The splitting of rapidity-odd directed flow of produced particles in Au+Au collisions at STAR

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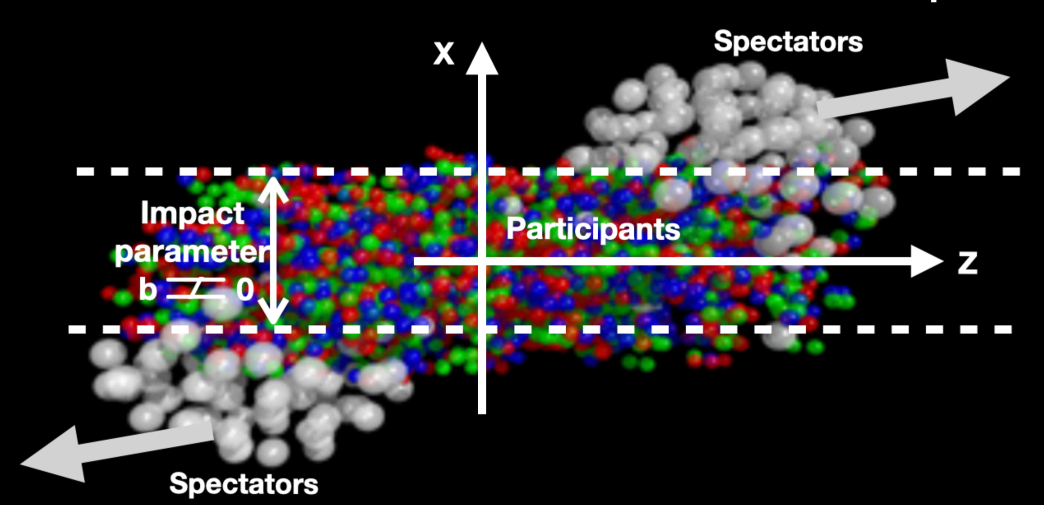
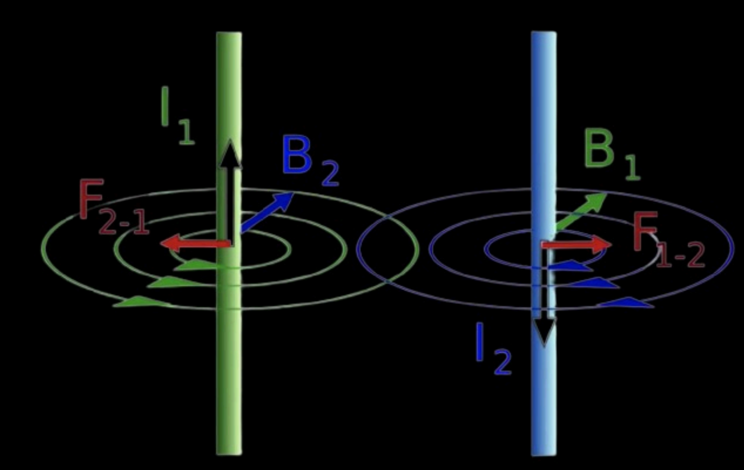
Abstract

Rapidity-odd directed flow (v_1) of hadrons in relativistic heavy-ion collisions can provide insights into the ultra-strong electromagnetic (EM) field [1]. EM-field-driven effect on v_1 could be contaminated due to the transported quarks from colliding nuclei [2]. To avoid such complications, we focus on particle species for which all constituent quarks are produced, as opposed to those possibly transported, and examine the coalescence sum rule with various combinations of produced hadrons in Au+Au collisions at 27 and 200 GeV. For such combinations a systematic violation of the sum rule is observed with increasing difference in the electric charge of the associated constituent quarks. The results suggest that the constituent quark sum rule could be violated in the presence of a strong EM field that drives the v_1 of produced quarks and anti-quarks to opposite directions. The measured splitting of v_1 is stronger at lower collision energy.

