Transverse Energy-Energy Correlators in the Color-Glass Condensate at the Electron-Ion Collider

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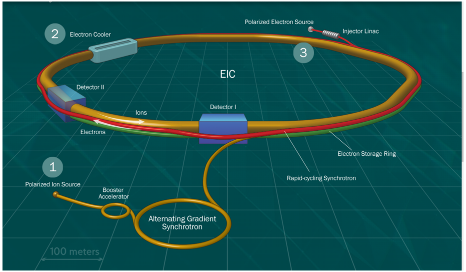
SURGE collaboration

Topical Collaboration PI Meeting

Studying nuclear physics at high energy

- Open questions in high-energy nuclear physics:
  - How are the quarks and gluons distributed in space and momentum inside the nucleon?
  - How does gluon saturation affect nuclear structure?
- Hoping to get answers at the EIC
- But: Probing the nuclei using QCD is difficult
  - Perturbation theory breaks down for small energies
    $\Rightarrow$ Nonperturbative contributions
- Sensitivity to the nonperturbative region can be large



These difficulties might be ameliorated in transverse energy-energy correlators!

Transverse energy-energy correlators (TEEC)

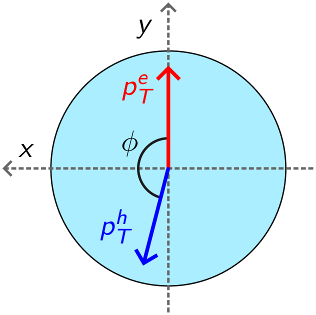
- Event-shape observable: Sum over all produced particles
- Pairs of outgoing particles weighted by their transverse energy E_T

  $\Rightarrow$ Less sensitive to the nonperturbative region
- "Transverse" compared to the beam line
- TEEC for electron-hadron production:

$$\frac{d\Sigma^{\text{TEEC}}_{e+h}}{d\tau} = \sum_h \int d\sigma \, \frac{E_T^e E_T^h}{E_T^e \sum_i E_T^{h_i}} \delta\left(\tau - \frac{1+\cos\phi}{2}\right)$$

  - $\phi =$ azimuthal angle between the produced particle pair

$e + p/A \to e' + h$



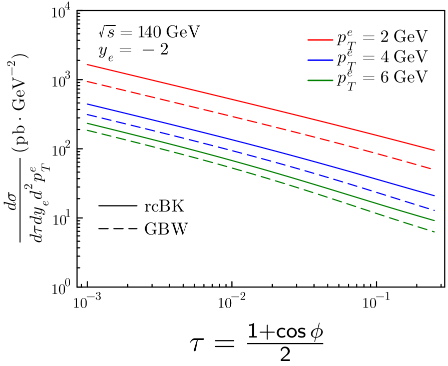
$$\tau = \frac{1+\cos\phi}{2}$$

Proton targets at the EIC

- TEEC for lepton-hadron production in the process

$$e + p/A \to e' + h$$

- Interaction with the target nucleus in nonperturbative
    - Small-x limit: Can be described using the color-glass condensate effective field theory
    - Contains the effects of gluon saturation
- We consider two models for the interaction with the nucleus (called rcBK and GBW)
- Up to a factor of two difference between the models: Additional constraints for the models



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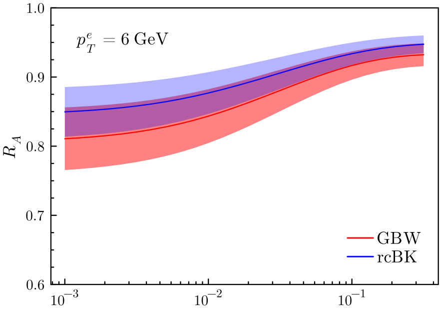
Nuclear suppression factor



$\tau = \frac{1+\cos\phi}{2}$

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- Saturation effects different in protons and heavy nuclei

  $\Rightarrow$ Comparing the two tells us about saturation

- Nuclear suppression factor

$$R_A = \frac{1}{A} \frac{\mathrm{d}\sigma_{eA}}{\mathrm{d}\tau\,\mathrm{d}y_e\,\mathrm{d}^2\boldsymbol{p}_T^e} \Bigg/ \frac{\mathrm{d}\sigma_{ep}}{\mathrm{d}\tau\,\mathrm{d}y_e\,\mathrm{d}^2\boldsymbol{p}_T^e}$$

  where A is the mass number of the nucleus

- Without saturation $R_A \to 1$

Nuclear modification of $15-20\%$ can be expected in the back-to-back limit ($\tau \ll 1$)

Outlook for transverse energy-energy correlators

Transverse energy-energy correlators:

- Event-shape observables that are generally less sensitive to the nonperturbative physics
- Small-x limit: sensitive to saturation

Outlook:

- TEEC can also be used for measuring spatial and momentum distribution of partons in the nuclei

A lot of potential for high-accuracy comparisons between theory and experiment at the EIC!

Relation to the milestones of the Topical Collaboration

- This work directly addresses the first goal of the SURGE Collaboration as laid out in the proposal:

  "Identify observables that are sensitive to gluon saturation"

- Plans for the future:
  - In the back-to-back limit, compare to the NLO calculation of single- and double-inclusive hadron production by Bergabo and Jalilian-Marian (Phys.Rev.D 107 (2023) 5, 054036)

    $\Rightarrow$ Collaboration between Kang, Penttala and Jalilian-Marian
  - TEEC can be also calculated to NLO for further comparisons
  - Closely related to the milestone

    "Perform NLO computations for dihadron production in $e + A$" (year 2-3)