NEUTRON RESEARCH
in AUSTRIA
2013 - 2017

Contents

(Material compiled by Hartmut Abele and Gerhard Krexner in late 2018,
partly with help of ILL)

GENERAL VIEW

Introduction

The present report on neutron-related research based in Austria covers roughly the last five years and follows the general concept of a previous document (Neutron Research in Austria 2008 - 2012) presented in 2013. Similarly to this earlier report, it is motivated in the first place by the intended renewal of the current Austrian Membership in the ILL (Institute Laue-Langevin, Grenoble, France) covering the five years period 2014-2018 and expiring soon. The report comprises various data which may serve as a basis for a comprehensive evaluation of the Austrian Membership by demonstrating that both, quantitatively and qualitatively, the scientific output witin this period of time can be considered excellent by international standards and clearly warrants continuation of the Austrian Membership for another five years 2019-2023.

On the other hand, it is obvious that neutron-related research in Austria is not exclusively performed at the ILL and an assessment of the usefulness of Austria's Membership has to be set within the larger scope of neutron-related science in general. Therefore, following the section on ILL Membership, a separate chapter is devoted to research and activities at the Atomic Institute of the Vienna University of Technology ('Atominstitut') whose research reactor constitutes the 'home base' of neutron research in Austria. In addition, lists of publications based on neutron-related research from various other (mostly academic) institutions in Austria have been included independently of whether experiments had been done at ILL or various other neutron laboratories.

The report is structured in the following way: A general part tries to present the Austrian membership at ILL in a broader context and to provide some additional background information considered useful both for a comprehensive assessment of the present situation as well as for an evaluation of potential future developments. The next section relating to the ILL comprises statistical material and coverage of research by the media mainly taken from ILL data bases with the kind help of ILL staff. As already mentioned, the third part is dedicated to the presentation of the Atominstitut.

The concluding compilation of publications of various Austrian user groups is organized according to research institutions (i.e. mostly university institutes). The period of time covered is essentially 2013-2017 though publications of the year 2018 have been taken into account to the extent that statistics were already available at the time of composing the report.

Apart from the Atominstitut, regular use of neutrons is made at

- Technical University of Vienna (Institute of Solid State Physics)
- University of Vienna (Faculty of Physics, Faculty of Chemistry, Faculty of Earth Sciences)
- Montanuniversität Leoben: Institute of Physics, Department of Physical Metallurgy and Materials Testing
- University of Graz: Institute of Molecular Biosciences
- University of Innsbruck: Institute of Physical Chemistry

Further users which occasionally performed neutron-related research over the last five years, exist at

- Austrian Academy of Sciences (Stefan Meyer Institute for Subatomic Physics, Erich Schmid Institute of Materials Science)
- University of Natural Resources and Life Sciences (Vienna)
- University of Salzburg
- University of Linz
- Technical University of Graz
- Medical University of Graz
- University of Applied Sciences Joanneum
- International Atomic Energy Agency (IAEA)
- Institutions treasuring cultural heritage such as museums
- Austrian industry (various companies)

As becomes apparent from a comparison with previous reports the Austrian user community has continuously expanded over the years not only in number but also in the scope of research topics.

Where cooperations between groups exist the assignment of publications to a particular group is necessarily somewhat arbitrary. However, in general, publications were listed only once. The compilation is fairly comprehensive (though not fully complete) and estimated to comprise over 90 percent of neutron-related research in Austria including also work performed at neutron labs other than ILL such as the spallation source ISIS or the FRM2 reactor in Munich.

Generally, no strict separation between work at ILL and at other neutron labs was aimed at. Experiments performed at different neutron sources frequently examine complementary aspects of a particular problem and, therefore, are interconnected and sometimes even published together. On the other hand, the publications quoted in the section about ILL, of course, overlap strongly with the publications listed in the context of the various research groups.

Neutron Science in Austria before joining the ILL

1. Following the majority of European countries at the time Austria, in the late 1950s, established a Nuclear Research Centre located at Seibersdorf about 30 km south of Vienna. There, a light-water swimming pool-type reactor (ASTRA) was operated from 1960-1999 with a power of up to 9.5 MW. Research was centred mainly on nuclear physics and complemented by isotope production, irradiation experiments, dosimetry, etc. Several neutron spectrometers were built; however, possibilities for scattering experiments were strongly limited due to the reactor design (light-water moderator, lack of tangential beam lines).

In consequence of a strategic decision of the Seibersdorf Centre to abandon fundamental in favour of applied research the interest in neutron scattering techniques faded in the 1980s. In addition, the general interest in nuclear expertise gradually decreased as a consequence of the negative result of the referendum on the use of nuclear power in Austria in 1978. After the shut-down of the reactor, activities at Seibersdorf are today restricted to providing services such as calibration of instruments and formation of experts mainly in the fields of ionizing radiation, radioactivity, dosimetry and measurement techniques as well as radiation protection.

Nevertheless, for about 20 years the research centre Seibersdorf was instrumental in the formation of a significant number of students in nuclear physics and instrumentation some of which had the opportunity to work and take part in experiments at the newly founded ILL in Grenoble at a very early stage.

2. On the other hand, at the university level, the 'Atominstitut of the Austrian Universities' was established in Vienna as a common institution offering access to research on and with neutrons. It was equipped with a TRIGA Mark II research reactor (250 kW) which became critical in 1962 and is still in operation today (for more details see below).

3. A 1 kW Argonaut reactor for teaching nuclear reactor theory and nuclear physics was installed and operated at the TU Graz from 1965 to 2005.

4. In the late 1970s, growing awareness of the strength of neutron scattering techniques requiring access to powerful neutron labs led to various co-operations initiated by individual researchers or smaller research groups. Maybe one of the most visible results of these efforts was the installation of the Austrian cold three axes spectrometer VALSE at the new ORPHÉE reactor at the LLB Saclay which was successfully operated by the Institute of Experimental Physics of the University of Vienna over two decades (1980-2002).

However, such steps were not capable of eliminating the basic shortcomings arising from the lack of an Austrian National Laboratory for neutron scattering then available in a number of other smaller European countries such as CH, DK, N, S, NL, B, H, CZ, etc. This situation together with the wish to open the access to neutrons for a wider community of Austrian researchers beyond physics finally led to an initiative to join the ILL (operated by three Associates, namely France, Germany and United Kingdom) which eventually succeeded in 1990 when Austria became the third scientific member state after Switzerland and Spain.

This was an important step forward towards the implementation of neutron scattering techniques in Austria on a wider scale. Yet, this decision to focus exclusively on the ILL had also negative repercussions on established co-operations with other European neutron labs due to the decrease or canceling of support from the Austrian Ministry of Science for non-ILL based activities. In addition, the lack of a broad basis of Austrian scientists sufficiently trained in applying neutron scattering techniques in their research became soon evident.

ILL Membership: CENI – OeAW

The ESFRI Landmark institution ILL (Institut Max von Laue-Paul Langevin) is an international research centre at the leading edge of neutron science and technology. As the world's flagship centre for neutron science, the ILL provides scientists with a very high flux of neutrons feeding some 40 state-of-the-art instruments, which are constantly being developed and upgraded. Including all the relevant scientific domains, the ILL covers also nuclear and particle physics with a fraction of about 5 instruments.

The ILL was founded in 1967 as a bi-national enterprise between France and Germany with the UK joining later in 1973. In addition to these three Associate Members operating the ILL, about 10 countries have entered a partnership with ILL as Scientific Members: Spain, Switzerland, Austria, Italy, the Czech Republic and more recently Sweden, Belgium, Slovakia, Denmark, Poland and India.

As a service institute the ILL makes its facilities and expertise available to visiting scientists. Every year, some 1400 researchers from over 40 countries visit the ILL. Up to 800 experiments selected by scientific review committees are performed annually. Research focuses primarily on fundamental science in a variety of fields such as condensed matter physics, chemistry, biology, nuclear physics, materials science, etc., but also tries to respond to an increasing number of emerging industrial applications and societal needs.

The ILL provides scientists with a very high flux of neutrons feeding some 40 state-of-the-art instruments, which are constantly being developed and improved. The Millenium upgrade program having started in 2000 has recently been completed. Another upgrade program, named Endurance has been initiated from 2015 onwards and will result in a further gain in instrument performance of at least one order of magnitude. This programme will be rolled out into two phases over 8 years and assure the position of ILL as the world's leading laboratory for neutron-related research.

In being a scientific member of ILL, Austria is represented by the Austrian Academy of Sciences since 1990. Presently, Austria is part of the consortium CENI (Central European Neutron Initiative) having formed by successive joining of the Czech Republic (1999), Hungary (2005), and Slovakia (2009). Representatives of the CENI member states regularly meet once a year (the last meeting took place in May 2017).

The present Agreement between ILL and CENI covering a period of five years (Jan 2014 - Dec 2018) entitles Austria to use 1.3 percent of the ILL beam time (the entire CENI beam time amounts to 2.2 percent). Talks aiming at a renewal of the Agreement for the period 2019 – 2023 have started some time ago and are expected to be concluded soon.

NESY – User organization in Austria / NESY Winterschool

The Austrian user communities applying neutrons and synchrotron radiation are comparatively small and, therefore, are organised in a common section of the Austrian Physical Society formed in 1996 and named NESY (Research with Neutrons and Synchrotron Radiation). The association with the Austrian Physical Society, however, is purely historical and NESY is open to all scientists using neutrons and synchrotron radiation in Austria. NESY serves as a forum for distribution of pertinent information and for discussing issues of common interest. Meetings take place twice a year typically.

In order to broaden the user base and to facilitate overcoming various barriers in accessing large scale Neutron and Synchrotron facilities a biennial winter school for young scientists (mostly PhD students and Postdocs) has been recurrently organized starting in 1999 at the Planneralm. The venue of the school was recently transferred to Altaussee (likewise in the Austrian Alps). The program is composed both of basic introductory lectures on neutron scattering and synchrotron radiation and, interchangeably, topical lectures on various fields such as biology, materials, etc. To provide an impression of the scope of the School the program of the 2017 course is included below. The next School is to take place in March 2019 (cf. http://nesy.unileoben.ac.at/de/6430/).

10th European Winter School & Symposium on Neutron and Synchrotron Radiation

including topical highlight lectures on Biological Systems

Altaussee (Austria), 6 – 10 March 2017

6th March — CERIC Satellite Event / Structural Biology

11:00-16:00	CERIC Satellite Event		
16:00-16:30	Welcome Coffee & Tea		
16:30-16:45	Conference Opening	R. T. Lechner	MU Leoben (AT)
16:45-17:00	Austrian NESY Activities	O. Paris	MU Leoben (AT)
17:00-17:30	Hard X-ray spectroscopy of biological Material using synchrotron radiation	C. Streli	Atominstitut Wien (AT)
17:30-17:50	Energy Dispersive White Beam Diffraction: Translating Photon Energy into the 3rd Dimension for One-Shot Texture analysis	T. Grünewald	ESRF Grenoble (FR)
17:50-18:20	Protein crystallography at the ILL	N. Coquelle	ILL Grenoble (FR)
20:00-21:00	Synchrotron Radiation and Structural Biology	C. Mueller-Dieckmann	ESRF Grenoble (FR)
21:00	Poster Session		

7th March — Sources & Instrumentation for Extreme Conditions

08:30-09:30	Synchrotron Radiation – Instrumentation and Techniques	H. Amenitsch	TU Graz / ELETTRA (IT)
09:45-10:45	Neutrons – Instrumentation and Techniques	K. Hradil	TU Wien (AT)
11:00-12:00	Extreme Conditions & FEL	R. Miletich	Uni Wien (AT)
17:15-17:45	Visualizing matter with high resolution and quantitative contrast with X-ray ptychographic tomography	A Diaz	SLS / PSI Villigen (CH)
17:45-18:05	Using Atomic Scale X-Ray Photon Correlation Spectroscopy to Study Atomic Diffusion in Glasses	C.Tietz	Uni Wien (AT)
18:05-18:25	Investigating Alkali Borate Glasses via Total X-Ray Scattering	K. Holzweber	Uni Wien (AT)
18:25-18:55	Long wavelength Neutron Diffraction at the ILL: the case of myelin structure	B. Deme	ILL Grenoble (FR)
20:00-21:00	A multi-pronged approach to understanding Staufen protein, a multifunctional RNA-binding factor	L. Spagnolo	Uni Glasgow (UK)
21:00	Poster Session		

8th March — Biology & Materials in Biology

08:30-09:30	Protein Structure: Determination, Analysis, and Applications	T. Pavkov-Keller	Uni Graz (AT) / acib
09:45-10:45	Elastic SAXS / SANS of Complex Biomembrane Mimetics	G. Pabst	Uni Graz (AT)
11:00-12:00	In-situ X-ray Scattering on Soft Matter	H. Peterlik	Uni Wien (AT)
17:15-17:45	Structure and mechanism of respiratory complex I, a giant molecular proton pump	L. Sazanov	IST Austria (AT)
17:45-18:05	Structural Characterization of the Surface Layer Proteins from Probiotic Lactobacilli	M. Eder	Uni Graz (AT)
18:05-18:35	Structural Biology at the Austrian Centre of Industrial Biotechnology (acib)	K. Gruber	acib / Uni Graz (AT)
20:00-21:00	Synchrotron-based multiprobe imaging to study adaptive natural materials	P. Fratzl	MPI of Colloids and Interfaces, Potsdam (D)
21:00	Poster Session		

9th March — Engineering, Materials & Magnetism

08:30-09:30	Scanning X-ray and Neutron Diffraction on Polycrystalline Materials	J. Keckes	MU Leoben (AT)
09:45-10:45	Research with Neutrons and Synchrotron Radiation on Advanced Titanium Aluminides	S. Mayer	ESI & MU Leoben (AT)
11:00-12:00	Studies of paramagnetic excitations near an electronic ground state instability – Inelastic and quasi-elastic neutron scattering studies	H. Michor	TU Wien (AT)
17:15-17:45	Crystalline high-performance polymers by non-classical syntheses	M. Unterlass	TU Wien (AT)
17:45-18:05	Dummy atom modelling of helical nanostructures from solution scattering data	M. Burian	TU Graz / ELETTRA (IT)
18:05-18.25	The influence of water adsorption on the nanostructure of tooth: A Small-Angle X-ray Scattering study	L. Ludescher	MU Leoben (AT)
18:25-18:45	Ion electrosorption in supercapacitor electrodes studied by in-situ small-angle X-ray scattering	C. Koczwara	MU Leoben (AT)
20:00	NESY Meeting		
10th March	**Semiconductors & Nanostructures**		
08:30-09:30	Organic Semiconductors: The Influence of the Thin Film Structure on the Device Performance	R. Resel	TU Graz (AT)
09:45-10:45	Structure, valence and magnetism of doped oxide semiconductors studied with x-ray absorption spectroscopy	A. Ney	Uni Linz (AT)
11:00-12:00	Band Structure Mapping using Angle Resolved Photoemission Spectroscopy: Application to Topological Insulators and Rashba Systems	G. Springholz	Uni Linz (AT)
12:00-12:30	Prizes & Closing		

From Austron to ESS

Driven by early enthusiasm following the fall of the Iron Curtain and motivated by the wish to increase scientific competitiveness in Central Europe the project of hosting a world-leading spallation neutron source in Austria (coined AUSTRON) was developed in the 1990s. The final concept proposed a source of 0.5 MW average beam power which, due to an additional storage ring, would feature a dual frequency mode of operation (10 Hz and 50 Hz pulse rates) combining the advantages of low and high frequency beams.

The source was planned to considerably surpass ISIS but was somewhat less ambitious than the new spallation sources realised later in the US and Japan. Detailed construction plans for the accelerator complex were already available before 2000 and soon followed by an extensive design study comprising a suite of more than 20 instruments. Since AUSTRON was building mostly upon well-proven design principles, technically, there was little risk involved and the scheduled construction time until completion could be short. On the European level, the AUSTRON spallation source and the new

FRM2 reactor in Munich would have complemented each other in a similar way as ILL and ISIS have already done for a long time. Unfortunately, this project did not work out, however, part of the momentum created by this initiative continued into the new project MedAustron, an Ion-Beam Cancer therapy centre raised somewhat later in Wiener Neustadt some 50 km south of Vienna.

The strongest forward-looking interest today is in the construction of the European Spallation Source (ESS) as one of the largest science and technology infrastructure projects currently being built. The facility design and construction include a linear proton accelerator, a heavy-metal target station, a large array of state-of-the-art neutron instruments, a suite of laboratories, and a supercomputing data management and software development centre. Several sections of ESS are presently in the early stages of installation and commissioning, yet the facility planned to become the most powerful neutron source in the world will become fully available to users only in the early 2020s.

S18 / CRG at ILL

The Atominstitut in Vienna operates the CRG instrument S18 at the ILL which is a perfect crystal spectrometer. Presently, S18 is set up as a multi-purpose instrument for neutron interferometry and Ultra Small Angle Neutron Scattering (USANS) spectroscopy with wide range tunability of wavelength. It is the subject of a separate Agreement with ILL which, however, implies a valid Membership of Austria in ILL. From the very beginning, neutron interferometer experiments have been one of the most useful tools for the investigation of quantum mechanical phenomena on a very fundamental basis. Over the last decades many different types of interferometer experiments have been performed, ranging from fundamental quantum investigations to applied measurements such as precise measurements of coherent neutron scattering lengths. The former exploits the exceptionally wide possibilities of neutron interferometry to conduct matter-wave-interference experiments and the latter is an important basis for performing neutron scattering investigations in general.

