INSTITUTE FOR NUCLEAR RESEARCH
4026 Debrecen, Bem tér 18/c, 4001 Debrecen, Pf. 51.
Tel: 06-52-509200, Fax: 06-52-416181
E-Mail: director@atomki.mta.hu; Webpage: http://www.atomki.mta.hu

I. Main duties of the research unit in 2016

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 task was carrying out the second phase of the tandetron project. The GINOP applications (operative program for economic development and innovation, funded by the government from EU sources) won in 2016 will open new perspectives in the infrastructural development of the institute. Further tasks in 2016 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 2016

II. a) Outstanding research results

Theoretical Physics

In quantum informatics, the amount of classical resources needed to simulate a bipartite hybrid quantum setting has been investigated. The EPR steering scenario involves a trusted and an untrusted part (a so-called black box system) by sharing a bipartite entangled quantum state. Local quantum measurements carried out on the untrusted part may influence the trusted part by remotely steering its quantum state. This "spooky action at a distance" was first described by Schrödinger in 1936 and has been put on a firm basis by Wiseman et al. in the context of quantum information in 2007. Since then, numerous experiments have confirmed the phenomenon. The EPR steering is simulated classically by substituting entanglement with classical communication between the untrusted and trusted parts. It has been proven that an infinite amount of classical communication is required from the untrusted party to the trusted party in order to simulate EPR steering correlations arising from a pure two-qubit entangled state.

The nonlocal properties of the N-party W-type states have been investigated. W-type states play a crucial role in quantum networks, particularly, in quantum memories. In case of general N, one may inquire what is the minimal number of particles that must be removed from the W-type state so that the resulting state becomes local. This number is found to be bigger than (2N/5) for large N. This result supports the high persistency of W-type states under particle loss, which is a useful property in present-day quantum information technologies.

It was shown that a new symmetry may exist in atomic nuclei, which connects the low-lying shell-model-like states and the highly excited cluster states. This cluster-shell dynamical symmetry is a new version of the multichannel dynamical symmetry. In this symmetry-adapted framework the complete spectrum from the ground state up to the highly excited molecular configurations can be described in a unified way. In favorable situations, the high-lying excitations can even be predicted from the description of the low-lying states.

Calculations for the ^{28}Si nucleus indicate that this new symmetry exists in Nature. From the quartet model description of the low-energy states, the complete spectrum of the high-lying $^{12}C+^{16}O$ cluster states was predicted, and was found to be in very good agreement with the experimental observation. This is the first theoretical attempt that treats the two regions in a unified way; furthermore, the high-energy states were obtained as pure predictions. The model includes also the newly observed superdeformed band (the features of which were also predicted previously). This study proved the old conjecture as well, which states that the $^{12}C+^{16}O$ molecular states are excitations in the superdeformed valley corresponding to the second minimum of the potential energy.

Particle Physics

In collaboration with researchers at Eötvös University (ELTE) and the University of Wuppertal, an estimate was given for the mass of the hypothetical particle, called the axion. The axion, if it exists, could by itself solve two intriguing problems of present day particle physics. Firstly, it has been known for decades that the strong interaction of quarks and gluons could, in principle, violate time reversal symmetry. However, mysteriously enough, experimentally no such violation has been found. The axion could provide a simple and natural explanation of why strong interactions have to respect this symmetry. Secondly, axions are thought to be a prime candidate for providing the bulk of dark matter that has only been detected through its gravitational influence, but its composition is still unknown. The most important obstacle in experimental searches for axions is the complete lack of information about its possible mass. The estimate, given by the present work, published in *Nature*, provides important input for designing future experiments to search of axions.

Based on earlier results, the effective model that describes localized quark modes in the high temperature quark-gluon plasma state of strongly interacting matter has been investigated. An interesting feature of this effective model is that it is suitable to describe not only the quark-gluon plasma state, but also the low temperature hadronic state, as well as the transition region between the two states. Detailed studies of the model in its transition region revealed that it can account for all the important aspects of the QCD transition. This research and the one above, about the axion mass, were both undertaken by the MTA Atomki *Lendület* (*Momentum*) Quantum Chromodynamics Research Group.

In 2016 the Atomki group took part in the calibration and continuous monitoring of the CMS pixel detector, thereby optimizing the efficiency and resolution of the detector. These results also contributed to the pixel detector based luminosity measurements of LHC. In addition, the group also adjusted the simulation parameters to reproduce the measured efficiency of the pixel detector.

The group was asked to check the endcap positioning system, the possibilities for its further operation and also possibly to take over the data analysis. Based on the analysis of raw data acquired in the past few years, it turned out that the measurements are not reliable enough, and due to the high number of faulty measurements, it was not possible to reconstruct the position of the endcap. Starting from this conclusion, the construction of a new system was proposed that could measure the position of the new GE2/1 muon detector reliably and with the required precision.

