FERMILAB-PUB-15-054-PPD

The transverse momentum dependencies of charged kaon Bose-Einstein correlations in the SELEX experiment

The SELEX Collaboration

G.A. Nigmatkulov[i], A.K. Ponosov[i,1], U. Akgun[n], G. Alkhazov[j], J. Amaro-Reyes[l], A. Asratyan[f], A.G. Atamantchouk[j,1], A.S. Ayan[n], M.Y. Balatz[f,1], A. Blanco-Covarrubias[l], N.F. Bondar[j], P.S. Cooper[d], L.J. Dauwe[o,1], G.V. Davidenko[f], U. Dersch[g,3], A.G. Dolgolenko[f], G.B. Dzyubenko[f,1], R. Edelstein[b], L. Emediato[q], A.M.F. Endler[c], J. Engelfried[l], I. Eschrich[g,2], C.O. Escobar[q,4], N. Estrada[l], A.V. Evdokimov[f], I.S. Filimonov[h,1], A. Flores-Castillo[l], F.G. Garcia[q,d], V.L. Golovtsov[j], P. Gouffon[q], E. Gülmez[a], M. Iori[p], S.Y. Jun[b], M. Kaya[n,5], J. Kilmer[d], V.T. Kim[j], L.M. Kochenda[j], I. Konorov[g,6], A.P. Kozhevnikov[e], A.G. Krivshich[j], H. Krüger[g,7], M.A. Kubantsev[f], V.P. Kubarovsky[e], A.I. Kulyavtsev[b,d], N.P. Kuropatkin[j,d], V.F. Kurshetsov[e], A. Kushnirenko[b,e], J. Lach[d], L.G. Landsberg[e,1], I. Larin[f], E.M. Leikin[h], G. López-Hinojosa[l], T. Lungov[q], V.P. Maleev[j], D. Mao[b,8], P. Mathew[b,9], M. Mattson[b], V. Matveev[f], E. McCliment[n], M.A. Moinester[k], V.V. Molchanov[e], A. Morelos[l], A.V. Nemitkin[h], P.V. Neoustroev[j], C. Newsom[n], A.P. Nilov[f,1], S.B. Nurushev[e], A. Ocherashvili[k,10], Y. Onel[n], S. Ozkorucuklu[n,11], A. Penzo[r], S.V. Petrenko[e], M. Procario[b,12], V.A. Prutskoi[f], B.V. Razmyslovich[j,13], D.A. Romanov[i], V.I. Rud[h], J. Russ[b], J.L. Sánchez-López[l], A.A. Savchenko[i], J. Simon[g,14], G.V. Sinev[i,15], A.I. Sitnikov[f], V.J. Smith[m], M. Srivastava[q], V. Steiner[k], V. Stepanov[j,13], L. Stutte[d], M. Svoiski[j,13], V.V. Tarasov[f], N.K. Terentyev[j,b], I. Torres[l,16], L.N. Uvarov[j], A.N. Vasiliev[e], D.V. Vavilov[e], E. Vázquez-Jáuregui[l,17], V.S. Verebryusov[f,1], V.A. Victorov[e], V.E. Vishnyakov[f], A.A. Vorobyov[j], K. Vorwalter[g,18], J. You[b,d], R. Zukanovich-Funchal[q]

[a]Bogazici University, Bebek 80815 Istanbul, Turkey
[b]Carnegie-Mellon University, Pittsburgh, PA 15213, U.S.A.
[c]Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil
[d]Fermi National Accelerator Laboratory, Batavia, IL 60510, U.S.A.
[e]Institute for High Energy Physics, Protvino, Russia
[f]Institute of Theoretical and Experimental Physics, Moscow, Russia
[g]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany
[h]Moscow State University, Moscow, Russia
[i]National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia
[j]Petersburg Nuclear Physics Institute, St. Petersburg, Russia
[k]Tel Aviv University, 69978 Ramat Aviv, Israel
[l]Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico
[m]University of Bristol, Bristol BS8 1TL, United Kingdom
[n]University of Iowa, Iowa City, IA 52242, U.S.A.
[o]University of Michigan-Flint, Flint, MI 48502, U.S.A.
[p]University of Rome "La Sapienza" and INFN, Rome, Italy
[q]University of São Paulo, São Paulo, Brazil
[r]University of Trieste and INFN, Trieste, Italy

