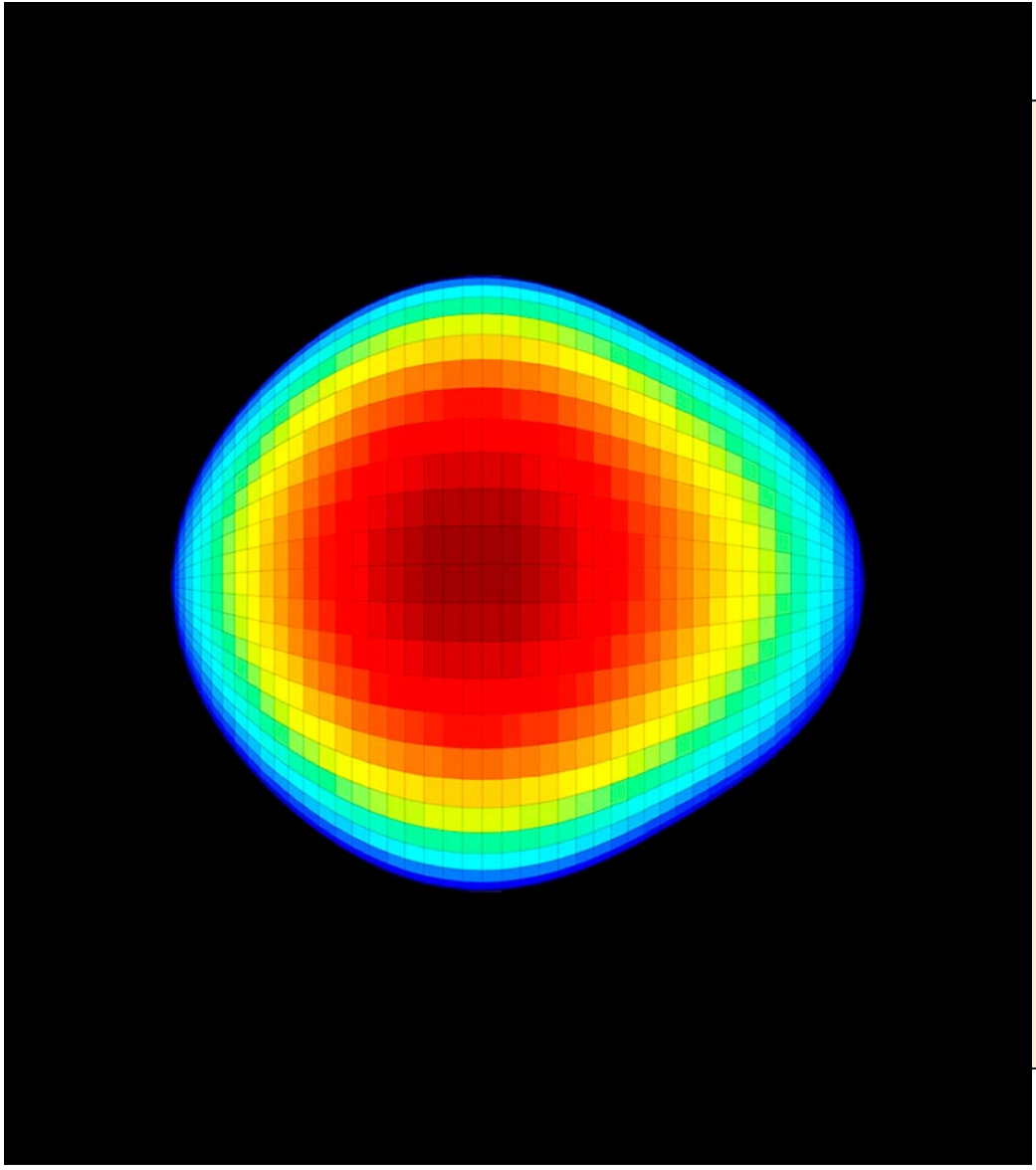


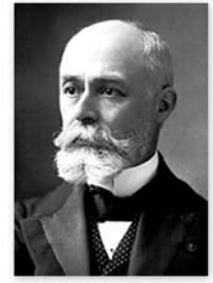
The nucleus in the spotlight

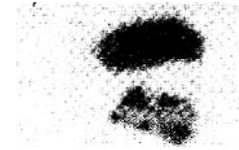
The development of nuclear physics in Lund – electrostatic accelerators, electron accelerators, Ur-MAX, LUSY, MAX-lab and some aspects of applied nuclear physics.

The development during 1896 – 1939

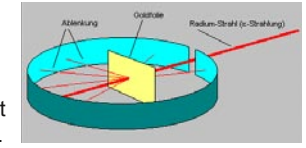
One could say that nuclear physics was born in 1896, with the findings of Henri Becquerel concerning phosphorescent crystals.

