INSTITUTE FOR NUCLEAR RESEARCH

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I. Main duties of the research unit in 2018

The main duty of the institute in fundamental research focusing on atomic, nuclear and particle physics, as well on nuclear astrophysics was carrying out aligned, cutting edge research work with large-scale international collaborations, making balanced use of the local research infrastructure and that of the leading international research centres. Among the infrastructural developments related to the running GINOP projects (operative program for economic development and innovation, funded by the government from EU sources) the two most significant were completing the reconstruction of the building housing the Laboratory of Climatology and Environmental Physics (ICER) and continuing the second developing stage of the Tandetron Laboratory. With the latter one a world-class infrastructure has been established (three different top-performing ion sources; high-accuracy energy stability; nine beam lines), allowing for increasing the competitiveness of Hungarian researches. Further tasks in 2018 were participating in university education, training of PhD students and international specialists, as well as organizing outreach activities to promote sciences. A new type of task appeared in the second half of the year, when negotiations started between the Hungarian Academy of Sciences and the Ministry of Innovation and Technology: observing these and estimating their possible outcome, as well as the consequences of the latter concerning the operation of the institute represented a notable challenge.

II. Outstanding research and other results in 2018

II. a) Outstanding research results

Theoretical physics

The so-called *bound entangled states* represent a very weak form of entanglement in nature. In fact, these states are so weakly entangled that given an infinite number of copies, no pure state entanglement can be distilled from them. Nevertheless, they prove to be useful in certain quantum protocols such as quantum key distribution, data hiding, or generation of certified randomness. One of the open problems in quantum information science is whether bound entangled states can be useful in quantum metrology. This problem has been solved affirmatively by showing that multipartite bound entangled states can outperform separable states in linear interferometers, demonstrating their metrological advantage and usefulness with respect to separable states.

In coupled-channels models the poles of the scattering S-matrix are located on different Riemann sheets. Physical observables are affected mainly by poles closest to the physical region. It was shown that all poles of the S-matrix can be located by an expansion in terms of a properly constructed complex-energy basis. It was found that the shadow pole of ^{5}He, an important nucleus for fusion energy source, migrates between Riemann sheets if the coupling strength is varied, so the effect of the pole changes.

Natural catastrophes such as landslides and earthquakes are often caused by fractures emerging under compression and shear. It was demonstrated that the degree of structural disorder has a substantial effect on the compressive failure of heterogeneous materials. In particular, the structure of sedimentary rocks, relevant for earthquakes, was reconstructed on computer and the compression process of cylindrical samples was simulated. Numerical and analytical calculations revealed that approaching catastrophic failure, two conjugate shear bands emerge, whose orientation and structure depend on the degree disorder. Notably, the effect of disorder could be cast into a scaling law with universal exponents.

The consequences of various symmetries have been studied for the three-alpha spectrum. In particular, the permutation symmetry of the identical (alpha) particles, the antisymmetry of the nucleons, the (D_{3h}) point symmetry of the regular triangle and the U(3) dynamical symmetry was considered. It turned out, surprisingly, that different symmetries result in similar spectra. Therefore, the similarity of the D_{3h} energy level scheme to the experimental one does not prove that this symmetry is present in the whole spectrum.

A chapter has been prepared for the monograph *PT Symmetry in Quantum and Classical Physics*, which summarizes the results of PT-symmetric quantum mechanics, the pseudo-hermitian extension of quantum mechanics. This field was initiated in 1998 by C. M. Bender, the editor and author of the monograph, after noticing certain mathematical curiosities characterizing some complex potentials. The theoretical elaboration of the subject has been done by researchers from various fields of physics. Eventually, several theoretical predictions were proved by experiments in quantum optics. The named chapter gives a 40-page summary on exactly solvable problems of PT-symmetric quantum mechanics, which gave significant support to the theoretical foundation of the field.

Particle physics

In collaboration with the CERN EP-DT group tests have been performed on fiber optic sensors. A phenomenological model has been developed to describe how ionizing radiation affects fiber optic sensors. Through a comprehensive study of the results the eight parameters characterizing the model have been determined. The parameters have been verified independently using a method based on the analysis of experimental data with curve-fitting.

