Sam Ting's last fling

The International Space Station's one chance of scientific greatness rests on a high-profile refugee from the world of the particle accelerator — but is it too long a shot to be worth taking? **Eric Hand** reports.

In 1994 Dan Goldin, then the administrator of NASA, was on the look out for sexy scientific ideas. In particular, he needed something that would endear the International Space Station — a merger of America's earlier space station plans with those of Russia — to scientific sceptics unimpressed by the experimental opportunities it offered. Roald Sagdeev, the former director of a major Soviet space research institute, mentioned to Goldin that Samuel Ting, a Nobel prizewinning particle physicist, was toying with ideas for a spaceborne magnet that would sift antimatter from the stream of particles from beyond the stars. "He said, 'Okay, where is this guy? I want to see him immediately,'" recalls Sagdeev.

By 1995 Ting, a professor at the Massachusetts Institute of Technology in Cambridge, had won Goldin's agreement that NASA would give his Alpha Magnetic Spectrometer (AMS) space on the station, and a shuttle flight to get it there. Part of that agreement was that the agency would not have to pay for the AMS to

be built. Instead Ting got the Department of Energy (DOE), which funds US particle physics, to oversee the AMS — and undertook to round up most of the funding from foreign governments.

That he did. Thirteen years on, and by some accounts US\$1.5 billion down the line, a vast team of physicists from 16 countries has put all but the finishing touches to the AMS. But since returning to flight after the loss of the Columbia in 2003, the shuttles — due to retire in 2010 — have been devoted almost entirely to completing the space station. A dedicated AMS flight was dropped from the manifest in 2005, and reinstating one seemed, until recently, out of the question.

Yet Ting, 72, has soldiered on. A Nobel prize and decades running huge particle-physics collaborations give him considerable heft; few physicists have the clout to get an Italian foreign minister to plead their case to US secretary of state Condoleezza Rice. And the presidential campaign has provided extra leverage to

the weight Ting brings to bear on lifting the AMS into the sky. An extra shuttle flight is a nice thing to promise Florida voters worried about jobs that will disappear when the shuttle is grounded for good, and both candidates for the presidency have recently made such promises. Congress has sent on to the White House a bill authorizing Ting's shuttle flight.

Over tea in an empty but opulent dining room at the Mayflower Hotel — Ting's campaign headquarters in Washington DC — he folds himself into a chair and cracks open a laptop full of documents, charts, even old clips from *The New York Times* lauding his past achievements. "I know all the technical details," he says. "I'm the one responsible if something goes wrong. I don't do anything else but this." Every day for 13 years, it has been his focus, an all-consuming passion and worry; every day except, that is, for ten days in 1998, when the prototype AMS-01 was flown on the shuttle Discovery. With the experiment floating weightlessly, gathering data from particles

ILLUSTRATION: P. DISLEY

passing through its doughnut-shaped magnet, Ting felt himself relax. "For the first time, I realized that if something went wrong, there was nothing I could do."

Ting's case, bolstered by slide after slide from the laptop, is that the AMS will open up a new spectrum to astronomy: that of charged particles. Antimatter left over from the Big Bang is an imagination-grabbing example of the sort of thing it might find. But only an example: the real need for the AMS, in Ting's mind, is to discover the utterly unforeseen. One of his slides lists the originally cited aims of a huge range of 'big' science projects over the past 50 years — and the discoveries for which they are famous. The two are always different. "What you will see," he says, in his slow, soft voice, "it's hard to predict."

The numerous opponents of the AMS, however, think that they can predict the project's results — and that they are likely to be relatively underwhelming. No current theory leads them to expect the presence of antimatter nuclei in space of the sort Ting talked to Goldin about. There are other things, they say, on which the money that would be needed to launch the AMS could be better spent — things the astrophysical community has evaluated and prioritized. But Ting will have none of it. In 1976, his Nobel lecture offered a tale of careful experiment proving theorists wrong. Experiments are most meaningful when they disagree with theory, he says, with an emphatic tone that brooks no dissent. "The advancement of physics depends on you destroying other people's perceptions."

