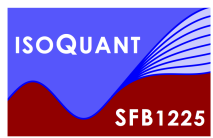
Two-particle azimuthal correlations as a probe of collectivity in deep inelastic electron-proton scattering at HERA

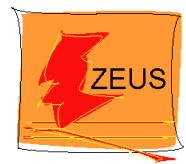
Dhevan Gangadharan
On behalf of the ZEUS Collaboration

Universität Heidelberg
GSI

EPS 2019, July 13^{th}

UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386



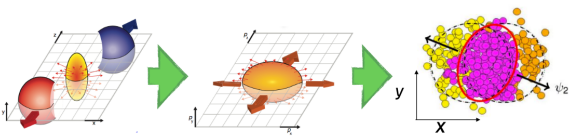


Collectivity in large systems

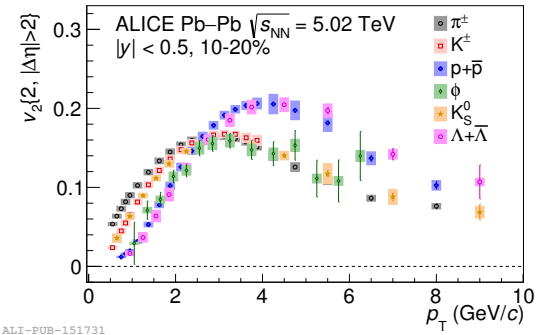
Collectivity: multiparticle correlations which arise from a **common** physical mechanism

$v_n^2 \propto \langle \cos(n(\phi_1 - \phi_2)) \rangle$ exact only in case of correlations wrt the reaction plane of the collision.

Non-central heavy-ion collision



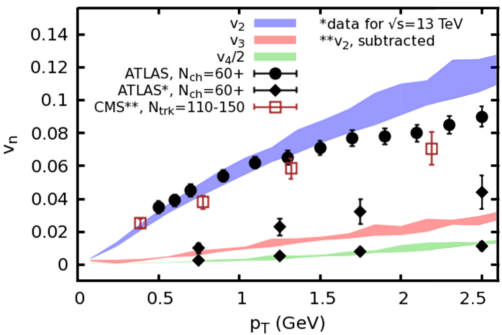
Initial collision geometry & event-by-event fluctuations cause an azimuthal asymmetry in momentum space wrt a **common** symmetry plane.



Several particle species exhibit similar features of collectivity.

Searching for collectivity in small systems

superSONIC for p+p, $\sqrt{s} = 5.02\,TeV, 0-1\%$

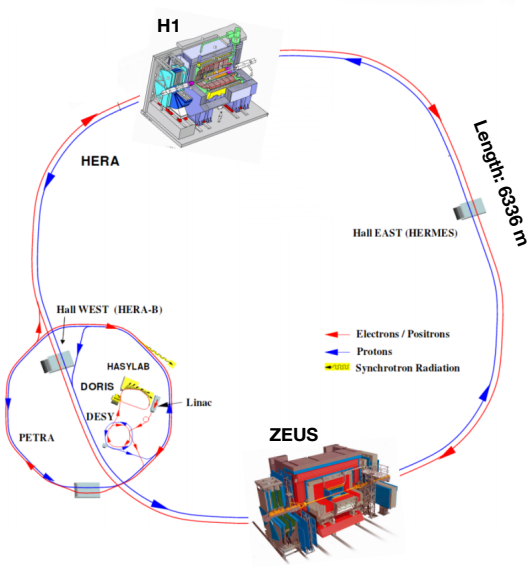


Weller & Romatschke Phys.Lett. B774 (2017) 351-356

Correlations in pp collisions reveal features similar to larger systems like pA and AA.