The most popular possibility to extend the standard model of particle physics is by assuming supersymmetry (SUSY), a new symmetry of the model that also predicts the existence of a host new particles, so far not observed. Making use of data taken by the CERN CMS detector, a search for signatures of the existence of these SUSY partner particles has been performed. In order to separate the signal from the background, razor variables and top quarks with high Lorentz boost have been used. The number of observed events turned out to be statistically compatible with the standard model based estimate of the expected background. Combining these results with those of another similar razor analysis, the excluded region in the parameter space of SUSY models could be extended. In particular, the existence of gluinos up to an energy of 2.0 TeV and that of the squarks up to 1.14 TeV could be excluded.

Using lattice field theory methods, the appearance of localized quark states has been studied in the high-temperature quark-gluon plasma phase of strongly interacting matter. This was the first study of this problem using a quark discretization that preserves the so-called chiral symmetry, a symmetry that is of fundamental importance in the low-energy physics of strongly interacting systems. It has been shown that the appearance of localized quark states happens exactly at the transition temperature to the quark-gluon plasma phase. The result provides evidence that quark localization is strongly connected to the transition to the quark-gluon plasma.

Recently, Atomki researchers observed a peculiar peak in the spectrum of the pair of fermions ejected by lithium atoms bombarded with protons. This peak was tentatively explained by the interaction between a new, so far not observed particle and the fermions. The hypothesized new particle, a protophobic boson, named the X-boson, should have a mass of 16.7 MeV. Due to the short range (12 fm) of the interaction, it is a challenge to disentangle the effects of the finite nuclear size and those of the possible new particle in any observation aiming to verify the protophobic nature of the interaction. In the present work an analysis has been performed to demonstrate how the new X-boson could affect the properties of both conventional and muonic hydrogen and deuterium. It was shown that the most promising systems to distinguish nuclear size and X-boson effects are muonic atoms with low to medium nuclear charge.

Nuclear Physics

According to the shell model, nucleons are located in orbits in the nuclei. Recent theoretical calculations predict that the change of the shell closures in neutron-rich nuclei is caused by the tensor interaction between neutrons and protons. Studying the structure of ^{77}Cu in an international collaboration, Atomki researchers found that the energy difference of the outermost spin-partner orbits is halved while moving from the stability valley to the drip line, in accordance with the expected effect of the tensor force.

Performing knock-out experiments with radioactive ion beams in the R3B international collaboration, Atomki researchers showed that the neutrons were emitted in pairs from the highly excited states of ^{18}C. The correlation between the emitted neutrons is extremely strong, indicating that the valence neutrons form 2-nucleon clusters in this nucleus.

The so-called Landau-Migdal g' parameter is the most important parameter for understanding the pion condensation in nuclear matter, and it also plays a role in interpreting the rapid cooling process occurring in the core of neutron stars. In an experiment carried out in collaboration with Japanese colleagues, the double magic nucleus ^{132}Sn was produced as a radioactive beam at RIKEN. The double differential cross sections of the ^{132}Sn(p, n) reaction were measured to determine the strength distribution of the Gamow-Teller giant resonance, from which the Landau-Migdal parameter was deduced, putting a constraint on the previously measured data.

The γγ decay of the X (17) boson, which was observed earlier at Atomki and associated with the dark matter, was investigated to determine whether it is a vector (J^π = 1^+) or an axial vector (J^π= 0^-) particle. The X(17) boson was created at the Tandetron Laboratory of Atomki in the ^{3}H(n, γ) ^{4}He nuclear reaction, while at the FRM-II high flux reactor in Munich the 3H(p, γ)4He reaction was used for the same purpose. Using highly-efficient and high resolution $LaBr_3$ (Ce) detectors, the decay of the excited state of ^{4}He by emission of two γ-rays was detected. This provides a good basis for measuring the γγ angular correlation expected from the decay of X (17).

