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OUTLOOK FOR STUDIES OF GAMMA-GAMMA COLLISIONS AT PEP*

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Abstract

A preview of the two-photon physics that can be expected to result from the initial PEP program is presented. The experimental detectors are discussed with emphasis placed on their capabilities and limitations to do studies of gamma-gamma interactions.

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Introduction

The detectors that comprise the initial experimental program at PEP are outlined in Table I. These detectors have been primarily designed to study the annihilation process $e^+e^- \to \gamma^* \to X$, with only the Two-Gamma forward spectrometer specifically intended to study the two-photon process. The remaining detectors offer a wide range of capabilities and limitations, but for the purposes of this preview they can be summarized as follows. The Mark II, TPC, and HRS are magnetic solenoids. Each offers essentially complete particle identification and precise momentum and energy measurements in the central polar angle region, but has generally worse to nonexistent capabilities in the more forward regions that are covered by endcaps. The Magnetic Calorimeter (MAC) and the Direct Electron Counter (DELCO) are highly specialized detectors. MAC is designed to provide hadron calorimetry and muon identification over nearly 4π solid angle, while the DELCO detector is capable of electron identification with a high degree of background rejection.

Table I. PEP Detectors. The approximate acceptance of the central and endcap parts of each detector is separately given.

Detector	Type	Acceptance
TPC/Two Gamma	Time Projection Chamber	Central > 45° Endcap > 15°
	Forward Spectrometer	21 mr - 180 mr
MAC	Magnetic Iron Calorimeter	Central > 15° Endcap > 10°
HRS	High Resolution Spectrometer	Central > 35° Endcap > 17°
DELCO	Direct Electron Counter	Central > 45° Endcap > 12°
MARK II	Solenoid Spectrometer	Central > 45° Endcap > 20°
	Small Angle Tagger	21 mr - 80 mr

Since the Mark II, TPC, and HRS detectors are quite similar to each other, I will choose one of them (the Mark II) and discuss it in some detail. A brief section will be devoted to the MAC detector, and finally the Two-Gamma detector will be presented and its unique capabilities discussed. For the remainder of this discussion I will assume that the average luminosity of the PEP machine is 10^{31} cm^{-2} sec^{-1} (or 10^{-2} nb^{-1} sec^{-1}), and a typical experiment will be assumed to consist of an integrated luminosity of $\sim 50{,}000$ nb^{-1}.

For polar angles greater than $\theta \simeq 45°$, the Mark II detector, shown in Fig. 1, provides charged particle identification, momentum measurement, and photon detection and calorimetry. The properties of the central part of this detector have been given elsewhere in these proceedings.[1] At the angles between $20° \lesssim \theta \lesssim 45°$, the endcaps of the detector and the inner drift chamber provide charged particle tracking and photon detection, but with reduced efficiency and poorer resolution. The small angle tagger (SAT) offers charged particle tracking and electron calorimetry (no magnetic field) in the region 21 mr < θ < 82 mr. The probability that a two-photon event will produce an electron in the SAT ranges from 7% to 12% per side, depending upon the minimum photon energy allowed by the constraints of the physics and the remainder of the detector.

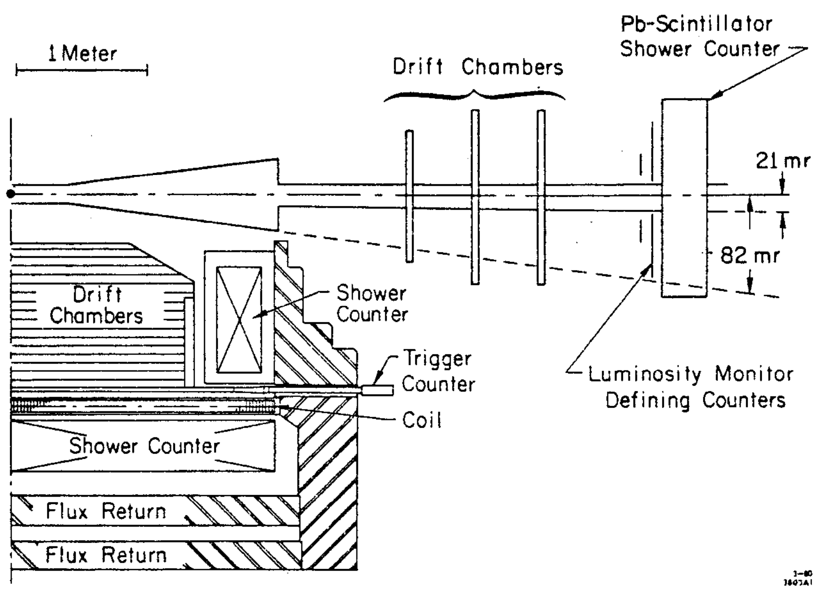

Fig. 1 Sliced view of the Mark II detector. The muon detection system is not shown, nor is the inner tracker drift chamber.

