Energy correlators from RHIC to EIC

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SURGE collaboration
May 20 2025
RHIC/AGS annual users' meeting

Lots of recent interest in energy correlators....

355. Imaging the Jet-Induced Medium Response with Energy Correlators
Arjun Srinivasan Kudinoor (Massachusetts Institute of Technology)
4/7/25, 5:00 PM
Jets Oral Parallel session 5
In heavy-ion collisions, jets formed from hard-scattered partons experience an overall energy loss and have a modified internal structure compared to vacuum jets. These modifications are a result of the interactions between the energetic partons in a jet shower and the strongly coupled quark-

1049. Energy correlators for gluon splitting to heavy quarks
João Martins da Silva (LIP - Lisboa / ULisboa - IST)
4/10/25, 9:00 AM
Jets Oral Parallel session 8
Energy correlators inside of high energy jets provide a powerful tool to image the intrinsic and emergent angular scales of QCD. They have the potential to provide unprecedented insight on the interplay between vacuum scales inside of a jet and its medium modification. Energy correlators

557. Measuring energy-energy correlators in p-Pb collisions at ALICE
Anjali Nambrath (University of California Berkeley (US))
4/7/25, 6:00 PM
Jets Oral Parallel session 5
Jet substructure is a powerful tool for testing QCD in elementary particle collisions. The two-p energy-energy correlator (EEC), defined as the energy-weighted cross section of particle pairs

318. Theory overview of jet substructure and energy-energy correlators
Alba Soto Ontoso (Universidad de Granada (ES))
4/10/25, 2:45 PM
Oral Plenary session 5:Jets

541. Modification of the Jet Energy-Energy Correlator in Cold Nuclear Matter
Dr Chathuranga Sirimanna (Duke University), Yu Fu (Duke university)
4/8/25, 11:50 AM
Jets Oral Parallel session 18

1099. sPHENIX measurement of Large R_L Energy-Energy Correlator on Calorimeters in Dijet events in pp at 200 GeV
Skaydi Grossberndt (Graduate Center and Baruch College, CUNY)
Jets Poster Poster session 1
The sPHENIX experiment is a state-of-the-art detector at the Relativistic Heavy Ion Collider (RHIC) which represents the first detector with both electromagnetic and hadronic

981. The first measurement of energy-energy correlator of jets in PbPb collisions at CMS
Jussi Viinikainen (Vanderbilt University (US))
4/10/25, 10:20 AM
Jets Oral Parallel session 8
Energy-energy correlators can isolate physics of different angular scales, which has attracted a lot of interest recently to study it in heavy ion environments. Any modification from proton-proton

556. Probing jet modification in the QGP using N-Point Energy Correlators in Pb-Pb collisions with ALICE
Ananya Rai (Yale University (US))
4/7/25, 6:20 PM
Jets Oral Parallel session 5
In heavy-ion collisions, jets propagating through the quark-gluon plasma undergo interactions with the medium. These interactions modify the internal structure of jets, making jet substructure an

803. Measurement of J/ψ energy correlator in p+p collisions at $\sqrt{s} = 500$ GeV at STAR
dandan shen (shandong university)
Heavy flavor & quarkonia Poster Poster session 2
The J/ψ meson, consisting of a charm quark and its antiquark, serves as an exceptional testing ground of Quantum Chromodynamics (QCD). However, our understanding of its underlying

68. Measurement of the N-point energy-energy correlator from the collinear limit to the back-to-back limit in e+e- collisions at 91 GeV with the ALEPH experiment
Yen-Jie Lee (Massachusetts Inst. of Technology (US))
Jets Poster Poster session 1
Hard probe measurements in e+e− collisions are vital for comparative studies in proton-proton and heavy-ion environments, offering a clean reference free from hadronic initial state effects. The

317. Experimental measurement of jet substructure and energy-energy correlators
Wenqing Fan (University of Houston (US))
4/10/25, 2:20 PM
Plenary session 5:Jets

890. The model study of flavor dependence for energy-energy correlation functions in pp collisions.
Hyungjun Lee (Sungkyunkwan University (KR))
Jets Poster Poster session 1
Jets are collimated bunches of hadrons, and they serve as a useful tool for studying QCD. Jets are generated from the hard scattering processes of quarks and gluons in particle collisions, such as

139. Tackling selection bias in heavy-ion jets with energy correlators
Dr Jack Holguin (The University of Manchester), Jack Holguin
4/7/25, 5:20 PM
Jets Oral Parallel session 5
The first measurement of the two-point energy correlator (EEC) in Pb-Pb collisions has revealed its sizeable modifications with respect to the p-p baseline. Nevertheless, challenges arise in

