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I. Main tasks of the research institute in 2009

The main tasks of the research institute, according to the deed of foundation, are the following: fundamental and applied research in nuclear-, atomic-, and in particle physics. The researchers of the institute apply physical knowledge and methods in other fields of science (material sciences, earth science and environmental research, medical-biological research) and also in practice. They develop equipments and methods for fundamental and applied science. The institute participate in graduate education and takes on tasks in undergraduate education. The institute performs supplementing activities in the area of its fundamental activity.

II. Outstanding research and other results, and their socio-economic impact in 2009

Quantum mechanics

An effective method of obtaining exact solutions of the one-dimensional Schrodinger equation has been extended to problems with position-dependent effective mass. In contrast with previous results obtained in this field, the method guarantees that the effective mass will not have zeros or singularities, furthermore, it contains the constant-mass case as special limit. As an example a potential was considered, which possesses certain characteristics of both the harmonic oscillator and the Morse potential, and its energy eigenvalues and the corresponding normalized wave functions have been presented in closed form.

It is known, that any of the quantum correlations can be reproduced by performing two-event measurements on two distant parts of a pair of maximally entangled quantum systems in the frame of the classical model, if we allowed two bits of communication between the two distant subsystems. The researchers of the Institute proved, that these two bits are necessary too.

We present a fundamental concept - closed sets of correlations - for studying nonlocal correlations. We argue that sets of correlations corresponding to information-theoretic principles, or more generally to consistent physical theories, must be closed under a natural set of operations. Hence, studying the closure of sets of correlations gives insight into which information-theoretic principles are genuinely different, and which are ultimately equivalent. This concept also has implications for understanding why quantum nonlocality is limited, and for finding constraints on physical theories beyond quantum mechanics.

Let us perform measurements on two separated parts of a physical system. Let us consider the set of joint probabilities of the outcomes of measurement performed on the subsystems. In case of classical physical systems, the set is a convex body bounded by flat surfaces. These surfaces are characterized by the so called tight Bell inequalities. According to quantum theory, Bell inequalities may be violated, therefore, by performing measurements on a quantum system we may get points outside the classical set. If we allow all quantum systems, the full set, the so called quantum body is also a convex set, larger than the classical one, fully incorporating it. It has been shown by our researchers that against the expectations the

quantum body we get by confining ourselves to finite-level quantum systems (systems of finite dimensionality) is neither convex, nor it incorporates the full classical set.

Particle physics

Researchers of Atomki carried out significant innovation by positioning the muon detectors of the CMS in the previous years. They continued to play an important role in the last year too by operating the established structure, and by participating in further developments.

In 2009 they continued their project on developing a general method for computing next-to-next-to leading order corrections to jet cross sections. They have given the analysis results for the integrals of the approximate squared matrix elements over the one-parton unresolved phase space.

Nuclear physics

The fission probability of ^{232}U has been measured using the ^{231}Pa(^{3}He,df) reaction with an energy resolution of 11 keV in the excitation energy region of E^* = 4.0–6.4MeV. A number of sub-barrier fission resonances have been observed for the first time in the excitation energy range below E^* = 4.8 MeV and interpreted as rotational bands with a rotational parameter characteristic to a hyperdeformed nuclear shape ($\hbar^2/2\Theta$ = 1.96 ± 0.11 keV). The angular distribution of the associated fission fragments was measured to deduce the K value of the rotational bands.

The neutron rich Carbon nuclei are weakly bound and their valence neutrons show halo like structure. This situation allows for an unusual nuclear behaviour. To study the quadrupole properties of heavy C nuclei, the ^{20}C nucleus has been investigated through inelastic scattering on a lead and a liquid hydrogen target in RIKEN, Japan. It has been shown that the Coulomb excitation of this nucleus has an anomalously small cross section relative to the nuclear excitation. This observation can only be interpreted by assuming that the quadrupole motion of the valence neutrons are much more weakly coupled to that of the nuclear than it is usual in nuclei close to the stability.

In earlier studies it has been shown that the single particle energies of the neutrons are rapidly changing with changing the number of protons. This phenomenon leads to the disappearance of the N=8 and N=20 shell closures in extremely neutron rich nuclei. To search for the behaviour of the single particle states in other regions of the nuclear chart, isomeric states of ^{131}In were studied in GSI within the RISING collaboration. The energy of a $17/2^+$ isomeric state has been determined in this nucleus. From a shell model analysis of the result it has been shown that taking away 2 protons from the ^{132}Sn nucleus results in a 600 keV reduction of the N=82 shell gap. This value suggests that the N=82 shell closure will disappear at Z=40, that is in ^{122}Zr.

The level structures of the odd-N ^{127}Ce and ^{129}Ce isotopes have been investigated and extended to higher spin using the Euroball and Eurogam γ-ray spectrometers. Several new band structures were observed in each isotope and configuration assignments were extended with Woods-Saxon cranking calculations. Our researchers found, that the negative-parity bands in the light odd-N cerium isotopes exhibit unusually large values of signature splitting, consistent with nonaxial shapes for these structures. It is believed that this arises due to polarization of the γ-soft core by high-j neutrons from the upper $h_{11/2}$ midshell. These results provide further evidence for static triaxial shapes in atomic nuclei.

In the study about the development of the detection technique the full-energy peak efficiency calibration and the energy resolution measurements of 2"x2" $LaBr_3$ γ-ray detector were performed for γ-ray energies in the 700 keV–17.6 MeV range. To determine the absolute efficiency of the detector γ-sources and (p,γ)-reactions – generated by the 5 MV Van de Graff accelerator of the institute – have been used. The experimentally determined relative energy resolution of the crystal was proved to be the best among the other types of scintillation detectors.