The Mark II trigger is expected to be a logical combination of information acquired from the separate subsystems of the detector. On each beam crossing the drift chamber electronics produces a fast count of the number of charged tracks. The liquid argon signals are summed to give the total energy deposited in each of the modules, and a count of the number of modules with energy exceeding a fixed threshold is determined. The SAT shower counter signals are also discriminated and made available to the trigger logic. The trigger logic itself is fully programmable and can produce a trigger on any combination of subsystem signals. This situation is typical of the large detectors used at e^+e^- storage rings.

Most of the two-photon processes that produce hadrons in the final state can be normalized to the QED process $ee \to ee\mu\mu$. The visible cross section for this is calculated[2] to be 4.4nb at a beam energy of 15 GeV. "Visible" events are those that result in two final state muons, both at $\theta > 45°$ and both with transverse momenta greater than 100 MeV. To properly separate the μ-pair final state from other two-prong events it is necessary to require that the mass of the pair exceed approximately 1.4 GeV. This effectively reduces the detectable cross section to about .2nb, or a rate of .002 Hz. It may prove impossible to operate the detector with a two-prong trigger due to large background rates. If this is the case then the SAT trigger will provide a sample of two-prong events but with a corresponding reduction in event rate.

Detection of resonance production by $\gamma\gamma$ collisions can, in principle, be done in two ways. Either the decay products of the resonance can be detected, or the existence of the resonance can be deduced by detecting both of the final state electrons. The resolution in the $\gamma\gamma$ center of mass energy provided by the Mark II SAT is $\sim$700 Mev, which implies that the detection of a narrow resonance must be done by reconstructing the decay products. The kinematics of the two-gamma process are perhaps best thought of in terms of the longitudinal rapidity variable y ($\equiv \frac{1}{2} \ln (E+p_L) / (E-p_L)$). The length of the rapidity spectrum of hadrons produced in a $\gamma\gamma$ collision is given by $\ln (s/m^2)$, where $s = 4E_b{}^2$ is the maximum $\gamma\gamma$ c.m.s. energy, and m is the effective mass of the produced final state. A central detector like the Mark II is limited to a fixed rapidity interval ΔY ($\sim$1 unit for the Mark II), and so the acceptance of the detector scales as $(\Delta Y / \ln (s/m))$. This effectively nullifies the energy dependence of the production cross section $\sigma \sim (\ln (E/me))^2 (\ln s/m^2)$. For example the Mark II has been used at SPEAR to detect the production of the η' (958) by two photons. An integrated luminosity of 18 pb^{-1} resulted in $\simeq$ 70 detected η's. At a beam energy of 15 GeV an integrated luminosity of 18 pb^{-1} will yield $\approx$100 detected η's.

The need to reconstruct a decay mode of a given resonance makes it difficult to detect higher mass states with a central detector. If, for example, the charmed pseudoscaler η_c has a 10% branching fraction into a decay mode that, in turn, is detected 1% of the time, then

50 pb^{-1} will result in only 2-3 detected events. The decay mode $\eta_c \rightarrow 4\pi$ will have a detection efficiency of about 5% at a beam energy of 15 GeV, and substantial improvement cannot be made without increasing the solid angle acceptance of the detector.

Gamma-gamma collisions that proceed through a hard-scattering subprocess are expected to provide interesting tests of models of hadronic interactions, and perhaps ultimately, tests of QCD.[3] These processes are experimentally accessible through the detection of high transverse momentum hadrons, either single particles or multiparticle jets. The simple point coupling of the photon to quark lines, shown in Fig. 2a, will produce hadronic jets with a power law P_T^{-4} behavior. Fig. 2b is

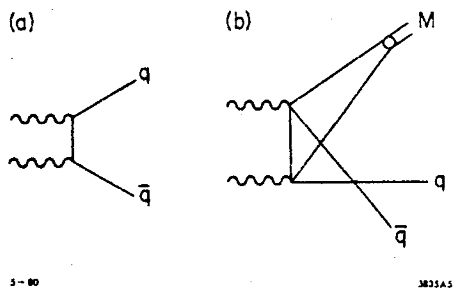

Fig. 2 a) Point coupling of photons to fermions. b) Constituent interchange diagram that results in a single meson at high transverse momentum balanced by an opposing quark jet.

