Ghost-like neutral particle observed

The positrons of distinctive energy observed in heavy-ion collisions over the past three years have now been mirrored by the surprising discovery of pairs of photons in similar circumstances.

THREE years have passed since people studying heavy-ion collisions were first struck by the observation of positrons with a characteristic energy of just above 300 keV among the collision products, but nobody is yet very much the wiser. It now seems generally to be agreed that the purported explanation of the positrons as a kind of incidental consequence of the disturbance of the Dirac sea of electrons of negative energy by the potential field of two heavy nuclei in collision (see *Nature* **320**, 209; 1986) will not by itself suffice. Indeed, with the passage of time, evidence has further accumulated to support the original claim that there is a new phenomenon to be explained, but a definitive explanation seems still a long way off.

Part of the trouble now is that there is almost too much observational evidence to be accounted for. At the West German heavy-ion laboratory at Darmstadt, experiments have now demonstrated both that the positrons observed form pairs with electrons of equal energy (which is not surprising) but also that there are no fewer than three characteristic energies (624, 720 and 815 keV for the pair of electrons) in collisions between uranium and thorium ions (carrying just under 6 MeV of energy per nucleon). More recently, a French group working at Darmstadt has found evidence for a fourth energy-level, at just under 1,500 keV.

But now there is even bigger surprise. A group from Stanford University and the Lawrence Berkeley Laboratory working at the Lawrence Berkeley ion accelerator called super-HILAC have found pairs of oppositely travelling photons among the products of the collision of uranium and thorium ions at the same energy of 5.9 MeV per nucleon (K. Danzmann, W.E. Meyerhof *et al. Phys. Rev. Lett.* **59**, 1885; 1987). By all accounts, the development has given super-HILAC's supporters, recently dismayed that the average energy per nucleon is so much smaller than likely to be available at the latest generation of ion-collision machines, reason to hope that there will be a new lease of life for it.

From the outset, it has been apparent that one way of accounting for the original observations, and perhaps the most intriguing, would be to postulate the existence of an electrically neutral particle capable of spontaneous decay into an electron pair. Indeed, again since the beginning, there has been talk of the possibility that the neutral particle concerned might be the elusive axion — the particle whose existence is suggested by the need to reconcile charge and parity non-conservation in weak interactions with the observation that strong nuclear interaction behave as people would expect, but which has also been widely canvassed as the origin of the missing mass (over and above that observed in galaxies) required to close the Universe. But people have plainly been anxious not to make too much of that almost out of superstitious fear that to do so might make the phenomenon go away.

But if a neutral particle is capable of decaying into an electron-pair, may it not also decay into a pair of photons? That seems to have been the starting-point for the observations now reported from the work with super-HILAC. A little reflection will show that the detection of oppositely moving pairs of photons in an experiment in which an ion beam (U^{40+}) collides with a fixed Th target are far from child's play, if only because the frame of reference in which the emitted photons (both γ-rays) have equal energy is itself moving at a measurable fraction of the velocity of light (making necessary a 6° offset between the forward and backward directions of paired detectors. And then, given that the super-HILAC arrangement is bound to be an effective way of making X-rays and γ-rays copiously, there will be a huge background within which to search for coincident pairs of photons.

Evidently it should help to know at what energy to look for pairs of coincident photons, which is another of the reasons why the result of Danzmann *et al.* is such a surprise. For it turns out that there is indeed a statistically significant signal — a clutch of oppositely directed photons of equal energy — but that their mutual energy lies at none of the four known levels of the supposed neutral system recognized from the positron observations, but at a fifth level, corresponding to 1,062 keV (with a standard error of merely 0.1 per cent). The authors reckon they can exclude other decays into a pair of photons from states whose total energy is less than 2,000 keV.

What can be the origin of these puzzling signals? Modestly, the super-HILAC group acknowledges that its search for photon-pairs has been a hunt for needles in a haystack. In a range of energy in which the background produces nearly 700 coincidences of oppositely travelling, equally energetic electrons, they have what they call an excursion of 167 events to hold up as their prize — the equivalent of five or six standard deviations, corresponding to a chance fluctuation of one in 10 million or so. In reality, the significance of their signal rests on the narrowness of its energy distribution; the 0.1 per cent line-width is taken to be a measure of the intrinsic properties of the state from which it is derived.

What kind of neutral particle may, when it decays, yield observable products with at least five sharply separated energies? The temptation to say that the truth may be more complicated in that there may be neutrinos as well, carrying away unmeasured amounts of energy, must be suppressed. The snag then is that the measured energy of the photon and electron pairs would not be sharp.

If, on the other hand, the unidentified neutral source of both the electron and photon pairs is a single particle such as an axion, it would be necessary to add the mass of an electron-pair to the kinetic energy of the electron-pairs observed at Darmstadt to obtain the allowed masses of the neutral particle. On that arithmetic, the state of the system observed at Berkeley is the lowest of those recognized. The supposed neutral system is thus a curious animal which, in its lowest state, decays into a pair of γ-rays and which has four more energetic states each of which decays predominantly into an electron-pair. There is no reason why an axion should satisfy these conditions. It is no wonder that people have begun to brood about the possibility that the structure concerned is some kind of atom constituted exclusively of fermionic matter. But ordinary positronium (an electron and positron bound together) will apparently not fill the bill.

Could it be that para-positronium, in which the two electron spins are parallel to each other, will meet the need, providing the long lifetime for the ground state implied by the narrow linewidth of the ground state? Whatever the explanation, it will also have to be explained why such an exotic material should be formed in heavy-ion collisions. Is it simply conjured out of the electrodynamic vacuum?

Where this surprising set of observations will lead is still, apparently, an open question. As always, the best resolution of the problem will be that people should collect more data. **John Maddox**