Detection of particles of dark matter from the spectrum of secondary particles in high-energy proton-proton collisions in a thermodynamic model

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Abstract. In a simple hydrodynamic model, the transverse momentum distributions are found for Λ hyperons formed in pp collisions at ultrarelativistic energies. The calculated spectra are compared with the experimental data obtained for various colliders in a wide range of proton collision energies, including the data from experiments at the Large Hadron Collider. An interpretation of the transverse momentum spectra of soft photons 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. A tube model is proposed on the basis of combining two-dimensional quantum chromodynamics and quantum electrodynamics. 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 reaction $p+C\rightarrow 2\gamma+X$. To interpret the obtained experimental data on the spectra of emitted photons depending on their mass, it is proposed to use the formulas obtained for massive particles, setting the mass of a boson decaying into two photons equal to 38 MeV. It was proposed to consider bosons X17 and X38 as particles of dark matter.

1. Introduction

This work is dedicated to the most actual and fundamental physical problems. Here in common parlance the most complex interactions of protons and cores are examined and one of the largest mysteries of the modern natural science - the issue of the dark matter particles to which many works are dedicated (for example, see fundamental reviews of the academician of the Russian Academy of Sciences V.A. Rubakov in the magazine "Success of physical sciences" [1.2] is examined. 5% of the mass of the whole Universe only is its visible part and the rest one is the dark matter and the dark energy.

Continuing Fermi, Pomeranchuk and Landau works in the area of the statistic model of the multiparticle production, based on works [3-5], we offer the algorithm of the distribution according to the transverse impulse - Λ hyperons formed in pp encounters in case of energies $\sqrt{s}$ 53, 200, 900 and

7000 gigaelectronvolts [5]. Calculated spectra Λ hyperons agree for experimental data and calculations upon the model of quark-gluon strings [6].

Analyzing experimental data [8] after [7] upon spectra of soft photons according to the transverse impulse, this work offers interpreting the spectrum hardening [8] as the expression of the deposit of a new boson X17 particle, with the weight of around 17 MeV which is the candidate for the role of dark matter particles. The algorithm of calculation of the boson X17 weight on the basis of the tube model. On the basis of this algorithm the weight of one other new particle - boson X38 with the weight of 38 MeV is received and the comparison to experimental data [9] is carried out for the detection of this particle in photon spectra emitted in the reaction $\mathrm{p}+\mathrm{C}\rightarrow 2\gamma+\mathrm{X}$ if the colliding proton impulse amounts to 5.5 GeV/s.

Methods offered for the examination have the common character and are applicable to different sections of the heavy ion physics [10-12], the physics as a whole and the technics [13-20]. So the thermal emission can be examined in case of the gas discharge [13], of the optics of quantum transitions [14] and quantum points [15] the tube model developed by us can be used during the construction of design models of tube, building, bridge fluctuations [16-18] and dynamic processes in the transportation [19-20]

2. Model

According to works [3-5] the process of the multiple production of secondary particles in pp encounters in case of a high power can be imagined using the thermodynamic or hydrodynamic rules similar to encounters of heavy ions of different powers [10-15]

Really the one-inclusive spectrum of massless secondary particles $a+b\rightarrow d+X$ where d is a particle is as follows:

$$E_1\frac{d\sigma}{d^3\vec{p}_1}=F(P-p_1)\,|\langle|M|\rangle|^2\,, \tag{1}$$

where $F(P-p_1)$ is a Lorentz-invariant space-temporal phase-space volume

$$F(P-p_1)=\Pi_{i=2}^{i=N}\frac{d^3p_i}{E_i}\delta^{(4)}(P-p_1-\sum_{i=2}^{N}p_i)\ , \tag{2}$$