Sam I am

Ting's record backs up his belief in the transformative value of daring experiment. "By being just that much more clever or careful than everybody else, Sam's able to get stuff out that other people missed," says John Ellis, a theorist at CERN, Europe's particle-physics facility near Geneva. It was through such painstaking measurement that Ting won his Nobel prize in the first place. At Brookhaven National Laboratory in Upton, New York, Ting managed to pick the signature of a new particle out of a very messy energy spectrum with almost-over-the-top levels of instrumentation, and a monumental insistence on thoroughness. When Ting shared the 1976 Nobel Prize in Physics for the discovery, the prize committee described his feat as being "like hearing a cricket near a jumbo jet".

As Ting's reputation grew, so too did the size and scope of his experiments. By 1983, Ting was leading what became the largest physics

collaboration in the world: the L3 experiment at CERN's Large Electron Positron (LEP) collider, the first machine to occupy the vast tunnel that now houses the Large Hadron Collider (LHC). With almost 500 physicists, L3 employed more people than any of the other three experiments spaced around the LEP ring.

It was also remarkably international, cementing in place Ting's reputation as one of his discipline's great fixers. An American born in Michigan and raised in Taiwan, he got China to supply special crystals to the detector — its first foray into high-energy physics at that level — while getting

the Soviet Union to contribute an Eiffel Tower's worth of iron. His leadership approach was not exactly democratic, but he accomplished things quickly and decisively, says David Stickland, a CERN physicist who worked on L3. He recalls a time when Ting was asking the DOE for an upgrade to the LEP experiment. The DOE rejected his proposal. "Sam just stood up and said, 'I reject your rejection,'" recalls Stickland. "He really operates outside the norms that way."

"For the first time, I realized that if something went wrong, there was nothing I could do."

— Samuel Ting

Sam Ting at Brookhaven displaying the results that won him a Nobel prize in 1976.

L3 ran on the LEP until the accelerator was closed down in 2000. But Ting's attempts to build something even bigger were thwarted. The coalition he put together for a detector to grace America's planned Superconducting Super Collider involved 1,000 scientists from 90 institutions in 13 countries; but it suffered internal strains, and the collider's management rejected it in 1991. Pivoting back to CERN, Ting suggested putting a revamped L3 onto the LHC. Unusually for him, this was a comparatively cheap proposal. But CERN rejected it.

Licking their wounds, Ting and his close collaborators began to think about something smaller and simpler — a break from the demands of giant collaborations, according to Ulrich Becker of the Massachusetts Institute of Technology, who has worked with Ting since 1965. The idea for the AMS was born on a coffee break from L3 work. "I had this dream to build an experiment that would have fewer than 100 collaborators and could fit on a table," Becker says. The idea endured: the scale didn't. The project has involved not 100 but 500 scientists, from 56 institutions. At 7 tonnes, it would need the sort of table a minibus can be parked on. Its extraordinary 0.86-tesla magnetic field is 17,000 times bigger than Earth's and five times greater than a sunspot's. If the AMS didn't spend half its energy cancelling out the field lines that would otherwise stray beyond its confines, the space station wouldn't stay stationary very long. "Sam Ting doesn't like to do small things," says Becker.

Big-Bang refugees

The AMS team sees celestial charged particles, also called cosmic rays, as a way to look into a problem that particle physics has not yet solved on its own terms: why is the Universe mostly matter, not antimatter? Processes that favour matter over antimatter clearly played a role in the Big Bang. How those processes played out, though, is still something of a mystery. The contribution the AMS team hopes to make to this debate is to see whether the Universe's bias against antimatter is as complete as is normally assumed.

If any antimatter did escape the annihilations of the early Universe, then there could be stray antiatoms still around today. And if an antihelium nucleus — the lightest antiatom that can't have been formed by any known process since the Big Bang — were to pass through the central void in the AMS's doughnut, its mass and charge would be immediately revealed by the way its trajectory bent in that awesome magnetic field. The distinctive curve of antihelium would be a revolutionary discovery. That of any heavier antimatter would be simply mind-boggling — a sign of antagalaxies

and antistars somewhere far off and as yet unobserved, their nuclear fires fusing together the antimatter equivalent of the stuff of which Earth, and humans, are made.

