Diffraction in e-p and e-ion collisions

Azimuthal correlations in photoproduction and deep inelastic ep scattering at HERA	*Marta Ruspa*
Corigliano Calabro, Italy	16:40 - 17:00
The LHCspin project	*Marco Santimaria*
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Detectors and physics at the Electron-Ion Collider	*Charlotte Van Hulse*
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Electron-Ion Collisions at the LHeC and FCC-eh	*Jani Penttala et al.*
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Far-Forward detectors at the Electron-Ion Collider	*Aleksandr Bylinkin*
Corigliano Calabro, Italy	18:05 - 18:25
Discussion: ep and e-ion physics	*Prof. Daniel Tapia Takaki et al.*
Corigliano Calabro, Italy	18:25 - 18:45


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HOTELS&RESORTS
Diffraction
and Low-x

GRAZIE!

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Diffraction and Low-x 2022

Sept 26th – Sept 30th, Corigliano Calabro (Italy)

AZIMUTHAL CORRELATIONS IN PHOTOPRODUCTION AND DEEP INELASTIC SCATTERING AT HERA

MARTA RUSPA

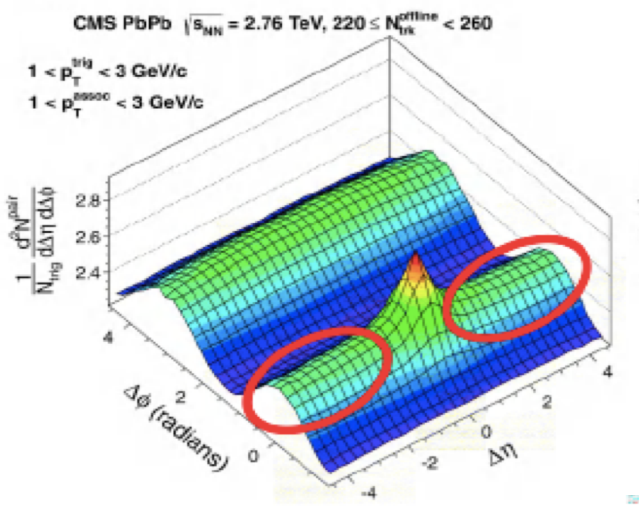
Univ. Piemonte Orientale & INFN-Torino, Italy

Motivation

In **heavy ion collisions** evidence of long-range correlatic

in Δη for particle pairs produced at small $\Delta\phi$ (**ridge**)

→ understood as **fluid-like behaviour (QGP)**



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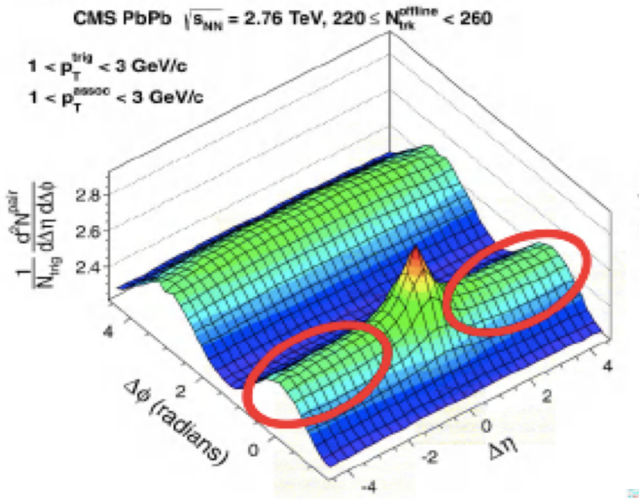
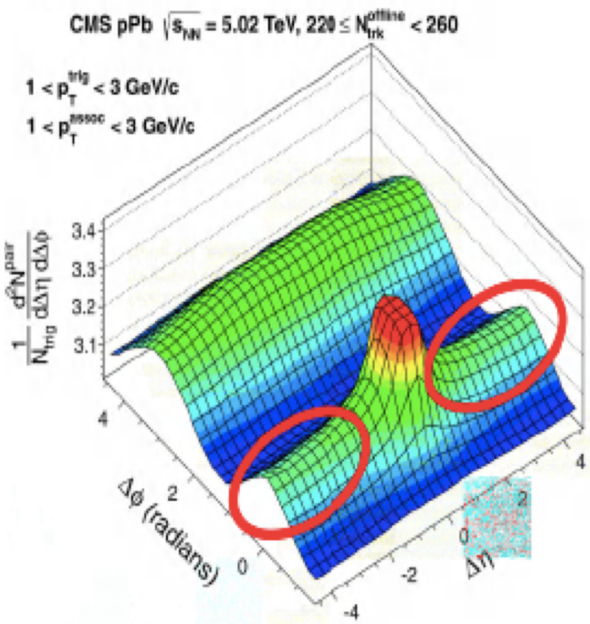
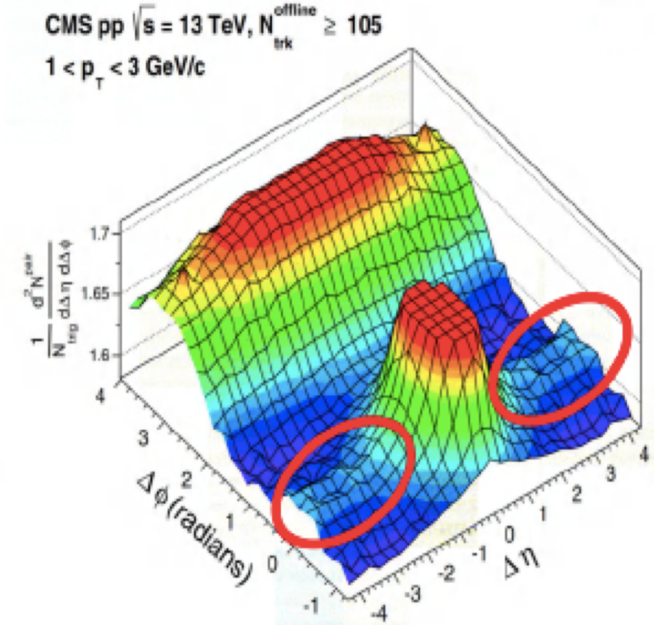


Also at LHC similar structure in **pPb and pp systems**





What happens in an even smaller systems, i.e. electron-proton collision?

JHEP12 (2021) 102, JHEP 04 (2020) 070 (H1: H1prelim-20-033)

Keywords in this measurement

- **DIS** vs **photoproduction:** the probed region in DIS (~ 1/Q) is typically much smaller than the proton while in photoproduction it can be of order the proton's size, $1/\Lambda_{QCD} \approx 1$ fm → interaction region in γp resembles that in pp and pA

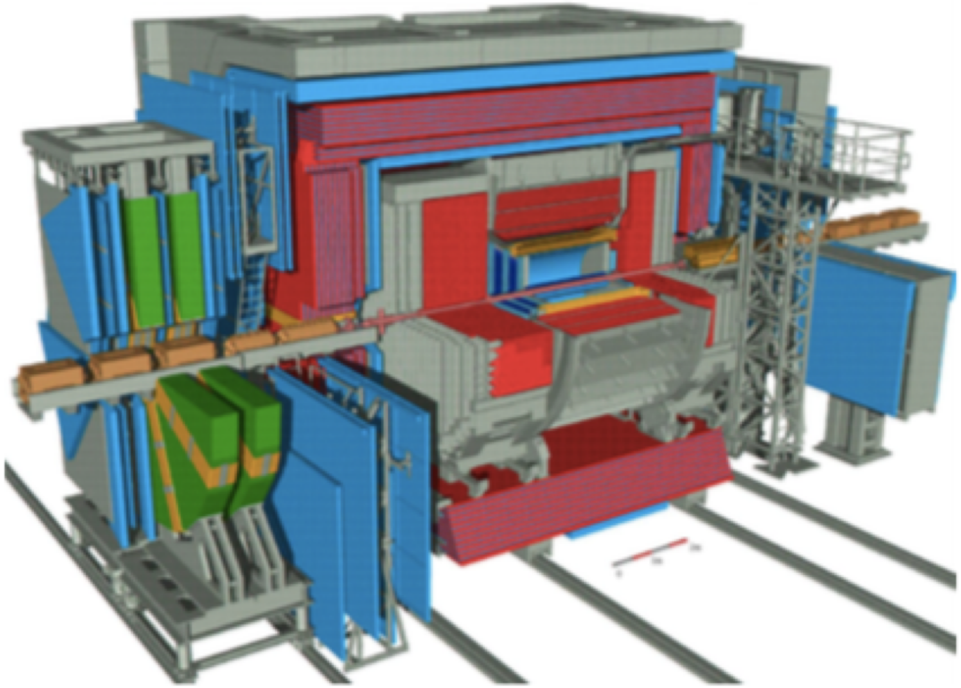
- **MPI:** 2 → 2 initial partonic scatterings in a single ep collision can be investigated with resolved γp at HERA . Again bridge to heavy-ion collisions where copius MPI→ rescattering between partons → QGP

- Collision zone in the plane transverse to the beam axis irregular, eccentricities in the initial state arise depending on degree of rescattering and imply momentum asymmetries in the final state →**azimuthal correlations** can quantify asymmetries

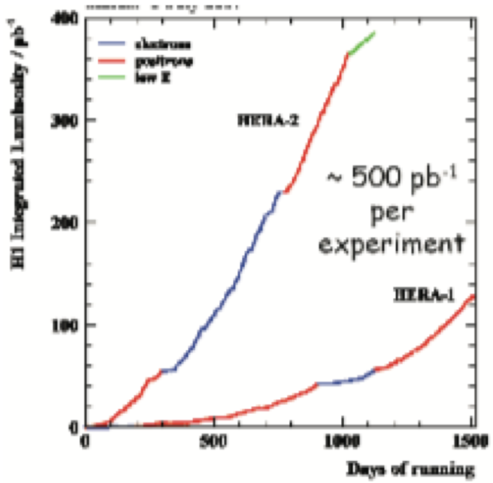
- **2-particles azimuthal correlations** may be biased by unrelated two-particle correlations such as resonance decays. **4-particle azimuthal correlations** less biased (two-particle background subtracted)

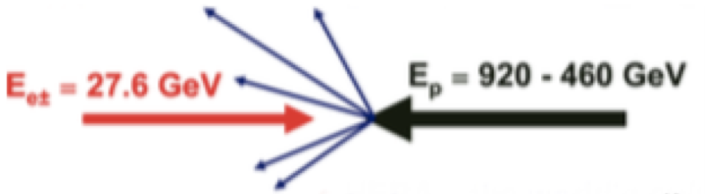
.

