Experimental results on the synthesis and study of the properties of isotopes of elements Cn, Fl and Mc at the SHE Factory

Dastan Ibadullayev[1,2*],Vladimir Utyonkov[1*],Oganessian Utyonkov[1*]

1. Flerov Laboratory of Nuclear Reactions,Join Institute for Nuclear Research,Dubna,Moscow region,Russia

2. Department of Nuclear Physics,Eurasian National University,Astana,Astana,Kazakhstan

* ibadullayev@jinr.ru,Utyonkov@jinr.ru,Oganessian@jinr.ru

Abstract: This work presents the results of the experiments performed at the FLNR, JINR Superheavy Element Factory (SHE Factory). The experiments were carried out on the basis of the new cyclotron DC-280 with an intensity of accelerated particles of up to 6.5 pμA and gas filled separator DGFRS-2 and were aimed at study of the ^{243}Am + ^{48}Ca, ^{242}Pu+^{48}Ca and ^{238}U+^{48}Ca reactions. The main goal of this experiments consisted in determining the capabilities of the SHE Factory for the production and study of new isotopes of known superheavy elements up to Og (Z=118), as well as the synthesis of new ones with Z>118. In the first experiments Fifty-five new decay chains of ^{288}Mc and six chains assigned to ^{289}Mc were detected. The α decay of ^{268}Db with an energy of 7.6–8.0 MeV, half-life of ~16^{+6}_{-4} h, and a branch of ~55^{+20}_{-15}% was registered for the first time, and a new spontaneously fissioning isotope ^{264}Lr with a half-life of $4.9^{-2.1}_{-1.3}$h was identified. The cross section for the ^{243}Am(^{48}Ca, 3n) ^{288}Mc reaction was measured to be $17.1^{+6.3}_{-4.7}$ pb, which is the largest value for the known superheavy nuclei at the island of stability. The new isotope ^{286}Mc was synthesized, and its half-life of 20^{+98}_{-9} ms and α-particle energy of 10.71 ± 0.02 MeV were determined. The decay properties of ^{286}Fl and ^{287}Fl, as well as their α-decay products, have been updated from 25 and 69 new decay chains, respectively. Additionally, 16 decay chains of ^{283}Cn were observed in the ^{238}U+^{48}Ca reaction. During the experiment, the maximum intensity of the ^{48}Ca ion beam was 6.5 pμA. The stability of the target was measured at such high intensities. Possibility of existing of isomeric states in the ^{287}Fl consecutive α decays is discussed. A new α line with energy of 100-200 keV lower than the main one at 10.19 MeV was observed for the first time for even-even ^{286}Fl. The maximum cross section of $10.4^{+3.5}_{-2.1}$ pb was measured for the ^{242}Pu(^{48}Ca,3n)^{287}Fl reaction.

Keywords: gas-filled separator;superheavy element factory;cross section;isotope;island of stability;decay chain;target;isomeric states.

Some experimental R&D progress for decay measurement of exotic clustering structure

XiGuang Cao[1,2]

1. SSRF,Shanghai Advanced Research Institute, Chinese Academy of Sciences,Shanghai,Shanghai,China

2. SSRF,(2. Shanghai Institute of Applied Physics, Chinese Academy of Sciences,Shanghai,Shanghai,China

Abstract: Based on the detailed analysis of multi-alpha decay from the excited light nuclei, a new compact and robust detector array with glued 5×5 CsI array coupled with SiPM array as readout device for coincident measurement of charged particles was designed and constructed. We develop a novel highly integrated preamplifier with charge and current sensitive dual readout for the charged detectors, which will greatly improve the PID in photonuclear reaction and heavy-ion collisions. The intelligent algorithms have been applied to identify the fragments emitted from heavy-ion collisions by training identification models with different strategies. The potential applications of these progresses to study the exotic clustering structure are presented.

Keywords: Cluster decay;Telescope array;SiPM;Preamplifier;Machine learning;Particle identification

Multi-modal fission in 176,186Pt formed in fusion of 32S + 144,154Sm

Hairui Duan[1],Chengjian Lin[1*],Huiming Jia[1*]

1. China Institute of Atomic Energy,China Institute of Atomic Energy,BeiJing,BeiJing,China

* cjlin@ciae.ac.cn,jiahm@ciae.ac.cn

Abstract: The observation of unexpected mass-asymmetric fission in neutron-deficient 180Hg dramatically expanded the region of mass-asymmetric fission across the nuclide chart, and has led to intense experimental and theoretical investigations in the fission of sub-lead nuclei. The fission modes and shells which dictate these modes in sub-lead nuclides are still unresolved issues. In order to further study the fission modes of sub-lead nuclei at the near-barrier energy region, new high-statistical data of the fragments in fusion fission of 32S + 144,154Sm have been correlated measured in the near-barrier energy region using the CUBE fission spectrometer at The Australian National University. The fission modes of 176,186Pt at higher excitaiton energy have been analyzed based on the mass distribution.

In this talk, I will present some preliminary results of extracting the mass distribution by the dual-velocity method, fitting the mass distribution, and analyzing the fission modes. The results show that there are two fission modes in 176Pt and 186Pt, symmetrical and asymmetric. This study gvies a further support for the proton shell at ZL~35 of fission fragments.

Keywords: Multi-modal fission modes;mass distribution;shell effect

[1] A. N. Andreyev, et al. New Type of Asymmetric Fission in Proton-Rich Nuclei[J]. Physical Review Letters, 2010, 252502.

[2] E. Prasad, et al. Observation of mass-asymmetric fission of mercury nuclei in heavy ion fusion[J]. Phys. Rev. C 91, 064605 (2015).

[3] B.M.A.Swinton-Bland, et al. Multi-modal mass-asymmetric fission of 178Pt from simultaneous mass-kinetic energy fitting[J]. Physics Letters B,2023, 837,137655.