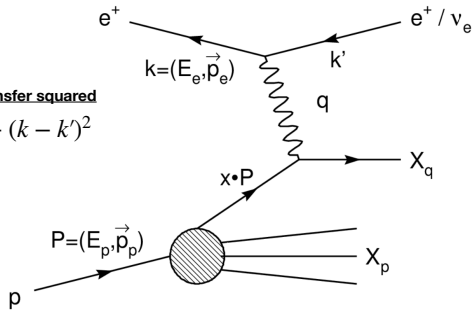
Measurements in even smaller systems such as *ee* and **electron-proton** can test the onset of collectivity.

The HERA collider and experiments



- Location: DESY, Hamburg, Germany
- Data taking: 1992 - 2007
- 27.6 GeV electrons/positrons
  920 GeV protons
  $\rightarrow \sqrt{s} = 318$ GeV
- H1 & ZEUS - 4π detectors
- HERA I+II:
  500 pb^{-1} per experiment

Deep inelastic scattering in electron-proton collisions



Four momentum transfer squared

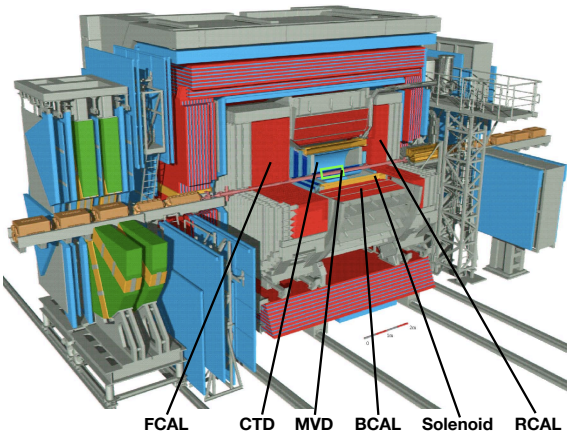
$$Q^2 = -q^2 = -(k - k')^2$$

Bjorken x

$$x_{Bj} = \frac{Q^2}{2P \cdot q}$$

- DIS means $Q^2 \gg M^2_{proton}$ and $x_{Bj} < 1$.
- Inclusive electron-proton collisions consist of neutral current (NC) and charged current events.
- ZEUS recorded data with triggers for specific physics processes.
- We investigate Deep Inelastic Scattering (DIS) NC events, where a scattered lepton is reconstructed with high efficiency, and there is no specific selection on the final state.

ZEUS detector



Charged particles are tracked in the central tracking detector (CTD) and micro vertex detector (MVD) in a 1.43 T magnetic field.

NC DIS trigger is based on identifying the scattered-electron from the pattern of energy deposits in the CAL.

Data sample, event and particle selection

Data sample

ZEUS data preservation efforts enable new analysis of HERA data.
HERA II : 355 M events, 46 M after DIS selection

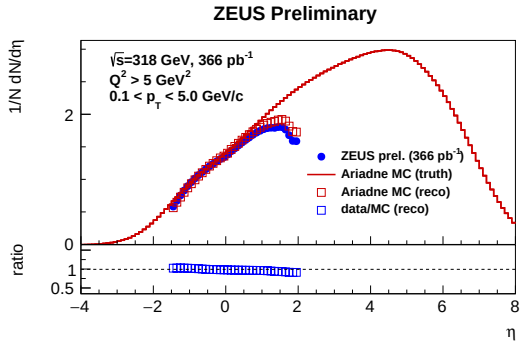
Event selection

$Q^2 > 5$ GeV^2
$E_e > 10$ GeV
$\theta_e > 1.0$
Consistency with DIS:
$47 < E - p_z < 69$ GeV$/c$

Track selection:

$0.1 < p_T < 5.0$ GeV$/c$
$-1.5 < \eta < 2.0$

Particle pseudorapidity distribution



- Large parts of the 'proton fragments' move out of the tracking acceptance.
- Monte Carlo describes data within $\sim 15\%$.

