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I. Main duties of the research unit in 2015

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 centers. Considering developments, the main tasks were closing the first phase of the tandetron project, upgrading the laboratory of material science, as well as that of the sample-preparation system at the laboratory of environmental physics. In applied science special focus was on strengthening isotope analyitics and ion-beam physics. Further tasks in 2015 were participating in university education, training of PhD students and international specialists, as well as organizing outreach activities to promote sciences.

II. Outstanding research and other results in 2015

II. a) Outstanding research results

Quantum Physics

The problem of closing the detection loophole in Bell tests using multipartite quantum systems has been studied. Families of multipartite Bell inequalities have been constructed for which the least detection efficiency for their violation could be considerably lowered compared to the bipartite scenario. One research was focused on the N-qubit W state, whereas in an another work a coherent mixture of the W state and the product state has been applied in the Bell test. The obtained results are applicable in communication complexity problems and device-independent quantum information protocols.

The phenomenon of Einstein-Podolsky-Rosen (EPR) steering is a form of nonlocality, which captures the fact that by making a measurement on half of an entangled pair, it is possible to remotely ``steer'' the state of the other half. It has been investigated whether EPR steering can be generalized beyond quantum theory giving rise to the notion of postquantum steering. While provably there is no postquantum steering in the bipartite case, its existence has been proven in case of three parties. The presented results also give new insight into the rich structure of multipartite quantum systems.

A chapter was written for the first monograph on pseudo-Hermitian quantum mechanics after the invitation of Carl Bender, the initiator and leading researcher of the field. The chapter that is close to fifty pages in length, extends the theory and classification of exactly solvable potentials to PT-symmetric complex quantum mechanical problems, and discusses the specific properties of these potentials arising due to non-Hermiticity. These aspects are illustrated by a number of examples from the 15 years' literature of the subject.

The positions of the l=0 S-matrix poles are calculated in generalized Woods-Saxon (GWS) potential and in cut-off generalized Woods-Saxon (CGWS) potential. In the case of the GWS potential the wave functions are reflected at the nuclear radius, therefore the distances of the resonant poles depend on the radius parameter of the potential. In CGWS potential the wave

function can be reflected at larger distance, where the potential is cut to zero and the derivative of the potential does not exist. The positions of most of the resonant poles do depend strongly on the cut-off radius of the potential, which is an unphysical parameter. Only the positions of the few narrow resonances in potentials with barrier are not sensitive to the cut-off distance.

The system of four strongly bound nucleons is called a quartet. Shell-like quartet models give account of the microscopic structure of the quartets. Interacting-boson-type models employ entirely the elegant and efficient group theoretical techniques. Two fully algebraic models were invented for the description of the shell-like quarteting. One of them is a phenomenological model, in which the nucleonic degrees of freedom are not taken into account, while the other one is a semi microscopic approach, which treats the nucleons one-by-one. (The model space of this latter one is a symmetry-governed truncation of the no-core shell model.) The U(3) space-symmetry (of the Elliott model) is used for the description of the excitation spectrum in both cases. Due to its transparent symmetry properties the relation of this quartet model to the shell, collective and cluster models is also well-defined.

Particle Physics and Detector Development

An effective model was developed to describe the localized quark states appearing in the high-temperature quark-gluon plasma phase of strongly interacting matter. An additional feature of this model is that it is capable of describing the qualitative behavior of quark states not only in the quark-gluon plasma, but also in the hadronic phase, and also through the cross-over separating the two. It was also demonstrated that close to the cross-over, the spatial structure of the quark states exhibits a multi-fractal structure similar to that of electron states appearing at the Anderson transition. This research was supported by the *Lendület (Momentum) Program* of the Hungarian Academy of Sciences.

The functional Renormalization Group (fRG) and Conformal Field Theory (CFT) are two succesfull methods to study the phenomena of phase transitions. Zamolodchikov's C-theorem and c-function are the links between fRG and CFT. By investigating the sine-Gordon quantum field theory, the c-function was determined for the first time in the framework of fRG for a non-trivial case. Furthermore, the influence of the truncation effects of fRG on the spontaneous symmetry breaking has been studied.

The concept of the position monitor of the GEM detector has been finalized [GEM_TDR]. This concept, as well as the technical report of the R&D activity to date has been successfully presented at the responsible CMS board. In 2015, approximately 1300 complete measurements were carried out with the position monitors system of the barrel component of the CMS muon detector. The data contribute to increasing the accuracy of the physical analyses. The fiber optic sensor system consisting of about 300 sensors has been operated continuously. The Atomki group took part in the calibration of the pixel detector of the CMS, and also carried out its synchronization.

The LIGO constructed in the USA is currently the most effective gravitational wave detector on Earth. This observatory is where the first detection of theoretically predicted energetic cosmic processes, like the merging of two black holes, could take place. An Atomki team joined the LIGO Physical Environment Monitoring system as a member of the Eötvös

Gravity Research Group, where they participate in the operation and development of the infra-sound microphones, as well as in the evaluation of signals obtained from them.

Nuclear Physics

One of the currently most active topics in low-energy nuclear physics studies is to reveal the features of nuclei far away from stability in the vicinity of ^{78}Ni, which is expected to be doubly magic, and to explore the effects of the significant neutron-excess in these nuclei. The researchers of Atomki joined international collaborations to study the structure of heavy iron, cobalt and copper nuclei in beta-decay and radioactive beam induced reactions at the RIKEN Nishina Center in Japan, as well as via transfer reactions at the National Heavy-Ion Accelerator Center GANIL in France. On the basis of the obtained results, rearrangements in the energies of the single-particle states due to the neutron-excess could be found.