Abstract

We report on the measurement of the charged kaon correlation functions k_T dependencies using 600 GeV/c Σ^-, π^- and 540 GeV/c p beams from the SELEX (E781) experiment at Tevatron. One-dimensional $K^{ch}K^{ch}$ correlation functions are constructed in three transverse momentum ranges. The emission source parameters λ and R are extracted. The analysis shows a decrease of the source radii with the kaon pair transverse momentum for all beam types.

Keywords: Correlation femtoscopy, HBT intensity interferometry, kaon-kaon interactions, Bose-Einstein correlations
PACS: 25.75.Gz, 13.75.Lb

Email address: `nigmatkulov@gmail.com` (G.A. Nigmatkulov)

[1] Deceased

[2] Present address: University of California at Irvine, Irvine, CA 92697, USA

[3] Present address: Advanced Mask Technology Center, Dresden, Germany

[4] Present address: Instituto de Física da Universidade Estadual de Campinas, UNICAMP, SP, Brazil

[5] Present address: Kafkas University, Kars, Turkey

[6] Present address: Physik-Department, Technische Universität

Preprint submitted to Physics Letters B *January 20, 2015*

1. Introduction

In this paper we present results from $K^{ch}K^{ch}$ correlation femtoscopy study in 600 GeV/c $\Sigma^- C(Cu)$, $\pi^- C(Cu)$ and 540 GeV/c $p\ C(Cu)$ interactions from the SELEX (E781) experiment [1] at the Tevatron FNAL. The correlation femtoscopy method allows to study spatio-temporal characteristics of the emission source on the level of 1 fm = 10^{-15} m. The method is based on the Bose-Einstein enhancement of identical boson production at small relative momentum. The quantum statistics correlations were first observed as an enhanced production of the identical pion pairs with small opening angles in proton-antiproton collisions by G. Goldhaber, S. Goldhaber, W.-Y. Lee and A. Pais in 1960 (GGLP effect) [2]. Later, in the 1970s Kopylov and Podgoretsky suggested to study the interference effect in terms of the correlation function, proposed the mixing technique to construct the uncorrelated reference sample and clarified the role of the space-time characteristics of particle production [3, 4, 5]. Then two-particle correlations at small relative momentum were systematically studied for lepton-lepton, lepton- and hadron-hadron, and heavy-ion collisions. In heavy-ion collisions at the Super Proton Synchrotron (SPS) [6, 7, 8, 9, 10, 11] and at the Relativistic Heavy Ion Collider (RHIC) [12, 13, 14, 15] it was found that the system created in such collisions is well described by the ideal-fluid hydrodynamics followed by the statistical hadronization [16]. By using the width of the quantum statistical enhancement one can measure the radii R of the emitting source. The drop of the extracted radii with increasing pair transverse momentum may be interpreted as the decrease of the “homogeneity lengths”[17] due to collective transverse flow.

A comparison of femtoscopic measurements in lepton- and hadron-induced [18, 19] collisions with heavy-ion collisions shows similar systematics [20, 21]. These analyses usually study pions, however measurements of heavier particles may provide an additional information about the size, orientation and dynamical timescales of the emission region.

2. Experimental Setup and Data Selection

The SELEX (E781) detector is a three-stage magnetic spectrometer designed for charm hadroproduction study at $x_F > 0.1$. We report on the analysis of 1 billion events of 600 GeV/c $\Sigma^- C(Cu)$, $\pi^- C(Cu)$ and 540 GeV/c $p\ C(Cu)$ interactions recorded during the 1996-1997 fixed target run. About 2/3, 1/6 and 1/6 of the data were obtained on Σ^-, π^- and p beams, respectively.