1145. Flash talk: Charged energy correlators in small systems with ALICE
Tucker Hwang (University of California Berkeley (US))
4/12/25, 11:30 AM
Oral Awards & flash talks

979. First measurement of full event energy-energy correlation in high-Z tagged events in PbPb collisions in CMS
Ms Yi Chen (Vanderbilt University (US))
4/9/25, 9:40 AM
Jets Oral Parallel session 28
The production of a Z boson provides a clean handle to control the population of events to be

772. New angles on energy correlators
Ankita Budhraja (Nikhef)
Jets Poster Poster session 1
Energy correlators have come to the forefront for studying high energy particle collisions. Their natural separation of physical effects at different scales have made them very attractive for studying a wide range of phenomena in high energy particle physics. E.g. the most precise

544. Charged energy correlators in small systems with ALICE
Tucker Hwang (University of California Berkeley (US))
Jets Poster Poster session 1
Energy-energy correlators (EECs), which are energy-weighted cross-sections of particle pairs, offer

793. Measurement of N-Point Energy Correlators in Heavy-Ion Collisions at STAR
Andrew Tamis (Yale University)
Jets Poster Poster session 1
In proton-proton collisions, hard-scattered partons will undergo perturbative fragmentation and hadronization, resulting in a collimated collection of hadrons that can be measured as a jet. Two- and three-point energy correlators have been shown experimentally in proton-proton collisions to

660. Multipoint Energy Correlators in Heavy Ion Collisions at RHIC Energies from Simulation
Benjamin Kimelman (Vanderbilt University)
Jets Poster Poster session 1
Energy-energy correlators and their three point counterpart have recently been of great interest to the heavy ion jet community as they directly provide the virtuality scale and are relatively simple to

Contributions from Quark Matter 2025!

Energy–energy correlators (EEC)

- One of the first infrared-safe event shapes in QCD:

  Dates back to late '70s

  Basham, Brown, Ellis, Love, Phys.Rev.Lett. 41 (1978) 1585,

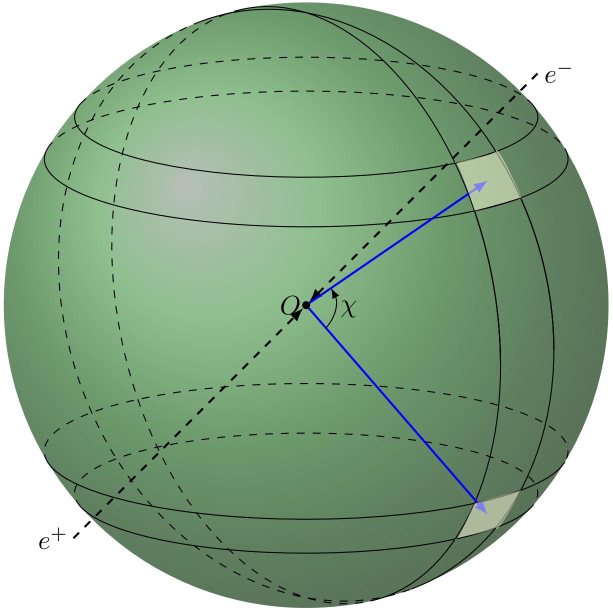
  Basham, Brown, Ellis, Love, Phys.Lett.B 85 (1979) 297-299

- Weight **pairs of particles** by their **energies**
  - Less sensitivity to non-perturbative

    (= low energy) physics

Definition of the EEC:

$$\frac{d\Sigma}{d\chi} = \sum_{i,j} \int dE_i dE_j d\theta_{ij} \frac{d\sigma_{ij}}{dE_i dE_j d\theta_{ij}} \frac{E_i E_j}{Q^2} \delta(\chi - \theta_{ij})$$



Moult, Zhu, JHEP 08 (2018) 160

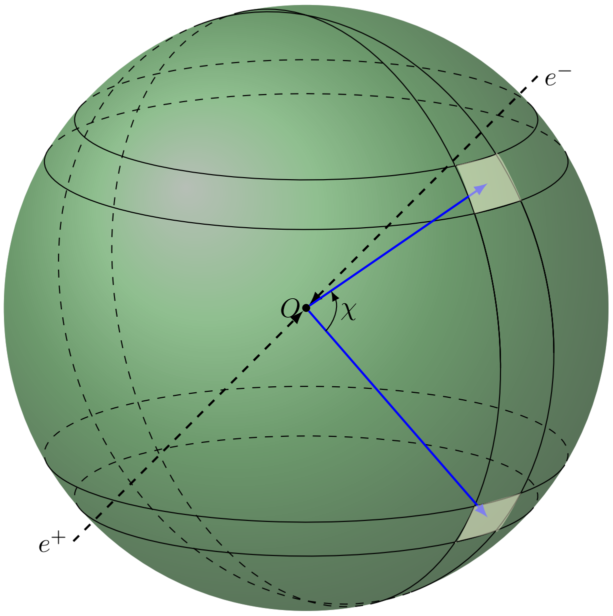
Energy–energy correlators (EEC)