The β decay of ^{192,190}Pb has been studied using the total absorption technique at the ISOLDE (CERN) facility. Combining the measured data with QRPA theoretical calculations allows to infer that the ground state of the ^{190}Pb and ^{192}Pb isotopes is spherical. These results represent the first application of the shape determination method using the total absorption technique for heavy nuclei, and in a region where there is considerable interest in nuclear shapes and shape effects.

To study the Gamow-Teller (GT) transitions from the Tz = +1 nucleus ^{42}Ca to the Tz = 0 nucleus ^{42}Sc, a (p,n)-type (^{3}He,t) charge-exchange reaction was performed at 140 MeV/nucleon and scattering angles around 0^{o}. The main part of the observed GT transition strength was found to be concentrated in the lowest 0.611 MeV, $J^{\pi}= 1^{+}$ GT state. Random-phase-approximation calculations including an attractive isoscalar interaction showed that the 0.611 MeV state can be interpreted as a "*low-energy super-Gamow-Teller state*." Assuming an isobar-analogous structure in A = 42 isobars, analogous T = 1, 1 + states are also expected in ^{42}Ca. Based on the ^{42}Ca(p,p) spectra measured at 0^{o}, this strength is distributed over the 10–12 MeV region of ^{42}Sc.

The perspectives for the planned photo-nuclear experiments at the new Extreme Light Infrastructure - Nuclear Physics (ELI-NP) facility were published. The novel and high-precision data expected from these experiments are indispensable in various applications of nuclear physics too. The parameters of the ELI-NP gamma beam system, as well as the emerging experimental program were presented. Experiments planned with the nuclear resonance fluorescence technique were discussed, together with photo-nuclear reaction measurements, photo-fission experiments, the study of nuclear collective excitation modes and the competition between various decay channels.

The structure of neutron-rich Br and La nuclei obtained from the cold neutron induced fission of ^{235}U was investigated using the EXILL Ge detector array deployed at the Institut Laue-Langevin (ILL), Grenoble. For the first time, medium-spin excited levels were identified in ^{88}Br. The ground state of this nucleus was proposed to be 1^{-}, changing the adopted (2^{-}) value. The newly observed low-energy levels were interpreted as members of the $\pi p_{3/2} \nu (d_{5/2})^3$ and $\pi f_{15/2} \nu (d_{5/2})^3$ multiplets. At higher energy, the coupling of the $g_{9/2}$ proton to the $(d_{5/2})^3$ seniority-3 multiplet was demonstrated.

The $^{22}Ne(p,\alpha)^{23}Na$ reaction is the experimentally least known component in the neon-sodium cycle of hydrogen burning due to unobserved resonances in the Gamow window. For the first time, LUNA collaboration directly detected three new resonances at energies of 156.2 keV, 189.5 keV and 259.7 keV, and determined their strengths with 2-7% uncertainty. In addition, upper limits for three other resonances were greatly reduced. The derived new reaction rate is a factor of 20 higher than the recent evaluation at a temperature of 0.1 GK, and this may have considerable influence on the description of nucleosynthesis in asymptotic giant branch stars.

The heavy, proton-rich isotopes are produced in the astrophysical gamma process. The synthesis of these *p*-isotopes is simulated by large nuclear reaction networks. The necessary cross section data are supplied by the Hauser-Feshbach statistical model, which requires a global optical potential. The cross sections of the $^{107}Ag(\alpha,\gamma/n)$ and $^{164,166}Er(\alpha,n)$ reactions were measured to investigate the reliability of the model predictions. It was found that the theoretical reproduction of the experimental data requires the introduction of a new term in the imaginary component of the alpha-nucleus optical potential. This improvement may have strong influence on the isotopic abundances obtained from gamma process networks.

Knowledge on the $^{18}F(p,\alpha)^{15}O$ cross section at astrophysical energies is crucial to understand the nova explosion phenomena. The investigation of this cross section is not feasible using direct techniques at the required low energy, because the intensity of radioactive beams is too low compared to that of stable beams. Therefore, the Trojan horse method was applied for the first time to a radioactive ion beam induced reaction studying the $^{18}F(p,\alpha)^{15}O$ process at low energies relevant to astrophysics, via the three-body reaction $^{2}H(^{18}F,\alpha^{15}O)n$. As a result, the spin-parities were assigned to all relevant levels.

Applied Nuclear Physics

Various 3D structures were fabricated in liquid PDMS polymer by multiple tilting of the substrate to the irradiating microbeam. As a result, very smooth, high aspect ratio and stable microstructures can be formed. At the irradiated areas the adhesion, elastic modulus and the refractive index change as well, because of the ion irradiation induced chemical processes, depending on the applied ion fluence. The aspect ratio of PDMS pillars created by casting method is very limited because of the low Young's modulus of the elastomer made with the commercial cross-linker. With PBW method, applying appropriate proton fluence, the aspect ratio of the micropillars can be significantly increased.

The external microbeam set-up was installed as the extension of the existing microprobe. The external beam set-up, based on the system of Oxford Microbeams, is equipped with two X-ray detectors for PIXE analysis, a digital microscope, two alignment lasers and a precision XYZ stage. Exit windows with different thicknesses and of different materials are used according to the actual demands. It was shown that the integrated charge could be measured reliably by a beam chopper installed in the vacuum chamber through which the beam is extracted. The applicability was demonstrated in the field of archaeometry, on Bronze Age hoards from Hungary.

The application of the miniPET3 camera was extended for the visualization of biochemical processes in plants. ^{11}C-methionine and $^{64}CuCl_2$ PET compounds were used to study the uptake and translocation of amino acids and microelements in maize. The heterogenic catalytic transformation of ^{11}C-labelled methanol was studied on metal oxide catalysts in

collaboration with the Bulgarian Organic Chemistry Department. The high resolution MiniPET-3 camera, developed in ATOMKI, was used for monitoring of catalytic processes in collaboration with the Technical University, Eindhoven.