Transport coefficients of quark matter at finite temperature and baryon density

Guoyun Shao[1*],Chonglong Xie[1],Weibo He[3]

1. School of Physics,Xi'an Jiaotong University,Xi'an,Shaanxi,China

3. School of physics,Peking University,Beijing,Beijing,China

* gyshao@mail.xjtu.edu.cn

Abstract: In this talk, we report the recent progress on the transport coefficients of quark-gluon plasma at finite temperature and density. The calculation was performed within the framework of kinetic theory with the relaxation time approximation based on the binary elastic scatterings of quark quasiparticles. The temperature and chemical potential dependent masses of particles, including u, d, s quarks, their antiparticles, and exchanged mesons, are calculated in the Polyakov-loop extended Nambu--Jona Lasinio~(PNJL) model. The results indicate that, at small chemical potential, the value of η/s has a minimum near the Mott dissociation of mesons and increases rapidly in the lower-temperature side of the chiral crossover phase transition. At large chemical potential (high density), η/s in the QGP phase is dominated by temperature, and the value of η/s is greatly enhanced at lower temperature. At intermediate temperature and chemical potential near the QCD phase transition, the situation is relatively complicated. The behavior of η/s is influenced by the competition between temperature, density effect, and QCD phase transition. We will also discuss the behaviors of other transport coefficients, including the bulk viscosity, thermal conductivity, etc.

Keywords: shear viscosity;chiral phase transition;meson dissociation

[1] Weibo He, Guoyun Shao, Chonglong Xie, etc, arXiv:2403.05946 & work in progress

Analyzing the effect of input parameters on the synthesis of superheavy nuclei

Jingjing Li[1]

1. College of Materials Science and Technology,Nanjing University of Aeronautics and Astronautics,Nanjing,Jiangsu,China

Abstract: Analyzing the effect of input parameters on the synthesis of superheavy nuclei

Keywords: fusion reaction;superheavy nuclei;dinuclear system model;evaporation residue cross section

The radiative capture reaction 8Li(n, γ) 9Li and 8B(p, γ) 9C investigated by the Gamow shell model

Xiaobao Wang[1],Guoxiang Dong[1],N. Michel[2],M. Płoszajczak[3*]

1. School of Science,Huzhou University,Huzhou,Zhejiang,China

2. Institute of Modern Physics,Chinese Academy of Sciences,Lanzhou,Gansu,China

3. Grand Accélérateur National d'Ions Lourds,CEA/DSM - CNRS/IN2P3,Caen,Calvados,France

* marek.ploszajczak@ganil.fr

Abstract: The 8Li(n, γ) 9Li reaction plays a critical role in several reaction chains leading to the nucleosynthesis of A > 12 nuclei. The 8B(p, γ) 9C reaction plays an important role in the hot pp chain, which can serve as an alternative to produce the CNO nuclei. Due to the unstable nature of 8Li and 8B, the direct measurements of the both reactions experimentally are difficult if not impossible. The existed data are from the indirect measurement and the uncertainties are large. In this talk, we would like to introduce our recent work on the radiative capture reaction 8Li(n, γ) 9Li and 8B(p, γ) 9C by the Gamow shell model (GSM) in the coupled-channel representation (GSM-CC). The GSM-CC is a unified microscopic theory for the description of nuclear structure and nuclear reaction properties.

The GSM-CC approach reproduces the experimental low-energy spectrum, neutron emission threshold, and spectroscopic factors in 9Li. The GSM-CC calculations suggest that the 8Li(n, γ) 9Li reaction can reduce heavyelement production via the main chain 7Li(n, γ) 8Li(α, n) 11B(n, γ) 12B(β +) 12C. The experimental low-energy levels and the proton emission threshold in 9C are reproduced by the GSM-CC. The GSM-CC value for S(0) is close to the astrophysical factors determined in most indirect measurements. It is also smaller than most previous theoretical predictions. As a consequence, the critical temperature and density at which the proton capture reaction 8B(p, γ) 9C becomes faster than beta decay is predicted by GSM-CC to be higher than previously expected.

Keywords: radiative capture reaction;Big Bang nucleosynthesis;Resonance reactions;A=8 mass gap

[1] Gamow shell model description of the radiative capture reaction 8Li(n, γ) 9Li, Guoxiang Dong, Xiaobao Wang, N. Michel, M. Płoszajczak, Physical Review C 105, 064608 (2022); PRC 108, 049902(E) (2023).

[2] Gamow shell model description of the radiative capture reaction 8B(p, γ) 9C, Guoxiang Dong, Xiaobao Wang, N. Michel, M. Płoszajczak, Physical Review C 107, 044613 (2023)； PRC 108, 049903(E) (2023).

α-clustering effect from the formation of a pocket structure in the α-nucleus potential

Hailan Zheng[1],Daming Deng[2*],Zhongzhou Ren[1*]

1. School of Physics Science and Engineering,Tongji University,Shanghai,Shanghai,China

2. College of Physics and Optoelectronic engineering,Shenzhen University,Shenzhen,Guangdong,China

* ddm@szu.edu.cn,zren@tongji.edu.cn

Abstract: In this report, we study the pocket structure in the α-nucleus potential with the newly developed dynamic double-folding potential and explain the formation mechanism of the pocket structure. The formation of the pocket is due to the strong Pauli repulsion when the α cluster and daughter nucleus are largely overlapped. The existence of the nuclear medium effect is essential to the physical self-consistency of the pocket position. This finding highlights the importance of the medium effect on the nucleon-nucleon interaction and provides solid theoretical support for the understanding that α clustering occurs at the surface of heavy nuclei.

