Search for collective effects in electron-proton collisions with ZEUS

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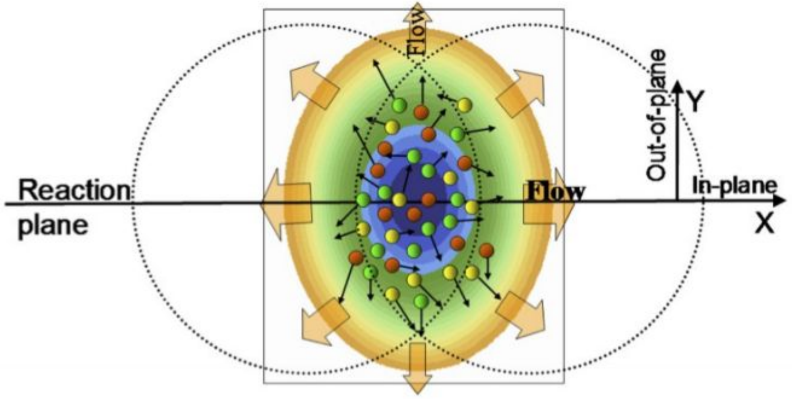
Collectivity and related anisotropy in heavy ion collisions

Response of matter produced in the heavy ion collision to the geometry of the initial state.

Produced particles receive a stronger boost along the short axis of the geometry wrt to the long axis (see ellipse on the right)

The amplitude (v_n) of the resulting anisotropy is quantified with a Fourier decomposition:

$$\frac{dN}{d(\varphi - \Psi_R)} = \frac{N_0}{2\pi}(1 + 2\sum_n v_n \cos[n(\varphi - \Psi_R)])$$



Analysis techniques

In this presentation, we focus on the measurement of 2-particle correlations:

$$c_n\{2\} = \langle\langle 2 \rangle\rangle \equiv \left\langle\left\langle e^{in(\phi_1-\phi_2)} \right\rangle\right\rangle \qquad v_n\{2\} = \sqrt{c_n\{2\}}$$

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

The correlation will be studied as a function of event multiplicity, separation of tracks in pseudorapidity, and as a function of transverse momentum.

Different mechanisms resulting in 2-particle correlations

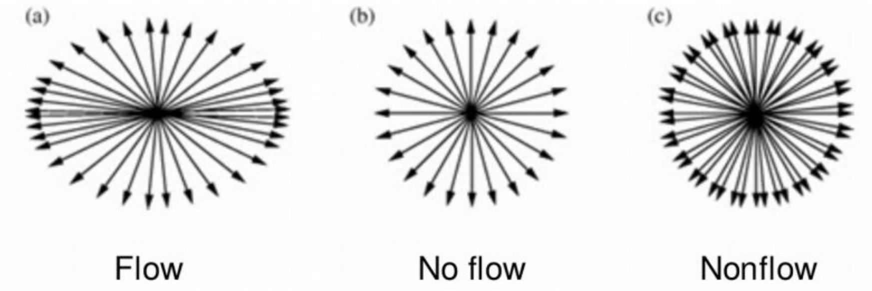
Multiple mechanisms contribute to (multi)particle correlations, from the initial state to response to the initial geometry.

Correlations contain flow, flow fluctuations and nonflow.

$$\langle\langle e^{in(\phi_a - \phi_b)}\rangle\rangle = \langle v_n^2\rangle + \delta_n$$

Flow fluctuations: $\sigma_{vn}^2 = \langle v_n^2\rangle - \langle v_n\rangle^2$

Nonflow: δ_n : resonances, jets, decays, momentum conservation



Suppression of δ_n (suppression of few particle correlated clusters):

- High multiplicity $\delta_2 \sim 1/M$
- Pseudo-rapidity gap (particles from jets and decays are mostly closeby in η)

Data/MC samples and tracks

~30 * 10^6 million DIS events
Efficient trigger above certain Q^2 (~5-10 GeV)

Tracks:
$0.1 < p_T < 5$ GeV/c
$-1.5 < \eta < 2.0$

Monte carlo:
ari_incl_nc_DIS
Ariadne_Low_Q2_NC_DIS
Lepto_low_Q2_NC_DIS

Analysis

Analyzed data sets (common ntuples)

	Trigger events ($x10^6$)	
Period	**ALL (official)**	**DIS**
03p	3.7	0.24
04p	47	4.6
05e	132	1.7
06e	44	7.0
06p	87	12
07p	41	5.4
All	355	31

DIS: Detected electron, $Q^2 > 5$ GeV, $E_e > 10$ GeV, $47 < E-p_z < 69$ GeV, $\theta_e > 1$, $e_p > 0.9$, exclusion of some problematic detector areas

Event selection

- DIS / PHP trigger selection
- $-30 <$ vertex Z < 30 cm
- Fraction of tracks associated to event vertex > 0.1
- N_{vtx} tracks > 0
- Event vertex from beam spot (R_{xy}) < 0.5

Track selection

- $0.1 < p_T < 5$ GeV/c
- $-1.5 < \eta < 2.0$
- Tracks constrained to the vertex (orange.Trk_prim_vtx = true)
- Exclude scattered electron (orange.Trk_id[itrack] != orange.Sitrknr[0])
- Trk_Imppar < 1.0 cm

Correcting for detector effects

Particles reconstruction efficiency as a function of p_T, η, φ, *charge* and *event multiplicity* is considered.

