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SEARCH FOR HIGH ENERGY MULTIGAMMA EVENTS; POSSIBLE CONSEQUENCE OF MAGNETIC MONOPOLE PAIRS OR OF HIGH Z LEPTONS

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I. INTRODUCTION

Several cosmic-ray experiments involving the exposure of photographic emulsions at high altitudes have shown the existence of high energy multi-gamma-ray events.[1] These events could not be accounted for by conventional electromagnetic showers originating from a single high energy gamma. Rather they appear to be a result of a large number of gammas produced simultaneously from a single interaction. These events remained a mystery for a number of years until recently when Ruderman and Zwanziger[2] put forward a plausible explanation which attributes these high energy multi-gammas as due to the creation and subsequent annihilation process of magnetic monopole pairs. The important point, which has been emphasized by Ruderman and Zwanziger and also by Teller,[3] is that when a pair of monopoles are produced they will rapidly annihilate ($t \sim 10^{-22}$ sec) due to the very strong coulomb attraction and will leave behind remnant photons. The multiplicity of these photons is expected to be large ($\sim 1/\alpha$). Therefore, with energies available at ISR, the production of free monopole pairs would be less probable than the characteristic annihilation processes, either real or virtual. Very recently, T. D. Lee[4] suggested that another possible process which involves the creation of pairs of highly charged leptons ($Z > 10$) can also be responsible for these multigamma events discussed above. In fact, any charged particle with a very strong electromagnetic coupling would yield such events.[4] In the event obtained by deBenedetti, there were 14 gammas with a total energy of > 40 GeV.

The primary objective of the present proposal is to search for high energy multigamma events at the ISR and to study the characteristics and nature of these multigammas in order to gain a better understanding of the origin of such processes. We would also try to ascertain whether or not magnetic monopoles or high Z leptons are responsible for them.

A secondary objective is to simultaneously search for individual monopoles that might be created by the colliding beams.

II. THEORETICAL DISCUSSIONS

A possible mechanism for the production of high multiplicity γ-ray events in proton-proton collisions is the following process:

$$p_1 + p_2 \rightarrow \text{hadrons} + \gamma' \quad , \tag{1}$$

$$\gamma' \rightarrow n\gamma \tag{1'}$$

In Eq. (1), p_1, p_2 are colliding protons and γ' is a time-like virtual photon with momentum q which subsequently decays into $n\gamma$. A possible Feynman diagram for γ' is shown in Fig. 1.

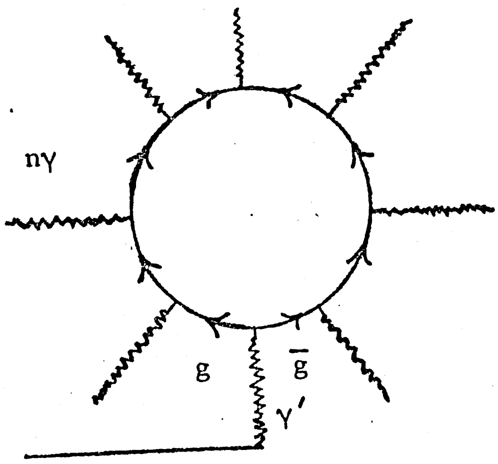

Fig. 1

The particle, g, propagating around the loop in Fig. 1 is presumed to have a very strong interaction with the photon field ($g^2/\hbar c \sim 1/\alpha$) so that the photon multiplicity which is proportional to $g^2/\hbar c$ is large. It is important to note that this effect can be felt even below threshold for g, $\bar{g}$ production. The most obvious candidate for g is the Dirac magnetic monopole which has been shown by Dirac to have a coupling strength of $\frac{1}{\alpha}\frac{n^2}{4}$ where n is an integer. However, as mentioned previously, a highly charged lepton or any particle with a similar very strong electromagnetic interaction will yield a multigamma event.

