Measurement of Directed Flow of ϕ Meson in $\sqrt{s_{NN}}$ = 4.5 GeV Au+Au Collisions at STAR Detector

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Abstract

Previous measurements between $\sqrt{s_{NN}}$ = 11.5 - 200 GeV Au+Au collisions for directed flow, v_1, of ϕ meson at STAR (Solenoid Tracker At RHIC) from the BES-I (Beam Energy Scan program Phase I) have shown negative trend of ϕ meson flow until 11.5 GeV with conclusions limited by statistics [1]. We present new measurement from $\sqrt{s_{NN}}$ = 4.5 GeV Au+Au collisions from the STAR fixed-target run and compare with the previous data. Within statistical error bars, the new slope at 4.5 GeV is -0.013±0.022 (stat) ±0.018 (sys). Further analysis using data from BES-II (2019-2021) will have better precision due to increased particle acceptance and much higher statistics.

Motivation

ϕ mesons have small hadronic cross sections which makes them less influenced by late stage interactions than other hadrons [2-5]. Thus their anisotropies such as the directed flow should be small if the system is always in a hadronic phase. On the other hand, the closeness of ϕ mass to the nucleon and its $s\bar{s}$ quark constituents makes them suitable to test the deviation of net-nucleon and net-meson v_1 at energies below 7.7 GeV where there could be a breakdown of the assumption that s and $\bar{s}$ quarks have the same flow [1].

Experimental Setup (FXT)

Fig. 1 shows a schematic diagram of STAR fixed-target (FXT) experiment setup. The target was a gold foil placed at one end of Time Projection Chamber (TPC). Accelerated gold ions hit the target from right and produced particles were measured by detectors on the left. The acceptance for the TPC and Time-of-Flight (TOF) detector was between pseudorapidity η = [0, 1.5].

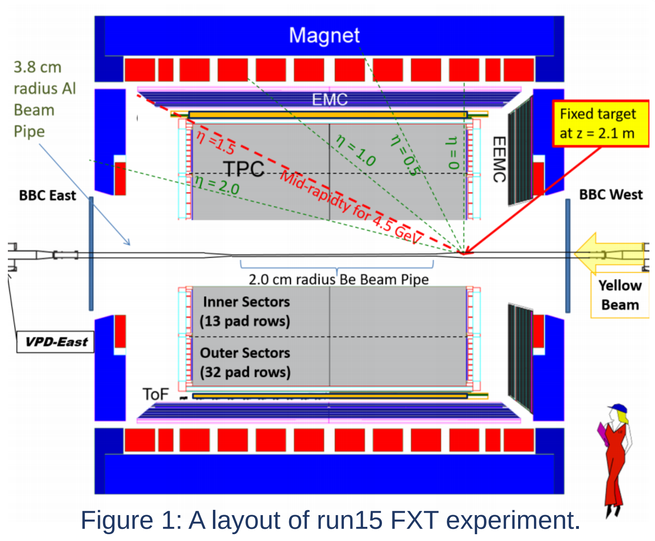

Figure 1: A layout of run15 FXT experiment.

Analysis Method

ϕ mesons are reconstructed using their decay to kaons: $\phi \rightarrow K^+K^-$ (branching ratio 49.2 ±0.5 %) [6]. Kaons are identified with TPC and TOF.

The background to the K^+K^- invariant mass is constructed using mixed events from similar vertex z (V_Z) section and centrality.

The event plane approach was used in directed flow signal extraction. The event plane was built from Beam-Beam Counters (BBC) inner tiles, then recentered and flattened.

Due to the STAR FXT geometry, BBC event plane resolutions, R_n, were estimated by the three event plane method involving two random event planes from the TPC detector.

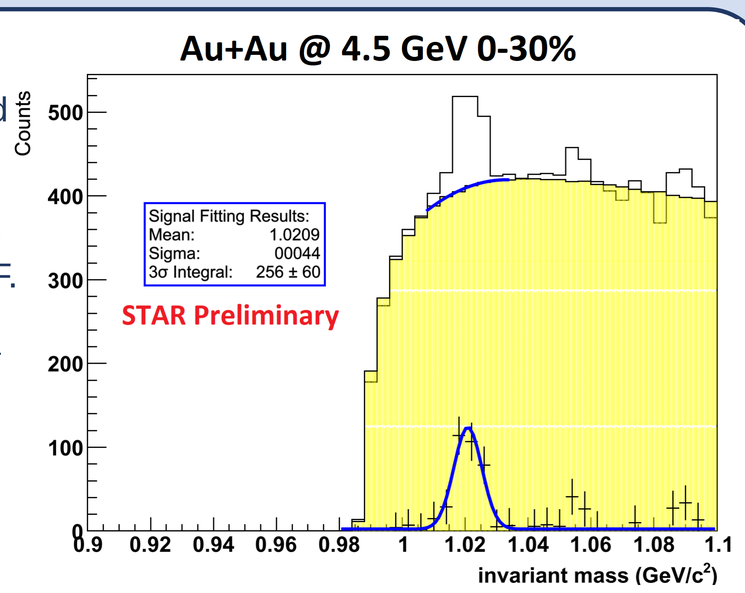

Figure 2: Mixed & normal events K^+K^- invariant mass from pseudorapidity [-1.5, 0]. The signal is extracted by subtracting the mixed event background, and is fit with a gaussian to find the peak of the invariant mass.

Directed flow of ϕ mesons is calculated,

$$v_1 = \langle cos(\phi - \psi_1) \rangle / R_1 \quad (1)$$

where ϕ is the azimuthal angle of ϕ meson.