α-clustering effect;α decay;nuclear medium effect

The production of neutron-rich nuclei with Z=95-100 in multinucleon transfer reactions considering the effect of deformation relaxation

Jun-jun Cai[1],Li-Lin Zhou[1],Gen Zhang[1*],Feng-Shou Zhang[2],Long Zhu[3],Lu-Qi Li[4]

1. Guangxi Key Laboratory for Relativistic Astrophysics, School of Physical Science and Technology,Guangxi University,Nanning,Guangxi Zhuang Autonomous Region,China

2. The Key Laboratory of Beam Technology of Ministry of Education, College of Nuclear Science and Technology,Beijing Normal University,Beijing,Beijing,China

3. Sino-French Institute of Nuclear Engineering and Technology,Sun Yat-sen University,Zhuhai,Guangdong,China

4. Institute of Nuclear Physics,China institute of atomic energy,Beijing,Beijing,China

* zhanggen@gxu.edu.cn

Abstract: In this report, within the framework of the dinuclear system model, the isotopic yield distributions of the $^{136}Xe+^{249}Cf$ and $^{86}Kr+^{248}Cm$ multinucleon transfer reactions taking into account deformation relaxation have been calculated, which are in good agreement with the existing experimental data, while the results on the neutron-rich side are in better agreement with the experimental data than the ones without deformation relaxation. The different ground-state deformations of the projectile lead to a decrease in the potential energy surface with time evolution for the $^{136}Xe+^{249}Cf$ reaction, while the $^{154}Sm+^{249}Bk$ reaction shows the opposite evolutionary trend, and the effect of the evolution of the potential energy surface on the cross section due to fragment deformation relaxation is analysed. As the incident energy increases, it does not give a significant increase in the final cross section. Finally, we predict the cross section for the reaction $^{238}U+^{249}Cf$, in which the high N/Z ratio of ^{238}U leads to the production of 49 new neutron-rich isotopes with cross sections larger than 1 pb in the range Z=95-100.

Keywords: Multinucleon Transfer Reactions;Dinuclear System Model;Relaxation of deformation

Fusion reaction rates of astrophysical interest

Vazgen Sargsyan[1]

1. Bogoliubov Laboratory of Theoretical Physics (BLTP),Joint Institute for Nuclear Research (JINR),Dubna,Moscow Region,Russia

Abstract: For fusion reactions of astrophysical interest, the existence of a maximum of astrophysical S -factor is revealed within the extended quantum diffusion approach. The calculated fusion cross-sections are compared with the available experimental data and discussed. In our approach the S -factor maximum is a result of disappearing of the short range nucleus-nucleus interaction forces at the large external turning point distances. We propose an analytical expression, predicting very reliably, the dependence of the S -factor maximum on the ion mass and charge numbers, which may be used not only in stellar burning studies but also as a guidance for future experiments. Another interesting behavior of the obtained S -factor is its strong dependence on Ec.m. at the collision energies below the maximum which will reduce considerably the stellar burning rates and its temperature dependence.

Keywords: Deep sub-barrier fusion (capture);Astrophysical S-factor;Nuclear astrophysics;Nuclear reaction rates

Correlation between the charge radii difference in mirror partner nuclei and the symmetry energy slope

Rong An[1*]

1. School of Physics,Ningxia University,Yinchuan,None Selected,China

* rongan@nxu.edu.cn

Abstract: Correlation between the charge radii difference of mirror partner nuclei $\Delta{R_{\mathrm{ch}}}$ and the slope parameter of symmetry energy L has been built to ascertain the equation of state of isospin asymmetric nuclear matter. In this topic, the influence of the isoscalar compression modulus on the $\Delta{R_{\mathrm{ch}}}$ is systematically investigated by Skyrme density functionals theory.

Keywords: symmetry energy; mirror-pair nuclei; the equation of state of nuclear matter; energy density functional theory

Influence of entrance channels on production of exotic isotopes in multinucleon transfer reactions

penghui chen[1*],Zhao-Qing Feng[2*]

1. department of physics,Yangzhou university,Yangzhou,Jiangsu,China

2. School of Physics and Optoelectronics,South China University of Technology,Guangzhou,Guangdong,China

* chenpenghui@yzu.edu.cn,fengzhq@scut.edu.cn

Abstract: Within the framework of the dinuclear system model, the influence of mass asymmetry and the isospin effect on the production of exotic actinides have been investigated systematically. The isotopic yields populate in multinucleon transfer reactions of ^{48}Ca, ^{86}Kr, ^{136}Xe, ^{238}U bombarding on ^{248}Cm are analyzed and compared with the available experimental data. Systematics on the production of unknown actinides from Ac to Lr via the available stable elements on Earth (from Ar to U) as projectiles-induced reactions with ^{232}Th, ^{238}U,and ^{248}Cm are investigated thoroughly. Potential-energy surface and total kinetic-energy distribution for the reaction system are calculated and can be used to predict the production cross-section trends. It is found that the heavier projectile leads to the wider isotopic chain distribution for the same target. The heavier target-based reactions prefer to produce plenty of exotic actinides through both mechanisms of deep-inelastic and quasifission reactions. Isospin relaxation plays a crucial role in the colliding process, resulting in an actinide isotopic distribution that tends to shift to the drip lines. Massive new actinides have been predicted at the level of nanobarn to millibarn. The optimal projectile-target combinations and beam energies are proposed for the forthcoming experiments.

Keywords: Multinucleon transfer ;Entrance channel;Actinide isotopes

Fusion enhancement in the collisions with 44Ca beams and the production of neutron-deficient 245–250Lr isotopes

Lilin Zhou[1],Junjun Cai[1],LuQi Li[2],Zilong Wang[1],Rui Zhu[1],Xiao-Ye Zhang[1],Long Zhu[3,4],Gen Zhang[1*],Feng-Shou Zhang[5,6,7]

1. School of Physical Engineering and Science and Technology,Guangxi University,Nanning,Guangxi,China

2. Institute of nuclear physics,China Institute of Atomic Energy,Beijing,Beijing,China

3. Sino-French Institute of Nuclear Engineering and Technology,Sun Yat-sen University,Zhuhai,Guangdong,China

4. Guangxi Key Laboratory of Nuclear Physics and Nuclear Technology,Guangxi Normal University,Guilin,Guangxi,China

5. The Key Laboratory of Beam Technology of Ministry of Education,Beijing Normal University,Beijing,Beijing,China

6. Institute of Radiation Technology,Beijing Academy of Science and Technology,Beijing,Beijing,China

7. Center of Theoretical Nuclear Physics,National Laboratory of Heavy Ion Accelerator of Lanzhou,Lanzhou,Gansu,China

* zhanggen@gxu.edu.cn

Abstract: Within the framework of the isospin-dependent quantum molecular dynamics model and statistical evaporation model, the production of neutron-deficient 245–250Lr isotopes is investigated. The fusion probability in the reaction 44Ca + 209Bi is larger than that with 40Ca beam, especially at a lower incident energy and smaller impact parameter, which is attributed to a lower dynamical barrier in 44Ca + 209Bi. The neck between the projectile and target grows faster in the reaction with 44Ca beam, and the N/Z ratio in the neck is larger, resulting in a lower dynamical barrier. Based on the fusion reactions of 40,44Ca + 209Bi and 46,48Ti + 203Tl, we predicted six new Lr isotopes, 245–250Lr, with the maximal evaporation residue cross sections of 3.5 fb, 69 pb, 0.2 nb, 0.4 nb, 1.7 nb, and 1.8 nb, respectively.

