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 $\phi$-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 $\phi$ production mechanism$^{[2]}$ → info not “diluted” by hadronic phase

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

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

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$^{[1]}$ A. Shor, Phys. Rev. Lett. 54 (1985) 11  
The STAR Experiment

We used the high-statistics 200 GeV Au+Au data to measure the $\phi$ observables at STAR:

- ~13.5 M minbias (0-80%) events
- ~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

![Graph showing $1.0 < p_T < 1.2 \text{ GeV/c}$ distribution](image)

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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:

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

$$v_2 = \langle \cos(2\phi) \rangle$$
The $\phi$ experiences significant elliptic flow! (result is mean of 2 different, but consistent methods):

- 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 $K^0_S$ 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/coallescence models\(^{[3]}\))

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- For $p_T>2\text{ GeV/c}$, $\phi$ $v_2$ is more consistent with $K^0_S$ than $\Lambda$ (favors NCQ$^{[1]}=2$)
- Consistent with $v_2$ of other multi-strange hadrons ($\Xi$, $\Omega$)$^{[2]}$ i.e. s-quarks flow!

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*Sarah Blyth, Strangeness in Quark Matter 2006, Los Angeles*
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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 $K^*$ [1] in $R_{CP}$

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

- Described by recombination/coalescence models [2]

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 ($p_T < 8\,\text{GeV/c}$) mainly due to recombination of thermal quarks ($\text{TT}$)
- Seems to match data well

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

- **BUT**... $\Omega/\phi$ ratio has similar shape to other baryon/meson measurements
- Model matches data for $p_T < 4\,\text{GeV/c}$
**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\(^2\)
- $p$QCD 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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...hints of THERMALIZATION?

PARTONIC COLLECTIVITY & DECONFINEMENT

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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)
  - Good channel to search for modifications of hadron properties due to the hot medium$^{[2]}$
  - Will be a challenge: $\phi \rightarrow e^+ + e^-$ (BR~$10^{-4}$)
  - 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