T71989 OTKA Report

The main aim of this OTKA project was to prepare ourselves experimentally and theoretically for the experiments in FAIR. Because of the internationalization of FAIR, its building phase has shifted by about 5 years. The predicted start of the experiments are about 2017. This also shifted the completing of the CBM detector also to around 2018. Therefore here we can present mainly results only on its precursor experiment NA61/SHINE which is located in CERN at SPS accelerator and FOPI at GSI.

NA61

NA61 is still in the preparatory phase therefore the scientific results are just starting to coming.

One of the most striking features observed at BNL-RHIC was the suppression of high p_T production in central A+A collisions relative to peripheral A+A or p+A or p+p collisions, whose ratios are denoted by R_{CP}, $R_{A+A/p+p}$ and $R_{A+A/p+A}$, respectively. This is generally interpreted as a sign of parton energy loss in hot and dense strongly interacting matter created at the early stage of nucleus-nucleus collisions. This interpretation implies that the suppression should decrease towards lower energies where the initial energy and parton density are expected to be much smaller

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Numerous results on the energy dependence of hadron yields and spectra indicate that the onset of deconfinement may be located at SPS energies. Existing data on central and peripheral Pb+Pb collision at 158 GeV/nucleon from the NA49 experiment allow measurement of the ratio R_{CP} up to about 3.5 GeV/c in transverse momentum. The NA49 experiment, however, has only limited statistics on p+p and p+Pb collision data at top ion-SPS energy. Therefore, future data runs were planned which were successfully collected and their analysis was started. The proposed FAIR-CBM high luminosity experiment has also a great potential in this field, as it will be able to populate the momentum space up to the kinematic limit. In order to exploit the unique possibilities of the high luminosity CBM a completely new trigger system was presented by us at CHEP'09 conference in Prague [1]. Special attention was given to the FAIR-CBM experiment as a unique high luminosity facility for future continuation of the measurements at very high p_T with emphasis on the so-called mosaic trigger system to use the highly parallel on-line algorithm.

The second item where the NA61 experiment plays a pioneering role is the working out of the prototype of the zero degree calorimeter PSD. This calorimeter is designed for measurements of energy of projectile spectators in nucleus-nucleus interactions and for the determination of the centrality of interactions. The calorimeter consists of 44 independent modules with the longitudinal segmentation. Each sandwich type module comprises 60 lead scintillator layers with the thickness satisfying the compensation condition. The light readout from scintillators is performed by the WLS fibers viewed by the micropixel avalanche photodiodes. The obtained energy resolution $\sigma(E)/E \approx 55\,\% / \sqrt{E\,(\mathrm{GeV})}$ is in good agreement with the simulation results. Examples of its application to data analysis are given. The Budapest contribution to PSD was essential, though the detector part was produced by Russian colleagues the read-out hardware system, the on-line read-out and calibration were made by Hungarian collaborators. Article is submitted to Russian journal PTE (Pribori i tehnika eksperimentov) [2].

The first experimental results on pA interactions in NA61/SHINE experiment were presented in connection with the T2K neutrino experiment at 30 GeV on Carbon target which can be regarded as test-run for CBM at moderate luminosity. The T2K long-baseline neutrino oscillation experiment in Japan needs precise predictions of the initial neutrino flux. The highest precision can be reached based on detailed measurements of hadron emission from the same target as used by T2K exposed to a proton beam of the same kinetic energy of 30 GeV. The corresponding data were recorded in 2007-2010 by the NA61/SHINE experiment at the CERN SPS using a replica of the T2K graphite target. In [3] details of the experiment, data taking, data analysis method and results from the 2007 pilot run are presented.

FOPI

The investigations of EOS in heavy-ion reactions, carried out in the frame of the FOPI Collaboration at GSI/Darmstadt, have been concentrated on the in-medium production and properties of strange particles in the (sub)threshold region. In the actual period three types of experiments were carried out by the Collaboration.