Some remarks concerning the present status of neutron scattering in Austria

The beam time statistics of ILL (see Section on the ILL below) shows that the allocated beam time has been continuously rising over the last 5 year period so that Austria presently uses the ILL membership not only very efficiently but even considerably beyond the extent (1.3 percent) fixed in the current Agreement covering the five years 2014 - 2018. From the compilation in the present report it becomes also obvious that the scope of neutron-related activities in Austria deviates somewhat from the typical distribution of topics investigated at ILL or at other leading neutron labs. There is a strong emphasis on fundamental research on and with neutrons and work performed in this area can be considered to be truly excellent and highly competitive on an international level. Nevertheless, also the breadth of neutron scattering and applications in condensed matter physics, chemistry, materials science, biology, etc. are continuously rising as a consequence of various efforts aiming at extension and diversification in these fields.

Some peculiarities characterising the present situation are the following:

For various reasons the neutron scattering community in Austria has, for a long time, been nearly one order of magnitude smaller compared to other European countries of similar size and the importance attached to neutron scattering as a tool to investigate structure and dynamics of condensed matter was low in comparison to investments in other fields of science. Though this has changed considerably over the last years there is still a significant backlog in absolute numbers.

Unlike other European countries Austria does not dispose of any research centres focusing on basic research. The Austrian Academy of Sciences runs several research institutes but none of them is strongly involved in neutron science. Therefore, an expansion towards a broader range of subjects can be achieved only if neutrons are strongly represented at the University level. Such is the case at the Technical University of Vienna where the activities at the Atominstitut are well represented in the curriculum of the Faculty of Physics so that permanently a sufficient number of students are introduced into this field and trained both in the course of their studies and during their Master and PhD theses.

However, this is not the case for any other Austrian university. Contrary to the situation in Germany, Switzerland, Hungary, Czech Republic, etc. there is not a single chair devoted to research applying neutron scattering techniques and the larger part of the researchers having used neutron scattering over the last two decades now have left Austria, are retired or will soon do so. The emphasis has for a long time been on other fields and for a scientist specializing in neutron scattering it is virtually impossible to get an academic position in Austria. Students doing their theses in this area afterwards have either to switch for another field or pursue their scientific career abroad.

Accordingly, scattering techniques and neutron science in general are practically absent in the curricula. X-ray techniques such as diffraction and small-angle scattering are present, however, at least to some extent. In addition, it is possible to acquire practical expertise in using X-rays in university labs which are usually available. As a consequence, a rising number of students and university staff scientists exploit the possibility to do experiments at synchrotrons such as ESRF (Austrian membership), Elettra (Austrian SAXS beamline), DESY, and others.

Measures to foster the position of neutron based research in Austria by creating a larger user community, therefore, primarily have to address the situation at the universities.

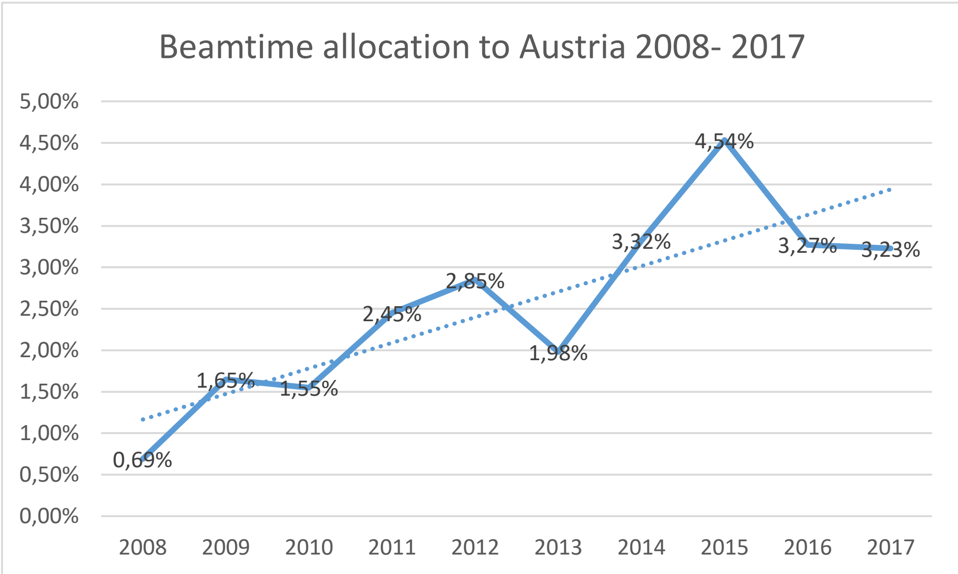
Future Perspectives of Neutron Science in Austria

In discussing the future of neutron-related research in Austria it is important to be aware of a long-standing problem: On the one hand it is evident that large scale facilities based on international cooperation play an ever increasing role for top level research (half a century ago there was only CERN, today there exist a considerable number of large international facilities and many more projects are on the ESFRI roadmap). On the other hand, this is in no way taken into account in the Austrian research budget which does not envisage any substantial funding to finance participation in next-generation facilities. Therefore, projects such as XFEL or ESS are presently not accessible and there is an increasing risk that Austria will be decoupled from some of the most significant and fascinating directions of future research.

The point of view of the Austrian neutron community can be summarised as follows: Given the present situation, a renewal of the membership at ILL appears absolutely indispensable for maintaining the current level and scope of research with neutrons in Austria. At the same time, however, this has to be accompanied by further measures forming a suitable framework for further exploiting the potential of the participation in the ILL and to prepare for future developments.

ILL Statistics and Beam Time Allocation

The Figure below illustrates the development of ILL beamtime allocation to Austria over the 10 years 2008-2017 showing a continuous upward trend over one decade which is, by the way, further confirmed by very recent data form 2018.

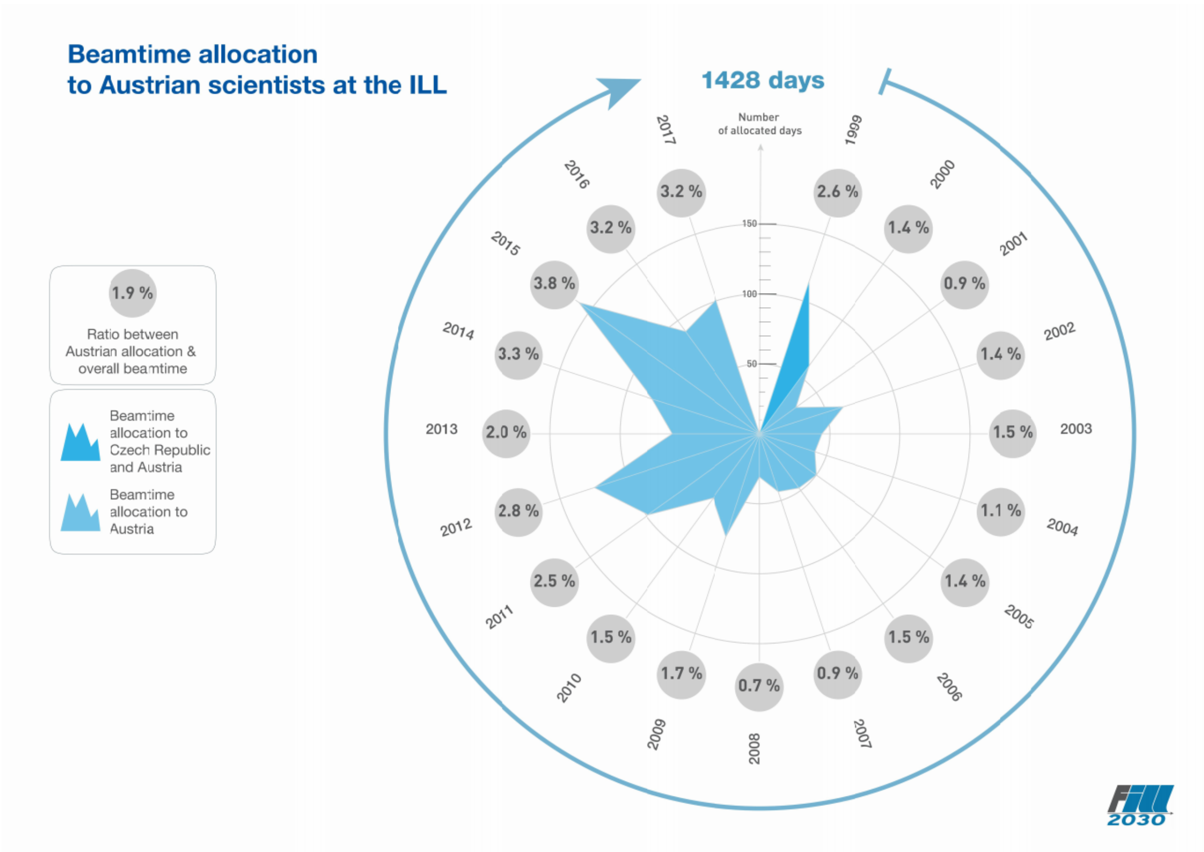


The Austrian proportion of beam time has been steadily rising and has by far surpassed the 1.3 percent beam time fixed for the period covered by the current Agreement 2014-18.

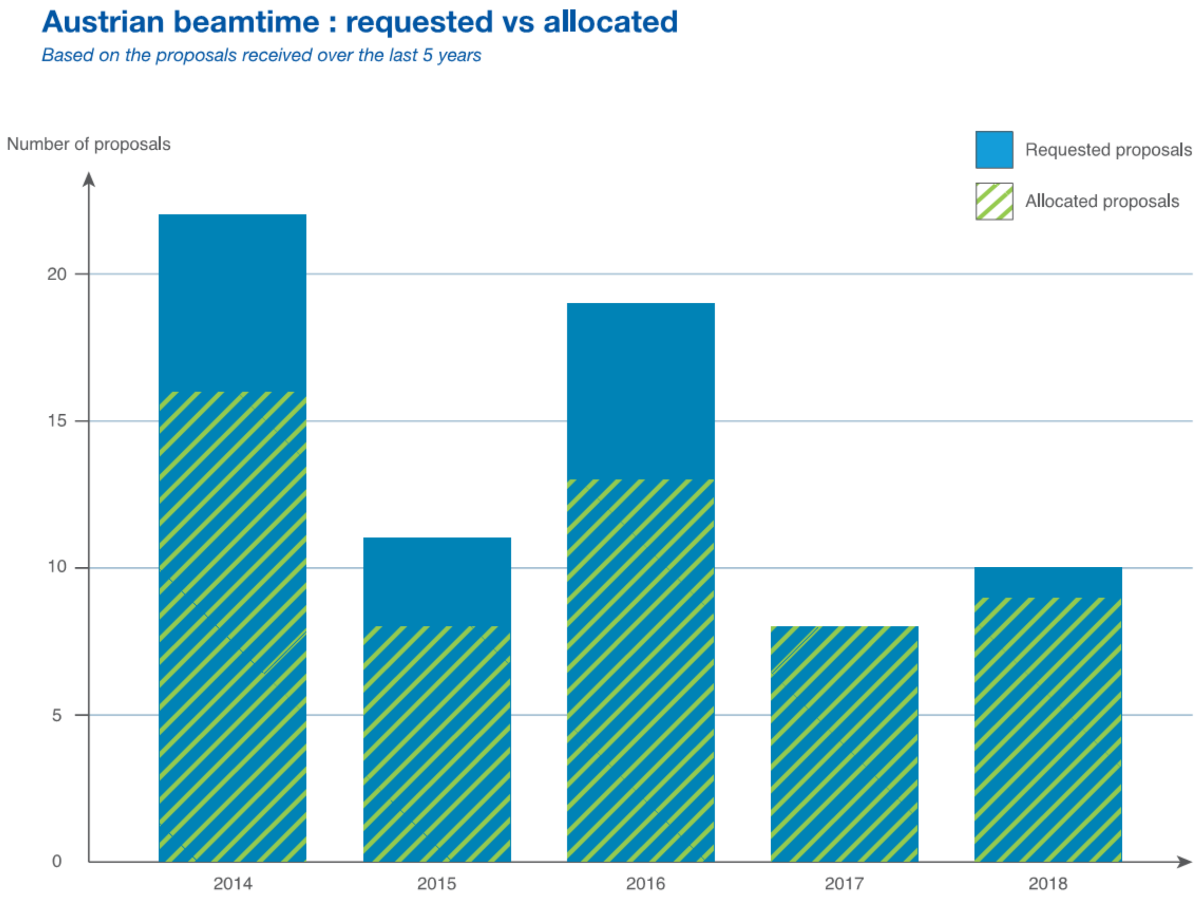
This is also born out by the statistics in the following Table containing the average use of all CENI partners over the years 2014-2018 (The Czech Republic represents a particular case: CZ has invested considerably beyond the CENI contract by constructing a new instrument at ILL and, therefore, has been allocated beamtime for development and testing).

	Beamtime contractually	Beamtime contractually + overuse 1,5	Average annual use 2014-2018
AT	1.30 %	1.95 %	3.30 %
CZ	0.53 %	0.80 %	1.42 %
SK	0.12 %	0.18 %	0.27 %
CENI	1.95 %	2.93 %	4.99%

A further illustration of the beamtime allocation to Austria over a larger time period (1999-2017) is shown in the graphics below. The absolute numbers of days corresponding to a certain percentage of beamtime vary from year to year according to the total number of instrument-days offered by ILL in each year which may fluctuate sizably.



A comparison of requested and allocated beamtime shows that Austria's success rate in the application for beamtime is significantly higher than the average success rate at ILL which typically lies around 60 percent:



Austrian PhD Students at ILL 2010-2018

The Table below shows that on the average about two Austrian thesis students are working full time at ILL within the framework of the CENI Agreement. By working on advanced research topics at the world's leading neutron laboratory these students undergo high quality formation unavailable in Austria. (Master or PhD Theses involving experiments at ILL but not being associated with long-term stays are not listed here !)

ID	Arrival Date	External Funding	University	Uni Supervisor	ILL Division /Group	ILL Supervisor	Thesis Subject
CENI-1	01.10.2010	50%Austria, 50%ILL	TU Vienna	H.Abele	NPP	P.Geltenbort	Quantum interference and gravitation effects of UCN's
CENI-2	01.10.2011	50%Austria, 50%ILL	TU Vienna	H.Abele	NPP	O.Zimmer	Gravitationally induced phases in neutron interferometry
CENI-4	01.09.2012	50%Austria, 50%ILL	TU Vienna	H.Abele	NPP	P.Geltenbort	Probing the electric neutrality of the neutron
CENI-3	01.10.2012	50%Austria, 50%ILL	TU Vienna	H.Abele	NPP	P.Geltenbort, O.Zimmer	Generation and detection of multipartite entanglement in the neutron
SPEC-2-2013	01.10.2013	100%ILL	TU Vienna	H.Abele	NPP	P.Geltenbort	
CENI-9	01.11.2013	50%Austria, 50%ILL	TU Vienna	H.Abele	NPP	P.Geltenbort, O.Zimmer	Neutron Interferometry
CENI-12	01.02.2014	81%Austria, 19%ILL	TU Vienna	E.Jericha, Y.Hasegawa H.Abele	NPP	P.Geltenbort	Installation of a multi-purpose neutron instrument
CENI-7	15.03.2014	50%Austria, 50%ILL	TU Vienna	M.Zawisky, Y.Hasegawa, H.Abele	NPP	P.Geltenbort, O.Zimmer	Beta decay of the neutron
CENI-5	01.04.2014	50%Austria, 50%ILL	TU Vienna	E.Jericha, Y.Hasegawa, H.Abele	NPP	P.Geltenbort, O.Zimmer	Beta decay of the neutron
CENI-6	17.08.2015	50%Austria, 50%ILL	OeAW	E.Widmann G.Konrad	NPP	T.Soldner	NoMoS
CENI-8	01.10.2016	50%Austria, 50%ILL	TU Vienna	H.Abele	NPP	P.Geltenbort	Neutron Interferometry as Test for Standard Model and Newtonian Gravitational Forces
CENI-10	01.10.2016	50%Austria, 50%ILL	TU Vienna	H.Abele	NPP	T.Jenke	The quantum bouncing ball gravity resonance spectrometer
CENI-14	02.05.2017	50%Austria, 50%ILL	OeAW	E.Widmann G.Konrad	NPP	O.Zimmer	NoMoS – A neutron decay products momentum spectrometer
CENI-13	01.09.2017	50%Austria, 50%ILL	TU Vienna	H.Abele	NPP	H.Lemmel, O.Zimmer	Weak values of neutrons: foundations and application
181_19	Accepted-foreseen in 2018	100%ILL	Univ Graz	G.Pabst	LS	Y.Gerelli, L.Porcar	Coupling of Leaflet Structure and Collective Fluctuations in Asymmetric Lipid Vesicles
181_33	Contract to start Mid Sept-Oct 2018	100%ILL	TU Vienna	H.Abele	NPP	T.Jenke, P.Geltenbort	Application of a Ramsey-like spectroscopy method to gravity resonance spectrometry

The 2015 Walter Hälg Prize was awarded to Helmut Rauch

The prestigious Walter Hälg Prize, the most prominent distinction in the field of neutron physics was awarded to Prof. Helmut Rauch 'for his outstanding and seminal contributions to the fundamental aspects of neutron physics and optics and many related aspects of quantum physics'.

