Rapidity Dependent Transverse Flow at RHIC

- $\pi, K, p$ spectra vs $y$ for central Au+Au at 200 GeV
- mean $p_T$ vs $y$ ($0 < y < 3.5$)
- Blast-Wave Fits vs $y$ ($y \sim 0, 1, 2, 3$)
- Summary

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Characterizing “Thermal” Source with Transverse Flow

- Curvature and Slope of $m_T$ spectra increase with particle mass
  - measure inverse slope parameter ($T_{obs}$), $<p_T>$ of identified particles
  - $T_{obs} = T_{fo} + \text{mass} \cdot \beta^2$

- Hydro-inspired Blast-Wave fits to deduce freeze-out parameters
  - Local thermal equilibrated source or boosted system
  - parameterization with Flow velocity ($\beta$), freeze-out Temperature ($T_{fo}$) and System Geometry (size and profile)
  - Schnedermann et al. PRL48(1993)

$$\frac{dn}{m_T dm_T} \propto \int_0^R r \, dr \, m_T \, K_1 \left( \frac{m_T \cosh \rho}{T_{th}} \right) I_0 \left( \frac{p_T \sinh \rho}{T_{th}} \right)$$

- Thermal Freeze-out Temperature: $T$
- boost angle: $\rho = \tanh^{-1} \beta$
- Transverse velocity: $\beta(r) = \beta_s (r/R_{max})^\alpha$

How does Transverse Flow develop with rapidity?
- $<p_T>$ vs $y$
- BW Fit with $T, \beta, \alpha$ vs $y$
\pi^+ \text{ and } \pi^- (0-5\% \text{ Au+Au at } \sqrt{s_{NN}} = 200 \text{ GeV}) (0 \leq y \leq 3.5)

- Pion spectra shown with power-law fits (Divided by 10 successively from top)
- Fitting ranges for BW fits shown with dashed lines (-resonance, -"hard" part)
- "Inverse Slope" (from 0.3-1.0GeV): slowly decrease with rapidity (~220MeV -> ~200MeV)
- dN/dy shape: close to a Gaussian with $\sigma(\pi^+) \sim \sigma(\pi^-) \sim 2.3$
K* and K-(0-5% Au+Au at $\sqrt{s_{NN}} = 200$ GeV) ($0 \leq y \leq 3.3$)

- Kaon spectra shown with $m_T$ exponential fits (Divided by 10 successively from top)
- Inverse Slope: smoothly decrease with rapidity (~300MeV -> ~230MeV)
- $dN/dy$ shape: close to a Gaussian with $\sigma(K^+)\sim 2.4$ $\sigma(K^-)\sim 2.1$
proton and pbar spectra shown with Gaussian fits
- Spectra are summed over rapidity ranges of $\delta y=0.4-0.6$ due to statistics+acceptance
- $\Lambda$ feed-down corrections are not applied
• Calculated from fitting spectra
• \( \langle p_T \rangle \) decrease with \( y \): \( \pi \sim 10\% \) K and \( p \sim 15-20\% \) drop from \( y=0 \) to \( y\sim 3 \)
• AMPT and 3D-Hydro model under-predict \( \langle p_T \rangle \)
• 3D-Hydro describe \( y \)-dependence qualitatively with a single \( T_{th} \) value (\( T_{th} = 100 \) MeV, \( T_{ch} = 170 \) MeV)
Spectra with BW Fits at $y \sim 0, 1, 2, 3$ ($T, \beta_s, \alpha$ in the fit $R_{\text{max}} = 13\text{fm}$)

\begin{align*}
\beta_s &= 0.737 \pm 0.016 \\
\text{Temp} &= 0.118 \pm 0.004 \\
\alpha &= 0.313 \pm 0.042
\end{align*}

\begin{align*}
\beta_s &= 0.776 \pm 0.020 \\
\text{Temp} &= 0.099 \pm 0.005 \\
\alpha &= 0.365 \pm 0.063
\end{align*}

\begin{align*}
\beta_s &= 0.763 \pm 0.072 \\
\text{Temp} &= 0.105 \pm 0.014 \\
\alpha &= 0.460 \pm 0.107
\end{align*}

\begin{align*}
\beta_s &= 0.495 \pm 0.130 \\
\text{Temp} &= 0.137 \pm 0.009 \\
\alpha &= 0.114 \pm 0.334
\end{align*}
Fits done with a fixed $\alpha = 0.31$ (Uncertainty in $\alpha$ increase with $y$)

- $T$ increases as $\beta$ decreases with rapidity
- BW parameters better defined for smaller $y$
Fits done with a fixed $\alpha$ ($y=0$ value) and $T$ (or $\beta_s$)

$\beta_s$ decrease with $y$ :~25% decrease from $y\sim0$ to $y\sim3$

$\beta_s = 0.74-0.54$ ($<\beta> = 0.64-0.47$), $T=100-138$ MeV

Naïve picture: lower particle density $\rightarrow$ easier/faster to be frozen $\rightarrow$ higher temperature
Summary

• BRAHMS measured identified hadron spectra in $0 \leq y \leq 3.5$ in Au+Au at $\sqrt{s_{NN}} = 200$ GeV

• $<p_T>$ increase with particle mass and decrease with rapidity

• Blast-Wave parameterization describes data with $T$ and $\beta$

• Hydro-dynamical behavior/re-scattering in a wide rapidity range at RHIC
  - Strong collective transverse flow: $<\beta> \sim 0.64 - 0.47$
  - Thermal Freeze-out temperature: $T \sim 100 - 137$ MeV
  - Transverse flow decrease ($\sim 25\%$) with rapidity from $y=0$ to $y\sim3$ while temperature tends to increase
  - Consistent with Hydro calculations, especially at $y\neq0$? Constraint for models.