We measured the Ni+Ni, Ni+Pb and the Ru+Ru collisions in the energy range 1.5-1.9 A*GeV with the upgraded FOPI setup. The detector system was extended with a high-resolution RPC barrel, and with a new DAQ system, ensuring a high-statistics data collection. Such reactions provide the unique possibility to study the nuclear matter at hight temperatures around 100 MeV and baryon densities about 2-3 times the normal nuclear matter densities. The special aim was to measure simultaneously K+ and K- mesons, in particular their azimuthal emission patterns, close to the threshold, and to compare the data to state-of-the-art transport calculations with and without the assumption of an in-medium potential. The results of this comparison demonstrate the different propagation patterns of K+ and K- mesons inside the compressed and heated nuclear medium and favour the existence of a KN potential, repulsive for K+ and attractive for K-. One has to note, that the theoretical models do not give a satisfactory description of all observed phenomena. Nevertheless, the observed dependencies and sensitivities point to the feasibility to extract the strength of the in-medium potentials from a complete set of flow data [4],[5].

Investigation of pi- A collisions around the strangeness production threshold. It is assumed, that strange particles are produced in heavy-ion reactions predominantly via pions in the intermediate state. To understand this elementary process we carried out experiments on the pi- induced strangeness production on different target nuclei from C to Pb at a pion momentum of 1.15 GeV/c. The aim was first, to decide whether the reaction occurs mainly on the surface, or in the interior of the nuclei. The more important point was to see the possible existence of a KN potential in this low density nuclear medium (normal nuclear matter density). The analysis of the data has shown, that the momentum distribution of the K0 mesons depends significantly on the target mass, and the interpretation was consistent with the existence of a KN potential of about 20 MeV [6]. These predictions do not give, however, a good description for the simultaneously measured K+ data.

Theory

In the theoretical side our main aim was to construct a transport code which can be applied to higher energies, at CBM and at PANDA. Since the experiments will start much later, finishing the transport code was not so urgent, however, finally we achieved this goal. We built in the Pythia package in the code used at lower energies. We wrote an interface connecting our model with Pythia. We refitted the parameters of the model to the experimental data. We are just applying this model to antiproton-proton and antiproton-nucleus collisions at PANDA energies. Our main work in this project was, however, to study hadrons in vacuum and in matter, to find signals for chiral restoration, building a model which can be used later on to study the phase diagram of the strongly interacting matter, or other medium effects, like kaon in matter: kaon-nuclear potential which can be relevant for the FOPI experiment and also for neutron star properties.

Transport

We had a transport model of BUU type developed for low energies[7]. We have considered the propagation of broad resonances within a kinetic theory (transport) approach to heavy-ion collisions [8,9]. Vector mesons are described by spectral functions and these are evolved in space and time by a testparticle method. The corresponding experiments are aimed at seeking for imprints of chiral symmetry restoration as particular aspect of in-medium modifications of hadrons. This lets us focus on the treatment of ρ and ω mesons. We have utilized here transport equations which are approximations of the much more involved Kadanoff-Baym equations. Compared to an approach wherein the spectral function is frozen in after creation the present framework let the spectral functions evolve towards the vacuum spectral functions. Therefore, the in-medium modifications are washed out in particular for the ω meson. In contrast to earlier expectations the ω peak does not suffer a significant modification, even when assuming a strong shift of the peak position in line with the experiments.

We apply our transport code to analyze the new experimental data of inclusive $K\pm$ and φ production in the reaction Ar (1.756 AGeV) + Kcl [10]. With a given parameter set (in-medium masses parametrizing the influence of the ambient baryon medium on spectral properties of hadrons, mean field, equation of state, and individual cross sections) the available data are well described and the good agreement with previous data for the reaction Ni (1.93 AGeV) + Ni is ensured. The question is arisen how important is the feeding from φ decays for the K^- yield. While the astonishingly large ratio of φ/K^- is reproduced within error bars, the decay channel $\varphi \rightarrow K+K-$ is nevertheless subleading for K- production.

