Investigation of possible hadronic flow in p+Pb collisions at the LHC

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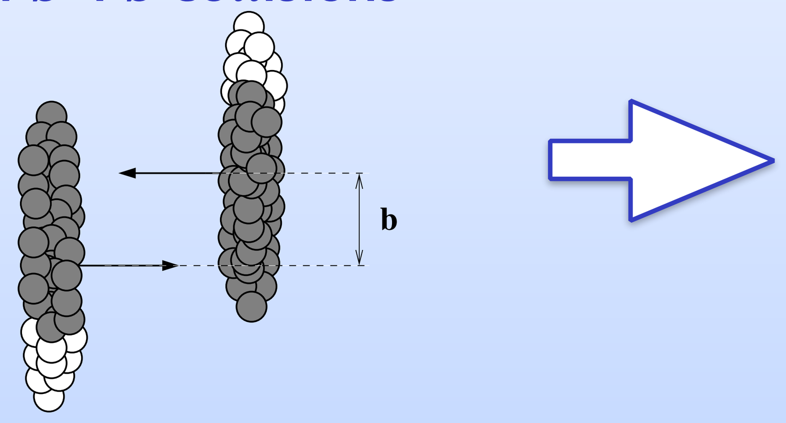
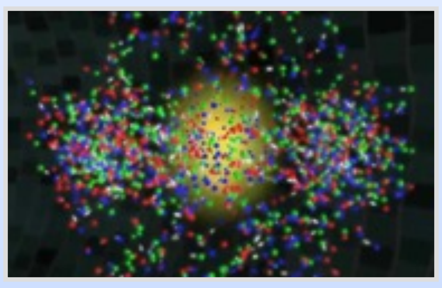
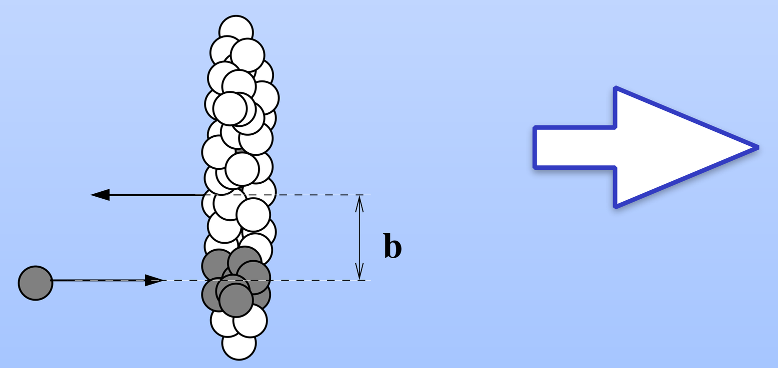
Pb+Pb collisions





