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K-meson production and isospin-symmetry in pp and AA collisions

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The production of K mesons in pp and AA collisions at high energies is analyzed. We have showed that the ratio $R_K = \frac{\sigma_{K^+}+\sigma_{K^-}}{2\sigma_{K_S^0}}$ calculated within the similarity approach, including the gluon TMD at low QCD scales[5], and using the Lund model in the form of MC generator PYTHIA [14] is above 1 even at the conservation of the isospin-symmetry. It is about 1.18 at $\sqrt{s}$ =11.9 GeV (the NA61/SHINE data [1]) and it decreases up to 1, when the energy increases up to a few TeV (ALICE data). The reason of this is related to the dynamics of the kaon production. This energy behavior of R_K practically does not depend on the sort of the beam or target.

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As it is well known, in the quark sector there is the flavor symmetry, which means that interactions are independent of the quark type (flavor), when quarks are massless. For light quarks up (u) and down (d) it reduces to the isospin symmetry. The difference $m_u - m_d$ is about 2 MeV, which is much smaller than the QCD scale $\Lambda_{QCD} \simeq 250$ MeV, therefore for light quarks the isospin symmetry is conserved. For K-meson production it leads to the equality of the cross sections of charged $K^+ + K^-$ mesons to the neutral ones $K^0 + \bar{K^0}$ in the final state.

Recently the suggestion on the violation of isospin-symmetry in AA kaon production has appeared [1]. This suggestion is based on the experimental data on the ratio $R_K = \frac{\sigma_{K^+} + \sigma_{K^-}}{2\sigma_{K^0_S}}$, which shows that $R_K > 1$ at 2-3 GeV< $\sqrt{s}$ <200-300 GeV and $R_K = 1$ at $\sqrt{s} = 3$ TeV.

In this paper we check a role of dynamics of kaon production in pp and AA collisions $pp \to KX$ and $AA \to KX$. Let us refer to the similarity approach offered in [2, 3] on the hadron production in $A - A$ collisions at their small transverse momenta. It is modified in [4, 5]. The conservation law of four-momenta is the following:

$$(N_A P_A + N_B P_B - p_1)^2 = (N_A m_0 + N_B m_0 + M)^2, \tag{1}$$

where N_A and N_B are the fractions of the four-momentum transmitted by nucleus A and nucleus B, the forms of N_A, N_B are presented in [2–4]; P_A, P_B, p_1 are the four-momenta of nuclei A, B and hadron h, respectively; m_0 is the mass of the nucleon; M is the mass of the particle providing conservation of the baryon number, strangeness and other quantum numbers. It allows us to find the minimal value of M. For π-mesons $m_1 = m_\pi$ and M =0. For antinuclei $M = m_1$ and for K^--mesons $M = m_1 = m_K$, m_K is the mass of the K-meson. For nuclear fragments $M = -m_1$. For K^+-mesons $m_1 = m_K$ and $M = m_\Lambda - m_0$, m_Λ is the mass of the Λ-baryon.

The inclusive spectrum of hadron h produced in the AB collision can be parameterized as a general universal function dependent of the similarity parameter Π, as it was shown in [6]:

$$E d^3\sigma_{AB}/d^3p \;=\; A_A^{\alpha(N_A)} \cdot A_B^{\alpha(N_B)} \cdot F(\Pi) \tag{2}$$

where $\alpha(N_A) = 1/3 + N_A/3$, $\alpha(N_B) = 1/3 + N_B/3$ and function $F(\Pi)$ is the inclusive spectrum of hadron production in the NN collision . Here $F(\Pi)$ at $y = 0$ has the same form as the inclusive spectrum $\rho_{NN}(x = 0, p_t)$ [7, 8]:

$$\rho_{NN}(y = 0, p_T) \;=\; \rho_q(y = 0, p_T) \;+\; \rho_g(y = 0, p_T)\;, \tag{3}$$

with substitution of transverse momentum p_T by Π [4, 5].

The function Π has the following form [2, 3]:

$$\Pi = \min \frac{1}{2}\sqrt{(u_A N_A + u_B N_B)^2}, \tag{4}$$

where u_A and u_B are the four-velocities of nuclei A and B, is found from the minimization of Eq. 4 by solving the equation [2, 3] at $y = 0$ and $N_A = N_B = N$:

$$\frac{d\Pi}{dN} = 0 \tag{5}$$

The exact solution of Eq. 5 at $y = 0$, as

$$N = \frac{\Pi}{\cosh(Y)} \equiv \frac{2m_0\Pi}{\sqrt{s}}, \tag{6}$$

was obtained in [2, 3], for details see, also [4]. In Eq. 6 Y is the rapidity of colliding nuclei.

