Azimuthal correlations in photoproduction and deep inelastic *ep* scattering at HERA

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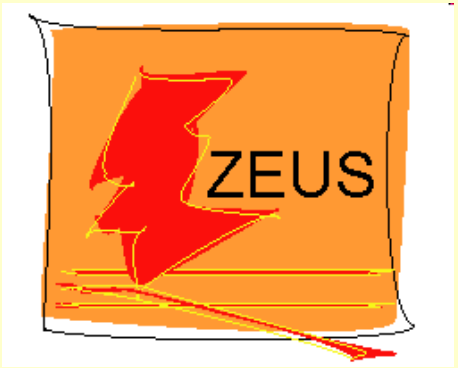
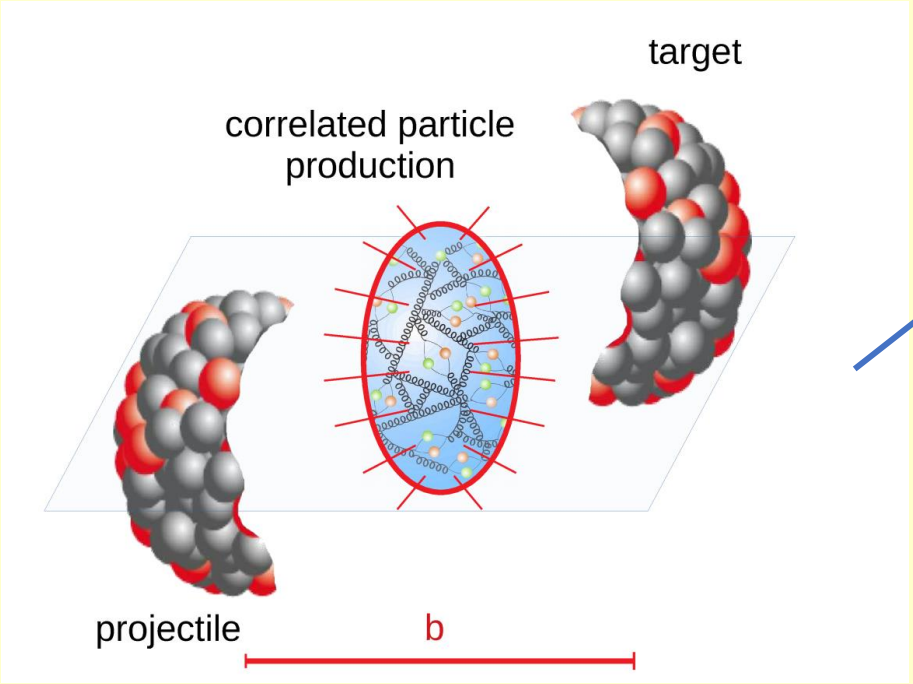
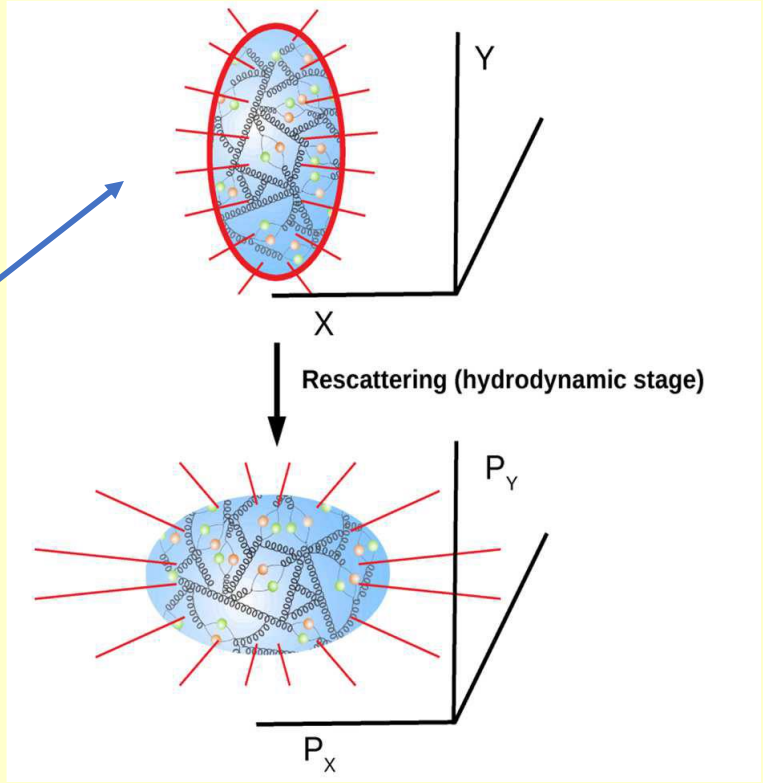


The physics picture for heavy ion collisions.



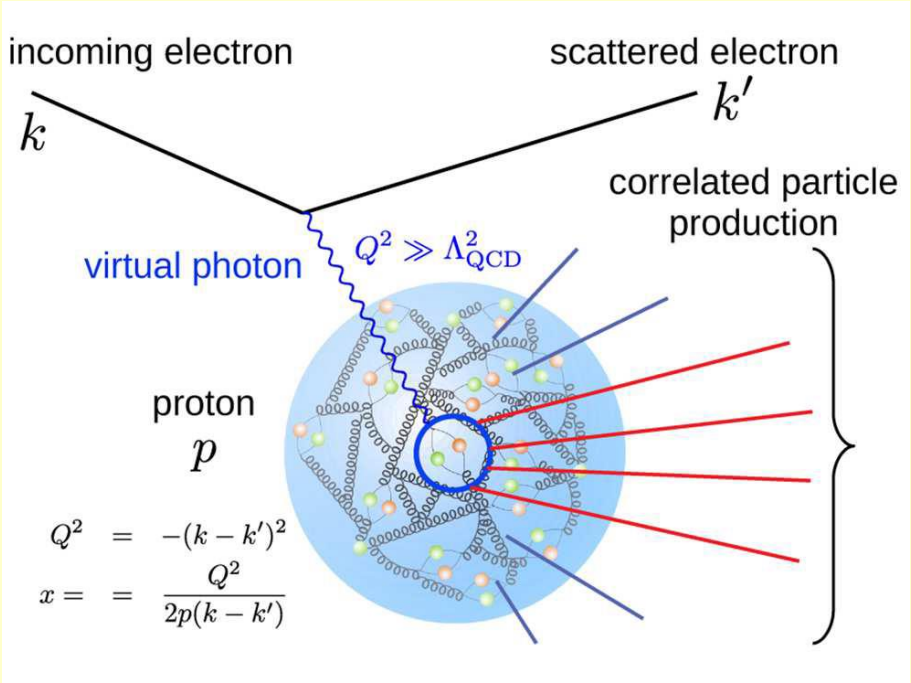


Two **heavy ions** collide, producing a central dense, hot mixture of partons.
- Hydrodynamic models describe this.