The ZEUS experiment and DIS at HERA

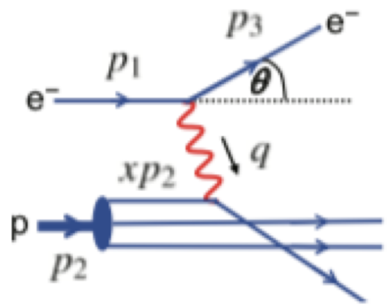


ZEUS experiment @ HERA
DESY, Hamburg, 1992 - 2007





$\Rightarrow \sqrt{s} = 318$ GeV



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

Data and simulation

2003-2007 ZEUS data, 366 pb^{-1}

- **Standard DIS** ($Q^2 > 5$ GeV^2) and **γp** ($Q^2 < 1$ GeV^2) **selection**

- **Track selection**

  $0.1 < p_T < 5$ GeV

  $-1.5 < \eta < 2.0$

- **High multiplicity**

  efficiency-corrected charged primary particles in the kinematic acceptance, $N_{ch} > 20$

Monte Carlo simulation:

- for DIS: **ARIADNE** (color dipole model) **and LEPTO** (Lund string model)
- for γp: **PYTHIA** (versions 6.22 and 8.303)

PYTHIA 8 **predictions with and without MPI** are compared to the data

Three different levels of MPI are chosen with p_{T0}^{ref}= 2, 3, and 4 GeV. corresponding to 8.3, 3.8 and 2.2 mean number of MPI per event

Formalism

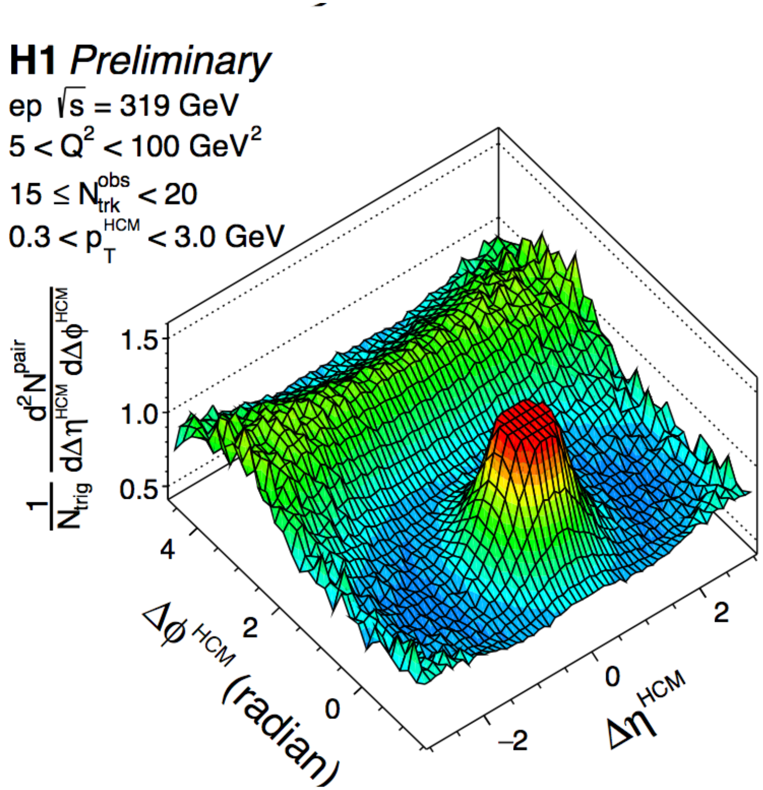
- Also **two-dimensional correlation functions**

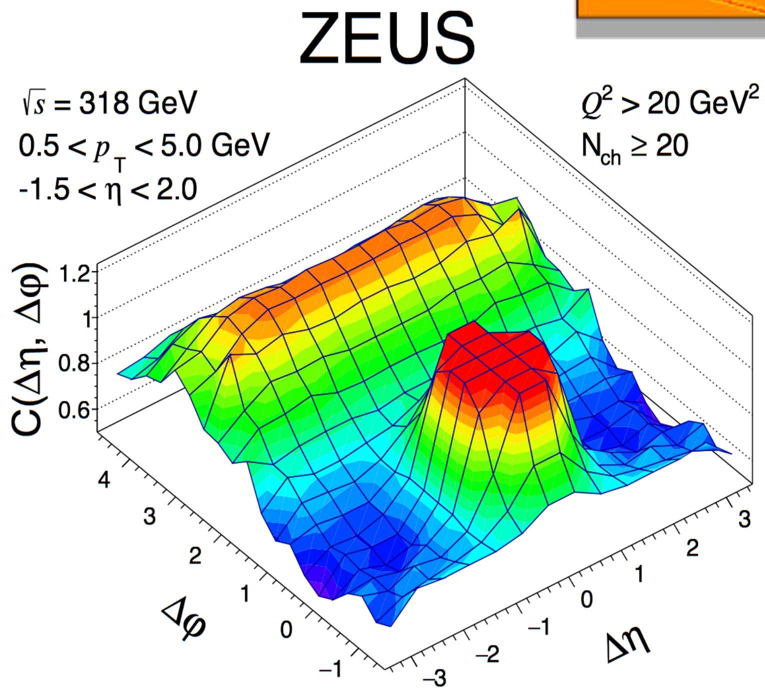
$$C(\Delta\eta, \Delta\varphi) = \frac{S(\Delta\eta, \Delta\varphi)}{B(\Delta\eta, \Delta\varphi)}$$

- S (signal)
- B (background)

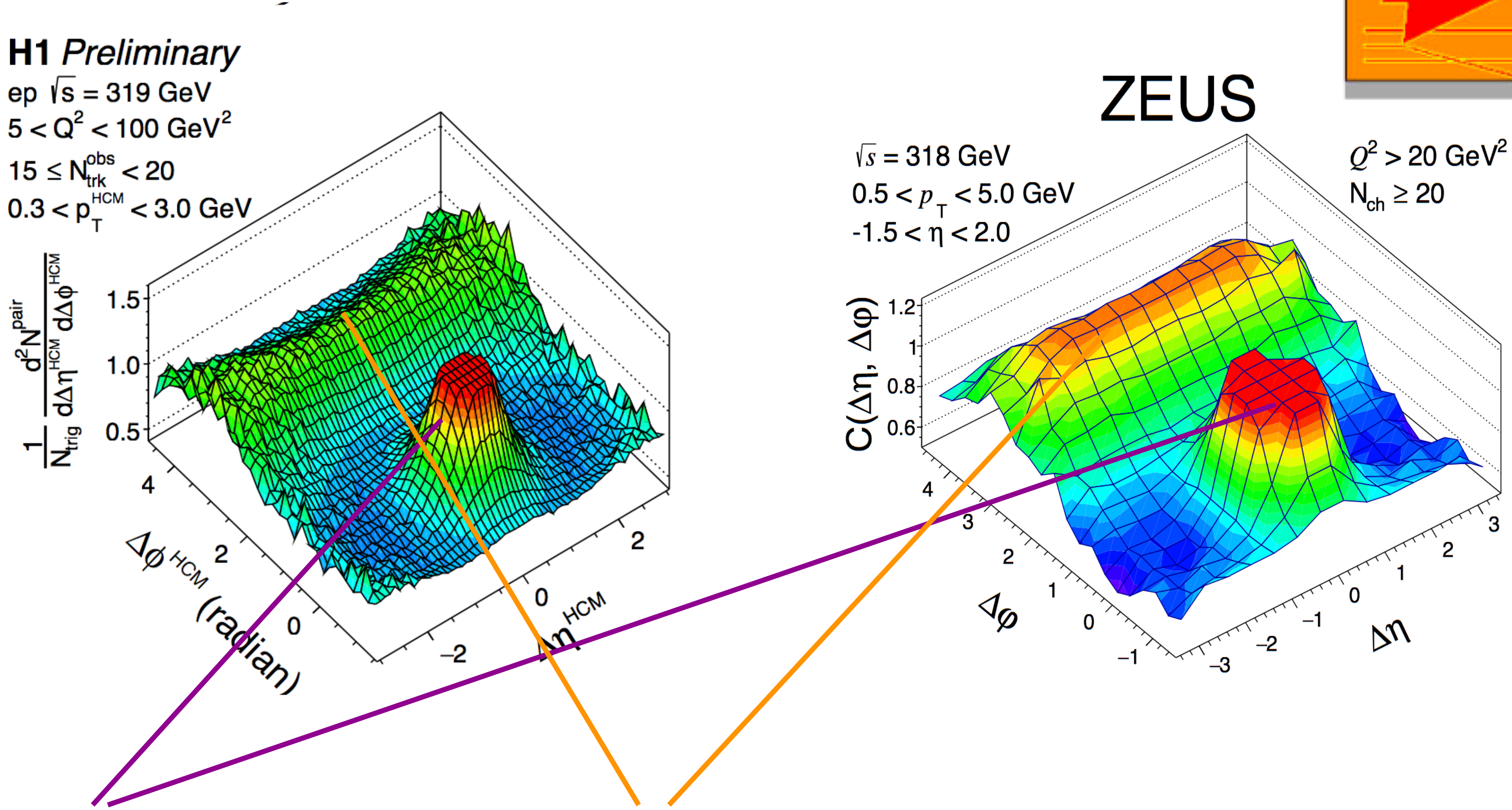
formed with pairs from the same- and mixed-event

Ridge in DIS?


