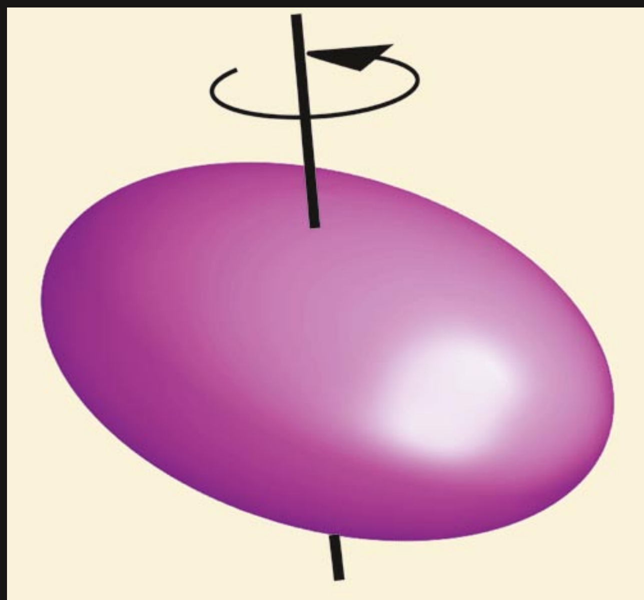


Symmetry in the world of atomic nuclei

The properties of atomic nuclei and the existence of superheavy nuclei.

Atomic nuclei shake, rattle and roll!

By the time of his death in 1979, Sven Gösta Nilsson had established an active research group working on rapidly rotating nuclei. The spirit within the group is illustrated by the words of Sven Åberg.

> *Every Friday morning during the autumn of 1974, the mathematical physics group took the ferry from Malmö to Copenhagen to take part in Ben Mottelson's weekly course on the latest findings in high-spin nuclei. This was always followed by extensive discussions, including Aage Bohr, Ikuko Hamamoto and Ben himself. We prepared ourselves for these discussions on the way over on the ferry, and our table was always covered with sheets of paper with long calculations. Mottelson's lectures seemed easy to understand until we took the ferry back to Malmö and tried to analyse what he had actually said in detail.*