A double, Frisch-gridded ionisation chamber equipped with eight units of ΔE-E detectors, has been developed for investigating the photo-fission process and rare fission decay modes at ELI-NP (Magurele, Romania). This novel detector array will allow for the simultaneous measurement of the energy, charge, mass and angular correlations of the fission fragments in photon-induced fission processes. Furthermore, the ΔE-E telescopes also makes it possible to identify the light fission products from the rare ternary fission process and to measure their energy and angular distribution. The test and calibration of the detectors has been performed at the cyclotron laboratory of Atomki using a ^{252}Cf source and the ^{235}U(n_{th},f) reaction, in collaboration with Romanian colleagues.

The DIAMANT charged-particle detector system, maintained by Atomki, has been coupled to the AGATA (Advanced GAmma Tracking Array) γ- and NEDA neutron-detector systems operational at GANIL (Caen, France). Researchers from Atomki participated in the set-up and test of the digital signal processing based data acquisition of these detector systems, as well as in the AGATA+DIAMANT+NEDA experiment campaign, in which heavy-ion beams provided by the accelerator facility at GANIL have been used to investigate exotic nuclei by in-beam γ-ray spectroscopy.

Isospin symmetry breaking interactions and effects caused by changes in the nuclear shapes have been studied with the EXOGAM-DIAMANT-NWALL detector system at GANIL by measuring the energy differences of the analog states in the ^{23}Mg–^{23}Na mirror nuclei. For the interpretation of the results a novel effective interaction derived from a realistic, charge-independent chiral nucleon-nucleon potential has been applied. It has been shown that mirror-energy differences provide information on the nuclear skin, and that changes of the nuclear skin along the yrast-band are strongly correlated with differences in the neutron and proton occupation of the $s_{1/2}$ halo orbits.

In order to understand the observed oxygen-sodium abundance anticorrelation in Globular Cluster stars, the knowledge of the ^{22}Ne(p, γ)^{23}Na reaction has to be improved. Exploiting the unique low background conditions of the LNGS deep underground facility (Gran Sasso, Italy), the LUNA collaboration measured the direct capture cross section of this reaction at unprecedented low energy. Upper limits have also been provided for the strengths of two astrophysically important resonances. Based on the results the uncertainty of the ^{22}Ne(p, γ)^{23}Na reaction rate has been reduced by three orders of magnitude, which contributes to the better understanding of the origin of sodium in the Universe.

For an improved modelling of the stellar synthesis of heavy, proton-rich isotopes in the astrophysical γ-process, the study of proton- and alpha-induced reactions is needed. (α, γ) and (α,n) cross sections have been measured for the first time on the ^{191}Ir and ^{193}Ir isotopes using a novel approach. The thick target measurement was combined with the activation method carried out by the detection of the characteristic X-ray emission of the reaction products. By comparing the results with model calculations, reaction rate data can be provided for the astrophysical models and the theoretical calculations can be made more reliable.

Applied Nuclear Physics

With the application of thin SiN foils differential cross sections of proton-induced gamma rays and backscattered protons were determined for Si and N nuclei in the energy range of 3-4 MeV. The quantitative PIGE and NRA analysis of these elements requires accurate cross section data, especially because of the presence of resonances. The measured gamma-ray and particle production cross section data will be available to the ion beam community through IBANDL (Ion Beam Analysis Nuclear Data Library).

The effects of ion irradiation on the chemical, surface and elastic properties of the widely used polydimethylsiloxane (PDMS) polymer were investigated as a function of the ion fluence, induced by high-energy ionizing radiation (2 MeV proton). The infrared spectroscopy measurements showed significant chemical changes in the material: silicatization of the polymer by the formation of an inorganic silica like final product (SiO_x). Atomic force microscopy measurements performed in contact-mode point-spectroscopy showed that the Young's modulus of PDMS can be controlled in the range of 240 MPa to 49 GPa. Compared to the 3-4 MPa of the reference material this indicates a more than four orders of magnitude increase in the elastic modulus of the material.

