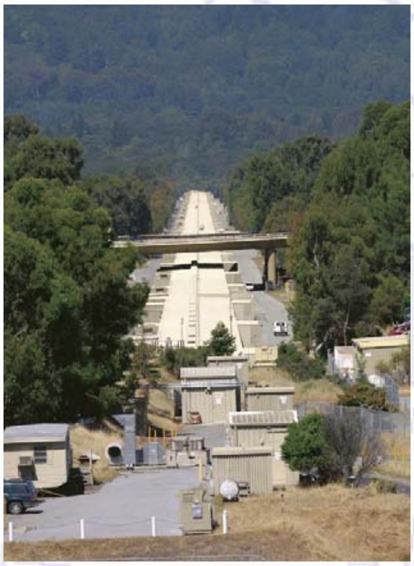
Why do we Exist?



PEP II accelerator

Dr *Fergus Wilson's* work on antimatter continues a long tradition in Bristol's Physics Department. In 1928 Paul Dirac, a Bristol graduate, first proposed the existence of antimatter; in 1933 Guiseppe Occhialini proved it existed; and in 1944 Occhialini came to Bristol where he was instrumental in the discovery of the pion particle. Both won a Nobel Prize for their pioneering work…

Everyone knows that the *Starship Enterprise* was powered by antimatter, but in fact antimatter really exists and scientists from the University's Physics Department are creating it in a massive particle accelerator, here on Earth. They hope to answer a very fundamental question: why do we exist?

When the universe was created in the Big Bang 13.7 billion years ago, it existed as pure energy. Over time, this energy was converted into matter and antimatter in equal amounts, as described by Einstein's famous equation, $E=mc^2$. Yet today, all the antimatter has apparently disappeared. Where has it gone? And why didn't it destroy all the matter to leave a universe devoid of galaxies, stars, planets and human life?

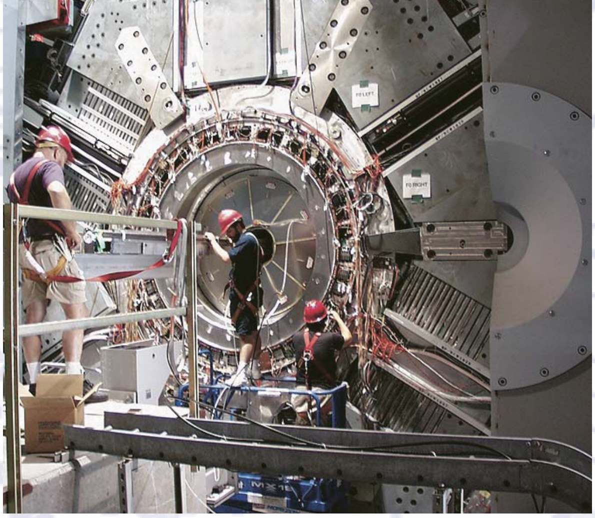
Scientists explain how sub-atomic particles interact in terms of the 'Standard Model' of particle physics. There are four types of forces: electromagnetic, weak, strong and gravity. The electromagnetic force binds electrons to an atom; the weak force is responsible for radioactive decay; the strong force holds the nucleus of atoms together; and gravity acts between everything that has mass. The masses of a matter particle and its antimatter partner are the same, but some of their other properties have opposite signs. For example, the proton and anti-proton have the same mass but different electrical charge and so behave in equal but opposite ways under the electromagnetic force.

We have to produce our own antimatter here on Earth

If there is a very slight difference in the strength of any of these interactions, the relative amounts of matter and antimatter present will change over the enormous timescales that the universe has been in existence – perhaps by enough to explain the universe we see today. We believe that only the weak force shows this so-called 'asymmetry', but to study its effect we have to produce our own antimatter here on Earth and see how it behaves.

In 1993, an international collaboration of 550 physicists from 72 institutes and 10 nations was formed to build an experiment to study the properties of antimatter. The experiment, known as BaBar, took five years to build at a cost of $110 million and is expected to continue running until at least 2008. Bristol University scientists helped design and build its state-of-the-art electronics.

