High Acceptance Di-Electron Spectrometer (HADES)
(JINR participation)

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Detailed materials on the HADES project can be found at http://www-hades.gsi.de

The High Acceptance Di-Electron Spectrometer at SIS18

HADES is a versatile detector for a precise spectroscopy of e^+e^- pairs (dielectrons) and charged hadrons produced in proton, pion and heavy ion induced reactions in a 1-3.5 GeV kinetic beam energy region. The detector has been set-up at GSI, Darmstadt. The main experimental goal is to investigate properties of dense nuclear matter created in the course of heavy ion collisions and ultimately learn about in-medium hadron properties (like masses, decay widths). The matter created in such collisions differs from the one studied at SPS, RHIC or LHC because it consists mainly of baryons (nucleons and its excited states- baryon resonances) and little mesons and can be compressed up to 3 times nuclear matter density for about 10-12 fm/c. Dielectron pairs originating from in-medium hadron decays and rare strange hadrons (kaons, hyperons) are the main probes measured in the experiment. Since conclusions on in-medium effects rely strongly on the understanding of hadron properties in vacuum and their production mechanism in nucleon-nucleon collisions a complementary program focusing on e^+e^-, kaon and hyperon (Σ, Λ) production in elementary collisions is also in progress.

Collisions of heavy ions allow to probe nuclear matter at high densities and temperatures. These studies have the astrophysical applications, namely, the composition, equation of state- mass-radius relation for compact massive stars (supernova and neutron stars). Dense nuclear matter can be created in elativistic heavy-ion collisions. The baryon density and the temperature of the fireball reached in such collisions depend on the beam energy.The phases of strongly interacting matter are shown schematically in figure 1. The "liquid" phase is realized in atomic nuclei at zero temperature and at saturation density (300 million tons/cm^3). At low densities, the nucleons (i.e. protons and neutrons) behave like a gas. As the temperature and the density are raised, the nucleons are excited into "baryon resonances" which subsequently decay into pions and nucleons.

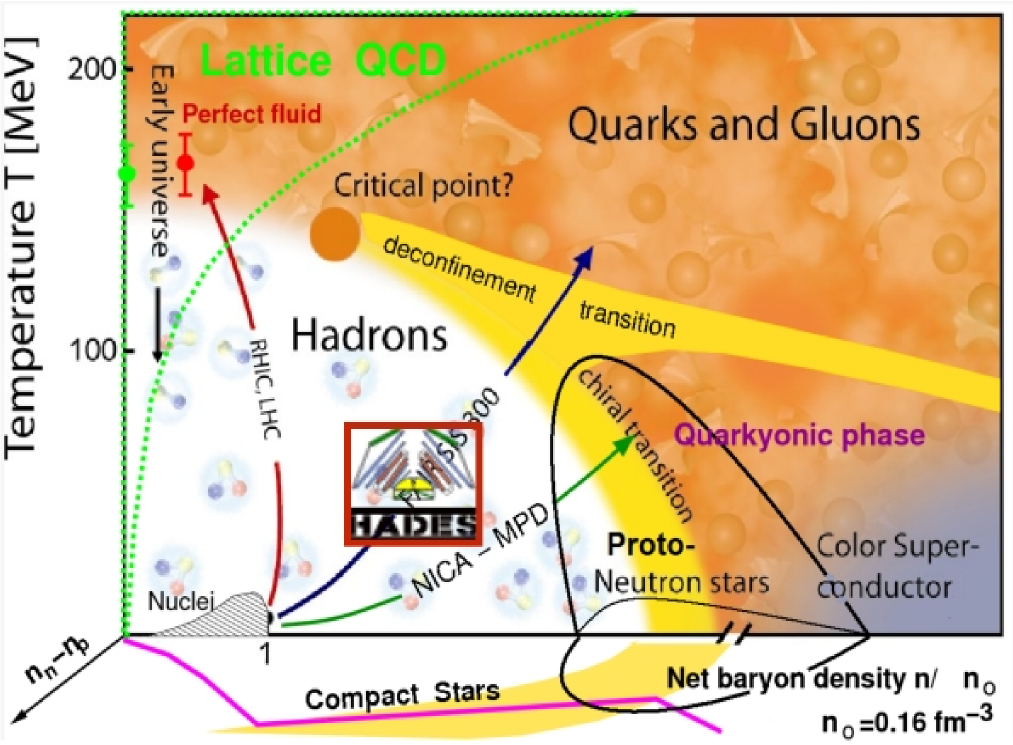

Figure 1: A schematic phase diagram of strongly interacting matter.

This mixture of nucleons, baryonic resonances and mesons is called hadronic matter.In highly compressed cold nuclear matter - as it may exist in the interior of neutron stars - the baryons also lose their identity and dissolve into quarks and gluons. The critical density at which this transition occurs, however, is not known. The same is true for the entire high-density area of the phase diagram. At very high densities and low temperatures, beyond the deconfinement transition, a new phase is expected: the quarks are correlated and form a color superconductor. At the "critical point" the deconfinement/chiral phase transition is predicted to change its character.

The physics motivation for HADES includes the investigation of in-medium modification of light vector mesons as well as the study of dilepton continium in the warm (T<100MeV) and dense(up to $3\rho_0$) hadronic matter at SIS18, GSI. Due to good hadron identification the studies of the strange particles including so-called multistrange hyperons (Λ, Ξ, Ω) and hypernuclei are possible. The HADES strategy is the systematic di-electron and hadron measurements in NN, AA, pA, πN and πA collision.

In future HADES will be a part of the CBM (Compressed Baryonic Matter) experiment at the Facility for Antiproton and Ion Research (FAIR). The CBM experiment will enable researchers to investigate, among other things, processes in supernovae and neutron stars with unprecedented precision. The HADES spectrometer after upgrade will be able to study nuclear reactions in the energy range from 2 to 10 GeV/nucleon.

The HADES detector

The HADES spectrometer is devoted to the 2-nd generation of the di-electron detectors and it is designed to detect these electron-positron pairs heavy ion collisions, which provide information about the properties of the quark-antiquark pairs. The HADES is also able to detect and identify the hadrons what gives the opportunity to study strangeness and multi-pion production. The schematic view of the HADES detector is presented in figure 2.

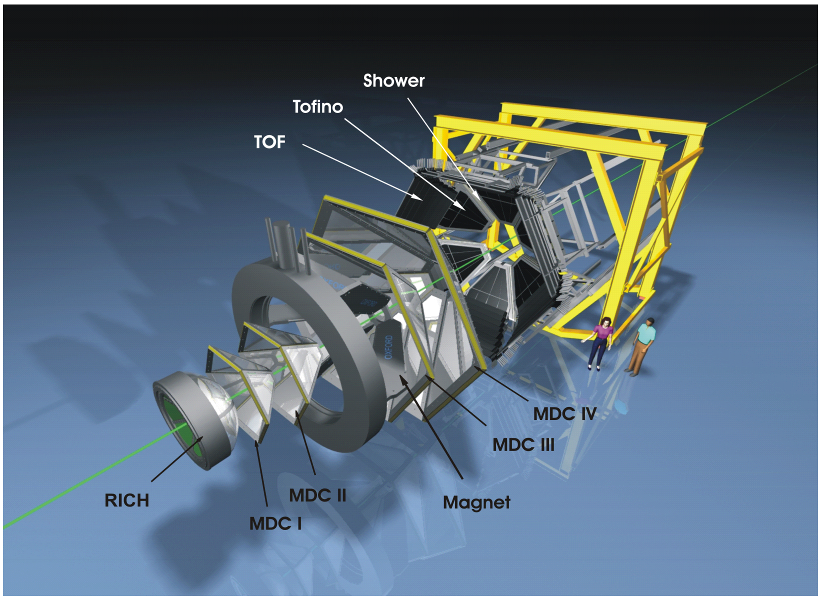

Figure 2: A schematic view of the HADES detector. Magnet is a superconducting toroid, MDC I-IV are the four planes of the multi-drift chambers, RICH is a Ring Imaging Cherenkov detector, Shower is a the pre-shower detector, TOF and TOFINO are the scintillation counters and Resistive Plate Chambers for time-of-flight measurements.

HADES is a large acceptance magnetic spectrometer operating with proton, deuteron and heavy ion beams extracted from the SIS18. It uses directed beam from the synchrotron or optionally secondary pion beams produced in a production target 15 m upstream from the HADES target point. It combines a magnetic spectrometer with detector systems specialized in detecting rare decay products such as electrons and positrons from conversion decays of hadrons. The spectrometer features a sophisticated superconducting toroid, low-mass drift chambers, a ring-imaging Cherenkov detector using a CsI photocathode and a pre-shower detector.The time-of-flight system uses diamond start detectors and scintillator and resistive plate based stop detectors. A tracking system consists of a set of 6 superconducting coils producing a toroidal field and drift chambers and a multiplicity and electron trigger array for additional electron-hadron discrimination and event characterization. A two-stage trigger system enhances events containing electrons. The detector system is characterized by an 85% azimuthal coverage over a polar angle interval from 18 to 85 degree, a single electron efficiency of 50% and a vector meson mass resolution of 2.5%. Identification of pions, kaons and protons is achieved combining time-of-flight and energy loss measurements over a large momentum range. The details of the HADES spectrometer are described elsewhere [1]. In addition the Forward Wall (FW) [2] is used for the measurements of the spectator protons and reaction plane determination. The schematic cut view of the HADES with FW during the experiment with deuteron beam is shown in figure 3.

