FUF-75-171-E
T-0230

#230

UM HE 75-9
FERMILAB-PUB-75-171-E

Search for Anomalous Multiphoton Production at Fermilab Energies*

David L. Burke, H. Richard Gustafson
Lawrence W. Jones and Michael J. Longo

University of Michigan
Ann Arbor, Michigan 48104

Abstract

We have carried out a search for anomalous multi-photon production in n-nucleus collisions at Fermilab energies. A detector consisting of a lead converter placed between two wide-gap optical spark chambers was used to detect photons produced by neutrons incident on a CH_2 target. A search was made for anomalous events with relatively large opening angles as might be produced in the annihilation of a magnetic monopole pair, as well as events with extremely small opening angles, such as those observed by Schein *et al.* and others in emulsions exposed to cosmic rays. No evidence for anomalous multigamma production of either type was found. An upper limit $\approx 2.7\ \mu b$ is placed on the cross section for producing "Schein" events by neutrons which is $\sim 10^{-2}$ that deduced from the cosmic ray measurements.

*Work supported by U.S. National Science Foundation.

Numerous searches for free magnetic monopoles have all yielded negative results and have set extremely small upper limits on monopole production cross sections.[1,2,3] It has been suggested, however, that due to the long-range strong magnetic force between a pole and an antipole the production of a pole pair would be followed by their annihilation into a large number of photons. The number of photons produced depends primarily on the magnetic pole strength g, which must be quantized so that

$$eg/\hbar c = n/2 \ , \quad n = 1,2,3,.... \qquad (1)$$

Ruderman and Zwangiger[4] have suggested that the annihilation of magnetic monopole pairs produced by high-energy photons provides a possible explanation for several anomalous jets of pure photons observed in emulsions exposed to cosmic rays.[6,7,8,9] These events, first observed by Schein et al.,[6] have several peculiar properties, notably their high degree of collimation, lack of charged particles, and the large number of photons produced. Their properties are summarized in Table I.[10] Using the dimensions of the emulsion stacks, times of exposure, and altitudes of flight, we can estimate the cross sections for Schein event production by cosmic photons as well as by neutrons produced in the atmosphere. For production by photons of $E \geqslant 100$ GeV we obtain a cross section ~3 mb per nucleon. The cross section for production by neutrons is ~0.3 mb per nucleon.[11]

The experimental arrangement used in this search is shown in Fig. 1. A neutron beam[12] with a maximum energy of 300 GeV (most probable energy ≈240 GeV) was incident on a 6.8 cm thick CH_2 target. Charged particles and photons were detected by a wide-gap optical spark chamber array downstream of the target. The spark chambers had an active area of 1 m^2 and each consisted of two 15 cm gaps. The chambers were each terminated by 1 kΩ and pulsed by separate Marx generators to nominally 130 kV.[13] A lead converter 6.4 mm thick between the 2nd and 3rd gaps covered the active area of the chambers except for a 2.5 cm D. hole centered on the beam. Immediately behind the lead was a set of trigger counters whose total thickness was 3.8 cm. Thus there was a total of 1.22 rad. lengths of material between the spark chambers.

One side view of all four gaps was photographed as well as a 90° stereo view of the central 50 cm of the first gap. On the same 35 mm film frame, a "beam's eye" view of the last gap was obtained through the screen electrode as shown in Fig. 1. The efficiency of the chambers as measured by the number of tracks lost in going from one chamber to the other was >95% (integrated over the angular range 0° to 25°) and was shown to be independent of the number of tracks to ≈30 tracks. As many as 175 tracks have been observed in the last gap.

The trigger counters were used to select events of potential interest. Because we were interested in events with many photons which were accompanied by few charged particles, a pulse height cut on the target counter (T) was employed to limit the number of charged particles produced in the target to typically three or four. In addition, four counters, each covering one quadrant of the active chamber area, were used to require that a large number (~10) of charged particles be produced in the lead converter. Two triggers were formed by placing the target counter in coincidence with each of the four quadrant counters (trigger A) or with the sum of the quadrant counters (trigger B).

In addition to these selective triggers, data were also taken with an inclusive trigger which required at least one charged particle in the T counter and at least one of the quadrant counters. This trigger was used to normalize the selective triggers to the CH_2 inelastic cross section. We estimate this normalization to be accurate to ±5%.

A summary of the data taken is given in Table II. With the target at the 3 m position, triggers A and B were used to search for events which produce an anomalous number of photons more or less isotropically in the nucleon-nucleon CMS. At the 31.5 m target position, both triggers were used to search for anomalous events with photons collimated to <16 mr. In addition, trigger B was used at this position to look for off-axis jets of photons with opening angles ≤1 mr.