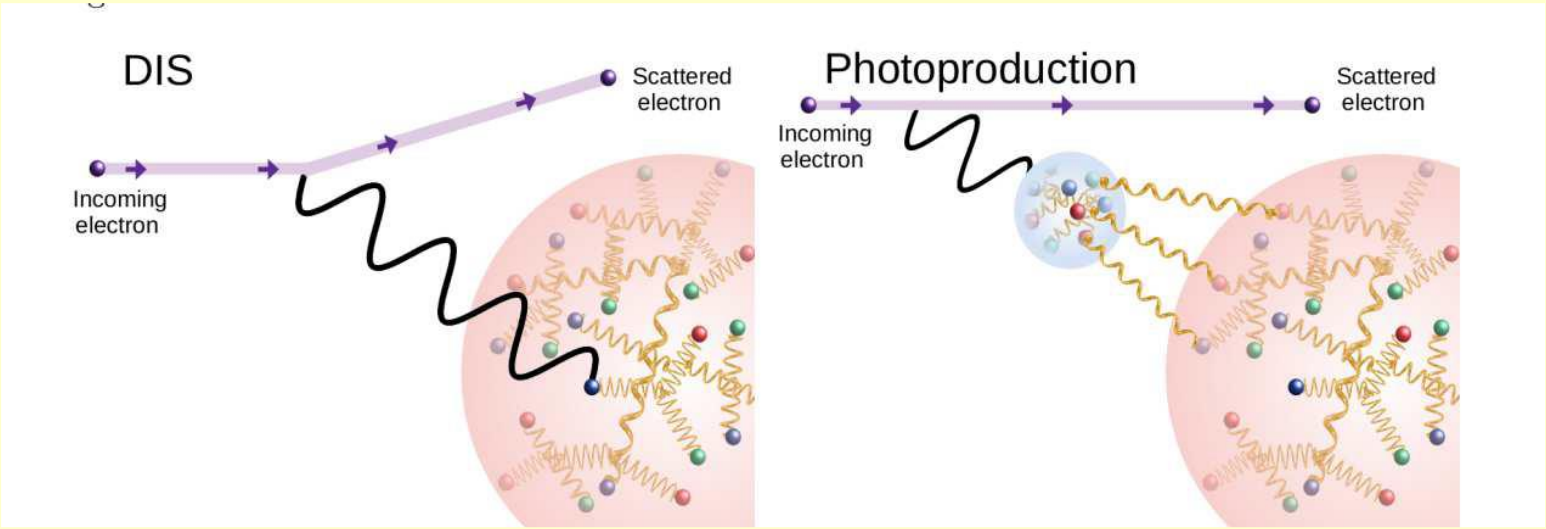
The partons emerge giving a multihadronic state -- retains memory of its origins in terms of correlations.

Is this picture still valid for "light" collisions, between real and virtual photons and protons?

Electron/positron –proton scattering



More specifically:

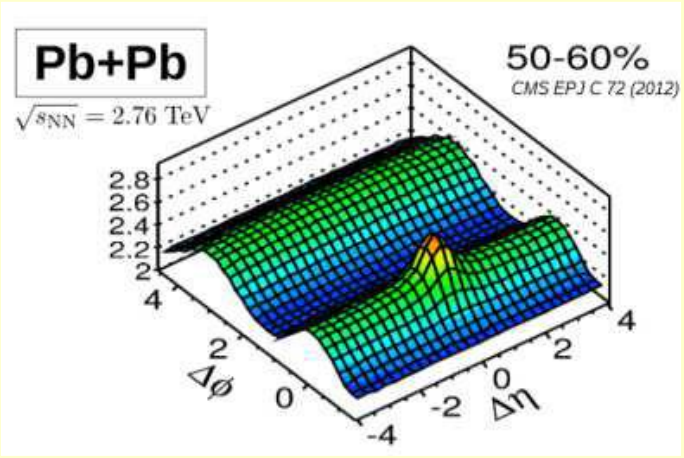


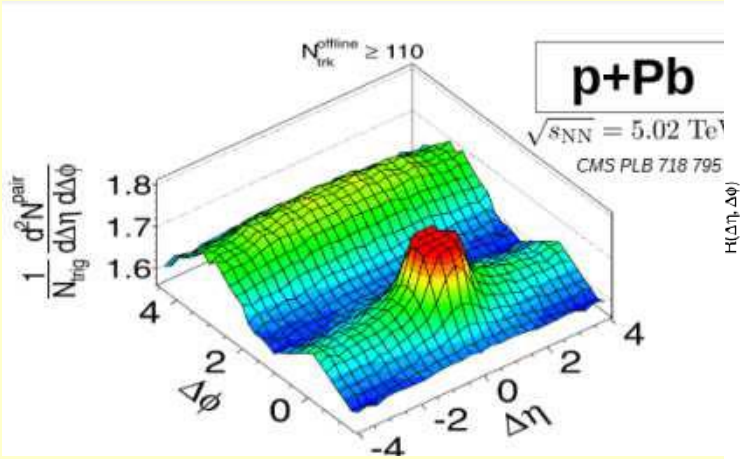
Also *direct photoproduction*.

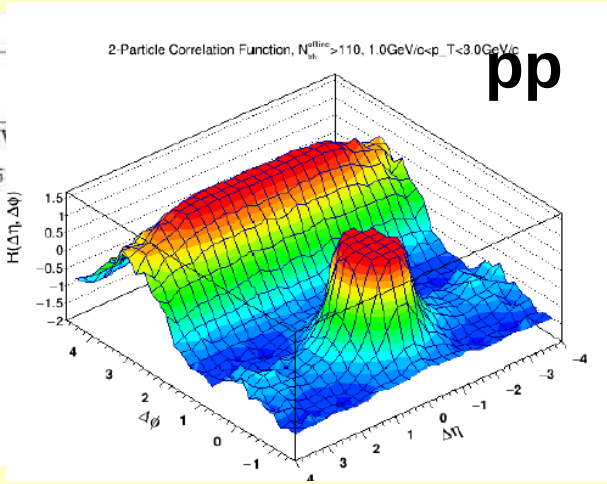
Resolved photoproduction (dominates).