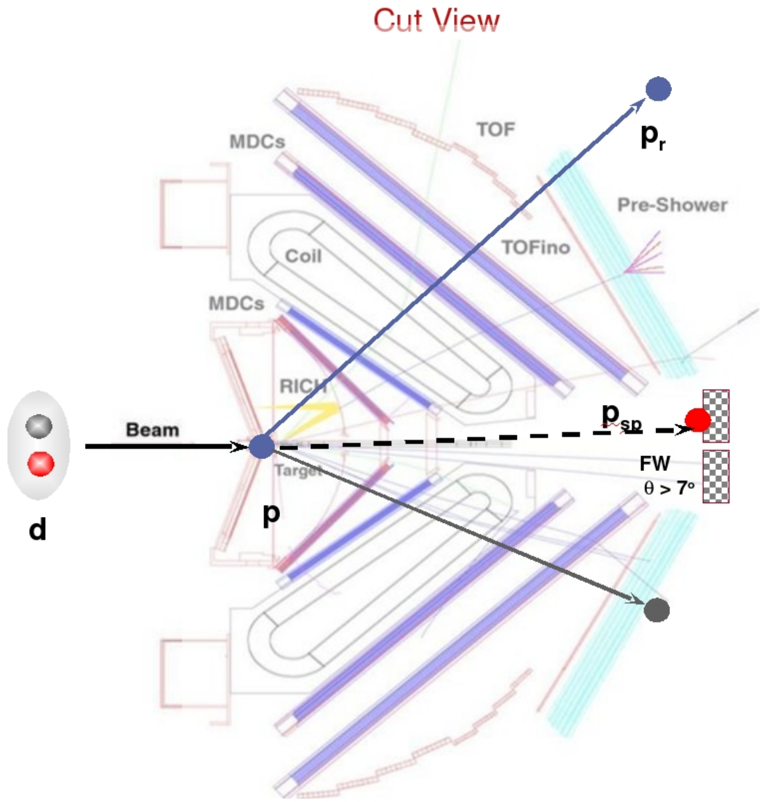

Figure 3: A schematic view of the HADES with FW during the experiment with deuteron beam. Spectator proton is detected by the FW.

JINR contribution in HADES detector

A tracking system of HADES consists of a set of 6 superconducting coils producing a toroidal field and 4 planes of multi-wire drift chambers (MWDCs) [3,4]. The JINR physicists were responsible for the design, production and maintenance of the 2-nd plane of low mass multi-wire drift chambers [5,6]. Each plane contains 6 separate modules with 6 chambers with different wire orientations. The intrinsic space resolution of the 2-nd plane was achieved as 57 μm and 112 μm for the Y and X coordinates, respectively. This plane is used as a reference plane in the tracking procedure. Cathode and field wires are produced from aluminium. The FEE electronics for drift chambers has been developed also at JINR [7]. The picture of the 2-nd MWDC plane installed at HADES detector is shown in figure 4.

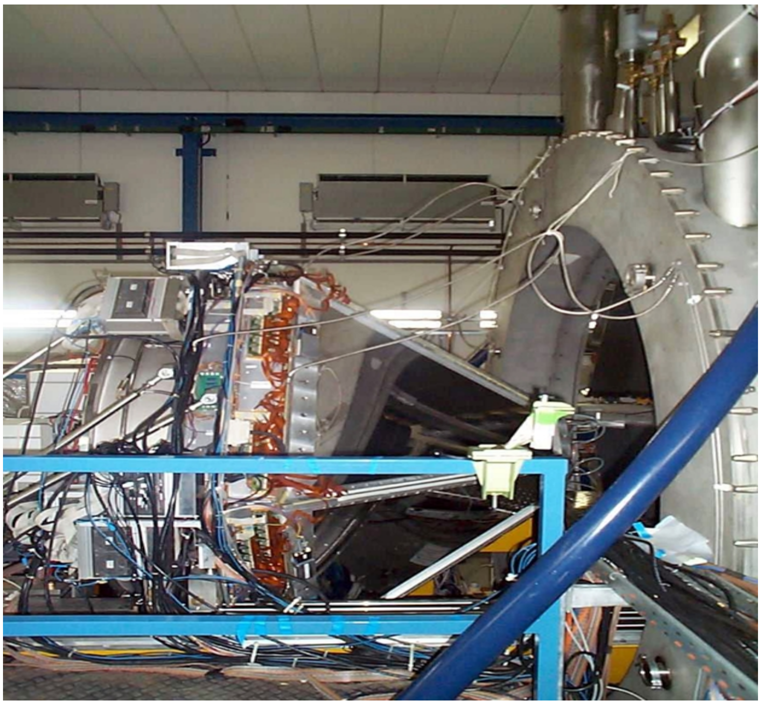

Figure 4: 2-nd MWDC plane installed at HADES spectrometer.

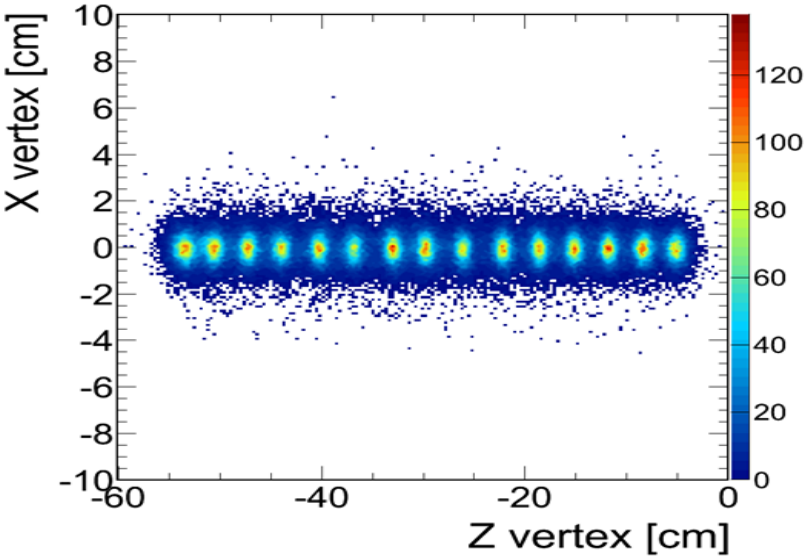

Figure 5: The reconstructed Z position of the segmented Au target (15 segments).

JINR physicists developed tracking software for the momentum and vertex reconstruction [8]. The results on the primary vertex reconstruction for the segmented Au target is shown in figure 5. The results obtained in Au+Au run in 2012. One can see clearly 15 segments with 2 mm in diameter each. JINR participated also in the development of the alignment procedure for HADES [9].

Recent experimental results from HADES

The available HADES data obtained in recent years and plans on next 3 years are indicated in table 1. Now HADES collaboration analyzes the data obtained before 2012 and in 2 last data taking campains (after first HADES setup upgrade).

Table 1: The HADES data and investigated observables.

Date	**Reactions**	**Observables**
Before 2012	**C+C, p+p, Ar+KCl, d+p, p+Nb at 1 - 3.5 AGeV**	**dielectron spectra, medium effect, Δ Dalitz decay, vector meson, hadronic channels, reference for medium effects**
2012	**Au+Au at 1.23 AGeV**	**Low mass e^+e^- "excess"; kaon production : K^0s, $K^\pm$, Hyperon production; Λ,Σ,Ξ(1321); φ production; Λ-p, p-p, ππ correlations**
2014	**π+p, π+A at 1.7, 0.656-0.800 GeV**	**Strangeness in-medium; resonances in di-electron and di-pion channel**
2018	**Ag+Ag**	
2019	**π+p (CH2-C), π+A**	
2020*	**p+A, p+p at 4.5 GeV**	

*Not confirmed yet

The main scientific direction of HADES program is the systematic studies of the vector meson production and di-lepton continium in the e+e- mode.

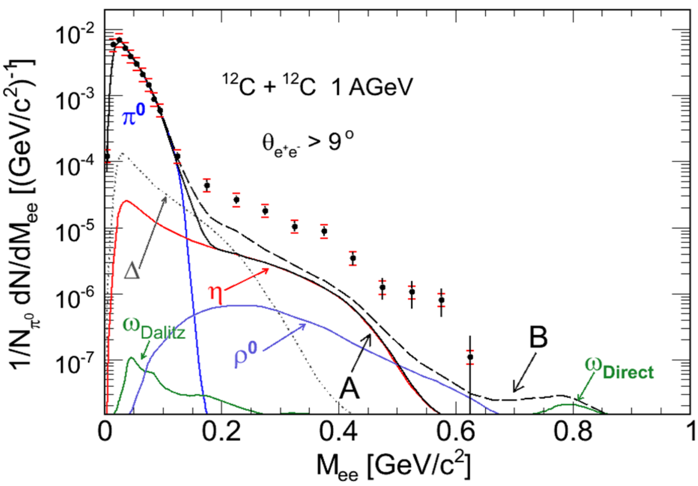

Figure 6: Di-electron spectrum for C-C reaction at 1 AGeV obtained with HADES.

