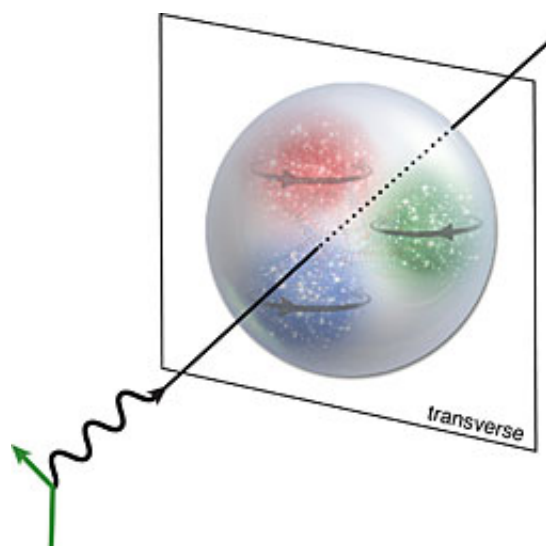


# Quarks' spins dictate their location in the proton

April 2 2013, by Kandice Carter



In a proton, quarks with spin pointed in the up direction (red and blue) tend to gather in the left half of the proton as seen by the incoming electron, whereas down-spinning quarks (green) tended to gather in the right half of the proton.

A successful measurement of the distribution of quarks that make up protons conducted at DOE's Jefferson Lab has found that a quark's spin can predict its general location inside the proton. Quarks with spin pointed in the up direction will congregate in the left half of the proton, while down-spinning quarks hang out on the right. The research also confirms that scientists are on track to the first-ever three-dimensional inside view of the proton.

The [proton](#) lies at the heart of every atom that builds our [visible universe](#), yet scientists are still struggling to obtain a detailed picture of how it is composed of its primary building blocks: quarks and gluons. Too small to see with ordinary [microscopes](#), protons and their quarks and gluons are instead illuminated by [particle accelerators](#). At Jefferson Lab, the CEBAF accelerator directs a stream of electrons into protons, and huge detectors then collect information about how the particles interact.

According to Harut Avakian, a Jefferson Lab staff scientist, these observations have so far revealed important basic information on the proton's structure, such as the number of quarks and their momentum distribution. This information comes from scattering experiments that detect only whether a quark was hit but do not measure the particles produced from interacting quarks.

"If you sum the momenta of those quarks, it can be compared to the momentum of the proton. What scientists were doing these last 40 years, they were investigating the momentum distribution of quarks along the direction in which the electron looks at it – a one-dimensional picture of the proton," he explains.

Now, he and his colleagues have used a new experimental method that can potentially produce a full three-dimensional view of the proton.

The new method measures neutral pions, made of one quark and one [antiquark](#), as they are produced in collisions of fast-moving electrons with protons.

In addition to the momentum distribution, this method allows one to infer the spatial position of the quark as it was hit – how far the quarks are away from the proton's center and if their spins are pointing in the up or down direction. It projects a spatial image of the proton's quark content in the plane transverse to the electron beam.

"It is the transverse space distribution. And so the one-dimensional picture is extended to a three-dimensional image that allows us to understand how those little quarks are distributed in the space. That is, we learn at the same time how far they are from the center and what are their momenta," Avakian says.

To make the measurement, the researchers needed to thwhack a number of quarks with electrons just hard enough for the quarks to absorb energy from the electrons and then give it away again, without ever breaking up the protons.

"This is the method of exclusive electron scattering, where you don't destroy the proton, you just touch a single quark," explains JLab Theorist Christian Weiss. "The electron hits the quark, and this quark shakes off a pion. The quark returns to the proton, and the proton remains intact and recoils. You measure the pion and the recoiling proton in addition to the scattered electron. This method gives you much more control than traditional inclusive scattering, where you do not detect the produced particles."

However, the experimental data alone isn't enough. To extract detailed information, the experimenters must plug their data into a complicated theory expressed as a set of mathematical expressions, called generalized parton distributions. The expressions combine to provide detailed information on how both the quarks and gluons, together called partons, behave inside the proton. It's thought that these generalized parton distributions, along with other information, will provide the first-ever three-dimensional view of the proton's structure.

"It's like you have some mosaic. These are parts of your mosaic. To get the picture, you need all these pieces to put together," Avakian says.

The CLAS collaboration conducted the experiment in Jefferson Lab's

Experimental Hall B in the spring of 2005. The first result was published last fall in the journal *Physical Review Letters*.

They found that it was possible to successfully carry out an experiment using this tricky method of probing the proton without destroying it to get the data they need for the generalized parton distributions. They plugged the data into two theoretical models of generalized parton distributions that simulate the spin and location of the quarks and allow one to recover a genuine three-dimensional image of the proton.

"The position of the quark depends on how its spin is pointing or on its momentum. The spin of the quark affects the probability to find the quark in a certain point in space," Avakian explains.

In particular, they found evidence that transversely spinning quarks with their spin pointed in the up direction tended to gather in the left half of the proton as seen by the incoming electron, whereas transversely spinning quarks with their spin pointed in the down direction tended to gather in the right half of the proton. He says the result confirms that protons are complex systems, with a rich internal structure and sophisticated dynamics, referred to as Quantum Chromodynamics.

"The [quarks](#) are not just distributed in momentum in one direction. They have momenta, positions, and everything is moving around. As of now, we don't understand very well the dynamics, such as how this spin is correlated with the position and the momentum. That's what we are trying to study - the interplay of the quark's internal motion and their spin with their spatial position in the system," Avakian says.

In the meantime, Avakian and Weiss both agree that this successful experiment has broader implications. It has proven that the exclusive electron scattering method can be used to begin filling in the information needed for generalized parton distributions toward obtaining that three-

dimensional view of the proton. Physicists worldwide are working toward that common goal, and the technique pioneered here can also be applied at much higher energies, beginning with Jefferson Lab's CEBAF accelerator at 12 GeV and later with a future Electron-Ion Collider. Similar measurements can also be performed in scattering experiments with proton beams at facilities such as GSI in Germany and at Japan's High Energy Accelerator Research Organization, known as KEK.

"The physics community consider this as a first-priority task: To understand the 3D structure of the nucleon," Avakian says.

**More information:** [prl.aps.org/abstract/PRL/v109/i11/e112001](http://prl.aps.org/abstract/PRL/v109/i11/e112001)

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