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News from hadron structure calculations with twisted mass fermions

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Outline

- introduction and current status of hadron structure computation within the ETMC
- a method to extract PDF from the lattice
- matching the quasi PDF with the physical one
- feasibility study and first results for the matrix elements
- future plans and challenges

News from hadron structure

- hadron structure is an essential part in understanding QCD
- many ongoing computations on this topic within the ETMC

→ new results for g_a and $< x >_{u-d}$ of the proton at the physical point, cf. plenary talk by Martha Constantinou on Monday

→ study of $< x >_{u,d}$ of the pion, mentioned by Bartosz Kostrzewa in session 8B on Friday

→ ongoing computation for $< x >_g$ with currently perturbative renormalization of the singlet operator

→ many more...

Introduction

- to understand the structure of a hadron it is important to know the distribution of its partons
- $q(x)$ probability of finding a parton q with a momentum fraction x of the parent hadron

- deep inelastic scattering: important tool to access the structure of nucleons

$\rightarrow$ measure cross section $\rightarrow$ extract structure functions

$\rightarrow$ quark and gluon distributions via phenomenological fit

- why PDF from the lattice

$\rightarrow$ computation from first principles

$\rightarrow$ perturbation theory only has access to small x region

$\rightarrow$ PDF fit depends on approach

PDF from lattice QCD

quark distributions via the light cone operator

$$q(x,\mu^2) = \frac{1}{2\pi}\int d\xi^- e^{-ixp^+\xi^-}\langle N(p)|\bar{\psi}(\xi^-)\gamma^+ L(\xi^-,0)\psi(0)|N(p)\rangle$$

- $\rightarrow$ $\xi^- = t - z$, $L(\xi^-,0)$ Wilson line from ξ^- to 0
- $\rightarrow$ light cone dominated ($\xi^2 \sim 0$)
- $\rightarrow$ not computable on Euclidean lattice ($\xi^2 = t^2 + \vec{x}^2$)

we can compute moments of PDFs:

$$q_n = \int_0^1 dx\, x^{n-1} q(x) = \frac{1}{(p^+)^n}\langle N(p)|\bar{\psi}(0)\Gamma(i\overleftrightarrow{D}^+)^n\psi(0)|N(p)\rangle$$

- $\rightarrow$ first moments possible
- $\rightarrow$ higher moments difficult

PDF from lattice QCD II

new idea proposed by Ji, 2013 [arXiv:1305.1539]

$\rightarrow$ quasi distributions

$$\tilde{q}(x, \mu^2, p^z) = \frac{1}{2\pi} \int d\Delta z \; e^{-ixp^z \Delta z} \langle N(p^z) | \bar{\psi}(\Delta z) \gamma^z L(\Delta z, 0) \psi(0) | N(p^z) \rangle$$

- $\rightarrow$ purely spatial, can be simulated on the lattice
- $\rightarrow$ computable at finite momentum p^z
- $\rightarrow$ z can be any spatial direction
- $\rightarrow$ $L(\Delta z, 0)$ is the Wilson-line form 0 to Δz in the z direction

Matching lattice results with the PDF

- quasi distribution is computed on the lattice at finite momentum

→ needs to be corrected

$$\tilde{q}(x,\mu,p^z) = \int \frac{dy}{|y|}\, Z\left(\frac{x}{y},\frac{\mu}{p^z}\right) q(y,\mu) + \mathcal{O}\left(\frac{\Lambda_{QCD}^2}{(p^z)^2},\frac{M_N^2}{(p^z)^2}\right)$$

- we need large momenta in order to have a small correction
- Z can be expressed as a series in α_s

→ needs to be computed perturbatively (cf. Xiong et al., 2013 [arXiv:1310.7471])

Road map

- computation of matrix elements on test ensemble
  - implementation of operator and verification of matrix elements
  - algorithmic tests: stochastic vs. sequential method
  - test HYP smearing of Wilson line
- running high statistic production on large ensemble
- check for systematic effects
  - finite momentum effects
  - excited state effects
- non-perturbative renormalization
- compute quasi distribution from matrix elements
- matching to physical PDF
- use ensemble at the physical point

