Violation of mass ordering for multi-strange hadrons at RHIC and LHC


Shiori Takeuchi
Sophia University

Collaborators:
Koichi Murase, Tetsufumi Hirano, Pasi Huovinen and Yasushi Nara
Contents

- Introduction
- Model
  - Integrated dynamical model
- Results
  - Hadronic rescattering effect
  - Mass ordering and its violation
- Summary
INTRODUCTION
Quark Gluon Plasma in relativistic heavy ion collisions

Hadronic observables → information throughout the space-time evolution

collision  thermalization  QGP  hadronization  rescattering

http://qgp-data.phy.duke.edu/transport/
Quark Gluon Plasma in relativistic heavy ion collisions

Multi-strange hadrons

→ small cross sections and less rescatterings

→ DIRECT INFORMATION ABOUT QGP?

Hadronic observables

→ information throughout the space-time evolution


http://qgp-data.phy.duke.edu/transport/
Violation of mass ordering due to less rescatterings of $\phi$ meson

Hydro + cascade

STAR experiment


Violation of mass ordering
due to less rescatterings of $\phi$ meson

Hydro + cascade

STAR experiment

Purpose of this study: systematic and quantitative study of hadronic rescattering effects on the spectra of multi-strange hadrons


Integrated dynamical model


- Kinetic transport model (JAM)
- Cooper-Frye formula (T=155MeV)
- Lattice EoS (s95p-v1.1)
- (3+1)D ideal hydro model
- Initial condition: MC-Glauber

Au+Au 200 GeV, Pb-Pb 2.76 TeV event-by-event simulation
$p_T$ spectra at the RHIC energy from an integrated dynamical model
$v_2(p_T)$ at the RHIC energy from an integrated dynamical model

$\pi$, $K$ and $p$ (hidden-) strange hadrons
$p_T$ spectra at the LHC energy from an integrated dynamical model
\( v_2(p_T) \) at the LHC energy from an integrated dynamical model

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

\[ v_2^2 \]

\[ \pi, K, \rho, \phi, \Lambda, \Xi, \Omega \]
Integrated dynamical model


Options in JAM

Case 1: full calculation (DEFAULT)

Case 2: switch off the hadronic rescatterings

Au+Au 200 GeV, Pb-Pb 2.76 TeV event-by-event simulation

Kinetic transport model (JAM)

Cooper-Frye formula (T=155MeV)

(3+1)D ideal hydro model

Initial condition: MC-Glauber

Lattice EoS (s95p-v1.1)
RESULTS
Rescattering effects on $\langle p_T \rangle$

$\pi$, $K$, $p\phi\Lambda$, $\Xi$, $\Omega$

$\frac{\langle p_T \rangle_{(fluid)}}{\langle p_T \rangle_{(final)}}$

Au-Au 200GeV

$|y| < 1$, MB events

$m$ (GeV/c$^2$)
Rescattering effects on $\langle p_T \rangle$

\[ \frac{\langle p_T \rangle_{(fluid)}}{\langle p_T \rangle_{(final)}} \]

- $\pi$
- $K$
- $p\phi\Lambda$
- $\Xi$
- $\Omega$

**Data:**
- **Au-Au 200GeV**
- $|y| < 1$, MB events

**Graph:**
- Hydro+JAM

**Axes:**
- $m$ (GeV/c$^2$)
- $\langle p_T \rangle_{(fluid)}/\langle p_T \rangle_{(final)}$ range 0.82 to 1.08

**Plot Details:**
- Points represent data points for different mass values, indicating the ratio of $\langle p_T \rangle$ in the fluid and final states.
Rescattering effects on $\langle p_T \rangle$

$m_T$ scaling

$$\frac{dN}{p_T dp_T} \propto e^{-m_T/T_{\text{eff}}}$$

- common flow velocity, $v_f$
- freeze-out at $T_f$

\[ T_{\text{eff}} = T_f + m v_f^2 / 2 \]
Rescattering effects on $\langle p_T \rangle$

$m_T$ scaling

\[ \frac{dN}{p_T dp_T} \propto e^{-m_T/T_{\text{eff}}} \]

- common flow velocity, $v_f$
- freeze-out at $T_f$

$T_{\text{eff}} = T_f + m v_f^2 / 2$
Rescattering effects on $\langle p_T \rangle$

$\pi, K, p\phi, \Lambda, \Xi, \Omega$

$m_T$ scaling

$$\frac{dN}{p_T dp_T} \propto e^{-m_T/T_{\text{eff}}}$$

- common flow velocity, $v_f$
- freeze-out at $T_f$

Multi-strange hadrons → deviation from the $m_T$ scaling

$m_T$ scaling

$$T_{\text{eff}} = T_f + m v_f^2/2$$

- common flow velocity, $v_f$
- freeze-out at $T_f$
Rescattering effects on $v_2$

