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Collective effects in small collision systems from PYTHIA8 and EPOS4 simulations

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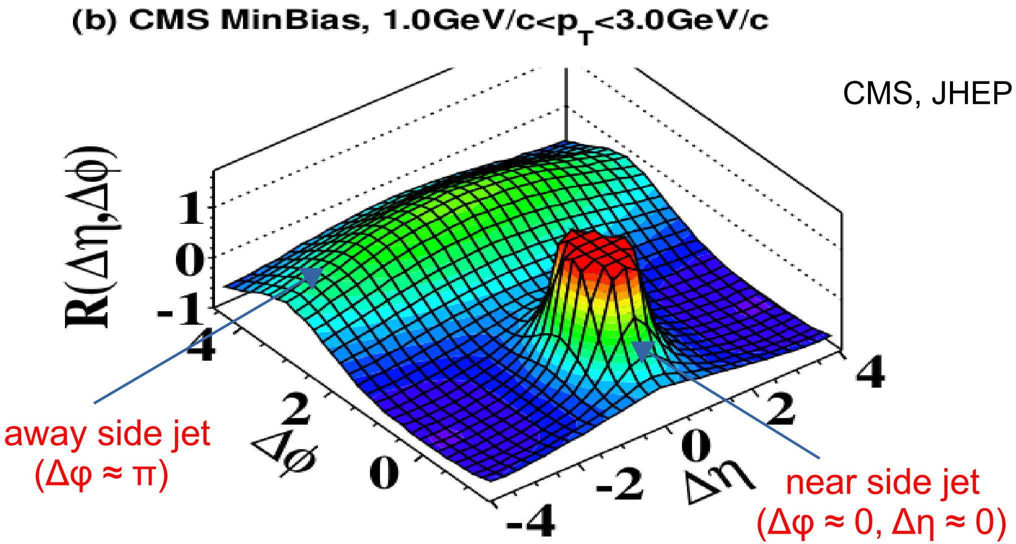
(Institute of Space Science – INFLPR Subsidiary)

Ridge in pp: first observation



CMS, JHEP 1009 (2010) 091

- Minimum bias pp
  - Nonflow contributions
    - Near-side jet peak (+resonances, HBT effects)
    - Recoil jet in away side

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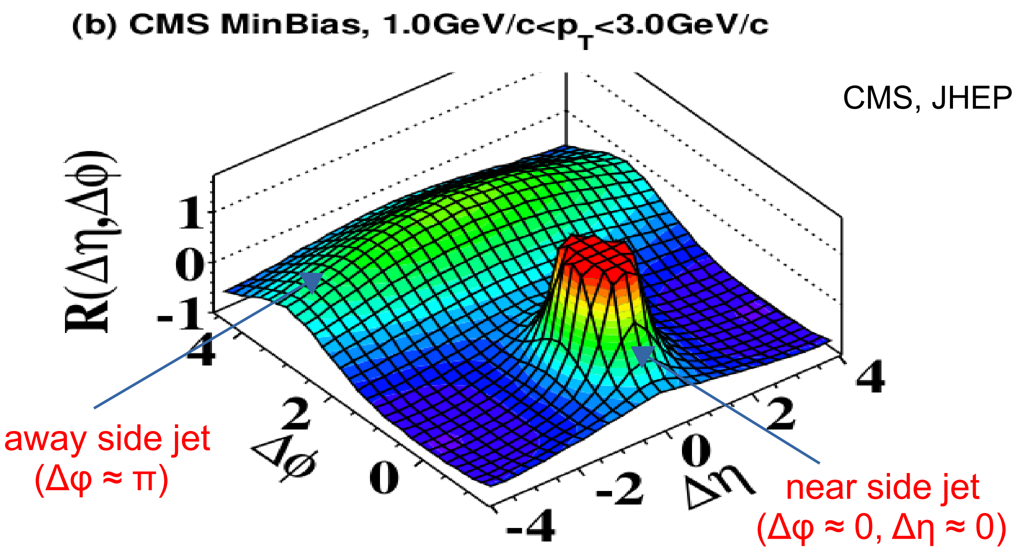
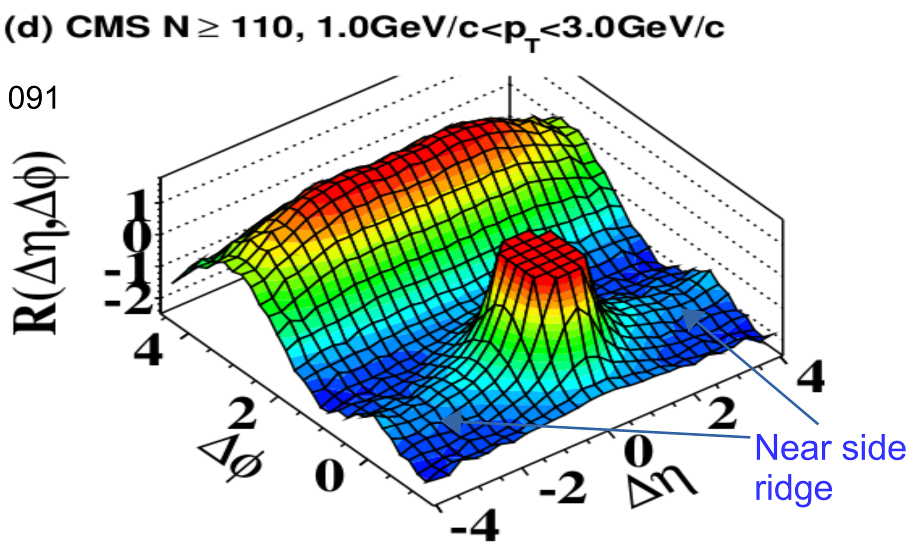


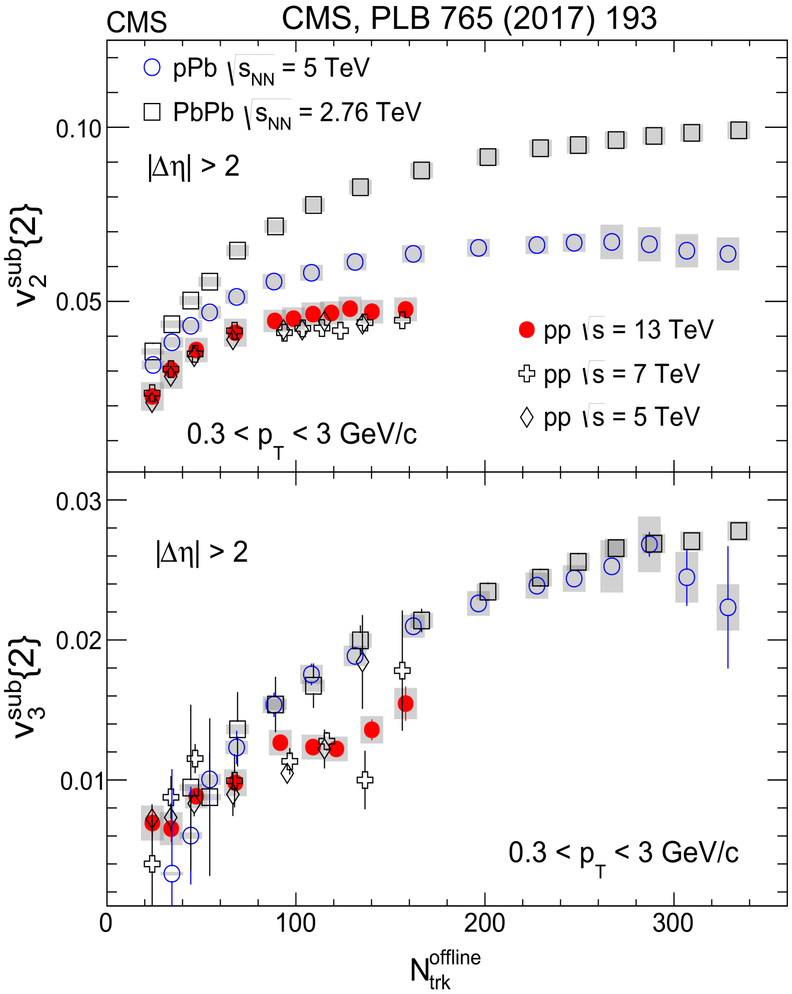


- Minimum bias pp
  - Nonflow contributions
    - Near-side jet peak (+resonances, HBT effects)
    - Recoil jet in away side