The beam particle was identified as a meson or a baryon by a transition radiation detector. Interactions occurred on segmented targets, which consisted of 2 copper and 3 diamond foils separated by 1.5 cm clearance and had a total thickness of 5% of an interaction length for protons. Particles were tracked in a set of 20 vertex Silicon Strip Detectors (SSD) arranged in 4 sets X, Y, U and V views, with a strip pitch of 20-25 μm. The particle momentum was measured by deflection of the track position by two magnets M1 and M2 in a system of proportional wire chambers and silicon strip detectors. Momentum resolution of a typical 100 GeV/c track was $\sigma_p/p \approx 0.5\%$. A Ring Imaging Cherenkov detector (RICH) of the experiment performed particle identification in a wide momentum range and provided 2 σ K/π separation up to 165 GeV/c [22].

In this analysis we used primary tracks that have vertex silicon track segment matched with downstream segment measured in the M2 spectrometer, with the momentum from 45 to 165 GeV/c and identified in the RICH detector with the likelihood to be a kaon exceeding any other hypothesis. After applying these cuts 5438097, 701814 and 115338 identical charged kaon pairs were selected on Σ^-, π^- and p beams, respectively.

3. Correlation Femtoscopy

The two-particle correlation function is defined as the ratio of the probability to measure two particles with momenta $\vec{p}_1$ and $\vec{p}_2$ to their single particle probabilities:

$$C(\vec{p}_1, \vec{p}_2) = \frac{P(\vec{p}_1, \vec{p}_2)}{P(\vec{p}_1)P(\vec{p}_2)}. \tag{1}$$

Experimentally, one studies the correlation function $C(\vec{q})$ in terms of relative momentum $\vec{q} = \vec{p}_1 - \vec{p}_2$ and

---

München, 85748 Garching, Germany

[7] Present address: The Boston Consulting Group, München, Germany

[8] Present address: Lucent Technologies, Naperville, IL

[9] Present address: Baxter Healthcare, Round Lake IL

[10] Present address: NRCN, 84190 Beer-Sheva, Israel

[11] Present address: Süleyman Demirel Universitesi, Isparta, Turkey

[12] Present address: DOE, Germantown, MD

[13] Present address: Solidum, Ottawa, Ontario, Canada

[14] Present address: Siemens Healthcare, Erlangen, Germany

[15] Present address: Duke University, Durham, NC 27708, USA

[16] Present address: Instituto Nacional de Astrofísica, Óptica y Electrónica, Tonantzintla, Mexico

[17] Present address: SNOLAB

[18] Present address: Allianz Insurance Group IT, München, Germany

average momentum $\vec{K} = (\vec{p}_1 + \vec{p}_2)/2$ of two particles:

$$C(\vec{q}, \vec{K}) = \frac{A(\vec{q}, \vec{K})}{B(\vec{q}, \vec{K})} \cdot D(\vec{q}, \vec{K}), \qquad (2)$$

where $A(\vec{q}, \vec{K})$ is the measured distribution of relative momentum within the same event, $B(\vec{q}, \vec{K})$ — the corresponding distribution for pairs of particles from different events (event-mixed distribution) and $D(\vec{q}, \vec{K})$ is a so-called correlation baseline that describes all non-femtoscopic correlations such as, for instance, the correlations caused by the energy and momentum conservation-induced correlations [23]. In the simplest case non-femtoscopic effects can be parameterized by a second order polynomial. Event mixing was done using only events with two or more identical charged kaons, grouped by production target. Kaons from adjacent events for each target were combined to provide an uncorrelated experimental background.