Becquerel hypothesized that phosphorescent materials, such as some uranium salts, might emit penetrating X-ray-like radiation when illuminated by bright sunlight. His first experiments appeared to confirm this. However, by May 1896, after other experiments involving non-phosphorescent uranium salts, he arrived at the correct explanation, namely that the penetrating radiation came from the uranium itself, without any need for excitation by an external energy source.



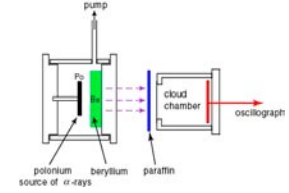


Henri Becquerel
Image of Becquerel's photographic plate which has been fogged by exposure to radiation from a uranium salt. The shadow of a metal Maltese Cross place between the plate and the uranium salt is clearly visible.



Scattering of α-particles against a gold foil, 1911.

Ernest Rutherford
The first nuclear reaction was carried out in 1919: $\alpha + {}^{14}N \rightarrow p + {}^{17}O$.



James Chadwick
The neutron was discovered in 1932.

Nuclear physics comes to Lund

The dropping of the atomic bombs on Japan in 1945 changed the world, and nuclear physics became a new area of research, even in Lund.

Manne Siegbahn's PhD student, Sten von Friesen, arrived in Lund in 1946, and was housed in a temporary building with four small rooms. In one of the rooms Hellmuth Hertz was planning the installation of a Van de Graaff accelerator, while in another a Wilson cloud chamber was being constructed for the detection of cosmic radiation. In the fourth room, Krister Kristiansson analysed nuclear emulsions, while Sven Johansson developed electronic gamma detectors.

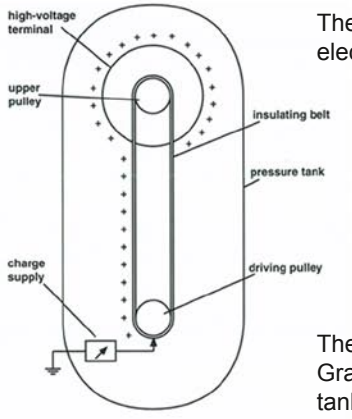
The research group in nuclear physics in the mid 1950s.

Inserted above from the left: Eskil Möller, Bibijana Dobovisek, Lennart Stigmark, Berndt Waldeskog.

Above from left: Erik Alinder, Börje Persson, Åke Isberg, Nils Norlind, Erik Hellstrand, Lars Hansson, Per-Olof Fröman, Uno Persson.

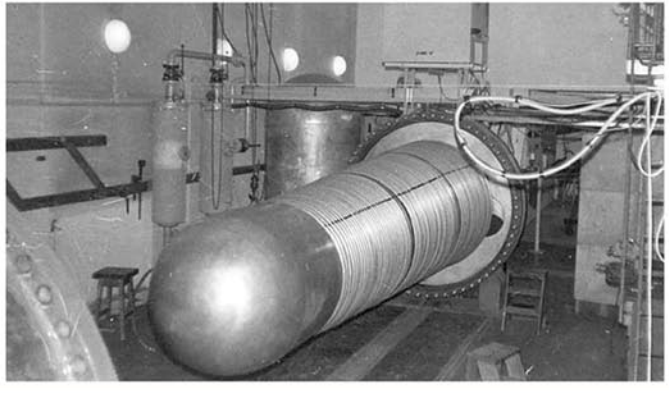
In the middle from the left: Nils Starfelt, Nils Svantesson, Laboratory assistent, Elvir Andersson, Bengt Forkman, Hans Ryde, Kjell Jönsson, Börje Pettersson, Jan Cederlund.

In the front from the left: Göran Leide, Birgit Lindqvist, Holger Sköldborn, Sven Johansson, Sten von Friesen, Kurt Lidén, Krister Kristiansson, Hellmuth Hertz.



The principle of an electrostatic generator.

The department's first Van de Graaff accelerator. The pressure tank surrounding the accelerator can be seen in the foreground.



Sten von Friesen travelled to the USA to study new accelerators. He decided that a Van de Graaff accelerator was ideal since it was possible to carry out precise measurements with such a machine, while being relatively inexpensive to run.

