Portrait of ATOMKI: the Institute of Nuclear Research of the Hungarian Academy of Sciences

History

In Hungary nuclear physics research was started in Debrecen by Alexander Szalay (1909-1987) back in the 30's. He had been a postdoc of Nobel-laureate biologist Albert Szent-Györgyi in Szeged and of Lord Rutherford in Cambridge. ATOMKI was founded in Debrecen later, in 1954, to provide improved conditions for his and his pupils' research. Without striving for the confidence of the communist rulers, Professor Szalay established his reputation among them back in the late forties, when his investigations led to the discovery of uranium deposits in Hungary.

The Institute was meant to pursue scientific research in certain areas of experimental nuclear physics and to develop research instruments. The institute has become the main centre of accelerator-based nuclear and atomic physics in Hungary. But the founding fathers were engaged not only in pure physics research. From the very beginning they have been interested in interdisciplinary applications and in the dissemination of nuclear techniques as well. For example, the uranium prospecting diverted Szalay to the field of geochemistry, from where he proceeded to agrochemistry and food chemistry. He discovered a mechanism of the uranium accumulation in coals, subsequently recognized that a similar mechanism should make the trace elements inaccessible to plants on peat soils, and explored the consequences of this finding in the nutrition chain.

In the early years the country was pretty isolated, but the institute's state of isolation was gradually easing up from the mid-sixties. The bureaucratic constraints stimulated co-operation with Soviet institutions, so that some of our research teams did some good physics in Dubna up to the eighties. At the same time, we were gradually opening to the West, and towards the end of the eighties, we already had a lot of joint projects with western institutions.

In the period of stringency in hard currency the institute became self-supporting in high tech. In the seventies and eighties instrument construction was also stimulated by a pressure to make money to support ourselves. In the sheltered "socialist world market" there was a demand for nuclear and electronic instruments of the kinds made in the institute originally for internal use. Thus the scientists and engineers were given extra pecuniary rewards for production work. In this way this business expanded rapidly, and became part and parcel of our activity and seemed indispensable for our survival. In the heydays of high demand for our products, we had about 300 employees altogether.

The prolonged economic crisis starting in the mid-eighties, the toppling of the communist regime and the advent of open economy shook the whole research establishment of the country. In ATOMKI the crisis hit the production activity most and it virtually disappeared at the beginning of the nineties. Correspondingly, the number of our employees plummeted in those years, bottoming at 190 now, with about 90 scientists among them.

At the same time, the economic crisis of the country incurred budget cuts one year after the other. In the early nineties this was accompanied by the opening up of more and more resources for project funding, which made it possible to buy a few expensive instruments as well. Our more extensive international cooperation, our intense pursuit of project grants and our participation in university education have created an atmosphere of dynamism. Then, after a period of acute impoverishment in the mid-nineties, we underwent a period of consolidation, and we hope for a lasting period of upturn to come.

The institute is now devoted to research in basic nuclear, atomic, particle and solid-state physics and to applying physics in other fields (e.g., surface science, earth sciences and environmental research, research on and production of radioisotopes and radiopharmaceuticals etc.). Roughly half of the activity goes to basic research, and half of the basic research is nuclear physics. Particle physics is as yet slim but not insignificant. Some experimentalists and engineers work for CERN, and the theory group make perturbative QCD calculations. The institute contributes to higher education as well. It has an association treaty with the Debrecen University Federation, and from the full merger of the members of this Federation due in 2000, it will become associated with the unified University of Debrecen.

Owing to the shortage of modern facilities, to the low and staggering level of funding and, furthermore, to the neophyte zeal to look westwards, international cooperation has a much larger significance in this laboratory than is usual in European laboratories. Most of the cooperative projects were started as fellowship visits by members of the institute, but have by now become joint endeavours involving ATOMKI groups rather than individuals. Therefore, we count some of the results obtained by performing experiments partly or exclusively at foreign institutions as our own to the extent of our involvement.

This laboratory portrait will be concerned with basic (mostly low-energy) nuclear physics. Emphasis will be laid on experimental physics, although theoretical work will also be reviewed. In addition to results based on Debrecen experiments, experiments performed abroad will also be covered.

