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ON A POSSIBLE ORIGIN OF A RESONANCE-LIKE STRUCTURE IN THE TWO-PHOTON INVARIANT MASS SPECTRUM OF THE REACTION $pp \to pp\gamma\gamma$.

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Abstract

We show that the resonance-like structure found by the *CELSIUS-WASA Collaboration* in the two-photon invariant mass spectrum of the reaction $pp \to pp\gamma\gamma$ is rather a signature of the NN-decoupled dibaryon resonance $d_1^\star(1956)$ that is produced in the radiative process $pp \to \gamma d_1^\star$ and then undergoes radiative decay into two protons $d_1^\star \to pp\gamma$. It is found that a contribution of the dibaryon mechanism $pp \to \gamma d_1^\star \to pp\gamma\gamma$ of the reaction $pp \to pp\gamma\gamma$ to the invariant mass spectrum of its photon pairs can reasonably well reproduce the experimentally observed spectrum in the vicinity of the resonance-like structure.

1 Introduction

The resonance-like structure found by the *CELSIUS-WASA Collaboration* in the two-photon invariant mass spectrum of the exclusive reaction $pp \to pp\gamma\gamma$ at 1.2 and 1.36 GeV has been taken by the authors of Ref. [1] as evidence for dynamical formation of the S-wave dipion resonance σ [2] in the pp collision process. It was assumed [1] that this structure might result from interference between the process $pp \to pp\sigma \to pp\gamma\gamma$ and one of the double pp-bremsstrahlung. However, such an interpretation is at least questionable merely because the amplitude of the double pp-bremsstrahlung is unknown in the energy range considered in Ref. [1] where this process, to our knowledge,

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has not been investigated yet either experimentally or theoretically. The aim of this paper is to propose an alternative interpretation of a possible origin of this structure which is based on the dibaryon mechanism of the two-photon emission in NN collisions [3, 4].

2 The dibaryon mechanism of two-photon emission in NN collisions

The dibaryon mechanism of two-photon emission in NN collisions $NN \to \gamma d_1^\star \to NN\gamma\gamma$ governs the electromagnetic transition between the initial and final NN states by a sequential emission of two photons, one of which is caused by production of the NN decoupled dibaryon resonance $d_1^\star$ and other by its subsequent decay. In the overall center-of-mass system the energy of the photons E_γ^F associated with the d_1^* production is determined by the dibaryon mass M_R and the energy of colliding nucleons $W = \sqrt{s}$ as $E_\gamma^F = (W^2 - M_R^2)/2W$. The energy of photons E_γ^D emerging as a result of the d_1^* decay in the resonance rest frame is given by $E_\gamma^D = (M_R^2 - M_{NN}^2)/2M_R$, where M_{NN} is the invariant mass of the final NN state. The matrix element for the $NN \to NN\gamma\gamma$ transition will in general be a function of the four-momenta of the incoming and outgoing particles together with the mass and quantum numbers of the resonance $d_1^\star$ which are still not established. It can be written in the form $\mathcal{M} = \mathcal{M}_F \cdot \mathcal{D}(p_R) \cdot \mathcal{M}_D$, where $\mathcal{M}_F$ and $\mathcal{M}_D$ are the matrix elements for the dibaryon formation and decay, $\mathcal{D}(p_R) = 1/(p_R^2 - M_R^2 + iM_R\Gamma_R)$ is the propagator of the dibaryon with the four-momentum p_R and Γ_R is its decay width. In this work the $pp \to pp\gamma\gamma$ transition has been treated within the assumption that at large distances the NN-decoupled six-quark d_1^* state is a bound $p\Delta(1232)$ state with the spin-parity $J^P = 0^-$ and the isospin $I = 2$ [5]. Owing to a relatively small energy ~ 80 MeV released in the d_1^* decay, the matrix element $\mathcal{M}_D$ was derived in terms of a simple picture in which the decay $(p\Delta)_{bound} \to pp\gamma$ proceeds via the virtual $\Delta^+ \to p\gamma$ $M1$-transition. As a radial wave function for the bound $p\Delta$-state we have considered two functional forms: the Gaussian $R_G(r) = N_G \cdot r\exp(-b_G^2 r^2)$ and the Fermi-type (or Woods-Saxon) distribution $R_F(r) = N_F \cdot (1 - j_0(\kappa_F r))$ for $r < R_0$ and $R_F(r) = N_F \cdot C_F \cdot [1 + \exp[a \cdot (r - R_0)]]^{-1}$ for $r \geq R_0$, where $r = |\mathbf{r}_\Delta - \mathbf{r}_p|$, $a = \sqrt{2m_{red}E_b(d_1^*)}$, m_{red} is the reduced mass of the $(p\Delta)$-system, $E_b = M_\Delta + m_N - M_R$ is the binding energy of this system, $N_{F(G)}$ are the normalization constants, the parameters C_F, R_0 and κ_F are defined from the continuity requirements for $R_F(r)$ and its first and second derivatives at $r = R_0$. The specific form of the correlation function $f(r) = 1 - j_0(\kappa_F r)$

