charged particles, would bristle with electricity, possibly interfering with satellite communication. And the plume could well wreak havoc on civil aviation. “How would British Airways deal with its jets being grounded for 5 months?” asks Thordarson. “Planners would be smart to think ahead about how they might deal with such a contingency,” says Christopher Newhall, a volcanologist with the U.S. Geological Survey in Seattle, Washington. However, he notes, “the chances of the next one happening in our lifetimes is relatively low.”

At the moment, Iceland’s fissures do not seem to be up to trouble. “We have not seen potential precursors for an eruption,” says Freysteinn Sigmundsson of the Nordic Volcanological Centre in Reykjavik, who serves on the science committee of Iceland’s civil defense department. Precursors could include earthquakes, deformation of the earth’s crust, or an uptick in geothermal heat.

But volcanic fissures are hard beasts to track. A full-blown fissure eruption would follow an upsurge in magma from reservoirs near the crust-mantle boundary about 10 to 20 kilometers below the surface. Before the next Laki-type eruption, huge volumes of magma need to accumulate—as much as 15 cubic kilometers, roughly the amount generated under all of Iceland over a span of 100 years, Sigmundsson says. Although a strategy for monitoring precursors of such events remains elusive, he says, satellite radar imagery can detect crustal deformation—and thus magma accumulation—as deep as the crust-mantle boundary. “Judging from Laki, we would have 3 to 4 weeks of precursor activity,” mainly in the form of earthquakes,” Thordarson says.

Yet there are uncertainties galore. High magma pressure at Grímsvötn and Katla—a volcano just to the southwest of Laki—could trigger a failure of the plate boundary between the volcanoes, which in turn could spark a fissure eruption, Sigmundsson says. Civil defense officials will remain vigilant for signs of such an event, he says: “We’re following the situation closely.”

A Laki-esque eruption could also occur in other volcanic systems in Iceland. Katla’s current bout of insomnia is particularly disconcerting. The biggest fissure eruption in recorded in history was that of the Eldgjá fissure just east of Búland and connected via its plumbing to Katla. Over 6 years beginning in 934 C.E., Eldgjá spewed about twice the amount of sulfurous materials into the air as Laki later produced. “Eldgjá had a huge environmental impact and probably stopped settlement of Iceland for some years,” says Thordarson. “In that eruption the fissure and Katla volcano erupted simultaneously.”

Current scientific interest in Laki and its ilk stems in some measure from a new appreciation for the observations of Steingrímsson, who saw the eruption as a religious apologue that would die with him unless he committed it to paper. As he wrote in his forward to *Eldrit*, “I thought it would be unfortunate if these memories should be lost and forgotten upon my departure.” The deformed, fluoride-laden bones that Hildur and Baxter have unearthed may provide another powerful testament to the peril of taking Iceland’s fissures lightly.

Thordarson, for one, is intent on persuading colleagues and the general public that Laki is a sleeping giant that cannot be ignored. “We’re much better off if we prepare ourselves for the worst-case scenario,” he says. “I’m not trying to be a doomsayer. But it could happen tomorrow.”

–RICHARD STONE

High-Energy Physics

Rara Avis or Statistical Mirage? Pentaquark Remains at Large

Two years after its surprise appearance in debris from a nuclear collision, some researchers suspect an exotic particle may be a will-o’-the-wisp

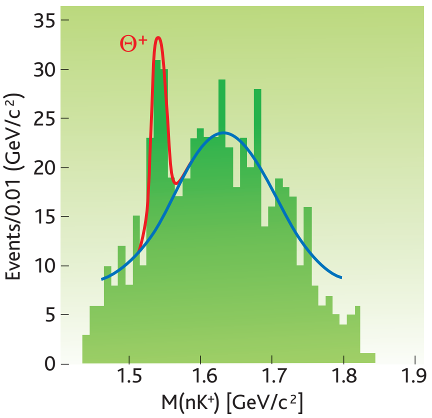
Two years ago, scientists in Japan and then the United States made headlines around the world by announcing that they had found an unusual particle. This creature, dubbed the Θ^+ (theta-plus), was apparently made of five quarks rather than the two or three quarks that make up all other known quarky matter in the universe. That unique property would make the so-called pentaquark a totally new way to probe the forces that hold atoms together (*Science*, 11 July 2003, p. 153). “It’s a fantastic beast—if it exists,” says Ted Barnes, a physicist at Oak Ridge National Laboratory in Tennessee.