Therefore, $\alpha(N) = 1/3 + 2m_0\Pi/(3\sqrt{s})$. Function $F(\Pi)$ has the following form [4]:

$$F(\Pi) = \Big[A_q \exp\Big(-\frac{\Pi}{C_q}\Big) + \\ + A_g\sqrt{p_T}\phi_1(s)\exp\Big(-\frac{\Pi}{C_g}\Big)\Big]\sigma_{tot} \quad (7)$$

, where

$$\Pi(s, m_{1T}, y) = \left\{\frac{m_{1T}}{2m_0\delta_h} + \frac{M}{\sqrt{s}\delta_h}\right\}\cosh(y)G, \quad (8)$$

$$G = \left\{1 + \sqrt{1 + \frac{M^2 - m_1^2}{(m_{1T} + 2Mm_0/\sqrt{s})^2\cosh^2(y)}\delta_h}\right\}. \quad (9)$$

Here $\phi_1(s) = 1 - \sigma_{nd}(s)/\sigma_{tot}(s)$, see [4, 9], $\delta_h = \left(1 - \frac{s^h_{th}}{s}\right)$; $s^\pi_{th} \simeq 4m_0^2$; $s^{K^+}_{th} = (m_0 + m_K + m_\Lambda)^2$; $s^{K^-}_{th} = (2m_0 + 2m_K)^2$; $M = m_\Lambda - m_0$; $m_\Lambda = 1.115$ GeV; $m_K = 0.494$ GeV; $s_0 = 1$ GeV^2 introduced to make s/s_0 dimensionless; $m_0 = 0.938$ GeV; p_{1T} and m_{1T} are the transverse momentum and transverse mass of the produced hadron 1; $\sigma_{nd} = (\sigma_{tot} - \sigma_{el} - \sigma_{SD})$ is the non-diffractive cross-section; $\sigma_{tot}, \sigma_{SD}$ and σ_{el} are the total cross-section, the single diffractive cross-section and the elastic cross-section of pp collisions, respectively. See details in [4, 5, 9].

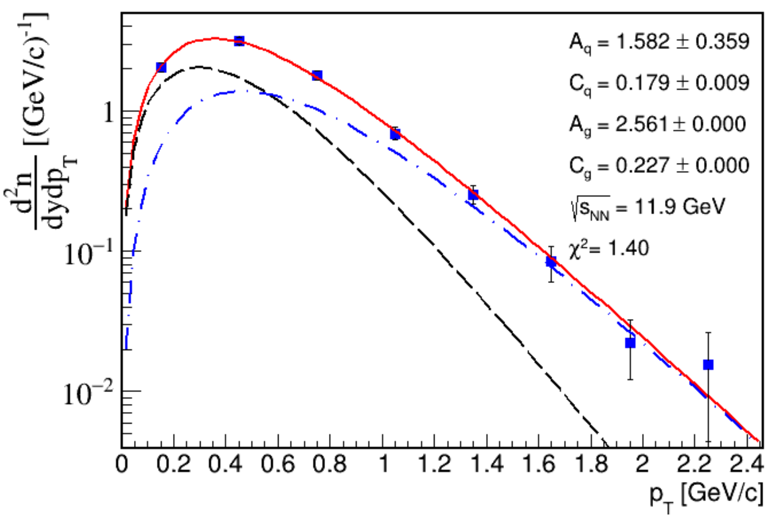

Figure 1: The inclusive p_T-spectrum of $K^0_S = \frac{1}{2}(K^0 + \bar{K}^0_S)$ produced in $ArSc$ collisions at $\sqrt{s} = 11.9$ GeV and $y = 0$ calculated within the similarity approach called as BMLZ [5]; black dashed and blue dashed-dotted lines are the quark and gluon contributions, respectively. The NA61/SHINE experimental data are taken from [1].