By virtue of the limited statistics available for the π^- and p beams only the one-dimensional femtoscopic charged kaon analysis of correlation functions in terms of invariant relative momentum $Q = \sqrt{(\vec{p}_1 - \vec{p}_2)^2 - (E_1 - E_2)^2}$ was performed. In order to extract the size of the emission region one can use the Goldhaber parametrization, which assumes that the emitting source of identical bosons is described by a spherical Gaussian density function:

$$C(Q) = \left(1 + \lambda e^{-R^2 Q^2}\right) \cdot D(Q), \qquad (3)$$

where λ describes the correlation strength, R — size of the emitting source and $D(Q)$ is the baseline distribution. The momentum correlations of particles emitted at nuclear distances are also influenced by the effect of final-state interaction (FSI) — Coulomb and strong interactions [24, 25, 26, 27]. For identical kaons the effect of strong interactions is negligible. Correlation function of identical bosons should increase at low relative momentum except for small values where Coulomb interaction becomes dominant. One may take it into account by modifying Eq. (3):

$$C(Q) = \left((1 - \lambda) + \lambda K(Q)\left(1 + e^{-R^2 Q^2}\right)\right) \cdot D(Q), \quad (4)$$

where the factor $K(Q)$ is the squared like-sign kaon pair Coulomb wave function integrated over a spherical Gaussian source [28, 29, 30].

4. Results and Discussion

The results discussed in this Letter were obtained with the same detector setup, cuts and fitting procedures giving an opportunity to compare the properties of the emission region for different hadron-induced collisions. The analysis was performed for three average pair transverse momentum $k_T = \left|\vec{p}_{T1} + \vec{p}_{T2}\right|/2$ ranges: $(0 - 0.3)$, $(0.3 - 0.55)$, $(0.55 - 1)$ GeV/c and for the three beam types: Σ^-, π^-, p. Due to small differences in the measured correlation functions, the positive and negative kaon four-momentum distributions were combined in the numerator and the denominator before constructing the ratio.

In order to reduce non-flat baseline, the Monte Carlo event generator PYTHIA-6.4.28 [31] with Perugia 2011 tune [32] was used. Correlations from MC events do not contain Bose-Einstein correlations and final-state interactions and only make contributions to the non-femtoscopic term $D(Q)$ in Eq. (4). In Fig. 1 we compare the MC correlation distributions with data normalized such that $C(Q) = 1$ for $0.5 < Q < 0.8$ GeV/c, where quantum statistical correlations are absent and the influence of the non-femtoscopic effects is small. It is seen that PYTHIA describes the experimental baseline in the region $Q > 0.5$ GeV/c where the effect of femtoscopic correlations is negligible. In the region $Q < 0.5$ GeV/c the enhancement of the experimental correlation functions is coming from quantum statistics correlations and the decrease of the correlation functions in the region $Q < 0.1$ GeV/c is due to Coulomb repulsion of the like-sign charged kaons.

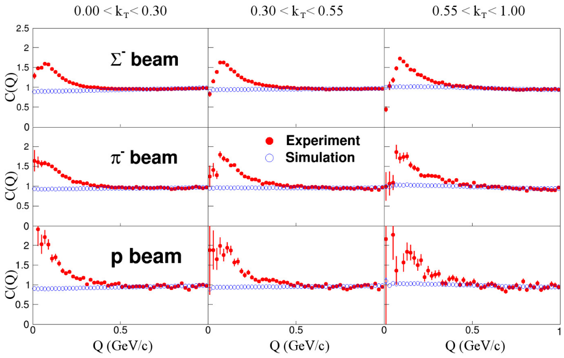

Figure 1: Comparison of experimental (full circles) and simulated (open circles) correlation functions of identical kaons. Three rows represent data obtained for Σ^-, π^- and p beams respectively and three columns represent three pair transverse momentum ranges: $(0 - 0.3)$, $(0.3 - 0.55)$, $(0.55 - 1)$ GeV/c. Positive and negative kaon pairs are combined.