- “Inclusive” observable
  - Sum over all produced particles
  - Compared to jets: no jet algorithm
- Less sensitivity to non-perturbative hadronization
  - Momentum-sum rule for fragmentation functions:

$$\int_0^1 dz\, zD(z,\mu) = 1$$

⇒ Possible to focus on other parts of the process

$$\frac{d\Sigma}{d\chi} = \sum_{i,j} \int dE_i dE_j d\theta_{ij} \frac{d\sigma_{ij}}{dE_i dE_j d\theta_{ij}} \frac{E_i E_j}{Q^2} \delta(\chi - \theta_{ij})$$



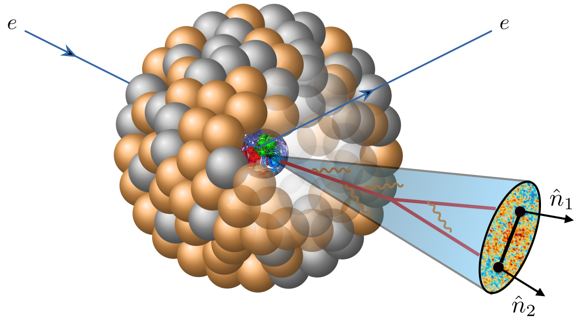
Moult, Zhu, JHEP 08 (2018) 160

Different limits of energy correlators

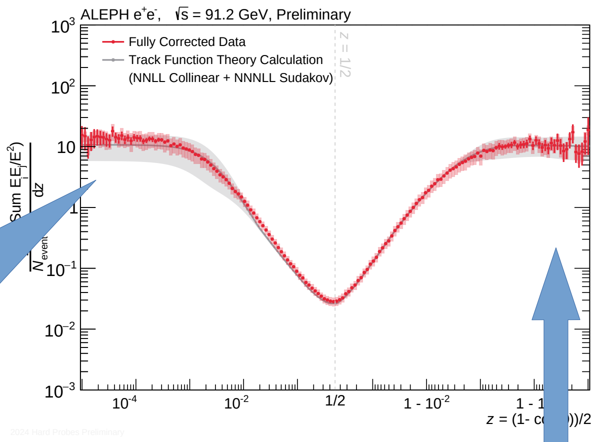
Measured as a function of the angle θ between the particle pair:

Bossi et al., PoS LHCP2024 (2025) 228

Different regions allow us to probe different physics!



Devereaux et al., 2303.08143 [hep-ph]



Collinear region: Jet physics

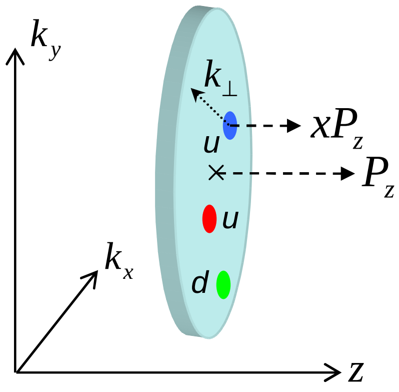
Talk by Beatrice Lian-Gilman on Wednesday

Back-to-back region:

- Transverse-momentum dependent parton distributions

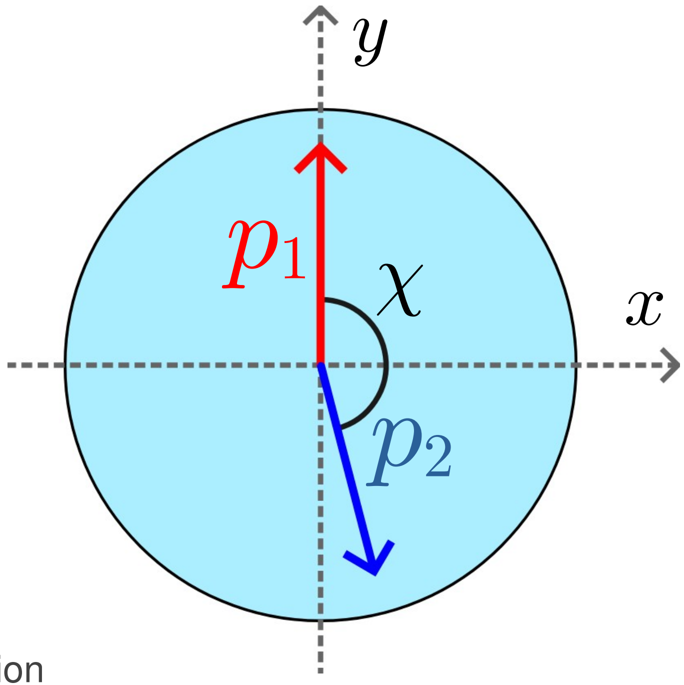
Back-to-back limit: $\chi \approx 180°$

- *y*-axis: large momentum $p_1 - p_2$
- *x*-axis: small momentum $p_1 + p_2$
  - Sensitive to the small transverse momentum of the partons in hadrons!



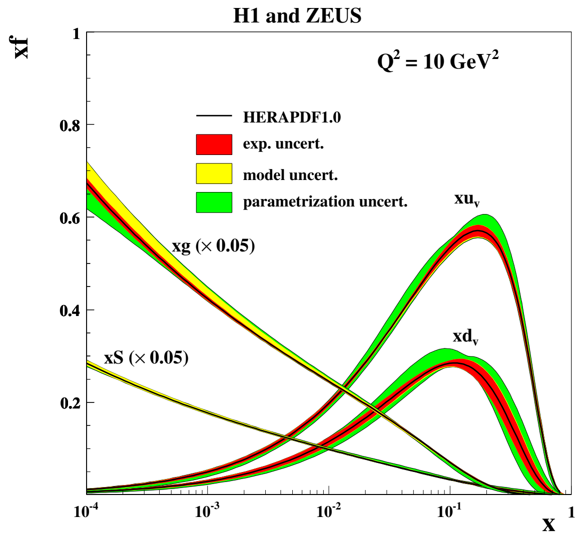
Leads to the transverse-momentum dependent (TMD) factorization

⇒ Can be computed at high precision



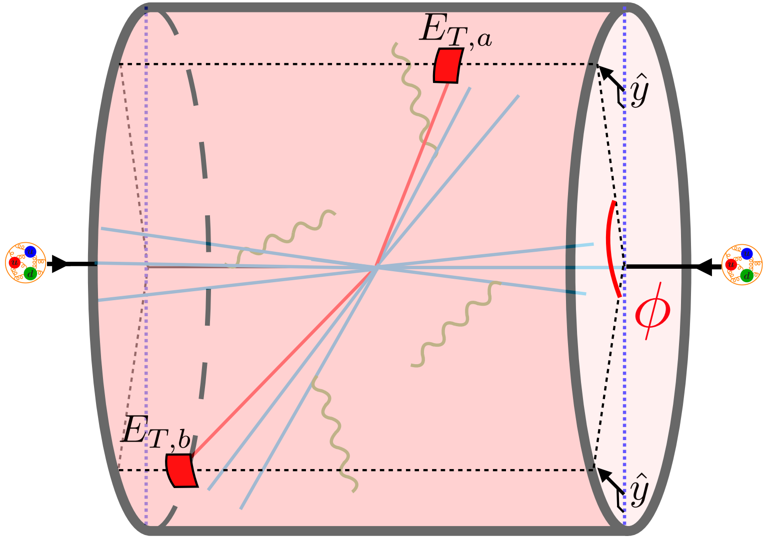
Small-*x* physics and saturation

- Back-to-back region also sensitive to **gluon saturation**
- What is gluon saturation?
  - High energies (small *x*): gluon distribution dominates
  - Rapid growth tamed by gluon recombination effects (= non-linear effects in QCD)
  - Gives rise to **saturation scale** Q_s
- Saturation effects important when momentum $\simeq Q_s$
  - Difficult to detect — important to find observables sensitive to saturation
  - Energy correlators a promising observable!