The DIAMANT ancillary detector, developed in the Atomki, for the identification of light charged particles by Atomki, has been successfully applied in experiments carried out with the EXOGAM (GANIL, France) and the AFRODITE (iThemba LABS, Republic of South Africa) gamma-ray spectrometers. The aim of the experiment was the identification of large ground state deformation proposed for certain A~130 nuclei near the proton drip-line.

The $^{3}He(\alpha,\gamma)^{7}Be$ reaction, which is important for the big-bang nucleosynthesis and for the energy generation of starts, has been studied in a wide energy range using a novel approach: a recoil separator.

Alpha-induced reaction cross sections on ^{113}In have been measured and the astrophysical consequences have been drawn.

Based on a high precision alpha elastic scattering experiment on ^{89}Y, the alpha-nucleus potential and its dependence on the neutron number has been studied.

A theory claiming that the radioactive decay half-lives can depend on the temperature, has been confuted by studying the decay of ^{74}As in a wide temperature range.

The half-life of the m1 isomer in ^{154}Tb has been determined with high precision.

The lifetime of the first excited state of ^{12}Be has been measured and the disappearance of the N=8 magic number far from stability has been confirmed.

By studying its mirror nucleus, ^{20}Mg, the decoupling of the valence neutron in ^{20}O has been confirmed.

From theoretical cluster studies of ^{36}Ar we have predicted that hyperdeformed bands can be evolved in this nucleus, and the relevant phases can be generated most easily by the $^{24}Mg + ^{12}C$ and $^{20}Ne + ^{16}O$ processes. Independent experimental observations, out of our institute, using the mentioned reactions, confirmed the existence of the hyperdeformed band in the ^{36}Ar.

The researchers of the institute played a significant role in the development of the one-particle base (Berggren-representation), containing the Gamow states with complex energy. A paper summarizing the results of the previous decades was published in 2009. This article is a review of the information about the Berggren-representation and the applications in the shell model ranging from the giant resonances to the exotic light nuclei.

The excitation function of proton induced nuclear reactions on Mo, Er, Tm, Hf, Zr, Cd targets, deuteron induced nuclear reactions on Hf, Co, Fe, Zr targets, alpha-particle induced nuclear reactions on Ho, Hf targets, and ^{3}He-particle induced nuclear reactions on Zn, Pd, Cd, Ta, Pt targets were measured and theoretically calculated to broaden the nuclear database of IAEA – bearing great importance in medical and industrial applications.

Atomic physics

The energy distributions of positrons scattered on water target have been measured in coincidence with the remnant ions at 100 eV and 153 eV incident energies. Our researchers observed using coincidence technique, that the remainder system of the positron scattering were either H_2O^+ ions or the fragments of OH^+ and H^+ ions. The maxima of the distributions associated with the production of OH^+ and H^+ are about 5–10 times smaller than that for $H2O^+$.

A systematic set of measurements for studying the fragmentation of small molecules (H_2O, H_2S, CH_4, C_6H_6) by slow, highly charged ion impact has been completed. Three significant observations can be listed: i) ions with identical electronic structure and velocity but with slightly different charges (N^{6+}, O^{7+}), provided large differences in the dominant fragmentation channels for all the targets, ii) for target molecules with very similar structures (H_2O and H_2S) the fragmentation pattern was also very different, iii) unexpected angular distribution of the fragments has been found in some of the fragmentation channels for the water molecule, which can not be explained yet. International collaborations have been developed for a theoretical understanding of the results.

A new set of experiments has been started also at ARIBE in Caen, within the ITS LEIF framework. The aim is to study the spectra of autoionized electrons emitted from at least doubly excited neutral molecules and molecular ions, created in charge-changing collisions. Surprisingly, the first spectra exhibited rather large yields of negative ions, which naturally appear when measuring electron spectra by energy dispersive methods. The observation can be relevant in the study of radiation damage mechanisms.

The analysis of the experimental data from the DORIS III (Hamburg, Germany) measurement was finished and the present experimental left-right asymmetry parameters confirmed the earlier obtained data from MAX-II measurement (Lund, Sweden). In the present work the measurement was performed in an experimental environment different from the earlier one, but the parameters of asymmetry showed a very good matching. The agreement between the two data sets suggests that the left-right asymmetry in the angular distribution of the photoelectrons originates from the photon-atom interaction itself.

The measurements of the angular distribution of Kr 4p photoelectrons, carried out on the synchrotron DORIS III (Hamburg, Germany) showed, that resonant excitation of the Kr 3d shell significantly modifies the angular distribution of the 4p photoelectrons. Beside the dipole force there are considerable contribution originating from higher multipoles too. The comparison of the experiments and our theoretical model unequivocally shows that the individual particle model is not suitable for the description of the direct and non direct ionization processes.

Semiclassical approximation has been used for evaluation of the deexcitation and annihilation cross sections of the Positronium, staying initially in high angular momentum state, in collision with heavy projectile. Importance of dipole and sudden collision mechanisms were indentified at low and high impact energies, respectively. Different scaling law of the cross sections with respect to the principal quantum number has been explored for the different collision mechanisms.

In the case of collision of low (3-25 keV) energy antiprotons and He atoms the double ionization cross sections were determined experimentally for the first time.

Ionization of positronium in linearly polarized laser field was studied. For solving the problem, classical and quantum mechanical approaches were used. The calculations were

compared to the results obtained from the exact solution of the time dependent Schrödinger equation.