Particle weights are extracted in two steps:

1. p_T-η-*charge* efficiency is calculated by comparing generated and reconstructed yields in simulation
2. φ weights are extracted from data, after filling φ-η-*charge*-*event multiplicity* maps with the weights from step 1

The product of 1. and 2. gives the track weight. Weights are calculated separately for each dataset.

The 2-particle correlation is modified to include weights:

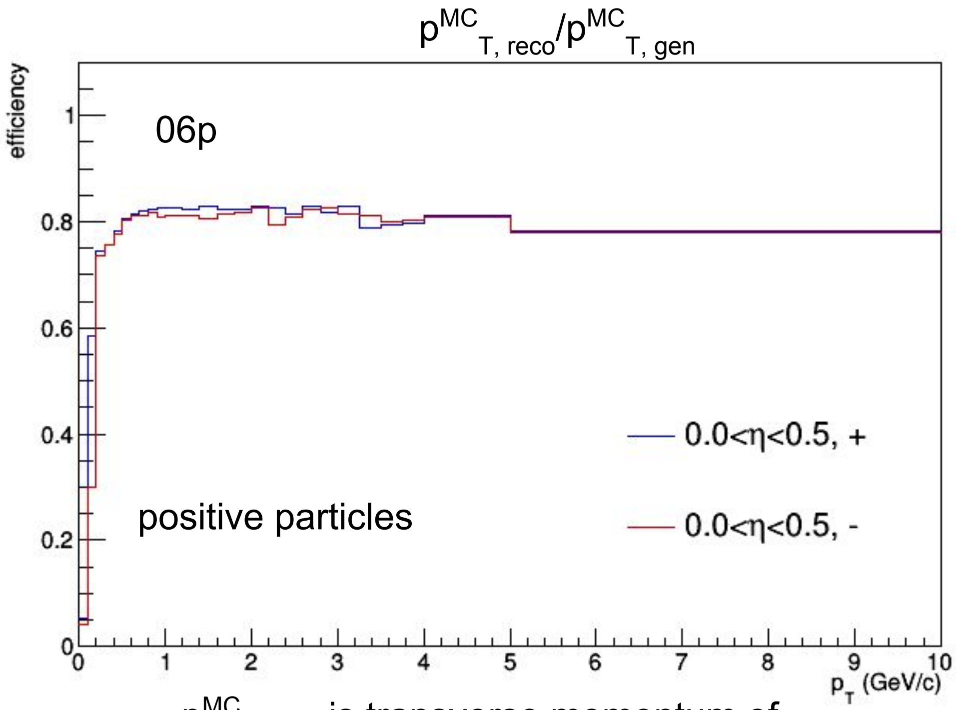
$\langle c_n \rangle = \Sigma\, w_i w_j \cos(n\varphi_i^a - n\varphi_j^b) \,/\, \Sigma\, w_i w_j$

Determining p_T-η efficiency

<u>Charged primary particle</u>:

- Charged particle with lifetime τ > 1 cm/*c*
- Production vertex < 1cm from event vertex (to exclude production from secondary interactions)

Specie	Width Γ (GeV)	Mean proper lifetime τ (ps)	(cm/c)
p^+	0	∞	∞
γ	0	∞	∞
K^0	0	∞	∞
e^-	0	∞	∞
n	7.478×10^{-28}	$8.861 \times 10^{+14}$	$2.656 \times 10^{+13}$
μ^-	2.996×10^{-19}	$2.212 \times 10^{+06}$	$6.63 \times 10^{+04}$
K^0_L	1.287×10^{-17}	$5.148 \times 10^{+04}$	1543
π^+	2.528×10^{-17}	$2.621 \times 10^{+04}$	785.7
K^+	5.317×10^{-17}	$1.246 \times 10^{+04}$	373.6
Ξ^0	2.27×10^{-15}	291.9	8.751
Λ	2.501×10^{-15}	264.9	7.943
Ξ^-	4.02×10^{-15}	164.8	4.941
Σ^-	4.45×10^{-15}	148.9	4.464
K^0_S	7.351×10^{-15}	90.14	2.702
Ω^-	8.071×10^{-15}	82.1	2.461
Σ^+	8.209×10^{-15}	80.72	2.42



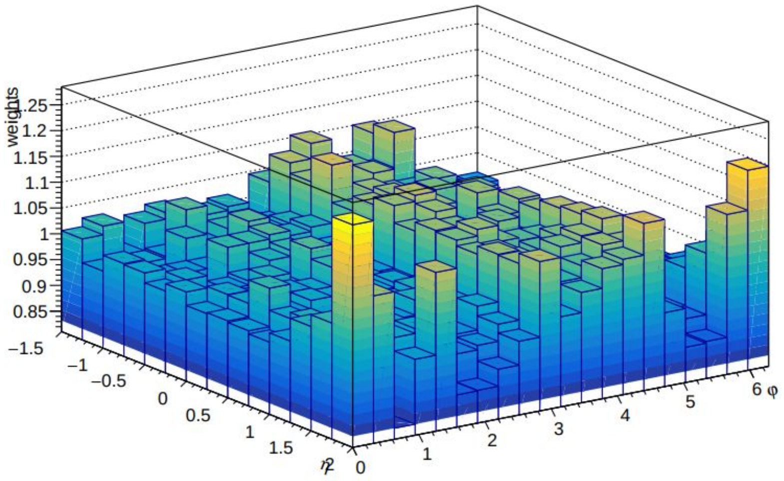
$p^{MC}_{T,\,reco}$ is transverse momentum of reconstructed primary particle matched to true primary particle

Determining φ-weights from data

Particle yields are measured in *η-φ-charge-M* bins, after weighting with acquired p_T-*η-charge* weights in the previous slides.