Keywords: The isospin-dependent quantum molecular dynamics model; Fusion evaporation reaction; Dynamical barrier

The production of neutron-rich nuclei around N=126 in the multinucleon transfer reactions with potential pockets

Gen Zhang[1*],Long Zhu[2],Feng-Shou Zhang[3]

1. School of Physical Science and Technology,Guangxi University,Nanning,Guangxi,China

2. Sino-French Institute of Nuclear Engineering and Technology,Sun Yat-sen University,Zhuhai,Guangdong,China

3. College of Nuclear Science and Technology,Beijing Normal University,Beijing,Beijing,China

* zhanggen@gxu.edu.cn

Abstract: The production of neutron-rich nuclei around N=126 in multinucleon transfer reactions with potential pocket is investigated by dinuclear system model. The quasifission rate is modified by parabolic approximation method, and the contribution of quasifission yields is added into the production cross sections. The calculated cross sections of the target-like fragments in ^{64}Ni+^{208}Pb reaction reproduce the experimental data very well. The potential energy needed to overcome in ^{64}Ni+^{202}Pt is the lowest among the reactions induced by ^{64}Ni beam, resulting in the highest production cross sections of unknown neutron-rich nuclei around N=126. The effect of incident energy on the production cross sections is studied, and the optimal incident energy to produce these unknown nuclei is obtained. Seven unknown neutron-rich isotopes with Z=73-75 around N=126 are predicted.

Keywords: multinucleon transfer reactions; N=126; neutron-rich nuclei; dinuclear system model

Towards a Unified Effective Nuclear Force based on Structure Properties

Cenxi YUAN[1*]

1. IFCEN,Sun Yat-sen University,Zhuhai,Guangdong,China

* yuancx@mail.sysu.edu.cn

Abstract: In the Configuration Interaction Shell Model (CISM) framework, we try to deduce a unified nuclear force based on nuclear structure properties, such as excitation energies.

Keywords: Configuration Interaction Shell Model; Effective Nuclear Force; Nuclear Structure Property

Investigations on the resonances of trineutron and tetraneutron systems

Niu Wan[1]

1. School of Physics and Optoelectronics,South China University of Technology,Guangzhou,Guangdong,China

Abstract: Recently the experimental result for the resonant state of tetraneutron system is strikingly reported in Duer et al. [Nature (London) 606, 678 (2022)]. Here we investigate the properties of both trineutron and tetraneutron systems within the framework of tensor-optimized antisymmetrized molecular dynamics (TOAMD) and inverse analytical continuation in the coupling constant method. Under the bare AV8' nucleon-nucleon interaction with TOAMD, we first calculate the binding energies of the artificial bound states by two modifications of the system Hamiltonian: (1) enhancing the attractive part of the AV8' potential and (2) confining the systems in external well. Then the IACCC is employed to follow the resonance pole trajectories out of the artificial bound states. The enhancement cannot generate the requisite bound states, while the external well can make for the resonance poles. The model dependence of the resultant resonances of trineutron and tetraneutron are also discussed.

Keywords: multineutron system; resonant state; analytical continuation

[1] F. M. Marqués and J. Carbonell, Eur. Phys. J. A 57, 105 (2021).

[2] R. Lazauskas and J. Carbonell, Phys. Rev. C 72, 034003 (2005).

[3] S. Gandolfi, H.-W. Hammer, P. Klos, J. E. Lynn, and A. Schwenk, Phys. Rev. Lett. 118, 232501 (2017).

[4] J. G. Li, N. Michel, B. S. Hu, W. Zuo, and F. R. Xu, Phys. Rev. C 100, 054313 (2019).

[5] Duer et al., [Nature (London) 606, 678 (2022)].

[6] T. Myo, H. Toki, K. Ikeda, H. Horiuchi, and T. Suhara, Prog. Theor. Exp. Phys. 2015, 073D02 (2015).

[7] J. Horáček and L. Pichl, Commun. Comput. Phys. 21, 1154 (2017).

Probing the temperature dependence of nuclear dissipation with second-chance survival probability

Wei Ye[1*]

1. Department of Physics,Southeast University,Nanjing,Jiangsu,China

* yewei@seu.edu.cn

Abstract: Temperature dependence of dissipation [1] is applied to analyze fission data of excited nuclei, but there exists a controversial on this application [2]. Second-chance survival probabilities (Psur2) are proposed here as a new observable to explore nuclear dissipation properties. We calculate Psur2 of 28S + 204Pb, 26Si + 204Pb, and 36Ar + 180W reactions in the framework of the Langevin model. It is shown that Psur2 is quite sensitive to the strength of dissipation. Moreover, we find that Psur2 depends on friction more strongly than on bombarding energy, indicating the robustness of the observable in constraining the dissipation strength. These results suggest that a measurement of the second-chance survival probability [3,4] of neutron-deficient heavy systems at a high energy not only puts a stringent constraint on the dissipation strength, but also it can provide an avenue to more clearly probe the dependence of nuclear dissipation on temperature [5].