European Neutron Scattering Association

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Published on Thursday, 05 February 2015 12:42 | Written by admin |

The 2015 Walter Hälg Prize

Every two years the European Neutron Scattering Association, ENSA, awards the prestigious Walter Hälg Prize to a European scientist for an outstanding programme of research in neutron scattering with a long term impact on scientific and/or technical neutron scattering applications.

ENSA Press Release (July 16th 2015)

The selection committee for the 2015 Walter Hälg Prize is delighted to announce that the winner of the 2015 Walter Hälg prize is Prof Dr Helmut Rauch.

It is a great pleasure to announce that the 2015 Walter Hälg Prize has been awarded to Prof Dr Helmut Rauch for his outstanding and seminal contributions to the fundamental aspects of neutron physics and optics and many related aspects of quantum physics.

His contributions to the development of neutron interferometry in the 1970's have led to an understanding of important aspects of neutron physics and quantum mechanics. Importantly his contributions provided confirmation of the wave nature of the neutron over macroscopic length scales, and the proof of the 4π symmetry of neutron spin ½ particles. More broadly the development of neutron interferometry has led to the development and application of ultra-small angle scattering, USANS. His contributions have led to a greater understanding of many key fundamental issues in quantum mechanics, involving the non-separability and non-locality of quantum physics, the Bell-like inequality and quantum contextuality.

Prof Dr Rauch studied at the Technical University in Vienna, where he obtained his Diploma and Doctorate. He was appointed full professor in Experimental and Neutron Physics at the Technical University in 1970. He was director of the Nuclear Physics Institute of the Technical University for almost 20 years, and director of the Atominstitut of the Austrian Universities in Vienna for more than 3 decades. His pioneering work was carried out largely at the TRIGA reactor in Vienna and at the high flux reactor at the Institute Laue Langevin, in Grenoble, France.

Who is Walter Haelg?

Selection of Press and Media Coverage of

ILL research involving Austrian scientists

nature International weekly journal of science

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Bouncing neutrons probe dark energy on a table-top

An experiment measuring gravity's effects at the quantum scale finds no deviations from Newton's laws.

Elizabeth Gibney

18 April 2014

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Searching for dark energy with neutrons: With neutrons, scientists can now look for dark energy in the lab

Date: April 16, 2014

Source: Vienna University of Technology

Summary: It does not always take a huge accelerator to do particle physics: First results from a low energy, table top alternative takes validity of Newtonian gravity down by five orders of magnitude and narrows the potential properties of the forces and particles that may exist beyond it by more than one hundred thousand times. Gravity resonance spectroscopy is so sensitive that it can now be used to search for Dark Matter and Dark Energy.

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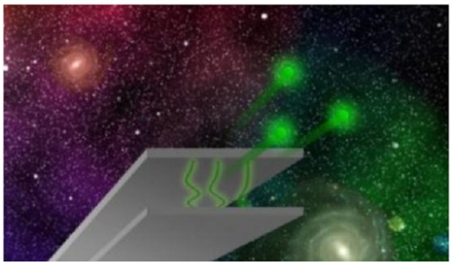

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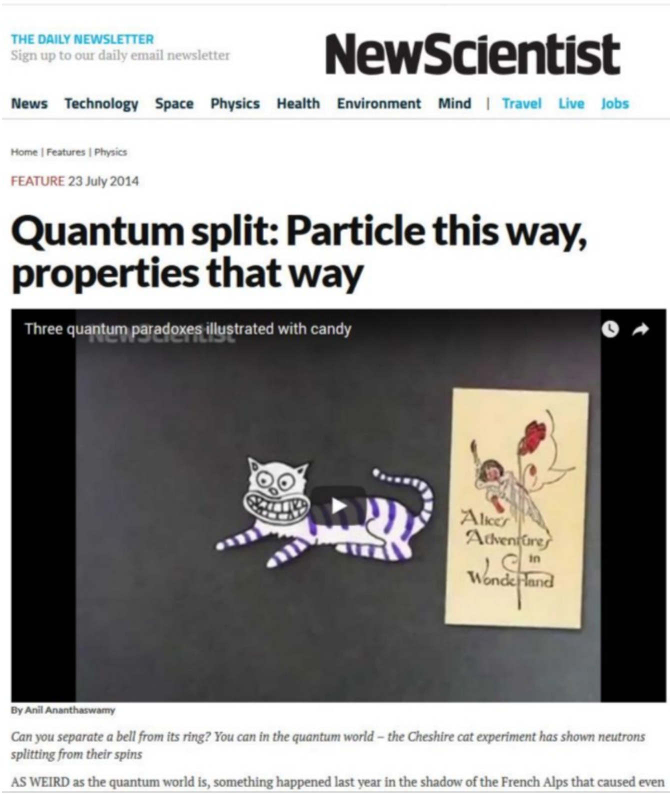

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FEATURE 23 July 2014

Quantum split: Particle this way, properties that way

Three quantum paradoxes illustrated with candy

By Anil Ananthaswamy

Can you separate a bell from its ring? You can in the quantum world – the Cheshire cat experiment has shown neutrons splitting from their spins

AS WEIRD as the quantum world is, something happened last year in the shadow of the French Alps that caused even

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'Quantum Cheshire Cat' becomes reality

By James Morgan
Science reporter, BBC News

29 July 2014

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Quantum physics: the curious case of a neutron and its spin

Scientists succeed in separating a particle from its physical properties, a phenomenon they called the 'quantum Cheshire cat'

Clive Cookson AUGUST 8, 2014

Mystery of the 'Cheshire Cat' of quantum physics solved: Scientists manage to separate a particle from its spin

- **Scientists separated a neutron from its magnetic moment for the first time**
- **Research was carried out by a team from Vienna University of Technology**
- **The groundbreaking study involved the so-called 'Cheshire Cat' experiment**
- **This involves separating a particle from one of its quantum properties**
- **It is likened to detecting a ball separately to its rotation in our 'macro' world**

By JONATHAN O'CALLAGHAN
PUBLISHED: 18:29 BST, 29 July 2014 | **UPDATED:** 21:00 BST, 29 July 2014

One of the peculiar laws of quantum physics is that a particle can be in two different physical states at the same time - like how the Cheshire Cat could separate itself from its smile.

If, for example, a beam of neutrons is divided into two beams using a silicon crystal, it can be shown that the individual neutrons can travel simultaneously along both paths in what is known as a 'quantum superposition'.

And now scientists have measured this bizarre property, which means that they might be able to control the behaviour of neutrons in future

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Scientists separate a particle from its properties

Wed, 07/30/2014 - 9:59am by

Can neutrons be located at a different place than their own spin? A quantum experiment, carried out by a team of researchers from the Vienna University of Technology, demonstrates a new kind of quantum paradox, called the "Cheshire cat".

Researchers from the Vienna University of Technology have performed the first separation of a particle from one of its properties. The study, carried out at the Institute Laue-Langevin (ILL) and published in *Nature Communications*, showed that in an interferometer a neutron's magnetic moment could be measured independently of the neutron itself, thereby marking the first experimental observation of a new quantum paradox known as the "Cheshire cat". The new technique, which can be applied to any property of any quantum object, could be used to remove disturbance and improve the resolution of high precision measurements.

The idea of a quantum Cheshire cat was proposed theoretically last year. It is based on the well known character from Alice in Wonderland who can vanish leaving his smile behind. In quantum physics, the term refers to an object whose properties can be separated from its physical location so that the two can be measured at different places. While this is clearly not possible in our everyday experience, where objects are spatially linked to their properties, the laws of quantum mechanics allow it to be achieved.

Catching a quantum Cheshire cat

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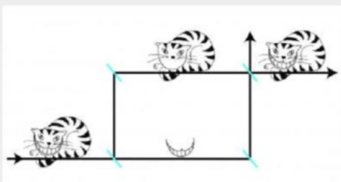
The Quantum Cheshire Cat: Scientists separate a particle from its properties

Posted July 30, 2014

Researchers from the Vienna University of Technology have performed the first separation of a particle from one of its properties. The study, carried out at the Institute Laue-Langevin (ILL) and published in Nature Communication, showed that in an interferometer a neutron's magnetic moment could be measured independently of the neutron itself, thereby marking the first experimental observation of a new quantum paradox known as the 'Cheshire Cat'.



This is a diagram of the Cheshire cat experiment. Credit: Vienna University of Technology

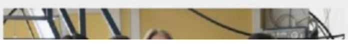
The new technique, which can be applied to any property of any quantum object, could be used to remove disturbance and improve the resolution of high precision measurements.

The idea of a Quantum Cheshire Cat was proposed theoretically last year. It is based on the well known character from Alice in Wonderland who can vanish leaving his smile behind. In quantum physics, the term refers to an object whose properties can be separated from its physical location so that the two can be measured at different places. While this is clearly not possible in our everyday experience, where objects are spatially linked to their properties, the laws of Quantum Mechanics allow it to be achieved.

Catching a quantum Cheshire Cat

Quantum mechanics already tells us that particles can be in different physical states at the same time, a phenomenon known as superposition. For example if a neutron beam is divided in two using a crystal, individual neutrons do not have to decide which of the two paths to take. Instead, they can travel along both paths at the same time in a quantum superposition.

"This experimental technique is called neutron interferometry", says Professor Yuji Hasegawa



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Scientists identified the molecular process that makes your armpits smell bad *(3 days ago)*

Why most cruise ships and luxury yachts are white, while container ships are all kinds of colours? *(3 days ago)*

SEAT is integrating Shazam into its cars and it is somehow related to safety

Cocktail Party Physics

Celebrating the Silly and the Sublime: the Best Physics Papers of 2014

It's tradition for various science media outlets to publish their lists of biggest scientific breakthroughs of the year right about now.

By Jennifer Ouellette on December 17, 2014

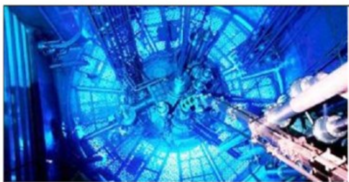
It's tradition for various science media outlets to publish their lists of biggest scientific breakthroughs of the year right about now. And no doubt those breakthroughs deserve the attention and acclaim. But let's face it, most scientific papers don't get lauded as major breakthroughs; science progresses incrementally. We at the cocktail party think such

LATEST NEWS

The Floor Is (Usually) Not Lava

The quantum Cheshire cat: Scientists separate a particle from its properties

Wed, 07/30/2014 - 4:56pm by ECN Staff



This is the core of High-Flux Reactor at the Institut Laue-Langevin (ILL) in Grenoble, where a unique kind of measuring station is operated by the Viennese team, supported by Hartmut Lemmel from ILL. Credit: The Institut Laue-Langevin

The Quantum Cheshire Cat: Can a particle be separated from its properties? On July 29, the prestigious journal, *Nature Communications*, published the results of the first Cheshire Cat experiment, separating a neutron from its magnetic field, conducted by Chapman University in Orange, CA, and Vienna University of Technology.

Chesire Cat"Well! I've often seen a cat without a grin," thought Alice in Wonderland, "but a grin without a cat! It's the most curious thing I ever saw in my life!" Alice's surprise stems from her experience that an object and its property cannot exist independently. It seems to be impossible to find a grin without a cat. However, the strange laws of quantum mechanics (the theory which governs the microscopic world of atoms; and the most successful theory in history) tell us that it is indeed possible to separate a particle from its properties—a phenomenon which is strikingly analogous to the Cheshire Cat story. The quantum Cheshire Cat is the latest example of how strange quantum mechanics becomes when viewed

Observer un « chat de Cheshire quantique » dans un interféromètre à neutrons

18 septembre 2014

LPTM - UMR 8089

En analysant les résultats d'une expérience d'interférométrie de neutrons, des physiciens ont pour la première fois mis en évidence un effet dénommé « chat de Cheshire quantique ». Dans le sous-ensemble des résultats sélectionnés selon le protocole dit « de mesure faible », tout se passe comme si les neutrons passaient par une voie de l'interféromètre tandis que leur moment magnétique passait par l'autre voie.

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Depuis que l'on sait que toute mesure quantique perturbe le système mesuré, les physiciens ont cherché à limiter les conséquences de cette limitation générale en imaginant des protocoles de mesure adaptés aux buts poursuivis : avoir une sensibilité optimale, éviter l'action retour, etc. L'un de ces formalismes, dénommé « mesure faible » consiste à effectuer une mesure habituelle en se restreignant à des états préparés dans un état initial choisi et finissant leur évolution dans un état final choisi lui aussi. Dans ce cadre, le physicien théoricien Yakir Aharonov avait entrevu la possibilité d'obtenir un « Chat du Cheshire quantique », c'est-à-dire un résultat de mesure pour lequel tout se passe comme si les propriétés physiques d'une particule étaient dissociées spatialement de cette dernière. C'est ce phénomène particulier que vient de mettre en évidence pour la première fois une collaboration austro-franco-américaine de physiciens issus du Laboratoire de Physique Théorique et Modélisation - LPTM (CNRS/Univ. Cergy-Pontoise), de la *Vienna University of Technology* et de la *Chapman University*, dans une expérience réalisée à l'ILL et menée dans le cadre du projet AMADEUS[1]. Ce travail est publié dans la revue *Nature Communications*.

Dans cette expérience, un faisceau de neutrons issu du réacteur de l'ILL est envoyé dans un interféromètre réalisé à partir d'un monocristal parfait de silicium et dont la géométrie est de type Mach-Zehnder. Dans ce dispositif interférométrique, les deux bras de l'interféromètre sont séparés l'un de l'autre de 4 cm, soit environ 1 million de fois la longueur de cohérence des neutrons, de sorte qu'il est possible d'agir et d'effectuer des mesures sur chacun des deux bras sans perturber l'autre. L'état initial préparé correspond à une superposition linéaire correspondant à l'équiprobabilité d'un passage dans les deux voies de l'interféromètre et pour laquelle le moment magnétique pointe vers le haut dans une voie (voir *I* dans la suite) et vers le bas dans l'autre (voie *II* dans la suite). En sortie, on quitte l'interféromètre par l'une des sorties (ce qui correspond dans l'interféromètre à une superposition moitié-moitié des deux voies) et un moment magnétique pointant vers le bas. On mesure tout d'abord la présence du neutron dans chacune des deux voies par une mesure d'absorption. Le résultat montre que le neutron est passé par la voie *II* (celle pour laquelle dans l'état initial le moment magnétique pointait vers le bas) et qu'il est absent de la voie *I* (celle pour laquelle dans l'état initial le moment magnétique pointait vers le haut). Dans une seconde mesure, on place successivement dans chacune des deux voies un champ magnétique faisant tourner le moment magnétique. Lorsque l'on place ce champ dans la voie *I*, on observe un effet sur le signal de sortie (le moment magnétique initialement vers le haut tournant, il acquière une composante vers le bas, et ainsi peut interférer avec la composante passée par l'autre voie). En revanche lorsque l'on place le champ magnétique dans la voie *II*, lorsque le moment magnétique acquiert une composante dirigée vers le haut, cette dernière est éliminée des mesures puisque l'on ne conserve en sortie que les neutrons pointant vers le bas. L'effet apparent est donc nul. Au final, les résultats de ce protocole de mesure ont l'apparence du « chat de Cheshire » sensible à l'absorption dans une seule voie de l'interféromètre et au champ magnétique dans l'autre voie.

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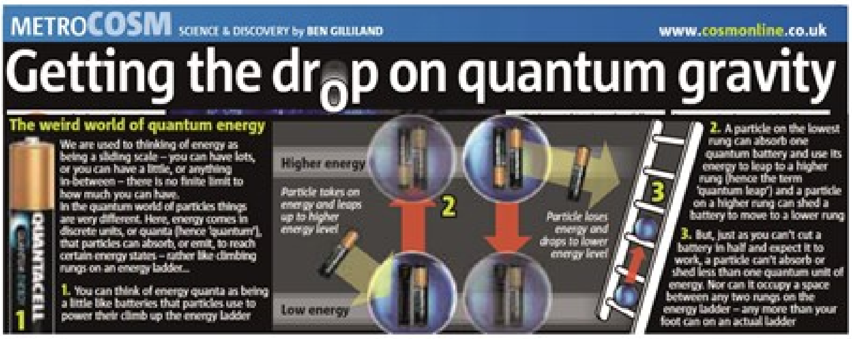
Gravitationsgesetz

Newton im Neutronen-Check



PHYSIQUE QUANTIQUE

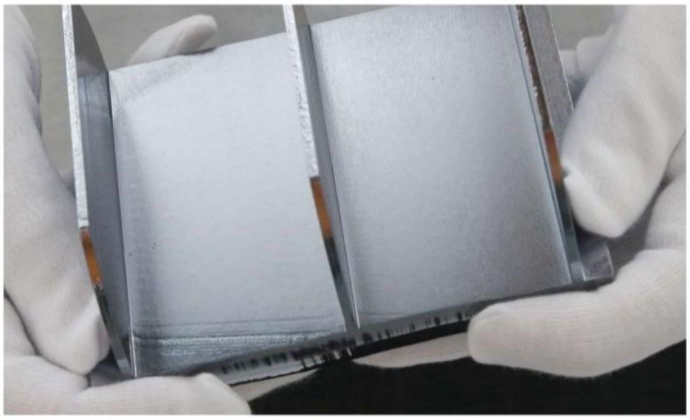
L'UBIQUITÉ DES NEUTRONS A ÉTÉ SAISIE SUR LE VIF

"J'ai souvent vu un chat sans sourire, pensa Alice. Mais un sourire sans chat ! C'est la chose la plus curieuse que j'ai jamais vue de ma vie !" Une équipe de physiciens vient de vivre la même expérience surréaliste que la célèbre héroïne de Lewis Carroll, à quelques détails près : au lieu d'un chat, les scientifiques ont regardé un neutron, et ils n'ont pas le moins du monde été surpris... puisque le curieux phénomène était très exactement prédit par les lois quantiques de l'infiniment petit. Exploitant le puissant faisceau de neutrons de l'Institut Laue-Langevin, à Grenoble, les chercheurs ont pu mesurer la présence d'un neutron à un endroit, et son spin, cette petite orientation magnétique portée par les particules, quatre centimètres plus loin. *"Cela montre une fois de plus que la théorie quantique n'est pas simplement un artefact mathématique, un outil efficace pour faire des calculs,* conclut Alexandre Matzkin, physicien au CNRS, qui a participé à l'étude. *Ça existe. Les particules se comportent réellement comme les équations le prédisent."* Les neutrons sont bel et bien capables de faire apparaître leur silhouette ici, et leur sourire là ... comme l'inquiétant chat du Cheshire. M.F.

