Fermi National Accelerator Laboratory

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Improved Limit on Axion Production in 800-GeV Hadronic Showers*

R. Guo [a] and D. M. Kaplan
Northern Illinois University
DeKalb, Illinois 60115

D. M. Alde, T. A. Carey, M. J. Leitch, P. L. McGaughey, C. S. Mishra[b], J. M. Moss, and J.-C. Peng
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

C. N. Brown and W. E. Cooper
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

M. J. Wang
Case Western Reserve University
Cleveland, Ohio 44106

M. L. Barlett and G. W. Hoffmann
University of Texas
Austin, Texas 78712

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Fermi National Accelerator Laboratory, Batavia, IL 60510

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University of Texas, Austin, TX 78712

A search for neutral penetrating particles has been made by use of an 800-GeV proton beam incident on the magnetized beam dump of the Fermilab experiment 605/772 spectrometer. Limits on the mass and couplings of such particles are presented. These improve on the limits obtained from a previous run with the same apparatus, and axions coupling only to e^+e^- are now ruled out up to masses of 2.7 MeV/c^2.

Using the experiment 605/772 spectrometer at Fermilab, we have improved upon an earlier measurement[1] of axion production and decay into e^+e^- pairs which was made with the same apparatus. The E605/772 spectrometer[2,3] was initially constructed to study the production of leptons and hadrons at high transverse momentum. A 4.0-m-long copper beam dump, located within the first analyzing magnet of the spectrometer, absorbed the 800-GeV proton beam. Heretofore unseen particles could be produced in the resulting hadronic and electromagnetic shower. If (like the axion) these particles interact weakly with matter, they could traverse the beam dump without being absorbed. A subsequent decay to e^+e^- in the 8.5-m-long decay volume before the end of the first spectrometer magnet would be detected in the spectrometer with high efficiency. The increased sensitivity of this new measurement over the previous one was principally the result of a shorter beam dump and a 20 times larger incident proton flux.

The data for this analysis were from 5×10^{14} protons incident on the dump. These data were recorded by triggering on summed energy deposition greater than 150 GeV in the electromagnetic calorimeter. The electromagnetic calorimeter[2,3] covered the full acceptance of the spectrometer. It consisted of a 19-radiation-length lead-scintillator sandwich with an energy resolution of $\sigma_E/E = 0.43/\sqrt{E(\mathrm{GeV})}$.[3]

The off-line analysis selected events containing only two tracks of opposite charge reconstructed in the wire chambers and scintillation hodoscopes, with each track pointing to a shower in the calorimeter consistent with electron identity,[3] and with neither track satisfying muon identification criteria in the muon detectors located downstream of the calorimeters. The track pair was required to have a reconstructed vertex at or downstream of the downstream face of the beam dump, reconstructed mass less than 150 MeV/c^2, and reconstructed vertical angle θ_y satisfying $-4 < \theta_y < 4$ mrad., consistent with traversal of the magnetized beam dump by a neutral particle. Events satisfying either of two additional selection criteria constituted the final data sample. Criterion 1 required each track to have at least 150 GeV/c momentum. Criterion 2 required each track to have at least 90 GeV/c momentum, the pair to have at least 300 GeV/c momentum, and the pair vertex to be at least 1.1m downstream of the end of the beam dump. (This second criterion was designed to enhance sensitivity to axions with lifetimes $> 5 \times 10^{-14}$s.) Nine events were found satisfying either of these criteria, of which eight satisfied the first criterion and six satisfied the second. The masses of these pairs, all less than 40 MeV/c^2, were consistent with zero mass within the resolution of the spectrometer. Figure 1 shows the vertical and horizontal angular distributions of these pairs. These angular distributions are consistent with those expected from radiation of e^+e^- pairs by high-energy muons originating in the initial shower and traversing the beam dump. However, the limits presented below

are not based on such an assumption, but (more conservatively) take account of the possibility that these events may be decays of axions.

We have calculated limits on the production of axions in the mass range $1.022 < m_A < 16$ MeV/c^2 assuming that they couple only to e^+e^- pairs. The brehmsstrahlung production of this particle in the initial hadron shower at the upstream face of the dump,

$$e + Z \rightarrow e + \text{axion} + Z,$$

is a function of only one coupling constant. The subsequent absorption of the particle in the beam dump and decay of the particle to e^+e^- downstream of the dump is a function of the same coupling. Limits can be calculated as a function of the particle mass and this single coupling constant.

The flux of π^0s , photons, electrons, and axions was calculated as in the previous paper[1], using a phenomenological fit to thick-target-production spectra of π^0s and the bremsstrahlung formula for axion production of Tsai.[4] The number of e^+e^- pairs was calculated by standard Monte Carlo techniques as a function of the axion mass and coupling to e^+e^-. The area in Figure 2 labeled "EXCLUDED REGION" is bounded by the limit derived from our earlier measurement[1] and by the two limits derived from the two data samples discussed above. The latter correspond (respectively) to observation of 13.0 events satisfying criterion 1 and 10.5 events satisfying criterion 2; these are the 90%-confidence-level limits given observation of 8 and 6 events in the two samples. Taken with the $g-2$ limit[1], these new results exclude pseudoscalar particles lighter than 2.7 MeV coupling only to e^+e^-.