In each *η-charge-M* slice, weights are calculated to make φ uniform while maintaining the integral in the slice.

05e, M=10, positive



Study of systematics

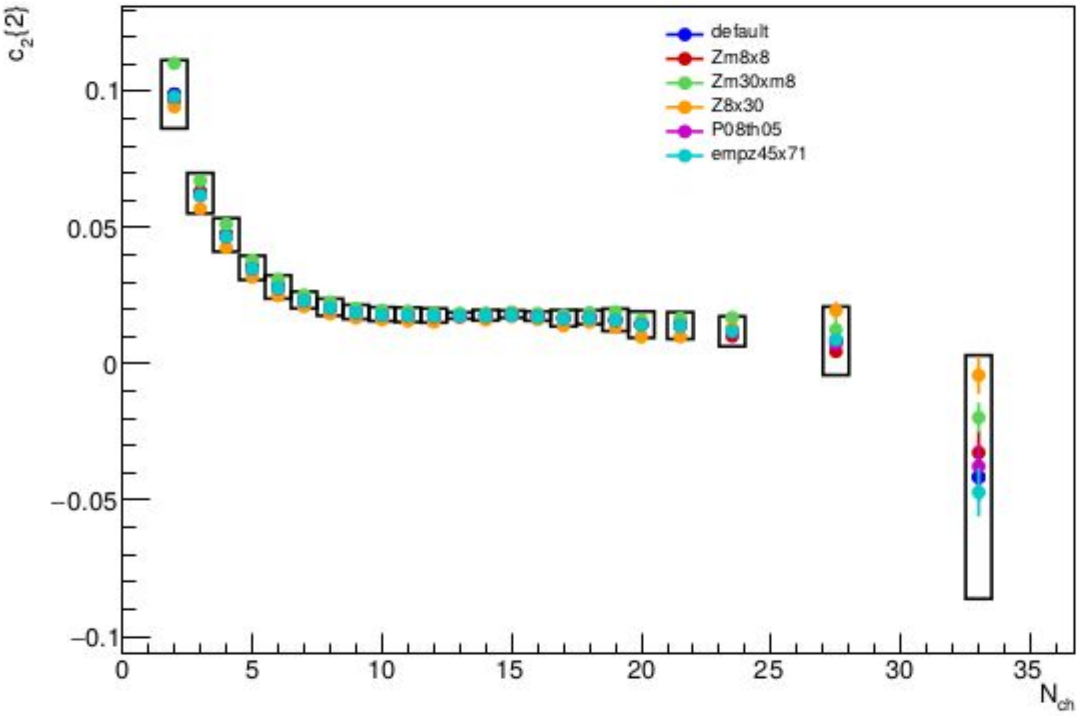
Class	Default	Variation
DIS event selection	$47 < E-p_z < 69$	$45 < E-p_z < 71$ $46 < E-p_z < 68$
	$\theta_e > 1.0$ $P_e > 0.9$	$\theta_e > 0.5$ $P_e > 0.8$
	$E_e > 10$	$E_e > 9$ $E_e > 11$
	Chimney cut, radius cut, CAL crack cut	
Event quality selection	$-30 < Z_{vtx} < 30$ cm	$-30 < Z_{vtx} < -8$ cm $-8 < Z_{vtx} < 8$ cm $8 < Z_{vtx} < 30$ cm
	Fraction of tracks constrained to vertex = 0.1	0.2
	$R_{vtx} < 0.5$ cm	$R_{vtx} < 0.7$
Track selection	Impact parameter < 1.0 cm	p_T dependent
Corrections	Particle weights with ari_incl_nc_DIS_lowQ2	Other MC samples

Systematic error calculation

Of the so far explored variations, the event Z vertex gives the largest deviations.

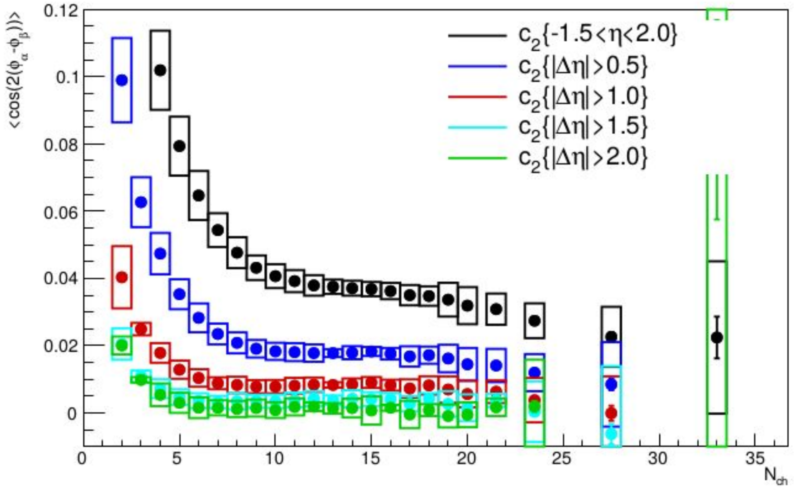
For variations for which we cannot account/correct and as long as they are within acceptable limits, the deviations are added in quadrature.

