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ON THE REACTION $pp \to pp\gamma$ AS A MEANS OF TEST FOR NARROW DIBARYON STRUCTURES

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The location of possible narrow dibaryon resonances in $pp\gamma$ reaction is discussed. Contributions from the charge (convection) and magnetic (spin) currents of colliding protons are taken into account. It is shown that measurement of the photon energy spectrum is more suitable for observation of possible narrow dibaryon resonances than the widely used detection of all final particles with coplanar momenta.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR

О реакции $pp \to pp\gamma$ как средстве обнаружения дибарионных резонансов

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Обсуждается проявление возможных узких дибарионных резонансов в реакции $pp \to pp\gamma$. Учитываются вклады от зарядовых (конвекционных) и магнитных (спиновых) токов сталкивающихся протонов. Показано, что измерение энергетического спектра фотонов является более эффективным для обнаружения узких дибарионных резонансов, чем обычно используемая регистрация всех трех конечных частиц с компланарными импульсами.

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1. Introduction

In ref. [1] the expedience was stressed of the search for dibaryon resonances [2—7] in $pp\gamma$ reaction. Two bremsstrahlung mechanisms discussed in [1] were there referred to as the «external» and «internal» photon radiation. In the second case, when the elastic decay mode of the dibaryon $B, B \to pp$, is either strongly suppressed (e.g., by the isospin selection rule, if $I(B) \geq 2$) or strictly forbidden by the Pauli principle, when $J^P(B) = 1^+, 3^+, \ldots$ and $I(B) = 1$, the resonance increase of the two-photon yield in $pp \to \gamma B \to \gamma\gamma pp$ is an unambiguous indication of the dibaryon resonance excitation with the mass $M(B) < 2m_p + m_\pi$. In a less exotic case of the «external» radiation, when the decay $B \rightarrow pp$ is allowed, the usual mechanism of photon radiation from the external nucleon lines of the corresponding Feynman diagrams will dominate.

In [1] the convection currents of charged particles were only taken into account in a simple explicit formula for the bremsstrahlung cross-section near a resonance. This approximation is justified only for the soft photon emission. However, in this case, according to the Low theorem [8], the bremsstrahlung cross-section is fully defined by the «physical» nucleon-nucleon scattering cross-section. So, to obtain qualitatively new information, one should concentrate on measurements and calculations of the hard photon production. This, in turn, requires to take account of the photon radiation by magnetic moments of interacting protons which is becoming to dominate over the non-spin-dependent convection current already at comparatively low photon energies (e.g., around 40 MeV for $T_{\mathrm{lab}} \cong 300$ MeV). Taking into account the spin-dependent (magnetic) contributions we are able to investigate the influence of different spin-parities of the assumed dibaryon resonance on the observable cross-sections. We hope also to obtain more pronounced effects of those resonances which are seen most clearly in the spin-dependent observables of the polarized proton-proton scattering.

At last, to estimate sensitivity of bremsstrahlung cross-sections expressed via different sets of kinematical variables to dibaryon resonances, the calculations will be done with the use of the so-called «Harvard set» of variables, the angles of all final particles in the coplanar geometry, almost exclusively used in all experiments on the $pp\gamma$ reaction we have known.

2. The Outline of Calculations and Results

In addition to usual assumptions underlying the potential model calculations of the NN-bremsstrahlung [9—15] we consider a hypothetical possibility of the presence in the nucleon-nucleon total T-matrix of such resonance contributions which are not described by standard NN-potentials induced by the meson exchanges. The excitation mechanism of these dibaryon resonances may be related with the rearrangement (or reclusterization) of the nucleon constituents (mesons, quarks, etc.) during their interaction in a given reaction. In that case the apparently small widths $\Gamma(B) \rightarrow NN$ of all known candidates for dibaryon resonances with the mass $M(B) < 2m_p + m_\pi$ [2—5] may result from the bad overlap of the wave functions of two final nucleons (i.e., two $3q$-clusters) and the dibaryon B composed of quite different quark clusters, e.g., composed of the coloured

4-quarks and/or diquarks: $B \to q^4 + q^2$ or $B \to 3q^2$. Then the effective interaction-range responsible for the $B \to NN$ transition might be of an order of the quark wave function extension inside the nucleon, that is definitely smaller than the meson potential originating from meson exchanges at the periphery of nucleons.

