Future perspectives at SIS-100 with HADES-at-FAIR

I. Fröhlich, G. Agakishiev, A. Balanda, G. Bellia, D. Belver, A.V. Belyaev, A. Blanco, M. Böhmer, J. L. Boyard, P. Braun-Munzinger, P. Cabanelas, E. Castro, S. Chernenko, T. Christ, M. Destefanis, J. Díaz, F. Dohrmann, A. Dybczak, L. Fabbietti, O.V. Fateev, P. Finocchiaro, P. Fonte, J. Friese, T. Galatyuk, J. A. Garzón, R. Gernhäuser, A. Gil, C. Gilardi, M. Golubeva, E. Grosse, F. Guber, M. Heilmann, T. Hennino, R. Holzmann, A.P. Ierusalimov, I. Iori, A. Ivashkin, M. Jurkovic, B. Kämpfer, K. Kanaki, T. Karavicheva, D. Kirschner, I. Koenig, W. Koenig, B. W. Kolb, R. Kotte, A. Kozuch, A. Krása, I. Koenig, W. Kühn, A. Kugler, A. Kurepin, J. Lamas-Valverde, S. Lang, J. S. Lange, K. Lapidus, T. Liu, L. Lopes, M. Lorenz, A. Mangiarotti, J. Marín, J. Markert, V. Metag, B. Michalska, J. Michel, D. Mishra, E. Morinière, J. Mousa, C. Müntz, L. Naumann, R. Novotny, J. Otwinowski, Y. C. Pachmayer, M. Palka, Y. Parpottas, V. Pechenov, O. Pechenova, T. Pérez Cavalcanti, J. Pietraszko, W. Przygoda, B. Ramstein, A. Reshetin, A. Rustamov, A. Sadovsky, P. Salabura, A. Schmah, R. Simon, Yu.G. Sobolev, S. Spataro, B. Spruck, H. Ströbele, J. Stroth, C. Sturm, M. Sudol, A. Tarantola, K. Teilab, P. Tlusty, M. Traxler, J. Markert, R. Trebacz, H. Tsertos, I. Veretenkin, V. Wagner, M. Weber, M. Wisniowski, J. Wüstenfeld, S. Yurevich, Y.V. Zanevsky, P. Zhou, P. Zumbruch

(HADES collaboration)

1 Invited contribution presented at the XLVII International Winter Meeting on Nuclear Physics, Bormio (Italy), Jan. 26-30, 2009

Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud, 95125 Catania, Italy
LIP-Laboratório de Instrumentação e Física Experimental de Partículas, 3004-516 Coimbra, Portugal
Smoluchowski Institute of Physics, Jagiellonian University of Cracow, 30-059 Kraków, Poland
Gesellschaft für Schwerionenforschung mbH, 64291 Darmstadt, Germany
Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf, 01314 Dresden, Germany
Joint Institute of Nuclear Research, 141980 Dubna, Russia
Institut für Kernphysik, Johann Wolfgang Goethe-Universität, 60438 Frankfurt, Germany
II. Physikalisches Institut, Justus Liebig Universität Giessen, 35392 Giessen, Germany
Istituto Nazionale di Fisica Nucleare, Sezione di Milano, 20133 Milano, Italy
Institute for Nuclear Research, Russian Academy of Science, 117312 Moscow, Russia
Physik Department E12, Technische Universität München, 85748 München, Germany
Department of Physics, University of Cyprus, 1678 Nicosia, Cyprus
Institut de Physique Nucléaire d’Orsay, CNRS/IN2P3, 91406 Orsay Cedex, France
Nuclear Physics Institute, Academy of Sciences of Czech Republic, 25068 Rez, Czech Republic
Departamento de Física de Partículas, University of Santiago de Compostela, 15782 Santiago de Compostela, Spain
Abstract

Currently, the HADES spectrometer undergoes an upgrade program to be prepared for measurements at the upcoming SIS-100 synchrotron at FAIR. We describe the current status of the HADES di-electron measurements at the SIS-18 and our future plans for SIS-100.

1 Current experimental status

The experimental determination of hadron properties inside strongly interacting media (normal nuclear or hot and dense matter) is one of the very interesting challenges in hadronic physics (see [1] for a review). As the strong coupling $\alpha_s$ becomes very large below the QCD scale $\Lambda_{QCD} \approx 200$ MeV, non-perturbative effects as confinement and the breaking of chiral symmetry rule the nature of strong interactions in the universe (beside extreme cases like neutron stars) solely. Experimentally, the approach to get a deeper understanding of these features is to create nuclear matter under extreme conditions in the laboratory which can be done by employing heavy ion reactions, only.

