# On the question of the detection of new particles possible candidates for the role of dark matter particles

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It is proposed to improve the agreement with experimental data in comparison with the previous works of the spectrum of soft photons in terms of transverse momentum in pp collisions with an incident proton momentum of 450 GeV/$c$ in order to clearly isolate the signal about the detection of the $X17$ boson. An interpretation has been proposed for the detection of a boson with a mass of 38 MeV in the spectra of photons emitted in reactions of protons with carbon nuclei at an incident proton momentum of 5.5 GeV/c

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Hardening of the soft photon spectrum in particle collisions is a puzzle for nuclear physicists. At the same time, while signals from the Large Hadron Collider corresponding to new particles outside the Standard Model are lacking, the search for such particles remains one of the primary goals of modern physics. Relying on the works of Fermi [1], Pomeranchuk [2], and Landau [3] focused on the statistical model of multiple particle production, we used the thermodynamic model [4,5] to interpret [5–8] the spectra of soft photons in terms of transverse momentum in $pp$ collisions with an incident proton momentum of 450 GeV/$c$ ($c$ is the speed of light) [9].

The aim of the present study is to characterize the features of the spectrum of soft photons by isolating a well-pronounced contribution of new particles while improving the statistical model for the adiabatic reduction in temperature at the stage of expansion of a composite system and taking into account the correction to the Boltzmann distribution of multiplicity of emitted photons.

It was noted in [9] that the traditional bremsstrahlung mechanism cannot reproduce the obtained spectrum of soft photons. The introduction of a new particle (the $X17$ boson with a mass of 17 MeV, which was discovered in the Hungarian ATOMKI group experiment [10]) helps rectify this discrepancy. The mentioned boson is neutral, is not a baryon, and, consequently, may be regarded as a candidate dark matter particle, but the ATOMKI data require independent confirmation. Trying to explain the results reported in [9], Wong [11] has simply adjusted the temperatures for the unperturbed photon spectrum and the $X17$ boson contribution.

We have determined this temperature and calculated the corresponding contribution from the decay of the $X17$ boson into two photons. We have also clarified the effect of the $X38$ boson with a mass of 38 MeV, which was discovered in reactions of protons with carbon nuclei at an incident proton momentum of 5.5 GeV/$c$ [12], on the photon spectrum. Several different explanations have been proposed for the existence of these particles, such as the existence of the fifth force [13–15], dark matter [16–18], an axion [19,20], an instanton [21], a QED meson (QED is quantum electrodynamics) [22], or a tetraquark [23]. An interpretation of new bosons within the electromagnetic tube model with unified two-dimensional quantum chromodynamics and two-dimensional quantum electrodynamics has been discussed in [4,5]. The masses of bosons $X17$ and $X38$ were obtained this way.

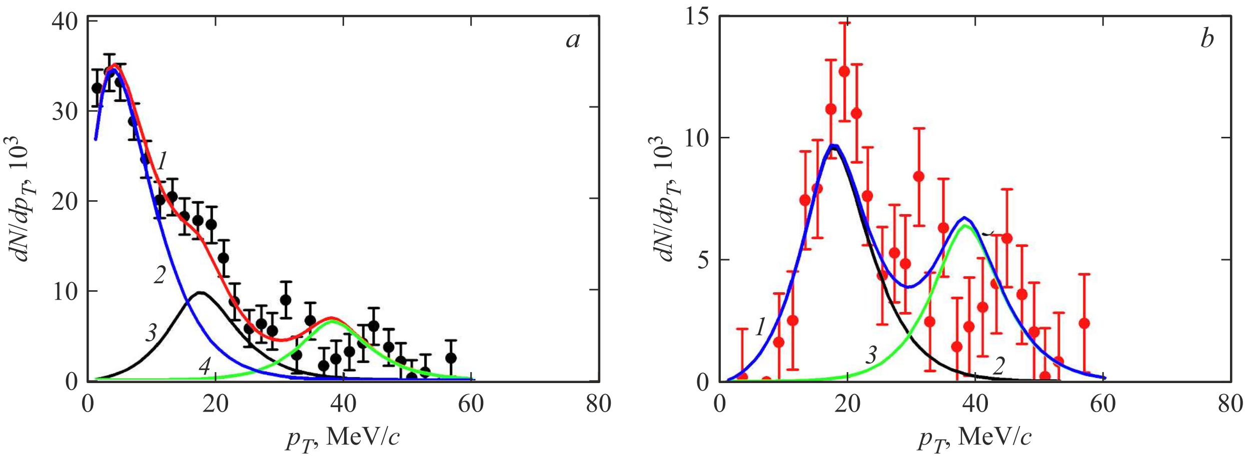
The following distribution for massless ($m = 0$) and massive ($m > 0$) particles is more correct than the distribution of multiplicity $N$ by transverse momentum used in [4–8]:

$$\frac{dN}{dp_T} = CT p_T \sqrt{p_T} \exp\left(-\frac{\sqrt{m^2 + p_T^2} - m}{T}\right), \qquad (1)$$

where $p_T$ is the transverse momentum, $m$ is the particle mass, and $C$ is the normalization factor. One needs to use ultrarelativistic hydrodynamics to determine temperature $T$. Additional (compared to the previous analysis) factor $\sqrt{p_T}$ outside the exponential function arises in transition from the Bose–Einstein distribution to the Boltzmann distribution [24]. It is possible to introduce the microcanonical distribution or non-extensive Tsallis statistics [25] into analysis, but we do not do this here.

Instead, we simplify the description. We believe that owing to the redistribution of initial energy $E_0$ in three directions, a third of the energy is converted into thermal one, and the remaining part is converted into kinetic energy of the longitudinal expansion of a Lorentz-contracted system. Indeed, since Pascal's law is actually fulfilled in the present case, the mean squares of projections of particle momenta

$$\langle p_x^2\rangle = \langle p_y^2\rangle = \langle p_z^2\rangle = p^2/9 \qquad (2)$$




*a* — Experimental spectrum of soft photons [9] (dots) and the results of calculations with the $X17$ boson (curve *1*) and without it (curve *2*). Curve *3* — contribution from the $X17$ boson; curve *4* — contribution from the $X38$ boson with a mass of 38 MeV. *b* — The same experimental data from [9] (dots) with the background (curve *2* in panel *a*, which was calculated using formula (1)) subtracted. The net contribution of bosons $X17$ and $X38$ is represented by curve *1*, while curves *2* and *3* correspond to the individual contributions of bosons $X17$ and $X38$, respectively.

may be expressed in terms of total momentum $p$. However, pressure $P$ is the average value of the momentum projection flux through unit surface ($P = \sqrt{\langle p_x^2 \rangle} nc$), and energy density $e = ncp$, where $n$ is the particle number density and $c$ is the speed of light. Therefore, we obtain an ultrarelativistic equation of state

$$P = \frac{e}{3}. \quad (3)$$

At relativistic energies, the number of particles is not conserved, but may be determined from equilibrium considerations. Specifically, thermodynamic potential

$$\Phi = E + PV - TS \quad (4)$$

is expressed in terms of energy $E$, pressure $P$, entropy $S$, volume $V$, and temperature $T$. Since $\Phi = \mu N$ and chemical potential $\mu$ turns to zero at equilibrium (i.e., $\frac{d\Phi}{dN} = 0$), the following relation holds true for energy density $e$ and entropy density $s$:

$$e + P = Ts. \quad (5)$$

Using known relations

$$dE = -PdV + TdS, \qquad dP = sdT, \quad (6)$$

and taking (3) into account, we find

$$s = s_0(T/T_0)^3, \qquad e = e_0(T/T_0)^4, \quad (7)$$

where constants $s_0$ and $e_0$ are determined from the initial conditions. The temperature of massless particles is determined this way [4,5]. This is how one can characterize the transverse momentum distribution for the resulting plasma with strong interaction [4].

Our interpretation of the photon momentum spectra consists in the use of formula (1) at $m = 0$ with the temperature for photons set according to (7), where, owing to the smallness of the coupling constant for the electromagnetic interaction, initial kinetic energy $E_0$ of protons in the center-of-mass system was reduced by the corresponding factor (i.e., by a factor of $137 \times 14.7$, as in [5]). The number of emitted particles and their energy are proportional to the coupling constant, which is 14.7 for the strong interaction and 1/137 for the electromagnetic interaction. Here, energy

$$E_0 = \sqrt{2m_pc^2(2m_pc^2 + E_1)} - 2m_pc^2,$$

where $E_1 = \sqrt{p^2c^2 + m_p^2c^4} - m_pc^2$ is the kinetic energy in the laboratory system, $p = 450\,\mathrm{GeV}/c$ is the incident proton momentum, and $m_p$ is the proton mass. The reduced temperature of electromagnetic plasma [4.5] corresponding to thermal energy $E_T = E_0/3$ was found to be equal to $T = 3.8\,\mathrm{MeV}$. In contrast to [5–8], we introduced the additional isentropic temperature reduction according to relation (7) using the formula

$$T^3V = T_0^3V_0, \quad (8)$$

where $T_0$ is the initial temperature prior to expansion [5] and $V_0/V = G$ is the Lorentz volume contraction.