Fig. 2 shows the correlation functions obtained after correction of experimental correlation functions by the simulated functions (in order to reduce non-femtoscopic correlations) for each beam type and k_T range and the fits were performed using Eq. (4). In the current analysis the Coulomb function $K(Q)$ was integrated over a

Table 1: $K^{ch}K^{ch}$ source parameters for Σ^-, π^- and p beams. Statistical and systematic errors are presented.

Beam type	k_T [GeV/c]	λ	R [fm]
Σ^-	(0.00 – 0.30)	0.71 ± 0.02 ± 0.10	1.29 ± 0.02 ± 0.13
	(0.30 – 0.55)	0.67 ± 0.02 ± 0.08	1.14 ± 0.02 ± 0.09
	(0.55 – 1.00)	0.70 ± 0.04 ± 0.15	0.96 ± 0.04 ± 0.03
π^-	(0.00 – 0.30)	0.64 ± 0.05 ± 0.13	1.16 ± 0.05 ± 0.12
	(0.30 – 0.55)	0.68 ± 0.06 ± 0.09	1.07 ± 0.05 ± 0.09
	(0.55 – 1.00)	0.44 ± 0.10 ± 0.13	0.95 ± 0.14 ± 0.10
p	(0.00 – 0.30)	1.01 ± 0.14 ± 0.05	1.48 ± 0.12 ± 0.22
	(0.30 – 0.55)	0.86 ± 0.15 ± 0.12	1.33 ± 0.11 ± 0.12
	(0.55 – 1.00)	0.60 ± 0.22 ± 0.31	1.09 ± 0.21 ± 0.08

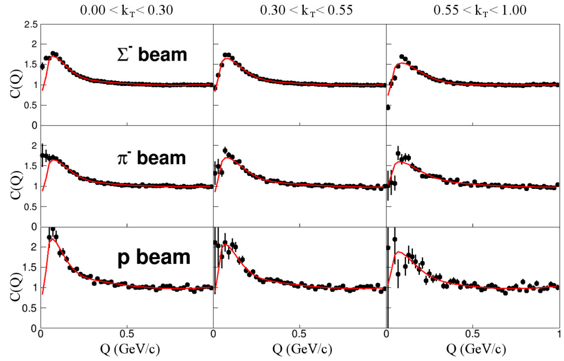

Figure 2: The correlation functions of $K^{ch}K^{ch}$ system versus relative four-momentum after the correction on non-femtoscopic correlations. The fits were performed using Eq. 4 and the columns and rows are defined as in Fig. 1.

spherical source of 1 fm.

Fig. 3 and Tab. 1 show extracted parameters of the correlation strength λ and radii R for all beam types and three pair transverse momentum regions. Fig. 3 shows decrease of the charged kaon source radii with k_T for all Σ^- (circles), π^- (squares) and p beams (triangles). Only statistical errors are shown. It is seen that the source radii obtained for the meson beam are systematically smaller than those obtained for the baryon beams. At the same time the measured radii for Σ^- is smaller then for the p beam within 2σ. This difference is probably arising from the different production mechanisms due to the leading particle effect [33, 34] and different contamination from the resonances [35].

The main contribution to the systematic uncertainties (up to 19%) is coming from the baseline determination in the PYTHIA simulation. In order to estimate systematical uncertainties due to the fitting procedure different non-femtoscopic forms were used [36, 37, 38]:

$$D(Q) = a, \tag{5}$$

$$D(Q) = a + bQ, \tag{6}$$

$$D(Q) = \sqrt{a + bQ^2 + cQ^4}, \tag{7}$$

$$D(Q) = a(1 + e^{-bQ^2}). \tag{8}$$

The systematic error from varying the Q fit range is below 1%. Changing the radius of the Coulomb source in the range from 0.5 fm to 1.5 fm has negligible effect on the extracted radii.