an example of a proposed[3a] constituent-interchange process (CIM) that would result in a cross section characterized by P_T^{-6}. Shown in Fig. 3 is the number of untagged events that produce jet pairs within the acceptance of the Mark II as calculated with the model of Ref. 3a. Experimentally it will almost certainly be necessary to work with tagged events in order to eliminate backgrounds from radiative annihilation events. This will result in a reduction in the number of events by a factor of four to five, and thus, only a few events are expected at $x_T > 0.4$. Reconstruction of

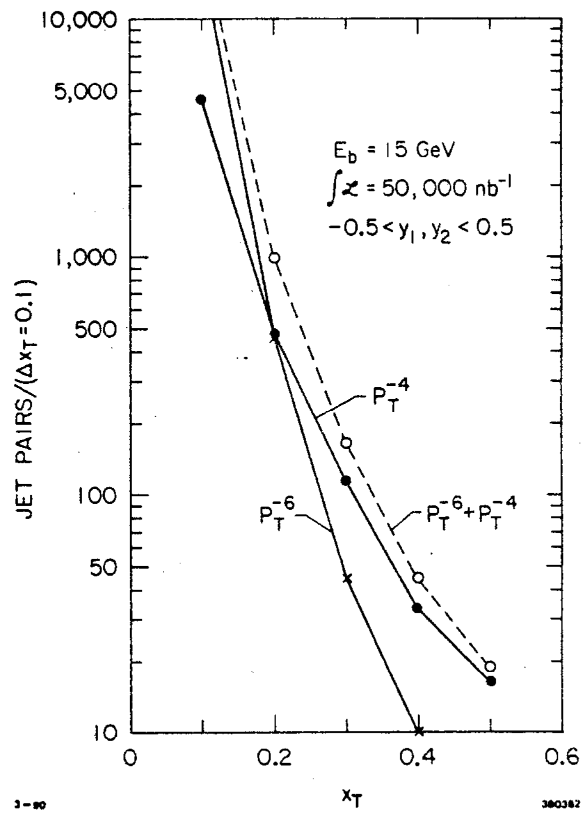

Fig. 3 Jet production by gamma-gamma collisions. The number of untagged events that produce a pair of jets within the acceptance of the Mark II is shown as a function of scaled transverse momentum.

individual jets produced at x_T below 0.4 will become increasingly difficult, and so, the analysis will probably proceed by measuring the distribution of a sphericity-like variable, and then making comparisons to Monte Carlo calculations based on various models. This is similar to the problem of finding jet signatures in e^+e^- annihilation events at SPEAR.

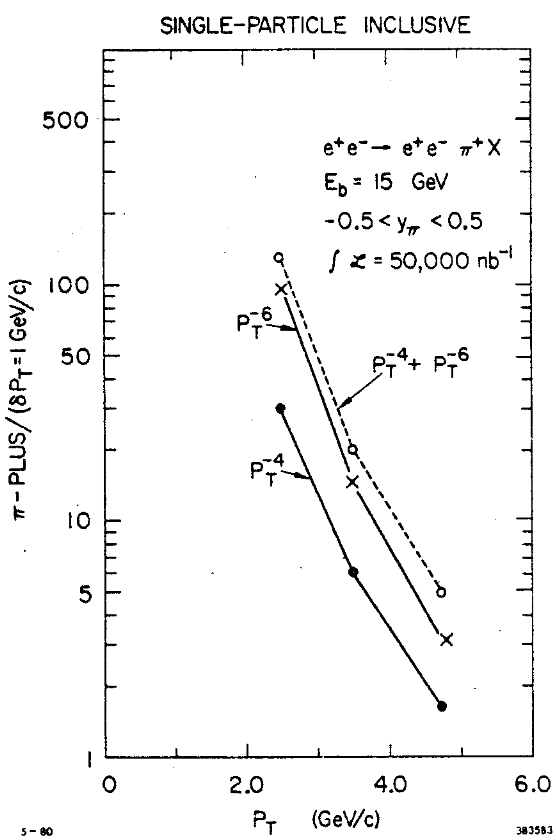

Fig. 4 Single pion production at high transverse momentum. Untagged event yields are shown for the production of π^+. Neutral pions and π^- will be produced at the same rate.