Study the feasibility: setup

- first computations were done on a test ensemble

→ $N_f = 2$ twisted mass fermions

→ generated by the ETM collaboration

→ $16^3 \times 32$,

→ 540 measurements

→ $a \approx 0.085$ fm, $m_{PS} \approx 340$ MeV

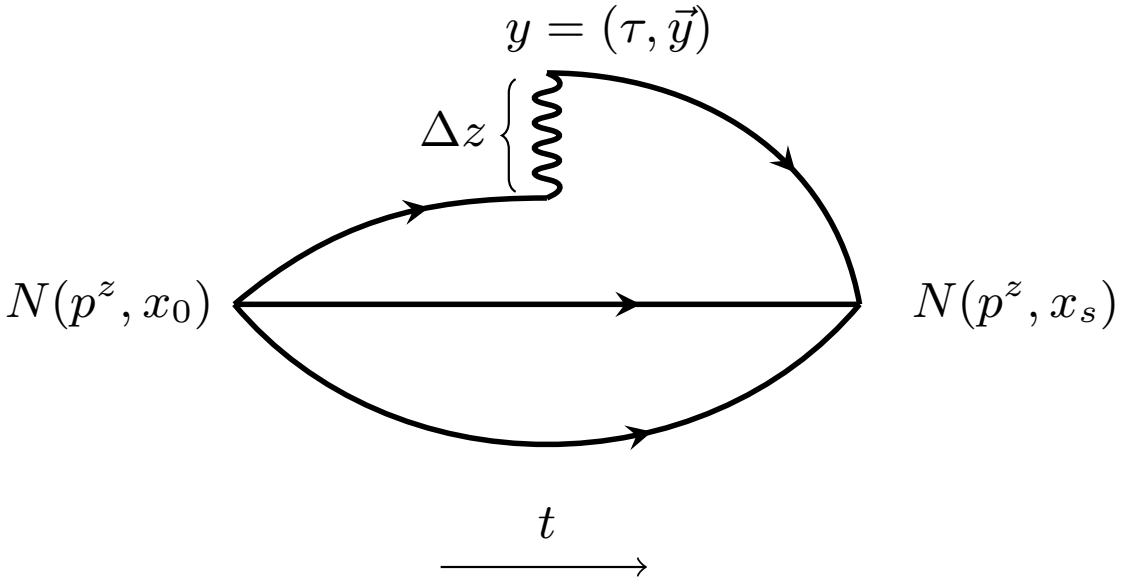
→ Gauss smeared nucleon fields

Study: The matrix element we compute

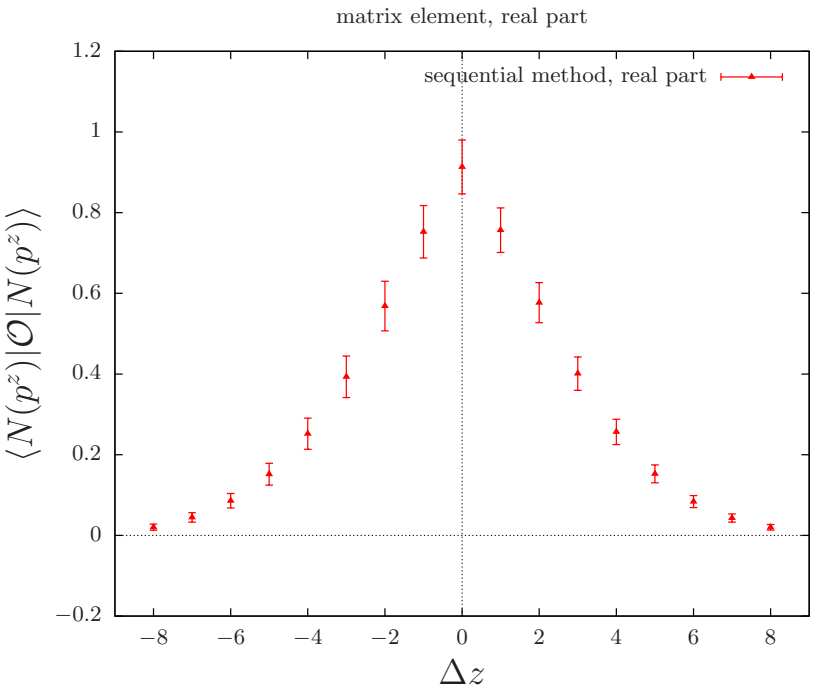
- the following plots will show the matrix element of the operator $\langle N(p^z)|\bar{\psi}(\Delta z)\gamma^z L(\Delta z, 0)\psi(0)|N(p^z)\rangle$, for several values of Δz