In collaboration with the Momentum Mobility Research Group of the Research Centre for Humanities (MTA BTK), as well as with Hungarian museums, the composition of Bronze Age gold objects was determined using PIXE analysis, in order to differentiate between the sources of the material. In the frame of the IPERIONCH EU H2020 project, the possible geological sources of prehistoric stone tools was identified. As a part of a multidisciplinary research, mummified bones from the Dominican church of Vác were investigated. Lead poisoning was found in the case of the owner of an apothecary, who deceased in 1763.

A method was developed to produce ^{7}Be radioisotope, and it was successfully applied to various kinds of samples. Sample surfaces irradiated with different doses have been investigated. It was confirmed that the applied particle doses do not damage the sample surface from tribological point of view.

Production circumstances of ^{161}Tb radioisotope have been elaborated utilizing secondary neutrons generated by protons from a low-energy cyclotron. Based on this study, the therapy relevant ^{161}Tb could be easily available for basic medical research in Hungarian centers.

New experimental cross sections have been determined for charged particle nuclear reactions, which will support the establishment of various reference data bases, help to develop proper theoretical models, and will be utilized in practical applications. The investigated target elements are: Al, Ti, Mn, Ni, Cu, Ag, Ir, Pt. Atomki researchers played a determining role in coordinated research projects (CRP) and technical cooperation (TC) programs initiated by the IAEA. The new on-line version of the IAEA Positron Emitter and Gamma-Emitter databases has been prepared. Experimental data have been compiled into the IAEA EXFOR database.

The development and application of Positron Emission Tomography (PET) methods has been carried out in several areas. Radiochemical separation of the ^{52}Mn radioactive PET isotope has been developed for routine production based on ion exchange chromatography. The resulting stock solution was used to test manganese uptake of maize seedlings with a miniPET3 camera, and the visualization of the process was optimized. PET imaging for hybrid maize stress tolerance, which accelerates plant phenotyping to an order of magnitude, has been developed. A PET-based method was used to imitate photosynthesis of corn seed with ^{11}C-labeled carbon dioxide. A dynamic analysis of the conversion of ^{11}C-labeled methanol in an energy cell was performed with a miniPET3 camera, which demonstrated the inhomogeneous functioning of the energy cell. A new method has been introduced to map and analyze the electro-oxidation process of methanol fuel cells to increase cell efficiency.

Both for d+Be neutrons with 3.4 MeV mean energy and for d+D neutrons with 12.5 MeV energy it was found that the relative sensitiviy of the thermoluminescent dose response of the 30Y2O3·30P2O5·40SiO2 vitroceramics is independent of the dose in the 0–100 Gy region. The dose response is a linear function of the dose for gamma photons, but it is non-linear for beta-particles. This material seems to be suitable for monitoring the radiation damage of vitroceramic-based electric insulators and optics, expected to be used in future nuclear technologies.

Atomic and Molecular Physics

Negative ions play important role in fundamental atomic physics, since stable anion formation is governed by electron correlation. In case of fluorine anions Atomki researchers experimentally studied the single photon induced direct Photo Double Detachment (PDD) process, which is a result of electron correlation between the 1s and 2p shells of the F^- ion.

Using the new high-intensity VUV photon source and the ESA-22 3D spectrometer, the energy- and angle-resolved photoelectron distribution was measured for the valence shell electrons of the tetrahydrofuran (THF) molecule in the 2-13 eV electron energy range. This is the first measurement of the angular distribution of photoelectron emission from THF. The theoretical calculations that take multipole interactions into account reasonably reproduced the experimental results.

Unexpectedly large losses of ultracold ground-state molecular samples make it difficult to reach quantum degeneracy experimentally. These losses are large, even when only elastic collisions are expected. An extended theoretical work has been performed for designing ways to suppress inelastic or reactive processes between colliding particles in cold quantum gases. In ultracold collisions of K and Cs atoms it was found possible to map out the possible repulsive excited states, which can be optically coupled by using blue detuned laser field to the initial colliding particle state. This way, one may prevent the atoms to come close to each other, leading to a reduced rate of inelastic collisions.

