SPACE

Protons are like neutron stars

World-first measurement finds pressure inside a proton is 10 times greater than inside a neutron star.

Quarks inside a proton experience pressure an order of magnitude greater than is found at the heart of a neutron star, where matter is so densely packed that a teaspoonful would weigh more than Mount Everest, according to the first measurement of the internal mechanical properties of subatomic particles.

A team headed by nuclear physicist Volker Burkert of the Thomas Jefferson National Accelerator Facility in the US reports in *Nature* that quarks, the building blocks of protons and neutrons, are subjected to a pressure of 100 decillion pascal (10^{35} Pa) at the centre of the proton.

"We found an extremely high outward-directed pressure from the centre of the proton, and a much lower and more extended inward-directed pressure near the proton's periphery," explains Burkert.

A proton is made up of three quarks, bound together by what physicists call the strong force. It is one of four fundamental forces that condition the universe. Two of these – electromagnetism and gravity – produce effects that govern macro-scale interactions. The other two, known as strong and weak, operate on a subatomic scale and determine nuclear reactions.

The idea of peering inside the proton was dreamed up in 1966 by an American physicist named Heinz Pagels, who showed how the internal pressure distribution could in principle be measured using gravity particles called gravitons. He thought it would never work in practice, however, "because of the extreme weakness of the gravitational interaction".

"It took about 30 years for researchers to realise that this could also be measured using a pair of photons," says Burkert.

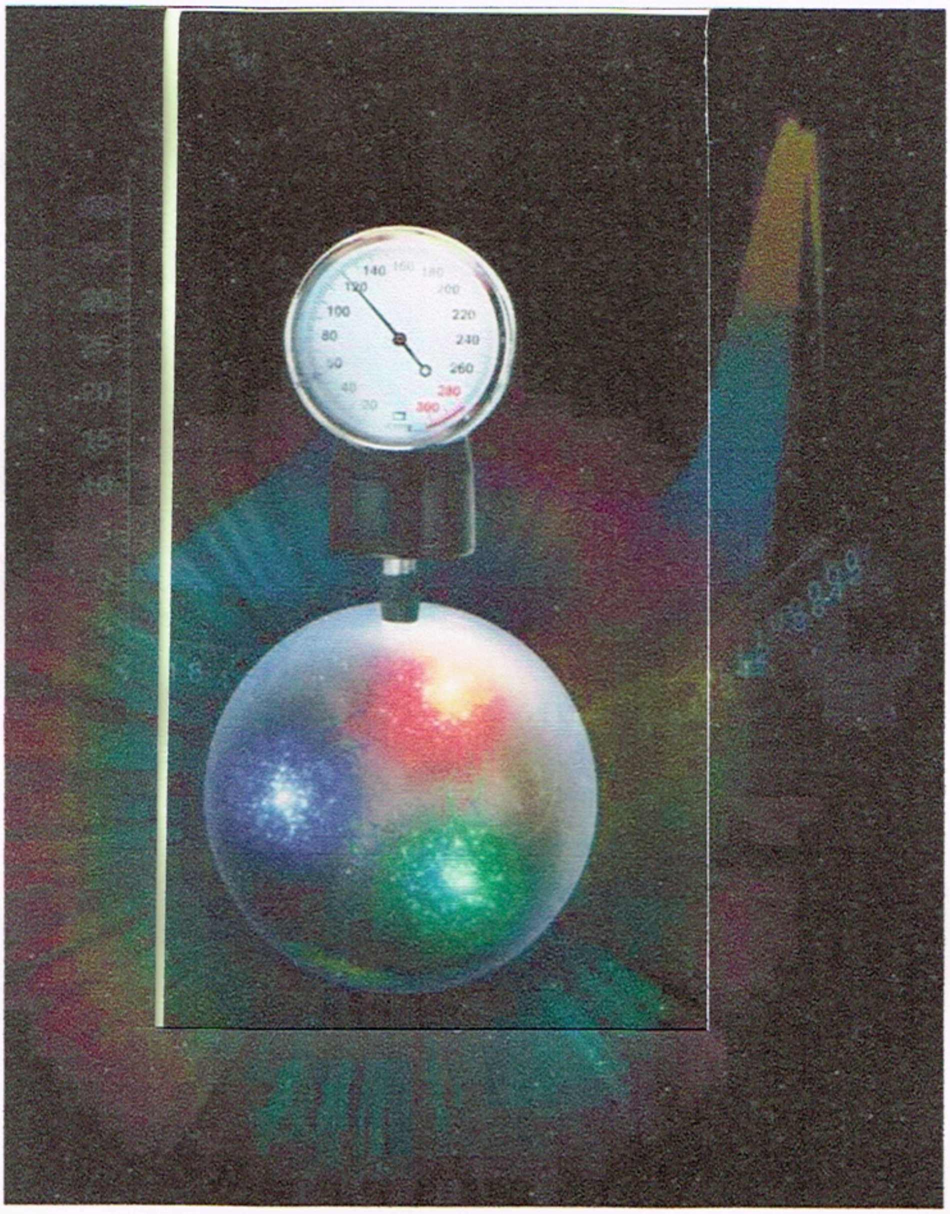
In this technique, called 'deeply virtual Compton scattering', high-energy electrons are fired at protons, exchange virtual photons with them, and spit out real photons as a result. If the electron is moving fast enough, it will interact with a single quark rather than the proton as a whole.

By analysing the subsequent behaviour of the proton, electron and photons, the secrets of the proton's interior can be revealed.

The first experiments on proton quark pressure were conducted in 2005, Burkert says, but it took more than a decade of work to gather and understand the data.

The findings provide valuable data for testing models of quark behaviour, but these results are only the beginning. The next particle Burkert has in his sights is the neutron, with experiments planned to begin in 2019.

"We see this as opening a new direction in fundamental research," he explains. "It is much too early to think of any concrete applications."



Quarks inside a proton experience a pressure even greater than the atom-crushing forces found inside neutron star. CREDIT: DOE'S JEFFERSON LAB