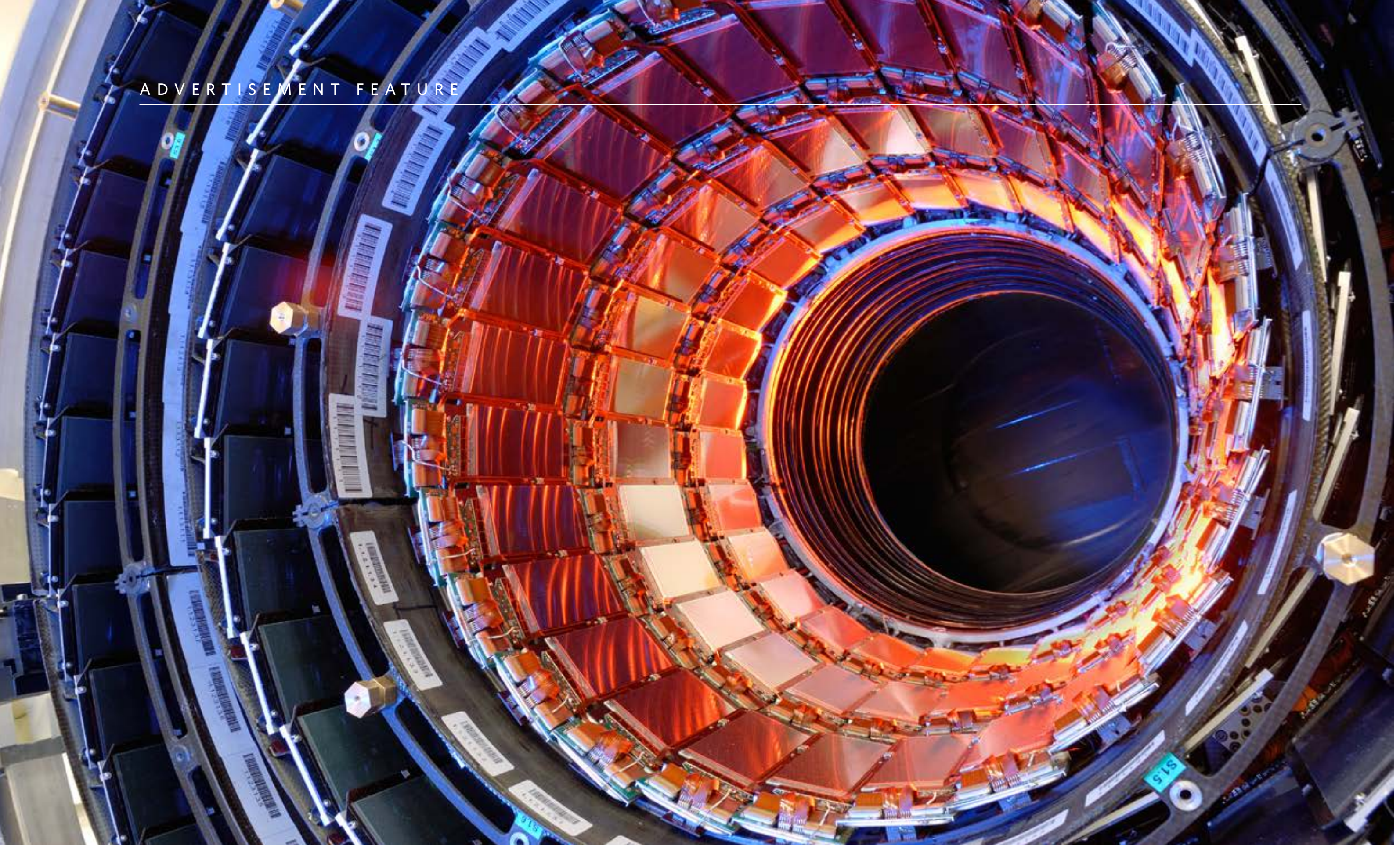

Image courtesy of CERN

THE LIGHT-BASED TECH BEHIND SOME OF PHYSICS' BIGGEST BREAKTHROUGHS

From sensing cosmic neutrinos to detecting the elusive Higgs boson, LIGHT-BASED TECHNOLOGY is empowering breakthroughs in physics.

In the early 1980s, Japanese physicist Masatoshi Koshiba was constructing a pioneering experimental facility to detect neutrinos from the Sun. Neutrinos are chargeless, invisible and notoriously difficult to detect. Glimpsing evidence of ghost-like subatomic particles demanded elaborate facilities and sensitive instruments that didn't exist at the time.

Neutrinos, which usually pass through the Earth without interacting with it, were known to very occasionally interact with water, releasing faster-than-light particles and so causing a faint blue flash — the eerie Cherenkov radiation seen in nuclear reactor pools. However, detecting the flash and converting it into a measurable electrical signal would require amplifying it by 10 million times.