During the evolution of the fireball, created in the course of heavy ion collisions, the properties of nuclear matter change drastically (see [2] for a detailed discussion): starting as a hot and dense intermediate state eventually with “free” (i.e., only partly or weakly bound) quarks and gluons the system cools down until the exchange of resonance species stops (chemical freeze-out) and finally the particles do not scatter any longer elastically (thermal freeze-out). Our goal is, however, to gather information of the early phase, i.e., before the chemical freeze-out occurs.

One of the main probes (if not the only one) which carry undistorted information over the entire history are di-leptons ($e^+e^-$ or $\mu^+\mu^-$) as they are not hampered by final-state interactions. This included the first-chance radiation (bremsstrahlung), radiation from short-lived resonances (the real “messengers” which have a life time shorter then those of the fireball) and post-freeze-out sources, such as the late $\pi^0$ and $\eta$ Dalitz decays, which can be subtracted if their yields and distributions at the freeze-out point are precisely known. Now, after a successful decade of measurements of electromagnetic probes (summarized in [3, 4]) there is common agreement that only by systematic studies in various systems over a wide energy range, conclusions of the
Future perspectives at SIS-100 with HADES-at-FAIR

following questions can be drawn: when does the onset of deconfinement appear, and how it is related to chiral symmetry restoration?

Recently, HADES [5] has added valuable measurements of di-electron mass spectra for light $A + A$ [6] systems as well as for (quasi-free) $p + N$ collisions [7] at kinetic beam energies of 1-2 AGeV and 3.5 GeV, which has triggered a lot of theoretical activities [8]. One of the main features of HADES is that at the same time it measures also hadrons: pions for absolute normalization [9] and hadrons containing strangeness [10].

To summarize the setup at this point, HADES is a magnetic spectrometer, consisting of up to 4 planes of Mini Drift Chambers (MDC) with a toroidal field created by a superconducting magnet. Particle identification is based on momentum and time-of-flight measurements. In addition, a Ring Imaging Cherenkov detector (RICH) and an electromagnetic Pre-Shower detector provide electron identification capabilities.

HADES will continue its program at its current place at SIS-18, and then move to the upcoming FAIR accelerator complex. Here, HADES will continue its experimental program up to kinetic beam energies per nucleon of 8 GeV at SIS-100. This is one of the main reason for upgrading the HADES detector and its trigger and readout system, which will be outlined in the following.

2 The upgrade program for HADES-at-FAIR

2.1 Motivation

In the kinetic beam energy range of 2-40 AGeV, the di-lepton landscape is completely “terra incognita”. At energies starting from 8 GeV, the CBM experiment [11] will measure di-electrons and di-muons. HADES, on the other hand, will provide the link between 2-8 GeV. Therefore the setup will be moved into the CBM cave and share the same beam line (see fig. [1]).

The advantage of re-using the HADES setup is that has all required features for di-electron measurements (as well as strangeness), and a higher acceptance as CBM for energies up to 8 AGeV. However, it needs a larger granularity (realized by the addition of the new RPC detector (“Resistive Plate Chamber”), discussed elsewhere [12]), better tracking and a slightly modified RICH detector. Furthermore, the large data volumes, expected in experiments with heavy collision systems (Au+Au) already at SIS18 and with higher energies at the new FAIR facility, require bandwidths which cannot be achieved by the current system. Since the currently used data acquisition system was designed ten years ago, it was reasonable to reconsider the whole concept and make use of new technologies.

In addition, higher statistics would allow for the multi-differential measurement of additional degrees of freedom of the virtual photon ($\gamma^* \rightarrow e^+e^-$): As the virtual photon is not mass-less it has two polarization quantities, which are sensitive to the hadronic source and its possible polarization. One of them (the longitudinal polarization), which becomes manifest in the helicity angle $\theta^{ee}_e$, can be used for nailing down the composition of the cocktail [13] and the nature of any additional excess [14].
Two other parameters are the emission angles of the virtual photon. Here, the discussion of the azimuthal angle makes only sense in the context of a measurement of the reaction plane.

2.2 Forward wall

Future HADES experiments at FAIR will therefore profit from a Forward Wall (FW) consisting of 288 plastic scintillator cells, which has been added to the HADES setup in 2007. The FW was already used in 2007 to detect spectator protons in the break-up of projectile deuterons with an incident energy of 1.25 AGeV [7]. The FW, consisting of 140 small cells (4x4 cm\(^2\)) close to the symmetry axis, 64 middle cells (8x8 cm\(^2\)) and 84 big cells (16x16 cm\(^2\)), is positioned seven meters downstream from the target.