H1 Preliminary
ep $\sqrt{s}$ = 319 GeV
$5 < Q^2 < 100$ GeV^2
$15 \leq N_{trk}^{obs} < 20$
$0.3 < p_T^{HCM} < 3.0$ GeV
$\frac{1}{N_{trig}} \frac{d^2N^{pair}}{d\Delta\eta^{HCM} d\Delta\phi^{HCM}}$
1.5
1.0
0.5
4
2
0
$\Delta\phi^{HCM}$ (radian)
−2
0
2
$\Delta\eta^{HCM}$


ZEUS
$\sqrt{s}$ = 318 GeV
$0.5 < p_T < 5.0$ GeV
$-1.5 < \eta < 2.0$
$Q^2 > 20$ GeV^2
$N_{ch} \geq 20$
C(Δη, Δφ)
1.2
1
0.8
0.6
4
3
2
1
0
−1
Δφ
−3
−2
−1
0
1
2
3
Δη

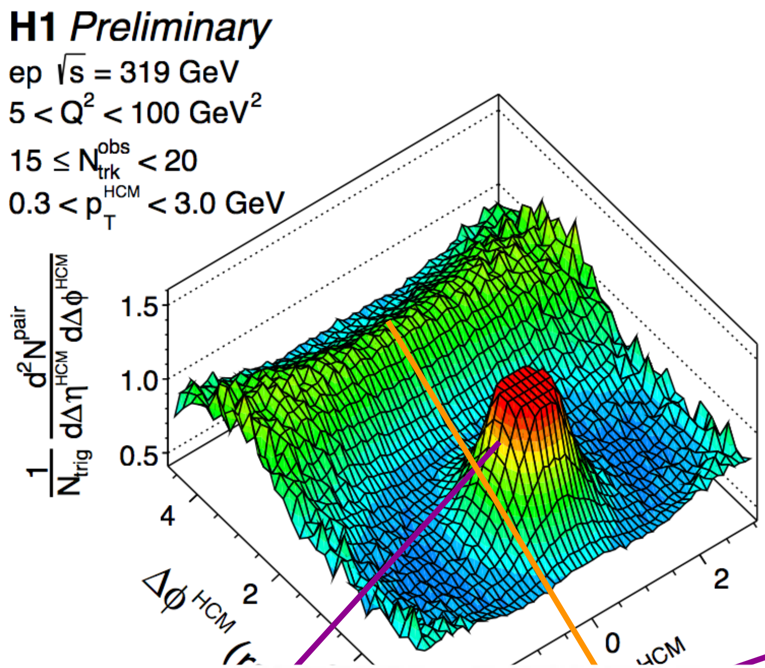
Ridge in DIS?

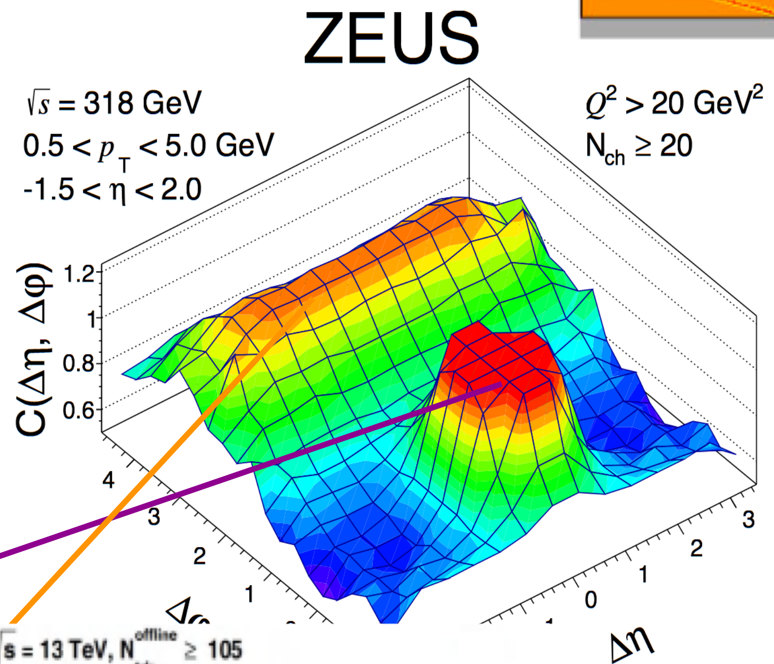


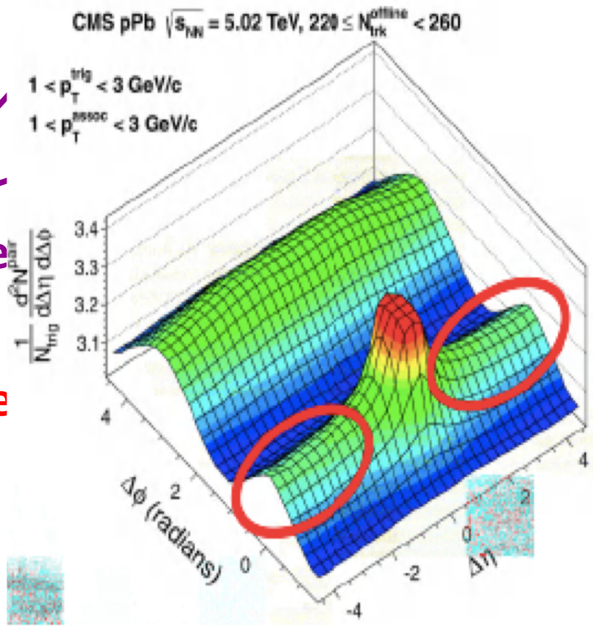
Near-side ($\Delta\varphi \sim 0$) peak and away-side ridge clearly visible

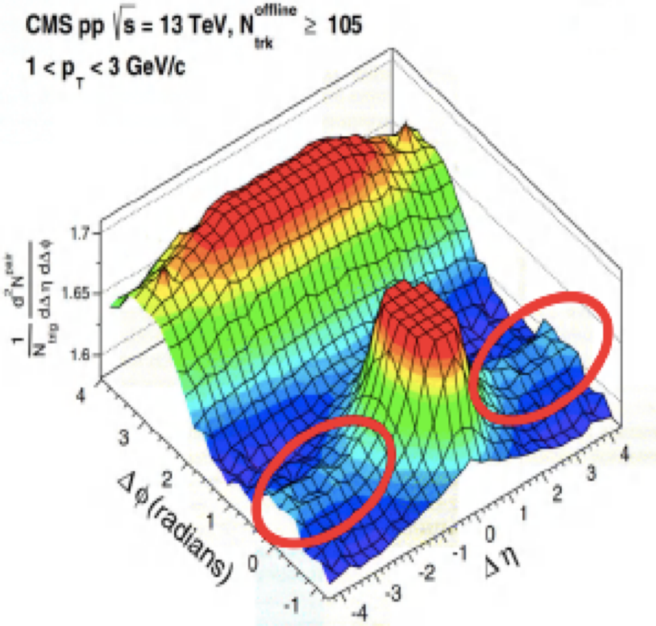
No visible long-range near-side double ridge

Ridge in DIS?