H1 and ZEUS Colaborations, JHEP 01 (2010) 109

Transverse energy–energy correlators (TEEC)

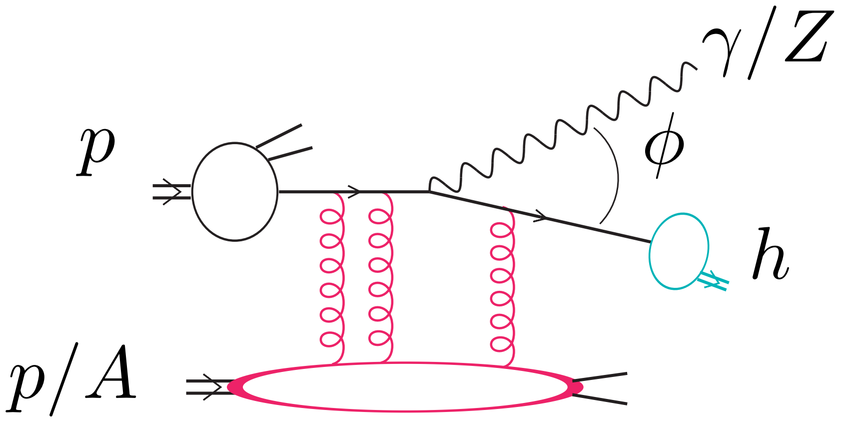


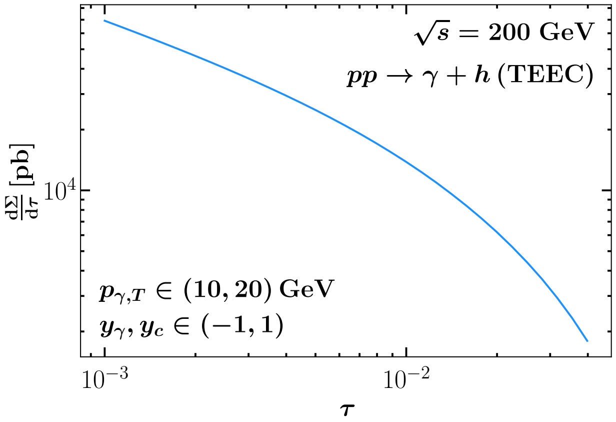
Gao et al., Phys.Rev.Lett. 123 (2019) 6, 062001

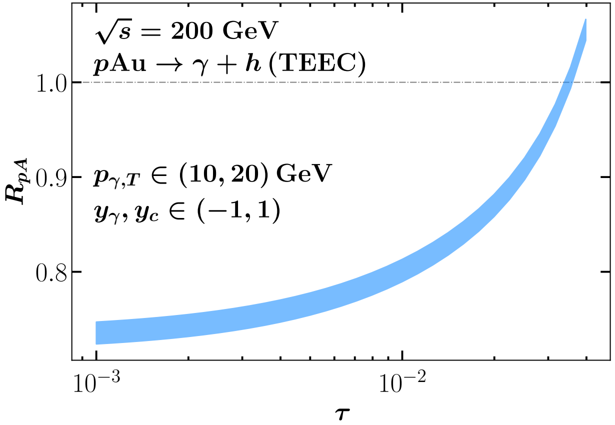
- Generalization of the EEC
  - Weight by the **transverse** energy
  - More suitable for hadronic colliders where there is no spherical symmetry (compare to e^+e^-)
  - Measured in terms of the **azimuthal** angle ϕ