Keywords: second-chance survival probability;temperature dependence of nuclear dissipation ;stochastic model

[1] P.Paul and M. Thoennessen, Annu. Rev. Nucl. Part. Sci. 44, 65 (1994);
D. J. Hofman et al., Phys. Rev. C 51, 2597 (1995);
I. Dioszegi et al., Phys. Rev. C 61, 024613 (2000).
[2] S. G. McCalla and J. P. Lestone, Phys. Rev. Lett. 101, 032702 (2008).
[3] E. A. Cherepanov et al., J. Phys. G 9, 931 (1983);
A. N. Andreyev et al., Z. Phys. A 345, 389 (1993).
[4] Y. R. Yanez et al.,Phys. Rev. Lett. 112, 152702 (2014).
[5] N. Wang and W. Ye, Phys. Lett. B 843, 138010 (2023).

Reactions of weakly-bound nuclei at near-barrier energies

Chengjian Lin[1*],Lei Yang[1],Nanru Ma[1],Huiming Jia[1],Peiwei Wen[1]

1. Department of Nuclear Physics,China Institute of Atomic Energy,Beijing,Beijing,China

* cjlin@ciae.ac.cn

Abstract: Reaction dynamics of weakly-bound nuclei at energies near the Coulomb barrier is a topic of current interest. In this talk, I would like to address recent progresses achieved by the NRG group in CIAE, mainly including the following topics:

1) Optical potentials of weakly-bound nuclear systems. The optical potentials of ^{6}He+^{209}Bi and ^{6}Li+^{208}Pb systems have been extract by both the elastic scattering and transfer reactions at energies from above the barrier to extremely below the barrier. An abnormal threshold anomaly phenomenon has been observed clearly. Results show that the dispersion relation cannot describe the behavior between the real and imaginary parts of the potentials for both systems. Some possible reasons are discussed.

2) Breakups of weakly-bound stable nuclei. Correlations of breakup fragments have been measured for ^{6,7}Li+^{209}Bi systems by the complete kinematics method with a large solid-angle covered detector array. Various breakup components (prompt and delayed breakups) and breakup modes (a+p, a+d, a+t, and a+a) have been identified, and their branching ratios varying with the energy are investigated. The angular correlations are also investigated to further study the breakup mechanisms. Possible influences on fusion reactions are discussed.

3) Reactions with proton-rich unstable nuclei. A series of experiments (^{17}F+^{12}C, ^{89}Y, ^{58}Ni, ^{208}Pb, ^{7}Be+^{120}Sn, ^{209}Bi, and ^{8}B+^{120}Sn) have been performed at the RIBLL1 at IMP (China) and CRIB at CNS (Japan). For the ^{17}F+^{58}Ni system, the quasielastic scattering, exclusive and inclusive breakups, and total fusion cross sections were obtained for the first time. Results show that the non-elastic breakup is dominant, and the incomplete fusion plays a minor role. An enhancement of total fusion at sub-barrier energy was observed, which may arise from the couplings to the continuum states. For the ^{8}B+^{120}Sn system, fragments of ^{8}B breakup were detected in coincidence with high statistics. The correlation information on the relative energy and opening angle reveals that the prompt breakup mechanism dominates, occurring predominantly on the outgoing trajectory. As a large environment, the continuum of ^{8}B breakup may not significantly influence elastic scattering and complete fusion.

More details will be presented at the workshop.

Keywords: second-chance survival probability;temperature dependence of nuclear dissipation ;stochastic model Nuclear reaction dynamics;Weakly-bound nucleus;Near-barrier energy;Optical model potential;Breakup mechanism;Breakup effect

[1] L. Yang, C.J. Lin, N.R. Ma et al., Fundamental Research, in press, DOI: 10.1016/j.fmre.2023.10.006

[2] Lei Yang, Chengjian Lin, Nanru Ma et al., Science Bulletin 68, 775 (2023).

[3] L. Yang, C. J. Lin, H. Yamaguchi et al., Nat. Commu. 13, 7193 (2022).
[4] L. Yang, C.J. Lin, H. Yamaguchi et al., Phys. Lett. B 813, 136045 (2021).
[5] C. H. Rong, J. Rangel, Y. S. Wu et al., Eur. Phys. J. A 57, 143 (2021).
[6] Yong-Jin Yao, Cheng-Jian Lin, Lei Yang et al., Chin. Phys. C 45, 054104 (2021).
[7] L. Yang, C.J. Lin, Y.X. Zhang et al., Phys. Lett. B 807, 135540 (2020).
[8] L. Yang, C. J. Lin, H. M. Jia et al., Phys. Rev. C 101, 054603 (2020).

Revisit the effective mass splitting with HICs

Yingxun Zhang[1*]

1. Department of Nuclear Physics,China Institute of Atomic Energy,Beijing,Beijing,China

* zhyxciae@hotmail.com

Abstract: In my talk, I will present a new version of ImQMD model which use the extended Skyrme momentum dependent interaction. Based on this model, we revist the isospin sensitive observable, the spectral of the neutron to proton yield ratios. Our analysis show that the slope of the spectral of neutron to proton yield ratios is directly related to the magnitude of effective mass splitting. By comparing the calculation to the data, different signs of effective mass splitting are observed at low and high kinetic energy region.

Keywords: extended Skyrme momentum dependent interaction; effective mass splitting; heavy ion collisions

https://doi.org/10.48550/arXiv.2311.04026

Kaon production in HADES Au+Au collisions at $\sqrt{s_{\rm NN}}=2.4$ GeV

Gao-Feng Wei[1*]

1. School of Physics and Electronic Science,Guizhou Normal University,Guiyang,Guizhou,China

* wei.gaofeng@gznu.edu.cn

Abstract: Within an upgraded isospin- and momentum-dependent transport model by including the kaon production, we study the kaon prodution in heavy-ion collisions (HICs) at SIS (Darmstadt Schwerionen Synchrotron, GSI) energies. Based on simulations of a centrality of 0-40\% Au + Au collision at $\sqrt{s_{NN}}=2.4$~GeV, a typical reaction that has been carried out by the HADES Collaborator, we find that the medium modification of kaon masses plays a vital role in studying the kaon multiplicities in HICs, and is also unavoidable for the successful interpretation of the HADES data on kaon rapidity distributions and transverse mass spectra. Moreover, we also find that the kaon transverse and directed flows are affected significantly by both the kaon potential or dispersion relation and medium modification of kaon masses, and thus could be used in HICs as the sensitive probes to detect the kaon potential or dispersion relation as well as the medium modification of kaon masses.