Azimuthal correlations

We measure 2-particle correlations:

$c_n\{2\} = \langle\langle 2\rangle\rangle = \langle\langle e^{in(\phi_\alpha - \phi_\beta)}\rangle\rangle$

The inner brackets denote the average in a single event.
The outer brackets the average over all events.

The correlations are studied as a function of

- event multiplicity
- separation of particles in pseudorapidity
- relative/mean pair transverse momentum (in backup)

Correcting for detector effects

Applied particle weights:

- w_{eff}: Monte Carlo based efficiency weights as a function of charge, p_T and η (on average ~ 1.1).
- (w_φ: Data-driven φ-weights as a function of charge, η and event multiplicity (typically between 0.95 and 1.05).

Corrected event multiplicity:

$N_{ch} = \sum w_{eff}\ w_\varphi$

Two-particle correlation:

$c_n\{2\} = \langle w_{eff}^{\alpha}\ w_\varphi^{\alpha}\ w_{eff}^{\beta}\ w_\varphi^{\beta}\ \cos(n(\varphi_\alpha - \varphi_\beta))\rangle$

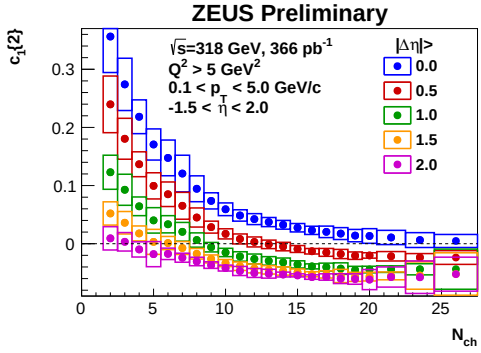
Systematic uncertainties

Considered sources of systematic uncertainties:

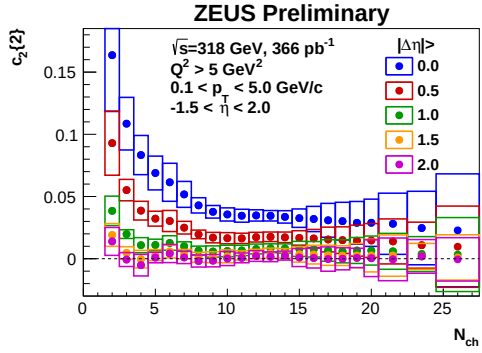
- event selection
- trigger
- tracking efficiency
- Monte Carlo closure test (dominant source)
  - A long investigation has been performed
  - An improved track selection criteria has been found
  - To be incorporated in the eventual published results

Variations are added bin-by-bin in quadrature to the total systematic uncertainty.

Multiplicity-dependent $c_1\{2\}$ and $c_2\{2\}$ with increasing η-separation

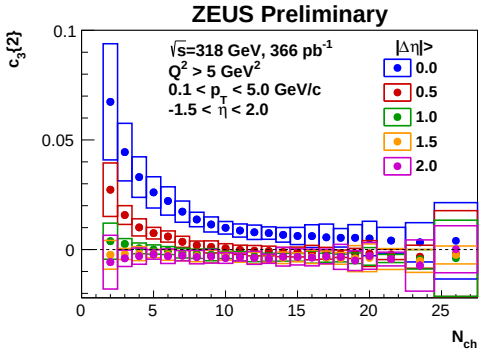


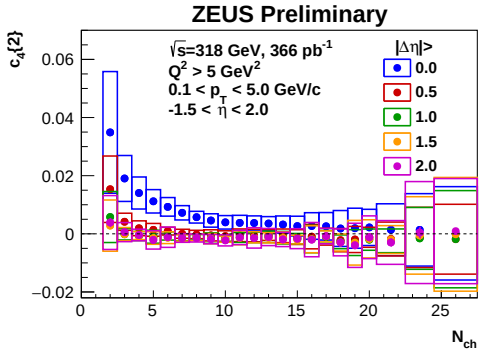
$|\Delta\eta| > 2.0 : c_1\{2\}$ changes sign $\rightarrow$ consistent with momentum conservation.



