Referee Report on the project HADES (JINR participation) in 2022-2024

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HADES is a large-acceptance dilepton spectrometer for e+e- measurements in heavy ion reactions in the 1-3.5 GeV kinetic beam energy region, with the main motivation to study medium modifications of hadron properties. It also has good hadronic capabilities to investigate properties of dense nuclear matter created in heavy ion collisions. Since these studies rely heavily on comparisons to vacuum expectations, HADES possesses a complementary program of hadron-nucleon elementary interactions.

The HADES spectrometer is comprised of a superconducting toroid magnet, four planes of low-mass multi-wire drift chambers (MWDCs), a resistive plate time-of-flight system, a forward scintillator hodoscope wall for spectator measurements, a ring-imaging Cherenkov detector, and a lead-glass electromagnetic calorimeter. The apparatus covers 85% azimuth over a polar angle 18-85^{o}, with a single electron efficiency of 50% and a mass resolution of 2.5%.

The JINR team is responsible for the design, production and maintenance of the 2-nd plane MWDC and FEE electronics. Each plane contains 6 separate modules with 6 chambers of different wire orientations. The intrinsic space resolution of MWDC-II was achieved to be 57 μm and 112 μm for the Y and X coordinates, respectively. The JINR team also developed tracking software for the momentum and vertex reconstruction.

During the spring 2019 run, the JINR team provided 30 MWDC expert shifts. The team successfully repaired a sector of MWDC-II that was broken at end of the run. The team actively participates in MWDC readout upgrade using new FEE. The team contributes to the ring reconstruction algorithms of the new RICH detector. The team continues to develop the track finder algorithm for the MWDCs and the new forward straw tracker.

HADES has recently produced several high-profile physics. Most noticeably, it is found that e+e- emission exhibits a temperature of 70 MeV with in-medium broadening of the ρ meson [Nature Phys. 15 (2019) 1040]. Strong and yet similar absorption of K- and ϕ mesons was first observed in π-nucleus collisions of heavy nuclei [Phys.Rev.Lett. 123 (2019) 022002]. Anisotropic flow harmonics of protons, deuterons, and tritons are measured in Au+Au collisions at $\sqrt{s_{NN}}$=2.4 GeV which are sensitive to the equation of state [Phys.Rev.Lett. 125 (2020) 262301]. The 1st-4th order proton number moments and cumulants are corrected for efficiency and volume fluctuations and extensively examined in $\sqrt{s_{NN}}$=2.4 GeV Au+Au collisions, providing an important low-energy data point in the search for the critical point [Phys.Rev.C 102 (2020) 2, 024914].

Since 2019, HADES has published 10 physics papers in refereed journals and 4 technical papers. The JINR group is responsible (principal authors) for one technical paper. JINR group members continued their theoretical calculations of di-electron production in πN interactions at intermediate energies relevant to HADES measurements [arXiv:1907.10298]. The JINR group participated in the analysis of multi-pion production in nucleon-nucleon interactions at intermediate energies and presented their model study which will be useful to guide HADES simulations of hadron interactions [EPJ Web Conf. 204 (2019) 06006].

The HADES collaboration has ~120 authors; 5-6 authors are from JINR. The JINR group has 10 participants in HADES with total 3.1 FTE. One member (Ierusalimov) devotes 1.0 FTE, and three others (Belyaev, Troyan, Lebedev) devote 0.5 FTE each. All of them involve in software development and simulation. The overall physics productivity of the JINR team seems reasonable, in proportion to their participation on HADES. It would be advisable for the group to carry one flagship analysis/physics to more visibility, for example, the multi-pion production in elementary reactions for which the JINR group is traditionally strong.

The future direction of HADES in 2020-2024 is well defined with several physics thrusts: pp at 4.5 GeV, criticality in Au+Au at 0.2-0.8 GeV, medium effects in p+Ag at 4.5 GeV, iso-spin effects and dibaryon d*(2380) in NN collisions, baryon coupling to mesons in pion induced reactions. The JINR group plans to continue the support and maintenance of the MWDC-II hardware and software. The group plans to take part in the analysis of the pp data at 4.5 GeV to study di-electron and hadronic observables. The team is participating in the MWDC upgrade project, software development for tracking in MWDC, Forward Detector, and RICH, and in the preparation/simulation of the HADES/CBM physics program at SIS100. The requested 25 k€/yr for 2022-2024 within BMBF-JINR grant and JINR-Czech Republic program is reasonable.

In conclusion, HADES has well-defined physics programs for the next a few years. JINR's contributions to the hardware, software, and upgrade program of HADES are important for the overall success of the experiment. The JINR group has contributed a fair share of HADES physics productivity and is reasonably visible. The requested budget is justified for the scope of the project. I recommend the JINR HADES project be continued with the first priority.

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