Quality assurance system for the production of $^{55}CoCl_2$ solution prepared for medico-biologic experiments was developed, and the specific activity of the end product, as well as the concentration of the contaminating transient metals was determined. New method was developed for separation of ^{163}Ho from the irradiated Erbium, in collaboration with Indian researchers in the frame of international collaboration ECHO, which was established for the measurement of neutrino mass. Collaborating with the institute NECSA, South Africa, the dominant effect of Auger electrons was experimentally proven in the releasing process of daughter radio-isotopes using $^{103}Pd/^{103m}Rh$ *in vivo* generators.

Study of proton and deuteron induced nuclear reactions important for optimization of radio-nuclide production for nuclear medicine and for various nuclear technologies have been continued first of all, on rare-earth target materials. New activation cross sections and production yields data were provided on Ag, Al, Ba, Cd, Ce, Cu, Er, Hg, La, Lu, Mo, Nd, Pd, Pr, Sn, Sr, Ta, Tb, Ti, Tm, Zn and Zr materials. The experimental data were included in recommended nuclear reaction cross section data libraries, and were compared with predictions of nuclear theories. The investigated reactions are related to the production of diagnostic and therapeutic medical radio-isotopes, accelerator and target technology, thin layer activation, nuclear analytical technology and astrophysics.

The sensitivity to neutrons of a Mg-Ar and a tissue-equivalent ionization chamber relative to their sensitivities to γ-photons and the neutron response function of a detector with an NE-213 scintillator and a digital signal processor were measured with quasi-monoenergetic d+D neutrons at E_n = 9.5 and E_n = 12.1 MeV. An arrangement was developed at the p+Be neuron source at the MGC-20E cyclotron for irradiation testing of fission chambers. Fluxes of neutrons and ions escaping H-mode plasmas of the KSTAR tokamak (NFRI, Daejeon, Republic of Korea) were measured, testing a potential plasma diagnostics technique for ITER. The IAEA and literature data bases were extended by cross section data, mainly from proton and deuteron induced nuclear reactions.

Atomic Physics

In an earlier study the ionization of Li by 1.5 MeV/amu O^{8+} ions was investigated. Good agreement was found with the experimental results from perturbative and coupled-channel calculations based on an extended independent electron model. Last year similar treatment was applied to the Li^{2+} - Li collisions at 2290 keV/amu. Similar to the O^{8+} case, it was found that the outer-shell ionization is realized via a single-step process. However, for the inner-shell ionization the theoretical models failed to reproduce the experimental results, which might indicate the significant role of multi-electron processes involving ionization from the valence shells.

The classical trajectory Monte Carlo (CTMC) method is one of the most efficient theoretical models of the atomic collision processes. In the previous years the atomic CTMC was successfully extended for the description of collisions between ions and simple molecules (water, methane). The latest results concerning scattering of fast (1 MeV) protons on an RNA base molecule, uracil demonstrated the applicability of the CTMC method for the

treatment of the ion induced ionization of large molecules. As a new feature of the model, the interactions with the molecule core were described by a multi-center potential built from screened atomic potentials. The results were compared with experimental data and with the predictions of quantum mechanical theories.

It was shown that negative ions are ejected from gas-phase water molecules when bombarded with positive ions at keV energies, typical of solar-wind velocities. This finding is relevant for studies of planetary and cometary atmospheres, as well as for radiolysis and radio-biology. Emission of both H^- and heavier (O^- and OH^-) anions, with a larger yield for H^-, was observed in 6.6 keV $^{16}O^+ + H_2O$ collisions. The experimental setup allowed separate identification of anions formed in collisions with many-body dynamics from those created in hard, binary collisions. Most of the anions were emitted with low kinetic energy due to many-body processes. Model calculations showed that both nucleus-nucleus interactions and electronic excitations contribute to the observed large anion emission yield.

In the frame of an EU-FP7 collaboration, an important experiment was carried out in 2014 in the ECR Laboratory jointly by the Atomki ECR team and by an Italian group (INFN, Catania). It was investigated that what kind of X-ray radiation is released by the plasma of the ECR ion source at different plasma setting modes. Based on the analysis of these results in 2015, a more exact answer can be given to the question of where, how, when and why the highly charged ions of the plasma are created.

Multiple ionization/excitation of C^+ ions subsequent to absorption of a single photon was investigated by measuring final ionic charge state C^{q+} (q=2,3,4). The production of C^{q+} ions was associated with the rearrangement of the resonantly excited K-shell denoted as C^{+*} $1s^12s^22p^2$ (^2P, ^2D), where, in addition to the single-Auger electron emission, double- and triple-Auger decay channels are also allowed. The observation of the C^{4+} ion is the first unambiguous confirmation for the existence of triple-Auger decay.

The behavior of ions guided by electric charge up and transmitted through capillaries of a few microns in a millimeter thick glass plate has been studied as the function of time. In the beginning of the charge up process, a chaotic behavior was observed: the ions were transmitted in several separate beams, which appeared instantaneously and then disappeared suddenly, meanwhile their direction was changing. After a while they merged to a stable and relatively homogeneous single beam. The transition to stable beam occurred earlier as the ion energy was increased. The reason for the chaotic behavior is still an open question. It is likely that the disturbing effect of neighboring capillaries and the overcharge due to the low conductivity plays a role in it.