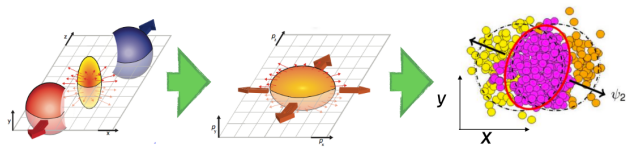
$|\Delta\eta| > 2.0 : c_2\{2\}$ consistent with zero.

Multiplicity-dependent $c_3\{2\}$ and $c_4\{2\}$ with increasing η-separation

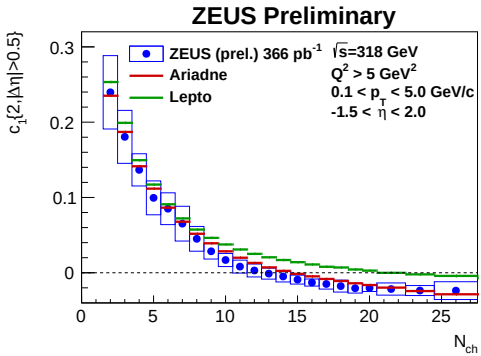


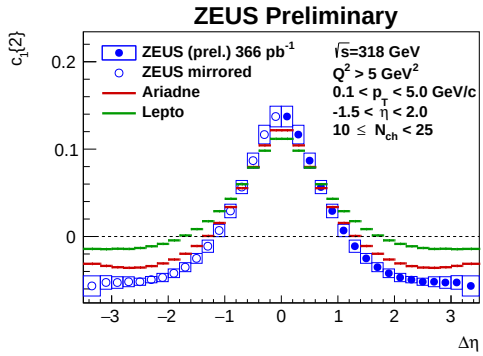


Higher harmonics probe event-by-event geometric fluctuations in heavy-ion collisions.
$|\Delta\eta| > 2.0$: $c_3\{2\}$ and $c_4\{2\}$ are consistent with zero in DIS.



Model comparison for $c_1\{2\}$





Simulations: ARIADNE[1] (dipole cascade model), LEPTO[2] (DGLAP cascade)

True level particle selection:

Charged hadrons with lifetime $\tau > 1$ cm/c

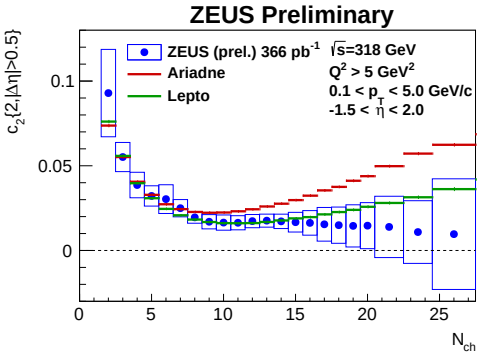
- produced directly in the interaction
- decayed from particles with $\tau < 1$ cm/c

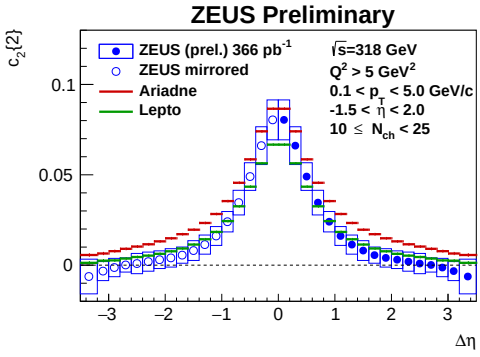
[1] L.Lönnblad, Comp. Phys. Comm. 71 (1992) 15