Gamma-ray and conversion-electron spectroscopy

Formerly nuclear-physics experiments were mainly done on the 5-MeV Van de Graaff accelerator. A thematic layout of this home-made accelerator is shown in Fig. 1. To facilitate ion-beam analysis, a microbeam facility was installed recently. Now the accelerator is mostly used for PIXE, PIGE (proton-induced X-ray and γ-ray) and RBS (Rutherford backscattering) analyses on environmental, geological and archeological samples, but nuclear reaction measurements for astrophysics are also performed. The cyclotron, an MGC–20E produced by the Yefremov Institute, St. Petersburg (then Leningrad), was installed in 1986. It accelerates protons (5–18 MeV), deuterons (2–10 MeV), helions (6–27 MeV) and α-particles (5–20 MeV) with extracted beam intensities of a few tens of μA. The present beam lines are shown in Fig. 2.

In nuclear physics research γ-ray and conversion-electron spectroscopy became dominant after the end of the seventies. The central subject was a systematic investigation of medium-weight nuclei that contain odd numbers of protons and neutrons. The emitted γ-rays were detected with hyperpure germanium detectors, and the conversion electrons with a home-made superconducting magnetic spectrometer, shown in Fig. 3 [1], which has almost as good energy resolution as the best germanium detectors. An example, in Fig. 4, for the determination of the internal conversion coefficients is taken from a recent work [2]. Since 1986 an enormous amount of data has been measured; some 700 new γ-transitions and 250 new excited states have been found. The level and decay schemes have been interpreted in terms of the interacting boson-fermion-fermion model.

Gamma-ray spectroscopy of medium-heavy nuclei is now pursued with ATOMKI participation in the framework of the NORDBALL collaboration in Aarhus (Denmark), where the focus is on approaching the unstable doubly magic nucleus ^{100}Sn; see e.g. [3].

Another line of γ-ray spectroscopy with the participation of ATOMKI is the spectroscopy of high-spin states. One of the main topics studied recently is the termination of rotational bands. The observed termination shows that beyond a certain spin value collective behaviour and deformed shape are overwhelmed by non-collective behaviour, which is possibly accompanied by a change of deformation towards the spherical shape. In a shell-model picture a band is associated with a certain type of the arrangements of the nucleons, in which the sum of the single-particle angular momenta is limited, and that accounts for the band termination. Members of ATOMKI have taken part in recent experiments to search for terminating bands using the EUROGAM2 spectrometer at the Vivitron accelerator at IReS, Strasbourg. Terminating bands in ^{101}Rh, ^{102}Rh and ^{103}Pd have been reported [4].

Another line of high-spin physics done with the participation of ATOMKI elsewhere in Europe is the study of superdeformed states, which are states in which elongated nuclei are twice as long as thick. A member of ATOMKI was involved in finding the very first such state at Daresbury (UK) in the early eighties [5]. More recently, we have been taking part in experiments at Legnaro (Padova) and in Strasbourg.

ATOMKI has joined EXOGAM, which is a project of γ-ray spectroscopy of unstable nuclei prepared by collisions with radioactive beams at GANIL (Caen, France). This project is to broaden not only the high-spin studies but the ^{100}Sn research as well.

Hyperdeformed states in the actinides

A new line of experimental research was started in Debrecen when, in 1992, a split-pole magnetic spectrograph was received from Vrije Universiteit, Amsterdam, as a gift (shown in Fig. 5). A new focal-plane detector was constructed, and the data-acquisition system was re-built in Debrecen, with the use of modern electronics. This combination of a high-current accelerator and a magnetic spectrometer turned out to be an efficient tool for studying low cross-section nuclear reactions.

One of the new projects using the spectrograph is the investigation of hyperdeformed states (states with a ratio of 3:1 for the long to the short axis) formed in the course of fission. These studies are complementary to the searches for hyperdeformed high-spin states, for which 4π γ-arrays are used elsewhere, but up till now indications for the existence of hyperdeformed bands have only been found, without any individual states identified.

In a fissioning system hyperdeformed states may be accessible if the energy between the the fission fragments as a function of the interfragment distance, interpreted as a potential, has at least three minima, and the third minimum is deep enough to accommodate quasibound levels. Such two-cluster states may be reached by exciting a fissioning state by a low-energy reaction. These states, viewed as rotational states, have moments of inertia compatible with axis ratio 3:1.

