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IT IS POSSIBLE TO OBSERVE PHOTON SPLITTING IN A STRONG COULOMB FIELD

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НОВОСИБИРСК

It is Possible to Observe Photon Splitting in a Strong Coulomb Field

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ABSTRACT

The possibility of experimental observation of photon splitting process in a strong Coulomb field is discussed. The principle scheme of experiment is proposed. The background processes are analyzed. The estimations show the reality of the experimental scheme under discussion with respect to the counting rate and background conditions.

As known, virtual creation and annihilation of electron-positron pairs induce the nonlinear self-coupling of an electromagnetic field. The light by light scattering is one of the characteristic processes of nonlinear quantum electrodynamics. In external Coulomb field the processes of Delbruck scattering [1] (coherent photon scattering) and photon splitting into two photons are possible as well (Fig. 1,*a*,*b*). The study of these processes is of a great importance to verify nonlinear QED in a strong field.

At present, Delbruck scattering is studied in detail both theoretically and experimentally (see, e. g. [2–6] and references cited therein). The photon splitting process is investigated now only theoretically [7–11] and in the lowest order of perturbation theory. Of course, it is necessary also to study the value of the Coulomb corrections to get a possibility to compare the theoretical predictions and experimental results. The advanced calculations are in the progress at Novosibirsk Institute of Nuclear Physics (INP). Unfortunately, up to now nobody has observed this effect experimentally. Note that the possibility of observation has been discussed during a long time. In particular, the photon splitting observation in single crystals has been considered [12].

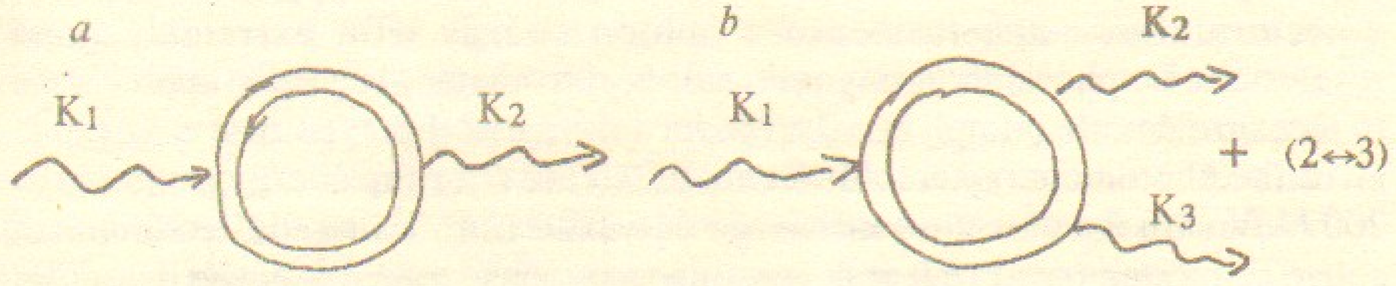

Fig. 1. *a* – Diagram for the Delbruck amplitude. The double line represents an electron Green function in the Coulomb field. *b* – Diagram for photon splitting in a Coulomb field.

In the present paper we suggest the principle scheme of the experiment to observe the photon splitting in a strong Coulomb field. As it will be seen, this scheme gives one the possibility to overcome the difficulties arisen in previous attempts to find effect under discussion [6]. Our paper has been initiated by the discussion of the experimental program for NEP storage ring constructed now in INP [13]. We consider here the experimental features taking into account the parameters of NEP.

Let us pass now to the discussion of the experimental scheme. First of all we emphasize that it is necessary to detect both photons in the final state. This is due to the fact that the main contribution to the exclusive (γ, γ) cross section comes from e^+e^--pair production with hard-photon bremsstrahlung. The cross section of the last process is two orders of magnitude larger then that corresponding to the photon splitting [9, 14]. It has been the origin of the wrong interpretation of experimental data in DESY [6].

Then the method of initial photon beam obtaining is very essential for the experiment under consideration. Usually, one exploits the hard-photon bremsstrahlung of electrons in the field of heavy nucleus or laser back scattering from high energy electron beam. In both cases the probability of double photon radiation along the electron beam direction is very significant and this process gives a large background for the photon splitting experiment. Apparently, it is difficult to distinguish two photons from double bremsstrahlung and ones appear from photon splitting. For real experimental situation this background exceeds the main effect. Therefore, it should be suppressed. We suggest to do that using the collimation of the initial photon beam (see below). Then, the photons will be detected in the range of the collimator's shadow.