C'est grâce à ce faisceau de neutrons que les physiciens ont observé le dédoublement d'une particule et de l'une de ses propriétés.

New method allows for quick, precise measurement of quantum states

January 12, 2017, Vienna University of Technology



Triple Laue (LLL) neutron interferometer. Credit: Vienna University of Technology

Nuclear spin tomography is an application in medicine. The patient absorbs and re-emits electromagnetic radiation in all directions, which is detected and reconstructed as 3-D images or 2-D slice images. In a fundamental science laboratory, quantum state tomography is the process of completely characterizing the quantum state of an object as it is emitted by its source, before a possible measurement or interaction with the environment takes place.

This technique has become an essential tool in the emerging field of quantum technologies. The theoretical framework of quantum state tomography dates back to the 1970s. Its experimental implementations are nowadays routinely carried out in a wide variety of quantum systems. The basic principle of quantum state

Experimental Demonstration of Direct Path State Characterization by strongly measuring Weak Values

Nuclear spin tomography or magnetic resonance tomography MRT (often also referred to as *magnetic resonance imaging MRI*) is a (human) medical application of *nuclear magnetic resonance NMR* most people known either from hospitals or medical drama television series. Here, the patient absorbs and re-emits electromagnetic radiation in all directions in space, that are later detected and from which 3D images (or 2D slice images) can be reconstructed. If we now switch from medical examination room to fundamental science laboratory, by replacing the patient by a *quantum object* and the electromagnetic radiation by a *quantum measurement*, we finally end up with a procedure referred *quantum state tomography* – the basic principle is quite similar.

Quantum state tomography (see here for details) is the process of reconstructing, or more precisely completely characterizing, the quantum state of an object which is emitted by a source. This technique has become an essential tool in the emerging field of quantum technologies, such as quantum communication or quantum computing. The theoretical framework of quantum state tomography dates back to the 1970s, and experimental implementations are nowadays routinely carried out in a wide variety of quantum systems. The basic principle of quantum state tomography is to repeatedly perform measurements from different spatial *direction* – on the quantum systems in order to uniquely identify the system's quantum state. Nevertheless, for quantum state tomography a lot of computational post-processing of the measured data is required to deduce the initial quantum state from the observed measurement results – all

Press review

Acoustic Rabi oscillations between gravitational quantum states and impact on symmetron dark energy
Gunther Cronenberg, Philippe Brax, Hanno Filter, Peter Geltenbort, Tobias Jenke, Guillaume Pignol, Mario Pitschmann, Martin Thalhammer & Hartmut Abele
https://www.nature.com/articles/s41567-018-0205-x

English

ILL, July 2018
No sign of symmetrons
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EurekAlert, 24.07.2018
No sign of symmetrons
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No sign of symmetrons yet, physicists report
https://phys.org/news/2018-07-symmetrons-physicists.html

Scitech Europa, 24th July 2018
Looking for symmetrons and dark matter
https://www.scitecheuropa.eu/symmetrons-dark-matter/88162/

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"Dark Energy's Known Unknown" -- Could It Be the Symmetron Field That Pervades Space Much Like the Higgs Field
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Think above sky, 24.07.2018
"Dark Energy's Known Unknown" — Could It Be the Symmetron Field That Pervades Space Much Like the Higgs Field
https://www.thinkabovesky.com/2018/dark-energys-known-unknown-could-it-be-the-symmetron field-that-pervades-space-much-like-the-higgs-field/

TodayChan, 24.07.2018
No signal of symmetrons but, physicists report
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German

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Keine Spur von Symmetronen
https://www.tuwien.ac.at/aktuelles/news_detail/article/126092/

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Doch keine fünfte Kraft: Die Dunkle Energie bleibt dunkel
https://diepresse.com/home/science/5469420/Doch-keine-fuenfte-Kraft_Die-Dunkle-Energie-bleibt-dunkel

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Wiener Physiker stellen Theorie zu Dunkler Energie in Frage
https://futurezone.at/science/experimente-von-wiener-physikern-schwaechen-theorie-ueber-dunkle-energie/400070450

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https://science.orf.at/stories/2926079/

ORF, 24.07.2018
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Theorie zu Dunkler Energie geschwächt
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Keine Spur von Symmetronen
http://www.oe-journal.at/index_up.htm?http://www.oe-journal.at/Aktuelles/!2018/0718/W4/52407tuWien.htm

Publication Statistics

The Table below lists the number of publications with Austrian authors based on research at ILL 1999 – 2017. The percentage of Austrian publications has always been at least twice as high as the financial contribution to ILL. In addition, the fraction of high impact publications among the Austrian publications is significantly higher than the ILL average. Finally, the numbers below taken from the ILL data base represent a lower limit to the actual number of Austrian publications since not all papers based on research done at ILL are in fact registered in the ILL data base.

Publication Date	Publications with ILL experiments	Austrian (+ILL Author)	Austrian (no ILL Author)	% of Austrian publications
1999	520	11	5	3%
2000	622	19	7	4%
2001	497	7	2	2%
2002	612	16	3	3%
2003	486	10	2	2%
2004	567	16	4	4%
2005	529	11	4	3%
2006	529	10	6	3%
2007	486	8	5	3%
2008	529	10	3	2%
2009	561	11	1	2%
2010	546	16	6	4%
2011	512	16	9	5%
2012	495	12	4	3%
2013	502	8	3	2%

2014	504	13	4	3%
2015	460	5	1	1%
2016	458	11	3	3%
2017	494	15	0	3%

ILL Publications 2013-2017

As already mentioned above, the following compilation is not exhaustive. Discrepancies arise, e.g., when follow-up publications based on earlier work at ILL are not recorded in the ILL data base due to neglect of the authors to register them. Nevertheless the list covers the vast majority of papers where explicit reference to work at ILL is made.

1. Ali T., Steiner S., Ritter C., Michor H.,
Neutron diffraction study of superconducting $La_3Ni_2{}^{11}B_2N_{3-\delta}$,
Journal of Alloys and Compounds **716**, 251-258 (2017).

2. Constable E., Raymond S., Petit S., Ressouche E., Bourdarot F., Debray J., Josse M., Fabelo O., Berger H., deBrion S., Simonet V.,
Magnetic and dielectric order in the kagomelike francisite $Cu_3Bi(SeO_3)_2O_2Cl$,
Physical Review B **96**, 014413-1-014413-12 (2017).

3. Denkmayr T., Geppert H., Lemmel H., Waegell M., Dressel J., Hasegawa Y., Sponar S.,
Experimental demonstration of direct path state characterization by strongly measuring weak values in a matter-wave interferometer,
Physical Review Letters **118**, 010402-1-01402-5 (2017).

4. Freeman P.G., Giblin S.R., Hradil K., Mole R.A., Cermak P., Prabhakaran D.,
Magnetic excitations of the charge stripe electrons below half doping in $La_{2-x}Sr_xNiO_4$ (x = 0.45, 0.4),
Physical Review B **95**, 064403-1-064403-6 (2017).

5. Golub M., Lehofer B., Martinez N., Ollivier J., Kohlbrecher J., Prassl R., Peters J.,
High hydrostatic pressure specifically affects molecular dynamics and shape of low-density lipoprotein particles,
Scientific Reports **7**, 46034-1-46034-11 (2017).

6. Guerrero C., Lerendegui-Marco J., Domingo-Pardo C., Casanovas A., Dressler R., Halfon S., Heinitz S.,

Kivel N., Köster U., Paul M., Quesada-Molina J.M., Schumann D., Tarifeno-Saldivia A., Tessler M., Weissman L., Aberle O., Andrzejewski J., Audouin L., Bacak M., Balibrea J., Barbagallo M., Becvar F., Berthoumieux E., Billowes J., Bosnar D., Brown A., Caamano M., Calvino F., Calviani M., Cano-Ott D., Cardella R., Cerutti F., Chen Y.H., Chiaveri E., Colonna N., Cortes G., Cortes-Giraldo M.A., Cosentino L., Damone L.A., Diakaki M., Dupont E., Duran I., Fernandez-Dominguez B., Ferrari A., Ferreira P., Finocchiaro P., Gobel K., Garcia A.R., Gawlik A., Gilardoni S., Glodariu T., Gonçalves I.F., González E., Griesmayer E., Gunsing F., Harada H., Heyse J., Jenkins D.G., Jericha E., Käppeler F., Kadi Y., Kalamara A., Kavrigin P., Kimura A., Kokkoris M., Krticka M., Kurtulgil D., Leal-Cidoncha E., Lederer C., Leeb H., Lo Meo S., Lonsdale S.J., Macina D., Marganiec J., Martinez T., Masi A.,

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Neutron Physics at the Atominstitut

2013 – 2017

Contents

1 Introduction

The Atominstitut (ATI) was established in 1958 as an inter-university institute, and in 1962 opened at its current location on the Prater with the commissioning of the TRIGA Mark II research reactor. As part of the reform of the university system, the ATI was integrated 2002 into the Faculty of Physics at the TU Wien and is now dedicated to today's broad range of research and education in the fields of atomic, nuclear, particle and reactor physics, environmental analysis and radiochemistry, radiation physics and radiation protection, as well as low-temperature physics, neutron physics, quantum physics and quantum optics. **The scientific work ranges from very fundamental questions about symmetries and interactions to applied tasks such as checking the radiation resistance of commercial resins for the construction of ITER**.

The ATI research activity falls into three 3 main research directions:

- Fundamental Interactions and Symmetries
- Quantum Science and Technologies
- Radiation Physics and its applications

It is planned that the institute of High energy physics (HEPHY) and the Stefan Meier Institut (SMI) of the Austrian Academy of Sciences will join forces and move into a new building to be completed at the premises of the ATI. It is then natural to integrate the particle physics activities (theory and experiment) of the ATI and TU-Wien with the OeAW institutions into a new research centre which will be structured in three scientific departments, reflecting the three research activities high energy physics, hadron physics and precision experiments..

Two-day Celebration of the 51st anniversary of TRIGA reactor Vienna, 7th March 2013

Fuelled by these prospects for the future, Atominstitut celebrated the 51st anniversary of the reactor with a two-day event on the 6th and 7th of March 2013, with a visit from Federal Minister of Science and Research, Prof. Karl-Heinz Töchterle. The anniversary celebrations were launched with a TU Forum event. At this tried and tested series of events the TU Wien addresses its social responsibility and deals with issues with a “technical background that polarise”. At the TU Forum “Forschung am

Praterreaktor" (Research at the Prater reactor) held on 6th March 2013 it provided an opportunity to learn more about the history of the reactor and the research currently being done at the ATI. The lecture theatre was packed. On the 7th of March this was followed by a scientific symposium, which was, in keeping with the number 51, dubbed the 50+ symposium. The keynote presentations were given by A. Borio (International Atomic Energy Agency (IAEA)) *TRIGA Research Reactors: Essential Tools for Nuclear Science Development and Nuclear Capacity Building,* W. Kutschera (Univ. of Vienna), *Radiation Physics - A Wide-Ranging Research Field*, D. Cardwell (Univ. of Cambridge), *Recent Developments in Bulk Superconductivity,* S. Werner (NIST), *Observation of Aharonov-Bohm Effects by Neutron Interferometry,* F. Thielemann (Univ. of Basel), *Formation of the Elements of the Universe*, W. Ertmer (QUEST, Univ. of Hannover), *Quantum and Atomic Optics: From Fundamentals to Applications.* The official opening in the evening started with a musical introduction and welcome address by the Director of the Institute, Prof. Schmiedmayer, Prof. Fröhlich, Vice-President for Research at the TU Wien, Prof. Badurek, Dean of Physics, Prof. Töchterle, Federal Minister for Science and Research, Prof. Van der Bellen, representing the city of Vienna, Deputy Director General Dr. A. Bychkov, IAEA, Dr. J.M. Crété, IAEA (Safeguards Training). Prof. Rauch and Prof. Schmiedmayer presented the history and highlights of the past 50+ years. The keynote lecture "das Neutron in der Wissenschaft" (The Neutron in Science) was given by Prof. Dubbers from Heidelberg, Doctor honoris causa of the TU Wien.

1.1 Exchange of the fuel elements

The replacement of the fuel elements has guarantee that it will still be possible to use the reactor for research and training in the fields of atomic, nuclear, particle and reactor physics, radiation physics and radiation protection, environmental analysis and radiochemistry as well as nuclear measurement technology and solid state physics in the future, too. The reactor is of particular importance to the International Atomic Energy Agency (IAEA). For instance, all of the IAEA's safeguard inspectors are trained at the TRIGA reactor.

The institute depends on access to major international research facilities such as C.E.R.N., the European Synchrotron Radiation Facility (ESRF) and the Institute Laue-Langevin (ILL), due to international research collaborations and integration into international research projects. Due to Austria's membership of the ILL, the institute is able to conduct experiments there, which are granted according to a competitive application procedure, and it operates the neutron interferometer S18 at the ILL as a permanent branch of the TRIGA reactor. The collaborations in the field of nuclear fusion (ITER, Fusion for Energy) are governed by way of the association with EURATOM.

Prof. Schmiedmayer, who chaired the gala evening, looks forward to the speech by Minister Töchterle

Musikalische Einleitung durch unsere ausgebildete Konzertpianistin und Dissertantin K. Buczak

Dekan G. Badurek führt den 4π - Krawattentrick vor

Bundesminister K. Töchterle, Vizerektor A. Prechtl,
Dekan G. Badurek

Van der Bellen, Frau Cortolezis-Schlager ÖVP-Wissenschaftssprecherin † , Bundesminister K. Töchterle

Van der Bellen, Beauftragter der Stadt Wien für Universitäten & Forschung

Familie Rauch im Gespräch

Festredner Prof. D. Dubbers im Gespräch mit Prof. H. Rauch und Prof. A. Zeilinger

2 Projects in Neutron Physics

Introduction

Neutrons are powerful tools for addressing questions from the domains of particle physics to computer tomography: Neutrons provide information on quarks and leptons, about nucleo synthesis in supernova explosions, as well as on combustion processes in engines or the structure of St. Stephen's Cathedral. A key domain of our group is neutron polarimetry and neutron optics, in particular interferometry with perfect crystals and the observation of interference effects between a neutron's spin up state and down state. Many neutron physics observables are sensitive to physics beyond the standard model emerging from superstrings, supersymmetry or other Grand Unified Theories. Neutrons test gravitation at small distances by quantum interference deep into the theoretically interesting regime. Priority Programme 1491, which is funded by the FWF and the German DFG and coordinated by the Atominstitut, has defined four main areas of emphasis, three of which the Atominstitut is also working on with its own projects. Ultra-small-angle neutron scattering measures density fluctuations on the micron scale. At low contrast this method is superior to other methods such as electron force microscopy.