Simple correlation functions:

- Count pairs of particles in given kinematic interval in same event
- Normalise to same quantity using particle pairs taken from separate events
- Apply efficiency corrections, etc



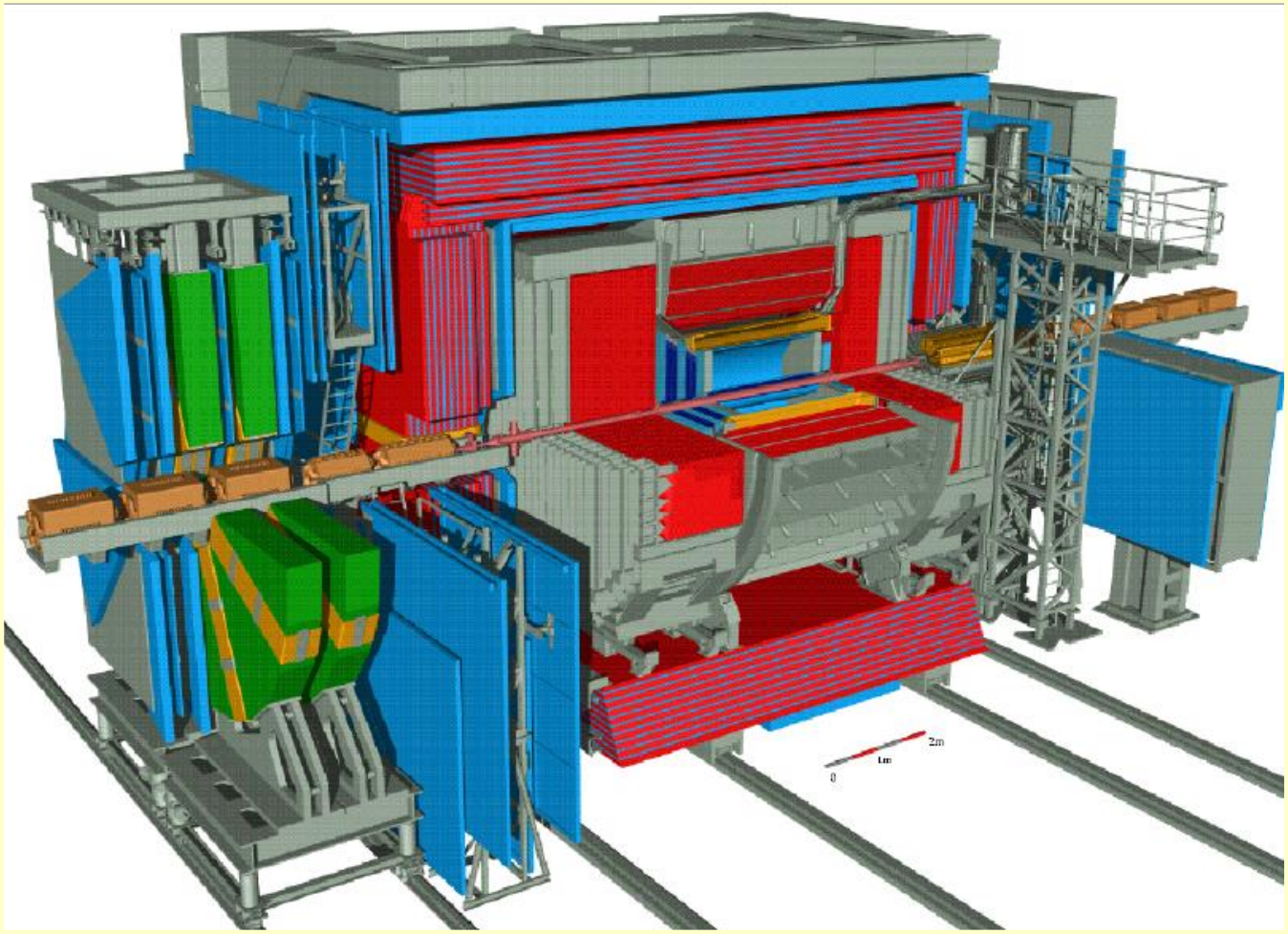


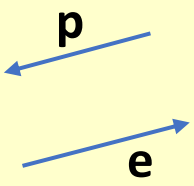


CMS: A very strong "hydrodynamic ridge" in **Δϕ versus Δη**, declines in strength in passing from nucleus-nucleus to proton-proton collisions.

ZEUS Detector (1992-2007)

- Asymmetric
- Compact
- High energy resolution
- general purpose tracking

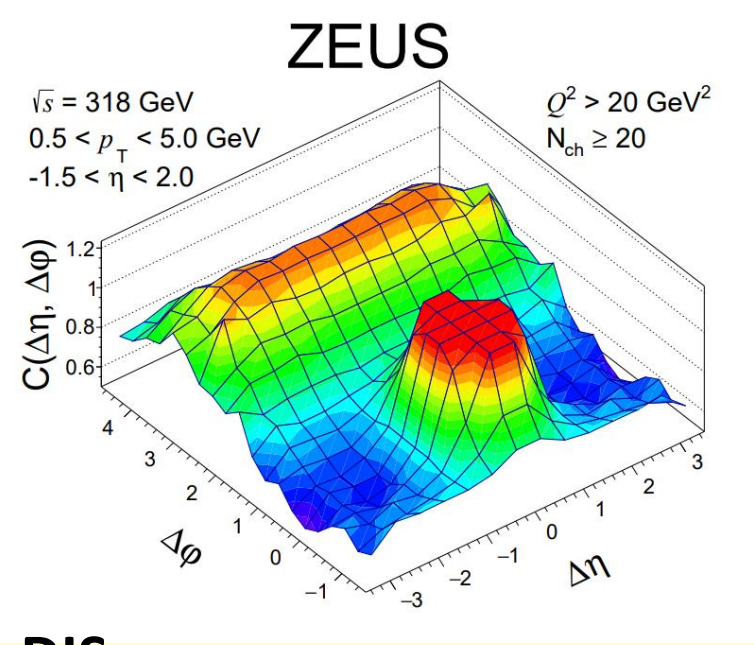




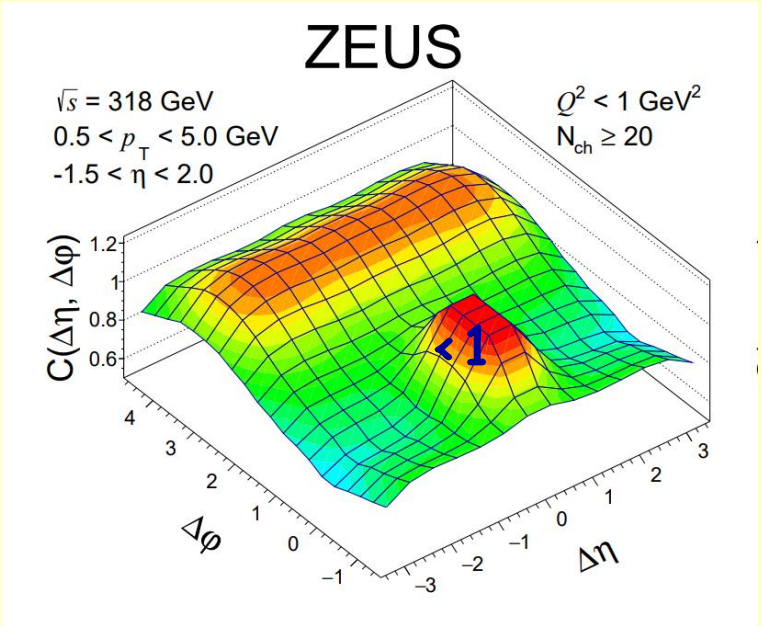
Recent ZEUS results from photoproduction, following DIS results.