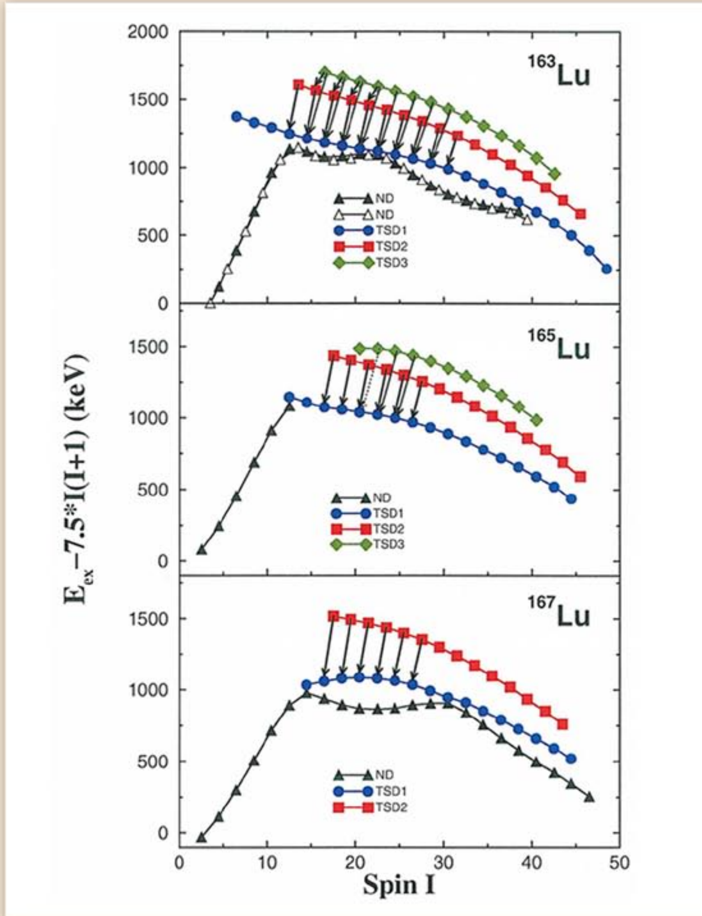
The lady from Japan

Ikuko Hamamoto came to the Niels Bohr Institutet in Copenhagen in the 1960s thanks to a stipend from Japan. When the Professorship in Mathematical Physics in Lund became vacant in 1979, due to the death of Sven Gösta Nilsson, Hamamoto was appointed to the position in the face of fierce international competition.

Hamamoto was to spend over 40 years working in Copenhagen and Lund. A few years after retiring, she returned to Tokyo, where she is still very active in theoretical nuclear research.

Ikuko Hamamoto, Professor in Mathematical Physics at Lund University between 1982 and 2001.

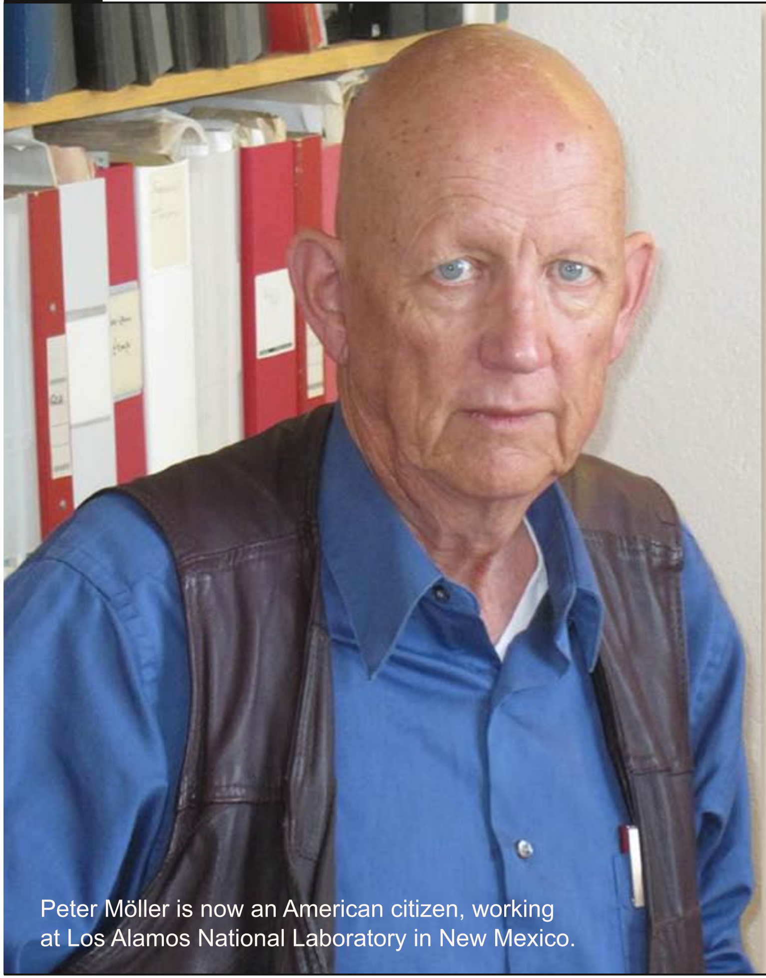
Wobbling modes



Ikuko Hamamoto has been interested in understanding and interpreting nuclear physical phenomena with a focus on particle-vibrational coupling in nuclei in order to obtain knowledge on the collective and single-particle motion in the nucleus.

In the search for triaxial nuclear shape she made basic predictions as to the features of electromagnetic transitions characterizing triaxial shape and suggested and pinned down that the experimental finding by G B Hagemann et al. in 2001 is the discovery of wobbling mode.

An expert in the calculation of nuclear masses



Peter Möller is now an American citizen, working at Los Alamos National Laboratory in New Mexico.

