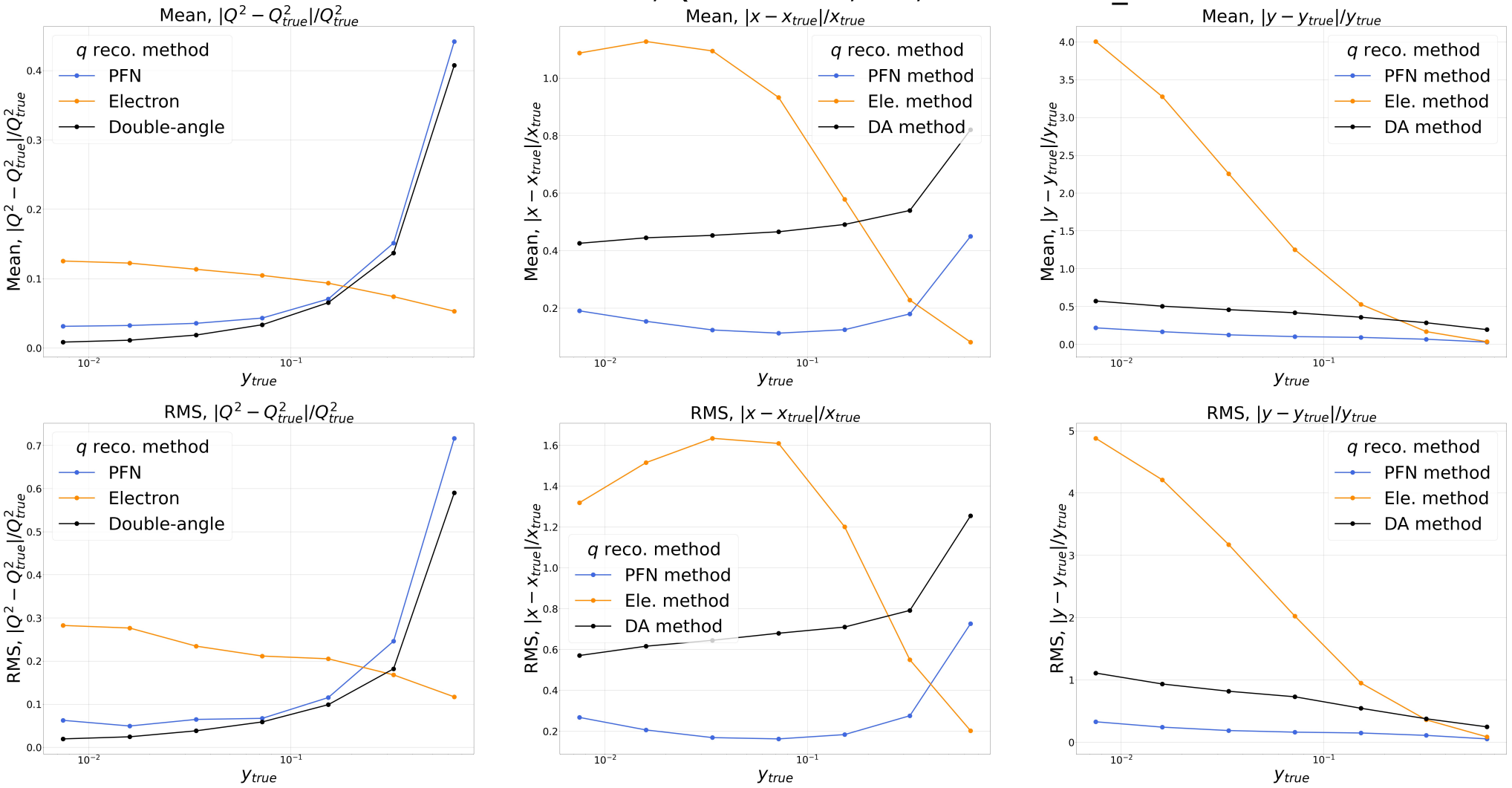
Impacts on inclusive-DIS resolutions

DIS kinematic resolutions, $Q^2 > 1GeV^2$, π^+, $z > 0.2$ ePIC_23.07.1



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