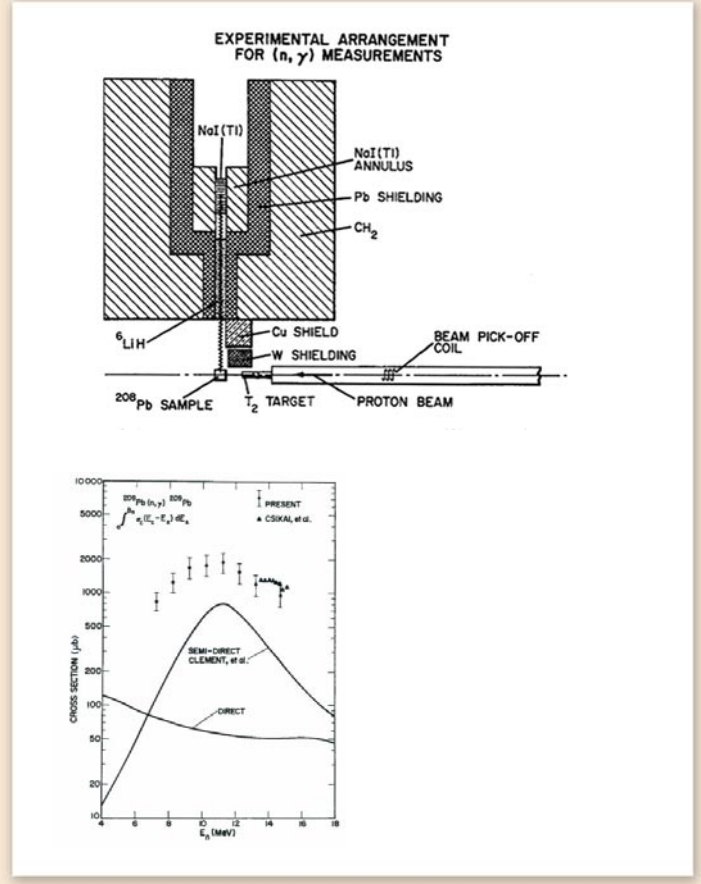
A newly formed group started to construct their own Van de Graaff accelerator in what is now the department's library.

The accelerator consisted mostly of homemade components, and was completed and ready for use in 1956.

Accelerated protons

The Van de Graaff accelerator could produce high voltage up to 3 MV. It was used to accelerate protons, which led to different kinds of processes when they collided with atomic nuclei. For example, Ingvar Bergqvist and Nils Starfelt studied fast neutrons resulting from these collisions.

These neutrons could in turn be captured and bound in other nuclei; a process of considerable theoretical interest. Fast neutrons can combine with the lead nuclei in two ways: Directly or indirectly via a resonance. Both capture processes are involved.



The pelletron accelerator

In 1972 the Van de Graaff accelerator was replaced with a new electrostatic accelerator, a *Pelletron*, in which the charge is transported by a chain of metal spheres called pellets, hence the name.

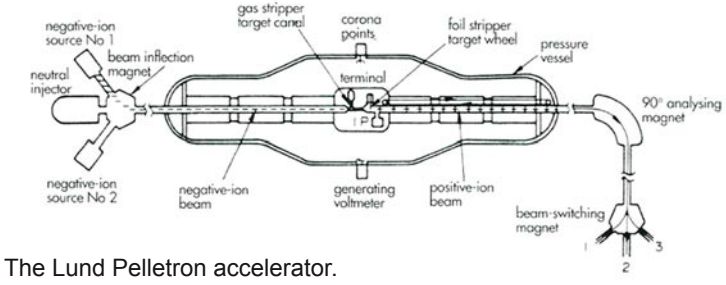
A voltage of 6 MV could be obtained with this accelerator, and it was to prove important for the Department of Physics. Apart from basic nuclear physics research, the PIXE method (particle-induced X-ray emission) for the analysis of trace elements was developed by Sven Johansson using this accelerator.

The technical head of the new Pelletron laboratory was Ragnar Hellborg, who held the position for over 30 years. He was assisted by two research engineers, Kjell Håkansson and Christer Nilsson.

Ragnar Hellborg, Pelletron specialist.

Kjell Håkansson research engineer and recipient of a prestigious award from the Swedish Academy of Engineering Sciences (IVA).

Christer Nilsson, research engineer and top-level cyclist.

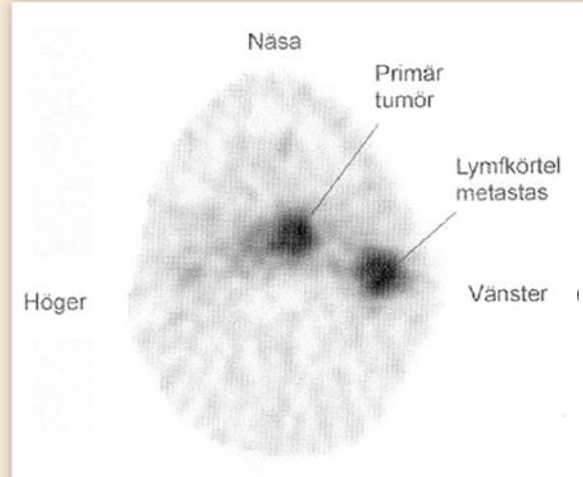


The Lund Pelletron accelerator.