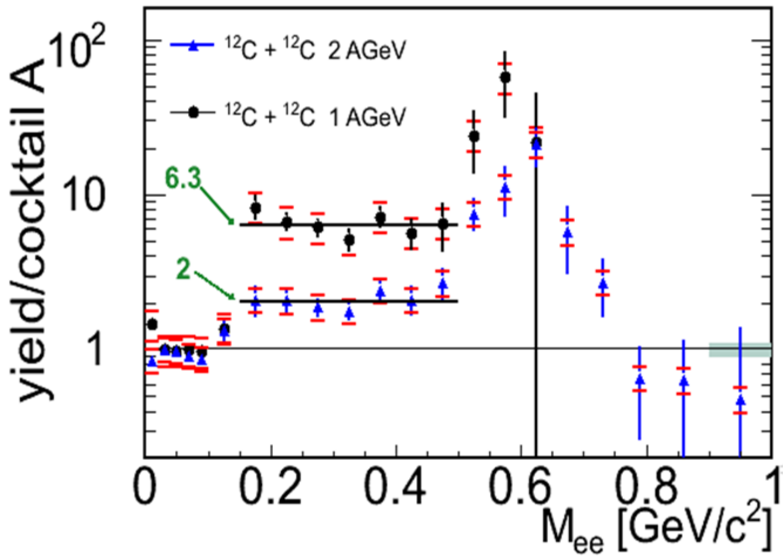

Figure 7: The ratio of the di-electron yields for C-C reaction at 1 AGeV and 2 AGeV obtained with HADES.

The results of the emission of e+e- pairs from C+C collisions at an incident energy of 1 A GeV [10] are shown in figure 6. The measured production probabilities, spanning from the π^0-Dalitz to the ρ/ω invariant-mass region, display a strong excess above the cocktail of standard hadronic sources (6.3. times). The bombarding-energy dependence of this excess is found to scale like pion production, rather than like eta production. The invariant-mass spectrum of the e+e- pairs produced in C+C collisions at an incident energy of 2 A GeV [11] also demonstrates the excess by 2 times in the M_{ee} range of 0.15-0.6 GeV/c^2 (see figure 7). The data are in good agreement with results obtained in the former DLS experiment [12,13]. The detailed studies of the origin of the DLS «puzzle» motivated the measurements of electron pair production in elementary p+p and d+p reactions at 1.25 GeV/u with the HADES spectrometer [14]. For the first time, the electron pairs were reconstructed for n+p reactions by detecting the proton spectator from the deuteron breakup by Forward Wall [8]. We find that the yield of electron pairs with invariant mass $M_{ee} > 0.15$ GeV/c^2 is about an order of magnitude larger in n+p reactions as compared to p+p. A comparison to model calculations demonstrates that the production mechanism is not sufficiently described yet. The electron pair spectra measured in C+C reactions were found being compatible with a superposition of elementary n+p and p+p collisions, leaving little room for additional electron pair sources in such light collision systems.

The results on dielectron production in Ar+KCl collisions obtained by HADES at 1.76 AGeV [15] are shown in figure 8. For the first time ω mesons were reconstructed in a heavy-ion reaction at a bombarding energy which is well below the production threshold in free nucleon-nucleon collisions. The omega multiplicity has been extracted and compared to the yields of other particles, in particular of the φ meson. At intermediate e+e- invariant masses, a strong enhancement of the pair yield over a reference spectrum from elementary nucleon-nucleon reactions was found suggesting the onset of non-trivial effects of the nuclear medium. Transverse-mass spectra and angular distributions have been reconstructed in three invariant mass bins. In the former unexpectedly large slopes are found for high-mass pairs. The latter, in particular the helicity-angle distributions, are largely consistent with expectations for a pair cocktail dominated at intermediate masses by Δ-Dalitz decays.

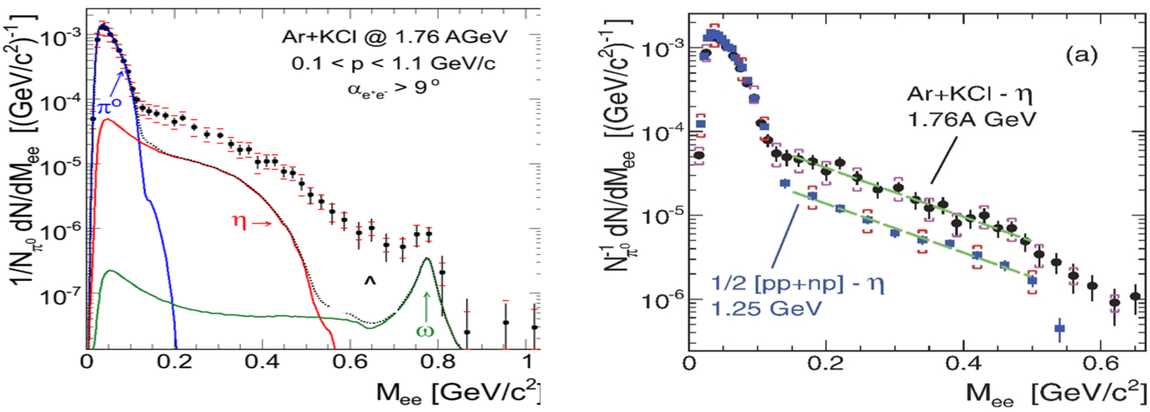

Figure 8: The di-electron yield for Ar-KCl reaction at 1.76 AGeV obtained with HADES [15]. Left panel represent the comparison with the cocktail. Right panel is the comparison of the Ar+KCl data with a reference spectrum from elementary nucleon-nucleon reactions.

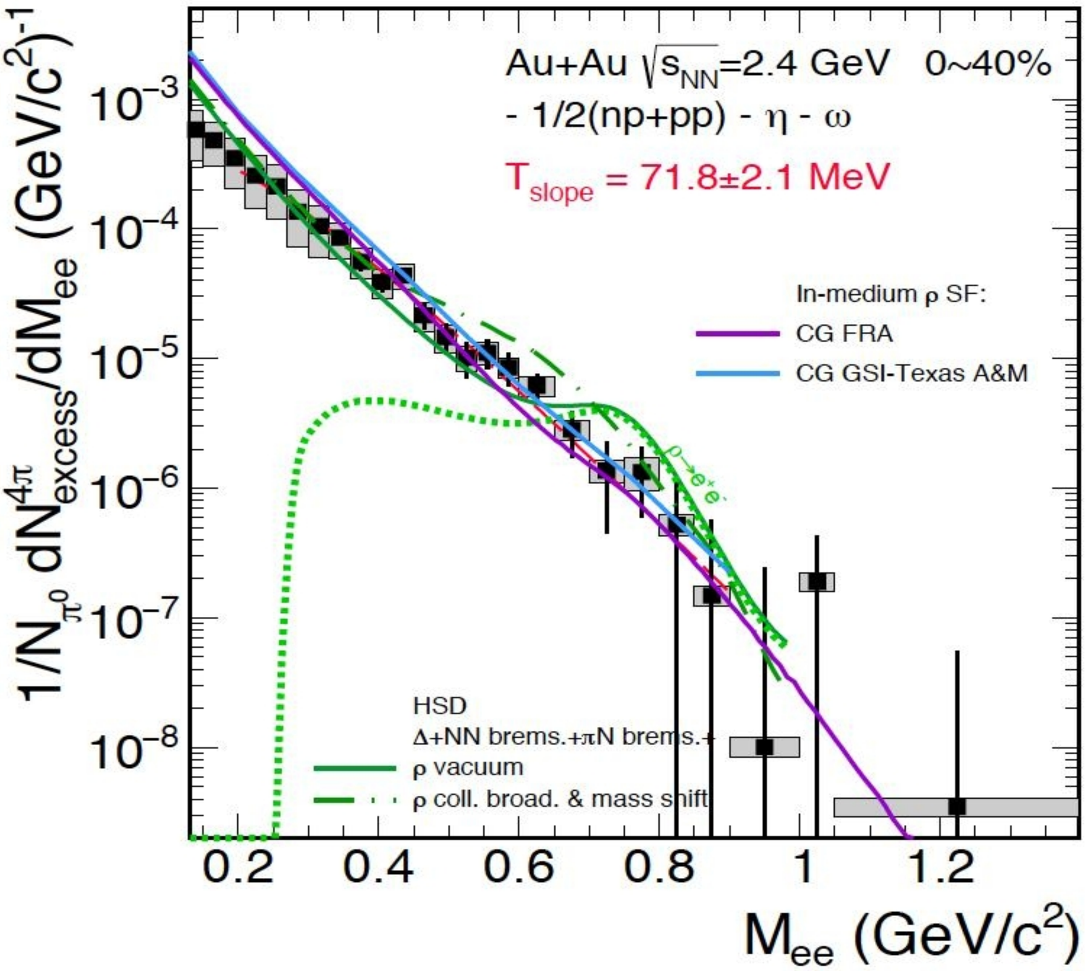

Figure 9. The di-electron yield for Au+Au reaction at 1.23 AGeV obtained with HADES. The solid lines are the coctail calculations for diffent models without η- and ω- mesons contribution. The dashed line is the contribution of the ρ -meson decay.

