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I am very pleased and honored to succeed to Mark Huyse as a chairman of the Nuclear Physics News editorial board. *Nuclear Physics News* is a unique journal in our field. Starting from a European initiative sponsored by NuPECC, it became rapidly a fully international journal supported also by the United States, Canada, and Japan. Thanks to that, it is open to all that happens in nuclear physics worldwide. I do not think that there exist many other journals that give such a large overview of the laboratories and of the actuality in any field of physics. This openness is also reflected by the composition of the editorial board of *Nuclear Physics News*, which includes physicists from Europe, America, and Japan. It can also be appreciated by the articles presenting the activities of laboratories worldwide.

To achieve this result, *Nuclear Physics News* relies on the good will of the authors but also on the people who help to select the right person to write the article, members of the editorial board, members of NuPECC, or correspondents. It is really a difficult task to cover all that is happening in nuclear physics worldwide and up to now, it was not easy to find correspondents in emerging countries like China or India. It is clear that we have to make any possible efforts to incorporate more closely these countries and to avoid limiting the nuclear physics community to the historically most active countries. Emerging countries will play an increasing role in the next decades and it is important to know their projects and their realizations.

The European Community gathers today nearly half a billion of inhabitants and is a leading economical power. Unfortunately, the organization of Europe is not at the level of its ambitions and research in particular suffers from an administration more based on the labyrinth of Daedalus than on the straight design of the classical French gardens. On the other hand, we heavily rely on the framework programs that are launched periodically by the EC. In particular, several nuclear physics projects will participate in the 7th program, which is starting this year, and it is extremely encouraging to see that several infrastructure projects are already well positioned, being retained in the selection list of ESFRI. As a theorist, however, I feel deeply the lack of possibilities to present small (at the European level) projects to a simple administrative authority. Our American colleagues have succeeded in the realization of two programs whose funding in Europe would not be obvious. The first is the creation of a Japan-U.S. theory institute in RIKEN for physics with exotic nuclei, called Justipen. It provides funding for travel and local support of American physicists visiting the center. Initiatives of the same kind exist between some European countries and Japan (even Belgium has its own) but, due to the small number of theoreticians in any European country, it remains very limited and does not have the same visibility. A more ambitious American program is devoted to the set up of a very general method to study nuclear structure physics. It is based on existing methods and codes, which should be generalized by physicists and rewritten in a more efficient way by computer scientists. Computer codes developed in Europe have been included in the package that will be improved by the analysts. Of course, the authors of the codes are involved in this program, at an individual level. However, cooperation between similar efforts in Europe and in the United States would give a much broader visibility to the European researchers and a better way to benefit from their efforts to develop new theoretical models. I do not think that such a program could be developed in Europe: it is too small to be included in the big programs of the 7th framework but too large and involving physicists from too many countries (theory groups are small…) to be a cooperation between individual countries.

To finish on a positive note, I would like to report on a success that the Belgian nuclear physics community has recently obtained. Belgium institutions are, to say the least, not simple, with a federal government, three communities, and three regions that do not coincide and as many parliaments as institutions. However, the federal government has a substantial program (IAP) to favor collaborations between research groups based in different parts of the country. Thanks to that, a research program

The views expressed here do not represent the views and policies of NuPECC except where explicitly identified.

in nuclear structure has been selected and is substantially supported. This success can be related to a program focussed on a few topics on which the Belgian teams have a recognized expertise. It is also due to a close collaboration between theory and experiment that already existed but that the IAP will permit to strengthen. A nice feature of this IAP is that, compared to previous programs, it has been extended to include laboratories outside Belgium, GSI, Ganil, Köln, and the CSNSM in Orsay. The financing of these extra collaborations is limited but it is a step in the right direction to favor interregional collaborations that are not limited to a single country.

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Bucharest Tandem Van de Graaff Accelerator

DOREL BUCURESCU, GHEORGHE CATA-DANIL, AND NICOLAE-VICTOR ZAMFIR 1

Introduction

The Tandem Van de Graaff accelerator is one of the main experimental facilities of the "Horia Hulubei" National Institute of Physics and Nuclear Engineering (IFIN-HH) in Bucharest-Magurele (http://www.nipne.ro). The institute, with more than 300 scientists, is the most significant player in the Romanian physics research landscape. Its activities cover a broad range of research in basic and applied nuclear physics and related areas:

- Theoretical Physics
- Atomic, Nuclear, and Particle Physics
- Life and Environmental Physics
- Radioisotopes and Radiopharmaceuticals
- Technological Irradiations
- Radioactive Waste Treatment and Storage
- Decommissioning of Nuclear Facilities
- Nuclear Engineering
- Training in nuclear activities

Since its foundation, more than 50 years ago, the institute, through its nuclear facilities, Cyclotron, Nuclear Reactor, and Tandem Accelerator, played the leading role in the formation and development of nuclear activities in Romania.

Facility Description

Nuclear physics research with accelerated ion beams is mainly performed in Romania at the Van de Graaff Electrostatic Tandem Accelerator (http://tandem.nipne.ro), a National Research Facility financed by the Romanian Authority for Scientific Research. Access to experiments is open to institutes and universities from Romania, as well as to groups from other countries on the basis of mutual agreements (beam-time requests can be submitted on-line through the accelerator Web page). The accelerator runs approximately 3600 hours/year and there are about 30 different users. Outside users can benefit from a high standard guest house, located close to the laboratory. Figure 1 is a general view of the Tandem Accelerator.

This accelerator was built by the High Voltage Engineering Corporation (USA) in 1973 and it was later upgraded from the original terminal voltage of 7.5 MV (FN type) to 9 MV. In order to operate the accelerator at 9 MV on the terminal, a new voltage divider was designed and installed, and an improved technique was applied for the analysis of the insulating gas composition [1]. Because it is located in a seismic area, the major earthquakes affected its structure. During the 1977 earthquake (magnitude 7.2 on Richter scale) due to the extremely high resonant mechanical stress, the inner structure collapsed inside the tank [2]. After only 9 years (1986) another earthquake (magnitude 6.8 on the Richter scale) deviated the acceleration column with 63 mm at the terminal position. As a consequence, a mechanical earthquake protection system was constructed and installed [3] (partially shown in Figure 2).

Figure 1. *A general view of the main vault of the Bucharest 9 MV Van de Graff Tandem Accelerator.*

Figure 2. *View of one of the four tank supports, part of the tandem earthquake protection system, equipped with an elastic GERB unit with springs and viscodampers.*

The accelerator currently delivers 28 ion species ranging from protons (intensities of 700 nA at 10 MeV) to gold (intensities of 10 nA at the maximum energy). Negative ions injected in the accelerator are produced by 3 ion sources: a duoplasmatron for p, ^{12}C, ^{14}N, ^{16}O, ^{19}F, ^{32}S, a duoplasmatron source dedicated to $^{3,4}He$ ions and a sputtering source for most of the elements. In addition there is in operation an ultra-clean sputtering source for Accelerator Mass Spectrometry (AMS) applications, followed by a 90 degrees magnetic analyzing and injection at zero degrees, shown in Figure 3.

There are seven beam lines for a wide variety of experiments, equipped with commercially available detectors for photons, charged particles, and neutrons, associated with standard nuclear electronics.

Presently, the machine is undergoing a major refurbishing process: the vacuum equipment, electrical power supplies, high voltage charging system, sputtering ion source are in the process of being replaced. Also the automatic control of the ion-optics elements (magnetic and electric lenses, analyzing, and bending magnets) and beam diagnosis will be installed according to updated technology in the near future.

In the Tandem experimental area, there is also installed a standalone 14 GHz *Electron Cyclotron Resonance Ion Source* (RECRIS), constructed in collaborations with scientists from Frankfurt University and CERN [4]. It can deliver a variety of highly charged ion beams (H, N, O, Ar) at low energies used for atomic physics and condensed matter studies. Figure 4 shows a view of the RECRIS setup.

Research Program

Over the years, a rich research program in both nuclear and atomic physics was developed, using beams accelerated by the Tandem accelerator. The nuclear physics studies in the first decade were centered on both nuclear reaction mechanisms and nuclear structure.

First experiments on *reaction mechanisms* at low energies exploited the good energy resolution of the tandem beams. One such direction was the study of the isobaric analogue resonances (IAR). As an interesting result, intermediate structures were observed near some IAR and there were related to configurations (hall-ways) in which very likely the number of excited particles and holes is larger than that for the door-way states, but much smaller than in the case of the compound nucleus configurations. Isobaric analogue resonances were observed for the first time in the actinide region by proton scattering on a ^{238}U target [5]. A resonance analog to a parent state in continuum (in ^{13}C) was observed in ^{13}N, by means of the $^{12}C(p,p)$ excitation function, thus pointing to a more general concept of IAR. In another series of experiments, the (p,n) threshold anomaly, that is, an anomalous behavior of the cross-section occurring at the opening of a neutron channel, was predicted and observed in the proton elastic scattering from *sd*-shell nuclei [6]. This anomaly from the (p,p) channel is induced by the 2*p* wave zero-energy neutron analogue state.

With the first heavy ion beams, reaction mechanism studies were extended to incomplete fusion processes. A study of nonequilibrium processes, and, in particular, of the projectile breakup channel, was made for various projectiles (^{11}B to ^{19}F) of 3 to 5 MeV/A on light targets, and a strong dependence on the projectile was evidenced [7].

Gamma-ray spectroscopy at Tandem appeared as a natural continuation of the previous studies performed for several years at the Cyclotron with alpha-particle beams [8]. With the availability of heavy ion beams at Tandem, *nuclear structure* studies were mainly performed with in-beam gamma-ray techniques and fusion-evaporation reactions, to study medium-mass nuclei, including: lifetimes measured with the recoil distance method (see, for example Ref. [9]); magnetic moment

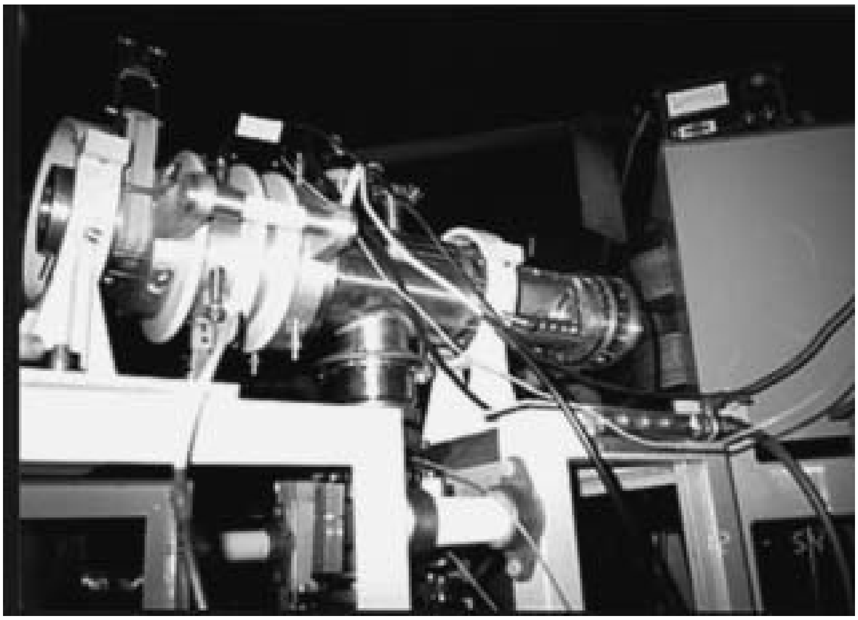

Figure 3. *The Sputtering Source dedicated to AMS studies.*

(g-factor) measurements by means of the recoil-into-gas integral perturbed angular correlation technique [10]; and study of new isomeric states [11].

The *atomic physics* studies concentrated on the experimental determination of atomic collision parameters such as: integral and differential ionization cross-sections of the inner (K and L) shells; integral and differential alignment parameters; multiple ionization effects; double vacancy production in the inner shells (see, for example, Ref. [12]).

Currently, the experimental program at our Tandem accelerator is concentrated mainly on three directions: nuclear structure, atomic physics, and applied nuclear physics. Some recent results will be briefly outlined.

Many research themes are related to strong international collaborations with other laboratories, such as Köln, Munich, Yale, Legnaro, Padova, Orsay, Dubna, GANIL, GSI, and RIKEN. It is worth mentioning that the Tandem accelerator was the main facility of the European (Framework Program–5) Centre of Excellence *Inter-Disciplinary Research and Applications based on Nuclear and Atomic Physics (IDRANAP)*. Presently the research activity is connected to European Projects in the Framework Program–6: EURONS, EURISOL, EURATOM.

Nuclear Structure Physics

Nuclear Structure studies at the Bucharest Tandem Accelerator are mainly dealing with the gamma-ray spectroscopy of low-lying, yrast and non-yrast excited levels.

