HADES searches for dark matter

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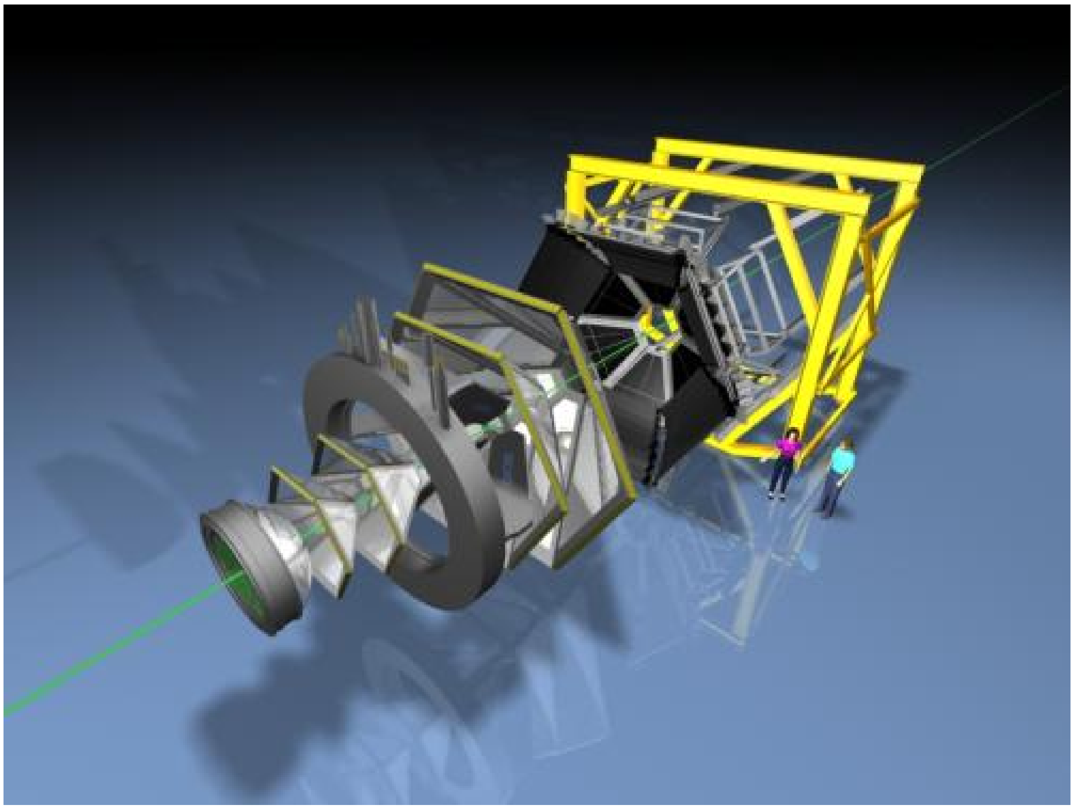

HADES at the GSI in Darmstadt/Germany searches for dark matter candidates.
Credit: 3-D Rendering: A. Schmah/HADES

Although Dark Energy and Dark Matter appear to constitute over 95 percent of the universe, nobody knows of which particles they are made up. Astrophysicists now crossed one potential Dark Matter candidate – the Dark Photon or U boson – off the list in top position. This is the result of recent HADES experiments, where researchers from the

Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and from 17 other European institutes try to pin down the nature of Dark Matter. These negative results – recently published in *Physics Letters B* – could even lead to challenges of the Standard Model of particle physics.

The interpretation of current astrophysical observations results in the striking mass-energy budget of matter in the universe: 75% Dark Energy and 20% Dark Matter. Only about 5% of the universe consists of "ordinary", baryonic matter.

Many attempts have been made to explain the nature of Dark Matter. Researchers believe that Dark Matter is comprised by hitherto unknown particles which do not fit into the Standard Model of particle physics. The Standard Model is a theoretically sound quantum field theory with fundamental matter particles, such as quarks (bound in hadrons, e.g., baryons) and leptons (e.g., electrons and neutrinos), which interact via exchange of force-carrier quanta, called gauge bosons (e.g., photons). Some of these species acquire their masses by the interaction with the Higgs boson. While evidences for the Higgs boson were found recently at CERN, the Standard Model looks now complete when supplemented by some neutrino masses, and nothing else seems to be needed to understand the wealth of atomic, sub-nuclear and particle physics phenomena. Nevertheless, Dark Matter appears not to be explained by any of the constituents of the Standard Model. This status of the affair has initiated worldwide efforts to search for Dark Matter candidates.

