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PHOTON-PHOTON COLLISION EXPERIMENTS AT SPEAR (*)

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Résumé. — L'anneau de collision électron-positron de SLAC, ainsi que le dispositif de détection magnétique utilisé avec cet anneau, sont décrits dans le présent rapport. Des problèmes expérimentaux d'ordre général, concernant d'éventuelles expériences de collision photon-photon sur l'anneau SPEAR, ainsi que l'expérience proposée par Masek *et al.*, sont discutés.

Abstract. — The SLAC electron-positron colliding beam facility and its associated magnetic detector facility are described. General experimental problems in performing photon-photon collision experiments at SPEAR and the proposed experiment of Masek *et al.*, are discussed.

1. **Introduction.** — This talk will attempt to indicate in realistic terms the future prospects for photon-photon collision experiments at SPEAR. It will start with a description of the colliding beam facility itself, both as it operates now and as it will operate after the completion of the SPEAR improvement program next year. The magnetic detector facility, which is the only permanent experimental apparatus at SPEAR, is also described. After some general remarks on the problems of doing two photon experiments at SPEAR, we will describe the one experimental proposal which has been formally submitted on this subject.

2. **The colliding beam facility.** — Construction of the SLAC electron-positron colliding beam facility, SPEAR [1], began in August 1970 and was completed 20 months later in April 1972. The first two physics experiments began tuning their apparatus and taking data in January of this year. One experiment, using the magnetic detector, has the primary goal of studying one photon annihilation into hadrons [2]. The other experiment is testing quantum electrodynamics by observing various nonhadronic final states [3].

The layout of SPEAR is shown in figure 1. It is a single ring composed of separated function magnets. The rf system operates on the 40th harmonic of the 1.28 Mc orbit frequency. Only one of the 40 possible rf buckets is filled with electrons and positrons so that the beams collide only in the center of two interaction regions. This has important experimental consequences which we will discuss later.

Recently, we have been running SPEAR at its present maximum practical energy, 2.6 GeV per beam. The typical peak luminosity has been 6×10^{30} cm^{-2}.s^{-1} with 45 mA each of electrons and positrons circulating. The pressure in the interaction region has been approximately 10^{-8} torr. The rms length of the beam interaction region is currently 15 cm. Beam lifetimes are typically two hours. The beam filling procedure is fairly complicated. Electron and positron beams are injected from the linear accelerator at 1.5 GeV and then accelerated in SPEAR to the desired energy. This process requires about a half hour.

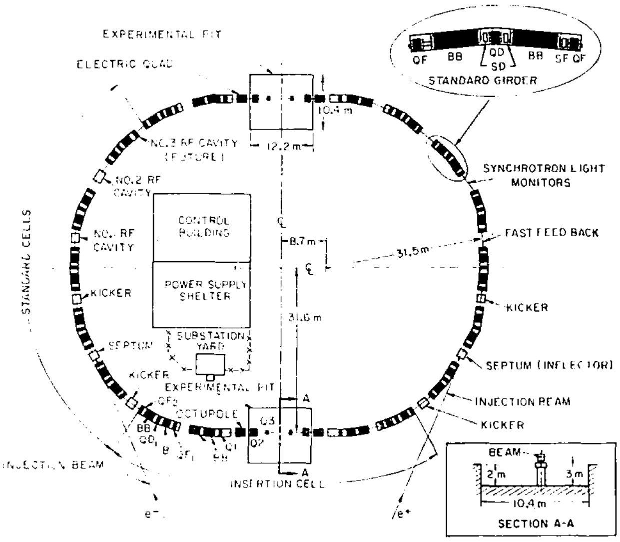

FIG. 1. — Layout of SPEAR.

SPEAR will have a major shutdown starting in July 1974 to complete an improvement program which will increase the maximum energy per beam to 4.2 GeV and eventually to 4.5 GeV. Physics experiments in the higher energy regions should start in January 1975. One very beneficial side effect of the improvement program will be an increase of the rf to 358 Mc. This will decrease the beam bunch length by a factor of 7 and facilitate identification of hadrons

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by time-of-flight techniques and the separation of beam-beam from beam-gas interactions. The gas pressure in the interaction region is expected to remain the same.