With this conceivable picture in mind, we adopt the following scheme of an estimation of the influence of dibaryon resonances on the observed characteristics of bremsstrahlung: a nonresonance (background) photon spectrum is calculated in the framework of the traditional scheme based on realistic meson potentials well-describing the observed «nonresonance» NN scattering phase shifts, while the excitation of the dibaryon resonances is taken into account by introducing a phenomenological resonance term in the amplitudes of NN interaction. Thus, we represent a partial amplitude T_J of the nucleon-nucleon scattering with a total angular momentum J as a sum of two terms

$$T_J = A_J + B_J, \qquad (1)$$

where $A_J(B_J)$ corresponds to a nonresonance (resonance) scattering. For the resonance amplitude B_J, presumably related with the short-range part of the NN interaction, we keep its parametrization formally coinciding with the usual on-shell scattering amplitude

$$B_J = e^{2i\delta J}\left(-e^{i\varphi}\frac{\frac{1}{2}\Gamma_J}{\sqrt{s} - M_B + i\frac{1}{2}\Gamma_{\text{tot}}}\right)C(s), \qquad (2)$$

where M_B is a mass of the dibaryon resonance, Γ_J (Γ_{tot}) is a partial (total) width, ϕ is a relative phase shift between resonance and nonresonance amplitudes,

$$C(s) = \exp\left\{-\frac{\sqrt{s} - M_B}{\Gamma_J}\right\}. \qquad (3)$$

We keep the notation and the parametrization of the cut-off factor $C(\sqrt{s})$ suggested in the work [7]. The off-shell nonresonance amplitude A_J is determined by the solution of the Lippmann—Schwinger-type equation [11—15] with the use of the one-boson exchange Bonn potential (OBEPQ) [16]. Calculations were carried out in the momentum space and the partial waves with the total momentum $J < 6$ were considered. Diagrammatically,

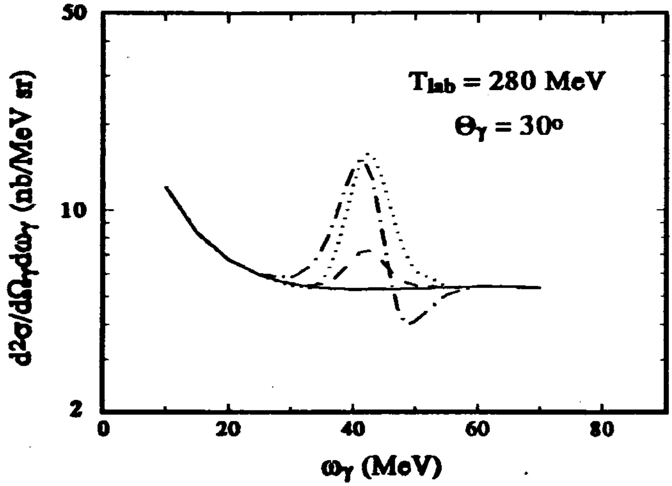

Fig.1. The inclusive $pp\gamma$ cross sections as a function of ω, the c.m.photon energy, at a fixed θ_γ, the c.m. photon angle, and at the incident nucleon kinetic energy T_{lab} = 280 MeV. The solid line denotes the background bremsstrahlung spectrum. The dashed, dash-dotted and dotted lines denote the γ-spectra for the dibaryon resonance excitation with quantum numbers $J^P = 0^+$, 1^- and 2^+, respectively

the strong pp-interaction enters the $pp\gamma$-amplitude in the form of a single-scattering and double-scattering (or «rescattering») blocks. Since in our calculation non-resonance $pp\gamma$ amplitudes play the role of the background amplitudes we neglect the rescattering corrections for the first approximation.