Study of high-spin states populated with heavy-ion fusion-evaporation reactions. High-spin structures were studied in medium-mass ($A \sim 70$–130) slightly neutron-deficient nuclei, in fusion-evaporation reactions induced by ion beams from Li to F, by in-beam gamma-ray spectroscopy experiments (gamma-ray excitation functions, angular distributions, γ-γ, charged

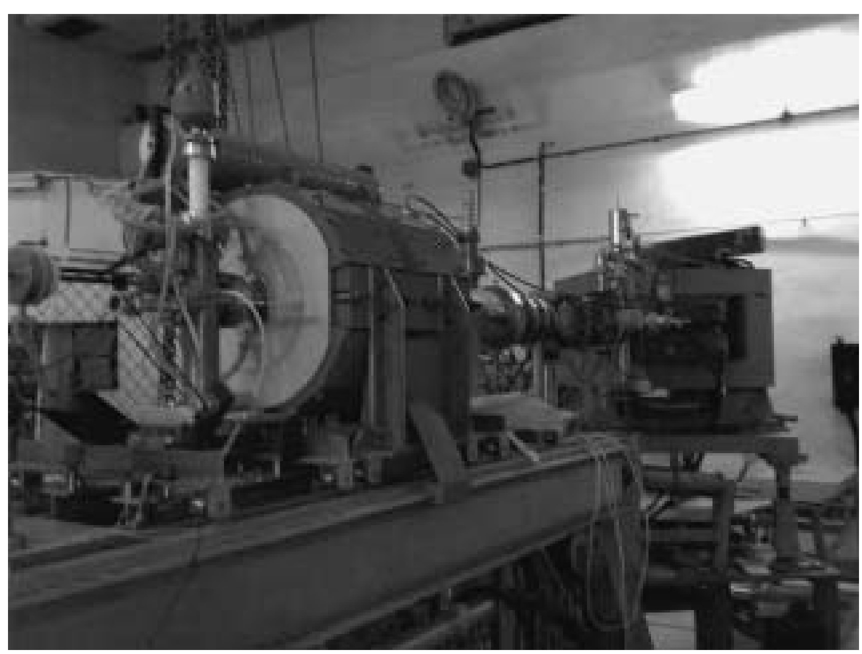

Figure 4. *The ECR ion-source RECRIS setup.*

particle – γ, and neutron – γ coincidences, lifetimes of excited states by the Doppler shift attenuation (DSA) and recoil distance (RD) methods). Different nuclear structure phenomena were observed and studied. "Transitional" nuclei in the A~80–90 region were studied rather systematically. In many of these nuclei high spin states were studied for the first time, thus enriching the picture of the systematic evolution of nuclear structure over isotopic and isotonic chains. Such systematics allowed extensive comparisons with different nuclear structure models, and especially the algebraic models (interacting boson and boson-fermion models). Isomeric states were also observed and studied, as is the case of two new short-lived isomeric states observed in ^{84}Y. The decay scheme was determined in experiments at the Tandem, and their lifetimes and magnetic moments were measured in experiments at the Cyclotron of our Institute [13]. A new setup was recently developed for lifetime measurements of isomeric states by using an autocorrelation single-crystal scintillation time spectrometer. Some experiments performed at our accelerator complemented experiments at large-scale facilities. For example, high-spin band structures were measured in ^{96}Tc first in Bucharest experiments, with spin assignments in the lower part of the level scheme based on detailed gamma-ray angular distributions and DCO-ratios; these structures were then extended to higher spins by analyzing data from a EUROBALL experiment. Another example is the study of high-spin states in ^{91}Y and ^{95}Nb; the first gamma-rays of band-like structures in these nuclei were assigned in Bucharest by γ-γ, neutron-γ, and charged particle-γ coincidence experiments, and extensions at higher spins were obtained in an experiment with the GASP array (Legnaro) [14].

Study of low-spin states populated with non-selective reactions. Such studies, complementary to those with heavy-ion beams, were performed for different medium mass nuclei (A ~ 70–150) with the (p,nγ) reaction at low energies. Due to its lack of selectivity, this reaction allowed the observation of complex level schemes, which are quasi-complete for a certain spin window. In spite of the rather small velocity of the recoiling nuclei, level lifetimes can be also determined in such reactions, with the DSA method because at incident energy close to the threshold of the studied levels, one avoids the problem of the cascade feedings. An illustration of this type of study is in Ref. [15], where many new low-spin levels were observed in ^{139}Ce with the (p,n) reaction, while high-spin structures were studied with the ^{12}C+^{130}Te reaction.

Nuclear structure investigations by off-beam gamma-ray spectroscopy. Gamma-ray spectroscopy following beta decay is very useful in cases where a detailed level scheme at low spins and excitation energies is necessary in order to assess the validity of certain theoretical model predictions. Such a case, of outstanding current interest, is the search for fingerprints of nuclear structure paradigms such as dynamical symmetries, and critical shape phase transition points (like E(5), the critical point between the U(5) and O(6) dynamical symmetries, and X(5), between U(5) and SU(3), respectively). Very often, information on such low-lying states (such as their spin value, or branching ratios of their decay) can be obtained through gamma-ray spectroscopy following beta-decay. Such studies were done, very often, 30–40 years ago and, in order to have precise data, new measurements should be performed using modern tools, especially high resolution coincident gamma-ray spectroscopy. We have used for such studies beta emitter sources prepared by different reactions, which, depending on the parent nucleus lifetime, were measured either by using a beam chopping system, or were simply transported aside from the beam line, in front of the gamma-ray detectors. Such an approach was used to study the level schemes of ^{100}Ru, ^{124}Te, and ^{64}Zn, which is proposed as a good candidate for the E(5) symmetry [16].

Atomic Physics

Atomic Physics studies in recent years concern mainly heavy ion–atom collision mechanisms at intermediate energies. Recent experimental studies approached the ionization in the K-K and K-L level matching regions, namely: 2pσ and 3dσ molecular orbitals ionization cross-sections and vacancy transfer probabilities [17]. Multiple ionization probabilities of the outer shells of the target atom and equilibrium charge states of the projectile in the solid target were also obtained.

Applications of Nuclear Methods

A large fraction of the beam time at the Tandem accelerator is dedicated to the use of IBA (Ion Beam Analysis) methods in a wide spectrum of applications for different scientific or economic domains. The methods include PIXE (Particle Induced X-Ray Emission), PIGE (Particle Induced Gamma ray Emission), RBS (Rutherford Back-Scattering), NRBS (Non-Rutherford Back Scattering spectrometry), ERDA (Elastic Recoil Detection Analysis), and offer high precision capabilities for materials analysis and characterization.

PIXE type of analysis was used in archaeometrical researches, to study the composition of ancient Greek, Roman, and Dacian silver and gold coins, and Neolithic obsidian tools and ceramics pigments [18]. Part of these studies were performed within the frame of the European Union Actions COST G1 ("Ion Beam Study of Art and Archaeological Objects") and G8 ("non-destructive analysis and testing of museum objects"). PIXE and related IBA techniques have been implemented for the characterization of biomineral structures such as bones, dental enamel, and biomaterials. Use of wide beam, thick target PIXE on such materials for which good reference materials are missing, and the complementary ERDA method allowed the evaluation of relative concentrations of up to 20 elements with $Z > 14$ per specimen [19]. Analysis of the trace and dominant element concentrations allowed the discrimination of diabetes-induced changes in bones, and the study of dental enamel demineralization. Studies now in progress extend the application area of IBA methods to those mentioned before and other related biological materials. A high potential of the PIGE method for precise measurements of Carbon in steels was recently demonstrated [20]. ERDA capability for studying the profile of helium implanted in different materials is also important to assess the behavior of nuclear matrices where helium is produced by the disintegration of actinides. Such studies were performed, for example, for ceramics, which are considered promising materials for nuclear waste immobilization and/or transmutation. Recoil spectrometry has been extended to the analysis of hydrogen and helium, which are important elements in a wide variety of thin film materials [21]. One should also mention radiation damage studies performed with irradiation of materials with different beams. As an example, samples of KU1 quartz glass (a candidate for optical transmission components of future thermonuclear reactors) were irradiated with 12 to 15 MeV protons, in order to study the degradation of their optical transmission properties, as a part of the cooperation in the frame of the EURATOM program [22].

An accelerator mass spectrometry (AMS) setup is being installed on one of the beam lines [23]. Experimental AMS studies were performed with ^{26}Al (with a sensitivity level of 10^{-14} for the isotope to element ratio), and tritium and deuterium (for the diagnosis of fusion experiments).

Finally, we mention a medical application of nuclear methods, namely, the boron neutron capture therapy (BNCT). An experimental set-up was designed and is under development [24], to provide thermal and epithermal neutrons (from the (p,n) reaction on ^{7}Li), to irradiate aqueous cells solutions.

Plans for the Future

The research program at the Bucharest Tandem Accelerator is increasingly related to the large European projects in Nuclear Physics: FAIR and SPIRAL2. It is based on the fact that such a small scale facility, together with the other similar facilities, is complementary in many respects to Large Scale Facilities (LSF):

- more "classical" research directions, which can still lead to important contributions to the field.
- represents an ideal place for educating young scientists; they go through all stages of an experiment and really achieve the desirable skills needed for future LSF groups.
- represents an appropriate place for developing instruments or experimental methods intended for a LSF.
- The Bucharest Tandem Accelerator is financed by Romanian authorities. This support may become stronger, if it is demonstrated that by developing the in-house activity, the participation of the Romanian groups at the European LSFs increases in efficiency.

In order to achieve these goals it is necessary to have a strong program of enhancing the experimental capabilities. Regarding the scientific program the main directions will be:

In-beam Gamma-Ray Spectroscopy

For this purpose, a small array of six (at present) HPGe detectors, with efficiencies between 30% and 60%, will be used, together with several Silicon detectors for charged particles and liquid scintillator detectors for neutrons. This system will allow the study, by $\gamma\gamma$ coincidences, of the high-spin states of other nuclei close to the stability line in the medium mass region, which are little known at present—such nuclei are populated with relatively low cross-sections in heavy ion induced reactions.

A modern plunger device for lifetime measurements with the recoil distance method is under construction.

Off-Beam Gamma-Ray Spectroscopy for Nuclear Structure and Nuclear Astrophysics

A transport system of the irradiated targets in a low-background area combined with a high efficiency array of gamma detectors and conversion electrons will serve to continue the off-beam studies in order to pin down nuclear structure details. These empirical parameters will contribute to further mapping of the evolution of nuclear collectivity. A parallel program will be devoted to measure cross-sections of reactions relevant for nucleosynthesis.

Proton Induced Fission Studies on Actinides

An array of 81 plastic scintillator detectors for neutrons (constructed and used in experiments at RIKEN) will be installed at the Bucharest Tandem, in connection with a VME acquisition system. It will be used to measure, for the first time, the correlation function of the neutrons emitted in proton induced fission, as well as neutron nuclear data.

New Applications of IBA Methods

More performing experimental setups are under development, using different beams both in vacuum and in air, for the analysis of a large variety of samples. Studies of the modification of properties of materials by irradiation with accelerated particle beams will be also continued.

Atomic Physics

New studies of the inner shell vacancy production and sharing in heavy systems at intermediate bombarding energies will be performed. Studies of atomic physics and material science will also be performed using our new facility of 14 GHz ECR ion source, TOF spectrometer, and position-sensitive detectors. Atomic processes in lower Z collision systems and energies, with relevance for plasma and fusion physics, will be studied.

Testing Detectors and Experimental Methods for Large Scale International Projects (FAIR, SPIRAL2, AGATA, CERN, ITER)

Active participation of the Romanian nuclear research groups in the Large Scale International Projects has and will have a high priority. In-house research in this direction could use Tandem accelerator beams for testing different new detection systems and experimental methods. These works will be performed mainly in large international research teams.

Accelerator Mass Spectrometry

The extremely high detection sensitivity of AMS in conjunction with the enhanced values observed for ^{129}I relative to other fission products makes the measurement of ^{129}I with AMS an efficient tool for nuclear safeguards, detecting and preventing accidental or deliberate discharge of small nuclear debris that otherwise would remain undetected by radioactivity measurements. The goal of future experiments is to measure, monitor, and investigate the transport of ^{129}I in the vicinity of three nuclear power plants in Eastern Europe: Kozloduy (Bulgaria), Cernavoda (Romania), and Chernobyl (Ukraine).

The extensive refurbishing process presently being undertaken, the strong scientific program, together with the high level achievements and results, show that the Bucharest Tandem Accelerator is an active part of the European Infrastructure in Nuclear Physics.

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Trapped Radioactive Isotopes: micro-laboratories for fundamental Physics (TRIμP)

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Introduction

Rare and short-lived radio isotopes offer unique possibilities for investigating fundamental physical symmetries, for applied physics, and for nuclear structure studies [1]. The main motivation for investigating fundamental symmetries and fundamental interactions is to explore the validity of the Standard Model (SM) in particle physics. This includes improving of the known limits and searches for New Physics. Such research can be performed in high-precision measurements at low energy. This approach is complementary to searches physics beyond the SM in High-Energy physics experiments. In particular, high accuracy can be achieved, when suitable radioactive isotopes can be cooled and stored in atom or ion traps [2,3].

With this goal the TRIμP (Trapped Radioactive Isotopes: μ-(micro)laboratories for fundamental Physics) facility at the Kernfysisch Versneller Instituut (KVI) was proposed and funded. The main incentive is to provide a state-of-the-art user facility for high-precision studies. In particular, atomic trapping of radioactive isotopes is foreseen as a central tool for the intended experiments. The research interests of the local group concentrate on time reversal (T) invariance. In this context we will measure β-recoil correlations in nuclear β-decay, where the V-A theory of the Weak Interaction may be violated. A second line of research is the search for permanent electric dipole moments (EDMs), in particular in Ra isotopes, where a large window exists to find New Physics.

Trapping of radioactive nuclei using atomic traps generates pure samples that can be easily manipulated to facilitate the precision experimental research. Here we report on some relevant physical aspects, and we discuss the construction and commissioning of various parts of the TRIμP facility.

Physics Background

Symmetries play an important and crucial role in physics. Global symmetries give rise to conservation laws and local symmetries yield forces. Based on such symmetries, the SM describes accurately all observations in particle physics. It needs four fundamental forces from strong, electromagnetic, weak, and gravitational interactions mediated by gauge bosons, three generations with four fundamental fermions each, and the Higgs mechanism to generate their masses. Even recent spectacular observations in neutrino oscillation experiments can be included with moderate modifications. This far-ranging theory lacks, however, a deeper and more satisfactory explanation for many described facts. The open questions include the large number of some 30 free parameters in the SM, the hierarchy of fundamental fermion masses, the number of particle generations and the origin of parity (P) violation and combined charge symmetry (C) and parity (CP) violation. In combination with Standard Cosmology, the dominance of matter over antimatter in the universe remains a mystery. Also dark matter and dark energy remain unexplained. In order to provide solutions to such intriguing problems speculative extensions have been invented, such as supersymmetry, left-right symmetry, technicolor and many others. However, they have no status in physics, yet, unless they can be experimentally verified.

Studies of discrete symmetries have a robust discovery potential for finding New Physics. For example, P violation has been put by hand into the SM to account for the observed left-handedness in weak interactions allowing only left-handed bosons as mediator. Searches for a violation of maximum parity violation, which manifests itself, for example, in β-decay asymmetries may be interpreted as limits on masses of right-handed bosons or may provide evidence for their existence, which in itself would mean a (partial) restoration of parity symmetry. Some of the most stringent limits in this field come from precision β-decay experiments.

