Special setup uses polarized rubidium and xenon as transmitter and receiver system for exotic fields

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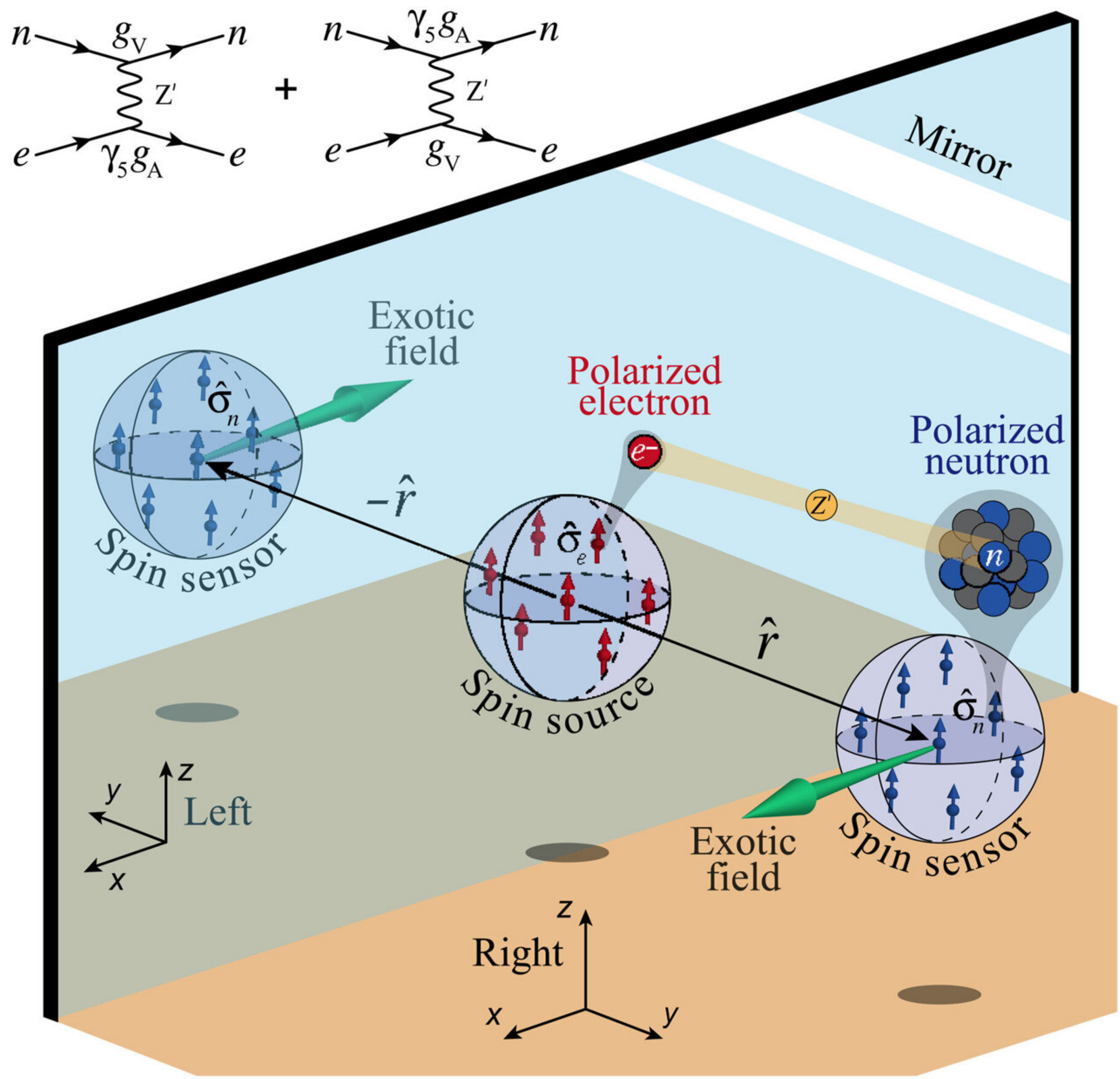

Illustration of POSS interaction. The exotic interaction between electrons and neutrons involving the exchange of Z′ bosons can be described by the Feynman diagrams. As a parity-odd interaction, the induced exotic pseudo-magnetic field changes sign under a parity transformation as shown in the mirror. Credit: *Science Advances* (2023). DOI: 10.1126/sciadv.ade0353

In the search for new forces and interactions beyond the Standard Model, an international team of researchers involving the PRISMA Cluster of Excellence at Johannes Gutenberg University Mainz (JGU) and the Helmholtz Institute Mainz has now taken a good step forward. The researchers, among them Prof. Dr. Dmitry Budker, are using an amplification technique based on nuclear magnetic resonance.