The esfri_neutron_landscape_group-report[1] 2016 refers to this fundamental physics programme in the following way:

"As a probe, very slow neutrons are employed very effectively for fundamental physics studies: for example to sense the quantisation of the gravitational field, opening up possibilities to understand in detail the characteristics of the gravitational force, **inaccessible by other means**. It should be noted too that neutron beams are used to study the fundamental properties of the neutron itself – such as its lifetime as a free particle, … and the possible presence of a very weak

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[1] ESFRI Scripta Volume I

Neutron scattering facilities in Europe
Present status and future perspectives
ESFRI Physical Sciences and Engineering Strategy Working Group Neutron Landscape Group, Scientific editors: Colin Carlile and Caterina Petrillo, ISBN: 978-88-901562-5-0

electric dipole moment, all essential inputs to understanding the dynamics of the Big Bang and the evolving structure of the cosmos today. Neutron interferometry has convincingly demonstrated that all quantum effects exhibited by 'waves' and specifically light are also exhibited by 'particles' such as neutrons. This has been a spectacular success. Here the use of very slow neutrons - Ultra Cold Neutrons - which are produced predominantly at reactor sources, are essential. The information obtained has much wider implications for fundamental physics, touching, for example, on the validity of the Standard Model and complementing the work performed at high-energy physics laboratories such as CERN. "

The Quantum Bouncing Ball

Space, time and cosmology: delving deeper, with new resonance spectroscopy techniques

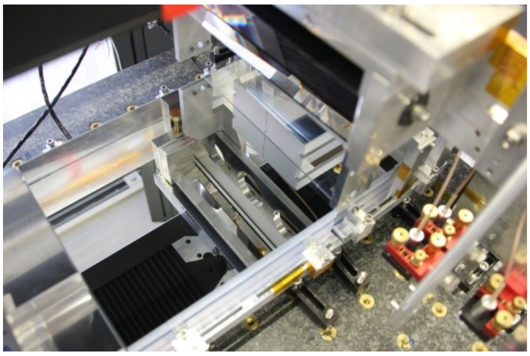
J. Bosina, G. Cronenberg, H. Filter, A.N. Ivanov, T. Jenke, T. Rechberger, M. Thalhammer & H. Abele

The qBounce project involves experiments with gravity using quantum interference techniques. The neutron as a quantum object has become a precision tools for measurements with the aim of investigating some of the pressing questions of space, time, and cosmology:

- what makes up "dark matter", that inexplicable form of matter which accounts for most of the mass in the universe,
- what is "dark energy", held to be responsible for accelerating the expansion of the universe.

Dark matter or dark energy particles interacting with ultra-cold neutrons would change the neutrons' quantum mechanical energy levels in the gravity field measured by the qBounce project. This would bring to light those particles of dark matter or dark energy. If such particles existed, they would not only shift existing gravitational energy levels but also, ultimately, force the entire universe apart. The qBounce project provides a completely new opportunity to confirm, or definitively refute, the existence of additional fields and forces similar to gravitation.

Gravity Resonance Spectroscopy



Neutron reflector used by *q*BOUNCE-experiment

The team at TU Vienna is working on an analysis of the Standard Model of particle physics and gravitation, with the neutron as object. We started with an analysis of the candidate particles capable of inducing deviations from Newton's inverse square law of gravity at short distances. Some of these, such as the so-called axion, are also dark matter candidates, whilst others, like the chameleon, might be responsible for the expansion of the universe. The experiment sets up a quantum system interacting with gravity – i.e. a neutron placed in the gravity potential of the earth, and a reflecting mirror. We used a resonance spectroscopy technique modelled on magnetic resonance spectroscopy and specifically developed for the purpose. The new technique, baptised "gravity resonance spectroscopy" allows theories of gravity at short distances to be tested. For this, however, we require an extremely intense flux of ultra-cold neutrons. The PF2 facility at the Institut Laue-Langevin (ILL) is unique in this respect. The experiment could not be performed anywhere else.

Results

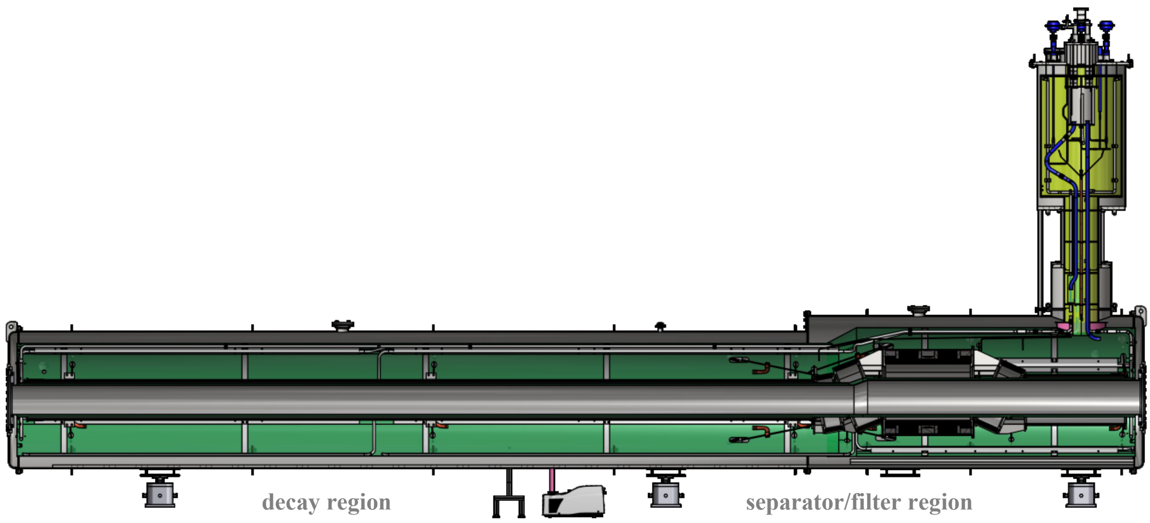
The project has developed and tested a new resonance spectroscopy technique free of any kind of electromagnetic side-effect. Whilst improving the sensitivity of the techniques now available, our precision experiments were able to exclude large fractions of the parameter space for dark matter and dark energy particles. As regards the theoretical basis of the work, the project has addressed aspects of gravitation which go far beyond the Einsteinian theory of gravitation[1,2]

[1] Gravity Resonance Spectroscopy Constrains Dark Energy and Dark Matter Scenarios, T. Jenke et al., PRL 112, 151105 (2014).
[2] *Neutrons constrain dark matter and dark energy scenarios*, T. Jenke et al., Scientific Highlights Article of the Annual Report 2014, Institute Laue-Langevin (2014).

On the way to precision spectroscopy of neutron beta decay on the 10^{-4} level

G. Badurek, J. Erhart, H. Fillunger, E. Jericha, M. Klopf, G. Konrad, W. Mach, R.K. Maix, D. Moser, H. Saul, X. Wang & H. Abele

The neutron and neutron beta decay provides particle physics at low energies and high precision. It advances our comprehension of the fundamental properties of nature[2] beyond the scope of our present understanding of the underlying symmetries and interactions. The neutron and quantum physics group is strongly involved in this endeavour both theoretically as well as experimentally[1]. The centre of activities is concentrated around the development of the *PERC* facility. Being part of an international collaboration, this facility is dedicated to the study of neutron beta decay with unprecedentedly high precision aiming at an accuracy level of 10^{-4} for all derived quantities[3]. The charged decay products of the neutron, the electron and the proton, will be guided and controlled by an elaborate magnet system, which is illustrated in the accompanying sketch. This system consists of 14 individual superconducting coils up to 8 m long and 6 T strong. The total length is 12 m and the instrument will be delivered in 2018. Together with its huge return yoke and a suite of dedicated spectrometres it will be set up at the *Mephisto* cold neutron beam line in the east hall of the FRM II reactor in Garching near Munich. A user instrument will be the NoMoS RxB spectrometer[4] built by G. Konrad and her group in the frame of an NFG-grant. Besides the improvement of the magnet system, our group has concentrated on several tasks with respect to PERC. A novel technique in temporal and spectral neutron beam tailoring was developed[5]. Conclusions have been drawn on the design of a low-background neutron beam stop to be placed in the separator and filter region.



[2] *Precision experiments with cold and ultra-cold neutrons*, H. Abele, Hyperfine Interact. 237 (2016) 155.
[3] *High Precision Experiments with Cold and Ultra-Cold Neutrons*, H. Abele et al., JPS Conf. Proc. 8 (2015) 026001.
[4] *R x B drift momentum spectrometer with high resolution*, X. Wang et al., Nucl. Instrum Methods A 701 (2013) 254.
[5] *Neutron detection in the frame of spatial magnetic spin resonance*, E. Jericha et al., Nucl. Instrum. Meth. A 845 (2017) 552.

PERC follows a set of dedicated instruments for the study of various aspects of neutron beta decay where our group has been involved in the PERKEO III and aSPECT[6,7] collaborations. In the framework of PERKEO III the decay parameter *C* was measured in 2014/15 and the analysis of *A* and *C* have been performed. The aSPECT collaboration measured parameter *a* in 2013. Results for all these quantities are expected early 2018 and hint at accuracies in the range of 10^{-3} to 10^{-2}. Regarding the future of PERC related activities, they may well lie in the context of he European Spallation Source ESS, which offers particularly favourable conditions owing to the pulsed time structure of its neutron beams[8].

[6] *The magnetic shielding for the neutron decay spectrometer aSPECT*, G. Konrad et al., Nucl. Instrum. Meth. A 767 (2014) 475.
[7] *Measurement of the electron-antineutrino angular correlation coefficient,* R. Maisonobe et al., PoS EPS-HEP2015 (2015) 595.
[8] *Beam line parameters for PERC at ESS*, C. Klauser, H. Abele, T. Soldner, Phys. Proc. 51 (2014) 46.

Theory

H. Abele, A.N. Ivanov, R. Höllwieser, M. Pitschmann, M. Wellenzohn

A main focus of research of the theory members of the neutron physics group has been the search for dark matter (Axions) and dark energy (Quintessence) with the qBounce experiment.

Dark matter has been postulated in order to provide additional gravitational attraction, which is necessary to keep galaxies together. A leading candidate of dark matter is the Axion, which has originally been devised to solve the strong CP problem. If it exists, the Axion - or a similar scalar particle - would lead to a force on the neutron sourced by the mirror of the qBounce setup. We have derived new EDM constraints on such forces and compared these constraints to those derived from direct searches in fifth-force experiments, as in the qBounce experiment. Surprisingly, we found that for a generic light scalar, unrelated to the strong CP problem, present bounds from direct fifth-force searches are more stringent than those inferred from EDM limits for interaction ranges near the Axion window[1].

Another "dark" ingredient of our universe, dark energy, has been postulated in order to account for the observed acceleration of our universe. Several hypothetical "screening mechanisms" have been devised to prevent them from being ruled out by the stringent solar system tests. For experimental detection, it is necessary to know the corresponding field profiles for the qBounce setup. Therefore, we have derived the field profile for the chameleon field confined between two parallel plates and filled with air at pressure $P = 10^{-4}$ mbar at room temperature with a typical Ratra-Peebles self-interaction potential with index $n = 1$.[2] Furthermore, we have analyzed the non-relativistic approximation of the Dirac equation for neutrons moving in space-times with a static metric, viz. moving in the weak gravitational field of the Earth and such a hypothetical chameleon field. The corresponding effective potential has been derived and the chameleon field as a possible source of a torsion field has been discussed.[3] Furthermore, we have analyzed the Dirac equation for neutrons within linearized massive gravity. The obtained results can be used in terrestrial laboratories for the detection of gravitational waves and fluxes of massive gravitons emitted by cosmological objects. The neutron spin precession within linearized massive gravity has been calculated, which - in principle - can be measured by neutron interferometers. A further topic of investigation concerns the precision analysis of neutron β-decays. We have revisited the bound state β-decay of the free neutron into hydrogen. Radiative corrections have been taken into account for the calculation of the branching

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[1] *Distinguishing axions from generic light scalars using electric dipole moment and fifth-force experiment*, S. Mantry et al., Phys. Rev. D **90** (2014) no. 5, 054016.

[2] *Exact solution for chameleon field, self-coupled through the Ratra-Peebles potential with n=1 and confined between two parallel plates*, A.N. Ivanov et al., Phys. Rev. D **94** (2016) no. 8, 085005.

[3] *Nonrelativistic approximation of the Dirac equation for slow fermions in static metric spacetimes*, A.N. Ivanov et al., Phys. Rev. D **90** (2014) no. 4, 045040.

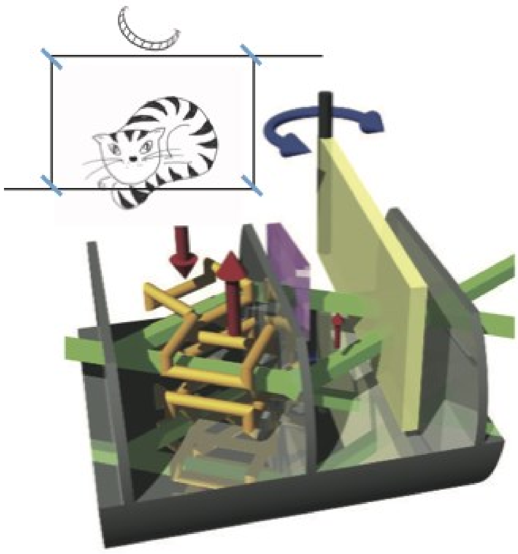
ratio. Furthermore, the dependence of the probabilities of decay on hadronic phenomenological coupling constants, describing the most general effective weak lepton-nucleon interactions, have been analyzed. Our results imply that the bound state beta-decay is ruled out as a suitable laboratory for searches of electroweak models with left-right symmetries, contradicting previous claims in the literature.[4]

[4] *Bound-state β^--decay of the neutron re-examined*, A.N. Ivanov et al., Phys. Rev. C **89** (2014) no. 5, 055502.

Fundamental Tests of Quantum Mechanics with Neutrons

B. Demirel, T. Denkmayr, H. Geppert-Kleinrath, H. Abele, T. Jenke, H. Lemmel, S. Sponar, H. Rauch, and Y. Hasegawa

Neutron interferometry, where an interference effect of matter waves passing through a perfect silicon-crystal interferometer is observed, is one of the most fruitful approaches to study the foundations of quantum mechanics. Utilizing neutron interferometry, a phenomenon - which seems absurd at the first sight - namely the so-called *quantum Cheshire Cat*, was studied in a recent experiment[1]. The experiment was performed at the Institut Laue Langevin (ILL), in Grenoble, France. The principle is illustrated aside (top): the cat itself is located in one beam path, while its grin is located in the other. In our realization of the quantum Cheshire Cat, the neutron plays the role of the cat, while the cat's grin is embodied by the neutron's spin. The actual experimental confirmation makes use of a novel concept referred to as "*weak measurements*", which was introduced by Yakir Aharonov in 1988.



(top) scheme, (bottom) interferometric setup

Our neutron interferometric confirmation of the emergence of the quantum Cheshire Cat is depicted beside (bottom)[2]. The system is initially prepared in such a way that after entering the beam splitter its quantum state is given by a maximally entangled *Bell-state*. To determine the neutrons' *population* in the respective interferometer's paths, a weak absorber of known transmissivity is inserted, revealing the neutron's presence in the *upper* path. Next weak measurements of the neutrons' *spin component* in each path are performed by applying an additional weak magnetic field in one or the other beam path. This field should cause spinor rotations, if the neutrons' magnetic moment is present in the respective path: this allows probing the presence of the spin. The small magnetic field leads to emergence of interference fringes in the *lower* path, whereas no significant change in the intensity modulation is observed in the *upper* path; demonstrating a *property* of a quantum system can behave as being *spatially separated* from the place of the *particle's presence*. In a different neutron interferometric experiment phase shifts associated with a coupling to scalar fields, more precisely to dark energy chameleon fields, were investigated[3]. The obtained results set new limits on the coupling

[1] Observation of a quantum Cheshire Cat in a matter-wave interferometer experiment, T. Denkmayr et al., *Nature Communications* **5**, (2014) 4492.
[2] Weak values obtained in matter-wave interferometry, S. Sponar et al., *Physical Review A* **92** (2015) 062121.
[3] Neutron interferometry constrains dark energy chameleon fields, H. Lemmel et al., Phys. Lett. B **743** (2015) 310.

constant, which are a factor of 30 below the previous ones by gravity spectroscopy. *Neutron polarimetry has been used to test various types of error-disturbance uncertainty* relations over the last few years. Recently, an *information-theoretical* or *entropic* approach of a *tight* error-disturbance uncertainty relation, where error and disturbance are defined via correlations between input states and measurement outcomes[4], as well as a new tight relation for *mixed spin ensembles*[5], were demonstrated successfully at the 250 kW TRIGA reactor installed at the Atominstitut in Vienna.

[4] Experimental test of entropic noise-disturbance uncertainty relations for spin−1/2 measurements, *G. Sulyok et al.*, *Physical Review Letters* **115**, (2015) 030401.

[5] Experimental Test of Residual Error-Disturbance Uncertainty Relations for Mixed Spin-1⁄2 States, B. Demirel et al., *Physical Review Letters* **117** (2016) 140402.

A new large-area neutron interferometer

T. Potocar, H. Abele, T. Jenke, M. Zawisky

In order to maximize the interferometers' angular and gravitational sensitivity a new large-area perfect crystal interferometer has been prepared (Fig. 1). Its outstanding features are summarized in the table below. As a speciality of the new interferometer type the middle plates (3,4) are much thicker than the other plates for exhausting the angular sensitivity.