The di-electron yield obatined for Au+Au reaction at 1.23 AGeV at HADES is shown in Figure 9. The solid lines are the coctail calculations for diffent models without η- and ω- mesons contribution. The dashed line is the contribution of the ρ -meson decay. The data are described satisfactorily taking into account in-medium modification of ρ -meson.

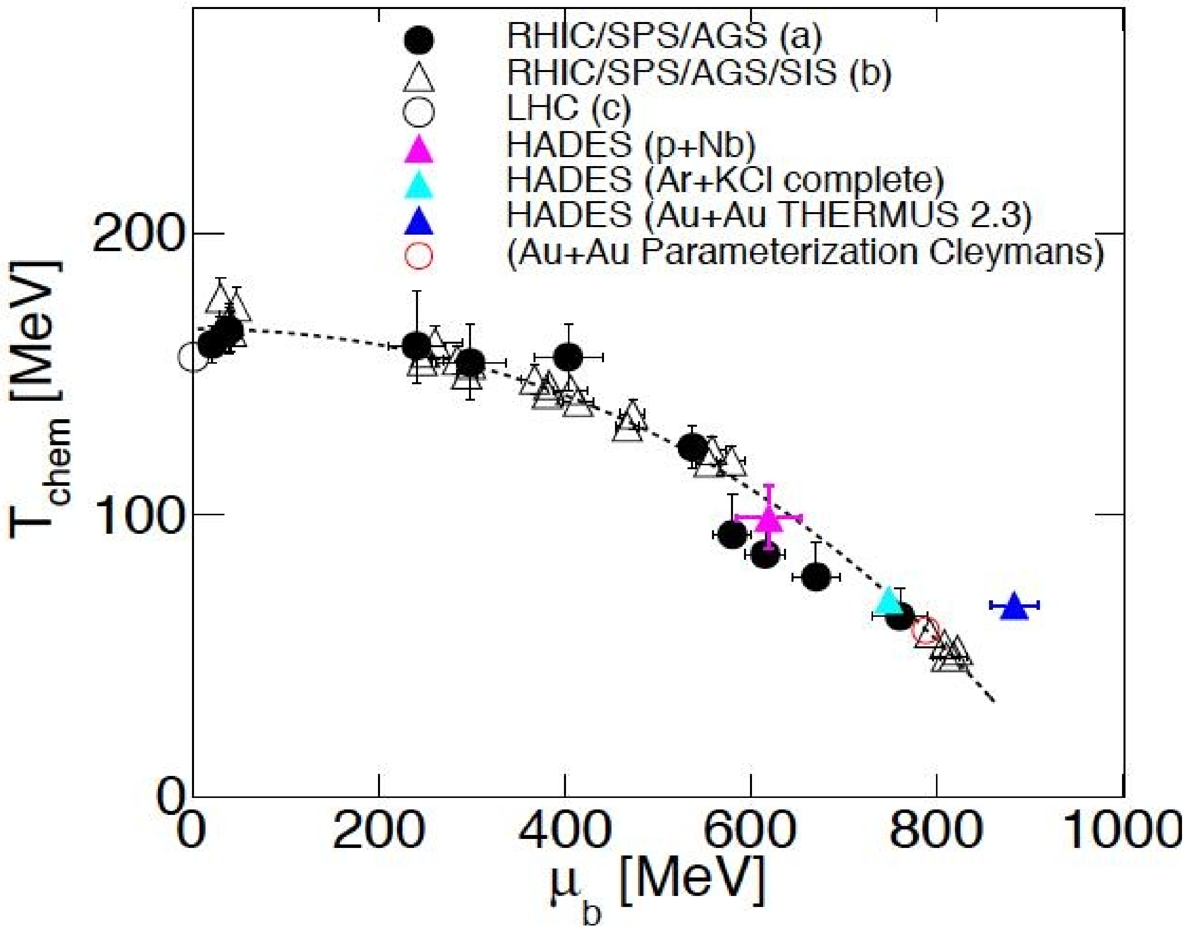

Figure 10: Chemical freeze-out points in the T_{chem}- μ_b plane. The dashed curve correponds to a fixed energy per nucleon of 1 GeV, calculated according to [16]. Black points are the world data. The color ones are obtained by HADES for different systems.

Two manifestations, namely, the description of yields and regularity of freeze-out parameters, were tested by comparing the obtained freeze-out parameters from a statistical model [17] to HADES data obtained from p+Nb, Ar+KCl and Au+Au collisions at center of mass energies of $\sqrt{s_{NN}}$= 3.2 GeV, $\sqrt{s_{NN}}$= 2.6 GeV and $\sqrt{s_{NN}}$= 2.42 GeV, respectively. It was made the rather surprising finding that the statistical model is able to describe the p+Nb data as well as the larger systems like the Ar+KCl or Au+Au data, which questions the often drawn connection between the agreement of statistical models with particle yields in heavy-ion collisions (HIC) and thermalization. Furthermore, it was found that the excess of the Ξ^- is already present in cold nuclear matter. Given the rates of higher-lying N* resonances predicted by the statistical model fit, it was found feed down of these states a rather implausible explanation for the excess of the Ξ^- yield over the model value. In addition, the importance of a precise knowledge of the hadron spectrum for interpretation of HIC data is stated. The HADES data of central Au+Au collisions are in rather good agreement with the statistical model.

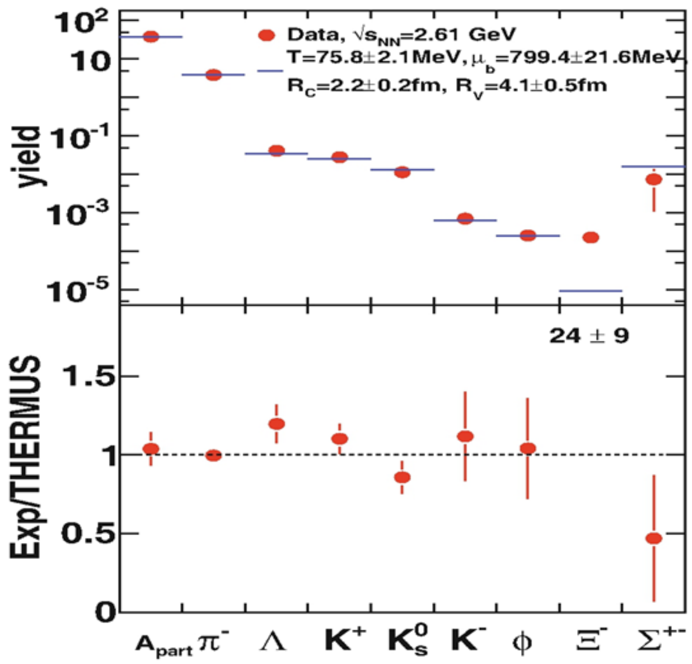

Figure 11: The comparison of the different hadron yields in Ar+KCl collisions at 1.76 AGeV with the THERMUS model [17].

HADES has good hadron identification neccessary for the studies of hadrons including strange weekly decaying particles (K_0^s, Λ and Ξ). The results on the comparison of the different hadron yields obtained in Ar+KCl collisions at 1.76 AGeV with the THERMUS model [17] are given in figure 11. The experimental data are in good agreement with the theory except for the Ξ production which excesses the model prediction [18] more than 20 times. The lattest HADES result on the Ξ production in p+Nb interaction at 3.5 GeV [19] confirms also the Ξ yield excess over the different models predictions. Note, that new data on the Ξ production will be obtained in Ag+Ag run in 2018.

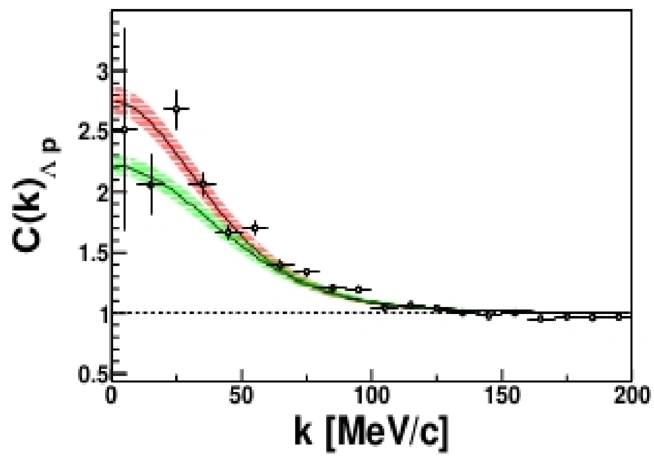

Figure 12: Comparison of the experimental Λp correlation function (open circles with error bars) to the LO (green) and NLO (red) scattering parameter set. The error bands in the theory curves correspond to the errors of the Λp source size determination .