The contribution of photon emission in the $X17$ boson decay may be presented in the form [5], but modified to include factor $\sqrt{p_T}$ and with the same normalizing coefficient as in formula (1) (see the figure).

This interpretation of the spectrum of soft photons (its hardening) may be regarded as further evidence in favor of the existence of a new particle (the $X17$ boson). The contribution of the $X38$ boson, which was predicted in experiments carried out in Dubna [12], is also consistent with these experimental data.

Having refined the calculation here, we managed to obtain a better description of the soft exponential part of the spectrum of emitted photons and isolate clearly the contribution of the decay of bosons $X17$ and $X38$ into two photons in relativistic kinematics (see panel *b* in the figure). At its maximum, the $X17$ boson contribution is on the order of four standard deviations. However, further experimental confirmation is needed. These new particles may manifest themselves in cosmic rays of ultra-high energies on the order of $10^{11}$ GeV, which cannot be probed at modern accelerators. We were able to reproduce the burst detected in experiments [26,27] by introducing bosons $X17$ and $X38$ into calculations. An approximation of the experimental spectrum of cosmic rays proportional to $E^{-3}$ and the contribution of the $X$-boson decay into photons characterized in accordance with blackbody radiation relations were used in the corresponding formulae.

Blackbody radiation finds wide application in experimental physics and engineering [28,29]. Note that our approach may be used to create black absorbers and emitters (warm „black holes") in nanoelectronics [30], and modifications of blackbody radiation for „black holes" may help substantiate phenomenological quantum gravity [31].

Thus, a simple thermodynamic model for the emission of soft photons, which play a significant role in cosmology and may be related directly to dark matter decays [32], was proposed.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### Conflict of interest

The authors declare that they have no conflict of interest.

## References


[1] E. Fermi, Prog. Theor. Phys., **5**, 570 (1950). DOI: 10.1143/ptp/5.4.570

[2] I.Ya. Pomeranchuk, Dokl. Akad. Nauk SSSR, **78**, 889 (1951) (in Russian).

[3] L.D. Landau, Izv. Akad. Nauk SSSR. Ser. Fiz., **17**, 51 (1953) (in Russian). [*Collected papers of L.D. Landau*, ed. by D. Ter Haar (Pergamon Press, Oxford, 1965), paper 74].

[4] A.T. D'yachenko, Phys. Atom. Nucl., **83**, 1597 (2020). DOI: 10.1134/S1063778820090069.

[5] A.T. D'yachenko, Phys. Atom. Nucl., **85**, 1028 (2022). DOI: 10.1134/S1063778823010179.

[6] A.T. D'yachenko, E.S. Gromova, J. Phys.: Conf. Ser., **2131**, 022054 (2021). DOI: 10.1088/1742-6596/2131/2/022054

[7] A.T. D'yachenko, A.A. Verisokina, M.A. Verisokina, Acta Phys. Pol. B, Proc. Suppl., **14**, 761 (2021). DOI: 10.5506/APhysPolBSupp.14.761

[8] A.T. D'yachenko, A.A. Verisokina, M.A. Verisokina, Phys. Part. Nucl., **54**, 462 (2023). DOI: 10.1134/S1063779623030127.

[9] A. Belogianni, W. Beusch, T.J. Brodbeck, F.S. Dzheparov, B.R. French, P. Ganoti, J.B. Kinson, A. Kiirk, V. Lenti, I. Minashvili, V.F. Perepelitsa, N. Russakovich, A.V. Singovsky, P. Sonderegger, M. Spyropoulou-Stassinaki, O. Villalobos Baillie, Phys. Lett. B, **548**, 129 (2002). DOI: 10.1016/S0370-2693(02)02837-X

[10] A.J. Krasznahorkay, M. Csatlós, L. Csige, Z. Gácsi, J. Gulyás, M. Hunyadi, I. Kuti, B.M. Nyakó, L. Stuhl, J. Timár, T.G. Tornyi, Z. Vajta, Phys. Rev. Lett., **116**, 042501 (2016). DOI: 10.1103/PhysRevLett.116.042501

[11] C.-Y. Wong, J. High Energy Phys., **2020**, 165 (2020). DOI: 10.1007/JHEP08(2020)165

[12] K. Abraamyan, C. Austin, M. Baznat, K. Gudima, M. Kozhin, S. Reznikov, A. Sorin, EPJ Web Conf., **204**, 08004 (2019). DOI: 10.1051/epjconf/201920408004; arXiv: 1208.3829; arXiv:2311.18632v1 [hep-ex]