Quark-Gluon Plasma

p+Pb collisions

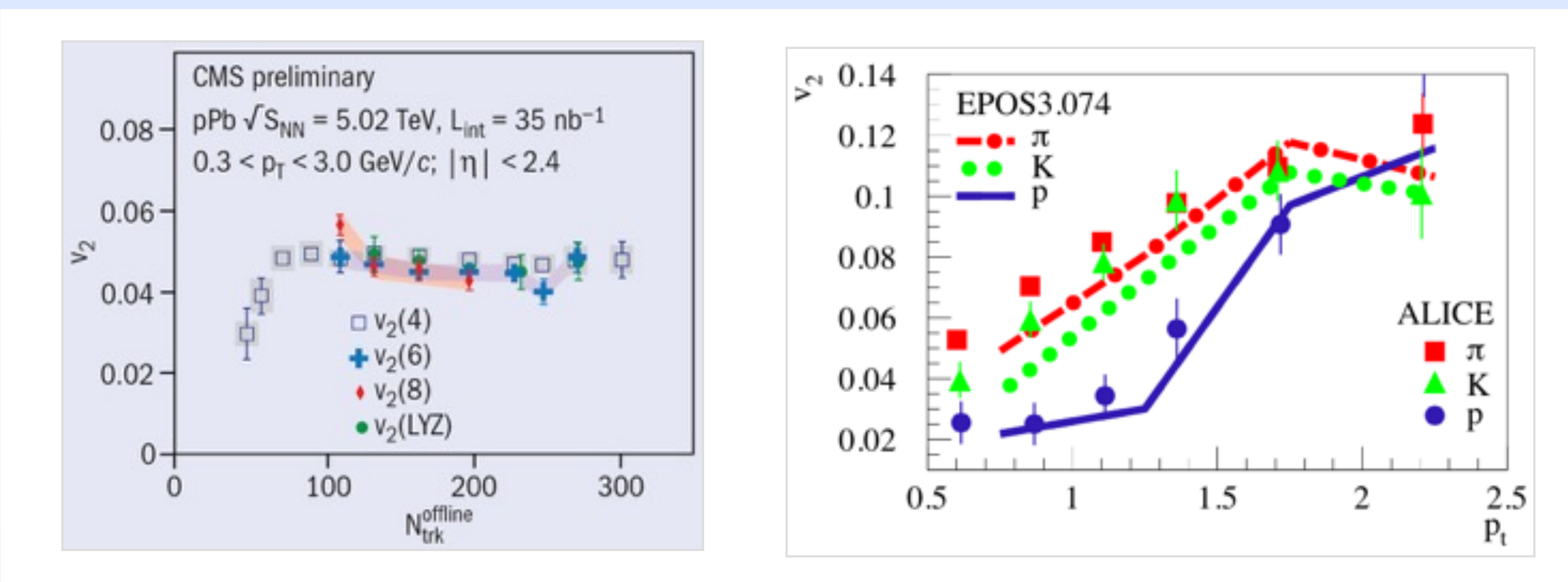


QGP? cold nuclear matter?

Introduction

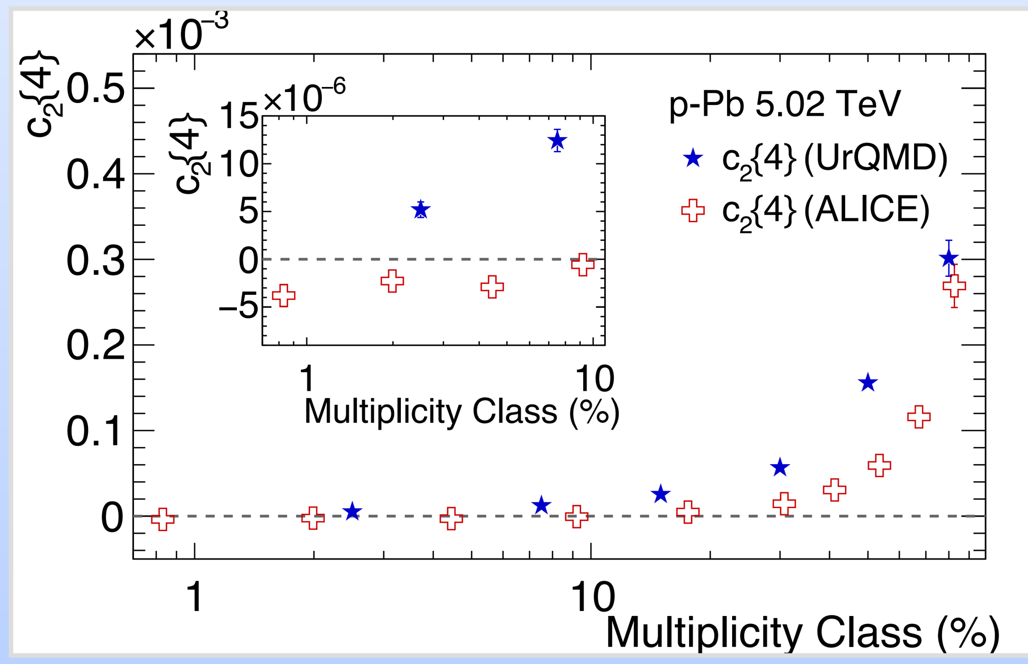
- The Large Hadron Collider (LHC) has provided strong evidences for the creation of Quark-Gluon Plasma (QGP) in Pb+Pb collisions at 2.76 TeV [1].
- The original purpose of p+Pb collisions was to provide reference data for the Pb+Pb collisions, especially on the cold nuclear matter effects.
- However, a large amount of unexpected results have been discovered in p+Pb collisions:
  - multi-particle azimuthal correlations [2]
  - mass-dependence of $v_2(p_T)$ of identified particles [3]
- Natural question for the created matter:
  - Can QGP be produced in p+Pb collisions?
  - Could this matter be described by hydrodynamics (fluid-like)?

Evidences of flow in p+Pb collisions



- Non-zero multi-particle correlations observed in p+Pb collisions
  - evidence of anisotropic flow, claimed by ALICE/ATLAS/CMS Collaborations.
- Identified particle $v_2(p_T)$ show mass ordering in p+Pb collisions [3]
  - indication of flow
  - hydrodynamic calculation reproduces the similar feature [4]

