Excess-Proton Directed Flow in 19.6 GeV Au+Au Collisions

E. Duckworth (educkwor@kent.edu), Kent State University, *for the STAR Collaboration*

Abstract

Directed flow of particles is an important feature seen in heavy-ion collisions and is a sensitive probe of the equation of state (EoS) of the matter produced in the collisions. Model calculations have also predicted that directed flow could be a sensitive probe of the softening of EOS associated with a first order phase transition. Directed flow of protons and anti-protons are of particular interest as they offer sensitivity to both the contributions from the transported quarks and also the medium generated component from the produced quarks. We will present measurements of the directed flow of protons and antiprotons from 19.6 GeV Au+Au collisions, using high statistics BES-II data from STAR. The new results have significantly reduced uncertainties and allow the study of how the two contributions vary over different centrality and transverse momentum regions.

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Motivation

- Proton directed flow, v_1, offers a sensitive probe of the equation of state of the matter produced in the collisions

- dv_1/dy of net protons at mid-rapidity exhibits non-monotonic behavior as a function of collision energy

$$v_{1,net} = \frac{(v_{1,p} - r v_{1,\bar{p}})}{1-r}$$

Here r is number of protons to anti proton ratio.

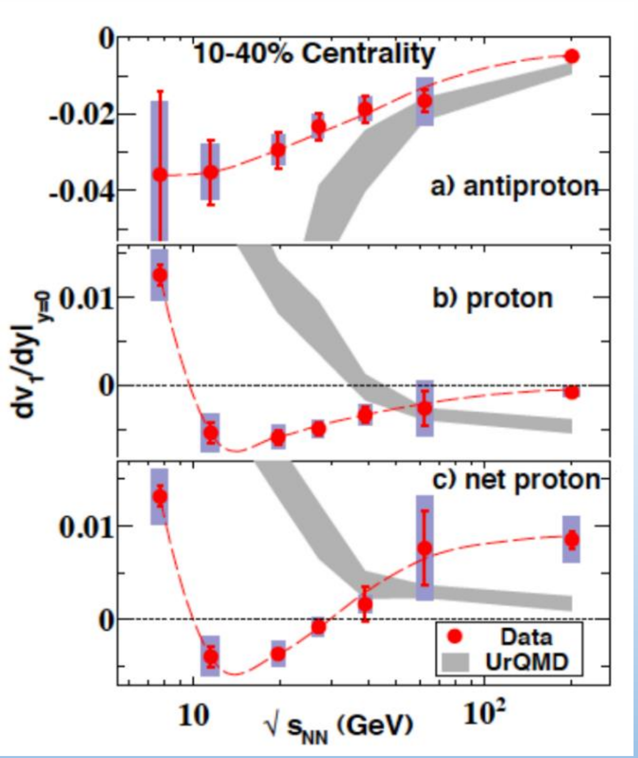
- This behavior occurs at much higher energies than models predict
  - Y. Nara et al., Phys. Rev. C 94, 034906 (2016).

- Alternatively, we can look at excess proton v_1 to better understand the origin of the proton v_1 and its beam energy dependence

$$v_{1,excess} = \frac{(v_{1,p} - v_{1,\bar{p}})}{1-r}$$

- The difference between excess proton v_1 and net proton v_1 we will call the medium v_1. Simple algebra tells us that the medium v_1 is equal to anti-proton v_1

- For this presentation we will be looking at excess proton v_1 at 19.6 GeV using the BES II dataset, which has 10x the amount of data of BES I, allowing for a more accurate measurement.



