

Measurement of the azimuthal decorrelation angle between the leading jet and the scattered lepton in deep-inelastic scattering at HERA



#### On behalf of the ZEUS Collaboration





14th Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2022) Lake Buena Vista, FL, August 30, 2022



DOE NP contract: DE-SC0013405

Bernd Surrow

1



Analysis Details

Results

#### Summary and Outlook



Workshop Jets at the EIC 3D imaging (https://indico.bnl.gov/event/ 8066/), November 23-25, 2020







**D** EIC



Center of Mass Energies:	29GeV - 140GeV
Luminosity:	$10^{33} - 10^{34} \text{ cm}^{-2}\text{s}^{-1} / 10 - 100 \text{ fb}^{-1} / \text{ year}$
Highly Polarized Beams:	70%
Large Ion Species Range:	p to U
Number of Interaction Regions:	Up to 2!

- Award of DOE CDO\*: December 2019
- Site selection at BNL: January 2020
- Award of DOE CD1\*: June 2021
- O Anticipated award of CD2: ~January 2024
- Anticipated start of construction (CD3): ~April 2025
- Anticipated start of operation (CD4): ~April 2032-2034

\* CD: Critical Decisions - DOE Project Approval Process 4

Bernd Surrow



#### HERA

HERA: Hadron-Electron Ring Accelerator

(Hadron-Elektron Ring Anlage)

World's First Electron-Proton Collider Facility at DESY, Hamburg, Germany





#### **ZEUS** Experiment at HERA





- High ET dijet photoproduction at HERA (PRD 76 (2007) 072011, arXiv:0706.3809)
- Inclusive jets with anti-kt and SIScone algorithms (arXiv:1003.2923, Phys. Lett. B 691 (2010) 127-137)
- Inclusive jets in photoproduction (arXiv:1205.6153, Nucl. Phys. B864 (2012), 1-37)
- Isolated photons accompanied by jets in DIS (arXiv:1206.2270, Phys Lett B 715 (2012) 88-97)
- Isolated photons plus jets in PHP (arXiv:1312.1539, Phys.Let B (2014)
  Volume 730, 293-301)
- More on isolated photons plus jets in PHP (arXiv:1405.7127, JHEP 2014 (23))
- O Diffractive di-jet production in DIS (Eur. Phys. J. C 76 (2016) 16)
- Diffractive photoproduction of isolated photons at HERA (arXiv: 1705.10251, Phys. Rev. D 96 (2017) 032006)
- Further studies of isolated photon production with a jet in deep inelastic scattering at HERA (arXiv: 1712.04273, J. High Energ. Phys. (2018) 2018: 32)





Previous azimuthal jet results at hadron-hadron colliders:



Conclusions for results at Tevatron (DO) and LHC (ATLAS and CMS):

- NLO describes data better than LO calculations.
- MC generators describe data fairly well discrepancies at  $\Delta \phi \sim \pi$  where soft gluon radiation dominates.
- Suggest employing results to tune MC generators.



Motivation Transverse-Momentum Distribution Functions (TMD)



Probe Transverse-Momentum Distribution Functions (TMD) using azimuthal angular correlations of final state lepton and jet measurements - Complementary to Semi-Inclusive DIS measurements with added benefit of no need for TMD fragmentation functions!

- Lepton-Jet Correlations in DIS at the EIC: X. Liu et al., PRL 122 (2019) 192003
- Lepton-jet correlations in DIS: X. Liu et al., PRD 102 (2020) 094022
- HERA measurements: Probe TMD at small x!



## Analysis Details

e

- Event selection
- HERA II (2004-2007) data 0 sample: 330pb<sup>-1</sup> at  $\sqrt{s} = 318 GeV$
- Jet reconstruction:  $k_T$  algorithm 0
- Q<sup>2</sup>:  $10 \text{GeV}^2 < Q^2 < 350 \text{GeV}^2$ 0
- 0 Basic selection criteria: Jets
  - $\Box \quad E_T^{Jet} > 2.5 \text{GeV}$
  - $|\eta_{Jet}| < 1$
- Basic selection criteria: Lepton 0
  - $\Box \quad E_T^{lepton} > 10 \text{GeV}$
  - $140^{\circ} < \theta_{lepton} < 180^{\circ}$
- 14th Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2022) Lake Buena Vista, FL, August 30, 2022





### Analysis Details

#### Simulation - Conceptual framework



14th Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2022) Lake Buena Vista, FL, August 30, 2022 11



## Analysis Details



14th Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2022) Lake Buena Vista, FL, August 30, 2022

Bernd Surrow



# Results

Results



• Azimuthal angle jet/lepton measurement for different number of jets ( $\Delta \phi$  for leading jet!)

• Range:  $\pi/2 < \Delta \phi < \pi$ 

• Agreement with MC simulations (Ariadne 4.12) at the level of 5% (Jets  $\geq 1$ )!



# Results

Comparison to theory





# Results

- Unfolding and Systematic Uncertainties Final result / Publication plans
  - Unfolding in 1-D will be performed with the TUnfold package
  - Differential cross section measurements will be presented at different p<sub>T</sub>, Q<sup>2</sup> and jet multiplicity regions
  - The following sources of systematic uncertainties were considered for normalized cross sections measurements, consistent with previous ZEUS analyses:
    - The energy of the scattered lepton was varied by its known scale uncertainty of 2%
    - The jet energy scale was varied by 4% for values of  $E_{jet}^{T} < 10 \text{ GeV}$  and 2.5% for  $E_{jet}^{T} > 10$ GeV
    - The uncertainty due to the selection cuts was estimated by varying the values of the cuts within the resolution of each variable
    - The differences in the measurements obtained by using ARIADNE and Lepto-MEPS to correct the data for detector effects and bin migration
    - The decorrelation angle was varied to account for its resolution effect in the measurements

15



- Comparison to LHC results
  - Decorrelation measurements for different jet multiplicities per event, exhibit similar behavior
  - High jet multiplicity events dominated by soft gluon radiation
  - Agreement with the MC model degrades at high jet multiplicities, pointing to the need for improvements in the theoretical description







- Prelim. ZEUS results of decorrelation measurements of lepton and leading jet in DIS, similar to previous ZEUS γ-jet results and other experiments in proton-proton collisions
- Probe Transverse-Momentum Distribution Functions (TMD) using azimuthal angular correlations of final state lepton and jet measurements Complementary to Semi-Inclusive DIS measurements with added benefit of no need for TMD fragmentation functions!
- The MC predictions from ARIADNE describe the main features of data well. However, some discrepancies are observable!
- Dedicated predictions for ep collisions are in progress!
- Final Differential cross-section measurements/publication will be presented at different  $p_T$ , Q<sup>2</sup> and jet multiplicity bins.
- Decorrelation measurements of lepton and leading jet in DIS will provide an important probe of TMDs at EIC!



# Thank you!

# Amilkar Quintero (Temple University)

## and

# Jae Nam (Temple University)