Interpreting anomalous electron pairs as new particle decays

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Abstract

In heavy particle decays found in cosmic ray interactions recorded in the JACEE emulsion chambers, multiple electron pairs were previously reported. These pairs apparently originated from conversions of photons emitted in the decays. It is difficult to explain the overall properties of these decays in terms of known heavy particle decay modes. A recently published compilation of low-energy nuclear data suggests existence of excess electron pairs with invariant mass about 9 MeV/c^2, which may be explained by postulating a new neutral boson decaying into the electron pair. The feasibility of explaining the JACEE electron pairs with this hypothesis is presented.

1 Introduction

Among the cosmic ray interaction events recorded in the JACEE emulsion chambers, two events were found in which production and decays of heavy particles were observed (Wilczyńska 1990, Asakimori 1994). These are decays of charged particles into just one charged particle and neutrals; four photon conversions into electron pairs were found in the vicinity of the decay vertex in each of the events.

The analysis of the decays led to a conclusion that these are most probably bottom meson decays. The identification of the decay mode is not clear. It is difficult to reconcile the characteristics of known heavy particle decays with the observed decay properties, like conversion distances and/or multiplicities of photons emitted in these decays. A hypothesis was also considered that the observed electron pairs are due to decays of some neutral particles rather than photon decays. The available experimental evidence was, however, judged too weak to be compelling.

More recently, a compilation was published of experimental data on e^+e^- emission in nuclear transitions above 12 MeV (de Boer et al, 1997). In several low-energy nuclear experiments (de Boer 1996, Buda 1993 and 1996, Höistad 1993, Schadmand 1995 and 1996) internal pair conversion was studied and an apparent excess of e^+e^- pairs was found at invariant mass about 9 MeV/c^2. While in each experiment individually the deviation may be insignificant, the combined results appear to point to an overall anomaly. The e^+e^- excess may be explained by assuming emission of a new neutral boson which decays into the electron pair. This new particle would be emitted in competition with internal pair conversion.

A similar effect was found in collisions of nuclear beams at higher energy (several to 200 GeV/nucleon) with nuclear emulsion (El-Nadi 1988, de Boer 1988 and 1989, El-Nadi 1996). An excess of e^+e^- pairs persists at invariant mass 12.2 ± 2.6 MeV/c^2, which corresponds to average lifetime of the hypothetical particle $1.4 \pm 0.4 \cdot 10^{-15}$ s. In this paper, we try to find out whether the anomalous electron pairs found in JACEE events can be related to those seen in the other experiments.

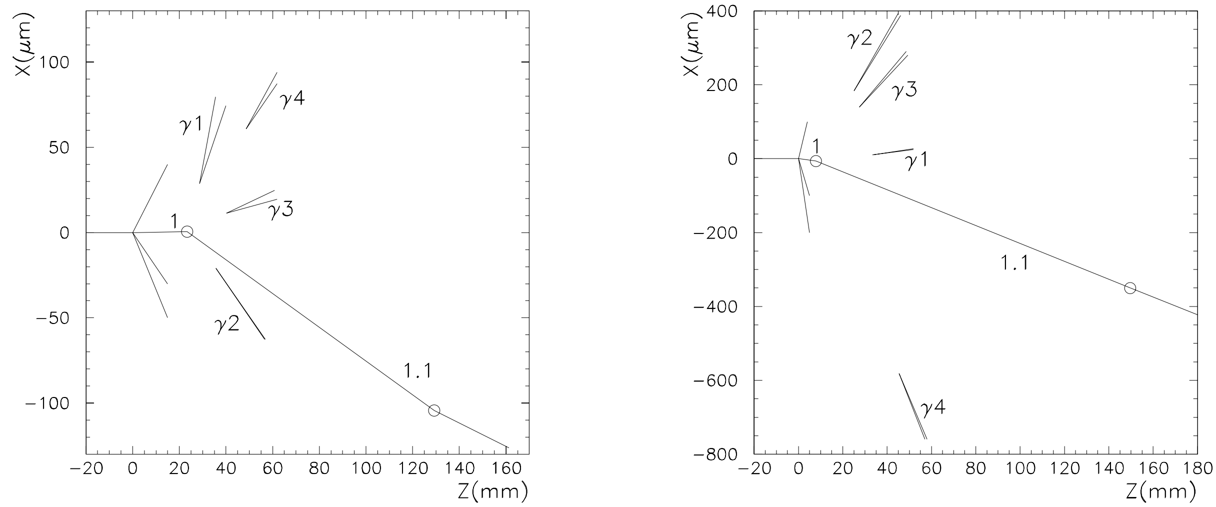

Figure 1: Projection of decays of particle 1 in Event 1 (left) and in Event 2 (right). γ_1, γ_2, γ_3 and γ_4 are electron pairs from apparent photon conversions. The decay vertices of particles 1 and 1.1 are marked by circles.

