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MULTIPLY-STRANGE HADRON CORRELATIONS IN CENTRAL AU+AU COLLISIONS FROM STAR AND PARTON RECOMBINATION MODELS

B. I. Abelev[a] (for the STAR Collaboration)

[a]University of Illinois at Chicago,
Chicago, IL 60607, USA, *betya@uic.edu*

The initial predictions of parton recombination model expected no jet-like azimuthal correlations for multi-strange baryons in the intermediate (2-4 GeV/c) p_T region. STAR measurements of (multi)strange hadron correlations in d+Au and Au+Au collisions have shown jet-like structures for all measured species with no variation in correlation strength based on strangeness content. The theoretical explanations that followed those results have suggested that observed azimuthal correlation signal is not a direct result of jet fragmentation, but rather expanding medium response to the propagating parton or "phantom jet". With both scenarios preserving the correlation in azimuthal space, differences are expected between the two in the pseudo-rapidity space ("jet" vs. "ridge"). To advance our understanding of the nature of these correlations, we extend our correlation analysis into $\Delta\phi-\Delta\eta$ space to explore jet and ridge components of di-hadron correlation separately for Ω and Ξ baryons. The data presented are from high statistic Au+Au data sample collected by STAR in 2004.

Strange Hadron Production in $\sqrt{s_{NN}}$ = 19.6 GeV Au+Au Collisions with STAR at RHIC

Helen Caines[a] for the STAR Collaboration

[a]Physics Department, Yale University,
New Haven, CT, 06520, U.S.A, *helen.caines@yale.edu*

We report on a new analysis of low-energy data taken during the first RHIC run in 2001. With the recorded 200K events, we have studied the strange particle spectra up to $p_T \sim$ 2GeV/c. In this paper we will present their yields and ratios as a function of p_T and centrality and compare them to those from collisions at 62 and 200 GeV. Direct comparison will also be made with the results from Pb+Pb collisions at the very similar collision energies recorded by the NA49 and NA57 experiments at the CERN/SPS ($\sqrt{s_{NN}}$ =17.3 GeV). STAR's new data should help in understanding the long-standing discrepancies in the measured hadron yields between these two experiments.

The "Critical Point Search" energy scan, preliminarily planned for the 2010 RHIC heavy-ion run, will set a milestone in our field. These 19.6 GeV data prove the feasibility of performing detailed studies at low energies at RHIC. The goal is to collide ions at several beam energies between $\sqrt{s_{NN}}$ = 5 and 200 GeV recording several million events at each point. Details of STAR's specific plans for studying strangeness production with the energy scan will be presented.

The Thermal Production of
Strange and Non-Strange Hadrons

F. Becattini[a], P. Castorina[b] and H. Satz[c]

a) Dipartimento di Fisica, Universitá di Firenze, and INFN Sezione di Firenze
b) Dipartimento di Fisica, Università di Catania, and INFN Sezione di Catania
c) Fakultät für Physik, Universität Bielefeld, D-33501 Bielefeld, Germany

The thermal multihadron production pattern observed in different high energy interactions poses two basic problems: (1) why do even elementary interactions with comparatively few secondaries (e^+e^- annihilation) show thermal behaviour, and (2) why is there in such interactions a suppression of strange particle production? We show that the recently proposed mechanism of thermal hadron production through Hawking-Unruh radiation can naturally account for both. The presence of the event horizon due to colour confinement leads to thermal behaviour, but the resulting temperature depends on the strange quark content of the produced hadrons, leading to a deviation from full equilibrium and hence to a suppression of strange particle production. We apply the resulting formalism to multihadron production in e^+e^- annihilition over a wide energy range and show that it provides an excellent description of the observed abundances. They are here determined in terms of the (known) QCD string tension and bare strange quark mass, so that the description contains no open parameters. Heavy ion collisions can through final state rescattering lead to complete equilibration, removing the strangeness suppression of elementary interactions.