The group was also involved in the determination of the position of the new GE1/1 muon detector chambers. The key component of the system proposed last year is a distance measurement sensor developed by the group. This sensor is based on a new innovative

application of the fiber optic FBG sensors that have already been in extensive use at the CMS. The prototype of the sensor has been built, and test measurements verified preliminary expectations. The results also gave indications for necessary further development and modifications.

The Mátra Gravitational and Geophysics Laboratory (MGGL) was established in 2015. The laboratory is located 88 meters below ground level in an abandoned mine near Gyöngyösoroszi. Its main goal is to perform preliminary investigations whether the location is suitable for housing a gravitational wave detector that may be installed here in the future. Among others, the laboratory also operates an infrasound monitoring system developed by Atomki.

Nuclear Physics

Researchers of Atomki studied the angular correlation of the electron-positron pairs created in high energy nuclear transitions with a spectrometer built in Debrecen. Such angular correlations can be described theoretically with exponentially decreasing curves. However, in the case of the 18.15 MeV transition of ^{8}Be, a significant peak-like deviation from the above predicted curve was observed, which could not be interpreted in terms of nuclear physics. At the same time, such a deviation can be explained by assuming the creation and decay of a new particle called dark photon in some theoretical predictions. The dark photon was introduced to mediate the interaction between some dark matter particles, similarly to the photon that mediates the electromagnetic interaction. The Atomki results were published in *Physical Review Letters*, which was followed by a very positive report in *Nature*.

The structure of Fe isotopes was studied at GSI in the framework of an international collaboration. The known long-lived isomeric state of ^{54}Fe was observed in the two-neutron knock-out reaction, although its structure has to involve at least four unpaired nucleons. This state could be populated only if one of the neutrons in ^{54}Fe was excited in the high-energy collision. Therefore, the observation of the metastable state is the consequence of the excitation of a nucleon.

New results have been reached in multiple chirality, which is the most recent research topic of spontaneous chiral symmetry breaking in rotating nuclei. Two pairs of positive- and negative-parity doublet bands have been identified, together with eight strong electric dipole transitions linking their yrast positive- and negative-parity bands in ^{78}Br. Comparing the experimental properties of the observed bands with microscopic multidimensionally-constrained covariant density functional theory and triaxial particle rotor model calculations, the observed bands were identified as multiple chiral doublet bands with octupole correlations. This observation was the first example of chiral geometry in octupole soft nuclei, which also shows that nuclear chirality can be robust against octupol correlation, too. The level scheme of the studied nucleus has been displayed on the cover page of *Physical Review Letters.*

Exploiting the unique possibilities offered by the deep underground accelerator of the LUNA international collaboration, the strength of the astrophysically most important low energy resonance has been measured in the $^{17}O(p,\alpha)^{14}N$ reaction. This key reaction of advanced hydrogen burning takes place in various astrophysical environments and determines, among others, the ratio of stable oxygen isotopes observed in the universe. Based on the new experimental results, the rate of this reaction is roughly a factor of two higher than estimated

before, which influences directly the calculated isotopic ratios. The new results allow the explanation of the so far enigmatic isotopic ratios measured in some presolar stardust grains.

Cross section measurement of (α,γ) and (α,n) reactions has been carried out on the rare noble gas isotope ^{124}Xe for the first time, using the cyclotron accelerator of Atomki and a gas cell developed in Atomki for activation experiments. The obtained results put a constraint on the possible reaction paths leading to the production of ^{124}Xe in core-collapse supernovae.

One of the most important findings of recent years' studies concerning heavy element nucleosynthesis is that α-nucleus optical potentials used for reaction cross section calculations are not able to give a good description of the reactions at low, astrophysical energies. With the aim of studying this optical potential, a comprehensive investigation of the α+^{64}Zn system was carried out by measuring elastic and inelastic scattering, as well as α-induced reaction cross sections on ^{64}Zn. The identity of total cross sections obtained from elastic scattering and compound reactions has been proven with high precision. It has been shown that the new global potential recently developed in Atomki gives a good description of the measured data.

Applied Nuclear Physics

Due to their high stability, thin (50-500 nm) silicon nitride films are widely used in nuclear physics experiments as silicon and nitrogen standards, or as high-vacuum windows. It is, therefore, important to determine the physical and chemical properties of such foils. The density, thickness and the composition of some commercially available silicon nitride films were determined using ion beam analytical techniques and profilometry. It was found that the density of the studied films was significantly less (~15-20%) than the values specified by the manufacturer, and which has been used in the SRIM software.

Particle induced γ-ray emission (PIGE) is one of the useful techniques of Ion Beam Analysis (IBA). However, for the implementation of a standardless quantitative PIGE analysis, reliable and accurate cross section data are needed. For the improvement of IBANDL, the international database of IBA, one has to assess available nuclear data, and to perform accurate cross section measurements. In the present work the assessment of differential γ-ray emission cross sections was carried out in (d,pγ) nuclear reactions on ^{12}C, ^{14}N and ^{16}O, which can be applied in standardless PIGE analyses.