Applications in Atomic Physics, Solid State Physics, Surface Sciences

A deactivation-resistant Pd-ZrO_2/f(functionalised)-MWCNTs catalyst was obtained for formic acid electrooxidation in direct formic acid fuel cell (DFAFC). It was found that the highest stability was obtained for a catalyst without any further treatment after synthesis. In deactivation experiments this catalyst demonstrated the highest activity, in spite of the fact that its initial activity was lower than for catalyst without ZrO_2 addition (Pd/f-MWCNTs). The lower initial activity of the Pd-ZrO_2/f-MWCNTs catalysts can be attributed to the presence of non-conductive ZrO_2 nanoparticles incorporated into the carbon nanotubes support.

A new analysis was performed for the X-ray excited KLL Auger spectra of Cu and Ni metals measured earlier. An improved description was used for the effects of inelastic scattering of the electrons in the solids, applying complex peak shapes for the satellite structure of each diagram line. The contributions from surface, bulk, intrinsic and extrinsic plasmon excitations were deconvoluted using the Partial Intensity Analysis method and energy loss distributions obtained from experimental reflection electron energy loss spectra of the same samples. The relative Auger-transition energies derived from the analysis were in good agreement with previous experimental works and the results of cluster molecular orbital multi-electron calculations. The intensity ratio $I(^3P_2/^3P_0)$ agreed with the result of relativistic calculations better, than those reported earlier. Four satellite peaks were identified at the low-energy side of each Auger diagram line of Ni.

Using X-ray photo-electron spectroscopy (XPS), the relation between the electronic structure and the optical/electric properties was studied in the case of graphene-like GeS nanolayers. It was proven that a surface oxidation process regulated precisely was a necessary step to form an optimal structure. After heat treatment, an increase in oxygen concentration was detectable, which did not change due to illumination by a laser beam. In the case of the $As_{20}Se_{80}$ system, measurements at 4-77 K proved that photo induced mass transport takes place at low temperatures as well. The diffusion activation energy characterizing the process was also determined.

In the ECR Laboratory of Atomki, regions enriched in Si were created by Si ion beams on the surface of medical Zr ceramics, with the purpose of increasing the adherence of the Zr ceramics to other materials. It was shown that due to the insulator nature of the Zr, it was necessary to place a stainless steel grid over the sample surface to achieve a proper surface conductivity, which can result an adequate quantity and depth distribution of the Si. Furthermore, the change of the bio-activity of Ti surfaces bombarded by Ca+Si ions was studied. It was found that the surface modified by ions penetrating into several tens of nm depth shows a more favorable and better bio-active behavior, than the original Ti surface.

Environmental Physics

Cellulose based ^{14}C dating has been performed on 10 meter deep peat profile from Mohos peat bog (East Carpathians, Romania). The peat sediment of Mohos represents a period from 11.500 calendar year B.P. to present based on radiocarbon dating, so the accumulation rate of the peat and the preserved isotopic climate information cover the whole period. From the ^{18}O content of the peat-cellulose conclusions can be drawn on the complex climatic changes, while the ^{13}C isotope composition reflects the wetness periods of the past. The examined peat sample clearly shows that warming occurred during the late-Pleistocene, based on increasingly negative carbon and oxygen delta values as going back in time.

The effect of a large scale construction work on urban aerosol pollution was investigated in the city of Debrecen, Hungary during the years of a recent tramline constrution. It was found that the effects of the construction were local (500-1000 meters), and did not expand to the whole city. In the immediate neighborhood of the construction site aerosol concentration was 20 to 30 times higher than the background urban values further away. The elemental composition of atmospheric particulate matter did not change significantly during the construction, while the local concentration of Mn, Cr, Fe and Ni exceeded the mean values of

the previous years considerably. Furthermore, occasionally extremely high lead and heavy metal concentration were measured.

Anomalous behavior of the spatial and temporal variations of radon was found in the air of some dry carbon dioxide spas (ie. Bardócz Mofette, Hargitafürdő Mofettes) located in the vicinity of Harghita and Ciomadul Mountains in Transylvania. The observations were interpreted assuming at least partially different sources, entry points and fluxes of radon and carbon dioxide gases entering the pools of the mofettes. These results can be applied to optimise the design of the pool geometries. The use of personal radon dosimetry was recommended to the spa staff members, without which uncertainty in the estimates of personal radon exposures could reach one order of magnitude.

During the environmental isotope investigation of groundwater samples from the Turonian Aquifer of Tadla Basin, Morocco, it was confirmed that the recharge of all these water samples occurred during the Holocene. The calculated noble gas solubility temperatures of the confined part of the aquifer are varying around the recent mean annual soil temperature, while the noble gas temperatures of the unconfined part of the aquifer are a few degree C higher than expected. Based on these data, it was concluded that the Turonian aquifer might be a potential place for Late-Pleistocene palaeoclimate reconstruction, in case the research area is extended in the direction of flow-path towards the western part of the basin, and towards the foothills of the Phosphates Plateau.

The geological background and anhtropogenic concentration, as well as the daily amount of gadolinium were determined in the waste water of Debrecen. Known amount of contrast agent analogue was released into the waste water canal system, and the concentration and amount were monitored at different stages of waste water treatment. The average concentration of Gd in the waste water remained unchanged after removing solid particles. The amount of anthropogenic gadolinium was 60-70% of the total. Strong correlation was found between the amount of contrast agent used daily, and the quantity of anthropogenic gadolinium measured at the incoming sampling point of waste water plant. The waste water technology could not decrease significantly the concentration of anthropogenic gadolinium, so it finds its way through the waste water plant to the surface waters.

