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EXPERIMENTAL EVIDENCE OF VIRTUAL COMPTON SCATTERING OUTLOOK OF STUDYING $\gamma\gamma$ PROCESSES WITH DCI

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Résumé. — Une expérience effectuée à Orsay a mis en évidence un processus qui présente quelques analogies avec les processus $\gamma\gamma$: à savoir la diffusion Compton virtuelle. La seconde partie de cette communication décrit sommairement les possibilités d'effectuer des expériences $\gamma\gamma$ avec la nouvelle machine actuellement en construction.

Abstract. — An experimental evidence, obtained at Orsay of a reaction somewhat related to the $\gamma\gamma$ processes, namely the virtual Compton scattering is reported. Then the outlook of studying $\gamma\gamma$ experiments with the new machine now in construction is briefly discussed.

1. **Introduction.** — The first storage ring built at Orsay, called ACO, is an $e^+ e^-$ machine with a peak energy of 540 MeV per beam. Its maximum luminosity is about 10^{29} cm^{-2} s^{-1}. These characteristics make it quite difficult to study $\gamma\gamma$ processes, but it has been possible to observe with ACO a reaction somewhat related to these processes, namely virtual Compton scattering.

I shall first report on this experiment and then briefly discuss the outlook of studying $\gamma\gamma$ processes with the second machine now in construction at Orsay. This larger machine is called DCI.

2. **Virtual compton scattering.** — Experimental evidence has been obtained by a group [1] working at Orsay of virtual Compton scattering ($e^+ e^- \to e^+ e^- \gamma$, see Graph of Fig. 1) at a total center of mass energy of 990 MeV. The cross section of this reaction has been computed by Kessler [2]. This process has also been considered by Bjorken [3]. It leads to valuable tests of QED and of the validity of the Williams-Weizsäcker approximation.

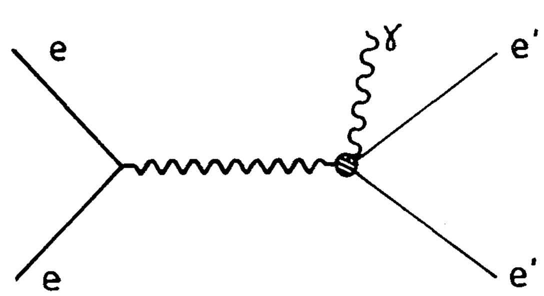

FIG. 1. — Feynman diagram of virtual Compton scattering.

The apparatus used for this experiment has already been described in detail elsewhere [4]. Let me just remind you of its main characteristics : optical, cylindrical spark chambers determine charged and neutral particle trajectories. Two views of the events are photographed : one view is a projection on a plane normal to the beams, and the other one is a projection on a plane that contains the beam line. For each track, the polar angle θ and the azimuthal angle φ are determined with a 1.5 degree accuracy. The geometrical acceptance (defined by $0° < | \theta | < 50°$ and $7.5° < | \varphi | < 157°5$) is about two thirds of the total (4π) solid angle. Bhabha scattering is used to normalize all cross sections measured. The integrated luminosity obtained at 990 MeV is 3.1×10^{33} cm^{-2}.

The main purpose of this experiment was the study of the production and decay modes (both charged and neutral) of vector mesons. In order to check the data analysis, the cross section of the $e^+ e^- \to 2\gamma$ annihilation process was also measured. Since there is some probability that one of the photons materializes in the vacuum chamber of the ring (1 mm steel) e-γ events were also looked for and analysed. Figure 2 gives the $\Delta\theta$ and $\Delta\varphi$ plots, i. e. the number of $\gamma\gamma$ and e-γ events whose two tracks make given angles in the longitudinal and transverse views respectively. As can be seen, most of these events are coplanar. But while most of the $\gamma\gamma$ events are also colinear, a significant fraction of the e-γ events are *not* colinear.

Within some well-defined cuts, one is left with 118 $\gamma\gamma$ and 14 e-γ colinear and coplanar events. The ratio of these two numbers is in agreement with the one calculated from the known conversion rate in the

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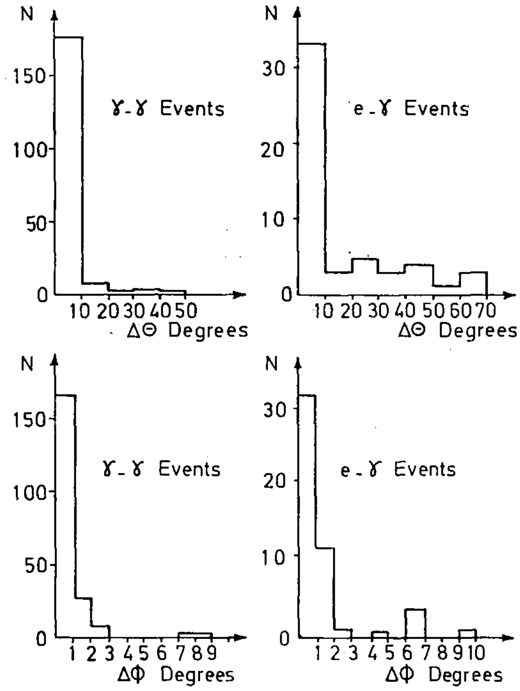