Isotope production for medical studies

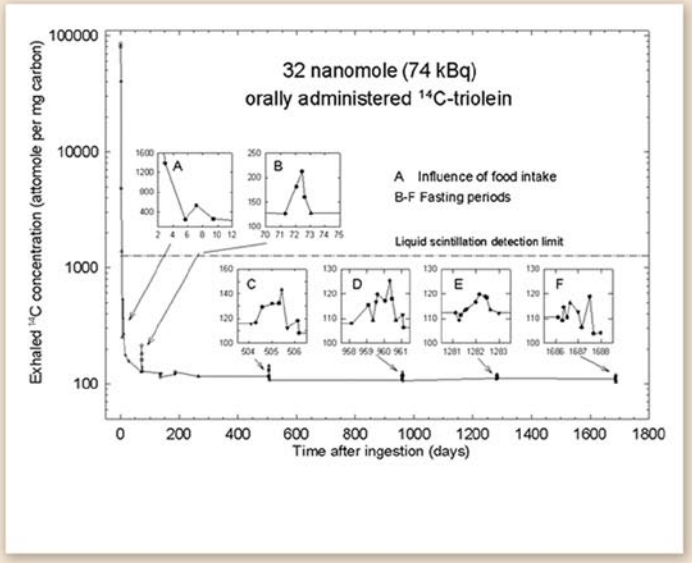
The isotope ^{18}F is produced by the nuclear reaction $^{18}O(p,n)^{18}F$, and is used in human medical investigations. After irradiation of ^{18}O-rich water with protons, the ^{18}F atoms are extracted and injected into the patient. The host molecule is incorporated into the metabolism in the patient's body and collects in tumours. The radiation from the decay of the ^{18}F atom is then measured.

The method is called positron emission tomography (PET), and provides a three-dimensional image of the region being studied.



These early PET studies were made possible by Ragnar Hellborg, and provided the basis for the further development of medical radiation physics.

^{14}C – a versatile tool



During the 1990s, the Pelletron accelerator was adapted for mass spectrometric analyses of several rare isotopes, mainly the detection of ^{14}C in geological, archaeological, environmental radiological, and medical studies.

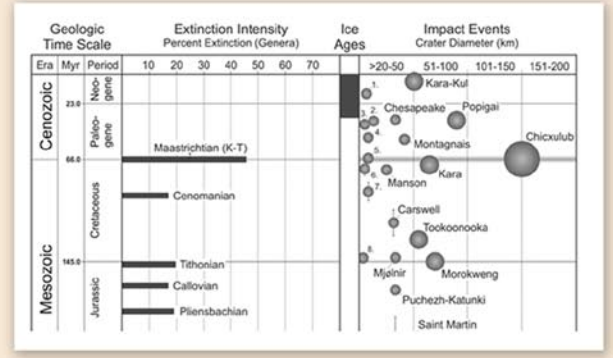
An example is given in the figure to the left, which shows how the technique is used to determine the radiation dose to a person from a ^{14}C-labelled pharmaceutical. Traces of the radionuclide could be detected in the patient's breath four years after the pharmaceutical had been administered. Kristina Eriksson Stenström has developed this and other methods.

Meteorite showers

A possible meteorite impact.

Luis Alvarez hypothesis that the dinosaurs died out as the result of a collision of an asteroid with the earth is based on measurements of iridium close to the impact site. Asteroids have higher iridium contents than the earth's crust.

Per Kristiansson and Birger Schmitz' group at the Division of Nuclear Physics constructed an advanced Iridium Coincidence Spectrometer (ICS) for geological stratigraphic studies of iridium that provide evidence of other major impacts during the earth's history.

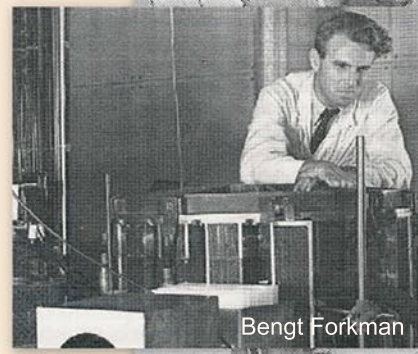


The giant resonance

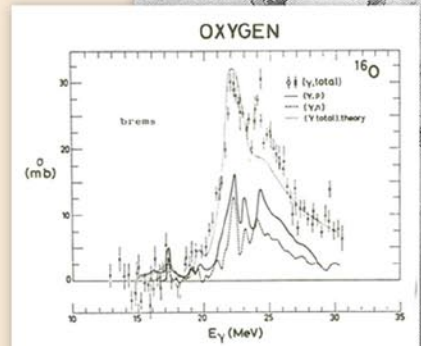
When high-energy photons impinge on an atomic nucleus it starts to vibrate. Photons were produced by a 35 MeV electron synchrotron which was donated to the department by the Royal Institute of Technology (KTH) in 1953. This machine became known as *Ur-MAX*.