The low-energy limit of electrostatic spectrometers for measuring molecular fragments is ~2 eV. In many cases, however, the significant energy range is 0.1-2 eV. For covering this range, a large solid angle, free space Time-of-Flight system was developed for measuring both the energy and angular distributions of the fragments. In the first experiment the distribution of the emerged protons from the 20 keV collisions O^{2+} + H^2 was measured in the 35°-145° observation angle range. A good overall agreement was found with the predictions of the statistical collisional model developed by the group earlier.

Production of highly charged ions is limited by plasma instabilities in ion sources. A pioneering experimental campaign was carried out at the Atomki ECR ion source in

INFN/LNS (Catania, Italy) collaboration. The plasma chamber was modified and surrounded by an arsenal of diagnostics tools (including detectors, cameras, and probes). This setup allowed not only to detect the plasma instabilities but also to quantitatively describe them by introducing a new 'instability strength' parameter. Plasma conditions leading to instabilities were identified, which also allowed for damping the intensity and the frequency of the instabilities.

The kinetic modelling of cold ionised media, such as interstellar molecular clouds, planetary atmospheres, fusion and technological laboratory plasmas, relies on electron induced molecular processes. In the framework of multichannel quantum defect theory, dissociative recombination and roto-vibrational excitation cross sections of molecular cations have been determined. Moreover, creation probabilities of generally metastable neutral atomic fragments have been estimated. The obtained data are relevant in cold ionised environments.

Multiple ionization of C^+ ions (C^{1+}+hυ→ C^{1+*}→ $C^{(1+n)+}$+ne, n=1, 2, 3) by single photon impact was investigated by synchrotron (PETRA III) radiation near the K-shell resonant excitation photon energies (hυ=250-330 eV). A series of previously not observed resonantly excited states have been found, which decayed by the emission of 3 electrons. These results are relevant both in astrophysics and life sciences.

Theoretical investigations were carried out for the proton-induced ionization of the H and He atoms, as well as of the H_2 molecule. The calculations were made by means of the classical trajectory Monte Carlo method and the continuum-distorted-wave-eikonal-initial-state model, both extended in the present work for treating molecular collisions. Calculated multiple differential cross sections were found to be in reasonable agreement with experiment. For 1 MeV proton impact the results of the classical and quantum calculations showed excellent agreement with each other and with a set of accurate experimental data as well.

Surface Physics

Catalytic activity and stability of AuPd nanoparticles in formic acid electro-oxidation fuel cells were studied by X-ray photoelectron spectroscopy (XPS) and surface chemical investigations. AuPd nanoparticles were deposited by a polyol method on ZrO_2 decorated and functionalised (with a hydrothermal method) multiwall carbon nanotubes (f-MWCNT). It was found that the ZrO_x nanoparticles are anchored at nanotubes by a non-stoichiometric way, by carboxylic groups through Zr-O-C bonds. The AuPd nanoparticles have a ternary phase (Pd/AuPd/Au). According to the chemical bonds, metallic Pd, Pd oxides (PdO, PdO_2), and Pd-O-Zr phase can be found on the surface of f-MWCNTs.

The method of reflection electron energy loss spectroscopy was used for spectroscopy measurements. The optical constants of transition metals (Cr, Co, Pd), like the refractive index *n*, the extinction coefficient and the complex dielectric function were determined from the energy loss function by the Kramers-Kronig analytical formula. The spectra of graphite samples were modelled by Monte Carlo simulation using the classical transport theory at primary energies of 500-5000 eV. The results were in good agreement with experiments if the secondary electrons were also taken into account besides elastic and inelastic scattering components.

Atomic islands induced by diffusion were observed on surfaces of Ni/Cu nanolayers. A new, unique measuring technique was used for the investigation of nanoscale atomic migration. The activation energy of low temperature nanodiffusion processes was determined, which could not be measured directly by another method up to now. It was also shown that atoms migrated from deep layers of the nanostructure to the surface by grain boundary and surface diffusion processes induced by thermal activation form atomic islands, rather than a continuous layer, as stated previously in the literature.