FIG. 2. — $\Delta\theta$ and $\Delta\varphi$ plots for $\gamma\gamma$ and e-γ events.

vacuum chamber. One then finds an experimental cross section equal to $(5.09 \pm 0.6) \times 10^{-32}$ cm^2. The agreement with the theoretical value of the annihilation cross-section (5.02×10^{-32} cm^2) gives us confidence in the analysis performed, in particular in the Monte Carlo calculation.

Nevertheless, 19 coplanar e-γ events are observed with a $\Delta\theta$ larger than 10 degrees. A machine background of 3 such events can be excluded at a 95 % confidence level. Furthermore, only 3 such events are expected from the conversion of one of the photons of 2 γ annihilation events. Then 16 ± 3 events must originate in another process.

The kinematics of these events suggest a non-annihilation process where a virtual photon, close to its mass shell, is scattered by an incoming lepton (e^- or e^+). The outgoing real photon and the lepton which has undergone this virtual Compton scattering are emitted at wide angles, but are almost coplanar with the beam line. They are not necessarily colinear. The other outgoing lepton is practically forward-emitted, outside the detector acceptance.

Obviously, Bhabha scattering with radiation of one of the outgoing leptons also contributes to such e-γ coplanar, but mostly non colinear, events. But in such a process, the other lepton scatters also at wide angle and should be detected. In fact, 40 $e^+ e^- \gamma$ events were observed from which one can infer that the contamination of the observed e-γ events by such $e^+ e^- \gamma$ radiative Bhabha scattering events where one lepton has escaped detection is negligible. More precisely, a calculation made by the Kessler group, which takes into account the exact acceptance of the set-up, shows that the contamination of the virtual Compton scattering by the radiative Bhabha scattering is much less than 10 % when only one of the two electrons is observed.

The experimental cross section was found to be $(6.4 \pm 2.2) \times 10^{-33}$ cm^2, in very good agreement with the theoretical value obtained by Kessler in the Williams-Weizsäcker approximation which is 6.7×10^{-33} cm^2.

Figure 3 shows a comparison between the experimental and the theoretical distributions of $\Delta\theta$. The statistics are a little poor but the agreement looks good.

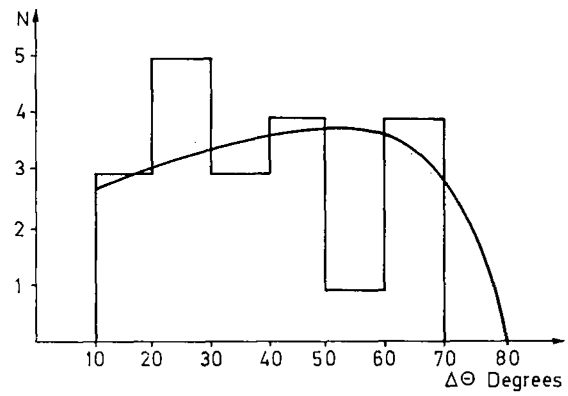

FIG. 3. — Comparison between the experimental and the theoretical distributions of $\Delta\theta$.

A newer experiment performed last year at Orsay should allow an increase of the statistics by a factor 15. The analysis is now under progress.

3. **Outlook of $\gamma\gamma$ experiments with DCI.** — Now, I would like to give you some information on the new storage rings which are being built at Orsay under the direction of Marin.

The most interesting feature of this machine is the so-called « four beam space charge compensation ». In a storage ring, the transverse beam density — and therefore the luminosity — is limited by an incoherent beam-beam effect due to space charge forces acting in the interaction region (s). A strong reduction of these forces can be achieved by having a pair of bunches, one of electrons and the other of positrons, travelling along together in the interaction region and clashing against an other pair of such bunches. If the currents and the transverse densities of each of the four bunches can be made very nearly equal, space charge forces cancel out, and one can increase the number of stored particles and therefore the luminosity of the machine. Such a scheme is the one adopted in DCI, the new Orsay machine [5]. It consists of two identical storage rings, one built on top of the other. In each ring, one can store two counter-rotating bunches of equal intensities, one of electrons and one of positrons.

Leptons of opposite charge circulate in the same direction in the two rings. Four Y magnets and eight vertical bending magnets deflect the 4 beams in such a way that they cross on the same orbit in two common straight sections. These sections are 6 meters long. One is used for injection, and the other one for particle physics (see Fig. 4).

