Elliptic flow results from STAR
Outline

1. Introduction.
2. The STAR experiment.
3. Search for signals in the energy and system size dependence of elliptic flow to study the phase diagram of strongly interacting matter
   a. Looking for signatures for the partonic degrees of freedom (PDoF)
   b. Phase transition (PT): Softest Point of the EoS
4. Summary and Conclusions.
1. Introduction

Elliptic Flow

- In non central collisions the coordinate space configuration is anisotropic, but the initial momentum distribution is isotropic.
- Interaction among constituents generate a pressure gradient which transforms the initial coordinate space anisotropy into the observed momentum space anisotropy → anisotropic flow
- Elliptic flow is sensitive to the early stage of collision dynamics.
  ⇒ A unique hadronic probe of the early stage

Heavy Ion collision → Partonic phase → Hadronic phase

\[ \varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \]

\[ v_2 = \langle \cos 2\phi \rangle, \quad \phi = \tan^{-1} \left( \frac{p_y}{p_x} \right) \]
The STAR Experiment

• TPC: Q, x, p, dE/dx
• TOF: time of flight

• $\pi^\pm, K^\pm$ and p: dE/dx in TPCs
• $K^0_s, \Lambda, \Xi, \Omega$: decay topology + inv. mass. + dE/dx
• $\varphi$: inv. mass. + dE/dx

3. Signals to discover PDoF and PT

Scenarios for Partonic Matter and Phase Transition

a) Partonic degrees of freedom

- Do we see partonic collectivity at top RHIC energies?
- Does ideal hydrodynamic work at RHIC energies?
- Is NQ scaling only a geometry effect?

b) Phase transition
Partonic Collectivity

Heavy Ion collision

Partonic collectivity

• Collectivity develops on the quark level and persists on the hadron level after hadronization.

Hadronic collectivity

• Collectivity develops on the hadronic level and will be different for every hadron species due to their cross-section.
At low $p_t$ ($\leq 2$ GeV/c) hadronic mass ordering effect is visible.

At high $p_t$ ($> 2$ GeV/c) number of quarks ordering.

$\Rightarrow$ Collectivity develops at the partonic stage
Partonic Collectivity

\(Au + Au, \sqrt{s_{NN}} = 200 \text{ GeV}\)

\(Cu + Cu, \sqrt{s_{NN}} = 200 \text{ GeV}\)

- \(v_2\) of light and multi-strange hadrons are scaling by the number of quarks
- \(\Rightarrow\) also visible for \(\Phi\) and \(\Omega\) which indicates that the collectivity develops at the partonic level

Ideal Hydrodynamics

- Ideal hydrodynamics fails to describe the data
  - Missing of $v_2$ fluctuations?
  - Viscosity (non-zero $\eta/s$)?
  - Incomplete thermalization?

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Huovinen priv. communication 2003, 2006
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Cu + Cu, $\sqrt{s_{NN}} = 200$ GeV

0-60% Event plane method (FTPC)

$V_2$ vs. $p_T$ (GeV/c)


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Centrality Dependence

**a. Partonic degrees of freedom**

- **Partonic degrees of freedom**
  - **Au+Au collisions**
    - $v_2$ scaled by the eccentricity to remove initial geometry effects.
    - No $\varepsilon_{\text{part}}$ scaling is observed.
    - $v_2/\varepsilon_{\text{part}}$ is larger for central collisions compared to peripheral ones which indicates stronger collectivity in central collisions.

$\Rightarrow$ scaling by the number of quarks is visible for all centralities

Scenarios for Partonic Matter and Phase Transition

3. Signals to discover PDF and PT

a) Partonic degrees of freedom

b) Phase transition

• Will we see a change of the EOS in the RHIC Beam Energy Scan (BES)?
b. Phase Transition

Signatures for a Phase Transition - BES Program

At the phase transition from hadronic matter to quark-gluon plasma the EOS is softer in a mixed phase.

This should be visible in a deep minimum of proton $v_2$ at midrapidity known as softest point.

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Hydro calculation shows a minimum for the elliptic flow when passing through a change of the EOS from hadronic matter to quark-gluon plasma.
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b. Phase Transition

Signatures for a Phase Transition - BES Program

- At the phase transition from hadronic matter to quark-gluon plasma the EOS is softer in a mixed phase.

- This should be visible in a deep minimum of proton v2 at midrapidity known as softest point.

- Hydro calculation shows a minimum for the elliptic flow when passing through a change of the EOS from hadronic matter to quark-gluon plasma.

- The breaking of v2 number of quark scaling will indicate a transition from partonic to hadronic world.

  ⇒ Important to measure multi-strange particles especially Ω and φ v2

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b. Phase Transition

Signatures for a Phase Transition - BES Program

\( Au + Au, \sqrt{s_{NN}} = 9.2 \text{ GeV} \)

- \( v_2 \) results from 9.2 GeV test run with 3k good events.

BES Program

\( Au + Au, \sqrt{s_{NN}} = 39 \text{ GeV} \)

\( Au + Au, \sqrt{s_{NN}} = 7.7 \text{ GeV} \)

- Analysis of \( v_2 \) results for charged and PID hadrons are ongoing.


Signatures for a Phase Transition - BES Program

**Au + Au, $\sqrt{s_{NN}} = 9.2$ GeV**

- $v_2$ results from 9.2 GeV test run with 3k good events.

**BES Program**

- Analysis of $v_2$ results for charged and PID hadrons are ongoing.

Summary and Conclusions

a) Partonic degrees of freedom

- NQ scaling works for Au+Au $\sqrt{s_{NN}} = 62.4/200$ GeV and Cu+Cu at $\sqrt{s_{NN}} = 200$ GeV collisions.
- Ideal hydrodynamics fails to reproduce the data from Au+Au and Cu+Cu collisions.
- $v_2/\varepsilon_{part}$ shows larger $v_2$ for central compared to peripheral collisions
  \[ \Rightarrow \text{scaling by the number of quarks is visible for all centralities} \]

b) Phase transition

- The EOS will be softer in a mixed phase. This should be visible:
  - Collapse of proton $v_2$ at midrapidity
  - Minimum of $v_2$ for charged particles when trespassing a change of the EOS

- $v_2$ NQ scaling will break in a hadronic scenario.
The End and Thanks for Your Attention