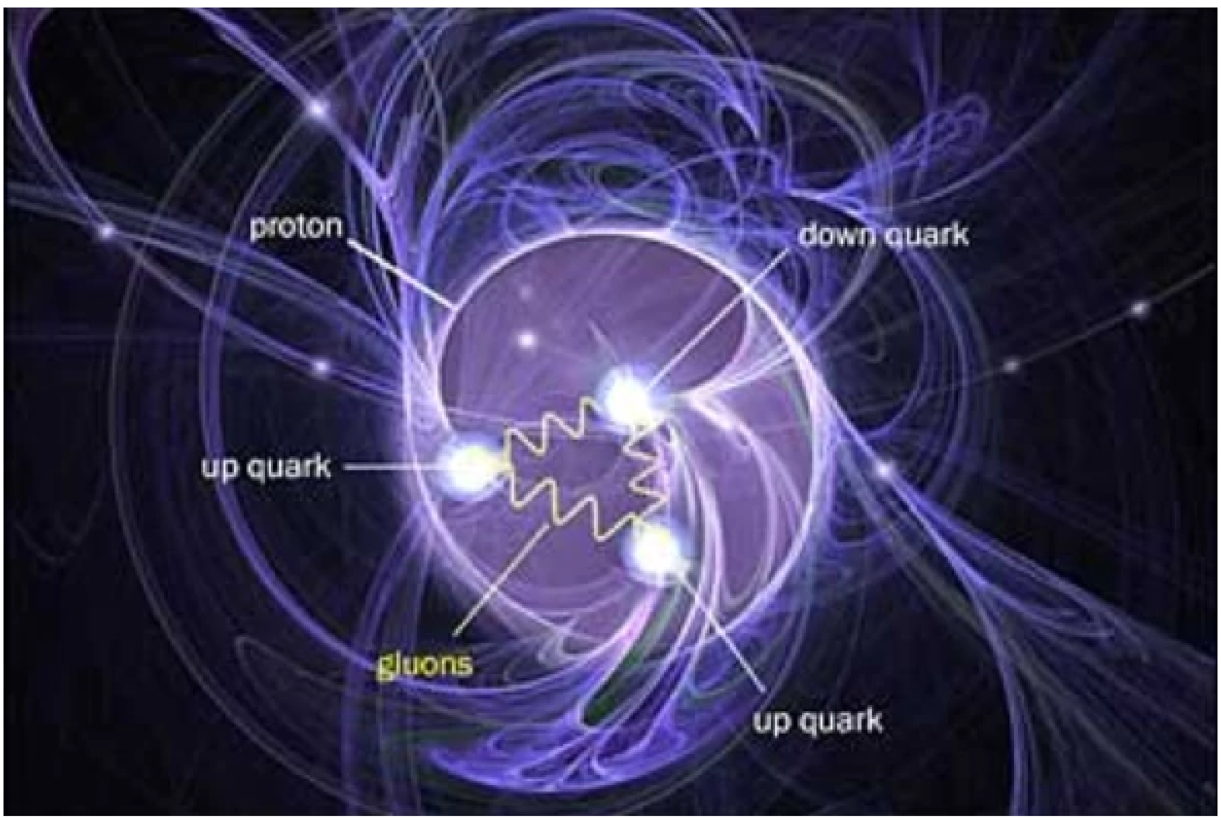
Proton Spin Mystery Gains a New Clue

Physicists long assumed a proton's spin came from its three constituent quarks. New measurements suggest particles called gluons make a significant contribution

By Clara Moskowitz on July 21, 2014



Credit: Brookhaven National Laboratory

Protons have a constant spin that is an intrinsic particle property like mass or charge. Yet where this spin comes from is such a mystery it's dubbed the "proton spin crisis." Initially physicists thought a proton's spin was the sum of the spins of its three constituent quarks. But a 1987 experiment showed that quarks can account for only a small portion of a proton's spin, raising the question of where the rest arises. The quarks inside a proton are held together by gluons, so scientists suggested perhaps they contribute spin. That idea now has support from a pair of studies analyzing the results of proton collisions inside the Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory in Upton, N.Y.