ϕ production in In-In collisions and the ϕ puzzle

M. Floris[a] for the NA60 Collaboration

[a]Dipartimento di Fisica, Università degli studi di Cagliari e INFN, Sezione di Cagliari
S.P. per Sestu km 0.7, Monserrato, Cagliari, I-09042, Italy, *michele.floris@ca.infn.it*

The NA60 experiment measured dimuon production in In-In collisions at 158 AGeV. This talk presents a high statistics measurement of $\phi \rightarrow \mu\mu$ with the specific objective to provide insight into the ϕ puzzle, i.e. the difference in the inverse T slopes and absolute yields measured by NA49 [1] and NA50 [2] in the kaon and lepton channel, respectively.
The T slope parameter, extracted from exponential fits to the transverse momentum spectra in the full range $0 - 3$ GeV, shows a strong increase with centrality. Partial fit ranges, matched to the lower-p_T coverage of NA49 and the high-p_T coverage of NA50, show for the latter a flatter centrality dependence and smaller average values of T than for the former. However, the differences are at most 15 MeV, presumably due to radial flow. This suggests that the difference between the T slopes measured by NA49 and NA50 in Pb-Pb, which reaches $\sim$ 70 MeV in the most central collisions, is too large to be explained in terms of radial flow alone.
The absolute yield as a function of centrality was also measured. The ϕ enhancement in In-In reaches a factor of about 4 in the most central collisions with respect to previous proton-proton measurements. The comparison to the NA49 $\phi \rightarrow KK$ results shows that

the yield in the lepton channel is larger than in the kaon channel, as previously suggested by the NA50 experiment.
The measurements of the T slopes and of the yield in In-In may thus reinforce the idea that in-medium kaon absorption and rescattering, tending to deplete the observed $\phi \rightarrow KK$ in particular at low transverse momentum, is at the basis of the high T slopes and reduced yield observed in the kaon channel with respect to the lepton channel [3-4].

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Strange baryon resonance production from quark coalescence at RHIC

G. Hamar and **P. Lévai**

RMKI Research Institute for Particle and Nuclear Physics,
Budapest, 1121, Hungary
dhamy@stella.eotvos.elte.hu
plevai@rmki.kfki.hu

Strange baryon resonances have been measured at RHIC energies in *pp* and *AuAu* collisions [1]. The yield of these relatively rear particles could shed some light on the production mechanism of baryons, especially the highly excited baryon states. We have investigated strange particle yields and ratios in a quark coalescence model, and the robustness of coalescence calculations [2]. We extended our work and focused on the baryon production, especially the formation of baryon resonances. The obtained results display a strong dependence on the baryon wave functions. We compare our results to thermal models and available experimental data.

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Strangeness production in Au+Au collisions at $\sqrt{s_{NN}} = 62.4 GeV$

I.C. Arsene[a,b] for the BRAHMS Collaboration

[a] Physics Department, University of Oslo,
Oslo 0316, Norway *i.c.arsene@fys.uio.no*

[b] Institute for Space Sciences,
Bucharest-Magurele, 76900, Romania, *aic@venus.nipne.ro*

The BRAHMS experiment [1] have recorded data for Au+Au collisions at c.m. energy of 62.4 GeV. The setup measures charged particles and has excellent identification capabilities ($\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$) over the widest rapidity range at RHIC, ≈ 1 unit away from the beam rapidity at 62 GeV. This feature enabled us to shed some light on one of the predicted signals of quark gluon plasma, strangeness enhancement. From the AGS energies up to the highest RHIC energy we observed experimentally an enhancement of the strangeness to pion ratio in nucleus-nucleus collisions compared to the one in p+p collisions with a maximum at the lower SPS energies. At AGS the data was well reproduced by hadronic cascade models [2], e.g. RQMD, while at SPS energies it was claimed that the known "horn" dependence of the K^+/π^+ ratio on $\sqrt{s_{NN}}$ is a consequence of the onset of deconfinement [3]. In the Au+Au collisions at 62.4 GeV, within our acceptance, the $\bar{p}/p$ ratio varies from very high values at mid-rapidity (≈ 0.4) to very small ones at y=3 (≈ 0.015), characteristic to mid-rapidity SPS data. We observed that there is a strong dependence of the K^+/π^+ ratio with the $\bar{p}/p$ ratio when looking at SPS results [4] in mid-rapidity together with our results in different rapidity slices. Although the initial conditions for the collisions at RHIC(62 GeV) and SPS are expected to be substantially different, the compared systems develop the same chemistry which seems to be determined by the baryo-chemical potential. In this work we will show measured yields of identified particles from the 10% most central Au+Au collisions at 62.4 GeV. We will also show and discuss the rapidity and baryo-chemical potential dependence of the K/π ratios together with comparisons to results from other energies and from theoretical models (UrQMD [5], AMPT [6]).

