Collective effects in PYTHIA 8 simulations of pp and p-Pb collisions

C. Brandibur, A. Danu, A. Dobrin, A. Manea

Institute of Space Science (RO)

INSTITUTE OF SPACE SCIENCE
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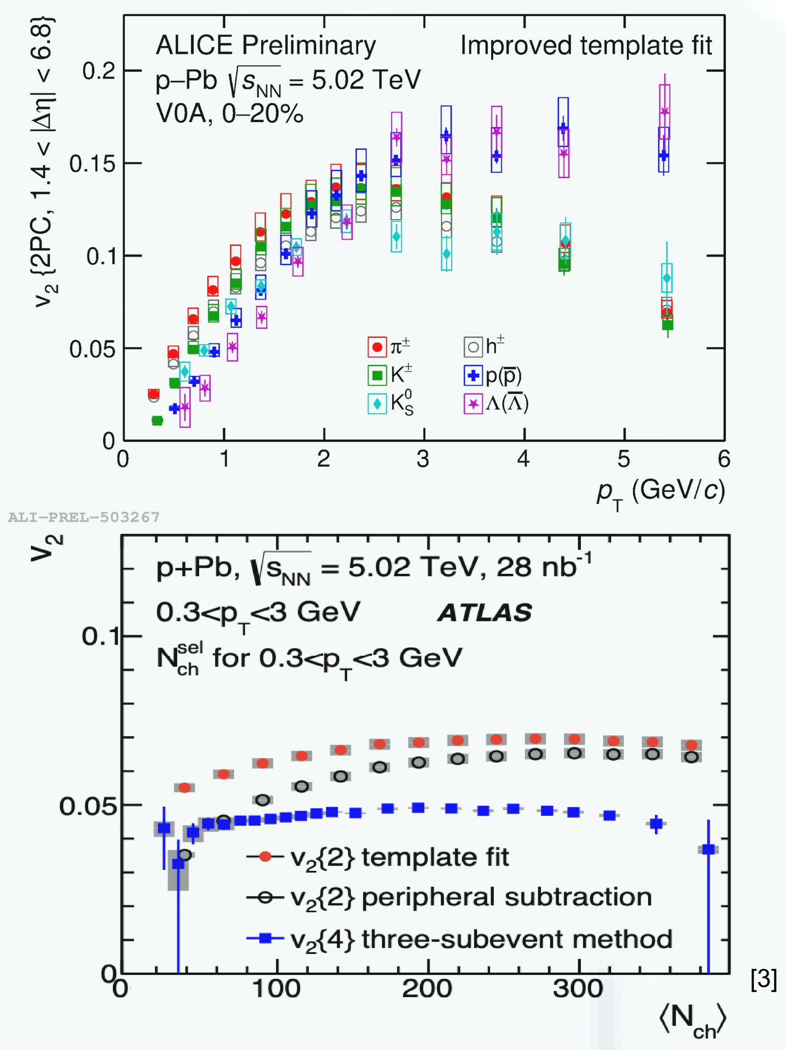
Introduction



- Collective effects in small collision systems
  - Final state effects (Hydrodynamics, Parton escape)
  - Initial state effects (Color Glass Condensate Glasma, Color-field domains)

How to disentangle initial vs final state effects?

- Scalar product (SP) method [4]

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

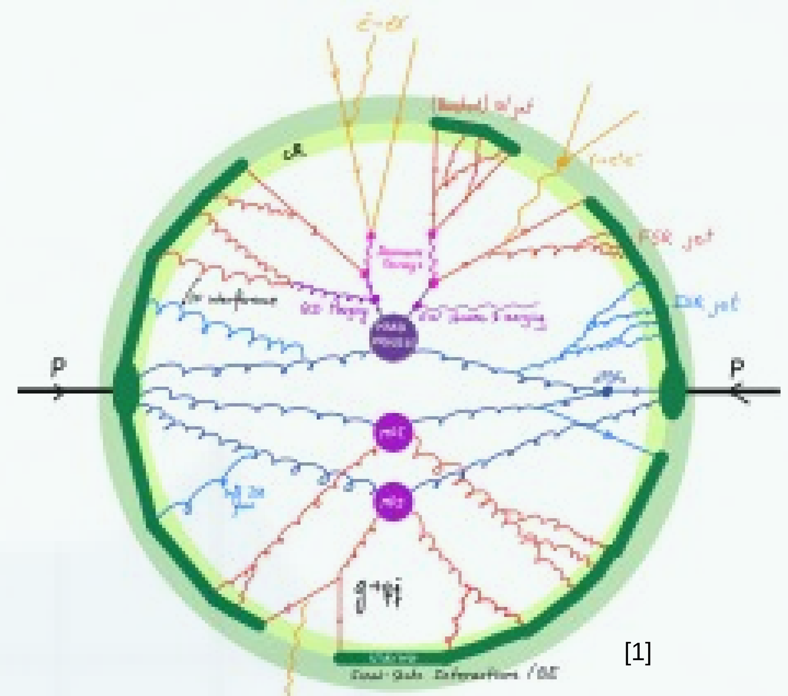
Particle of Interest	Reference Particles
$u_{n,x}=\cos(n\varphi)$	$Q_{n,x}=\sum_i \cos(n\varphi_i)$
$u_{n,y}=\sin(n\varphi)$	$Q_{n,y}=\sum_i \sin(n\varphi_i)$