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[a]Present address: University of Illinois at Chicago, Chicago, IL 60680.

[b]Present address: Fermilab, Batavia, IL 60610.

[1]C. N. Brown *et al.*, Phys. Rev. Lett. 57, 2101 (1986).

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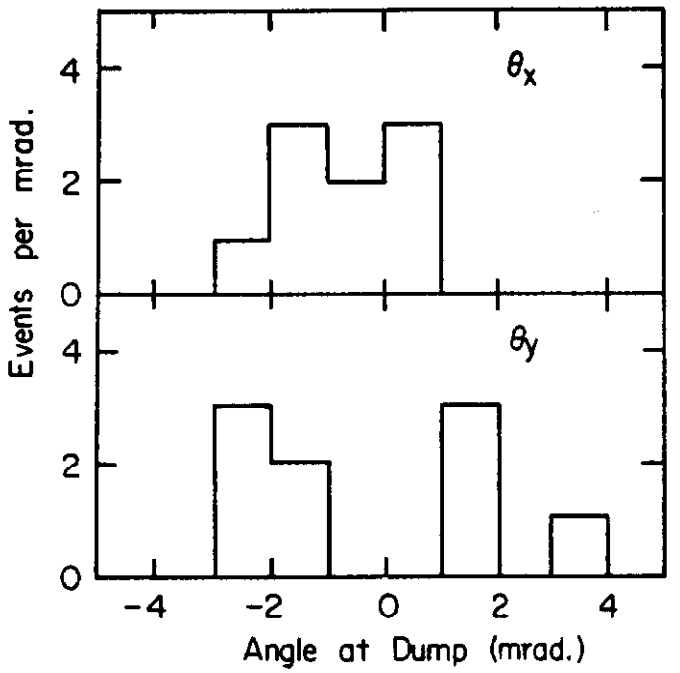

FIG. 1. Observed angular distributions in the bend (y) and non-bend (x) views of the collinear e^+e^- pairs at the downstream face of the beam dump.

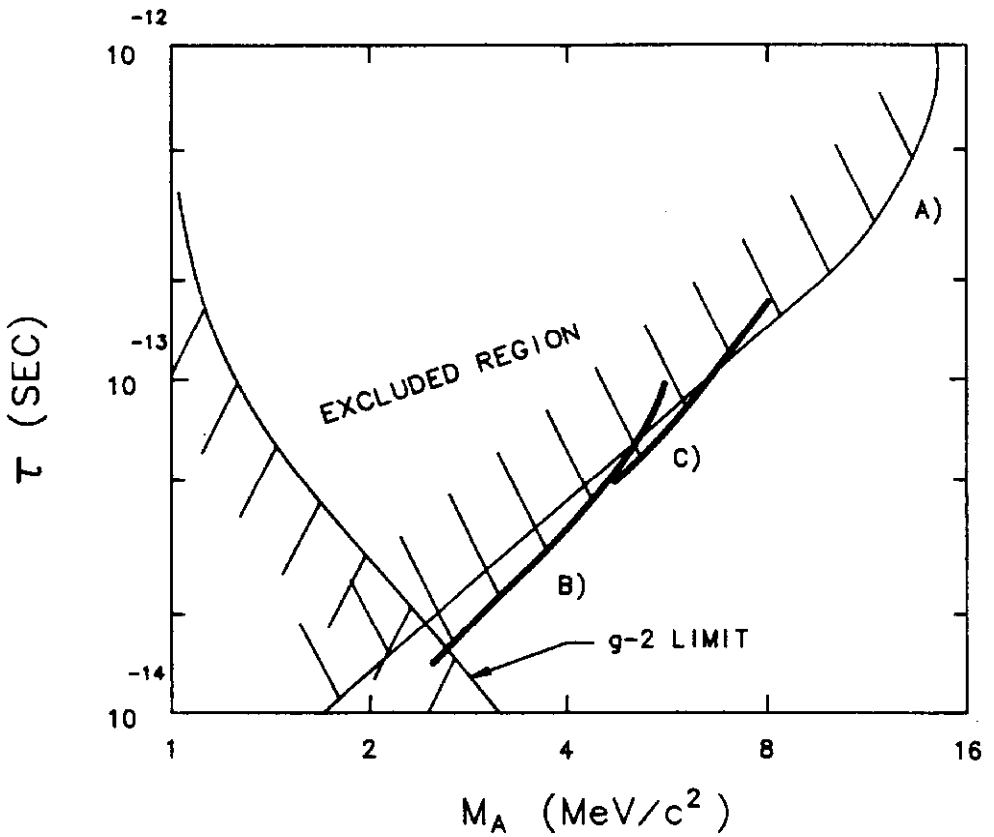

FIG. 2. Limits on mass and lifetime of an axionlike particle from (curve A) Brown *et al.* (Ref. 1) and (curves B and C) this experiment (criteria 1 and 2, respectively). Also shown is the limit from $g-2$ measurements.