JHEP 04 (2020) 070, arXiv:1912.07431; JHEP 12 (2021) 102, arXiv:2106.12377;

Long-range two-particle correlations in ep /γp in ZEUS



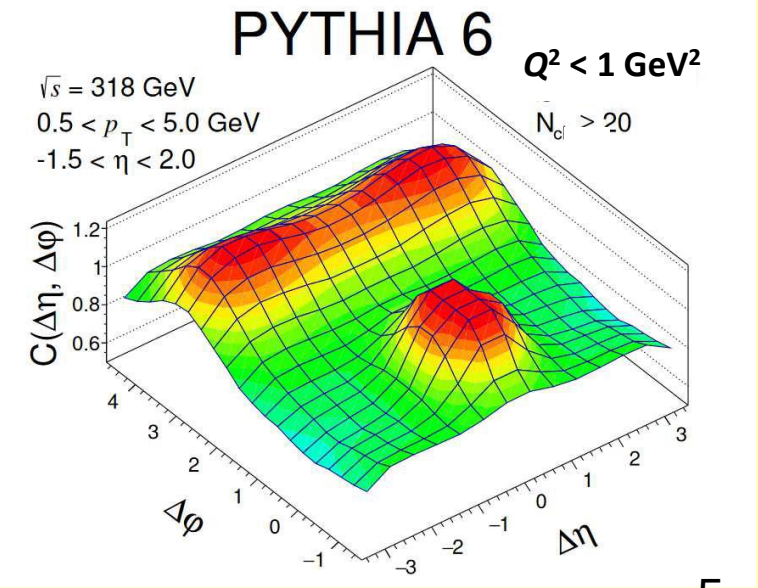
DIS



Photoproduction

These are long-range correlations corrected to the true particle level.

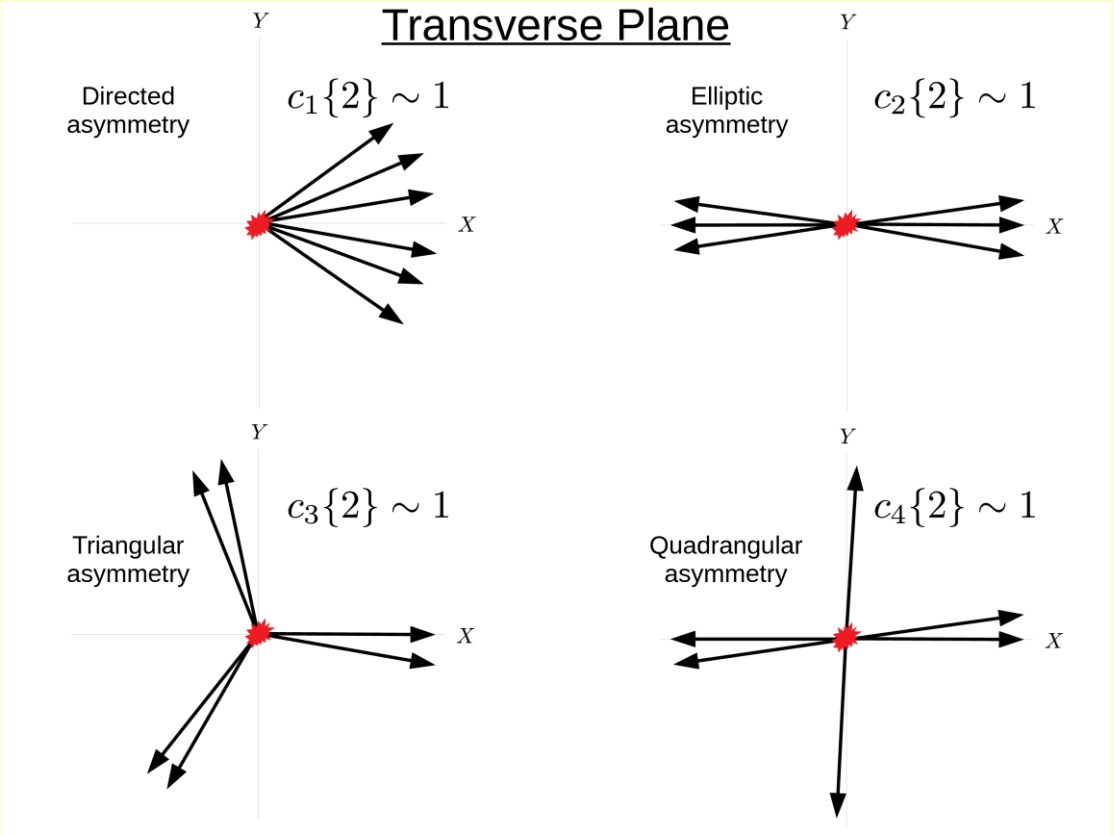
No ridge, and PYTHIA gives a very reasonable description.



Further correlation coefficients studied in ZEUS analyses.