There is an EU directive concerning the reduced use of fossil based fuels, as well as placing this process under the control of authorities. A novel methodology was developed by Atomki researchers to use a simplified AMS technique based ^{14}C analytical method to quantify and verify the biogenic component portion in mixed fuels. Analytical parameters, like robustness, reproducibility, efficiency, scattering, overall uncertainty and detection limit of the novel method were studied using real mixed fuel samples with various biogenic content obtained form the MOL Company. The typical analytical 1 sigma error is +/- 0.2-0.3 m/m % for the biogenic content, even if the mixture has less than 10% biogenic compounds.

New K-Ar radiometric age data proved, that - contemporaneously with the formation of the Western Carpathians - about 15 million years ago, geochemically and petrologically comparable intrusions formed at shallow depth in the External Carpathians, which have rather similar volcanological features. The radiometric age data confirmed that considering the age of the 600 km long magmatic belt, an evolution trend can be observed from Northwest to Southeast. This trend is comparable, and therefore is probably genetically related to the evolution of the Carpathian Basin during the Neogene Epoch.

Four different sulfide mineral assemblages have been distinguished in the charnockitic footwall of the South Kawishiwi intrusion (Duluth Complex, Minnesota, USA) on the basis of mineralogical, petrological and geochemical studies. Formation of three of the mineral assemblages [pirrhotite- pentlandite-chalcopyrite; chalcopyrite-pyrrhotite and the bornite-chalcopyrite-millerite- PGE (PGE=platinum group element) mineral assemblage] up to 100 m from the intrusion-footwall contact can be associated to the formation of the secondary permeability of the granitic footwall rock. The partial melting and the formation of the secondary ``permeability'' of the footwall granite took place ate 600-1000°C. The mineral assemblages listed above prove that the footwall of the Duluth Complex is locally enriched in Cu and precious metals; therefore the exploration for base and precious metal (platinum, gold) deposits at in the footwall of the Duluth Complex is promising.

Tertiary remobilization of footwall hosted secondary Cu-Ni-PGE mineralization was investigated in one drill core from the Spruce Road deposit (South Kawishiwi intrusion, Duluth Complex, Minnesota, USA). Formational fluid flow, subsequently to the formation of the Duluth Complex remobilized the secondary mineralization and deposited a tertiary assemblage characterized by the pyrite-magnetite-chalcopyrite assemblage. The ore mineralization is associated to local greenschist facies alteration of the host rock dominated by quartz, calcite, prehnite, pumpellyite and chlorite. Pressure and temperature conditions were around 200-250°C and 500-700 bar. Sulfur isotope studies clearly confirm the genetic differences between the secondary (8‰) and tertiary (4 –5‰) mineralization processes.

II. b) Science and society

In 2015 Atomki reached the general public via the dissemination project, the programs of Researcher's Night and Physicists' Days, as well as by hosting visitor groups.

Within the framework of the dissemination project ``*Distribution of Atomki's Scientific Results – Comprehensible-Available Physics''* (TÁMOP-4.2.3-12/1/KONV-2012-0057), an interactive film entitled ``*Miasma - Devil's Stone''* was created. In this computer adventure game the investigation is about the famous meteorite landing near Debrecen in 1857, and the mystery can be unveiled only using the scientific instruments of Atomki. Players may get help throughout the game from various hints. In order to advance in the game, logical thinking and some knowledge in physics and natural sciences are necessary. The DVD of the interactive film was distributed as a free appendix enclosed to the April issue of the popular Hungarian science journal *Természet Világa*.

The first performance of the adventure game was organized in February in a cinema hall, which was filled with secondary school students and teachers invited from from Debrecen and its surroundings. Before the premiere, the audience had an opportunity to test the game on computers. Later the creators of the film were introduced and some parts of the film were screened as illustration. Videos, both short and long taken at this event are available on the internet.

Within the framework of the same project, a booklet for children entitled ``*Litte Johnny's questions about physics''* was published. It presents a discussion between a small boy and his father about everyday phenomena and their explanation. It contains many illustrations and is reminiscent of the popular TV classes of Professor Öveges from the sixties and seventies.

The same project gave opportunity to create the new web page of Atomki, where the main menu entitled ``*Physics for everyone''* targets anyone interested in physics. The virtual tour is a special element of the web page, introducing those facilities and laboratories of the institute, which are not accessible for visitors. Each laboratory has a film ``*how does it work?''* and ``*what is it for?''*, furthermore, the virtual visitor is free to choose several viewpoints to look around and to read brief descriptions of the instruments.

The ten popular publications written by Atomki researchers in 2015 are available on the web page. Most of them were published in *Természet Világa*, while one appeared in the Hungarian edition of *National Geographic*.

On Researcher's Night a lecture was presented about a joint 2014 expedition of Atomki researchers and the divers of the Hungarian Defence Forces. The goal of this expedition was to map the sediment of several tarns in the Retyezát mountains in Romania.

The 2014-15 season of the István Hatvai Physics Competition for secondary school pupils was organized under the patronage of Atomki. Atomki researchers contributed to the success of this prestigeous problem solving competition (named after a renowned 18'th century physics professor of the Debrecen Reformed College) by submitting problems and correcting solutions. The closing ceremony also took place in Atomki.

The Physicists' Days in Atomki were organized for the 36'th time, this time dedicated to the International Year of Light. With this program the institute joined to campaign ``*Research Institutes with Open Doors''* within the framework of the nationwide Celebration of Hungarian Science. The lectures about light were attended by primary school pupils and seniors as well, altogether by an audience of 269 during the four days. In the mornings school groups from Debrecen and its surroundings arrived to see some of the 26 different unconventional physics classes. 46 classes were delivered, and altogether 1345 visitor hours were spent.