As a further example, an EDM of a fundamental particle violates both P and T symmetry. An EDM also violates CP, if unbroken combined CPT symmetry assumed. EDMs are induced in any particle through higher order loop effects with the CP violation mechanism known in the SM, for example, from K and B systems. However, the amounts of such EDMs are several orders of magnitude below present experimental limits, which opens a large window for finding New Physics as proposed in speculative models, where EDMs are predicted in some cases up to the present limits.

New sources of CP-violation are of particular interest in connection with a model of Sacharov, which offers a route to explain the matter-antimatter asymmetry [4]. They may be found through large EDMs or T-violating correlations in nuclear β-decays.

The TRIμP Facility

The experimental procedure to obtain radioactive nuclides in a trap is shown in Figure 1. Typically the nuclides of interest are produced in inverse kinematics. Choosing a heavy ion beam from the superconducting K600 cyclotron AGOR of KVI and using a light element as target, the reaction products have high yields and are well focused. The production target is, therefore, a H, D, or He gas target cooled to liquid nitrogen temperature for higher density [5]. The different reaction products are separated from the beam in a dual magnetic separator and then stopped in an ion catcher. They are extracted from this device and focused into a three-stage radiofrequency quadrupole (RFQ), where they are gas cooled and collected in a potential well as its last stage. Pulsed extraction from there results in a bunched ion beam. This is sent into an ultra-high vacuum setup, where after neutralization the atoms are collected in a magneto-optical (MOT) trap. The actual experiments take place in an adjacent measurement chamber to which the atoms can be transferred with light forces.

The TRIμP Dual Magnetic Separator

The TRIμP separator [6] consists of two dipole sections. The first one separates the primary and secondary beam, with the secondary beam dispersed in the intermediate focal plane. The second section brings the secondary beam back to an achromatic focus at the exit of the separator. One can add an absorber in the intermediate plane, which allows for removing unwanted products that are produced with the same rigidity as the desired secondary beam. In this respect the TRIμP separator is similar to the magnetic separators used for fragmentation reactions such as at GANIL and MSU. Beyond this feature, the TRIμP separator includes a gas-filled mode where it functions as a recoil spectrometer. In this case the production target is located in the intermediate focal plane (Figure 2).

Typical reactions are charge exchange reactions and stripping reactions (Table 1). In Figure 3 the strongly focused production is demonstrated, as can be observed from the production distribution in the dispersive plane. The main yield is produced in about $\Delta p/p = 1 - 2\%$ momentum bite, whereas the momentum acceptance of the separator is 4%. This allows one to use thick targets, our target is 10 cm long and capable to hold several bar of gas [7]. The AGOR cyclotron follows an upgrade program to achieve heavy ion beams with 1 kW of beam power. Up to now 300 W have been already extracted.

We have succeeded in separating isotopes of interest with below 0.5% background, for example, in the case of ^{21}Na, ^{12}B, and ^{12}N. These were the first fast beams delivered to external user groups who measured. These experiments involved measuring the ^{21}Na β/γ branching ratio [7] as an input in calculations of β–ν correlations, and β-decays of A = 12 nuclei into excited states of ^{12}C and subsequent decay into 3 α-particles [8], which is of high interest for stellar ^{12}C production.

Ion Catcher

The ion catcher is a compact thermal ionizer (TI). Originally a He-gas filled ion catcher was foreseen. However, this would appear to have led to severe efficiency and rate limitations [9]. Even when rate limitations do not play a role the fraction of surviving ions in the stopping process remains well below 100%. In the preparation phase the survival of energetic ions when injected into gas stopper was extensively studied [10]. Due to collisional neutralization at

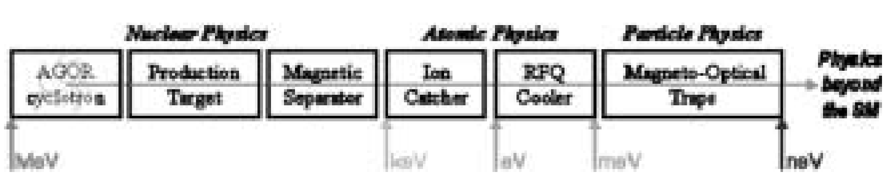

Figure 1. *Schematic of the TRIμP facility.*

Figure 2. *Photograph of the separator before closing the roof of its cave. The dipole sections consist of two dipole magnets each. Focusing is provided by quadrupole duplets. Between both sections a vacuum chamber is located that houses diagnostic elements and in the gas filled mode also the target.*

rather high energies, the fraction of ions left after stopping is mainly determined by the ratio of cross sections for neutralization and for restripping of neutral atoms. In a recent cryogenic test (maximal reduction of contaminants) the survival fraction of ionized Rn in different noble gasses remained below 30% [11]. As the radioactive products eventually will need to be trapped in atom traps it is mostly alkali and alkali earth atoms and elements of very similar atomic level schemes, which are of interest. For these reasons a TI was chosen as a first solution. For TI's very high extraction efficiencies have consistently been reported for the elements of interest. The TI consists of tungsten foils inside a tungsten cavity of about 30 cm^3 and is heated by electron bombardment above 2500 K. An electric field gradient allows extraction through an exit aperture [12]. For testing this device we employed ^{20}Na, which is convenient because it has a short life time ($T_{1/2} = 0.448$ s) and decays with a branching of 16% by α particles. By chopping the primary beam and measuring the time dependence of the α particle appearance on a detector downstream of the TI, the effective half life of the source was deduced to be about 1 s. So far we have reached efficiencies of about 5% for ^{20}Na, for ^{21}Na ($T_{1/2}$ = 22.5 s) this will be a factor 5 higher. Improving the design to increase the gain is in progress.

Radiofrequency Cooler/Buncher

The ion catcher is followed by a Radio Frequency Quadrupole (RFQ) cooler and buncher. It has a novel design that minimizes the wiring and vacuum feedtroughs (Figure 4). It has two He gas filled stages for collisional cooling. They are differentially pumped. The ions are transversely confined by the rf-field and a dc field gradient guides them towards a Paul trap at the end of the device. The RFQ cooler and buncher have been tested with $^{133}Cs^+$ and $^{23}Na^+$ beams from an ion source. The Paul trap potential well is used to accumulate particles. Pulsed extraction trough a switched potential drift tube allows for their transport without the need for a high voltage platform. The cooler and also the buncher efficiency are nearly 60%. The longitudinal cooling time (required for bunching) was about 1 ms, delivering bunches of at least 5×10^4 prticles [12].

Atom Trapping

One project that our group is working on is the measurement of β-ν correlations in β-decay with the final goal to measure the time reversal violating *D* coefficient, which describes the β–ν momentum correlation for decays of polarized nuclei. The neutrino information is inferred from

Table 1. Typical nuclides produced with the TRIµP facility. Typical production rates are 10^4 / s per particle nA beam and per 1 bar target pressure.

Product	Beam	E [MeV/u]	Reaction
^{21}Na	^{21}Ne	20	(p,n)
^{21}Na	^{20}Ne	22.3	(d,n)
^{12}B	^{11}B	22.3	(d,p)
^{12}N	^{12}C	22.3	(p,n)
^{19}Ne	^{19}F	10	(p,n)
^{20}Na	^{20}Ne	22.3	(p,n)
^{21}Na	^{21}Ne	43	(p,n)
^{22}Mg	^{23}Na	31.5	(p,2n)

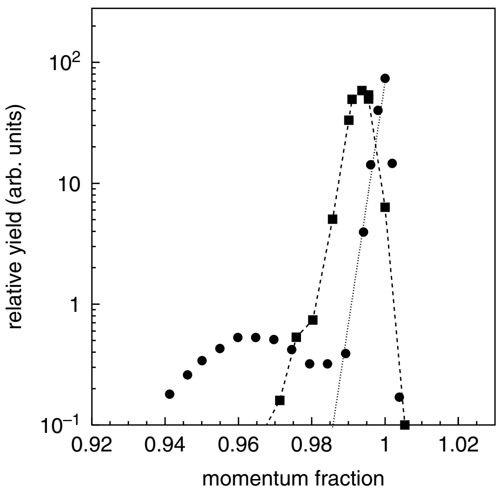

Figure 3. *Momentum dependence of the reactions p(^{21}Ne, ^{21}Na)n at 43 MeV/nucleon and d(^{20}Ne, ^{21}Na)n at 22.3 MeV/nucleon. The dependence for the first reaction is indicated by the filled circles. The dotted line through the sharp rising part of the distribution is an exponential characteristic for the reaction radius. The filled squares give the distribution of the stripping reaction; the dashed line is to the guide eye.*

the recoiling nucleus. The sample being studied will reside in a Magneto-optical trap (MOT), as has been done for ^{21}Na [13] and ^{38m}K [14], to be able to measure the recoiling ion. We are currently developing the trapping system. The atoms are collected in a MOT formed by six circularly and pairwise counter-propagating laser beams in the center of a magnetic quadrupole field. This is located in a UHV small glass cell with an optimized volume ratio for the laser beams and the chamber. A hot foil neutralizer is used to catch incoming ions and emit them as atoms. Such a device has been set up and tested successfully with a stable Na beam. Currently a reaction microscope is being constructed in an adjacent vacuum chamber. Its purpose is to detect the recoiling ions out of a MOT trapping region in coincidence with the emitted β-particles.

To prepare for radium trapping, first the technical approach is studied with the chemical homologue barium. This step is necessary as the atomic level energies of the relevant levels in Ra are not sufficiently known and as the development of new optical trapping techniques for atoms with complex level structure succeeds faster with stable isotopes. The only high efficient option for laser cooling is offered by the $^1S_0$-$^1P_1$ transition out of the ground state. The $^1S_0$-$^3P_1$ intercombination line is a low efficient alternative with a high potential for a later second stage cooling. The main difference compared to other successfully laser cooled atoms arises from the decay into a number of metastable D states. On an average an atom scatters some 340 photons on the $^1S_0$-$^1P_1$ transition before it will decay into one of the metastable states and the atom is removed from the cooling cycle. This corresponds to a velocity change of only 1.5 m/sec—not enough for efficient laser cooling. This obstacle can be overcome by using additional lasers to drive the atoms from the metastable states back into the ground state. This repumping is done by lasers at 1500 nm and 1130 nm. Among the problems to be solved were the breaking of dark resonances by the set of coherent lasers, which would destroy any cooling effects [10].

The velocity distribution of the atomic beam is measured by observing the Doppler shift of the $^1S_0$-$^1P_1$ transition induced by a weak probe 553.7 nm laser beam at 45° with respect to the atomic beam. Curve a in the inset of Figure 5 shows the Maxwell-Boltzmann velocity distribution of the Ba atomic beam measured with the probe laser. Curve b was obtained with the repump lasers and the strong cooling laser directed against the atomic beam. The shift in velocity of the atoms is about 60 m/sec. This corresponds (see Figure) to an enhancement of slow atoms by a factor 5. This shows for the first time in practice that with the use of repumpers, laser cooling of atoms with complex level

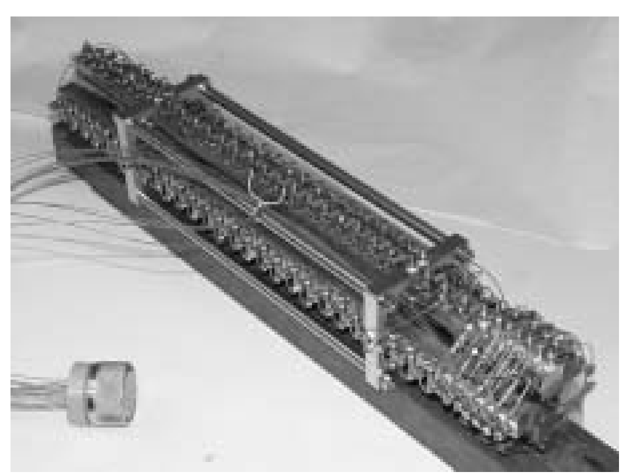

Figure 4. *Photograph of the RFQ, a single connector is used for the vacuum feed through. Most of the wires are to operate the trap section.*

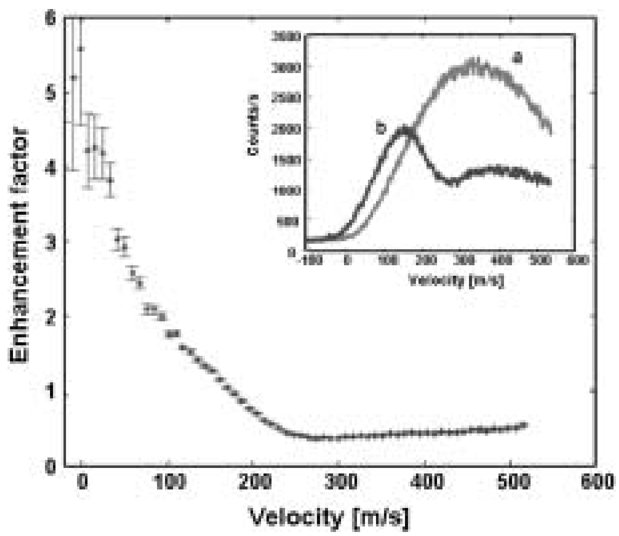

Figure 5. *Enhancement of the Ba f lux due to laser cooling.*

schemes is feasible [15]. The next steps are first-time trapping of barium atoms in a MOT followed by Ra atomic spectroscopy to obtain precise level energies and transition probabilities and Ra atom trapping.

Conclusion

At present all key components of the TRIμP facility exist and have been tested individually. This includes the production and transport devices for radioactive slow ion beams as well as a versatile optical laboratory to provide the necessary laser beams for atomic spectroscopy, trapping and manipulation. We are currently in the last stages of installing all equipment in the experimental area. We expect to start the scientific research program on β-decays and EDM searches in the beginning of 2007. We are ready to receive proposals from external users groups to utilize our facility.

Acknowledgments

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Quantum Interferometry with Nucleons

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History

The optical phenomenon of interferometry dates back to ~1680 when Robert Hooke first described Newton rings. An elaborated explanation of interferometry appeared however only more than a hundred years later, when Thomas Young performed double-slit experiments (Figure 1), actually to try to observe the particle nature of light. Instead, Young gave us the well known formula for the interference pattern,

$$d \cdot \sin\theta_n = n \cdot \lambda\ ,\ \ n = 0, \pm 1, \pm 2..... \qquad (1)$$

in terms of the light wavelength (λ) and the distance between the two slits (d), that gives a solid backup to the wave nature of light.

