Production of light flavor hadrons measured by PHENIX at RHIC

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For PHENIX collaboration
Motivation
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○ Light flavor hadrons in A+A & p+A → properties of the produced medium & reaction dynamics;

![Relativistic Heavy-Ion Collisions diagram](image)
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- Light flavor hadrons in A+A & p+A → properties of the produced medium & reaction dynamics;
- Different hadrons properties → observables in the soft sector & high-p_T probes & signatures of the onset of collectivity in collisions of small systems;

<table>
<thead>
<tr>
<th></th>
<th>(\pi^0)</th>
<th>(\eta)</th>
<th>(\omega)</th>
<th>(K^*)</th>
<th>(K_S)</th>
<th>(\phi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass, MeV</td>
<td>135</td>
<td>548</td>
<td>782</td>
<td>892</td>
<td>498</td>
<td>1019</td>
</tr>
<tr>
<td>Quark content</td>
<td>(u\bar{u}</td>
<td>d\bar{d})</td>
<td>(\frac{1}{6}(u\bar{u} + d\bar{d} - 2s\bar{s}))</td>
<td>(\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}))</td>
<td>(d\bar{s})</td>
<td>(\frac{1}{\sqrt{2}}(d\bar{s} + s\bar{d}))</td>
</tr>
<tr>
<td>Lifetime, fm/c</td>
<td>2.5(\times)10^7</td>
<td>1.6(\times)10^5</td>
<td>23</td>
<td>4.16</td>
<td>2.7(\times)10^{13}</td>
<td>46</td>
</tr>
</tbody>
</table>
Motivation

- Light flavor hadrons in A+A & p+A → properties of the produced medium & reaction dynamics;
- Different hadrons properties → observables in the soft sector & high $p_T$ probes & signatures of the onset of collectivity in collisions of small systems;
- PHENIX measured $\pi^0$, $\eta$, $K^*$, $K_S$, $\phi$ & $\omega$ in p+p, p/d/3He+Au, Cu+Cu, Cu+Au, Au+Au & U+U:
  - ✓ Baseline measurements in p+p collisions;
  - ✓ Study of the parton energy loss in heavy ion collisions;
  - ✓ Cold nuclear matter effects in small systems;
- Comparison to higher energy experiments and theoretical model predictions.
The PHENIX Detector

Central Arm, $|\eta| < 0.35$, $\Delta\phi - 2\times 90$
Results were found to be consistent between the different decay modes; well described by the Tsallis distribution functional form with only two parameters:

- $T = 112.6 \pm 3.8 + (11.8 \pm 7.0)m_0[\text{GeV}/c^2]$ MeV;
- $n = 9.48 \pm 0.14 + (0.66 \pm 0.39)m_0[\text{GeV}/c^2]$

(Phys.Rev.D83:052004)

- Baseline to compare with more complex and heavy p+A and A+A;
- Event generators tuning;
- Available parametrizations of fragmentation functions.
$\pi^0, \eta, K_S, K^*, \varphi & \omega$

Reconstruction in $p+A & A+A$

<table>
<thead>
<tr>
<th>System</th>
<th>Decay modes</th>
<th>BR, %</th>
<th>Detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^0$</td>
<td>$\gamma \gamma$</td>
<td>$\sim 99$</td>
<td>EMCal</td>
</tr>
<tr>
<td>$\eta$</td>
<td>$\gamma \gamma$</td>
<td>$\sim 39$</td>
<td>EMCal</td>
</tr>
<tr>
<td>$\omega$</td>
<td>$\pi^0 \gamma$</td>
<td>$\sim 8.4$</td>
<td>EMCal</td>
</tr>
<tr>
<td>$K_S$</td>
<td>$\pi^0 \pi^0$</td>
<td>$\sim 30$</td>
<td>EMCal</td>
</tr>
<tr>
<td>$K^*$</td>
<td>$K^\pm \pi^\mp$</td>
<td>$\sim 67$</td>
<td>DC+ToF</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>$K^+ K^-$</td>
<td>$\sim 49$</td>
<td>DC+ToF</td>
</tr>
</tbody>
</table>
Large Systems
Light mesons $R_{AB}$ at $\sqrt{s_{NN}}=200$ GeV

- New results in asymmetric Cu+Au at $\sqrt{s_{NN}}=200$ GeV & in deformed U+U at $\sqrt{s_{NN}}=192$ GeV;
Light mesons $R_{AB}$ at $\sqrt{s_{NN}}=200$ GeV

- In most central collisions $\phi$ & $K^*$ are less suppressed than $\pi^0, \eta, K_s & \omega$ in the intermediate $p_T$ range;
In most central collisions φ & K* are less suppressed than π₀, η, Kₛ & ω in the intermediate p_T range;