A novel microfluidic device was designed for capturing circulating human tumour cells. The parts were made from PDMS polymer. Proton beam writing (a direct write method) was used to create straight and tilted microstructures in liquid phase PDMS polymer resist material. These microstructures were integrated in PDMS based microfluidic devices, jointly with collaborating partners. The MTA-PE Translational Glycomics Group (Pannon University, Veszprém) tested the efficiency and the hydrodynamic characteristics of the microfluidic systems with yeast cells.

Six measurement campaigns were carried out within the H2020 IPERION CH (*Integrated Platform for the European Research Infrastructure ON Culture Heritage)* project. Elemental compositions of Byzantine and Italian glass objects were determined, chert samples from the Pyrenees were examined, and the study concerning religious textiles was continued. Studies extending the knowledge on a silver treasure collection kept in the National Museum were carried out. The elemental composition of gold and bronze objects from Hungarian museums

was also determined. Resistance of sensitive materials toward ion beams was investigated systematically.

A new method was developed for the separation of ^{52}Mn from irradiated metal chromium. The method is based on the different stability of various metal-chloro-complexes. The Cr-chloro complex passes through the column of anion exchanger resin without interaction, while the Mn-chloro-complex retain on the column with an amount of 3 dead-volume. A radiochemical yield of approximately 60% was reached, furthermore, no potentially contaminating ^{51}Cr radioisotope was detected in the product. ^{52}Mn, as a PET radioisotope is very promising for in situ PET-MRI diagnostics, where the paramagnetic Mn is used to replace the Gadolinium contrast material used earlier, which was found to have toxic effects.

During thin layer activation, a wear measurement method based on the minor components has been developed by using new radioisotopes that have not been applied before. Different radioisotopes have been produced in the samples with different irradiations, which made it possible to monitor the wear of the samples at different places, as well as to perform the wear test of different counterparts at the same time. For this purpose, further cross sections have been determined for using with thin layer activation, including the α- and ^{3}He-particle induced reactions that have not been used frequently up to now. These new data were also uploaded into the charged particle database of IAEA.

Rare earth elements were studied for the optimization of radioisotope production. New experimental reaction cross sections were determined for recommended nuclear data libraries, the improvement of theoretical models, and for the application of the data in everyday practice. Investigations concerned Al, Ti, Ca, Cd, Cu, Mo, Sc, Sr, Ti, Tm, Y and Zn as target materials. New therapeutic medical radioisotopes (^{67}Cu, ^{186}Re, ^{47}Sc) were produced. The formation of non-radioactive copper during the production of ^{64}Cu was investigated via proton and deuteron-induced nuclear reactions. ^{nat}Gd+d reactions were studied in order to develop the production of the medically relevant ^{155}Tb and ^{161}Tb radioisotopes.

Activated ceramics were measured, thus detecting the fusion products escaping the plasma of the KSTAR fusion facility (South Korea). It was proven that the $30Y_2O_3{\cdot}30P_2O_5{\cdot}40SiO_2$ glass ceramic powder gives thermoluminescent answer to the fast neutron and γ-dose, which might facilitate the measurement of radiation damage of the glass ceramic materials to be used in future nuclear technologies.

Radiation damage of SiPM devices were measured in the mixed γ-neutron field of broad spectrum p+Be sources. The dark current increased as a function of the neutron flux, and it also showed temperature dependence. The change in the break-down voltage was not significant in the $\Phi \leq 10^{12}$ n/cm^2 flux range.

Atomic and Molecular Physics

Ionization of methane and water molecules has been studied by ion impact as a function of the perturbation strengths, *q/v* of the projectile ion. The aim was to map the projectile energy and charge state regions, which are relevant for ion-beam cancer therapy. Differential electron emission cross sections were measured by the impact of 1 MeV H^+, He^+ and 650 keV N^+ ions. The differential cross sections have been determined for the electron emission in a broad energy and angular range. The obtained results were interpreted by classical and quantum mechanical model calculations. Remarkable results have been achieved in the

extension of classical and quantum mechanical ion-atom collision models for treating molecular targets. The extended models and a statistical theory, newly developed in the group, have also been successfully applied for other collision problems published in the literature.

Atomki researchers were invited to perform an experiment of their choice in the field of electron spectroscopy at the BESSY-2 synchrotron facility, Berlin. One of the selected topics is fundamental for improving photoionization theories: the measurement of the full 3D angular distribution of He 1*s* and Ne 2*s* photoelectrons. Another measurement was performed for exploring the anisotropies in the emission of K-photoelectrons from the carbon atoms of the biologically relevant tetrahydrofuran molecule. This was the first case to measure the full, real 3D angular distribution of the photoelectron emission, and to study its symmetries free from theoretical assumptions.

Single photons of the infrared light cannot ionize atoms, only multi-photon absorption can provide the necessary energy transfer. Atomki researchers, in collaboration with the *Lendület* (*Momentum)* Research Group for Ultrafast Nano-optics in the MTA Wigner PRC, measured the photoemission from Xe atoms in such multiphoton ionization processes. An electron spectrometer-system, developed in Atomki, was applied at the beamline of the femtosecond laser of the collaborating group. A series of multiphoton ionization peaks was identified, and the dependence of the process on the laser parameters was investigated. This fundamental study is also a preparatory stage for future work at ELI-ALPS.