The graph shows the ratio of $v_2$ (fluid) to $v_2$ (final) for various hadrons ($\pi$, $K$, $p\phi\Lambda$, $\Xi$, $\Omega$) as a function of mass ($m$) in GeV/c$^2$. The data is for Au-Au 200GeV collisions with $|y| < 1$, MB events.
During the hadronic stage,

- about 20% of final $v_2$ is generated for pion

**Rescattering effects on $v_2$**

![Graph showing $v_2$ vs. mass (GeV/c^2) for Au-Au 200GeV events with $|y| < 1$, MB events. The graph includes data points for various hadrons (π, K, ρ, Λ, Ξ, Ω), and a trend line for hydro+JAM model.]
During the hadronic stage,
- about 20% of final $v_2$ is generated for pion
- $v_2$ of other hadrons change little
Rescattering effects

\[ \frac{\langle p_T \rangle_{\text{(fluid)}}}{\langle p_T \rangle_{\text{(final)}}} \]

\[ m \text{ (GeV/c}^2) \]

\[ \frac{V_2_{\text{(fluid)}}}{V_2_{\text{(final)}}} \]

\[ m \text{ (GeV/c}^2) \]

**BOTH** \( \langle p_T \rangle \) and \( v_2 \) of multi-strange hadrons

\( \rightarrow \) less affected by the hadronic rescatterings
Rescattering effects on $v_2(p_T)$

Au-Au 200GeV, $|y| < 1$, MB events
Rescattering effects on $v_2(p_T)$

Slope:

$$dv_2/dp_T \approx v_2/\langle p_T \rangle$$

Rescattering effects on $v_2(p_T)$

Slope:

$$\frac{dv_2}{dp_T} \approx \frac{v_2}{\langle p_T \rangle}$$


$\pi$: $v_2$ increases

Au-Au 200GeV, $|y| < 1$, MB events
Rescattering effects on $v_2(p_T)$


Slope:

$$\frac{dv_2}{dp_T} \approx \frac{v_2}{\langle p_T \rangle}$$

$\pi$: $v_2$ increases

$p$: $\langle p_T \rangle$ increases

Au-Au 200GeV, $|y| < 1$, MB events
Rescattering effects on $v_2(p_T)$

\[ dv_2 / dp_T \approx \frac{v_2}{\langle p_T \rangle} \]


$\pi$: $v_2$ increases

$p$: $\langle p_T \rangle$ increases

Clear mass ordering

Au-Au 200GeV, $|y| < 1$, MB events
Mass ordering at the RHIC energy

\[ m_{\pi} < m_p < m_{\phi} \]

\[ v_2^\pi > v_2^p > v_2^\phi \]
Mass ordering at the RHIC energy

w/ rescattering

$|y| < 1$, MB events

Hadronic rescatterings cause the violation of mass ordering

$m_\pi < m_p < m_\phi$

$v_2^\pi > v_2^p > v_2^\phi$

$v_2^\pi > v_2^\phi > v_2^p$
Violation of mass ordering occurs at the LHC energy
Freeze-out time distribution

Au-Au 200GeV, |y| < 1, MB events

Less rescatterings of multi-strange hadrons
→ early freeze-out
Freeze-out time distribution

Less rescatterings of multi-strange hadrons
→ early freeze-out
Summary

Hadronic rescattering effects on transverse observables are studied
◆ At both the RHIC and the LHC energies
◆ Within an integrated dynamical model
Summary

**Hadronic rescattering effects** on transverse observables are studied

- At both the RHIC and the LHC energies
- Within an integrated dynamical model

**Multi-strange hadrons** less rescatter and freeze out earlier than non-strange hadrons.

- Direct information just after fluid stage
- "Penetrating probes"
Back up
Freeze-out time distribution

Pb-Pb 2.76TeV, |y| < 1, MB events

- Early freeze-out of multi-strange hadron
- Longer life-time of the QGP at the LHC energy
Freeze-out time distribution

Au-Au 200GeV, |y| < 1, MB events

Switch off $\Xi(1530) \rightarrow \Xi$

[Decay width: $\Gamma = 9.9\ MeV \sim 1/(20\ fm/c)$]

Primodial $\Xi$: a clear peak like other multi-strange hadrons
Mass dependences of $<p_T>$ and $v_2$

(a) $\pi$ $K$ $p\phi\Lambda$ $\Xi$ $\Omega$
- default
- without rescattering
- without rescattering or decay

(b) $\pi$ $K$ $p\phi\Lambda$ $\Xi$ $\Omega$
- default
- without rescattering
- without rescattering or decay
Penetrating probes

- EM probes (photons, leptons)
  - not affected by the hadronic rescatterings
  - come from different stages of a collision

- Multi-strange hadrons
  - less affected by the hadronic rescatterings
  - come just after the hadronization