Analysis Details

Data Set:
Fixed-target 4.5 GeV Au+Au collision
Number of events: ~1.28 Million

p_T selection:
Proton: [0.4, 2] (GeV/c)
Pion & Kaon: [0.2, 1.6] (GeV/c)

Particle Identification:
Particle identification has been performed using information about ionization energy loss in TPC and velocity from TOF.

Results & Comparison

Directed flow, v_1, of ϕ meson was extracted using the invariant mass method [7]:

$$v_1^{Sig+Bg}(invM) = \frac{Sig}{Sig+Bg} v_1^{Sig} + \frac{Bg}{Sig+Bg} v_1^{Bg} \quad (2)$$

where v_1^{Sig+Bg} is estimated as a function of invariant mass, "Sig" is the signal yields and "Bg" is the background yields. "v_1^{Bg}" is obtained from a 2nd-order polynomial fit to "$v_1^{Sig+Bg}(invM)$" and "v_1^{Sig}" is extracted from fitting which is corrected for event plane resolution on event-by-event basis.

We use three rapidity bins [-1.5, -1], [-1, -0.5], [-0.5, 0] and calculate the ϕ meson v_1 in each bin. The rapidity is shifted by -1.52, and the data is mirrored around midrapidity. The actual (center-of-mass) rapidity acceptance of TPC at FXT 4.5 GeV is $-0.02 < y\text{-}y_{cm} < 1.5$. The results are fit with a linear function to extract the slope (dv_1/dy).

The slope is shown in Fig. 4 together with published results [1] as a function of E_{CM}.

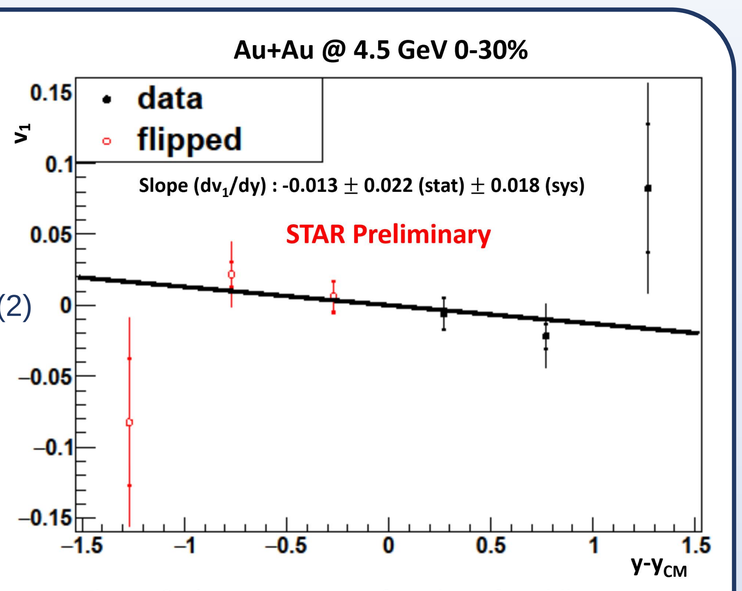

Figure 3: ϕ meson v_1 as a function of rapidity. x-axis is shifted by -1.52 to put midrapidity at zero. Fitting range is [-1.53, 1.53].

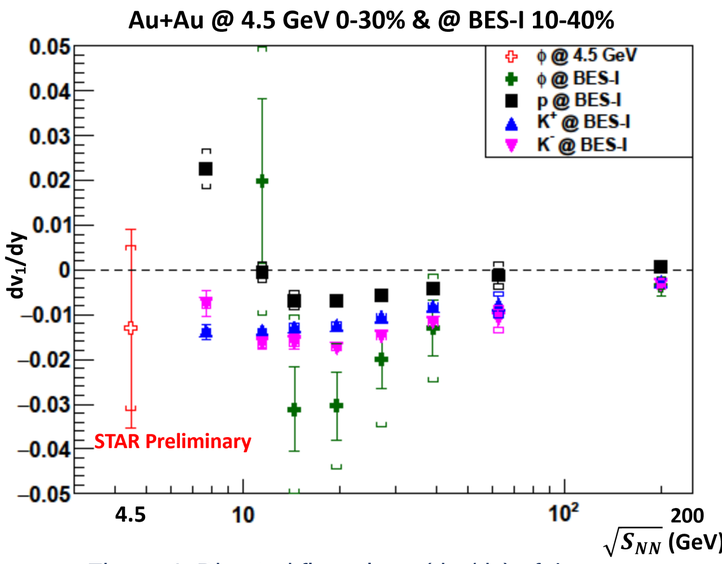

Figure 4: Directed flow slope (dv_1/dy) of ϕ mesons vs. center of mass beam energy. The present FXT 4.5 GeV result has centrality 0-30%, while the published data at the remainder of the energies have centrality 10-40%.

The value of $\langle p_T \rangle$ of identified K^+, K^- and ϕ meson are 637±0.2 (stat), 517±0.2 (stat), 925±0.4 (stat) (MeV/c) respectively.

Summary

- First ϕ meson directed flow result at $\sqrt{s_{NN}}$ = 4.5 GeV is presented and compared to other published data at higher energies.
- **The ϕ meson dv_1/dy at 4.5 GeV FXT is -0.013 ± 0.022 (stat) ± 0.018 (sys), consistent with zero and also consistent with the negative values seen above 11.5 GeV, within statistic and systematic uncertainties.**
- Data with larger pseudorapidity acceptance and 100 times as much statistics will be available from future STAR experiment runs.

References

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