Emission of two electrons has been investigated in 100 keV He^{2+} - He collision. The determining role of the final state e-e interaction in forming the shape of energy and angular distribution of emitted electron has been demonstrated in a calculation based on the continuum distorted wave approximation. Mechanism of electron capture into the projectile's continuum has been investigated in detail. This process, the so called two electron cusp, has been studied experimentally previously in the institute in 100 keV He^0 – He collision. Our study is able to interpret the most important experimental results.

A technique was developed in which 2-dimensional angular distribution of ions, atoms with a few keV energies and UV photons exiting from nanocapillaries is measured by a position sensitive MCP detector. The separation of the different charge states of the ions is performed by an electrostatic deflection. The neutral particles are identified by the differences in the amplitude distribution.

Solid-state physics, surface physics, material science, and statistical physics

The ion guiding phenomenon in insulating capillary samples of polyethylene terephthalate and polycarbonate was investigated at the ECR ions source of Atomki, and within an international collaboration at Zernike LEIF facility at KVI, Groningen (The Netherlands). They studied in details the successive developing of charged up patches inside the capillaries and the accompanying neutralization of a fraction of the incident ions. The latter was performed in Debrecen with 3 keV Ar^{7+} ion beam. The capillary samples with diameter of 50 200 and 400 nm were produced by etching ion tracks in foils of 10-50 μm thickness. The ions transmitted trough the capillaries were separated according to their charge state by an electric field and their intensity were measured by a MCP position sensitive detector. It was found that majority of the ions kept their initial charge state but a few percent of them were fully neutralized. The intensity of ions with lower charge state was below the detection limit. In cases of different tilt angles of the samples, the angular distribution of the transmitted ions and the created atoms were also measured by the position sensitive detector in function of time. The mean emission of angle of the ions showed a strong oscillatory behaviour in accordance with earlier experiments, but for the atoms it was much less pronounced. The intensity of the atoms, however, shows a very dynamic behaviour: starting from a small value it grew much rapidly than the intensity of ions. These observations have lead to a new model of neutralization in capillaries, which may promote the understanding of the guiding phenomenon as well.

Using Monte Carlo simulations it was shown for the first time that guiding electrons through insulator nanocapillaries differs completely from the case of highly charged ions. While ions get through without direct collisions with the surface because of the charging of the inner surface of the capillary, in guiding electrons the direct interactions with the capillary surface appearing as series of elastic and inelastic scattering play a significant role.

The magnitude of the error caused by neglecting interference effects and inaccurate consideration of elastic scattering in simulating reflection electron energy loss spectra of solid Si was estimated. Different theoretical approaches were applied to describe electron energy loss processes, as well as the electron trajectories, using different primary electron energies (800 and 2000 eV) and geometrical configurations. Comparing the results from the different theoretical models with the available experimental data, it is shown that the error caused by neglecting interference effects is considerably smaller than the error caused by the inaccurate

consideration of the effects of elastic electron scattering, even at a relatively low (800 eV) primary electron energy. Using the dielectric function and the differential cross sections for elastic electron scattering as input parameters, the results of the calculations show much better agreement with the data derived from the experiment than the earlier works.

Using elastic peak electron spectroscopy and Monte Carlo simulation of electron scattering the mean free path for inelastic electron scattering (IMFP) in 3d transition metals (Mn, Cr, Co and Fe) and in NiFe alloys of different compositions was determined for the primary electron energy range of 4-8 keV. Except the Co, the obtained IMFP values agree well with the corresponding values derived using predictive formulae or calculated from optical data. When accounting for the inelastic electron scattering background of photoelectron or Auger spectra excited from the mentioned metals accurately, these electron transport parameters are necessary.

Alloy-metal Auger parameter shifts were determined experimentally from electron spectra photoinduced by hard X-rays and the charges transferred between components were calculated using density functional theory (applying the Wien 2K program package) in the case of NiFe alloys of different compositions. For the Fe component, a linear dependence was found between the transferred charges and the corresponding alloy-metal Auger parameter shifts, allowing the estimation of the transferred charge (determining for alloy stability) from Auger parameter analysis when the composition of the alloy is known.

The ground and excited (with an 1s vacancy) state electronic density of states (DOS) in 3d transition metals (Cu, Ni, Mn, Co, Cr and Fe) were determined using the density functional theory and the Wien 2K program package. From the density of the occupied and unoccupied electronic states the joint density of states (jDOS) was derived. Applying the model and algorithm proposed by Werner the electron energy loss functions were obtained from experimental REELS spectra of these transition metals. The determined distributions are necessary for accurately describing the electronic structure effects reflected in the shape of the core photoelectron lines in the given metals.

Electron excitation and transport processes induced by simultaneous XUV and NIR radiation near tungsten surfaces were studied. As a first step the velocity distribution of photoelectrons excited by XUV photons was described, then the propagation of the electrons in the solid (taking into account both elastic and inelastic scattering) until they escape from the sample. The distributions of the emitted electrons by their energies and location of creation were determined. It is found that using attosecond timescale, the emission of the electrons excited from core levels is delayed compared to those electrons excited from the conduction band.

It was shown that in the spectra of electrons backscattered elastically from ice surfaces the peaks attributable to H and D can be identified easily. Their Monte Carlo calculations are in good agreement with their experimental observations.

The grain size dependence of physical properties of superionic crystal nanopowder composites and ceramics embedded in different carriers was determined (in cooperation with the University of Uzhgorod, Ukraine).

The effects of the parameters of the layer structures (atomic number contrast, ratio of layer thickness, shape of interfaces, mixing of layers) and the scattering energy on the diffraction intensity distribution were determined (using model calculations) for interpretation of anomalous X-ray diffraction measurements.

