Quarks 'swing' to the tones of random numbers

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7	6	2	3	2	7	9	4	2
7	1	4	8	4	3	6	3	9
6	7	3	8	9	4	7	9	4
1	7	7	9	7	6	5	7	4
8	2	1	6	5	8	7	6	3
7	4	1	2	7	6	8	1	7
5	4	1	7	4	7	9	8	9
9	4	9	1	8	8	6	9	3
2	3	3	6	2	8	8	6	1

A matrix is a rectangular array of numbers. A random matrix can be compared to a Sudoku filled with random numbers. Matrices are part of the equations governing the movements of the particles. In a random matrix there are numbers that are entered randomly, while there are still certain symmetries, for example, you can require that the numbers in the lower left should be a copy of the numbers above the diagonal. This is called a symmetrical matrix.

At the Large Hadron Collider at CERN protons crash into each other at incredibly high energies in order to 'smash' the protons and to study the elementary particles of nature - including quarks. Quarks are found in each proton and are bound together by forces which cause all other known forces of nature to fade. To understand the effects of these strong forces between the quarks is one of the greatest challenges in modern particle physics. New theoretical results from the Niels Bohr Institute show that enormous quantities of random numbers can describe the way in which quarks 'swing' inside the protons. The results have been published in *arXiv* and will be published in the journal *Physical Review Letters*.

Just as we must subject ourselves, for example, to the laws of gravity and not just float around weightless, quarks in protons are also subject to the laws of physics. Quarks are one of the universe's smallest, known building blocks. Each proton inside the atomic nucleus is made up of three quarks and the forces between the quarks are so strong that they can never - under normal circumstances, escape the protons

Left- and right-handed quarks

The quarks combined charges give the proton its charge. But if you add up the masses of the quarks you do not get the mass of the proton. Instead, the mass of the proton is dependent on how the quarks swing. The oscillations of the quarks are also central for a variety of physical phenomena. That is why researchers have worked for years to find a theoretical method for describing the oscillations of quarks.

The two lightest quarks, 'up' and 'down' quarks, are so light that they can be regarded as massless in practice. There are two types of such massless quarks, which might be called left-handed and right-handed. The mathematical equation governing quarks' movements show that the left-handed quarks swing independently of the right-handed. But in spite of the equation being correct, the left-handed quarks love to 'swing' with the right-handed.

Spontaneous symmetry breaking

"Even though this sounds like a contradiction, it is actually a cornerstone of theoretical physics. The phenomenon is called spontaneous symmetry breaking and it is quite easy to illustrate", explains Kim Splittorff, Associate Professor and theoretical particle physicist at the Niels Bohr Institute, and gives an example:

A dance floor is filled with people dancing to rhythmic music. The male dancers represent the left-handed quarks and the female dancers the right-handed quarks. All dance without dance partners and therefore all can dance around freely. Now the DJ puts on a slow dance and the dancers pair off. Suddenly, they cannot spin around freely by themselves. The male (left-handed) and female (right-handed) dancers can only spin around in pairs by agreeing on it. We say that the symmetry 'each person swings around, independent of all others' is broken into a different symmetry 'a pair can swing around, independent of other pairs'.

Similarly for quarks, it is the simple solution that the left-handed do not swing with the right-handed. But a more stabile solution is that they hold onto each other. This is spontaneous symmetry breaking.

Dance to random tones

"Over several years it became increasingly clear that the way in which the left-handed and right-handed quarks come together can be described using a massive quantities of random numbers. These random numbers are elements in a matrix, which one may think of as a Soduko filled in at random. In technical jargon these are called Random Matrices", explains Kim Splittorff, who has developed the new theory together with Poul Henrik Damgaard, Niels Bohr International Academy and Discovery Center and Jac Verbaarschot, Stony Brook, New York.

Even though random numbers are involved, what comes out is not entirely random. You could say that the equation that determines the oscillations of the quarks give rise to a dance determined by random notes. This description of quarks has proven to be extremely useful for researchers who are looking for a precise numerical description of the quarks inside a proton.

It requires some of the most advanced supercomputers in the world to make calculations about the quarks in a proton. The central question that the supercomputers are chewing on is how closely the left-handed and right-handed quarks ’dance’ together. These calculations can also show why the quarks remain inside the protons.

One problem up until now has been that these numerical descriptions have to use an approximation to the 'real' equation for the quarks. Now the three researchers have shown how to correct for this so that the quarks in the numerical calculations also 'swing' correctly to random numbers.

New understanding of the data

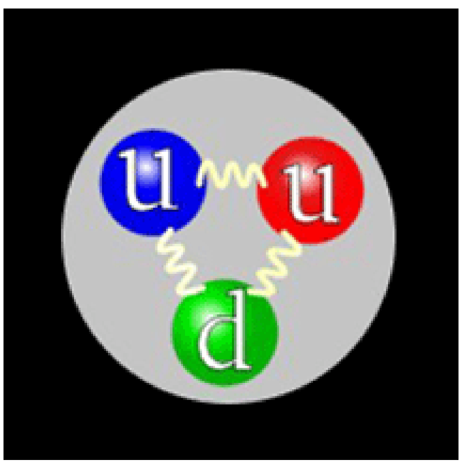
”Using our results we can now describe the numerical calculations from large research groups at CERN and leading universities very accurately”, says Kim Splittorff.

”What is new about our work is that not only the exact equation for quarks, but also the approximation, which researchers who work numerically have to use, can be described using random matrices. It is already extremely surprising that the exact equation shows that the quarks swing by random numbers. It is even more exciting that the approximation used for the equation has a completely analogous description. Having an accurate analytical description available for the numerical simulations is a powerful tool that provides an entirely new understanding of the numerical data. In particular, we can now measure very precisely how closely the right-handed and left-handed quarks are dancing", he says about the new perspectives in the world of particle physics.

Facts on Quarks

Quarks are one of the universe's smallest, known building blocks.

Each proton inside the atomic nucleus is made up three quarks. There are six different kinds of quarks: Up, down, top, bottom, charm and strange and their anti-quarks. Ordinary matter consists only of up- and down-quarks and electrons.



A particle made up of quarks is affected by the strong nuclear force, which is one of the four forces of nature. The force binds the quarks together and is approximately 10^{33} times stronger than gravity and 100 times stronger than the electro-magnetic force. But the range is small, equivalent to an atomic diameter of approximately 10^{-15} m.

More information: Article in arXiv

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