The expected average energy and angular distribution of the $n\gamma$'s is derived by assuming that the photons are isotropic and of equal energy in the rest frame of the virtual photon. Transforming to the center of mass of the colliding protons (which is essentially the lab frame for ISR) yields the laboratory energy and angular distribution of the photons for various values of q^2. We will examine large $-q^2$. However, we do not necessarily require $-q^2 \geq 4m^2{}_g$ which is the threshold for g, $\bar{g}$ production since the effect can be felt for $-q^2 < 4m^2{}_g$ and in fact the transition from below threshold to above threshold may only involve a cusp effect in the nγ cross section and would not necessarily imply a significant enhancement of the nγ cross section. The expected energies of the photons will be from a few hundred MeV to a few GeV. These photons will be distributed over a significant part of the available 4π geometry. In particular, at the maximum q^2 they will be distributed isotropically. For lower values of q^2, some collimation about one of the protons is expected with half the photons in a narrow cone ($\tan\theta \sim 1/\gamma\beta$ where β is the velocity of the $q \geq 0$ frame and γ the corresponding Lorentz factor), and the rest in a diffuse cone. It is clear that for large $-q^2$, these cones cover a large solid angle. We would expect these cones are appreciably larger than the cones for pion production.

If these multigamma events are seen, then the question arises as to whether they are induced by magnetic monopoles or by particles such as leptons with high Z. The angular distribution could be an important factor in answering this question since the parity of a photon emitted by a monopole is opposite to that of a photon emitted by a particle with an electric charge. Therefore the photon propagator between the proton and the monopole in the loop will lead to pseudoscalar terms in the differential cross section. This should lead to a different angular distribution of multigammas induced by monopoles than for multigammas induced by high Z leptons.[5]

There is no way of reliably estimating the cross section for the process under investigation. The process (1) has been studied theoretically and experimentally, though not at the energies and q^2 values available at ISR.[6-8] For (1′) there is no way of obtaining a reliable estimate because of the large coupling. Therefore, for the purposes of estimation, we will assume that:

$$\frac{d\sigma_{g\bar{g}}}{dq^2}(q^2,E)_{(\text{real, virtual})} \sim K\frac{d\sigma_{\mu^+\mu^-}}{dq^2}(q^2,E) \qquad (2)$$

where K is a constant. Equation (2) takes into account the hadronic structure and the constant K is the ratio of the coupling $[(\gamma' \rightarrow g\bar{g})/(\gamma' \rightarrow \mu^+\mu^-)]^2$. If we interpret these couplings as dissociation probabilities as suggested by Goto,[9] then the maximum value of K is $1/\alpha$. Therefore, the total cross section for $n\gamma$ production would be 10^{-36}cm^2 for $-q^2 > 25(\text{GeV})^2$. However, we believe that this restriction on K by Goto, which is supposed to follow from some sort of unitary argument may not be justified. Therefore, it may be more appropriate to use the elementary coupling for K; then K would be $1/\alpha^2$ and the cross section would be 10^{-34}cm^2.

III. EXPERIMENTAL PROCEDURE

a) Detection of Multigamma Events

The basic requirement of our detection system is the capability to distinguish between a multigamma event and conventional high energy showers such as those from the decay of multiple π^0's. The former is characterized by the simultaneous appearance of a large number of energetic showers, while the latter is characterized by showers accompanied by a number of charged particles. Furthermore, in the case of showers from π^0's, the average pion transverse momentum is restricted, therefore, the angular distribution of these showers can be quite different from that of the multigamma events. Our detection system is designed to record the development of each shower by measuring the energy deposition during its development.

A sketch of our detector system showing both the plan view and the side view is shown in Fig. 2. The sketch is approximately in scale and the dimensions of the detector units are indicated. A cross-sectional view of the detector unit is shown in Fig. 3. The detector unit is designed to make sure that the showers due to incident photons are developed in the lead glass. The first two layers of the detector unit are thin scintillation and Cerenkov counters. The main portion of the detector unit consists of wire proportional chambers interspersed with lead-glass hodoscope elements (2" x 4" x 20" or 4" x 4" x 20") with the exception that W_c and W_t are chambers operated in the saturated mode. The total thickness of each detector unit is ~ 20" providing a total of 16 radiation lengths of lead glass. The detector arrangement shown in Fig. 2 consists of ten such units, which covers 60% of total solid angle.