- High multiplicity pp
  - Near side ridge, typical of collective systems
    - Decomposed into Fourier harmonics

$$1+\sum_{n=1}^{\infty} 2 v_n \cos(n(\varphi-\Psi_n))$$

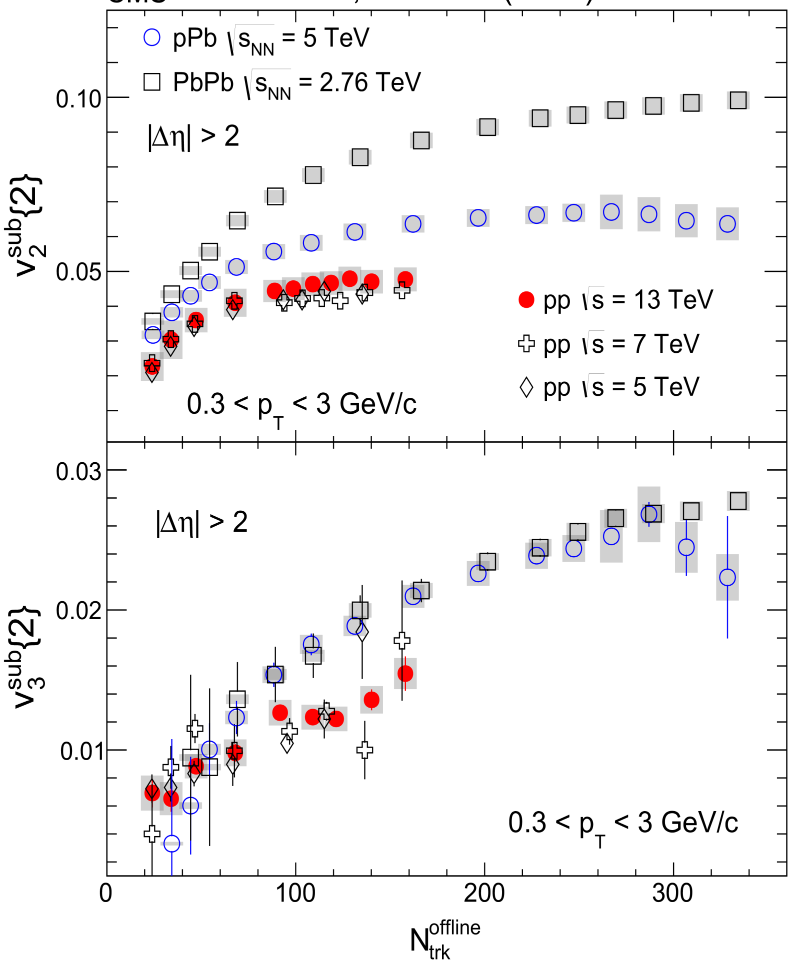
v_n coefficients

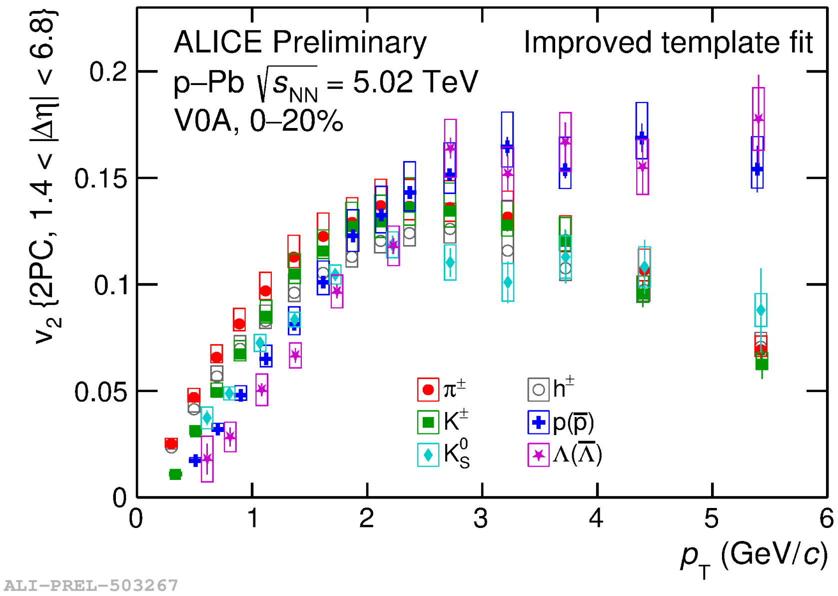


- v_n dependence on collision system but not on energy

v_n coefficients

CMS, PLB 765 (2017) 193





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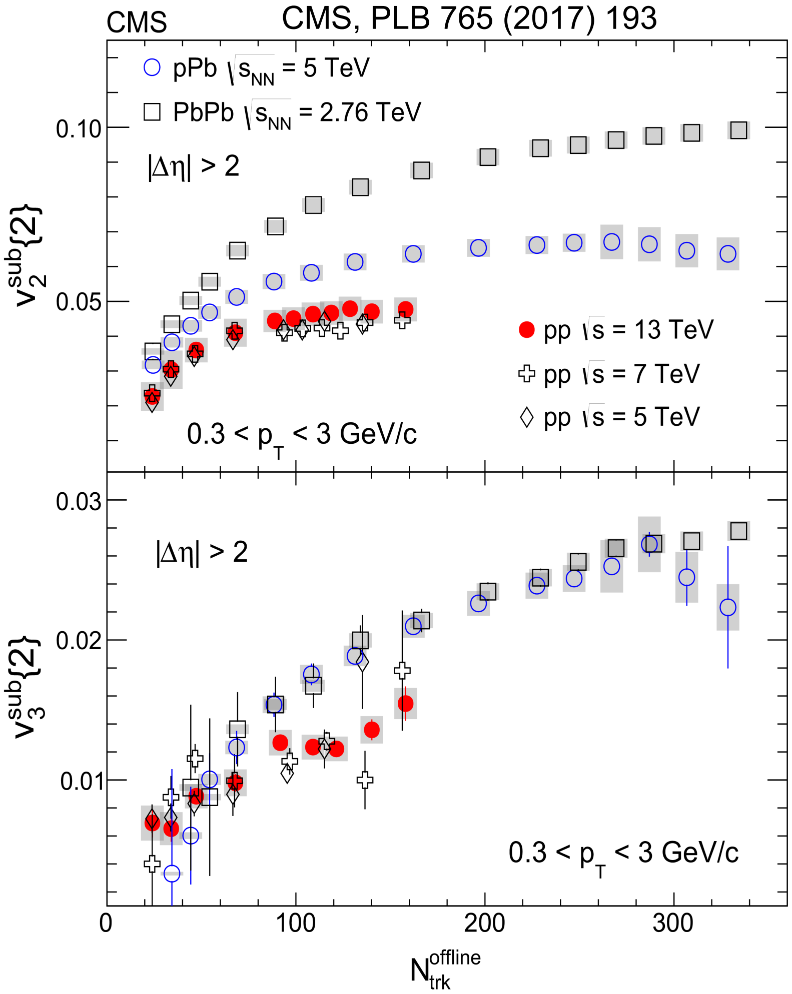
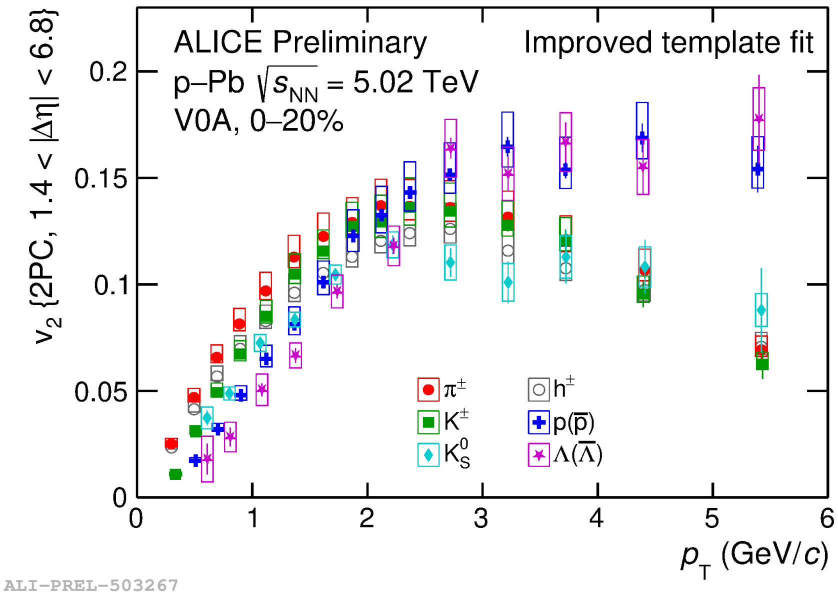
- Mass ordering observed in high multiplicity p-Pb and pp collisions
  - Test particle type dependence at high p_T

