PARTICLE PHYSICS

Neutrino Hunters Go Nuclear to Tackle Antimatter Deficit

A team in China and others around the globe hope an obscure property of neutrinos may answer the question of why the universe isn't full of antimatter

HONG KONG—It's nearly 1:30 a.m. when three unmarked cars ease into a deserted tunnel linking Hong Kong's central business district and Aberdeen, a residential community in the island's southwest corner. About halfway through the mountain passage, which is closed for maintenance, the cavalcade rolls to a halt beside a cavernous service hall. A young man leaps out and unlocks a steel door, and his colleagues swarm into a tiny, humid room hewn from granite. After a couple of hours of fiddling with electronics and scintillation counters, the group huddles around a computer. "We have a signal," says a young physicist, beaming with pride.

This is no spy operation. The physicists in the Aberdeen Tunnel are testing their scintillation counters by spotting muons, particles produced when cosmic rays slam into the upper atmosphere. The setup is a prelude to an ambitious attempt to slay one of physics's most obdurate dragons: Why is there so much more matter than antimatter in the universe? Construction is planned to begin in 2007 on the main attraction 55 kilometers northeast on the mainland: the Daya Bay Neutrino Experiment—a set of detectors up close and personal with a nuclear power plant. Last month, the Chinese government pledged $6.25 million to the effort.

Daya Bay and four similar efforts worldwide are vying to measure a fundamental property of neutrinos, ghostly particles that rarely interact with normal matter. Only in the past decade have physicists confirmed that neutrinos have mass, albeit minuscule, and oscillate between three flavors: electron, muon, and tau neutrinos. Physicists have enumerated four measurable oscillation properties: three "mixing angles" and the charge-conjugate parity (CP) value. Two angles are known from studies of neutrinos from the sun, the atmosphere, reactors, and accelerators. Only an upper limit has been reached for the third mixing angle, θ_{13}, while the CP value remains an enigma.

CP is of supreme significance: If neutrinos violate CP, that could explain why antimatter is now so scarce. Quarks are proven CP violators, but that's "not enough" to explain the matter-antimatter imbalance, says Ming-Chung Chu, a theoretical physicist at the Chinese University of Hong Kong. "CP violation in neutrinos is what we really need to go after," adds physicist Kam-Biu Luk of the University of California, Berkeley, and Lawrence Berkeley National Laboratory. The only way to solve the riddle is to first measure θ_{13}.

Enter Daya Bay and its brethren. They will use nuclear power plants to study θ_{13}. The nuclear chain reaction produces a flood of electron antineutrinos, which are assumed to have the same fundamental properties as neutrinos. All five experiments will install a detector near a reactor to measure antineutrino flux and then place an identical detector a certain distance away. The few antineutrinos that might oscillate as they travel that distance will evade the second detector because it can register only electron antineutrinos. This dip in antineutrino flux would yield θ_{13}. Most theorists believe that the target value—$\sin^2 2\theta_{13}$—lies between its present limit of 0.19 and 0.01, says Maury Goodman, a neutrino physicist at Argonne National Laboratory in Illinois.

Limbering up. Kam-Biu Luk examines a scintillation counter in the Aberdeen Tunnel.

The Race for θ_{13}

Project	Location	Present power (gigawatts)	Start-up (projected)	Maximum sensitivity* (est. after 3 yrs.)
Angra	Brazil	6	2013	0.007
Daya Bay	China	11.6	2010	0.008
Double Chooz	France	8.7	2007	0.02
KASKA	Japan	24.3	2009	0.015
RENO	South Korea	17.3	2009	0.03

*$\sin^2 2\theta_{13}$

Sources: Kam-Biu Luk; Maury Goodman; Argonne National Laboratory; Fumihiko Suekane; Institut National de Physique Nucléaire et de Physique des Particules.

Physicists need as large a supply of antineutrinos as possible, because few will actually interact with the detectors, and even fewer will oscillate and show up as a deficit. The detectors must be shielded from background radiation that can mimic the antineutrino signature. The teams plan to cocoon their detectors—in all five cases, massive tanks filled with a gadolinium-doped scintillator solution—inside a mountain or in an underground shaft and sheathe them in water or metal to absorb particles other than antineutrinos. However, cosmic-ray muons can barrel through these defenses. And that's why Aberdeen Tunnel is a good warm-up: Physicists hope to learn how to differentiate between the flashes caused by muons and antineutrinos.

Daya Bay won't be the first out of the gate. The French-led Double Chooz group aims to start taking data next year. Nor will Daya Bay have access to the biggest antineutrino source: The Japanese KASKA team intends to track the particles from the world's most powerful assemblage of reactors, the Kashiwazaki Kariwa Nuclear Power Plant near Niigata. "It's a healthy competition," says KASKA physicist Fumihiko Suekane of Tohoku University. But thanks in part to favorable positions right up close to the Daya Bay Nuclear Power Plant and its neighboring Ling Ao plant, the Daya Bay experiment is poised to be the first to reach the 0.01 benchmark within 3 years of start-up.

Whether that will be good enough to snare θ_{13} is an open question. "It's unknown exactly how sensitive these experiments will be," cautions Goodman, the U.S. co-spokesperson for Double Chooz. He says that initial measurements "will be steps along the way to more precise experiments."

The Daya Bay collaboration is headed by Luk and Wang Yifang of the Institute of High Energy Physics in Beijing, who have assembled a 100-strong team from 24 institutions in four countries. The group has cash in hand from the Chinese Academy of Sciences, and commitments are expected this fall from China's Ministry of Science and Technology and other agencies. The U.S. Department of Energy is also backing Daya Bay with $800,000 for R&D this year and is expected to add more. "It's groundbreaking for us. Hong Kong has never been involved in a physics project of this kind," says Chun-Shing Jason Pun of the University of Hong Kong. And it is strengthening scientific links across the Taiwan Strait, with three Taiwanese and seven mainland institutions taking part.

There's always a chance that the predictions are wrong and that the θ_{13} value will be much smaller than 0.01, perhaps even 0—and frustratingly out of reach. That would leave experimentalists and theoreticians alike scratching their heads. Chu, for one, is not perturbed by that prospect. "That would mean new physics," he says. "Either way, we can't lose."

–RICHARD STONE

PHOTO CREDIT: R. STONE/*SCIENCE*

Published by AAAS