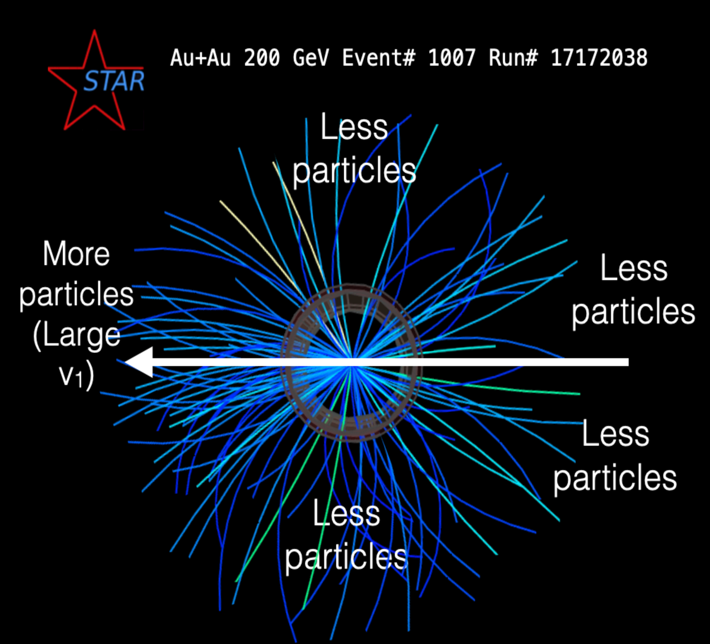
I. Electromagnetic (EM) field in heavy ion collisions

- Charged spectators produce electric currents (like two parallel current-carrying wires in opposite directions
- The currents produce strong magnetic fields ~ 10^{14} -10^{18} Gauss — Strongest field ever produced in the laboratory
- The field has observable consequences on the produced particles