The experiment is based at the Stanford Linear Accelerator Center (SLAC) in California, USA. The world's longest building, it holds a three-kilometre-long particle accelerator called PEP-II that creates bunches of electrons and positrons travelling at close to the speed of light. The bunches are stored in two rings of magnets with electrons and positrons travelling in opposite directions. At one point the two rings cross and it is here that the particles collide – 250 million times every second. Most of the time these interactions are uninteresting but about three times a second we create an Upsilon particle. This particle is unstable and has the useful feature that a billionth of a billionth of a second later it decays – changes – to a matter particle called a B-meson and its antimatter partner, the anti-B-meson. Because the two particles are created in the same way, we are uniquely able to observe both matter and antimatter at the same time. By comparing how the two particles behave we can look for differences. We do this by surrounding the collision point with our BaBar detector, designed to measure the decay products of the mesons and reconstruct what happened to the original particles. →



BaBar detector

PEP ring

Modern particle detectors are highly complex pieces of apparatus – BaBar weighs 1,200 tonnes. They have to run for up to a year at a time without any repairs and, because SLAC is built on the San Andreas fault, BaBar must be earthquake-resistant as well. Millions of channels of data have to be read out using custom-designed and commercial high-speed electronics. In fact, it is estimated that the new generation of detectors will produce the same amount of data per second as is transferred over the whole of Europe's telecommunication network in a day. The data are then processed in real time by large farms of computers before being sent around the world to be analysed.

The experiment currently has about 150 million events stored in what we believe is the world's largest computer database. We are looking for discrepancies of just one part in a million, so we are only beginning to scratch the surface. We have, nonetheless, been able to make some important discoveries. In 2001 we were able to show that there was indeed a difference in the weak force between matter and antimatter. Since then we have made a number of measurements that confirm our first results. In 2003 we even discovered a new sub-atomic particle that has had the theorists scratching their heads.

The good news is that the results agree with our theoretical model for particle interactions (the Standard Model) and all previous measurements. Unfortunately, the Standard Model prediction for the amount of asymmetry we should expect is far too small to account for the current universe. We've known for sometime that our theories do not explain everything and this just confirms that there must be other more exotic theories to describe the universe – perhaps string theory or super-symmetry will come to our rescue.

The BaBar experiment has proved that there is a difference in the way that matter and antimatter interact. We've shown that this asymmetry is a mechanism that can partly explain why all the antimatter created after the Big Bang has been annihilated leaving a universe dominated by matter, but it cannot be the whole story.

Bristol and the BaBar experiment will continue to push back the frontiers of our knowledge and complete our understanding of the universe. We are already working on the next generation of experiment, called LHCb, which will be 100 times more powerful than Barbar. It should be ready in 2008. ■

> We have shown that there is a difference in the weak force between matter and antimatter

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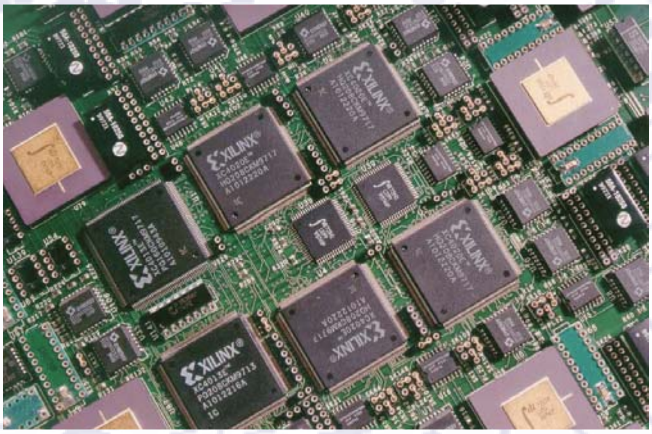
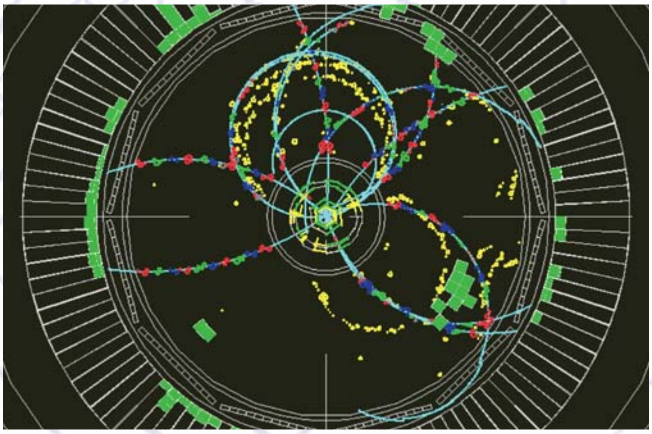
This project was funded by the Particle Physics and Astronomy Research Council (PPARC).



Electronics



A computer reconstruction of a Babar collision