To date, luminosities at SPEAR have been limited by the incoherent two-beam instability with natural beam sizes. Thus, up to rf power and voltage limits, the luminosity increases as E^4. The region in which the luminosity has been measured is indicated by a solid curve in figure 2, and its extrapolation to higher energies is indicated by a dot-dashed line. Although it is theoretically possible to increase luminosities to the aperture and rf power limits indicated in figure 2 by « artificially » increasing the beam size, attempts to do so have been unsuccessful so far. Experimenters are specificially requested not to design and propose experiments requiring higher luminosities than those indicated by the extrapolated curve [4]. In fact, an experimenter should only expect to receive one quarter of the indicated luminosity averaged over clock time. The factor of one quarter accounts for beam lifetime, filling time, accelerator and SPEAR down time, and accelerator physics studies.

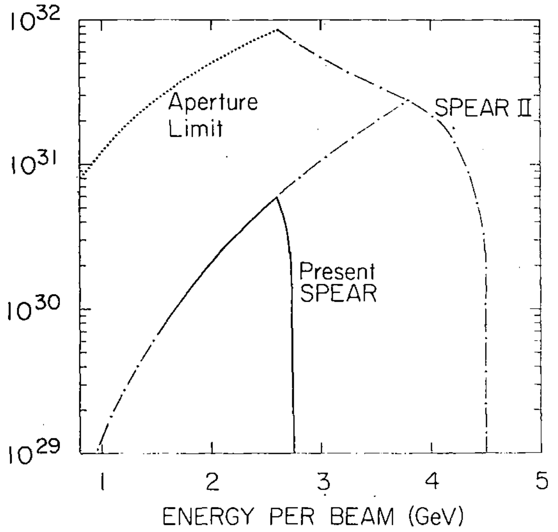

FIG. 2. — SPEAR luminosity. The solid line represents measured luminosities. The dot-dashed line is an extrapolation of the measurements to SPEAR II energies and various rf power and voltage limits. The dotted line indicates the theoretical limit due to aperture size.

3. **The magnetic detector facility.** — The east interaction region contains no permanent experimental apparatus. It is intended that a diversified program of experiments will be conducted in it, each experiment to run for no longer than four calendar months.

The west interaction region contains a large magnetic detector. Although it was designed specifically to observe one photon processes, with some modifications or additions, it may also prove useful for the observation of two photon events.

A telescopic view of the detector is shown in figure 3. Starting from the interaction region, the detector consists of a cylindrical scintillation counter about the beam pipe, eight gaps of small-angle stereo cylindrical magnetostrictive spark chambers, a cylindrical array of 48 scintillation trigger counters, the aluminum solenoid coil, a cylindrical array of 24 lead-scintillator shower counters, 20 cm thick iron flux return, and two gaps of planar magnetostrictive spark chambers.

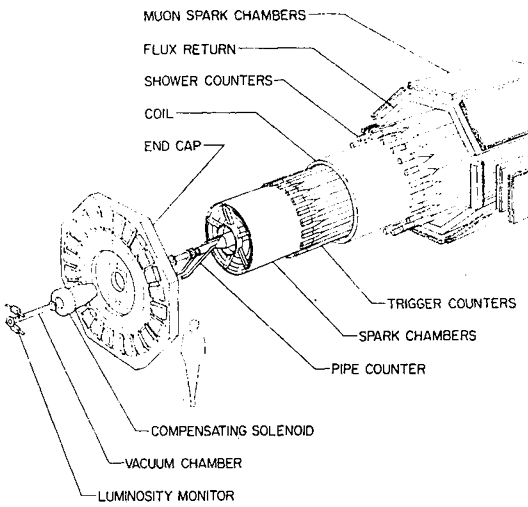

FIG. 3. — Telescopic view of the SPEAR magnetic detector.

The pipe counter, which is actually composed of two semicylinders, has a radius of 13 cm and a length of 91 cm. It is useful primarily in reducing triggers from cosmic rays.