We will see that for our purpose it is necessary to measure the energy of initial and final photons with sufficiently good accuracy. As usual, the energy of initial photon will be determined by measuring of the initial and final electron energies. To measure the energies of final photons it is convenient to use magnetic pair spectrometer. It is known that this type of the photon detectors allows one to measure photon energy with extremely good resolution. Emphasis that magnetic pair spectrometer especially appropriate to measure double photon events. Modern device of this type (see e. g. [15]) gives the photon energy resolution about 0.5 MeV for the energy range up to 200 MeV with the detection efficiency of two percent. Using the technique of active convertor (see [16]) it is possible to increase essentially the detection efficiency. One can get also a high space resolution for conversion point which allows one to obtain the angular distribution of events.

Figure 2 shows the principle scheme of experiment. The electron beam in NEP passes through very thin internal target T1 and create the photon beam

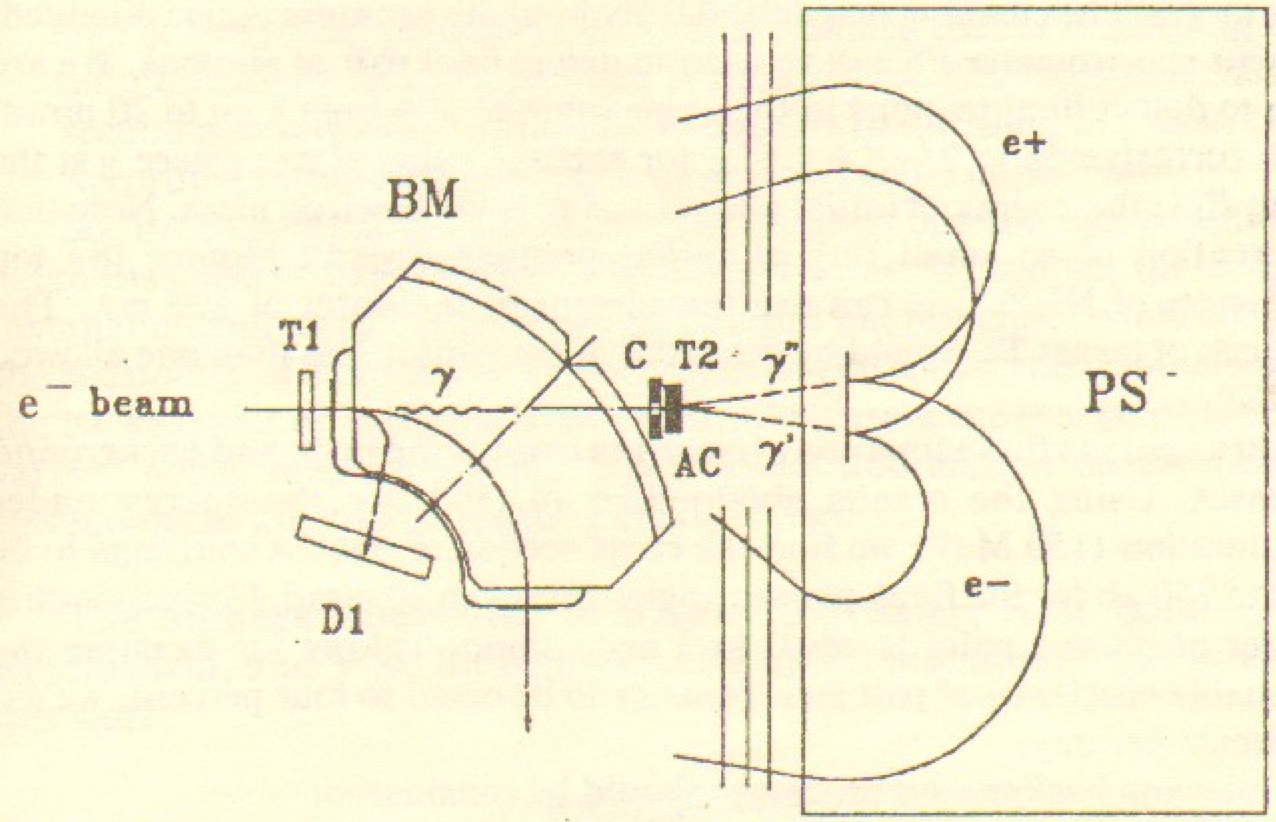

Fig. 2. Principal scheme of the experimental arrangement: e^- is internal electron beam; T1 is convertion target; BM is bending magnet of storage ring; D1 is set of detectors for tagging; C is the lead collimator; T2 is an Uraniun target; AC are the set of anticoincident counters; PS is the pair spectrometer.

by bremsstrahlung. Target T1 is located at the end of straight section. The energy of electrons in NEP is planning to be 200 MeV. The revolution frequency for NEP is 52 MHz.