In order to observe and study systematically the ECR plasma we made a high number of high-resolution visible light plasma photos and movies. The effects of the main external setting parameters (gas pressure, gas composition, magnetic field, microwave power and frequency)

were studied to the shape, colour and structure of the plasma. The double frequency mode (9+14 GHz) was realized and photos of this special "star-in-star" shape plasma were recorded. A study was performed to analyze and understand the colour of the ECR plasmas. The analysis of the photo series gave a great deal of qualitative and valuable physical information on the nature of ECR plasmas. To the best knowledge of the researchers their work is the first systematic study of ECR plasmas in the visible light region.

Observations on the two-dimensional sine-Gordon quantum field theory model has proved, that the Kosterlitz-Thouless-Berezinskii (KTB) type phase transition – which plays a key role in the interpretation of the electric transport properties of layered high transition temperature superconductors – can be considered as the transition phase between the two attraction fields of the phase diagram. The scheme dependence of the renormalization of the two-dimensional sine-Gordon models was studied too, namely, they observed the dependence of the results from the different methods of renormalization groups.

Magnetic nanolayers prepared by electrochemical deposition were studied using a mass spectrometer of secondary neutral particles (SNMS). Depth profile analysis of FeCoNi alloys explained how the well known preferential deposition modifies the composition of elements in the 150 nm layer-thickness from the substrate. Use of SNMS in this field is completely original. Information obtained with this method is revolutionary new.

Depth profile and thermal stability measurements were performed on Ge and GaAs semiconductor layered structures prepared by CVD in collaboration with Parma Institute of Electronic and Magnetic Materials. Results concerning thermal stability play a significant role in the production of semiconductors.

In the course of the observation of hydrogeneted amorphous Si (a-Si) layers with SNMS structural changes induced by thermal treatment of various length, were monitored using low angle X-ray diffraction and transmission electron microscopy. Study of these phenomena is one of the most important lines of the solar cell research.

Thin film samples were prepared from isotopes of Se proceed to the installation and first test measurements of a new isotope collecting chamber. The obtained samples were processed in various chemical reactions. This gave the possibility of the production of biosynthetic nanoparticles marked with isotopes for research based on tracing with stabile isotope.

Detection technique and signal processing

The characteristic electron energy loss processes in Si, Ge, diamond and CdTe semiconductor, as well as in GSO, LSO, LYSO, BaF_2 and CsI scintillators were studied by the help of REELS measurements. It is found that the distributions of the probabilities of different energy loss processes (induction of plasmons, interband transitions, giant resonances, etc.) are different for particular detectors. In general, there exists a dominant process (e.g. plasmon excitation in the case of Si and Ge, excitation of giant resonances in various scintillators) that - through the primary energy partition - limits the achievable energy resolution. This finding is fundamental for explaining the capability of the recent detectors and for the research of new detector materials.

A procedure and a user-friendly program package was developed for the applications – and for comparison of the respective results- of the most advanced models and algorithms used for deriving the electron energy loss probability density functions from experimental REELS spectra. The knowledge of the differential probabilities for surface and bulk excitations has a crucial importance for the better understanding of electron transport processes taking place

near the surface as well as for accurate evaluation of experimental electron spectra or for determining the complex dielectric function of materials.

In connection with CdTe semiconductor detectors (for detection of gamma rays) the factors responsible for the broadening of the spectral peaks (the scattering of the charges induced by the radiation and collected by the electrodes, as well as the electric noises) were studied as a function of the temperature, the voltage and the timing constant of the forming amplifier. It is found that there exists such a combination – characteristic for the given system – that ensures the best resolving power.

A theoretical model was developed for describing the detection mechanism in monolith scintillation detectors, having three-dimensional sensitivity. Standard deviation of spatial coordinates for several various photodetector - scintillator systems were calculated. The effect of the statistical fluctuation in the numbers of photons on the position resolution provoked by scintillation and electronic noise was separately studied.

The energy and time resolving, as well as the particle discrimination capability of $LaBr_3$ scintillation detectors was studied for developing combined, particle–gamma ray detector systems.

In connection with the development of a time-of flight positron emission tomograph (TOF PET) based on LYSO scintillator and fast photoelectron multiplier, the achievable time resolution was studied, with a special attention to the deviating average flight times for the individual electron multipliers and to the scatter of the flight times within a single tube that can be attributed to the scatter of the electron trajectories.

The Cardiotom Mark1 mobile tomographic gamma camera has been updated with high performance electronics and data acquisition, image reconstruction and presentation software. The camera serves now the education of the MSc students at the Royal Institute of Technology, Stockholm, Sweden. The newly installed hardware and software solutions are fully perspicuous and well separated in order to serve the better understanding of the principles of the gamma camera and ectomography.

High performance data acquisition and OpenGL based visualization software has been developed for micro channel plate position sensitive detector, installed at the Atomki ECR Ion Source Laboratory. The software is able to acquire and visualize data using the high speed FPGA based data acquisition system via Ethernet network.

The formerly developed PalmtopMCA multichannel analyzer acquisition and evaluation software has been extended in order to support the handling of not one but several independent PalmtopMCAs by one PC.

The digital signal processor developed for the processing of PET detector signals was successfully applied to process the pulses coming from $LaBr_3$ scintillation detectors.

Ion beam analysis

The aerosol database which characterizes the aerosol exposure in the East Hungary region was extended. Sources of urban aerosol were determined by using ion beam analytical techniques and statistical methods with a sampling provided hourly time resolution. Chemical composition of aerosol particles interesting from the point of view of origin (Saharan dust) or of health impact (workplace aerosol polluted with heavy metal) were determined by single particle analysis carried out on a scanning nuclear microprobe.