STAR Collaboration, Phys. Rev. Lett. **112** (2014) 162301

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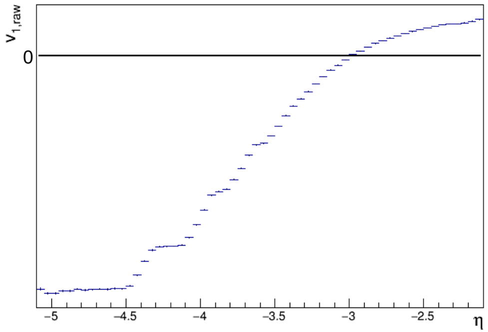
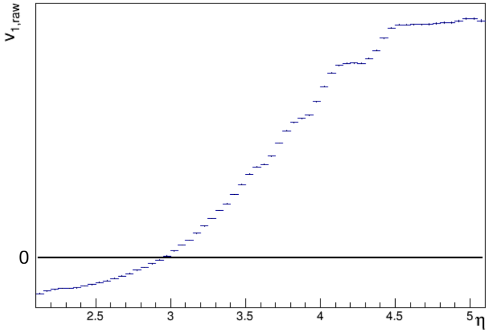
Event Plane Calculation

- The Event Plane was measured by the Event Plane Detector (EPD) based on number of Minimally Ionizing Particles (nMIP)
- At 19.6 GeV, the v_1 of the MIP signal changes sign at high η



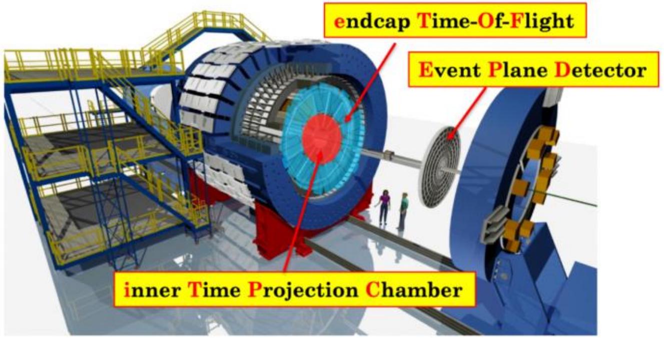


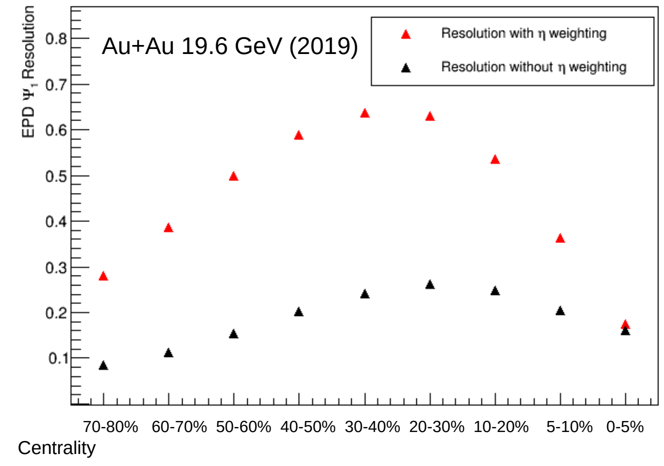
- To account for this, the EPD signal was weighted by the raw v_1 measurement

$$\vec{Q} = \hat{x} \sum_{i \in tile} w_i \cos\phi_i + \hat{y} \sum_{i \in tile} w_i \sin\phi_i$$

$$w_i = w(nMIP) * v_{1,raw}(\eta)$$

- This allowed us to significantly increase our resolution of the v_1 signal





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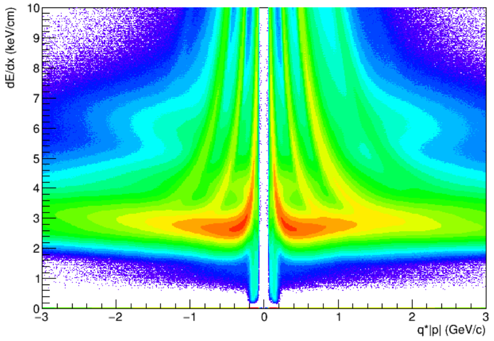
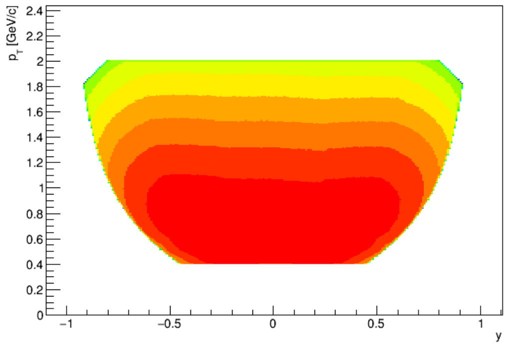
Particle Identification