$\langle|M|\rangle$ - the matrix element not heavily depending on the p_1 impulse. In the approximation of massless $F(P-p_1)\sim|(P-p_1)^2|^{N-3}$ particles and in the mass center system

$$F(P-p_1)\sim E^{2(N-3)}\left(1-\frac{E_1}{E}\right)^{2(N-3)}\sim\exp\left(-\frac{E_1}{T}\right) \tag{3}$$

in case of $N>>1$ where E is a complete power, P is a complete impulse, N is a number of formed particles, $E_1\approx|\vec{p}_1|$ is a power of the emitted particle. Then in case of the quickness $y_1=0$ the distribution upon the transverse impulse is as follows:

$$\frac{dN}{dp_T}\sim p_T\exp\left(-\frac{p_T}{T}\right), \tag{4}$$

which can be rewritten for particles with the weight of m subject to the environment movement with the speed of $<\vec{\upsilon}>$ as

$$\frac{dN}{dp_T} = Cp_T \exp\left(-\gamma \frac{\sqrt{m^2 + p_T^2} - m - <\vec{\upsilon}> \vec{p}_T}{T}\right), \tag{5}$$

where p_T is the transverse impulse, γ is a Lorentz factor, m is a particle mass. For the determination of the T temperature and the average speed of $<\vec{\upsilon}>$ it is necessary to use the ultrarelativistic hydrodynamics.

Here we simplify the description thinking that to the thermal energy $E_0/3$ of the initial E_0 energy in the mass center system is transferred and the kinetic energy $E_k = 2m_0\left(\frac{1}{\sqrt{1-<\upsilon>^2}} - 1\right)$ is found as the difference between E_0 and the E_T thermal energy where m_0 is a proton stationary mass. Hereof the massless particle temperature is found

$$T = \left(\frac{3}{g_Q}\frac{E_0}{3\gamma_0 V_R}10^9\right)^{1/4}, \tag{6}$$

where $g_Q = (2\times 8 + \frac{7}{8}2\times 2\times 3\times 3) = 47$ is a statistic weight of 6 quarks and 8 gluons, $\gamma_0 = \frac{m_0 + E_0}{m_0}$ is a Lorentz factor, $V_R = (1.2)^3$ is a volume factor taking into account the volume increase in case of the system extension at the stage of formation of secondary particles. The expression (6) for the temperature is formed from the expression for the energy thickness of $e = \frac{4\pi g_Q 6T^4}{(2\pi\hbar c)^3}$ and $E_T = eV$ where V is a volume of encountering protons, c is a light speed, $\hbar$ is a Planck's constant, the factor g_Q takes into account 8 gluons with their polarization potentials and 6 three-color quarks with their backs. In the formula (5) we think that the temperature T and the speed $<\upsilon_\perp>$ are determined at the moment of the system collision with the particle formation with the weight of m.

3. Results

Here we have mentioned the comparison of hyperon Λ spectra calculated according to the formula (5) to experimental data [21-24] received for E_0 energies of 53, 200, 900 and 7000 GeV for the proton encounter in different colliders. During the comparison to experimental data we have selected the multiplier C which is proportional to the temperature T because the complete number of emitted particles amounts to $\sim T^3$. For the curved line *1* the temperature amounts to $T = 134$ MeV, for the curved line *2* - $T = 187$ MeV, for the curved line *3* - $T = 272$ MeV, for the curved line *4* - $T = 454$ MeV. We shall note that our calculation reproduces experimental data not worser than the model of quark gluon strings [6], see Figure 1. As noted in [5], the registration of the resonance formation does not influence on the spectrum form substantially. In Figure 1 data in relative values are mentioned, therefore design curved lines are connected with them by means of the normalizing constant C in the formula (5), but the constant C was selected in proportion to the temperature T with the proportionality coefficient which is common for all examined cases.