$c_2\{2\}$ $\{\Delta\eta>0.5\}$ vs N_{ch}



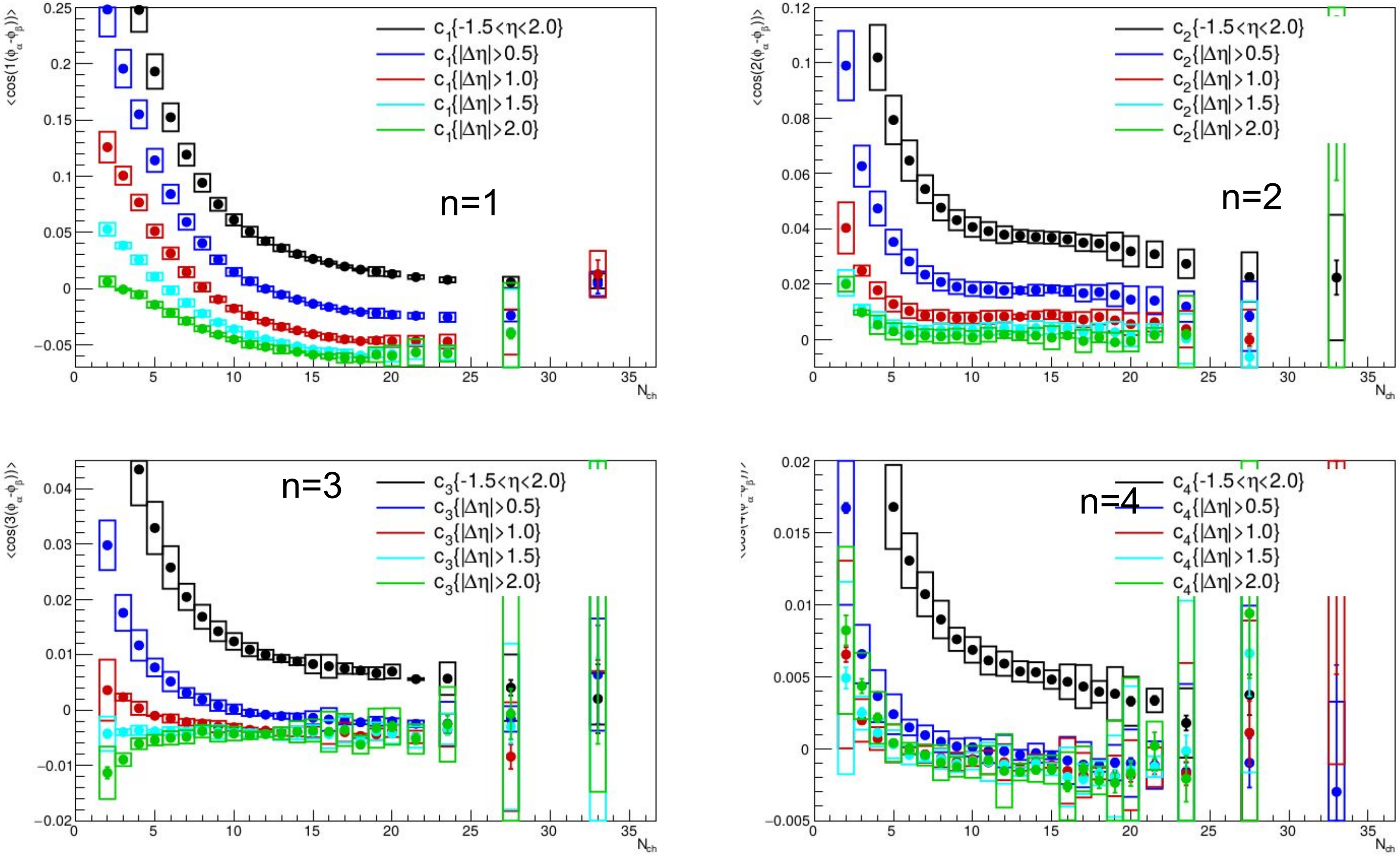
Aim for preliminary

2_n-particle correlations as a function of event multiplicity for different pseudo-rapidity separation

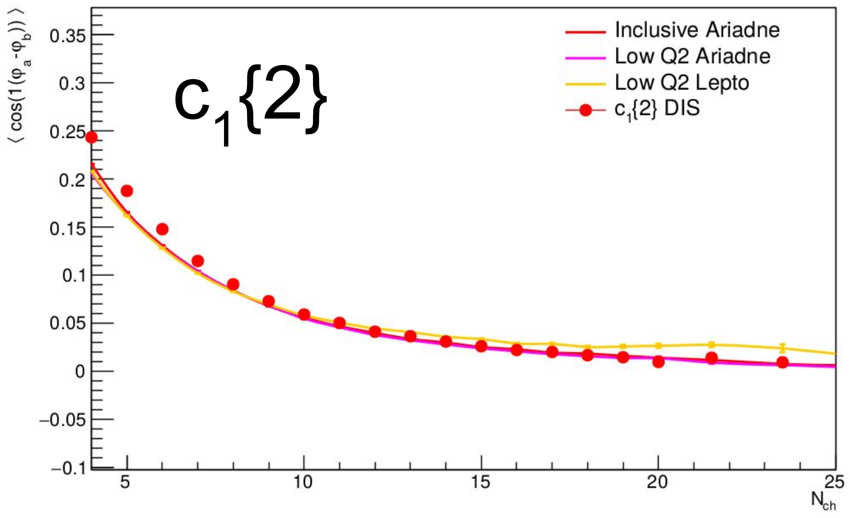


- Multiplicity range is statistically limited from 2 to approximately 30
- Increasing η separation leads to weaker correlations (suppressed nonflow)
- After initial drop, correlations become weakly dependent on N_{ch}