In the frame of international cooperations, chemical and physical methods were used to modify the surface structure for various purposes of surface functionalization. Surface physics methods were used to qualify surface structure modifications performed by chemical and electro-spray techniques in order to increase the bioactivity on the surfaces of medical implants. Structural and chemical changes induced by low energy sputtering in the surface layer of two-component alloys PbTe, SnTe and GeTe were studied. The role of sputtered particle backflow and of the effect of preferential sputtering originating from atomic mass difference were investigated

Environmental Science

The crystallization age of the Recsk Magmatic Complex has been debated for decades. In the present study, zircon U-Pb ages were determined on various rock specimens and were found to fall consistently between 29.9 and 29.4 million years. Based on apatite and zircon (U-Th)/He age data the former thickness of the cover sequences as well as their erosion history could be estimated. With the help of thermal modelling ~ 1500 m cover thickness, and almost complete erosion by the late Miocene was calculated.

Combined zircon U-Th-Pb and (U-Th)/He dating, petrological and geochemical investigations were applied to refine the eruption chronology of the South Harghita. The obtained eruption ages revealed a large gap in the volcanic activity between 1.6 and 1.0 million years, which was coupled with a sharp change in the geochemical composition. The magmas erupted after the time gap were enriched in potassium and incompatible elements. The extrusions of the small-volume lava domes younger than 1 million years were often separated by prolonged quiescence periods (up to 100 thousand years), which has a large significance in volcanic hazard assessments.

It was found that the ore mineralization in the granitic footwall of the Duluth Complex (Minnesota, USA) is related to positive temperature anomalies of the intrusion. Locally, in the vicinity of magma conduit channels of the gabbroic intrusion, where temperatures exceeded the 900 °C, Cu-Ni-Pt-Pd sulfide liquid penetrated into the granite and formed sulfide deposits. Partial melting of the granitic footwall was only moderately controlled by the F/Cl ratios of the fluids, migrating in the footwall.

A new series of measurements was performed on samples that were part of early measurements on radiocarbon (^{14}C) dating made in 1948–1949. New results showed generally good agreement to the data published in 1949–1951 and their expected ages, despite vast changes in technology. Several samples were dated at four different international acknowledged laboratories, as an intercomparison exercise to demonstrate the state-of-the-art performance and capability of ^{14}C dating nowadays. In addition, new measurements on samples from other Egyptian materials used by Libby and co-workers were also made.

The ^{14}C content in 484 individual tree rings formed in the periods AD 770–780 and 990–1000 and originating from 44 different trees from five continents was measured. Distinct ^{14}C excursions starting in the boreal summer of 774 and the boreal spring of 993 ensure the precise dating of the tree rings. A meridional decline of 11-year mean atmospheric radiocarbon concentrations was identified across both hemispheres. Corroborated by historical eye-witness accounts of red auroras, the results suggest a global exposure to strong solar proton radiation.

A substantive and fluctuating offset was observed in measured radiocarbon ages between plant material growing in the southern Levant versus the standard Northern Hemisphere radiocarbon calibration dataset derived from trees growing in central and northern Europe and North America. This likely relates to differences in growing seasons with a climate imprint. This finding is significant for, and affects, any radiocarbon application in the southern Levant region and especially for high-resolution archaeological dating—especially surrounding the timeframe of the earlier Iron Age. The data point to lower (more recent) ages by variously a few years to several decades.

The eruption of the Thera (Santorini) volcano offers a critically important marker horizon to synchronize archaeological chronologies. Using calendar-dated tree rings, an annual resolution radiocarbon time series was created for the period 1700–1500 BC to validate radiocarbon calibration of materials from key eruption contexts. Results show an offset from the international radiocarbon calibration curve, which indicates a shift in the calibrated age range for Thera toward the 16th century BC. This finding sheds new light on the long-running debate focused on a discrepancy between radiocarbon (late 17th–early 16th century BC) and archaeological (mid 16th–early 15th century BC) dating evidence for Thera.