Besides the above program Atomki hosted 22 groups with 642 visitors this year (primary, secondary school pupils and university students, interested adults), who spent there 1983 visitor hours. The company of 55 Greek secondary school students earned the unofficial title for the group arriving from the farthest place. The main attractions were the demonstration of radioactivity and its properties at the Visitor Center, and cryophysical experiments illustrating phenomena taking place at very low temperature.

III. Presentation of national and international R&D relations in 2015

Besides large-scale international collaborations (e.g. CERN-CMS, LIGO-EGRG, LUNA, etc.) bilateral cooperations play an important role in the operation of Atomki. The latter were broadened by new French (CNRS), Polish (PAN), Japanese (RIKEN, Sapporo University) and South African (NECSA) connections.

In September Atomki hosted the meeting Sign (*Sign Problem in QCD and Beyond*) 2015, which was the fourth in the series of international workshops organized in every one and a half years. Atomki also hosted the INARIE (*Integrating Access to Pan-European Research Infrastructures in Central and Eastern Europe*) and *Atomki for ELI* workshops in December and April, respectively. The PIPAMON 2015 (*Photon and fast Ion induced Processes in Atoms, MOlecules and Nanostructures*) workshop in March and the 3rd XLIC General Meeting (XUV/*X-ray Light and Fast Ions for Ultrafast Chemistry*) in November were also organized by Atomki.

There were five foreign visitors spending at least 3 months in Atomki (one each from Austria,

China, Iran, Romania and Ukraine), including Joachim Burgdörfer from the Vienna Technical University, who arrived for five months within the *Distinguished Guest Scientist Fellowship Programme* of the MTA (Hungarian Academy of Sciences). Atomki also received an MTA *Domus* fellow from the University of Uzhgorod, Ukraine.

The International Advisory Committee held its yearly session in Atomki on November 30, when it discussed the state of research in particle physics and applications in atomic physics.

Participation in higher education continued to play an important role in the activity of Atomki researchers in 2015 too. Altogether 39 of them contributed to this by holding 1008 classes within 62 courses and 535 practical classes within 30 courses. Atomki hosted 16 PhD, 6 MSc and 14 BSc students in 2015, while 5 students were involved in extra-curricular research work. Atomki researchers spent altogether 5625 hours on supervising students. The student researcher fellowship program continued in Atomki with the participation of 8 and 6 students in the spring and autumn semesters, respectively. Besides the University of Debrecen, Atomki researchers participated in the educational and/or research activity of the universities of Szeged, Miskolc, Győr, as well as in that of the Budapest University of Technology and Economics and the University of West Hungary.

Altogether 45 Atomki researchers were involved in PhD education, six of them as ``core members'' of doctoral schools. Three of them belonged to the physics, and two to the informatics doctoral school of the University of Debrecen, while one belonged to the environmental physics doctoral school of the University of West Hungary.

Among research institutes, Atomki traditionally has strongest links with the Wigner Research Centre for Physics, while ELI-ALPS (Extreme Light Inftrastructure, Attosecond Light Pulse Source, Szeged) can be named as a new partner. MVM Paks Nuclear Power Plant Private Llc. is the most significant industrial collaborator of Atomki.

IV. Brief summary of national and international research proposals, winning in 2015

The tandetron accelerator of the Atomki Accelerator Centre was inaugurated by the president of the Hungarian Academy of Sciences in December 2015. This new instrument was financed by an infrastructure grant of the HAS, won by a consortium of several research groups. Currently only a simple beam channel system is installed to it, which is expected to be developed further, possibly from further grants. It will be used for a wide range of fundamental and applied research activity in atomic and nuclear physics, nuclear astrophysics, ion-beam analytics and micro-engineering.

The major projekts starting in 2015 in Atomki are:

- IPERION CH (*Integrated Platform for the European Research Infrastructure ON Culture Heritage*). This Horizon 2020 project started in September 2015 with the total budget of 94.25 k EUR.
- *ESS (European Spallation Source), RF-LPS system integration,* December 2015, 2.2 M EUR.
- *Multipartite nonlocality,* OTKA, K111734, January 2015, 48 months, 17.223 k HUF.
- *Lattice quantum chromodynamics with chiral fermions*, OTKA, K113034, January 2015, 48 months, 24.511 k HUF.
- *Atomic nuclei in extraordinary conditions*, OTKA, NN114454, April 2015, 36 months, 20.946 k HUF.

V. List of important publications in 2015

Cseh J.: Algebraic models for shell-like quarteting of nuclons. Phys Lett B, 743: 213. (2015) http://arxiv.org/abs/1409.0124

Lévai G.: PT symmetry in Natanzon-class potentials. Int J Theor Phys, 54 paper 2724. 36 (2015) http://real.mtak.hu/30453/

Pál K.F., Vértesi T.: Closing the detection loophole in tripartite Bell tests using the W state. Phys. Rev. A, 92, paper 022103 (2015) http://arxiv.org/abs/1504.05934

Khachatryan V., Bencze Gy., Hajdu C., Hidas P., Horváth D., Siklér F., et al. (2811), Béni N., Karancsi J., Molnár J., Pálinkás J., Szillási Z., Makovec A., (CMS+LHCb Collaboration): Observation of the rare $B_s^0 \rightarrow \mu^+\mu^-$ decay from the combined analysis of CMS and LHCb data. Nature 521 7551:68-72 (2015)
OA: http://www.nature.com/nature/journal/v522/n7554/full/nature14474.html

Giordano M.: Renormalization of gauge theories on general anisotropic lattices and high-energy scattering in QCD. Phys Rev D, 92: 034514 (2015) http://arxiv.org/abs/1506.04529

