Speedy protons and the puzzling atomic nucleus

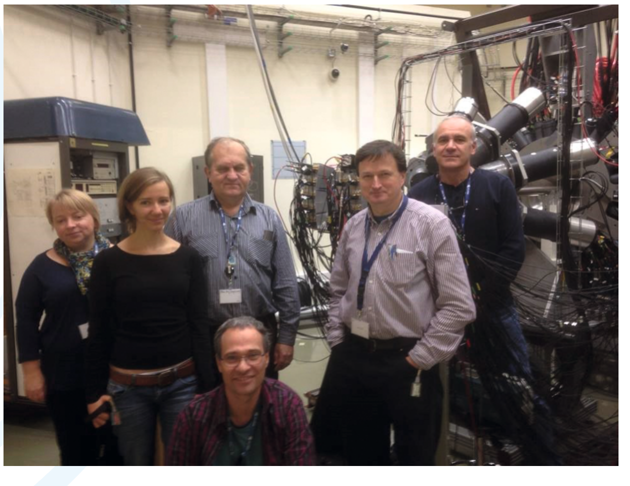
The Proteus cyclotron at the Cyclotron Centre Bronowice (CCB), apart from its medical applications, is also an extremely useful source of energetic protons for basic nuclear research.

The properties of the nucleus of an atom are almost incomprehensible: while containing up to 99.99% of the total mass of the atom, its volume is almost a quadrillion (a million times a billion) times smaller than that of the volume of the atom as whole. Therefore, the matter density of the atomic nucleus is immense.

One may then think that an atomic nucleus of such minute size and such immense density, is immutable - that it cannot be changed or induced to move. However, this is not the case. The nucleus is a complex system – it contains several positively charged protons (to balance the negative charges of electrons in the atom) and some neutrons of no charge, both termed as “nucleons".

On the one hand, the laws of the atomic nucleus are those of the micro-world, which in no way resemble those we are commonly used to. For example, we know that within the nucleus, the energy of nucleons, despite of them being in constant motion, is strictly defined. Indeed, one may imagine that these nucleons are placed on shelves of well-defined energies – such shelves are called orbitals. On the other hand, the nucleus when viewed as a whole, appears to quite accurately demonstrate some familiar properties - for example, those of a drop of a liquid. To understand this dual nature of the atomic nucleus is a major challenge of modern nuclear physics. Experiments using proton beams produced by the Proteus cyclotron at CCB will further elucidate this issue.

One of the complex research tools to be used in our experiments at the CCB is HECTOR - a system of detectors able to register gamma-ray quanta of high energy, combined with KRATTA – another system of detectors able to identify and measure the energy of charged particles of lighter elements.



A team of physicists from Krakow and Milan assembles the HECTOR and KRATTA detection systems at the CCB

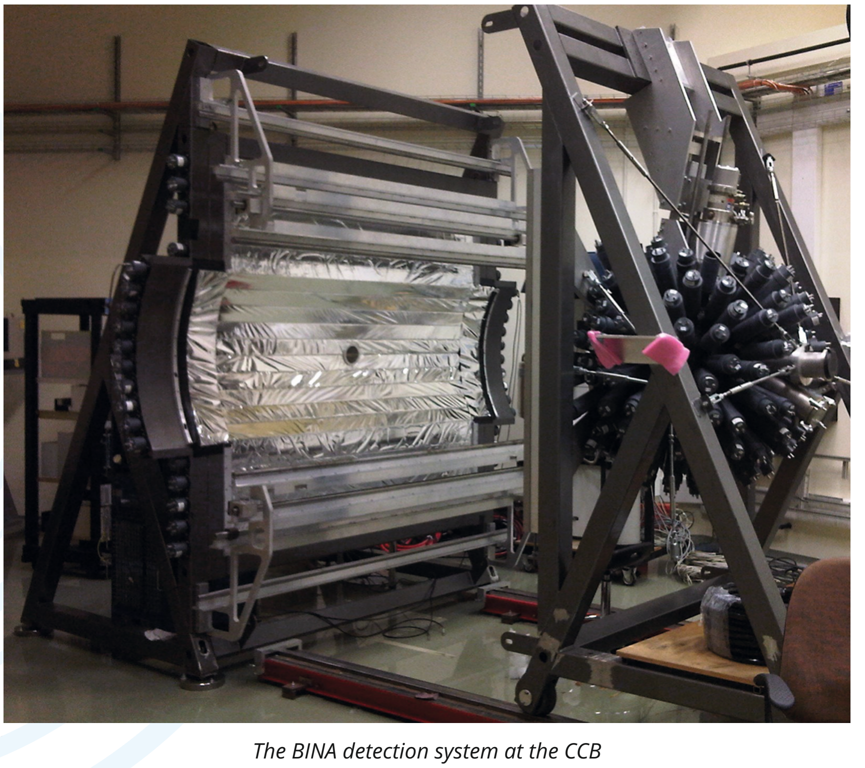
INNOVATIVE ECONOMY
NATIONAL COHESION STRATEGY

EUROPEAN UNION
EUROPEAN REGIONAL
DEVELOPMENT FUND

The atomic nucleus can vary its state in many ways: by moving its nucleons up to higher energy "shelves", by turning around, or by vibration. One category of such vibrations is vibration of all protons against all neutrons – these are known as giant resonances. Vibrations of the neutron "skin" only – known as pygmy resonances – can also appear; this type of vibration occurs in nuclei in which there are many more neutrons than protons. Such neutrons then form a neutron "skin" around the nucleus. In measurements performed at the CCB, highly accelerated (or speedy) protons will set off vibrations in nuclei set up across their paths, in which giant or pygmy resonances will form. The HECTOR and KRATTA systems of detectors are then be able to take detailed measurements of gamma quanta emitted by the vibrating nuclei, and thus to deduce their properties - such as the shape of the nucleus, distributions of neutrons relative to those of protons, or even to explain the observed unique distribution of elements in the universe.

Such observed and measured properties of the atomic nucleus are also described by theory. The goal of such theoretical investigations is to be able to predict the properties of nuclei which have so far not been studied. But to do so, thorough knowledge of forces that act between nucleons is required. For quite some time we have been able to calculate the force with which two nucleons interact (dependent on distance, among other factors). However, this is not enough. When dealing with three or more nucleons (which are present in all nuclei, except those of the lightest element - hydrogen), new forces emerge. These are three-body forces, which operate only if three nucleons are present. Three-body forces can be tested by colliding a proton with a system of two nucleons, such as a the hydrogen nucleus with only one neutron - a deuteron. Research along these lines is also under way and will be continued using proton beams from the CCB cyclotron. The detection system in this case is the BINA detector which is used to record the direction of flight and the energy of the two protons emitted after a collision of a proton with a nucleus of deuterium.

The research programme which applies the proton beams from the CCB cyclotron complements research carried out at major research centres in Europe and elsewhere. Our International Advisory Committee, composed of Polish and foreign scientists of international renown, will help us to maintain the highest scientific quality of this research.



The BINA detection system at the CCB

INNOVATIVE ECONOMY
NATIONAL COHESION STRATEGY

EUROPEAN UNION
EUROPEAN REGIONAL
DEVELOPMENT FUND