ANL/PHY/CP-99369

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OCT 13 1999
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Production of φ Meson in Au+Au Collisions at 11.7 A·GeV/c

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for the E917 collaboration

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First Measurement of φ meson production in Au+Au collisions has been conducted by E917 at BNL-AGS via selecting events with identified K^+K^- pairs. Preliminary results on the invariant mass spectra of K^+K^- pairs and the m_T spectra are presented. Also, the inverse slope T, $\frac{dN}{dy}$, the ratio of ϕ/K^-, ratio of $\frac{\phi}{K^+K^-}$ and their centrality dependences are extracted in a rapidity range of $y = 0.9 - 1.4$. Indications on the possible mechanisms of φ production are discussed.

1 Introduction

The production of φ mesons in ultra-relativistic heavy-ion collisions is a topic of considerable interest. The φ meson is the lowest mass bound state of $s\bar{s}$ quarks with hidden strangeness. Enhanced production of φ mesons via the coalescence of s and $\bar{s}$ quarks during hadronization has been suggested as one of the signals for the possible formation of a quark-gluon plasma, in contrast to the φ meson production in ordinary pp collisions where it is suppressed by the

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OZI rule.[1] The small decay energy for $\phi \rightarrow K^+ K^- (m_\phi - 2m_K = 32 MeV)$ and the consequent narrow width($4.43 MeV$) suggest that the ϕ meson yield should be very sensitive to any modifications of kaon and/or ϕ meson properties in the hot and dense hadronic matter, which could serve as a good experimental observable for the chiral symmetry restoration.[2][3] In addition, accurate measurements of the yield and m_t spectra are of importance in understanding the strangeness production and dynamics of heavy ion collisions at the AGS (ρ, T) regime. In this contribution, preliminary results on the centrality dependence of ϕ-meson production are presented.

2   Measurement and Analysis

The data were taken using the E917 apparatus, which is based on the E802 magnetic spectrometer[4], upgraded with an improved data aquisition system, an enlarged trigger chamber and a high resolution beam vertex detector during the E917 1996-97 operation at AGS. A second-level trigger was implemented to select events with pair(s) of kaon candidates of either sign, or events with candidate $\bar{p}$ tracks. Centrality selections are based on off-line software cuts on the projectile energy deposited and measured in the Zero-degree CALorimeter(ZCAL). The number of total participants(N_p) for each centrality bin is estimated from the measured E_{zcal}.

In the off-line analysis, measured time-of-flight is used to unambiguously identify kaons up to a momentum of 1.75 GeV/c. Typical tracking momentum resolution is $\delta p/p = 1.0 \sim 1.5\%$. All events used in the analysis were required to pass standard beam-quality cuts which eliminate overlapping events and upstream interactions of beam particles. The absolute momentum scale is checked by reconstructing Λ's from $p\pi^-$ pairs in the same data set. This procedure is also used to establish that there was no significant variation in the momentum scale over the entire running period. The invariant mass of $K^+ K^-$ pairs was then constructed, as shown in Fig. 1 A distinct peak is seen above the background. Within the limit of current statistics of the data, the mass and width of the measured ϕ are found to be consistent with the values of free ϕ mesons. Details of the analysis can be found elsewhere.[5]

3   Preliminary Results

3.1 m_T spectra and $\frac{dN}{dy}$

Transverse mass spectra of ϕ-meson for data with different centrality cuts are obtained. An example is shown in Fig. 1. The inverse slopes T and $\frac{dN}{dy}$ are

extracted by fitting the m_T spectra to the form of

$$E\frac{d^3N}{dp^3} = \frac{dN}{dy} \cdot \frac{1}{2\pi(m_\phi T + T^2)} \cdot e^{-(m_T - m_\phi)/T}, \qquad (1)$$

and are shown in Table 1. The error bars shown are statistical only. The ϕ yield per participant is also listed, which shows a steady trend of increase as N_p, though the statistical uncertainties are comparable to the scale of the increase. One can see that the $\frac{dN}{dy}$ of peripheral AuAu is close to the corresponding $\frac{dN}{dy}$ measured in central SiAu [6] (7% TMA, at a higher energy of $\sqrt{s} = 5.39$ GeV). This is in contrast to the big differences of kaon yields seen in SiAu and AuAu: kaon yields in Si+Au are significantly larger than those in Au+Au for the same N_p, which is consistent with the different collision geometries for kaon production in the two system. [7] We now observe a rather weak dependence of ϕ yield on both the $\sqrt{s}$ and the different collision geometries in Au+Au($\sqrt{s}$ = 4.87GeV) and in Si+Au at close N_p.