We define a "neutral prong" to be a track that appears in gaps 3 or 4 for which there is no associated track in gaps 1 and 2 (see Fig. 1). The scanning procedure consisted of counting the number of neutral prongs in each event. Each event for which this count exceeded a particular value (typically 25 to 30) was then rescanned by a physicist. In the rescan the number of vertices produced in the lead by neutral particles which could be resolved by eye was noted. In all cases except the search for Schein jets it was assumed that the number of photons converted in the lead could be counted in this manner. Since all of the photons in a 1 mr jet would strike the lead within a 3.3 cm D. circle, other methods had to be used to search for Schein events. (See below.)

The results for the 3 m target position are summarized in Table III. As a guide to the number of γ's "expected" from a monopole pair annihilation we use a calculation made by Newmeyer and Trefil.[5] From a thermodynamic model they estimate $\bar{N}_\gamma$, the average number of γ's, to be 32, 59, 91 for n= 2,3,4 resp. (Eq. 1.) The probability of a photon converting in the lead is $\approx$0.60, and if we assume the photons are emitted approx. isotropically in the N-N CMS, about half the photons strike our detector. Thus, for a given $\bar{N}_\gamma$ we expect $\approx 0.3\ \bar{N}_\gamma$ vertices in the detector. Table III lists, for each value of $\bar{N}_\gamma$, the expected average number of vertices $\bar{N}_V$, the number of events observed with $\geq \bar{N}_V$ vertices, and the corresponding limits on the cross section for producing anomalous events. No events were observed with >14 vertices.

The 28 events observed with 10 or more vertices are consistent with the background expected from π^0 production and from neutron interactions in the lead. A Monte Carlo simulation based on extrapolations to large multiplicities of recent FNAL bubble chamber data on charge multiplicity and π^0 production fits the distribution we observe without invoking anomalous production. The cross section limits in Table III are per nucleon and have been corrected for our triggering efficiency (8% to 65% depending on multiplicity) and the probability of an anomalous event meeting our scanning and event selection criteria (13% to 100%).

The 31.5 m target position was designed specifically to look for highly collimated events of the Schein type. We therefore can assume that such events would be within the ±16 mr angular range accepted by the detector. The cosmic ray events (Table I) had 15 - 20 vertices in the first 1.22 rad. lengths.[14] For comparison in Table IV we list the number of events we observed with ≥7,9 or 12 vertices. The largest number of vertices observed was 9 and again the data were well fitted by the Monte Carlo without anomalous production. The cross section limits in Table IV include corrections for triggering and detection efficiency.

Trigger B in which all four quadrant counters were summed was used to look for Schein jets produced with appreciable transverse momentum. For events in which the photon jet has $\langle P_\perp \rangle \approx 0.35$ GeV/c, a typical value in hadronic interactions, the lateral displacement at the detector of a jet with momentum 100 GeV/c would be ≈10 cm.

The limits in Table IV are based on vertex counting. Photons from Schein events whose opening angles were ≤1 mr would appear in the chambers as a single unresolved vertex with 30 or more prongs. We therefore looked carefully at events of this type. It was found that of the 75 events with ≥30 prongs initiated by a neutral particle, 58 had prongs going backward into gaps 1 and 2. It is unlikely that a photon will produce any backward traveling particles in 1.22 rad. lengths and we assume these events are due to neutron interactions in the lead. For the remaining events the angular distribution of secondary tracks which a Schein event should produce was considered. The typical photon energy is about 2 GeV.[6-9]

A Schein event producing 15-20 pairs would be expected to produce at least 10-15 tracks within 31 mr in our detector (i.e., the higher energy electron from each pair has a 70% chance of remaining within an angle ≤31 mr).

We have measured and reconstructed the 17 events in question. The largest number of prongs produced within 31 mr of any point on the "vertex" was found to be 8. Within 55 mr the largest number of prongs was found to be 12. We conclude that these events are due to neutrons and at a 90% confidence level place an upper limit on the cross section for Schein events of $\sigma(90\%) \leq 2.7\ \mu b$ per nucleon after correcting for the detection efficiency.

The 31.5 m of air ahead of our detector and the target total ≈0.2 rad. length. Thus there is a high probability that upon reaching the detector the photons from a Schein event would be accompanied by a pair (or more) of charged particles within the cone of the jet.[15] To search for photon jets accompanied by 2 or more charged particles, the film was scanned for events containing 2 or more tracks in gaps 1 and 2 within 3 cm of each other as determined by all views. No constraint was placed on the number of additional charged particles outside of the assumed jet except that imposed by the trigger. Electron pairs formed by single photons will generally produce fewer prongs in the lead than a pair (or more) of electrons accompanied by a large number of photons. While Schein events should produce 30 to 40 prongs, we see no events which produced more than 29. The observed distribution of prongs produced in the lead by these particles is well fitted by a Monte Carlo simulation which assumes that the charged particles are electrons unaccompanied by any photons. We again conclude that no Schein events are observed and place an upper limit on the cross section of $\sigma(90\%) \leq 7.9$ μb per nucleon.