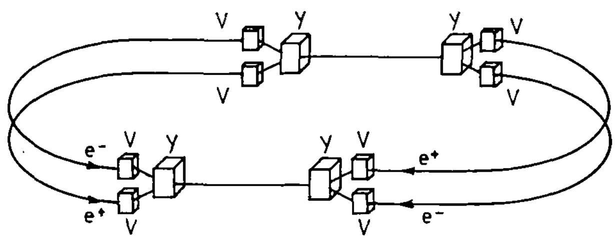

FIG. 4. — DCI : Trajectories of the 4 beams.

Since $\gamma\gamma$ processes can take place not only in $e^+ e^-$ collisions but also in $e^+ e^+$ or $e^- e^-$ collisions, the luminosity of DCI as far as such processes are concerned is twice the one obtained for annihilation reactions. This is an advantage when performing $\gamma\gamma$ experiments since the « contamination » due to annihilation is reduced by a factor of 2. Nevertheless, in several respects, DCI is not well adapted to $\gamma\gamma$ experiments : the magnetic structure of the machine, its very low duty cycle, and the high intensities of the bunches are unfavourable features. It seems impossible to insert focussing quadrupoles in the interaction straight section. Without such a focussing, an energy tagging of the initial leptons scattered in $\gamma\gamma$ process is extremely difficult. The chromatic orbit separation provided by the Y magnets located at the end of the interaction straight section is quite small. Tagging counters would have to be located too close to the central orbit of the stored particles. Furthermore the intensities of the stored bunches are so high that, whenever the bunches cross, a series of tagging counters would be hit by leptons which have undergone beam-beam Bremsstrahlung.

Since DCI, like Doris, is a two ring machine, one can operate it with electrons (or positrons) only, thus eliminating all annihilation processes. There would be only one beam per ring, and no cancellation of space charge forces. This implies a large reduction of the stored bunch intensities that can be partly overcome by filling all the buckets in synchrotron phase space, i. e. by going from one to eight bunches per beam. Figure 5 shows the luminosity estimated for two operating points of the machine. This luminosity is close to 10^{31} $cm^{-2}.s^{-1}$. Since the luminosity is 20 times lower and is achieved with 8 bunches per beam instead of one, the background which is mainly due to beam-beam Bremsstrahlung is considerably reduced. Whenever bunches cross, the number of leptons which have undergone Bremsstrahlung is 160 lower in the two beam operation than in the 4 beam operation. The background coincidence rate in the tagging counters is therefore cut down by a factor 2.5×10^4. Furthermore, the injection and tuning time for two beams should be quite shorter than for four beams. On the other hand the beam-beam life time should be longer. Therefore, the average luminosity over a long period of time will not be as reduced as it might appear from a direct comparison of the peak luminosities.

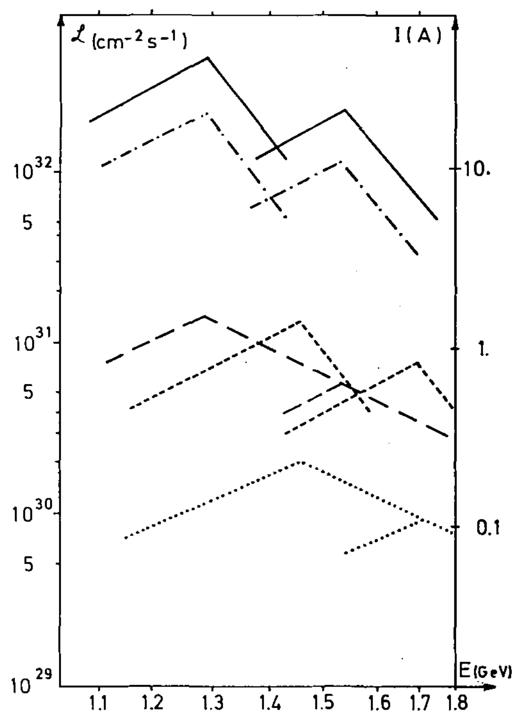

FIG. 5. — DCI : Luminosities and currents at $\nu_z = 2.85$, $\nu_x = (3.85$ and $4.85)$.

4 beam operating mode

——— Luminosity for $\gamma\gamma$ processes ;
— . — Luminosity for annihilation processes ;
— — — Current per bunch.

2 beam operating mode

- - - - - Luminosity for $\gamma\gamma$ processes.
. . . . . . Current per bunch.

Table I shows the main characteristics of the machine in the two operation modes.