Resonant vibrations are created between the protons and neutrons in the nucleus by photons in the energy range 15 - 35 MeV. Surprisingly, the resonance showed a clear structure. This structure provided strong evidence of the validity of the shell model of the nucleus, which states that individual nucleons move in well-defined orbits, despite the fact that the nucleus is so dense.

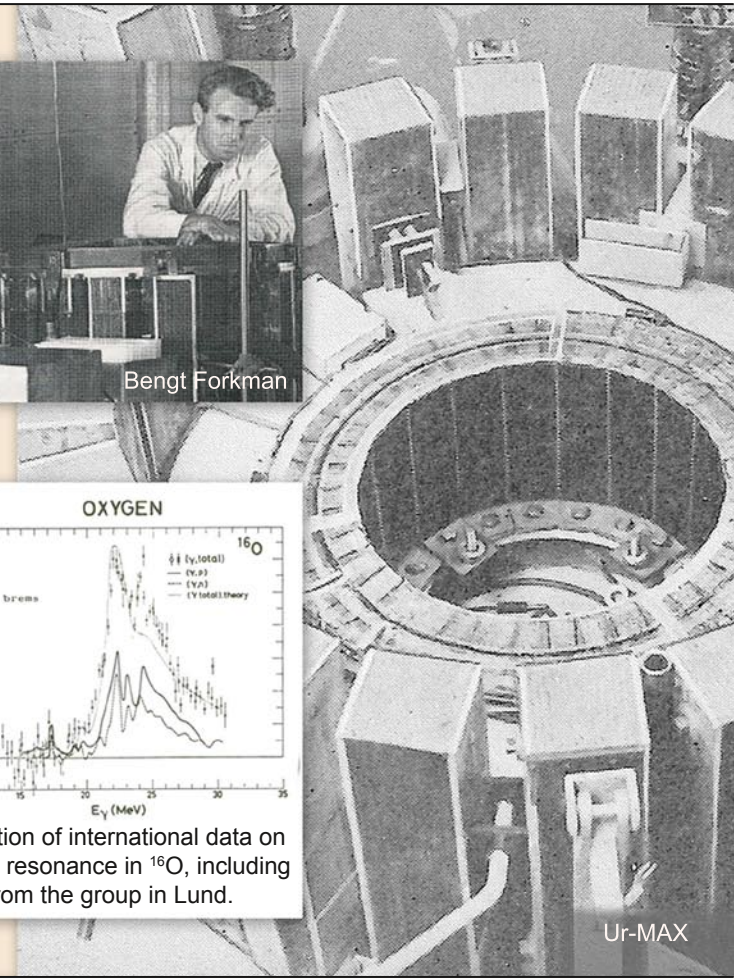
Pioneers in the field were Sven Johansson and his PhD student Bengt Forkman.