Antimatter does not have to be primordial. Its lightest particles can be made in various ways, some known and comparatively prosaic, some fanciful and as yet unseen. Some theories hold, for example, that the decay of small black holes might produce antineutrons stuck to anti-protons. Other processes can make these too, but those coming off black holes would move peculiarly slowly — something the AMS's sensitivity to mass, charge and speed would pick up. Cold dark matter (CDM) — hypothetical particles thought to account for most of the mass of the Universe — could be a contemporary source of distinctive antimatter too, in the form of high-energy positrons given off when the CDM particles decay. And then there's strange matter — matter made up from more types of quark than just the two basic ones that make up neutrons, protons and their antiparticles. The AMS could conceivably detect light, long-lived particles of this quark matter.

These wonders sold the idea to Goldin in the 1990s. But they have not convinced the astrophysicists who account for most of NASA's astronomical constituency. Once every decade the US National Academies produce a major report stacking up astronomers' research projects against each other. NASA uses these reports as prioritized shopping lists. The decadal report that came out in 2001 makes only a desultory mention of the AMS, treating it as if it was something outside the report's purview, destined to happen regardless. "The AMS was something that came out of high-energy physics

Sam Ting (right) surveys the AMS experiment with representatives from China.

as a big project at a high level," says Thomas Gaisser, of the University of Delaware in Newark and the panel chair responsible for reviewing projects such as the AMS for the decadal report. "The people who had been working in the cosmic-ray fields for a long time didn't like the competition, basically." The decadal report did not endorse the mission.

The antihero

In a letter from February of this year, Craig Hogan, chair of an astrophysics advisory committee to NASA, noted that the AMS also went unmentioned in a 2003 National Academies report that was specifically supposed to consider cross-community projects dealing with the nature of cosmic matter. "The overall health of the astrophysics programme is put at risk by any mission whose science value has not been transparently compared with other missions," wrote Hogan, director of the Center for Particle Astrophysics, at the Fermi National Accelerator Laboratory in Batavia, Illinois. Ting responds by pointing out that the AMS is not a NASA astrophysics mission. No NASA science money has been used, and no NASA scientists have worked on it. In terms of being reviewed for scientific merit he notes DOE reviews performed in 1995, 1999 and 2006, in addition to multiple reviews by European agencies.

Another line of attack is now opening up. When the AMS was first proposed, tests for antimatter in cosmic rays had hardly been tried: the new window on the Universe they offered was wide open. Now there are some data. BESS (Balloon-borne Experiment with a Superconducting Spectrometer) has looked for antimatter in

cosmic rays on three high-altitude balloon flights around Antarctica; the PAMELA (Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) satellite was launched in 2006. Both, oddly enough, are cheap descendents of an earlier cosmic-ray experiment proposed for the US space station in the 1980s. Their verdict on primordial antimatter? It probably isn't there. "Will AMS provide any fundamental answers that BESS and PAMELA haven't?" asks John Mitchell, US principal investigator for BESS at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "The answer is, probably, no."

This doesn't mean that the AMS has no chance of finding primordial antimatter: but the window has closed down a lot. And Ting's nippy little rivals are also making inroads into other science that the AMS could have had to itself. There are enticing, as

yet unpublished, hints that PAMELA is seeing some of the high-energy positrons that might be expected from decaying cold dark matter (see *Nature* 454, 808–809; 2008). If this turns out to be the case, the news for the AMS might be bittersweet. Its far greater power and spectral range would be excellent for further analysing those positrons, and so the case for launch would be strengthened. But rather than opening a new window on the Universe, its primary purpose would be reduced to that of follow-up to someone else's discovery.

In the meantime, as PAMELA gathers more data, the AMS just sits at CERN, where it was assembled. Over the summer, technicians calibrated it, blasting it with high-energy particles. At the end of this year, the AMS will be taken to a European Space Agency facility in the Netherlands, where it will be tested in

A technician checks the spectrometer.

"Sam just stood up and said, 'I reject your rejection'."
— David Stickland

space-like conditions. As early as June 2009, the AMS could be ready to cross the Atlantic, tied down in a 747 Lufthansa cargo plane, to Kennedy Space Center on Merritt Island, Florida — if a shuttle were waiting.

