Recent RHIC Results on Bulk Properties

Richard Hollis

21st June 2007

RHIC & AGS Users’ Meeting
The Road Ahead

- Bulk properties measurements at RHIC
  - New measurements and expanded systematics

- Scaling with $N_{\text{part}}$, $N_{\text{ch}}$ or $\varepsilon_{\text{part}}$

- Simple Scaling Rules
Systematic Studies

- RHIC input
  - Energy
  - Collision system (species)

- Experimental input
  - Rapidity
  - Species
  - System size/configuration

- Varied Cross-section
  - esp. hard collisions
  - Influence toward bulk properties

- Study dominating effect
  - $N_{\text{part}}$ or fractional cross-section

- Probe range of $x_F$
- Relative enhancement of baryons to mesons
- Path length and collective effects

Do systematic studies paint a consistent picture of bulk particle production?
Total Charged Hadron Distributions

dN/d\eta
flow\{v_2,v_1,\sigma(v_2)/v_2\}
Multiplicity

- Latest Results
  - Au+Au (Peripheral)
  - Cu+Cu (22.4 GeV)

- Mid-rapidity
  - Factorization in energy and centrality

- $4\pi$
  - Extended longitudinal scaling – factorizes in energy and centrality

Factorization persistent across all systems
Elliptic Flow

- Similar systematic dependencies as multiplicity
- Mid-rapidity:
  - $v_2/\varepsilon_{\text{part}}$ scaling holds over a broad range of collision energy and system sizes
- $\eta$ dependence
  - $v_2/\varepsilon_{\text{part}}$ holds over large $\eta$ range
  - Extended longitudinal scaling

Geometrical scaling with $\varepsilon_{\text{part}}$
Directed Flow

- $v_1$ is found to scale with collision energy, not collision species
  - Comparison of same overlap geometry
- Extended longitudinal scaling applies
Elliptic Flow Fluctuations

- Large fluctuations in the $v_2$ signal
- Geometrical Properties are imprinted on the data:
  - Eccentricity via Flow

\[ \text{Au+Au @ 200 GeV} \]
Final Charged Particle Distribution Summary

- Final distributions provide a consistent picture of particle production driven by simple scaling laws:
  - Energy, centrality factorization
  - Detailed initial geometrical configuration ($\varepsilon_{\text{part}}$)

- How do differential measurements compare
p_T Distributions

Yield versus p_T
v_2{p_T}
Freeze-out properties
Yield versus $p_T$

- Mid-rapidity yields versus $p_T$
  - Factorization in energy and centrality

- Similar behavior to bulk yields
Elliptic flow at mid-rapidity

- Latest Results:
  - $v_2(p_T)$ (200 GeV)

- $v_2(p_T)$ shape independent of centrality and system size

$v_2(p_T)$: universal scaling?

PRL 98, 162301 (2007)
Kinetic freeze-out properties

- Latest Results:
  - Freeze-out properties

- Freeze-out temperature and flow velocity follow a common dependence with number of charged particles at mid-rapidity

- Mean-\(p_T\) follow same trend

Similar dependence noted by PHENIX (JPS 2007)

**Scaling of low-\(p_T\) properties with \(N_{ch}\)**
Chemical freeze-out properties

- Latest Results:
  - Cu+Cu at 200 and 62.4 GeV
- Universal chemical freeze-out temperature, $T_{ch}$, is observed for all studied systems
p_T Distributions Summary

- First differential measurements:
  - “Universal scaling” of elliptic flow versus p_T
  - N_{ch} scaling of kinetic freeze-out properties
Chemical properties

Strangeness production
Baryon enhancement
$v_2(KE/n_q,y)$
Strangeness production – $K^\pm$

- Latest Results:
  - $62.4 \text{ GeV Au+Au}$

- Charge “splitting” of $K/\pi$ as observed at SPS

- “Chemical equivalence” with SPS energies
Strangeness production – $\Lambda$

- Latest Results:
  - $\Lambda$ scale reasonably with $N_{\text{part}}$ for the same energy
  - Enhanced strangeness production due to core of core/corona model
    - More core per $N_{\text{part}}$ in Cu+Cu collisions