Bengt Forkman

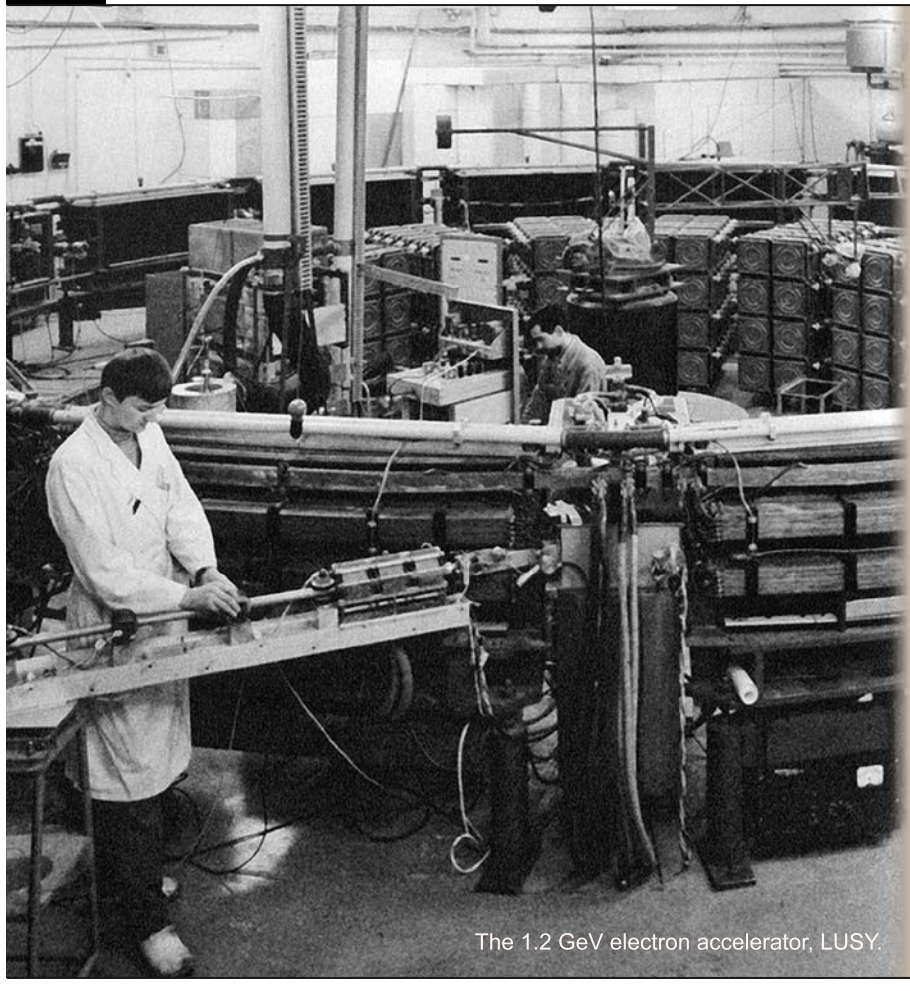


Compilation of international data on the giant resonance in ^{16}O, including results from the group in Lund.



Ur-MAX

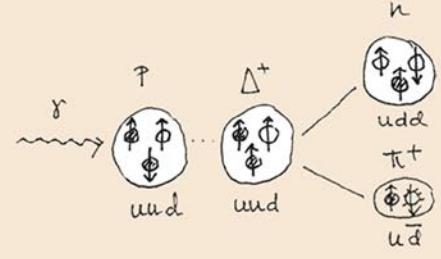
LUSY



The 1.2 GeV electron accelerator, LUSY.

When the 1.2 GeV (1 200 MeV) electron synchrotron LUSY was inaugurated in 1962, the Photo Nuclear group, under the leadership of Bengt Forkman, began a series of studies on high-energy photoreactions way above the giant resonance at about 20 MeV.

At photon energies around and above 150 MeV, other absorption processes, called Δ resonances, take place. The direction of spin of one of the three quarks in the target nucleon can be reversed, leading to increased adsorption. During de-excitation photopions can be emitted.



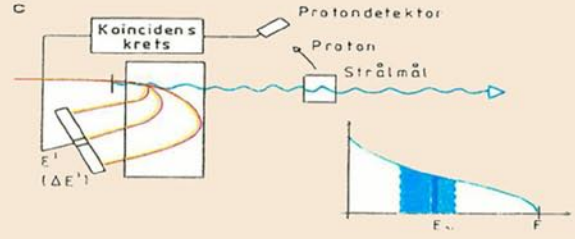
Schematic illustration of the spin flip of a quark in a nucleon.

Tagged electrons

When it was time to decommission LUSY, plans were initiated for a new facility for nuclear photoreaction experiments. These plans developed into what later became MAX-lab, where nuclear photoreaction physics was carried out until Spring 2015.

A large part of the equipment is dedicated to a technique called tagging, where single photons with a specific energy can be labelled or tagged. This allowed experiments to be carried out with photons of well-defined energy.

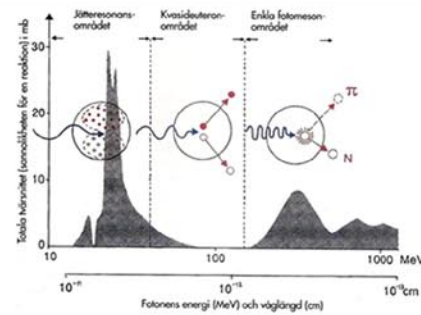
Kurt Hansen and Bent Schröder beside the tagging magnet.



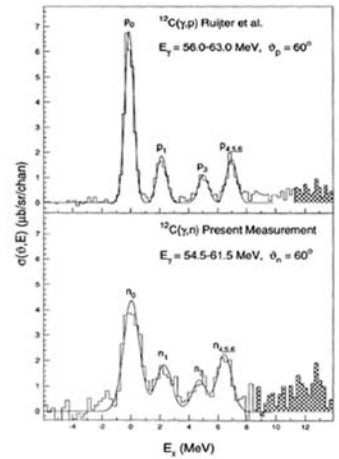
The electron, which has been slowed-down, is deflected in a magnetic field and then detected in one of many detector traps. This provides the energy of the electron, and the energy of the initial photon can then be determined.