The properties of the X-ray emission by the ECR plasma were studied in Italian collaboration (INFN-LNS, Catania). Variations in the X-ray spectra as the function of the setting parameters of the ion source (magnetic field, RF power, RF frequency) were recorded by SSD and HPGe detectors. A special pinhole X-ray camera was used to obtain the structural changes of the plasma through plasma images. The results of the volumetric measurements and plasma imaging, as well as the technical details of applied methods were published in 2016. The work was supported in part by the European Union's Horizon 2020 research and innovation program under grant agreement No 654002 (ENSAR2-MIDAS MIDAS).

Surface Physics

Graphene oxide samples prepared from graphite were reduced by different reducing agents in microwave conditions and at different temperatures in order to determine the concentration of surface elements and oxygen group components, as well as the average number of graphene layers in stacked nanostructures. It was found that reduction methods resulted in variations of C/O and oxygen groups/(C sp2 bond) ratios, and an average graphene layer number. The analysis of C KLL Auger spectra, which reflects the electron state density of carbon nano materials and which was excited by X-ray, was performed in order to determine the D parameter characterizing the ratio of C sp2/sp3 bonds. The ratio of C sp2/sp3 bonds determined for a wide range of carbon nano materials produced by different methods was generally found to be identical with the values calculated from C 1s photo electron spectra. The main sources of error in determination of bond ratios by D parameter analysis were also identified.

Steel surfaces coating with a Zn(Ti) layer is a well-known procedure to prevent corrosion. In a research project aiming at increasing the efficiency of corrosion protection, thermodynamical calculations were carried out to describe the internal structure of the coating layer, and to reveal the physical/chemical processes that take place inside it. The

results of calculations were compared with those obtained from mass spectrometry and electron spectroscopic measurements. The layer structure of chemical states formed in the protective layer was determined. It was found that the thickness of the coating layer decreased with the increase in bath temperature, while the thickness of the titanium oxide layer, which is responsible for the effective corrosion protection, increased. The colour of the coating layer depends rather on optical interference than on the chemical state of titanium.

Nanometer thick layered structures were studied by sputter-based depth profile analysis. On the one hand, different depth profile methods were compared to realize the best depth resolution in SiGe systems, while on the other hand, particle re-deposition onto the sample surface accompanying low energy sputtering of PbTe crystals was studied. It was found from surface morphology measurements that in the case of low energy sputtering (<160 eV) the sputtered particles stayed near the surface. This phenomenon allows Pb and Te particles to re-deposit on the surface, accompanied by a characteristic crystal structure growth.

Environmental Science

The age-depth profile of Dunaszekcső loess sediment was investigated by AMS ^{14}C analyses of altogether 64 different samples including charcoal and ten different species of snails/mollusk remains. A systematic ^{14}C age offset was detected, when different preparation methods were compared on the same charcoal samples. The observed age discrepancy between the differently prepared samples was more significant if the charcoal was older and/or less preserved. ^{14}C age of some mollusk species was rather close to that of the charcoal samples from the same layers. Thus, those mollusk species are good candidates for age profile determination studies of loess sediments covering the last 40 thousand years of environmental evolution history.

The issue of diagenetic alteration of carbonate deposits in caves (speleothems) was investigated by isotope analytical and environmental archeology methods. This process has serious consequences for speleothem-based paleoclimate studies. The atmospheric ^{14}C bomb-peak signal from the 1960's was applied for dating the recently formed stalagmites and flowstones. The detected diagenetic alteration and its isotopic effects should be taken into consideration during sampling strategies and isotope data evaluation in climatic studies.

St. Anna Lake is located in the younger crater of Ciomadul's twin craters, the youngest volcano in the Carpatho-Pannonian Region. The chronology of the St. Anna volcanic crater lake sediment was defined with ^{14}C method. The studies aimed at identifying the environmental changes preserved in the lake sediments from the time of the volcanic eruption to present days. In order to study these changes, it is essential to have a high-resolution chronology for the sediment; for this a relatively new method, the pollen-based radiocarbon dating was applied. Based on these investigations, it was possible to detect the environmental changes of the last 27 thousand years.

The two major recharge areas of Hungary are the Danube-Tisza Interfluve and Nyírség. Using the combination of the tritium-peak method and numerical transport modelling the average groundwater recharge has been calculated to be 7-11 % of annual precipitation. As an independent estimation of recharge rate, the vertical moisture distribution of the unsaturated zone was also investigated. While the recharge rates calculated by the ^{3}H bomb peak and the $^{3}H/^{3}He$ methods agree well with each other, the two approaches to recovering recharge rates are predicated on different recharge properties. The bomb-peak method focuses the time marker of the peak, while $^{3}H/^{3}He$ age depth profile averages the last four to

five decades, therefore this latter might provide a better estimation of long term recharge. Contrary, the recharge rates calculated from the moisture content are reliable only for the last 18-24 months.