We prepared fissioning states of ^{236}U and ^{234}U by (d,p) reaction and measured the fission probability as a function of the excitation energy of ^{236}U and ^{234}U. The basic measurements were done in Debrecen and were repeated with better energy resolution in Munich [6, 7]. In Debrecen the energy of the outgoing protons was analysed by the magnetic spectrograph, and the fission fragments were detected in coincidence by two home-made position-sensitive avalanche detectors. These detectors have two wire planes, with delay-line read-out, corresponding to the horizontal and vertical directions. Rotational-like bands were found, with parameters corresponding to hyperdeformed shapes. Some representative results are shown in Figs. 6 and 7. A great number of hyperdeformed bands were found. They are built on high-lying, possibly two-particle, excitations. The observed level density and the excitation energy of the "ground state" in the third minimum (3.1±0.4 MeV), deduced for the first time, are consistent with the theoretical predictions.

Neutron skin and neutron halo

Neutron-rich nuclei present a challenge to our understanding of the systematic behaviour of nuclei. Contrary to the proton drip-line region, our knowledge on the neutron drip-line is limited to the lightest systems. That is where neutron halos have been discovered, which are very extensive and dilute one- or two-neutron orbits around compact cores, occupied by the least bound one or two neutrons. For heavier neutron-rich nuclei it is expected that there is a bulk of neutron matter overflowing the volume of the self-conjugate core. The primary empirical information that can be obtained on these phenomena is the neutron skin thickness, i.e., the difference between the radii of the neutron and proton densities. In Debrecen both experimentalists and theoreticians are interested in the neutron-rich nuclei.

The Debrecen physicists have recently taken part in experiments of two types to determine the neutron skin thickness. At KVI, Groningen (the Netherlands) the inelastic excitation of the giant dipole resonance via the isoscalar α projectile was used [8, 9]. The extremely low cross section of this process was amplified by α–γ coincidence measurements. At RCNP, Osaka the neutron-skin thickness was extracted from the total L=1 strength of the spin-dipole resonance (SDR) [10]. This resonance can be strongly excited by (p,n) reactions in inverse kinematics.

The shapes and density distributions of unstable nuclei far off the stability region are of particular interest, and can be studied by producing radioactive beams of these nuclei and performing scattering experiments with them. An ATOMKI group is poised to do such experiments at RIKEN, Wako (Japan) and at GSI, Darmstadt.

Reactions for astrophysics

One of the first studies of (α, γ) reactions responsible for the synthesis of light proton-rich nuclei (p-processes) was done at the ATOMKI cyclotron (and at Bochum) [11, 12]. The theoretical estimates that enter into the models of nucleosynthesis had to be corrected following this work.

The process ^{7}Be(p,γ)^{8}B is a key to the solar neutrino puzzle since it determines a branching of the pp-chain and thereby the flux of the high-energy neutrinos. The ^{7}Be going into the target is produced at the cyclotron of ATOMKI via the reaction ^{7}Li(p,n)^{7}Be. The cross section of the ^{7}Be(p,γ)^{8}B reaction is being measured in Bochum.

A resonance in the reaction ^{36}Ar(p,γ)^{37}K determines the reaction rate in hot and explosive hydrogen burning. A recent measurement at the Van de Graaff accelerator has modified the known parameters of this resonance [13].

ATOMKI members are also involved in astrophysical studies with radioactive beams. One such study has been the accurate determination, at RIKEN, of the ^{44}Ti half-life, which is difficult in this half-life range (100 years), but important for astrophysics. The key point in this experiment was that, with a beam of ^{44}Ti, a well controlled number of ^{44}Ti nuclei were implanted into a plastic scintillator.

Nuclear theory

Nuclear theory research in ATOMKI was started intensively rather late, but now it is one of the strongest lines. It may be divided into studies of methodology and of particular nuclear problems.

The traditional field in methodology is the description of unbound states, associated with poles of the scattering matrix, with a kind of 'extended' quantum mechanics, in which unbound states are included among the basis states, along with the bound states and some scattering states [14]. The focus is now on elaborating methods for locating and describing resonances of composite systems. We contributed to the mathematical foundation and practical adaptation of various techniques based on square integrable basis functions (real stabilization method, complex scaling, analytical continuation in the coupling strength, parametrized state density method).

