The Interplay of Theory and Experiment

by Leila Belkora, Office of Public Affairs

"Theory" is one of those confusing words—like "force" or "momentum"—that has a much more precise meaning in physics than in everyday English. In common parlance, a theory may be little more than a hunch. Sometimes, a nonscientist understands "theory" to mean what a researcher should have found, but didn't. No wonder, then, that physicists who describe themselves as theorists get quizzical looks. "I encounter people with only a vague idea of what I do," says Fermilab theorist Gerhard Buchalla. "They think 'experiment' is when you do an experiment, and 'theory' is when you analyze the data."

In fact, few theorists get a peek at an experimenter's raw data. Theorists deal in the mathematical and conceptual foundations of physics. They consider particles and forces in the abstract, rather than seeking their electronic signatures in particle detectors. Yet, ultimately, their goal is to predict and quantify what is real. Theorist Grigorii Pivovarov, visiting Fermilab from the Institute for Nuclear Research in Moscow, summarizes his profession's ideal as follows: "To be a theorist is to try to imagine possibilities that are not frequent in ordinary life, so one could suggest ideas to experimentalists.... One of the most striking examples is the discovery of antiparticles, which was pure theory, without experimental anticipation."

Antiparticles have the same mass as their regular counterparts, but opposite charge; they constitute only a tiny fraction of the matter in the universe, and usually vanish in collisions with particles almost as soon as they appear.

The story of Nobel laureate Paul Dirac's discovery of antimatter, as told by Fermilab Director John Peoples, beautifully illustrates the interplay of theory and experiment. "When Dirac wrote out his formula [in 1928], it was clear that there were mathematical solutions to the equation that represented particles, like electrons, that went backward in time, or were

Photo by Reidar Hahn

Fermilab Director John Peoples leans on a magnet in the Antiproton Source, where antiprotons collect before colliding with protons in Fermilab's Tevatron. Antiparticles, though every bit as real as particles, were predicted by theory before experimentalists found them.

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antiparticles," says Peoples. "At the time, people didn't like [the idea of] a positively charged electron. Dirac tried to make the predicted particle a proton, but that effort failed, and there was a lot of confusion."

In the meantime, says Peoples, Caltech physicist Carl Anderson conducted a series of experiments on cosmic rays, including flying cloud chambers in B-29 airplanes to record the tracks of these energetic particles at high altitude. "It was clear from these experiments that there had to be a positively and negatively charged electron," says Peoples. "Once people gained confidence that the solution to the mystery was the existence of the electron and its antiparticle, they said, 'What about the proton? Should there be an antiproton?' Then the Bevatron accelerator was built [in Berkeley], with enough energy to create proton-antiproton pairs of particles."

Thus, while discoveries may come from either quarter, history suggests that there would be no meaningful theory in the absence of experiment, and no sense in experiment without theory. Theorists describe their contribution as building a framework for understanding laboratory results, like scaffolding around the emerging edifice of empirical knowledge. For Fermilab theorist Chris Quigg, "The essence of making progress is making links between different results.... Where something doesn't make sense, the result might not be right, or the framework might not work."

Despite the partnership of theorists and experimentalists in building a tower of knowledge, each according to his strength in mathematics or hands-on construction, they occasionally take potshots at each other. "The difference between theorists and experimentalists?" chortles one physicist, seizing the opportunity to set the record straight, "That's easy: one of them is the good guys. And the other is scum."

Part of the rivalry comes from the uncertainty about who will steal the limelight with the next major step forward. Theorists believe they have in hand a robust theory of the fundamental building blocks of nature—quarks and leptons—and their interactions. This 'Standard Model' includes the effects of electromagnetism, relativity and quantum mechanics, and accounts for the behavior of matter on a wide range of scales, from galaxies down to the gluons that bind quarks in a proton. But challenges remain at even smaller scales, and the race is on to explore that domain.

Theorist Edward Witten of the Institute for Advanced Studies in Princeton sees developments in the last two decades as a triumph of theory. "Experiment was in the lead from the early discoveries of the particles, almost all of which were surprises, right up to the consolidation of the Standard Model in the late 1970s," acknowledges Witten. Subsequently, he says, theory leaped forward. Theorists predicted the masses and properties of the W and Z particles before experimentalists found them at CERN, the European Center for Particle Physics, and although Fermilab's discovery of the bottom quark was a surprise, its follow-on discovery of the top quark in 1995 was expected. "This theoretical framework of physics [...] has been very successful, perhaps surprisingly so, as experiments have gone to higher energies," concludes Witten.

Fermilab theorist Chris Hill says the uncharted territory in physics today is at the small scale of 10^{-17} cm, in a field known as supersymmetry. "People always think we deal in atoms," says Hill, "but we're dealing with sizes that are as small compared to an atom, as an atom is small compared to a person's head."