Oxbow lake sediments of Tisza River preserve the changes caused by floods. The concentration changes of heavy metals (Pb, Cu, Zn) in the sediments were correlated with changes in the water level data. From this analysis the riverbed sediment accumulation rate can be determined. Results were confirmed with ^{137}Cs chronology as well. The importance of these findings is twofold: 1) it is possible to trace the heavy metal pollutions back to the last hundred years, and 2) it was possible to determine the oxbow lakes sediment accumulation level. Heavy metal pollutions on Tisza River occurred regularly as early as the time of the Austro-Hungarian Empire, and had significant impact on the wildlife. As the sedimentation rate reaches 2-4 cm/yr, the filling or disappearance of the floodplain riverbeds can be anticipated in a near future.

High mountain lake sediments were sampled with a novel technique in the Retezat Mountains (Southern Carpathians, Romania). The inorganic and organic content of the sediments, as well as plant remains preserve the climate and environmental changes of the last thousand years. The trace of the cooling event that occurred 8200 years ago could be detected in the sediment of Taul dintre Brazi Lake. The frequency of forest fires could be reconstructed in the case of the Taul dintre Brazi and Lia lakes, many of which were traced back to natural causes. Soil erosional processes following the forest fires were detected from the organic matter and ash content of the sediments.

In a case study, the building infiltration rate and indoor air quality have been investigated in two buildings: one equipped with passive house technology and a conventional one. In contrast with expectations, the average particulate matter concentration was found to be higher in the building with passive house technology than in the conventional one. The concentration and the average of the indoor/outdoor ratios for coarse fraction particles (particles bigger than 2.5 μm) were significantly higher in houses with passive house technology, indicating a remarkable accumulation mechanism. According to these findings, the effective filtration of the outdoor air and the cleaning of the indoor air is of primary importance in passive houses.

A combination of elemental analyzer and stable-isotope spectrometry (EA-IRMS) was adopted for total carbon and simultaneous $d^{13}C$ stable isotope measurement of aerosol samples. The total carbon analysis was compared to an alternative off-line combustion method. It was shown by combined total carbon and isotope analyses that there is no significant stable isotope shift during the on-line combustion of aerosol filters. The inter-comparison results showed good correlation between the on-line and off-line total carbon analysis techniques. Thus, the novel on-line method can be used for high throughput and fully automated on-line total carbon and combined $d^{13}C$ analyses of aerosol samples.

The radiocarbon activity concentration of the inorganic and total carbon content of groundwater was determined for the complete monitoring well network of the Püspökszilágy Radioactive Waste Treatment and Disposal Facility (RWTDF), together with the analysis of soil and air samples. As the most important result of the research, it was proven that by the current monitoring practice based on the determination of the inorganic fraction, only less than 30% of the total radiocarbon content of the groundwater can be detected in certain wells

with high radiocarbon content. It has been established that to receive more precise emission control and dose estimation during the environmental monitoring of the RWTDF, the radiocarbon concentration of the total dissolved carbon content of the groundwater should be measured, not only that of the inorganic fraction.

II. b) Science and society

Activities of Atomki reaching the public in 2016 were *Researchers' Night*, the national selection contest to the international *Science on Stage* festival, *Physicists' Days* and hosting visiting groups.

The central event of *Researchers' Night* (2016.09.30.) was the lecture `*Did isotopes exist in the past? - Paleoclimatic reconstruction with isotopes*'. It was shown that studying geological findings can help us understand the processes that took part in the distant past. This can be done by the precise measurement of the concentration or of isotopes, elements and trace elements, or that of their ratios. The audience of 88 learned about the methods of determining age, as well as temperature data from the past.

Atomki was the co-organizer of the national selection contest (2016.10.7-9) to the *Science on Stage* festival. This event served as a preparation for the international *Science on Stage* festival that will take place in Debrecen in June 2017. The main goal of this event is to give primary and secondary school teachers an opportunity to share their ideas and practices in teaching sciences, mathematics and informatics, but it is also a perfect occasion to reach the general public. Nearly 100 candidates presented their projects at the national event, 40 of whom qualified to the international festival.

Physicists' Days (2016.11.21-25.) were organized for the 37'th time in Atomki . This year's topic was dark matter and dark energy. The four lectures given on this subject were attended by an audience of 392 in total, ranging from primary school pupils to pensioners. In the mornings, Atomki received visitor groups from 21 schools based in Debrecen and in distant cities, to attend 24 different unconventional lectures. Altogether 57 lectures were given and 1715 visitor hours were spent. Last evening the visitor center of Atomki opened and welcomed 14 interested individuals, who learned the basics of radioactivity. 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 346 visitors this year (primary, secondary school pupils, university students and interested adults), who spent there 763 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 center 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 primary targets of the outreach activity of Atomki are school-age pupils and interested adult laymen, nevertheless the institute takes every opportunity to reach further groups. Such an opportunity came on June 5, 2016, when Atomki was invited to present a full-day program at the jubilee event of the MKB (Hungarian Foreign Trade Bank) *Professors' Club*. The audience enjoyed lectures, experimental demonstrations, science-related stage and musical performances, as well as a panel discussion on unconventional methods of the popularization of science.