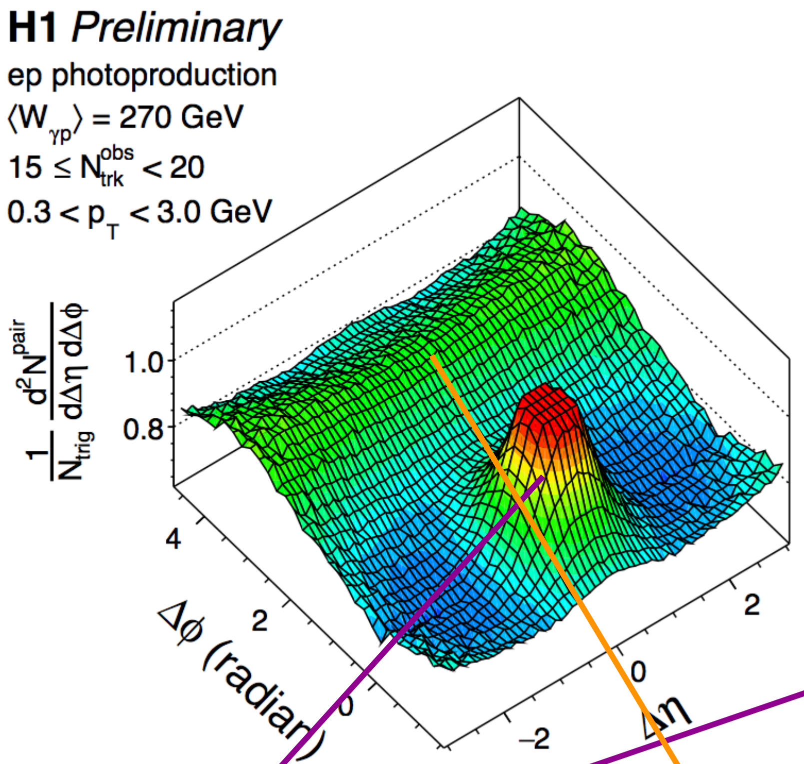


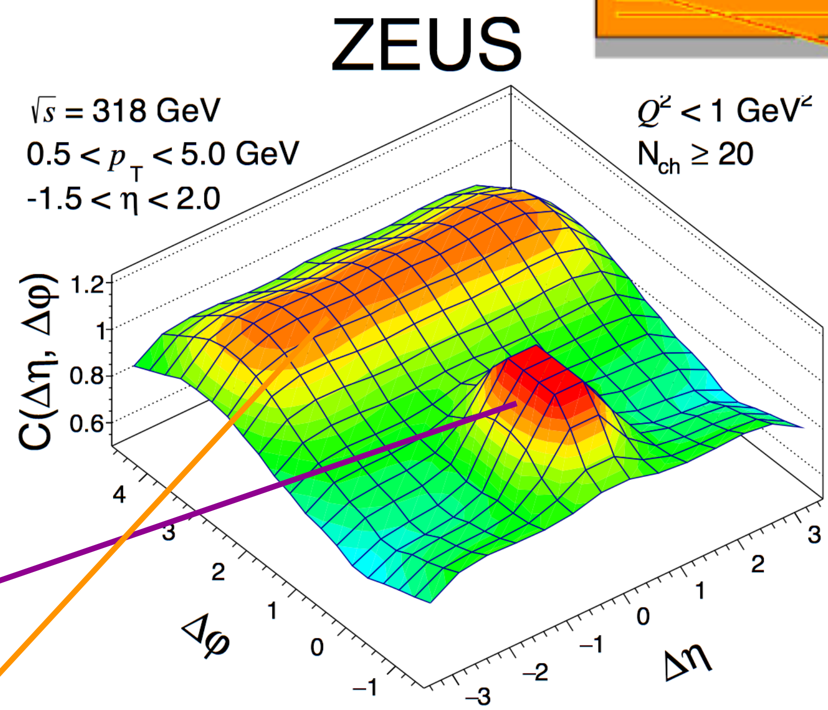


Near-side

No visible

Ridge in photoproduction?

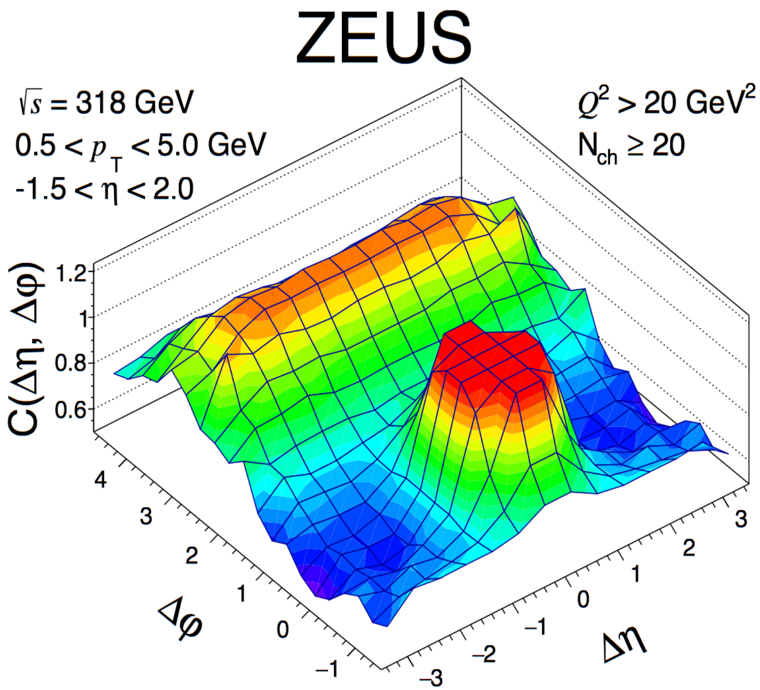


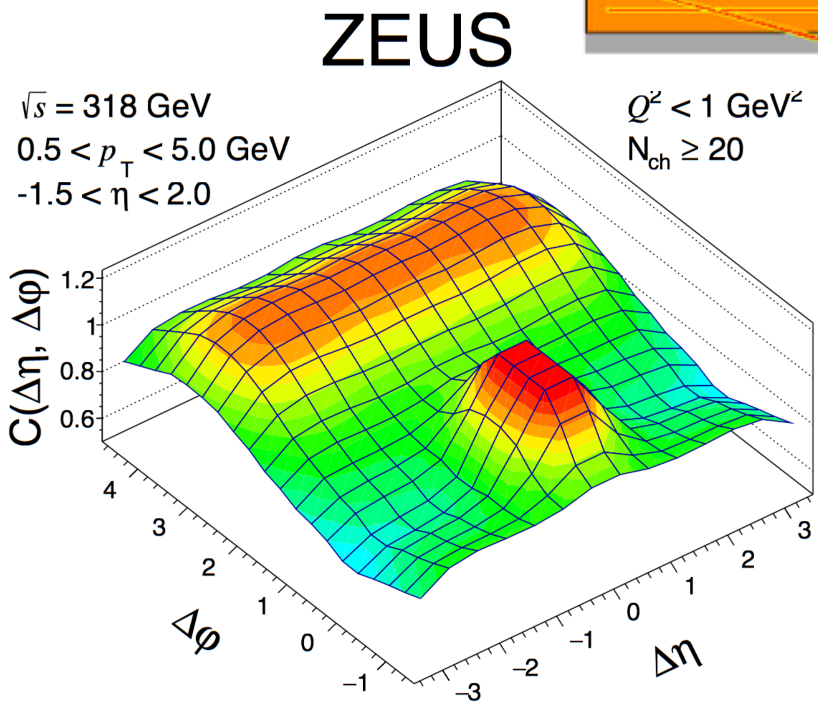


Near-side (Δφ ~0) peak and away-side ridge visible

No visible long-range near-side double ridge

Ridge in photoproduction?





Correlation strenght decreases from DIS to photoproduction

Formalism

- **2-particle and 4-particle azimuthal correlations** defined as

$$C_n\{2\} \equiv \langle \cos\left[n(\varphi_1 - \varphi_2)\right]\rangle\,,$$
$$C_n\{4\} \equiv \langle \cos\left[n(\varphi_1 + \varphi_2 - \varphi_3 - \varphi_4)\right]\rangle$$

- φ_i the azimuthal angle of particle *i*
- *n* the harmonics
- ⟨ ⟩ averages over pairs and quadruplets (corrections for non-uniform acceptance taken into account by proper weights)

- Also **two-dimensional correlation functions**

$$C(\Delta\eta, \Delta\varphi) = \frac{S(\Delta\eta, \Delta\varphi)}{B(\Delta\eta, \Delta\varphi)}$$

- S (signal)
- B (background)
formed with pairs from the same- and mixed-event

- In the plots are shown **cumulants:**

$$c_n\{2\} = C_n\{2\}$$

$$c_n\{4\}(p_{\mathrm{T},1}) \equiv C_n\{4\}(p_{\mathrm{T},1}) - 2\,c_n\{2\}(p_{\mathrm{T},1}) \times c_n\{2\},$$

- **Alternative approach:** Fourier transform of C($\Delta\eta,\Delta\varphi$)→ **flow coefficients** v_n typical of the anisotropic hydrodynamic expansion in heavy -ion collisions