Another classical example of **amplitude** interferometry, where the waveform is responsible for the pattern, was adopted by Albert Michelson, describing his speed of light interferometer in 1887 [1]. This started a hot discussion around the aether concept, reaching its peak as late as 1928 [2], still with Michelson as front figure.

At that time the particle nature of light was established, especially in the doctoral thesis of Louis de Broglie from 1924, where he concluded that light has a dual performance as waves and particles. Experiments on the photoelectric and Compton effects had shown this behavior but it took another 25 years for anyone to realize that **intensity** interferometry could be useful. This happened when R. Hanbury-Brown and R. Q. Twiss constructed a photon interferometer [3] for astrophysical purpose although Dirac had expressed that: "Interference between two different photons never occur." Visual light was impossible to use, since photon fluctuations (shot noise) here are much larger than the expected wave noise. Radio waves are better from this point of view and soon the first experiment, with coordinated antennas, placed at large relative distance, attempted to measure the Cygnus A and Cassiopeia A stars as **radio** sources. In fact the noise correlations between the antennas were in practice measured. Correlations did occur and the angular sizes were published in 1952 [4]. More than 50 years later, the sizes of astrophysical objects are still measured with Michelson-Morely interferometers but now in attempts to search for objects that possibly emit gravitational radiation, such as black holes [5].

In 1960 intensity interferometry was introduced into particle physics and just as the astrophysical use of interferometry became known as the HBT effect, particle physics interferometry got its acronym, GGLP, after the authors of the first article [6] in this field.

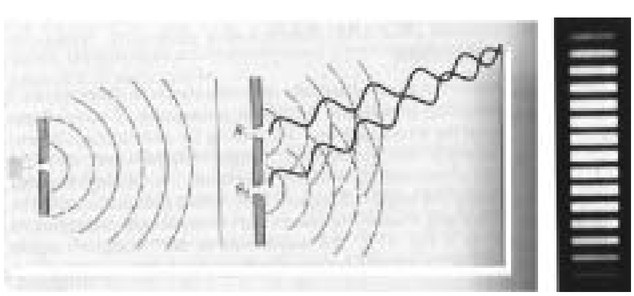

Figure 1. *Thomas Young's drawing of the double-slit phenomenon and of the experimental light pattern from 1809.*

Bose-Einstein Interferometry

In Ref. [6], the goal was to understand the big difference between the two-pion relative angle (θ_{ij}) distributions for like-pairs ($\pi^+\pi^+$ or $\pi^-\pi^-$) and unlike-pairs ($\pi^+\pi^-$) appearing in $\bar{p} + p$ reaction that releases an energy of 2.1 GeV in the cm system. The GGLP effect had to be developed for **Bose-Einstein** statistics because pions are bosons with integer spin. The experiment used a propane bubble chamber from which thousands of events were scanned and identified with a semi-automatic reading device that allowed statistics of

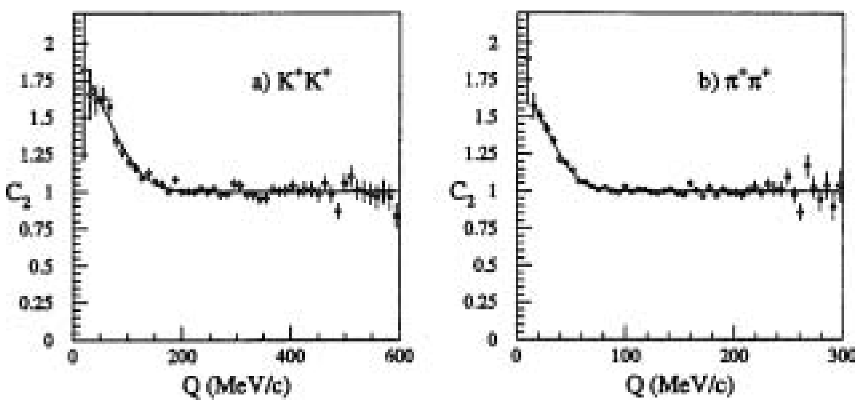

Figure 2. *$\pi^+\pi^+$ and K^+K^+ correlations from $^{28}Si + ^{197}Au$ reactions at 13.7A GeV [7].*

only a few thousand events. Even with this small statistics, the comparison between experimental and theoretical correlation data made it quite likely that interferometry does appear and since then many two-meson correlation experiments in nuclear reactions have confirmed this. When nuclei are involved it is however important to consider effects of re-scattering and therefore the first *KK* correlation studies were important because the kaon interaction with nucleons normally is negligible due to strangeness conservation. Figure 2 shows $\pi^+\pi^+$ and K^+K^+ correlation functions (as described in next chapter) obtained from the same, $^{28}Si + ^{197}Au$ at 13.7A GeV (GeV per nucleon) reaction, which confirm that quantum statistical models with proper relativistic dynamics and Coulomb effects can describe well sources of meson correlations. Mesons can however not be treated as point-like particles—the Gamow limit—so the relevant information from the correlation functions, is the space-time extension of the production source (see next section). Space and time extension are in fact difficult to distinguish between in high energy nuclear reactions except possibly for very slow emission processes, like evaporation, where the space-like correlation dominates. We will next discuss these signatures for **two-fermion** interferometry.

Fermi-Dirac Interferometry

The easiest particles to utilize in any experimental study of reaction dynamics and particularly in interferometry studies are protons, which are frequently emitted even in reactions at energies well below the Fermi limit. Protons have half-integer spin and are thus fermions. The basic two-proton correlation formalism for Fermi-Dirac statistics was first worked out by the Nobel Laureate Roy Glauber [5] and later on introduced to nuclear reactions by Steven Koonin in the 1970s [8]. There, all final-state interactions are introduced and it turns out that both nuclear and Coulomb interaction affect the form of the correlation function at small momentum vector difference, $\vec{q} = 1/2 \cdot (\vec{p_1} - \vec{p_2})$. Generally, a more recent formulae [9] for the correlation function reads,

$$C(\vec{q},\vec{P}) = \int d^3r \frac{\int d^3\vec{R} \cdot f(\vec{P},\vec{r_1},t_e) \cdot f(\vec{P},\vec{r_2},t_e)}{\left|\int d^3\vec{r_1} \cdot f(\vec{P},\vec{r_1},t_e)\right|^2} \cdot \left|\Psi_{12}(\vec{q},\vec{R})\right|^2 \quad (2)$$

where, $\vec{P} = 1/2 \cdot (\vec{p_1} + \vec{p_2})$, $\vec{r} = \vec{r_1} + \vec{r_2}$, $\vec{R} = \vec{r}/2$ and t_e is the time for emission of both particles. At this time the Wigner functions in space and phase-space are introduced,

$$f(\vec{P},\vec{R},t_e) = \int_{-\infty}^{t_e} dt \cdot g(\vec{P},\vec{R} - \vec{v}_P (t_e - t), t) \quad (3)$$

The emission probability, g, is given by the emission model and information beyond that is obtained by comparing theoretical and experimental correlation functions where the experimental function is the ratio between two-particle and singles cross-sections,

$$C(q) = \frac{\sigma_{12}(\vec{p_1},\vec{p_2})}{\sigma_1(\vec{p_1}) \cdot \sigma_2(\vec{p_2})} \quad (4)$$

To avoid absolute measurements and the difficulty to select exactly the same nucleons for two-particle and singles measurements are normally simplified to the ratio between the number of correlated and non-correlated two-proton events,

$$C(q) = const \cdot \frac{N_c(q)}{N_{nc}(q)} \quad (5)$$

The CHIC Interferometer

Toward the end of the 1980s the CHIC collaboration [10] started a long fermion interferometry program. The first, modest apparatus consisted of sixteen 10 cm thick CsI crystals [11], mounted in a dense array outside a thin window of a target chamber and four hexagonal liquid scintillators, 15 cm thick and 15 cm in diameter mounted 3 m behind the chamber (Figure 3) [12]. The finite size of the detectors and the necessary window thickness created a fairly high energy threshold for protons, ~7 MeV, which prevented a safe estimate of the correlation function for pp pairs close to q = 0. Due to the fact that the mutual Coulomb interaction shifts the interferometry peak to q > 10 MeV/c, important information was yet to be expected. Other pp correlation experiments from this period, on heavy-ion reactions at such low energy that the time-like part of the correlation between two protons could be neglected, exhibited a spatial extension of the emission source of ~5 fm. This is characteristic for a compound nucleus reaction.

Our first combined pp/nn data for reactions at 30A MeV [12] showed, however, a different pattern (Figure 4). A clear nn peak was found for small q values and because also the pp results showed a higher peak than the compound-evaporation formalism predicted, at least one new source had to be considered that emits nucleons on a much faster time-scale (a “dynamical” source). The idea to use the combination of p and n detectors as an an np interferometer was now raised [13], with the motivation that this would allow the separation of the three major contributions to the small-angle correlations, namely quantum interference (Pauli effect), strong interaction, and mutual Coulomb interaction. Before starting complete nn/np/pp experiments a substantial work with numerical calculations, Monte-Carlo simulations and in-beam tests [14] was, however, found to be essential to understand all problems with scattered neutrons, that for example produce cross-talk in the nn array.

At about the same time as the CHIC np-interferometer became operational a similar setup was introduced by Kryger et al. [15] to study 4A MeV heavy-ion reactions. Here, the np correlations showed a strong singlet d-peak which together with the d*/d ratio again pointed to one single evaporative source for nucleons. To our surprise the np correlation function at higher energies, 30A MeV, did not require the additional, faster emission source [16]. The peak at q < 20 MeV/c was instead quite small in e.g. Ar + Au reactions (Figure 4). This created speculations whether

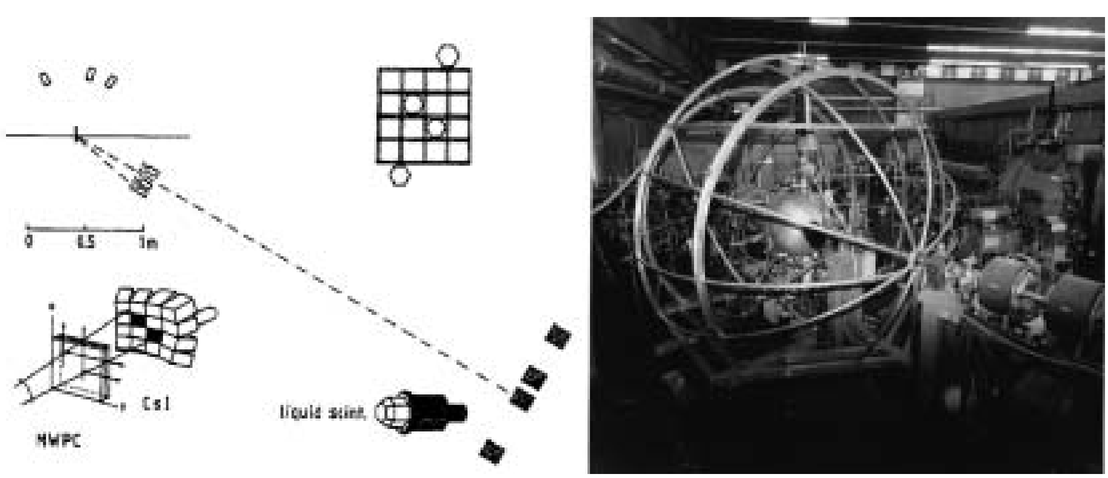

Figure 3. *The very first CHIC interferometer for simultaneous nn, np, and pp correlation measurements (left) [12] and a photo of a modern CHIC setup at IFN Catania (right).*

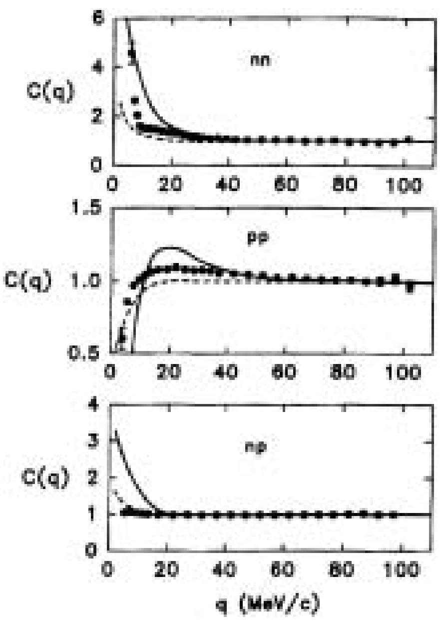

Figure 4. *First CHIC data on simultaneous nn, np, and pp correlation functions obtained in Ne + Ar collisions at 30A MeV [16].*

an abnormally strong spin-1 (negative correlation peak) component of the two-particle wavefunction must be assumed [17] or whether the explanation was due to the proton, interacting destructively with the mean Coulomb field [18]. The latter explanation was somewhat favored by the fact that the np correlations in reactions with lighter targets, did show a stronger np peak [16].

After the first combined pp-np-nn experiments at the SARA cyclotron in Grenoble, a long series of experiments followed with stepwise extension and improvements of the detector arrays and with the introduction of impact parameter defining projectile fragmentation detector systems. These experiments, carried out at RIKEN in Tokyo and at the superconducting cyclotrons in LNS, Catania and KVI, Groningen (AGOR) attacked new physics questions, some of them now to be discussed.

Individual Emission Sources

The first Catania experiment [19] utilized a 45A MeV Ni beam, operating with 2/3 suppression of bursts of 1 ns width to obtain enough time between those bursts, 210 ns, to measure time-of-flight, even for very low energy neutrons. This experiment was very much triggered by the description of heavy-ion reactions in this energy region as a combination of fast and slow, dynamical and statistical processes. In particular the relatively slow but dynamical neck emission process, had just been introduced [20,21]. Detailed evaluations of combined singles and correlation data needed a simple phenomenological model and consequently we modified the Csörgö-Helgesson model [22] to include several sources, each characterized by velocity, flow, temperature gradient, and particle evaporation. The comparisons stressed that not even "dynamical" compound nucleus description could account for the combination of the high-energy tails in singles data and space-time form of the correlation data. A separate, strongly interacting source had instead to be introduced and to our surprise the symmetric, Ni + Ni, reaction exhibited this much stronger than the asymmetric (Ni + Al, Pb) reactions (Figure 5). This source was characterized by the cm velocity of the participating matter and a temperature that was close to the expected Fermi **gas** temperature (here 9.4 MeV). It also turned out that selecting only those (~10%) nn pairs that have the largest momentum elongation, , makes the correlation peak for Ni + Au reactions as high as for Ni + Ni reactions. These results strongly support the idea of the dynamical (neck) formation, a result which was later confirmed in 61A MeV reactions [19,23] where, however, a complicated four-source scenario had to be introduced to explain all details.