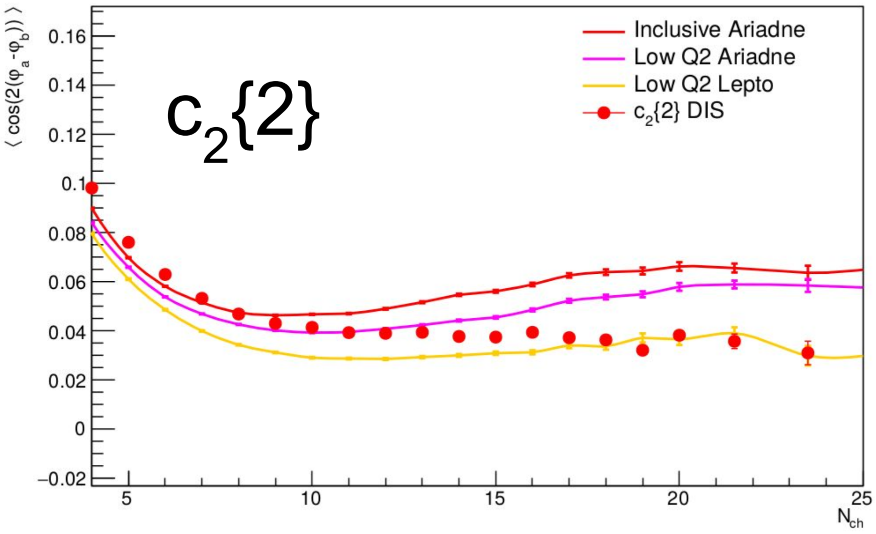
2_n-particle correlations as a function of event multiplicity for different pseudo-rapidity separation



Comparison to MC



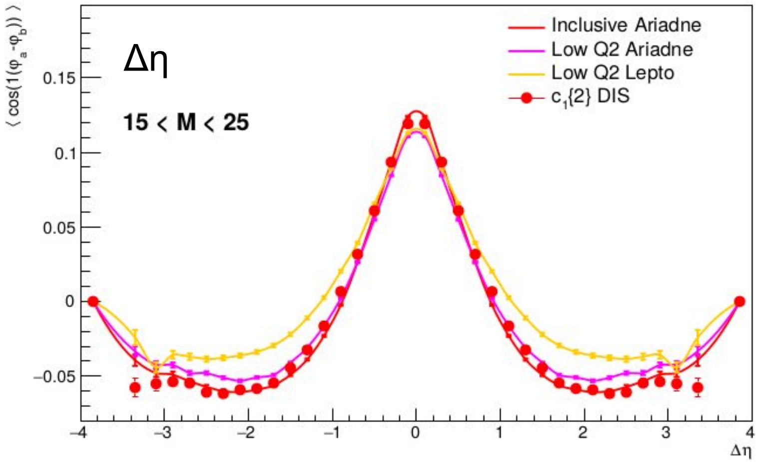
At higher multiplicity, well described by Ariadne

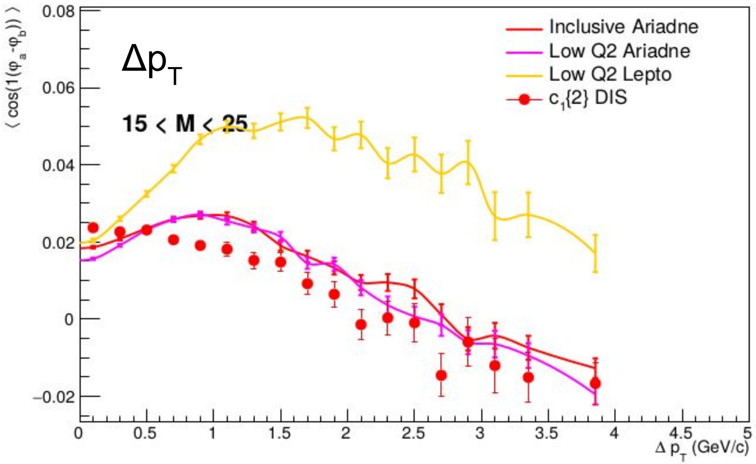


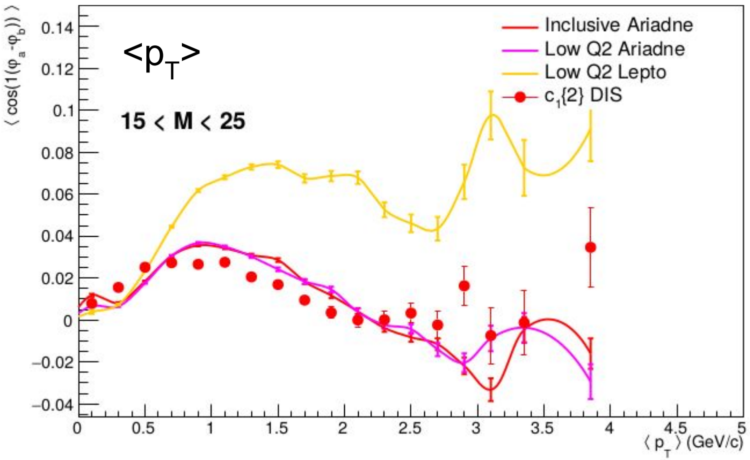
At highest multiplicity, well described by Lepto