As one can see from Tab. 1 the λ parameter is correlated with the source radii that may be explained as: 1) non-Gaussian shape of the source due to contamination from the resonance decays and non-spherical shape of the source and 2) imperfect description of the baseline by PYTHIA. The former means that in hadronic collisions non-Gaussian shape of the source in 'x–y–z' planes plays more important role than in heavy-ion collisions.

The decrease of the source radii with pair transverse momentum was previously observed in heavy-ion collisions and interpreted as a collective hydrodynamic behavior (collective flow) [39, 40]. The first direct comparison of correlation femtoscopy in $p + p$ and heavy-ion collisions under the same detector conditions, reconstruction, analysis and fitting procedures was performed by the STAR collaboration [21]. It was shown that $p + p$ collisions also have the transverse momentum scaling. However, the interpretation of these results is still unclear, but the similarities could indicate a connection between the underlying physics.

The transverse momentum dependence was also observed for $\pi\pi$ in e^+e^- [41, 42] and pp collisions [21, 43, 37, 44]. For the very first time a similar analysis of charged kaon Bose-Einstein correlations for more than one pair transverse momentum and multiplicity ranges was recently performed by the ALICE collaboration at the LHC in pp collisions at $\sqrt{s}$ = 7 TeV [36]. It was shown that $K^{ch}K^{ch}$ femtoscopic radii decrease with pair transverse momentum for middle and high multiplicity ranges.

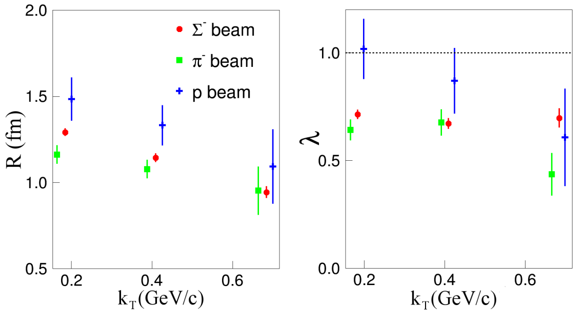

Figure 3: $K^{ch}K^{ch}$ source parameters R and λ measured for Σ^- (circles), π^- (squares) and p (triangles) beams as a function of pair transverse momentum k_T. The errors shown are statistical only.

There are several possible processes that may lead to the k_T dependencies in the hadronic collisions:

1. The space-momentum dependence of the femtoscopic radii may be generated by long-lived resonances [45]. In particular this may play a significant role in high multiplicity bins, where the bulk collective flow is predicted [46].

2. T. J. Humanic proposed a model [47] based on space-time geometry of hadronization and effects of final-state rescattering between hadrons that reproduces both multiplicity and transverse mass dependence measured at the Tevatron [48].

3. In small systems the string fragmentation should generate momentum and space correlations, such as k_T dependence of the source radii. However, there are almost no quantitative predictions that may be directly compared with data. Moreover, the Lund string model is not able to reproduce the mass dependence of the radii [41, 49, 50, 18].

4. Hydrodynamic bulk collective flow may lead to the k_T dependence that is very similar to the one from heavy-ion collisions.

These mean that the origin of the pair transverse momentum dependence of the femtoscopic radii in hadronic collisions is still unclear and further theoretical studies are needed in order to understand the underlying physics.

5. Summary

The charged kaon Bose-Einstein correlations were measured in the SELEX experiment. One-dimensional $K^{ch}K^{ch}$ correlation functions in terms of the invariant momentum difference were constructed for Σ^-, π^- and p beams and three pair transverse momentum ranges: $(0-0.3)$, $(0.3-0.55)$ and $(0.55-1)$ GeV/c. The source parameters of correlation strength λ and radii R were extracted for all beam types and for three pair transverse momentum ranges and are shown in Tab. 1. The slight decrease of the femtoscopic radii R with pair transverse momentum was observed for all three beam types. The source radii obtained for the π^- beam have smaller values compared to the baryon beams. The difference in the measured radii between the Σ^- and p beams is observed.