Experiments at MAX-lab

There is reason to believe that photons with an energy above the giant resonance, but under the threshold for photopion production (30 - 150 MeV), interact with quasideuterons, i.e. unstable neutron–proton pairs. Bent Schröder took over the leadership of the nuclear photoreaction group when MAX-lab became available for experiments.

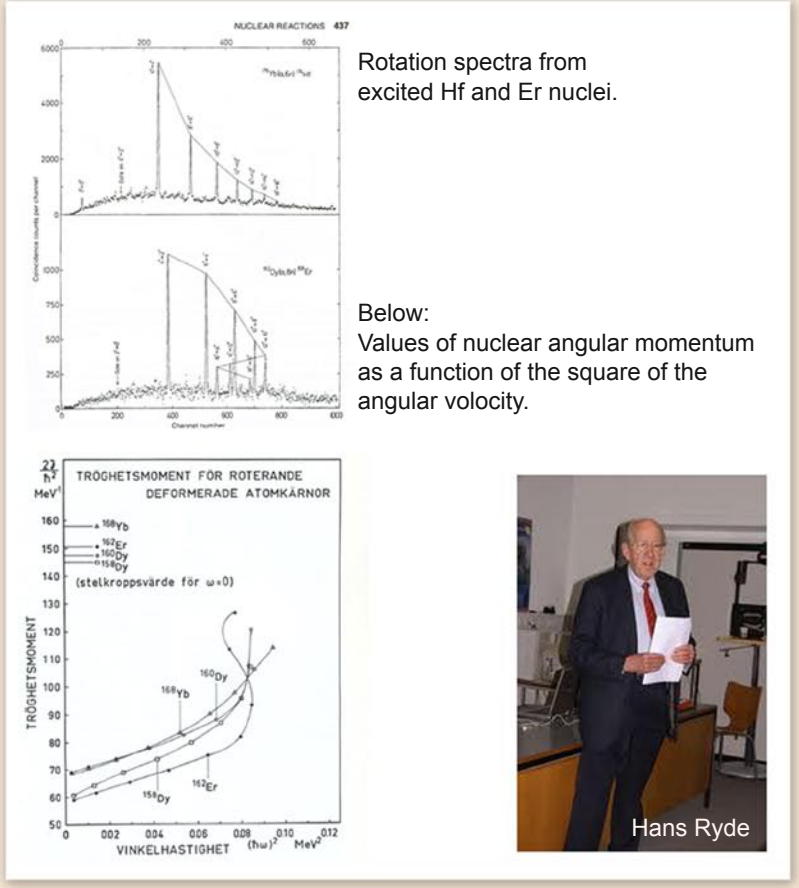


Schematic illustration showing how photons with different energies interact with an atomic nucleus.



The two curves that show the production of neutrons and protons when ^{12}C is irradiated with photons with an energy of about 60 MeV are identical. This provides incontrovertible proof of the validity of the quasideuteron model.

Rotating nuclei



Rotation spectra from excited Hf and Er nuclei.

Below:
Values of nuclear angular momentum as a function of the square of the angular volocity.

Hans Ryde

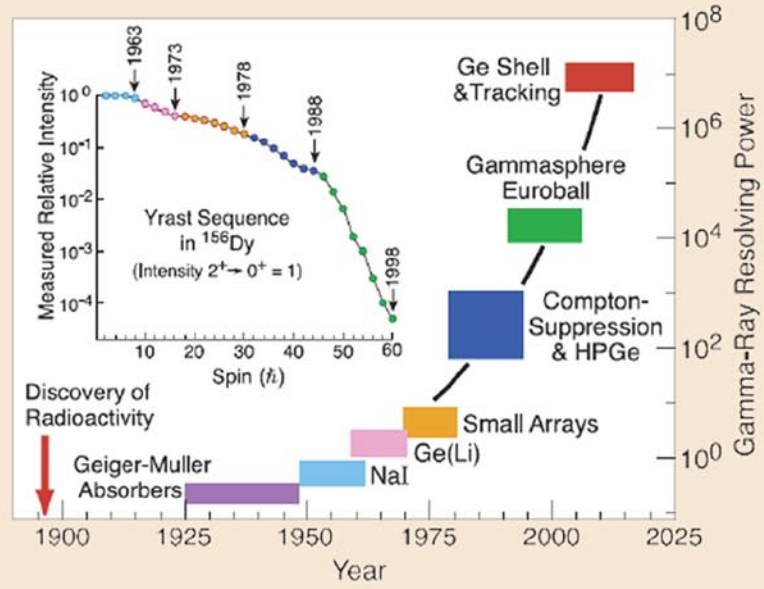
Hans Ryde took over from Sten von Friesen in 1975. Ryde was interested in the motion of particles inside the nucleus. Irradiating a nucleus with α-particles can cause it to rotate. At nuclear spins above 14^+, the energy of the nucleus shows a dip or minimum; something happens to the nucleus at the quantum number 16^+. The nucleons in the nucleus normally rotate in pairs, but at high rotational energies this coupling is broken by the Coriolis force.