Dileptons are among the most important signals studied in heavy ion collision experiments. Due to the high complexity of nuclear collision processes, the experimental results can be interpreted only via comparison with model calculations. Transport models need the cross sections of elementary hadronic collisions as input, therefore a good understanding of the elementary cross sections is essential. We have developed an effective field theoretical model to calculate the $\pi N \rightarrow Ne+e-$ cross section[11]. We constructed an effective Lagrangian including nucleons (N), all 16 3- or 4-star resonances below 2 GeV, π, γ and ρ via (VMD). We add form factors at each vertex for any hadron line (which equals 1 for on-shell hadrons). To achieve gauge invariance we have generalized the method for calculation of photo-production of pions by Davidson-Workman to direct production of massive photons and to production through ρ. The NNπ and ππρ couplings are well-known, the rest of the couplings can be derived by taking the γ and ρ as gauge fields except the resonance couplings, where the RNπ and RNρ coupling constants were determined by the appropriate partial width of R, while the RNγ couplings were fitted to the pion photoproduction data. For dilepton production we obtained that below 1.5 GeV the invariant mass spectra monotonically decreasing, above it the rho-form factor create a peak at high masses. The spectrum is dominated by the Born-term, but the N(1680) and N(1520) and their interference terms are sizable, too. This work appeared as an editor's special suggestion in Phys. Rev. C

Chiral symmetry, Linear Sigma model

At CBM, a very active field of research will be the understanding of the chiral phase transition of the strong interaction. In order to investigate the chiral phase transition at finite temperature and densities

in the framework of some model a crucial step is to establish its zero temperature properties.
In this period we investigated the properties of the lowest energy part of the meson sector – below approximately 2 GeV – of the strong interaction at zero temperature from phenomenological point of view. The considered particles can be divided into four groups, namely the pseudoscalars (π (pion), K (kaon), η, η'), the scalars (a_0, K_0^*, 2 f_0's) the vectors (ρ, K^*, ω, Φ) and the axialvectors (a_1, K_1, 2 f_1's). Since at low energies the fundamental theory of strong interaction, the QCD, is very hard to solve, we used an effective model – the (axial-)vector extended linear sigma model (ELSM) –, which share the same global symmetry properties as the fundamental theory, but it is much easier to solve. In the ELSM the particles are $q\bar{q}$ states and are arranged – due to their transformation properties under chiral transformation – into nonets (each above mentioned group corresponds to a nonet). However, if the experimental data are considered, it can be found that in the scalar sector there are more particles than we can describe with a single nonet, namely there are two a_0's (a_0(980) and a_0(1450)), two K_0^*'s (K_0^*(800) and K_0^*(1430)) and five f_0's (f_0(500), f_0(980), f_0(1370), f_0(1500) and f_0(1710)) below the 2 GeV limit. The question naturally emerge that which particles belong to the scalar nonet. In the published works presented briefly below we managed to give answer – among others – to this question.
In the first three papers [12,13,14] we presented the explicit form of the model, addressed the above mentioned scalar nonet problem, presented the three-level masses given by the spontaneous symmetry breaking, and discussed technical difficulties of particle mixing within and among the different meson sectors. In the following work [15] beside the tree-level particle masses we calculated various decay widths of the (axial-)vector and scalar particles. With the help of the experimental values – taken from the PDG – through a χ^2 minimalization process we managed to determine the parameters of the Lagrangian. The minimalization process amounts in that we choose a parameter set in such a way that the deviation of the calculated physical masses and decay widths from their experimental values be within their experimental errors. As a first step we only investigated the (a_0, K_0^*) pairs and found that the lowest χ^2 is given by the (a_0(1450), K_0^*(1430)) combination. In other words, according to our analysis the scalar $q\bar{q}$ a_0 and K_0^* particles can be assigned to the physical a_0(1450) and K_0^*(1430), respectively. Concerning on the f_0's, through another χ^2 minimalization with the fixed (a_0(1450), K_0^*(1430)) combination, we concluded after a thorough analysis [15] that both f_0 masses lie above 1 GeV, and can be assigned to the physical states f_0(1370) and f_0(1710). In general we can say that the obtained parameter set describe all the experimental data very well. In the [16, 17, 18, 19, 20] works we discuss some consequences/aspects of the above solution, like the η - η' mixing and the $U(1)_A$ anomaly term.