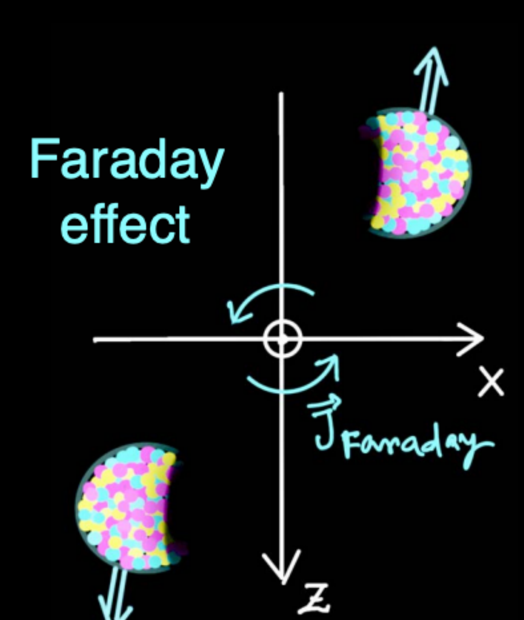


IIA. Directed flow (v_1) splitting

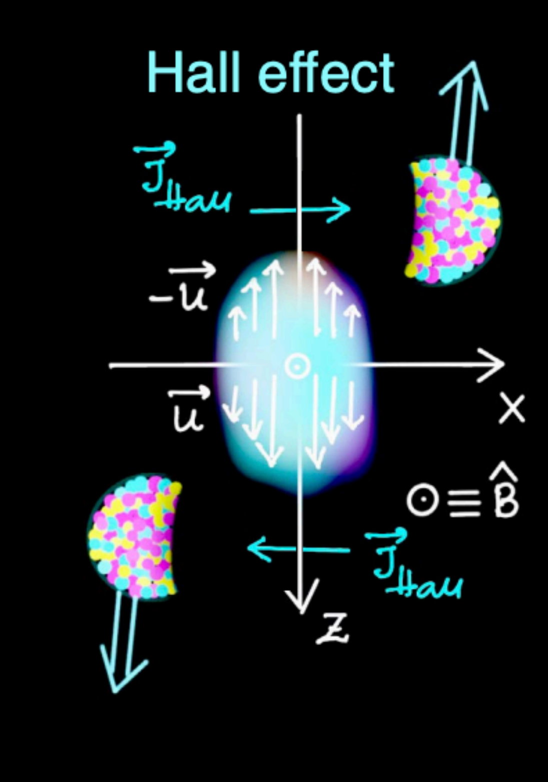


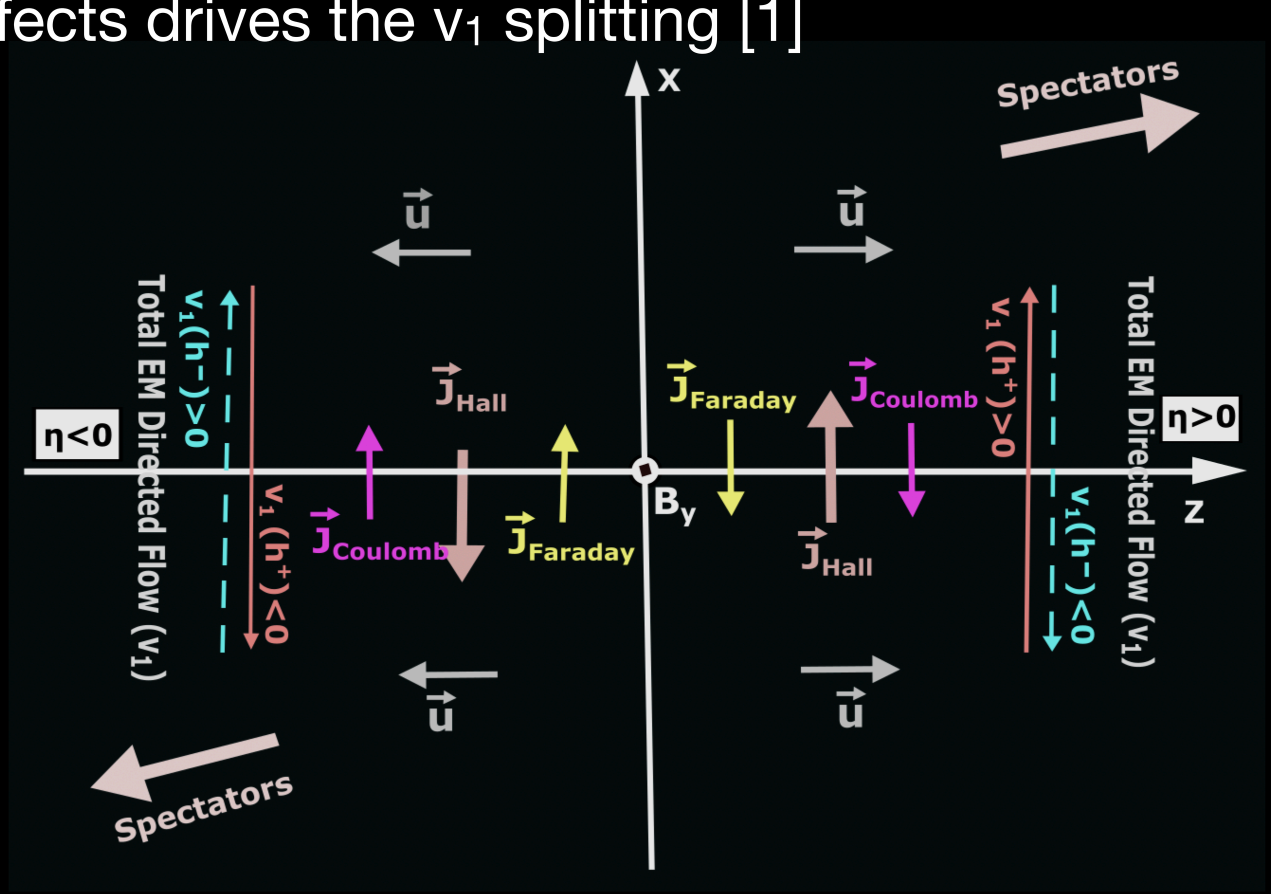
- First order harmonic in the Fourier expansion of azimuthal distribution of final state particles — Directed flow (v_1)
- The v_1 describes collective sideward motion of particles
- Difference in v_1 between particles with same masses but different charges — v_1 splitting

