Investigation of baryons structure in the HADES experiment

One of the key issues of modern hadron physics is investigation of excited states of nucleons, so-called resonances, to get the insight in the strong interaction, which influence the mass of the visible matter in the Universe. Nucleons are described as a bound state of three quarks surrounded by a sea of gluons and quark-antiquark pairs. The knowledge of the properties of different nucleon resonances is crucial for understanding of the Quantum Chromodynamics (QCD), the quantum field theory of strong interactions. There are many evidence showing that nucleon and its resonances cannot be regarded as simple states of three static quarks. A big role is played by dynamics of gluon interactions leading to the light quark (u, d, s) mass generation and the spontaneous chiral symmetry breaking. The latter leads to appearance of quark condensates which can be interpreted as a so-called meson cloud surrounding quarks and counterbalancing the vacuum pressure. Such clouds are visible in the baryon electromagnetic structure, charge distribution inside the baryon, and are called form factors. In this project we would like to focus on the energy range, where significant effects of mesonic cloud play an important role and are expected to show-up.

The physics of baryon resonances is a major challenge to hadronic physics due to the nonperturbative nature of QCD at these energies. While methods such as chiral perturbation theory are not inclined to N^* physics, lattice QCD has only recently begun to contribute to this field. Thus, most of the theoretical work on the nucleon excitation spectrum has been performed within quark models. These models predict a much richer resonance spectrum than has been observed in $\pi N \to \pi N$ scattering experiments, included in Particle Data Book. The obvious question is: where are the “missing” resonances?

One of the explanation is that the “missing” resonances may couple weakly to πN channel, which is a predominant source of knowledge about baryon properties. There are many experiments which investigate the baryon structure with the use of the pion, electron or photon beams. One of them is the HADES experiment, located at GSI Helmholtz Institute in Darmstadt, exploring baryonic matter at zero (vacuum) and moderate temperatures. HADES performs measurements with pion-nucleon, nucleon-nucleon and heavy ion collisions. One of the research objectives of HADES are studies of baryon resonance production and their hadronic and electromagnetic decays. Especially, by measuring Dalitz decays ($\to$ nucleon e^+e^-) of baryon resonances and determining the baryon internal structure and the role of a pion cloud. This establishes the reference information for studies of the virtual photon radiation (pairs e^+e^-) from hot and dense baryonic matter, and in particular, the understanding of masses of hadrons decaying into dilepton channel. HADES was measuring nuclear reactions with kinetic beam energies in the range of 1–3.5 GeV/nucleon. Once the SIS18 synchrotron upgrade is completed, it will become possible to reach even higher resonances excitations.

The prominent results and excellent detector performance led to decision of using the HADES spectrometer also with the future FAIR accelerator facility, currently under construction in Darmstadt. HADES is currently the only experiment in world which measures rare penetrating probes like dilectrons at moderate temperatures and large baryonic potential by means of a pion, proton, and heavy ion beams in energy range $\sqrt{s}$ = 1–4 GeV.