In Eq. [7] the first term is the quark contribution and the second one is the gluon one to the inclusive $(NN \to hX)$ spectrum [7, 8]. Using Eq. 2 the inclusive p_T spectra of $K^\pm$ mesons produced

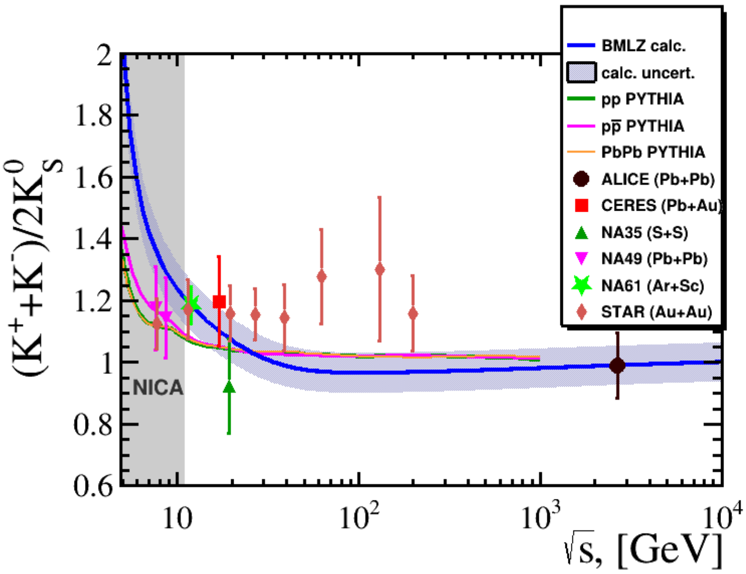

Figure 2: The ratio $R_K = \frac{\sigma_{K^+}+\sigma_{K^-}}{2\sigma_{K^0_S}}$, as a function of $\sqrt{s}$ calculated within the similarity approach called as BMLZ [5] (blue line) and the Lund model [14] (green-pp, purple-$p\bar{p}$, yellow-$PbPb$). The experimental data are taken from [1].

in $ArSc$ collisions at y =0 and initial momenta per nucleon 13 GeV/c $\leq P_0 \leq$ 150 GeV/c have been calculated in [5]. They have resulted in the satisfactory description of the NA61/SHINE data [13]. The inclusive p_T-spectrum of $K^0_S = \frac{1}{2}(K^0 + \bar{K}^0_S)$ produced in $ArSc$ collisions at $\sqrt{s}$ = 11.9 GeV and $y = 0$ calculated within the similarity approach is presented in Fig.1. The black dashed and blue dashed-dotted lines are the quark and gluon contributions, respectively. The NA61/SHINE experimental data are taken from [1]. Fig. 1 shows the satisfactory description of these data. Let us note that the gluon contribution to this inclusive spectrum dominates compared to the quark one at $p_T >$ 0.3 GeV/c. This dominance is due to the transverse momentum gluon distribution (TMD), see details in [10–12].

Then, we have calculated the cross-sections of $K^{\pm}$ and K^0_S mesons produced in $ArSc$ collisions, as the integrals over p_T of inclusive p_T spectra of these charge and neutral spectra presented in [5] and Fig. 1.

Assuming the isospin-symmetry for u and d quarks the sum of cross-sections of charged kaons $(\sigma_{K^+} + \sigma_{K^-})$ can be the same for proton-proton (pp) and neutron-neutron (nn) interactions.

Using these we have calculated the ratio $R_K = \frac{\sigma_{K^+}+\sigma_{K^-}}{2\sigma_{K^0_S}}$, as a function of $\sqrt{s}$ for $ArSc$ collisions. It is presented in Fig. 2 (blue line) compared to the world data. One can see that it is about 1.18 at $\sqrt{s}$ =11.9 GeV (the NA61/SHINE data [1]) and it decreases up to 1, when the energy increases up to a few TeV (ALICE data). Let us note that the ratio R_K calculated within the LUND model using the MC generator PYTHIA results in approximately the same $\sqrt{s}$ dependence for pp (green line) and $PbPb$ (yellow line) collisions. The similar results have been obtained within the BMLZ approach for pp and $ArSc$ interactions. The calculations of R_K within these models have taken into account only the nuclear PDF ignoring other nuclear effects, rescatterings and others.

Our calculations do not contradict to the world data at $\sqrt{s}$ = 6-40 GeV and $\sqrt{s}$ = 3 TeV. In the energy region of 40 GeV < $\sqrt{s}$ < 200 GeV there is an excess to the STAR data, having too large error bars, over our calculations. Therefore, it is desirable to check the isospin-symmetry violation by improving the measurement accuracy.

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