HIGH-ENERGY COLLISIONS OF PROTONS AND NUCLEI AND THE POSSIBILITY OF DETECTING DARK MATTER PARTICLES IN THE SPECTRA OF SOFT PHOTONS*

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Interpretation of the spectra of soft photons in transverse momentum in pp collisions is proposed taking into account the $X17$ boson with a mass of 17 MeV — a new particle, a possible candidate for the role of dark matter particles. On the basis of combining two-dimensional quantum chromodynamics and quantum electrodynamics in the tube model, the masses of dark matter particles are found. An interpretation is proposed for the detection of a 38 MeV boson in the spectra of photons emitted in the reactions of protons with carbon nuclei at an incident proton momentum of 5.5 GeV/c. The $X38$ boson with a mass of 38 MeV has a mass close to the boson mass obtained by us, equal to 35 MeV for an electromagnetic tube. This new particle was discovered in experiments carried out recently in Dubna for the p+C$\rightarrow 2\gamma + X$ reaction. It was proposed to consider bosons $X17$ and $X38$ as particles of dark matter.

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1. Introduction

Continuing the works of Fermi, Pomeranchuk and Landau on the statistical model of multiple particle production [1–3], see also [4, 5], based on the works [6–8], we have proposed an algorithm for finding the transverse distribution of secondary particles. This approach can be applied to the search for dark matter particles, to which many works are devoted (see, for example, [9, 10]).

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Analyzing, following [11], the experimental data [12] on the spectra of soft photons depending on the transverse momentum, in this work it is proposed to interpret the hardening of the spectrum [12] as a manifestation of the contribution of a new $X17$ boson particle with a mass of about 17 MeV, which is a candidate for the role of particles dark matter. An algorithm for finding the mass of the $X17$ boson based on the tube model is proposed. Based on this algorithm, the mass of another new particle, the $X38$ boson with a mass of 38 MeV, was obtained and compared with experimental data [13] on the detection of this particle in the spectra of photons emitted in the reaction at an incident proton momentum of 5.5 GeV/c.

2. Transverse momenum distributions of secondary particles

According to works [1–3], the process of multiple formation of secondary particles in pp collisions at high energy can be represented using the laws of thermodynamics or hydrodynamics [4, 5]. At rapidity $y = 0$, the transverse momentum distribution has the form of

$$\frac{\mathrm{d}N}{\mathrm{d}p_{\mathrm{T}}} \sim p_{\mathrm{T}} \exp\left(-\frac{p_{\mathrm{T}}}{T}\right), \tag{1}$$

which can be rewritten for particles of mass m in the form of [5]

$$\frac{\mathrm{d}N}{\mathrm{d}p_{\mathrm{T}}} = CTp_{\mathrm{T}} \exp\left(-\frac{\sqrt{m^2 + p_{\mathrm{T}}^2} - m}{T}\right), \tag{2}$$

where p_{T} is the transverse momentum, m is the mass of the particle. To find the temperature T and velocity, it is necessary to use ultrarelativistic hydrodynamics [3]. Here, we simplify the description, assuming that as a result of thermalization due to the redistribution of the initial energy E_0 in three directions, energy is transferred to thermal energy $E_{\mathrm{T}} = E_0/3$, which determines the distribution of particles in the transverse direction (pressure $P = e_0/3$). The rest of the energy is converted into the kinetic energy of the longitudinal expansion with $P \sim e$, since the system is Lorentz compressed. From here we find the temperature of massless particles

$$T = \left(\frac{E_0}{g_Q V_R} 10^9\right)^{1/4}, \tag{3}$$

where E_0 is the kinetic energy in the center-of-mass system in GeV, $g_Q = (2\times 8 + \frac{7}{8} 2\times 2\times 3\times 3) = 47$ is the statistical weight of 6 quarks and 8 gluons, $V_R = (1.3)^3$ is the volume factor that takes into account the increase in volume during the expansion of the system at the stage of formation of secondary particles. Expression (3) for temperature is obtained from the expression for the energy density $e = \frac{4\pi g_Q 6T^4}{(2\pi\hbar c)^3}$ and $E_{\rm T} = eV$, where V is the volume of colliding protons, c is the speed of light, $\hbar$ is Planck's constant, g_Q is the factor that takes into account 8 gluons with their polarizations and 6 tricolor quarks with their spins. We believe that the temperature T determined by formula (3) at the moment of expansion of the system at high energies is close to the temperature of the resulting mass m particles.