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Energy and System Size Dependence of ϕ-meson Production in STAR

J.H. Chen[a] for the STAR Collaboration

[a] Nuclear Science division, Shanghai Institute of Applied Physics, CAS
Shanghai, 201800, P.R. China, *jhchen@physics.ucla.edu*

We present the beam energy and system size dependence of ϕ (s$\bar{s}$) meson production in Cu+Cu and Au+Au collisions at $\sqrt{s_{NN}}$ = 62.4 and 200 GeV measured in the STAR experiment at RHIC. The new data from Cu+Cu collisions and recently published data from Au+Au collisions [1] are presented for measurements made at mid-rapidity ($|y| < 0.5$) for $0.4 < p_T < 5$ GeV/c. At a given beam energy, the transverse momentum distributions for

ϕ mesons are observed to be similar in yield and shape for Cu+Cu and Au+Au colliding systems at similar numbers of participating nucleons (N_{part}). A result different from observations on colliding ion size dependence of strange hadron production at AGS and SPS energies. The Npart normalized ϕ meson yields in nucleus-nucleus collisions are found to be enhanced relative to those from p+p collisions with a different trend compared to strange baryons. The enhancement for ϕ mesons are observed to be higher at 200 GeV compared to 62.4 GeV. These observations for the produced ϕ ($s\bar{s}$) mesons suggest that the source of enhancement of strange hadrons is related to the formation of a dense medium in high energy nucleus-nucleus collisions and cannot be solely due to canonical suppression of their production in smaller systems.

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The ratios of identified strange associated hadrons in the mach-cone region in STAR

J. X. Zuo for the STAR Collaboration[a]

[a]Nuclear Physics Division, Shanghai Institute of Applied Physics, CAS,
Shanghai, 201800, P. R. China, *zuojiaxu@sinap.ac.cn*

At RHIC, jet production can probe the properties of the extremely dense nuclear matter formed in heavy ion collisions. Di-hadron correlations are an effective way to study jets and dense medium interactions in these high multiplicity collisions. Identified particle correlations can provide additional information on: jet quenching, the baryon to meson ratio enhancement, the particle and anti-particle production mechanisms, and mach-cone emission pattern. We report di-hadron correlations of neutral strange baryons (Λ) and mesons (K_S^0) in Au + Au collisions at $\sqrt{s_{NN}}$=200 GeV in STAR. Our study is performed with unidentified hadron triggers and identified associated particles. From this analysis, we hope to learn about parton densities near jets traversing the medium, the process of hadron formation and the di-hadron correlation away-side shape. We extract baryon to meson and baryon to anti-baryon ratios for associated particles as a function of $\Delta\phi$. The shape of these ratios on the away-side is studied. It is useful to understand the away-side's pattern and its production. The particle-type composition in the two away-side mach-cone peaks is compared to that in the near-side peak. These ratios may help to elucidate the origin of the mach-cone like correlation patterns. The particle ratios are both modified on the away-side of jets compared to the near-side of jets.

ϕ and $\omega - \rho$ production in d-C, d-U, S-U and PbPb at SPS energies

D. Jouan[a] for the NA50 collaboration

[a]Institut de Physique Nucléaire, CNRS/IN2P3 et Université Paris Sud
Orsay, 91406, France, *jouan@ipno.in2p3.fr*

ϕ and $\omega - \rho$ production have been measured by the NA50 experiment through the dimuon channel [1,2] in various systems ranging from p-W to Pb-Pb, and as a function of the cen-

trality of the collision.
Results from the last Pb-Pb measurement performed in 2000 are presented, together with earlier d-C, d-U and S-U measurements, where d-C and d-U bring a complementary estimate of the ϕ and $\omega - \rho$ alpha parameter performed by previous experiments [4]. The observed behaviour in ion induced collisions is very different from the one observed with light projectiles.
The study is performed in transverse mass (M_T) domains, where the $\phi/(\omega + \rho)$ ratio is the most closely related to the strangeness saturation factor γ_s.
Updated values of ϕ multiplicity vs. M_T, using new branching ratios from the Particle Data Group, are determined and compared to other experiments, partially solving the so called "phi puzzle" [5].