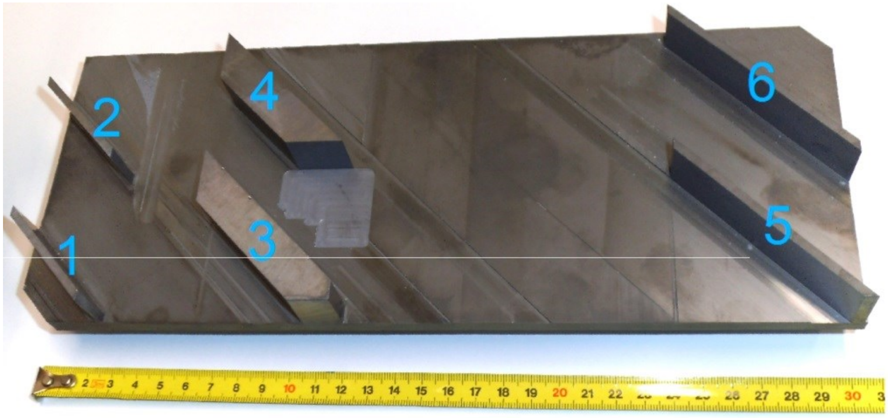


Fig. 1 The new large-area neutron interferometer

Ingot diameter	15.4 cm
Ingot orientation	(100)
Interferometer length	30 cm
Path lengths of the beams inside the interferometer	30 cm
Separation of beams 1-5 / 2-6	6 cm
Enclosed beam areas: Loop 1-2-3-4	50 cm^2
Loop 3-4-5-6	100 cm^2
Loop 1-2-5-6	150 cm^2
Overall geometric perfection	$\approx 2\ \mu m$
Surface normal to lattice planes deviation	53 ± 1 sec of arc
Lamella thickness: 1, 2, 5, 6	2.986 mm
3, 4	14.997 mm

Etching depth	25.4 μm
Surface roughness	< 1 μm

In a first run at the ILL-S18 the visibility of interference fringes has been proven, but the setup yet has to be adapted to large-area interferometers[1].

Another large neutron interferometer has been employed for the systematic investigation of the diffraction phases induced by Laue transmission[2] and the search for the hypothetic chameleon fields[3].

[1] Large Crystal Neutron Interferometer Measurements, T. Potocar, PhD-thesis, TU-Vienna, April 2016
[2] Neutron interferometric measurement and calculations of a phase shift induced by Laue transmission, T. Potocar, M. Zawisky, H. Lemmel, J. Springer, M. Suda, Acta Cryst. A **71** (2015) 534-541
[3] Neutron interferometry constrains dark energy chameleon fields, H. Lemmel et al., Phys. Lett. B **743** (2015) 310

DFG/FWF Priority Programme 1491

"Precision Experiments in Particle and Astrophysics with Cold and Ultracold Neutrons" 2010 – 2018

First programme phase in cooperation with FWF

The aim of this priority programme is to address basic open questions in particle and astrophysics using a specific tool: the neutron, which allows the search for new physics becoming manifest itself as small deviations from expectations. Many neutron physics observables are sensitive to physics beyond the Standard Model emerging from superstrings (hypothetical gauge bosons in large extradimensions), supersymmetry (electric dipole moment prediction at the experimental limit) or other Grand Unified Theories (charge quantization). Basic properties of the quark-mixing Cabibbo-Kobayashi-Maskawa (CKM) matrix need to be tested. The breaking of symmetries such as parity P, time reversal T and combined charge conjugation and parity symmetry CP shall be investigated. CP violation is a requirement for dynamic generation of the baryon-antibaryon asymmetry of the universe. The research program will focus on five *Priority Areas*, which are directly related to specific physics/astrophysics issues and instrumentation.

- *CP-symmetry violation and particle physics in the early universe.* The focus is a next generation experiment to measure the neutron electric dipole moment with a sensitivity increased by at least one order of magnitude within the next six years.
- *The structure and nature of weak interaction and possible extensions of the Standard Model.* The focus will be on novel experiments on neutron β-decay related to symmetries and weak interaction.
- *Tests of gravitation with quantum objects.* The aim is to improve the experimental sensitivity of neutrons to gravity and to hypothetical short ranged forces.
- *Charge quantization and the electric neutrality of the neutron.* The aim is to make an improved measurement on the value of the neutron’s electric charge.

The intended gain in experimental precision requires *the development of new or improved measurement* techniques.

- *New techniques: particle detection, magnetometry and neutron optics.* Within the next three years, in the field of magnetometry, residual fields should be measured on a < 5 fT level meeting the requirements of neutron electric dipole measurements. New particle detectors are needed for the expected high count rate of cold and ultra-cold neutrons, efficient low-energy proton counting as well as low-energy electron spectroscopy. High-intensity experiments with instant count rates of up to 10^8/s require detectors with fast self triggering readout electronics, pulse-shape analysis, and data acquisition. The research programme requires developments of specialized neutron optics. One major issue is the control of systematic effects such as depolarization in neutron guides, the influence of magnetic field fluctuations on neutron polarization, and spin rotation.

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TRIGA reactor

The new I&C system of the TRIGA MARK II reactor Vienna

Staff: *M. Villa, R. Bergmann, H. Böck*

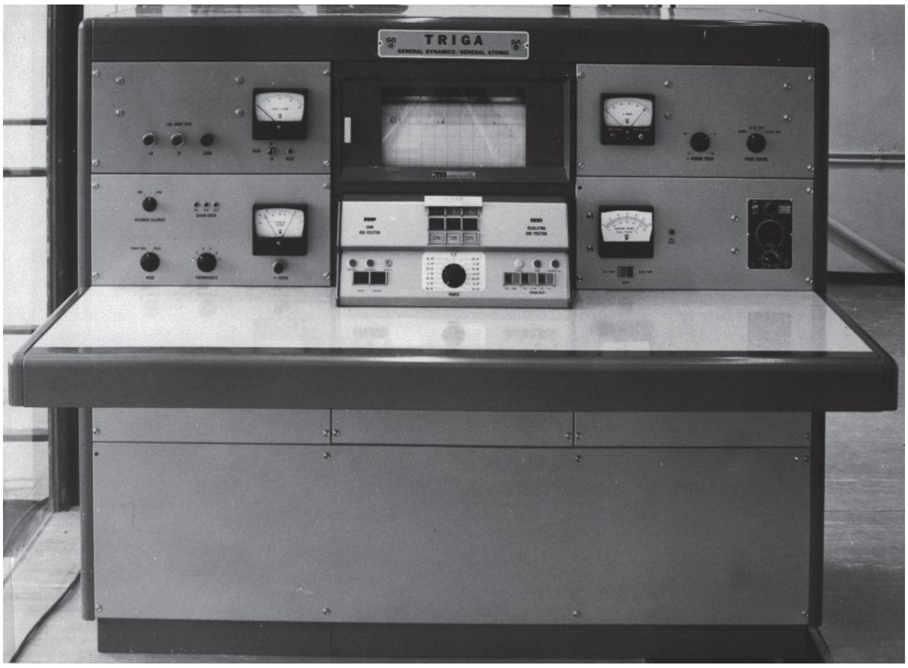
People involved in the project: *H. Böck, R. Bergmann, A. Musilek, J. Sterba, and M. Villa*

Introduction

The TRIGA Mark-II reactor was installed by General Atomic (San Diego, California, U.S.A.) in the years 1959 through 1962, and went into operation for the first time on March 7, 1962. The TRIGA Mark II reactor in the Viennese Prater is part of the Atominstitut which was founded in 1958 as an inter-university institute for all Austrian universities and started operation in 1962, when the TRIGA Mark II research reactor of the institute was officially opened. As part of the reform of the university system, the Atominstitut was integrated 2002 into the Faculty of Physics at the TU Wien. The operation of the reactor since 1962 has averaged 220 days per year, without any long outages. During the last 50 years 3 different **Instrumentation & Control (I&C)** systems were in use to control the reactor power and safety related parameters. In 2012 the TU Wien decided to replace the existing 20 years old I&C system and started an open call for tender. From 3 different vendors, Skoda, Invap and GA, the Skoda Company located in Pilsen was chosen in November 2013. The main work is done together with the subcontractor dataPartner.

HISTORICAL BACKGROUND

The TRIGA Mark II research reactor of the TU Wien is in operation since the 7th March 1962. When TRIGA reactors were developed in the mid-fifties, the typical state of the art of I&C systems was based on vacuum tubes. At the Atominstitut this type of I&C systems produced by the company General Atomic (GA) was in use until 1968.

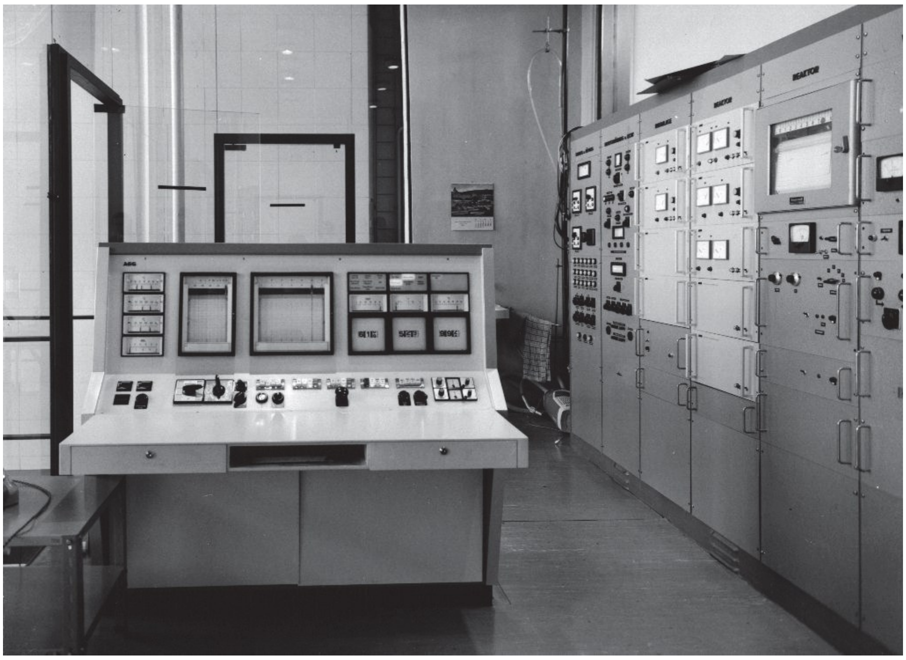


Original Electronic Tube Type Reactor Instrumentation 1962 to 1968

Towards the end of the sixties transistors replaced electronic tubes also in I&C systems, and a new type of TRIGA instrumentation based entirely on transistors were marketed. Therefore, during the seventies many TRIGA reactors converted to such types of I&C systems which in a few cases are still in use. At the Atominstitut this replacement took place in 1968. This type of reactor instrumentation produced by the company AEG was easy to maintain and spare parts could easily be replaced for about 20 years until they slowly disappeared form the market.

As a result, a new type of digital and modern software based I&C systems were developed and are available from the early nineties onward. As software based I&C systems were usually not accepted by the regulatory authorities, a hard-wired back up system for safety related parameters were required and, therefore, a combination of both was the state-of-the-art I&C system in most of TRIGAs world-wide for long time. In 1992 the old transistor based I&C system was replaced by a new digital software based I&C system produced by the company GA.

Nowadays, after use for more than 20 years of software/hardwired digital I&C systems various components of those have again reached their end of life-time. Therefore, the University decided the fourth time to replace the old I&C system by a new one. These new generation 4-digital I&C systems are capable to monitor and control variables and parameters of physical and other processes, component and system statuses, as well as to react on predefined project limits and safety conditions.



Transistorized Reactor Instrumentation 1968 to 1991

Digital Reactor Instrumentation 1992

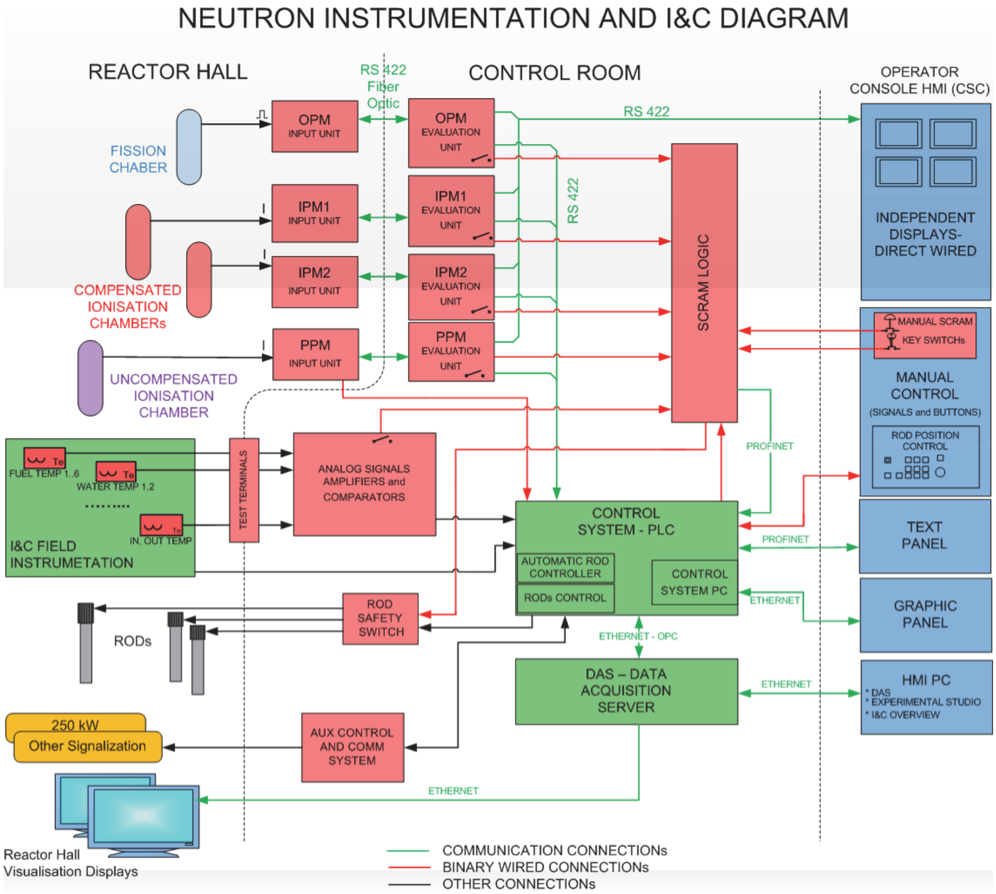
SYSTEM ARCHITECTURE

Generally, system and equipment architecture follows the existing concepts. The whole system consists of SCRAM logic, neutron flux measurement channels (OPM - Operational Power Measurement, IPM – Independent Power Measurement, and PPM - Pulse Power Measurement), I&C field instrumentation, control system, new operator's console and data acquisition system.

Neutron Detectors

The following three different types of detectors for neutron flux measurements are used on the TRIGA® reactor:

- 1 pc of fission wide-range chamber for neutron flux measurements and for reactor control from source range (about 5 mW) to nominal power (250 kW). It works in Campbell mode – Photonis type CFUL08.
- 2 pcs of compensated ionization chamber for reactor control and especially for safety functions from source range to nominal power – Centronic type RC6
- 1 pc of non-compensated ionization chamber for measurements in pulse mode (peak till 250 MW, energy till 12 MWs. It measures amplitude, length and shape of pulse.) – Centronic type RC7.



Instrumentation & Control Overview Diagram

Neutron Flux Measurement Channels

- 1 pc wide-range operational channel – Operational Power Measurement (OPM)
- 2 pcs wide-range safety channels – Independent Power Measurement (IPM)
- 1 pc wide-range pulsing channel – Pulse Power Measurement (PPM)

Signals read from chambers are directly numerically processed to reactor power value and reactor power change rate – period in wide-range channels. The power value is converted to common units and can be expressed in %, cps, A or W. Actual values are updated every 100 ms and are sent via optical serial line to an independent display and via second optical interface to a control system. These channels open Safety Relay contacts in the Scram Logic loop if measured values exceed the preset protection set points or in the case of any system internal failure is indicated. All channels consist of the two following units:

- Input unit for processing neutron chamber signal and converting the analog signal into digital domain for transmission to the evaluation unit.
- Evaluation unit for comparison of the neutron flux measured values against the safety system set points.

The hardware platform is based on Texas Instruments Hercules safety microcontrollers. These microcontrollers are based on ARM Cortex-R dual-lockstep IP cores and are designed specifically for IEC 61508 safety critical applications.

The software is developed in C programming language using Texas Instruments ARM compiler and tools. The software development respects recommended practices and guidelines, e.g. MISRA standard or NUREG CR-6463 guidelines.

Channels are equipped with test signal generators, which allow auto diagnostics and safety function check every time before the reactor is started up.

Scram System

The TRIGA type reactor is the only nuclear reactor in this category with worldwide excellent safety record of over 50 years due to inherent features such as the intrinsic characteristic of the standard reactor U-Zr-H fuel. It results in safe and reliable self-shutdown while the temperature coefficient acts independently of any external controls in the event of an accidental reactivity insertion. That offers true "inherent safety", rather than relying on "engineered safety" features. Nevertheless, the new I&C System provides additional external means to assure that the TRIGA reactor safely shuts down in unexpected power or temperature deviations.

Scram Logic Circuit

The entire SCRAM circuitry is hardwired and is not affected by any software based systems or the Control or Data acquisition system.

Automatic SCRAM logic is implemented on relay logic, consisting of certified safety relays. The design allows for 100% testability features and accurate analysis of the safety function reliability. The safety relays are capable to perform self-diagnosis. Power relays are continuously diagnosed at every contact switching. Diagnosis is mainly focused on sticking relay control (checks and evaluates the time till contacts open). The diagnosis consists of two redundant computation branches. If at least one of the branches evaluates the safety condition failure, it opens the output contactor contacts (reactor trip).

Output contactors disconnect power to magnets and pneumatic valve resulting in drop of control rods (reactor trip).

