φ-meson Production in Heavy-Ion Collisions at RHIC

Sarah Blyth
for
The STAR Collaboration

Strangeness in Quark Matter 2006
The medium produced in HI collisions is very short-lived → we need probes which carry information from the early stage to find out about the medium constituents:

The $\varphi$-meson ($S\bar{S}$) is a clean probe from early time:

- **Small $\sigma$** for interactions with non-strange particles$^{[1]}$
- Relatively long-lived (41 fm/c) → decays outside the fireball
- Previous measurements have ruled out $K+K$ coalescence as $\varphi$ production mechanism$^{[2]}$ → info not “diluted” by hadronic phase

The $\varphi$ can provide info on particle production mechanisms / medium constituents:

- The $\varphi$ is a meson but as heavy as $\Lambda,p$ baryons
  - Differentiate between mass-type or meson/baryon-type dependencies

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$^{[1]}$ A. Shor, Phys. Rev. Lett. 54 (1985) 11
We used the high-statistics 200 GeV Au+Au data to measure the $\phi$ observables at STAR:

- $\sim 13.5$ M minbias (0-80%) events
- $\sim 13$ M central triggered (0-10%) events

**Measured decay channel:**

$\phi \rightarrow K^+ K^-$ ($BR = 49.1\%$)

- STAR TPC used to identify $K$ via $dE/dx$ in TPC gas

**STAR Detector**

- Event-mixing method used to estimate background from uncorrelated $K^+ K^-$ pairs
- Final subtracted $m_{inv}$ distribution fitted with Breit-Wigner + straight line
Elliptic flow provides early time information on the collectivity of particles from heavy-ion collisions:

- Non-central A+A collisions result in an azimuthally anisotropic distribution of particles in coordinate-space.
- Density gradients and interactions between the particles lead to an asymmetry in momentum-space.
- Signal is self-quenching with time – EARLY TIME OBSERVABLE!

Expanding in a Fourier series:

$$E \frac{d^3 N}{d^3 p} = \frac{1}{\pi} d^2 \frac{N}{dp_T^2 dy} [1 + 2v_1 \cos(\phi) + 2v_2 \cos(2\phi) + ...]$$

$$v_2 = \langle \cos(2\phi) \rangle$$
Early time information:

- For $p_T < 2$ GeV/c, $\phi$ flows as much as other ID'd particles, consistent with hydro. mass-ordering.
- For $p_T > 2$ GeV/c, $\phi$ $v_2$ is more consistent with $K_S^0$ than $\Lambda$ (favors NCQ$^{[1]}=2$).
- Consistent with $v_2$ of other multi-strange hadrons ($\Xi$, $\Omega$)$^{[2]}$ i.e. s-quarks flow!

Particle production mechanisms:

- Further evidence of species-type dependence of $v_2$ at intermediate $p_T$ (described by recombination/coalescence models$^{[3]}$)

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Sarah Blyth, Strangeness in Quark Matter 2006, Los Angeles
The shape of the $\phi p_T$ spectra provide information on the mechanisms of particle production:

- $\phi p_T$ spectra show a systematic centrality-dependent evolution in shape

- For **peripheral collisions**, a pQCD power-law tail is evident
  - Peripheral spectra favor a Levy function description

- For **central collisions**, exponential and Levy functions fit spectra equally well
  - The **power-law tail is suppressed** by the medium produced in central collisions
For both centrality groupings, $R_{CP}$ of $\varphi < 1$:

- $\varphi$ yield suppressed in central compared to peripheral collisions:

Particle grouping behaviour:

- Like for $v_2$, $\varphi$ follows same trend as $K^0_S$ and $K^*$ \cite{1} in $R_{CP}$

- Confirmation of meson-baryon dependence of $R_{CP}$ rather than mass-type dependence

- Described by recombination/coalescence models\cite{2}

\begin{itemize}
  \item \[1\] STAR Collab., Phys. Rev. C 71 (2005) 064902
  \item \[2\] R. J. Fries \textit{et al.}, Phys. Rev. C 68 (2003) 044902
\end{itemize}
Comparison with model expectations on particle production can give insight on the constituents of the medium produced in heavy-ion collisions:

- **R. Hwa's recombination model**[1]:
  - $\phi$ and $\Omega$ (sss) spectra ($p_T < 8$ GeV/c) mainly due to recombination of thermal quarks (TT)
  - Seems to match data well

- **BUT...** $\Omega/\phi$ ratio has similar shape to other baryon/meson measurements
- Model matches data for $p_T < 4$ GeV/c

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[1] R. Hwa & C-B Yang, nucl-th/0602024
Conclusions

- **Large elliptic flow** (despite small $\sigma$) at low $p_T$
- NCQ-scaling of $v_2$ for $p_T > 2$ GeV/c (similar to $\Omega$ (sss))
- Reco. models describe data well\(^1\)

- $R_{CP}$ critical confirmation of **baryon-meson** dependence of RHIC observables
- Scaling described by reco. models

- Central data well-described (intermediate $p_T$) by reco. model\(^2\)
- pQCD power-law tails suppressed in central compared to peripheral spectra
- Central $\Omega/\varphi$ ratio well-described by **thermal quark reco.** model up to $p_T \sim 4$ GeV/c\(^2\)

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\(^2\) R. Hwa & C-B Yang, nucl-th/0602024
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Further interesting predictions can be investigated using $\phi$-meson observables:

- **Measurement of angular correlations with respect to a $\phi$-meson trigger particle**\(^{[1]}\):
  - Investigates particle production mechanism

- **$\phi$ di-lepton decay channel is a very clean probe from the early stage ($e^+$-$e^-$ do not interact strongly)**

\[ \phi \rightarrow e^+ + e^- \]

- Good channel to search for modifications of hadron properties due to the hot medium\(^{[2]}\)
- Will be a challenge: $\phi \rightarrow e^+ + e^-$ (BR $\sim 10^{-4}$)
- STAR Full barrel Time Of Flight (TOF) detector (installed by 2008) will be a huge asset in making this measurement!

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\(^{[1]}\) R. Hwa & C-B Yang, nucl-th/0602024
EXTRA SLIDES...
For $p_T > 2$ GeV/c, $\varphi v_2$ is more consistent with $K^0_S$ than $\Lambda$ (favors NCQ=2):

**Statistical errors only:**

<table>
<thead>
<tr>
<th>pT range</th>
<th>Compare NCQ =</th>
<th>$\chi^2$</th>
<th>ndf</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_T &gt; 1.5$ GeV/c</td>
<td>2 (meson)</td>
<td>2.517</td>
<td>5</td>
</tr>
<tr>
<td>$p_T &gt; 2.0$ GeV/c</td>
<td>2 (meson)</td>
<td>2.481</td>
<td>4</td>
</tr>
<tr>
<td>$p_T &gt; 2.25$ GeV/c</td>
<td>2 (meson)</td>
<td>0.618</td>
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</tr>
<tr>
<td>$p_T &gt; 2.25$ GeV/c</td>
<td>3 (baryon)</td>
<td>5.886</td>
<td>3</td>
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</tbody>
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**Statistical & Systematic errors:**
(Added in quadrature)

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<tr>
<td>$p_T &gt; 1.5$ GeV/c</td>
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<td>1.226</td>
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<tr>
<td>$p_T &gt; 2.0$ GeV/c</td>
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<tr>
<td>$p_T &gt; 2.25$ GeV/c</td>
<td>2 (meson)</td>
<td>0.388</td>
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<td>$p_T &gt; 2.25$ GeV/c</td>
<td>3 (baryon)</td>
<td>2.974</td>
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</tr>
</tbody>
</table>
The turn-over of baryon/meson ratio shifts to higher $p_T$ as a function of strangeness content:

- $\Omega/\phi = \text{sss}/\text{ss} \sim s$
- $\Lambda/K^0_S = \text{uds}/u(d)s$
- $p/\pi = \text{uud}/u(d)d \sim u$