Impact materials from the Barringer Meteor Crater were investigated by micro analytical methods (micro-XANES, micro-PIXE and ED-SEM) based on synchrotron, scanning nuclear microprobe and electron microprobe, results were achieved in the field of geological metamorphism caused by cosmic collision.

High lateral resolution RBS analysis was carried out for the nuclear astrophysics group of the institute in order to investigate the composition, thickness and homogeneity of targets used for astrophysical p-process studies.

Structural changes, caused by ion beam milling, were studied in Si/Cr multilayers. Elemental composition, surface topography and interlayer diffusion were determined by high lateral resolution. Comparative analysis was carried out between micro-RBS, Spectroscopic ellipsometry and AES depth profiling.

A new evaluation method has been developed for the characterization of spectral features of Si pin photodiode modified by area selective implantation.

High lateral resolution hydrogen analysis has been carried out on biological samples, polymer foils, and samples of diffusion studies on hydrogenated Si/Ge multilayers.

A silicon microturbine was made in collaboration between the institutes HAS-Atomki and HAS-MFA. This is the first demonstration of a silicon device containing a moving part made by proton beam writing (PBW) and subsequent selective porous Si (PS) etching. This work resulted in an international interest, shown by the fact that the Singapore group, being world leader in this field, cited it on their pbeam.com website.

Optical structures (e.g. optical gratings, Fresnel lenses, etc.) were created for the first time by direct write micromachining method in poly-(dimethylsiloxane) (PDMS). PDMS was previously used as a replicating material only. The new paper already resulted in two inquiries for international collaborations.

As an application of the PBW method a working microreactor was made and its operability was demonstrated.

Environmental analysis and dating

The method to determine the radon potential of building sites has been improved and applied to constructions of industrial storage buildings.

A gasgeological numerical model has been developed to describe the transport of mofette gases in near surface soils. The results of the model calculations were used in the conceptual design of a gas-collecting construction aimed to supply a dry carbon dioxide spa with medicinal gas.

The monitoring of atmospheric CO_2 has become the part of the measurement program at the baseline stations of the World Meteorological Organization's Global Atmosphere Watch (GAW) network. The measurements show that the growth rate of atmospheric CO_2 varies in a much wider range than the anthropogenic emission. The reasons might be revealed by the measurements carried out on continental areas covered by vegetation (both source and sink of CO_2), as well as by CO_2 isotope composition (^{14}C, $^{13}C/^{12}C$, $^{18}O/^{16}O$) measurements. To get a clear picture on the anthropogenic CO_2 two continuous $^{14}CO_2$ sampler units have been installed at two elevation levels (10m and 115m) along the TV-transmitter tower of Antenna Hungária Corp. in Hegyhátsál monitoring station, where high precision atmospheric CO_2 mixing ratio measurement has been running since 1997. Our researchers and the researchers of the NMS sponsored by the HSRF joined to the monthly measurements of the continental

background values. This is the first station in Europe where the fossil fuel contribution of CO_2 is directly measured at two different levels at the same place and time.

It is clear from the ^{14}C data that the fossil CO_2 contribution at Hegyhátsál during the winter is small (cc. 5 ppm) comparing to those measured in the vicinity of several European towns (cc. 20 ppm) and to the background value (cc. 380 ppm). Hegyhátsál could be a primary, baseline monitoring site of the forming ICOS network, which could improve the calculated emission data (inverse modelling) especially for eastern Central Europe.

New radiocarbon data measured in cooperation with NFS ^{14}C AMS Laboratory, Arizona, provided valuable information on the behaviour of the Ciomadul volcano. Contrary to the assumptions the volcano Ciomadul was active in the last 50 000 year not once but twice 40 000 and 27 000 years before.

Two 2 m long ice cores were extracted from the floor ice of Bortig Ice Cave and based on tritium concentration measurements the change in the rate of ice-development in the last 60 years was determined. The highest annual accumulation rate (6.74 cm/yr) was between 1958 and 1963 and gradually decreased to 0.54 cm/yr for the recent decades. The explanation of this significant decrease must be climate related (surface temperature increase combined with decrease in the amount of snow). This result emphasizes the fast change of the climate, and its consequences. Our researchers worked together in this project with the researchers of the Department of Physical Geography ELTE, the MTA GKL, and the Emil Racovita Institue of Speleology, Rumania.

A new method of chemical sample preparation for liquid scintillation ^{14}C measurements was developed in Atomki in 2005. This CO_2 "inhalation-absorption" method was improved in 2009 and it became a routinely used, quick, inexpensive and simple method, extending the capacity of the ^{14}C laboratory by 500-600 ^{14}C analysis/year. It can be an effective, inexpensive alternative solution for other LSC laboratories too.

The sensitivity of noble gas mass spectrometers usually depends on the pressure in the ion source. Tritium content determination of environmental water samples are done by the mass spectrometric measurement of the ^{3}He generated in the course of tritium decomposition. The pressures of the ^{3}He originated from the tritium sample in the ion source and the pressure of the ^{3}He in the background of the inlet system are smaller by several orders of magnitude than the pressure of ^{3}He removed from the smallest amount of air employable in the calibration. This might cause systematic error which was corrected earlier by the measurement of standard samples. To avoid this systematic error we use a special isotope dilution technique: known amount of ultrapure ^{4}He is given to the incoming sample and thus the partial pressure of all the helium in the mass spectrometer will be similar to the pressure of the calibration helium. The measurement of more than 50 water samples with known tritium concentration, in 2009, proved that the former systematic error was eliminated and the precision of the tritium measurements has become better than 2.3% above 1 TU. This new, isotope dilution method is a suitable method for helium measurements in other fields of science, where the pressure and isotope content of the sample gas are significantly different compared to the parameters of the calibration gas.