Detection of single particles at high transverse momentum is, of course, free of the reconstruction problems inherent to jet studies, but at a given P_T the event rates are lower. Shown in Fig. 4 is the single π^+ untagged yield within the Mark II acceptance as taken from Ref. 3a. The tagged fraction is approximately 20%, which means that events at $P_T > 3.0$ GeV will be scarce. Nevertheless, yields at lower P_T become quite large and studies of these inclusive cross sections should be a basic measurement made by the central detectors at PEP.

A Large Solid Angle Calorimeter: MAC

A section of the Magnetic Calorimeter (MAC) is shown in Fig. 5. This detector is capable of hadron calorimetry ($\sigma \simeq 55\%/\sqrt{E}$) for polar angles larger than 10° and electromagnetic calorimetry ($\sigma \simeq 18\%/\sqrt{E}$) at $\theta > 30°$. Muons with momenta greater than 1 GeV are identified by counters external to the calorimeter. Initially only a luminosity monitor will be available for detecting electrons near the beam pipe. The tagging fraction is ~1-2%.

MAC is a large-acceptance, relatively homogeneous detector that is probably best suited to measure the total hadronic $\gamma\gamma$ cross section. This cross section is a fundamental parameter of $\gamma\gamma$ physics, yet it is quite difficult to properly measure. MAC represents a significant

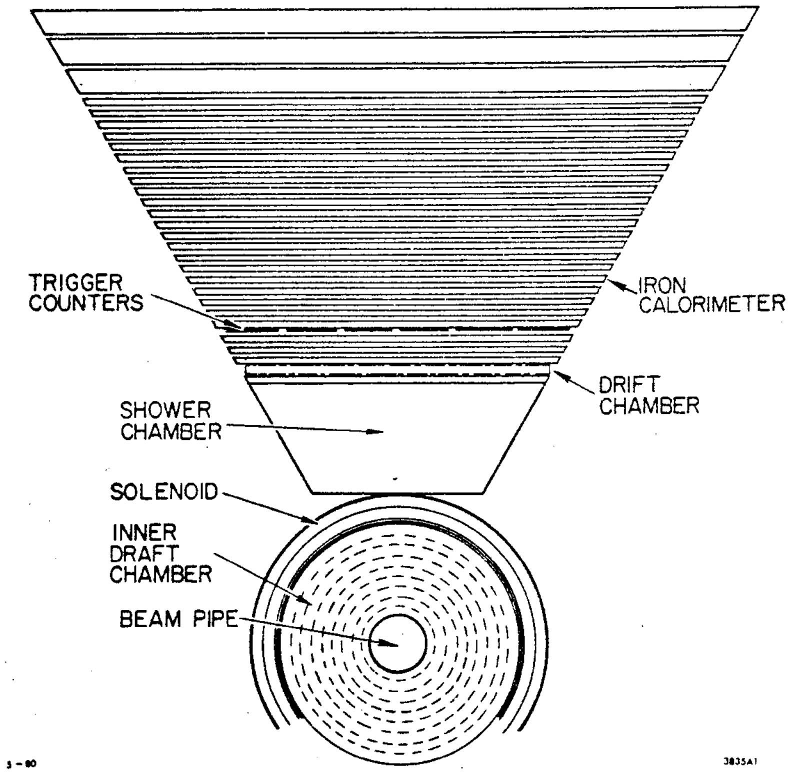

Fig. 5 Sliced view of one section of the MAC calorimeter. The outer muon detection system is not shown.

increase in total acceptance relative to the more conventional solenoidal detectors, and a significant improvement in calorimetry can be expected even for the forward-peaked two photon process.

A Dedicated Detector: Two Gamma

The Two-Gamma small angle spectrometer[4], shown in Fig. 6, has been designed to specifically study the two-photon process. The detector includes the angular region from 21mr to 180mr in both the forward and backward directions. Taken in combination with the TPC solenoid, the solid angle coverage is essentially complete. (Neither detector covers the range $180\text{mr} \lesssim \theta \lesssim 240\text{mr}$.)

Septum magnets with $\int B \cdot dl = 3$ kg · m and drift chambers measure charged particle momenta with $\delta P/P \lesssim 1\%$ for momenta below 3 GeV/c. The bulk of the hadrons that enter the spectrometer are expected to have momenta in this range. Time-of-flight hodoscopes provide 3σ separation of π's and K's up to momenta of 1.7 GeV/c, and K/p separation up to 2.8 GeV/c. At angles between 21mr and 100mr, arrays of sodium iodide crystals are used to measure electron energies ($\sigma \simeq 1\% / E^{1/4}$); Pb-scintillator shower counters ($\sigma \simeq 12\%\sqrt{E}$) provide electromagnetic calorimetry at larger angles (100mr-180mr).

