Search for Positive Particles of Masses about $500m_e$ and $1400m_e$

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The mass spectrum of positive particles in a secondary beam from the Bevatron has been measured at a distance of 90 ft from the internal target. At a confidence level of 93% the proportion of particles with mass between $420m_e$ and $630m_e$ in the 1-Bev/c beam is estimated to be $<6\times10^{-8}$. An upper limit of about 3×10^{-6} is obtained for the proportion of particles of mass approximately $1400m_e$ in the 2.3-Bev/c beam.

THE purpose of this article is to report experimental results of a search for positive particles with masses in the regions 420–630 m_e[1] and 1050–1500 m_e.[2] The bearing of these results on the existence of such particles clearly involves a discussion of particular models of production and decay, which will not be attempted here.

Positive particles of known momentum emitted at 26.5 deg from an internal heavymet target in the Bevatron were selected according to velocity by a coincidence between two high-pressure methane gas Čerenkov counters[3] and two pairs of time-of-flight scintillation counters 40 ft apart. These counters are constructed so that Čerenkov light at different angles is collected into one of two zones. One zone extends from 0 deg to 6.7 deg, and the other from 7.4 to 20 deg. In this way different groups of particles were detected concurrently and beam purity was improved by anti-coincidence methods. Further beam purification was obtained with the use of a scintillation counter which discriminated between the pulse height produced by a single particle and that produced by two particles arriving within 50 mμsec of each other.

To obtain the mass spectrum of the beam, the pressure in the Čerenkov counters and the tuning of the time-of-flight counters were varied. Measurements of the mass spectrum 90 ft from the Bevatron target can be summarized as follows.

At a momentum of 1 Bev/c, the beam was tuned for particles of mass between 420 m_e and 630 m_e in steps of about 50 m_e. For each setting, about 3×10^7 particles (76% protons, 24% π^+ mesons, and 0.1% K^+ mesons) passed through the channel without any coincidence count occurring in the Čerenkov and scintillator system. Figure 1(a) shows the upper limits to the relative intensities of components with different mass values. At a confidence level of 93% the proportion of particles with any mass in this region is estimated to be $<6\times10^{-8}$ in the secondary beam described.

At a momentum of 2.3 Bev/c the beam (96% protons, 4% π^+ mesons, and 0.2% K^+ mesons) was tuned for particles with masses between 1050 and 1500 m_e. Here, however, there was a significant background counting

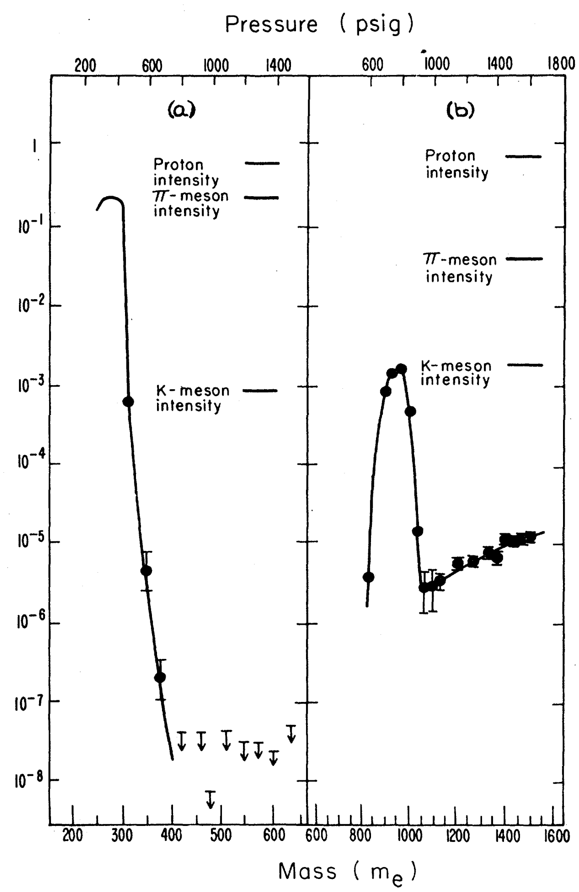

FIG. 1. Coincidence rate in the Čerenkov and scintillation counters normalized to the total flux of particles in the selected beam. (a) results at 1 Bev/c; no count was recorded for any mass selection between $420m_e$ and $630m_e$, as indicated by the arrows. The bar at the tail of each arrow indicates the rate if one count had been obtained. (b) Results at 2.3 Bev/c; the background coincidence rate rises with pressure because of proton-induced delta rays.