Applying gates, not only in P_{tot} but also polar angle gates, directional gates, velocity gates for unlike particles,

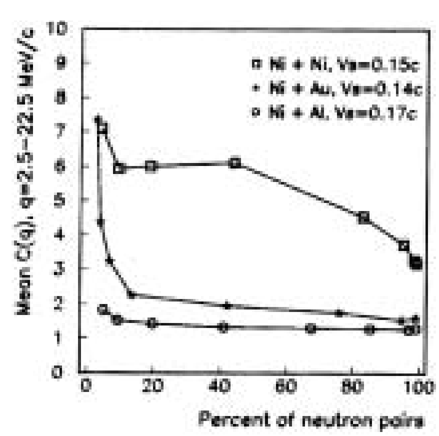

Figure 5. *The strength of the nn correlation function weighted over the q = 2.5–22.5 region vs the contribution of the highest P_{tot} pairs [23].*

etc. was indeed found necessary to identify the various sources. Also impact parameter gating gives complementary information about the complicated source pattern by selecting different reactions and we will turn to such attempts now.

Impact Parameter

One way to probe the impact parameter of heavy ion reactions at intermediate or high energy is to determine as completely as possible the projectile disintegration. In the LNS and KVI experiments we connected the BaF_2 wall ARGOS [24] and the KVI phoswich wall [25] with high granularity in the forward angular region, $\Theta < 20°$, from which most fragmentation information comes These walls were first of all very effective in removing background events if at least one $Z \geq 2$ fragment was required in the master trigger. A selection of impact parameter ranges is indeed possible in addition but generally we learned that the multiplicity of correlated pairs in the event probes centrality equally well when large enough detector arrays were introduced. In recent experiments we have utilized the 32-module liquid scintillator detector EDEN [26] and extended the CsI detector EMRIC [11] to comprise 20 CsI modules. By making it possible to place single detectors or sub-clusters almost anywhere outside a target chamber we can measure C(q) in any angular range with low-energy cutoffs, 2 MeV for n and 6 MeV for p, allowing correlation functions to be studied from $q = 8$ MeV/c for pp-, 6 MeV/c for np-, and 4 MeV/c for nn correlations. The affection of the reaction impact parameter on correlation data will be discussed further, in context with chronology and isospin effects.

Chronology

The richness of information from simultaneous nn, np, and pp correlation measurements comes from the possibility to single out the wave function symmetrization effect and the final-state strong interaction and Coulomb effects. Standard interferometry analysis on **like-particle correlations** can in addition provide information on emission times if both particles surely come from the same, static source. Comparing average emission times for different like-particle pairs or like-particle pairs from two different sources infers a kind of emission chronology with the drawback that the information is model dependent.

There is, however, another very interesting possibility to study the emission clock from **unlike-particle correlations**. This arises from the fact that final-state interactions depend not only on relative space-time coordinates but also on the possible asymmetry in emission source. First, this fact was utilized for charged particle pairs which experience mutual Coulomb repulsion [27] but soon the technique was extended to any kind of interacting, non-identical particle pairs by Lednicky [28] who utilized the asymmetry of the initial np wavefunction instead. Introducing the conditions on the np correlations that either $E_n > E_p$ or $E_p > E_n$, provides two correlation functions, which we can denote C_n and C_p. If $C_n > C_p$ in a certain q region (positive correlations), neutrons are (on the average) emitted earlier than protons and vice versa. This creates a shape in the $C_{n(p)}$ correlation functions or even more pronounced in the $C_n(q)/C_p(q)$ ratio which is sensitive to the relative emission time, Δt. The ratio can be positive or negative, depending on which kind of particle that is emitted first (on the average). A "classical understanding" of this phenomenon may be based on the following reasoning. If the proton is emitted first, then its distance to the neutron will become larger if $E_p > E_n$, than if $E_n > E_p$ (Figure 6). A larger distance means a weaker correlation and thus enhanced $C_n(q)/C_p(q)$.

Such a complicated quantum mechanical phenomenon as the chronology effect is not easy to interpret. We therefore simulated a simple one-source emission process with the Csörgö-Helgesson model [22] and this indeed fully verified the Lednicky proposal (Figure 7, curves). The data, shown as points in Figure 7, come from the KVI experiment on the $^{36}Ar + ^{27}Al$ reaction at 61A MeV [29]. Particularly the angular and total-momentum dependences of the np and pp correlation functions support strongly the dissipative binary reaction scenario, where early dynamical emission is followed by slower statistical evaporation. The reverse kinematics

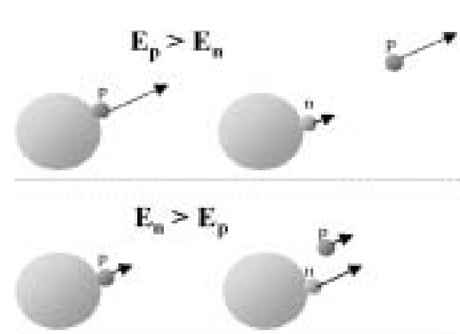

Figure 6. *A popular (classical) interpretation of the chronology effect.*

seems to enhance the early dynamical emission component at backward angles. The velocity-gated np correlations at backward angles (upper, left) shows an even stronger dip in the C_n/C_p ratio than the simulations and this indeed indicates that neutrons are, on the average, emitted earlier than protons. Forward measurements (upper, right), exhibit a positive correlation for $q < 40$ MeV/c but a (weak) anti-correlation at higher q values. There is no dip in the C_n/C_p ratio, which in fact indicates that here protons are emitted somewhat earlier than neutrons, in agreement with result for the $^{58}Ni + {}^{27}Al$ reaction at 45A MeV [30].

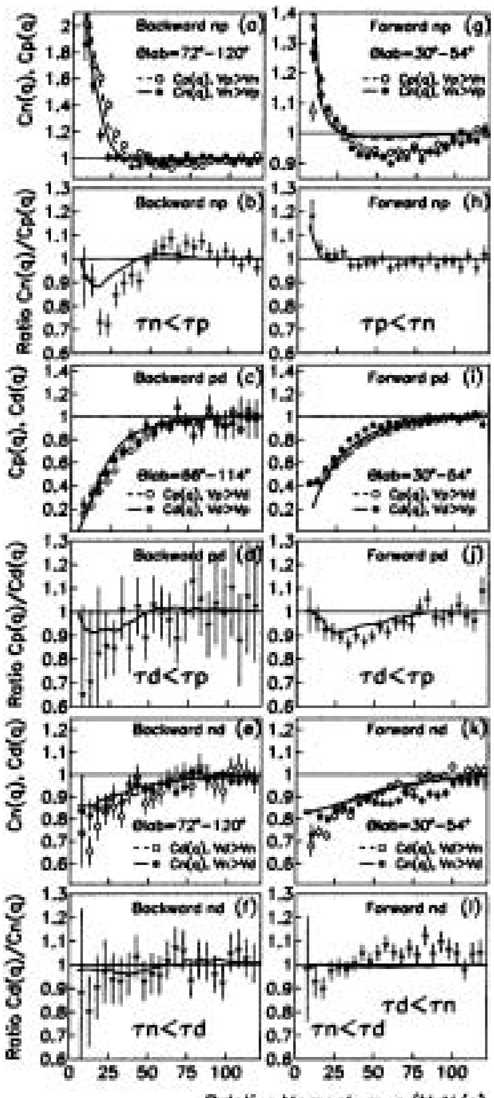

Figure 7. *C_n and C_p correlation functions and the C_n/C_p ratio as a function of the relative momentum (q) for np (upper), pd (middle) and nd (lower) pairs emitted around 90° (left) and 45° (right) laboratory angles [29]. Curves are the results of the one-source simulation.*

Correlations between Heavier Particles and Strangeness Carrying Mesons

Interferometry measurements require extremely good energy resolution and accurate energy calibration [31] of the detector systems and for heavier particles a complete mass resolution is of course needed. By proper lapping of surfaces and wrapping of crystals we obtained complete mass resolution up to $A = 10$ for the CsI(Tl) detectors mentioned above. This meant for example that additional chronology information from nd and pd pairs could be achieved (Figure 7, mid and lower parts). These data show that deuterons can either be emitted at an average time in-between neutrons and protons, $\tau_n < \tau_d < \tau_p$, for fast emission processes or earlier than both neutrons and protons for slow, projectile residue emission [31], a result that is confirmed for heavier systems, Xe + Sn at 50A MeV, in inclusive two-particle data by Guorio et al [32], who claim that deuterons are emitted substantially (~250 fm/c) earlier than protons in hard and relatively fast scattering processes.

At much lower beam energies, ~4A MeV, correlation analysis of light fragments confirms statistical compound nucleus decay and even the time-scale of the preceding fission process can sometimes be determined [33]. At much higher energies, 400A MeV, heavy ion experiments with the FOPI detector system at GSI [34] have stressed the difference between the longitudinal and transversal heavy particle correlation functions. This difference confirms the existence of a strong collective expansion when a relatively heavy participant is formed. At even higher energy, meson chronology has been used to tackle the problem of how to observe strangelets in the frame of the distillation process, which follows the creation of quark-gluon plasma. Because strange and anti-strange particles are not produced at the same time in a baryon rich system under low bag constant, it is believed that K^+K^- chronology can be used to observe such a scenario [35].

Chronology may thus help to answer fundamental EOS questions for different phases. One old question for the liquid-gas region is what form the asymmetry term has and we turn to this question now.

Isospin Effects

The isospin dependence of the nuclear EOS is the most uncertain property of neutron-rich matter and nevertheless essential for the understanding of asymmetric nuclei as well as neutron stars. It has been studied by heavy ion collision experiments with isotope separated beam and/or target nuclei. For central collisions, a stiff EOS causes high momentum neutrons and protons to be emitted almost simultaneously, thereby leading to strong correlations. A soft EOS delays on the other hand the proton emission, which weakens the np correlation. This effect of the symmetry energy becomes weaker with increasing impact parameter and incident energy and the momentum dependence of both the isoscalar nuclear potential and the symmetry potential influence significantly the space-time properties of the nucleon emission source. Very recently the use of intereferometry has shown promising progress in the studies of the asymmetry potential. It is, however, important to remark, once more, that complete reaction models are necessary tools to extract the proper isospin dependence from data.

The first CHIC experiment, devoted to the isospin question, utilzed 61A MeV $^{36}Ar + ^{112,124}Sn$ collisions [36,37]. Emission from the different sources is now enhanced or suppressed by introducing angular and P_{tot} cuts. In Figure 8 three sources are identified in this way, a fast intermediate velocity source possibly representing nucleon-nucleon scattering (left), a semi-fast intermediate velocity source possibly representing neck-emission (mid) and a slower source possibly representing (dynamical) target-residue evaporation Obviously, the height of the pp and np correlation peaks is progressively reduced with increasing emission time. Comparing results for the two Sn isotopes exhibits a significant isospin effect, with an increased height of the correlation functions for the more neutron-rich target. This indicates shorter average emission times in the $^{36}Ar + ^{124}Sn$ system. Before making definite conclusions from such results it is, however, important to notice that the correlation function depends on the space-time extent of the emitting source. Both the smaller size of the $^{36}Ar + ^{112}Sn$ system and its larger excitation energy per nucleon speaks for shorter emission times. On the other hand, the change in neutron number implies a different symmetry energy, which also affects the n and p emission times. Neutrons are expected to be emitted faster in the neutron-rich system, which should give an enhanced correlation strength for the $^{36}Ar + ^{124}Sn$ system A more elaborate analysis that introduces velocity gates and also investigates pd and nd correlations [38] confirms that neutrons are, on average, emitted earlier than protons in all cases. This is particularly true for the particles emitted from the target residue, indicating that the residues in the two reactions were formed differently due to the symmetry interaction. Deuterons, being formed mainly by coalescence, appear to have emission times that fall

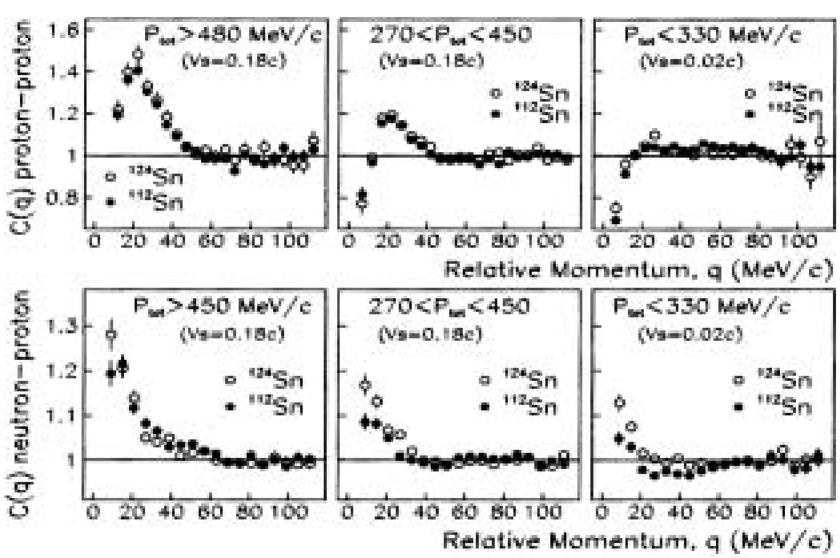

Figure 8. *pp (upper) and np (lower) correlation functions in $^{36}Ar + ^{124,112}Sn$ collisions at 61A MeV in a high* P_{tot} *(left), medium* P_{tot} *(mid) and low* P_{tot} *(right) gates.* v_s *denotes the reference frame in which* P_{tot} *is calculated [37].*

in-between those of neutrons and protons. No sizeable isospin effects in the emission sequence of deuterons and protons are, however, found.