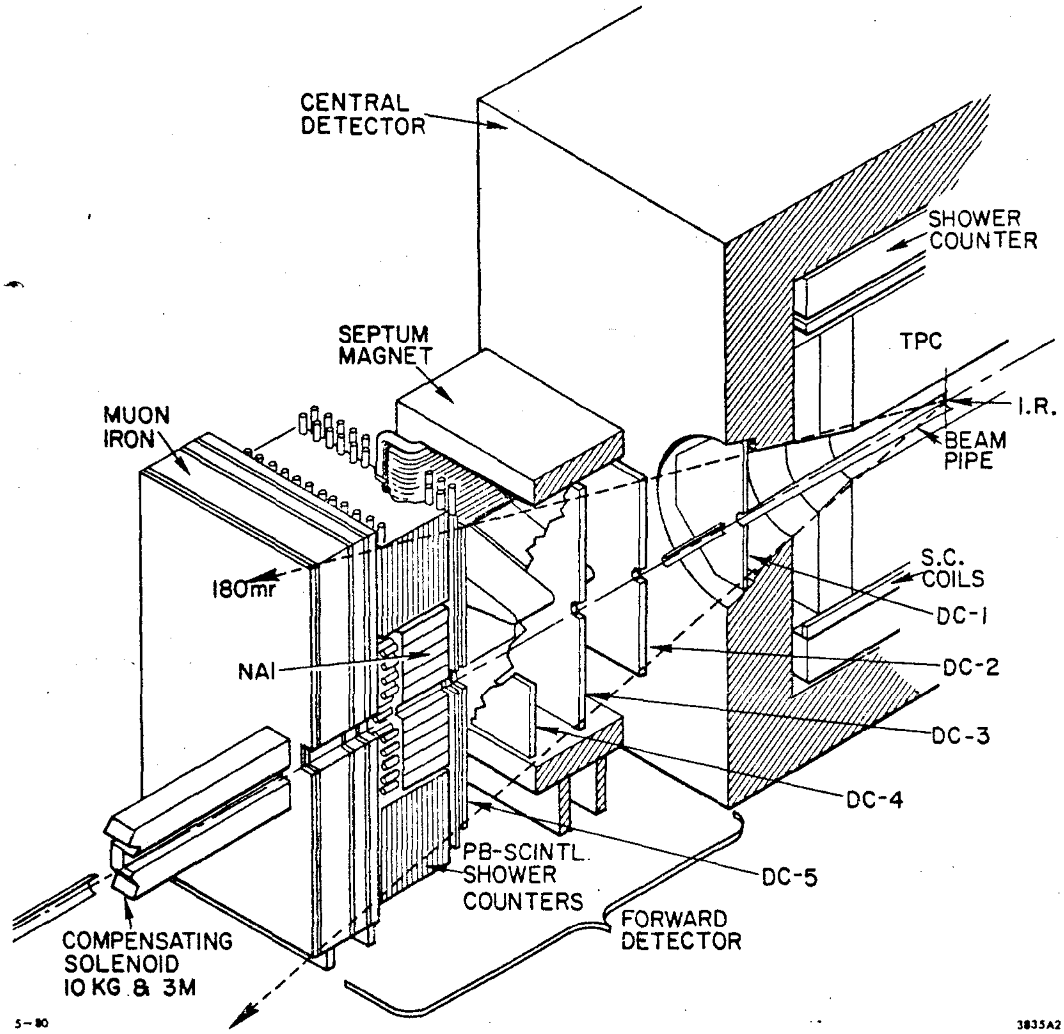

Fig. 6 The Two-Gamma forward spectrometer. Also shown schematically is the TPC solenoidal detector. There are two arms to the spectrometer, one on each side of the central detector.

Identification of muons with momenta greater than 1 GeV is done in more or less standard fashion with drift chambers embedded in iron absorber. The pion misidentification is 1% at momenta of 3 GeV/c.

Obviously the $\gamma\gamma$ physics that can be studied with these detectors includes as a subset the physics that has been discussed in the previous sections. I will therefore limit the following discussion to those features that are unique to the Two Gamma/TPC combination. Particularly of interest is the resolution of the NaI and the detection of particles in the angular range below θ = 180mr.