Ali, Pietarinen, Stirling, Phys.Lett.B 141 (1984) 447-454

RHIC: Vector-boson tagged TEEC





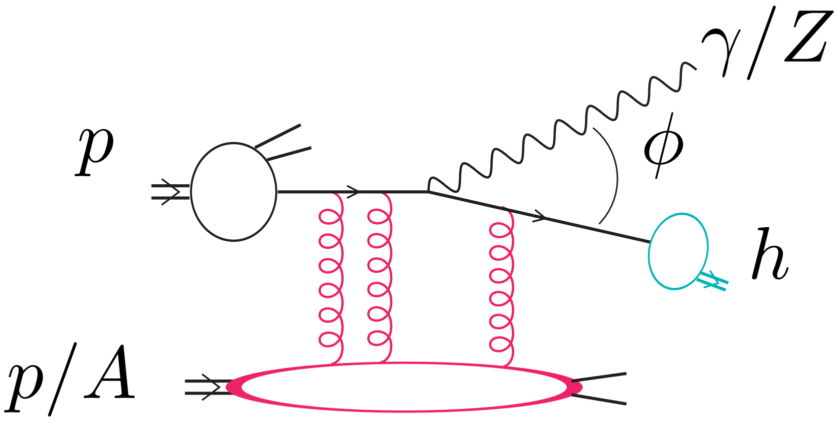


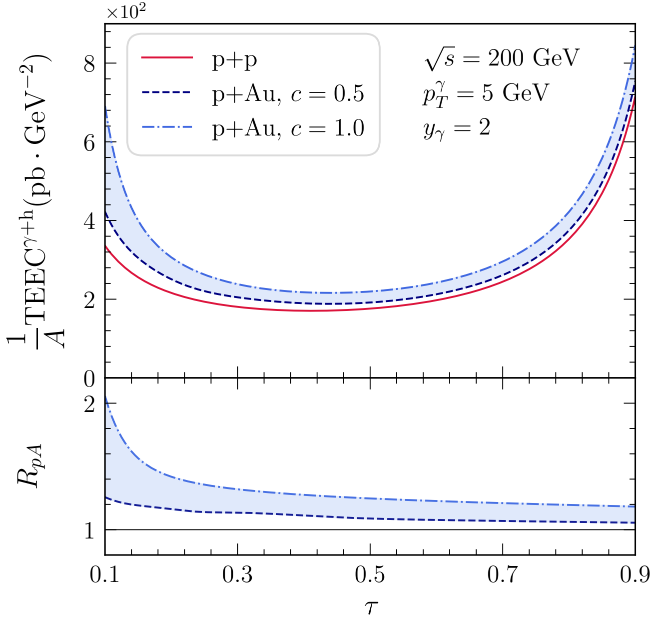
TMD computation in the back-to-back limit ($\tau \ll 1$) $\quad \tau = \frac{1}{2}[1 + \cos\phi]$

Kang, Lee, JP, Zhao, Zhou, 2410.02747 [hep-ph]

Study nuclear effects with the nuclear suppression factor $\quad R_{pA} = \frac{1}{A}\frac{\Sigma^{pA}}{\Sigma^{pp}}$

RHIC: Vector-boson tagged TEEC





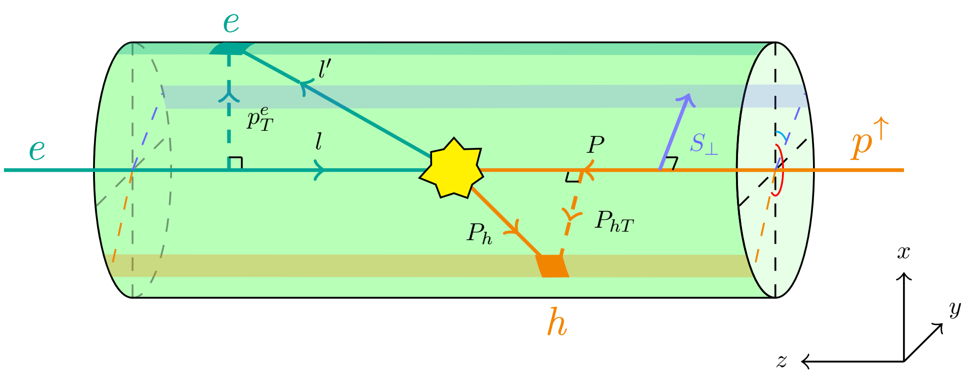
Small-x computation to study gluon saturation

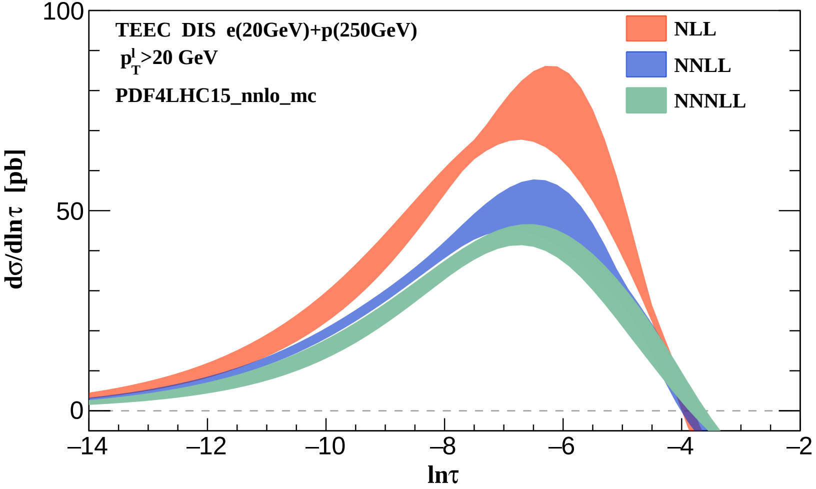
Kang, Kao, Li, JP, 2504.00069 [hep-ph]