v_n coefficients





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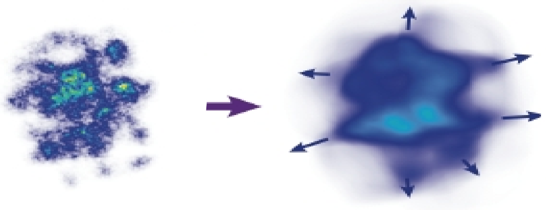
What is the origin of these collective effects?

Sources of collectivity

- Final state effects
  - Initial spatial eccentricities converted into momentum anisotropies via final state interactions
    - Hydrodynamics
    - Parton transport
    - Parton escape



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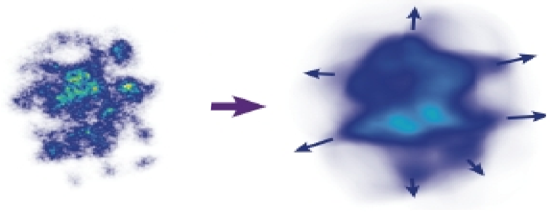

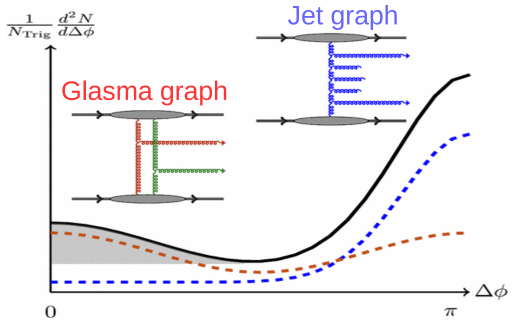

- Initial state effects
  - Initial momentum anisotropies from initial interactions
    - Color Glass Condensate (CGC) Glasma
    - Color-field domains

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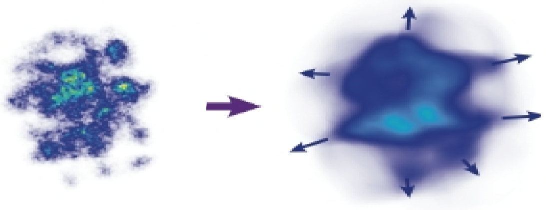

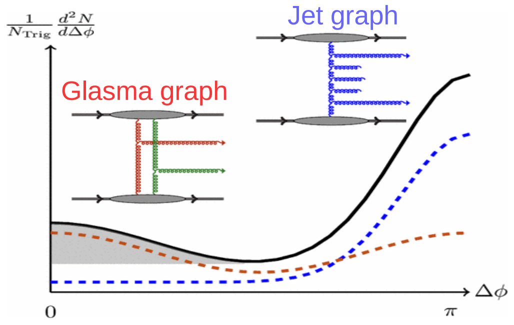

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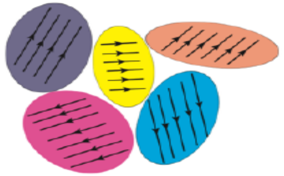
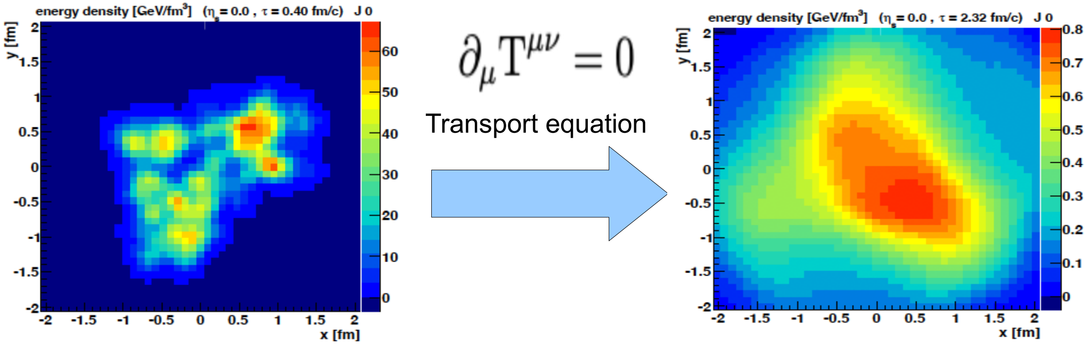


How to disentangle different regimes?

Our approach: macroscopic vs microscopic models

K. Werner, arXiv: 2306.10277



- Macroscopic model: EPOS4
  - Core–corona model with statistical hadronization
  - Collective effects from hydrodynamical evolution of the medium

Our approach:
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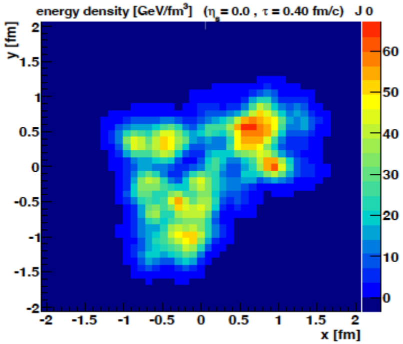
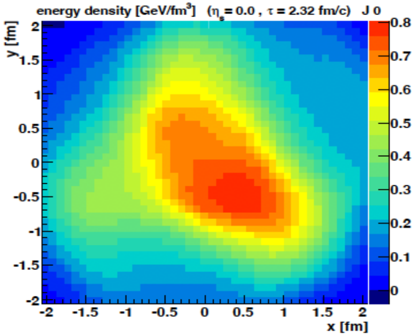
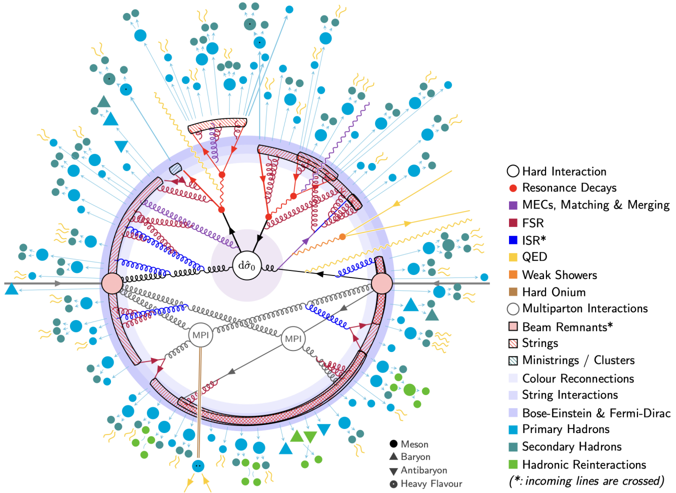