The occurrence of multigamma events is established by the requirement that at least 24 wires among the chambers W_t in all units fire (equivalent to ~ 24 or more simultaneous gamma rays). Chambers W_c identify the number of charged particles and veto the system when there are more than several charged particles. The normal π^o background events are rejected by W_c, because they always are accompanied by charged particles (see Appendix). Wire chambers determine the positions of the showers, whereas the lead-glass counter hodoscopes together with wire chambers determine the energy of each shower. The scintillation counter S and wire chamber W_c monitor the incident charged particles. A block diagram of the logic system is shown in Fig. 4. Chambers W_c and W_t in coincidence give an event signal to trigger the system. The number of charged particles and gammas are registered in shift registers. Pulse height and position information from counters and chambers are obtained with sample-and-hold units, analogue multiplexer and analogue-to-digital converter.

A high multiplicity π^o event could be confused with a monopole induced multigamma event. This background can be reduced by restricting the charge multiplicity to as small a value as possible while at the same time setting the threshold for γ multiplicity to a high value such as 24 (actually the expected multiplicity is $\sim 1/\alpha$). We assume the hadron multiplicities obey Poisson distributions. The average π^o, π^+, π^- multiplicity is approximately 6 at ISR energies. The probability for producing the average number of π^o's and no charged particles is down by a factor of 10^{-4} from the probability for producing the average number of charged particles. In addition, the probability of producing $12\pi^o$ is 10^{-3} times the average. This provides a total factor of 10^{-7} or a cross section of $3 \times 10^{-33} cm^2$. Of course, this cross section is rapidly reduced even more when multiplicities greater than 12 are considered. A detailed discussion of this matter is given in the Appendix. In addition, we shall observe mostly large angle high multiplicity γ events. Since the average pion transverse momentum is restricted, the selection of large angle events reduces the background by an additional estimated two orders of magnitude. Therefore, a rejection ratio of 10^9 should be readily obtainable. This is the case assuming a significant percentage of the monopole induced γ's occur at large angles. In a careful data analysis, additional background rejection can be obtained.

The number of π^o background events is expected to decrease rapidly as the number of π^o's increases. An enhancement at a large number of simultaneous showers (> 24) would be a strong indication of the existence of multigamma events.

The cross section for pp interactions is $\sim 30 \times 10^{-27} cm^2$. Therefore, the average event rate is 10^5/sec. Since the time resolution of our system is $\sim$ 10 nsec, the probability of having several pp interactions within this time resolution is very small. (The probability of having even two pp interactions within the time resolution is down by a factor of 10^3.) The trigger conditions mentioned in section 2 will reduce this probability by an additional factor of 10^9. Background events due to gas scattering are estimated to be lower than the π^0 background and also these gammas are of very low energy.

Particles incident from directions other than that of the interaction region could be rejected by monitoring anticounters positioned around the detector.

b) Free Monopoles

It is less probable to produce free monopoles than a monopole pair which annihilates immediately. However, if a free monopole is produced with sufficient momentum and if thin windows can be provided it can pass through the vacuum chamber and give a large signal in the thin scintillation and Cerenkov counters. The ratio of these two signals is different for a monopole and high Z particle.[10]

IV. EXPECTED EVENT RATES

With the design luminosity of $4 \times 10^{30} cm^{-2} sec^{-1}$, the number of multigamma events per day is

$$N = L\sigma t = 3.5 \times 10^{35} \sigma \qquad (3)$$

where σ is the total cross section for multigamma production and t is the time in seconds.

If one assumes a production cross section of $10^{-36} cm^2$ as derived from Goto's argument and a collection efficiency of 75%, then one can expect to obtain approximately 30 events in 100 days. However, if one assumes a production cross section of $10^{-34} cm^2$, which we do not feel is unreasonable, then one would expect to obtain 3000 events in the same period.