In recent years much work has been spent on elaborating a workable and reliable solution to the highly challenging three-body problem with Coulomb interaction [15]. There is growing support for the correctness of the approach among foreign experts, but there is no breakthrough in the numerical results as yet. A reliable variational method has been elaborated for the description of quantum mechanical few-body (up to, say, seven-body) systems, in cooperation with a Niigata group (Japan), which may involve composite particles as well [16, 17]. This method is based on a trial function, which is sampled stochastically from a pool of functions ('correlated Gaussians').

The study of special problems is strongly linked with the methodological studies. The unbound states considered are giant multipole resonances, ground states of nuclei beyond the drip lines and resonant and virtual states of light nuclei. Moreover, cluster decay has been described in various models. The theoreticians of ATOMKI claim to have solved the absolute width problem of α-decay [18, 19]. They have reproduced the decay width of a heavy α-decaying nucleus in a microscopic model with all parameters tied to independent experimental data. Most recently, the shell correction to the liquid-drop model has been made applicable to drip-line nuclei [20].

In the 80's and 90's considerable effort has been devoted to (multi)cluster or quasimolecular states, in which nucleons are clumped into clusters. Such states have been described both in microscopic models (i.e., with explicit reference to all nucleonic degrees of freedom) and in a phenomenological algebraic model, in which the dynamics of the system is formulated in terms of abstract symmetry considerations.

The microscopic studies have led to a coherent theory of clustering [21]. The cluster-model studies have also been extended to reactions, and the extremely strong thermonuclear transition t+d$\rightarrow\alpha$+n through the $\frac{3}{2}^+$ resonance of ^{5}He has been demonstrated to arise from the two-pole structure of the resonance [22]. More recently, the neutron-halo nuclei and other light exotic nuclei with A=3–11, which can be described in terms of 2–6 clusters, have come into focus. The structure calculations are performed in the framework of the stochastic variational approach.

The algebraic models of multicluster systems are very useful phenomenological tools to account for series of quasimolecular resonances. The fully developed recent version of the model [23] assumes SU(3) intrinsic structures of the clusters and U(4) symmetry for the intercluster motion, allows for the Pauli principle in a harmonic-oscillator approximation and makes it possible to treat alternative clusterizations simultaneously. The model sheds light on the structural aspects of heavy-cluster decay [24].

Conclusion

The present-day ATOMKI has evolved from an experimental physics laboratory situated in a remote corner of the Eastern Bloc, without technological hinterland and cut from the rest of the world of science. Fortunately, the growth period of science coincided with a slow political thaw, in which the walls of isolation have eroded. Meanwhile, the institute has survived deep famines and damiging political atmosphere, but there were periods in its history when it received both financial injections and ample fresh blood. It is now a learned institution of some significance, with a reasonable balance of theory, experiment and application, from which an ever-growing number of interesting research results are published, mainly owing to its multiple international ties. International cooperation plays more and more the role of a life-support system, and, at the same time, it gives the rationale of the existence of the institute.

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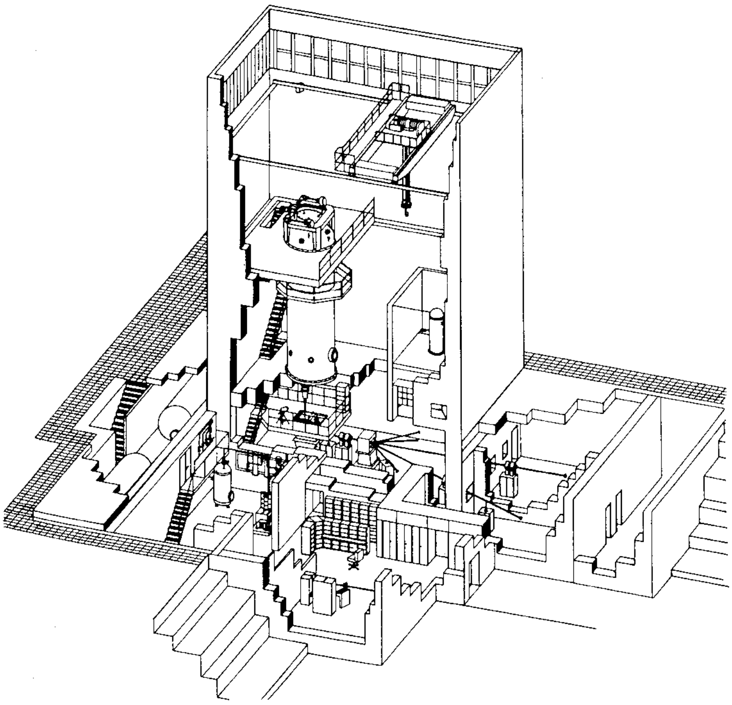