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[1] *1958 Annual International Conference on High-Energy Physics at CERN*, (CERN Scientific Information Service, Geneva, 1958). p. 153 ff.

[2] *Proceedings of the 1960 Annual International Conference on High-Energy Physics at Rochester*, (Interscience Publishers, Inc., New York, 1960) page 393 ff. T. Yamanouchi, Phys. Rev. Letters **3**, 480 (1959).

[3] B. Cork, D. Keefe, and W. A. Wenzel, Proceedings of the 196 International Conference on Instrumentation for High Energy Physics, Lawrence Radiation Laboratory, Berkeley, California, September, 1960 (to be published), IIa, 10; V. Cook, B. Cork, T. F. Hoang, D. Keefe, L. T. Kerth, W. A. Wenzel, and T. F. Zipf, Phys. Rev. (to be published).

rate at each point studied. At 2.3 Bev/c a proton can create delta rays above the Čerenkov threshold in the gas counters and so cause a spurious coincidence, since its velocity is also high enough to be acceptable to the time-of-flight circuit. This background rate increases with increasing gas density in the counters, as can be seen from Fig. 1(b). Assuming that a counting rate corresponding to any particular mass value of three standard deviations above background would have been interpreted as significant, one arrives at an upper limit of about 3×10^{-6} for the proportion of particles of mass approximately 1400 m_e in the secondary beam.

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Pion Production in Electron-Positron Collisions*

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The properties due to the presence of symmetries in pion production processes in electron-positron collisions are discussed. Cross sections are calculated for the production reactions $e^++e^-\rightarrow\pi^0+\gamma$, $e^++e^-\rightarrow e^++e^-+\pi^0$, and $e^++e^-\rightarrow\pi^++\pi^-$. The photon spectrum for the reaction $e^++e^-\rightarrow\pi^++\pi^-+\gamma$ is also calculated. The role of form factors and some of the possible effects of resonant strong interactions are discussed.

I. INTRODUCTION

The prospect of clashing electron-positron beams is certainly an attractive one.[1,2] The electron-positron system possesses simplifying features because of its high degree of symmetry. In addition, many interesting particle production processes occur with cross sections proportional to the same order of the electromagnetic coupling constant as the cross section for e^++e^- elastic scattering. Examples of such processes are the production of $\mu^++\mu^-$, $\pi^++\pi^-$, and K^++K^- pairs. Further, such experiments offer an unambiguous way of studying certain strong interactions between pairs of particles in situations which are not complicated by the presence of additional strongly interacting particles.

Because of the presumably fundamental role of the pion in strong interactions, perhaps the most fundamental of these possible experiments are those involving pion production. Some of the symmetry properties relevant to these pion production processes are discussed in Sec. II. In Sec. III the results of calculations of π^0 production cross sections are given. Section IV contains the results of calculations for $\pi^++\pi^-$ pair production and the associated process of $\pi^++\pi^-+\gamma$ production, i.e., radiative pion pair production. Some discussion is given of the most likely effects of strong interactions, such as the introduction of form factors and the occurrence of resonances. Since the techniques of quantum electrodynamics are now well known,[3,4] calculational matters are only sketched, and this is done in the Appendix. The conventions used are those of Feynman.[3]

II. SYMMETRY CONSIDERATIONS

Since the electron and the positron form a particle-antiparticle pair, one has the possibility of charge conjugation invariance in addition to the usual symmetries such as space inversion, rotational invariance, and Lorentz invariance. It will be seen that this additional symmetry is of prime importance in most of the examples to be discussed, just as it is extremely useful in positronium.[4,5]

For high-energy scattering problems the conventional formalism, which involves an analysis into spin and orbital angular momentum states, is inconvenient. A

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