To do: systematic on simulation

Differential $c_1\{2\}$ comparisons with MC



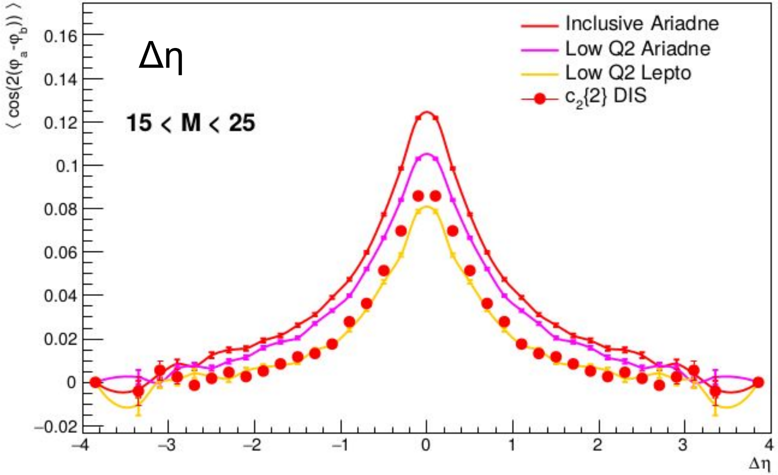


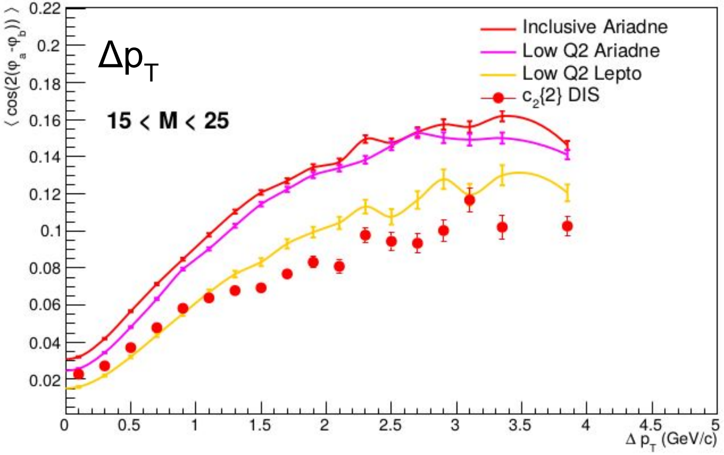


Good agreement for Ariadne, less for Lepto

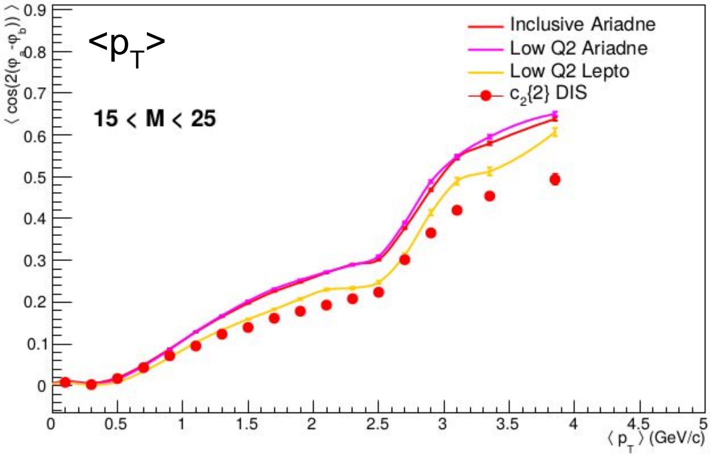
To do: systematic on simulation

Differential $c_2\{2\}$ comparisons with MC





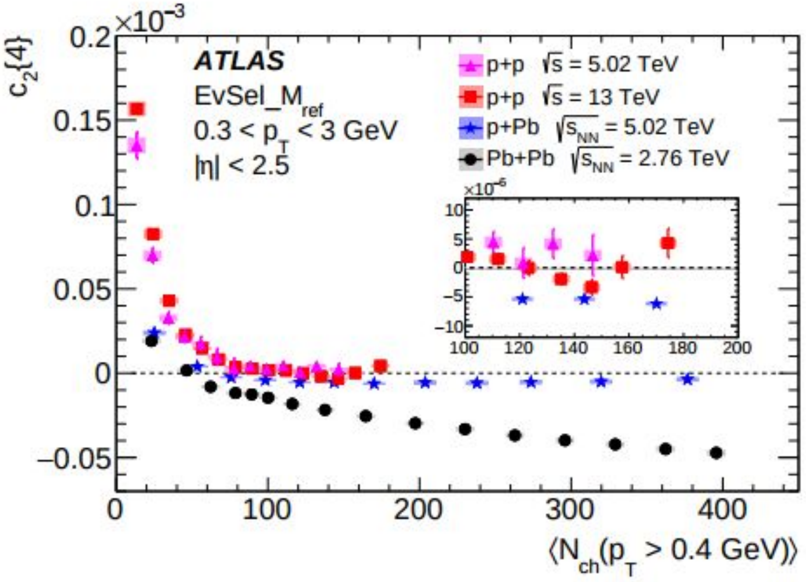
Good agreement for Lepto, less for Ariadne