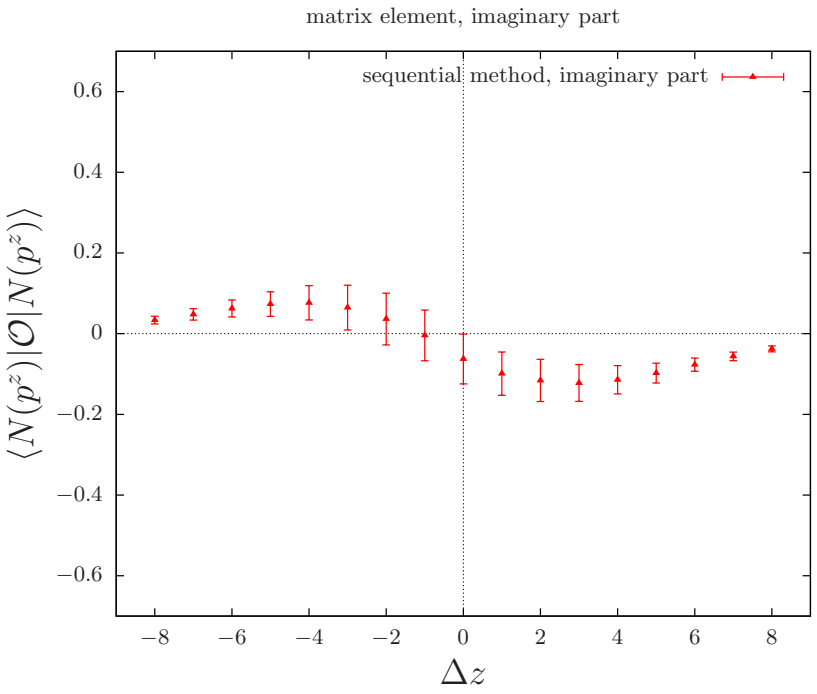
$\rightarrow$ note: boosted nucleon $\rightarrow$ momentum injection at the sink

$\rightarrow$ first results are with momentum 1 $\rightarrow$ 6 different possible momenta on the lattice



Results for matrix element



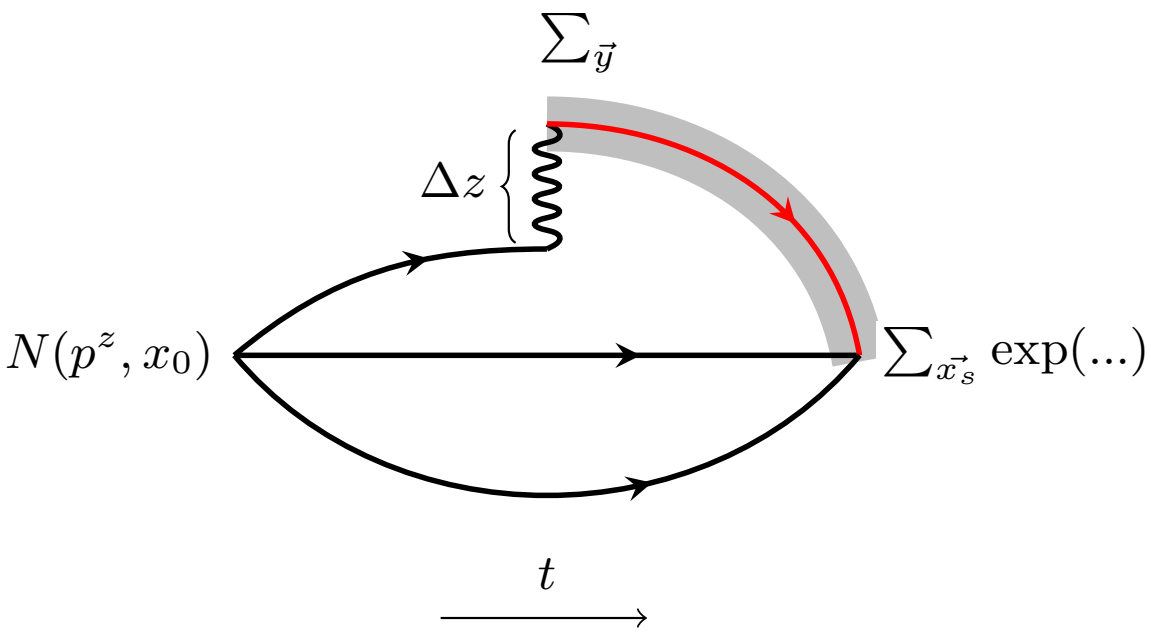


- similar to first results presented by Lin et al., 2014 [arXiv:1402.1462]

