Charge asymmetry dependence of $K v_2$
in Au+Au collisions at STAR

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Outline

Introduction
The search of Chiral Magnetic Wave (CMW) at STAR
Why K $v_2$?

Results
Charge asymmetry dependence of K $v_2$ in 200 GeV
Charge asymmetry dependence of K $v_2$ in 27, 39, 62 GeV

Summary
Chiral magnetic wave (CMW)

Theoretical

Chiral Separation Effect

\[ j_A = \frac{N_c e}{2\pi^2} \mu_V B \]

Chiral Magnetic Effect

Experimental

\[
\frac{dN_{\pm}}{d\phi} = N_{\pm} \left[ 1 + 2\nu_2 \cos(2\phi) \right] \\
\approx \bar{N}_{\pm} \left[ 1 + 2\nu_2 \cos(2\phi) + A_{\pm}r \cos(2\phi) \right]
\]

\[
\Delta v_2^{CMW} \equiv v_2(\pi^-) - v_2(\pi^+) \approx r A_{\pm}
\]

CMW measurements are of high interest recently. $\pi$ are suggested to be the best probe to study CMW.
Why to use K to test CMW?

- Pions are suggested to be the best probe to study CMW

  "We think the main contribution should come from pions… However at this point we cannot make definite statements about the ratios protons to pions or kaons to pions"

  “… the large differences in the absorption cross sections… of negative and positive kaons in hadronic matter at finite baryon density, are likely to mask or reverse this difference in the hadron resonance “afterburner” phase of a heavy ion collision…”

  “… the smaller difference in the absorption cross sections of negative and positive pions potentially may make it possible to detect the electric quadrupole moment of the plasma through the difference of elliptic flows of pions”

- Kaons serve as an important check
  Can strange quark be affected by chiral effect?
  Does the large difference in absorption cross section affect the measurement?
Hydrodynamics study suggests that, with wider $p_T$ coverage, $K$ slope should be opposite to $\pi$ slope with larger magnitude, since

$$v_2(\pi^+) < v_2(\pi^-)$$

$$v_2(K^+) > v_2(K^-)$$

“… We demonstrate that the STAR results can be understood within the standard viscous hydrodynamics without invoking the CMW…”

“… the slope $r$ for the kaons should be negative, in contrast to the pion case, and the magnitude is expected to be larger… Note that in these predictions are integrated over $0 < p_T < \infty$. In order to properly test them, a wider $p_T$ coverage is necessary…”

RHIC-STAR
Analysis strategy

- For each event:
  calculate $A_{ch}$, $v_2$

- For the whole data sample:
  $A_{ch}$ correction, extract linear relationship and slope, error estimation

- $A_{ch}$: $|\eta| < 1$, DCA < 1 cm, low $p_T$ (anti)proton removed

- $v_2$: Q-Cumulants method (2 sub-events) with 0.3 $\eta$ gap between POI and RFP
  PID($\pi$, K) is applied by TPC+ToF
Previous Kaon result at STAR (presented in SQM2013, QM2014)

Q.-Y. Shou [for the STAR Collaboration], Nuclear Physics A 931, 758 (2014)

(0.15 < p_T(K) < 0.5 GeV/c)

Our previous point:
combining mid-central bins (20-60%)
slightly above zero
within CMW prediction

Biggest issue: statistics

“… given the narrow coverage in p_T they are not sufficient to draw firm conclusions. “
Previous Kaon result at STAR

(0.15 < p_{T}(K) < 0.5 \text{ GeV/c}) Fitting with large uncertainties
If $p_T$ upper limit goes to 1 GeV/c

Comparing with preliminary results, linear relationship largely improved with negative intercept
Slope(K) in $\sqrt{s_{NN}}$ 200 GeV

Centrality dependence of slope parameters for K behave similarly to that of $\pi$, indicating that K could be another possible probe?

error bars are only statistical
Does this observation conflict with our knowledge of (anti-)particle flow?
No, since the intercepts are negative.