IIB. EM field drives the v_1 splitting

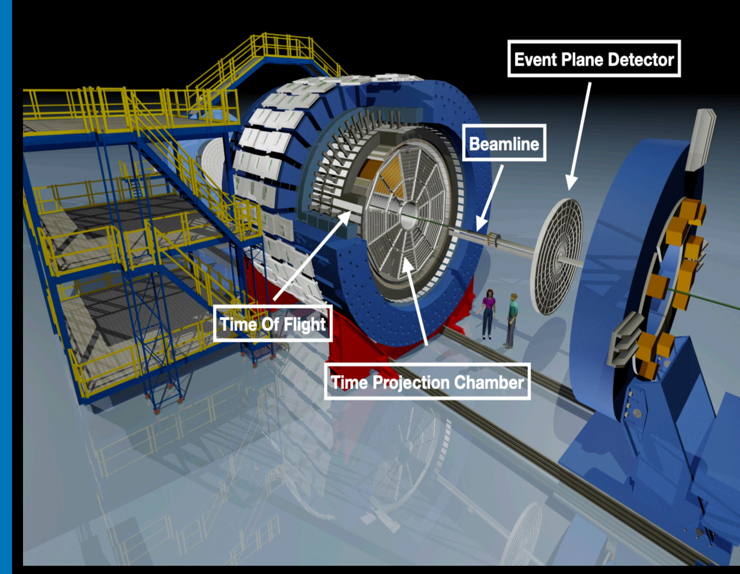


- As the spectators move, magnetic field decreases with time — Faraday Effect
- Spectators also exert Coulomb force
- Lorentz force pushes the charged particles perpendicular to initial velocity and magnetic field — Hall effect
- Combination of Faraday, Coulomb and Hall effects drives the v_1 splitting [1]