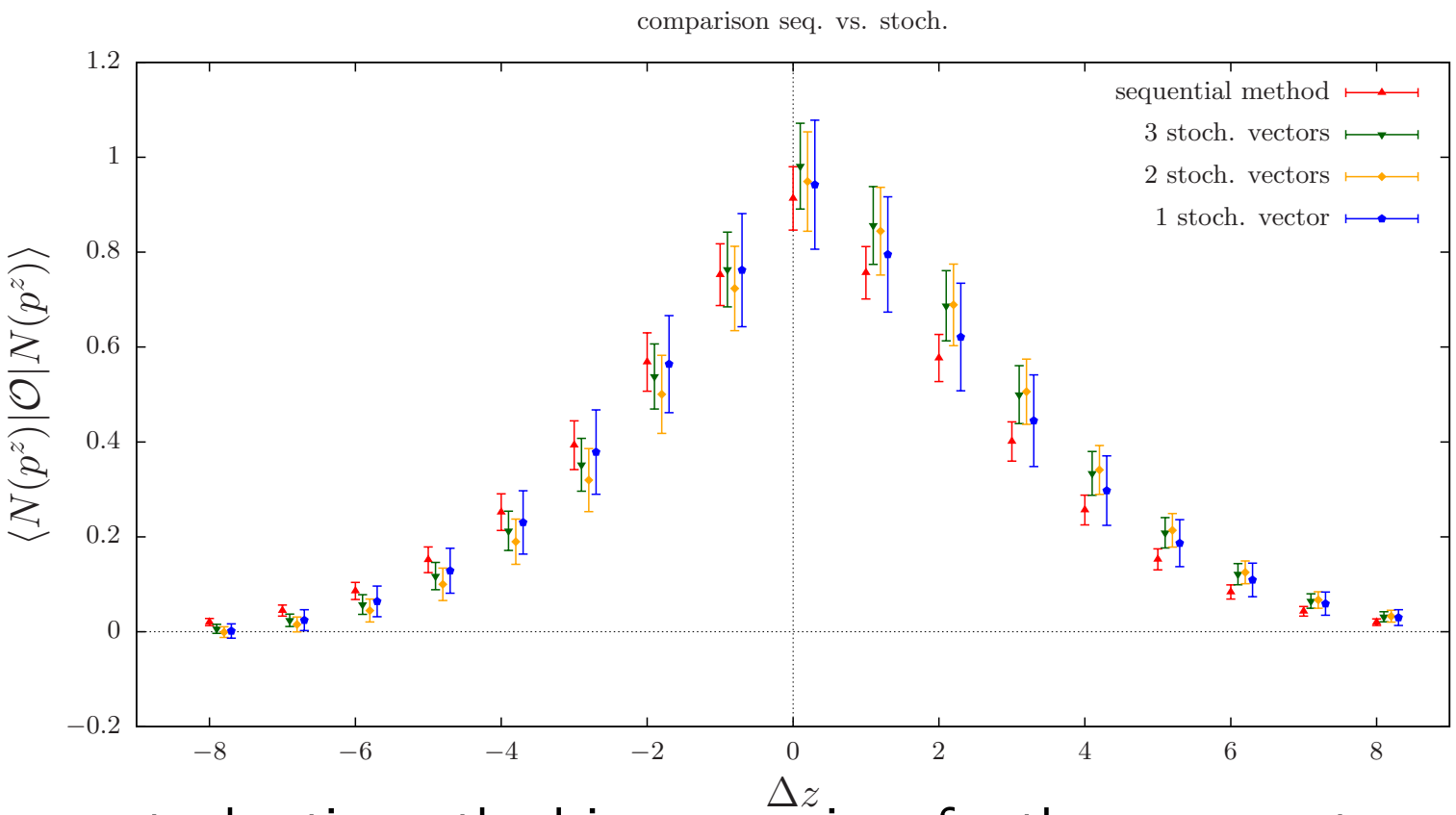
Study: sequential vs. stochastic

- sequential method
+ "exact method", i.e. no additional noise
− unflexible

- stochastic method
+ larger statistics with one set of inversions
+ access to all momenta
− stochastic noise