2 Characteristics of the decays

One of the JACEE multiphoton decays was found in a 50 TeV/nucleon helium interaction (Event 1 - Wilczyńska 1990). This decay is sketched in Figure 1, along with the decay in Event 2 discussed below. A singly-charged particle (track 1) decays into just one charged particle (track 1.1), which in turn undergoes another decay downstream. Four electron pairs, apparently resulting from early photon conversions, labeled $\gamma 1, \gamma 2, \gamma 3$ and $\gamma 4$, were found in the vicinity of particle 1 decay vertex. The energies of these pairs were determined to be 5, 130, 470 and 230 GeV, respectively, with accuracy about 30%. The transverse momentum balance at the decay vertex is complete within experimental errors, so that some analysis of the decay could be made. The decaying particle was shown to be a bottom particle. None of the Cabibbo-Kobayashi-Maskawa favored decay channels can account satisfactorily for the observed features of the decay. The conclusion was that the decay in question most probably is a charmless decay $B \rightarrow D_s \eta\eta$.

A very similar decay was found in another event (Event 2), a 4 TeV/nucleon beryllium interaction (Asakimori 1994). Again, a charged particle decays into one charged particle, with four photon conversions at short distances associated with the decay vertex. The energies of the photons in this event were estimated at 70, 50, 50 and 20 GeV. The decaying particle in this event must be a charmed or bottom particle. The accuracy of electron pair energy determination in this event is slightly worse (about 50%) so that the decay analysis cannot be as detailed as that in Event 1.

The decays in Event 1 and Event 2 are so similar to each other that they may be the decays of the same heavy particle. However, the interpretation of these two decays combined is even more difficult than Event 1 alone - see (Asakimori 1994). There are many features which make the explanation of these two decays difficult. For instance, the conversion distances of the photons are rather short and the invariant masses of $\gamma\gamma$ pairs do not agree with π^0 mass – only one $\gamma\gamma$ combination in Event 2 reconstructs the π^0 mass. This may imply that either the photons come from sources other than π^0 decay (e.g. η meson decays) or there were more π^0's (and consequently photons) emitted from the decay and these additional photons were not detected. In case of large number of photons emitted, the observed short conversion distances would be easily explained, but the large number of photons would imply a much larger mass of particle 1, allowing its strong decay, which would contradict the observation. In short, the close similarity of these two decays might suggest that they are examples of *the same* decay channel of a bottom particle, presumably a charmless b quark decay. However, there are strong arguments against such an interpretation, based on known decay branching ratios. It is doubtful, statistically, that Event 2 represents also a charmless bottom decay, although such a decay would be consistent with our observation. In case the two events discussed are examples of *different* particle decays, their apparent similarity is puzzling, especially that they were found in a small sample of 15 low-multiplicity events analyzed in search for secondary decays. The observed decay topologies cannot be explained by a hypothesis that they are due to secondary particle interactions, rather than decays. A hypothesis was also discussed that these electron pairs originate from decays of a new neutral particles rather than from photon conversions, but the experimental evidence in favor of this hypothesis was found insufficient, so this hypothesis was dismissed. Thus, as discussed in (Wilczyński 1997), the two multiphoton decays observed by JACEE are, in a sense, an anomaly yet to be explained.

3 Invariant masses of the electron pairs

The JACEE detector is an emulsion chamber (Burnett 1986) in which double-sided emulsion plates are interleaved with other materials: plastic, iron and lead target plates in the target section of the chamber and lead plates and X-ray films in the calorimeter section. Positions of charged particle tracks in an emulsion plate are measured with submicron accuracy, so that the emission angles of secondary particles in an interaction are measured very well. The small thickness of the various layers in the chamber (55 micron thick emulsion layers and several hundred micron thick target plates) ensure that the distances, like conversion distances of the photons, are measured with good accuracy.