Aad G., Krasznahorkay A. Jr., Pásztor G., Bencze Gy., Hajdu Cs., Házi A., et al. (5132) Horváth D., Béni N., Czellár S., Karancsi J., Molnár J., Szillási Z., Makovec A., (ATLAS+CMS Collaboration): Combined measurement of the Higgs boson mass in pp collisions at $\sqrt{s}$ = 7 and 8 TeV with the ATLAS and CMS experiments. Phys Rev Lett, 114: 1803 (2015) http://arxiv.org/pdf/1503.07589.pdf

Defenu N., Mati P., Marian I.G., Nándori I., Trombettoni A.: Truncation effects in the functional renormalization group study of spontaneous symmetry breaking. JHEP 2015: 141. (2015) http://arxiv.org/abs/1410.7024

Újfalusi L., Giordano M., Pittler F., Kovács T.G. and Varga .I: Anderson transition and multifractals in the spectrum of the Dirac operator of Quantum Chromodynamics at high temperature. Phys Rev D, 92: 094513 (2015) http://arxiv.org/abs/1507.02162

Vajta Zs., Dombrádi Zs., Elekes Z., Aiba T., Nori Aoi., Baba H., et al. (21)., Fülöp Zs., Sohler D.: Gamma-ray spectroscopy of ^{19}C via the single-neutron knock-out reaction. Phys Rev C, Nucl Phys 91: 064315 (2015) http://arxiv.org/abs/1504.07394

Kiss G.G., Szücs T., Raucher T., Török Zs., Csedreki L. Fülöp Zs. Gyürky Gy., Halász Z.: Measurement of (α,n) reaction cross sections of erbium isotopes for testing astrophysical rate predictions, J Phys G 42: 055103 (2015) http://arxiv.org/abs/1503.01853

Ornelas A., Kiss G. G., Mohr P., Galavíz D., Fülöp Zs., Gyürky Gy., et al. (5) Máté Z., Somorjai E.: The ^{106}Cd(α, α)^{106}Cd elastic scattering in a wide energy range for gamma process studies, Nucl Phys A: 940, 194 (2015) http://arxiv.org/abs/1504.07703

Elekes Z., Tímár J: Nuclear Data Sheets for A = 128, Nucl Data Sheets 129: 191-436 (2015) doi:10.1016/j.nds.2015.09.002

Cavanna F., Depalo R., Aliotta M., Anders M., Bemmerer D., Best A. et al., (27) Elekes Z., Fülöp Zs. Gyürky Gy., Somorjai E., (LUNA Collaboration) : Three new low-energy resonances in the ^{22}Ne(p,γ)^{23}Na reaction. Phys Rev Lett 115: 252501 (2015) http://arxiv.org/abs/1511.05329

Santamaria C., Louchart C. , Obertelli A., Werner V., Doornenbal P., Nowacki F., Authelet G. et al. (60), Dombrádi Zs., Vajta Zs: Extension of the N=40 Island of Inversion towards N=50: Spectroscopy of ^{66}Cr, ^{70,72}Fe, Phys Rev Lett 115: 192501, (2015) http://www.osti.gov/pages/biblio/1224927-extension-island-inversion-towards-spectroscopy-cr-fe

Larusso G., Nishimura S., Xu Z.Y., Jungclaus A., Shimizu Y., Simpson G. et al (68) Vajta Zs.: β-Decay Half-Lives of 110 Neutron-Rich Nuclei across the N=82 Shell Gap: Implications for the Mechanism and Universality of the Astrophysical r Process. Phys Rev Lett 114: 192501 (2015) doi: 10.1103/PhysRevLett.114.192501

Benzoni G., Morales A. I., Watanabe H., Nishimura S., Coraggio L., Itaco N., et al (42) , Dombrádi Zs., Kuti I., Sohler D., Vajta Zs.: Decay properties of ^{68,69,70}Mn: Probing collectivity up to N = 44 in Fe isotopic chain, Phys Lett B: 751, 107-112, (2015)
OA: http://www.sciencedirect.com/science/article/pii/S0370269315007765

Morfouace P., Franchoo S. Sieja K., Matea I., Nalpas L., Niikura M., Dombrádi Zs., et al (39), Sohler D., Vajta Zs.: Evolution of single-particle strength in neutron-rich ^{71}Cu, Phys Lett B 751: 306-310, (2015) http://franchoo.web.cern.ch/franchoo/physics/plb751.pdf

Corsi A., Boissinot S., Obertelli A., Doornenbal P., Dupuis M., Lechaftois et al. (54) Sohler D.: Neutron-driven collectivity in light tin isotopes: Proton inelastic scattering from ^{104}Sn. Phys Lett B 743: 451 (2015) OA doi: doi:10.1016/j.physletb.2015.03.018

Huszánk R., Rajta I., Cserháti Cs.: Direct formation of high aspect ratio multiple tilted micropillar array in liquid phase PDMS by proton beam writing. Eur Pol J 69: 396 (2015) http://real.mtak.hu/29234/

Huszánk R., Rajta I., Cserháti Cs.: Proton beam lithography in negative tone liquid phase PDMS polymer resist. Nucl Instr Meth B 348: 213 (2015) http://real.mtak.hu/29235/

Csedreki L., Szíki G.Á., Szikszai Z., Kocsis I.: Resonance parameters of the reaction ^{12}C(d,pγ)^{13}C in the vicinity of 1450 keV for accelerator energy calibration. Nucl Instr Meth B 342: 184-187 doi:10.1016/j.nimb.2014.09.038

Tárkányi F., Hermanne A., Takács S., Ditrói F., Ignatyuk A. V.: Activation cross-sections of proton induced reactions on natSm up to 65 MeV. Nucl Instr Meth B 346: 26-44 (2015) http://real.mtak.hu/32183/