For illustrative estimations of the influence of the dibaryon resonances on the observed characteristics of the $pp\gamma$-reaction we have chosen as an example the isovector dibaryon resonance with mass M_B = 1969 MeV, width $\Gamma_{tot} \cong \Gamma(B \to pp)$ = 9 MeV shown up in the experiment dealing with the ^{3}He(p,d)X reaction [5]. The resonance was observed as the narrow peak in a missing mass spectrum at the level of $\pm 3\sigma$, with the relative accuracy of the reaction cross-section measurement of $\Delta\sigma/\sigma = \pm 3.5$ %. The inclusive spectrum of the photons produced in the pp interaction at the kinetic energy of the incident protons T_{lab} = 280 MeV is shown in Fig.1. The solid curve corresponds to the nonresonant background cross section and the dashed, dash-dotted and dotted curves correspond to formation of the dibaryon resonances with the spin-parities 0^+, 1^- and 2^+, respectively. In this case the relative phase ϕ was put equal to zero. From this figure it is seen that

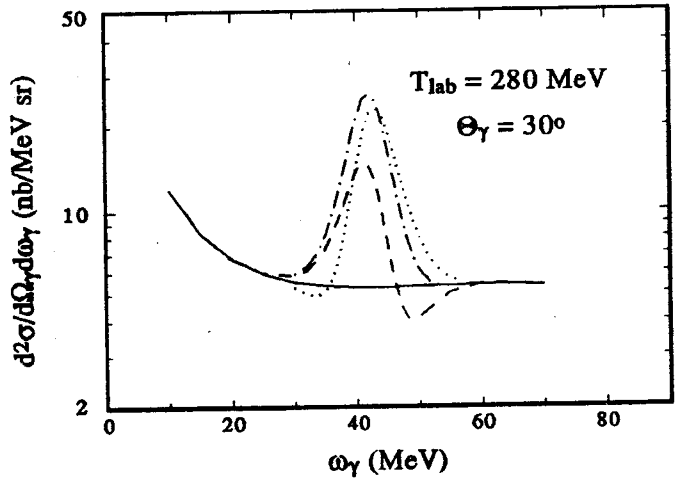

Fig.2. The inclusive $pp\gamma$ cross-sections at $T_{\rm lab}$ = 280 MeV for the dibaryon excitation with $J^P = 1^-$ versus the relative phase ϕ between the background and resonance amplitudes. The solid line is a background spectrum. The dashed, dash-dotted and dotted lines are spectra with ϕ = 0°, 90° and 180°, respectively

with the chosen parameters of the resonance, the exceeding of the resonance peak above the background is ranging from 40% at $J^P = 0^+$ to 100% at $J^P = 1^-, 2^+$. The influence of the relative phase shift ϕ on the shape of the resonance spectrum at $J^P = 1^-$ is shown on Fig.2. The dashed, dash-dotted and dotted curves correspond to the values of ϕ = 0°, 90° and 180°, respectively. For the same resonance (i.e., at $J^P = 1^-$) in Fig.3 the contributions from the convection (dashed curve) and the magnetization (dotted curve) currents to the total cross section of the resonance excitation (dashed-dotted curve) are shown.

Thus, it is seen that narrow dibaryon resonances should exhibit themselves as the conspicuous resonance-like structures over smooth background in the photon energy spectrum of the $pp\gamma$-reaction. Moreover, the positions of these resonance peaks depend on the energy of incident protons and their calculable and noticeable shifts with the controlled changing of the initial proton energy may serve as the decisive argument in favour of those much-disputed dibaryons. Unfortunately, there are no data on the photon energy spectra at present.

As to the popular geometry of the $pp\gamma$-experiments with the coplanar detection of all final particles (the so-called Harvard geometry), one can see that the specially chosen proton angles should be used to face the dibaryon

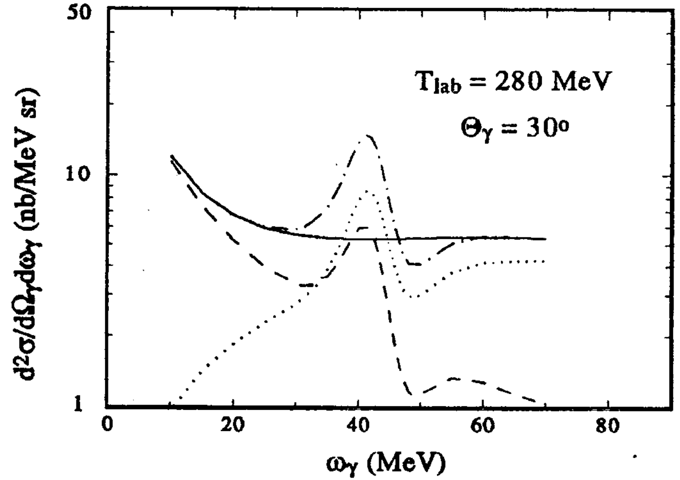

Fig.3. The convection (dashed line) and magnetic (dotted line) current contributions to the total (dash-dotted line) bremsstrahlung cros section for the dibaryon resonance excitation with $J^P = 1^-$. The solid line is the nonresonance γ-spectrum