The first measurement of Λp and pp correlations via the femtoscopy method in p+Nb reactions at $\sqrt{s_{NN}}$= 3.18 GeV has been performed with the High Acceptance Di-Electron Spectrometer (HADES) [20]. By comparing the experimental correlation function to model calculations, a source size for pp pairs of $r_{0,pp}$ = 2.02± 0.01(stat) fm and a slightly smaller value for Λp of $r_{0,\Lambda p}$ = 1.62± 0.02(stat) fm is extracted. Using the geometrical extent of the particle emitting region, determined experimentally with pp correlations as reference together with a source function from a transport model, it is possible to study differentsets of scattering parameters. The Λp correlation is proven sensitive to predicted scattering length values from chiral effective fieldtheory. It is demonstrated that the femtoscopy technique can be used as valid alternative to the analysis of scattering data to study the hyperon-nucleon interaction.

JINR group data analysis

JINR group is actively involved in the analysis of the experimental data obtained with a deuteron beam at 1.25 AGeV. The two-pion production in nucleon-nucleon (NN) collisions is a rich source of information about the baryon excitation spectrum and the baryon-baryon interactions. In addition to the excitation of a resonance decaying into two pions, which can also be studied in the πN → ππN and γN → ππN reactions, the simultaneous excitation of two baryons can be investigated in the NN reactions. By giving access to single and double baryon excitation processes, which both play an important role in the NN dynamics in the few GeV energy range and contribute significantly to meson and dilepton production, the two-pion production appears as a key process towards a better understanding of hadronic processes. In comparison to the one-pion decay mode, it presents a different selectivity with respect to the various resonances. In particular, the excitation of baryonic resonances coupled to the ρ meson can be studied with the two pions in the isospin 1 channel. This is of utmost interest for a better understanding of the dilepton production in nucleon-nucleon reactions, where these couplings manifest clearly, and also in nucleon matter due to the expected modifications of the ρ meson spectral functions. Finally,the comparison of two-pion production in pp and np channels could shed some light on the origin of the surprisingly large isospin dependence of the dilepton emission observed by the HADES experiment [14]. In particular, the ρ production mechanism via ΔΔ final state interaction, which does not contribute in the pp channel, was recently proposed as an explanation for the different dilepton yield measured in pp and pn channels [21]. It is therefore important to check the description of the double Δ process in the two-pion production channels.

The JINR group is analyzing the tagged quasi-free np → npπ+ π− reaction with HADES at a deuteron incident beam energy of 1.25 GeV/nucleon ($\sqrt{s}$ ∼ 2.42 GeV/c for the quasi-free collision) [22]. For the first time, differential distributions for π π production in np collisions have been collected in the region corresponding to the large transverse momenta of the secondary particles. The invariant mass and angular distributions for the np → npπ+ π− reaction are compared with different models. This comparison confirms the dominance of the t-channel with ΔΔ contribution. It also validates the changes previously introduced in the Valencia model to describe two-pion production data in other isospin channels, although some deviations are observed, especially for the π+ π− invariant mass spectrum. The results of the analysis for the mass distributions are presented in figure 13. The best description of the data are obtained using modified OPER model [23].

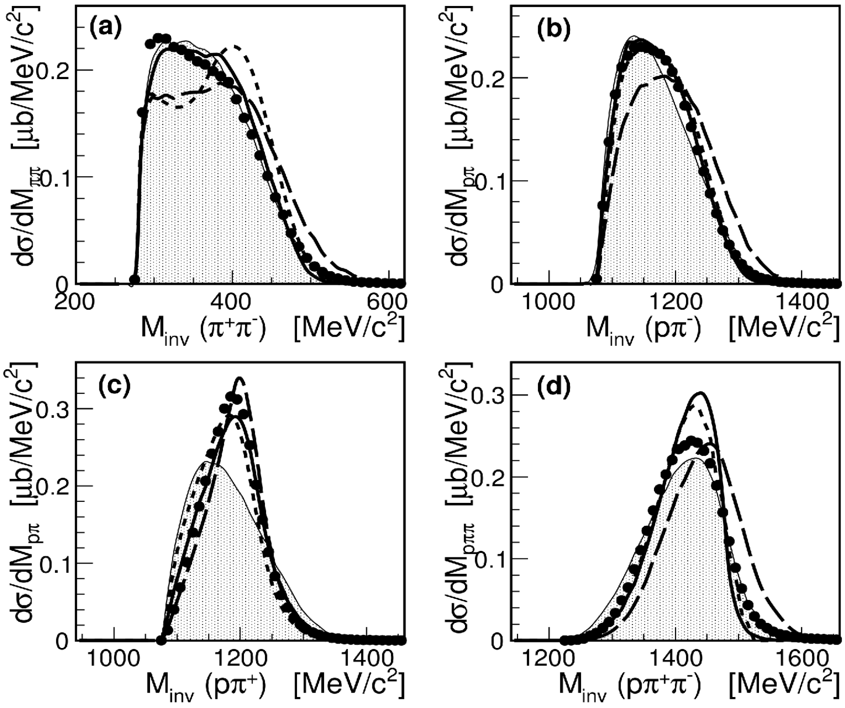

Figure 13: Distributions of the π+ π− (a), pπ− (b), pπ+ (c) and pπ+ π− (d) invariant masses for the np → npπ+ π− reaction at 1.25 GeV [22]. The experimental data are shown by solid symbols. The theoretical predictions within HADES acceptance from differentd models are given by the solid, dashed and long-dashed curves, respectively. The shaded areas show the phase-space distributions.

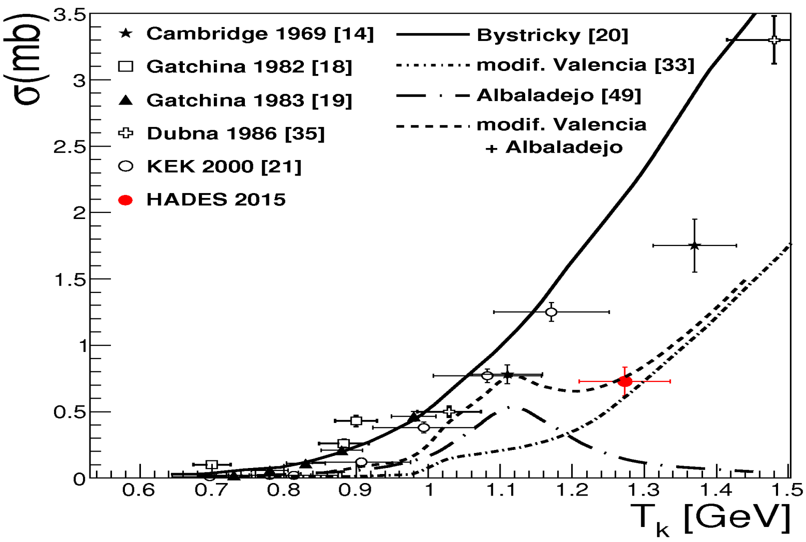

Figure 14: HADES measurement for the quasi-free np → npπ+ π− reaction using a deuterium beam at 1.25 GeV/nucleon (full red dot) compared to world data shown by various symbols. The horizontal error bars indicate the spread of the neutron momentum in the different measurements. The full and short dash- dotted curves display respectively the ”Bistricky parametrization” used for the OPER model [23] normalization and the predictions model [21].

The long dash-dotted curve is the estimate for the contribution of the dibaryon resonance. The dashed curve is the sum of model [21] and dibaryon resonance contributions. See ref.[22] for the details.

The extracted total cross section shown in figure 14 is also in much better agreement with the model taking into accout the dibaryon resonance [21]. HADES new measurement [22] puts useful constraints for the existence of the conjectured dibaryon resonance at mass M∼ 2.38 GeV and with width Γ ∼ 70 MeV. HADES data call for the development of a full model, including in a consistent way the t-channel processes, based on the modified Valencia model and the s-channel processes including the dibaryon with above quoted parameters, which could provide a solid framework for the interpretation of the two-pion production data.

