Quark-gluon string tension fluctuations and the effect on strange particle yields

V. N. Kovalenko, A. M. Puchkov† (†a.puchkov@spbu.ru)
St. Petersburg State University (SPbSU), 7/9 Universitetskaya nab., St. Petersburg, 199034 Russia

Abstract

In various microscopic string models (see, e.g., [1]-[8]), the Schwinger mechanism [9, 10]—which features a characteristic Gaussian exponential—is used to describe particle transverse-momentum spectra. On the other hand, experimental data on inclusive hadron production spectra exhibit pronounced thermal behavior. A. Bialas [11] proposed resolving this contradiction by accounting for fluctuations in the string tension κ, modeled by a Gaussian distribution. However, the probability distribution proposed in [11] peaked at $\kappa = 0$, which seems physically incorrect in the context of QCD confinement: a string possesses finite average energy density, so the probability of zero tension should vanish. In the present work, we modify the Bialas approach by assessing the local string tension fluctuations around its mean value. We demonstrate that not only the mean value of the string tension but also its fluctuations influence the strangeness production, and the treatment of these fluctuations allows for a better description of strange particle yields.

Charged Particle Yields in AA Collisions

1. Multi-pomeron exchange model in AA collisions:

$\rho(N_{ch}, p_t)$ is the distribution function over multiplicity N_{ch} and transverse momentum p_t:

$$\rho(N_{ch}^1, ...N_{ch}^{\tilde{N}}; p_t^1, ..., p_t^{\tilde{N}}) = N_{\rm norm} \sum_{\nu=1}^{\tilde{N}} \sum_{n=1}^{\infty} P_n \cdot P(n, N_{ch}^\nu) \cdot g(p_t;\, m_\nu\,, t_{\rm eff}(n,\beta))\,, \quad (1)$$

where P_n is the probability of producing n pomerons in an AA collision, $P(n, N_{ch}^\nu)$ is the probability that N_{ch}^ν particles of species ν are produced from n pomerons as a result of hadronization, and the last factor $g(p_t^\nu; m_\nu\,, t_{\rm eff}(n,\beta))$ determines the probability that a particle of species ν has a transverse momentum p_t^ν.
Here [9, 10, 4, 5]

$$g(p_t^\nu; m_\nu\,, t_{\rm eff}(n,\beta)) = g_0(2S_\nu+1) \exp\left(-\frac{\pi(p_t^2+m_\nu^2)}{t_{\rm eff}(n,b)}\right) \equiv g_{\rm Schwinger}\,, \quad (2)$$

$$t = 0.566\ {\rm GeV}^2\,,\ \ k = 0.255 + 0.0653\ \ln\sqrt{s}\,,\ \ \beta = 1.16\left[1 - \left(\ln\sqrt{s} - 2.52\right)^{-0.19}\right]\,.$$

2. Effective string tension in AA collisions [5]:

$$t_{\rm eff}(n,b) = t\left(n \cdot \frac{S_0}{S(b)}\right)^\beta, S_0 = 6\ {\rm fm}^2, S(b) = R_0^2(2\xi - \sin(2\xi)), \xi = \arccos\left(\frac{b}{2R_0}\right). \quad (3)$$

Assume that the string tension fluctuates according to the Maxwell-Boltzmann distribution:

$$P = \sqrt{\frac{2}{\pi}}\frac{\kappa^2}{\sigma^3} \exp\left(-\frac{\kappa^2}{2\sigma^2}\right)\,. \quad (4)$$

Let $t_{\rm eff} = \kappa^2$. Then, the convolution of (4) with (2) yields:

$$\widetilde{g}_{\rm MB}(p_t^\nu; m_\nu\,, \sigma) = g_0(2S_\nu+1)\left(\frac{\sqrt{2\pi}m_{t,\nu}}{\sigma} + 1\right) \exp\left(-\frac{\sqrt{2\pi}m_{t,\nu}}{\sigma}\right)\,, \quad (5)$$

where $m_{t,\nu} = \sqrt{p_t^2 + m_\nu^2}$ is the transverse mass.
An alternative expression was obtained in [11]. The convolution of (2) with a Gaussian distribution centered at zero takes the form:

$$\widetilde{g}_{\rm Bialas}(p_t^\nu; m_\nu\,, \sigma) = g_0(2S_\nu+1)\sigma \exp\left(-\frac{\sqrt{2\pi}m_{t,\nu}}{\sigma}\right)\,. \quad (6)$$

If a normal distribution with a non-zero maximum is used, its convolution with (2) can be represented as an integral:

$$\widetilde{g}_{\rm Gauss}(p_t^\nu; m_\nu, t_{\rm eff}, \sigma) = \widetilde{g}_0(2S_\nu+1)\frac{1}{\sqrt{2\pi}\sigma}\int_0^\infty \exp\left(-\frac{(t-t_{\rm eff})^2}{2\sigma^2}\right) \exp\left(-\frac{\pi m_{t,\nu}^2}{t}\right) {\rm d}t. \quad (7)$$