Keywords: Kaon production; kaon potential; medium modification of kaon masses; heavy-ion collision

Equation of State of Neutron Star Cores

Bao-Jun Cai[1],Bao-An Li[2],Zhen Zhang[3]

1. Shanghai,Shanghai,China

2. Physics,Texas A&M-Commerce,Commerce,TX,United States

3. Sino-French Institute of Nuclear Engineering and Technology,Sun Yat-sen University,Zhuhai,Guangdong,China

Abstract: Given an Equation of State (EOS) for neutron star (NS) matter, there is a unique mass–radius sequence characterized by a maximum mass Mmax at radius Rmax. We first show analytically that the Mmax and Rmax scale linearly with two different combinations of the NS central pressure and energy density, by dissecting perturbatively the dimensionless Tolman–Oppenheimer–Volkoff (TOV) equations governing NS internal variables. The scaling relations are then verified via 104 widely used and rather diverse phenomenological as well as microscopic NS EOSs with/without considering hadron–quark phase transitions and hyperons, by solving numerically the original TOV equations. The EOS of the densest NS matter allowed before it collapses into a black hole is then obtained. Using the universal Mmax and Rmax scalings and Neutron Star Interior Composition Explorer and XMM-Newton mass–radius observational data for PSR J0740+6620, a very narrow constraining band on the NS central EOS is extracted directly from the data for the first time, without using any specific input EOS model. By similar analysis, we demonstrate that the ratio of pressure to energy density in NSs is generally upper bounded as $P/e \leq 0.374$, generalizing the apparent requirement ($P/e \leq 1$) set by the principle of special relativity (causality). Finally, the strong gravity in general relativity (GR) is found to play a twofold role in the peaked structure in the speed of sound squared: it compresses NS matter and modifies the pressure/energy density ratio from small values in Newtonian stars showing no s^2 peak to large ones for massive NSs possessing a peak in their s^2 profiles, and eventually takes away the peak in extremely compact/massive NSs approaching the causality limit.

Keywords: Equation of State; Neutron Star Cores; Stong-field Gravity; Speed of Sound

Precision mass measurement of the heaviest nuclei in Dubna FLNR

Aleksandr Rodin[1,*]

1. Joint Institute for Nuclear Research, 6 Joliot-Curie St, Dubna, Moscow Region, Russia, 141980

*rodin@jinr.ru

Abstract: A project of experimental setup for precise mass measurements of heavy and superheavy elements has been represented. Crucial parts of it are a cryogenic gas-filled ion stopping cell (Cryocell) and a multi-reflection time-of-flight mass-spectrometer (MR-TOF-MS). A detailed overview of the experimental setup parts planned for locating at the reconstructed cyclotron facility U-400R is given. The main parameters of complex are presented and the short analysis of planned research field is given. The cryocell tests results and the current status of the described experimental setup as a whole are adduced.

Collective modes in dense matter

Wei-Zhou Jiang[1,*]

1.Southeast University

* wzjiang@seu.edu.cn

Abstract: While the collective modes are used to determine the compression modulus, we investigate the zero sounds at high density and matter stability at low density based in the dielectric function in the relativistic random phase approximation. The zero sounds at high density are found to be associated with the stiffness of the nuclear equation of state (EOS). Together with data from the heavy-ion collisions, the zero sounds can be hopefully measured to constrain the nuclear EOS at high density. As for the static matter stability relevant to the core-crust transition of neutron stars, we demonstrated that the scalar fluctuation in the Dirac sea can effectively affect the core-crust transition density.

Dynamics of Little-Bang Nucleosynthesis

Kai-jia Sun[1,*]

1. Fudan University

*kjsun@fudan.edu.cn

Abstract: High-energy nuclear collisions provide a unique site for the synthesis of both nuclei and antinuclei at temperatures of $kT \approx 100 - 150$ MeV. In these little bangs of transient collisions, a quark-gluon plasma (QGP) of nearly vanishing viscosity is created, which is believed to have existed in the early universe within the first few microseconds after the Big Bang. Analyses of identified particles produced in these little bangs based on the statistical hadronization model for the QGP have suggested that light (anti)nuclei are produced from the QGP as other hadrons and their abundances are little affected by later hadronic dynamics. Here, we find a strong reduction of the triton yield by about a factor of 1.8 in high-energy heavy-ion collisions based on a kinetic approach that includes the effects of hadronic re-scatterings, particularly that due to pion-catalyzed multi-body reactions. This finding is supported by the latest experimental measurements and thus unveils the important role of hadronic dynamics in the little-bang nucleosynthesis.

Global quark spin correlations in relativistic heavy ion collisions

Zuo-tang Liang[1,*]

1. Shandong University

*liang@sdu.edu.cn

Abstract: Six years after the Nature cover paper on global Lambda hyperon polarizations by the STAR Collaboration at RHIC that confirms the global polarization effect in relativistic heavy ion collisions, the STAR Collaboration published their measurements on global vector meson spin alignments again in Nature. The results not only show that global polarization effect manifests itself also on vector meson polarizations but also reveal that strong spin correlations may exist for quarks and anti-quarks in the quark-gluon plasma produced in non-central relativistic heavy ion collisions. We propose a systematic scheme to describe such quark spin correlations and show in particular that the observed effective quark spin correlations contain contributions from the genuine spin correlations originated from the dynamical processes as well as those induced by averaging over other degrees of freedom. We show also that such correlations can be studied by measuring vector meson spin alignment together with the off-diagonal elements of the spin density matrix and spin correlations of hyperons and anti-hyperons. We present the relationships between these measurable quantities and the spin correlation of quarks and anti-quarks and make predictions for future experiments.