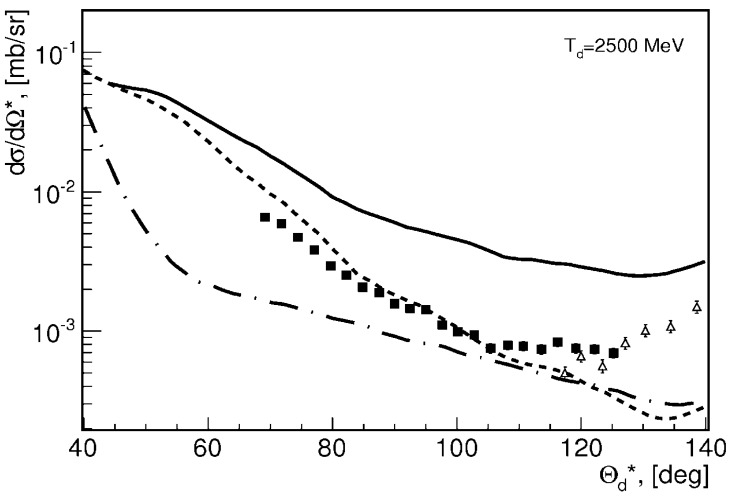

Figure 15: HADES measurement for the angular dependence of the dp → dp reaction cross section using a deuterium beam at 2.5 GeV (full squares) compared to world data shown by open symbols.

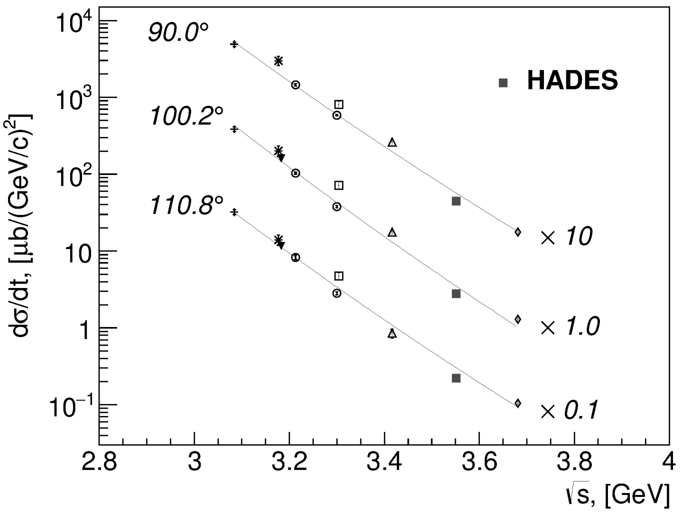

Figure 16: The energy dependence of the dp → dp reaction cross section for the fixed angles in the cms. HADES measurements at 2.5 GeV are shown by the full squares. Lines correspond to the parameterization s^{-16} coming from the constituent counting rules [24].

The JINR group is analyzing the experimental data on dp- elastic scattering obtained using a deuterium beam at 2.5 GeV. The HADES acceptance allows to measure this process at large transverse momenta where the manifestation of the short-range two-nucleon and three-nucleon correlations is possible. The results on the the angular dependence of the dp → dp reaction cross section using a deuteron beam at 2.5 GeV are shown in figure 15. The obtained at HADES data between 70 and 130 degrees in the center of mass are in good agreement with the experimental data obtained earlier at backward scattering angles. The theoretical predictions are obtained within the relativistic scattering model taking into account the single and double scattering terms shown by the dot-dashed and solid lines, respectively. One can see, the calculations taking into account the single scattering only and in addition double scattering underestimate and overestimate the HADES data, respectively. Certainly, the additional mechanisms like explicit Δ isobar contribution is required. The energy dependence of the dp → dp reaction cross section for the fixed angles in the cms is demonstrated in figure 16. HADES measurements at 2.5 GeV are shown by the full squares. Lines correspond to the parameterization s^{-16} coming from the constituent counting rules (CCR) [24]. One can see good agreement of the experimental data with the CCR predictions.

The results on dp-elastic scattering are adopted by the collaboration, the paper prepared for Eur.Phys.J.A passed 1-st turn of the internal HADES review.

JINR group MWDC-II repair

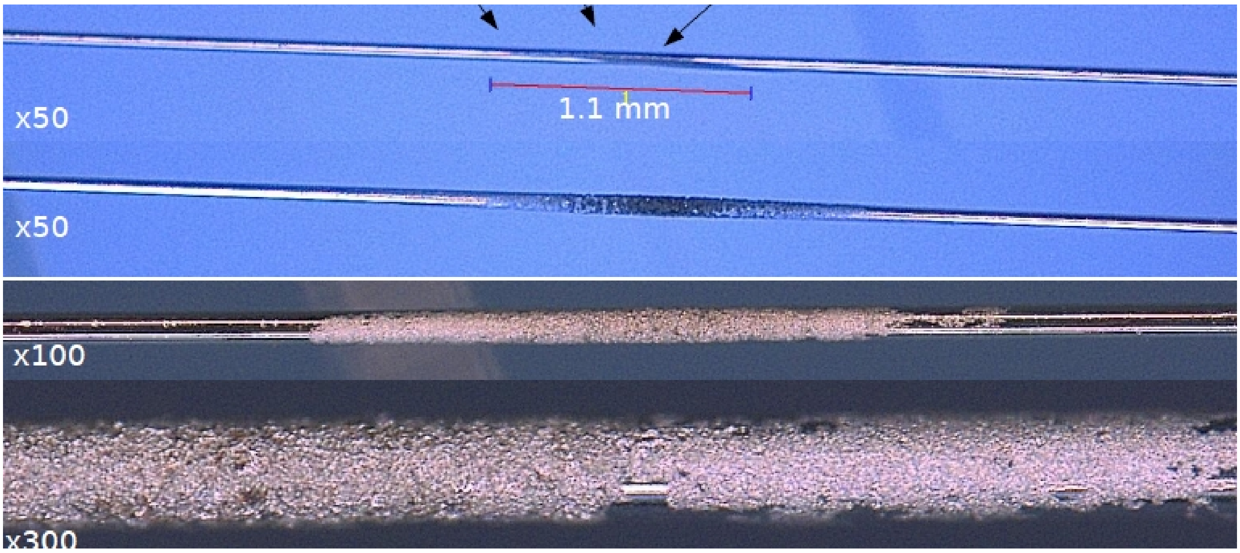

Figure **17:** Single wire plane, showing dark deposits on field wires (diameter 80μm, Al) with different magnification factors using optical microscope.

The future physics program of HADES at FAIR demands high detection standards, meanig in precision and also stability of the tracking system comprising four layersof planar drift chambers (MDC-I - IV). Unless the exposure of 18 beam-times within 15 years stable operation of the wire chambers has to be ensured for factors 2-3 higher particle load than the maximum so far.

Built in the end of 1990s the drift chambers operate started with a gas mixture of helium/isobutane (60/40) to gain the lowest material budget for the HADES detector. Later the gas was changed to Argon/isobutane (84/16) to increase the primary ionization. During the beam-time in 2012 (Au+Au reactions at Tkin = 1.23 AGeV) massive wire aging occurred, revealing in the Malter-Effect causing self sustained currents. Therefore, isobutane tending to polymerize was substituted and finally Ar/CO_2 (70/30) is used to prevent further aging in high load experiments. Since 2013 MDC II operating at high voltage of -1770 V (drift cell size 6 x 5 mm^2) and H_2O additive to recover stability. An overall stable operation was observed with theadmixture of 1000-3000 ppm water vapor to the counting gas, tested in beam and equivalent X-ray irradiation. During X-ray tests corresponding to the highest load so far a sense wire broke inside inside sector 4 of MDCII. The consequent repair offered the opportunity to microscopically investigate the reasons for stability breakdown, expected to be aging of wires since observed persistent Malter-effect points to wire deposits. The visual inspection of the drift chamber interior 13 wire planes, depicted in figure 17, revealed abundant black deposits randomly distributed on all cathode and field wires(aluminum, diameter 80 µm) providing the high voltage. Investigating the deposits material compounds by energy dispersive X -ray spectroscopy (EDX) found carbon oxide in several µm thick layers covering the wire surface. Further no sign for aging of anode wires (tungsten, diameter 20 µm) found. Cleaning all wires to remove deposits was tested manually and via solvents in an ultrasonic bath to be not successful. But operating with water vapor as gas additive turned out to be the stable solution and should also prevent further polymerization.

Figure **18:** The repairing procedure of the sector 4 of the Dubna MWDC-II at GSI.

During 2016-2018 JINR group together with GSI collegues made the following:

- -sector 4 was repaired and installed into the plane II of MWDC;
- -7-th sector was repaired and prepared as a spare for the data taking run;
- -gas mixture was optimized for the high rates;
- -X-rays tests in the HADES cave were performed to put into operation the chambers (last one was in March 2018).

The repairing procedure of the sector 4 of the Dubna MWDC-II at GSI is shown in figure 18.