It is known that the yield of ϕ production in pp collisions shows a very strong dependence on the energy: [8] over a narrow range of $\sqrt{s}$ from 4.53GeV to 6.80GeV, the yield increases by over 2 orders of magnitude. Here the weak dependence of ϕ yield on both $\sqrt{s}$ and collision system geometry may suggest that the dominant contribution of ϕ's are not from the nucleon-nucleon collisions in a heavy ion collision at AGS. However, to what extent the measured ϕ yields could be explained by secondary hadronic rescattering or other alternative mechanisms, not excluding a possible formation of a baryon dense QGP or the predicted medium modification of ϕ properties, presents an intriguing question worth of further consideration.

ZCAL cut	N_p	T (MeV)	$\frac{dN}{dy}$ ($y \sim 1.15$)	$(\frac{dN}{dy})/N_p$
00-23%	301	174±56	0.252±0.107	0.84±0.35
12-39%	202	229±55	0.129±0.027	0.64±0.14
23-76%	105	199±44	0.058±0.015	0.55±0.14
7% SiAu	84	215±24	0.056±0.016	0.67±0.19

Table 1: Inverse slopes, $\frac{dN}{dy}$, and normalized $\frac{dN}{dy}(\times 10^{-3})$ by N_p, as a function of total number of participants, N_p.

3.2 ϕ/K^- Ratio

The extracted ϕ yield as a function of N_p are compared to K^- yields at identical centrality and rapidity bins, and shown as ϕ/K^- ratio in Fig. 2. The ϕ/K^-
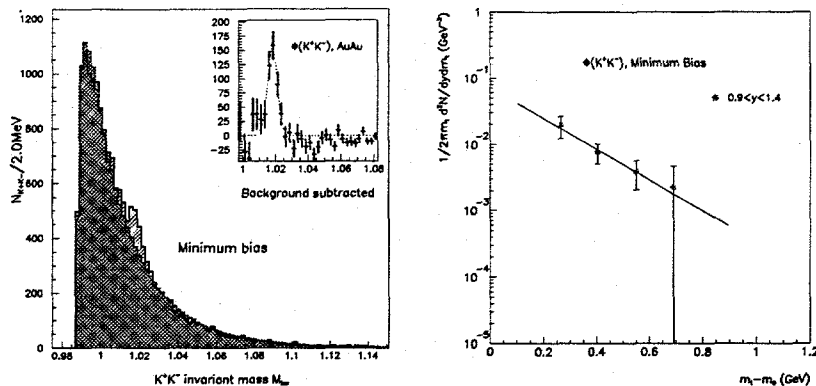
Figure 1: Left: The invariant mass distribution of K^+K^- pairs; Right: Transverse mass spectrum. Both are for minimum bias set of $19°$ setting.

ratio in Au+Au is seen to be larger than that measured in central Si+Au collision. This can be traced back to the differences in the observed contrast energy dependence of $\frac{dN}{dy}$ for ϕ and K^- as mentioned in section 3.1: a higher K^- yield in Si+Au than in Au+Au and the similar ϕ yield in the two systems at close N_p lead to a smaller ϕ/K^- ratio in Si+Au. A similar behavior is seen in the $\frac{\phi}{K^+K^-}$ ratio to be shown in the next.

It is already known that the $\frac{K^+}{K^-}$ ratio in AuAu at this beam energy is independent of N_p. Surprizingly, the ratio of ϕ/K^- also shows no significant dependence on centrality. This observation further extends the puzzle: while the differences among ϕ, K^+ and K^- are substantial(in terms of production, absorption, and in-medium effects if any), their relative abundance shows no signs of dependence on centrality. The underlying physics indications are yet to be revealed, which may lead to further understanding of the exact nature of strangeness production at AGS energy.