The experiment [12] studied soft photons emitted in pp collisions at an initial momentum of 450 GeV$/c$ on a fixed target. The interpretation of the experiment based on the bremsstrahlung mechanism does not reproduce the slope of the spectrum [12].

Wong [11, 14] proposed to interpret these data on the basis of the temperature spectrum, choosing the appropriate temperature and introducing the contribution from the decay of the $X17$ boson into photons. The existence of a new $X17$ boson particle with a mass approximately equal to 17 MeV was first experimentally predicted in [15] by the ATOMKI group.

Our interpretation of the momentum spectra of photons consists in using formula (2) at $m = 0$ with temperature for photons according to formula (3), where, due to the smallness of the coupling constant for electromagnetic interaction, the energy E_0 was reduced by the corresponding number of times, *i.e.* in 137×14.7 times. The corresponding temperature is $T = 5.9$ MeV. The contribution from the decay of the $X17$ boson with a mass of 17 MeV with the emission of a photon can be taken into account by formula (2) similarly to [8].

All distributions are proportional to temperature T in order to reproduce proportionality $N \sim T^3$. For the contribution of the emission of photons during the decay of the $X17$ boson, one can take into account that when the $X17$ particle decays into 2 photons, their angular distribution in the particle's rest frame is isotropic in angles. This distribution can be represented in an invariant form [5]

$$\mathrm{d}w = \frac{m}{2\pi p_1^*}\delta\left(2(p_X p_1) - 2mE_1^*\right)\frac{\mathrm{d}^3 p_1}{E_1}\,, \tag{4}$$

where p_1 is the momentum of one of the photons, p_X is the momentum of the X-boson, p_1^* and E_1^* are the momentum and energy of the photon in the X-boson rest frame. From (2) and (4), we find the contribution to the photons from the decay of the X–boson (here $\mu = 0$, $E_\pm = \pm p_1 + m$)

$$\frac{\mathrm{d}N}{\mathrm{d}p_{\rm T}} = CT\left((E_- + T)\exp\left(\frac{\mu - E_-}{T}\right) - (E_+ + T)\exp\left(\frac{\mu - E_+}{T}\right)\right)\,. \tag{5}$$

Unlike Wong's work, we did not fit the experimental data, but calculated the temperature using the formula. However, we do not claim the absolute value of the distribution. Therefore, our calculations were normalized to experimental data [11, 12]. Figure 1 (left) shows the experimental spectrum of soft photons — points [12], as well as the calculation with the $X17$ boson (solid line) and without it (dashed line), the dash-dotted line is the contribution from the $X17$ boson. It can be seen from the figure that, without taking into account the contribution from the $X17$ boson, the calculation underestimates the experimental data, and, taking this contribution into account, reproduces them. That is, such an interpretation of the spectrum of soft photons (its hardening) can serve as one more evidence in favor of the existence of a new particle — the $X17$ boson.