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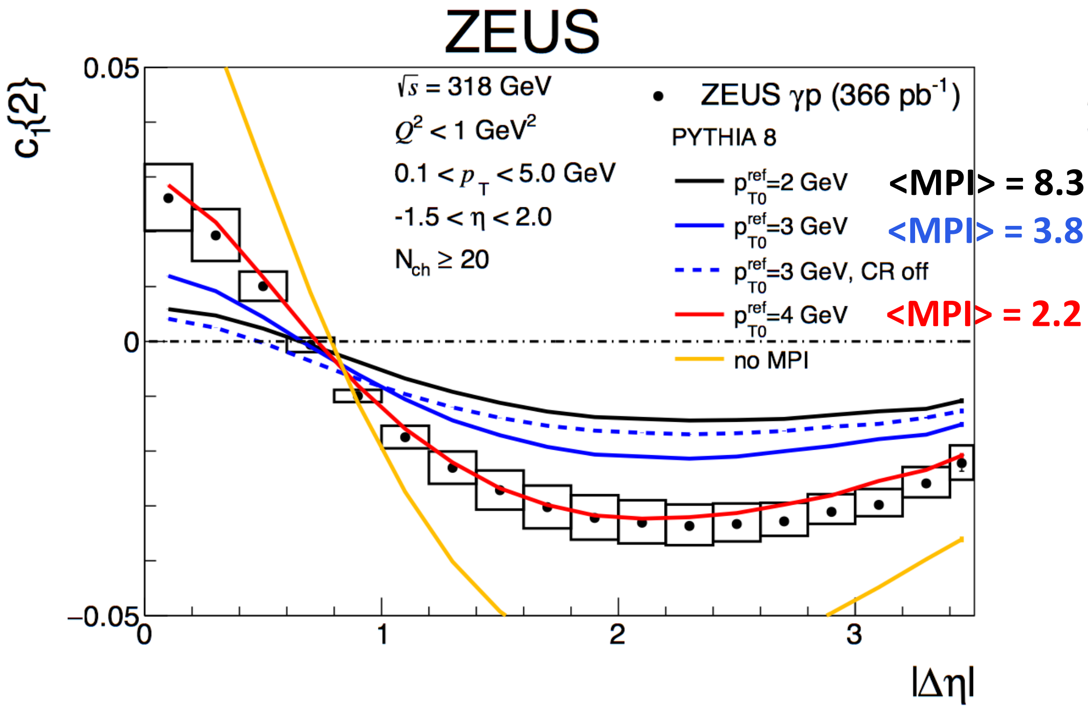
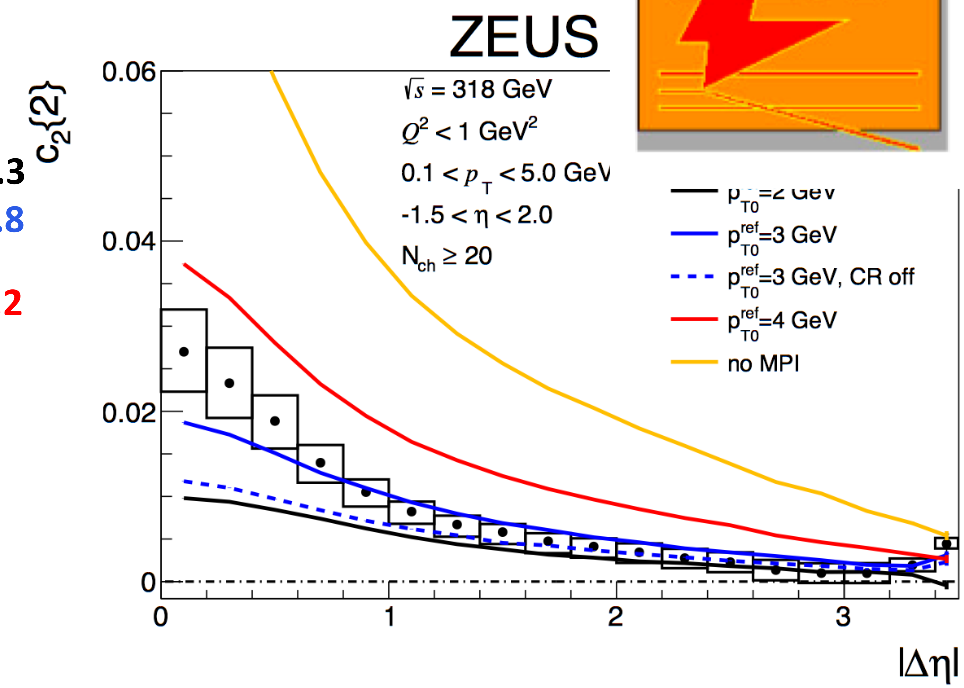
2-particle cumulants in photoproduction





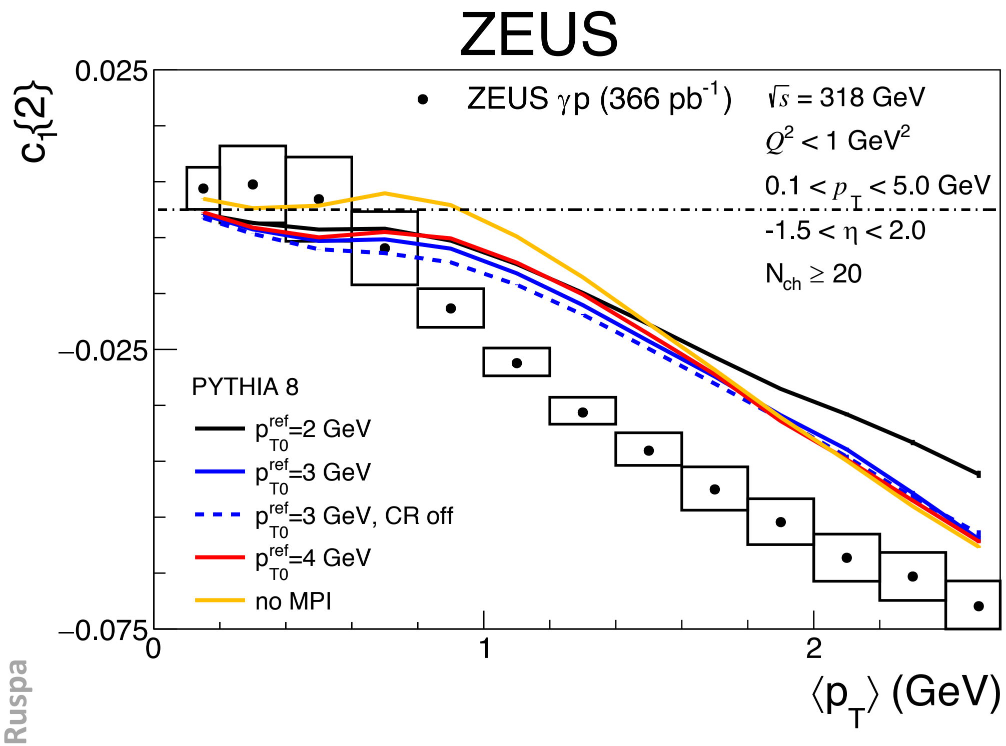
Negative (and decreasing) c_1

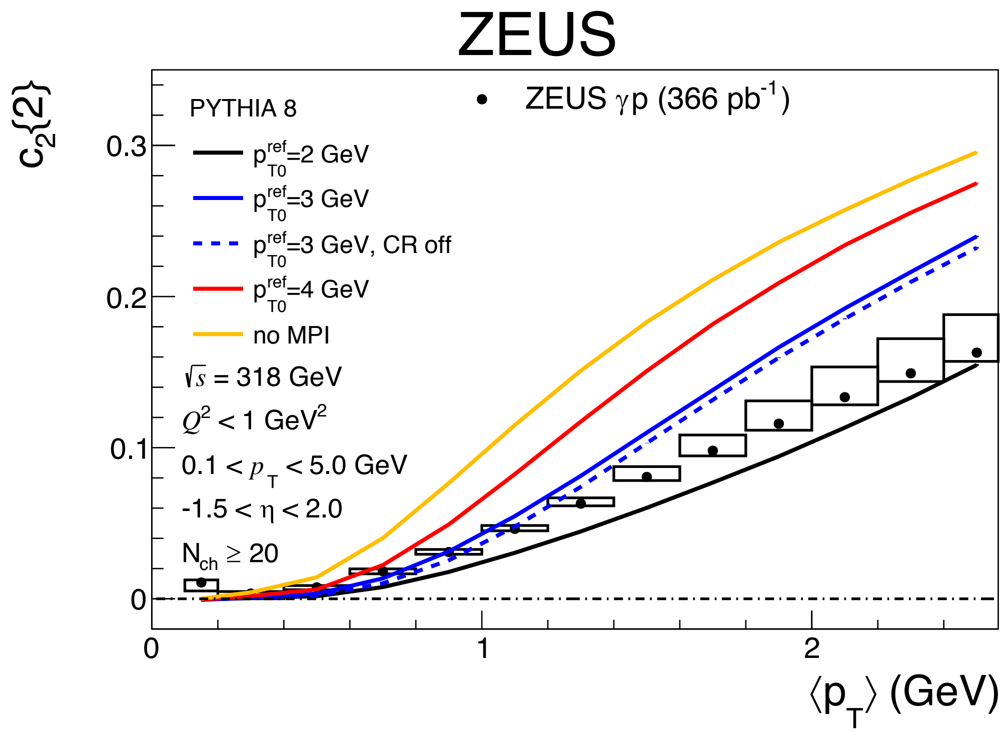
Positive (and decreasing) c_2

Short range correlation unrelated to collective fluidodynamics behaviour expected to **decrease with rapidity cut.**

C_1 negative much more than C_2 is positive, in constrast to heavy-ion collisions