Peter Möller continued Sven Gösta Nilsson's calculations on fission, and is today a leading expert in the field. Through meticulous research he has developed a detailed model for the calculation of nuclear masses.

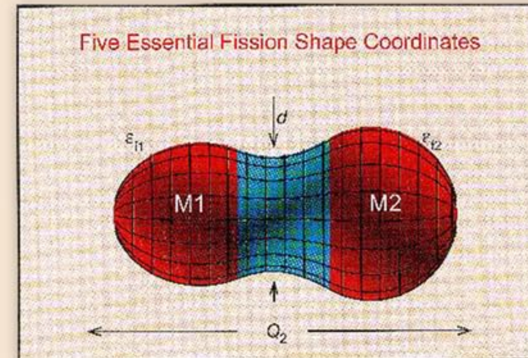
It is of great importance to be able to predict nuclear masses, for example, in order to understand astrophysical processes, and to be able to make predictions of the limit on the size of nuclei.

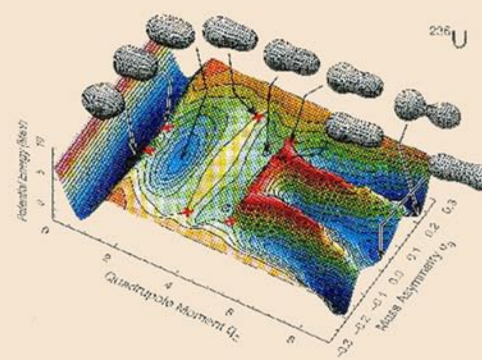
Möller's mass equation has long been the most reliable in the study of so-called superheavy elements.

Predictions of new elements

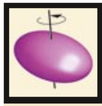
Elements heavier than uranium do not exist naturally on Earth in measurable quantities as they are unstable, and decay radioactively to lighter elements. However, it is possible using modern mass equations to predict so-called islands of stable superheavy nuclei.

Some superheavy elements can be created by the collision and fusion of other lighter elements in accelerators, and in recent years about 20 new elements have been added to the periodic table.





A *map* showing the shape of the uranium nucleus changes as it passes over the energy landscape consisting of peaks and valleys.



Captured by rotating nuclei

What happens to a nucleus when it rotates very rapidly? How do the protons and neutrons in the nucleus behave? How fast can it rotate before it breaks up?

Ingemar Ragnarsson is studying how the interior of the nucleus behaves and, through his research, has increased our understanding of how various quantum mechanical effects give rise to different nuclear shapes.

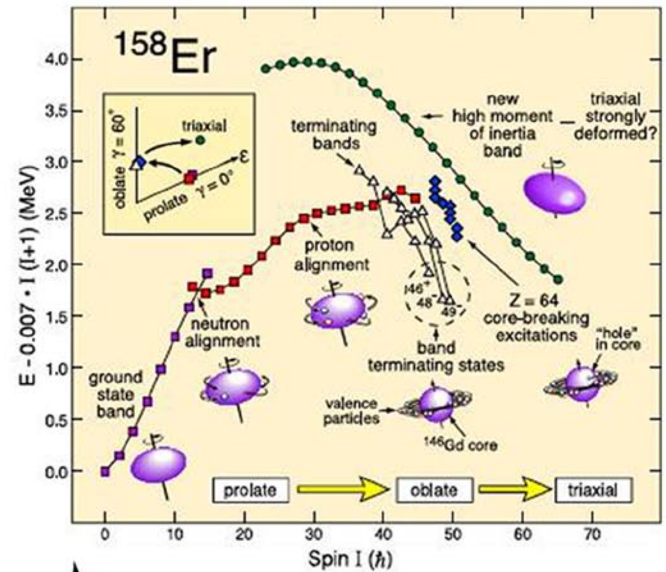
As the frequency of rotation increases, the rotation of the nucleus can suddenly cease, and the rotational motion is restricted to a relatively small number of nucleons. This is called band termination. Ragnarsson has developed a formalism that makes it possible to understand and predict this phenomenon.