Several difficulties remain however, even in this two beam operating mode of the machine. For instance, the energy tagging of the initial leptons is a problem not completely solved yet. Even with a magnetic detector which analyses the momenta of the particles produced in $\gamma\gamma$ collisions, there will be ambiguities about the nature of the final particles if one does not know the total center of mass energy by tagging the energy of the scattered leptons. These difficulties explain that no definite $\gamma\gamma$ experiment proposal has been made yet for DCI.

TABLE I

Main characteristics of DCI

		Operation mode 4 beams	Operation mode 2 beams
Maximum energy	1.8 GeV		
Energy dispersion (1.5 GeV)	$\sim 6 \times 10^{-4}$		
Maximum luminosity			
$e^+ e^-$ annihilation		$\sim 2 \times 10^{32}$ cm^{-2}.s^{-1}	0
$\gamma\gamma$ processes		$\sim 4 \times 10^{32}$ cm^{-2}.s^{-1}	$\sim 2 \times 10^{31}$ cm^{-2}.s^{-1}
Rings			
Number	2		
Orbit length	94.6 m		
Experimental section			
Number	1		
Length	6 m		
β function	$\beta_x = \beta_z \sim 2$ m		
Magnetic structure			
30° horizontal magnets	12 × 2		
10° vertical magnets	28 × 2		
10° Y-type magnets	4 × 2		
Insertion structure	symmetric, 2		
RF			
Rotation frequency	3.17 MHz (315 ns)		
Harmonic number	8		
Useful power per beam		125 kW	250 kW
Beams			
Number of beams		4	2
Number of bunches per beam		1	8
Intensity per beam		~ 1 A	~ 1.2 A
Intensity per bunch		~ 1 A	~ 150 mA
Bunch length (1.5 GeV)	$\sigma_l \sim 15$ cm		
Bunch cross section (1.5 GeV)	$4\pi\sigma_x\sigma_z \sim 10$ mm^2		
Beam-beam			
Life-time		~ 6 hours	~ 18 hours

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DISCUSSION

C. BERNARDINI. — I have two questions.

1) How will you get a precision monitor for the annihilation channel in the 4-beam operation mode of DCI ?

2) I have the feeling that the high currents you need will produce difficulties with the beam-gas background in DCI, as compared to other machines. Am I right ?

A. COURAU. — In my talk, I mentioned that DCI, when it runs with 4 beams, makes the tagging almost impossible because of the intensity of the currents stored and of the bad duty-cycle. I mentioned the intensity of the currents precisely because of the beam-gas bremsstrahlung. However, I insisted particularly on the beam-beam Bremsstrahlung since, due to the bad duty cycle, this latter background is enough to make the tagging impossible. We must notice that all beam-beam Bremsstrahlung events take place in the experimental section, and that their number is related neither to the vacuum nor to the current, but only to the luminosity.

C. BERNARDINI. — I am afraid you did not answer my questions completely.

P. MARIN. — Let me complement Courau's answer :

1) Concerning the monitoring, we will use the same scheme as everybody (low-angle scattering). In fact, accurate compensation will require that companion beams fly along the same line and are not separated by more than $\sigma/10$ or $\sigma/20$. It will also require that one should have the same beam cross section. So, within 10 %, the situation will be the same for $e^+ e^-$ luminosity and $e^+ e^+$ or $e^- e^-$ luminosity for the studies of two-photon processes. It will be possible to make an accurate luminosity masurement with a magnetic detector for the three different types of collisions $e^+ e^+$, $e^+ e^-$ and $e^- e^-$.

2) Why do we consider the beam-beam lifetime in the table of DCI characteristics, either for the 4-beam or for the 2-beam mode, when we are concerned with the background problem ? That is because the beam-beam process provides a background against which we cannot do anything. If one increases the luminosity, the beam-beam Bremsstrahlung goes up accordingly. As for the problem of beam-gas lifetime and beam-gas Bremsstrahlung, it is a technical one ; the situation can be improved there by taking out the vacuum chamber, running the beam (synchrotron light degassing) and increasing the pumping speed.

As to the comparison between the various rings, one has to normalize to the same luminosity. In this respect, DCI and SPEAR will not even differ by one order of magnitude for the stored currents. However, the photons from the synchrotron light will be harder in the case of DCI since the guiding field for the same energy will be higher.

S. ORITO. — I would like to make a comment which is not connected with the last talk in particular.

After listening to what has been said on all the problems in trying the « tagging » with SPEAR, DORIS and DCI, I feel ADONE would remain as the only machine where one can investigate at least the quasi-real photon-photon collisions in a clean way. Let me remind you that, at ADONE, the background conditions are rather clean and we have an efficient tagging system established. I think somebody there should build a longitudinal magnetic detector with a large solid angle and perform a good job on the photon-photon collisions. A few hundred events of the type $\gamma\gamma \to \pi^+ \pi^-$ could be collected within two years.