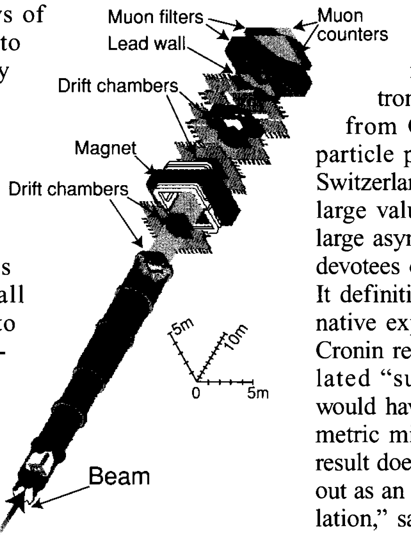
PARTICLE PHYSICS

Surprising Asymmetry Seen in Kaon Decays

CHICAGO—Once again, nature is teasing particle physicists. The Standard Model of subatomic particles, a body of theory that has survived several close shaves over the past few years, suggests that a lopsidedness in the laws of physics called direct CP violation should be small. Now data from millions of particle decays in the Tevatron particle accelerator at the Fermi National Accelerator Laboratory (Fermilab) near here point to a much larger asymmetry. Either the Standard Model is showing a crack—something theorists have long hoped for—or they have been applying the model incorrectly.

Either way, "it's a shocking result," says Bruce Winstein, a University of Chicago physicist on the experiment, called KTeV. For more than 30 years, CP violation has been known in a so-called indirect form, first observed by the University of Chicago's James Cronin and Princeton University's Val Fitch at Brookhaven National Accelerator Laboratory. Fitch and Cronin studied the decays of particles called kaons into the lighter pions. They showed that a long-lived kaon, called K-long, decayed about once out of 500 times into two pions instead of three, which would be forbidden if the laws of physics were unchanged when all particles are changed into their antimatter counterparts and space is reflected about all three of its axes. It was a new and unexpected asymmetry, and its discovery won Fitch and Cronin the 1980 Nobel Prize in physics. [Hints of similar asymmetry were recently seen in the decay of particles called B mesons at Fermilab (*Science*, 18 December 1998, p. 2169).]



Direct detection. Fermilab researchers tracked millions of decays of neutral kaons for signs of asymmetry.

Theorists later came up with an explanation for CP violation within the Standard Model by assuming that a K-long consists of a slightly lopsided mixture of an ordinary neutral kaon and its antiparticle, which added a kind of CP "impurity" in an otherwise symmetrical state. The same explanation predicted that CP violation would still be evident, but smaller, in decays of the neutral kaons themselves. So experimenters went looking for such "direct" CP violation.

But that would require keeping track of many more decays at once, including some that went to neutral pions, which are much more difficult to pick out than the mostly charged pions of the original experiment. It took decades of improvements in detector technology—and the design of a clever experiment—to pick out slight differences in the way kaons and antikaons decayed into several combinations of pions, says Sunil Somalwar, a KTeV collaborator at Rutgers University in Piscataway, New Jersey.

Because the team did a blind analysis of the data—eliminating any human bias by adding an unknown offset that was removed at the very end—they themselves did not know the answer until a few days before the University of Chicago's Peter Shawhan gave a seminar at Fermilab on 24 February. "It was one of the most remarkable moments I've ever experienced in a physics seminar," says Chris Quigg, a Fermilab theorist who is not a member of KTeV. "When he ripped the Post-It off" a viewgraph, revealing the value, "there was a quarter-note rest in the whole audience during which nobody breathed; and then a big gasp, collectively."

The number was far larger than suggested by earlier, sketchier results from the Tevatron, although some results from CERN, the European particle physics lab in Geneva, Switzerland, had also suggested a large value. In one respect, the large asymmetry offers solace to devotees of the Standard Model: It definitively rules out an alternative explanation of the Fitch-Cronin results based on a postulated "superweak" force that would have stirred up the asymmetric mixture. "What this new result does is basically throw that out as an explanation for CP violation," says Fitch. On the other hand, the asymmetry, about 300 times smaller than in the Fitch-Cronin experiment, is also several times larger than the Standard Model had suggested.