The four popular publications written by the researchers of Atomki in 2016 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. According to the feedbacks, the videos most popular with teachers are those four made within the program called *Traveling Physics* a few years ago: *Water*, *Natural protection systems of the Earth*, *Cold – warm* and *Energy*.

In 2016, 375 appearances in Hungarian media were registered in which Atomki or its staff was mentioned. More than one hundred were due to the experiment concerning dark matter. The other two most popular topics were the observation of gravitational waves and the results of nuclear astrophysics, which were obtained in international collaboration

III. Presentation of national and international R&D relations in 2016

The collaborative research activities of the institute are traditionally carried out in terms of large international collaborations (e.g. CERN-CMS, LIGO-EGRG, LUNA, etc.) and bilateral cooperations of various level. In 2016, the range of the latter ones has been extended by projects signed with the partner academies of neighbouring countries (Poland, Czech Republic, Slovakia), but new agreements were initiated with universities and institutions of distant continents too (Japan, China, Iran, Mexico, Egypt). Among new European connections INFN Frascati (Italy) and the Extreme Light Infrastructure – Nuclear Physics (ELI-NP) constructed in Bucharest should be mentioned. Among other ELI member institutes, cooperation with Extreme Light Infrastructure – Attosecond Light Pulse Source (ELI-ALPS), Szeged, keeps extending each year. In terms of a new project signed with the University of Oradea (Romania), students and professors can make professional visits to Atomki under an Erasmus program.

New domestic cooperations started mainly with the major research universities (University of Debrecen, Roland Eötvös University – ELTE, Budapest, University of Szeged, University of Pécs). Among research institutes, Atomki traditionally has strongest links with the Wigner Research Centre for Physics. A new remarkable development was establishing partnership with several *Lendület* (*Momentum*) groups funded by the Hungarian Academy of Sciences. In the commercial sector, MVM Paks Nuclear Power Plant Private Llc. is still the most significant industrial collaborator of Atomki.

In 2016, Atomki hosted three international workshops, but the researchers of the institute participated in the organization of numerous further scientific meetings. Among these the *EPS Young Minds Leadership Meeting* should deserve special attention, where the leaders of young physicits' associations met in Budapest under a project of the European Physical Society and discussed their work.

The International Advisory Committee held its yearly session in Atomki on November 7, when it was informed, among others, about the inauguration of the new matrix organization system in Atomki.

Participation in higher education continued to play an important role in the activity of Atomki researchers in 2015 too. They held altogether 58 theoretical and 37 practical courses. Atomki hosted 18 PhD, 19 MSc and 27 BSc students in 2015. The student researcher fellowship program continued in Atomki with the participation of 7 students both in the spring and

autumn semesters. Altogether 49 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.

IV. Brief summary of national and international research proposals, winning in 2016

Atomki had six successful GINOP applications(operative program for economic development and innovation, funded by the government from EU sources) in 2016, which will have significant impact on several research projects of the institute in the coming years. Besides these, two OTKA type NKFIH (National Research, Development and Innovation Office) and four international projects were started last year.

- *Isotope Climatology and Environmental Research Centre (ICER): consolidating recent- and palaeo-environmental geochemistry research and development at MTA Atomki*, GINOP-2.3.2-15-2016-00009, 48 months, 1966141 k HUF
- *Establishing a world class research environment at the new Tandetron Laboratory of MTA Atomki*, GINOP-2.3.3-15-2016-00009, 36 months, 941251 k HUF
- *Regional Centre of Excellence in Materials Science - Research Program and Infrastructure Development*, GINOP-2.3.2-15-2016-00041, 36 months, 279278 k HUF
- *Study of exotic nuclear phenomena at Atomki and ESFRI roadmap institutes*, GINOP-2-3.3-15-2016-00034, 36 months, 568779 k HUF
- *Exploration and development of a novel control software framework for research infrastructures*, GINOP-2.2.1-15-2016-00012, 36 months, 185500 k HUF
- *The new Laboratory for Heritage Science at MTA Atomki – Preparing for the participation in E-RIHS*, GINOP-2.3.3-15-2016-00029, 36 months, 421866 k HUF
- *Ion beams in materials modification and micro- and nanofabrication*, OTKA PD-121076, 36 months, 15087 k HUF
- *High precision nuclear astrophysics investigations*, OTKA K 121666, 48 months, 48000 k HUF
- *CRP on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production*, IAEA project, 17438/RO, 12 months, 4000 EUR
- *Use of Long-lived Radionuclides for Dating Very Old Groundwaters*, IAEA project 20533, 36 months, 18000 EUR
- *Nuclear Data for Accelerator Production of ^{67}Cu, ^{186}Re and ^{47}Sc*, IAEA project 20584, 60 months, 20000 EUR
- *European Nuclear Science and Application Research 2 — ENSAR2*, ENSAR project, 654002, 48 months, 47500 EUR

V. List of important publications in 2016

Nagy S., Vértesi T.:
EPR Steering inequalities with Communication Assistance.
SCIENTIFIC REPORTS, 6: 21634 (2016)
http://dx.doi.org/10.1038/srep21634

Diviánszky P., Trencsényi R., Bene E., Vértesi T.:
Bounding the persistency of the nonlocality of W states.