Acknowledgments

The authors are indebted to the staff of Fermi National Accelerator Laboratory and for invaluable technical support from the staffs of collaborating institutions. This project was supported in part by Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, Consejo Nacional de Ciencia y Tecnología (CONACyT), Conselho Nacional de Desenvolvimento Científico e Tecnológico, Fondo de Apoyo a la Investigación (UASLP), Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), the Israel Science Foundation founded by the Israel Academy of Sciences and Humanities, Istituto Nazionale di Fisica Nucleare (INFN), the International Science Foundation (ISF), the National Science Foundation, NATO, the Russian Academy of Science, the Russian Ministry of Science and Technology, the Russian Foundation for Basic Research (research project No. 11-02-01302-a), the Secretaría de Educación Pública (Mexico), the Turkish Scientific and Technological Research Board (TÜBİTAK), and the U.S. Department of Energy. We thank ITEP and National Research Nuclear University MEPhI (Moscow Engineering Physics Institute) for providing computing resources and support for data analysis and simulations.

The authors also would like to thank prof. Michael Lisa and prof. Richard Lednicky for helpful comments and fruitful discussions.

References

References

[1] J. S. Russ, N. Akchurin, V. A. Andreev, et al., ICHEP'98 Proc. Int. Conf. on High Energy Physics II (1998) 1259. `arXiv:hep-ex/9812031`.

[2] G. Goldhaber, S. Goldhaber, W. Lee, A. Pais, Phys. Rev. 120 (1960) 300–312.

[3] G. I. Kopylov and M. I. Podgoretsky, Sov. J. Nucl. Phys. 15 (1972) 219–223.