JINR group software development

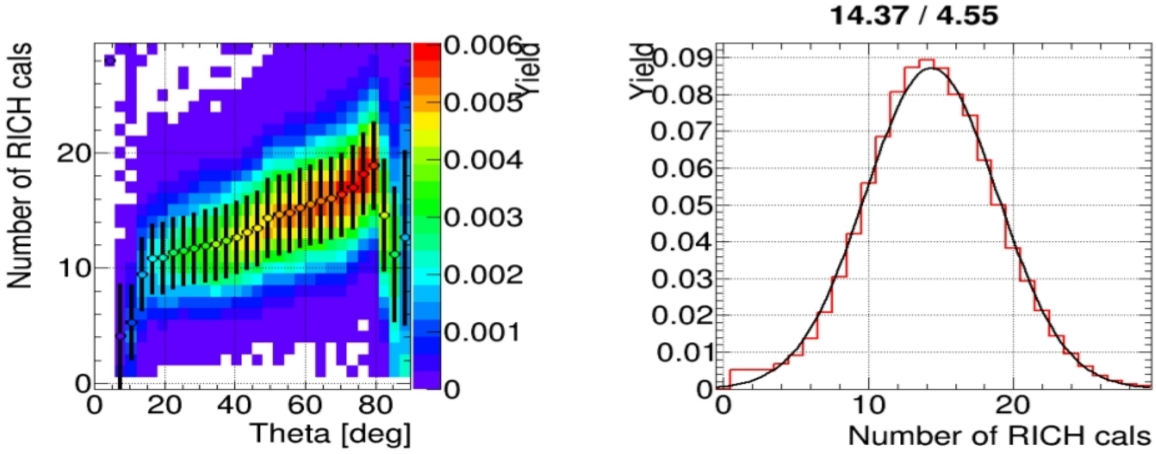

Figure **19:** Results of the cherenkov ring reconstruction in new RICH. Left panel represents the dependence of the number of the fired pixels in photodetectors as a function of the electron emission angle. The right panel show the distribution of the number of the MAPMT fired pixels per electron ring.

HADES and together with CBM collaboration constructed new RICH for the electron-positron pairs identification. The RICH detector will use 700 64-channel Hamamatsu H12700 Multi-Anode PMTs (MAPMP). A complete set of digitizing electronics, consisting of analog and digital front-end modules, power supply and data concentrator cards plugged into a backplane carrying 3×2 MAPMTs on the front side, and all readout modules on the backside was designed. In a joint effort the HADES RICH photon detector will be replaced by a subset of these MAPMTs together with a new FPGA-TDC based readout chain resulting in a significant improvement of e^+e^-- pair reconstruction efficiency for near future measurement campaigns in 2018-2020 yy.

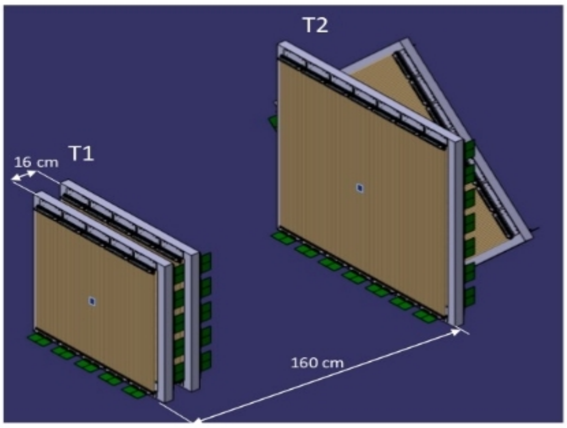

Figure **20:** Schematic view of the Forward Detector based on the PANDA straw tubes.

JINR contributes by the ring reconstruction algorithms based on the Hough transformation in new RICH. Results of the cherenkov ring reconstruction is shown in figure 19. Left panel represents the dependence of the number of the fired pixels in photodetectors as a function of the electron emission angle. The right panel show the distribution of the number of the MAPMTs fired pixels per electron ring.

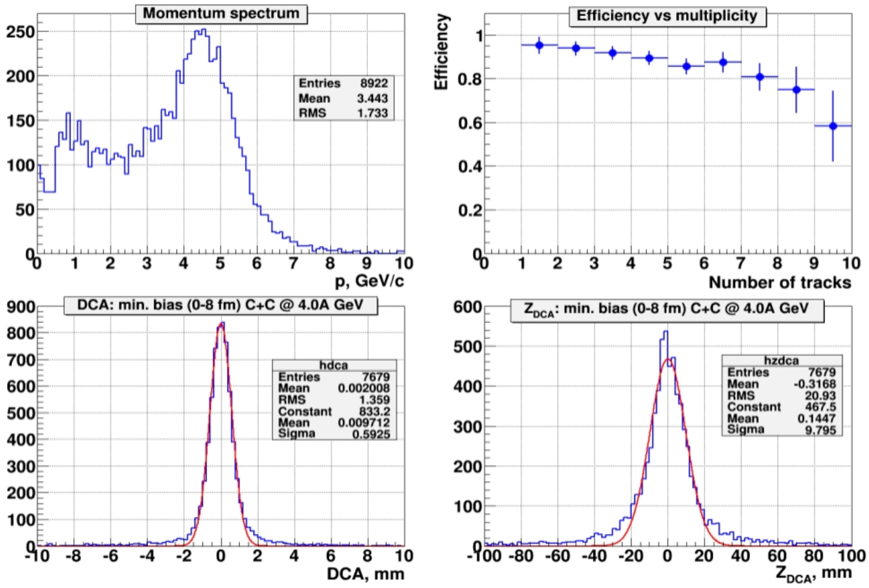

Figure **21:** The track reconstruction in HADES Forward Detector using algorithm based on the vector track finder approach.

New forward straw tracker has been proposed to increase HADES acceptance in the forward region (0.5°-6.5°) being important for some reaction channels in NN and πN collisions. Also this forward tracker can be important for the event plane reconstruction in HIC. It is based on the design of PANDA Forward Spectrometer. HADES Forward Detector consists of 4 stations schematically shown in figure 20.

JINR group develops the tracking algorithm based on the vector track finder approach. The results of the track reconstruction for C+C collisions for 4 AGeV is shown in figure 21. The algorithm demonstrates quite high efficiency even for the relatiively high track multiplicity, good primary and secondary verticies reconstruction.

Figure **22:** HADES MWDC tracking system (left) and demonstration of the track finder algorithm based on the solve of the G.Schubert problem for 4 straight lines (right).

JINR group continues to develop the track finder algorithm based on the solve of the G.Schubert problem for 4 straight lines (see figure 22). This new approach is very suitable for the wire (or strip) detectors, in particular, for HADES tracking system based on the MWDCs. Freely distributed ROOT class for this tracking approach is under development. 2 papers are in preparation.

JINR group data interpretation

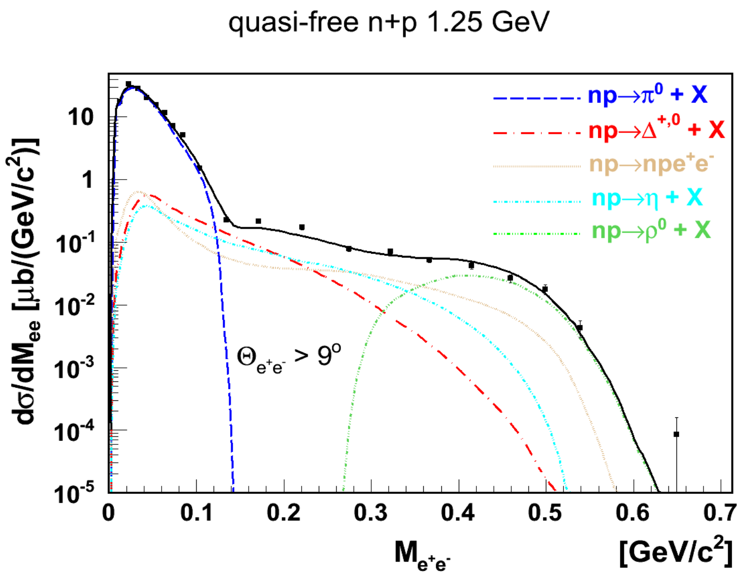

Figure **23:** The effective mass spectrum of e+e− -pairs. The black squares represent experimental data, the smooth curves result from calculations using the (OPER+OBE)- model involving the contributions of different np- channels [25].

The processes of dielectron production in deuteron-proton collisions at intermediate incident deuteron beam energies are analyzed in the spectator model within the one-pion exchange reggeized approach [25]. The investigation is focused mainly on the momentum and angle distributions of the proton-spectator and the proton emitted in quasi-free NN processes at small angles in the laboratory frame. It is shown that the inclusion of many channels in quasi-free NN interaction allows us to describe the HADES data quite satisfactorily at incident deuteron kinetic energies of about 2.5 GeV.

Dielectron production in the πN interaction at intermediate energies is studied [26]. The dominant contribution of the Δ-isobar creation in the intermediate state at incident pion momenta of about 0.3-0.4 GeV/c is shown. The experimental distributions over the angle and effective mass Me+e− of the e+e− pair are described satisfactorily. This stimulated us to present theoretical predictions for the Me+e− distribution in the process π−p→ne+e− at different incident momenta, which could be verified in HADES experiment with pion beam in 2019 y.