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Neutral and charged K meson reconstruction in central Pb+Au collisions at 158 A GeV in CERES experiment

M. Kalisky[a] for the CERES Collaboration

[a]GSI,
Darmstadt, 64291, Germany, *m.kalisky@gsi.de*

Over the last 20 years strangeness became one of the main probes in the relativistic heavy ion collisions [1]. The enhancement of the strange particle production and, particularly, the strongly nonmonotonic dependence of the K^+/π^+ ratio on the collision energy [2] attracted a lot of attention. In this talk we present results of a measurement of charged and neutral K meson production in central Pb+Au collisions at E_{lab} = 158 AGeV by the CERES collaboration. Kaons were reconstructed via their decays into charged pions: $K^0_S \to \pi^+\pi^-$, $K^+ \to \pi^+\pi^+\pi^-$, $K^- \to \pi^+\pi^-\pi^-$. While the K^0 analysis in the charged pion decay channel is an established technique it is for the first time in collisions of heavy nuclei (with the exception of the pioneering work of NA35 [3]) that it is being applied for charged kaons. The beam energy dependence of kaon production is a much discussed issue especially at SPS energies and an independent measurement with completely different systematics is therefore important. The charged and neutral kaon yields are compared to each other, to other experiments, and to theoretical predictions.

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System size dependence of di-hadron correlations with identified strange particles in STAR at RHIC

Christine Nattrass[a] (for the STAR Collaboration)

[a]Yale University,
New Haven, CT 06520, USA, *christine.nattrass@yale.edu*

Di-hadron correlations provide a means to study jet production and fragmentation in heavy ion collisions. Previous studies have shown that the near-side di-hadron correlation peak can be decomposed into two components, the *Jet* and the *Ridge*. The *Jet* is narrow in both azimuth and pseudorapidity, while the *Ridge* is narrow in azimuth but independent of pseudorapidity within STAR's acceptance. STAR's data from Cu+Cu and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and 62 GeV allow comparative studies of these components in different systems and at different energies.

We present data on correlations with both identified trigger particles and identified associated particles, including the first studies of identified associated particles in Cu+Cu, Ω triggered correlations in Cu+Cu and the energy dependence of these correlations. The yields are studied as a function of N_{part}, $p_T^{trigger}$, and $p_T^{associated}$. The data indicate that the *Jet* component in heavy ion collisions is independent of system size and has properties similar to that expected from vacuum fragmentation. The *Ridge* component is consistent between systems for the same N_{part} and seems to have properties similar to the bulk. The data also show no strong dependence on the strangeness content of the trigger particle, including the Λ, K_S^0, Ξ, and Ω. The small *Ridge* yield in Cu+Cu suggests that the observation of a near-side yield for Ω triggered correlations comes from a significant *Jet* component. Attempts have been made to explain the *Ridge* component, such as recombination, from momentum kicks, and from a plasma instability. The wealth of data presented will allow detailed tests, which may help distinguish between these models.

K^* production in Cu+Cu and Au+Au collisions at $\sqrt{s_{\rm NN}}$= 62.4 GeV and 200 GeV in STAR

S. Dash(for the STAR Collaboration)

Institute of Physics,
Bhubaneswar, Orissa, 751005, India. *sadhana@iopb.res.in*

The study of short lived resonances in relativistic heavy ion collisions can be used to understand the properties of the hot and dense medium created in such collisions.The resonances and their decay daughters undergo rescattering and regeneration in the dense medium which modifies their characteristic properties such as masses, widths, integrated yields and spectra shapes. We will present the measurement of K^* p_T spectra at mid-rapidity via its hadronic decay channel up to intermediate p_T region using the STAR detector in Au+Au and Cu+Cu collisions at $\sqrt{s_{\rm NN}}$= 62.4 GeV and 200 GeV. The K^* integrated yield, mean p_T, and particle ratios such as K^*/K and K^*/ϕ will be used to understand the interplay between regeneration and rescattering effects. Through a high statistics dataset collected in the year 2004, we present the results on K^* nuclear modification factor R_{AA} or R_{CP} to study how resonances fit into the baryon-meson effect observed in the R_{CP} of pion, proton, K_S and Λ in the intermediate p_T range. The same dataset is used to obtain v_2 of K^* which can potentially provide further information on K^* production mechanism in the hadronic phase and the number of quark scaling for resonances.

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Can thermal model really describe the measured data in STAR?