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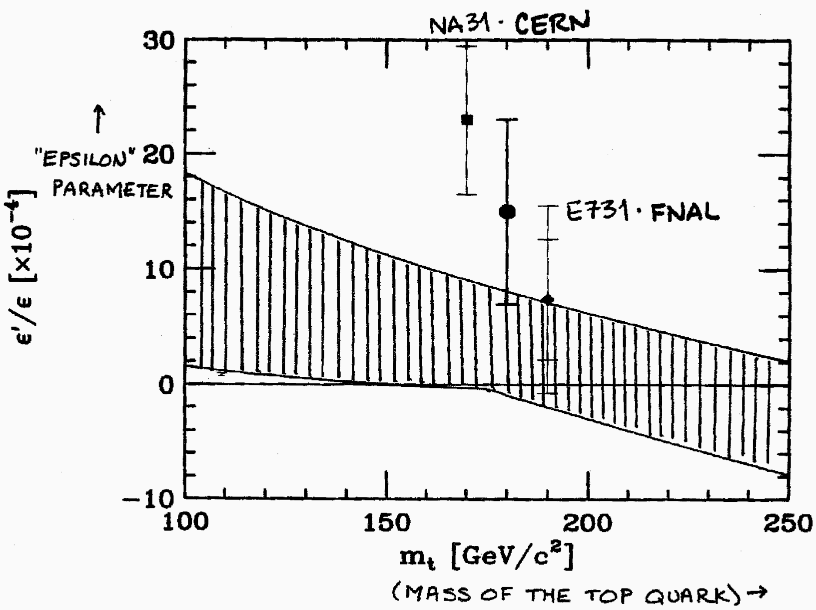

The convergence of theory and experiment, illustrated by a plot of predicted and recorded values for the so-called epsilon parameter. The epsilon parameter, on the vertical axis, is a measure of the degree to which matter dominates antimatter in the universe. The shaded area represents the range of theoretically predicted values, which depends on the mass of the top quark. The three experimental points, shown with error bars, come from Fermilab and CERN measurements of the epsilon parameter.

Chez Léon

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Wednesday Lunch July 24

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Profiteroles

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Barbecued Flank Steak with
Grilled Onion Guacamole
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Grand Marnier Soufflé

Wednesday Lunch July 31

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Thursday Dinner August 1

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Potato Fonteccia
Vegetable of the Season
Lemon Pie

Medical Office to Move

by Eric Berger, Office of Public Affairs

If you catch a bug or need a medical test in the next few days, you may need to look elsewhere for medical treatment because the Fermilab Medical Office closed its doors during the week of July 15.

To open up more space, the Medical Office moved from its first floor location to Wilson Hall's ground floor, near the main west entrance. "It will have a lot better access for ambulance service, more space to give the doctor an office and better record storage facilities," said Charles Marofske, head of Laboratory Services Section.

The new area's design will better accommodate patients, both those waiting and those undergoing treatment.

"There will be more room to move around in the visual and audio test areas," Marofske said. "The facilities in general will be more comfortable and the waiting room will be able to handle more traffic."

The Medical Office's doctor said the move will take about a week. During that time the Medical Office will remain closed except for emergencies. "We won't do routine examinations or blood pressures," Dr. David Morrison said. "But if there are injuries, of course we'll have to see them."

Morrison said the need for space has driven the move. While the new location will not enjoy the prominence that the current location does, he believes it will improve things over the long run.

"It may be a little bit less convenient for people who use the first floor," said Morrison, who has worked as Medical Office doctor since 1989. "But it will be very accessible to the west entrance on the ground floor. The new office will have a little more space and it will be laid out a little bit better."

Long range plans are already in the works to fill the space made available by the Medical Office move.

"The Travel Office and the Users' Office will be moved over there," Marofske said. "Current plans call for expanded meeting room space and some eventual cafeteria expansion." ■

Theory vs. Experiment

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Hill says the particles that the new theory predicts at these small scales (or equivalently, at high energies) are partners to the particles we already know, much as antiparticles are complements of regular particles. "Antiparticles are an inescapable consequence of relativity and quantum mechanics," he says, and "a more elaborate symmetry, yet to be observed" predicts a similar relationship between the matter particles and forces we know now and 'superparticle partners.'

Witten, who dazzled a Fermilab audience recently with a colloquium tying together the Standard Model, supersymmetry, string theory, and something he called "supergravity," issued a challenge to experimentalists to take back the lead by finding evidence for supersymmetry. "The discovery of supersymmetry is not just a yes or no question," he says. "The discovery would lead to a whole host of questions about how supersymmetry is realized, what are the superparticle masses....These questions really don't have preferred answers by theorists, and that is why it would be an experimentalists' game, probably for quite a while, if supersymmetry were discovered." ■

Photo by Reidar Hahn

Everyone's favorite theorist, Albert Einstein. Woodcarving by Fermilab Accelerator Operations head Bob Mau.