"The largest photomultiplier tubes available at the time were 8-inch (20-centimetre) in diameter, but what was needed was a 20-inch (51-centimetre) tube with a wide field of view," explains Tadashi Maruno, chief executive officer of Hamamatsu Photonics in Japan. "Professor Koshiba turned to Hamamatsu to collaborate on the development of this new detector. It was a formidable challenge, not just the technological aspects, but also the sheer number of tubes needed — almost a thousand."

It was one example of the type of technology development partnership for which Hamamatsu is now renowned. And it ultimately led to Koshiba being awarded the 2002 Nobel Prize in Physics for experiments that used photomultiplier tubes made by Hamamatsu. A second Nobel Prize was awarded in 2015 to Koshiba's successor Takaaki Kajita, who proved the existence of neutrino oscillations using a facility comprising more than 11,000 Hamamatsu photomultiplier tubes.

▲ Hamamatsu's silicon strip detectors line the Compact Muon Solenoid detector at the Large Hadron Collider at CERN.

MORE THAN OPTICAL TECH

Hamamatsu Photonics products such as X-ray tubes and a range of light detectors and lasers are found inside millions of medical, industrial and commercial devices. But it is the contribution to science and society that drives the company to tackle grand challenges in physics and advanced photonics technologies.

ADVERTISEMENT FEATURE

"Hamamatsu started producing vacuum photomultiplier tubes in the 1950s, and they are still in wide use today in their tens of thousands," says Maruno. "Over our 70 years, we've developed an extensive range of devices, many of them unique, developed for specific research or industrial needs. We're the only company that can produce detectors and emitters across the full spectrum from X-ray to infrared, and we're constantly pushing the boundaries of what's possible in our central research laboratories."

Unique silicon strip detectors and other components produced by Hamamatsu were key components in the first detection of the Higgs boson — the subatomic particle responsible for mass — at the Large Hadron Collider in Europe. This long-anticipated breakthrough was also awarded a Nobel Prize in 2013.

▲ Top: Tadashi Maruno and his engineering team at Hamamatsu. Bottom: An image of Orion Nebula taken by ORCA–Quest.

THE NEXT FRONTIER

The pursuit of ever more sensitive light detection has taken Maruno on a decades-long journey to achieve what was once unimaginable — spatially resolving the number of photons.

Conventional photomultiplier tubes capture the faintest light and produce an electrical signal that can be used for analysis, but the light is only resolved as an aggregate emission. The ability to count individual photons would open up entirely new possibilities for research, particularly in quantum applications where the separate observation of photons in entangled pairs of photons would be invaluable.

"I've always been interested in low-light imaging and detection, and I've been working on various devices for almost 40 years," says Maruno. "I always wondered whether it would be possible to detect individual photons. In recent years, we've developed a silicon-based device that can detect discrete photon events, but it can't distinguish between single and multiple photons arriving at once. Our new ORCA–Quest device is a 2D array of photon-detecting pixels that, for the first time, can distinguish and count individual photons reliably."

KILLING NOISE

Based on standard semiconductor technology and fabrication methods, the ORCA–Quest camera owes its ability to detect single photons to the reduction of device noise to almost zero. 'Noise' in this case refers to any interference caused by the device's electronics, atomic impurities in the semiconductor system, the environment and other light sources. In fact, at the single-photon level, almost anything can cause enough noise to drown out the single-photon signal.

"Our focus on reducing noise was critical to being able to detect individual photons," says Maruno. "We've successfully reduced noise to the 0.27 electron level by slowing down the readout electronics and eliminating all other sources of noise. We'd like to get that down to 0.15 electrons with future refinement, which would allow us to increase the temporal resolution beyond its current limit of 20,000 samples per second."

This camera that can spatially resolve photon numbers is expected to have many research applications, including the investigation of quantum phenomena such as duality, superposition and entanglement, and also biophysical processes, such as tracking single molecules and ultrasensitive total-internal-reflection fluorescence microscopy.

EMPOWERING FUTURE TECH

Hamamatsu has many new devices in development and is working with academic, industrial and commercial partners to create technologies that support new and future applications.

"Our laboratories typically have a 10–20 year development horizon, which allows us to take on challenges that seem improbable at first," says Maruno. "Very importantly, we have a strong corporate culture of using such challenges to gain new experience and knowledge, whether ultimately successful or not."

In this way, Hamamatsu is striving to be unique, to be part of research collaborations that explore uncharted realms and meet real needs that support science and society, backed by 70 years of continuous accumulated knowledge and expertise.

"For example, we're now developing hyper-output laser sources that are emerging as a critical technology for fusion energy," Maruno says. "To do this we're collaborating with some of the most advanced laboratories in the world."

"Photonics already plays a vital role in science and our daily lives," he adds. "But we believe it still has much more in store for us and will be a critical technology in our transition to a sustainable future." ■

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