Production of a New Light Neutral Boson in High-Energy Collisions

M. El-Nadi and O. E. Badawy
Physics Department, Faculty of Science, Cairo University, Giza, Cairo, Egypt
(Received 6 January 1986; revised manuscript received 8 February 1988)

Several examples of the production of electron-positron pairs were found in the interactions with emulsion of fragments resulting from the collision of ^{12}C and ^{22}Ne projectiles of 4.5 and 4.2 GeV/c per nucleon, respectively with emulsion nuclei. Taking into account the effect of the background, the results seem to suggest the existence of new neutral boson with mass 1.60 ± 0.59 MeV/c and a lifetime $(0.15 \pm 0.01) \times 10^{-14}$ sec.

PACS numbers: 25.70.Np, 14.80.Gt

In some recent works carried out at the Gesellschaft für Schwerionenforschung in Darmstadt,[1-5] a monochromatic narrow peak in the energy spectrum of positrons emitted in heavy-ion collisions was found, which might suggest the creation and decay of an unknown elementary boson in these collisions. On the other hand, Weinberg[6] and Wilczek[7] suggested the existence of a new pseudoscalar neutral boson as a result of the breaking of the U(1) symmetry.

In this Letter we report the existence of thirteen examples for the creation and decay of a light neutral boson into an electron-positron pair, which were found during the study of the interaction of the secondary fragments, resulting from the interaction of primary relativistic heavy projectiles with emulsion.[8] The secondary interacting fragments were ten $Z=2$ (five from primary ^{12}C projectiles and five from primary ^{22}Ne projectiles), one $Z=8$, and two $Z=10$ fragments from ^{22}Ne primary projectiles. The interaction shown in Fig. 1 was found a few years ago and a preliminary report was given elsewhere.[9] The resulting neutral particle was puzzling and thought to be a photon. The detection, later on, of these additional examples strongly supported the existence of a neutral light boson.

Nuclear photoemulsions of the types Nikfi-Br-2 of dimensions of 10×20 cm$^2 \times 600$ μm, and having sensitivity of 28 grains per 100 μm for highly relativistic singly charged particle tracks (in the plateau region) were used in these experiments. These plates were irradiated at the synchrophazatron, Dubna, U.S.S.R., with ^{12}C and ^{22}Ne ions of 4.5 and 4.2 GeV/c per nucleon, respectively. Coulomb-scattering measurements[10,11] were carried out on the electron tracks (whenever possible) with two different cell lengths to eliminate noise and spurious scattering. Other sources of errors are avoided following Ref. 11. The microscopes used are of the type KSM-1 and M5U-9. The details of the experiment may be found in Ref. 9.

In the measurements carried out in the present work the charge of the projectile fragments was determined by the Lacunarity method for $Z=2$ fragments, while the δ-rays method was used in the case of $Z=8$ fragment.[10]

In the present experiment about 700 secondary interactions of $Z=2$ fragments (perhaps α particles) emitted from about 1400 ^{12}C and 1200 ^{22}Ne primary interactions were studied. Moreover, out of 25 secondary interactions of $Z=10$ projectile fragments (perhaps inelastically scattered nuclei) from the ^{22}Ne beam, two electron-positron pairs were recorded.

Out of all these secondary interactions, thirteen examples of electron-positron pairs were observed to result from the decay of a neutral particle produced in these in-

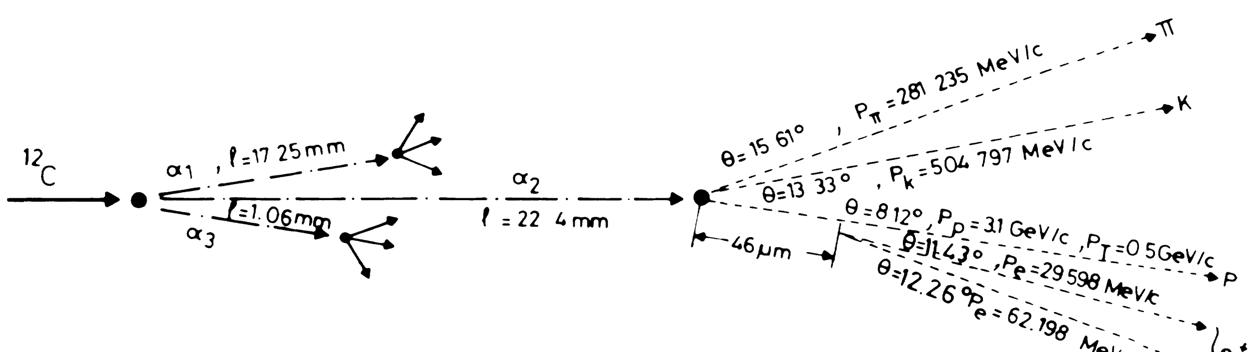

FIG. 1. The fragmentation of a ^{12}C 4.5-GeV/c per nucleon projectile into three $Z=2$ fragments. The fragment α_2 interacts with an emulsion nucleus after a distance of 2.24 cm producing a star. One of the products is a neutral particle which decays into an $e^{\pm}$ pair.