Specifically SCRAM Logic boards use:

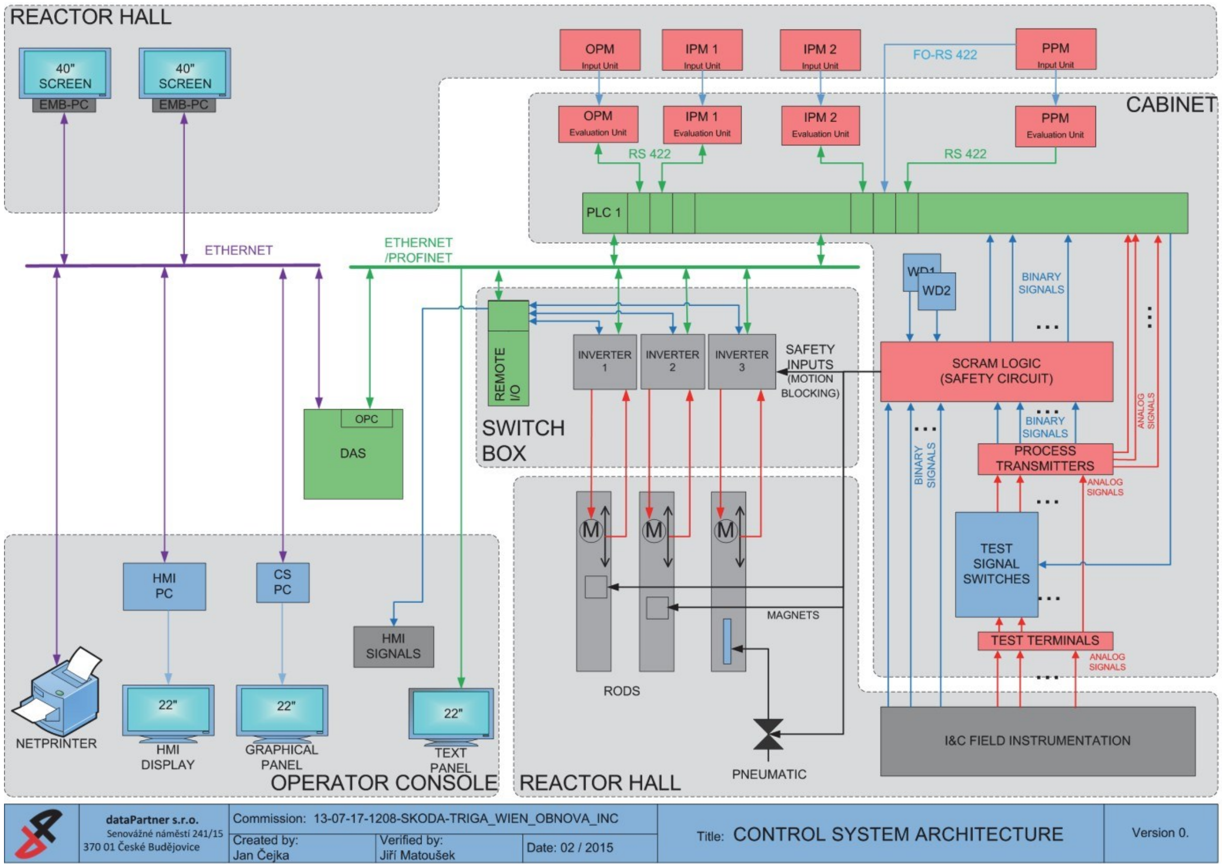
- Safety category relays. These are compact, slim relays conforming to:
    - EN Standards (EN50205 Class A, certified by VDE),
    - EN61810-1 (Electromechanical non-specified time all-or-nothing relays)
    - UL standard UL508 Industrial Control Device,
    - CSA standard CSA C22.2 No. 14 Industrial Control Devices

Reactor Control System

The Reactor Control System (RCS) is a modular distributed control system with Programmable Logic controllers **(PLCs)** in different locations. The fast industrial bus Profinet facilitates interfaces among the PLCs, displays, inverters, and other components. Profinet commands can implement requested rod position including maximum rod motion speed. RCS has the capability to self-diagnose status and failures of inverters and motors. The Siemens Simatic S7 PLC system, a widely used industrial control system in Europe, was selected for TRIGA reactor control.

Reactor Control System States

At any moment the reactor control system is in one of four possible states: *Standby*, *Shutdown*, *Pre-start Checks* and *Operation.*



Control System Architecture

Reactor Operation Modes

Manual Mode

In the Manual operation mode, the operator controls the drives manually, thus an operator manually controls the power output of the reactor without active automatic intervention of the control system (as long as the reactor power stays below the maximum pre-set levels).

Auto Mode

The reactor control system, when placed in Auto operation mode, will automatically control the position of the regulating rod or the safety rod or any combination of the two to maintain a specific power level. The remaining rods including the transient rod are under manual control.

The Pulse operation mode allows the reactor to produce a very high power, short duration pulse. This pulse effect is accomplished by firing the transient rod upward with compressed air.

The new I&C system of the TRIGA Mark II Reactor Vienna, November 2015

For storing all measured and computed variables at the operator console, a dedicated data acquisition and logging system (**DAS**) is used. DAS is based on industrial PC architecture; the data is stored on hard discs. It gathers data from the control system and stores it to the database for later recall, analysis or playback.

Safety Systems Qualification

All I&C structures and components are designed so that they can perform reliably their functions under the environmental conditions they will be submitted to during their mission time. The operability of I&C structures and components under the related environmental conditions was demonstrated by tests, analysis, operation experience, etc. The supplier's qualification procedures are established to confirm that the equipment is capable to meet the requirements for performing safety functions while subjected to environmental conditions existing prior to and at the time when it is required throughout operational life.

Qualification includes the following:

- Functional Tests
- Electro Magnetic Compatibility **(EMC)** Tests
- Accelerated Ageing Tests
- Seismic Tests

Seismicity

The equipment is designed, manufactured, and tested on the basis of the general dataPartner qualification procedures for seismic resistance which should also be valid for the actual realization site per Reference (IEC 980:1993, Recommended Practices for Seismic Qualification of Electrical Equipment of the Safety System for Generating Stations). The tests have been performed according to IEC 980: 1993 with acceptable results. The applied test earthquake intensity exceeds required seismicity criteria in the document ATIB1010 Sicherheitsbericht 2013**.**

Equipment Lifespan

The reactor site integrated radiation dose is so low that it does not significantly impact ageing of the equipment outside of the reactor, thus neutron flux measurement modules and SCRAM relays are tested for at least 15 years qualified lifetime by accelerated ageing methodology.

Software(SW)qualification

The system SW is developed and tested by standards, methodology, and QA procedures required by the Czech State Authority for a 10 MW research reactor LVR-15 in the Czech Republic. Safety System SW development follows Reference (IEC 60880, 2006: Nuclear Power Plants – Instrumentation and Control Important to Safety – Software aspect for computer-based systems performing category A functions). Including Graded Approach. Safety Related System SW development follows Reference (IEC 62138, 2004: Nuclear Power Plants – Instrumentation and Control important to Safety – Software aspect for computer-based systems performing category B or C functions) as it is documented accordingly.

Preise und Auszeichnungen

Prof. Dr. H. Rauch 2015 Walter Hälg Prize by the European Neutron Scattering Association

G. Konrad New Frontiers Research Groups Programme: NoMoS:*Beyond the Standard model Physics in Neutron Decay* the Austrian Academy of Sciences

Y. Hasegawa: Special Prize of Nagase Prize 2013 (Frontier science salon in Japan)

Gastvortragende

- **Camille Theroine** - European Spallation Source ESS -*Status of Fundamental Physics @ ESS* 5. Dezember 2014**Paule. J. Finlay** – KU Leuven – *Improving CKM Unitarity Limits via Low Energy Nuclear Physics* - 9. Jänner 2015
- **Ferenc Glück** - KIT – Karlsruher Institut für Technologie - *Direct neutrino mass measurement with KATRIN experiment* - 22. Jänner 2015
- **Martín González-Alonso** – Lyon Institut of Origins – *Precision measuremnts in beta decays at the LHC era* - 23. Jänner 2015
- **Florian M. Piegsa** – ETH Zürich – *Prospects for a new Neutron Electric Dipole Mement Search using a Pulsed Beam* - 17. April 2015
- **Heinz Pernegger** – Cern – *Development of state-of-the art pixel detectors for LHC and beyond* - 24. April 2015
- **Juri Schroffenegger** -Technische Universität München – *Interaction of ultra-cold neutrons with absorbing materials* - 20. November 2015
- **William Terrano** – University of Washington – *Exploring new Physics with Torsion Pendula* - 29. Jänner 2016
- **Giuseppe Vallone** - University of Padua – *Direct Measurement of Quantum Wave Function by Strong interaction* - 10. Juni 2016
- **Mike Snow** - Indiana University, Bloomington – *Searches for Exotic Interactions Unsing Slow Neutrons* - 11. Juli 2016
- **Rene Sedmik**- Universiteit Amsterdam – *Vaccum engergy on the tabletop: A START Proposal* - 9. September 2016
- **Dimitry Budker** – Johannes Gutenberg Universität – University of California at Berkeley - *Precession In the Dark: the CASPEr and GNOME experiments* - 4. November 2016
- **Michael Jentschel** – ILL – *How heavy are gamma rays?* - 19. Mai 2017
- **Ulli Köster** – ILL – *Radionuclides for medical applications and fundamental research* - 23. Juni 2017

- **Giovanni Manfredi** - Institut de Physique et Chimie des Matériaux de Strasbourg – *Probing gravity with neutrons and antimatter* - 3. März 2017
- **Sándor Varró** - Wigner Research Centre for Physics Budapest – ELI Szeged – *The 112 years of the photon From Einstein's light quanta and stimulated emission to etreme light* - 24. März 2017
- **Albert Young** - North Carolina State University - *Overview of beta decay research at the LANL UCN facility and the Triangle Universities Laboratory* - 7. September 2017
- **Emanuele Strano** - Laboratori Nazionali di Legnaro – *Present and future studies with the EXOTIC facility* - 27. Oktober 2017

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- The n_TOF Collaboration, CERN, Généve, Schweiz
- Maelle Kerveno, Gérard Rudolf, Jean-Claude Thiry, Université de Strasbourg & CNRS, Strasbourg, Frankreich
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Initiative for Neutron Scattering and Muon Spectroscopy, a collaboration of FZJ Forschungszentrum Jülich, Technical University München, Delft University of Technology, Laboratoire Léon Brillouin Saclay, Vienna University of Technology, St. Petersburg Nuclear Physics Institute & Technical University of Denmark

- Wim Bouwman, Jeroen Plomp, Ad van Well, Delft University of Technology, Delft, Niederlande
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- Burkhard Schillinger, Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II), Garching/München, Deutschland
- Ralf Schweins, Peter Lindner, Institut Laue-Langevin (ILL), Grenoble, Frankreich
- Schwerpunktprogramm 1491 des FWF und der deutschen DFG zusammen mit den
- Universitäten Heidelberg, Mainz, Jena, TU München, sowie FRM2, ILL, TU Wien
- *IAEA*
- *Eastern European Research Reactor Initiative (EERRI)*
- *Pablo Adelfang, Division of Nuclear Fuel Cycle and Waste Technology*
- *Danas Ridikas, Division of Physical and Chemical Sciences*
- *Günter Hillebrand, Nuclear Engineering Seibersdorf*
- *The Comprehensive Nuclear-Test-Ban Treaty - CTBTO*
- *Michel Giot, Studiecentrum voor Kernenergie – Centre d'Etude de l'Energie Nucléaire*
- *Areva Deutschland, Erlangen*
- *Joint Research Center / Institut for TransUranium elements (ITU), JRC*
- *Joint Research Center / Ispra, Decommissioning and Waste Management, JRC*
- *Karlsruhe University*
- *Gabriele Hampel, Johannes Gutenberg Universität Mainz, Institut für Kernchemie*
- *Iro Auterinen, Valtion teknillinen tutkimuskeskus / Technical Research Center (VTT)*
- *Gilles Bignan, Commissariat à l'Energie Atomique (CEA), Cadarache*

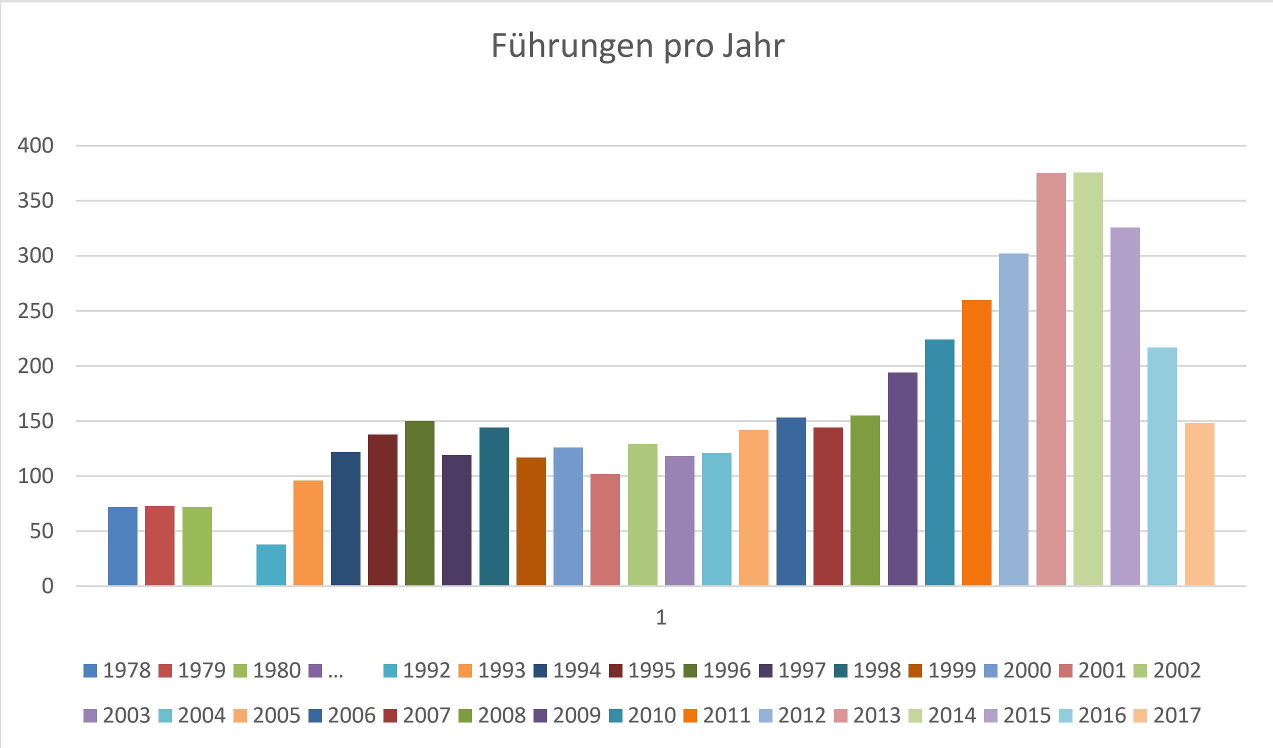
- *Andrea Borio di Tigliole, Nuclear Research Centre of the University of Pavia “Laboratorio Energia Nucleare Applicata” – LENA*
- *Johannes Hammer, ENSI Eidgenössisches Nuklearsicherheitsinspektorat*
- *Forschungsreaktor Universität Basel*
- *Luka Snoj, Jožef Stefan Institute*
- *John Billows, The Dalton Institute, University of Manchester*
- *Mitglied der deutschsprachigen Arbeitsgemeinschaft für Forschungsreaktorn (AFR)*
- *Mitglied der europäischen Research Reactor Operators Group (RROG).*

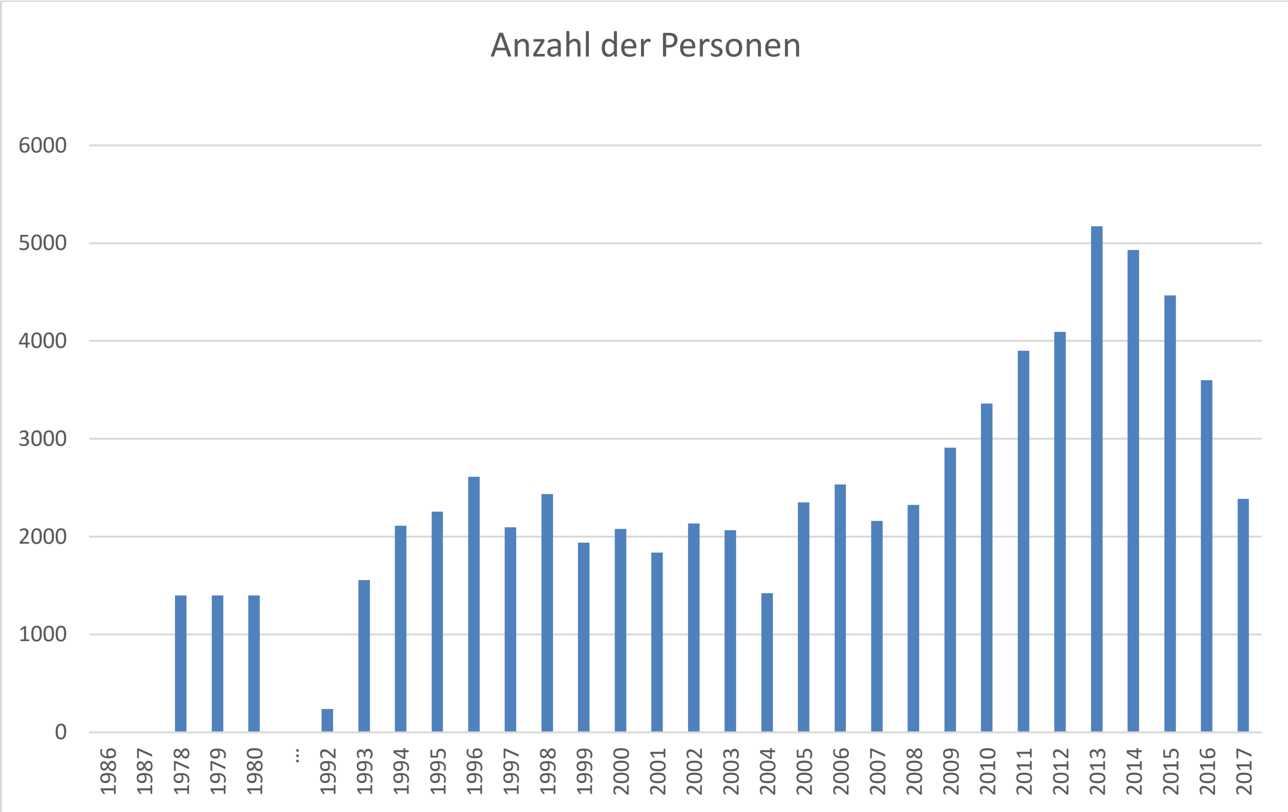
Public Relations, Öffentlichkeitsarbeit

Öffentlichkeitsarbeit

Führungen durch das Atominstitut

Im Zeitraum 2013 – 2017 fanden 1442 Führungen statt. Es wurden 20556 Gäste geführt.