Constraining the speed of sound in neutron stars by inverting neutron star observables in high-density EOS parameter space

Nai-bo Zhang[1,*]

1. Southeast University

*naibozhang90@foxmail.com

Abstract: The speed of sound (SS) measures the stiffness of nuclear Equation of State (EOS). Within the minimum model for neutron stars at beta-equilibrium, the relevant SS C_{s} is that of (n, p, e, mu) matter with its proton fraction determined by the density dependence of nuclear symmetry energy. Within a meta model EOS [1], we found that the C_{s} always shows a peak and then vanishes at a critical density ρ_t, indicating that the (n, p, e, mu) matter in neutron stars become mechanically unstable against phase transtions at higher densities [2]. Assuming a first-order hadron-quark phase transition occurs above ρ_t in neutron stars, by inverting several neutron star observables in a three-dimensional high-density EOS parameter space, we constrained the transition density ρ_t, transition strength, and speed of sound of quark matter. We found that the C_{s}^2 for quark matter has a lower limit of 0.35, above the so-called conformal limit predicted by the perturbatic QCD[3]. References: [1]NBZ, B.A. Li and J. Xu, Combined Constraints on the Equation of State of Dense Neutron-rich Matter from Terrestrial Nuclear Experiments and Observations of Neutron Stars, APJ 859, 90 (2018). [2] NBZ and B. A. Li, Impact of symmetry energy on sound speed and spinodal decomposition in dense neutron-rich matter, EPJA, 59, 86 (2023) [3] NBZ and B. A. Li, Properties of first-order hadron-quark phase transition from inverting neutron star observables, PRC, 108, 025803 (2023)

Spontaneous fission characteristics of heaviest nuclei synthesized in FLNR

ALEXANDR SVIRIKHIN[1,*]

1. Joint Institute for Nuclear Research

*a_svirihin@mail.ru

Abstract: The opportunity to have high intensity (> 1 pμA) accelerated beams of ions with A ≤ 60 together with the use of exotic targets provide the possibility to study many aspects of heavy ion induced reactions exploiting new generation of high efficiency, high resolution experimental setups. In recent years, decay properties of heavy nuclei at the focal plane of recoil separators ("decay spectroscopy") has been very intensively developed. The mixing of α decay with γ and β decay spectroscopy allows to investigate single particle states of heaviest nuclei as well as the spontaneous fission properties of isotopes in the Z = 98-105 and N = 152-162 region. The modernized multi-parameter detector SFiNX (Spontaneous Fission, Neutrons and x-rays) consisting of 116 He-3 neutron counters, scintillation detector and double sided silicon detector (DSSD, 128x128 strips) was installed at the focal plane of SHELS separator. Our report presents the data of experiments made in recent years. A brief overview of the planned experiments and approaches to improving the experimental methodology is given.

Two-particle HBT correlation in heavy ion collisions at intermediate energies

Pengcheng Li[1,*]

1. Huzhou University

*lipch@zjhu.edu.cn

Abstract: Determination of equation of state (EoS) for nuclear matter at high baryon density region is a topic of current interest in high-energy heavy-ion collisions and astrophysics. The pion/kaon HBT correlation (also called HBT interferometry) and intermittency are sensitive probe of the nuclear EoS.Within the UrQMD farmework, it is found that the correlations of protons, correlated proton pairs with small relative transverse momentum, will be boosted by hadronic interactions, these correlations contribute significantly to an intermittency analysis as performed at experiments. In addition，by adopting different EoSs, HBT correlations for charged pions in central Au+Au collisions at 2.4-7.7 GeV are calculated. The effects of a phase transition at high baryon densities are clearly observed in the explored HBT parameters. The results show that the available data on the HBT radii, R_O/R_S and $R_{O}^{2}-R_{S}^{2}$, in the investigated energy region favor a relatively stiff EoS at low beam energies, which then turns into a soft EoS at high collision energies consistent with astrophysical constraints on the high-density EoS of QCD. The specific effects of two different phase transition scenarios on R_O/R_S and $R_{O}^{2}-R_{S}^{2}$ are investigated. A phase transition with a significant softening of the EoS below four times the nuclear saturation density can be excluded using HBT data. The results highlight that the pion's R_O/R_S and $R_{O}^{2}-R_{S}^{2}$ are sensitive to the stiffness of the EoS and can be used to constrain and understand the QCD EoS in a high baryon density region.

Spectroscopy of heaviest nuclei at Dubna.

Alexander Yeremin[1,*]

1. Joint Institute for Nuclear Research

*eremin@jinr.ru

Abstract: Important information on the structure of Super Heavy Elements (SHE) can come from the study of lighter deformed transfermium (Z ~ 100-106) elements. The cross-section for the formation of these nuclei is many orders of magnitude higher than for $Z \geq 110$ so that detailed spectroscopy becomes possible. The opportunity to have high intensity (> 1 pμA) accelerated beams with $A \leq 60$ together with the use of exotic targets provide the possibility to study many aspects of heavy ion induced reactions exploiting new generation of high efficiency, high resolution experimental setups. In recent years α-, β- and γ- spectroscopy of heavy nuclei at the focal plane of recoil separators ("decay spectroscopy") has been very intensively developed. The mixing of α decay with γ and β decay spectroscopy allows to investigate single particle states behavior as well as the structure of little known elements in the Z = 100-104 and N = 152-162 region. Using SHELS recoil separator and GABRIELA (Gamma Alpha Beta Recoil Invetsigations with the ELectromagnetic Analyser) detector array the experiments aimed to the alpha, gamma and electron spectroscopy of the Fm – Db isotopes, formed at the complete fusion reactions with heavy ions 22Ne, 48Ca, 50Ti and 54Cr were performed at FLNR JINR. We performed experiments using method of high resolution alpha, EC and γ spectroscopy to study decay properties of 254,255,256,257Rf in the reactions 50Ti + 206,207,208Pb , 249,250,252,254No in the reactions 48Ca + 204,206,208Pb and 256No in the reaction 22Ne + 238U. In the close future it is planned to use GABRIELA system together with new gas-filled separator GRAND and very high intensity accelerated beams from DC280 cyclotron (SHE factory) to study decay properties of the 260,261Sg and daughter nuclides in the reaction 54Cr + 208Pb as well as 286,287Fl and daughter nuclides in the reaction 48Ca + 242Pu. Future developments and perspectives of experimental studies in spectroscopy of heavy and superheavy elements are discussed.