$$c_n\{2\} = \langle\langle \cos n(\varphi_i - \varphi_j)\rangle\rangle$$

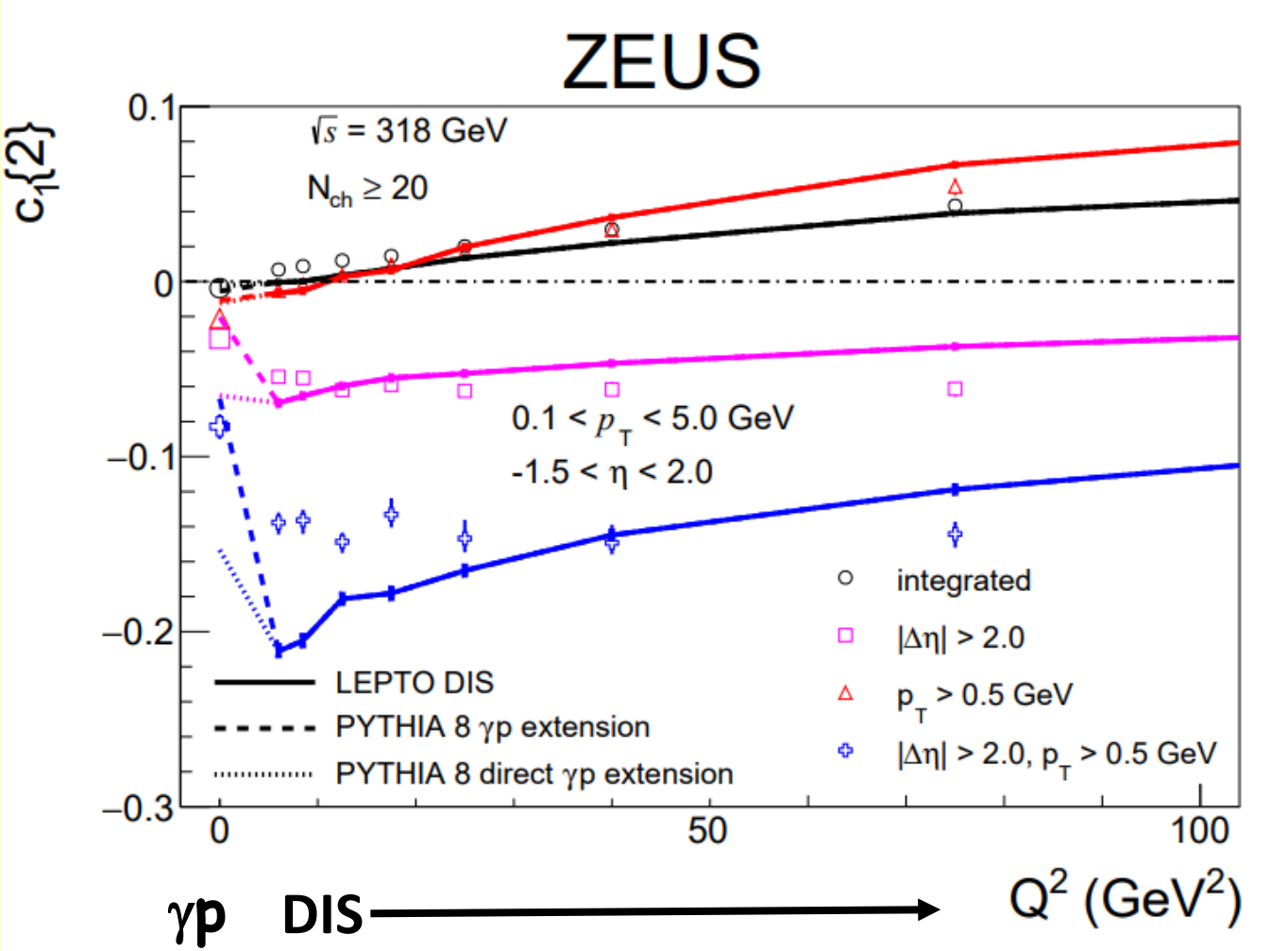
Degree number of particles

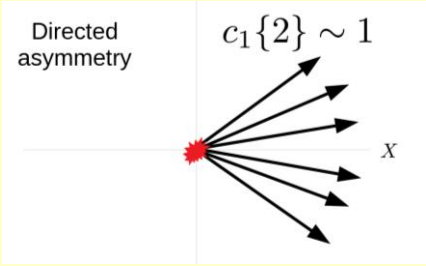


$$c_n\{2\} = \sum_e^{N_{\mathrm{ev}}} \left[\sum_{i,j>i}^{N_{\mathrm{rec}}} w_{ij} \cos\left[n(\varphi_i - \varphi_j)\right]\right]_e \Big/ \sum_e^{N_{\mathrm{ev}}} \left[\sum_{i,j>i}^{N_{\mathrm{rec}}} w_{ij}\right]_e$$

Corrected for single-particle reconstruction efficiencies.