- Cumulants [5]
  - 2- and 4-particle azimuthal correlations for an event

$$\langle 2\rangle \equiv \langle \cos(n(\varphi_i-\varphi_j))\rangle, i\neq j$$
$$\langle 4\rangle \equiv \langle \cos(n(\varphi_i+\varphi_j-\varphi_k-\varphi_l))\rangle, i\neq j\neq k\neq l$$

  - Averaging over all events → 2nd and 4th order cumulants

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

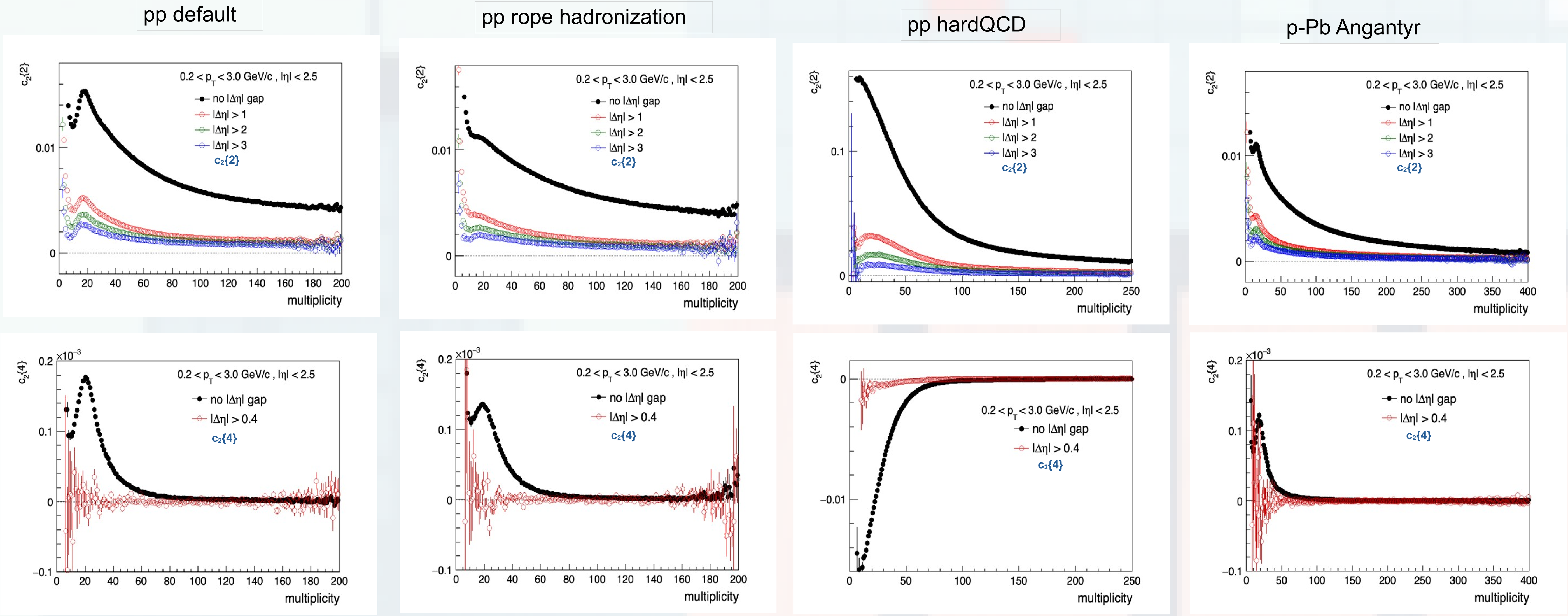


[1]