V. CONCLUSION

The proposed experiment will enable us to obtain quantitative information on the production of energetic multigamma events in p-p collisions in an energy region attainable previously only in cosmic radiation. The meager data obtained in cosmic ray experiments shows the existence of anomalous energetic multigamma rays which can be attributed to the creation and subsequent annihilation of magnetic monopole pairs or high Z lepton pairs. In fact, as recently suggested by T. D. Lee, it is even possible that these anomalous multigamma events could be attributed to a hadronic reaction in which a particle excited to an extraordinarily high angular momentum state is produced and subsequently decays stepwise with the emission of many gamma rays. Certainly this domain is completely unexplored and it would be very important to have quantitative information on multigamma events in p-p collisions. Furthermore, the necessity of understanding the background produced by the decay of multiple π^0's will provide us with information concerning the correlation mechanism in pion production.[11]

APPENDIX

THE π^o BACKGROUND PROBLEM

Because of the fact that the multi-γ production rate in p-p collisions could be quite small ($\sigma \sim 10^{-34} cm^2$), it is necessary to estimate the production rate of high multiplicity π^o events because of their prompt decay into 2 γ-rays they could be confused with monopole induced multi-γ events. We first must choose a reasonable model for pion production in p-p collisions since there is at present very little reliable data on high multiplicity π^o events. In general, if there is some simple dynamical mechanism operating in the production of pions (as we would certainly expect), then there would be strong correlations between the number of π^o and π^+, π^- mesons in a p-p collision. For example, if pions were produced via emission and decay of ρ mesons, there would be no way of producing a large number of π^o's with no accompanying charged pions. Therefore, to cut down the number of high multiplicity π^o events, the total charge of the collision process should be restricted to as low a value as possible (e.g. 2e). We next discuss the reduction in π^o background which ensues.

Recently, the multiperipheral model has had considerable successes in predicting multiplicities of pion production reaction.[12] This model predicts a Poisson distribution for pion multiplicities. A logical extension of this model, constructed by Caneschi and Schwimmer,[11] is to correlate π^o, and π^+, π^- multiplicities by assuming the pions are produced by the decay of ρ mesons and σ mesons emanating from the multiperipheral chain. The production of ρ's and σ's follows the Poisson distribution law. Under these assumptions, the cross section for producing N π^o mesons with no accompanying charged mesons is given by

$$\sigma = \frac{\sigma_o \left(\frac{1}{3}\right)^{N/2} \left(\frac{\bar{N}}{2}\right)^{N/2} e^{-3\bar{N}/2}}{\left(\frac{N}{2}\right)!} \qquad \text{(A)}$$

In Eq. (A), σ_o is the total inelastic cross section (~ 30 mb), $\bar{N}$ is the average π^o multiplicity (which is ~ 6 at ISR energies) and N is the number of π^o mesons produced in a specific event. Equation (A) is essentially the production cross section for N/2 σ mesons via the multi-peripheral model multiplied by the probability for each of these σ's to decay into $2\pi^o$'s [~ $(1/3)^{N/2}$]. In Table I the ratio σ_N/σ_o is calculated for several π^o multiplicities. It is important to note that the numbers in Table I decrease very rapidly with increasing N . They can be reduced further by looking for wide angle γ's since the π^o mesons should be collimated due to expected factors of the form $e^{-P_\perp/P_\perp^o}$ in the differential cross section for π^o production where $P_\perp$ is the transverse momenta and $P_\perp^o$ ~ 150 MeV. If the monopole-induced multigamma events are produced with a cross section in the range 10^{-34} - 10^{-36} cm^2 it would seem that a multiplicity distribution, peaking somewhere around N ~ 100, should clearly be visible above the π^o - γ background. (See Fig. 5.) Here the broken line shows the total π^o - γ background, whereas the dotted line shows the π^o - γ background for angles greater than 20^o with respect to the proton direction.