[13] J.L. Feng, B. Fornal, I. Galon, S. Gardner, J. Smolinsky, T.M.P. Tait, P. Tanedo, Phys. Rev. Lett., **117**, 071803 (2016). DOI: 10.1103/PhysRevLett.117.071803

[14] J.L. Feng, B. Fornal, I. Galon, S. Gardner, J. Smolinsky, T.M.P. Tait, P. Tanedo, Phys. Rev. D, **95**, 035017 (2017). DOI: 10.1103/PhysRevD.95.035017

[15] P.-H. Gu, X.-G. He, Nucl. Phys. B, **919**, 209 (2017). DOI: 10.1016/j.nuclphysb.2017.03.023

[16] P. Fayet, Eur. Phys. J. C, **77**, 53 (2017). DOI: 10.1140/epjc/s10052-016-4568-9

[17] Y. Liang, L.-B. Chen, C.-F. Qiao, Chin. Phys. C, **41**, 063105 (2017). DOI: 10.1088/1674-1137/41/6/063105

[18] L.-B. Jia, X.-Q. Li, Eur. Phys. J. C, **76**, 706 (2016). DOI: 10.1140/epjc/s10052-016-4561-3

[19] J. Kozaczuk, D.E. Morrissey, S.R. Stroberg, Phys. Rev. D, **95**, 115024 (2017). DOI: 10.1103/PhysRevD.95.115024

[20] J.A. Dror, R. Lasenby, M. Pospelov, Phys. Rev. Lett., **119**, 141803 (2017). DOI: 10.1103/PhysRevLett.119.141803

[21] M. Veselsky, V. Petousis, J. Leja, J. Phys. G, **48**, 105103 (2021). DOI: 10.1088/1361-6471/ac09db

[22] C.-Y. Wong, A.V. Koshelkin, Eur. Phys. J. A, **59**, 285 (2023). DOI: 10.1140/epja/s10050-023-01180-8

[23] H.-X. Chen, Mod. Phys. Lett. A, **39**, 2450057 (2024). DOI: 10.1142/S0217732324500573

[24] V.I. Goldansky, Yu.P. Nikitin, I.L. Rosental, *Kinematic methods in high-energy physics* (Routledge, 1989).

[25] C. Tsallis, J. Stat. Phys., **52**, 479 (1988). DOI: 10.1007/BF0101642

[26] M. Takeda, N. Hayashida, K. Honda, N. Inoue, K. Kadota, F. Kakimoto, K. Kamata, S. Kawaguchi, Y. Kawasaki, N. Kawasumi, H. Kitamura, F. Kusano, Y. Matsubara, K. Murakami, M. Nagano, D. Nishikawa, H. Ohoka, N. Sakaki, M. Sasaki, K. Shinozaki, N. Souma, M. Teshima, R. Torii, I. Tsushima, Y. Uchihori, T. Yamamoto, S. Yoshida, H. Yoshii, Phys. Rev. Lett., **81**, 1163 (1998). DOI: 10.1103/PhysRevLett.81.1163

[27] D.J. Bird, S.C. Corbató, H.Y. Dai, B.R. Dawson, J.W. Elbert, T.K. Gaisser, K.D. Green, M.A. Huang, D.B. Kieda, S. Ko, C.G. Larsen, E.C. Loh, M. Luo, M.H. Salamon, D. Smith, P. Sokolsky, P. Sommers, T. Stanev, J.K.K. Tang, S.B. Thomas, S. Tilav, Phys. Rev. Lett., **71**, 3401 (1993). DOI: 10.1103/PhysRevLett.71.3401

[28] V.F. Weisskopf, *Lectures given in the summer vacation programme 1969* (CEBN, Geneva, 1970).

[29] I.S. Gibin, P.E. Kotlyar, Usp. Prikl. Fiz., **7** (2), 188 (2019) (in Russian).

[30] S. Maslovski, C. Simovski, S. Tretyakov, New J. Phys., **18**, 013034 (2016). DOI: 10.1088/1367-2630/18/1/013034
[31] A. Addazi, J. Alvarez-Muniz, R. Alves Batista, G. Amelino-Camelia, V. Antonelli, M. Arzano, M. Asorey, J.-L. Atteia, S. Bahamonde, F. Bajardi, A. Ballesteros, B. Baret, D.M. Barreiros, S. Basilakos, D. Benisty et al., Prog. Part. Nucl. Phys., **125**, 103948 (2022). DOI: 10.1016/j.ppnp.2022.103948
[32] S.K. Acharya, B. Cyr, J. Chluba, Monthly Not. Roy. Astron. Soc., **523**, 1908 (2023). DOI: 10.1093/mnras/stad1540

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