[1] L.Lönnblad, Z. Phys. C. 65 (1995) 285

[2] G.Ingelman, A.Edin, and J.Rathsman, Comp. Phys. Comm. 101 (1997) 108

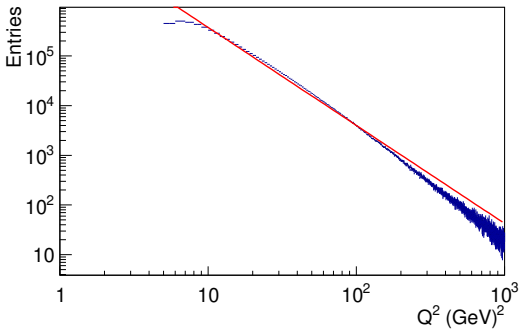
Model comparison for $c_2\{2\}$



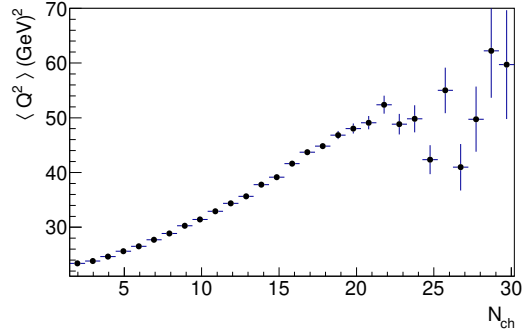


$c_2\{2\}$ better described by LEPTO than ARIADNE (unlike $c_1\{2\}$).

Generated Q^2 distributions in ARIADNE



- $5 \leq N_{\mathrm{ch}} < 15$.
- Red line is a fit of the form $a(Q^2)^b$ with $b \sim -2$.



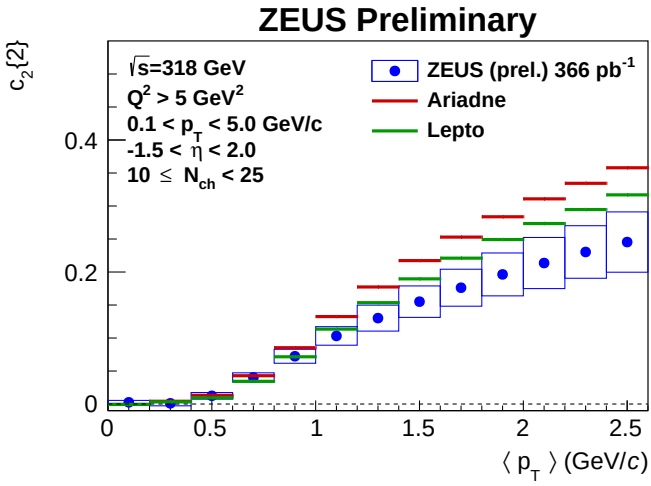
- Mean Q^2 versus N_{ch}.
- Q^2 increases by ~ 30 (GeV)^2 over the N_{ch} range of this analysis.

Summary

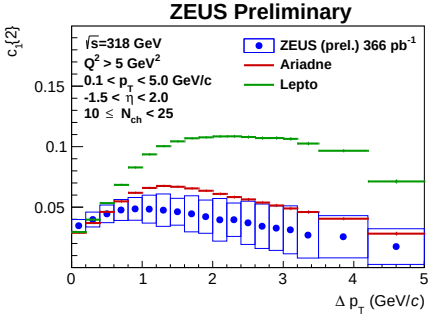
- Reported new preliminary results (ZEUS-prel-18-01) for 2-particle correlations in electron-proton collisions.
- $c_2\{2\}$ is consistent with 0 for large N_{ch} and $\Delta\eta$
- $c_1\{2\}$ changes sign for large $\Delta\eta$; a signature of momentum conservation.
- Comparisons to different Monte Carlo generators tuned to HERA data are able to reproduce overall features of the correlations.
- New analysis of ZEUS data adds information to the ongoing efforts in the search for collective effects in high multiplicity collisions of small systems at LHC and RHIC.
- Final results expected to be submitted for publication before the end of the year.