J.Takahashi[a] for STAR Collaboration

[a]Instituto de Fisica Gleb Wataghin, Universidade Estadual de Campinas,
Campinas, SP, 13087-970, Brazil, *jun@ifi.unicamp.br*

Statistical thermal models have successfully described the identified particle ratios of central collision data from both RHIC and SPS experiments providing information on the bulk properties of the system formed. However, different thermal models that consider various saturation parameters and different constraints, yield different results. Thus, it is important to understand the sensitivity and the limits of thermal model fits to really interpret correctly the physical properties of the system which is formed. With this in mind, we present a study of the thermal model parameters, obtained from currently available algorithms while applying different constraint conditions. Utilizing these results, we will present a systematic study of the geometry dependence of the freeze-out parameters for different event centralities in both Au+Au and Cu+Cu data. In addition, we study the dependence of thermal model fit parameters applied to particle ratios from different rapidity regions.

STRANGENESS PRODUCTION EFFECTS IN VISCOUS HADRONIC HYDRODYNAMICS

L. Turko

Institute of Theoretical Physics, University of Wroclaw
pl. Maksa Borna 9, 50-204 Wroclaw, Poland, *turko@ift.uni.wroc.pl*

RHIC experiments have been interpreted in terms of relativistic hydrodynamic of a thermalized nearly perfect fluid [1]. Indications came mainly from a large elliptic flow effect. However, analysis of initial conditions using the color glass condensate model requires a finite viscosity to reduce the elliptic flow to match the data [2]. There are other general arguments which imply that at least shear viscosity of matter created in heavy ion collision must be nonzero [3]. The final entropy content of the QGP phase at hadronization determines the observable particle multiplicity. The entropy content can be estimated assuming thermal momentum distributions from which equations of state arise. A more general formalism allowing for the consistent incorporation of dissipative and entropy producing mechanisms into the relativistic hydrodynamical framework is available [4,5]. In this approach which is described here, the hydrodynamic model with dynamical chemical reactions amongst multi-fluid fractions has been included.

The contributions due to the production of strangeness flavor is is the main *calculable* entropy source during the evolution of the QGP. Strangeness production leads to the *faster* cooling of the fluid. This is related to the conversion of the initial condition pressure into strangeness. Such chemical viscosity impacts flow and helps simulate low AdS/CFT viscosity.

This effect is taken account within the hydrodynamical model. The resulting "effective viscosity" decreases so the fluid becomes more and more "effectively perfect“. It is also considered the possible dynamical behavior of bulk viscosity terms. The relaxation time for strange and heavy quarks is substantially larger than for light quarks. This increase equilibrium-nonequilibrium "amplitude“, resulting in the increasing bulk viscosity term.

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Measurement of strangeness in ALICE

R. Vernet[a]

[a]Consorzio COMETA, Dipartimento di Fisica,
Catania, 95123, Italy, *renaud.vernet@cern.ch*

Since the beginning of the search for the Quark-Gluon Plasma (QGP), strangeness production has been an observable of large interest to probe the hot and dense medium created in heavy ion collisions. Already an essential measurement at AGS, SPS and RHIC, strangeness will be critical at LHC to answer fundamental questions related to chemical equilibration and expansion dynamics, and especially to probe a broad range of QCD regimes which have been hardly accessible so far.

Whereas LHC will provide exceptional experimental conditions to study Pb-Pb collisions, its first data will be p-p collisions whose analysis will be of major importance. Indeed, p-p collisions will not only serve as a benchmark for Pb-Pb physics, but will also allow testing of perturbative QCD and, in particular, probing the interplay between soft and hard processes in particle production. The amount of strange secondary vertices and resonances measured at LHC will by far overstep that of previous experiments, and ALICE will be perfectly suited for their detection up to high momenta, with good statistics even from the first collected

data, thanks to its large acceptance and state-of-the-art trajectography apparatus.
As part of the preparation of ALICE for the upcoming data, we give an overview of ALICE capability to measure strange particles. The simulations performed with the ALICE software environment will be presented both for p-p and Pb-Pb collisions. We show that the topological methods developed to identify strange (K^0_S, Λ) and multi-strange (Ξ, Ω) secondary vertices will make their measurement possible from the very first p-p data in a large range of momenta. We also address the detection of strange resonances ($K^0(892)$, $\phi(1020)$, $\Lambda(1520)$), describing their identification by means of invariant mass and background estimation methods. Prospects on the strangeness physics studies achievable from the first runs of p-p and Pb-Pb are discussed.

