Event anisotropy $v_2$ of identified hadrons and light nuclei in Au+Au collisions at $\sqrt{s_{NN}} = 7.7, 11.5$ and 39 GeV with STAR

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Quark Matter Annecy 2011
Outline:

- Introduction and Motivation
- The Beam Energy Scan and the STAR experiment at RHIC
- Particle Identification
- $v_2$ results @ 7.7, 11.5 and 39GeV
- Summary and Outlook
Introduction and Motivation

Goal:
• Signatures for a QCD phase transition → difference between the partonic and the hadronic degrees of freedom

How To?
• Onset of Quark-Gluon Plasma → e.g. Number of Constituent Quark (NCQ) scaling of $v_2$

The RHIC Beam Energy Scan (BES)

→ B. Mohanty: “STAR: results from the beam energy scan program” (Thursday 8:55)

NCQ scaling @ STAR:
The **Solenoid Tracker At RHIC (STAR)**
The Solenoid Tracker At RHIC (STAR)

Detector in year 2010:
- Full time-of-flight barrel

Data Collected:
- 4.2M @ 7.7 GeV
- 11M @ 11.5 GeV
- 17M @ 19.6 GeV
- 169M @ 39 GeV
- 160M @ 62.4 GeV
Particle Identification via TPC and TOF

- $dE/dx$ can separate the particles up to $\sim 1$ GeV/c
- First beam time period with full TOF system → Clean separation of $K,\pi$ up to 1.6 GeV/c
Reconstructed Particles

- Improved S/B ratio compared to previous results due to additional time-of-flight PID
**Inclusive Hadron \( v_2 \) @ 7.7, 11.5 and 39 GeV**

- Systematic study of inclusive charged hadron \( v_2 \)
- Various methods are used to extract \( v_2 \)
- Overall a good agreement between the different methods
- 7.7, 11.5 GeV: less difference between \( v_2 \{2\} \) and \( v_2 \{4\} \)
  \( \rightarrow \) non-flow, fluctuations

\[ \rightarrow \text{M. Mitrovski: "Elliptic Flow of charged particles in } \text{Au+Au collisions" (Poster session: ID 291, Board #19)} \]
Inclusive Hadron $v_2$ @ 7.7 GeV – 2.76 TeV

STAR Preliminary


- Comparison of $v_2(p_T)$ over several orders of magnitude in energy
- Overall $v_2(p_T)$ shape looks very similar
- Deviations of +/- 30% relative to 200 GeV at low $p_T$

→ S. Shi: “Inclusive charged hadron elliptic flow in Au+Au collisions” (Poster session: ID 281, Board #16)
All kaon species show similar $v_2(p_T)$ at 11.5 and 39 GeV.

- $v_2(K^+) > v_2(K^-)$ at 7.7 GeV
- $v_2(\pi^-) > v_2(\pi^+)$ at 11.5 and 7.7 GeV, identical at 39 GeV
Proton and $\Lambda$ $v_2$ @ 7.7, 11.5 and 39 GeV

- $v_2(p) > v_2(\bar{p})$ at all energies, increasing difference with decreasing energy, or larger $\mu_B$
- Same behavior for $\Lambda$ and $\bar{\Lambda}$
Particle-anti-Particle Difference in $v_2$

- Baryon-anti-baryons show at higher energies a constant difference of ~10%
- Difference for meson $v_2$ is ~0 at higher energies
- Huge increase of baryon-anti-baryon difference at 11.5 and 7.7 GeV → Baryon transport to mid-rapidity? → Absorption in hadronic environment?
- Significant difference between $K^+$ and $K^-$ at 7.7 GeV
- Opposite trend for $\pi^+$ and $\pi^-$

→ NCQ-scaling between particles and anti-particles is broken @ 11.5 and 7.7 GeV
$v_2$ vs. $(m_T - m_0)$ of Particles

- Meson ↔ Baryon splitting for particles @ 11.5 and 39 GeV
- Splitting is smaller @ 7.7 GeV
$v_2$ vs. $(m_T - m_0)$ of Particles

- Meson ↔ Baryon splitting for particles @ 11.5 and 39 GeV
- Splitting is smaller @ 7.7 GeV
- Φ-mesons @ 11.5 GeV show a different trend
$v_2$ vs. $(m_T - m_0)$ of Particles

- Meson ↔ Baryon splitting for particles @ 11.5 and 39 GeV
- Splitting is smaller @ 7.7 GeV
- $\Phi$-mesons @ 11.5 GeV show a different trend
- $\Phi$-mesons @ 7.7 GeV would need ~ a factor 5 more statistics to have a reasonable small error bar

Au+Au (0-80%), $\eta$-sub EP
Test of NCQ-Scaling for Particles: $v_2$ vs. $p_T$

- 39 GeV NCQ-scaling at intermediate $p_T$ looks similar to 200 GeV
- $\Phi$-mesons @ 11.5 GeV do not follow the trend of other hadrons!
- Rest of the particles follow NCQ-scaling, separated from anti-particles
Most of the particles follow one common $v_2$ distribution

Φ-mesons @ 11.5 GeV do not follow the trend of other hadrons:
Mean deviation from pion distribution: $0.02 \pm 0.008 (\rightarrow 2.6 \sigma)$

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Light nuclei can be used to study nucleon ↔ quark coalescence
Summary

- At 39 GeV the NCQ scaling looks similar to the results obtained at 200 GeV

- NCQ-scaling between particles and anti-particles is broken @ 11.5 and 7.7 GeV

- $\phi$-meson $v_2$ does not follow the trend of other particles at 11.5 GeV

Outlook

- Au+Au @ 19.6 and 62.4 GeV are ready, Au+Au @ 27 GeV is requested for 2012
  → 19.6 and 27 GeV important to scan in detail the region of interest!
Baryon $v_2$ @ 7.7, 11.5 and 39 GeV

- $v_2(p) > v_2(\bar{p})$ at all energies, increasing difference with decreasing energy, or larger $\mu_B$
- Same behavior for $\Lambda$ and $\bar{\Lambda}$
$v_2$ vs. $p_T$

- $\Phi$-meson $v_2(p_T) \ll v_2(p_T)$ of other particles @ 11.5 GeV
- Mass scaling of $v_2$ at low $p_T$, except for $\Phi$-mesons
Anti-Particles: $v_2$ vs. $m_T$

STAR Preliminary

Au+Au (0-80%), $\eta$-sub EP

$7.7$ GeV

$11.5$ GeV

$39$ GeV

$m_T$ - $m_0$ (GeV/c$^2$)
Combined TPC and TOF PID

- Combined TPC and TOF PID at high momenta
- Best separation of Kaons and Pions for the shown projection axis
  → Particle identification at high $p_t$
Anti-Proton PID @ 7.7 GeV

23.05.2011
Alexander Schmah - LBNL
Phi-mesons @ 11.5 GeV, Systematics

23.05.2011
Alexander Schmah - LBNL

STAR Preliminary

\( \phi v_2 \)
- Nasim
- Xiaoping
- Alex

\( \eta \) sub EP

Tranverse Momentum (\( p_t \)) in GeV

Au + Au @ 11.5 GeV
0-80 % Centrality

STAR Preliminary

\( \phi \rightarrow K^- + K^+ \)
(0-80%)

Minv
\( \phi - \Psi \)

STAR Preliminary

\( p_t \) [GeV/c]