The function of the cylindrical spark chambers is to track the charged particles and measure their momentum. The chambers are supported entirely from their ends, so that there are no massive support structures in the region in which momentum is measured. The wires are laid at angles of ± 2° and ± 4° to lines parallel to the beam to provide small angle stereo and about 1 cm position resolution along the beam direction.

In addition to being part of the trigger, the trigger counters provide time-of-flight information for discrimination against cosmic rays and for π-K-p separation. The rms time resolution for each counter is 320 ps.

The outer spark chambers serve primarily to separate hadrons and muons. Muons with momenta less than 500 MeV/c do not penetrate the iron flux return and cannot be separated from pions by the detector. Similarly, the shower counters do not provide any appreciable discrimination between pions and electrons below 500 MeV/c.

The solenoid is 3.6 m long and has a diameter of 3.2 m. The magnetic field of approximately 4 kg is longitudinal to the beam axis and is uniform to about ± 2 %.

Currently, the detector can trigger on particles emitted with polar angles to the beam between 50°

and 130° and can detect charged particles with polar angles between 40° and 140°. A set of magnetostrictive spark chambers made from printed circuit boards are now being produced. They will be placed perpendicular to beam near the end caps and will allow charged particle detection from 20° to 160°, or 94 % of the 4π solid angle.

We have been able to reduce the trigger rate in the magnetic detector to a few triggers per second by requiring two or more trigger counters and their associated shower counters to fire. The discrimination level on the shower counters is set so that they are highly efficient for minimum ionizing particles.

4. **General problems.** — The single bunch operation of SPEAR causes a serious problem for two photon experiments. All of the events, whether real or background, occur in the one nanosecond out of 781 in which the bunch is present in the interaction region. As a result, for most purposes a detector with time resolution of one ns is not any more useful than one with a time resolution of a hundred ns.

Let us assume that one wishes to do the ultimate two photon experiment by detecting all of the final state particles for all the processes which occur. It would be necessary to place electron detectors after the first set of quadrupole and bending magnets since approximately half of the electrons from two photon events remain inside the beam pipe until they are bent out by the magnetic field. Several people have investigated the positioning of such detectors at SPEAR [6]-[8]. It turns out that all of the electrons could not be detected, but it might be conceivable to detect as many as 40 % of them. The real problem with such detectors is that they would be intolerably swamped with background. Under the current SPEAR running conditions as outlined in section 2, an average of four electrons or positrons are lost from the beam in the long straight section around the interaction region for each pass of the two bunches. Most of these particles will end up in our electron detectors at precisely the proper time to simulate or confuse a two photon event.

In general one should exercise care in trying to use any detector which subtends small angles relative to the beam. This is particularly true of detectors which are not energy sensitive. For example, the magnetic detector pipe counter (which is described in Section 3) has had counting rates as high as 50 % of the orbital frequency.

A group from LBL has suggested that two photon events can be detected in the magnetic detector without detecting either the scattered electron or positron [9]. They point out that half of the two photon events have a hadronic transverse momentum of less than 20 MeV/c and this can be used to help distinguish these events from background such as electroproduction in the residual gas. Although certainly some information can be obtained with this technique, it will not be easy. The beam-gas background, i. e.,

$$e^{\pm} + CO_2 \to e^{\pm} + \text{hadrons} \tag{1}$$

occurs at a rate approximately two orders of magnitude larger than that for

$$e^+ e^- \to e^+ e^- + \text{hadrons} \tag{2}$$

for the present SPEAR conditions. Knies *et al.* [9] point out that

$$e^{\pm} n \to e^{\pm} p\pi^- \tag{3}$$

is particularly troublesome since kinematically it looks very much like

$$e^+ e^- \to e^+ e^- \pi^+ \pi^- . \tag{4}$$

Another background which can become troublesome when neither the scattered electron nor positron is detected is the hard radiative correction to one photon annihilation [10]. At 2.5 GeV, the cross section for

$$e^+ e^- \to \pi^+ \pi^- \gamma \tag{5}$$

is larger than the cross section for

$$e^+ e^- \to e^+ e^- \pi^+ \pi^- \tag{6}$$

for dipion masses in the region of the ρ mass.