Multi-strange Particles Production from Cu+Cu Collision at $\sqrt{s_{NN}} = 200GeV$ in the STAR Experiment

Xiaobin Wang [a,b] for the STAR Collaboration

[a]Department of Engineering Physics, Tsinghua University, Beijing 100084, China
[b]Department of Physics and Astronomy, University of California,
Los Angeles, California 90095-1547 USA, *wangxb@rcf.rhic.bnl.gov*

Strange quark production can be used to probe the partonic nature of dense matter created in nucleus-nucleus collision at RHIC. The enhancement of mid-rapidity strangeness production with different system size has been observed over a range of energies. In this talk, using a full data set of Cu+Cu collisions at $\sqrt{s_{NN}} = 200GeV$, we report the measurements of strange hyperon Λ^0, Ξ, Ω and their anti-particles at the STAR experiment. Nuclear Modification Factors R_{CP} for these particles are compared in detail and the physics implication is discussed. The multi-strange hyperon production per participant for Cu+Cu collisions will be compared with that from Au+Au and p+p collisions at the same beam energy.

SYSTEM SIZE DEPENDENCE OF STRANGE HADRON ELLIPTIC FLOW FROM 200 GEV AU+AU and CU+CU COLLISIONS

Y. Lu[a] for STAR collaboration

[a]Dept. of Modern Physics, USTC,
Hefei, Anhui, 230026, China, *luyan@ustc.edu.cn*

Collective flow reflects dynamical evolution in high-energy heavy ion collisions. In particular, the elliptic flow reflects early collision dynamics [1]. In Au+Au collisions at RHIC, two important insights have been extracted through the collective flow measurements: (i) the v_2 for all measured hadrons at low p_T region behave similar to the predictions by hydrodynamic models indicating possible early thermalization at RHIC; (ii) at the intermediate p_T region, the observed v_2 follows a scaling that depends on the number of quarks in a given hadron. This suggests that the coalescence as the underline mechanism for hadron formation and the development of partonic collectivity at RHIC. The colliding size dependence of v_2 will allow us to test the early thermalization hypothesis.

We present the results from a systematic analysis of the centrality dependence of strange hadron elliptic flow (v_2) measurement for K_S^0, $\Lambda+\bar{\Lambda}$, $\Xi^-+\bar{\Xi}^+$ and $\Omega^-+\bar{\Omega}^+$ in Au+Au collisions at 200 GeV. In addition, we present the preliminary v_2 results of K_S^0, ϕ and $\Lambda+\bar{\Lambda}$ from minimum bias Cu+Cu collisions at 200 GeV. For each centrality of Au+Au collisions at 200 GeV, we observe two scaling: (i) a (m_T-m) scaling at low p_T region ($p_T < 2$ GeV/c); (ii) a number-of-quark scaling at intermediate p_T region (2 GeV/c $< p_T < 6$ GeV/c). No universal scaling with participant eccentricity (ε_{part}) amongst different collision centralities has been observed. As a function of centrality, an increase in the p_T-integrated v_2/ε_{part} has been observed, indicating stronger collective flow in more central collisions. For multi-strange hadron ϕ and $\Omega^-+\bar{\Omega}^+$, their v_2 is consistent with the m_T-nq scaling. The Cu+Cu collisions results are compared with those from Au+Au collisions at a similar number of participants. We will also compare our data with results from hydrodynamic model calculations.

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Parton Properties at Hadronization for Bulk Dense Matter Produced in Nucleus-Nucleus Collisions

J.H. Chen[a], F. Jin[a], D. Gangadharan[b], H. Huang[b], Y.G. Ma[a]

[a] Nuclear Science division, Shanghai Institute of Applied Physics, CAS
Shanghai, 201800, P.R. China, *jhchen@physics.ucla.edu*

[b] Department of Physics and Astronomy, University of California at Los Angeles
Los Angeles, CA, 90095, USA, *huang@physics.ucla.edu*

Measurements of nuclear modification factors and elliptic flow v_2 for identified particles exhibit a constituent quark number scaling. Such scaling can be explained by quark coalescence or recombination models, which provide an intriguing framework for hadronization of bulk partonic matter. The essential degrees of freedom at the hadronization seem to be effective constituent quarks which have developed a collective elliptic flow during partonic evolution. We present constraints on momentum distribution for the effective constituent quarks at the hadronization. Our results were derived from measured Ω, Ξ, Λ and ϕ spectra, guided by quark coalescence/recombination models [1]. AMPT model [2] was also used to illustrate the physical picture and to compare with our results. The consistency in quark ratios derived from various hadron spectra provides clear evidence for hadron formation dynamics as suggested by coalescence/recombination models.

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