Understanding the Quark Coalescence Dynamics with Directed and Elliptic Flow of Identified Particles from the STAR BES-II Data

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Abstract

The coalescence sum rule accounts for distinct characteristics of the transported and pair-produced quarks in the coalescence mechanism and can explain many measured features of collectivity of identified particles. We present Λ $\Delta(dv_1/dy)$ measurements in Au+Au collisions at $\sqrt{s_{NN}}$= 7.7-27 GeV, which agrees with the coalescence sum rule across most analyzed energies. A coalescence-inspired test also links the v_2 of charged pions and antiprotons to the numbers of constituent quarks in the incident nuclei. The observed ratio of $(v_2^{\pi^-} - 2/3\, v_2^{\bar{p}})/(v_2^{\pi^+} - 2/3\, v_2^{\bar{p}})$ is consistent with 315/276, the ratio between the numbers of d and u constituent quarks in a gold nucleus.

Motivation

In the coalescence picture, the splitting between the v_1 of Λ^0 and $\overline{\Lambda^0}$ is expected to be consistent with the difference between proton and kaon $\Delta(dv_1/dy)$ due to quark content matching. This splitting may become negative in the presence of electromagnetic field despite Λ's neutral charge:

$$\Delta(dv_1/dy)_{[\Lambda^0(uds)-\bar{\Lambda}^0(\bar{u}\bar{d}\bar{s})]} \sim \Delta(dv_1/dy)_{[p(uud)-\bar{p}(\bar{u}\bar{u}\bar{d})]} - \Delta(dv_1/dy)_{[K^+(u\bar{s})-K^-(\bar{u}s)]}.$$

In the same picture, the v_2 of charged pions can be decomposed into

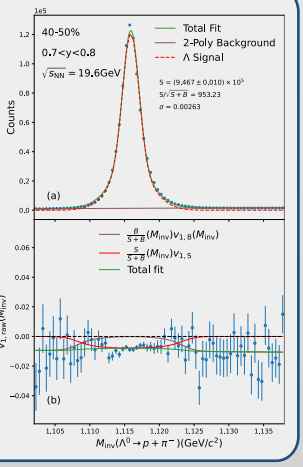
$$v_2^{\pi^-} = N^{\pi^-}_{\text{trans},d} \cdot v_2^{\text{trans},d} + \left(2 - N^{\pi^-}_{\text{trans},d}\right) v_2^{\bar{u}}$$
$$v_2^{\pi^+} = N^{\pi^+}_{\text{trans},u} \cdot v_2^{\text{trans},u} + \left(2 - N^{\pi^+}_{\text{trans},u}\right) v_2^{\bar{d}},$$

where $N^{\pi^{+(-)}}_{\text{trans},u(d)}$ is the number of transported $u(d)$ quark per $\pi^{+(-)}$. Under further assumptions, these can be rearranged to obtain[1]

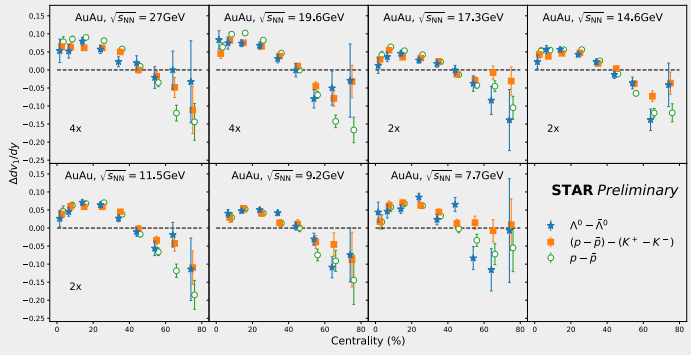
$$N^{\pi^-}_{\text{trans},d}/N^{\pi^+}_{\text{trans},u} = (v_2^{\pi^-} - 2v_2^{\bar{u}})/(v_2^{\pi^+} - 2v_2^{\bar{u}}).$$

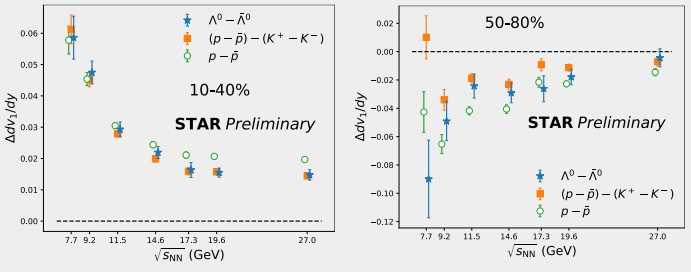
Methodology

- Λ reconstruction: KFParticle package[2].
- v_1 extraction: v_1 vs invariant mass method.
- Event planes construction: Time Projection Chamber (TPC) and Event Plane Detector (EPD).



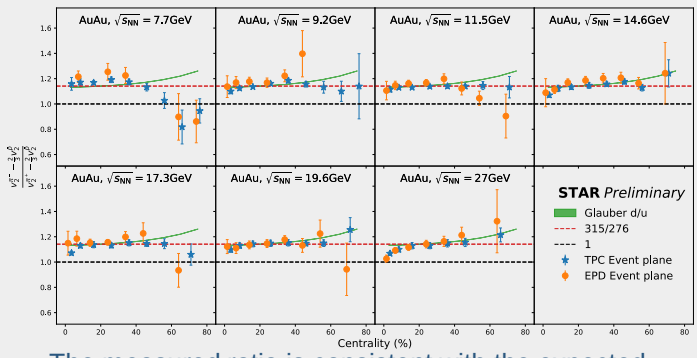
Λ v_1 Result





- Λ $\Delta(dv_1/dy)$ deviates from proton $\Delta(dv_1/dy)$, especially in mid-central collisions.
- Consistent with difference between proton and kaon splittings.

v_2 Result



- The measured ratio is consistent with the expected value of 315/276 in most analyzed energies.
- Centrality dependence mostly consistent with Glauber simulation but not conclusive.

Summary

- Both $\Delta(dv_1/dy)$ and v_2 measurements support the coalescence sum rule that considers the difference among quark flavors and origins.
- Studying quark coalescence is essential to interpret the $\Delta(dv_1/dy)$ behavior of Λ and other hadrons, when exploring possible electromagnetic field effects.

1. A. Goudarzi, G. Wang and H.Z. Huang, Phys. Lett. B 811 (2020) 135974
2. M. Zyzak, Dissertation thesis, Goethe University of Frankfurt, 2016.

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