But the beast might be mythical. Even though a dozen experiments have independently claimed to detect the Θ^+ particle in their data sets, and physicists at the Thomas Jefferson National Accelerator Facility (JLab) in Newport News, Virginia, are trying to corner the particle, some particle physicists are murmuring their disbelief. As negative results and inconsistencies pile up, many scientists suspect that pentaquark aficionados are chasing a phantom.

Edward Hartouni, a physicist at Lawrence Livermore National Laboratory in California, is part of a team that pored through the debris of a billion energetic particle collisions, searching for evidence of pentaquarks. If the particles exist, they should show up on data plots as a huge spike. They are missing. “There is no large peak here,” Hartouni says.

The case in favor

It’s hard to believe that something that has been spotted at so many laboratories might be an artifact. Indeed, these laboratories seem to have spotted the Θ^+ in different ways. Some, including the SPring-8 experiment in Japan and those at JLab, zap nuclei with light. Others, including experiments in Russia and Germany, smash mesons or protons or electrons into nuclei. The result in each case seems to be the same: a “peak” in the data that signals the brief life of a five-quark particle—whose mass is a bit more than one-and-a-half times that of the proton—that quickly decays into a handful of smaller particles.



Shaky pillar? Data spikes hinting at new type of matter have drawn fire from skeptics.

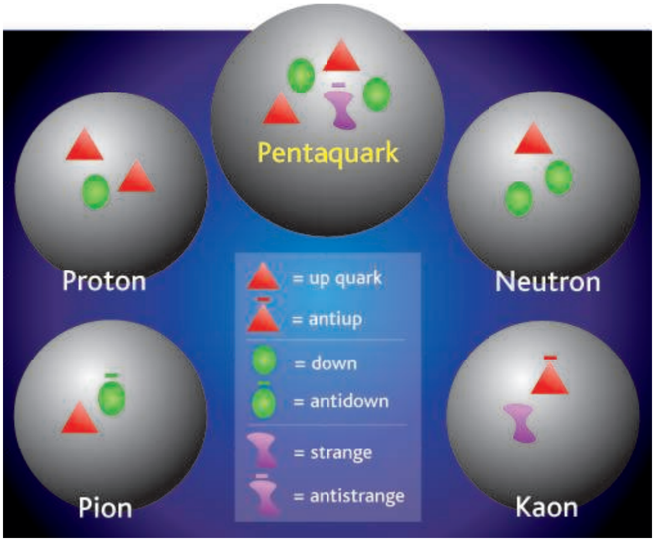
SOURCE: K. HICKS/OHIO UNIVERSITY

Particle physicists have been finding such peaks for decades. In the spray of debris after a collision, there’s a wealth of information as to what happened. Scientists with sufficiently good detectors can look at the tracks of the debris and identify what those particles were. By tracing the tracks backward and seeing how they combine or split apart or kink or curve, physicists can infer what sorts of particles were created in the smashup, how heavy they are, how much charge they carry, and what they decay into. Often, scientists will graph data in a way that shows the number of times that a certain collision yields an event with a giv-

Published by AAAS

en energy. A lump in that data will often indicate the repeated creation of a particle with a given mass-energy; for example, scientists running the right type of experiment will see a clear peak at 1520 MeV that indicates the creation of a three-quark particle known as the Λ(1520).

The better the detectors are and the more events are analyzed, the more starkly a particle's lump will stand out amid the bumps and wiggles of background noise and statistical fluctuations. According to Kenneth Hicks, a physicist at Ohio University, Athens, and member of the JLab team, lots of experiments have detected a peak that would signal the creation of the Θ^+ particle—a very narrow peak at about 1540 MeV—with good statistical significance. "Some appear to be very significant," he says. "About one dozen experiments have seen it with statistics better than 1 in 1000." Or, more precisely, there have been quite a number of "three-sigma" detections, which are the informal gold standard of statistical significance under many circumstances in particle physics. "Many [detections] are higher: four, five, six sigma," adds Hicks. Five- and six-sigma results are usually considered quite high quality, and one that turns out to be false can wind up being a high-profile embarrassment (*Science*, 29 September 2000, p. 2260).



Oddball. All other known quark-based particles contain either two or three quarks; controversial pentaquark would boast five.