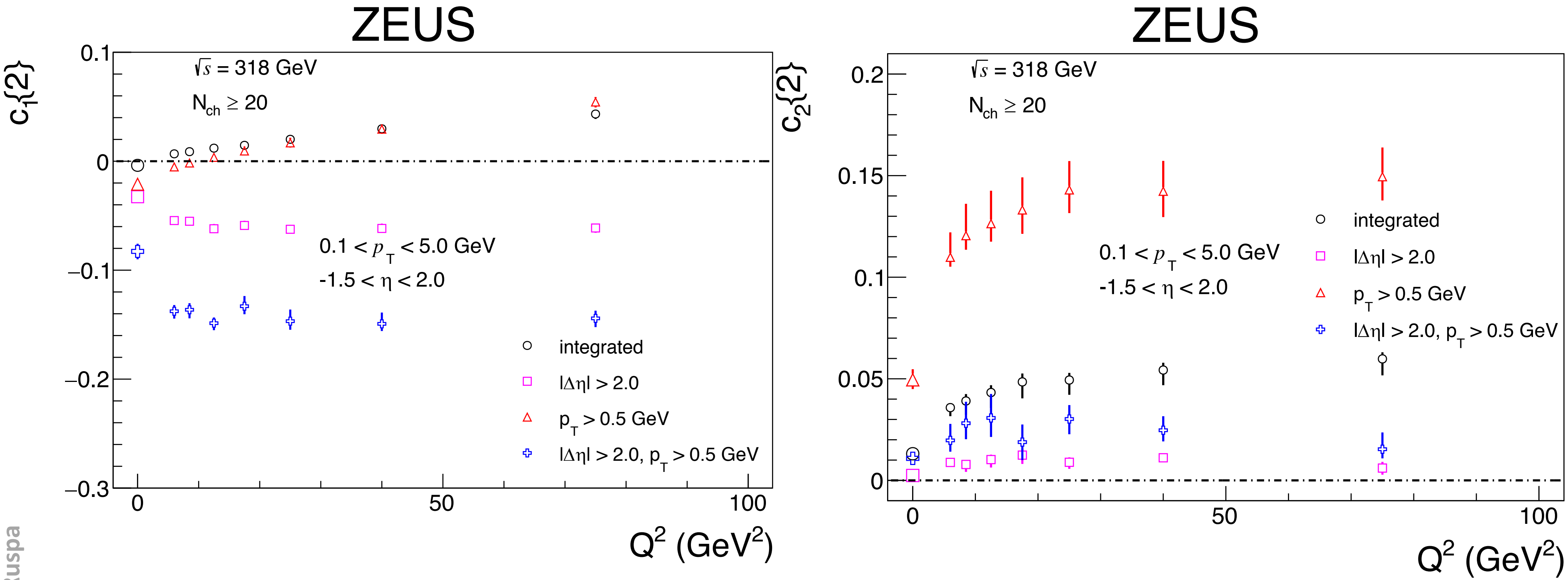
2-particle cumulants in photoproduction



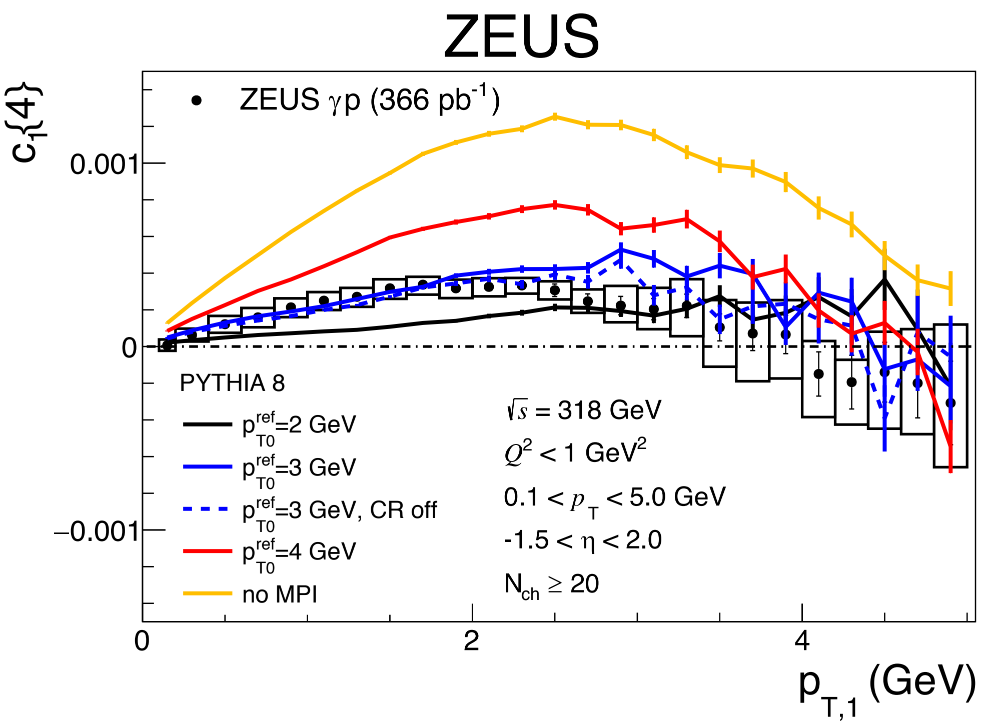


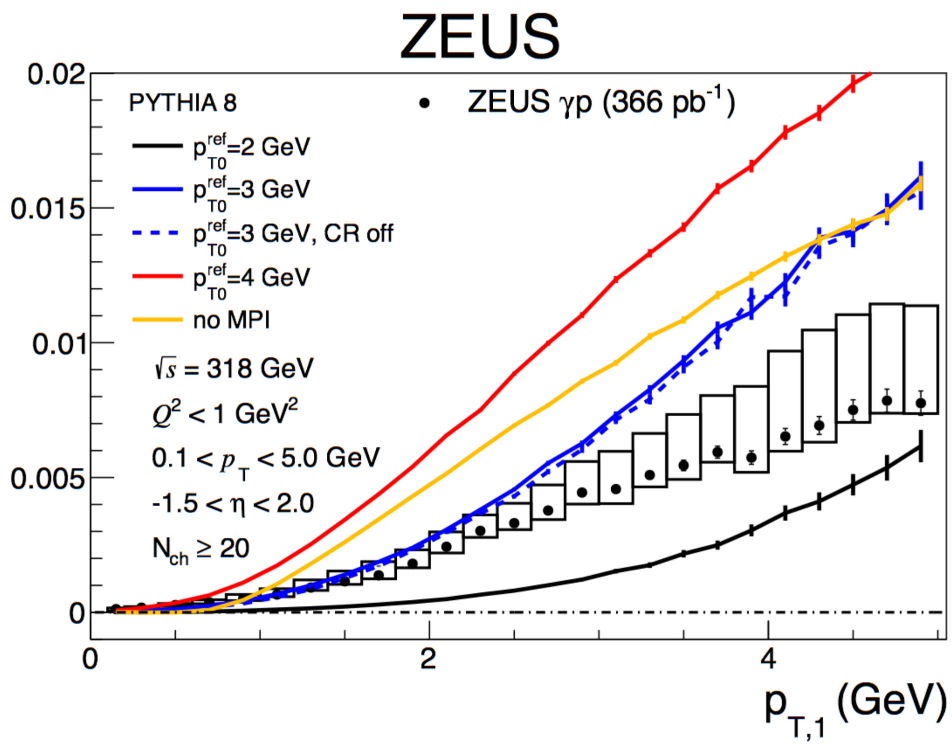
Correlation strenght grows with increasing p_T

