Modification of hadron productions in small systems observed by PHENIX

Mitrankov Iurii
For PHENIX collaboration
Flow measurements → strong evidence for QGP droplets in small systems;

Talk by Seyoung Han

Energy loss in the plasma?
If so, it would present itself in the hadrons spectra;

Interpreting Large systems
Talk by Anthony Hodges
Flow measurements → strong evidence for QGP droplets in small systems

Energy loss in the plasma?
  If so, it would present itself in the mesons spectra

Interpreting Large systems

[Diagram and graphs showing data for different systems and energy losses]
\( \pi^0 \) and \( \varphi \) \( R_{AB} \) in \( p+Au \)
$\pi^0$ and $\varphi$ $R_{AB}$ in p+Au, d+Au
$\pi^0$ and $\varphi$ $R_{AB}$ in $p+Au$, $d+Au$, $^3He+Au$
\[ \pi^0 \text{ and } \varphi \text{ } R_{AB} \text{ in } p+Au, \text{ d}+\text{Au, } ^3\text{He}+\text{Au} \]

AT INTERMEDIATE \( p_T \) RANGE:

- Ordering \( R_{pAu} > R_{dAu} > R_{HeAu} \) in 0-20%
\( \pi^0 \) and \( \varphi \) \( R_{AB} \) in \( p+Au, \ d+Au, ^3He+Au \)

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- \( \pi^0 \& \varphi \) \( R_{pAu} \approx R_{dAu} \approx R_{HeAu} \) in peripheral collisions
\( \pi^0 \) and \( \varphi \) \( R_{AB} \) in 
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- \( \pi^0 R_{AB} \)‘s consistent with each other at high-\( p_T \)
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**AT HIGH-\( p_T \) RANGE:**

- \( \pi^0 \) \( R_{AB} \)'s consistent with each other at high-\( p_T \)
- **Hint of suppression in central collisions!**
- **Hint of enhancement in peripheral collisions**
\( \pi^0 \) & \( \phi \) \( R_{AB} \) in p+Al, p+Au, d+Au, \(^3\text{He}+\text{Au}\)
In whole $\phi$ $p_T$ range $\pi^0$ & $\phi$ mesons $R_{AB}$'s are similar in p+Al/Au
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In whole $\varphi$ $p_T$ range $\pi^0$ & $\varphi$ mesons $R_{AB}$'s are similar in $p$/$d$/$^3$He+Au
\( \pi^0 \) & \( \phi \) \( R_{AB} \) in p+Al, p+Au, d+Au, \(^3\)He+Au

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In whole \( \phi \) \( p_T \) range \( \pi^0 \) & \( \phi \) mesons
\( R_{AB} \)'s are similar in p/d/\(^3\)He+Au

Might indicate that CNM effects are not responsible for the differences between \( \phi \) and \( \pi^0 \) seen in A+A
Comparisons to other light hadron’s $R_{AB}$ in p/d+Au collisions

6 November 2019

Iu. Mitrankov for PHENIX at QM’19
Comparisons to other light hadron’s $R_{AB}$ in p/d+Au collisions

Light mesons $R_{AB}$ exhibit similar shape in contrast to heavy-ion
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$\pi^\pm$ & $\bar{p}$ invariant yield in 0-5% described by SONIC and superSONIC

FLOW might be responsible for protons enhancement!
\( \pi^0 \) integrated yields & \( R_{AB} \) in 
\( p+Al, p+Au, d+Au,^3He+Au \)

\( \pi^0 \) at \( \sqrt{s_{NN}} = 200 \) GeV

Integrated yield \( (p_T > 8 \) GeV/c) vs. \( N_{\text{Coll}} \)

\( R_{AB}^{\pi^0} \) vs. \( N_{\text{Coll}} \)

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$\pi^0$ integrated yields & $R_{AB}$ in p+Al, p+Au, d+Au, $^3$He+Au

$\pi^0$ at $\sqrt{s_{NN}} = 200$ GeV

- $<R_{AB}^{\pi^0}>$ vs $N_{Coll}/N_{proj}$
- $R_{AB}^\pi > 8$ GeV/c

Correlated Glauber MC uncertainty

Systematic uncertainty data

statistical error

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\( \pi^0 \) integrated yields & \( R_{AB} \) in \( p+\text{Al}, p+\text{Au}, d+\text{Au}, ^3\text{He}+\text{Au} \)

\( \pi^0 \) at \( \sqrt{s_{NN}} = 200 \text{ GeV} \)

\( \langle R_{\pi^0}^{AB} \rangle \) (\( p_T > 8 \text{ GeV}/c \))