PHYSICAL REVIEW A, 93: 042113 (2016)
https://arxiv.org/abs/1605.05846

Cseh J., Riczu G.:
Quartet excitations and cluster spectra in light nuclei.
PHYSICS LETTERS B, 757: 312-316 (2016)
http://dx.doi.org/10.1016/j.physletb.2016.03.080

Pál G., Jánosi Z., Kun F., Main I. G.:
Fragmentation and shear band formation by slow compression of brittle porous media.
PHYSICAL REVIEW E - STATISTICAL, NONLINEAR AND SOFT MATTER PHYSICS, 94: 053003 (2016)
http://real.mtak.hu/28024/

Borsanyi S., Fodor Z., Guenther J., Kampert K.-H., Katz S. D., Kovacs T. G. et al. (13):
Calculation of the axion mass based on high-temperature lattice quantum chromodynamics.
NATURE, 539: 69-71 (2016)
https://arxiv.org/abs/1606.07494

Giordano M., Kovács T. G., Pittler F.:
An Anderson-like model of the QCD chiral transition.
JOURNAL OF HIGH ENERGY PHYSICS, 2016: (6) 007 (2016)
http://dx.doi.org/10.1007/JHEP06(2016)007

Krasznahorkay A., Csatlós M., Csige L., Gácsi Z., Gulyás J., Hunyadi M., et al. (14):
Observation of Anomalous Internal Pair Creation in 8Be : A Possible Indication of a Light, Neutral Boson.
PHYSICAL REVIEW LETTERS, 116: 042501 (2016)
https://arxiv.org/abs/1504.01527

Podolyák Z., Shand C. M., Lalović N., Gerl J., Rudolph D., Dombrádi Zs., et al. (64):
Role of the Δ Resonance in the Population of a Four-Nucleon State in the Fe 56 → Fe 54 Reaction at Relativistic Energies.
PHYSICAL REVIEW LETTERS, 117: 222302 (2016)
http://epubs.surrey.ac.uk/813076/1/54fe_isomer_resubmitted_14sept2016.pdf

Liu C., Wang S. Y., Bark R. A., Zhang S. Q., Meng J., Qi B., Nyakó B. M., et al. (47):
Evidence for Octupole Correlations in Multiple Chiral Doublet Bands.
PHYSICAL REVIEW LETTERS, 116: 112501 (2016)
http://real.mtak.hu/44699/

Bruno C. G., Elekes Z., Fülöp Zs., Gyürky Gy., Somorjai E., Szücs T., et al. (35):
Improved Direct Measurement of the 64.5 keV Resonance Strength in the O17(p,α)N14 Reaction at LUNA.
PHYSICAL REVIEW LETTERS, 117: 142502 (2016)
https://arxiv.org/abs/1610.00483

Halász Z., Somorjai E., Gyürky Gy., Elekes Z., Fülöp Zs., Szücs T., Kiss G.G., (10):
Experimental study of the astrophysical γ -process reaction Xe 124 (α,γ) Ba 128.
PHYSICAL REVIEW C, 94: 045801 (2016)

http://real.mtak.hu/46882/

Ornelas A., Gyürky Gy., Elekes Z., Fülöp Zs., Halász Z., Kiss G. G., et al. (15)
α scattering and α -induced reaction cross sections of Zn 64 at low energies.
PHYSICAL REVIEW C, 94: 055807 (2016)
http://real.mtak.hu/46884/

Csedreki L., Halász Z., Kiss Á. Z.:
Assessment of experimental d-PIGE γ-ray production cross sections for 12C, 14N and 16O and comparison with absolute thick target yields.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION B-BEAM INTERACTIONS WITH MATERIALS AND ATOMS, 380: 1-10 (2016)
http://real.mtak.hu/46887/

Rajta I., Huszánk R., Szabó A. T. T., Nagy G. U. L., Szilasi S., Fürjes P., et al. (13):
Tilted pillar array fabrication by the combination of proton beam writing and soft lithography for microfluidic cell capture: Part 1 Design and feasibility.
ELECTROPHORESIS, 37: (3) 498-503 (2016)
http://real.mtak.hu/32039/

Szikszai Z., Angyal A., Csedreki L., Furu E., Huszánk R., Kertész Zs., et al. (13)
Trans-National Access in the field of heritage science at the Laboratory of Ion Beam Applications, MTA Atomki.
TECHNE: RESEARCH IN PHILOSOPHY AND TECHNOLOGY, 43: 59 (2016)
http://real.mtak.hu/28008/