Another aspect of the chiral symmetry is the breaking of the $U(1)_A$ symmetry, which may show up in the η' mass. The $U(1)_A$ symmetry breaking is an operator relation that remains valid even when the spontaneously broken chiral symmetry is restored. However, whether its effect on the η' mass survives even when chiral symmetry is restored is a phenomenological question that has caught the interest of many researchers. The question has recently been revived as the RHIC data on two pion
Bose-Einstein correlation at 200 GeV/u Au+Au collision seems to suggest the quenching of the η' mass in medium. Its partial quenching in nuclear medium is also of great interest as such effects could be probed in finer detail in nuclear target experiments. Our analysis [21,22] which is based on a generalization of the Witten -Veneziano theorem for high temperatures and densities suggest that η' mass is decreasing in matter. It should be noted that the η' mass that is being quenched is the part of the mass that comes from the breaking of the $U(1)_A$ symmetry.

NΔπ system

We developed a fully covariant self-consistent model [23] for pion and isobar dressing in cold nuclear medium which takes into account nucleon and isobar short-range correlations through Migdal fourfermion interaction. Binding effects of the nucleon are included through mean-field mass and energy shifts. The obtained pion spectral function shows the expected broadening but not the softening present in less detailed models. Using the above model we calculated the photoabsorption on large nuclei in the isobar region including not only the s-channel isobar exchange but also background contributions stemming from u-channel nucleon exchange and t-channel pion exchange. Good agreement with measured cross-section is achieved after reducing the strength of the $\pi N\Delta$ coupling by 15% at saturation density compared to the vacuum value [24].

We investigated effects of consistent and inconsistent (in the sense of preserving or not preserving the number of degrees of freedom) $\pi N\Delta$ couplings in vacuum and nuclear medium [25]. Using a convenient basis which allows for relativistically covariant full treatment of the isobar self energy and propagator we showed that the seeming disadvantage of the consistent coupling coming from its higher derivative order can be simply compensated by a suitably chosen form-factor after which the effects of the two types of couplings on physical observables are practically indistinguishable, at least for nuclear densities not exceeding significantly the saturation density. The consistent coupling has the property of leading to simpler expressions for the isobar selfenergy in the mentioned complete basis.

Motivated by recent Fermilab proposals to measure nuclear parton distributions with high precision and in particular the antiquark distributions through Drell-Yan process we performed a study of the nuclear antiquark distributions taking into account the binding and Fermi motion as well as the modification of the pion cloud of bound nucleons [26]. Based on a recently developed model [23] we computed the medium change of the pion cloud of the physical nucleon by taking into account virtual transitions into bare nucleon and pion as well as isobar and pion states. The medium effect on the isobar turned out very important leading to significant enhancement of the pion cloud while the Pauli blocking of the transition containing the nucleon in the final state led to some suppression. The net effect is a modest enhancement of the nuclear Drell-Yan ratio per nucleon [26].