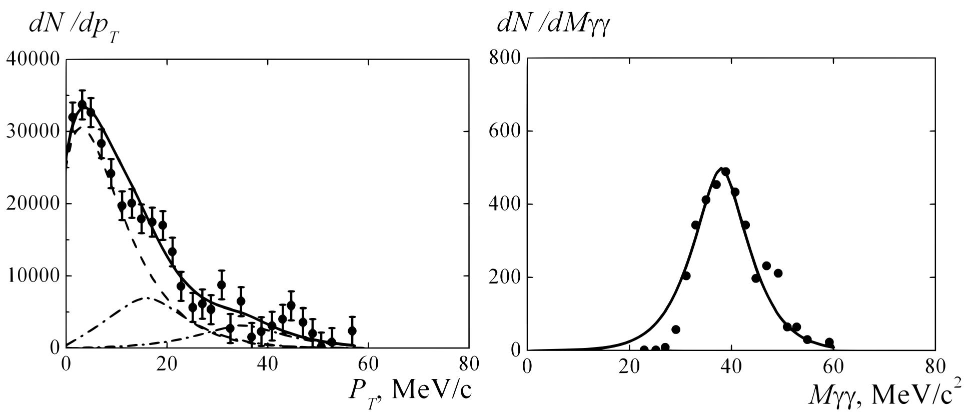

Fig. 1. Spectra of soft photons emitted in collisions of protons on a fixed target at a momentum of 450 GeV/c, depending on the transverse momentum of photons (left). The solid line is our calculation in accordance with formulas (3) and (5) taking into account the contribution of the emission of photons from the decay of the $X17$ boson, the dashed line is our calculation without taking into account the contribution of the $X17$ boson, the dash-dotted line is the contribution from the emission of photons during the decay of $X17$ according to formula (5), dots are experimental data from [11, 12]. The spectrum of photons emitted in the $p+\mathrm{C} \to 2\gamma + X$ reaction at the momentum of protons of 5.5 GeV/c (right). The solid curve is our calculation, the points are the processed experimental data from [13].

Figure 1 also shows, in accordance with formula (5), the contribution of photons from the decay of another new particle — the $X38$ boson with a mass of 38 MeV (dash-dotted line) predicted in the experiments carried out in Dubna [13]. However, its contribution manifests itself only at the tail of the spectrum and is faintly visible in the figure (left).

3. Discussion

The $X17$ boson predicted in [15] may appear in the spectrum of soft photons. This was considered in the previous section and reported in the works of Wong [11, 14], as well as in our work [8]. Wong [11] proposed an interpretation of this boson as a result of the unification of QCD and QED. In this case, the unification is performed for two-dimensional $\mathrm{QCD}_2 \times \mathrm{QED}_2$ in the tube model. For an oscillating rectilinear string tube, we obtain [8] the mass M

$$M^2 = 2\pi\rho n \,, \tag{6}$$

where n is the quantum number, ρ is the energy density. For the hadron tube, at $n = 1$, we obtain $M \approx 140$ MeV for the π^0-meson. For an electromagnetic tube with the same tube radius, we obtain the mass of the neutral boson $X17$ $M \approx 17$ MeV. The formula $M^2 = 2\pi\rho m$ can also be used to obtain resonances, where m is a multiply folded string with rotation. Thus, you can get the mass of a ρ meson, and for an electromagnetic string, we get a boson mass of 35 MeV at $m = 4$, obtained in Wong's work in a different way. Note that these results were obtained in our approach using formulas different from Wong's work. In his work [11], Wong proposes to interpret the $X17$ boson as a particle of dark matter, since it is neutral, not a baryon and can be a composite particle of astrophysical objects of large mass.

As for the $X38$ boson with a mass of 38 MeV, its mass is close to the boson mass we obtained, equal to 35 MeV for the electromagnetic tube in the previous section. This new particle was discovered in experiments carried out recently in Dubna for the $p+\mathrm{C}\rightarrow 2\gamma + X$ reaction with a proton momentum of 5.5 GeV$/c$ [13]. To interpret the obtained experimental data on the spectra of emitted photons depending on their mass, one can use formulas (3) and (5), setting the mass of the boson decaying into two photons $m = 38$ MeV. The temperature in the calculation corresponded to 3.7 MeV.

Figure 1 (right) shows a comparison of the experimental distribution of the spectrum of emitted photons depending on their mass (points from [13]) with our calculation — a solid curve, which was normalized to experimental data. One can see the agreement between the shape and position of the distribution maximum, experimental and obtained by us.

4. Conclusions

An interpretation is given of the experimental data on the spectra of soft photons using a new particle — the $X17$ boson, which is neutral and not a baryon. It can form massive dark matter objects in astrophysics. The presence of the mass of the $X17$ boson, equal to 17 MeV, is substantiated, proceeding from the electromagnetic tube when combining a two-dimensional

$QCD_2 \times QED_2$. Also the interpretation of experimental data on the detection of another boson particle — $X38$ with a mass of 38 MeV, discovered in Dubna at the accelerator at the Laboratory of High Energy Physics of the Joint Institute for Nuclear Research is presented.

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