Nuclear modification factors of strange mesons measured by PHENIX

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Motivation

- Strangeness content vs. first generation quarks in hadron production:
  - Strangeness enhancement, recombination and radial flow at moderate $p_T$
  - Energy loss flavor dependence at high $p_T$

- Pythia 8 and AMPT predictions:
  - Study from different perspectives (soft QCD, Lund Model, coalescence from QGP)

- PHENIX study different observables in a large variety of SYSTEMs
  - Minimal conditions to form a QGP and its properties
## Hadrons in this talk

### (hidden) strange

| h       | Quark content | Decay modes | BR, % | Mass, MeV |
|---------|---------------|-------------|-------|-----------|
| $K^+/K^-$ | $u\bar{s} / s\bar{u}$ | $\pi^0\pi^0$ | ~30   | ~498      |
| $K^0_S$  | $d\bar{s} - s\bar{d}$ | $\sqrt{2}$ |       | ~495      |
| $K^0/\bar{K}^0$ | $d\bar{s} / s\bar{d}$ | $\pi^+K^-$ | ~67   | ~896      |
| $\varphi$ | $0.9999 \cdot s\bar{s}$ | $K^+K^-$ | ~49   | ~1019     |

### light flavored

| h       | Quark content | Decay modes | BR, % | Mass, MeV |
|---------|---------------|-------------|-------|-----------|
| $\pi^0$  | $\sqrt{2}/u\bar{u} - d\bar{d}$ | $\gamma\gamma$ | ~99   | ~135      |
| $\pi^+ / \pi^-$ | $u\bar{d} / d\bar{u}$ | ~140      |
| $\omega$ | $\pi^0$ | ~8.4 | ~783   |
| $p/\bar{p}$ | $uud / u\bar{u}\bar{d}$ | ~938      |

### Other Hadrons

| h | Quark content | Decay modes | BR, % | Mass, MeV |
|---|---------------|-------------|-------|-----------|
| $\eta$ | $0.57 \cdot (u\bar{u} + d\bar{d}) + 0.60 \cdot s\bar{s}$ | $\gamma\gamma$ | ~39 | ~548      |
Small Systems
Ratios in small systems

No strangeness enhancement

A hint of proton enhancement

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Ratios in small systems

Radial flow or recombination
$R_{AB}$ in small systems

- $\varphi$ & $K^0$ $R_{AB}$ follows other light mesons $R_{AB}$
- Protons yields are enhanced in 0-20% $^3$He+Au
Recombination can explain protons $R_{AB} > \varphi R_{AB}$

X Radial flow
$R_{AB}$ in small systems

- No baryon and strangeness enhancement
$R_{AB}$ in small systems

✓ Pythia 8 is in well agreement with $R_{pAl}$ for $\varphi$

✗ Pythia 8 underestimates $\varphi$ $R_{AB}$ in $p/d/{}^3$He+Au

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\( R_{AB} \) in small systems

- \( \varphi \) \( R_{pAl} \) is well estimated by default AMPT calculations
- String melting AMPT well predicts \( \varphi \) yields in p/d/\(^3\)He+Au
$R_{AB}$ in small systems

• Minimal conditions to form QGP may lie in between
  • $p+Al$ and $p+Au$
Large Systems
New addition from Cu+Au & U+U collisions

Cu+Au

U+U

\[ R_{AB} \]

\[ p_T (GeV/c) \]

\[ \pi^0, 0-20\% \]
\[ \eta, 0-20\% \]
\[ \varphi, 0-20\% \]
\[ K_0, 0-20\% \]
\[ \omega, 0-20\% \]
\[ \pi^+, 0-20\% \]
\[ K^-, 0-20\% \]
\[ (p+p)/2, 0-20\% \]
\[ K^0, 0-20\% \]

\[ s_{NN} = 200 \text{ GeV} \]

\[ R_{AB} \]

\[ p_T (GeV/c) \]

\[ \pi^0, 0-20\% \]
\[ \eta, 0-20\% \]
\[ \varphi, 0-20\% \]
\[ K_0, 0-20\% \]
\[ \omega, 0-20\% \]
\[ \pi^+, 0-20\% \]
\[ K^-, 0-20\% \]
\[ (p+p)/2, 0-20\% \]
\[ K^0, 0-20\% \]

\[ s_{NN} = 192 \text{ GeV} \]

Scaling uncertainty from p+p - 9.7%
New addition from Cu+Au & U+U collisions

At intermediate $p_T$: $(p + \bar{p})/2 \geq \varphi, K^0, \pi^0, \eta R_{AB}$

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New addition from Cu+Au & U+U collisions

At intermediate $p_T$: Interplay of radial flow, strangeness + recombination
Flavor independent suppression at high-$p_T$

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New addition from Cu+Au & U+U collisions

- String melting AMPT well predicts $\varphi R_{CuAu}$
- Coalescence can explain $\varphi$ yields enhancement
- Pythia failed at central Cu+Au
New addition from Cu+Au & U+U collisions

\[ \langle R_{AB} \rangle \] of \( \phi \) meson scales with collision system size
Summary
Summary

Small systems:

Minimal conditions to from QGP may lie in between p+Al and p+Au:

✓ A hint of proton enhancement in p/d/\(^3\)He+Au
✓ String melting AMPT \(\varphi \ R_{p/d/\(^3\)He+Au}\) & Pythia and def AMPT for \(\varphi \ R_{pAl}\)

X But NO strangeness enhancement in small systems

Large systems:

No flavor dependence at high-\(p_T\) in heavy-ion collisions
Coalescence might be an answer for strangeness enhancement:

✓ String melting AMPT well predicts \(\varphi \ R_{CuAu}\)
Strange meson production scales with collision system size

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