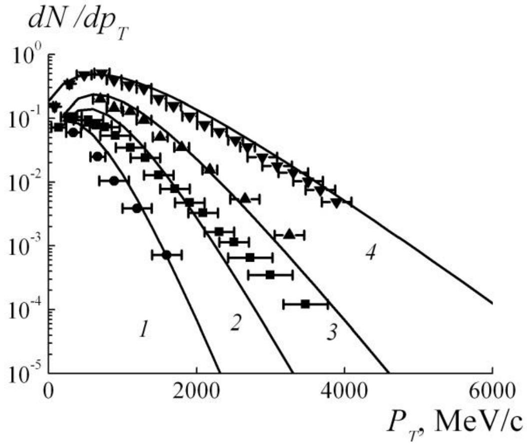

Figure 1. Distributions along the transverse impulse p_T Λ hyperons creating in proton encounters if the energy $\sqrt{s}$ is equal to 1- 53 GeV, 2 - 200 GeV, 3 - 900 GeV, 4 - 7 TeV. Continuous lines - calculation results per formulae (5, 6). Points are experimental data: circles are data from [21], squares are data from [22], triangles upwards are data from [23], triangles downwards are data from [24]

From Figure 1 we can see that the middle transverse impulse $< p_T >$ of emitted particles increases with the energy of encountering protons. It increases with the temperature and the mass of the emitted particle.

In the experiment [8] weak photons were studied emitted in pp encounters if the initial impulse is 450 GeV/s on the fixed target. The experiment interpretation on the basis of the bremsstrahlung mechanism does not reproduce the spectral tilt [9].

Wong in some works [7, 25] has suggested to interpreter these data on the basis of the temperature spectrum adopting the corresponding temperature and introducing the deposit of the X17 boson destruction to photons. The existence of a new particle - X17 boson with the mass approximately amounting to 17 MeV was forecasted in the work [26] of the ATOMKI team firstly experimentally.

Our interpretation of impulse spectra of photons consists of the use of the formula (5) in case of $m = 0$ with the temperature for photons according to the formula (6) where a canto the small quantity of the coupling constant for electromagnetic cooperation the energy E_0 was decreased the corresponding number of times i.e. 137 $\times$14.7 times. The corresponding temperature is $T = 7.4$ MeV. The deposit from the X17 boson destruction with the mass of $m \approx 17$ MeV with the photon emission van be taken into account per formula (7) similar to the work [5].

All distributions are proportional to the T temperature to reproduce the $N \sim T^3$ proportionality. It is more properly to use the Bose distribution subject to the environment movement for soft photons:

$$\frac{dN}{dp_T} = Cp_T T \left[\exp\left(\gamma \frac{\sqrt{m^2 + p_T^2} - m - < \upsilon_\perp > p_T}{T} \right) - 1 \right]^{-1} . \qquad (7)$$

For the deposit of the proton emission in case of the X17 boson destruction $C \sim \frac{p_T}{\sqrt{m^2 + p_T^2} - m}$ with $m = 17$ MeV was used, for photons in case of $m = 0$ the coefficient C does not depend on p_T. In contrast to Wong works we have not fitted experimental data but we have calculated the temperature per the formula. However we do not pretend to the absolute distribution value. Therefore our calculations were standardized by experimental data [7, 8].

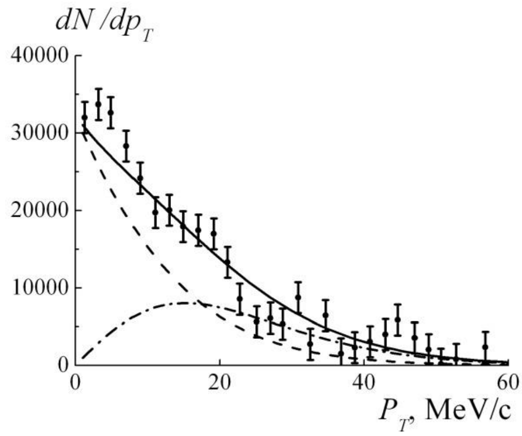

Figure 2. Spectra of soft photons emitted in photon encounters on the fixed target if the impulse is 450 GeV/s according to the transverse p_T photon impulse. The continuous line is our calculation according to the formula (7) subject to the deposit of the photon emission from the X17 boson destruction, the dashed line is our calculation without the X17 boson deposit, the dash-and-dot line is the deposit from the photon emission during the X17 destruction, points are experimental data from works [7,8].

In Figure 2 the experimental spectrum of soft photons is present - points [8] as well as the calculation subject to the X17 boson (continuous line) and without it (dashed line), the dash-and-dot line is the deposit from the X17 boson. From the figure it is seen that without the X17 boson deposit the calculation depreciates experimental data and subject to this deposit reproduces them.

