Investigation of collective effects in DIS with the ZEUS detector

Mariusz Przybycień

AGH University of Science and Technology, Krakow, Poland

(on behalf of the ZEUS Collaboration)
Motivation and definition of observables

- Observation of “ridge” structure in two-particle correlations in heavy ion collisions.
- Evidence for long range correlations in $\Delta \eta$ in case of particle pairs produced at small $\Delta \phi$ (ridge) in $p+Pb$ and $pp$ systems.
- Try to understand its origin - is it initial-, final- or mixed-state effect?

- Single-particle azimuthal yields of particle production are usually quantified by Fourier series expansion:

\[
E \frac{d^3 N}{d p^3} = \frac{1}{p_T} \frac{d^3 N}{d \phi d p_T d y} = \frac{1}{2 \pi p_T} \frac{E}{p} \frac{d^2 N}{d p_T d \eta} \left(1 + 2 \sum_{n=1}^{\infty} v_n (p_T, \eta) \cos (n(\phi - \Phi_n)) \right)
\]

where $v_n$ and $\Phi_n$ are the magnitude and phase of the $n$-th order anisotropy.

- The standard cumulant method is based on the $k$-particle azimuthal correlations, $\langle \{k\} \rangle$:

\[
\langle \{2\}_n \rangle = \langle e^{i n (\phi_1 - \phi_2)} \rangle \quad \Rightarrow \quad c_n \{2\} = \langle \langle \{2\}_n \rangle \rangle \quad \Rightarrow \quad c_n \{2\} = v_n^2 + \delta_2
\]

where $\delta_2$ represents a significant nonflow contribution from jets and resonance decays.
ZEUS experiment and deep inelastic $ep$ scattering (DIS)

$\sqrt{s} = 318$ GeV

$s = (p_1 + p_2)^2 \approx 2p_1 \cdot p_2$, \quad $y = \frac{p_2 \cdot q}{p_2 \cdot p_2}$, \quad $x = \frac{Q^2}{2p_2 \cdot q}$

$E_{et} = 27.6$ GeV

$E_p = 920 - 460$ GeV

$\Rightarrow \sqrt{s} = 318$ GeV
ZEUS experiment and deep inelastic $e\, p$ scattering (DIS)

\[ s = (p_1 + p_2)^2 \approx 2p_1 \cdot p_2, \quad y = \frac{p_2 \cdot q}{p_2 \cdot p_2}, \quad x = \frac{Q^2}{2p_2 \cdot q} \]

\[ \Rightarrow \sqrt{s} = 318 \text{ GeV} \]

\[ E_{\text{et}} = 27.6 \text{ GeV} \]

\[ E_p = 920 - 460 \text{ GeV} \]
DIS event selection and comparison with models

- **DIS selection requirements:**
  - scattered electron: $E_e > 10$ GeV and $\theta_e > 1$ rad
  - exchanged photon virtuality: $Q^2 > 5$ GeV$^2$
  - remove remaining photoproduction background: $47 < \sum_h E_h - p_{z,h} < 69$ GeV

- **Track selection:**
  - $0.1 < p_T < 5$ GeV
  - $-1.5 < \eta < 2$

- **Monte Carlo models used:**
  - **ARIADNE**: (color dipole model)
  - **LEPTO**: (Lund string model)

- **True level particle selection:** charge hadrons with $\tau > 1$ cm/c or decay products of shorter living particles.

- **Comparison of data with MC simulation:**
  - LEPTO - better description of data for $N_{ch} > 15$.
  - ARIADNE - better description of track distribution in the forward region and also of the shape of $p_T$ distribution.
DIS event selection and comparison with models

DIS selection requirements:
- scattered electron: $E_e > 10$ GeV and $\theta_e > 1$ rad
- exchanged photon virtuality: $Q^2 > 5$ GeV$^2$
- remove remaining photoproduction background: $47 < \sum_h E_h - p_{z,h} < 69$ GeV

Track selection:
- $0.1 < p_T < 5$ GeV
- $-1.5 < \eta < 2$

Monte Carlo models used:
- Ariadne: (color dipole model)
- Lepto: (Lund string model)

True level particle selection: charge hadrons with $\tau > 1$ cm/c or decay products of shorter living particles.

Comparison of data with MC simulation:
- Lepto - better description of data for $N_{ch} > 15$.
- Ariadne - better description of track distribution in the forward region and also of the shape of $p_T$ distribution.
Two-particle cumulants of order $n = 1 - 4$

For $|\Delta \eta| > 2$ all $c_n \{2\}$, but $c_1 \{2\}$ (momentum conservation), are consistent with zero.
For $|\Delta \eta| > 2$ all $c_n \{2\}$, but $c_1 \{2\}$ (momentum conservation), are consistent with zero.
Two-particle cumulants of order $n = 1 - 4$

For $|\Delta \eta| > 2$ all $c_n \{2\}$, but $c_1 \{2\}$ (momentum conservation), are consistent with zero.
Comparison of $c_1\{2\}$ with MC models

- $c_1\{2\}$ cumulant as a function of $N_{ch}$, $\Delta \eta$, $\langle p_T \rangle$ and $\Delta p_T$ is compared to model predictions.
- **ARIADNE** provides a reasonable description of $N_{ch}$, $\langle p_T \rangle$ and $\Delta p_T$.
- In case of $\Delta \eta$ **ARIADNE** is not able to follow the data at $|\Delta \eta| > 1$.
- For all observables **ARIADNE** gives significantly better description of the measured $c_1\{2\}$ than **LEPTO**.
Comparison of $c_2\{2\}$ with MC models

- $c_2\{2\}$ cumulant as a function of $N_{ch}$, $\Delta \eta$, $\langle p_T \rangle$ and $\Delta p_T$ is compared to model predictions.
- LEPTO provides a reasonable description of $N_{ch}$, $\langle p_T \rangle$ and $\Delta p_T$.
- In case of $\langle p_T \rangle$ and $\Delta p_T$ LEPTO is not able to follow the data at higher values of these observables.
- For all observables LEPTO gives significantly better description of the measured $c_2\{2\}$ than ARIADNE.
**Summary**

- First investigation of collectivity in deep inelastic electron-proton scattering.
- Measured two-particle cumulants $c_n\{2\}$ for $n = 2, 3, 4$ are consistent with zero for large multiplicity $N_{\text{ch}}$ or pseudorapidity separation $|\Delta\eta|$.
- $c_1\{2\}$ becomes negative for large $\Delta\eta$, what is expected due to momentum conservation.
- Monte Carlo models (Ariadne and Lepto) tuned to HERA data are able to reproduce overall features of the measured cumulants.
- Plan to measure four-particle cumulants in DIS as well as to investigate possible signs of collectivity in photoproduction.

Thank you for your attention!