At p_T > 5 GeV/c, φ, K*, π₀, η, Kₛ, ω R_AB exhibit similar shape;

R_AB in peripheral collisions consistent with each other within uncertainties.
The $\phi$ & $K^*$ integrated $R_{AB}$ at $p_T \gtrsim 2$ GeV/c shows less suppression than $\pi^0$ & $\eta$;

- The $\phi$, $K^*$, $\pi^0$, $\eta$ & $K_S$ integrated $R_{AB}$ at $p_T > 5$ GeV/c show same suppression level.
New results $\langle R_{CuAu} \rangle$ and $\langle R_{UU} \rangle$ are in agreement with previous $\langle R_{AuAu} \rangle$ and $\langle R_{CuCu} \rangle$;

- Production and suppression of the light mesons seem to depend on nuclear overlap size, but not on its geometry.
Small systems: p+Au, d+Au, $^3$He+Au
π⁰ & φ $R_{AB}$ in p+Au, d+Au, $^3$He+Au
\( \pi^0 \& \varphi \ R_{AB} \) in \( p+Au, \ d+Au, \ ^3He+Au \)

- Small systems consistent with each other at high-\( p_T \) in most central collisions;
- Hint of suppression at high-\( p_T \) in central collisions;
\( \pi^0 \) & \( \phi \ R_{AB} \) in p+Au, d+Au, \( ^3\text{He}+\text{Au} \)

- Small systems consistent with each other at high-\( p_T \) in most central collisions;
- Hint of suppression at high \( p_T \) in central collisions;
- \( \phi, \pi^0 \ R_{pAu} \approx R_{dAu} \approx R_{HeAu} \) in peripheral collisions.
$\pi^0$ & $\varphi$ $R_{AB}$ in p+Au, d+Au, $^3$He+Au
In most central collisions in the intermediate $p_T$ range ordering is seen.

- Suppression at $p_T \approx 5 \text{ GeV/c}$ indicates a system size dependence.
\[ \pi^0 \& \varphi \text{ } R_{AB} \text{ in } p+Au, \text{ } d+Au, \text{ } ^3\text{He}+Au \]

- In whole \( p_T \) range \( \varphi \) \& \( \pi^0 \) mesons \( R_{AB} \) show similar suppression level:
  - That might indicate that CNM effects are not responsible for the differences between \( \varphi \) and \( \pi^0 \) seen in A+A.
\pi^0 \& \phi \langle R_{AB} \rangle (\eta) in p/d/^{3}\text{He}+\text{Au}

\begin{itemize}
  \item \phi \langle R_{AB} \rangle in \text{Au-going – a hint of enhancement;}
  \item \phi \langle R_{AB} \rangle at midrapidity – equal to unity;
  \item \phi \langle R_{AB} \rangle in p/He-going – a hint of suppression;
\end{itemize}
\( \pi^0 & \phi \langle R_{AB} \rangle (\eta) \text{ in p/d/}^3\text{He+Au} \)

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- \( \phi \langle R_{AB} \rangle \) at midrapidity – equal to unity;
- \( \phi \langle R_{AB} \rangle \) in p/He-going – a hint of suppression;
- Same \( \phi \langle R_{AB} \rangle \) behavior was observed in p-Pb at \( \sqrt{s_{NN}} = 5.02 \text{ TeV} \) at ALICE. (Nucl.Phys.A932,218)
Using these data sets allow to discriminate the various CNM effects included in models like AMPT and EPOS.
Summary

➢ Large Systems:
  o Light mesons $\langle R_{AA} \rangle$ show same suppression level in Cu+Au, U+U, Au+Au and Cu+Cu;
    ✓ Production and suppression of the light meson seems to depend on nuclear overlap size, but not on its geometry and not on its density;
  o $\phi$ & $K^*$ exhibit a different suppression pattern compared to lighter mesons ($\pi^0$, $\eta$, $K_S$, $\omega$);
    ✓ The observation of these patterns in many collision systems can provide a contribution to the understanding of the strangeness enhancement competing with energy loss;

➢ Small systems:
  o The $\phi$ & $\pi^0$ mesons $R_{AB}$'s are consistent in p/d/3He+Au collisions in all centralities;
    ✓ That might indicate that cold nuclear effects are not responsible for the differences between $\phi$ & $\pi^0$ seen in Au+Au, Cu+Cu, Cu+Au and U+U collisions;
  o In most central collisions in the intermediate $p_T$ range there’s an ordering of $R_{pAu} > R_{dAu} > R_{HeAu}$ for both $\phi$ & $\pi^0$ mesons:
    ✓ The ordering might indicate a system size dependence;
  o These results can provide additional constraints for the models that try to explain CNM effects (like AMPT, EPOS).
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Thank you for your attention!