It is an accepted fact, that the tritium emission of nuclear power plants affects the tritium content of the precipitation. The change in the tritium content of the precipitation around the nuclear power plant of Paks with a tritium emission of 3 TBq/year was monitored. 56 precipitation samplers were planted around the chimneys of the power plant, and after an acceptable amount of rain we collected the water samples falling through the jet of smoke, containing tritium. Water samples far from the jet of smoke were collected too. Our measurements and model calculations proved that the tritium content of the precipitation is

increased as a result of the wash out only in the close vicinity of the power plant. The tritium content of the precipitation, falling out further than 5 km from the power plant was not affected by the emission of the power plant.

To investigate the flow of sap in the trees two new thermometric sap-flow meter with 4 channels were developed in our institute and were planted in the stand of the Long Term Ecological Research (LTER) area of the Síkfőkút Project of UD. Thereby 20 different trees were monitored simultaneously during the whole growing season with a time resolution of 5 minutes. The meteorological pedological, parameters, and the radial growth of the tree trunks were measured too. Physiological measurements of leaves were performed in every several weeks. New data series of the water transport in sessile oak (Quercus petraea) and austrian oak (Quercus cerris) trees and their hybrids were obtained. The observed correlations help understanding the climatic sensitivity of the oak species and assessment of their responses to climatic changes.

Based on the dating of clay minerals it has been determined that the low- and very low-grade metamorphism in the southern part of Tisia (Papuk Mts., Slovenia) took place in the Cretaceous age (Austrian and/or Subhercynian phases). The very low-grade metamorphism of minerals in the inner-Western-Telekesoldal nappe (Aggtelek-Rudabánya Mts.) was older, similarly to the accretion series of the inner West Carpathians it took place in the lower cretaceous (140-120 Ma).

Study of basalts proved, that leucite in the basanite of Hegyestű changes its structure at preheating on low temperature and therefore loses a significant part of its radioactive Ar content.

The phases of the eruption of the basalts containing Ti in the Czech-Saxon Mountains were separated.

Preparation of volcanic rocks for K/Ar dating collected in the King George Island, Antarctica, in 2009 was performed in an International Expedition to the Antarctica.

Geochronological study of the Neogene silicic volcanic activity of the West Carpathians has been completed. Compilation of the database and submission of the paper are in progress.

Radiochemistry

We succeeded in the separation of ^{103}Pd from rhodium target using the method of thermo-chromatography in collaboration with scientists from South Africa. Cooperating with the South-African researchers and with researchers from Dubna EAI a method was established for the production of ^{117m}Sn with large specific activity from enriched ^{116}Cd target. Both isotopes are promising candidates for therapy of tumors.

New method has been developed for the radiochemical separation and measurement of isotopes emitting beta and gamma radiation difficult to detect, and found in the radioactive waste of the Paks power plant (like ^{108}Ag, ^{79}Se és ^{107}Pd)

One of the emerging techniques for utilization of ^{11}C-radioisotope labelled reagent on catalyst is the imaging by positron emission tomography. The investigation of radio-reagent distribution in time and as a function of temperature can provide additional information about catalytically active sites. This mini PET technique has not yet been applied before in this field.

The conditions of production of ^{75}Br ($T_{1/2}$=1,6 h, PET), ^{76}Br ($T_{1/2}$=16,2 h, PET) isotopes were investigated with the help of nuclear reactions provoked by protons on natural and enriched

selenium with (^{77,78,80}Se) isotope composition. The measurement of the cross section data of the nuclear reactions producing the radio isotopes in the energy range of E_p<66 MeV was performed in international collaboration (iThemba LABS, South-Africa, NIRS, Japan). The accessible data of the excitation function were compilated and evaluated. Yield calculations were completed on the mentioned isotopes with the use of the fitted data. The optimal production parameters and the obtainable yields of various targets were determined.

III. Presentation of national and international relations

National research cooperation

Our institute maintains a net of widespread domestic cooperation on each research-field of our scientific activity. Especially important our collaboration with the following institutes:

- in the field of particle and nuclear physics and their applications: HAS RMKI, Departments of Experimental Physics, Theoretical Physics, Botany, of the University of Debrecen (DU), HAS AEKI, Institute of Nuclear Techniques of Budapest University of Technology, University of Szeged, Institute of Nuclear Medicine UD, NUKENRG Consortium.
- in the field of atomic physics and its applications: Departments of Experimental Physics, Solid State Physics, Applied Chemistry, Physical Chemistry, Prosthetic Dentistry of UD, Department of Experimental Physics of Budapest University of Technology, Department of Physics of the University of Miskolc, Department of Radio Chemistry of the University of Veszprém, Alkaloida Research and Development Ltd., HAS MFA, HAS RMKI.
- in the field of physics of condensed structures: HAS MFA, HAS SZFKI, HAS RMKI, HAS USZ Laser Physics Group, Departments of Solid State Physics and Physical Chemistry of UD, Department of Radio Chemistry of the University of Veszprém, Eötvös Loránd University, Laboratory of Nuclear Chemistry, TKI-Ferrite Manufacturing and Development Ltd., HAS Chemical Research Center, Kraft Projekt CC., University of Szeged, Paks Nuclear Power Plant CC.
- in the field of detection and signal processing techniques: Institute of Nuclear Medicine UD, Mediso Ltd., Department of Experimental Physics.
- in the field of ion beam analysis: departments and clinics of UD, HAS MFA, HAS SZFKI, HAS RMKI, HAS AEKI, HAS Air-chemistry Group of the Pannon University, Department of Archeology of the University of Szeged, National Institute of Environmental Sanitation Studies, National Meteorological Service, UD Clinic of Dermatology, Hungarian Ion beam Physics Platform (HIPP).
- in the field of environmental research and dating: ISOTOPTECH CC., departments of UD, Szeged, Pécs, Miskolc, and the Eötvös Loránd University, HAS GKI, MÁFI, ELGI, OKK-OSSKI, VITUKI, Paks Nuclear Power Plant CC, RHKT PBO of Püspökszilágyi, MECSEKÉRC Environmental Protection CC., MecsekÖKO Environmental Protection CC., HAS Institute of Archeology, National Museum of Hungary, Budapest History Museum, Hungarian Natural History Museum, Fácies Lp., Envicom 2000 Ltd., Hydrosys Ltd., Smaragd GSH Ltd., Enviroinvest Ltd., VIZITERV Environ Ltd. Nyíregyháza, Institute of Nuclear Techniques of the Budapest University

