Scaling Properties of Identified Hadron Transverse Momentum Spectra in Au+Au and Cu+Cu Collisions at RHIC-PHENIX

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Hadron production in heavy ion collisions at RHIC

- Hadron production mechanisms:
  - Thermal emission
  - Quark recombination
  - Jet fragmentation

- Bulk properties of the system:
  - Thermalization
  - Collective flow
  - Freeze-out (Chemical, Kinetic)

- High-\(p_T\) phenomena in the medium:
  - Jet quenching (Energy loss)
  - Particle correlation of jets

- Single particle spectra and particle ratios provide the most basic observables to investigate the mechanisms of hadron production.

- Particle Identification (PID) over wide \(p_T\) range is also crucial.
**Hadron production at intermediate $p_T$**

- Baryon/meson difference at intermediate $p_T$ (2~5 GeV/c)
  - Baryon enhancement in particle ratios
  - Splitting of $v_2$ strength into baryon/meson groups
- Now explained in quark recombination picture
- A transition from soft to hard production at intermediate $p_T$

**What is the next?**

**Purposes:**
- Relative contributions of hadron production mechanisms (soft/hard)
- Scaling properties of identified hadron $p_T$ spectra in different collision systems.
- Systematic scan over different collision systems (colliding species, beam energies) with available data obtained at PHENIX.

(Au+Au, Cu+Cu at $\sqrt{s_{NN}} = 62.4, 200$ GeV)

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- Central Arm Detectors
- Centrality and Reaction Plane
determined on an E-by-E basis.
- PID (particle identification) is
  a powerful tool to study hadron
  production.

Aerogel Cherenkov (PID)

**Aerogel Cherenkov (ACC)**
- p (p) ID up to 7 GeV/c
- K+ ID up to 4 GeV/c

**Time of Flight (TOF)**
- p (p) ID up to 4 GeV/c

**Drift Chamber**
- (momentum meas.)

**Tracking detectors**
- (PC1, PC2, PC3)

**Veto for proton ID**
Blast-wave Model Fit

- Blast-wave model is a hydrodynamic-inspired model.
- Extracting kinetic freeze-out properties with BW model.
- Simultaneous fit to $p_T$ spectra ($\pi/K/\rho$) for each centrality class.

\[
\frac{dn}{m_T \, dm_T} \propto \int_0^R dr \, m_T \, K_1 \left( \frac{m_T \, \cosh \rho}{T} \right) I_0 \left( \frac{p_T \, \sinh \rho}{T} \right)
\]

\[\rho = \tanh^{-1} \, \beta_r \quad \beta_r (r) = \beta_s \, f(r)\]

* Ref: PRC48(1993)2462

*Spectra for heavier particles has a convex shape due to radial flow.

(* Resonance decay feed-down correction not applied. Instead, tighter $p_T$ fitting range used. $\pi$; 0.6-1.2 GeV/c K; 0.4-1.4 GeV/c, p/pbar; 0.6-1.7 GeV/c)
- $N_{\text{part}}$ scaling of $T_{fo}$ between Au+Au and Cu+Cu
- Almost same $T_{fo}$ at $\sqrt{s_{NN}} = 62.4$, 200 GeV

$T_{fo} \sim 120$ MeV
Blast-wave Model Fit - $<\beta_T>$ vs. $N_{\text{part}}$

- $N_{\text{part}}$ scaling of $<\beta_T>$ between Au+Au and Cu+Cu
- Almost same $<\beta_T>$ at $\sqrt{s_{NN}} = 62.4$, 200 GeV
\( \langle p_T \rangle \) vs. \( N_{\text{part}} \)

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

\( \langle p_T \rangle \): \( \pi<K<p \) (mass dependence)

- Consistent with radial flow picture

\( \sqrt{s_{NN}} = 62.4 \text{ GeV} \)

- \( N_{\text{part}} \) scaling of \( \langle p_T \rangle \) between Au+Au and Cu+Cu

- Almost same \( \langle p_T \rangle \) at \( \sqrt{s_{NN}} = 62.4, 200 \text{ GeV} \)
Estimation of \( p/\pi \) at intermediate \( p_T \)

- Extrapolate low-\( p_T \) Blast-wave fit results to intermediate \( p_T \) in order to estimate \( p/\pi \) ratio.