Ting is still rueful, worried about the damage to US credibility in a project where foreign partners have footed most of the bill. “The US government made a commitment to fly it,” he says. “This should have been thought about a long time ago — not after more than \$1.5 billion has been spent.” To some, this seems to be protesting too much. The material costs of AMS-01 were just \$33 million. AMS-01 used a lower-field permanent magnet built by the Chinese for \$600,000, far cheaper than the superconducting Swiss toroid in the grown-up version, and there have been many other improvements. But can they really account for a hike in price to \$1.5 billion?

Simon Swordy, a cosmic-ray physicist at the University of Chicago in Illinois, takes what might be called a worldly view of the inflation: when a scientist initially sells a project, it should sound cheap; once it's built and ready to go, it's better to be expensive. “Ting wants to say, ‘You’ve already spent \$1.5 billion on this, you’ve just got to fly it.’” Ting responds by saying that the \$1.5-billion figure is an extrapolation of a \$1.2-billion NASA estimate made in 2005. That put the material costs of the AMS at \$179 million; the other billion was in overheads, facility costs, or salaries, reflecting in part NASA's shift to ‘full cost accounting’. Ting also points out that this cost estimate was made before the AMS was bumped off its shuttle flight, which is hard to square with the suggestion that he needed an artificially hefty price tag to get the AMS into space.

Whatever the costs, though, they are now, as economists put it, sunk. They cannot

be recouped whatever happens. In cost-benefit terms, the costs that matter are those needed to get to the end of the project, not those incurred since its beginning. An extra shuttle flight squeezed into a crowded 2010 would cost between \$300 million and \$400 million, according to a 2008 NASA estimate. Doing it later is an order of magnitude costlier: renewing shuttle contracts for the 2011 fiscal year would cost \$3 billion–4 billion. Engineers have explored other options for getting the AMS up — reconfiguring it as a free-flying satellite, for instance, or using the European Space Agency's Automated Transfer Vehicle to get it to the station. But at this stage, those options are not feasible, says Mark Sistilli, NASA's programme manager for the AMS.

Waste of space shuttle?

Shuttle managers need 18 months lead time to prepare a shuttle. If the schedule to retire the shuttles by October 2010 is kept, NASA managers say they need to know in early 2009. “Time is of the essence,” says Sistilli. Hence Ting's regular visits to the Mayflower Hotel — part of a campaign that is meeting with new success. On 27 September, both houses of Congress passed a NASA authorization bill that

specifically directs the agency to add another shuttle flight and to use it to take the AMS up to the space station. That bill is currently waiting for the president's signature or veto. Although the White House has so far been against such a flight, a veto is not seen as likely.

The worry for NASA astrophysicists is that if the bill authorizing the extra flight is enacted into law, it is by no means certain that Congress's appropriations committees will come up with extra money to pay for it. If that were the case, the NASA astrophysics budget

may have to pay for the AMS's ride, says Jon Morse, NASA's astrophysics division director. “That is the risk that currently exists.” If you want a bottom-line explanation of why the astrophysicists have not welcomed what they see as an un-peer-reviewed interloper, look no further. Congress could make the AMS flight a zero-sum game in which the \$300 million–400 million shuttle flight comes out of the \$1.3 billion astrophysics budget, and other missions will be cancelled or delayed.

The AMS team sees it from a different perspective. Ting has transcended the zero-sum game, using his political muscle to round up money, piecemeal, from the many international partners that would not otherwise have been available. The AMS scientists see the extra shuttle flight as not only the fulfilment of an original obligation, but also small compared with the \$1.5-billion overall price tag. With regards to the potential robbing of the astrophysics budget, Ting says the original agreement was not with NASA's science division. “There's no reason we should take money from them.” That said, he is not in a position to make that call.

And just as \$300 million is small, say Ting and his colleagues, when compared with \$1.5 billion, so \$1.5 billion is small compared with \$100 billion — a frequently bandied about figure for the total costs of the space-station programme. So far, they say, that astronomical sum has bought very little in terms of science: for 1% of the total, the AMS might go some way to redeeming that. “Can you name me one single important discovery done there?” asks Roberto Battiston, deputy principal investigator for the AMS. He recalls reading a list of 12 International Space Station highlights in 2007 that NASA published. It included the clubbing of a golf ball during a space walk, a stunt sponsored by a Canadian company; it did not include any science. “Honestly, I think the station is there for something more than that.”

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— John Ellis

A new home? This mock-up shows the AMS *in situ* on the space station — if it manages to get there.

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