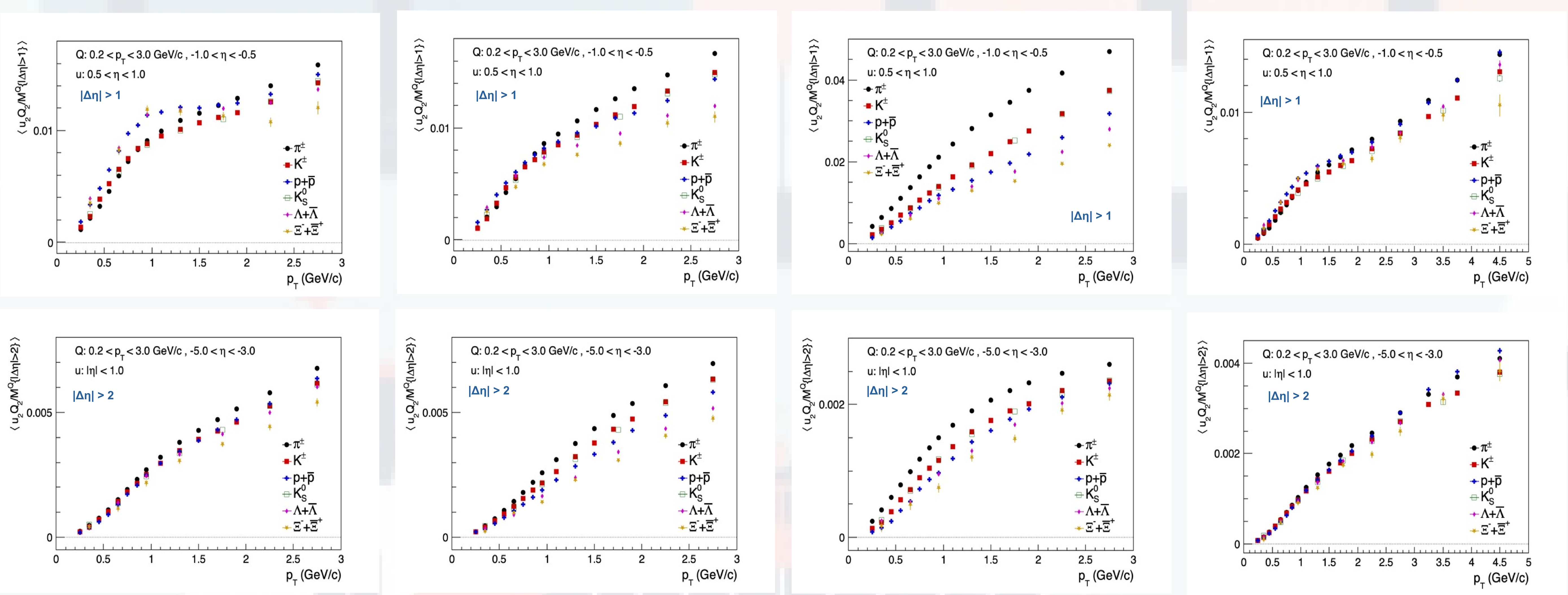
Microscopic model: PYTHIA8 [2]
- QCD strings with LUND fragmentation
- Collective effects from new processes
  - Color reconnection, rope hadronization, ...

Results: pp @ 13.6 TeV and p-Pb @ 5.02

pp default | pp rope hadronization | pp hardQCD | p-Pb Angantyr



- $c_2\{2\} > 0$ and $c_2\{4\} \sim 0$ at high multiplicities
  - Small dependence on |Δη| gap for $c_2\{2\}$
  - $c_2\{4\} \sim 0$ → expected for Gaussian fluctuations
- Differences between pp default, hardQCD and rope hadronizaton
- Similar trends in pp and p-Pb default



- Differences between pp default, hardQCD and rope hadronizaton
- Similar trends in pp and p-Pb default
- Small mass ordering for large |Δη| gap
  - More pronounced for rope hadronization and hardQCD
- Crossing between proton and pion u_2Q_2 for large |Δη| gap in p-Pb
  - No particle type grouping

Summary

- $c_2\{2\}$ decreasing with increasing multiplicity and |Δη| gap
  - Small dependence on |Δη| gap
- $c_2\{4\} \sim 0$ at high multiplicities
  - Expected for Gaussian fluctuations
- Mass ordering for u_2Q_2 when a large |Δη| gap is employed
  - Crossing between pions and protons u_2Q_2 in PYTHIA 8 Angantyr p-Pb simulations
    - No particle type grouping

References

[1] figure by P. Skands
[2] C. Bierlich et al., arXiv: 2203.11601
[3] ATLAS, PRC 97 (2018) 024904
[4] A. Bilandzic, PRC 83 (2011) 044913
[5] S. Voloshin et al., arXiv:0809.2949

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