I.e. this interpretation of the soft photon spectrum (its hardening) can serve one more evidence for the existence of a new particle - X17 boson.

4. Discussion

The X17 boson forecasted in the work [26] probably appears in the soft photon spectrum. It was discussed in the previous section and was informed in Wong works [7, 25]. In the Wong work [7] the interpretation of this boson as the result of assembly of QCD and QED. In this case the assembly is carried out for 2D $QCD_2 \times QED_2$ in the tube model.

Here we suggest the modified tube model [5]. In this case the tube energy strength ρ is formed from two parts:

$$\rho = A + G. \tag{8}$$

The first part A is determined by the field stress E:

$$A = 2\frac{1}{4\pi}E^2\pi r^2, \tag{9}$$

where the stress is $E = \frac{\Phi}{4\pi r^2} = \frac{g}{4\pi r^2}$ and the coupling constant $\alpha = \frac{g^2}{4\pi}$, r is a tube radius. The second part is reflected through the bag constant $B = 0.17$ in the amount of GeV/fm^3:

$$G = B\pi r^2 \frac{\alpha}{\alpha_S}, \tag{10}$$

where we introduce the equation α / α_S of the constant α to the constant of the hard interaction α_S. The constant α can be the constant of the hard interaction $\alpha = \alpha_S$ and can be the constant of the electromagnetic interaction $\alpha = \alpha_e = 1/137$. I.e. such as Wong [7] we consider both the hadronic in case of $\alpha = \alpha_S$ and the electromagnetic in case of $\alpha = \alpha_e$ of the tube. Tube radii are determined from the energy minimum corresponding to the length unit and the constant of the hard interaction $\alpha_S \approx 0.5$ as in the Wong work.

According to the tube model strained between two quarks [5] we can find masses of forming hadrons and in case of the electromagnetic tube the X17 boson mass.

For the fluctuating single-eyed tube string we receive the mass M:

$$M^2 = 2\pi\rho n, \tag{11}$$

where n is a quantum number. For the hadron tube in case of $n = 1$ we receive $M \approx 140$ MeV for the π^0 meson. For the electromagnetic tube in case of the same tube radius we receive the mass of the neutral X17 boson in the amount of $M \approx 17$ MeV. According to the formula $M^2 = 2\pi\rho m$ we can receive the resonance where is a m-fold mounted string with the rotation. So we can receive the mass ρ of the meson and for the electromagnetic string we receive the boson mass in the amount of 35 MeV in case of $m = 4$ received in the Wong work by other means.

We shall note that these results are received in our approach per formulae which are different from the Wong work. In his work [7] Wong suggests to interpret the X17 boson as the dark matter particle because it is neutral, is not a baryon and can be a compound particle of astrophysic's objects of the large mass.

5. X38 boson detection

As for X38 boson with the mass of 38 MeV then its mass is close to the boson mass received by us which is 35 MeV for the electromagnetic tube in the previous section. This new particle was found in experiments carried out recently in Dubna for the reaction $p + C \to 2\gamma + X$ in case of the impulse of colliding protons in the amount of 5.5 GeV [9]. To interpret the obtained experimental data on the spectra of emitted photons depending on their mass, it is proposed to use the formulas (5) or (7) obtained for massive particles, setting the mass of a boson decaying into two photons equal to $m = 38$ MeV. Because it is a resonance then the coefficient C shall be multiplied by the resonance multiplier $C \sim 1/((E - m)^2 + H^2)$ where E is a mass of two emitted photons, m is a mass equal to 38 MeV, H is a resonance width. The temperature during the calculation was equal to the value of 5.4 MeV

In Figure 3 the comparison of the experimental distribution of the spectrum of emitted photons depending on their mass (histogram from the work [9] with our calculation - a continuous curved line with the width $H = 0.25m$ which is standardized on experimental data) is provided. We can see the agreement of the form and the position of the distribution maximum which is experimental and is received by us.