- \( p+\text{Au} \)
- \( d+\text{Au} \)
- \( ^3\text{He}+\text{Au} \)
- \( p+\text{Al} \)

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- \( p+\text{Au} \)
- \( d+\text{Au} \)
- \( ^3\text{He}+\text{Au} \)
- \( p+\text{Al} \)

\( \pi^0 \) \( R_{AB} \)'s seem to scale with \( N_{coll}/N_{part}^{proj} \) for systems with same target at high-\( p_T \)

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$\pi^0$ integrated yields & $R_{AB}$ in $p+Al, p+Au, d+Au, ^3He+Au$

$p^0$ at $\sqrt{s_{NN}} = 200$ GeV

Int. $\pi^0$ yield (4 < $p_T$ < 6 GeV/c)

$\langle R_{AB}^{\pi^0} \rangle$ (4 < $p_T$ < 6 GeV/c)
$\pi^0$ integrated yields & $R_{AB}$ in $p+Al$, $p+Au$, $d+Au$, $^3He+Au$

$\pi^0$ at $\sqrt{s_{NN}} = 200$ GeV

- $p+Au$
- $d+Au$
- $^3He+Au$
- $p+Al$
- $p+p$

$N_{Coll}$ scaling

$\langle R_{AB}^{\pi^0} \rangle$ (4 < $p_T$ < 6 GeV/c)

$\pi^0$ $R_{AB}$ scales with $N_{coll}$
φ ⟨R_{AB}⟩ vs. rapidity in p+Al, p+Au, ^3He+Au
$\varphi \langle R_{AB} \rangle$ vs. rapidity in p+Al, p+Au, $^3$He+Au

$\varphi \langle R_{AB} \rangle$ in Au-going – a hint of enhancement
$\phi \left< R_{AB} \right>$ vs. rapidity in p+Al, p+Au, $^3$He+Au

$\phi \left< R_{AB} \right>$ in Au-going – a hint of enhancement

$\phi \left< R_{AB} \right>$ at midrapidity – equal to unity
φ ⟨R_{AB}⟩ vs. rapidity in p+Al, p+Au, $^3$He+Au

φ ⟨R_{AB}⟩ in Au-going – a hint of enhancement
φ ⟨R_{AB}⟩ at midrapidity – equal to unity
φ ⟨R_{AB}⟩ in p/He-going – a hint of suppression
Same $\langle R_{AB} \rangle$ behavior was observed for $h^\pm$ in $p+Au$ central collisions:
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- Backward rapidity shows large enhancement.
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✓ Forward rapidity shows suppression

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Strong centrality dependence
$h^\pm$ in p+Al and p+Au

$h^\pm$ $R_{AB}$ in p-going direction is described by EPPS16+PYTHIA and nCTEQ15+PYTHIA

$\langle R_{AB} \rangle$ vs. $N_{part}$ in A-going direction is described by pQCD multi scattering calculations

arXiv:1906.09928v1

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SUMMARY

➢ Integrated $\pi^0$ $R_{AB}$ seem to:
   ✓ scale with $N_{coll}$ at moderate $p_T$
   ✓ scale with $N_{coll}/N_{part}^{proj}$ for same target at high-$p_T$

➢ $\varphi$ & $\pi^0$ mesons $R_{AB}$’s are consistent in all centralities, while protons $R_{AB}$’s show enhancement in central collisions, $\pi^\pm$ and $\bar{p}$ are described by SONIC

➢ Hint of suppression for $\pi^0$ at high-$p_T$ in central collisions

➢ Strong rapidity and centrality dependence of charged hadrons production in small systems, which is well described by CNM effects
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THANK YOU FOR YOUR ATTENTION!
Using these data sets allow to discriminate the various CNM effects included in models like AMPT and EPOS.
BACKUP

$p^0 \sqrt{s_{NN}} = 200$ GeV

$N_{\text{Coll}}/N_{\text{proj}}^{\text{part}}$

$p+Au \quad ^3\text{He}+Au$

$d+Au \quad p+Al$

$p^0 \sqrt{s_{NN}} = 200$ GeV

$N_{\text{Coll}}/N_{\text{proj}}^{\text{part}}$

$p+Au \quad ^3\text{He}+Au$

$d+Au \quad p+Al$
Cold Nuclear E-loss

<table>
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<th>Ordering</th>
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<th>High-(p_T)</th>
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<td>X</td>
<td>V</td>
</tr>
<tr>
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<td>V</td>
<td>X</td>
<td>X</td>
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