Azimuthal correlations: $c_1\{2\}$ versus Q^2 $N_{ch} \geq 20$





integrated

$|\Delta\eta| > 2.0$

$p_T > 0.5$ GeV

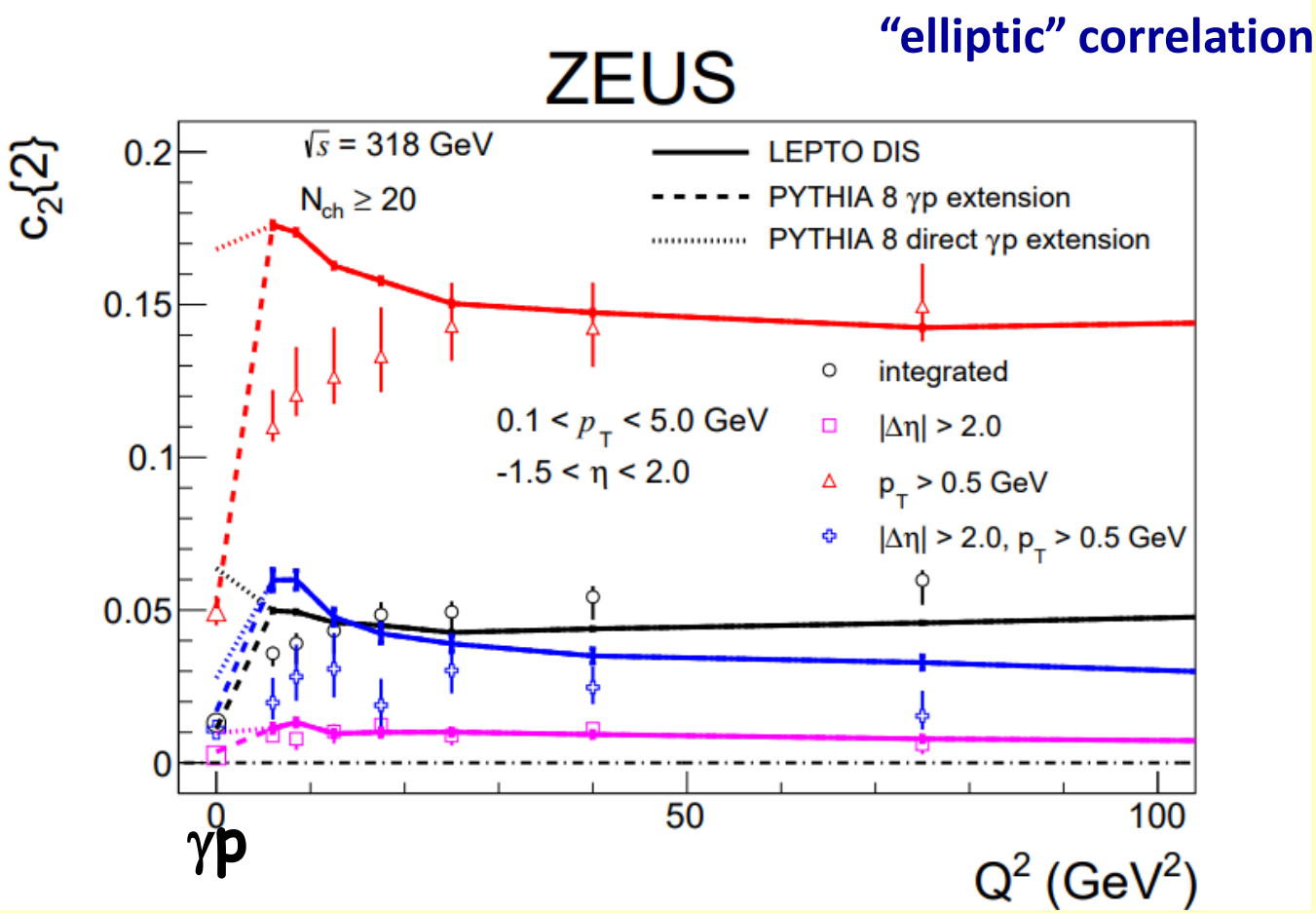
$|\Delta\eta| > 2.0$, $p_T > 0.5$ GeV

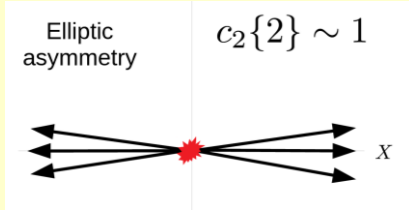
Transition: resolved **γp** to "direct" DIS

Standard models give a fair description of **γp** and of **DIS** at higher Q^2

Azimuthal correlations: $c_2\{2\}$ versus Q^2

"elliptic" correlations





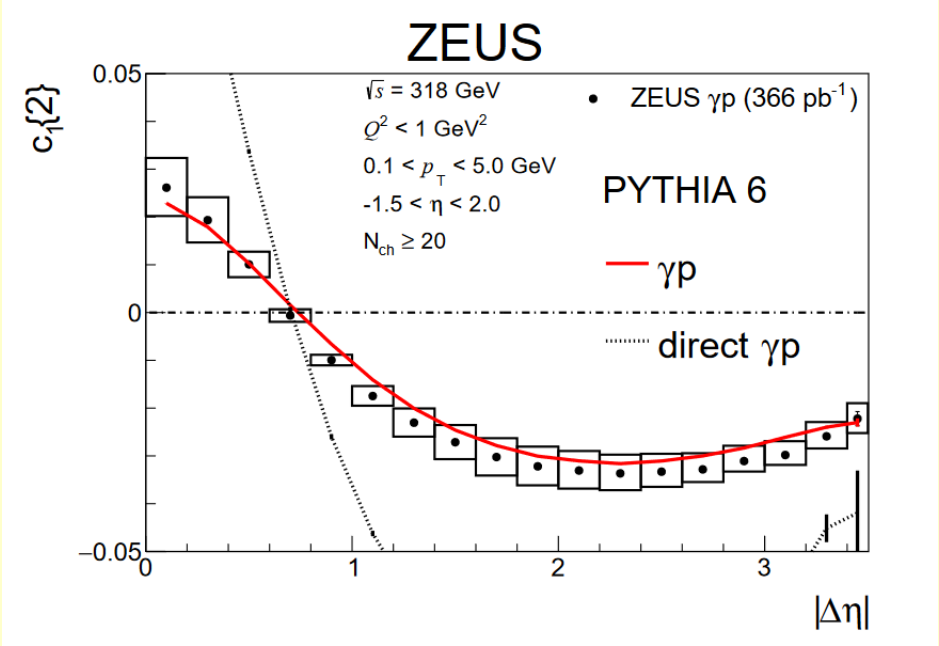
Transition: resolved **γp** to "direct" **DIS**

Standard MC models give a fair description of **γp and higher Q^2**

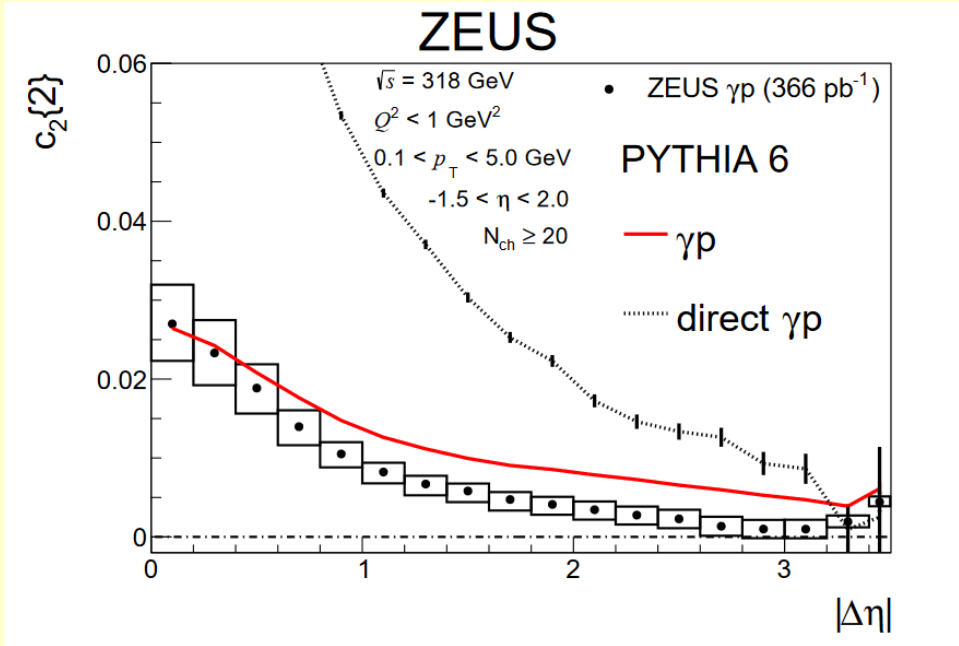
Two-particle azimuthal correlations: $c_1\{2\}$ and $c_2\{2\}$ vs. $|\Delta\eta|$

Photoproduction:

$c_1\{2\}$



$c_2\{2\}$



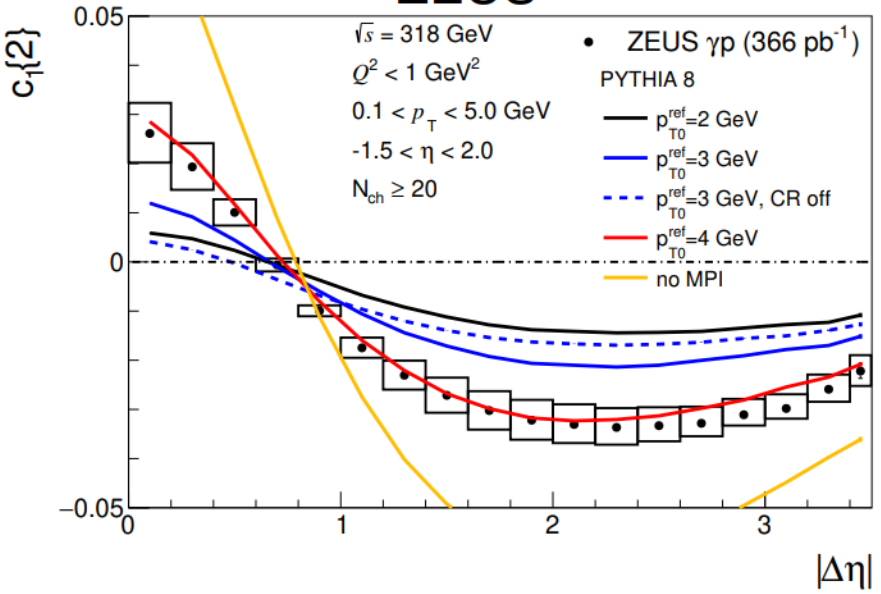
Data fully corrected to truth level, including all systematics.
Reasonably described by "default" PYTHIA-6 (used for efficiency corrections)

The resolved process dominates.

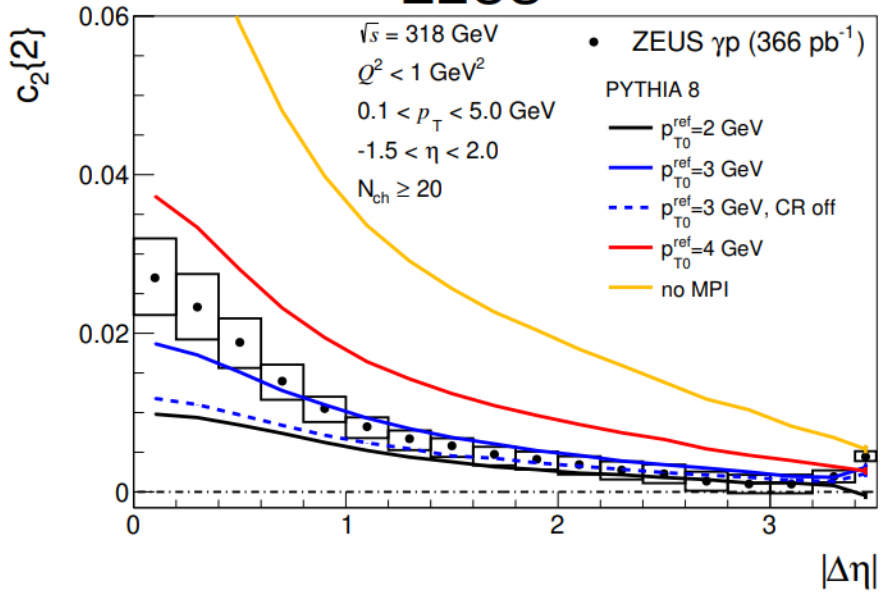
Two-particle azimuthal correlations: $c_1\{2\}$ and $c_2\{2\}$ vs. $|\Delta\eta|$

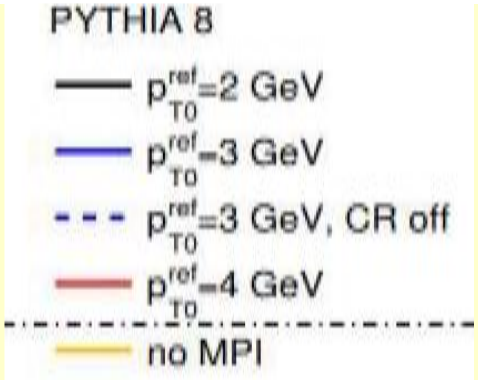
Photoproduction: effect of varying multiparton interaction level.

$c_1\{2\}$



$c_2\{2\}$



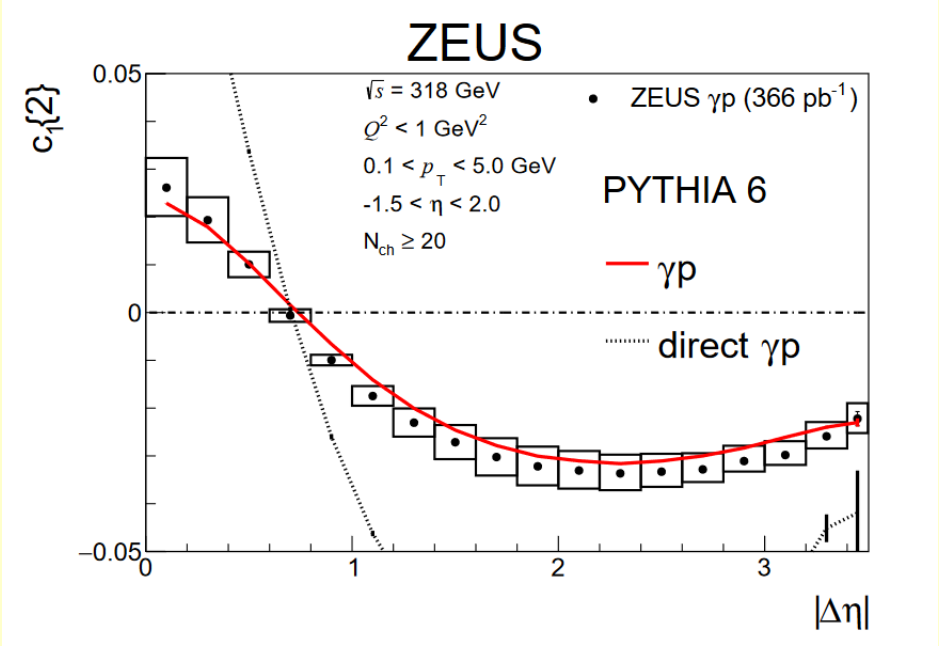


Reasonably described by PYTHIA-8 models with p_{T0} = 3±1 GeV, governing multi-parton interactions (2-8 parton interactions)