of Technology, National Meteorological Service, Scopia Lp., AktAnal Lp., RadAnal Lp.

- in the field of archeology: HAS Institute of Archeology, Budapest History Museum, National Museum of Hungary, and other institute of the domestic network of museums.
- in the field of radiochemistry: Institute of Nuclear Medicine UD

Participation in higher education

Our institute played an important role in the graduate and undergraduate education in 2009 too, and kept up the traditionally good relationship with the UD. The researchers of the Atomki announced 44 courses and gave 756 curricular lectures in the period of the report, contributing to the educational work of the UD. Two of our researchers gave lectures at the University of Szeged. The number of contact hours, held by our researchers at the UD, was 509 and the number of courses was 18. 39 researchers took part in the education. The institute participated in the following undergraduate trainings: physicist, physics teacher, informatics specialist, software designer mathematician, environmental science, and basic environmental science, agricultural environmental management engineer. Our researchers gave lectures, special practical courses in laboratories, and managed theses. Nine PhD students, 12 MSc students and 4 members of the Scientific Students' Associations worked in the institute during the year of the report, and the number of hours expended to advisory work was 1822.

Our institute announced the course called: Nuclear imaging together with the Physics Institute and Informatics Faculty of UD. The purpose of the course was to give a summary of the various imaging methods playing an important role in the practical application of nuclear physic.

The Environmental Physics Department of the UD works in Atomki. This department participates in the education of students in physics, environmental studies and environmental sciences.

International research cooperation

Apart from participations in international programs of numerous institutes and collaboration based on bilateral agreements and agreements made by the HAS (I. IV. section) the cooperation based on agreements between institutes, ad hoc and informal collaborations play a significant role too among the international cooperation of our institute. Such collaborations are the following:

- nuclear physics and applications – with research institutes of 22 countries, in 36 topics
- atomic physics and applications – with research institutes of 21 countries, in 39 topics
- detection and signal processing techniques – with research institutes of 5 countries, in 6 topics
- ion beam analysis – with research institutes of 6 countries, in 7 topics
- environmental research and dating - with research institutes of 11 countries, in 13 topics

IV. Brief evaluation of successful national and international grants

In the research work of Atomki there were 12 projects supported by the Hungarian Scientific Research Fund (OTKA) and 3 projects supported by the National Office for Research and Technology (NKTH) in 2009. The institute participated in 13 EU-projects and also in international comparative programs and trainings like ESIR, VIRI, EURATOM, TRI-TOFFY, TRIC2008. It is an important fact that one of the members of the institute received ERC Starting Grant for the years 2008-2013.

14 projects in international cooperation were supported by the Hungarian Science and Technology Foundation (TéT) based on bilateral intergovernmental S&T agreements with Argentina, Austria, Croatia, Czech Republic, France, India, Slovakia and South-Africa.

The bilateral agreements of the Hungarian Academy of Sciences with partner organizations of different countries gave possibility to perform research work in 20 projects with research institutes or universities of Belgium, Bulgaria, Czech Republic, Finland, Germany, Mexico, Poland, Portugal, Romania and Spain.

V. The most important publications and patents in 2009

1. Csige L., Csatlós M., Faestermann T., Gácsi Z., Gulyás J., Habs D., et al. (12), Krasznahorkay A.: *Hyperdeformed sub-barrier fission resonances observed in ^{232}U.* Physical Review C **80** (2009)1:R1301(5)
2. Elekes Z., Dombrádi Zs., Aiba T., Aoi N., Baba H., Bemmerer D., et al. (26), Fülöp Zs., Sohler D.: *Persistent decoupling of valence neutrons toward the dripline: Study of ^{20}C by gamma spectroscopy.* Physical Review C **79** (2009)1302(5)
3. Górska M., Caceres L., Grawe H., Pfützner M., Jungclaus A., Pietri S., et al. (51), Podolyák Zs., Dombrádi Zs. , Sohler D.: *Evolution of the N=82 shell gap below ^{132}Sn inferred from core excited states in ^{131}In.* Physics Letters B **672** (2009)4:313-316
4. Paul E. S., Revill J. P., Mustafa M., Rigby S. V., Boston A. J., Foin C., et al. (20), Nyakó B. M., Timár J., Zolnai L.: *High-spin states in ^{127}Ce and ^{129}Ce: Further evidence for triaxial nuclear shapes.* Physical Review C **80** (2009)5:4312(13)
5. Di Leva A., Gialanella L., Kunz R., Rogalla D., Schürmann D, Strieder F., et al. (19), Fülöp Zs., Gyürky Gy., Somorjai E.: *Stellar and primordial nucleosynthesis of ^{7}Be: Measurement of $^{3}He(alpha, gamma)^{7}Be$.* Physical Review Letters **102** (2009)23:2502(4)
6. Yalcin C., Güray R. T., Özkan N., Kutlu S., Gyürky Gy., Farkas J., et al. (11), Kiss G. Gy., Fülöp Zs., Simon A., Somorjai E.: *Odd p isotope ^{113}In: Measurement of alpha-induced reactions.* Physical Review C **79** (2009)5801(9)
7. Kiss G. Gy., Mohr P., Fülöp Zs., Galavíz D., Gyürky Gy., Elekes Z., et al. (11), Somorjai E.: *High precision $^{89}Y(alpha, alpha)^{89}Y$ scattering at low energies.* Physical Review C **80** (2009)4:5807(15)
8. Farkas J., Gyürky Gy., Yalcin C., Elekes Z., Kiss G. Gy., Fülöp Zs., Somorjai E., Vad K., Hakl J., Mészáros S.: *Measurement of embedded ^{74}As decay branching ratio at low temperatures.* Journal of Physics G Nuclear and Particle Physics **36** (2009)10:5101(8)
9. Imai N., Aoi N., Ong H. J., Sakurai H., Demichi K., Kawasaki H., et al. (39), Dombrádi Zs., Elekes Z., Fülöp Zs.,: *First lifetime measurement of 2+1 state in ^{12}Be.* Physics Letters B **673** (2009)3:179-182