$$\partial_\mu T^{\mu\nu} = 0$$

Transport equation



C. Bierlich et al., arXiv: 2203.11601



- Macroscopic model: EPOS4
  - Core–corona model with statistical hadronization
  - Collective effects from hydrodynamical evolution of the medium
- Microscopic model: PYTHIA8
  - QCD strings with LUND fragmentation
  - Collective effects from new processes
    - Color reconnection, rope hadronization, ...

Methods

Scalar product method

$$v_n\{SP\}=\frac{\langle\langle u_{n,k}Q_n^*/M\rangle\rangle}{\sqrt{\langle Q_n^{*a}Q_n^{*b}/(M^aM^b)\rangle}}$$

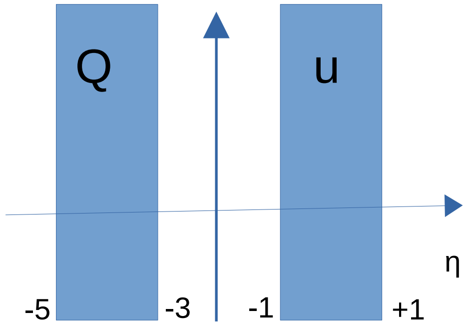
Particles of interest

$$u_{n,x}=\cos(n\varphi)$$
$$u_{n,y}=\sin(n\varphi)$$

Reference particles

$$Q_{n,x}=\sum_i\cos(n\varphi_i)$$
$$Q_{n,y}=\sum_i\sin(n\varphi_i)$$

S. Voloshin et al., arXiv:0809.2949



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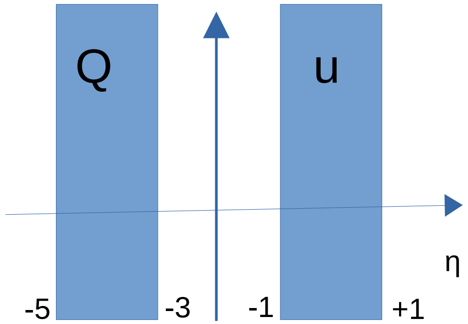
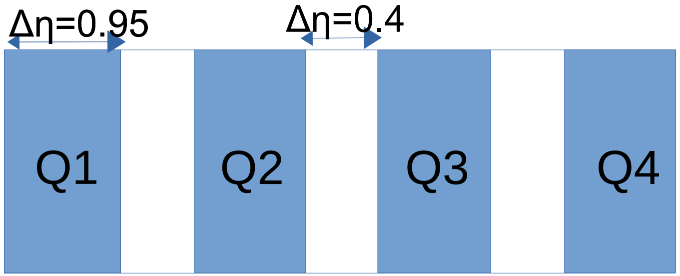


Cumulant method

- 2- and 4-particle azimuthal correlations for an event
- Averaging over all events → 2^{nd} and 4^{th} order cumulants

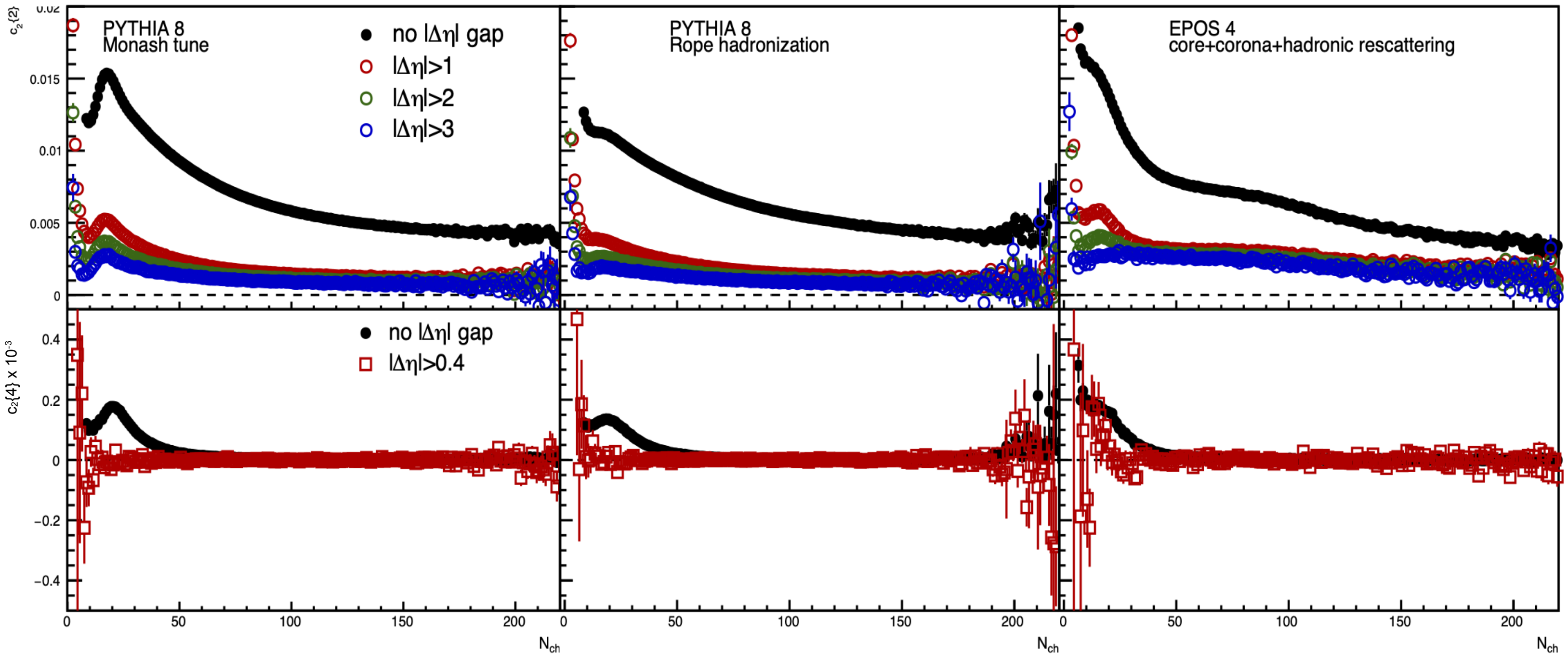
$$c_n\{2\}=\langle\langle 2\rangle\rangle=v_n^2$$
$$c_n\{4\}=\langle\langle 4\rangle\rangle-2\langle\langle 2\rangle\rangle^2=-v_n^4$$