From photoproduction to DIS
Long-range, high p_T



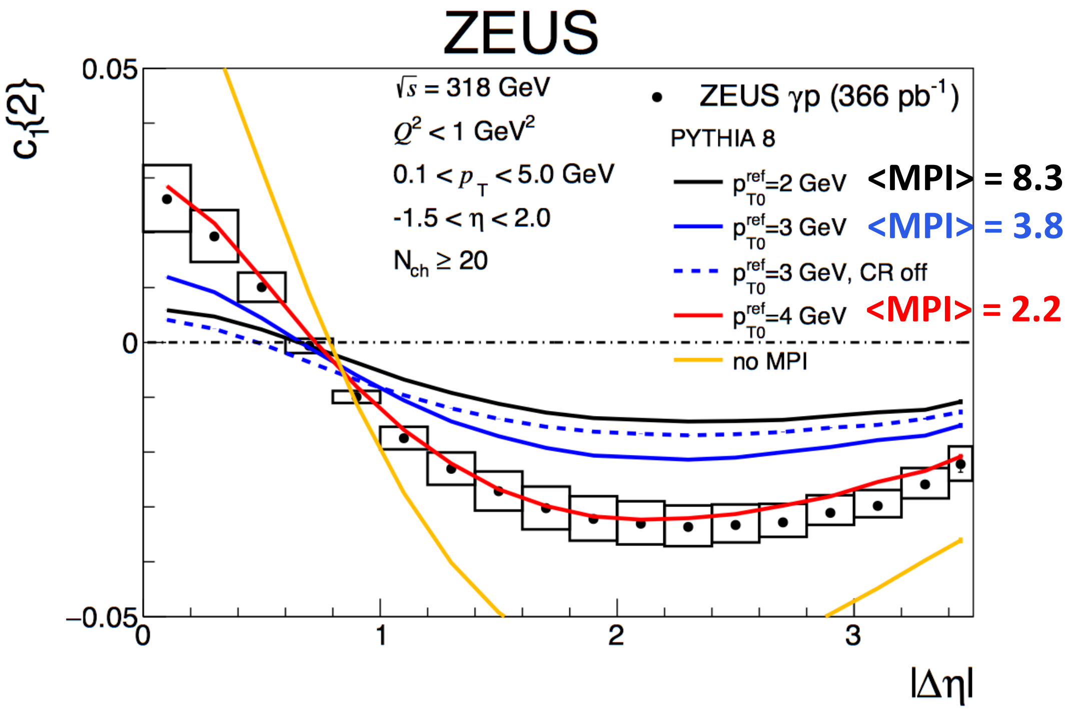
4-particle cumulants in photoproduction

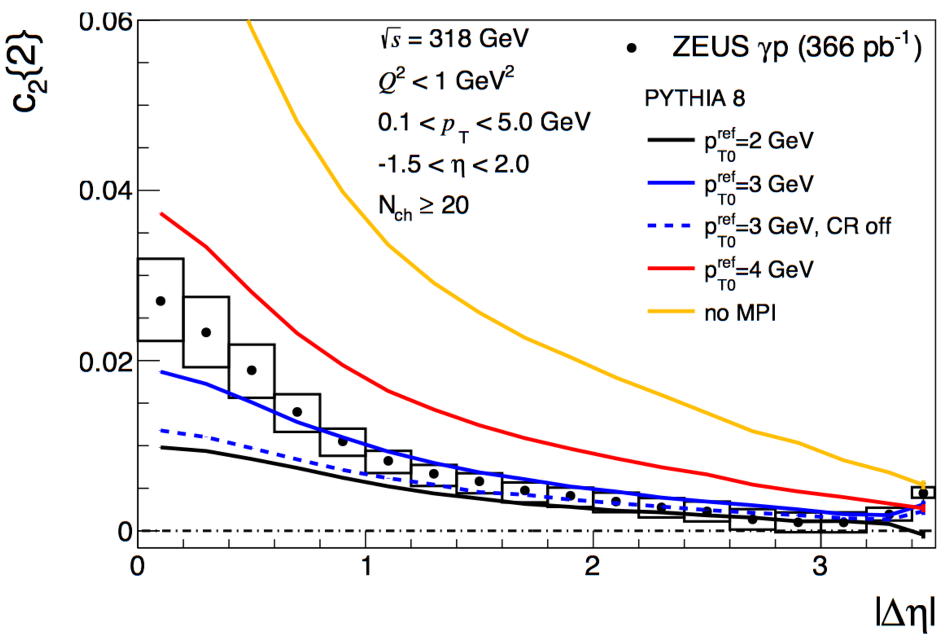




4-particle cumulant is mostly positive, in contrast to heavy-ion collisions

Sensitivity to MPI in photoprdocution



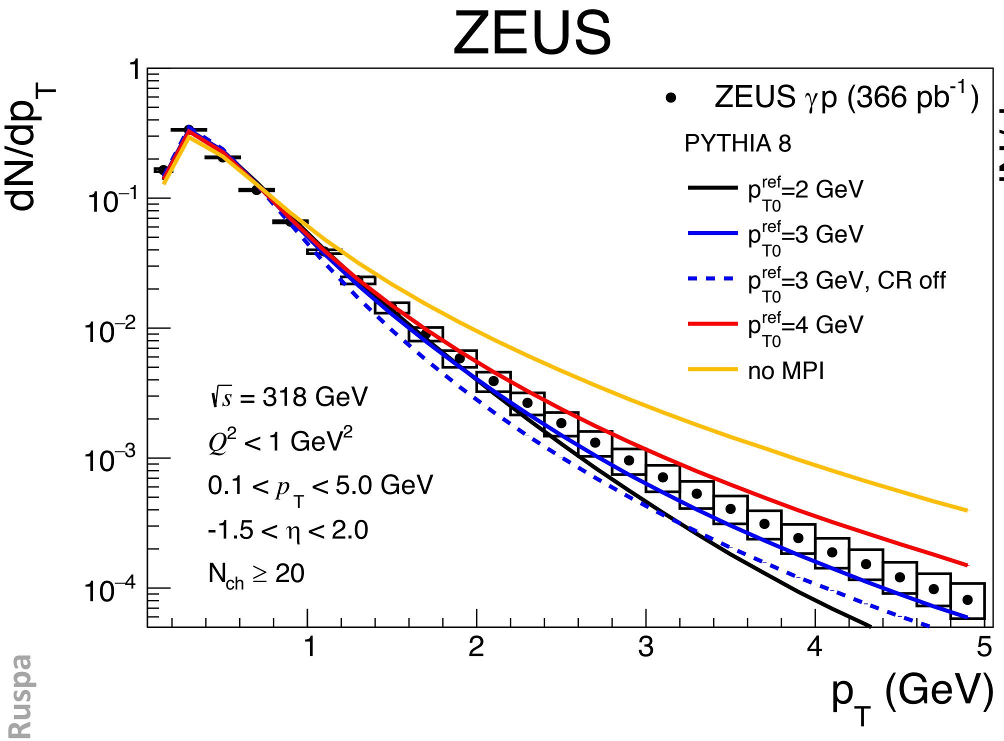


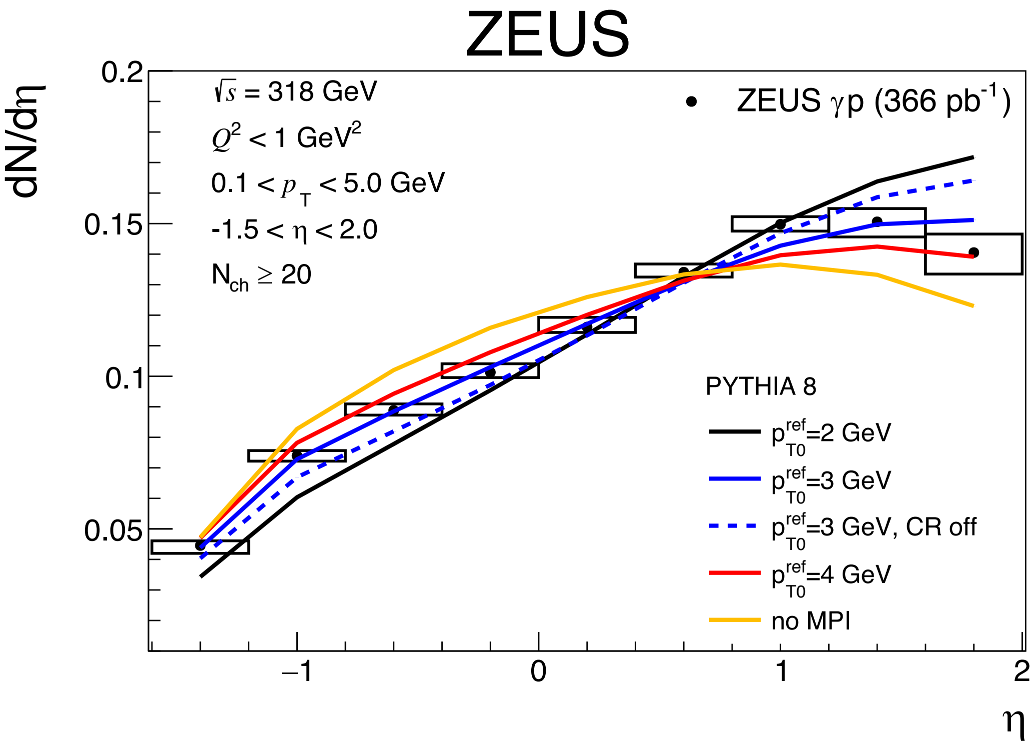
Mean number of MPI in PYTHIA 8 ranges from 2 to 8

NO-MPI and many MPI disfavoured

Correlations more pronounced with more MPI

Particle multiplicities





The inclusion of MPI in PYTHIA generally increases the number of events at high multiplicity and softens the p_T spectrum

The scenario in a snapshot

- Measurement of **charged-particle azimuthal correlations** by **ZEUS** in **DIS and photoproduction** do not show a long-range near-side ridge
  → **no collectivity**

- Data and correlation functions sensitive to the **number of MPI: a useful tool** to help understand the onset of collective behaviour?

- New insight on **particle-correlations in photon intiated scattering**
  → UPC at LHC and EIC