Figure 1: The 5 MV Van de Graaff accelerator and its beam channels.

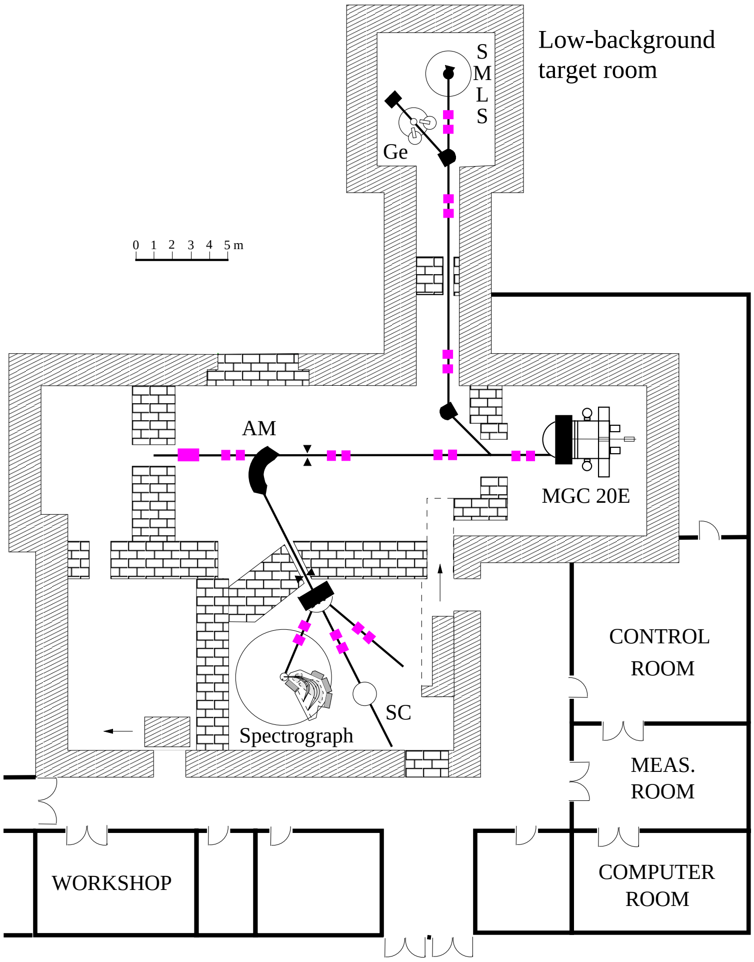

Figure 2: Schematic layout of the beam channels of the MGC 20E isocronous cyclotron. In the low-background target room the Superconducting Magnetic Lens Spectrometer (SMLS) and two Ge detectors on a turning table can be seen. The analysing magnet (AM), the scattering chamber (SC), and the split-pole magnetic spectrograph are also shown.

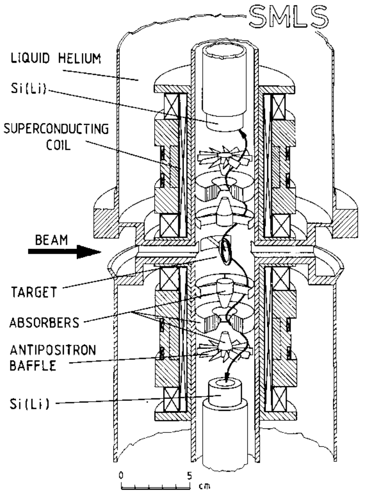

Figure 3: A sectional drawing of the superconducting magnet transporter lens spectrometer (SMLS).