A. Bilandzic et al., PRC 83, 044913 (2011)
J. Jia et al., PRC 96, 034906 (2017)

Results
pp at 13.6 TeV

$c_2\{2\}$ and $c_2\{4\}$

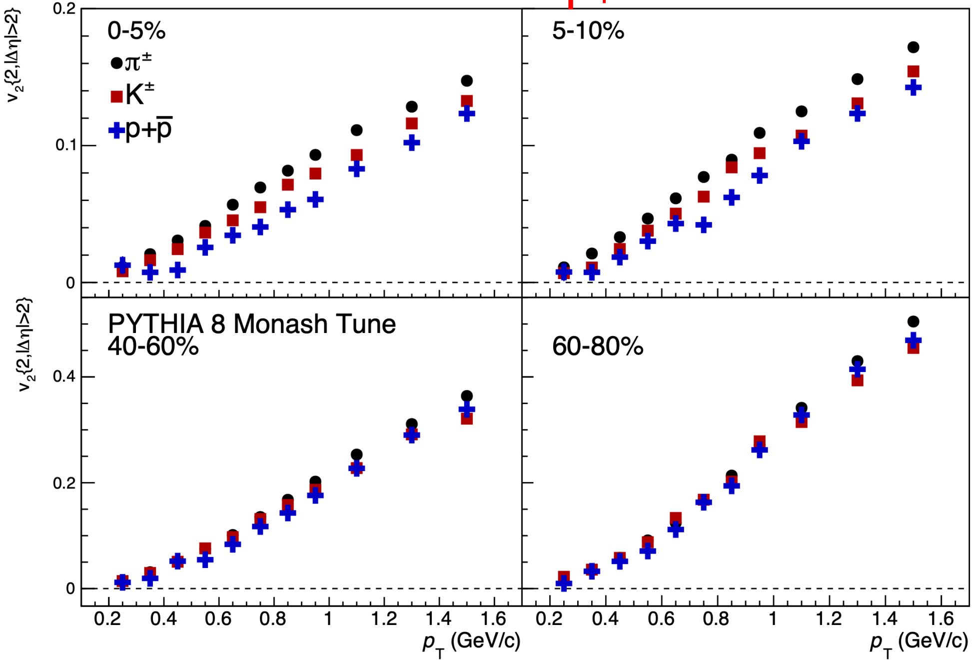


- $c_2\{2\}$ dependence with $|\Delta\eta|$ gap and multiplicity
- Differences between EPOS4 and PYTHIA8

- $c_2\{4\}$ dependence with multiplicity for $N_{ch} < 50$
- $c_2\{4\} \sim 0$ at high multiplicity

$v_2\{2, |\Delta\eta|>2\}$
PYTHIA8 Monash tune

Low p_T



- Mass ordering at low p_T at high multiplicity
- Evolution with multiplicity class

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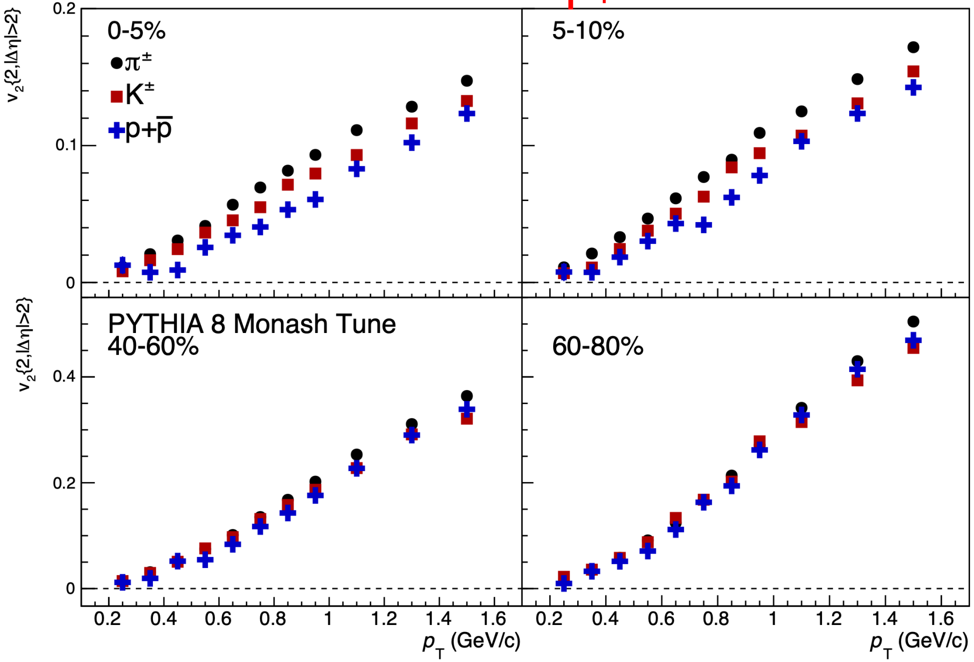

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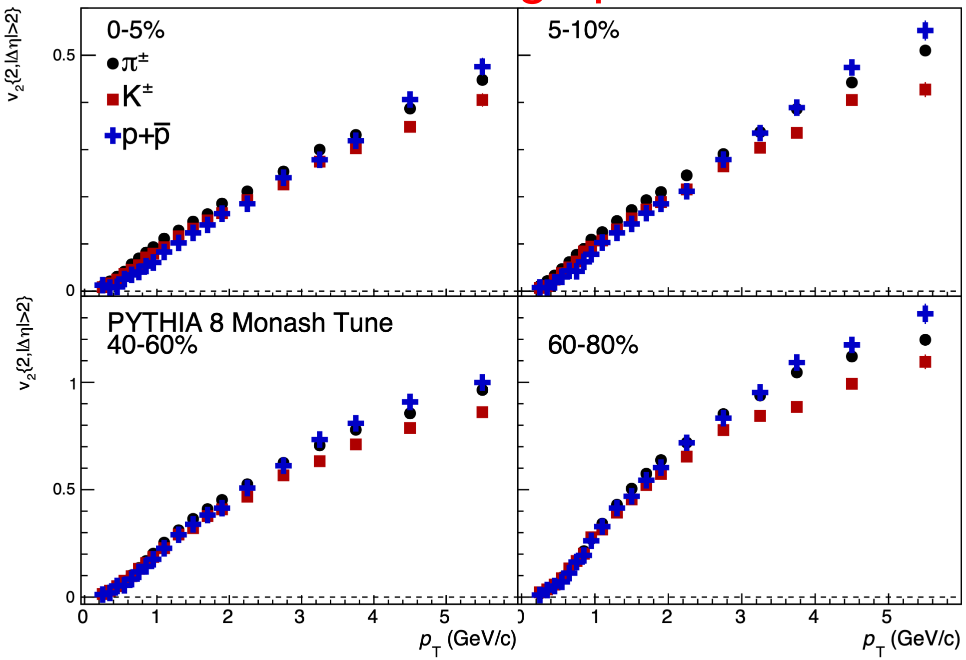

- Mass ordering at low p_T at high multiplicity
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- Crossing between meson and baryon v_2
- No particle type grouping