Ausstellung

H. Böck, M. Villa: IAEA General conference September 2013

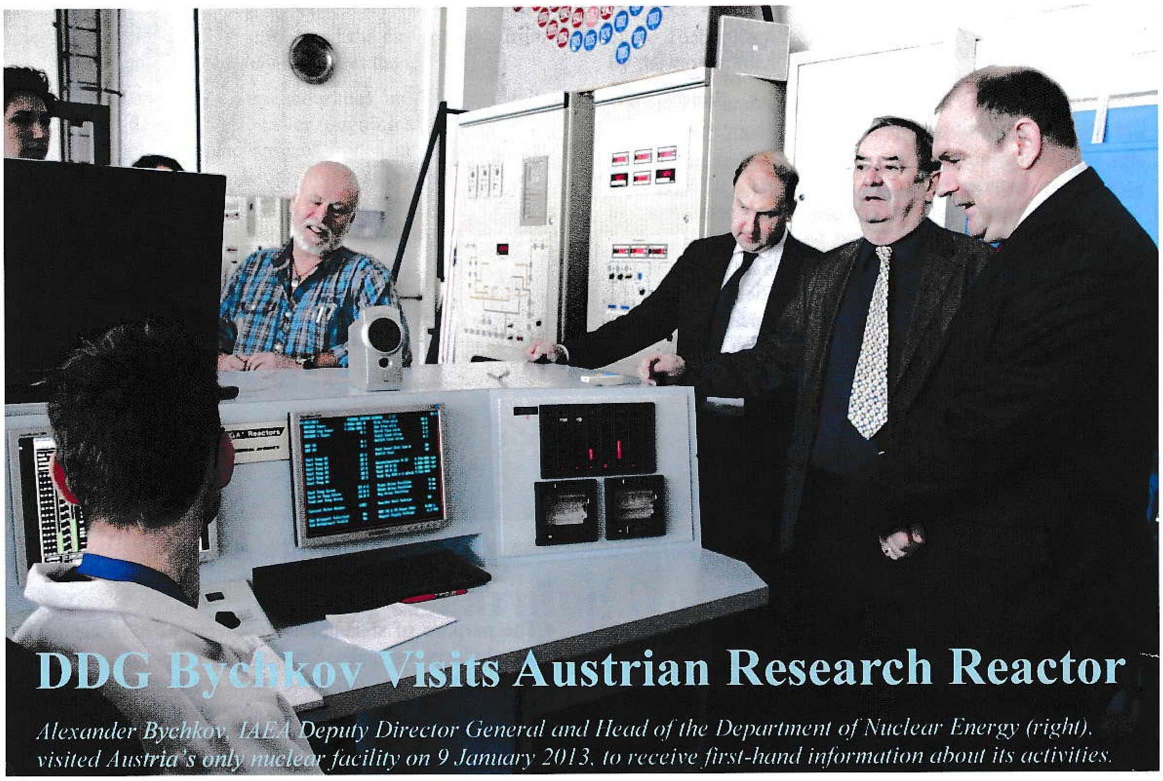
Kinderunis

2013: G. Badurek: „Kann man in Luft schwimmen?“

2016: Hartmut Abele, Erwin Jericha, Gertrud Konrad, Andreas Musilek

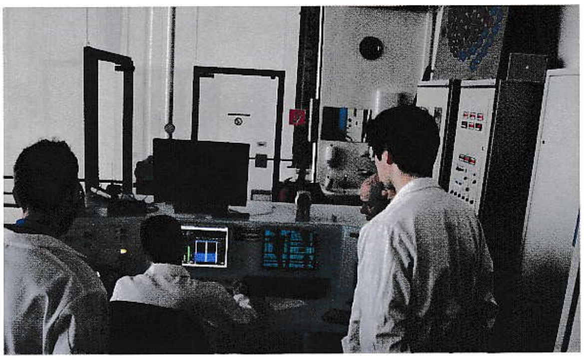
„Warum tanzen Polarlichter am Himmel? Experimente zur Bewegung geladener Teilchen“

Besuch des IAEA Deputy Directors A. Bychkov vom 9. Jänner 2013:



DDG Bychkov Visits Austrian Research Reactor

Alexander Bychkov, IAEA Deputy Director General and Head of the Department of Nuclear Energy (right), visited Austria's only nuclear facility on 9 January 2013, to receive first-hand information about its activities.



The Vienna University of Technology's Atominstitut serves as a training and research centre not only for the Austrian universities, but also at an international level.

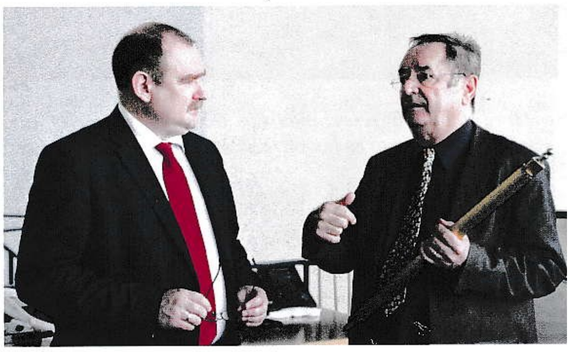
Inside the control room: Situated in Prater, Vienna's giant recreation area, this is where young scientists from across the world study and practice how to operate a nuclear reactor. As the only nuclear facility in Austria, the research reactor hosts numerous IAEA visitors each year, including diplomats, research fellows, and safeguards inspectors.

The panel on top-right shows the number and configuration of fuel assemblies that are currently inserted in the reactor core.

"There are over 60 countries operating research reactors," said DDG Bychkov during his visit, "whereas the number of countries with nuclear power reactors is only half of this."

"One of the core mission areas of the IAEA is to share good practices for research and development, isotope production and for applied studies. This reactor serves as a good example for IAEA Member States with only research reactors of how such facilities can be fully utilized," he added.

"We are very pleased with the cooperation we enjoy with the Vienna University of Technology research reactor and look forward to continued and improved joint work."



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Experiments";
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  "*Modeling of the Formation Entropy of the Silicon Vacancy*";
  Betreuer/in(nen): J. Summhammer, J. Vidal; Atominstitut, 2015; Abschlussprüfung: 25.11.2015.

- M. Thalhammer:
  "*Optimierung der Detektorsignalverarbeitung des Gravitationsexperiments qBounce*";
  Betreuer/in(nen): H. Abele, T. Jenke; Atominstitut, 2013; Abschlussprüfung: 06/2013.

- M. Wagner:
  "*3-Dimensional Simulation of Thermography Images based on PV-Cell Characteristics*";
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- G. Wautischer:
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- Alex Zdarzil:
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Teaching

141.064	PR	*Praktikum aus Neutronenphysik*	4.0	Abele
141.080	PA	*Projektarbeit Reaktortechnik*	8.0	Abele
141.102	PA	*Projektarbeit Neutronenphysik*	8.0	Abele
141.243	VO	*Selected Experiments of Atomic, Nuclear and Particle Physics*	2.0	Abele
141.255	PA	*Quantensprünge im Gravitationsfeld der Erde*	8.0	Abele
141.257	PA	*der Beta-Zerfall des Neutrons*	8.0	Abele
141.268	PV	*Privatissimum für Dissertanten*	5.0	Abele
141.543	SE	*Neutronen-und Festkörperphysik*	2.0	Abele
141.A12	PR	*Quantenphysik*	4.0	Abele
141.A54	SP	*Science TU You - Wissenschaftskommunikation in der Praxis*	2.0	Abele
142.026	PA	*Projektarbeit Experimentelle Hadronenphysik*	8.0	Abele
142.092	VO	*Atom-, Kern- und Teilchenphysik II*	4.0	Abele
142.093	UE	*Atom-, Kern- und Teilchenphysik II*	2.0	Abele
141.053	PR	*Praktische Übungen am Reaktor*	4.0	Abele
141.064	PR	*Praktikum aus Neutronenphysik*	4.0	Abele
141.080	PA	*Projektarbeit Reaktortechnik*	8.0	Abele
141.102	PA	*Projektarbeit Neutronenphysik*	8.0	Abele
141.255	PA	*Quantensprünge im Gravitationsfeld der Erde*	8.0	Abele
141.257	PA	*der Beta-Zerfall des Neutrons*	8.0	Abele
141.259	VO	*Gravitation: Einstein im Test*	2.0	Abele
141.543	SE	*Neutronen-und Festkörperphysik*	2.0	Abele

141.A12	PR	*Quantenphysik*	4.0	Abele
141.A54	SP	*Science TU You - Wissenschaftskommunikation in der Praxis*	2.0	Abele
141.A59	VO	*Raumzeit und Kosmologie*	2.0	Abele
142.026	PA	*Projektarbeit Experimentelle Hadronenphysik*	8.0	Abele
141.265	PV	*Privatissimum für Dissertanten*	5.0	Badurek
142.025	PA	*Projektarbeit Nukleare Festkörperphysik*	8.0	Badurek
142.440	VO	*Biological and Medical Applications of Nuclear Physics II*	2.0	Badurek
141.265	PV	*Privatissimum für Dissertanten*	5.0	Badurek
142.025	PA	*Projektarbeit Nukleare Festkörperphysik*	8.0	Badurek
142.081	VO	*Biological and Medical Applications of Nuclear Physics I*	2.0	Badurek
134.191	PA	*Wahlpflicht-Projekt: Medizinische Physik & Bildgebung*	6.0	Badurek
141.080	PA	*Projektarbeit Reaktortechnik*	8.0	Böck
141.113	PV	*Privatissimum für Dissertanten*	5.0	Böck
141.114	SE	*Seminar aus Reaktorsicherheit*	2.0	Böck
141.032	VO	*Reaktortechnik I - nuclear engineering I*	2.0	Böck
141.053	PR	*Praktische Übungen am Reaktor*	4.0	Böck
141.080	PA	*Projektarbeit Reaktortechnik*	8.0	Böck
141.026	PA	*Projektarbeit Neutronenoptik*	8.0	Hasegawa
141.064	PR	*Praktikum aus Neutronenphysik*	4.0	Hasegawa
141.102	PA	*Projektarbeit Neutronenphysik*	8.0	Hasegawa
141.227	PV	*Privatissimum für Diplomanden*	3.0	Hasegawa
141.228	PV	*Privatissimum für Dissertanten*	5.0	Hasegawa
141.236	VO	*Fundamental Physics with Polarized Neutrons*	2.0	Hasegawa

141.026	PA	*Projektarbeit Neutronenoptik*	8.0	Hasegawa
141.064	PR	*Praktikum aus Neutronenphysik*	4.0	Hasegawa
141.102	PA	*Projektarbeit Neutronenphysik*	8.0	Hasegawa
141.227	PV	*Privatissimum für Diplomanden*	3.0	Hasegawa
141.228	PV	*Privatissimum für Dissertanten*	5.0	Hasegawa
141.234	VO	*Fundamental Physics with Coherent X-Rays and Neutrons*	2.0	Hasegawa
141.A23	UE	*Physik für Elektrotechnik*	2.0	Hasegawa
141.002	VO	*Instrumental Activation Analysis of Environmental*	2.0	Ismail
141.051	PA	*Projektarbeit Neutronenaktivierungsanalyse*	8.0	Ismail
141.131	PV	*Privatissimum für Diplomanden*	3.0	Ismail
141.132	PV	*Privatissimum für Dissertanten*	5.0	Ismail
142.072	VO	*Physics of Exotic Atoms*	2.0	Ivanov
141.064	PR	*Praktikum aus Neutronenphysik*	4.0	Jericha
141.161	PR	*Graphical Programming and Experiment Control*	4.0	Jericha
141.242	VO	*Neutronen- und Röntgendiffraktometrie*	2.0	Jericha
142.025	PA	*Projektarbeit Nukleare Festkörperphysik*	8.0	Jericha
142.026	PA	*Projektarbeit Experimentelle Hadronenphysik*	8.0	Jericha
141.064	PR	*Praktikum aus Neutronenphysik*	4.0	Jericha
141.161	PR	*Graphical Programming and Experiment Control*	4.0	Jericha
141.543	SE	*Neutronen-und Festkörperphysik*	2.0	Jericha
142.025	PA	*Projektarbeit Nukleare Festkörperphysik*	8.0	Jericha
142.026	PA	*Projektarbeit Experimentelle Hadronenphysik*	8.0	Jericha
142.318	VO	*Neutronen- und Kernphysik*	2.0	Jericha

142.093	UE	*Atom-, Kern- und Teilchenphysik II*	2.0	Pitschmann
141.A59	VO	*Raumzeit und Kosmologie*	2.0	Pitschmann
141.223	VO	*Alternative nukleare Energiesysteme*	2.0	Rauch
141.272	SE	*Wiener Physikalisches Kolloquium*	2.0	Rauch
141.543	SE	*Neutronen-und Festkörperphysik*	2.0	Rauch
141.080	PA	*Projektarbeit Reaktortechnik*	8.0	Rauch
141.543	SE	*Neutronen-und Festkörperphysik*	2.0	Rauch
141.A20	VO	*Physik schwerer Reaktorunfälle*	2.0	Sdouz
138.008	UE	*Grundlagen der Physik II*	3.0	Sponar
138.007	UE	*Grundlagen der Physik I*	3.0	Sponar
141.102	PA	*Projektarbeit Neutronenphysik*	8.0	Summhammer
141.133	PV	*Privatissimum für Diplomanden*	3.0	Summhammer
141.217	VO	*Nachhaltige Energieträger*	2.0	Summhammer
141.102	PA	*Projektarbeit Neutronenphysik*	8.0	Summhammer
141.A19	VO	*Physik für Elektrotechnik*	3.0	Summhammer
141.026	PA	*Projektarbeit Neutronenoptik*	8.0	Villa
141.080	PA	*Projektarbeit Reaktortechnik*	8.0	Villa
141.114	SE	*Seminar aus Reaktorsicherheit*	2.0	Villa
141.504	PR	*Praktische Übungen aus Reaktorinstrumentierung*	4.0	Villa
141.658	VO	*Reaktortechnik*	2.0	Villa
141.A54	SP	*Science TU You - Wissenschaftskommunikation in der Praxis*	2.0	Villa
141.026	PA	*Projektarbeit Neutronenoptik*	8.0	Villa
141.053	PR	*Praktische Übungen am Reaktor*	4.0	Villa
141.080	PA	*Projektarbeit Reaktortechnik*	8.0	Villa
141.537	VO	*Reaktorphysik*	2.0	Villa

141.A54	SP	*Science TU You - Wissenschaftskommunikation in der Praxis*	2.0	Villa
141.064	PR	*Praktikum aus Neutronenphysik*	4.0	Zawisky
141.102	PA	*Projektarbeit Neutronenphysik*	8.0	Zawisky
141.158	VO	*Neutronenoptik und Tomographie*	2.0	Zawisky
142.026	PA	*Projektarbeit Experimentelle Hadronenphysik*	8.0	Zawisky
142.093	UE	*Atom-, Kern- und Teilchenphysik II*	2.0	Zawisky
141.064	PR	*Praktikum aus Neutronenphysik*	4.0	Zawisky
141.102	PA	*Projektarbeit Neutronenphysik*	8.0	Zawisky
141.A19	VO	*Physik für Elektrotechnik*	3.0	Zawisky
142.026	PA	*Projektarbeit Experimentelle Hadronenphysik*	8.0	Zawisky

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Technical University of VIENNA: Institute of Solid State Physics

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