Study: sequential vs. stochastic II

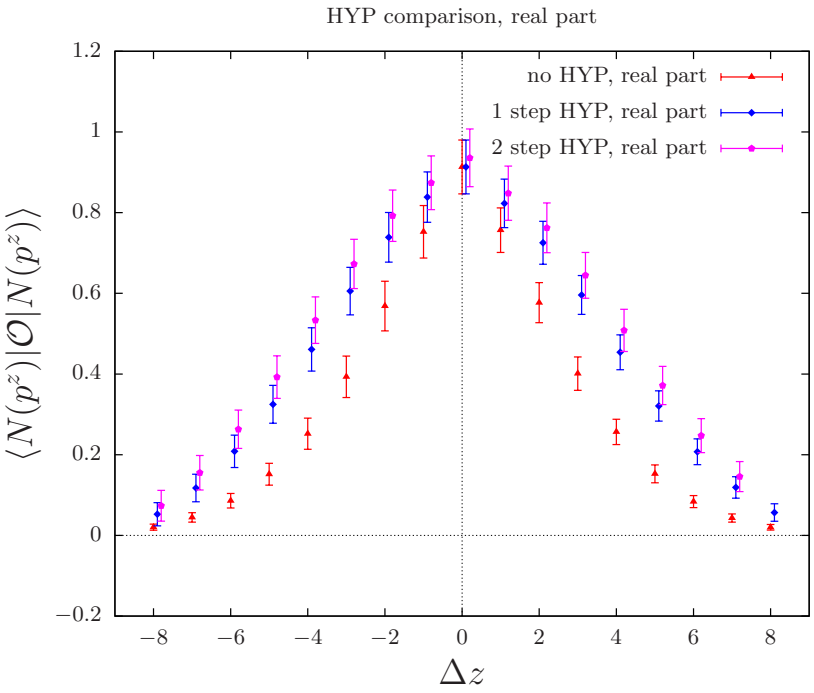


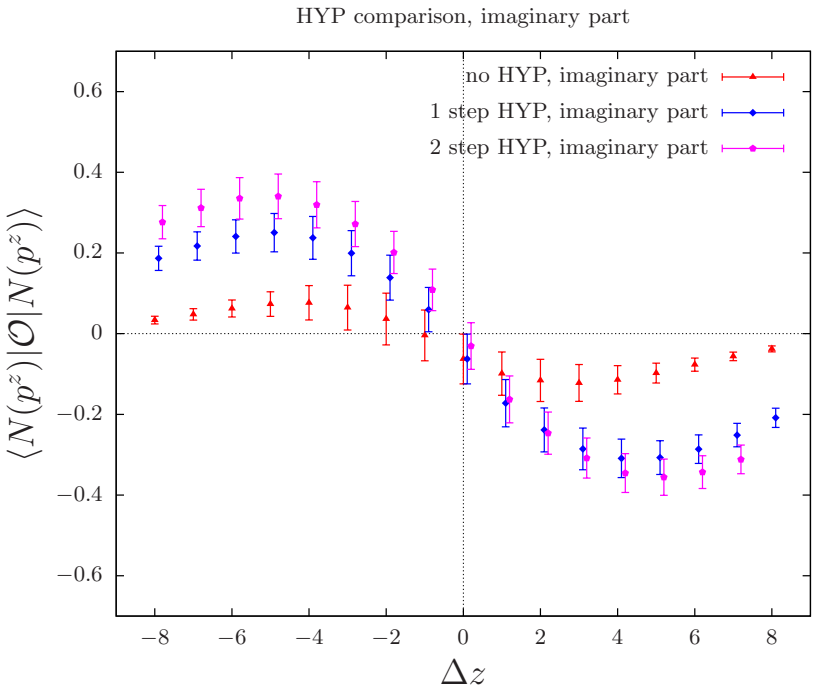
- stochastic method is converging, for the same cost seems equal to sequential