TABLE I. Detailed information about the thirteen $e^{\pm}$ decay pairs emitted from the secondary projectile fragments of ^{12}C and ^{22}Ne beams at $\sim$4.5 GeV/c per nucleon. Entries and definitions—Reaction: projectile (momentum, GeV/c per nucleon) (charge of projectile fragment) (fragment's interaction length in centimeters). e^+e^- pair: g^* (normalized grain density) = (grain density per 100 μm of the measured track)/(grain density per 100 μm in the plateau region), L =length of the track used in momentum measurement, θ_p =the opening angle of the pair in the lab system. Decaying neutral particle: θ_0 =emission angle of the neutral particle in the lab system, τ_l =lifetime in the lab system $=S/c=S/(3.00\times10^{10}$ cm/s), S =projected decay length (μm), τ_0 =lifetime in the rest frame of the decaying particle $=S(1-\beta^2)^{1/2}/\beta(3.00\times10^{10}$ cm/s).

Reaction	e^+ e^- Pair				Decaying Neutral Particle					
	Momentum (MeV/C) Lab. Sys.	g^* ±0.06	L mm	$\theta_p^\circ\pm\Delta\theta_p^\circ$	$\theta_0^\circ\pm0.1^\circ$	S micron	Mass MeV	Mass m_e	τ_l 10^{-13} s	τ_0 10^{-14} s
^{22}Ne (4.2)(10)(0.25)	51.5±11.4	1.00	2.8	0.76 ± 0.73	32.1	55	1.29 ± 0.55	2.53 ± 1.09	1.84 ± 0.07	0.20 ± 0.01
	66.6+14.8	1.03								
^{22}Ne (4.2)(8)(0.15)	106.1±9.9	0.98	7.5	0.20 ± 0.20	30.0	61	1.09 ± 0.17	2.14 ± 0.33	2.03 ± 0.07	0.11 ± 0.01
	112.1+10.5	0.99								
^{22}Ne (4.2)(2)(3.76)	134.84±22.5	1.06	2.7	0.63 ± 0.16	17.3	18	1.81 ± 0.53	3.54 ± 1.04	0.68 ± 0.07	0.04 ± 0.004
	142.16±22.8	1.02	2.5							
^{22}Ne (4.2)(2)(1.63)	Not measured, star location is near emulsion surface			2.15	5.72	13.5			0.45 ± 0.07	
^{22}Ne (4.2)(2)(12.8)	218.0±14.9	0.94	13.8	0.48 ± 0.34	0.71	13	2.13 ± 1.30	4.17 ± 2.54	0.43 ± 0.07	0.02 ± 0.003
	228.0±15.6	0.95	14.0							
^{12}C (4.5)(2)(2.24)	29.6±4.2	1.03	7.0	0.84 ± 0.50	11.8	46	1.26 ± 0.23	2.47 ± 0.45	1.50 ± 0.07	0.22 ± 0.01
	62.2±8.8	1.01								
^{12}C (4.5)(2)(3.98)	24.6±6.2	0.94	1.8	2.48 ± 0.71	7.6	39	2.03 ± 0.76	3.97 ± 1.48	1.30 ± 0.07	0.30 ± 0.02
	62.0±15.7	0.97								
^{22}Ne (4.2)(2)(1.84)	Not measured, star location is near emulsion surface			0.0	(a)	58	1.00			
^{22}Ne (4.2)(2)(7.65)	183.9±18.0	1.01	6.7	2.90 ± 0.58	2.7	6	8.99 ± 2.06	17.59 ± 4.03	0.20 ± 0.07	0.04 ± 0.01
	169.4±26.6	0.94	2.6							
^{22}Ne (4.2)(10)(1.10)	Not measured, star location is near glass			4.37	5.12	12			0.40 ± 0.07	
^{12}C (4.5)(2)(3.7)	125.01±30.0	0.96	1.3	3.61 ± 0.14	10.86	9	8.12 ± 3.55	15.89 ± 6.95	0.30 ± 0.07	0.05 ± 0.01
	130.95±35.0	0.89								
^{12}C (4.5)(2)(3.23)	Not measured, near glass			1.12	34.15	5			0.17 ± 0.07	
^{12}C (4.5)(2)(3.0)	Not measured, near glass				40.2	8			0.26 ± 0.07	
Back-ground decay pairs (giving 7 $e^{\mp}$ e^- pairs) from primary beam of 4.5 GeV/C/N α-particles in emulsion.										
Star #	370.0±21.5	1.00	19.0	2.82 ± 0.19	2.48	10	15.66 ± 2.32	30.65 ± 4.54	0.33 ± 0.07	0.05 ± 0.01
24-1127	273.0±28.6	0.98	5.8							
Star #	195.6±27.7	1.04	3.2	8.72 ± 0.18	7.99	8	26.80 ± 0.58	52.45 ± 1.14	0.26 ± 0.07	0.22 ± 0.06
26-620	158.8±35.2	0.99	1.3							
Star #	92.4±17.4	1.03	1.8	4.36 ± 2.30	28.62	8	12.51 ± 8.54	24.48 ± 16.71	0.26 ± 0.07	0.12 ± 0.03
28-381	291.8±37.4	1.00	3.9							
Star #	187.3±24.3	1.03	3.8	1.03 ± 0.10	13.3	8	3.13 ± 1.30	6.13 ± 2.50	0.26 ± 0.07	0.01 ± 0.003
27-408	152.8±19.33	1.00	4.0							
Star #	137.35±21.55	0.98	2.6	1.20 ± 0.20	10.52	14	1.88 ± 0.51	3.68 ± 1.00	0.47 ± 0.07	0.04 ± 0.01
31-35	49.93±7.29	0.97	3.0							
Star #	382.80±55.91	1.01	3.0	2.14 ± 0.12	6.84	8	7.55 ± 1.35	14.78 ± 2.64	0.26 ± 0.07	0.06 ± 0.01
33-1051	106.51±11.0	0.96	6.0							
Star # 32-956	Not measured, near surface			1.66	43.22	65			2.15	