Ditrói F., Tárkányi F., Takács S., A Hermanne A.:
Activation cross-sections of proton induced reactions on vanadium in the 37–65 MeV energy range.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION B-BEAM INTERACTIONS WITH MATERIALS AND ATOMS, 381: 16-28 (2016)
https://arxiv.org/abs/1610.03954

Ditrói F., Tárkányi F., Takács S., Hermanne A.:
Activation cross sections of proton induced nuclear reactions on gold up to 65 MeV.
APPLIED RADIATION AND ISOTOPES, 113: 96-109 (2016)
https://arxiv.org/abs/1610.04352

Juhász Z.:
Thermodynamic model for electron emission and negative- and positive-ion formation in keV molecular collisions.
PHYSICAL REVIEW A, 94: 022707 (2016)
https://arxiv.org/abs/1608.05303

Kovács S. T. S., Herczku P., Juhász Z., Sarkadi L., Gulyás L., Sulik B.:
Ionization of small molecules induced by H+, H e+, and N+ projectiles: Comparison of experiment with quantum and classical calculations.
PHYSICAL REVIEW A, 94: 012704 (2016)
http://real.mtak.hu/31853/

Loreti A., Kadokura R., Fayer S. E., Kövér A., Laricchia G.:
High-Resolution Measurements of e++ H2 O Total Cross Section.
PHYSICAL REVIEW LETTERS, 117: 253401 (2016)
http://real.mtak.hu/44700/

Sarkadi L., Fabre I., Navarrete F., Barrachina R. O.:
Loss of wave-packet coherence in ion-atom collisions.
PHYSICAL REVIEW A, 93: 032702 (2016)
http://real.mtak.hu/43934/

Sarkadi L., Nagy D.:
Forward electron emission in collisions of He2+ ions with Ar atoms with simultaneous capture of two electrons.
PHYSICAL REVIEW A, 94: 042709 (2016)
http://real.mtak.hu/43932/

Tőkési K., Varga D.:
Energy distribution of elastically scattered electrons from double layer samples.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION B-BEAM INTERACTIONS WITH MATERIALS AND ATOMS 369: 109-121 (2016)
http://real.mtak.hu/28025/

Lévai G., Godzsak M., Hakl J., Takats V., Csik A., Vad K., et al. (8):
Designing the color of hot-dip galvanized steel sheet through destructive light interference using a Zn-Ti liquid metallic bath.
METALLURGICAL AND MATERIALS TRANSACTIONS A-PHYSICAL METALLURGY AND MATERIALS SCIENCE, 47A: (7) 3580-3596 (2016)
https://arxiv.org/abs/1701.01616

Zayachuk D. M., Slynko E. I., Slynko V. E., Csik A.:
Oscillations and huge preferences of PbTe crystal surface sputtering under Secondary Neutral Mass Spectrometry conditions.
MATERIALS LETTERS, 173: 167-169 (2016)
https://arxiv.org/abs/1701.01597

Shvetsov-Shilovski N. I., Lein M., Madsen L. B., Räsänen E., Lemell C., Tokési K. et al. (8):
Semiclassical two-step model for strong-field ionization.
PHYSICAL REVIEW A, 94: 013415 (2016)
https://arxiv.org/abs/1604.05123

Újvári G., Molnár M., Páll-Gergely B.:
Charcoal and mollusc shell 14C-dating of the Dunaszekcso loess record, Hungary.
QUATERNARY GEOCHRONOLOGY, 35: 43-53 (2016)
http://real.mtak.hu/40865/

Karátson D., Wulf S., Veres D., Magyari E. K., Gertisser R., Hubay K., et al. (15):
The latest explosive eruptions of Ciomadul (Csomád) volcano, East Carpathians : a tephrostratigraphic approach for the 51–29 ka BP time interval.
JOURNAL OF VOLCANOLOGY AND GEOTHERMAL RESEARCH, 319: 29-51 (2016)
http://real.mtak.hu/47599/

Pál I., Magyari E. K., Braun M., Vincze I., Pálfy J., Molnár M., et al. (8):
Small-scale moisture availability increase during the 8.2-ka climatic event inferred from biotic proxy records in the South Carpathians (SE Romania).
HOLOCENE, 26: (9) 1382-1396 (2016)
http://real.mtak.hu/46162/

Simon E., Harangi S., Baranyai E., Braun M., Fábián I., Mizser Sz., et al. (8):
Distribution of toxic elements between biotic and abiotic components of terrestrial ecosystem along an urbanization gradient: Soil, leaf litter and ground beetles.
ECOLOGICAL INDICATORS, 60: 258-264 (2016)
http://real.mtak.hu/28026/

Janovics R., Kelemen D. I., Kern Z., Kapitány S., Veres M., Jull A. J. T., Molnár M.:
Radiocarbon signal of a low and intermediate level radioactive waste disposal facility in nearby trees.
JOURNAL OF ENVIRONMENTAL RADIOACTIVITY, 153: 10-14 (2016)
http://real.mtak.hu/28013/