Probing QCD matter via $K^{*0}$ and $\phi$ resonance production at RHIC

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Outline

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**Motivation**

**K*^0 and φ:**

- Factor of 10 difference in lifetimes
- Close to proton (baryon) mass
- Small hadronic interaction cross section for φ

- Lifetime of resonances are comparable to the typical lifetime of the fireball.
- Resonances in heavy-ion collisions can be used to study properties and evolution of the medium
The STAR Experiment

- Uniform acceptance
- Full azimuthal coverage
- Excellent particle identification capability
The signal is fitted with a Breit-Wigner function plus a linear residual background after mixed event background subtraction.
Mean transverse momentum at Top RHIC and LHC energies

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

\[ \langle N_{\text{part}} \rangle \]

- \( \pi^+ \)
- \( K^+ \)
- \( \phi \)
- \( K^0 \)

\[ \text{Au+Au 62.4 GeV} \]

\[ \text{Au+Au 200 GeV} \]

\[ \text{Pb+Pb 2.76 TeV} \]

Mean transverse momentum at top RHIC and LHC energies

- Mean $p_T$ increases with mass
- Mean $p_T$ of $K^*$ and $\phi$ close to proton (similar mass)
- Mean $p_T$ at LHC > Mean $p_T$ at RHIC, consistent with increased radial flow at LHC
Particle ratios ($K^{*0}/K$ and $\phi/K$) at top RHIC and LHC energies

Particle ratios ($K^{*0}/K^-$ and $\phi/K^-$) at top RHIC and LHC energies

$\langle dN_{ch}/d\eta \rangle^{1/3}$

$K^{*0}/K^-$ ratio decreases with increasing centrality

Particle ratios ($K^{*0}/K^-$ and $\phi/K^-$) at top RHIC and LHC energies

Dominance of hadronic re-scattering at top RHIC and LHC energies

K$^{*0}/K^-$ ratio decreases with increasing centrality

$\phi/K^-$ ratio is independent of centrality

K*$^0$ spectra measurement at lower BES energies

- Spectra is fitted with Levy fit
- Fit functions used to extrapolate yields in unmeasured regions
φ spectra measurement at lower BES energies

\[ \frac{d^2N}{(2\pi N_{\text{evt}}p_T dy dp_T)} \left( c^2/\text{GeV}^2 \right) \]

\begin{align*}
\text{Au+Au 7.7 GeV} & \\
\text{Au+Au 11.5 GeV} & \\
\text{Au+Au 19.6 GeV} & \\
\text{Au+Au 27 GeV} & \\
\text{Au+Au 39 GeV} & \\
\text{φ meson} & \\
\text{+ 0-10\%} & \\
\text{● 10\%-20\%/10} & \\
\text{□ 20\%-30\%/10^2} & \\
\text{△ 30\%-40\%/10^3} & \\
\text{◆ 40\%-60\%/10^4} & \\
\text{▲ 60\%-80\%/10^5} & \\
\text{– Levy Fit} & \\
\end{align*}

Particle ratios ($K^{*0}/K^{-}$ and $\phi/K^{-}$) at BES energies

$\phi/K^{-}$ ratio: independent of centrality

$K^{*0}/K^{-}$ ratio: decreases with increasing centrality, more re-scattering in central collisions

Collectivity in heavy-ion collisions

Overlapped region

Interactions
Pressure \( (P) \)

\[ y > x \rightarrow \frac{\partial P}{\partial x} > \frac{\partial P}{\partial y} \]

\[
E \frac{d^3 N}{dp^3} = \frac{1}{2\pi} \frac{d^2 N}{p_T dp_T dy} \left[ 1 + 2v_1 \cos(\phi - \Psi_R) + 2v_2 \cos 2(\phi - \Psi_R) + \ldots \right]
\]

- \( v_1 \) – Directed flow
- \( v_2 \) – Elliptic flow

\textbf{Sensitive to initial dynamics}
**φ** meson $v_1(y)$ from RHIC BES


\[ \sqrt{s_{NN}} = 7.7 \text{ GeV} \]

\[ \sqrt{s_{NN}} = 11.5 \text{ GeV} \]

\[ \sqrt{s_{NN}} = 14.5 \text{ GeV} \]

\[ \sqrt{s_{NN}} = 19.6 \text{ GeV} \]

\[ \sqrt{s_{NN}} = 27 \text{ GeV} \]

\[ \sqrt{s_{NN}} = 39 \text{ GeV} \]

\[ \sqrt{s_{NN}} = 62.4 \text{ GeV} \]

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

$dv_1/dy$ slope is extracted from a linear fit ($|y| < 0.6$)
\( \phi \) meson \( \frac{d\nu_1}{dy} \) from RHIC BES

For \( \sqrt{s_{NN}} > 14.5 \text{ GeV} \):

\[
\left( \frac{d\nu_1}{dy} \right) \text{ anti-} \Lambda \sim \left( \frac{d\nu_1}{dy} \right) \text{ anti-p} \sim \left( \frac{d\nu_1}{dy} \right) \phi
\]

- Particles which consist from produced quarks show similar behavior
$\phi$ $v_2$ from RHIC BES

Indication of small $\phi$-meson $v_2$ at 11.5 and 7.7 GeV

K*^0 \, v_2 \text{ from RHIC BES}

- K*^0 seems to follow the trend of \( \phi \, v_2 \) but with large uncertainty
- \( v_2 \) measurements will achieve better statistical significance with BES-II data
Summary

Invariant Yield:
- $K^*/K^-$ ratio in central Au+Au collisions is smaller than in d+Au (p+Au) and p+p collisions
- $\phi/K^-$ ratio does not depend on centrality

Consistent with hadronic re-scattering for resonances with short lifetime

Directed Flow:
- For $\sqrt{s_{NN}} > 14.5$ GeV: $(dv_1/dy)\text{ anti-}\Lambda \sim (dv_1/dy)\text{ anti-}p \sim (dv_1/dy)\phi$

Particles which consist from produced quarks show similar behavior

Elliptic Flow:
- Indication of small $\phi$-meson $v_2$ at 11.5 and 7.7 GeV
- $K^0 v_2$ seems to follow the trend of $\phi v_2$ but with large uncertainty

Dominance of hadronic interaction over partonic interaction at $\sqrt{s_{NN}} \leq 11.5$ GeV