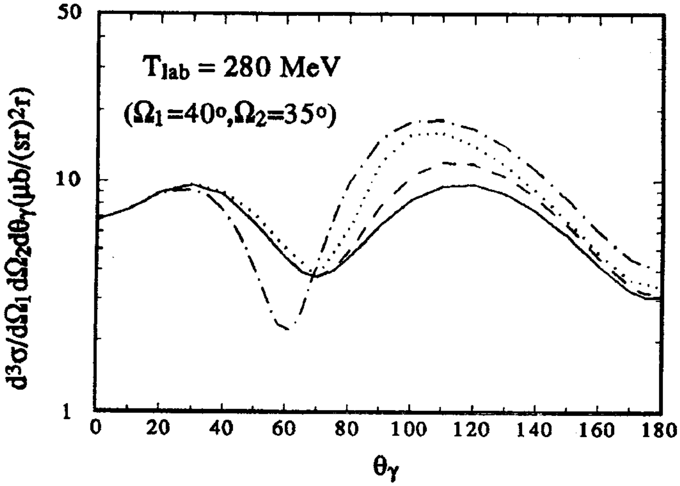

Fig.4. The coplanar geometry $pp\gamma$ cross-section as a function of $\theta_{\gamma,\mathrm{lab}}$, the photon laboratory angle, at T_{lab} = 280 MeV and for the final proton angles $\theta_{1(2),\mathrm{lab}}$ = 40° (35°). The solid line denotes the background bremsstrahlung spectrum. The dashed, dash-dotted and dotted lines denote the γ-spectra for the dibaryon excitation with $J^P = 0^+$, 1^- and 2^+, respectively

resonance effect at a given photon angle. As an example, in Fig.4 the $pp\gamma$-cross-section is shown as a function of θ_γ for T_p = 280 MeV and the final proton angles equal to 40° and 35°. Under chosen kinematics one can trace the presence of the dibaryon with mass 1969 MeV [7]. The solid curve corresponds to background, the dashed and the dash-dotted curves correspond to excitation of the dibaryon resonance with spin-parity 0^+, 1^- and 2^+, respectively. From this figure one can see that the influence of the resonance on the cross-section shape may be noticeable but quite different from a local variation commonly expected for a narrow resonance. The kinematic conditions of the most extensive and precise experiments at 280 MeV [9,10] were optimized on a search for the off-shell effects in the *NN*-interactions. Nevertheless they do put some restrictions on the parameters of possible dibaryons. In the region investigated the resonances with mass $M(B) < 1940$ MeV could only be seen. With the use of available data one can obtain a rough upper bound on $\Gamma_{tot} < 2$ MeV.