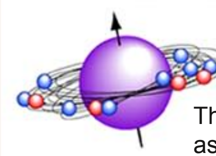
Ingemar Ragnarsson, Professor of Mathematical Physics.

Band termination

Ingemar Ragnarsson collaborates with experimental nuclear physicists, as this allows him to test his theoretical calculations of the detailed behaviour of nuclei, and to develop new models that can subsequently be used in his colleagues' experiments.

Apart from descriptions of band termination, Ingemar has also studied the structure of strongly deformed nuclei, so-called super-deformed nuclei. Together with Sven Gösta Nilsson he has written an important book on nuclear structure physics, called *Shapes and Shells in Nuclear Structure*.



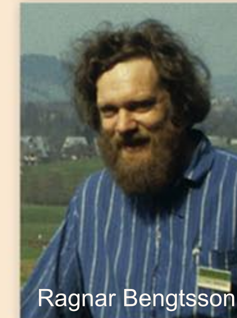


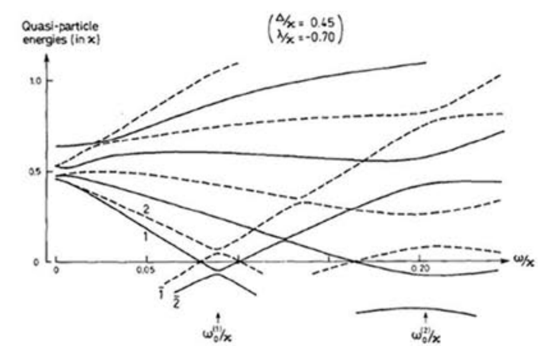
The nucleus of ^{158}Er exhibits different shapes as the frequency of rotation (spin) encreases (x-axis) with increasing spin, the shape changes from prolate (like a cigar) to oblate (like a pancake), and finally becomes triaxial (the three axes are different). When the shape of the nucleus is oblate, terminated band behaviour is seen, where the energy of the system (y-axis) varies irregularly.

Close encounters of the experimental kind!

Ragnar Bengtsson has devoted most of his research to the description of rotating nuclei. His most famous contribution to the field is the Bengtsson-Frauendorf formalism, which was developed at the end of the 1970s. Transforming the observed energy spectra into the rotating system allows a simple, general comparison with theoretical energy levels.

Bengtsson has long been involved in collaboration with international experimental groups in the quest to understand and describe experimentally observed energy spectra. These studies have led to an improved understanding of co-existing nuclear shapes and triaxial nuclei.





Energy levels in nuclei as a function of the rotational frequency of the nucleons, according to the Bengtsson-Frauendorf-formalismen. At the two frequencies indicated on the x-axis, the energy levels interact, giving rise to so-called *backbending*.

Researcher and organizer

Sven Åberg was director of the Division of Mathematical Physics between 2000-2016 and the President of the Royal Physiographic Society of Lund 2011.

First as a PhD student in the 1970s, and later as a researcher in the 1980s, Sven Åberg devoted much of his time to rapidly rotating nuclei, and contributed to our understanding of how rotation can cause superdeformation. The results were important for the experimental discovery of superdeformation in 1986.

Åberg also studied how exotic nuclei can be de-excited by emitting alpha particles or protons; a field that is currently of great interest.

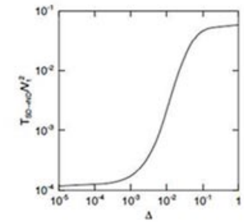
Initiator

Sven Åberg has also contributed to our understanding of central problems in nuclear structure physics, such as when nuclei become chaotic and the consequences of such phenomena.

He has introduced a condition for how quantum chaos enters a general many-particle system, sometimes referred to as the Åberg condition.

Other areas where he has made important contributions is pairing, level density, giant resonances and ultra-cold atomic quantum gases.

Sven has also taken the initiative for several summer schools for nuclear physics (together with Ben Mottelson) and has organized several international conferences on nuclear- and chaos physics. He has founded and run the Gemstone project at LTH, and NORDITA's Master Class in Physics. Projects aimed at talented High School Students in Sweden and PhD Students in the Nordic countries.