$v_2\{2, |\Delta\eta|>2\}$
PYTHIA8 rope hadronization

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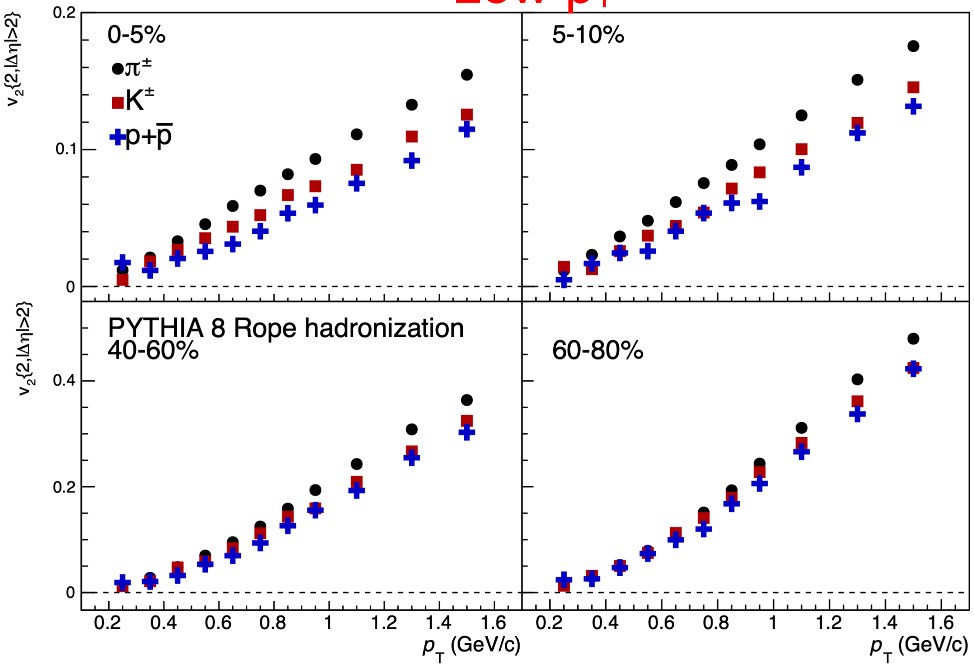

- Mass ordering at low p_T
  - More enhanced compared with Monash tune results
- Difference between rope hadronization and Monash tune

$v_2\{2, |\Delta\eta|>2\}$ PYTHIA8 rope hadronization

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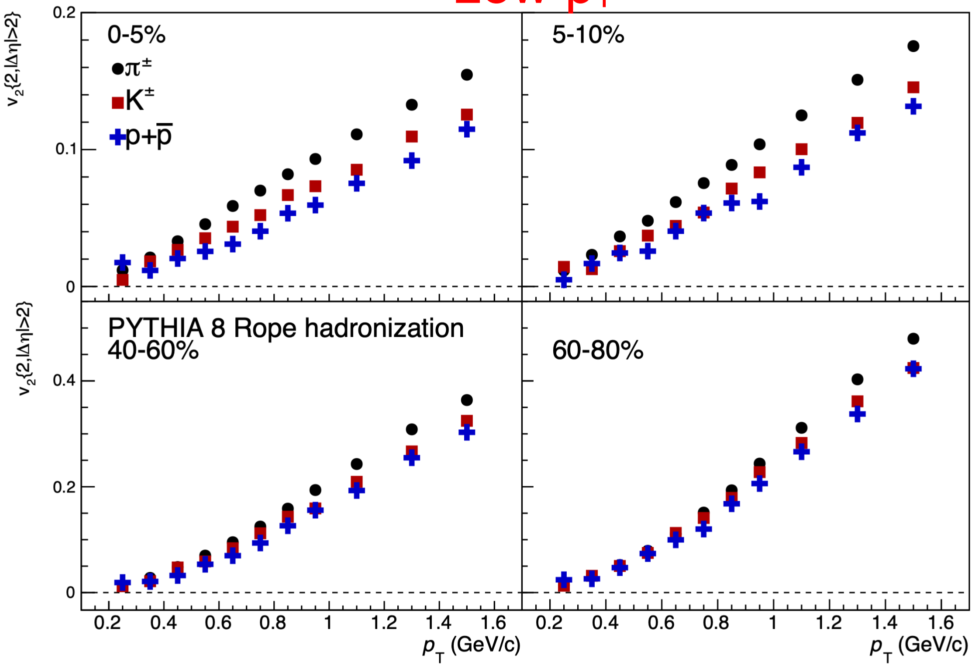

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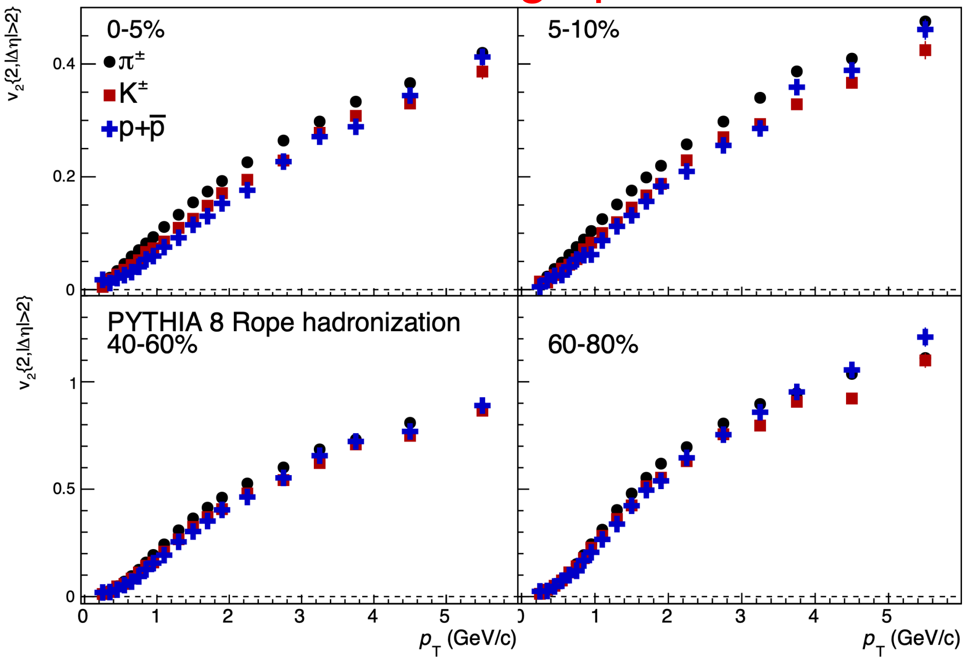

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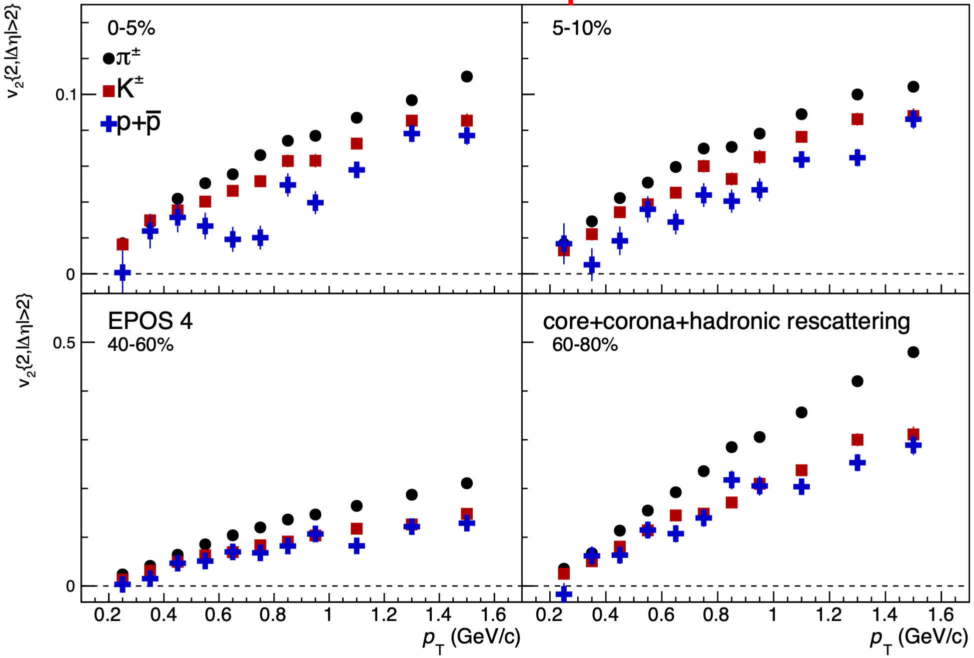
$v_2\{2, |\Delta\eta|>2\}$ EPOS4 core+corona+hadronic afterburner