The detection of two photon production of pion pairs, reaction (6), requires good particle identification. Its effective cross section in the SPEAR magnetic detector is 13 and 7 times smaller, respectively, than that for the production of electron and muon pairs. As indicated in section 3, such particle identification does not currently exist in the magnetic detector for particles with momenta less than 500 MeV/c. And 85 % of the pions produced via reaction (6) which trigger the magnetic detector have momenta below that value.

It is often assumed that one and two photon processes will be backgrounds for each other and will be difficult to separate experimentally. With the exception of a few special cases, such as the one we have just discussed, this is not the case in a large solid angle magnetic detector. Monte Carlo calculations for the SPEAR magnetic detector using reasonable assumptions for multiplicities and distributions show that if a cut is made in the visible energy distribution at one-third of the total energy, then 95 % of all observed two photon events lie below the cut and 97 % of all observed one photon events lie above the cut.

5. **Proposed experiment.** — So far only one experiment to study two photon processes at SPEAR has been proposed. The proposal comes from a group of experimenters from the University of California at San Diego led by George Masek [11]. As we will see, this experiment will avoid many problems that we have discussed.

The experiment will study the general two photon process

$$e^+ e^- \to e^+ e^- X \qquad (7)$$

by detecting the electron, the positron, and one of the decay products of X. As well as measuring the two photon cross sections as a function of the mass of X, including the low-lying $C = +1$ resonance states, the experiment has been designed to investigate the deep inelastic scattering of electrons on a photon target [12].

Figure 4 shows a cross section of one detector arm. There are two arms symmetrically placed about the interaction region and each arm is cylindrically symmetric.

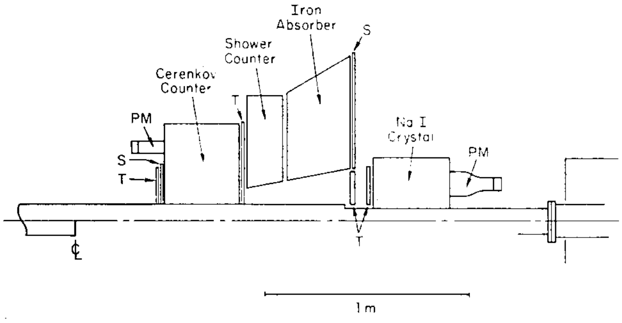

Fig. 4. — Apparatus for a proposed two photon experiment (Ref. [11]). The figure shows one of two symmetric arms in cross section. Each arm is cylindrically symmetric about the beam line. « S » indicates scintillation counters and « T » indicates drift chambers.

Each arm contains two detectors. The inner detector covers the angular region 50 to 160 mrad and the outer detector covers the region 160 to 500 mrad. The principal component of the inner detector is a 38 cm long NaI crystal viewed by eight 13 cm photomultipliers. The crystal will measure electron energies with FWHM resolution of about 2 %. Good energy resolution is needed to resolve the mass of hadronic state X. The NaI crystals give just enough resolution to resolve the π^0 and η final states. Although these crystals have excellent energy resolution, they are seldom used in high energy physics because of their poor time resolution. As we have discussed previously, one of the advantages (or disadvantages) of SPEAR is that good time resolution is unnecessary. Drift chambers in front of the crystal measure the electron trajectory.

The outer detector's function is to detect electrons which scatter at large angles and to detect decay products of X. In addition to drift chambers to measure particle trajectories, the detector consists of an atmospheric pressure Cerenkov counter to identify electrons, a lead-scintillator sandwich shower counter to identify and measure electron energies, and an iron absorber to separate muons from hadrons. The Cerenkov counter is needed for additional electron identification since a pion rejection of 1 in 10^4 is necessary to identify the high Q^2 deep inelastic events.

The trigger for recording data will be a particle in three of the four detectors.

Based on an integrated luminosity of 10^{38} cm^{-2}.s^{-1} at 3.8 GeV per beam (which is a factor of 3 to 4 above the guidelines we have listed), Masek *et al.* estimate that they will obtain 47 000 hadronic events including between 700 and 1 300 deep inelastic events ($\nu > 1.5$ GeV^2 and $Q^2 > 0.17$ GeV^2) and 400 to 600 events from each of the π^0, η, and η' final states.