The case against

Even so, some physicists remain unconvinced. For a start, the apparent sightings pose theoretical problems. The narrower the peak, in general, the more stable the corresponding particle, and pentaquarks shouldn't be all that stable. According to theories about the forces that bind nuclei into stable packages, it's difficult to see why a five-quark ensemble, for example, wouldn't rapidly decay into a baryon (with three quarks) and a meson (with two). "It should spontaneously fall apart," says Barnes. "There's no reason for it to stay together." If some unknown mechanism keeps it from splitting into fragments, it must bind the five quarks quite tightly to create the narrow peak.

Although this is difficult to understand, it might be the sign of exotic new physics for theorists to figure out. However, although the peak is narrow—25 MeV wide or smaller, with its apex pinned within 5 or 10 MeV—its center seems to move around. The experiments that claim to have seen the Θ^+ peg its mass-energy at anywhere between about 1525 MeV and 1555 MeV. "That's an extraordinarily large range," says Michael Longo, a physicist at the University of Michigan, Ann Arbor.

"It worries some people, but it doesn't worry me," counters Hicks, who argues that the inherent errors in pinning down masses can account for the differences between the experiments. "It's consistent within the error bars."

More disturbing to skeptics, though, is that a number of efforts to mine old data for signs of the Θ^+ have come up empty. For example, Longo's team reanalyzed the debris of proton-proton collisions at Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, and failed to find any five-quark particles. "One of the things we thought we would be able to see is the pentaquark state Θ^+," he says. "We thought we'd just verify the existence of the state. It just wasn't there." Hartouni's group also looked at collisions at Fermilab, and although they found a nice sharp peak that signaled the existence of the nearby Λ(1540) particle, there was no hint of a spike for the Θ^+ at 1540 MeV. "At 1540, we see essentially no [Θ^+] production," he says.

Hicks calls the Hartouni result "one of the most significant results of a nonobservation." But with so little known about how pentaquarks are produced, he says, it's possible that high-energy collisions like Fermilab's might not create pentaquarks in the same manner as the lower-energy collisions at JLab. Others are less sure. "If, in fact, the JLab results are confirmed, we have a true puzzle," says Hartouni. "If the production mechanisms are different, we have to think very hard as a field." Some, such as physicist Alex Dzierba of Indiana University, Bloomington, go even further and call the Fermilab results and an increasing number of other nonsightings from laboratories in the States and in Europe "an overwhelming body of negative evidence."

How, then, to account for the dozen sightings at different labs? There are a number of mechanisms that could lead to a hump in peakless data. Robert Chrien, a physicist at Brookhaven National Laboratory in Upton, New York, says the peaks could be artifacts caused when physicists weed out their data sets to reduce statistical noise. "As soon as you make cuts, you can introduce bias," says Chrien. "We once thought we saw a peak in a gamma ray spectrum exactly at an energy predicted by one of the theories," he says of an unrelated experiment—a peak that disappeared as soon as the biasing cuts were wiped out.

There are other possibilities, too. Dzierba suspects that some of the Θ^+ sightings are due to "ghost tracks": incorrectly reconstructed particle trails that plague high-energy physics experiments. Sometimes even the most sensitive equipment will see two particles when only one exists. Dzierba says an incorrect tally of certain reactions involving the Λ(1520), pions, and protons could make a peak at "precisely the mass of the Θ^+." Other exotic effects, such as a "reflection" of another peak, might cause a miragelike hump in the data. "There's lots of possibilities," says Barnes. However, he adds, coming up with alternative explanations for the pentaquark peak "doesn't really mean anything. You can't say it doesn't exist. The issue is going to get settled with a really good experiment."

That's what the folks at JLab hope, too. "As of now, there's no clear experimental evidence for either the existence or nonexistence of the Θ^+," says Stepan Stepanyan, a physicist at JLab, who has been performing a high-statistics search for the pentaquark at JLab. Although the team has gathered roughly five times as many data as the first JLab sighting, it is not yet ready to release its analysis. If the peak disappears or stays small, then the pentaquark will almost certainly be an artifact of the analysis. If the peak gets starker—and if the team is careful about their cuts and weeds out the ghost tracks and phantom reflections—then it will likely mean that the Θ^+ is real, and that a seemingly unstable beast gets stability from an unknown mechanism.

"The stakes are high," says Stepanyan. "If the Θ^+ exists, then our naïve picture of [nuclear] structure will change." If it doesn't exist, though, then the pentaquark hunters will add their names to the rolls of those who went hunting for big game and wound up on a wild-goose chase.

–CHARLES SEIFE

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