TABLE I

$\frac{\sigma_N}{\sigma_o}$	N (No. of π^o's)
1.7×10^{-7}	12
3.0×10^{-10}	16
3.3×10^{-12}	20
2.5×10^{-14}	24
1.37×10^{-16}	28
5.7×10^{-19}	32
1.9×10^{-21}	36
5.0×10^{-24}	40
1.1×10^{-26}	44
2.0×10^{-29}	48
3.1×10^{-32}	52

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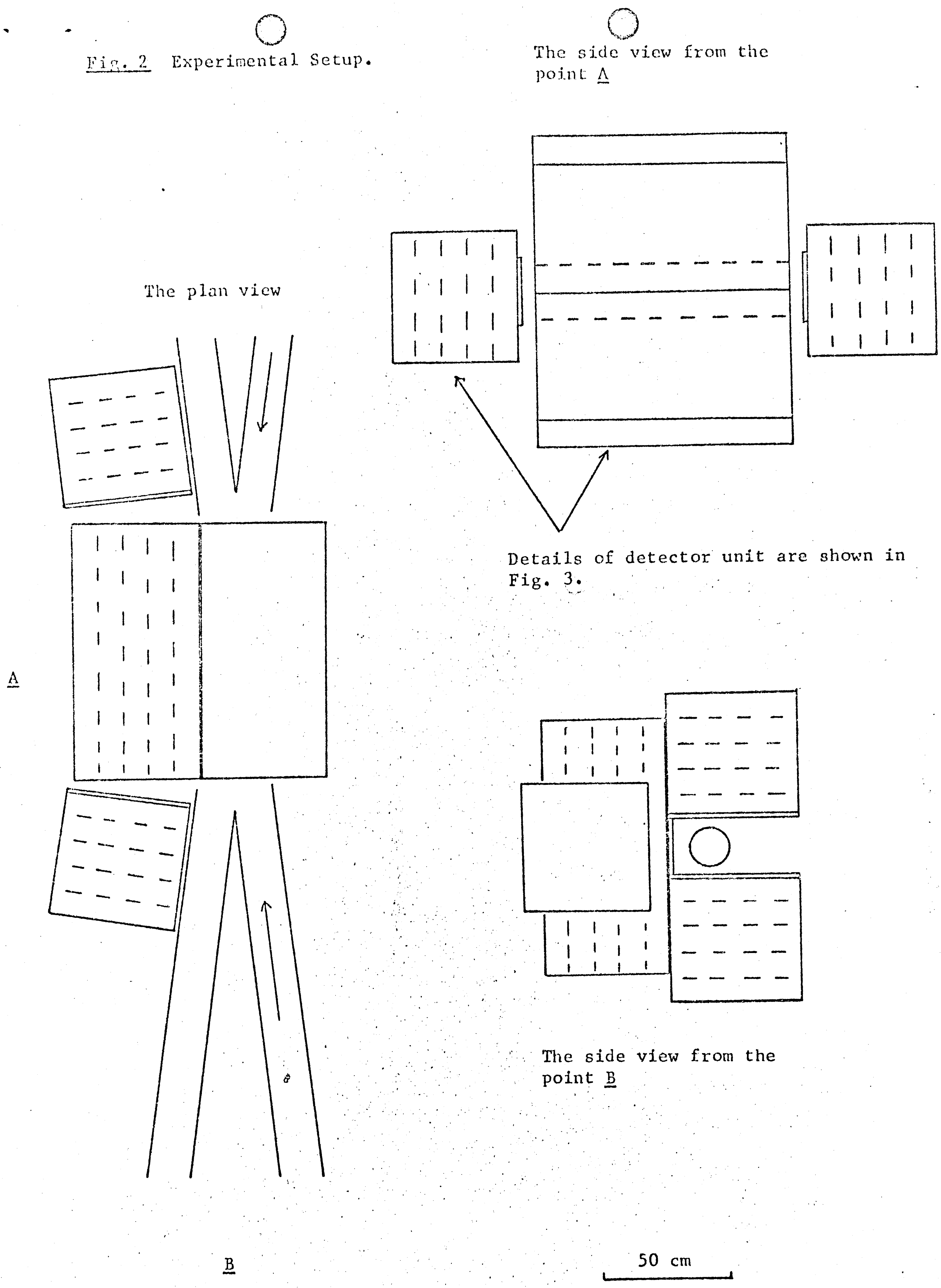
Fig. 2 Experimental Setup.