Low p_T



- Mass ordering at low p_T
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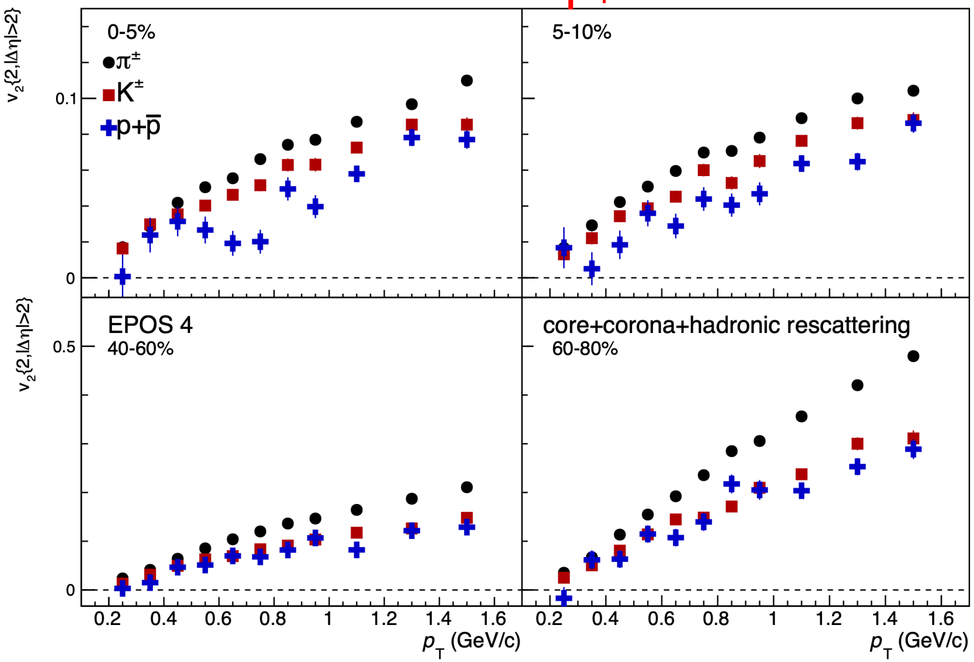

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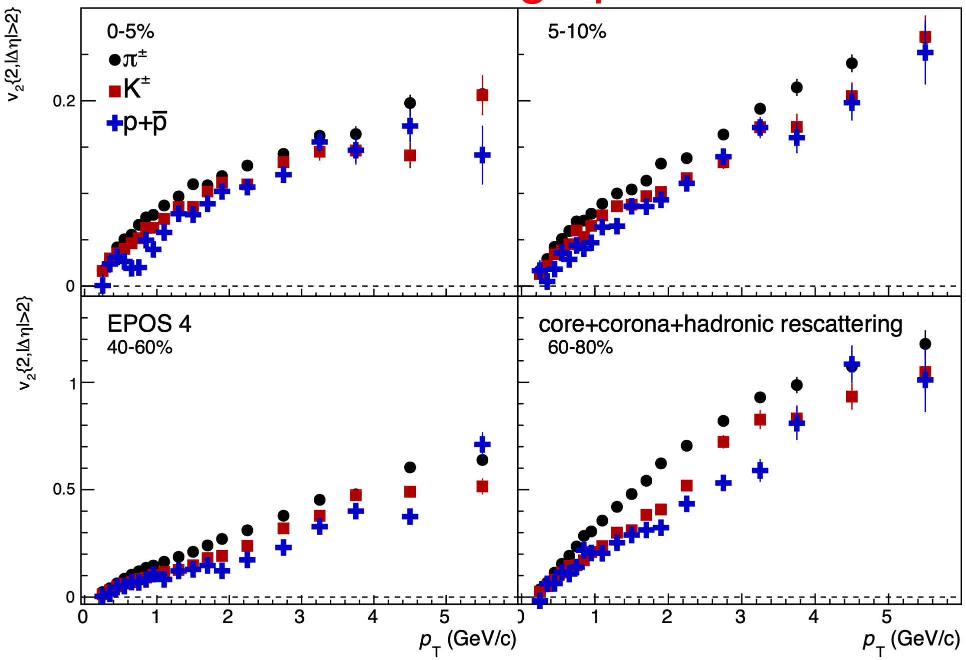

- Mass ordering at low p_T
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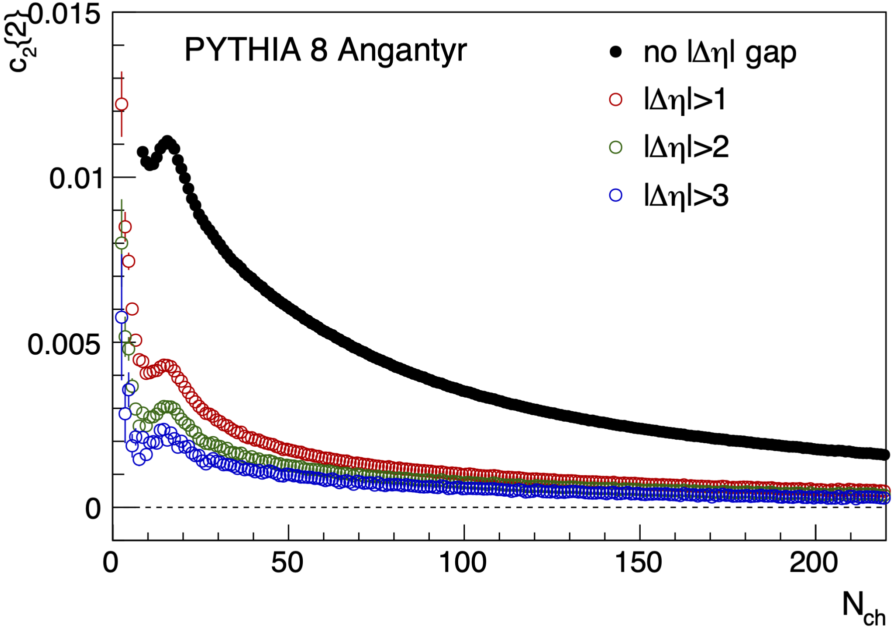
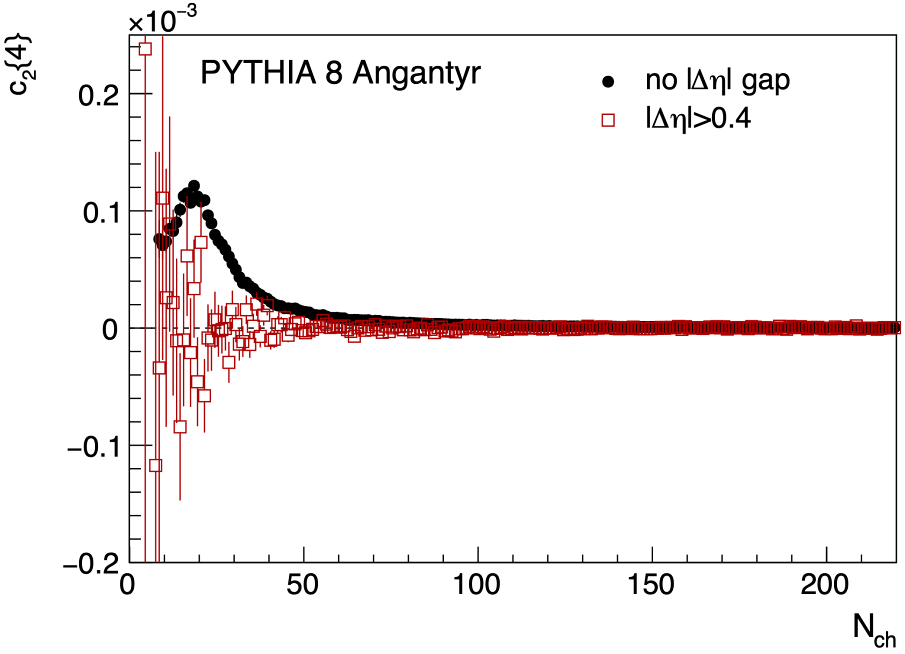
Results
p–Pb at 5.02 TeV