Recombination Model

- Recombination Model
  - Describes the $p_T$ dependence of strange particles
    - $K, \Lambda$
  - Fits provide good agreement with data
  - Qualitatively reproduces $\Lambda/K^0_S$ ratio
Baryon Enhancement

- Enhancement is maximal in the intermediate-$p_T$ region
  - Cu+Cu data exhibit the same systematic trends as for Au+Au system

![Graph showing enhancement in Cu+Cu data](QM2006)
Baryon Enhancement

- $N_{\text{part}}$ scaling for $p/\pi$
  - Integrated intermediate-$p_T$ region

- Moreover, $E_T$ scaling exists between 200 and 62.4 GeV ($p\bar{p}/\pi^-$)
  - Baryon transport contributes at 62.4 GeV for protons

Scaling of intermediate-$p_T$ properties with $E_T$
Recombination Revisited

- Recombination predicts other B/M ratios
  - Qualitative agreement.

- s-quark dependence on peak position is predicted
  - But at higher-$p_T$ than data suggests.
Recombination Revisited

- Validity test:
  - $\Omega, \phi$
- A good description of the multi-strange spectra
  - $\Omega$: dominated by thermal term
  - Look at $\Omega$ correlations
    - No near-side correlation expected

- Correlation observed
  - Magnitude of near-side correlation is independent of strange-quark content
Quark scaling of elliptic flow

- Latest Results:
  - $v_2/n_q$ scales with $KE_T/n_q$
  - Holds for Cu+Cu data
    - Once $\varepsilon$ is accounted for

PRL 98, 162301 (2007)
Identified $v_2$

- For different centrality bins:
  - No *universal* scaling

\[ v_2(p_T, \text{centrality}) \]

\[ p_T (\text{GeV/c}) \]

\[ v_2/p_T^2 \]

\[ \text{Min-bias, particle id'd} \]

\[ \text{Centrality Dependence} \]

\[ p_T/n_q (\text{GeV/c}) \]

\[ 0-10\%, 10-40\%, 40-80\% \]

\[ 0, 0.1, 0.2, 0.3, 0.4 \]

\[ 0, 0.5, 1, 1.5, 2 \]
Identified flow versus $p_T$ and rapidity
  - No appreciable difference in shape
    - cf. PHENIX flow at mid-rapidity
  - No difference in magnitude

Systematics fit into existing data
Chemical Summary

- Further differential measurements:
  - $\bar{p}/\pi - N_{\text{part}}$ scaling
  - Qualitative description of B/M ratios in the recombination picture
    - But fails to describe the multi-strange correlations
  - Universal scaling of identified $v_2(p_T)$
    - Observed for min-bias across system size
    - Not observed versus centrality
Summary

- Bulk properties measurements at RHIC
  - New measurements and expanded systematics

- Scaling with $N_{\text{part}}$, $N_{\text{ch}}$ or $\varepsilon_{\text{part}}$
  - For the bulk to intermediate-$p_T$ regions

- Simple Scaling Rules
  - Applicable over a broad range of centrality, energy and colliding species
Thanks!

- Credits:
  - BRAHMS
    - Flemming Videbaek
  - PHENIX
    - Barbara Jacak, Craig Ogilvie
  - STAR
    - Aihong Tang, Subhasis Chattopadhyay, Olga Barannikova, Rene Bellwied
  - PHOBOS
    - Wit Busza, David Hofman, Aneta Iordanova

Evan, 6 weeks and 2 days

29
21st June 2007
Back-up Slides
Core/corona

- Core – high density region
- Corona – low density region around the edge

My own simulations

- Based on similar ideas


Thesis (2005)

Richard Hollis
University of Illinois at Chicago
Particle Ratios versus system size

- Particle Ratios
  - 200 and 62.4 GeV
  - Au+Au and Cu+Cu

- Weak centrality dependence, no system size dependence of particle ratios