Still, theorists should not give in just yet to the temptation to look beyond the Standard Model, says Quigg. The calculations that predict a value for direct CP violation involve poorly known quantities like the mass of the strange quark. If, as some theorists have recently proposed, the strange quark is much lighter than has been assumed, all could be well again, he says. More data are on the way from CERN and the Tevatron, so particle physicists should soon know whether the new results are more tease than promise.

—JAMES GLANZ

BIG SCIENCE

Panel Backs Next-Generation Synchrotron

GAITHERSBURG, MARYLAND—A key federal panel last week recommended continued research toward a "fourth-generation" synchrotron, a machine capable of creating x-ray pulses billions of times more intense than current designs. The instrument could revolutionize many fields of science, from figuring out protein structures to understanding the physics of materials, by providing more detailed snapshots and movies of the atomic structures of molecules and materials. It's unlikely to be built in the next decade, however.

Last summer, the Department of Energy (DOE) asked the panel—made up primarily of university and industry-based scientists—for advice on how to proceed with novel synchrotrons. The panel's go-ahead is expected to prompt DOE to spend up to \$8 million a year this year and next on research and design ideas for the machine. If given another go-ahead in 2001, DOE would likely ask Congress for about \$100 million to build a test-bed facility at the Stanford Linear Accelerator Center. A full-scale facility, designed to accommodate around 1000 users a year, is expected to cost \$1 billion to \$2 billion.

While several different designs have been proposed for a fourth-generation synchrotron, the panel threw its initial support behind a so-called "hard x-ray free-electron laser," which would use gyrating beams of electrons traveling through a linear accelerator to create its x-ray pulses. The synchrotron would produce much higher intensity pulses than existing third-generation machines can, and the x-ray light waves in each pulse would be "coherent," with the crests and troughs of the waves traveling in lockstep. That property, the panel concluded, "has the potential to open new areas of science that are likely to be well beyond what can be anticipated by current scientific knowledge and predictions." One likely beneficiary is the nascent field of x-ray holography, where the blast of coherent x-rays triggers the emission of additional x-rays from atoms in a sample. By tracking how these waves interfere with one another, researchers can determine the location of nearby atoms in a three-dimensional sample in one step rather than the complex multistep approach used today.

The panel's endorsement "is a major event for the synchrotron community," says David Moncton, director of the Advanced Photon Source, a third-generation synchrotron at Argonne National Laboratory in Illinois. But to justify the enormous expense, "a more effective case for the science must still be made," says panel chair Stephen Leone of JILA—formerly known as the Joint Institute for Lab-

CREDIT: FERMILAB KTEV COLLABORATIONS

oratory Astrophysics—in Boulder, Colorado. He's confident that can be done. Whether the promise of great science is enough to convince Congress is another matter: DOE's budget is already feeling the strain of another major project, the $1.3 billion Spallation Neutron Source, which is expected to be completed in 2005. –ROBERT F. SERVICE

QUANTUM MECHANICS

Entangled Trio to Put Nonlocality to the Test

One of the strangest claims of quantum mechanics is that two particles can be "entangled"—inextricably linked at birth. In theory, a measurement on one entangled particle is linked to a degree that defies common sense to a measurement on the other, even though the pair may have traveled to opposite sides of the cosmos. Now physicists at the University of Innsbruck in Austria have created the same eerie link among a trio of photons, so detecting two of the photons preordains the result of the third measurement.

The feat, which the Innsbruck group reported in the 15 February issue of *Physical Review Letters*, allows researchers to close some loopholes in tests of the strange predictions of quantum mechanics. By studying pairs of entangled photons, physicists have already tested the quantum prediction that a measurement on one of the pair will instantly affect the outcome of a measurement on the other, even if they have traveled great distances apart since being created. But these tests have to be run over and over to be sure these "nonlocal" effects aren't due to chance, and purists find such statistical evidence dissatisfying. The entangled trio opens the way to a single measurement that will give one result if nonlocality is true and another if it is not. "This could be like a single shot test of quantum mechanics," says Vlatko Vedral of Britain's University of Oxford.