We know

\[ v_2(\pi^-) > v_2(\pi^+) \]

\[ v_2(K^-) < v_2(K^+) \]

so both

\[ v_2(\pi^-) - v_2(\pi^+) = v_2^{\pi}(\text{base}) + rA_{\text{ch}} > 0 \]

\[ v_2(K^-) - v_2(K^+) = v_2^K(\text{base}) + rA_{\text{ch}} < 0 \]

are valid
Within errors, slope(K) are consistent with the published slope(π), particularly in semi-central collisions.
Raw slope(K) in $\sqrt{s_{NN}}$ 19, 14 GeV

In $\sqrt{s_{NN}}$ 14, 19 GeV, slope(K) fluctuate with large errors
In $\sqrt{s_{NN}}$ 7, 11 GeV, statistics are too low to extract useful information for K

error bars are only statistical
raw slope - no $A_{ch}$ correction applied
The linear relationship between $A_{ch}$ and $\Delta v_2(K)$ (with widened $p_T$ range) are studied in Au+Au collisions in different energies, which are quite similar to the case of $\pi$.

In 200 GeV collisions, the centrality dependence of slope(K) (with widened $p_T$ range) shows the same behavior as that of $\pi$, in both trend and order of magnitude.

In 27~62 GeV collisions, particularly in semi-central collisions, slope(K) (with widened $p_T$ range) are consistent with slope($\pi$) within the uncertainties. At energies less than 27 GeV, due to the statistics, it's hard to draw solid conclusion so far.

This observation doesn't conflict with our knowledge of (anti-)particle flow since the intercepts are negative.

Thank you for your attention!
Backup
Data selection

- 200 GeV (Run10, Run11), 62 GeV (Run10), 39 GeV (Run10), 27 GeV (Run11)
  19 GeV (Run11), 14 GeV (Run14), 11 GeV (Run10), 7 GeV (Run10)

- Event: MB trigger, Vz < 30 cm, Vr < 2 cm

- \( A_{ch} \): \(|\eta| < 1\), DCA < 1 cm, low \( p_T \) (anti)proton removed (|\( n_{\sigma} | < 3\)

- \( v_2 \): Q-Cumulants method (2 sub-events) with 0.3 \( \eta \) gap between POI and RFP
  PID(\( \pi \), K) is applied by TPC+ToF in all \( p_T \)
$\pi$ p$_T$ spectra

$K$ p$_T$ spectra

$p_T$ cut at 0.5 already includes most of $\pi$, but not enough for $K$

PID: TPC+TOF for all p$_T$ range
Raw slope($\pi$, various $p_T$) in $\sqrt{s_{NN}}$ 200 GeV

Changing $p_T$ range doesn’t effect slope results, since $p_T$ cut at 0.5 already includes most of $\pi$
Test of autocorrelation

To test trivial autocorrelation between \( A_{ch} \) and \( v_2 \), \( K \) are removed when calculating \( A_{ch} \).

- The linear relationship can still be observed.
- Centrality dependence of slope doesn't change much.

\( \sqrt{s_{NN}} = 200 \text{ GeV}, p_T(K) \sim (0.15, 1) \text{ GeV/c} \)

Error bars are only statistical.
Differential $v_2$
Differential $v_2$

$K^+$  
$K^-$
Another set of slope(K) in $\sqrt{s_{NN}}$ 27, 39, 62 GeV

Error bars are only statistical, shaded band are systematical error, including track efficiency, DCA(K), $\Delta v_2$ extraction method (from Gang Wang)
$A_{ch}$ dependence of $K^+ - v_2$ in $\sqrt{s_{NN}}$ 200 GeV
π Mean $p_T$ for different $p_T$ upper limits

very small error bars (negligible)

$\Delta v_2$ ($\pi$)

Q: Why we integrate $p_T$ in [0.15, 0.5] GeV/c in previous analysis?
A: Keep mean $p_T$ effect at a minimum

We know ($v_2 \sim 0.1 \times p_T$) so ($0.002 \times 0.1 < 0.1\%$) \[\Delta v_2(\pi)\]
K Mean $p_T$ for different $p_T$ upper limits

very small error bars (negligible)

$p_T < 0.5$

Interval 0.004 GeV/c

$p_T < 0.6$

Mean $p_T$ in five $A_{ch}$ bins are supposed to be stable, but become fluctuant if $p_T$ upper edge increase

However, it’s still reasonable if we go higher on $p_T$ to get more statistics