The magnetic field of NEP bending magnet will be used for the analyzing of electron energies. The electrons of energy inside the range from 30 to 70 MeV will be detected by set of the counters D1. The accuracy of energy measuring expect to be about 0.5 MeV. Therefore, the tagged initial photons will have the energy from 130 to 170 MeV. The flux of tagged photons are chosen to be about 6 MHz. So, one photon will be created per nine turns of electron bunch in the mentioned range of energy. The main contribution to the angular spread of photons is determined by directedness of bremsstrahlung. This spread is about 2.5 mrad. The lead collimator C with the conic hole will be installed at 800 mm from the target T1. For the diameter of hole 4 mm about half flux of photons will pass through the collimator. The Uranium target T2 follows the collimator. The maximum count of the photon pairs is achieved at the target thickness of 0.6 radiation length. Moreover, the anticoincident scintillator counters AC will be used to suppress the background process. They give an information about e^+e^--pairs production in the target. The cleaning magnetic field behind the counters is also provided. The pair spectrometer PS will be used to detect final pair of photons. We are going to detect final photons in the angle interval of θ from 7 up to 20 mrad, which corresponds to $2/\gamma < \theta < 6/\gamma$ for average value of E_1; where γ is the E_1/m; E_1 is the energy of initial photon and m is the electron mass. Note that the creation of so small flux of initial photons doesn't require the top parameters of NEP. One can use the current of the order of 100 mA. The thickness of target T1 should be two order of magnitude less than one allowed for NEP.

Let us pass to the estimation of counting rate for the main and background processes. Using the results obtained in [9, 10], for the energy under consideration (150 MeV) we find the cross section of photon splittings to be equal to 250 μb for the final photon angles from 7 to 20 mrad. Corresponding number of photon pairs is equal to 3 per second. Taking for example the reasonable efficiency of pair spectrometer to be equal to four percent, we get 370 events per day.

Following background processes should be considered:

i. Double Compton effect from the atomic electrons ($\gamma e \rightarrow \gamma\gamma e$), It is easy to show that the contribution of this process is negligible.

ii. The e^+e^--pair production with two hard-photons bremsstrahlung. This background is suppressed with the help of balance between initial and final photon energies. For energy resolution better than one MeV this contribution is negligible too.

iii. Cascade process in which initial photon creates e^+e^--pair and these particles radiate two hard photons in the Uranium target. For our thickness of target the angular distribution of these photons is essentially wider than that for photon splitting. This is due to the multiple scattering of electrons and positrons in target. The balance of energy is also used. As a result the background is suppressed strongly and becomes of order of percent with respect to photon splitting process.

It is necessary to take into account that the probability of photon emission of the energy 20 MeV $< E_\gamma <$ 130 MeV is one order of magnitude larger than one in the interval 130 – 170 MeV. Here lower bound is determined by the energy detecting threshold of pair spectrometer. So, the following processes should be considered:

iv. Both photons radiated at one passage of the electron bunch through the target T1 create e^+e^--pairs and photons in Uranium target, where one of the initial photons is not marked in tagging system D1. Especially to suppress this background AC counters are provided. The inhibition signal from AC will appears if the total energy of e^+e^--pairs is more than 20 MeV. Under these conditions last background is about one percent.

v. One of two initial photons described in previous case iv is splitting where only one of these final photons is detected by pair spectrometer. The second photon in pair spectrometer appears in the same way as in case iv. According to AC counters this background can be neglected.

So, the suggested scheme of experiment gives one the real possibility to make first observation of photon splitting process. Of course, the details of installation and its parameters can be changed but principle conclusion about the possibility of experiment in discussion will be conserved. Emphasize that the background is expected to be small. Comparing the results obtained for various nuclei one can get the experimental information on the Coulomb corrections to the photon splitting cross section.

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