Beyond the Standard Model

Searching a needle in the haystack is simpler: one knows both the wanted object (the needle) and the place (the haystack). In the case of Dark Matter the object is unknown, and the localization, e.g. in galactic halos, is also not constraining the loci of interest. To specify the search goal one can envisage diverse hypothetical candidates, such as certain hypothetical particles beyond the Standard Model, which fulfill requirements qualifying them as constituents of Dark Matter.

Dark Energy drives the presently observed accelerated expansion of the universe. Dark Energy is homogeneously distributed and can be attributed to a cosmological constant or vacuum energy. In extreme cases it may cause, in the future, such a sudden expansion that anything in the universe is disrupted - this would be the Big Rip. Dark Matter, in contrast, is bumpy and is needed to explain the formation of the observed density distribution of visible matter in the evolving universe, evidenced by the hierarchy of structures from (super)clusters of galaxies, galaxies, stars, planets and other compact objects such as meteorites, etc.

Among the lists of candidates of Dark Matter is a hypothetical particle, often dubbed U boson or Dark Photon. These nicknames refer to the underlying theory construction: a second unitary ("U") symmetry allows for quanta which are, in one respect, similar to photons - namely gauge bosons - but in another respect different from photons - namely attributing to these quanta a mass, making them to Dark Photons because of a very weak interaction with normal matter. Very similar to photons the Dark Photons can decay into electron-positron pairs, if they have the proper virtuality. Combining the chain of hypotheses one arrives at a scenario, where an "ordinary" virtual photon converts into a Dark Photon which decays afterwards into an electron-positron pair.

Needle and Haystack

If a Dark Photon or U boson would exist with the assumed properties mentioned above and would have a mass, a certain width and a certain coupling strength to the photon, then the "needle" is specified: a resonance-type signal showing up at an invariant electron-positron mass equal to the U boson mass. The "haystack" is specified too: invariant mass spectra, i.e. electron-positron distributions. A prerequisite is an understanding of the overall shape of these distributions.

Up to now the search for such a signal of a U boson as a candidate for Dark Matter has remained unsuccessful. Together with many other searches for the other candidates of Dark Matter the situations becomes more and more intricate. Cosmology on precision level requires the existence of Dark Matter; however, the various experiments have not found any positive hint. The negative results on the U boson by HADES and other experiments make the hunt for new physics beyond the Standard Model more challenging. For instance, high-precision experiments on the magnetic moment of the muon delivered hints for a discrepancy with predictions by the Standard Model. The discrepancy has been proposed to be resolved by the U boson. But the recently achieved negative search results seem to exclude such an option. This gives the impression that the tension of the Standard Model and cosmological request of extensions as well as small deviations of the Standard Model predictions and data, such as the muon magnetic moment and other observables, is increasing, thus making this frontier of physics very fascinating with high discovery potential.

The HADES collaboration

HADES is an acronym of High-Acceptance Di-Electron Spectrometer. It is an optimized detector system operated by a European collaboration of about hundred physicists at GSI Helmholtzzentrum für Schwerionenforschung/Darmstadt. HADES is aimed at investigating virtual photon signals emitted as electron-positron pairs off compressed nuclear matter to understand the origin of the phenomenon "masses of hadrons" and test it in some detail.

The HADES collaboration has accumulated more than ten billion analyzable events during the last years. The notion "events" means that in collisions of energetic protons with target protons or atomic nuclei or in collisions of atomic nuclei with target nuclei, among other final-state particles, an electron-positron pair could occur. Sources of these pairs are, e.g., unstable hadrons being transiently produced in these collisions. The highly sophisticated apparatus HADES has the capability to select out of a huge background of other particles such electron-positron pairs which can be attributed to primary sources.

More information: G. Agakishiev et al. (HADES Collaboration), *Phys. Lett. B* 731, 265 (2014) dx.doi.org/10.1016/j.physletb.2014.02.035

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