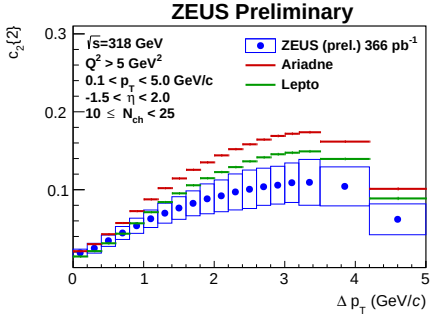
Backup

$c_2\{2\}$ vs. $\langle p_T \rangle$ $(n = 2)$ for high multiplicity events

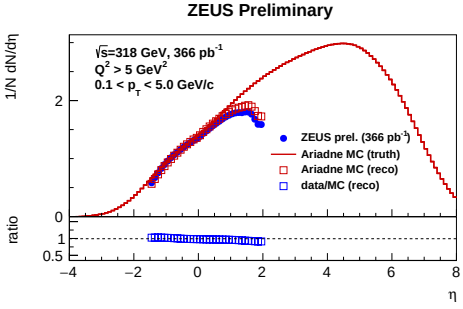


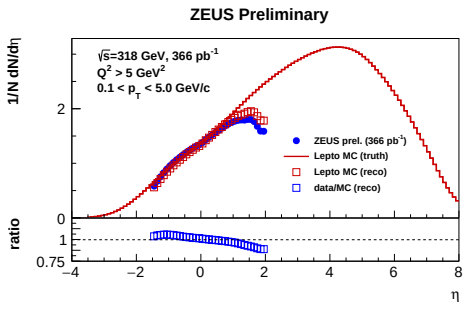
$c_n\{2\}$ vs Δp_T for first and second harmonic



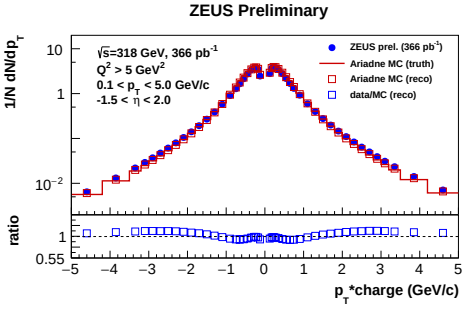


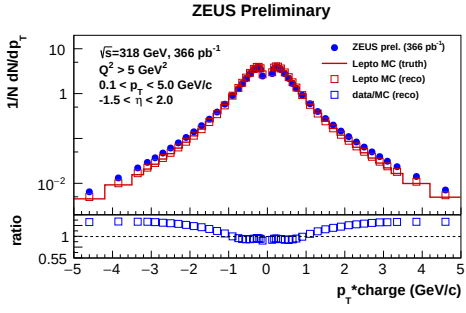
η distribution



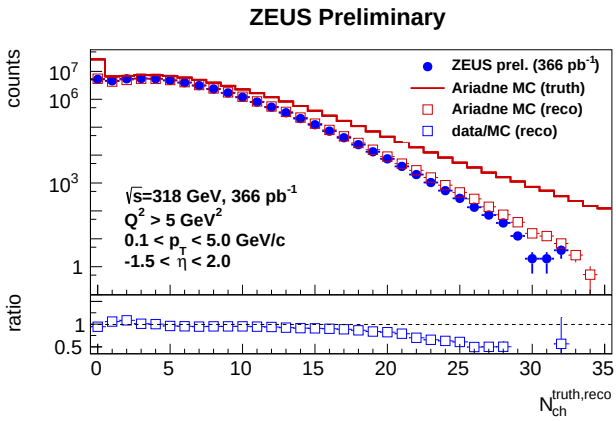


p_T distribution





Multiplicity distribution for DIS events



N_{ch} distributions:

- True N_{ch} distribution (line)
- Uncorrected N_{ch} distribution for data and simulation (open squares).

Uncorrected multiplicity N_{ch} up to ~ 30 tracks per event with a mean of $\langle N_{ch} \rangle \approx 4.5$