Ditrói F., Tárkányi F., Takács S., Hermanne A.: New developments in the experimental data for charged particle production of medical radioisotopes. J Radioanal Nucl Chem 305: 247-253 (2015) http://arxiv.org/abs/1503.00919

Neppl S., Ernstorfer R., Cavalieri A. L., Lemell Ch., Wachter G., Magerl E., et al. (10), Burgdörfer J: Direct observation of electron propagation and dielectric screening on the atomic length scale.
Nature 517: 342-346 (2015) http://tqd.itp.tuwien.ac.at/fileadmin/t/tqd/papers/nature14094.pdf
Sarkadi L: Classical treatment of the electron emission from collisions of uracil molecules with fast protons, Phys Rev A 92: 062704 (2015) doi: 10.1103/PhysRevA.92.062704

Nagy G.U.L., Rajta I., Bereczky R.J., Tőkési K.:Incident beam intensity dependence of the charge-up process of the guiding of 1 MeV proton microbeam through a Teflon microcapillary, Eur Phys J D 69: 102 (2015) doi: 10.1140/epjd/e2015-50718-3

Herczku P., Juhász Z., Kovács S. T. S., Rácz R., Biri S., Tóth J., Sulik B.: Guiding of Ar^{7+} ions through a glass microcapillary array. Nucl Instr Meth B 354: 71-74 (2015) doi:10.1016/j.nimb.2014.11.004

Müller A., Borovik A., Buhr T., Hellhund J., Holste K., Kilkoyne A. et al. (6) Ricz S.: Observation of a four-electron Auger process in near-*K*-edge photoionization of singly charged carbon ions. Phys Rev Lett 114**:** 013002 (2015) http://real.mtak.hu/31774/

Chesnel J.-Y., Juhász Z., Lattouf E., Tanis J.A., Huber B.A., Bene E., et al. (6) Kovács S.T.S., Herczku P., Sulik B.: Anion emission from water molecules colliding with positive ions: Identification of binary and many-body processes. Phys Rev A 91**:** 060701. (2015) http://arxiv.org/abs/1506.09006

Kövér L.: Coincidence, Resonant, and High-Energy Electron Spectroscopies – Resonant Auger, Electron Coincidence for Surface Analysis. Chapter in the: Encyclopedia of Analytical Chemistry, (2015) doi: 10.1002/9780470027318.a9390

Takáts V., Trunov M.I., Vad K., Hakl J., Beke D.I., Kaganovskii Yu. et al. (1): Low-temperaturephoto-induced mass transfer in thin As20Se80 amorphous films. Mat Lett 160: 558–561 https://dea.lib.unideb.hu/dea/handle/2437/216054

Kövér L.: Surfaces and interfaces: Combining electronic structure and electron transport models for describing electron spectra. Front Mat 2:35 (2015) OA doi: 10.3389/fmats.2015.00035

Frigeri C., Serényi M., Szekrényes Zs., Kamarás K., Csik A., Khánh N.Q.: Effect of heat treatments on the properties of hydrogenated amorphous silicon for PV and PVT applications. Sol Energy 119: 225-232 (2015) http://real.mtak.hu/31647/

Malolepszy A., Mazurkiewicz M., Stobinski L., Lesiak B., Kövér L., Tóth J., et al. (4)
Deactivation resistant Pd-ZrO2 supported on multiwall carbon nanotubes catalyst for direct formic acid fuel cells. Int J Hyd Energy 40: 16724-16733 (2015) doi: 10.1016/j.ijhydene.2015.08.048

Kéri M., Palcsu L., Túri M., Heim E., Czébely A., Novák L., et al. (1).: ^{13}C NMR analysis of cellulose samples from different preparation methods. Cellulose 22: 2211-2220 (2015) 10.1007/s10570-015-0642-y

Major I., Furu E., Haszpra L., Kertész Zs., Molnár M.:
One-year-long continuous and synchronous data set of fossil carbon in atomspheric PM2.5 and carbon dioxide in Debrecen, Hungary. Radiocarbon 57: 991-1002.(2015), http://real.mtak.hu/27792/

Benkó Zs., Mogessie A., Molnár F., Krenn, Poulson S.R., Hauck S.A., et al. (2):
Hydrothermal alteration and Cu-Ni-PGE mobilization in the charnockitic rocks of the footwall of the South Kawishiwi intrusion, Duluth Complex, USA. Ore Geol Rev 67: 170-188 (2015) OA doi:10.1016/j.oregeorev.2014.11.010

Benkó Zs., Mogessie A., Molnár F., Severson M.J., Hauck S. A., Raic S:
Partial melting processes and Cu-Ni-PGE mineralization in the footwall of the South Kawishiwi intrusion at the Spruce Road Deposit, Duluth Complex, Minnesota
Economic Geology Vol. 110, 1269-1293. (2015)

Seghedi I., Helvaci C., Pécskay Z.: Composite volcanoes in the south-eastern part of Izmir-Balikesir Transfer Zone, Western Anatolia, Turkey. J Volc Geo Res 291: 72 (2015) doi:10.1016/j.jvolgeores.2014.12.019

Orsovszki, G. Rinyu, L.: Flame-Sealed Tube Graphitization Using Zinc as the Sole Reduction Agent: Precision Improvement of EnvironMICADAS ^{14}C Measurements on Graphite Targets. Radiocarbon 57, 5 979-990 (2015) OA doi: 10.2458/azu_rc.57.18193

Tóth, M., Magyari, E.K., Buczkó, K., Braun, M., Panagiotopoulos, K., Heiri, O.:Chironomid-inferred Holocene temperature changes in the South Carpathians (Romania). Holocene 25: 569–582. http://real.mtak.hu/22236