In their work recently published in *Science Advances*, they use their experimental setup to study a particular exotic interaction between spins: a parity-violating interaction mediated by a new hypothetical exchange particle, called a Z' boson, which exists in addition to the Z boson mediating the weak interaction in the standard Model.

In the current setup, they were unable to detect this particle, but they were able to increase the sensitivity by five orders of magnitude compared to previous measurements. This allows researchers to set constraints on the strength of the interaction of the new exchange particle with Standard Model particles that are complementary to astrophysical observations and open up a previously inaccessible region.

Numerous theories predict the existence of exotic interactions beyond the Standard Model. They differ from the four known interactions and are mediated by previously unknown exchange particles. In particular, parity-violating interactions, i.e., where mirror-symmetric is broken, are currently experiencing a special interest.

On the one hand, because this would immediately indicate the particular type of new physics we are dealing with, and on the other hand, because their effects are easier to separate from spurious systematic effects, that usually do not show mirror-symmetry breaking. "In the current article, we take a close look at such an interaction between the spins of electrons and the spins of neutrons, mediated by a hypothetical Z' boson. In a mirrored world, this interaction would lead to a different result; parity is violated here," explains Dmitry Budker.

This "result" looks like this: The electron spins within a source are all aligned in one direction, i.e. polarized, and the polarization is continuously modulated, thus creating an exotic field that is perceived as a magnetic field and can be measured using a sensor. In a mirrored world, the exotic field would not point in the same direction as would be expected in a "real" mirror image, but in the opposite direction: the parity of this interaction is violated.

SAPPHIRE—the new gem in the search for new physics

"Spin Amplifier for Particle PHysIcs REsearch"—SAPPHIRE for short—is what the researchers have named their setup, which is based on the two elements rubidium and xenon. They have already used this technique in a similar form to search for other exotic interactions and for dark matter fields.

Specifically, in the experimental search for exotic spin-spin interactions, two chambers filled with the vapor of one of the two elements are positioned in close proximity to each other: "In our experiment, we use polarized electron spins of rubidium-87 atoms as a spin source and polarized neutron spins of the noble gas xenon, or more precisely the isotope xenon-129, as a spin sensor," says Dmitry Budker.

The trick is that the special structure and the polarized xenon atoms in the spin sensor initially amplify the field generated in the rubidium source: thus, the effect triggered by a potential exotic field would be a factor of 200 larger. Now the principle of nuclear magnetic resonance comes into play, i.e. the fact that nuclear spins react to magnetic fields that oscillate at a certain resonance frequency. Rubidium-87 atoms are also present in a small proportion in the sensor cell for this purpose. They in turn act as an extremely sensitive magnetometer to determine the strength of the resonance signal.

The detection of such an exotic field in the right frequency range would then be the clue to the new interaction we are looking for. Other special experimental details ensure that the setup is particularly sensitive in the frequency range of interest and less sensitive to spurious effects from other magnetic fields that inevitably also arise in the experiment.

"All in all, this is a rather intricate setup that has required a careful design and calibration. It is highly rewarding to work on such challenging and interesting problems with our long-time collaborators from the University of Science and Technology (USTC) in Hefei, China who hosted the experiment," reports Dmitry Budker.

After successful proof-of-principle, the scientists started the first series of measurements to search for the exotic interaction. Although they have not yet been able to find a corresponding signal after 24 hours of measurements, the five orders of magnitude increase in sensitivity has enabled them to set constraints on the strength of the new exchange particle's interaction with Standard Model particles.

Further optimization could even improve the experimental sensitivity to the special exotic interaction by another eight orders of magnitude. This makes it seem possible to use the ultrasensitive SAPPHIRE setup to discover and study a new physics with potential Z' bosons.

More information: Yuanhong Wang et al, Search for exotic parity-violation interactions with quantum spin amplifiers, *Science Advances* (2023). DOI: 10.1126/sciadv.ade0353

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