Investigating collective flow patterns and the influence of electromagnetic fields in relativistic proton-nucleus collisions

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based on Phys. Rev. C 101 (2020) 014917 [arXiv: 1909.06770]

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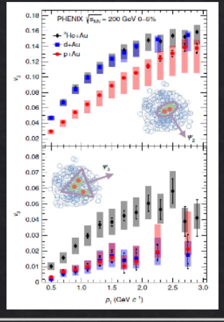
Many interesting phenomena in HICs driven by the intense electromagnetic (EM) fields produced since the early stage of the collision

Kharzeev, McLerran and Warringa, Nucl. Phys. A 803 (2008) 227

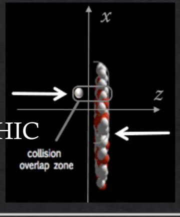
Earth's field ~ 1 G | laboratory ~ 10^6 G | magnetars ~ 10^{14}-10^{15} G | HICs ~ 10^{18}-10^{19} G ~ 5-50 m_π^2



Quark Gluon Plasma (QGP) initially expected to form only in high energy Heavy Ion Collisions (HICs)

Collective flow found in small systems as a signature of short-lived droplets of QGP

PHENIX Coll., Nature Phys. 15 (2019) 214



p+Pb at LHC, p/d/^{3}He+Au at RHIC

PHSD: Parton-Hadron-String Dynamics

- non-equilibrium transport approach for a microscopic description of HICs and small systems
- the DQPM defines QGP properties with dynamical masses and widths
- off-shell transport eqs. governs the evolution in QGP and hadronic stages
- quasiparticles propagate in dynamically generated EMF

$$e\mathbf{E}(t,\mathbf{r}) = \alpha_{em}\frac{1-\beta^2}{\left[(\mathbf{R}\cdot\boldsymbol{\beta})^2 + R^2(1-\beta^2)\right]^{3/2}}\mathbf{R} \qquad e\mathbf{B}(t,\mathbf{r}) = \boldsymbol{\beta}\times e\mathbf{E}(t,\mathbf{r})$$

RETARDED EM FIELDS

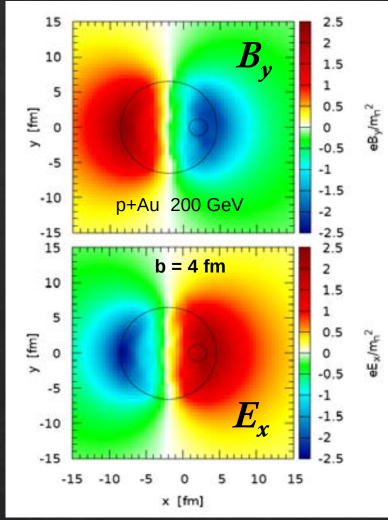
$$F_{em} = q(E + v\times B)$$

LORENTZ FORCE

Cassing and Bratkovskaya, Nucl. Phys. A 831 (2009) 215

Voronyuk, Toneev, Cassing, Bratkovskaya, Konchakovski and Voloshin, PRC 83 (2011) 054911

MAGNETIC FIELD ⊥ REACTION PLANE



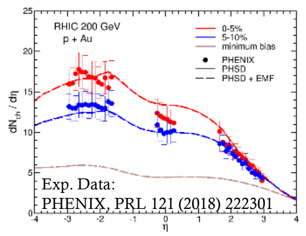
ELECTRIC FIELD // IMPACT PARAMETER AXIS

EM FIELDS

- symmetric systems: transverse momentum increments due to electric and magnetic fields compensate each other
- asymmetric systems: an intense electric fields directed from the heavy nuclei to light one appears in the overlap region
- proton-induced collisions: the fields are basically those generated by the heavy ion and E_x and B_y show comparable values up to about 2.5 m_π^2

p + Au @ 200 GeV

RAPIDITY DISTRIBUTIONS

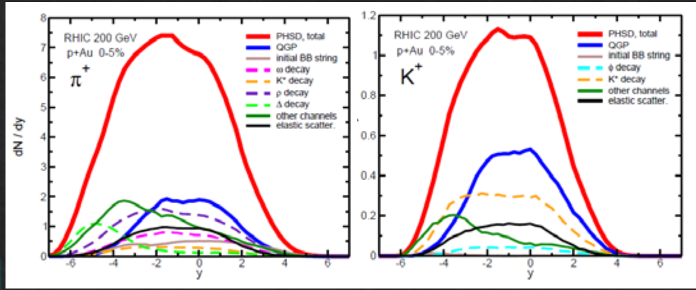


CHARGED PARTICLES

- ✓ enhanced particle production in the Au-going side (backward rapidity)
- ✓ asymmetry increases with centrality

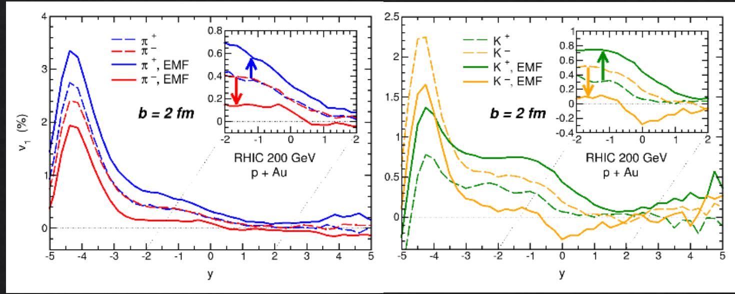
IDENTIFIED HADRONS

large amount of particles escapes the fireball just after production from QGP hadronization without further rescattering



$$v_1(y) = \langle\cos[\varphi(y)]\rangle$$

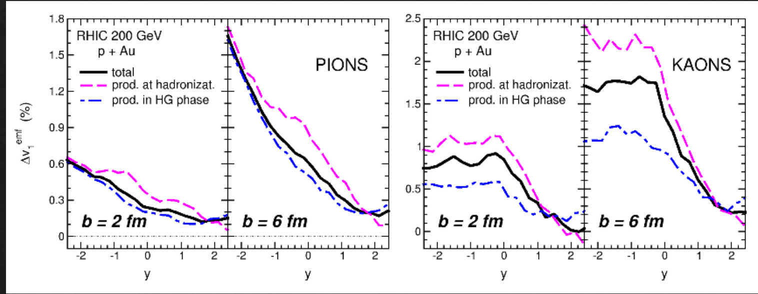
DIRECTED FLOW OF LIGHT MESONS



- ✓ for kaons different v_1 also in simulations without EM fields (imprint of the swirling initial state of HICs)
- ✓ electromagnetically-induced splitting between hadrons with same mass and opposite charge

EM SPLITTING

$$\Delta v_1^{emf} \equiv \Delta v_1^{(PHSD+EMF)} - \Delta v_1^{(PHSD)} \quad \text{with} \quad \Delta v_1 \equiv v_1^+ - v_1^-$$



- ❑ magnitude increasing with impact parameter and larger for kaons than for pions
- ❑ splitting generated at partonic level higher than that induced in the hadronic phase