Chaos-assisted tunneling from a super-deformed state to a normal deformed. The picture shows how the probability of tunneling (vertical axis) increases very dramatically if account is taken of the chaotic properties of the nucleus (horizontal axis). The mechanism involves that a superdeformed state can decay rapidly in accordance with experimental results.

Theoreticians in a spin!

Stig Erik Larsson took part in the development of the formalism and wrote a considerable part of the computer program used to describe triaxial rotating nuclei.

Georg Leander made crucial contributions in the field of pear-shaped nuclei and their rotation. Despite his youth, he had a leading role as a theoretician at Oak Ridge National Laboratory in the USA, before his untimely death as a result of cancer in 1989.

Tord Bengtsson, who started his PhD studies in 1979, soon revealed a talent for developing formalisms and writing computer programs. His program for describing energy levels and rotational bands in rapidly rotating nuclei is still used around the world today.


Stig Erik Larsson


Georg Leander


Tord Bengtsson

Success with open quantum systems

Tore Berggren obtained his PhD in Lund in 1966 for his work on the interpretation of the results of (p,2p)-experiments performed at the Gustav Werner Institute in Uppsala. His interpretation supported the shell model for nuclei.

In the 1960s he developed theories on resonant states in open quantum systems, where the particles were almost unbound and could leave the system.

In an important publication in 1967 he showed how such unbound states could be treated mathematically.

Tore Berggren was a reader in mathematical physics at LTH 1966 - 1996.

Tore Berggren 1931 - 1996

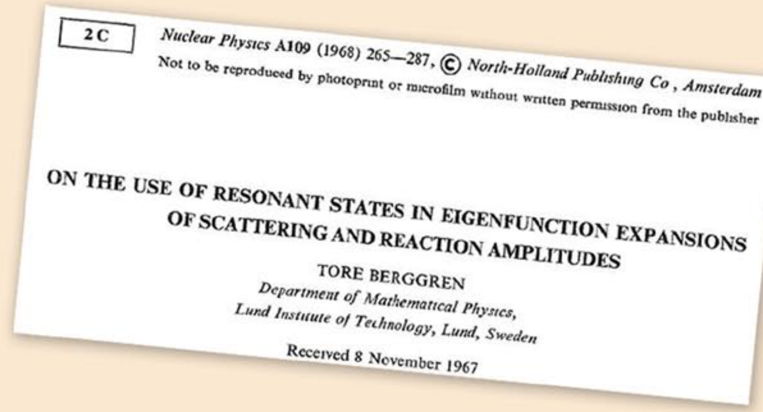
A Sleeping beauty

Many scientific papers include Tore Berggren's name in their title.

In 2007, a conference was held in Trento in northern Italy, to celebrate the 40th anniversary of Tore Berggren's important findings: *40 years of the Berggren representation*.

His findings have recently also proved useful in calculations on the nanoscale in experiments on quantum dots.

Tore suffered from a rheumatic disease, and died in 1996, only 64 years old. Unfortunately, he did not live to see the important international breakthrough of his theoretical work.



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ON THE USE OF RESONANT STATES IN EIGENFUNCTION EXPANSIONS OF SCATTERING AND REACTION AMPLITUDES