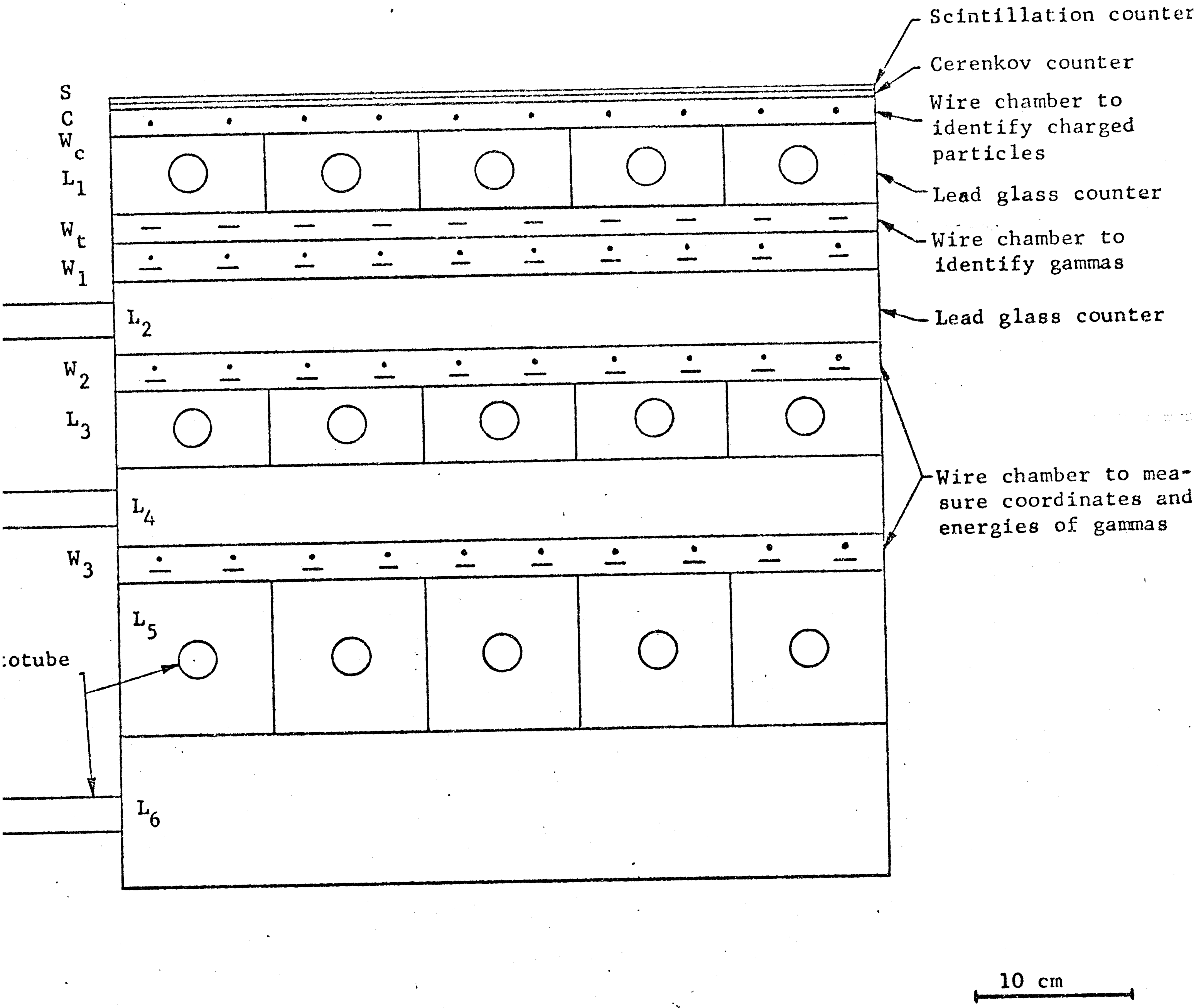


Fig. 3 Details of the detector unit.