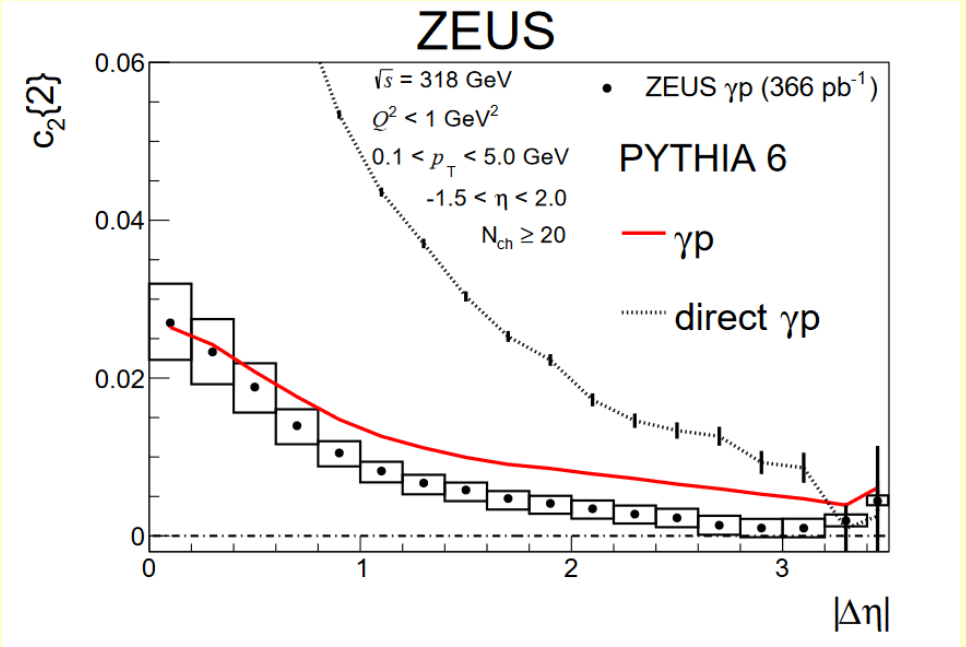
Four-particle azimuthal correlations: $c_1\{4\}$ and $c_2\{4\}$ vs. $|\Delta\eta|$

Photoproduction:

$c_1\{4\}$



$c_2\{4\}$



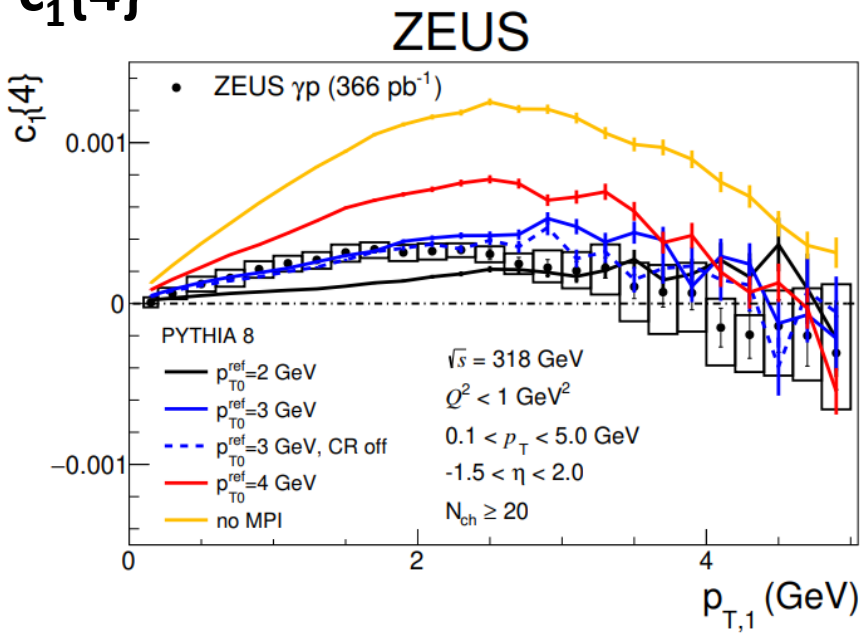
Reasonably described by “default” PYTHIA-6

The resolved process dominates.

Four-particle azimuthal correlations: $c_1\{4\}$ and $c_2\{4\}$ vs. p_T

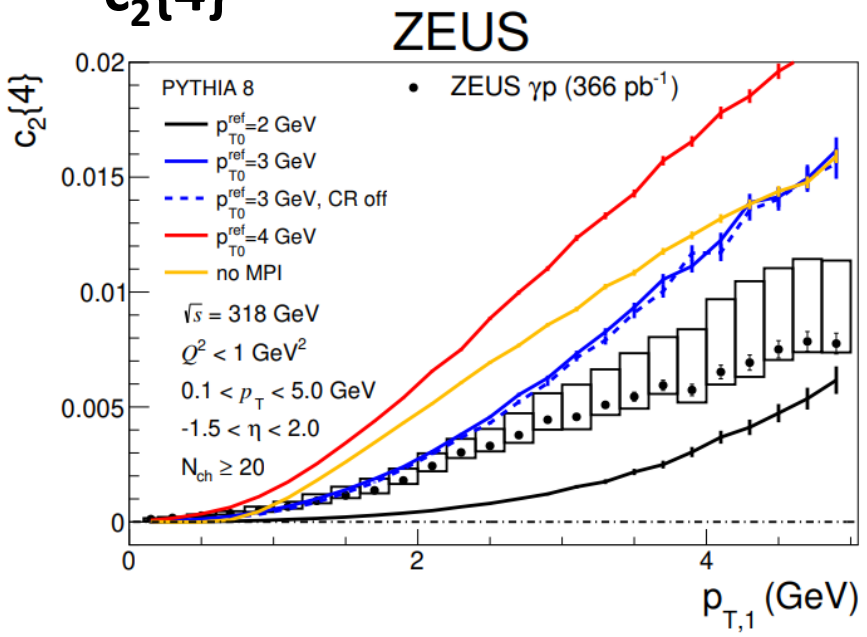
Photoproduction: effect of varying multiparton interactions.

$c_1\{4\}$

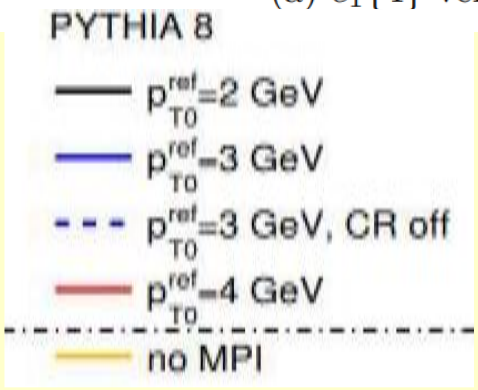


(a) $c_1\{4\}$ versus $p_{T,1}$.

$c_2\{4\}$



(b) $c_2\{4\}$ versus $p_{T,1}$.



Reasonably described by PYTHIA-8 models with p_{T0} = 3±1 GeV, governing multi-parton interactions (2-8 parton interactions)

Summary

Two- and four-particle azimuthal correlations in "high" multiplicity γp and ep collisions have been measured using **ZEUS** data from **HERA**.

No evidence for a double ridge structure is found in γp and ep collisions.

So, no confirmation of hydrodynamic correlation effects (only multiparticle effects as implemented in e.g. PYTHIA.)

(but multiplicities still lower than obtained with pp, heavy ions)

The data are reasonably described by existing particle physics MC models. The biggest qualitative differences between γp and DIS are confirmed to arise from resolved photon contributions for which multiparton interactions (PYTHIA model) seem necessary.