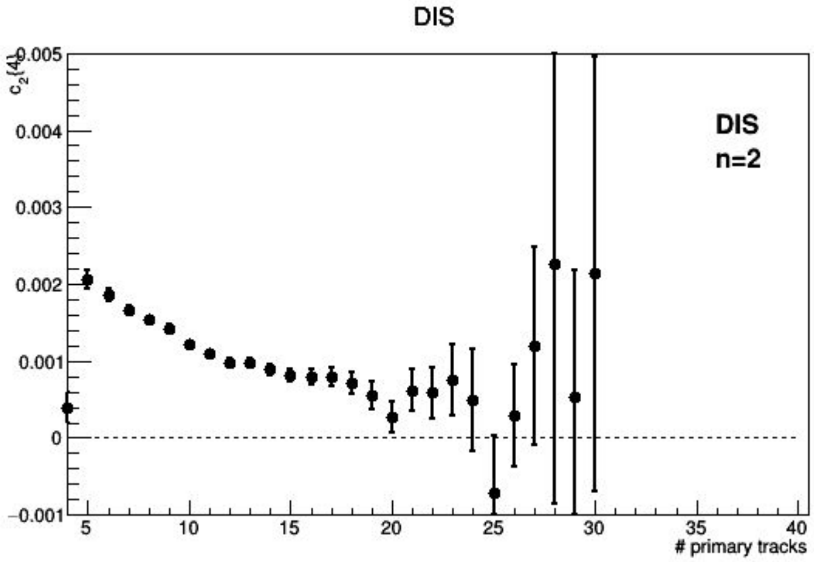


To do: systematic on simulation

4-particle cumulant at ZEUS

$$\langle 4 \rangle = \langle e^{in(\varphi_1+\varphi_2-\varphi_3-\varphi_4)} \rangle \qquad c_n\{4\} = \langle\langle 4 \rangle\rangle - 2\langle\langle 2 \rangle\rangle^2 \qquad v_n\{4\} = \sqrt[4]{-c_n\{4\}}$$





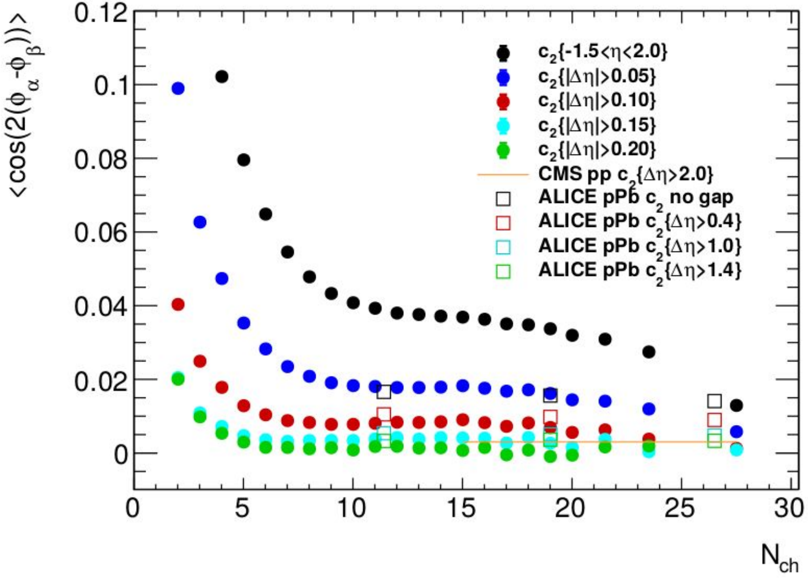
- Negative $c_2\{4\}$ for $<N_{ch}>$ above ~60 in pPb and PbPb
- For pp values are close to zero

- No hint of negative values
- Multiplicity range more limited than with 2-particle correlations

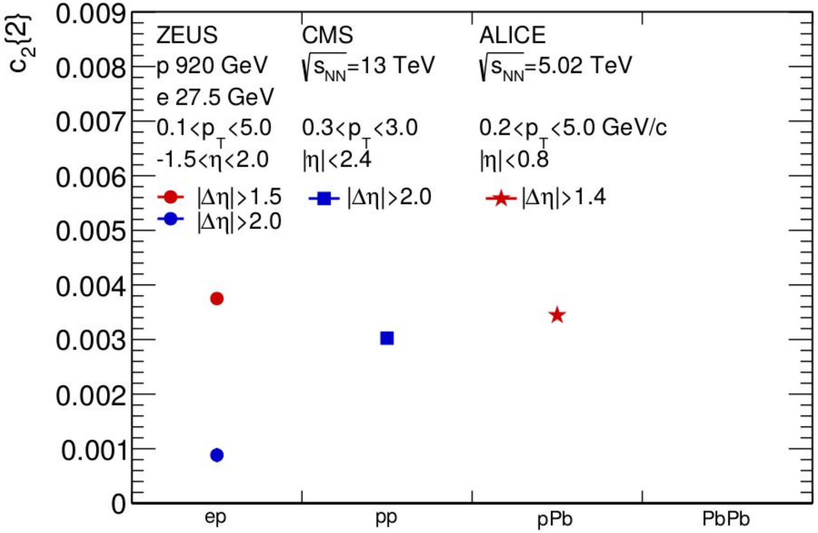
Comparison to other systems

These comparisons are not yet in their final conceptual form.

As a function of multiplicity



10 < N_{ch} < 20



Magnitude is roughly in ballpark of other systems, but comparison not straightforward

Physics messages

- No long range correlations at high (or any) multiplicity visible
- Measurement of the correlations for different harmonics, and as a function of multiplicity, pair pseudorapidity, pair transverse momentum, pair Δp_T
- Comparisons to different Monte Carlo generators
  - More understanding of the generators and the interpretation is still required
- Statistical limitation for 4-p cumulant
- Comparison to other systems

Todo for the results

- Add contributions to uncertainty in the measurement from
  - “chimney” cuts
  - Use other generators for tracking efficiency correction
  - Lepton “contamination” estimate
- Estimate uncertainty on simulation curves

Current error summation is sum of squares, which is the conservative option.