In order to determine the invariant mass of an electron pair, one needs to measure the energies and the relative emission angle of the electron and positron in the pair. In the JACEE chambers, the energies of high-energy electrons and photons are measured by analyzing the 3-dimensional development of the electromagnetic shower in the calorimeter section of the chamber.

At the very high energy interactions discussed here, the secondary particles emitted from the interaction vertex are highly collimated. Their tracks diverge slowly, before they can be resolved in downstream emulsion layers. For the high energy hadrons, the multiple Coulomb scattering is negligible and their emission angles can be reliably measured with accuracy better than 0.05 mrad. The situation is different, however, when measuring the angle between electron and positron tracks due to conversion of a high energy photon into an e^+e^- pair. Since the electron and positron are very collimated, their tracks must be measured at some distance from the conversion point, at which they can be resolved for a reliable measurement. Therefore, a correction must be made for multiple Coulomb scattering of both e^+ and e^- between the conversion point and the measurement point. For an electron of a given energy, only a correction based on the *average* value of the scattering angle distribution can be calculated using the multiple scattering theory (Caso 1998), and not the actual scattering angle in each case. Nevertheless, for our highest energy pairs (above 100 GeV) the calculated corrections are consistently smaller, by about an order of magnitude, than the measured angles between electron and positron in a pair. In addition, the (corrected) measured opening angles in these pairs are about an order of magnitude larger than average opening angles expected in photon conversions at these energies. Therefore, it is reasonable to assume that the measurement of the e^+e^- opening angle in the JACEE chambers is meaningful for high-energy pairs and can be used in a physics analysis.

The individual energies of electron and positron in an e^+e^- pair can be reliably measured only in three highest-energy pairs in Event 1, in which the two electromagnetic cascades due to electron and positron can be separately analyzed. This cannot be done in the remaining pairs. Also, the corrections for multiple scattering in these lower-energy pairs become of the order of the measured angle itself, so that the opening angle measurements are unreliable. Thus, the invariant masses of the e^+e^- system can be determined only in γ_2, γ_3 and γ_4 pairs in Event 1. The relevant measurement data for these pairs are shown in Table 1, along with the e^+e^- invariant mass and lifetime of the hypothetical neutral parent particle for each pair.

The e^+e^- invariant masses in the three pairs seem consistently different from zero, but significance of the

Table 1: Energies, E; e^+/e^- energy ratios, R; conversion distances, l; pair opening angles (corrected), β; invariant masses, M and lifetimes, τ for the three pairs in JACEE Event 1.

pair	E (GeV)	R	l (mm)	β (mrad)	M (MeV/c^2)	τ (10^{-15} s)
γ_2	130 ± 39	3:1	12.06 ± 0.15	0.109 ± 0.025	6.2 ± 2.6	1.9 ± 1.0
γ_3	470 ± 141	1:1	16.68 ± 0.14	0.177 ± 0.022	41.6 ± 15.7	4.9 ± 2.4
γ_4	230 ± 69	2:1	25.16 ± 0.14	0.238 ± 0.005	25.8 ± 9.1	9.4 ± 4.3

effect is only 2.8 to 3.6 standard deviations. It is necessary to stress that the corrections for multiple scattering of both e^+ and e^- are calculated as *average* values of the distribution of deflection angles. Thus, the errors quoted on invariant mass and lifetime of the hypothetical neutral particle are in fact lower limits of the errors.

4 Conclusion

Among the JACEE anomalous electron pairs discussed here, the e^+e^- invariant masses can be determined in 3 pairs. Although the experimental uncertainties are rather large, the calculated masses are different from zero. The three pairs analyzed are consistent with the hypothesis that light neutral particles were emitted at the bottom decay, and they subsequently decayed into the observed electron pairs. The calculated invariant masses and lifetimes of these hypothetical particles agree reasonably well with 9 MeV/c^2 and $1.4 \cdot 10^{-15}$ s quoted by de Boer et al.(1997) as a combined result of several low-energy nuclear experiments. In the very-high-energy JACEE events the experimental uncertainties and biases are clearly different, yet the effect seems to persist. The evidence available from JACEE alone in favor of the new particle hypothesis is, however, insufficient to verify this hypothesis.

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