($j_0(z)$ is the spherical Bessel function of 0^{th} order), describing effects of the soft core in the $N\Delta$-interaction potential is taken in accordance with the Ref. [6]. The parameter b_G^2 is chosen such that the rms radius of the $(p\Delta)$-state is the same for both versions of the wave function.
Unlike the decay process, the d_1^* formation one takes place at relatively high energies of colliding protons. Therefore, its mechanism may be more involved. The lack of an explicit theory of such a process forced us to resort to the phenomenology. Namely, we adopt $|\mathcal{M}_F|^2 c.m. \simeq A \cdot exp(-k_\perp/b)$, where A is the normalized constant, $k_\perp$ is the transverse momentum of a photon and b is a parameter. This formula was shown [7] to give a good fit for the reaction $pp \to \pi^+ d$ for incident proton momenta in the range $3.4 - 12.3$ GeV/c with $k_\perp \to p_\perp(\pi^+)$. According to [8], it is equal to 0.26 GeV/c at $E_{c.m.} = 3.0$ GeV. In our calculation we used $b = 0.6$ CeV/c. This value follows from the assumption that $b(pp \to \gamma d_1^\star)/b(pp \to \pi^+ d)$=rms radius($d$)/rms radius($d_1^\star$).
The effects of the final state interactions between decay protons in the $^3P_1$-state were included with the help of the phenomenological correlation function $f_{phen}(r) = 1 - j_0(\kappa r), \kappa = 3.93\ fm^{-1}$ by multiplying the $L = 1$ radial wave function of free motion by this function. The approximate relevance of this procedure is demonstrated numerically in [9].

3 The method of calculations and results

The calculations of the invariant mass spectra of photon pairs from the dibaryon mechanism of the reaction $pp \to pp\gamma\gamma$ at 1.36 GeV for the geometry and kinematics of the experiment [1] were done using the Monte Carlo method. A computer program for the MC calculations was made on the basis of the GENBOD event generator [11] which was used to randomly generate four-momenta of particles for the process $pp \to \gamma + d_1^\star \to \gamma + \gamma + pp$. A probability of any event was given by its weight $WT =$ '$\Sigma_{\sigma_{1,2,3,4}} \Sigma_{\lambda_{1,2}} |\mathcal{M}|^2$, where σ_i are the spin projections of the protons and λ_i stand for the polarizations of the photons. The calculated spectra for both forms of the radial wave function for the bound $p\Delta$-state are presented in Fig.1. Both spectra are seen to reproduce reasonably well the experimentally observed spectrum [1] in the vicinity of the resonance-like structure. The spectrum calculated with the matrix element from Ref. [10], which was obtained for the case of point-like dibaryon, is also shown in the same figure for comparison. In this calculation the effects of the final state interactions were ignored.
Our results show that the structure observed in the two-photon invariant mass spectrum of the reaction $pp \to pp\gamma\gamma$ by the CELSIUS-WASA collaboration is very likely to be due to the dibaryon mechanism of the reaction

$pp \to pp\gamma\gamma$ [3, 4]. They can thus be considered as one more confirmation of the existence of this two-photon production mechanism in NN collisions and, hence, the existence of the dibaryon $d_1^\star$ itself. In this connection we note that more experimental and theoretical studies are needed to completely clarify the situation with the existence of the dibaryon resonance $d_1^\star$.

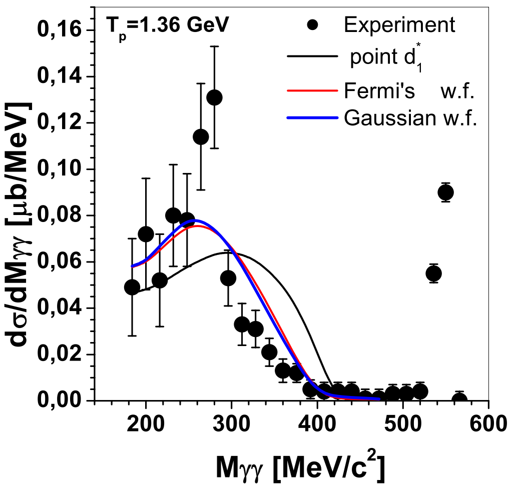

Figure 1: Experimentally observed two-photon invariant mass spectrum of the reaction $pp\gamma\gamma$ and those for the process $pp \to \gamma d_1^\star \to \gamma\gamma pp$ calculated with two different types of radial wave function of the bound $p\Delta$-state, Fermi's and Gaussian. The spectrum calculated with the matrix element from [10] is given by the black solid line.

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