3.3 $\frac{\phi}{K^+K^-}$ Ratio

The ratio of $\frac{\phi}{K^+K^-}$ are extracted for both central and peripheral bins, as shown in Fig. 2, together with a measured point from SiAu ϕ measurement.[6] For the first time, we observed that the ratio of $\frac{\phi}{K^+K^-}$ systematically decreases as N_p. Qualitatively this result follows the power-law behavior predicted by simple coalescence models which have been successful in describing the composite nuclei productions(d, t, etc.) at Bevalac and AGS energies.[9] [10] In anology to a deuteron being formed via coalescence of a proton and a neutron, naively
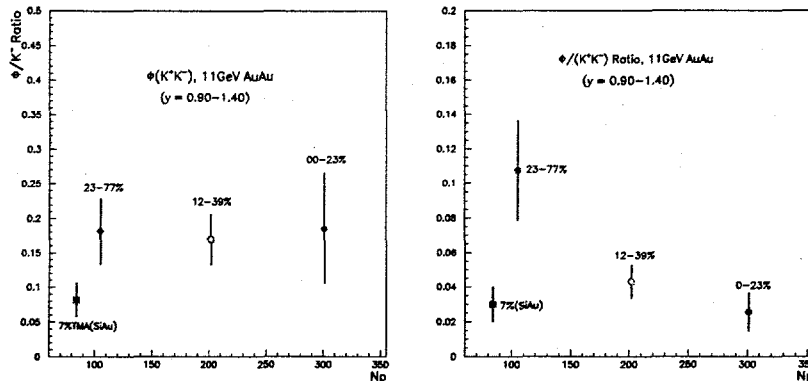
Figure 2: Centrality dependence of the ratio of $\frac{(dN/dy)_\phi}{(dN/dy)_{K^-}}$ and $\frac{(dN/dy)_\phi}{(dN/dy)_{K^+}\cdot(dN/dy)_{K^-}}$ at $y = 1.15 \pm 0.25$.

conceiving that a ϕ could be formed via a coalesecnce of a K^+ and a K^-, one would expect that $\frac{\phi}{K^+K^-} \propto \frac{1}{V_{src}}$, or $\frac{\phi}{K^+K^-} \propto \frac{1}{N_p}$, where V_{src} represents the volume of the source where the "composite ϕ" are emitted.

However, a coalescence mechanism for ϕ production cannot be as simple as the deuteron case, where the proton and neutron are seen as simply joining together without changing their internal structure. Calculations with a quark model of ϕ coalescence from kaons [11] in which the u and $\bar{u}$ quarks in kaons annihilate in a time-reversed decay process of $\phi \rightarrow K^+K^-$, indicates that the overall coalescences via K^+K^- and $K^0\overline{K}^0$ at quark level only account for at most $\frac{1}{8} \sim \frac{1}{4}$ of the measured ϕ yield in central SiAu at 14.6A·GeV/c, to which our measured peripheral ϕ yield is close. Even with an unjustified assumption that the ϕ is an $L = 1$, K^+K^- molecule of relatively larger size, the model still could only predict about 1/2 of the observed ϕ yield. Therefore, it is of importance that other mechanisms beyond the coalescence be included in a cascade model, such as RQMD, to explore the hidden origins of ϕ production at this energy and baryon density regime.

4   Summary

E917 has measured ϕ-meson production as a function of centrality in Au+Au collisions at 11.7 A·GeV/c:

- Within the current statistics significance, the mass and width of the measured ϕ are found to be consistent with the values of free ϕ mesons;

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- For the first time, the yield of ϕ is extracted as a function of centrality at AGS energy: From the measured peripheral to central bins, the $\frac{dN}{dy}$ increases by a factor of 4.3;

- The $\frac{dN}{dy}$ of the peripheral ϕ is close to that of central ϕ in Si+Au(7%TMA, $N_p \sim 84$) measured at a higher energy, showing a rather weak dependence on both $\sqrt{s}$ and the collision system geometry;

- No signs of significant centrality dependence is seen in the ϕ/K^- ratio;

- The ratio of $\frac{\phi}{K^+K^-}$ decreases from peripheral to central collisions which qualitatively follows the power-law behavior predicted in the simple coalescence models. Further coalescence calculations[11] at quark level fail to account for the measured ϕ yield.

The results presented are preliminary. Additional statistics and tests based on cascade models, such as RQMD, are critical in understanding the true nature of the observed ϕ signals.

Acknowledgments

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