- Particles were identified using both the TPC (dE/dx) and Time of Flight (TOF)
- For dE/dx, the Particle Identification was done using the Bischel function.
- The time of flight was used to calculate the squared mass of the particle, and a cut of $0.8 < m^2 < 1.0$ GeV^2 was applied
- To keep contamination from Pions and Kaons down, a P_t cut of $0.4 < P_t < 2.0$ GeV was applied

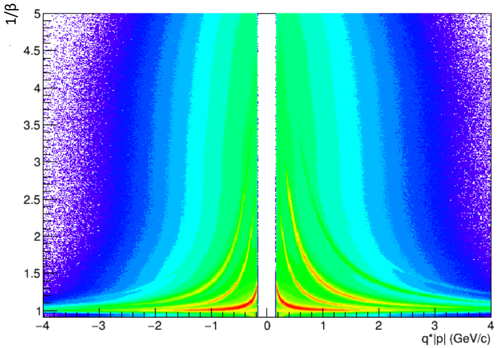
dE/dx vs. Momentum



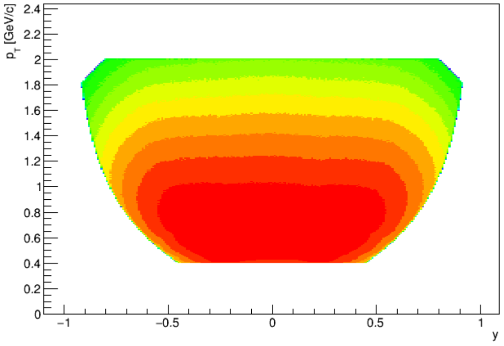
Proton Acceptance



1/β vs. Momentum



Anti-Proton Acceptance



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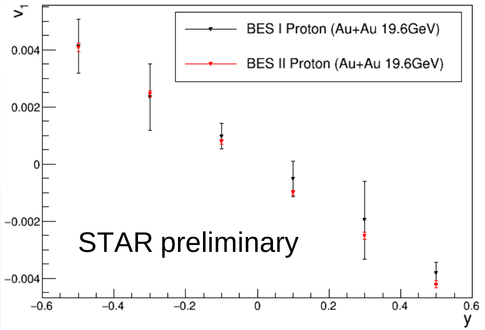
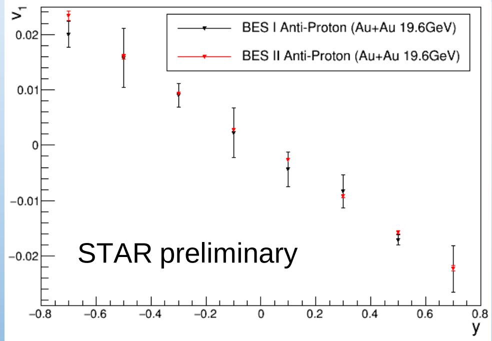
Proton v_1 vs. y at 10-40% Centrality



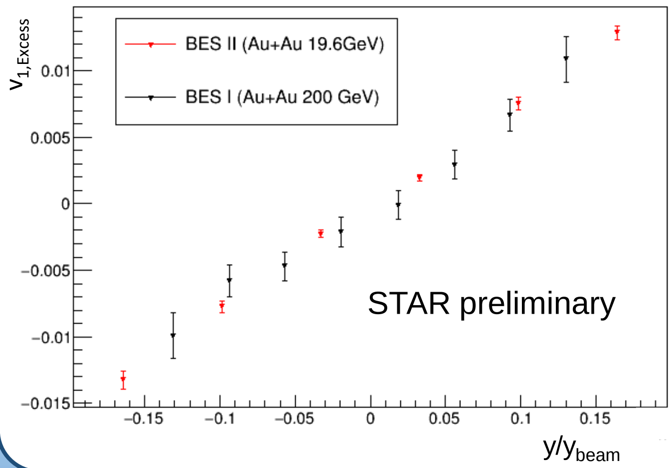
Anti-Proton v_1 vs. y at 10-40% Centrality