3. Charged particle yields:

$$Y_\nu \sim \langle N_{ch}\rangle (2S_\nu+1)\, g(p_t^\nu; m_\nu, ...)\,. \quad (8)$$

Results

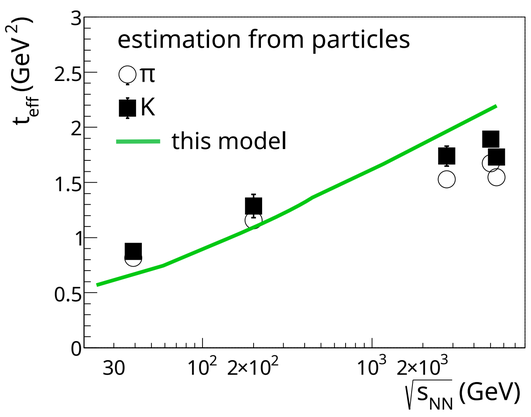


Fig. 1. Comparison of the average string tension in central nucleus-nucleus collisions in this model and the results obtained from the analysis of the experimental data [12]

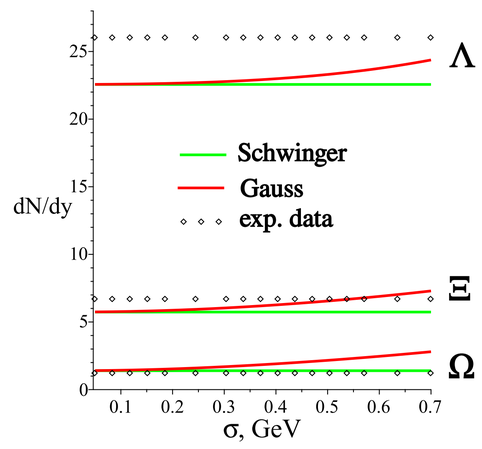


Fig 2. Production of Λ, Ξ, Ω in Pb-Pb collisions at 2.76 TeV in standard Schwinger and Gaussian string tension fluctuation approaches, compared with experimental data [13, 14]

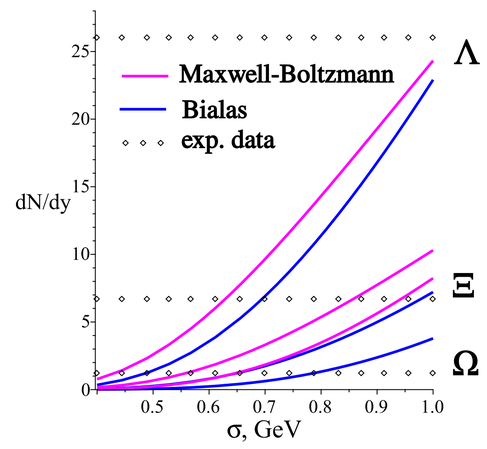


Fig 3. Production of Λ, Ξ, Ω in Pb-Pb collisions at 2.76 TeV in approaches with string tension fluctuations according to Maxwell-Boltzmann and Bialas [11], compared with experimental data [13, 14]

References

[1] E. G. Ferreiro and C. Pajares, J. Phys. G 23, 1961 (1997).
[2] N. Armesto, D.A. Derkach, G.A. Feofilov, Phys. Atom. Nucl. 71, 2087–2095 (2008).
[3] E. O. Bodnya, V. N. Kovalenko, A. M. Puchkov, G. A. Feofilov, AIP Conf. Proc. 1606, 273 (2015).
[4] V. N. Kovalenko, A. M. Puchkov, G. A. Feofilov, Bull. Russ. Acad. Sci. Phys. 80, 8 (2016).
[5] V. Kovalenko, G. Feofilov, A. Puchkov, F. Valiev, Universe. 8, 246 (2022).
[6] V. V. Vechernin, Phys. Part. Nucl. 54, 528 (2023).
[7] V. Vechernin, E. Andronov, V. Kovalenko, A. Puchkov, Universe 10, 56 (2024).
[8] E. V. Andronov, A. M.Puchkov, V. V.Vechernin, et al., Phys. Part. Nuclei 57, 1153–1157 (2026)
[9] J. Schwinger, Phys. Rev. 82, 664 (1951).
[10] T. D. Cohen and D. A. McGady, Phys. Rev. D 78, 036008 (2008); E. G. Gurvich, Phys. Lett. B 87, 386 (1979).
[11] A. Bialas, Phys. Lett. B 466, 301-304 (1999)
[12] O. Shaposhnikova, A. Marova, G. Feofilov, Phys. Atom. Nucl. (accepted, 2026).
[13] B. Abelev et al. (ALICE Collaboration), Phys. Rev. Lett. 111, 222301 (2013).
[14] B. Abelev et al. (ALICE Collaboration), Phys. Rev. C 88, 044910 (2013).

Acknowledgments

The authors acknowledge Saint-Petersburg State University for a research project ID: 153212394