The NaI measures the $\gamma\gamma$ c.m.s. energy of doubly tagged events with a resolution $\sigma_{m_x} \sim 150$ MeV. This is sufficient to detect a heavy resonance by searching for a peak in the missing mass m_x. Figure 7 shows the signal that can be expected[4] from a narrow resonance with mass of either 2.85 GeV or 6.0 GeV and with a partial width $\Gamma m \to \gamma\gamma = 13$ keV. In the case of the 2.85 GeV state, an integrated luminosity of 50 pb^{-1}

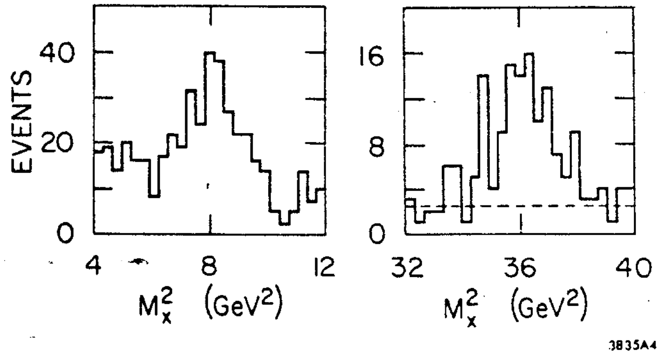

Fig. 7 Detection of heavy resonances using the Two-Gamma sodium iodide shower counters. (a) Signal expected from a 2.85 GeV resonance, and (b) a 6.0 GeV resonance. The plots are calculated for an integrated luminosity of 100 pb^{-1} and only events in which both photon energies exceed 5% of the beam energy have been included. This last requirement improves the resolution of the $\gamma\gamma$ CMS energy, but reduces the total event rate.

will yield about 50 events over a background of 75 events. As was discussed earlier, the efficiency for detecting light mass resonances by a central detector decreases with increasing beam energy. The addition of the small angle spectrometer to the central TPC will permit a careful study of the production of low mass states.

Observation of the production of heavy leptons produced by two photon collisions is an extremely interesting possibility. The decays of the leptons will result in a significant amount of energy loss to neutrinos. Events of this type can be observed if both of the beam electrons are detected in the NaI; a comparison of the $\gamma\gamma$ CMS energy M_x with the total energy visible in the remainder of the detector M_{vis}, will show a neutrino signature if $M_x >> M_{vis}$. The rate of tau production by $\gamma\gamma$ collisions, for example, is expected[2] to be equal to the corresponding rate in the annihilation process at a beam energy of 15 GeV. The nominal 50 pb^{-1} experiment would result in approximately 50 doubly tagged $\gamma\gamma \to \tau^+\tau^-$ events. Since most of the events are produced near threshold (because of the falling $\gamma\gamma$ energy spectrum), then a relatively clean signal should be seen. Searching for new particles in this manner has the feature that the entire energy range of the machine is scanned at one time. One is faced, however, with the need to detect the beam electrons and with the fact that nearly 4π calorimetry is necessary to eliminate backgrounds.

The photon structure function $F_2^\gamma\,(x,Q^2)$ has been calculated exactly to leading order in QCD, and estimates of higher order contributions have been carried out.[5] In contrast to hadronic structure functions, it is predicted that F_2^γ will be essentially constant over the range $.3 \lesssim x \lesssim .7$, for fixed Q^2. Furthermore, F_2^γ is expected to violate scaling with a factor of $\ln Q^2$ (i.e., $F_2^\gamma \sim \ln Q^2 \cdot f(x)$). Experimentally, however, measurement of this quantity is quite difficult. It is necessary to isolate events in which one of the photons is far off the mass shell. The energy of the target photon must be reconstructed, and the scattered electron must be detected and identified. To eliminate backgrounds from radiative Bhabha events it will also be important to detect at least one other produced particle. A parton-model estimate[4] indicates that with the Two Gamma/TPC detectors a luminosity of 50 pb^{-1} will result in a hundred or so events at $Q^2 > 3$ GeV and $x > 0.3$. Only a few events can be expected at $x > 0.7$. These are clearly low yield experiments and will require optimal beam conditions in order to be successful.

Comments

Two photon collisions will be a copious source of events visible to the detectors at PEP. Experiments will be difficult, however, and in many cases machine luminosities that are near to design specifications will be required. Despite nearly ten years of simmering theoretical discussion, experimentally the field is still largely unexplored. PEP and PETRA are perhaps the ideal locations to begin serious studies of gamma-gamma interactions.

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