Conclusions about the asymmetry term of the EOS from these results call for a comparison to a complete emission model. Such attempts have started recently and a first utilization of the BUU model seems to indicate that an isospin-stiff symmetry term, with $\gamma = 2.0$, in the momentum-independent mean-field potential,

$$U = A \cdot u + B \cdot u^{\sigma} + C \cdot u^{\gamma} \cdot \delta^{2} \tag{6}$$

is favorable in comparison to softer dependences with smaller γ.

Conclusions

Interferometry is a brilliant example of a phenomenon in physics that has been "rediscovered" and utilized in many, very different applications. The use of interferometry to explain phenomena, from Newton's rings to neutron stars, is unprecedented and it is interesting to notice that single or few persons or small collaborations, have been able to make the most important contributions. The work with the CHIC interferometer continues and we wish to take this opportunity to announce that data on pp, np, nn, dp, …. correlations in the doubly isotope separated reactions ^{112,124}Sn+^{58,64}Ni and ^{112,124}Sn+^{112,124}Sn from a new LNS experiment, is under analysis.

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Heavy Ion Tumor Therapy: From the Scientific Principles to the Clinical Routine

The idea of proton- and carbon-tumor therapy it is presently exploding in the medical community like a viral infection.

In 1946, when Robert Wilson published the physical advantages of ion beams for therapy, there was no reaction in the medical community, although this article appeared in *Radiology*, a well known medical journal.

When recently a private consortium set up a particle therapy and sold shares of a fund with a "guaranteed" annual profit of more than 20% after tax, the discussions on ion-therapy were stirred up in the public interest and in controversially discussed in many newspapers. In 2005, more than 20 informal requests on the general reimbursement for ion-therapy were put to the German health insurances. These requests came from some serious medical groups like University hospitals but also financial investment groups having no expertise in the field at all became eager to build such money "making" units.

Besides this financial aspect many members of the physical community claimed their intellectual property rights when the very successful clinical results of the clinical trials with proton and carbon ions were reported, although they have not contributed to the field nor treated any patients up to then. Nuclear physicists seeking for useful applications of their work, offer elaborate Monte Carlo codes to radiologists that could improve "everything" in heavy ion-treatment planning, even if the calculation of one single irradiation field would be more expensive than the budget given by the health insurance for a complete treatment. In addition, most of these calculations were not verified experimentally and proven to be useful for therapy.

Thus heavy ion tumor therapy became hype, but what is the reality?

After Bob Wilson's paper it took nearly 10 years for the first patient treatments at Berkeley and Harvard. In 1993 approximately 10,000 patients had been treated mainly with protons. Today this number is close to 45,000 patients, including 2,000 carbon ion patients from Chiba, Japan, and GSI Germany. The main rationales published in 1946 are still valid, but techniques and biological understanding of ion therapy have changed in parallel to the conventional treatment using high energetic photons from various sources, called "X-rays" by the physicians.

The Physical and Radiobiological Basis of Ion Beam Therapy

The main differences between X-rays and particles are a different biological action and a different depth-dose distribution. In life science the effects of radiation are quantified according to the dose which is defined as the energy deposited per unit mass and measured in Gray (1 Gy = 1 $\frac{Joule}{Kg}$). For X-rays, the dose decreases exponentially for larger penetration depth (Figure 1). Therefore, deep-seated tumors have to be irradiated from many sides in order to distribute the non-wanted dose in front of the tumor over a larger volume when delivering a lethal dose to the tumor. In the very modern technique of Intensity Modulated Radio-Therapy, IMRT, up to 10 fields from different directions are individually shaped according to the projection of the target volume. IMRT produces excellent tumor control rates but also a large volume of normal tissue exposed to radiation.

The major problem of all conforming X-ray therapies is the induction of secondary tumors. Their induction rate depends in a non-linear way from dose. After an initial increase the induction rate saturates at 3 Gy. So when the high doses of standard tumor therapy of 60 Gy are distributed over a larger volume of normal tissue the tumor induction becomes rather a volume than a dose effect: The larger volumes in IMRT will produce more late effects. This is the major reason why sophisticated strategies of conventional therapy are limited in their practical application, especially for young patients having a life expectance of more than 20 years.

A general solution of dose problem and in addition greater precision are possible with particle therapy. Ion beams have an inverse dose profile that produces a greater dose to the tumor than to the normal tissue in the entrance, even if only one treatment field is used (Figure 1). In the clinical practice at least two opposing fields are applied. In most of the older therapies, these fields are prepared in analogy to photon therapy using absorbers and other passive beam shaping material. Then, the pristine sharp beam from the accelerator is enlarged laterally by scattering foils and in depth by

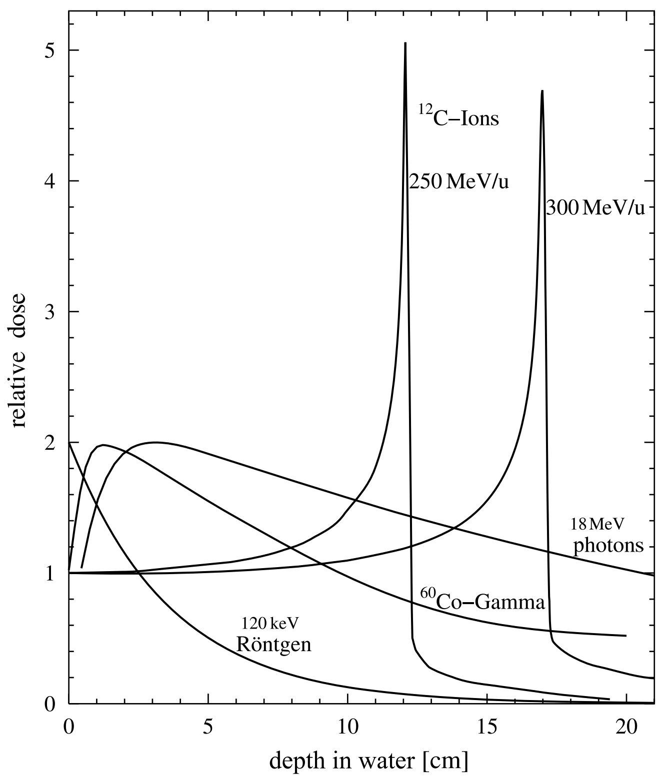

Figure 1. *Comparison of depth dose distribution in water as tissue equivalent. For high energy photons the dose decreases for larger depth but ions have an inverse profile with a maximum of dose at the end of the range, which allows a greater tumor dose at lower dose to the normal tissue around. Changing the energy this maximum can be shifted in depth.*

variable ridge filters, outer contours are defined by apertures. With this technique cylinder-shaped high dose volumes can be produced, enclosing the target volume but also enclosing a large volume of normal tissue outside the target volume. In the more recent particle-therapies developed at GSI and PSI an active beam shaping method, the Intensity Modulated Particle Therapy (IMPT) is applied. In this technique the target volume is dissected in layers of equal range and a "pencil" beam from the accelerator is guided by fast magnets over a net of pixels in each energy slice. At the end of one slice the energy is changed by the accelerator to the next slice.

Using IMPT a tumor can be delineated in all it contours with a precision of 2–3 mm (corresponding to a gradient from 90% to 10% of the dose), depending on the diameter of the beam used which is in practice 4–6 mm. Because of a higher atomic number, the lateral and range scattering is much smaller for carbon ions than for protons. In Figure 2 two treatment plans of proton and carbon are compared. For protons the dose gradients are about 3 times shallower than for carbon. This ratio is nearly independent from the particle energy and range and is important for the treatment of deep seated tumors close to critical organs. But for smaller ranges up to 2 cm as used in eye treatments the dose falloff even for protons is below 1 mm and better than the clinical requirements.

But the most important advantage of carbon treatment is the increase of the biological effectiveness in the Bragg maximum at the end of the range.

The Relative Biological Effectiveness

The dose defined as a measure of the radiation quantity it is not sufficient to quantify biological effects when radiations of different qualities are compared. It has been discovered very early that α - particles or neutrons produce for the same physical dose a 3–5 times greater biological effect. Therefore, the Relative Biological Effectiveness, RBE, was introduced as an empirical factor describing the dose-ratio of the different radiations necessary to produce the same effect. RBE values for ion beams ranges mostly from 1 to 5.

For the first heavy ion therapy at Berkeley, the RBE was treated as a fixed number that could be correlated to physical parameters like particle energy and atomic number and was measured in cell experiments (*in vitro)*. But again, it turned out that RBE is also a bad "quantum number" and depends not only on physical parameters but also on biological parameters like: the type of effect measured (cell inactivation or late genetic effects), the effect level (10% cell survival versus 80% survival), and the dose rate effects and more important on cellular repair capacity.

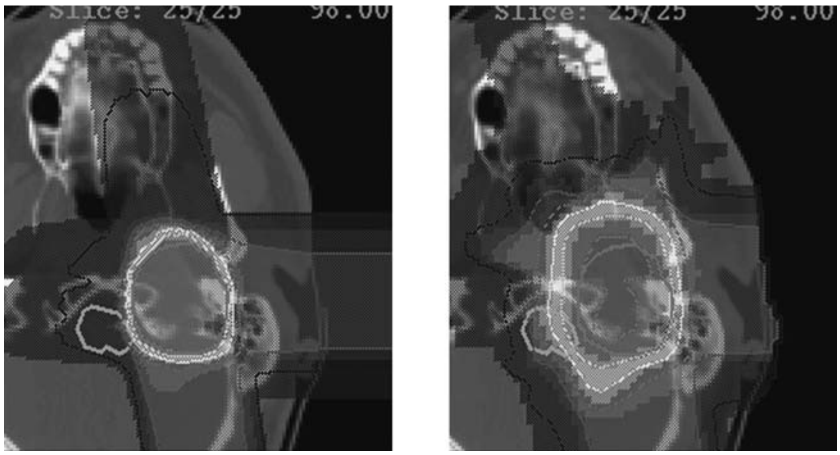

Figure 2. *Comparison of proton carbon treatment plan for the same patient but performed with different techniques. The dose from 100% (red) to 10% (blue) is given in a linear scale and super imposed to a CT scan, where in the top left the teeth of the patient are shown. For protons a passive beam shaping system was applied, for carbon ions an active system that yields a much greater conformity. Independent from these techniques is the dose gradients that depend on lateral and range straggling which are 3 times steeper for carbon than for proton independent from penetration depth. (Courtesy O. Jäkel DKFZ.)*

In 1980 at GSI, Darmstadt, a comprehensive program was initiated to measure RBE values for very different biological objects over the largest available range of particle energies and atomic numbers. These experiments were mainly performed at the accelerators of GSI, Unilac and later on SIS, but included also experiments at GANIL, Caen, MPIK, Heidelberg, and the BEVALAC, Berkeley. The purpose of these experiments was first to measure sensitivity and to calibrate biological systems that could be used in space research as biological detectors. But the results of these experiments helped also to clarify the various RBE dependencies in greater detail.

Because DNA—the most important bio-molecule—is double stranded, the biological effects depend on the local ionization density (in a nanometre scale) in the DNA: For low ionization densities, the damage is more or less stochastic distributed over the strands and neighboring molecules of the DNA. These lesions are normally easy to repair. For higher ionization density, correlated lesions can be produced at both DNA strands and also at the surrounding proteins (histones). These clustered lesions are more difficult to repair and sometimes repair fails. The complexity of the DNA damage in relation to the repair potential determines the effectiveness of the radiation type. Densely ionizing radiation produces clusters of DNA lesions that cannot be repaired by the cell, yielding proliferative cell-death or lyses of the cell (apoptosis). The value of the expected RBE depends therefore on the cellular repair capacity in response to the radiation quality. It turned also out that the elevated local ionisation densities and in RBE of carbon ions conincide with the elevated dose in the Bragg maximum. This means that the elevated dose of the Bragg maximum is potentiated in its biological action.

Based on this knowledge carbon ions were selected for particle therapy and a theoretical model for the Local Effect Model, LEM was developed for therapy planning.

Clinical Results

At GSI the construction of a heavy ion therapy unit started in 1993. In parallel at Chiba (Japan) heavy ion treatment started already with carbon ions, although the accelerator there was originally designed for heavier ions up to Argon. The treatment at GSI was performed since 1997 in cooperation with the University Radiotherapy and DKFZ, Heidelberg and FZR Dresden and yielded the same good tumor control as in Chiba, Japan. Up to now more than 300 patients have been treated at GSI with carbon ions, 2,000 at Chiba, Japan.

The quality of a tumor treatment can be judged from different view points. The most general question would be whether the treatment can cure the patient in general where cure means a 5 year tumor-free patient survival. This is closely connected to the question after local tumor-control. At first, one is intended to assume that tumor control and patient cure would be the same. But a primary tumor can produce metastases even a long time after it was removed. If metastases occur a good local control-rate does not mean patient cure but helps in many cases to prolong the patient's life and to reach a better quality of life, depending on the patient's general conditions and on the type of tumor. In Figure 3 the local tumor

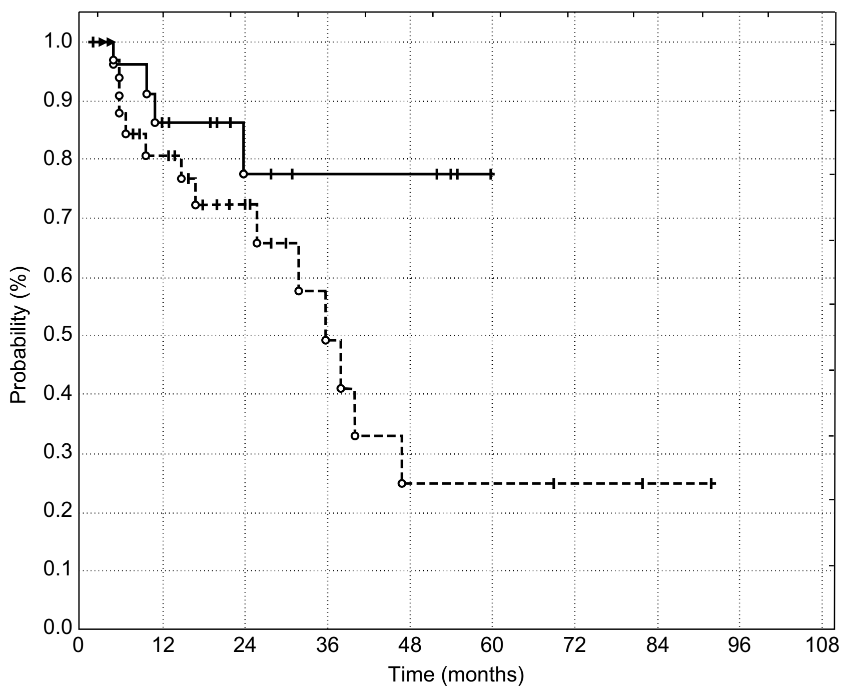

Figure 3. *Local control rate of salivary gland tumors are compared for about 30 patients in each arm: the lower curve represents patients treated with photon IMRT only. For the patients in the upper curve, 6 out of 20 fractions were replaced by carbon treatment. This rises the 5 year control rate at about 50%.*

control rate up to 5 years is shown for salivary gland tumors where in the course of a conventional treatment 6 of 20 fractions are given with carbon ions compared to treatments where all fractions are given with photons: The tumor-control rate increases from 25% to 75%, that is, by 50% for the carbon treatment. This is a great success but unfortunately this type of tumor has a tendency of 30–40% to produce metastases. So the good local tumor-control does not mean in all these cases a general better cure.