Physicists often explain spin as a particle's rotation, but that description is more metaphorical than literal. In fact, spin is a quantum quantity that cannot be described in classical terms. Just as a proton is not really a tiny marble but rather a jumble of phantom particles appearing and disappearing continuously, its spin is a complex probabilistic property. Yet it is always equal to one half.

Quarks also have a spin of one half. Physicists originally assumed that two of the proton's three quarks were always spinning in opposite directions, canceling one another out, leaving the remaining one half as the proton's total spin. "That was the naïve idea 25 years ago," says Daniel de Florian of the University of Buenos Aires, leader of one of the new papers, which was published July 2 in *Physical Review Letters*. "By the end of the '80s it was possible to measure the contribution of the spin of the quarks to the spin of the proton, and the first measurement showed it was 0 percent. That was a very big surprise." Later measurements actually suggested quarks can contribute up to 25 percent of the proton's total spin, but that still leaves the lion's share unaccounted for.

Gluons are also present inside protons as the representatives of the strong nuclear force, a fundamental interaction that binds the quarks together. Gluons each have a spin of 1, and depending on which direction it is they could add up to make most of rest of the proton's spin. Measuring their contribution is a tricky task. RHIC is the only experiment that can address the question, because it is the only particle accelerator built to collide "spin-polarized" protons, meaning that the particles are all spinning in a certain direction when they crash. (At the more powerful Large Hadron Collider in Switzerland, the particles' spins are not aligned.)

When two protons slam together, their interaction is controlled by the strong force, so gluons are intimately involved. If gluon spin is an important ingredient of proton spin, then the orientation of the colliding protons' spins should affect the outcome. Scientists would expect collisions between two protons whose spins were aligned would happen at a different frequency than collisions between those spinning in opposite directions. And according to recent data from RHIC, there is a difference. "If there is no preferred position, the difference will be exactly zero," says University of Oxford physicist Juan Rojo, a member of the so-called NNPDF Collaboration that wrote the second paper, which was submitted to *Nuclear Physics B*. "Since the asymmetry is not zero, this tells us the distribution of the spin is not trivial." Rojo's team calculated that gluons probably contribute about half the spin that quarks do to the proton. De Florian and his colleagues analyzed the same data from RHIC, but used a different mathematical analysis to calculate the gluon contribution. They also found that gluon spin must be significantly involved. "This data for the first time shows the gluon polarization is actually nonzero; we see the gluons are polarized," de Florian says. "Basically they could be responsible for the rest of the proton spin, but the uncertainty is very large."

Both teams say their work is just the beginning of the quest to understand how gluons affect proton spin. To be certain, a larger experiment is needed. The best candidate, they say, is a proposed electron–ion collider that could be built at Brookhaven. This machine would collide polarized protons at higher energies than RHIC does and could probe the contribution of higher-energy gluons to proton spin, rather than the relatively lower-energy range the current data do.

If gluon spin does not provide the balance of the missing proton spin, the rest might arise from the orbital angular momentum of the quarks and gluons swarming around inside the proton. Just as Earth rotates on its own axis as well as orbits the sun, quarks and gluons have their own internal spin, along with angular momentum that comes from their movement around the center of the proton. The question, says physicist Robert Jaffe of Massachusetts Institute of Technology, who was not involved in the research, is what portion of the total spin each of these elements contributes. He adds: "Measuring the gluon contribution to the proton spin is one step—an important one—to answer this question."

Resolving the proton spin crisis is vital not just for understanding spin, but to learn where protons and many other particles get their masses. The recently discovered Higgs boson is often said to be responsible for bestowing mass on all other particles. This is true, but is not the whole truth, Rojo says. In addition to the Higgs mechanism, another process is at work to give protons mass. This process is related to confinement—the reason quarks and gluons are always found confined within other particles, such as protons, and never alone. The dynamics of confinement also affect the spin polarization of quarks and gluons. "One of the most outstanding problems in modern theoretical physics is to understand confinement," Rojo says. "The better we understand the polarization distribution of quarks and gluons, the closer we get to an understanding of confinement. With our data we have the underlying mechanism for confinement and ultimately for where the mass of the protons comes from."

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