Largest effect at small τ = sensitivity to small momenta $\simeq$ saturation scale

$$Q^2_{s,A} \sim c \times Q^2_{s,p}$$

EIC: Electron–hadron TEEC





TEEC between the out-going electron

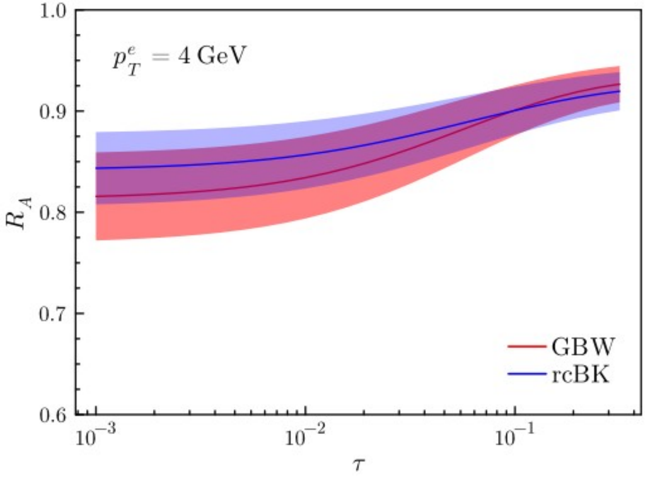
and produced hadrons

Li, Vitev, Zhu, JHEP 11 (2020) 051

EIC: Electron–hadron TEEC

Back-to-back limit: use combined approach from TMD factorization and small *x* to study saturation effects

Kang, JP, Zhao, Zhou, Phys.Rev.D 109 (2024) 9, 094012

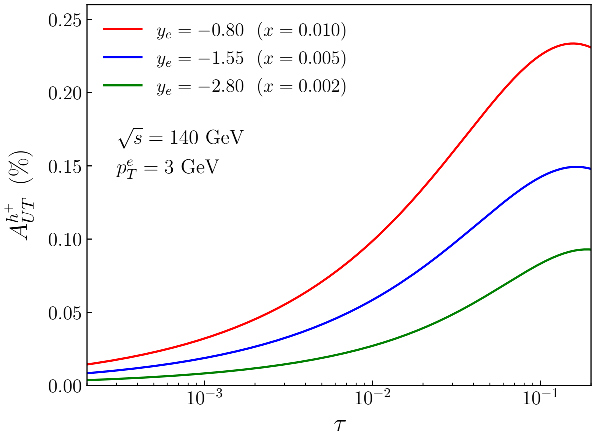


Polarized protons: also possible to study the Sivers asymmetry

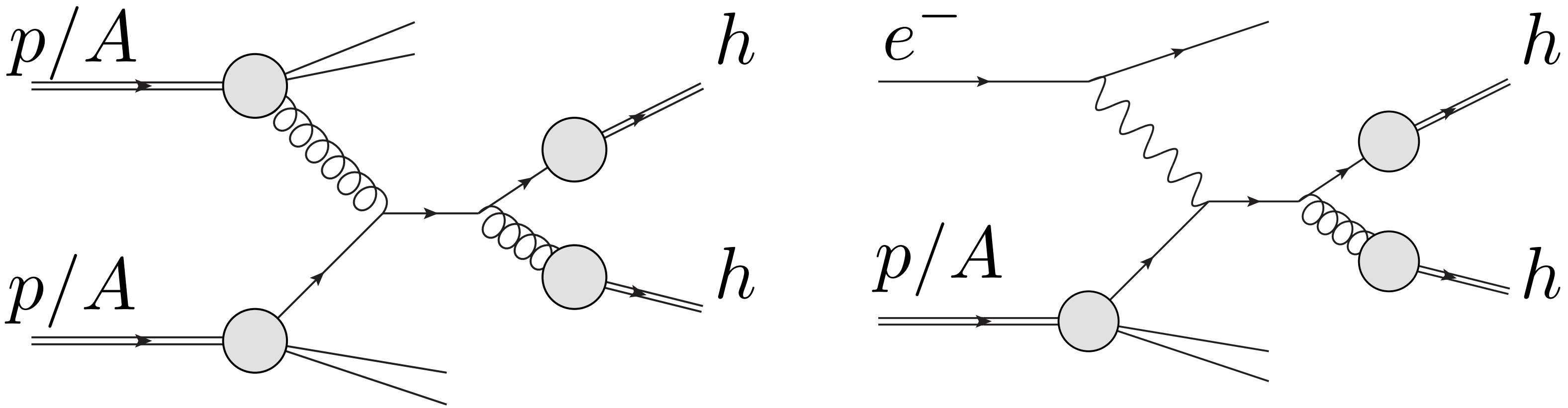
- Small *x*: corresponds to an **odderon** interaction

$$A_{UT} \sim \frac{\Sigma_{\rm pol}}{\Sigma_{\rm unpol}}$$

Bhattacharya, Kang, Padilla, JP, 2504.10475 [hep-ph]