(a)The narrow opening angle of the pair may give an upper limit of 1.00 MeV particle mass.

teractions. Detailed information about these thirteen examples are given in Table I.

Now, taking the mean free path for pair conversion[11] as 5 cm and the total field diameter of the measuring microscope used (MbE-9) as 120 μm, one gets for the number n of pairs expected from the decay of the π^0 mesons produced in these collisions:

$$n = N \times 700 \times 0.012/5 = 1.7N,$$

where N is the multiplicity of photons. A multiplicity $N=2$ (i.e., one $\pi^0 \rightarrow 2\gamma$) will give $n \sim 4$ as the number of photons resulting from the created π^0's. Moreover, the effect of the direct photon production is quite small, as it was found that at 5 GeV/c the number ratio γ/π^0 is $\sim 10\%$.[12] Thus one expects that the background contribution to the ten cases found is about four cases.

To examine experimentally this estimation of the background pairs, a primary beam of α particles at 4.5 GeV/c per nucleon interacting with the same emulsion was studied for the pairs resulting from this interaction. It was found that out of 1240 α interactions with the emulsion seven pairs were observed. These are given in the lower part of Table I. Thus one expects that 700 primary α interactions may produce four pairs. This is about the above calculated value. The fact that 700 secondary α interactions produce ten e^+e^- pairs, i.e., about 2.5 times the number produced from the same number of primary α interactions at the same energy may suggest that the secondary α's may have a larger interaction cross section. A similar study of the lepton pairs that can be produced from the interaction of the ^{22}Ne (at 4.2 GeV/c per nucleon) primary beam with emulsion showed that out of 515 Ne interactions with emulsion eight pairs were found.

It may be noticed from the present work that the suggested neutral boson is mostly produced in collisions between secondary projectile fragments and emulsion nuclei. Whether this is related to a nuclear deexcitation of excited projectile fragments needs further consideration.

If one now discards the last five examples in Table I as probably due to background contributions one may conclude that the average mass of the neutral boson that decayed into an electron-positron pair is $\sim(3.13 \pm 1.15)m_e$ or 1.60 ± 0.59 MeV and the lifetime is $\sim 0.15 \times 10^{-14}$ sec.

The authors are very grateful to the Joint Institute for Nuclear Research, Dubna, U.S.S.R. for supplying the irradiated emulsions. They are also highly indebted to Professor H. Lipkin of the Weizmann Institute of Science, Israel for bringing this problem to their attention. High appreciations are also due to Professor L. Van Hove, Professor B. Hyams (CERN), and Professor H. Heckman (L.B.L.) for advice.

[1]J. Schweppe *et al.*, Phys. Rev. Lett. **51**, 2261 (1983).

[2]M. Clemente *et al.*, Phys. Lett. **137B**, 41 (1984).

[3]T. Cowan *et al.*, Phys. Rev. Lett. **54**, 1761 (1985).

[4]A. B. Balantekin *et al.*, Phys. Rev. Lett. **55**, 461 (1985).

[5]B. Schwarzschild, Phys. Today **38**, No. 11, 17 (1985).

[6]S. Weinberg, Phys. Rev. Lett. **40**, 223 (1978).

[7]F. Wilczek, Phys. Rev. Lett. **40**, 279 (1978).

[8]M. El-Nadi *et al.*, Phys. Rev. Lett. **53**, 1971 (1984).

[9]M. El-Nadi *et al.*, in *Proceedings of the Seventh High Energy Heavy Ion Study, Darmstadt, West Germany, 1984,* edited by R. Bock, H. H. Gutbrod, and R. Stock (GSI, Darmstadt, West Germany, 1985).

[10]M. A. Bloomer, H. H. Heckman, and Y. J. Karant, Nucl. Instrum. Methods **215**, 247 (1983).

[11]W. H. Barkas, *Nuclear Research Emulsions* (Academic, New York, 1963), p. 263; C. F. Powell, P. H. Fowler, and D. H. Perkins, *Study of Elementary Particles by the Photographic Method* (Pergamon, London, 1959).

[12]M. Bardadin-Otwinowska, CERN Report No. CERN/EP85-168, 1985 (unpublished).