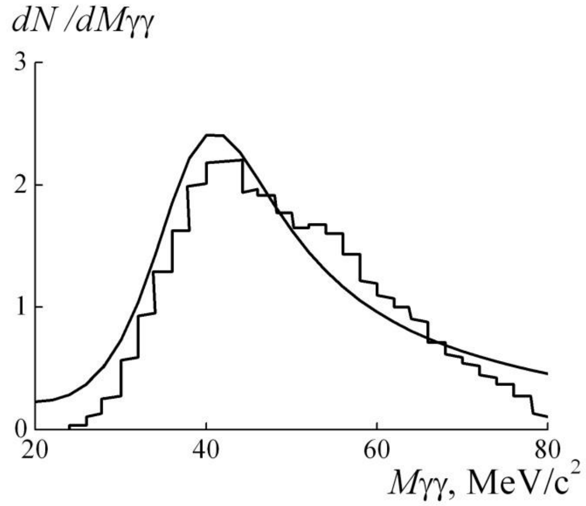

Figure 3. The spectrum of photons emitted in the reaction $p+C \rightarrow 2\gamma + X$ in case of the impulse of colliding protons in the amount of 5.5 GeV/s, the continuous curved line is our calculation with the width $H = 0.25m$, the histogram is experimental data from the work [9]

In Figure 4 the comparison of the experimental distribution of the spectrum of emitted photons depending on their mass (points from the work [9]) with our calculation are the continuous curved line with the width $H = 0.2m$ which is standardized to experimental data is provided. In the work [9] the additional processing of experimental data for the purpose of the better derivation of the X38 boson deposit is carried out. Absolute values were re-standardized. Our calculation was standardized to experimental data. We can see the agreement of the form and the position of the distribution maximum which is experimental and is received by us.

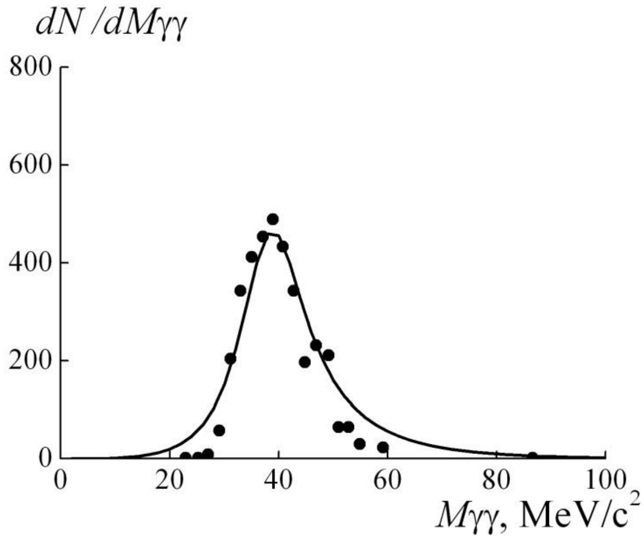

Figure 4. The spectrum of photons emitted in the reaction $p+C \rightarrow 2\gamma + X$ in case of the impulse of colliding protons in the amount of 5.5 GeV/s, the continuous curved line is our calculation with the width of H=0.2 m, points are processed experimental data from the work [9]

6. Conclusion

So, in the simplified hydrodynamic model (thermodynamic with the average spill speed of secondary particles) the description of hyperon and soft photon spectra for a wide area of high powers of encountering protons is found.

The interpretation of experimental data for soft photon spectra by means of the new particle - the X17 boson which is neutral and is not a baryon is given. It can create massive dark matter objects in the astrophysics. The existence of the X17 boson mass which is equal to 17 MeV is justified on the basis of the electromagnetic tube during the assembly of 2D $QCD_2 \times QED_2$. The interpretation of experimental data for the detection of one more new boson particle - X38 with the mass of 38 MeV opened in Dubna in the accelerator in the High energy Laboratory of the Joint Institute for nuclear research is given too.

The developed can be used not only in the physics of elementary particles but in the widest areas of physics and technics (see, for example, [13-20] because it combines the fundamental basis, the mathematical simplicity and visibility).

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