For carbon treatment, those patients should be selected that have the largest benefit according to the bio-physical properties of Carbon ions. Slowly growing tumors are very radio-resistant against photons because of their great repair capacity. Because carbon ions kick down the repair capacity for these difficult tumors a great benefit was expected and later on realized. For a complete carbon treatment, 5 year tumor-control rates of 80% have been reached, again much better than other treatments. This is true for both treatments, at Chiba and Darmstadt. But a greater conformity of the beam delivery with the scanning system reduces the side effects and increases the quality of life, so some of the patients even were able to do their professional work during and immediately after treatment.

A similar good response is now expected for prostate tumors that are radio-resistant too. The high RBE for these treatments will allow reducing the burden to the surrounding normal tissue like rectum and bladder and should therefore reduce the side effects. But prostate treatment has the problem that the organ can be at different positions from day to day and that it can move during treatment. Therefore a boost strategy of six carbon fractions within a larger field photon treatment has been applied for the first patients treated at GSI. In total 30 patients will be treated with carbon and 30 without to proof whether the predicted advantages can be realized in the clinical practice. The result of these treatments will be analysed in approximately two years from now.

Future Developments

The 3-dimensional scanning system as developed at GSI has been proven to be a prerequisite for the tumor therapy with the biologically very efficient heavy ion beams: Only if the treated volume can be restricted to the tumor volume and normal tissue can be spared, a good tumor control can be reached combined with small side effects. This has been realized for tumors in the head and neck area, along the spinal cord and to some extend in the pelvic region (prostate). Lung tumors having a great biological potential for heavy ion treatment cannot be treated with a scanning system up to now because the target volumes moves with the breathing. Therefore, developments have been started to correct the beam position during treatment. An on-line motion correction is in principle possible because the speed for organ movements in the thorax or pelvis is with 3 cm/s more than 100 times slower than the scanning system. Other problems to be solved before the clinical practice for moving target can start are a real time tumor tracking and a more sophisticated treatment planning.

Another permanent problem is the improvement of treatment planning and the RBE calculation in general. At present, using the Local Effect Model (LEM), it is possible to predict the carbon response better than 20% when the X-ray-response of the same tumor is known. This represents an extreme precision, considering other model calculations like the micro-dosimetric approach, which is one order of magnitude less accurate. So LEM is a big improvement. However, LEM is based on the average X-ray-response, that is, the tumor response reported for a large group of patients. But there is an individual variation in radio-sensitivity from patient to patient for the normal tissue and for the same type of tumor. If it would be possible to measure the individual radio-sensitivity at least for the normal tissue, the treatment planning could be shaped more individually and the dose could be adapted for each patient individually. This represents an important task to be carried out from biologists and physicians.

On the physics side improvement of heavy ion therapy can be achieved with less expensive accelerator technologies. Recently it has been demonstrated that short pulse lasers can accelerate protons or carbon ions up to a few MeV. For a potential use in therapy, these energies have to be increased to 150 MeV for protons and to 350 MeV/u for carbon ions. In addition, the repetition frequency should be close to the kHz region and the energy spectrum should have a narrow maximum at energies between 100 MeV/u to the full energy that could be changed from pulse to pulse, at least by a few percent. The development of a compact laser driven accelerators could reduce the size of a clinical unit and therefore its costs.

The International Situation

In Japan, two carbon facilities are in operation, one at Chiba since 1994 and one at Hyogo since 2002. A third one is planned at Gumna.

In Europe, Heidelberg is scheduled to start operation in 2007. Pavia, Italy in 2008 and Wiener Neustadt, Austria will probably follow one or two years later as well as Lyon, France, that has been approved in 2005. The initiatives at Pavia, Wiener Neustadt, and Lyon originate largely from the Proton-Ion Medical-Machine-Study PIMMS carried out at CERN in the years 1996–2000. PIMMS was aimed to provide a European design of all technical parts of a proton/carbon therapy center from which the different projects could take what they need.

In Germany the construction of a heavy ion center at Marburg was a part of the negotiations when the Giessen and Marburg University clinics where sold to the Rhön Klinikum AG,RKA,one of the largest private hospital suppliers.

The design of the RKA unit has the advantage that we started it from "the rear," the patient side, not from the accelerator (Figure 4). Therefore the flow of the patients has been optimized in order to keep the time for each patient short and of course having many patients that can be treated at the facility. In addition, a partnership model is planned where other clinics or specialized physicians can treat their patients at the Marburg center. This will increase the number of patients, especially in those cases where a boost treatment of a few fractions is indicated. It is also very important that the RKA will install a chair for clinical heavy ion radiobiology at the Marburg University in order to improve the treatment in the long term.

Many other initiatives are ongoing in Europe but it is not clear which ones will succeed. A general estimation in different countries came to the result that one heavy ion-center for 10 Mio. inhabitants would be appropriate to serve the needs of the tumor-patients. Whether this number is correct in the long term is not clear. When other large clinical facilities like CT scans, PET and NMR have been started, the projected numbers of facilities were one or two orders of magnitude below the present number of installations. As a consequence, the final number of installations will depend on many factors such as the cost and the medical benefit.

That a big market is expected for heavy ion shows the fact that at least four companies are offering complete proton/carbon therapy units. Siemens Medical Solutions has taken over the GSI know how and patents. It is involved now in the Heidelberg center and the general contractor for the technical part of the Marburg center. The ACCEL-company has made the Munich proton therapy center and the new facilities at PSI, Villigen. IBA has built also several proton facilities and is now marketing the CERN PIMMS design. Finally, the Japanese Mitsubishi company is offering and constructing such big therapy units, but they call them "micro-units."

The costs of one proton/carbon unit depend on size and degree of medical instalments and are between 120 to 180 Mio €. Heavy Ion treatment centers are by far the most expensive clinical apparatus, but the general success of the heavy ion therapy seems to justify these big investments because the cost of the treatment of a single

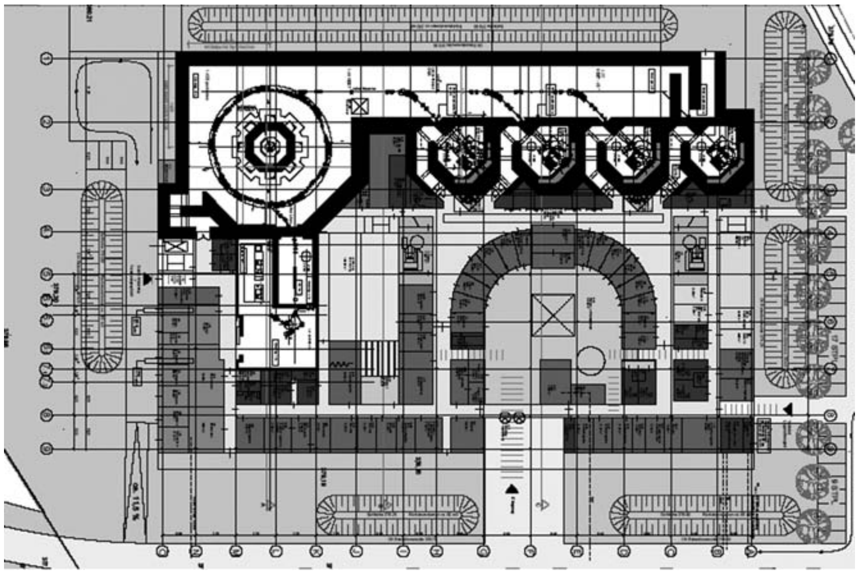

Figure 4. *The design of the Marburg facility is based on an extended study of the clinical workflow. Three treatment areas with a horizontal beam line and one with a 45° oblique beam will be used in an optimal way to shorten the treatment time for the patient (Rhön-Klinikum-AG and Brenner & partner, architects).*

patient of about 20,000 € will be comparable to surgery. Therefore, we hope that the number of facilities will increase according to the needs of the patients. But we also hope that heavy ion therapy will not become an object for financial speculations.

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Report on the NIC IX Conference

The 9th meeting of the biennial, international conference, Nuclei in the Cosmos ("NIC-IX") was just held at CERN from June 26 to 30, 2006, jointly organized by a team with members from the ISOLDE Collaboration and the nTOF Collaboration. This meeting was dedicated to the memory of Al Cameron, Ray Davis, and John Bahcall, all of whom passed away recently and who had played a major role in helping understand the production of and the role of nuclei in the cosmos. Financial support was provided by a wide range of institutions and commercial firms, along with CERN. Established in 1990, this interdisciplinary conference brings together astronomers, astrophysicists, cosmologists, and nuclear physicists to discuss the most important aspects of our Universe, with particular reference to the nuclear processes, responsible amongst others of origin of the chemical elements. This year, NIC-IX attracted 248 attendees (Figure 1) with about 20% female scientists. The Web page for the Conference is **www. cern.ch/nic9** and the proceedings of NIC-IX are being published by the "Proceedings of Science" (http://pos.sissa.it), an open access publishing service operated by SISSA.

A total of 74 talks were presented in plenary session with session topics ranging from observational data from stars, Big-Bang nucleosynthesis and cosmology, element production in the Universe, experimental and theoretical nuclear astrophysics, and nuclei far from stability. The focus of the conference this year was aimed more at experimental and theoretical nuclear physics although stellar observations and astrophysical models were also well represented.

A number of new and innovative techniques are now available or proposed for providing key data to understand nuclear processes in the cosmos, such as recoil mass separators for direct reaction rate studies, AMS techniques, radioactive beam systems, table-top storage rings, penning ion traps, and sophisticated gamma arrays.

From the presentations given on astrophysical observations, results

Figure 1. *Participants at the NIC IX Conference.*

from the INTEGRAL satellite on the observations of galactic radioactivities included the detection of ^{26}Al, ^{44}Ti, and—for the first time—of ^{60}Fe, but ^{22}Na and positron emission are not yet observed. Early nova explosions are estimated to occur at higher temperatures as compared to classical novae, but more studies are needed. A significant amount of observational data from systematic searches for ultra metal-poor halo stars is becoming available, which bear exciting insight in the early history of the Universe in general and in the mechanisms of nucleosynthesis by the "r-process" in particular. These observations are complemented by analyses of isotopic abundance pattern in presolar dust grains, which carry detailed information on various nucleosynthetic sources. The unstable ^{60}Fe, which was discovered in a deep sea manganese crust, provides evidence for a nearby supernova 2.4 M years ago.

A highlight for nuclear data has been finally a good estimate of the reaction rate for the radiative alpha capture on ^{15}O, a rate being pursued for over 20 years. Additional information was presented by several groups on the very important $^{12}C(\alpha,\gamma)^{16}O$ reaction, a key reaction for the processes responsible for the production of many elements. Direct measurement of radiative proton capture on ^{26g}Al and alpha capture on ^{40}Ca was also presented. Finally, several reaction rates for neutron-induced reactions have been reported, which will have important implications on the understanding of s-process nucleosynthesis and the age of the elements heavier than iron (the "neutron capture elements").

Another highlight of the conference was the presentation of successful, computer simulated, supernova explosion, using an asymmetrical/aspherical object with significant fluctuations following core collapse. A new role of neutrinos in explosive nucleosynthesis providing a bypass for waiting points in the rp process was presented. Considerable interest was devoted to the nature of the r-process and the possibility of two or more different r-processes. Important topics in this context were the possibility to create the necessary neutron-rich environment by antineutrino-proton interactions and the possible role of nuclear fission at the termination point of the r-process.

The conference was also a success from a social perspective with an interesting hike in the Jura mountains followed by wine and cheese tasting at a fromagerie, a tour of the Old Town in Geneva, and a memorable banquet on a traditional boat tour on Lake Geneva with music and dancing. A tour of the ISOLDE facility and the Atlas Experimental area was held on the Saturday following the conference.

The main conference was preceded by a specially organized, one week school for graduate students, and this was attended by about 50 young scientists including 30 on scholarships. Instructors included a diverse group of international scientists. In addition, two satellite workshops were held at the University of Basel (on nuclear reaction data for astrophysics) and the Observatory of Geneva (on Globular Clusters). During the conference week, outreach events on topics of the conference were organized for local secondary school students and for the public.

The next Nuclei in the Cosmos conference, "NIC-X," will be hosted by the Michigan State University/National Superconducting Cyclotron Laboratory and the Joint Institute for Nuclear Astrophysics, "JINA," in the United States.

John D'Auria
Vancouver

Good News for Nuclear Physics in ESFRI Facilities Roadmap

The long awaited Roadmap of European Large Scale Facilities was published by ESFRI in October and brought great news for the nuclear physics community. Out of 35 new projects identified as major pan-European ventures, 2 are nuclear physics projects—FAIR and SPIRAL2. Moreover the report also included a list of "Emerging Projects" that are still at an early stage, and again a nuclear physics project appears—DAPHNE2.