$c_2\{2\}$ and $c_2\{4\}$





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- Similarities between pp and p–Pb results

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$v_2\{2, |\Delta\eta|>2\}$ PYTHIA8 Angantyr

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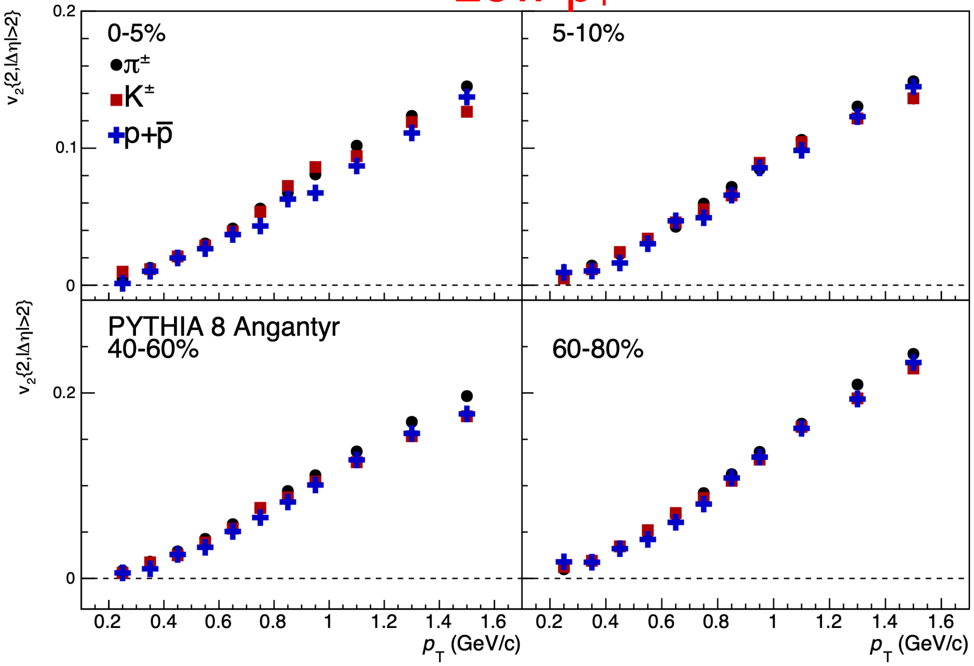
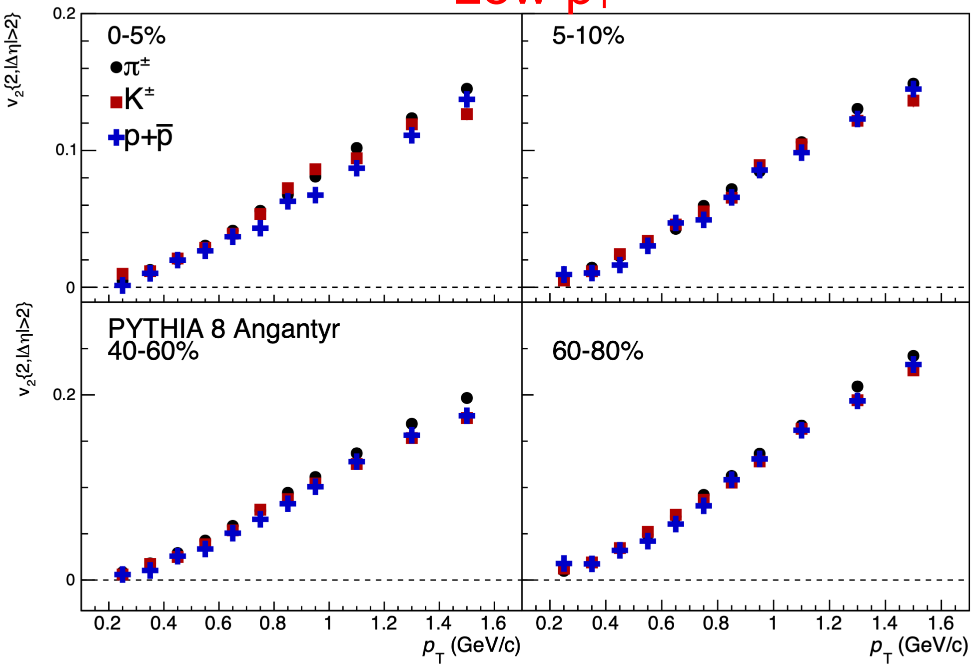


- Heavier particles have smaller v_2 than the lighter ones
- Similarities between multiplicity classes

$v_2\{2, |\Delta\eta|>2\}$ PYTHIA8 Angantyr

Low p_T



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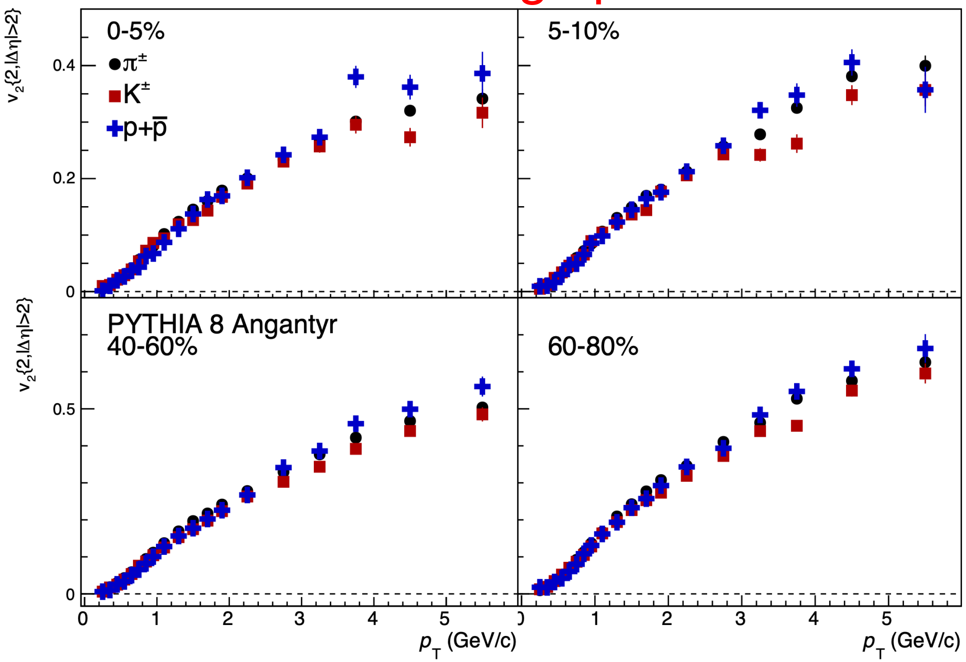

- Heavier particles have smaller v_2 than the lighter ones
- Similarities between multiplicity classes

- Crossing between pion and proton v_2
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Summary

- Investigate collective effects in EPOS4 and PYTHIA8 simulations
  - $c_2\{2\}$ dependence with $|\Delta\eta|$ gap and multiplicity
  - $c_2\{4\} \sim 0$ at high multiplicity
  - Mass ordering and crossing between pion and proton v_2
    - Evolution with multiplicity classes in both models