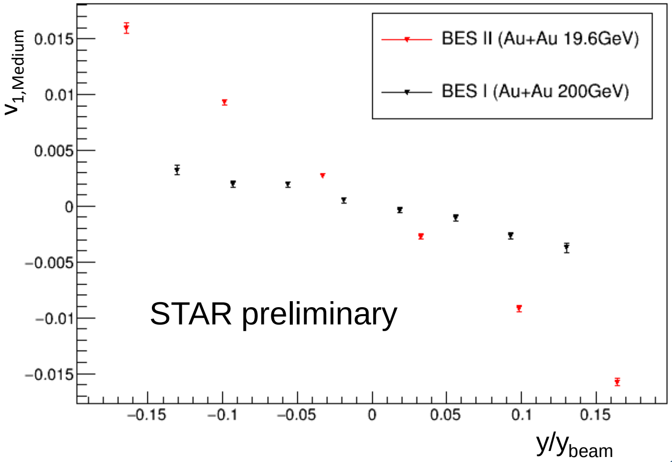
Excess Proton Flow

- Far improved precision from BES I
- Scaling observed for excess flow
- No scaling for anti-proton
- Excess flow could be linked to initial flow acquired by transported protons
- Anti-proton flow to QGP medium generated flow from later stage
- Error is combined statistical and systematic.
- BES 1 data: STAR Collaboration, Phys. Rev. Lett. 120 (2018) 62301

Excess Proton v1 vs. y_n at 10-40% Centrality



Medium v_1 vs. y_n at 10-40% Centrality



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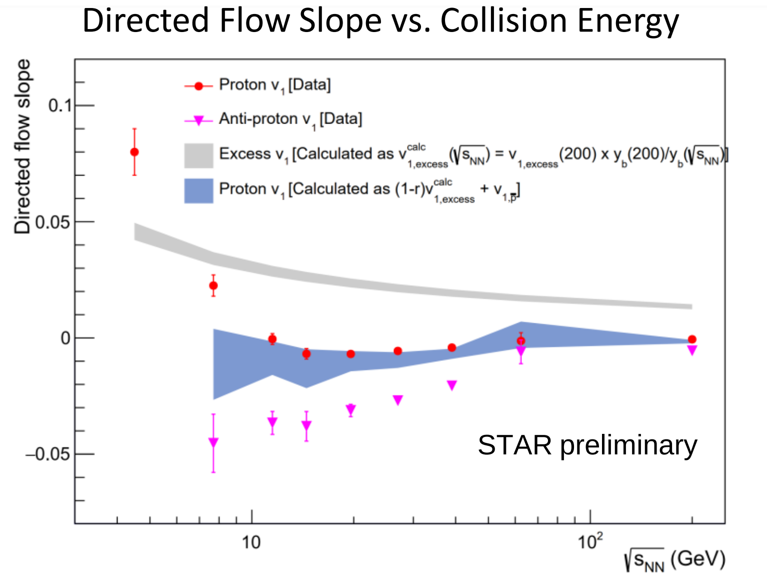
Summary

- There is non-monotonous behavior of proton v_1 vs collision energy
- This could be from two sources:
    - an excess component, contributing only to transported protons
    - a medium component contributing to both protons and anti-protons
- Scaling with beam energy is observed for excess component between 19.6 GeV and 200 GeV, but no scaling for medium component
- Extending to lower energies, there is indication of scaling breaking at 7.7 GeV
- Excess component could be more sensitive to the phase transition. BES-II lower energy measurements will provide more information



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S. Voloshin, Phys Rev C.55. (1997)1630

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