For the first time, clear evidence was provided of the positive correlation between the tritium concentration of meteoric precipitation and neutron flux modulated by solar magnetic activity. Trends were found in tritium time series for numerous locations worldwide (including that taken in Debrecen since 2001) which are similar to the variation of secondary neutron flux and sun spot numbers. This variability appears to have similar periodicities (12.4±1.8 years) to that of solar cycle (average of the last three cycles is 10.6 ±1.8 years). Frequency analysis, cross correlation analysis, continuous and cross wavelet analysis provide mathematical evidence that the correlation between solar cycle and meteoric tritium does exist.

A high-resolution age-depth model was established for quantitative palaeoclimate study from the Mohos peat bog, East Carpathian mountains. The investigated core presents a continuous 11 m long peat profile, with the best resolution chronology for the Carpathian mountains. For this, a relatively new method, the radiocarbon analysis of cellulose extracted from the Sphagnum fraction was applied. Results show that peat formation started at this area about 12 thousand years ago. Analyses of these core results enable a detailed paleo-climatic investigation of the whole Holocene period.

For the determination of atmospheric fossil CO_2 excess, the concentration and ^{14}C content of CO_2 has continuously been measured at the 10 and 115 m sampling elevations of a rural background station near Hegyhátsál. Based on the results, the atmospheric CO_2 concentration increased at both elevations in the last 10 years, while the ^{14}C content of the samples decreased. At the 115 m elevation, only a slight fossil CO_2 excess could be detected, while at the 10 m elevation, a fossil CO_2 excess of 5 and 2 ppm could be observed in the winter and summertime periods, respectively.

II. b) Science and society

Activities of Atomki reaching the public in 2018 were *Researchers' Night*, *Physicists' Days* and hosting visiting groups.

The central event of *Researchers' Night* (2018.09.28) was a lecture presented by a geochemist colleague, who joined an expedition to the Antarctic. He participated in collecting volcanic rock samples from King George Island, which were later analyzed at the potassium-argon (K/Ar) laboratory of Atomki. The audience of 46 learned how the measurements revealed the geological history of the area from a few hundred thousand to a few hundred million years ago.

Physicists' Days (2018.11.19-23.) were organized for the 39'th time in Atomki. This year's guiding theme was *Science without Borders*. Therefore, the four lectures gave insight into the world of nuclear and particle physics focusing on small sizes, as well as into the infinity of space, which is being discovered by humanity via instruments and theories. The total attendance was 224, ranging from primary school pupils to pensioners. In the morning hours Atomki received visitor groups from 27 schools based in Debrecen and even in some distant cities, to attend some of the 26 different types of unconventional lectures. Altogether 64 lectures were given and 1709 visitor hours were spent. With this one-week program, the institute joined to campaign *Research Institutes with Open Doors* under the nationwide event entitled *Celebration of Hungarian Science*.

Besides the above programs, Atomki hosted 18 groups with 398 visitors this year (primary, secondary school pupils, university students and interested adults), who spent there 892 visitor hours in total. The program was adjusted to the knowledge level and interest of the groups, and it contained lectures accompanied by experiments and laboratory visits. In the visitor centre the main features of radioactivity and its measuring methods were introduced, while cryophysical demonstration taught visitors about phenomena taking place at very low temperature.

The four popular publications written by the researchers of Atomki in 2018 are available on the webpage of Atomki.

Videos recorded during the lectures of *Researchers' Night* and *Physicists' Days* are available at the most popular file sharing portal. These videos attracted about 24 thousand viewings 2018.

In 2018, 80 appearances of Atomki and its researchers were recorded in the Hungarian media.

III. Presentation of national and international R&D relations in 2018

The collaborative research activities of the institute are traditionally carried out in terms of large international collaborations (e.g. CERN-CMS, LUNA, RIKEN, etc.) and bilateral cooperations of various level. Atomki researchers joined three new projects of the International Atomic Energy Agency (IAEA). New government level bilateral cooperations were signed with two French institutes, while the range of inter-institutional collaborations is demonstrated by the fact that Atomki could greet new partners from all five continents. A significant portion of these collaborations is related to radiocarbon dating for archeological and environmental archeological purposes, as well as for research in nuclear environment protection. Altogether close to 1300 such individual samples were measured in 2018.