- Hydrodynamic contribution for protons is one of the explanations of baryon enhancement.
- Other contribution is also needed: Recombination, Jet fragmentation

* No weak decay feed-down correction applied.
Baryon enhancement - $p/\pi$ vs. $N_{\text{part}}$

- $N_{\text{part}}$ scaling of $p/\pi$ between Au+Au and Cu+Cu at same $\sqrt{s_{NN}}$

Au+Au vs. Cu+Cu at 200 GeV

Au+Au vs. Cu+Cu at 62.4 GeV

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No $N_{\text{part}}$ scaling of $p/\pi$ ($p_{\text{bar}}/\pi$) in Au+Au between 62.4 and 200 GeV.
- $dE_T/dy$ scaling of $p_{\text{bar}}/\pi$ seen. => Proton production (at this $p_T$ range) at 62.4 GeV is partly from baryon transport, not only pair production. Nuclear stopping is still large at 62.4 GeV.

Phenix preliminary
Statistical Model Fit - $\mu_q$ vs. $N_{\text{part}}$

- $N_{\text{part}}$ scaling of $\mu_q$ between Au+Au and Cu+Cu
- Larger $\mu_q$ at $\sqrt{s_{NN}} = 62.4$ GeV than that at 200 GeV

$\mu_q \sim 8$ MeV
Summary

- Scaling properties of PID $p_T$ spectra tested with Au+Au and Cu+Cu data at $\sqrt{s_{NN}} = 62.4/200$ GeV.

- Bulk properties ($dN/dy$, $<p_T>$, kinetic and chemical freeze-out properties) are scaled with $N_{\text{part}}$ (~volume) at same $\sqrt{s_{NN}}$.

- $p(\bar{p}/\pi$ ratios:
  (1) $N_{\text{part}}$ scaling between Au+Au and Cu+Cu at same $\sqrt{s_{NN}}$
  (2) $dE_T/dy$ scaling between 62.4 and 200 GeV in Au+Au
  (3) $\bar{p}/\pi$ is a good indicator of baryon enhancement

On-going

- MRPC-type TOF counter ($\sigma_{\text{TOF}}$~100ps) was installed behind the Aerogel for high-$p_T$ PID upgrade. Run-7 has just started for 200 GeV Au+Au. Higher-$p_T$ physics can be reached.
Backup
Statistical Model Fit

- Extracting chemical freeze-out properties with statistical model fit.
- Fitting particle ratios of dN/dy (π/K/p) at y~0.
- Assuming chemical equilibrium of light quarks (u,d,s), \( \gamma_s = 1 \).
- Partial feed-down correction taken into account.

\[
\frac{N_i(T, \mu)}{V} = \frac{g_i}{2\pi^2} \gamma_s \int_0^\infty \frac{p^2 dp}{e^{(E_i - \mu_B B_i - \mu_s S_i)/T} + 1}
\]

- \( T_{ch} \), \( \mu_q \): relatively stable
- \( \mu_s \), \( \gamma_s \): not determined with this set of ratios (\( \pi/K/p \)). Strangeness info is short.

Ref:
- Phys. Rev. C71 054901, 2005
- nucl-th/0405068
- NPA698(2002)306C

\[ \sqrt{s_{NN}} = 200 \text{ GeV} \]
\[ \sqrt{s_{NN}} = 62.4 \text{ GeV} \]
If $\gamma_s$ is free, $T_{ch} = 155 \pm 7$ MeV.

- $N_{part}$ scaling of $T_{ch}$ between Au+Au and Cu+Cu
- Almost same $T_{ch}$ at $\sqrt{s_{NN}} = 62.4, 200$ GeV