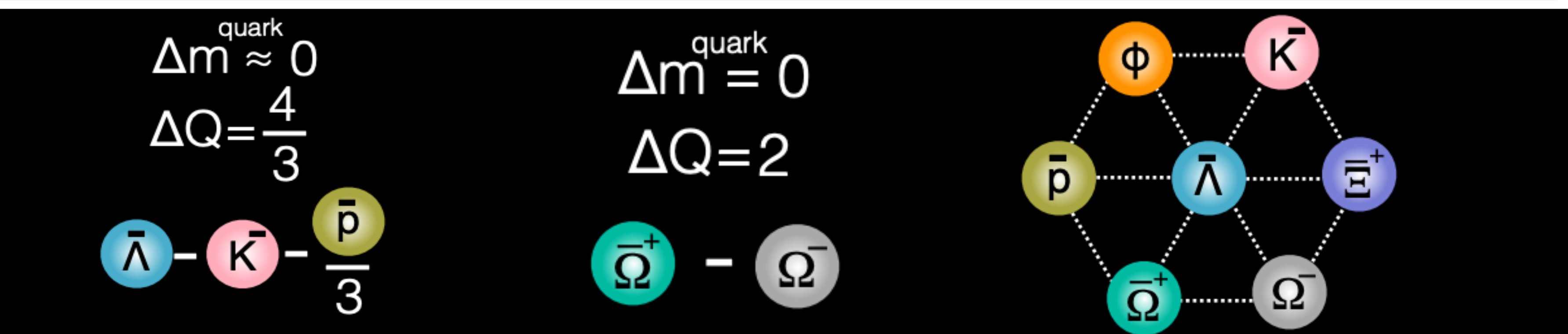


III. Experimental setup and analysis method

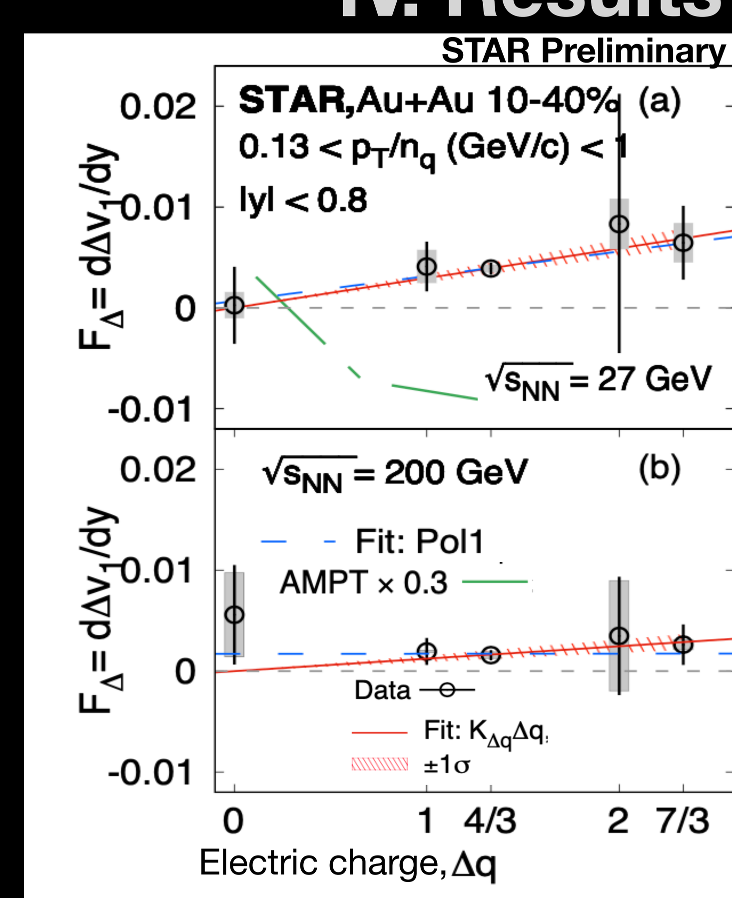


- STAR sub-detectors used: TPC+TOF for PID and EPD or ZDC for event plane
- Transported quarks (u, d) mimic EM-field-like v_1 splitting => Avoid particles with u, d quarks
- Assuming coalescence, measure the splitting between combinations of different produced particles with same mass and different charge — Splitting with charge [3]

Index	Quark Mass	Charge	Strangeness	Expression
1	$\Delta m = 0$	$\Delta q = 0$	$\Delta S = 0$	$[\bar{p}(\bar{u}\bar{u}\bar{d}) + \phi(s\bar{s})] - [K^-(\bar{u}s) + \bar{\Lambda}(\bar{u}\bar{d}\bar{s})]$
2	$\Delta m \approx 0$	$\Delta q = 1$	$\Delta S = 2$	$[\bar{\Lambda}(\bar{u}\bar{d}\bar{s})] - [\frac{1}{3}\Omega^-(sss) + \frac{2}{3}\bar{p}(\bar{u}\bar{u}\bar{d})]$
3	$\Delta m \approx 0$	$\Delta q = \frac{4}{3}$	$\Delta S = 2$	$[\bar{\Lambda}(\bar{u}\bar{d}\bar{s})] - [K^-(\bar{u}s) + \frac{1}{3}\bar{p}(\bar{u}\bar{u}\bar{d})]$
4	$\Delta m = 0$	$\Delta q = 2$	$\Delta S = 6$	$[\bar{\Omega}^+(\bar{s}\bar{s}\bar{s})] - [\Omega^-(sss)]$
5	$\Delta m \approx 0$	$\Delta q = \frac{7}{3}$	$\Delta S = 4$	$[\bar{\Xi}^+(\bar{d}\bar{s}\bar{s})] - [K^-(\bar{u}s) + \frac{1}{3}\Omega^-(sss)]$



IV. Results and discussions



- The v_1 splitting is measured using the combinations of produced particles at 27 and 200 GeV
- The splitting is stronger at 27 GeV
- The splitting appears to increase with electric charge (assuming coalescence sum rule)
- AMPT model (no EM field) fails to describe data
- The measured data is expected to be consistent with EM-field-driven effects

V. References

1. U. Gursoy, et al., Phy. Rev. C **98**, 055201 (2018); Phy. Rev. C **89**, 054905 (2014)
2. Y. Guo, et al. Phys. Rev. C **86**, 044901 (2012)
3. A. I. Sheikh, et al., Phy. Rev. C **105**, 014912 (2022)

Brookhaven National Laboratory

Supported in part by U.S. DEPARTMENT OF ENERGY Office of Science

International Conference on Physics and Astrophysics of Quark Gluon Plasma (ICPAQGP 2023)

07 - 10 Feb, 2023, Blue Lily Beach Resort, Puri, India