Multi-particle correlations $c_n\{m\}$

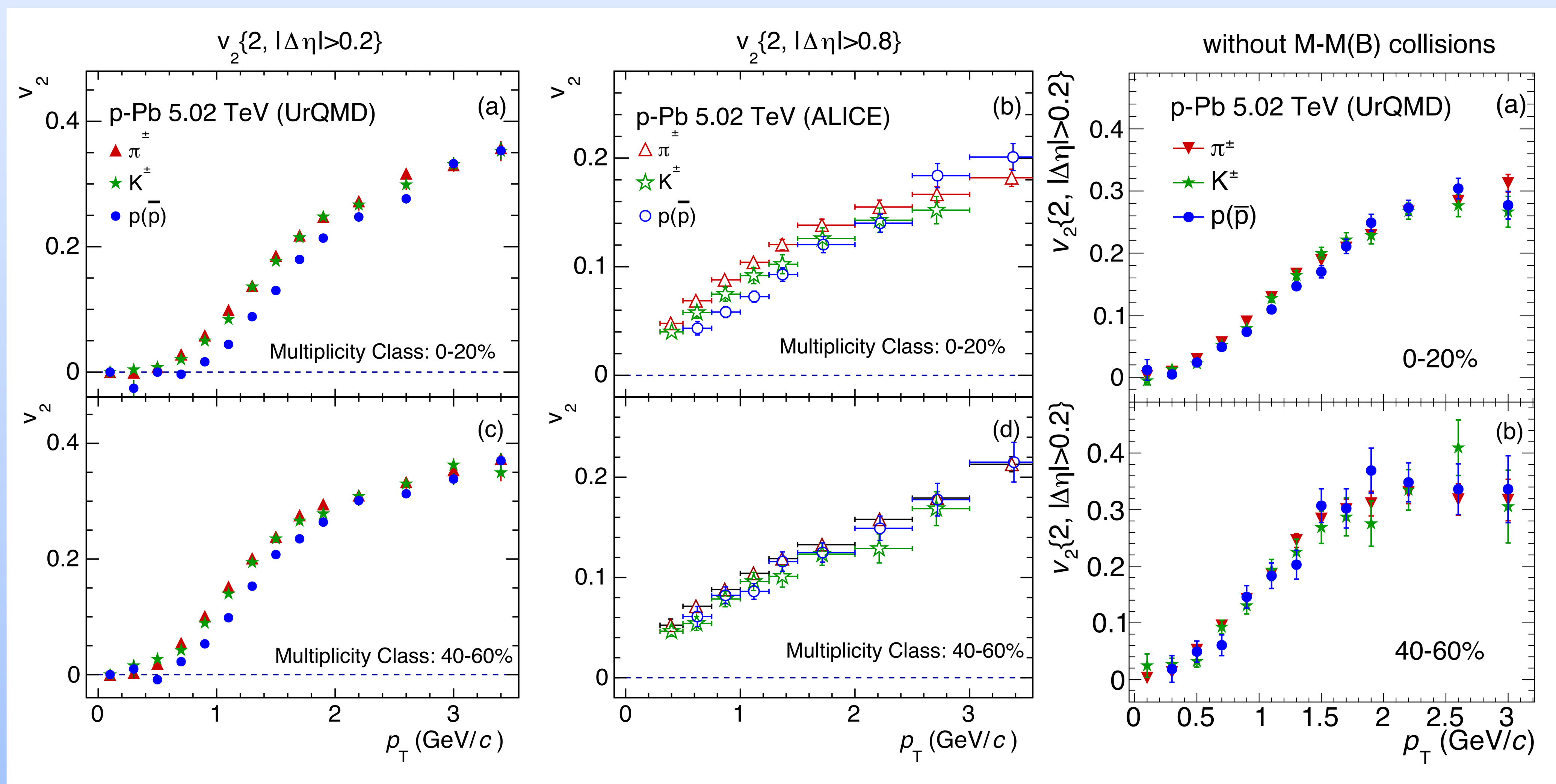


$$c_2\{4\} = -v_2^4$$

negative $c_2\{4\}$ gives the flow signature

- A negative sign has been observed for $c_2\{4\}$ in high multiplicity events in data (indication of flow) while UrQMD simulations only generate positive value of $c_2\{4\}$ (not a flow signature).

p_T-differential v_2 of identified particles



- UrQMD model (includes hadronic interactions only),
  - could not generate the flow signature
  - different from data
- However, a clear mass ordering of identified particle $v_2(p_T)$ has also been observed based on UrQMD simulations,
  - similar with what was found in data [3].
- Turn off main hadronic scattering in UrQMD
  - v_2 mass ordering disappears
  - different cross sections for baryons and mesons -> different hadronic interactions -> v_2 mass ordering
- **The v_2 mass ordering alone is not necessarily a flow signature associated with strong fluid-like expansions.**

Conclusions

- The azimuthal correlations in p+Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV are investigated based on the UrQMD model simulations.
- Comparison with the experimental data shows that UrQMD cannot reproduce the multiplicity dependence of two- and four-particle cumulants
  - the simulated hadronic p+Pb systems cannot generate enough collective flow as observed in experiment.
- However, the characteristic $v_2(p_T)$ mass ordering of pions, kaons, and protons is observed in UrQMD.
  - the consequence of hadronic interactions
  - not necessarily associated with strong fluid-like expansions.

[1] ALICE Collaboration, PRL105, 252302 (2010); ATLAS Collaboration, PLB 707 (2012) 330; CMS Collaboration, EPJC 72 (2012) 10052;
[2] ALICE Collaboration, PRC 90, 054901(2014); ATLAS Collaboration, PLB 725 (2013) 60; CMS Collaboration, arXiv: 1502.05382;
[3] ALICE Collaboration, PLB 726 (2013) 164
[4] K. Werner, et. al., PRL 112, 232301 (2014)

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