10. Cseh J., Darai J., Sciani W., Otani Y., Lépine-Szily A., Benjamim E. A., et al. (8): *Elongated shape isomers in the ^{36}Ar nucleus.* Physical Review C **80** (2009)3:4320(5)
11. Pál K. F., Vértesi T.: *Concavity of the set of quantum probabilities for any given dimension.* Physical Review A **80** (2009)4:2114(5)
12. Lévai G., Magyari E.: *The PT-symmetric Rosen-Morse II potential: effects of the asymptotically non-vanishing imaginary potential component.* Journal of Physics A **42** (2009)19:5302(12)
13. Tárkányi F., Hermanne A., Takács S., Ditrói F., Király B., Yamazaki H., et al. (9): *Activation cross sections of the natYb(p,xn)^{169}Lu reaction for indirect production of the therapeutic radionuclide ^{169}Yb.* Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms **267** (2009)17
14. Szelecsényi F., Steyn G. F., Dolley S. G., Kovács Z., Vermeulen Ch., van der Walt T. N.: *Investigation of the $^{68}Zn(p,2p)^{67}Cu$ nuclear reaction: New measurements up to 40 MeV and compilation up to 100 MeV*. Nuclear Instruments and Methods in Physics Research Section **B267**(2009)1877-1881
15. Juhász Z., Sulik B., Frémont F., Hajaji A., Chesnel J.-Y.: *Anisotropic ion emission in the fragmentation of small molecules by highly charged ion impact,* Nuclear Instruments and Methods in Physics Research B **267** (2009) 326–329.
16. Stolterfoht N., Hellhammer R., Fink D., Sulik B., Juhász Z., Bodewits E., et al. (8): *Dynamic properties of ion guiding through nanocapillaries in an insulating polymer.* Phys. Rev. A **79** (2009) 022901
17. Igarashi A. and Gulyás L.: *Annihilation cross section of protonium by electron impact*. Journal of Physics B **42** (2009) 033501
18. Schiessl K., Tőkési K., Solleder B., Lemell C. and J. Burgdörfer, *Electron Guiding through Insulating Nanocapillaries,* Phys. Rev. Lett. **102** (2009) 163201
19. Novák M.: *Local versus nonlocal description of the energy loss of electrons via plasmon excitation backscattering from solid surfaces,* Phys. Rev. **B80** (2009)045406.
20. Lemell C., Solleder B., Tőkési K. and J. Burgdörfer, *Simulation of attosecond streaking of electrons emitted from a tungsten surface*, Phys. Rev. **A79**(2009) 06290-1
21. Hunyadi M., Hashimoto H., Li T., Akimune H., Fujimura H., Fujiwara M., Gácsi Z., et al. (20): *Proton decay from the isoscalar giant dipole resonance in 58Ni.* Physical Review C **80** (2009)4:4317(7)
22. Kertész Zs., Szikszai Z., Szoboszlai Z., Simon A., Huszánk R., Uzonyi I.: *Study of individual atmospheric aerosol particles at the Debrecen ion microprobe.* Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms **267** (2009) 2236-2240
23. Szikszai Z., Uzonyi I., Kiss Á. Z., Síki G. Á., Vantelon D., Rózsa P.: *Investigation of impact materials from the Barringer Meteor Crater by micro-XANES and micro-PIXE techniques*. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms **267** (2009) 2229-2232
24. Rajta I., Szilasi S. Z., Fürjes P., Fekete Z., Dücső Cs.: *Si micro-turbine by proton beam writing and porous silicon micromachining*. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms **267** (2009) 2292-2295.
25. Nagy S., Nándori I., Polonyi J., Sailer K.: *Functional renormalization group approach to the sine-Gordon model.* Physical Review Letters **102** (2009)24:1603(4)
26. Vodila G., Molnár M., Veres M., Svingor É., Futó I., Barnabás I., Kapitány S.: *Mapping of tritium emissions using absorption vapour samplers.* Journal of Environmental Radioactivity **100** (2009)120-124

27. Gál J., Kalinka G., Nyakó B. M.: *Theoretical study of three-dimensionally position-sensitive scintillation detector based on continuous crystal.* Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **607** (2009)3:607-615
28. Anticic T., Gál J., Molnár J., et al. (90 - NA49 collaboration) : *Energy dependnence of transverse momentum fluctuations in Pb+Pb collisions at the CERN Super Proton Synchrotron (SPS) at 20A to 158A GeV.* Physical Review C **79** (2009)4:4904(18)