In conclusion we have seen no evidence for the production and subsequent annihilation of magnetic monopole pairs into photons. The cross section limits are ~2 μb. (See Tables III and IV). No evidence for Schein events has been seen and an upper limit of 2.7 μb has been placed on the production cross section due to neutrons. This cross section is $\sim 10^{-2}$ those estimated from the events observed in cosmic-ray emulsion experiments.

The authors wish to thank C.A. Ayre and P.V.R. Murthy for their help in carrying out this experiment. We also wish to acknowledge the assistance of H. Haggerty, P. Koehler, J. Sanford, and others of the Fermilab staff.

Footnotes

1. R.A. Carrigan, Jr., F.A. Nezrick, and B.P. Strauss, Phys. Rev. D, 10, No. 11, 3867 (1974).
2. L.M. Barkov et al., Soviet Physics JETP, 34, No. 5, 917 (1972).
3. R.R. Ross et al., Phys. Rev. D8, 698 (1973).
4. M.A. Ruderman and D. Zwanziger, Phys. Rev. Lett. 22, 146 (1969).
5. J.L. Newmeyer and J.S. Trefil, Nuovo Cim. 8A, 703 (1972).
6. M. Schein, D.M. Haskin and M. C. Glasser, Phys. Rev. 95, 855 (1954); see also, Proc. Rochester Conference on High Energy Physics, 1955, p. 117.
7. A. Debenedetti et al., Nuovo Cimento 12, 954 (1954). A. Debenedetti et al., Nuovo Cimento 2, 220 (1955).
8. M. Koshiba and M.F. Kaplan, Phys. Rev. 100, 327 (1955).
9. L.B. Silva et al., Nuovo Cimento 3, 1465 (1956).
10. See also, G.B. Collins et al., Phys. Rev. D, 8, 982 (1973).
11. A search for anomalous multigamma events produced by cosmic ray protons was made by the Echo Lake group. See J. Wilkes, Ph.D. thesis; University of Wisconsin, 1974 (unpublished).
12. For details of the spectrum see: M.J. Longo et al., Characteristics of the M-3 Neutral Beam at NAL, University of Michigan High Energy Group Report UM HE 74-18 (unpublished).
13. B.W. Loo, Doctoral Thesis, University of Michigan (unpublished).
14. The event No. 2 of Ref. 7 has a peculiar spatial distribution. It is reasonable to assume that the number of photons reaching our detector from an event of this type would produce ~20 pairs.
15. We estimate that a typical Schein-type event would be accompanied by ≥2 electrons in the detector 10% of the time.

Figure Captions

Figure 1 — Experimental apparatus

Table Captions

Table I — Properties of anomalous multiphoton events observed in emulsions.

Table II — Summary of data.

Table III — $\bar{N}_v$ is the average number of vertices expected for a given photon multiplicity $\bar{N}_\gamma$. The number of events observed with $\geq \bar{N}_v$ vertices is shown along with the corresponding cross section limits per nucleon.

Table IV — The number of events observed with $\geq N_v$ vertices and cross section limits for the 31.5 m target position.

Table I Properties of Reported Anomalous Multiphoton Jets

Reference	Estimated Energy (GeV)	Opening Angle (radians)	No. of Pairs Formed in 1.22 L following first pair
Schein et al.[6]	~90	$\sim.5\times10^{-3}$	18
DeBenedetti et al.[7]			
(1)	>40	$\sim10^{-3}$	14
(2)	>60	$\sim10^{-3}$	9(24 in 1.6 L)
Silva et al.[9]	>100	$\sim10^{-4}$	21(in 1.14 L)
Koshiba et al.[8]	~100	$\sim10^{-3}$	16

Table II. Summary of Data

Target Position	Trig.	Acceptance Angle	No. of Trigs.
3m	A	90° N-N CMS	6190
3m	B	90° N-N CMS	3814
31.5m	A	±16 mr (lab)	3129
31.5m	B	±16 mr (lab)	3907

