A new look into *ep* collisions using event shape variables

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Introduction

Scattering processes in *ep* collisions are broadly divided into *Neutral Current Deep Inelastic Scattering* (NC-DIS) and *photoproduction*. The processes are based on the virtuality (Q^2) of the exchanged photon; occurring at high ($Q^2 >> 1$ GeV/c) and low ($Q^2 \approx 0$) virtualitites, respectively. The low Q^2 regime is crucial for probing non-perturbative quantum chromodynamic (QCD) processes and understanding multi-partonic interactions (MPIs) within the proton. The ZEUS experiment at HERA performed two-particle $\Delta\eta$–$\Delta\phi$ correlations in *ep* collisions at $\sqrt{s} = 318$ GeV, investigating the role of MPI in particle production of *ep* photoproduction [1]. The study reported the two-particle correlations in *ep* photoproduction are markedly different from those observed in high-multiplicity hadronic collisions at RHIC or the LHC, with a prominent ridge in $\Delta\eta$ at the away side ($\Delta\phi = \pi$).

This contribution aims at analyzing $\Delta\eta$–$\Delta\phi$ correlations using event-shape variables, providing valuable insight into the origins of the away-side ridge and disentangling the hard components from the underlying event in *ep* photoproduction at $\sqrt{s} = 318$ GeV using PYTHIA.

Methodology

1. Two-particle correlations

The two-particle $\Delta\eta(\eta_1 - \eta_2)$–$\Delta\phi(\phi_1 - \phi_2)$ correlation function of all final state charged particles is defined as:

$$C(\Delta\eta, \Delta\phi) = \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}. \quad (1)$$

The numerator and denominator terms are defined by the $\Delta\eta$–$\Delta\phi$ correlations of the charged-particle pairs from the same and mixed event, respectively. Fig. 1 presents the correlation function for all final state charged particles from photoproduction processes in high multiplicity ($N_{\mathrm{ch}} > 20$) *ep* collisions. Similar to measurements from ZEUS, our results report the presence of a near side peak at $\Delta\phi = 0$ and an away side ridge in $\Delta\eta$ at $\Delta\phi = \pi$.

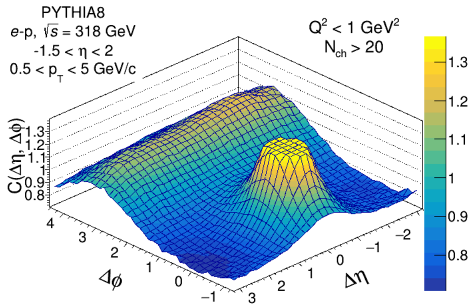

FIG. 1: Two-particle correlation, $C(\Delta\eta, \Delta\phi)$, of all charged particles at $\sqrt{s} = 318$ GeV, $Q^2 < 1$ GeV, and $N_{\mathrm{ch}} > 20$.

2. Transverse Spherocity (S_{O})

Transverse spherocity quantifies the energy flow in an event by categorizing events based on hard and soft event topologies [2].

$$S_{\mathrm{O}} = \frac{\pi^2}{4}\left(\frac{\Sigma_i |\vec{p}_{\mathrm{T_i}} \times \hat{n}|}{\Sigma_i p_{\mathrm{T_i}}}\right)^2 \quad (2)$$

where, $\hat{n}$ minimizes the entire quantity for an event. $\pi^2/4$ normalize the values between 0 and 1, so that

$$S_{\mathrm{O}} = \begin{cases} 0, & \text{“jetty” limit (hard events)} \\ 1, & \text{“isotropic” limit (soft events)} \end{cases}$$

To get further insight into the features of the correlation function, a differential study with transverse spherocity will allow one to separate jetty events with back-to-back topologies from the isotropic ones. The jetty-like and isotropic events correspond to $0-20\%$ ($0 < S_{\mathrm{O}} < 0.5$) and $80-100\%$ ($0.8 < S_{\mathrm{O}} < 1$) of the S_{O} distribution, respectively.

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Results and discussion

Fig. 2 presents the two-particle $\Delta\eta$–$\Delta\phi$ correlations for "jetty" events ($0 < S_O < 0.5$), showing a stronger near side peak and the pre-existing away-side ridge, asserting the importance of jetty topologies in *ep* collisions.

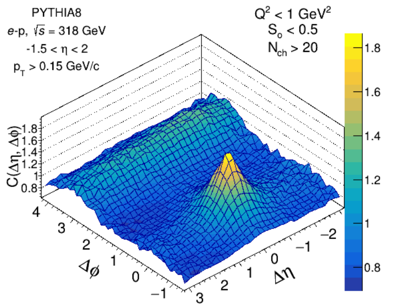

FIG. 2: Two-particle correlation function $C(\Delta\eta, \Delta\phi)$, of all charged particles for "jetty" events ($S_O < 0.5$)

Towards the isotropic limit, ($0.8 < S_O < 1$), the ridge disappears, replaced by the formation of a valley as seen in Fig. 3.

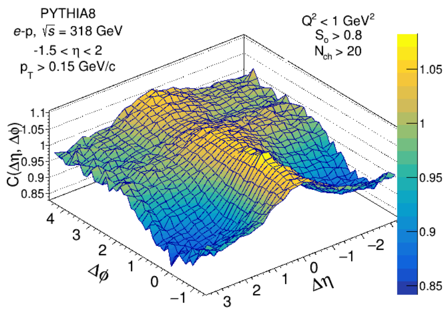

FIG. 3: Two-particle correlation, $C(\Delta\eta, \Delta\phi)$, of all charged particles for "isotropic" events ($S_o > 0.8$)

The double-peaked valley structure at $\Delta\phi = \pi$ is more apparent in the 1D $\Delta\phi$ distribution, reported in Fig. 4 for all charged particles in the interval $0.8 < S_O < 1$. This attribute, however, is an artifact of the events with jets, where one of the jet splits, causing the formation of a "Mercedes"-like event. These events, although being jet-dominated are misidentified as isotropic events.

These results conclude that transverse spherocity being an event shape classifier has shortcomings when it comes to certain mixed topologies. We explore the need for new event shape classifiers, such as flattenicity, where isotropic events can be further classified into purely "soft" events (MPI dominated) and ones with mixed topologies, to study MPI's and two-particle correlations in *ep* photoproduction.

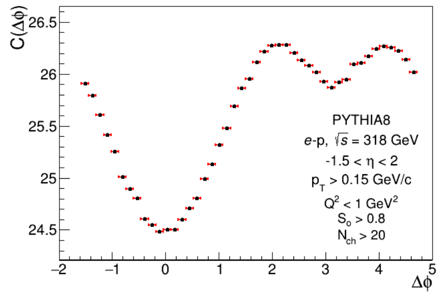

FIG. 4: Two-particle correlation, $C(\Delta\phi)$, of all charged particles for '"isotropic" events ($S_o > 0.8$)

References

1. I. Abt *et al.* [ZEUS], JHEP **12** (2021), 102 doi:10.1007/JHEP12(2021)102 [arXiv:2106.12377 [hep-ex]].
2. A. Ortiz, G. Paić and E. Cuautle, Nucl. Phys. A **941** (2015), 78-86 doi:10.1016/j.nuclphysa.2015.05.010 [arXiv:1503.03129 [hep-ph]].