Kaons in matter

In the past few years we have studied the interaction of antikaons with the lightest nuclei. Due to the assumed attraction between the anti-kaon and the nucleon one can expect the formation of nuclear clusters with nonzero strangeness. The basic input in any theoretical work in this field of strangeness nuclear physics is a reliable model of antikaon nucleon interaction. Thus our work started by designing phenomenological KbarN potentials, with special emphasis on the disputed one- or two-pole structure of the $\Lambda(1405)$ resonance. Correspondingly, we have constructed two versions of the two-channel Kbar N - $\pi\ \Sigma$ potentials, which reproduce all the existing experimental data, with the inclusion of isospin breaking effects through physical masses and Coulomb interaction. Our main conclusion was, that the available two-body experimental data do not allow a clear distinction between these possibilities, both versions are equally able to reproduce the data. The potentials are suitable for further few-body calculations.

The next subject was an investigation of the experimental observability of the $\Lambda(1405)$ resonance. Since it lies below the KbarN threshold and decays into the $\pi\Sigma$ channel, it can not be observed in two-body reactions with stable particles. It can be seen only as part of the final state in reactions involving 3 or more particles. The simplest of these is the $K^- + d \rightarrow \pi + \Sigma + n$ reaction, in which for a fixed incident kaon energy the neutron spectra - in principle - could show the shape of the $\Lambda(1405)$ resonance. The advantage of this reaction is, that its dynamics can be exactly described by Faddeev equations. We have performed the first Faddeev break-up calculation for this system, using the potentials, obtained in the previous work. The calculations were performed for relatively low energies

(P(lab) ~ 0-250 MeV/c) of the incident kaon and the results are not too encouraging. In the direct neutron spectra the kinematical effects mask completely the $\Lambda(1405)$ shape, while the somewhat artificial - deviation spectrum method can reveal some trace of the resonance, however, it is not clear how to relate the obtained shapes to the (two-body) resonance parameters.

References

1) A. Fulop, G. Vesztergombi: *Highly parallel algorithm for high p_T physics at FAIR-CBM,* J. Phys.: Conf. Ser. 219 (2009) 022032

2) O. Busygina, et al. (Gy. Vesztergombi, Z. Fodor): *Forward hadron calorimeter of the NA61/SHINE experiment at the CERN SPS,* submitted to Russian journal PTE (Pribori i tehnika eksperimentov)

3) N. Abgrall, et al. (Gy. Vesztergombi, Z. Fodor): *Pion emission from the T2K replica target:method, results and application,* Nucl. Instrum. Meth. A701 (2013) 99-114

4) FOPI Collaboration (M. L. Benabderrahmane et al., J. Kecskemeti, Z. Fodor): *Measurement of the in-medium K0 inclusive cross section in pi-induced reactions at 1.15 GeV/c,* Phys.Rev.Lett. 102 (2009) 182501

5) FOPI Collaboration (X. Lopez et al. J. Kecskeméti, Z. Fodor): *Measurement of K*(892) and K0 mesons in Al+Al collisions at 1.9 AgeV,* Phys.Rev. C81 (2010) 061902

6) FOPI Collaboration *Azimuthal Emission Patterns of K+ and of K- Mesons in Ni + Ni Collisions near the Strangeness Production Threshold,* (sent to ?)

7) Gy. Wolf, W. Cassing, U. Mosel: *Eta an Dilepton Production in Heavy-Ion Reactions*, Nucl. Phys. A552 (1993) 549

8) H.W. Barz, B. Kampfer, Gy. Wolf, M. Zetenyi: *Propagation of broad meson resonances in a BUU type transport model: Application to di-electron production*, The Open Nuclear and Particle Physics Journal 3 (2010) 1-15

9) Gy. Wolf, B. Kampfer, M. Zetenyi: *Propagation of Spectral Functions and Dilepton production at SIS Energies*, Physics of Atomic Nuclei, 2012. 75. 768

10) H. Schade, Gy. Wolf, B. Kampfer: *Role of phi decays for K-yields in relativistic heavy-ion collisions*, Phys. Rev. C81:034902 (2010)

11) M. Zetenyi, Gy. Wolf: *Dilepton production in pion--nucleon collisions in an effective field theory approach*, Phys. Rev. C86 (2012) 065209