The occupancy of single cells has been studied using UrQMD simulations [15] for semi-central Au + Au collisions at 1.0 AGeV compared to those at 8.0 AGeV; it stays below 0.5 in all cases. It should also be noted that UrQMD provides only spectator nucleons and no fragments, i.e. it overestimates the nucleon multiplicity, affecting mostly the inner part with 20 cm radius. The occupancy increases only about a factor two going from SIS18 to low FAIR energies. The reaction-plane angular resolution \(\sigma(\phi)\) deduced from proton hits in the FW is about 48 degrees.

This new, already working detector allows to measure the reaction plane, study elliptic flow and to define the relative azimuthal emission angle \(\phi\) of the virtual photon.

2.3 Calorimeter for HADES

Di-electron results obtained at SPS and RHIC demonstrate a large pair excess in the intermediate \((0.14 < M < 0.6 \text{ GeV}/c^2)\) mass region. An accurate determination of this excess depends on
precise knowledge of the hadronic cocktail, which for 2-40 AGeV is dominated in this mass region by the $\eta$ Dalitz decay. Furthermore, a convenient normalization of the di-electron spectra is naturally given by the $\pi^0$ yield.

For the SIS-18 energy range, the production of neutral mesons has been studied extensively by the TAPS collaboration via photon calorimetry. However, for the 2-40 AGeV range no data at all do presently exist, with the consequence that any interpretation of future di-electron data (i.e. the subtraction of the long-lived components) would have to depend solely on theoretical models, e.g. transport calculations or appropriate hydrodynamical models. In order to remedy this situation we propose to measure the respective $\pi^0$ and $\eta$ meson yields together with the di-electron data. This can be achieved by replacing the HADES Pre-Shower detector, located at forward angles ($18^\circ < \theta < 45^\circ$), with an electromagnetic calorimeter (ECAL).

The option, which is currently under investigation, is to recuperate a lead-glass calorimeter from the former OPAL experiment at LEP and adapt it to HADES. The existing OPAL modules have a geometry of 9.4x9.4 cm$^2$, 840 modules in total.

### 2.4 The new trigger and readout system

For the data rate of the new DAQ system, 100 kHz are aimed for $N + N$ collisions, and 20 kHz for heavy systems (Au+Au at 2 AGeV, Ni+Ni at 8 AGeV). To fulfill this goal, a new trigger and readout board (TRB), a multi-purpose electronic device with on-board DAQ functionality, has been developed [16]. A first version of this hardware, has already been used to read out the HADES forward wall mentioned above.

The readout electronics is on board and the data are transported to mass storage via 100 Mbit/s Ethernet and the UDP internet protocol. Optional time measurements are done using a 124-channel Time to Digital Converter (TDC) device based on the HPTDC [17]. As the concept has been tested successfully during HADES data taking periods, its design has been extended to serve as the new standard readout module for all HADES sub-detectors by adding a high-speed connector and pluggable dedicated detector-specific add-on modules [18]. But also the trigger distribution will be replaced by a tree-like trigger distribution via optical TRB-Hubs with only point-to-point links, realized with 2 Gbit/s optical links, which can also be used for the transport of the data. The planned computing nodes [19] (CN), the same type which is going to be used for
PANDA [20], providing high-speed pattern recognition, can easily be integrated. For the readout of the drift chambers a TRB-add-on has been made which contains 32 optical transceivers thus replacing the electrical connection which turned out to be a source of noise. On the front-end side, the counterpart, we have developed a very small, highly integrated optical end point driver card.

For easy monitoring and operation of the large number of modules needed, the TRBNet, a new hardware-independent network protocol has been developed. It allows the simultaneous (interleaved) distribution of trigger information, which has to be done with a low latency, and the transportation of large amounts of data using only one data link. Different logical channels provide priority levels, while buffers on each connection guarantee protection from data loss. Finally, multiple event builders (EB) are connected via Ethernet to the TRBNet. This concept is visualized in fig. 2.

3 Summary and outlook

In summary, we presented the concept of the “HADES-at-FAIR” project. The HADES spectrometer, after finishing the currently ongoing upgrade, is ready for experiments at the future SIS-100 synchrotron of the FAIR facility. We expect to fill the knowledge gap between 2-8 AGeV and provide first data at the very first day once the beam is injected into the CBM cave.