ESFRI (European Strategic Forum for Research Infrastructures) was established by the European Commission in 2002 and given the charge to produce a "Roadmap" that would identify the most important large-scale research infrastructures that were being planned and that should be recognized at a European level. ESFRI set up a number of expert panels to advise them and sought input from various sources. NuPECC provided a submission based on the last Long Range Plan (2004), which proved very influential with the nuclear physics working group. Indeed the final submission from that working group closely reflected this input. During the ESFRI process it was remarked on a number of occasions that the coherence of the nuclear physics community which NuPECC provides, and the way in which regular LRPs are prepared through community consultation, were an excellent example of how European science communities should work.

Apart from the "political" advantage of having our science gain high profile by having our facilities highlighted in this way, there is another more practical advantage. In the new EU Framework Programme (FP7), which will start next year, the Commission has introduced a new instrument that can provide funds toward the construction of new facilities. However, this support will only be available to facilities that appear on the Roadmap. Colleagues at FAIR and SPIRAL2 are now hard at work preparing material in anticipation of an approach from the EC when the FP7 starts.

Brian Fulton
NuPECC Chairman

Progress Report NuPECC 2006

Meetings of NuPECC in 2006

March 17 and 18, in Athens, June 9 and 10, in Krakow and October 27 and 28, in Bordeaux.

All meetings were started with a presentation of the situation of nuclear physics in the host country.

Membership Issues

Croatia and Romania became new members of NuPECC.

Personalia

Sotirios Harissopulos (DEMOKRITOS Athens) was nominated as Treasurer of NuPECC starting January 1, 2006.

Nuclear Physics News

NuPECC continues to publish the quarterly magazine *Nuclear Physics News* successfully in its 17th year. Six thousand copies of NPN are being read in Europe, North and South America, Asia, and Australia.

NuPECC Roadmap

Based on the NuPECC Long Range Plan 2004 "Perspectives for Nuclear Physics Research in Europe for the Coming Decade and Beyond" NuPECC published the "NuPECC Roadmap for Construction of Nuclear Physics Research Infrastructures in Europe." A copy can be found on the NuPECC website. This roadmap served as input for the ESFRI Working Group on Nuclear Physics preparing the Roadmap for the European Research Area.

ERA-NET in Nuclear Physics

NuPECC will become an Associated Member and act as the scientific advisory body for an ERA-NET in nuclear physics. This was further discussed at a meeting in Paris on October 6, 2006, convened and chaired by S. Galès, Deputy Director of IN2P3. A proposal will be handed in Spring 2007.

Working Group on High Intensity Stable Beams

The report of the Working Group ECOS (European Collaboration on

Stable Beams) chaired by F. Azaiez (Orsay) was handed in to NuPECC and published on the NuPECC Website. The recommendations were presented and discussed at a Town Meeting at CNRS/IN2P3 in Paris on October 5 and 6, 2006.

Integrated Infrastructure Initiative EURONS

NuPECC participates in the Integrated Infrastructure Initiative EURONS under the 6th Framework Programme of the European Commission, which started on January 1, 2005. This project will be part of the next NuPECC Long Range Plan, which is aimed at for 2009. It should start with a Town Meeting end of 2007; preparations for this will start in
1 late 2006.

Preparations for FP7

NuPECC established a Working Group in order to support preparations for FP7 within the community. The Working Group met with Co-ordinators of projects running in FP6 and representatives of the EU Commission in Brussels on March 9, 2006. The minutes of this meeting can be found on the NuPECC website.

PANS—Public Awareness of Nuclear Science

NuPECC continues its successful collaboration with the Nuclear Physics Board of the European Physical Society in this area. The next project will be an exhibition on “Art & Science” featuring the input of nuclear physics to the analysis and conservation of pieces of art. A Working group was formed, chaired by C. Leclerq-Willain (Univerity of Brussels).

Survey on Resources in Nuclear Physics

NuPECC is preparing a new survey on resources in nuclear physics in Europe. A questionnaire was sent out to more than 180 nuclear physics institutes in the NuPECC member states. The evalution is in progress. This survey represents the European part of an international initiative pursued by the Commission C12 (Nuclear Physics) of the International Union of Pure and Applied Physics IUPAP.

International Collaboration

Apart from the collaboration in IUPAP (see previous paragraph), NuPECC participates in the nuclear physics working group of the Global Science Forum of OECD. B. Fulton presented the NuPECC Roadmap at the first meeting in Washington on March 6 and 7, 2006. The next meeting is being held in Rome on October 10 and 11, 2006. The NuPECC Survey is also part of the agenda of that meeting.

Trans-Disciplinary Collaboration

B. Fulton was invited to give a report on NuPECC at the meeting of Restricted ECFA at CERN on November 30, 2006. The CERN Council explicitely mentions the collaboration with NuPECC in its recently published “European Strategy for Particle Physics.”

Reports from Outside Europe

R. Tribble, the new Chairman of the Nuclear Science Advisory Committee NSAC, reported on the status of nuclear physics in the United States.

Additional information can be found on the NuPECC Homepage under

http://www.nupecc.org

GABRIELE–ELISABETH KÖRNER
NuPECC Scientific Secretary

Element 111 Baptised Roentgenium—111 Years After the Discovery of the X-rays by Wilhelm Conrad Röntgen

On November 8, 1885 Wilhelm Conrad Röntgen discovered a new type of radiation that was able to pass matter to some extent—the X-rays (in German "Roentgestrahlen"). Immediately after this discovery the application of the X-rays started in many fields. One-hundred and eleven years later, on November 17, 2006 the element with the atomic number 111 was baptized "roentgenium," to honor the great scientist. For element 111, however, it took a little longer from discovery in the year 1994 to the decision concerning its name by the International Union of Pure and Applied Chemistry IUPAC in 2004. In a symbolic act the German Minister of Education and Science, Annette Schavan, and the leader of the GSI discovery group, Sigurd Hofmann, put the element with the chemical symbol "Rg" into its place in the periodic table. The celebration was attended by more than 600 guests and GSI employees and it received a wide press resonance.

Figure 1. ***Posing for the press***: *The SHIP group with its leader Sigurd Hofmann, the German Minister for Education and Science, Annette Schavan, and the Secretary of State in the Science Ministry of the State of Hesse, Joachim-Felix Leonhard (kneeling in the center; from right) (**Photo**: A. Zschau).*

The first atom of element 111 was identified at the velocity filter SHIP on December 8, 1994, at 5:49 a.m. via the detection of the α decay of its isotope ^{272}Rg. With the three events observed in the first experiment in 1994 and additional 3 events in a second one in 2000 the group around Sigurd Hofmann collected a total of 6 decay chains. Today, the heaviest isotope synthesized at GSI via cold fusion, that is, reactions based on the use of Pb or Bi targets, is ^{277}112. The synthesis of this isotope as well as of ^{272}Rg and ^{271}Mt (Z = 110) has recently been confirmed by Kosuke Morita and co-workers at the gas filled separator GARIS operated at the RIKEN Nishina Center for Accelerator-Based Science near Tokyo, Japan. ^{272}Rg has a half-life of 1.6 ms and an α decay energy of 10.82 MeV. A second isotope, ^{274}Rg, has been produced at RIKEN in the decay chain of ^{278}113, the heaviest nucleus produced up to now by cold fusion.

The research in the field of superheavy elements aims at the understanding of the properties of nuclear matter at the very edge of the chart of nuclides in terms of proton and neutron number. Experimental approaches to reach the predicted region of shell stabilized nuclei around proton number 114 to 126 and neutron number 184 have been pursued by various laboratories around the world since its prediction in the mid-1960s. Beyond the mere synthesis and identification of heavy nuclei, also their nuclear structure and chemical properties have become accessible by the refined and advanced methods, developed and applied at GSI and by various other research teams. Decay spectroscopy and single atom chemistry reach presently up to Z = 110, and Z = 108/112, respectively. The long predicted and awaited for "island of stability" of spherical superheavy elements is within reach, especially with the ongoing development toward higher beam intensities. We are close, taking into account also the "hot fusion" results from Dubna for ^{48}Ca induced reactions. The door has been opened. We have to just step in.

Dieter Ackermann
GSI Darmstadt

Prof. Dr. Aaldert Hendrik Wapstra (1922–2006): Grand Inquisitor of the Atomic Masses

It is with great sadness that we say "*adieu*" to our colleague Aaldert Wapstra who passed away at home in Amsterdam December 4, 2006.

Wapstra's career in nuclear physics spanned five decades from 1953 when he received his doctorate from the University of Amsterdam and became Professor at Delft Technical University, in 1955. In 1963, he joined the executive board of the IKO, which later became the premier subatomic physics institute of the Netherlands: NIKHEF. Succeeding Van Lieshout in 1971, he was director of NIKHEF until 1982. Although he retired in 1987, his active contribution to the Atomic Mass Evaluation continued through 2005.

The mass of an atom, when measured accurately enough, yields the nuclear binding energy which, in turn, has important implications in a wide range of subatomic physics. Because masses can be determined via the different techniques of decay spectroscopy, reactions or mass spectrometry, the production of a mass table requires a meticulous and rigorous evaluation procedure.

Aaldert Wapstra first provided such an evaluation, at the first international conference dedicated to atomic masses. With F. Everling, L. A. König, and J. H. E. Mattauch, he established the procedure for producing—and testing consistency of—the different results. Since that time, the so-called AME has been updated at regular intervals with the most recently published, 2003 evaluation comprising reliable masses for some 3,000 nuclides. It is the second most cited reference in nuclear physics and forms a unique, common benchmark for nuclear theory.

Aaldert helped formulate the definition of the mass unit, designated as *u*, for "unified" unit, equal to one twelfth the mass of ^{12}C. He liked to joke about its singular name: "Let us be firm in retaining the *u*, let us even make it a double-*u*!" as a reference to has last initial.

The evaluation is a veritable experimental exercise, requiring great fluency in the technical methods of measuring masses. In this regard, Aaldert was extremely interested in various breeds of mass spectrometers, offering such pearls of wisdom as: "My experience, in the course of 55 years in evaluating data, has been that precision measurements with non-focussing instruments should be considered with a healthy distrust."

At the 2004 conference of Exotic Nuclei and Atomic Masses, at Callaway Gardens, near Atlanta—44 years after attending the original conference on masses—Aaldert received the SUNAMCO medal in recognition of his long commitment and numerous achievements in the field. It was fitting that he received an award that he himself had presented others on previous occasions.

In addition to his technical and scientific skills, Aaldert was a great lover of culture. An accomplished pianist, he was particularly fond of music, having a subscription to Amsterdam's famous Concertgebouw. His taste in music was very modern, with the work of Messiaen figuring prominently. He was also a dedicated family man, composing poems for his Grandchildren for the feast of St. Nicolas each year.

Aaldert's fine blend of culture and scientific acumen made it a pleasure to receive him as a visitor in Orsay, where he came regularly for discussions concerning the evaluation. His experience and authority were only less impressive than his profound modesty. It will be difficult to carry on without him.

IKO:	Institute of Nuclear Physics Research
NIKHEF:	National Institute for Nuclear Physics and High Energy Physics
SUNAMCO:	Symbols, Units, Nomenclature, Atomic Masses and fundamental Constants; a commission of IUPAP: the International Union of Pure and Applied Physics

For more information see: http://amdc.in2p3.fr/bulletins/Ahw.html

GEORGES AUDI WITH DAVID LUNNEY
Csnsm-Orsay

calendar

February 28–March 2
GSI Darmstadt, Germany. Annual NUSTAR Meeting
http://www.gsi.de/forschung/kp/kp2/nustare.html

March 21–23
GSI Darmstadt, Germany. Annual NUSTAR Meeting
http://www.gsi.de/forschung/kp/kp2/nustar_e.html

March 26–31
Dresden, Germany. Nuclear Physics in Astrophysics III. XXI International Nuclear Physics Divisional Conference of the European Physical Society
http://www.f$_2$-rossendorf.de/pls/rois/cms?pNid=1429

May 7–18
Les Houches, France. Theoretical Nuclear Physics School "Exotic Nuclei: New Challenges"
http://leshouches.ganil.fr/

May 20–24
Vico Equense, Italy. 9th International Spring Seminar On Nuclear Physics Changing Facets Of Nuclear Structure
http://vico07.na.infn.it/

May 30–June 2
RIKEN, Wako-shi, Japan. Direct Reactions with Exotic Beams DREB2007
http://rarfaxp.riken.go.jp/DREB2007/

June 3–8
Tokyo, Japan. International Nuclear Physics Conference INPC 2007
http://www.inpc2007.jp/

June 11–14
Kyoto, Japan. Nuclear Structure: New Pictures in the Extended Isospin Space (NS07)
http://www.nucl.photsukubo.ac.jp/NSO7

June 11–15
Catania, Italy. International Symposium on Exotic States of Nuclear Matter (EXOCT 2007)
http://www.ct.infn.it/exoct2007/

June 17–23
Lisbon, Portugal. International Conference on Proton Emitting Nuclei and Related Topics
http://cfif.ist.utl.pt/~procon07/

June 24–29
Deauville, France. EMIS 2007
http://emis2007.ganil.fr/

July 3–7
Golden Sand Hoi An, Vietnam. International Symposium on Physics of Unstable Nuclei (ISPUN07)
http://www.inst.gov.vn/ispun07

July 16–20
Barelona, Spain. 14th International Conference on Recent Progress in Many-Body Theories (RPMB14)
http://congress.cimne.ups.es/rpmb14/frontal/Objectives.asp

September 3–7
Stratford-upon-Avon, England. Clusters '07
http://www.iop.org/Conferences/ForthcomingInstituteConferences/event7938.

September 10–14
Jülich, Germany. Eleventh International Conference on Meson-Nucleon Physics and the structure of the Nucleon (MENU 2007)
http://www.fz-juelich.de/ikp/menu2007

September 23–28
Davos, Switzerland. TAN 07 3rd International Conference on the Chemistry and Physics of the Transactinide Elements
http://tan07.web.psi.ch/

2008

November 9–14
Eilat, Israel. 18th Particle And Nuclei International Conference PANIC 08
http://www.weizmann.ac.il/conferences/panic08/

More information available under: **http://www.nupecc.org/calendar.html**