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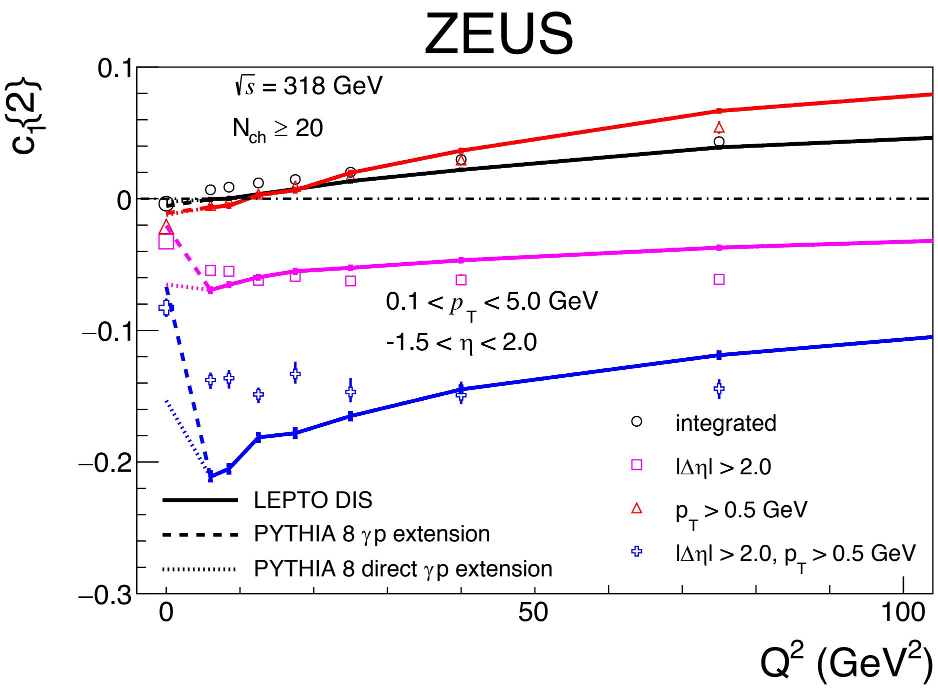
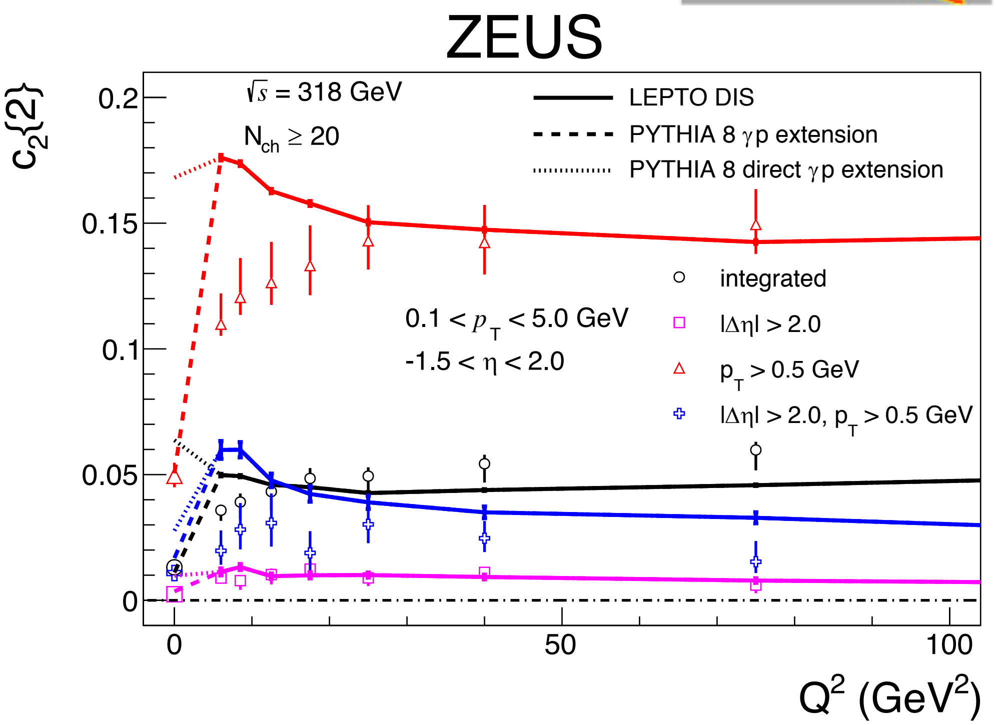
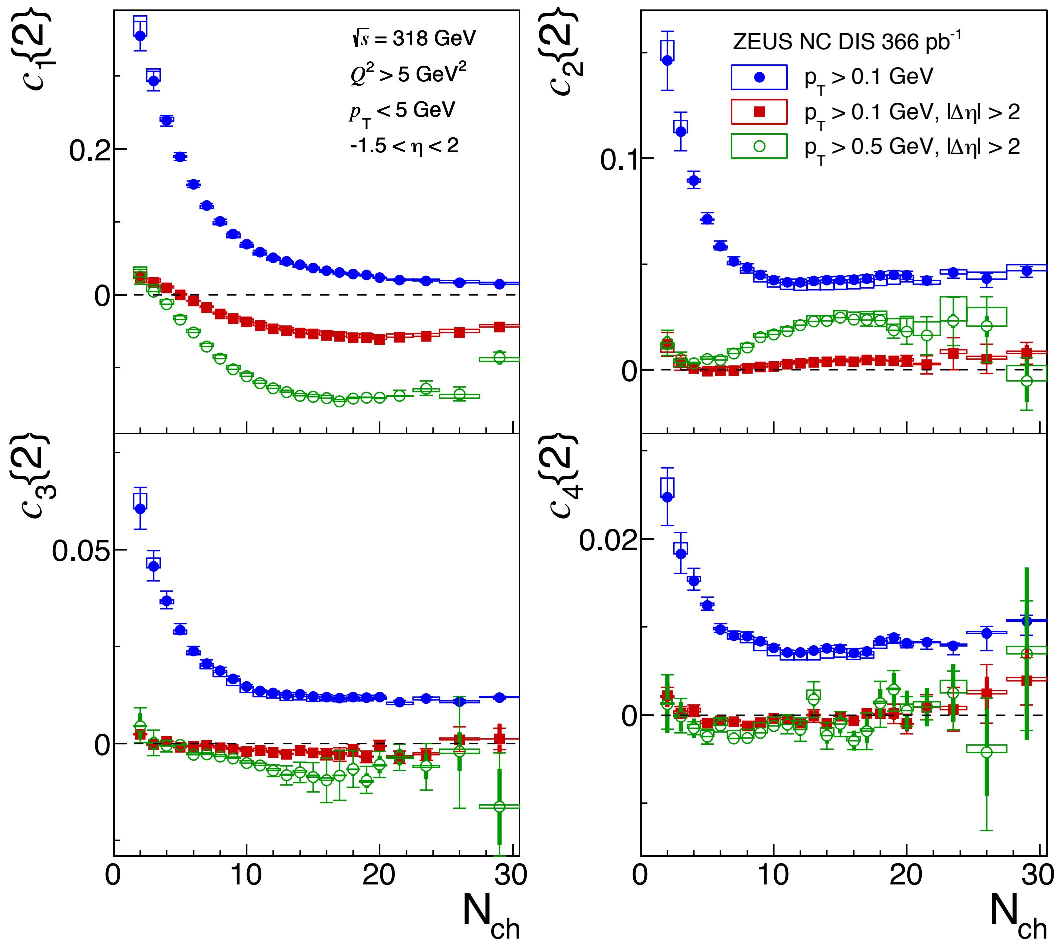
2-particle cumulants vs Q^2



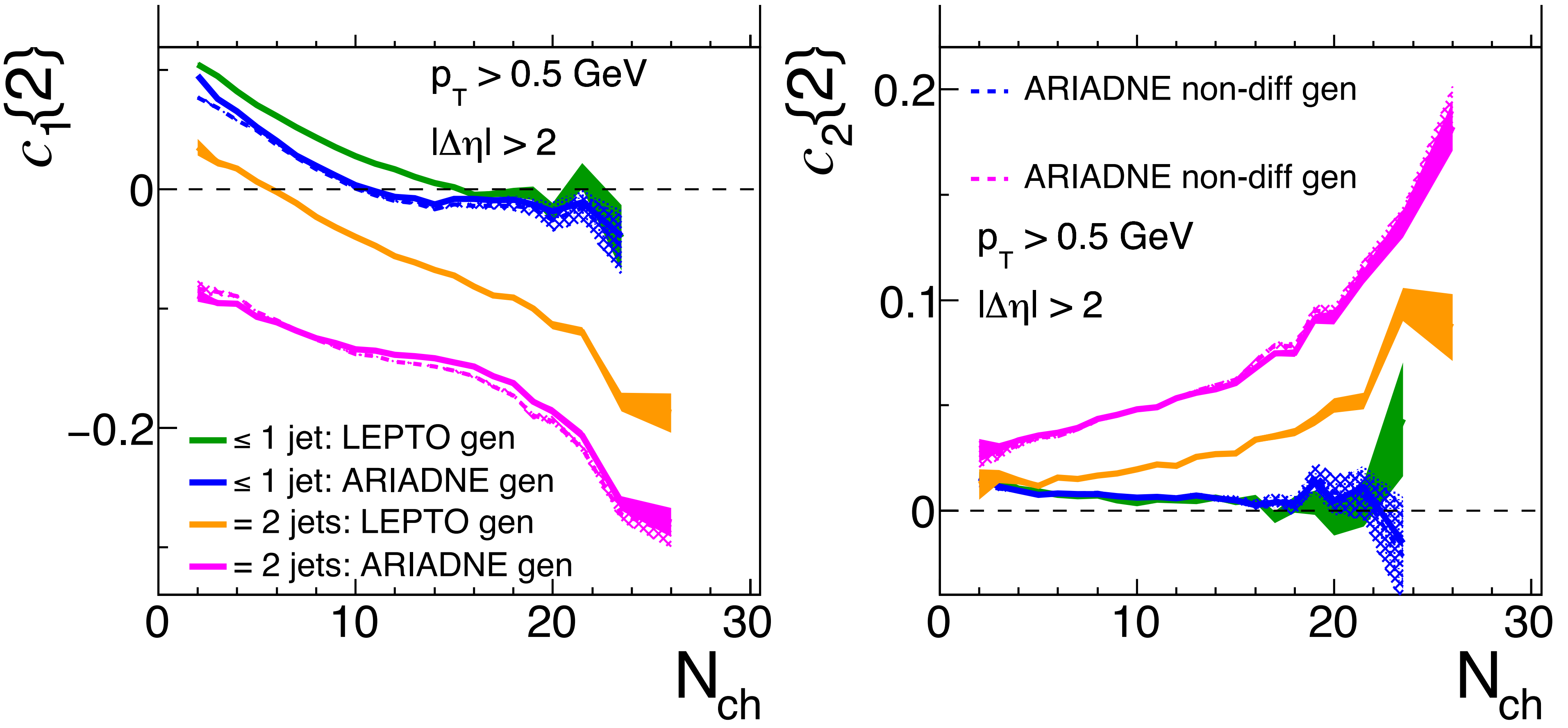


Resoved component in PYTHIA 8 (3 GeV) with MPI improves description

ZEUS



$c_1\{2\}$
$c_2\{2\}$
$c_3\{2\}$
$c_4\{2\}$
$\sqrt{s}$ = 318 GeV
Q^2 > 5 GeV^2
p_T < 5 GeV
-1.5 < η < 2
ZEUS NC DIS 366 pb^{-1}
p_T > 0.1 GeV
p_T > 0.1 GeV, |Δη| > 2
p_T > 0.5 GeV, |Δη| > 2
0.2
0.1
0.05
0.02
0
10
20
30
N_{ch}



$c_1\{2\}$
$p_T > 0.5$ GeV
$|\Delta\eta| > 2$
0
−0.2
≤ 1 jet: LEPTO gen
≤ 1 jet: ARIADNE gen
= 2 jets: LEPTO gen
= 2 jets: ARIADNE gen
0
10
20
30
N_{ch}
$c_2\{2\}$
0.2
0.1
0
ARIADNE non-diff gen
ARIADNE non-diff gen
$p_T > 0.5$ GeV
$|\Delta\eta| > 2$
0
10
20
30
N_{ch}