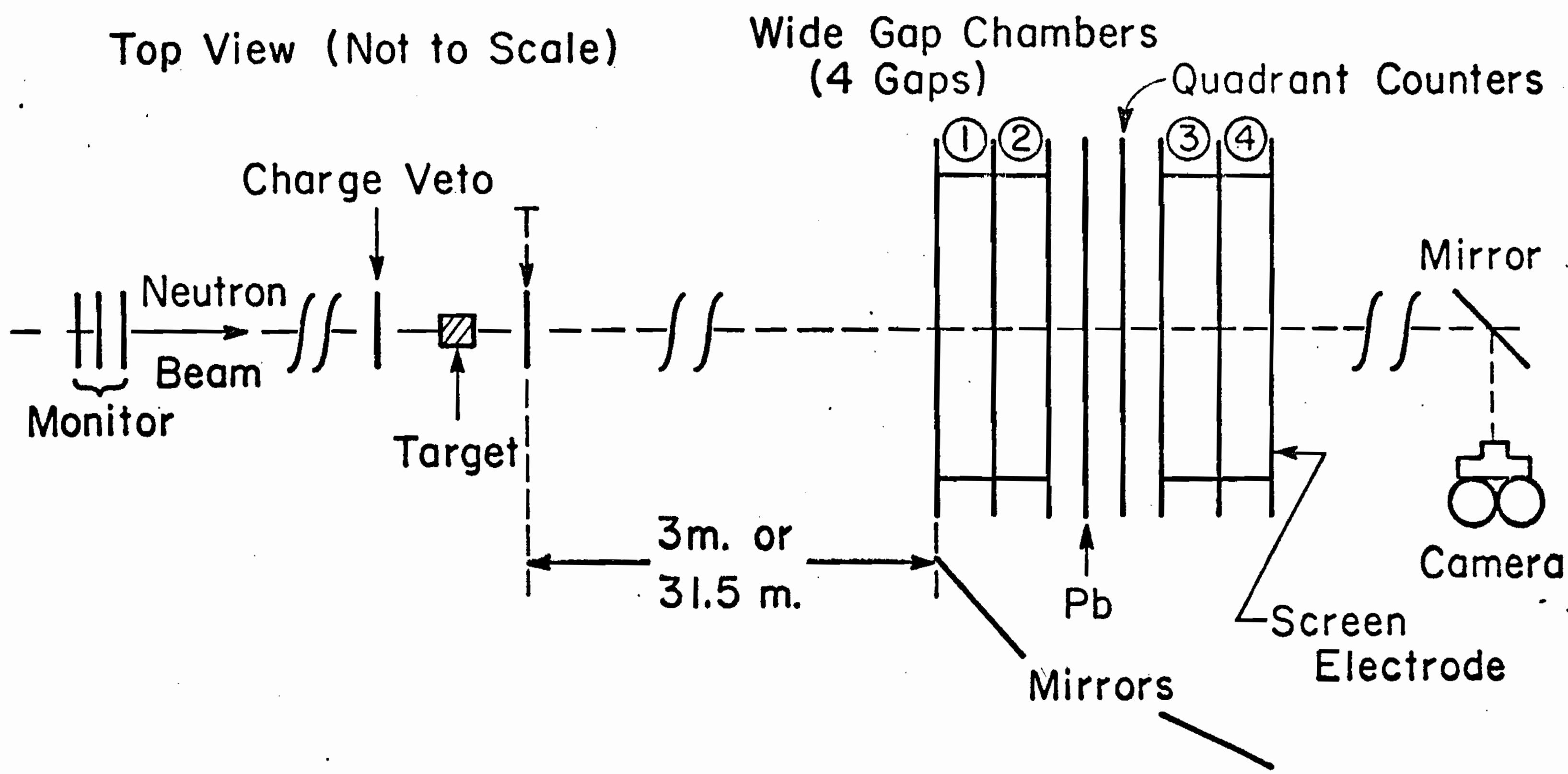
Table III 3 m Position

Trig.	$\bar{N}_\gamma$	Expected $\bar{N}_V$	Events $\geq \bar{N}_V$ Verts	σ(90%) μb
A	32	10	22[a]	≤13.2
	59	15	0	≤ .7
	91	27	0	≤ .5
B	32	10	6[a]	≤ 9.2
	59	15	0	≤ 2.3
	91	27	0	≤ 2.6

[a]Less than 6 charged prongs were required in gaps 1 and 2.

Table IV 31.5 m Position

Trig.	N_V	No. Events $\geq N_V$ Verts.	σ(90%) μb
A	7	10	≤3.7
	9	1	≤ .2
	12	0	≤ .2
B	7	0	≤8.5
	9	0	≤3.3
	12	0	≤3.0


Top View (Not to Scale)
Wide Gap Chambers
(4 Gaps)
Quadrant Counters
1
2
3
4
Charge Veto
T
Neutron
Beam
Monitor
Target
Mirror
Camera
3m. or
31.5 m.
Pb
Screen
Electrode
Mirrors