With unlimited funds, one can always find ways of improving any given experimental apparatus. That aside, it is my personal opinion that this proposed experiment will study two photon physics as well as it can be studied at SPEAR in the foreseeable future.

Acknowledgments. — I wish to thank Dr. S. J. Brodsky and many members of the SPEAR magnetic detector group for helpful discussions.

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DISCUSSION

P. KESSLER (Paris). — You have written down this extremely high figure of 47 000 hadronic events in $\gamma\gamma$ scattering. On what is that prediction based ? Which theory, which model ?

G. FELDMAN. — Masek *et al.* used the structure function estimates of Brodsky, Kinoshita, and Terazawa (Ref. 12).

R. GASTMANS (Leuven). — Will you have polarized $e^+ e^-$ beams in the future, and, if yes, is there any physics already planned using them ?

G. FELDMAN. — I think Roy Schwitters can give the best answers to those questions.

R. SCHWITTERS (SLAC). — I have studied the possibilities for significant transverse beam polarization occurring at the SPEAR Storage Ring and it appears that under many practical conditions, the polarization should build up according to the theory of Sokolov and Ternov. Therefore, the polarization is expected to build up with characteristic times of roughly 2 hours at 2 GeV to roughly 10 min at 4 GeV, with an asymptotic magnitude of approximately 90 % per beam.

A Wisconsin-Pennsylvania group has proposed to exploit polarization effects in the production of muon pairs in order to look for weak interaction effects contributing to this process. At the present time, they are studying the feasibility of measuring the polarization and are preparing to build apparatus which will detect Touschek scattering from which they feel they can deduce the beam polarization.

J. PEREZ Y JORBA (Orsay). — As for the polarization of the beams, I have two questions : Have you tried to look for a polarization affect by looking at the azimuthal distribution of your reaction ? And, are you close to a depolarization resonance ?

R. SCHWITTERS. — No polarization has been detected at SPEAR, but it is not expected to have been seen because the present state of data analysis is insufficient to observe it, and most of the running has been done near a spin resonance energy.

E. B. HUGHES (Stanford). — The NaI(Te) spectrometers recently used to test QED at SPEAR would also have been used to look for beam polarization at SPEAR. This would have required an additional running time of about 15 days. This time was not available due to the intense physics program underway.

C. BERNARDINI (Frascati). — Could you give the luminosity of SPEAR integrated over a long period (say : one week) ?

G. FELDMAN. — I can't give you an experimental number, but the guidelines indicated in my talk would give 9×10^{35} cm^{-2} at 2.6 GeV per beam for one week.

E. B. HUGHES. — At SPEAR the integrated luminosity provided over the most recent 35 days of operation was 2.7×10^{36} cm^{-2}.

G. FELDMAN. — Well, that's 60 % of the guide line value, but I think we had some unusually rough running during that period.

H. NEWMAN (CEA). — What are the methods that have been used at the SPEAR Magnetic Detector to measure the luminosity ?

G. FELDMAN. — There are some detectors to measure small angle $e^+ e^-$ scattering, but we probably will not be able to understand them to better than 20 %. However we can check QED by measuring the angular distribution of Bhabha scattering, and by comparing Bhabha scattering with muon pair production. We can then normalize the hadronic reactions to the leptonic reactions.

H. NEWMAN. — Do you think that there will be major subtractions needed for beam-gas interactions ? Given the relatively high pressure of 10^{-8} torr this may present a problem.

G. FELDMAN. — With the magnetic detector, I think we will be able to separate beam-gas and beam-beam interactions in a satisfactory way. In addition to the usual techniques that are available to non-magnetic detectors, we have some additional ones. For example, it is clear that a beam-gas interaction can never give a visible energy greater than that of one beam. Monte Carlo simulations of one photon annihilation events indicate that we should see more visible energy than that of one beam 70 % of the time.

C. BERNARDINI (Frascati). — Concerning beam-gas events : You showed a very special event having a peculiar angular distribution. Also, the energy criterion requires a good knowledge of the fraction carried by neutrals. I feel that background subtraction is not that simple.