→ but is more flexible

- we tested both, fully and not diluted noise vectors: results are comparable

Study: HYP smearing





- HYP moves the signal up, but does not decrease the noise
- we will do non-perturbative renormalization of the matrix elements $\rightarrow$ we may not need HYP smearing

First matrix elements from a large volume

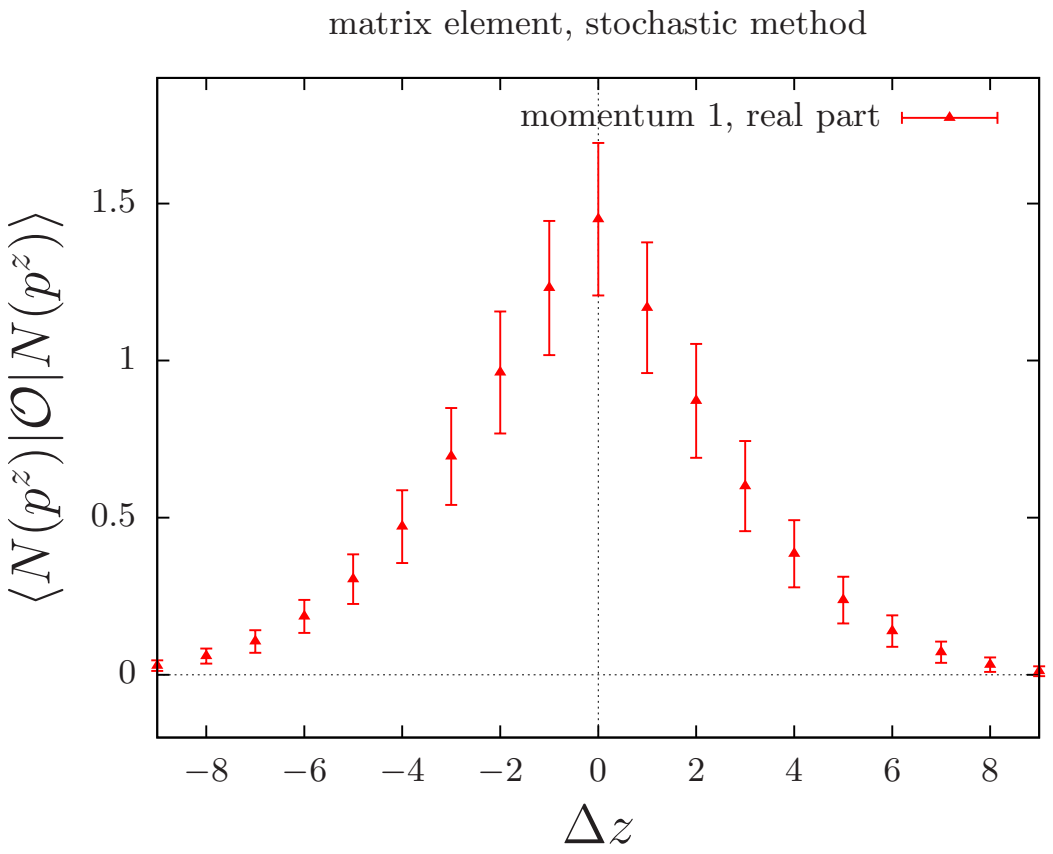
- next step: measurements on a production ensemble

→ $N_f = 2 + 1 + 1$ by ETMC, $32^3 \times 64$ (B55.32)

→ 240 measurements, (access to $\sim$ 30000 forward propagators on $\sim$ 4000 configurations)

→ $\beta = 1.95$ ($a \approx 0.082$ fm), $m_{PS} \approx 372$ MeV

→ no large cutoff or finite size effects



Conclusion

- first steps in testing a new proposal which might enable us to extract the PDF from lattice QCD
- ongoing study with encouraging results for matrix elements
- studied two different methods: sequential and stochastic

$\rightarrow$ to be flexible we will use the stochastic method in the future

- employed several steps of HYP smearing

$\rightarrow$ noise is not influenced

Future plans and challenges

- extensive study to have all the systematics under control
  - finite momentum effects: several momenta
  - excited state effects: vary source-sink separation
- non-perturbative renormalization
- compute quasi distribution from matrix elements
- matching to physical PDF
- PDF at physical quark mass: use $N_f = 2$ twisted mass clover ensemble

Thanks

Thank you for your attention and future discussions.