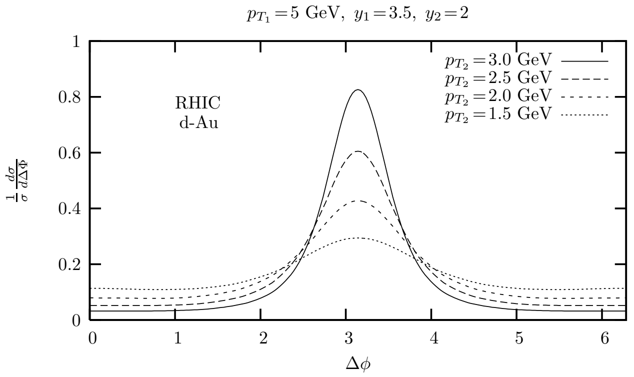
RHIC and EIC: Hadron–hadron or dijet TEEC



Dijets at HERA: Ali, Li, Wang, Xing, Eur.Phys.J.C 80 (2020) 12, 1096

Back-to-back limit: golden channel for saturation?

Marquet, Nucl.Phys.A 796 (2007) 41-60

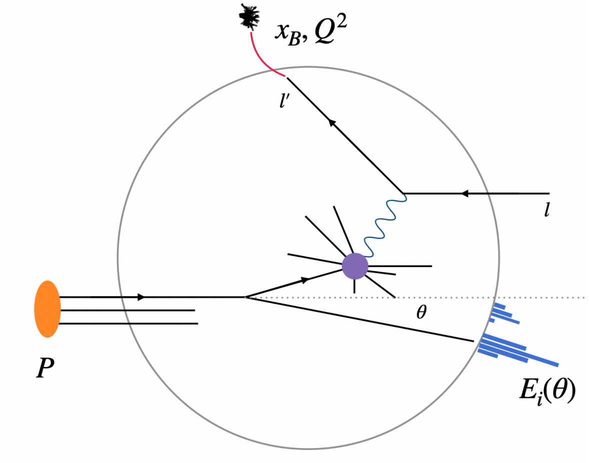


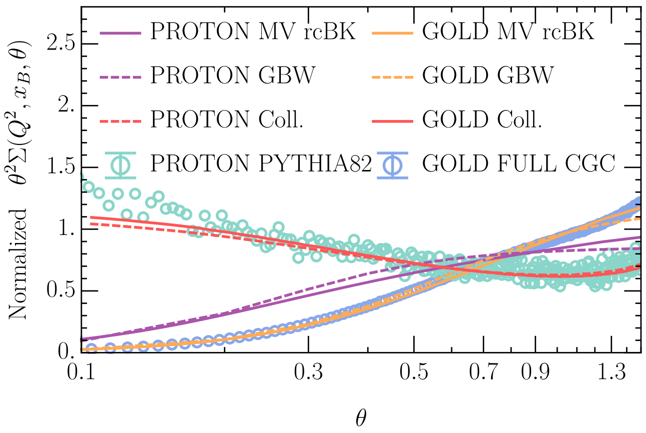
EIC: Nucleon energy correlators

Instead of looking at pairs of particles:

Look at correlations with the target hadron

- θ = angle with respect to the **target** beam
- Target region: **fracture functions** instead of fragmentation functions
- Phenomenology similar to the back-to-back TEEC





Liu, Zhu, Phys.Rev.Lett. 130 (2023) 9, 9

Cao, Liu, Zhu, Phys.Rev.D 107 (2023) 11, 114008

Liu, Liu, Pan, Yuan, Zhu, Phys.Rev.Lett. 130 (2023) 18, 18

Chen, Ma, Tong, JHEP 08 (2024) 227

Mäntysaari, Tawabutr, Tong, 2503.20157 [hep-ph]

Summary

- Energy correlators are a promising class of observables for understanding QCD and the hadronic structure
  - Lots of renewed interest in the recent years!
  - Less sensitivity on hadronization: possible to focus on different parts of the process
- Different kinematic regions ⇒ Probe different physics
  - Back-to-back region especially interesting for disentangling the 3D partonic structure of hadrons
- Energy correlators can be studied for many different processes in both RHIC and EIC
  - Plenty of things to do in both theory and experiment