TORE BERGGREN

Department of Mathematical Physics, Lund Institute of Technology, Lund, Sweden

Received 8 November 1967

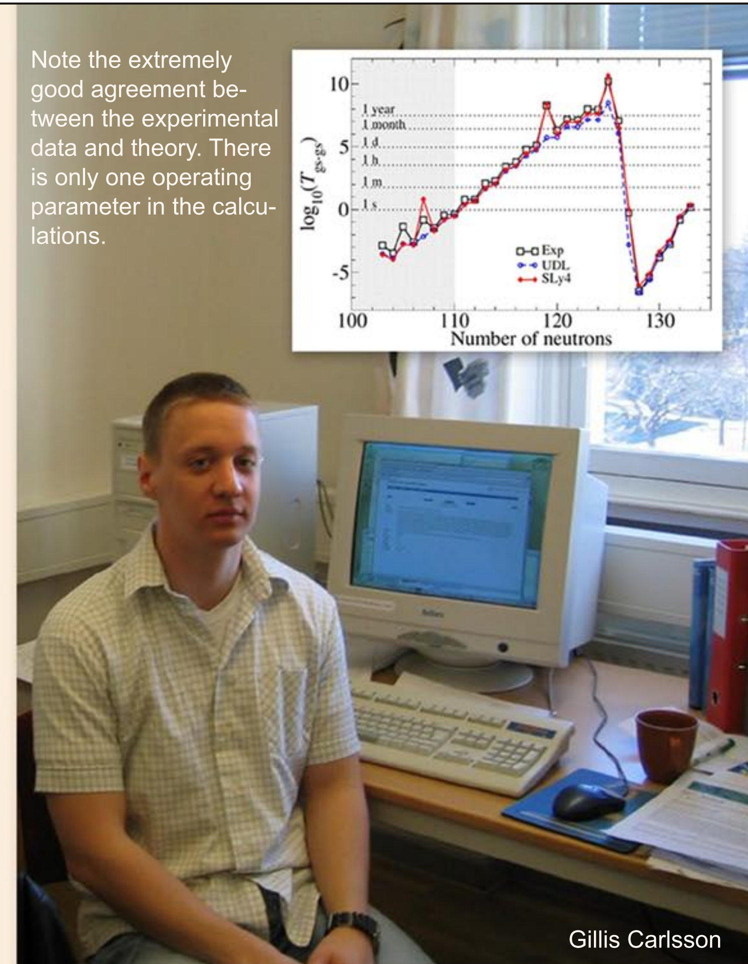
Tore Berggren's ground-breaking work from 1967.
It was found much later that his theories from the 1960s could be used to describe the structure of unstable nuclei by combining them with the shell model. His work paved the way for the formulation of an extensive many-particle theory for open quantum systems.

Alpha-particle-like states in the nucleus

Gillis Carlsson obtained his PhD in 2007 for his theoretical work on rotating atomic nuclei, with Ingemar Ragnarsson as supervisor.

His greatest interest lay in understanding the properties of nuclei based on the forces acting between nucleons. This is very difficult, and an important part of his work was thus devoted to finding approximations for the description of the motion of the nucleons in the nucleus.

In order to describe alfa-decay, he consideres how two protons and two neutrons close to the surface of the nucleus bind to form an α-particle that then has a small probability of tunnelling its way out of the nucleus.



Note the extremely good agreement between the experimental data and theory. There is only one operating parameter in the calculations.

Gillis Carlsson

An acclaimed speaker

Cecilia Jarlskog obtained her PhD in theoretical physics Lund in 1970, and was the first woman to obtain a doctoral degree in this subject at Lund University. In 1994 she returned from CERN to Lund as Professor of Theoretical Particle Physics at the Lund Institute of Technology (LTH).

Below an extract from the speech by J V Luce in July 2005 when Cecilia was awarded an honorary doctorate at Trinity College in Dublin in 2005.

> *She has skilfully and mathematically investigated the principles on which the sub-atomic and electronic constituents of matter cohere, or lose their symmetry. As a result of long-continued and penetrating research in this field she is in a position to discourse authoritatively on the formation and emergence of the physical world, and on the rationale of the observed properties of its smallest constituents.*

Cecilia Jarlskog is also an accomplished and much sought-after speaker.

The Jarlskog invariant

Cecilia Jarlskog has mainly devoted her time to research on the theory of the weak nuclear force, and she is most well known for having developed the Jarlskog invariant. This is an invariant quantity in particle physics associated with CP violation, it is the part of the interaction that differs between particles and antiparticles. She showed that this quantity is independent of the arbitrary phases required by quantum mechanics in the wavefunctions of quarks.

Jarlskog has also been involved in communicating the results of research to society as a whole and, amongst other positions, she has served as advisor to the Director General of CERN.