Documentation

Presentations:

Analysis proposal, September 2016

ZAF update, February 2017

ZAF update, June 2017

ZAF update, July 2017

ZAF update, August 2017

ZAF update, September 2017

ZAF update, Oktober 2017

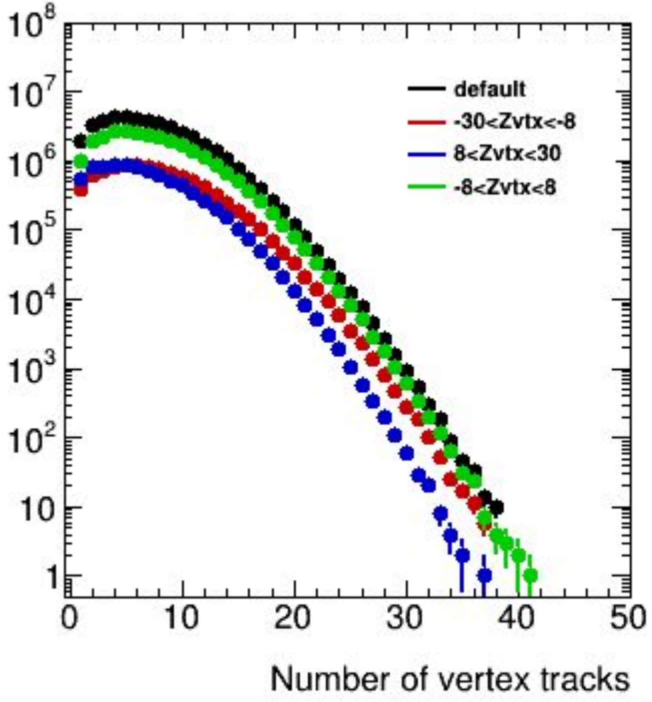
Analysis code:

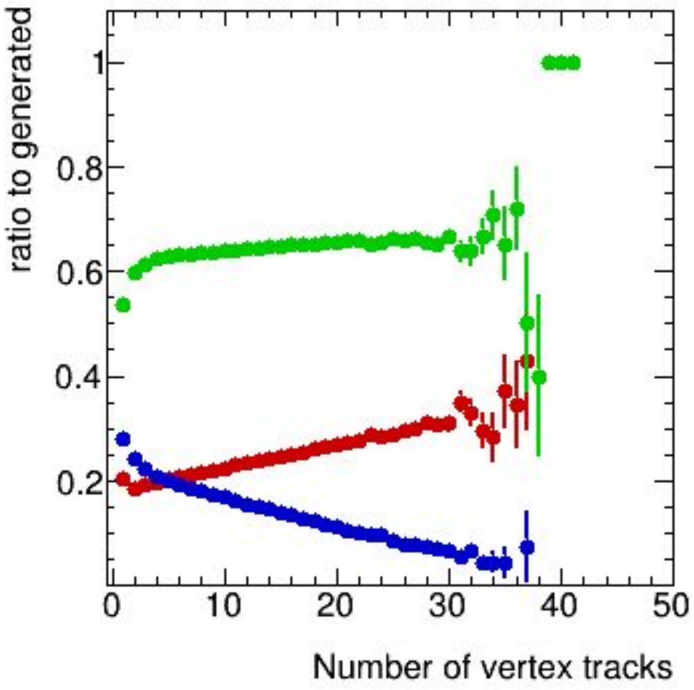
/afs/desy.de/user/o/onderwaj/zeus/analysis

Analysis Note:

/afs/desy.de/user/o/onderwaj/Note.pdf

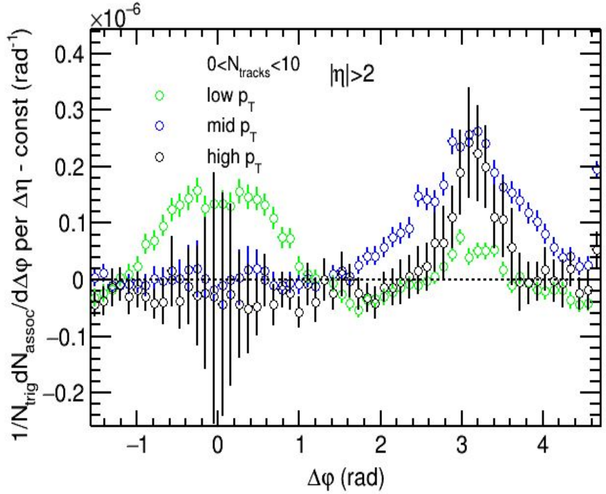
Number of vertex tracks vs Zvtx



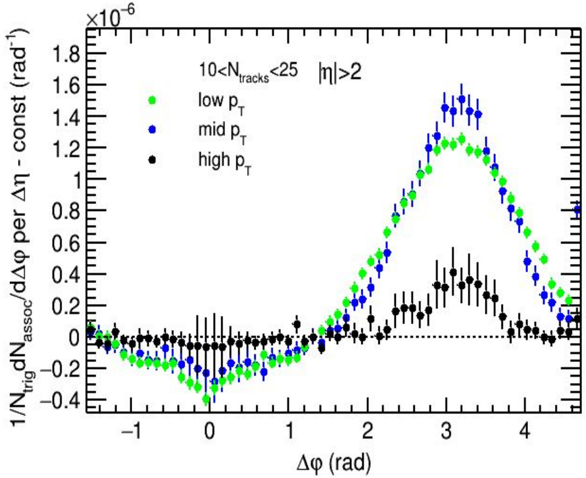


Δφ-Δη correlations

low-mult



mid-mult



High-mult