Now you see it...

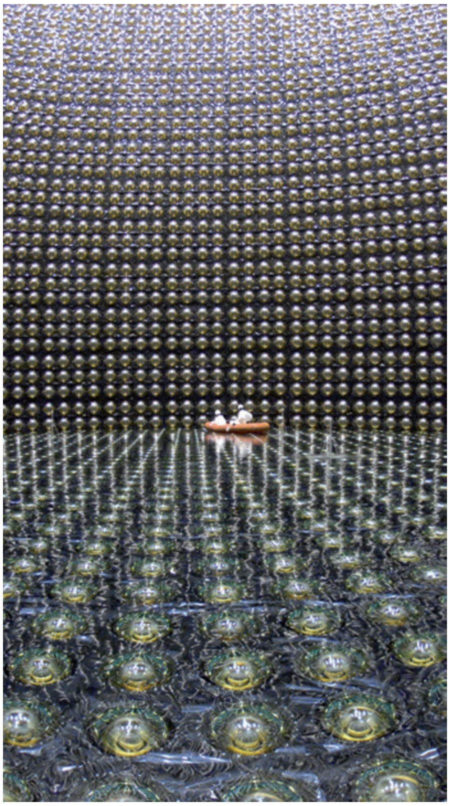
Particle physicists are strict about signals — five standard deviations is what's required. But discoveries may also emerge gradually from confusing effects that are initially of much lower significance.

'Discovery' can seem an absolute, a decisive step into a realm of new knowledge. Alexander Fleming discovered penicillin; Galileo discovered Io, Europa, Ganymede and Callisto, the four largest moons of Jupiter. The history of physics is peppered with 'eureka' moments, from Archimedes onwards. But often in modern physics, the process of discovery becomes more blurred — especially in modern particle physics, as the experiments and measurements become increasingly complex.

Much as we enjoy those Stockholm-worthy moments — for instance, the clean, clear signature of the *W* boson seen at CERN in 1983 — more typical is slow, steady progress towards the extraction of a statistically significant signal from a well-understood background. Such was the discovery of the top quark, at Fermilab, starting in 1992 with the first tentative hint, through a 1994 publication of "evidence for" its detection, to the definitive statement of "observation of" the top quark in 1995. Results from two separate pieces of apparatus, the CDF and D0 detectors, both observing the proton–antiproton collisions generated by Fermilab's Tevatron accelerator, finally converged on the desired, significant, '5-sigma' proof.

The physicists of the CDF and D0 collaborations now find themselves facing another data challenge. Earlier this year, CDF announced that they had found something odd. For those proton–antiproton collisions that result in the production of a *W* boson alongside two, identifiable jets of other particles, CDF seems to be picking up rather too many of them when the combined mass of the two jets is around 140 GeV c^{-2}, compared with the standard-model prediction. Assuming the background of other interactions (these collisions are very messy) and all systematics associated with the apparatus are understood, these CDF data show a tantalizing bump that has a statistical significance of 3.2 sigma (Aaltonen, T. *et al.* *Phys. Rev. Lett.* **106,** 171801; 2011). The team has subsequently added more data to the analysis, and the significance of the effect has crept up to 4.2 sigma — getting closer, but still not achieving that magic 5 sigma.

Yet, whatever it is that CDF sees, D0 doesn't. The other collaboration, working independently on its own data, last month published its analysis of *W*–dijet production, which was perfectly in accord with the standard-model prediction (Abazov, V. *et al.* arXiv.org:1106.1921; 2011). This necessary corroborative step underlines the importance of building at least two detectors at any accelerator that are complementary but not identical in their technology. For the moment, for all that the CDF result is straining against the barrier of 5-sigma significance, the disagreement between the analyses is unresolved. The D0 collaboration will be able to add more data to its analysis, as CDF has already done. And Fermilab has now announced the creation of a task force, involving members of both collaborations, to work through the details with as fine a tooth comb as necessary, to understand whether there is, or isn't, something there.



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Meanwhile, another particle-physics experiment on the other side of the world is also 'almost there' with an important discovery. T2K is a neutrino experiment, in which a beam of muon neutrinos is fired from the accelerator complex J-PARC, in Tokai, to the Super-Kamiokande detector (pictured) in a mine under Mount Kamioka, 295 kilometres away.

Neutrinos, which come in three types, have been shown to oscillate — that is, one type of neutrino changes into another as the particle propagates. What had not been proved experimentally, however, was that muon neutrinos specifically can oscillate into electron neutrinos. And yet this has important bearing on the degree of 'CP violation' that may be possible among neutrinos, and hence on our understanding of antimatter: it is in this violation of charge and parity symmetries that a measurable difference in the behaviour of matter and antimatter shows up.

T2K has now published data that "indicate" the appearance of electron neutrinos in a muon-neutrino beam. They have detected six instances of electron-neutrino appearance, compared with an expected background of 1.5 events. Once again, that vital statistical significance is just lacking and the collaboration admits that "more data are required to firmly establish" the result (Abe, K. *et al.* arXiv:1106.2822; 2011). Unfortunately that data will take a while to accumulate, as T2K was disrupted by the earthquake that hit Japan in March. The experiment should, however, be in operation again by the end of the year, and its definitive 5-sigma 'observation' will no doubt follow.

The mystery of the CDF bump remains to be solved. The Tevatron is scheduled for closure later this year, so the amount of data that will ultimately be available to CDF and D0 is firmly capped. However, over at CERN, the Large Hadron Collider has just reached another milestone: each of its general-purpose detectors, ATLAS and CMS, has now collected one inverse-femtobarn of data so far this year. The unit is somewhat obscure, but think of it as a 'good chunk' of data — importantly, it was the data-accumulation target for the end of 2011, but has already been met in June. Before long, ATLAS and CMS will also be in a position to check out the CDF bump.

But don't expect a eureka moment, necessarily. New physics may well emerge rather more gently — with ever increasing significance — from painstaking work. ❐