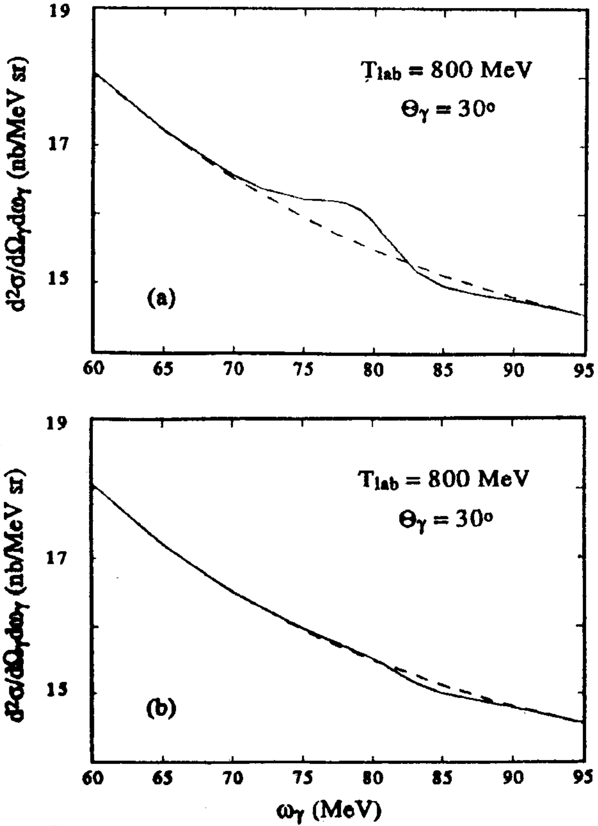

Fig.5. The c.m. inclusive cross sections at T_{lab} = 800 MeV. The dashed line is a background spectrum. The solid line denotes spectrum for the dibaryon resonance excitation in the $^3F_3$ (a) and $^3H_5$ (b) partial waves

Above the pion threshold there are also the candidates in the dibaryon resonances. So, the relatively narrow structure with the mass $M(B) = 2160$ MeV [6,7] was discovered in a measurement of the analysing power A_y in *pp*-scattering. From a phase shift analysis the resonance parameters were obtained [7]: $\Gamma_{tot} \cong 10$ MeV and $\Gamma_{pp}/\Gamma_{tot} = 0.15$ (0.06) if the resonance is observed in $^3F_3(^3H_5)$ partial wave. Fig.5 shows the spectra of the bremsstrahlung photons in the *pp*-interaction at T_{lab} = 800 MeV.

Though the use in the calculations of the Bonn potential is not justified at such a high energy, we present the results to demonstrate at least the qualitative picture of the resonance signal to nonresonance background relation in that case. In accomplished calculations all partial waves with $J < 9$ were taken into account. In Fig.5a(b) the theoretical calculations of the photon spectra with excitation of dibaryon resonance in partial wave $^3F_3(^3H_5)$ are presented. It is seen that the small elastic widths lead to strong decrease of the resonance-to-background ratio (this ratio reaches only 2% in the case of the resonance in $^3F_3$ wave and less than 1% for $^3H_5$ wave). Furthermore, to get rid of photons from the π^0-decays, one should detect all final particles of the $pp\gamma$ reaction to draw the needed photon energy distribution curve.

3. Concluding Remarks

The calculations performed in this work are approximate. In particular, the rescattering and relativistic spin corrections discussed, respectively, in refs. [14,15] are not considered. Like all other theoretical works in this field we don't consider the exchange current contributions, which for the $pp\gamma$-reaction are connected with the multimeson exchanges and which remain basically unexplored till now. We believe, however, that all aforementioned factors cannot qualitatively change the picture of the dibaryon resonance appearance if they do exist in the considered range of masses.

It appears worthwhile to note also that our scheme of introduction of the resonance effects into consideration has a general basis with some of the considered earlier attempts to go beyond the soft photon approximation based of the Low theorem [8]. Indeed, in [17], it was shown on the base of an exactly solvable potential model that one can reach a more accurate description of bremsstrahlung reaction, in comparison with a model-independent soft photon approximation, if the contributions from a peripheral, long-range part of potential are described exactly, while contributions from the short-range part of strong potential are taken into account according to the Low theorem, that is, by parametrization of the corresponding amplitudes through the on-mass-shell scattering phase shifts.

In our case, we identify the peripheral part of potential with a realistic meson NN potential and treat it as accurately as possible. We phenomenologically parametrize the action of an unknown short-range interaction, which is, presumably, originated from the quark rearrangement in the NN system, via the resonance NN amplitudes on mass-shell. To conclude, the more realistic calculations of this work give more reliable estimation of the possible dibaryon resonance signal over a non-resonant background, thus confirming the main conclusions of [1] and stressing the urgency of measuring the energy spectra of final photons. The moving «γ line», i.e., the dependence of the «resonance» photon energy on the energy of incident protons is also one of the most salient features of the existence of the narrow dibaryon resonance. Of course, for further detailed investigation (determination of the quantum numbers, etc.) different exclusive experiments (see, e.g. [18]) and measurements of the spin characteristics of the particles in the considered reaction will be needed as well.

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