Among the new domestic cooperations the consortial project signed with the University of Pécs and the Hungarian Academy of Sciences Centre for Energy Research (MTA EK) has to be mentioned. This project is running under the Nationa Excellence Program and aims at preparing for experiments to be carried out at ELI-ALPS (Szeged). Atomki also renewed its cooperation contract with the University of Debrecen. New projects started with certain departments of Széchenyi University (Győr) and the Roland Eötvös University (ELTE, Budapest).

In the commercial sector, MVM Paks Nuclear Power Plant Private Llc. is still the most significant industrial collaborator of Atomki. New contract was signed with TEVA Zrt. (Debrecen).

In 2018, Atomki researchers organized the *Nuclear Physics in Stellar Explosions* workhopot (Debrecen, 12-14 september), and the *International Conference on Many Particle Spectroscopy of Atoms, Molecules, Clusters and Surfaces* (Budapest, 21-24 august). Attendance was 50 and 110 from 15 and 25 countries, respectively.

The International Advisory Committee held its yearly session in Atomki on November 20, when lectures were presented, among others, by foreign members of the staff, as well as by colleagues returning home after a long leave.

Participation in higher education continued to play an important role in the activity of Atomki researchers in 2017 too. This concentrated mainly at the Faculty of Science and Technology of the University of Debrecen. Altogether 44 theoretical and 20 practical courses were held. Atomki hosted 29 PhD, 8 MSc and 19 BSc students in 2015. Altogether 52 Atomki researchers were involved in PhD education, seven of them as ``core members'' of doctoral schools. Five of them belonged to the physics, and two to the informatics doctoral school of the University of Debrecen. The student researcher fellowship program continued in Atomki with the participation of 4 students in the spring and 7 in the autumn semesters.

IV. Brief summary of national and international research proposals, winning in 2018

- *New, shape-related nuclear phenomena,* OTKA K128947, 48 months, 35 860 kHUF
- *Ionization and fragmentation processes in free atoms and molecules,* OTKA K128621, 48 months, 47 754 kHUF

- *Consortional assoc.: Novel tests of the strong interaction with the CERN CMS experiment*, OTKA K129058, 48 months, 11 020 kHUF
- *Symmetries in atomic nuclei: from phenomenology to microscopy*, OTKA K128729, 48 months, 17 900 kHUF
- *β-decays in explosive nucleosynthesis scenarios, OTKA NN128072*, 48 months, 42 268 kHUF
- *Ultrarövid fény- és elektronpulzusokkal indukált atomi és molekuláris folyamatok vizsgálata az ELI-ALPS-nál, módszer- és eszközfejlesztés*, NKFIH 2018-1.2.1-NKP-2018-00010, 48 months, 118 906 kHUF
- *Conservation and protection of ecosystems endangered by lack of thermal and freshwater in crossborder area*, ROHU_29, 24 months, 450 338 kHUF

V. List of important publications in 2018

Tóth G, Vértesi T: Quantum States with a Positive Partial Transpose are Useful for Metrology. PHYSICAL REVIEW LETTERS, 120: 020506 (2018)
https://doi.org/10.1103/PhysRevLett.120.020506

Id Betan R M, Kruppa AT, Vertse T: Shadow poles in coupled-channel problems calculated with the Berggren basis. PHYSICAL REVIEW C, 97: 024307 (2018)
https://arxiv.org/abs/1411.7151

Bene E, Vértesi T: Measurement incompatibility does not give rise to Bell violation in general. NEW JOURNAL OF PHYSICS, 20: 013021 (2018)
https://doi.org/10.1088/1367-2630/aa9ca3

Jentschura U D, Nándori I: Atomic physics constraints on the X boson. PHYSICAL REVIEW A, 97: 042502 (2018)
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