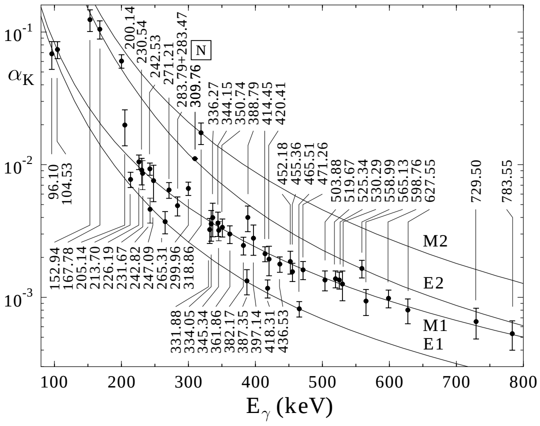

Figure 4: Experimental and theoretical (curves) internal conversion coefficients of ^{72}As transitions as a function of the γ-ray energy.

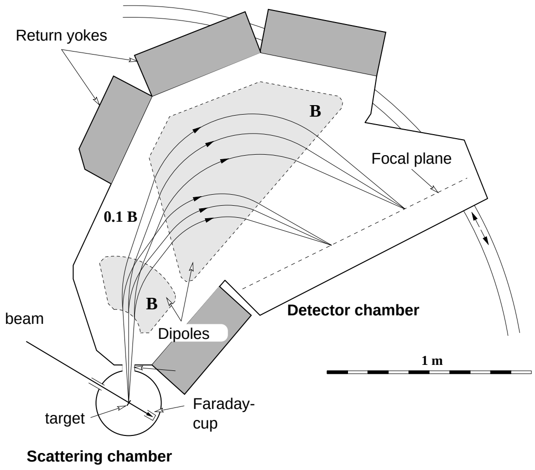

Figure 5: Layout of the split-pole magnetic spectrograph.

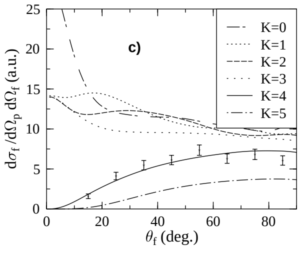

Figure 6: a) Proton spectrum measured for ^{236}U in coincidence with the fission fragments as a function of excitation energy, compared to the fitted rotational band; b) the results of the χ^2 analysis; c) experimental fission-fragment angular distribution for the 5.47 MeV resonance compared to the calculated ones.

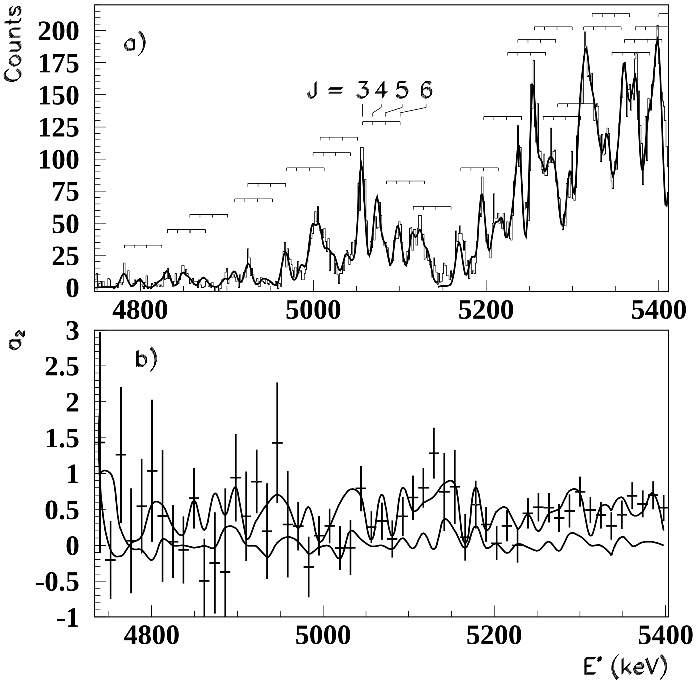

Figure 7: (a) Measured proton energy spectrum for ^{234}U fitted with 24 rotational bands with a common rotational parameter. (b) Experimental fission-fragment angular-distribution coefficients as a function of excitation energy compared to theory using $K = 1$ (upper curve) and $K = 3$ (lower curve) for all bands.