Because of these stakes, says Daniel Greenberger of the City University of New York, City College, a "race" was on to create such three-photon states. The winning Innsbruck team "did a phenomenal job," he says. "I think it's very significant," agrees Vedral. Besides allowing a yes-no test of quantum nonlocality, three-photon entanglement should also offer more efficient quantum communications, says senior team member Harald Weinfurter. Quantum communications, which promises to be more efficient and secure than normal optical signals, uses entangled states to pass information between participants using carefully prepared sets of photons shared among them in advance. "We are moving toward quantum communications," says Vedral. "It's got implications for quantum computing and all kinds of fundamental experiments," adds Greenberger.

The Innsbruck experiment begins with the same kind of crystal that spawns entangled photons in pairs. When a photon is fired into it, the crystal can split the photon into two daughters that each have half the frequency of the parent. Their common parentage means that the photons' properties are linked. For example, if the first one is horizontally polarized, the other has to be vertical. However, according to quantum mechanics, such properties remain indeterminate until they are actually measured, so if a measurement on one photon finds that it has vertical polarization, its sibling instantly "knows" that its own polarization is horizontal.

Photon tangle. Beam-splitting apparatus which muddles the identity of photons from two entangled pairs.

CREDIT: HARALD WEINFURTER

To entangle three photons, Weinfurter and his colleagues direct a high-frequency laser beam onto the photon-splitting crystal and wait for two photons to cleave simultaneously, giving two entangled pairs. Each time this happens, three of the four photons pass through a system of polarization-sensitive beam splitters and other optical elements, which tangle together the photons in such a way that it is impossible to tell them apart. "We interfere the particles in such a way that in the end you cannot decide any more which of the particles belongs to which pair," says Weinfurter.

Each entangled trio then heads toward three single-photon counters, each with a polarization filter in front of it. These are primed to look out for the trio, amongst other photons, by the detection at a fourth detector of the fourth, unentangled photon of the two pairs. The orientation of the polarization filters is set so that, if the photons are entangled, the counts in two of the detectors are correlated with those in the third—so simultaneous detection in all four detectors flags three-photon entanglement. Three independent photons would show no such correlation.

Recent theoretical work by the University of Calgary's Richard Cleve and others suggests that entangled trios could make quantum communication systems more efficient, reducing by a third the amount of communication required to share information. Equally tantalizing for quantum purists is the possibility of a simple yes-no test of nonlocality. Three-photon entanglement means that the experiment in effect registers a photon in one detector if nonlocality is operating, but in a different one if it isn't. "It's no longer a statement about probabilities, but it's really a statement about one event," says Weinfurter. The team has already made a first stab at the measurements and is analyzing the results, he says. The early news: "Quantum mechanics is correct." –ANDREW WATSON

INDIA BUDGET

Big Increase Seen as Answer to Sanctions

NEW DELHI—Indian researchers are feeling buoyed by a new budget unveiled last weekend that hands science its largest increase of the decade. A 20% hike that would benefit both civilian and defense sectors is seen as a shot in the arm for domestic efforts to overcome foreign sanctions imposed in the wake of last spring's nuclear tests. These large increments "reflect India's determination to fight … the sanctions and denial of technology," says Raghunath A. Mashelkar, director-general of the Council of Scientific and Industrial Research (CSIR).

The increases stand in sharp contrast to last year's budget, which favored the atomic, space, and defense R&D sectors but didn't provide enough for other departments to even keep pace with inflation (*Science*, 5 June 1998, p. 1520). Science and Technology Minister M. M. Joshi told *Science* that this year's planned outlay of $2.56 billion is proof that the prime minister's slogan of "hail science," coined after the blasts, "was not a hollow promise." Still, not everyone is pleased. M. G. K. Menon, a physicist and former science and technology minister, says that the overall budget "lacks any bold new initiatives," such as downsizing the general bureaucracy, and that it fails to invest sufficiently in civilian R&D. "The government has its priorities all wrong" through its emphasis on strategic research related to national security, he says.

To be sure, defense research still receives the lion's share of the government's science and technology investment, rising