The self-consistent approach based on similarity of inclusive spectra of hadrons produced in pp and AA collisions has been applied to describe the pion production at HADES energies [27]. This approach allows also to describe rather well the ratio of proton to anti-proton yields in AA collisions as a function of the initial energy at a wide range from a few GeV to a few TeV. Its modification is due to the quark-gluon dynamics to describe the inclusive spectra of hadrons produced in pp collision as a function of the transverse momentum at mid-rapidity. The satisfactory description of the pion pt-spectra in pp and AA collisions within this approach is shown.

HADES at SIS100 at FAIR

The high-intensity heavy-ion beams of the future FAIR accelerators offer excellent possibilities to produce and to investigate baryonic matter at highest densities in the laboratory. The research program comprises the study of the structure and the equation-of-state of baryonic matter at densities comparable to the ones in the inner core of neutron stars. This includes the search for the phase boundary between hadronic and partonic matter, the critical endpoint, and the search for signatures for the onset of chiral symmetry restoration at high net-baryon densities. HADES at SIS100 will be a part of the Compressed Baryionic Matter experiment. The FAIR accelerators deliver proton beams up to an energy of 90 GeV which permits investigations of elementary processes like charm production in an energy range where no data exist. Nuclear reactions in the energy range from 2 to 10 GeV/nucleon will be studied with an upgrade of the HADES spectrometer, which is currently being operated at the GSI SIS-8 accelerator. The HADES spectrometer will be placed upstream of the CBM setup in one cave (see figure 24).

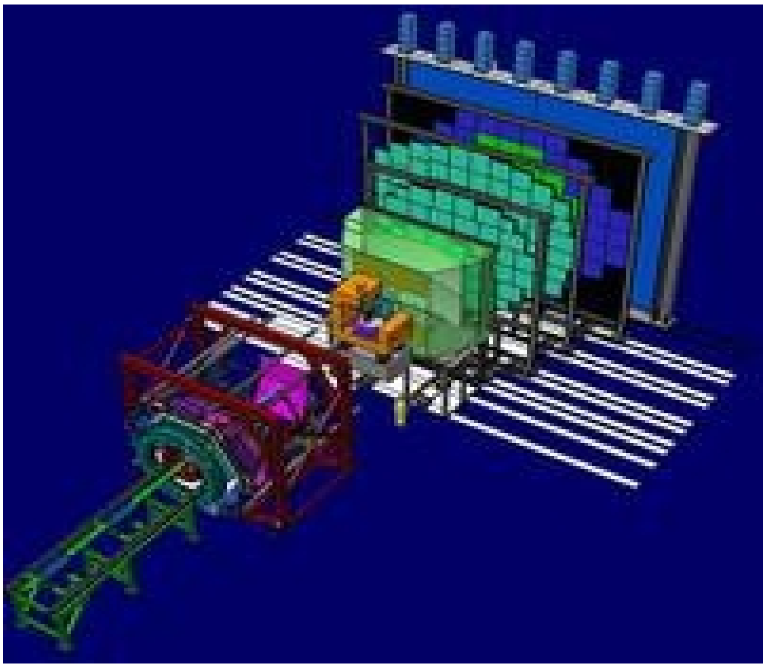

Figure **24:** The schematic view of HADES and CBM installed at one cave for the experiments at SIS100.

The physics with HADES at SIS100 is widely discussed. Due to tracking system based on the use of MWDCs HADES can work only for the Ni+Ni collisions at 14 AGeV. Nowadays the modification of HADES is going on both for the data taking compains in 2017-2018 at SIS18 and for SIS100 in future. The RICH and MWDCs will be upgraded. Electromagnetic Calorimeter wll be put into operation. The JINR physicists are participating in the MWDC upgrade project, software development and in the preparation of the physics program for HADES/CBM at SIS100.

Publications, presentations at the conferences

The main HADES results obtained in 2015-2018 yy were published (or accepted for publication) in regular journals [19-20], [22-23], [25-37] and as JINR Communication [38] (6 publications with JINR principal authors).

HADES results were reported at the international conferences [39-45] (4 speakers from JINR). JINR peoples made 15 presentations at HADES collaboration meetings in 2015-20018 yy. [46-60].

Plans and request for 2019-2020

The main direction of HADES activity in 2019-2020 is the data taking at SIS18 using pion and proton beams. The program of πA run planned in 2019 is to study strangeness and baryonic resonances production. Collaboration is planning to obtain new data in 2020-2021 in the p+A (p+p) reactions at 4.5 GeV to study multistrange baryons production and cold matter features. The JINR group will participate in the preparation and technical support during beam time of the plane 2 of MWDCs, the software support during data taking and DST production.

JINR group is planning to take a part in the analysis of the Ag+Ag data, which will be obtained at 1.76 AGeV in 2018 . The major goal is to study di-electron and hadronic observables of the dense matter. Also the JINR group is traditionally involved in the studies of the hadronic probes, especially, in elementary reactions. The physics includes multi-pion production in different reactions and their azimuthal correlations. Also the theoretical interpretation of HADES data will be continued.

The third direction is the JINR participation in HADES upgrade program and physics simulation for SIS100 at FAIR. JINR team is participating in MWDC-II upgrade program and software development for tracking in MWDC and Forward Detector, RICH.

The activity of JINR group in HADES is performed within MoU between GSI and JINR (see Appendix A). HADES MoU is also signed for 2018-2023 yy. Activity has been supported in 2015-2017 yy. by BMBF-JINR grant 25 kEuro/year). The request for 2018-2020 yy. is also about 25 kEuro/year within BMBF-JINR grant (see Appendix B).

Summary

JINR participants of the HADES project are working on mainteinance of Multiwire Drift Chambers with assosiated FEE before and during beamtime. Significant work has been done to put into operation 4-th sector of MWDC-II in 2016-2018 yy.

Main activity on the HADES project in 2019-2021 is the participation in in data taking at SIS18 for πA and pA collisions; the participation in the data analysis, simulation and theoretical interpretation for different reaction channels in Ag+Ag, NN, πA and pA collisions at 1.25-3.5 A GeV.

JINR team is participating in the HADES upgrade and physics program for SIS100. HADES heavy ion program at SIS18 with Au-Au at 1.23 A GeV and Ag+Ag at 1.65 A GeV can have a serious impact on the physics program of BM@N and MPD as well.

Participation in the HADES project help us to build new infrastructure for detectors construction (DetLab in blg.40), where the new detectors for MPD/NICA are under development.

The «HADES:JINR participation» was supported by grant of BMBF/JINR in 2015-2017 yy. New application for the period 2018-2020 yy has been submitted.

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Appendix A.

MoU between GSI and JINR

MEMORANDUM OF UNDERSTANDING

for Cooperation in the Investigation of Hot and Dense Baryonic Matter
and in the Development of the GSI and JINR Accelerator Facilities

between

GESELLSCHAFT FÜR SCHWERIONENFORSCHUNG mbH,
hereinafter referred to as GSI, Darmstadt

and

JOINT INSTITUTE FOR NUCLEAR RESEARCH,
hereinafter referred to as JINR, Dubna

May 2008

2.1. construction of pulsed ion source and in other areas of accelerator physics and technology is foreseen as well.

2.2. Cooperation in the design, calculation and fabrication of CBM, PANDA, MPD and SPD spectrometer magnets.

2.3. Continuation of the R&D work and further participation in the construction of both the CBM and PANDA set-ups for FAIR, and MPD and SPD for NICA as well. In particular, collaboration in the development of the inner and outer trackers and time-of-flight system.

2.4. Further participation at the HADES experimental program at SIS-18 and SIS-100.

2.5. Collaboration in the development of the shared software packages, in particular, for the Simulation, Reconstruction and Data Analysis in the frameworks of FAIRRoot and NICARoot as well as the development of different types of event generators.

2.6. Promotion of outstanding opportunities for excellent students and young researchers in both theory and experiment from JINR and GSI collaborating laboratories. The parties shall concentrate their efforts to attract young physicists and engineers for realization of the FAIR and NICA/MPD projects including their active participation in international graduate schools and young scientists meetings.

III. IMPLEMENTATION

3.1. Specific projects to be performed under this MoU shall be covered by the Working Agreements or Contracts to be negotiated and replaced as needed. These documents shall be developed by GSI and JINR and shall be considered as addenda to the present MoU. Such documents will address the scope of work for each project, responsibilities of each party, financial arrangements and any particular provisions or conditions that may not be covered or may be different from what is contained in the present MoU.

Appendix B.

Cost estimation for HADES project (JINR participation)

NN	Name expenses	Total cost (kEuro)*	2019 y.	2020 y .	2021 y.
	Direct expenses for the project:				
1	Nuclotron, hours.				
3	Computer link				
4	Laboratory design division, hours				
5	JINR workshops, norm-hours				
6	Materials	21	7	7	7
7	Equipment	18	6	6	6
8	Travelling expenses	36	12	12	12
	a) in countries not ruble zone	36	12	12	12
	b) In the countries of the ruble zone				
	c) on protocols				
	Total direct expenses	75	25	25	25

* from BMBF-JINR grant