Acknowledgments

The collaboration gratefully acknowledges the support by BMBF grants 06MT238, 06GI146I, 06FY171, and 06DR135, by the VI-146 and the Helmholtz Alliance Programm HA216/EMMI “Extremes of Density and Temperature: Cosmic Matter in the Laboratory” of the Helmholtz Association, by the DFG cluster of excellence EClist 153 and by Maier-Leibniz-Laboratorium Munich (Germany), by GSI (TM KRUE.GI/ME3.OF/STR), by grants MSMT LC07050, LA316 and GAASCR IAA100480803 (Czech Republic), by grant KBN 1P03B 056 29 (Poland), by INFN (Italy), by CNRS/IN2P3 (France), by grants FPA2006-09154, PGIDIT06PXIC296091PM and CPAN:CSD2007-00042 (Spain), by grant POCI/FP/81982/2007 (Portugal), by grant UCY-10.3.11.12 (Cyprus), by INTAS grant 06-1000012-8861 and by EU contract RII3-CT-2004-506078.

This work was supported by the Hessian LOEWE initiative through the Helmholtz International Center for FAIR (HIC for FAIR).

References

[1] R. S. Hayano and T. Hatsuda, arXiv:0812.1702 [nucl-ex].

[2] P. Braun-Munzinger and J. Wambach, arXiv:0801.4256 [hep-ph].

[3] I. Tserruya, arXiv:0903.0415 [nucl-ex].

[4] R. Rapp, J. Wambach and H. van Hees, arXiv:0901.3289 [hep-ph].
[5] G. Agakishiev et al. (HADES), arXiv:0902.3478 [nucl-ex].

[6] G. Agakishiev et al. (HADES), Phys. Lett. B 663 (2008) 43 [arXiv:0711.4281]; G. Agakishiev et al. (HADES), Phys. Rev. Lett. 98 (2007) 052302 [arXiv:nucl-ex/0608031].

[7] K. Lapidus et al. (HADES), arXiv:0904.1128 [nucl-ex].

[8] K. Schmidt, E. Santini, S. Vogel, C. Sturm, M. Bleicher and H. Stöcker, arXiv:0811.4073 [nucl-th]; E. Santini, M. D. Cozma, A. Faessler, C. Fuchs, M. I. Krivoruchenko and B. Martemyanov, Phys. Rev. C 78 (2008) 034910 [arXiv:0804.3702]; E. L. Bratkovskaya and W. Cassing, Nucl. Phys. A 807 (2008) 214 [arXiv:0712.0635].

[9] G. Agakishiev et al. (HADES), Eur. Phys. J A 40 (2009) 45 [arXiv:0902.4377]; P. Tlusty et al. [The HADES Collaboration], arXiv:0906.2309 [nucl-ex].

[10] G. Agakishiev et al. (HADES), arXiv:0902.3487 [nucl-ex].

[11] V. Friese, Nucl. Phys. A 774 (2006) 377; P. Senger et al., PoS CPOD2006 (2006) 018; V. Friese, PoS CPOD07 (2007) 056 (CBM).

[12] A. Blanco et al. (HADES), Nucl. Instr. and Meth. A 602 (2009) 691.

[13] E. L. Bratkovskaya, W. Cassing and U. Mosel, Z. Phys. C 75 (1997) 119 [arXiv:nucl-th/9605025]; E. L. Bratkovskaya, W. Cassing and U. Mosel, Phys. Lett. B 376 (1996) 12 [arXiv:nucl-th/9601018]; T. I. Gulamov, A. I. Titov and B. Kämpfer, Phys. Lett. B 372 (1996) 187; A. I. Titov and B. Kämpfer, Phys. Rev. C 76 (2007) 065211 [arXiv:0709.1393].

[14] R. Arnaldi et al. (NA60), arXiv:0812.3100 [nucl-ex].

[15] M. Bleicher et al., J. Phys. G 25 (1999) 1859 [arXiv:hep-ph/9909407].

[16] I. Fröhlich et al. (HADES), IEEE Trans. Nucl. Sci. 55 (2008) 59.

[17] M. Mota et al. 2000 IEEE Nuclear Science Symposium Conference Record, Volume 2, 9/155 - 9/159 (2000).

[18] M. Palka et al (HADES), NSS 2008 conference record, IEEE (2008) 1398.

[19] W. Kühn et al. (PANDA), J. Phys. Conf. Ser. 119 (2008) 022027.

[20] J. G. Messchendorp (PANDA), arXiv:0711.1598 [nucl-ex];