12) D. Parganlija, F. Giacosa, D. H. Rischke, P. Kovacs and Gy. Wolf: *A Linear Sigma Model with Three Flavors and Vector and Axial-Vector Mesons,* Int. J. Mod. Phys. A **26** (2011) 607

13) D. Parganlija, F. Giacosa, P. Kovacs and Gy. Wolf: *Masses of Axial-Vector Resonances in a Linear Sigma Model with Nf=3,* AIP Conf. Proc. **1343** (2011) 328

14) P. Kovacs, Gy. Wolf, F. Giacosa and D. Parganlija: *Zero temperature properties of mesons in a*

vector meson extended linear sigma model, EPJ Web Conf. **13** (2011) 02006

15) D. Parganlija, P. Kovacs, Gy. Wolf, F. Giacosa and D. H. Rischke: *Meson vacuum phenomenology in a three-flavor linear sigma model with (axial-)vector mesons*, *Phys. Rev. D* **87** (2013) 014011

16) D. Parganlija, P. Kovacs, Gy. Wolf, F. Giacosa and D. H. Rischke: *Phenomenology of Axial-Vector Mesons from an Extended Linear Sigma Model*, Acta Phys. Polon. Supp. **5** (2012) 1109

17) D. Parganlija, P. Kovacs, Gy. Wolf, F. Giacosa and D. H. Rischke: *Scalar mesons in a linear sigma model with (axial-)vector mesons*, AIP Conf. Proc. **1520** (2013) 226

18) F. Giacosa, D. Parganlija, P. Kovacs and Gy. Wolf: *Phenomenology of light mesons within a chiral approach*, EPJ Web Conf. **37** (2012) 08006

19) D. Parganlija, P. Kovacs, Gy. Wolf, F. Giacosa and D. H. Rischke: η, η′ *and eLSM*, PoS ConfinementX (2012) 117

20) P. Kovacs and Gy. Wolf, *Meson vacuum phenomenology in a three-flavor linear sigma model with (axial-)vector mesons:investigation of the U(1)_A anomaly term*, arXiv:1304.5362 [hep-ph]

21) Youngshin Kwon, Su Houng Lee, Kenji Morita, Gy. Wolf: *A renewed look at η′ in medium*
Phys. Rev. D86 (2012) 034014

22) Youngshin Kwon, Su Houng Lee, Gy. Wolf: *In-medium η′ mass reduction*, Few Body Syst. 54 (2013) 509-5128)

23) C.L. Korpa, M.F.M. Lutz, F. Riek: *Covariant and self consistent vertex corrections for pions and isobars in nuclear matter*, Phys. Rev. C80 (2009) 024901

24) F. Riek, M.F.M. Lutz, C.L. Korpa: *Photoabsorption off nuclei with selfconsistent vertex corrections*, Phys. Rev. C80 (2009) 024902

25) C.L. Korpa: *Effects of consistent and inconsistent isobar coupling in the nuclear medium*,
Phys. Rev. C85 (2012) 014601

26) C.L. Korpa, A.E.L. Dieperink: *Nuclear Drell-Yan effect in a covariant model*,
Phys.Rev. C87 (2013) 014616

27) J.Révai, N. V. Shevchenko: *Isospin mixing effects in the low-energy Kbar N − π Σ interaction*,
Phys.Rev. C79(2009) 035202

28) J. Révai: *Coupled-channels Faddeev equations for the* K^{-} + *d break-up reaction and the shape of the Λ(1405) resonance*, Few-Body Syst. 50 (2011) 339

29) J. Révai: *Neutron spectra from the low-energy* K^{-} + *d* → *π* + *Σ* + *n reaction and the shape of the Λ(1405) resonance*, Hyperfine Interact. 210 (2012) 103

30) J. Révai: *Signature of the Λ(1405) resonance in neutron spectra from the* K^{-} + *d reaction*,
Few-Body Systems, DOI 10.1007/s00601-013-619-z