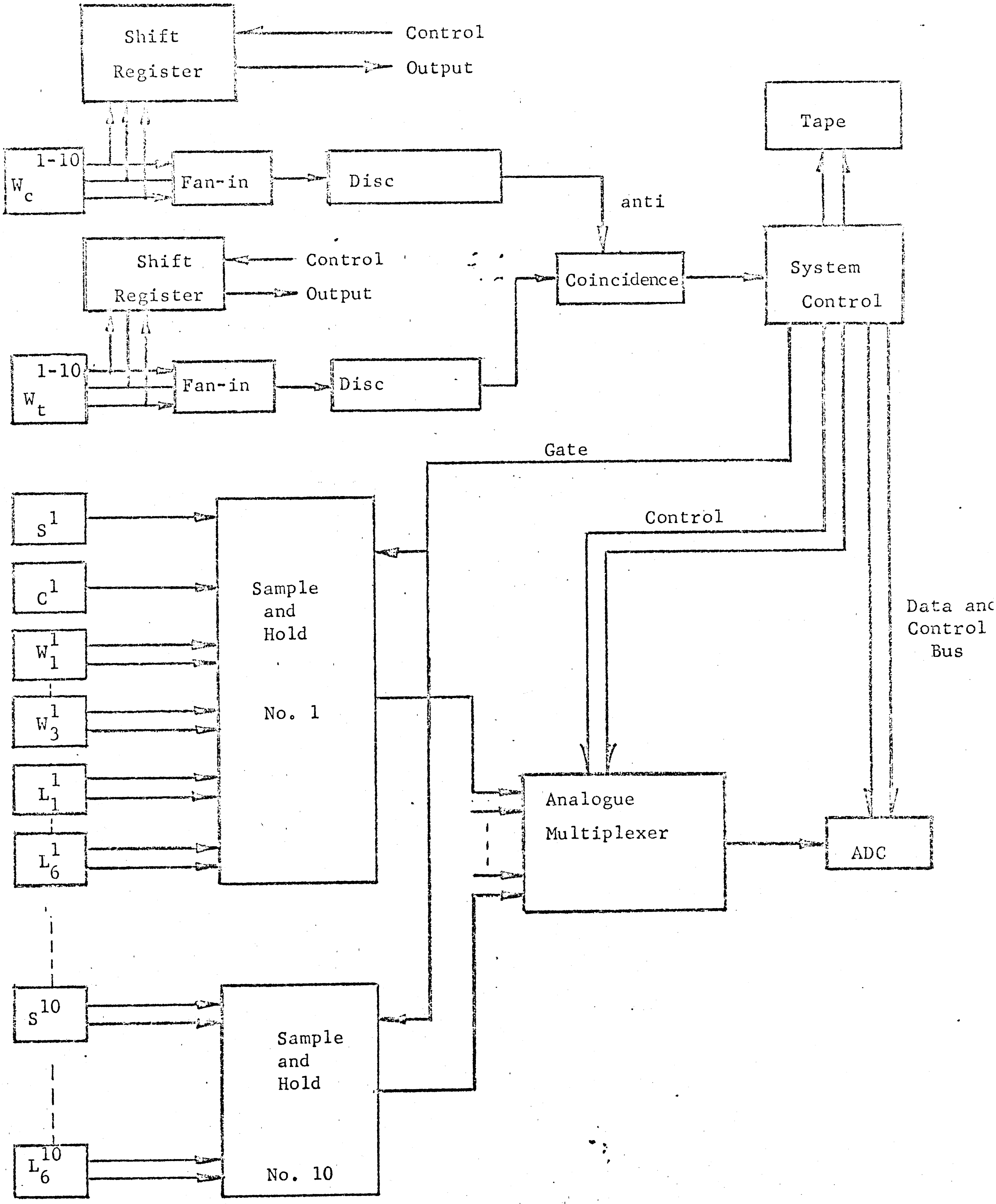


Fig. 4 Electronics Block Diagram.

Fig. 5. Distribution of Multiplicity $\sigma_{g\bar{g}} = 10^{-34} cm^2$, $P(N\gamma)$ = Poisson Distribution.