On the stability of hole states in molecules and clusters, a generic mechanism?

Eric Suraud[1,*]

1. Lab. Phys. Theo, Univ. P. Sabatier

*suraud@irsamc.ups-tlse.fr

Abstract: Recent investigations of the electron dynamics of molecules after irradiation with a short, strong XUV pulse have shown that under certain conditions a rather clean deep hole state can be generated which, in turn, leads to a remarkable dipole instability. This instability can be explored simplifying the excitation mechanism by instantaneous generation of a hole in one of the oc- cupied states of the system. We investigate how the dipole instability depends on the system, the state in which the hole is cut, and the amount of depletion which is given to the hole state. The mechanism might appear in other systems described by mean field approaches although the role of dynamical correlations might not be the definitive key here.

Theory of Fusion Probability for SHEs -- dynamical origin of enhanced fusion hindrance –

Yasuhisa Abe[1,*]

1. RCNP, Osaka Univ.

*tenshofour@gmail.com

Abstract: Reaction theory for SHE production is not yet available. Therefore, no one can predict production cross sections of Super-Heavy Elements. The reason is that we do not yet understand extremely small fusion probability, so-called fusion hindrance observed in massive heavy ion collisions. The talk aims to answer it.

Investigating the fusion and fission in a neutron-star environment

Martin Veselsky[1,*]

1. Institute of Experimental and Applied Physics, Czech Technical University in Prague

*martin.veselsky@cvut.cz

Abstract: The synthesis of hyper-heavy elements is investigated under conditions simulating neutron star environment. The constrained molecular dynamics approach is used to simulate low energy collisions of extremely n-rich nuclei. When introducing Coulomb screening and background of surrounding nuclei, the nuclear fusion becomes possible down to temperatures of 10^8 K and synthesis of extremely heavy and n-rich nuclei appears feasible. A possible existence of hyper-heavy nuclei in a neutron star environment could provide a mechanism of extra coherent neutrino scattering or an additional mechanism, resulting in x-ray burst or a gravitational wave signal and, thus, becoming another crucial process adding new information to the suggested models on neutron star evolution. Furthermore, probabilities of nuclear fission in a neutron star environment can differ dramatically from the same process in the laboratory, what can influence the nucleosynthesis of the heaviest elements in neutron star mergers.

Sub barrier Nuclear Dynamics

Aldo Bonasera[1,*]

1. Texas A&M University (LNS-INFN)

*abonasera@comp.tamu.edu

Abstract: We discuss theoretical models for the subbarrier fusion of light nuclei of astrophysical interest. A new triple alpha fusion model will be presented as well.

Experimental studies of the 232Th + 48Ca → 280Ds and 238U + 40Ar → 278Ds reactions: New isotopes 268Sg, 272Hs, 275Ds, and 275Ds.

Maksim Shumeiko[1,*]

1. Joint Institute for Nuclear Research Flerov Laboratory of Nuclear Reactions

*shumeyko@jinr.ru

Abstract: The 232Th + 48Ca reaction has been studied at the gas-filled separator DGFRS-2 online to the cyclotron DC280 at the SHE Factory at JINR. At three low 48Ca energies, three new even-even nuclides were synthesized for the first time: a spontaneously fissioning (SF) 268Sg with the half-life TSF = 13(+17; -4)s; an alpha decaying 272Hs with T½ = 0.16(+0.19; -0.06) s and Eα = 9.63 ± 0.02 MeV; and 276Ds with T1/2 = 0.15(+0.10; -0.04)ms, Eα = 10.75 ± 0.03 MeV, and an SF branch of 57%. The decay properties of these nuclei are in agreement with the systematics of experimental partial half-lives and α-decay energies of heavy known nuclei, as well as spontaneous-fission half-lives. The cross sections of the 4n-evaporation channel of 0.07(+0.17; -0.06)pb, 0.7(+1.1; -0.5)pb, and 0.11(+0.46; -0.09)pb were measured at 231, 238, and 251 MeV, respectively. At two higher projectile energies of 251 and 257 MeV, new isotope 275Ds with the half-life of 0.43(+0.29; -0.12)ms and α-particle energy of 11.20 ±0.02 MeV was synthesized in the 48Ca-induced reaction with actinide nucleus and identified by measuring correlated α-decays ending in known nuclei. The 238U + 40Ar reaction was studied at 212 MeV resulting in observation of 273Ds. The decay properties of nuclei originating from 273Ds and 275Ds are compared with theoretical calculations and decay schemes are proposed. The cross sections of the 232Th(48Ca,5n)275Ds reaction of 0.11(+0.46; -0.09)pb and 0.34(+0.59; -0.16)pb were measured at excitation energies of the 280Ds compound nucleus E* = 51 and 56 MeV, respectively. The cross section of the 5n-evaporation channel of the 238U + 40Ar reaction at E* = 49 MeV of 0.18(+0.44; -0.12)pb turned out to be comparable to that for 275Ds at close excitation energy. For the first time since 1983, when the first experiments on the synthesis of Ds isotopes in direct reactions of 40Ar, 48Ca with isotopes of actinide elements (232Th, 235,236,238U) were carried out, the reaction cross section was measured, which turned out to be an order of magnitude smaller than the cross section of the 226Ra(48Ca, 4n)270Hs reaction. When moving to heavier elements (Z > 110), the cross section increases, reaching a maximum value for elements 114-115, and then decreases by about 30 times for element 118. Such variation is in full agreement with theoretical models predicting shells at Z=108, N=162 and Z=114, N=184.

Nuclear Collective excitations Studied by SRPA

Chun-lin Bai[1,*]

1. Sichuan University

*bclphy@scu.edu.cn

Abstract: The electric 0+, 2+ and 3- states in 16O and Gamow-Teller transitions and magnetic M1 excitations in closed-shell nuclei are studied by HF+SRPA model.