In 1972 Hans Ryde and his group, working in Stockholm, discovered the so-called backbending effect in rapidly rotating nuclei.

New detectors

Much of what we know today about the atomic nucleus originates from experiments and measurements on γ rays. The transition from Geiger–Müller tubes and NaI(Tl) crystals to solid-state Ge detectors, combined with fast electronics made it possible to obtain γ ray spectra with considerably higher energy resolution. These have provided a great deal of knowledge on atomic nuclei.

The nuclear structure group in Lund has also contributed to this development.



The development of γ-ray measurements.

The *yrast* level in a nucleus with a given spin is the level with the lowest energy for that spin. This international term is derived from the Swedish word yrast meaning *the dizziest*.

Today's nuclear structure researchers

When Hans Ryde retired, a new generation of nuclear structure researchers took over: Claes Fahlander (from Uppsala), Dirk Rudolph (from Göttingen, Germany) and Joakim Cederkäll (from Stockholm).

They are engaged in studying increasingly inaccessible nuclides, in an attempt to answer questions such as: How many, or how few, neutrons can exist in a nucleus with a given number of protons? How heavy can a nucleus be? When does a nucleus become so unstable, that it cannot exist as a nucleus?

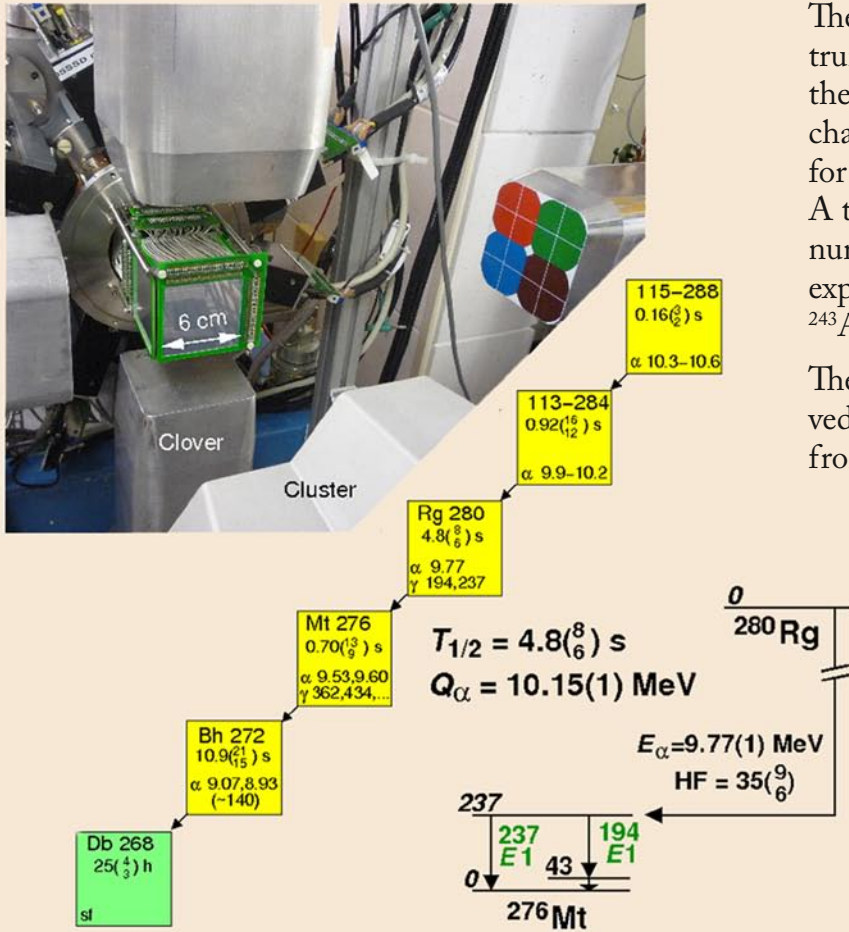
In other words – How many elements are there in the period table?

Claes Fahlander

Dirk Rudolph

Joakim Cederkäll

New element



The 2013 Scientific Report from GSI Helmholtzzentrum für Schwerionenforschung in Germany shows the experimental set-up used to study the decay chain of the isotopes 288-115, which was studied for the first time with high-resolution spectroscopy. A total of 30 atoms of the element with the atomic number 115 were identified during the 3-week experiment, during which a thin foil of radioactive ^{243}Am was bombarded with 6 trillion (10^{12}) ^{48}Ca ions.

The experiment was led by Dirk Rudolph, and involved no less than 51 collaborators, six of which were from Lund.