[4] G. I. Kopylov and M. I. Podgoretsky, Sov. J. Nucl. Phys. 18 (1974) 336.
[5] G. I. Kopylov and M. I. Podgoretsky, Phys. Lett. B 50 (1974) 472.
[6] J. Baechler, et al., Nucl. Phys. A 525 (1991) 327C.
[7] T. Alber, et al., Nucl. Phys. A 590 (1995) 453C.
[8] H. Beker, et al., Phys. Rev. Lett. 74 (1995) 3340.
[9] H. Beker, et al., Z. Phys. C 64 (1994) 209.
[10] I. G. Bearden, et al., Nucl. Phys. A 661 (1999) 435.
[11] I. G. Bearden, et al., Phys. Rev. Lett. 78 (1997) 2080.
[12] J. Adams, et al., Nucl. Phys. A 757 (2005) 102–183. arXiv:nucl-ex/0501009.
[13] K. Adcox, et al., Nucl. Phys. A 757 (2005) 184–283. arXiv:nucl-ex/0410003.
[14] B. B. Back, et al., Nucl. Phys. A 757 (2005) 28–101. arXiv:nucl-ex/0410022.
[15] I. Arsene, et al., Nucl. Phys. A 757 (2005) 1–27. arXiv:nucl-ex/0410020.
[16] A. Kisiel, W. Broniowski, M. Chojnacki, W. Florkowski, Phys. Rev. C 79 (2009) 014902. arXiv:0808.3363.
[17] S. V. Akkelin, Y. M. Sinyukov, Phys. Lett. B 356 (1995) 525.
[18] G. Alexander, I. Cohen, E. Levin, Phys. Lett. B 452 (1999) 159–166. arXiv:hep-ph/9901341.
[19] W. Kittel, Acta Phys. Polon. B 32 (2001) 3927. arXiv:hep-ph/0110088.
[20] Z. Chajęcki, Acta Phys. Polon. B 40 (2009) 1119. arXiv:0901.4078.
[21] M. M. Aggarwal, et al., Phys. Rev. C 83 (2011) 064905. arXiv:1004.0925.
[22] J. Engelfried, et al., Nucl. Instr. and Methods A 431 (1999) 53. arXiv:hep-ex/9811001.
[23] Z. Chajęcki, M. Lisa, Phys. Rev. C 78 (2008) 064903. arXiv:0803.0022.
[24] R. Lednicky, V. L. Lyuboshits, B. Erazmus, D. Nouais, Phys. Lett. B 373 (1996) 30.
[25] S. Voloshin, R. Lednicky, S. Panitkin, N. Xu, Phys. Rev. Lett. 79 (1997) 4766. arXiv:nucl-th/9708044.
[26] S. Pratt, Braz. J. Phys. 37 (2007) 871. arXiv:nucl-th/0612006.
[27] R. Lednicky, J. Phys. G.: Nucl. Part. Phys. 35 (2008) 125109. arXiv:http://stacks.iop.org/0954-3899/35/125109.
[28] M. G. Bowler, Phys. Lett. B 270 (1991) 69.
[29] Y. Sinyukov, R. Lednicky, S. V. Akkelin, J. Pluta, B. Erazmus, Phys. Lett. B 432 (1998) 248.
[30] J. Adams, et al., Phys. Rev. C 71 (2005) 044906. arXiv:nucl-ex/0411036.
[31] T. Sjostrand, S. Mrenna, P. Skands, JHEP 05 (2006) 026. arXiv:hep-ph/0603175v2.
[32] P. Z. Skands, Phys. Rev. D 82 (2010) 074018. arXiv:1005.3457.
[33] E. Braaten, Y.Jia, T. Mehen, Phys. Rev. Lett. 89 (2002) 122002. arXiv:hep-ph/0205149.
[34] T. Guitierrez, R. Vogt, Nucl. Phys. B 539 (1999) 189–214. arXiv:hep-ph/9808213.
[35] R. Lednicky, T. B. Progulova, Z. Phys. C 55 (1992) 295–305.
[36] B. Abelev, et al., Phys. Rev. D 87 (2013) 052016. arXiv:1212.5958v2.
[37] V. Khachatryan, et al., JHEP 05 (2011) 029. arXiv:1101.3518.
[38] S. V. Akkelin, Y. M. Sinyukov, Phys. Rev. D 85 (2012) 074023. arXiv:1106.5120.
[39] M. A. Lisa, S. Pratt, R. Soltz, U. Wiedemann, Ann. Rev. Nucl. Part. Sci. 55 (2005) 357. arXiv:nucl-ex/0505014.
[40] S. Pratt, Rhys. Rev. Lett. 53 (1984) 1219.
[41] A. Bialas, M. Kucharczyk, H. Palka, , K. Zalewski, Phys. Rev. D 62 (2000) 114007. arXiv:hep-ph/0006290.
[42] A. Bialas and K. Zalewski, Acta Phys. Polon. B 30 (1999) 359. arXiv:hep-ph/9901382.
[43] K. Aamodt, et al., Phys. Rev. D 82 (2010) 052001. arXiv:1007.0516.
[44] K. Aamodt, et al., Phys. Rev. D 84 (2011) 112004. arXiv:1101.3665.
[45] U. A. Wiedemann and U. W. Heinz, Phys. Rev. C 56 (1997) 3265. arXiv:nucl-th/9611031.
[46] K. Werner, I. Karpenko, T. Pierog, M. Bleicher, K. Mikhailov, Phys. Rev. C 83 (2011) 044915. arXiv:1010.0400.
[47] T. J. Humanic, Phys. Rev. C 76 (2007) 025205. arXiv:nucl-th/0612098.
[48] T. Alexopoulos, et al., Phys. Rev. D 48 (1993) 1931.
[49] G. Alexander, Acta Phys. Polon. B 35 (2004) 69. arXiv:hep-ph/0311114.
[50] G. Alexander, Phys. Lett. B 506 (2001) 45–51. arXiv:hep-ph/0101319.